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This is the Numba documentation. Unless you are already acquainted with Numba, we suggest you start with the *User manual*. 
1.1 A ~5 minute guide to Numba

Numba is a just-in-time compiler for Python that works best on code that uses NumPy arrays and functions, and loops. The most common way to use Numba is through its collection of decorators that can be applied to your functions to instruct Numba to compile them. When a call is made to a Numba-decorated function it is compiled to machine code “just-in-time” for execution and all or part of your code can subsequently run at native machine code speed!

Out of the box Numba works with the following:

- OS: Windows (32 and 64 bit), OSX, Linux (32 and 64 bit). Unofficial support on *BSD.
- Architecture: x86, x86_64, ppc64le, armv7l, armv8l (aarch64). Unofficial support on M1/Arm64.
- GPUs: Nvidia CUDA.
- CPython
- NumPy 1.18 - latest

1.1.1 How do I get it?

Numba is available as a conda package for the Anaconda Python distribution:

```
$ conda install numba
```

Numba also has wheels available:

```
$ pip install numba
```

Numba can also be compiled from source, although we do not recommend it for first-time Numba users.

Numba is often used as a core package so its dependencies are kept to an absolute minimum, however, extra packages can be installed as follows to provide additional functionality:

- scipy - enables support for compiling numpy.linalg functions.
- colorama - enables support for color highlighting in backtraces/error messages.
- pyyaml - enables configuration of Numba via a YAML config file.
- icc_rt - allows the use of the Intel SVML (high performance short vector math library, x86_64 only). Installation instructions are in the performance tips.
1.1.2 Will Numba work for my code?

This depends on what your code looks like, if your code is numerically orientated (does a lot of math), uses NumPy a lot and/or has a lot of loops, then Numba is often a good choice. In these examples we’ll apply the most fundamental of Numba’s JIT decorators, @jit, to try and speed up some functions to demonstrate what works well and what does not.

Numba works well on code that looks like this:

```python
from numba import jit
import numpy as np

x = np.arange(100).reshape(10, 10)

@jit(nopython=True)  # Set “nopython” mode for best performance, equivalent to @njit
def go_fast(a):
    # Function is compiled to machine code when called the first time
    trace = 0.0
    for i in range(a.shape[0]):  # Numba likes loops
        trace += np.tanh(a[i, i])  # Numba likes NumPy functions
    return a + trace  # Numba likes NumPy broadcasting

print(go_fast(x))
```

It won’t work very well, if at all, on code that looks like this:

```python
from numba import jit
import pandas as pd

x = {'a': [1, 2, 3], 'b': [20, 30, 40]}

@jit
def use_pandas(a):
    # Function will not benefit from Numba jit
    df = pd.DataFrame.from_dict(a)  # Numba doesn't know about pd.DataFrame
    df += 1  # Numba doesn't understand what this is
    return df.cov()  # or this!

print(use_pandas(x))
```

Note that Pandas is not understood by Numba and as a result Numb would simply run this code via the interpreter but with the added cost of the Numba internal overheads!

1.1.3 What is nopython mode?

The Numba @jit decorator fundamentally operates in two compilation modes, nopython mode and object mode. In the go_fast example above, nopython=True is set in the @jit decorator; this is instructing Numba to operate in nopython mode. The behaviour of the nopython compilation mode is to essentially compile the decorated function so that it will run entirely without the involvement of the Python interpreter. This is the recommended and best-practice way to use the Numba jit decorator as it leads to the best performance.

Should the compilation in nopython mode fail, Numba can compile using object mode. This is a fall back mode for the @jit decorator if nopython=True is not set (as seen in the use_pandas example above). In this mode Numba will identify loops that it can compile and compile those into functions that run in machine code, and it will run the rest of the code in the interpreter. For best performance avoid using this mode!
1.1.4 How to measure the performance of Numba?

First, recall that Numba has to compile your function for the argument types given before it executes the machine code version of your function. This takes time. However, once the compilation has taken place Numba caches the machine code version of your function for the particular types of arguments presented. If it is called again with the same types, it can reuse the cached version instead of having to compile again.

A really common mistake when measuring performance is to not account for the above behaviour and to time code once with a simple timer that includes the time taken to compile your function in the execution time.

For example:

```python
from numba import jit
import numpy as np
import time

x = np.arange(100).reshape(10, 10)

@jit(nopython=True)
def go_fast(a):
    # Function is compiled and runs in machine code
    trace = 0.0
    for i in range(a.shape[0]):
        trace += np.tanh(a[i, i])
    return a + trace

# DO NOT REPORT THIS... COMPILATION TIME IS INCLUDED IN THE EXECUTION TIME!
start = time.time()
go_fast(x)
end = time.time()
print("Elapsed (with compilation) = %s" % (end - start))

# NOW THE FUNCTION IS COMPILED, RE-TIME IT EXECUTING FROM CACHE
start = time.time()
go_fast(x)
end = time.time()
print("Elapsed (after compilation) = %s" % (end - start))
```

This, for example prints:

```
Elapsed (with compilation) = 0.33030009269714355
Elapsed (after compilation) = 6.67572021484375e-06
```

A good way to measure the impact Numba JIT has on your code is to time execution using the timeit module functions; these measure multiple iterations of execution and, as a result, can be made to accommodate for the compilation time in the first execution.

As a side note, if compilation time is an issue, Numba JIT supports on-disk caching of compiled functions and also has an Ahead-Of-Time compilation mode.
1.1.5 How fast is it?

Assuming Numba can operate in nopython mode, or at least compile some loops, it will target compilation to your specific CPU. Speed up varies depending on application but can be one to two orders of magnitude. Numba has a performance guide that covers common options for gaining extra performance.

1.1.6 How does Numba work?

Numba reads the Python bytecode for a decorated function and combines this with information about the types of the input arguments to the function. It analyzes and optimizes your code, and finally uses the LLVM compiler library to generate a machine code version of your function, tailored to your CPU capabilities. This compiled version is then used every time your function is called.

1.1.7 Other things of interest:

Numba has quite a few decorators, we’ve seen @jit, but there’s also:

• @njit - this is an alias for @jit(nopython=True) as it is so commonly used!
• @vectorize - produces NumPy ufunc s (with all the ufunc methods supported). Docs are here.
• @guvectorize - produces NumPy generalized ufunc s. Docs are here.
• @stencil - declare a function as a kernel for a stencil like operation. Docs are here.
• @jitclass - for jit aware classes. Docs are here.
• @cfunc - declare a function for use as a native call back (to be called from C/C++ etc). Docs are here.
• @overload - register your own implementation of a function for use in nopython mode, e.g. @overload(scipy.special.j0). Docs are here.

Extra options available in some decorators:

• parallel = True - enable the automatic parallelization of the function.
• fastmath = True - enable fast-math behaviour for the function.

cytypes/cffi/cython interoperability:

• cffi - The calling of CFFI functions is supported in nopython mode.
• ctypes - The calling of ctypes wrapped functions is supported in nopython mode.
• Cython exported functions are callable.

GPU targets:

Numba can target Nvidia CUDA GPUs. You can write a kernel in pure Python and have Numba handle the computation and data movement (or do this explicitly). Click for Numba documentation on CUDA.
1.2 Overview

Numba is a compiler for Python array and numerical functions that gives you the power to speed up your applications with high performance functions written directly in Python.

Numba generates optimized machine code from pure Python code using the LLVM compiler infrastructure. With a few simple annotations, array-oriented and math-heavy Python code can be just-in-time optimized to performance similar as C, C++ and Fortran, without having to switch languages or Python interpreters.

Numba’s main features are:

- **on-the-fly code generation** (at import time or runtime, at the user’s preference)
- native code generation for the CPU (default) and **GPU hardware**
- integration with the Python scientific software stack (thanks to Numpy)

Here is how a Numba-optimized function, taking a Numpy array as argument, might look like:

```python
@numba.jit
def sum2d(arr):
    M, N = arr.shape
    result = 0.0
    for i in range(M):
        for j in range(N):
            result += arr[i,j]
    return result
```

1.3 Installation

1.3.1 Compatibility

Numba is compatible with Python 3.7–3.10, and Numpy versions 1.18 up to 1.22.

Our supported platforms are:

- Linux x86 (32-bit and 64-bit)
- Linux ppcle64 (POWER8, POWER9)
- Windows 7 and later (32-bit and 64-bit)
- OS X 10.9 and later (64-bit and unofficial support on M1/Arm64)
- *BSD (unofficial support only)
- NVIDIA GPUs of compute capability 5.3 and later
  - Compute capabilities 3.0 - 5.2 are supported, but deprecated.
- ARMv7 (32-bit little-endian, such as Raspberry Pi 2 and 3)
- ARMv8 (64-bit little-endian, such as the NVIDIA Jetson)

*Automatic parallelization with @jit* is only available on 64-bit platforms.
1.3.2 Installing using conda on x86/x86_64/POWER Platforms

The easiest way to install Numba and get updates is by using conda, a cross-platform package manager and software distribution maintained by Anaconda, Inc. You can either use Anaconda to get the full stack in one download, or Miniconda which will install the minimum packages required for a conda environment.

Once you have conda installed, just type:

$ conda install numba

or:

$ conda update numba

Note that Numba, like Anaconda, only supports PPC in 64-bit little-endian mode.

To enable CUDA GPU support for Numba, install the latest graphics drivers from NVIDIA for your platform. (Note that the open source Nouveau drivers shipped by default with many Linux distributions do not support CUDA.) Then install the cudatoolkit package:

$ conda install cudatoolkit

You do not need to install the CUDA SDK from NVIDIA.

1.3.3 Installing using pip on x86/x86_64 Platforms

Binary wheels for Windows, Mac, and Linux are also available from PyPI. You can install Numba using pip:

$ pip install numba

This will download all of the needed dependencies as well. You do not need to have LLVM installed to use Numba (in fact, Numba will ignore all LLVM versions installed on the system) as the required components are bundled into the llvmlite wheel.

To use CUDA with Numba installed by pip, you need to install the CUDA SDK from NVIDIA. Please refer to Setting CUDA Installation Path for details. Numba can also detect CUDA libraries installed system-wide on Linux.

1.3.4 Installing on Linux ARMv7 Platforms

Berryconda is a conda-based Python distribution for the Raspberry Pi. We are now uploading packages to the numba channel on Anaconda Cloud for 32-bit little-endian, ARMv7-based boards, which currently includes the Raspberry Pi 2 and 3, but not the Pi 1 or Zero. These can be installed using conda from the numba channel:

$ conda install -c numba numba

Berryconda and Numba may work on other Linux-based ARMv7 systems, but this has not been tested.
1.3.5 Installing on Linux ARMv8 (AArch64) Platforms

We build and test conda packages on the NVIDIA Jetson TX2, but they are likely to work for other AArch64 platforms. (Note that while the Raspberry Pi CPU is 64-bit, Raspbian runs it in 32-bit mode, so look at Installing on Linux ARMv7 Platforms instead.)

Conda-forge support for AArch64 is still quite experimental and packages are limited, but it does work enough for Numba to build and pass tests. To set up the environment:

• Install miniforge. This will create a minimal conda environment.
• Then you can install Numba from the numba channel:

$ conda install -c numba numba

On CUDA-enabled systems, like the Jetson, the CUDA toolkit should be automatically detected in the environment.

1.3.6 Installing from source

Installing Numba from source is fairly straightforward (similar to other Python packages), but installing llvmlite can be quite challenging due to the need for a special LLVM build. If you are building from source for the purposes of Numba development, see Build environment for details on how to create a Numba development environment with conda.

If you are building Numba from source for other reasons, first follow the llvmlite installation guide. Once that is completed, you can download the latest Numba source code from Github:

$ git clone git://github.com/numba/numba.git

Source archives of the latest release can also be found on PyPI. In addition to llvmlite, you will also need:

• A C compiler compatible with your Python installation. If you are using Anaconda, you can use the following conda packages:
  – Linux x86: gcc_linux-32 and gxx_linux-32
  – Linux x86_64: gcc_linux-64 and gxx_linux-64
  – Linux POWER: gcc_linux-ppc64le and gxx_linux-ppc64le
  – Linux ARM: no conda packages, use the system compiler
  – Mac OSX: clang_osx-64 and clangxx_osx-64 or the system compiler at /usr/bin/clang (Mojave onwards)
  – Mac OSX (M1): clang_osx-arm64 and clangxx_osx-arm64
  – Windows: a version of Visual Studio appropriate for the Python version in use
• NumPy

Then you can build and install Numba from the top level of the source tree:

$ python setup.py install
Build time environment variables and configuration of optional components

Below are environment variables that are applicable to altering how Numba would otherwise build by default along with information on configuration options.

**NUMBA_DISABLE_OPENMP (default: not set)**
To disable compilation of the OpenMP threading backend set this environment variable to a non-empty string when building. If not set (default):

- For Linux and Windows it is necessary to provide OpenMP C headers and runtime libraries compatible with the compiler tool chain mentioned above, and for these to be accessible to the compiler via standard flags.
- For OSX the conda package `llvm-openmp` provides suitable C headers and libraries. If the compilation requirements are not met the OpenMP threading backend will not be compiled.

**NUMBA_DISABLE_TBB (default: not set)**
To disable the compilation of the TBB threading backend set this environment variable to a non-empty string when building. If not set (default) the TBB C headers and libraries must be available at compile time. If building with `conda build` this requirement can be met by installing the `tbb-devel` package. If not building with `conda build` the requirement can be met via a system installation of TBB or through the use of the `TBBROOT` environment variable to provide the location of the TBB installation. For more information about setting `TBBROOT` see the Intel documentation.

1.3.7 Dependency List

Numba has numerous required and optional dependencies which additionally may vary with target operating system and hardware. The following lists them all (as of July 2020).

- **Required build time:**
  - setuptools
  - numpy
  - llvmmlite
  - Compiler toolchain mentioned above

- **Required run time:**
  - setuptools
  - numpy
  - llvmmlite

- **Optional build time:**
  See Build time environment variables and configuration of optional components for more details about additional options for the configuration and specification of these optional components.
  - `llvm-openmp` (OSX) - provides headers for compiling OpenMP support into Numba's threading backend
  - `tbb-devel` - provides TBB headers/libraries for compiling TBB support into Numba's threading backend (2021 <= version < 2021.6 required).
  - `importlib_metadata` (for Python versions < 3.9)

- **Optional runtime are:**
  - `scipy` - provides cython bindings used in Numba's `np.linalg.*` support
- **tbb** - provides the TBB runtime libraries used by Numba's TBB threading backend (version >= 2021 required).
- **jinja2** - for "pretty" type annotation output (HTML) via the numba CLI
- **cffi** - permits use of CFFI bindings in Numba compiled functions
- **llvm-openmp** - (OSX) provides OpenMP library support for Numba's OpenMP threading backend.
- **intel-openmp** - (OSX) provides an alternative OpenMP library for use with Numba's OpenMP threading backend.
- **ipython** - if in use, caching will use IPython's cache directories/caching still works
- **pyyaml** - permits the use of a `.numba_config.yaml` file for storing per project configuration options
- **colorama** - makes error message highlighting work
- **icc_rt** - (numba channel) allows Numba to use Intel SVML for extra performance
- **pygments** - for "pretty" type annotation
- **gdb** as an executable on the `$PATH` - if you would like to use the gdb support
- **Compiler toolchain mentioned above, if you would like to use pycc for Ahead-of-Time (AOT) compilation**
- **r2pipe** - required for assembly CFG inspection.
- **radare2** as an executable on the `$PATH` - required for assembly CFG inspection. See here for information on obtaining and installing.
- **graphviz** - for some CFG inspection functionality.
- **pickle5** - provides Python 3.8 pickling features for faster pickling in Python 3.7.
- **typeguard** - used by runtests.py for runtime type-checking.
- **cuda-python** - The NVIDIA CUDA Python bindings. See CUDA Bindings. Numba requires Version 11.6 or greater.

- To build the documentation:
  - **sphinx**
  - **pygments**
  - **sphinx_rtd_theme**
  - **numpydoc**
  - **make** as an executable on the `$PATH`

### 1.3.8 Checking your installation

You should be able to import Numba from the Python prompt:

```bash
$ python
Python 3.10.2 | packaged by conda-forge | (main, Jan 14 2022, 08:02:09) [GCC 9.4.0] on...
Type "help", "copyright", "credits" or "license" for more information.
>>> import numba
>>> numba.__version__
'0.55.1'
```
You can also try executing the `numba --sysinfo` (or `numba -s` for short) command to report information about your system capabilities. See *Command line interface* for further information.

```bash
$ numba -s
System info:

______________________________
__Time Stamp__
Report started (local time) : 2022-01-18 10:35:08.981319
______________________________
__Hardware Information__
Machine : x86_64
CPU Name : skylake-avx512
CPU Count : 12
CPU Features :
64bit adx aes avx avx2 avx512bw avx512cd avx512vdqa avx512f vfmadd132x8 pfftm f16c
fma sse2 sse3 scap sse4.1 sse4.2 sse4a vsx xsave xsavec xsaveopt xsaves

______________________________
__OS Information__
Platform Name : Linux-5.4.0-94-generic-x86_64-with-
glibc2.31
Platform Release : 5.4.0-94-generic
OS Name : Linux
OS Version : #106-Ubuntu SMP Thu Jan 6 23:58:14 UTC
--2022

______________________________
__Python Information__
Python Compiler : GCC 9.4.0
Python Implementation : CPython
Python Version : 3.10.2
Python Locale : en_GB.UTF-8

______________________________
__LLVM information__
LLVM Version : 11.1.0

______________________________
__CUDA Information__
Found 1 CUDA devices
id 0     b'Quadro RTX 8000' [SUPPORTED]
  Compute Capability: 7.5
  PCI Device ID: 0
  PCI Bus ID: 21
  UUID: GPU-e6489c45-5b68-3b03-bab7-0e7c8e09643
  Watchdog: Enabled
  FP32/FP64 Performance Ratio: 32

```
(output truncated due to length)
1.4 Compiling Python code with @jit

Numba provides several utilities for code generation, but its central feature is the `numba.jit()` decorator. Using this decorator, you can mark a function for optimization by Numba’s JIT compiler. Various invocation modes trigger differing compilation options and behaviours.

1.4.1 Basic usage

Lazy compilation

The recommended way to use the @jit decorator is to let Numba decide when and how to optimize:

```python
from numba import jit

@jit
def f(x, y):
    # A somewhat trivial example
    return x + y
```

In this mode, compilation will be deferred until the first function execution. Numba will infer the argument types at call time, and generate optimized code based on this information. Numba will also be able to compile separate specializations depending on the input types. For example, calling the `f()` function above with integer or complex numbers will generate different code paths:

```plaintext
>>> f(1, 2)
3
>>> f(1j, 2)
(2+1j)
```

Eager compilation

You can also tell Numba the function signature you are expecting. The function `f()` would now look like:

```python
from numba import jit, int32

@jit(int32(int32, int32))
def f(x, y):
    # A somewhat trivial example
    return x + y
```

`int32(int32, int32)` is the function’s signature. In this case, the corresponding specialization will be compiled by the @jit decorator, and no other specialization will be allowed. This is useful if you want fine-grained control over types chosen by the compiler (for example, to use single-precision floats).

If you omit the return type, e.g. by writing `(int32, int32)` instead of `int32(int32, int32)`, Numba will try to infer it for you. Function signatures can also be strings, and you can pass several of them as a list; see the `numba.jit()` documentation for more details.

Of course, the compiled function gives the expected results:

```plaintext
>>> f(1,2)
3
```
and if we specified int32 as return type, the higher-order bits get discarded:

```python
>>> f(2**31, 2**31 + 1)
1
```

### 1.4.2 Calling and inlining other functions

Numba-compiled functions can call other compiled functions. The function calls may even be inlined in the native code, depending on optimizer heuristics. For example:

```python
@jit
def square(x):
    return x ** 2

@jit
def hypot(x, y):
    return math.sqrt(square(x) + square(y))
```

The @jit decorator must be added to any such library function, otherwise Numba may generate much slower code.

### 1.4.3 Signature specifications

Explicit @jit signatures can use a number of types. Here are some common ones:

- **void** is the return type of functions returning nothing (which actually return None when called from Python)
- **intp** and **uintp** are pointer-sized integers (signed and unsigned, respectively)
- **intc** and **uintc** are equivalent to C int and unsigned int integer types
- **int8**, **uint8**, **int16**, **uint16**, **int32**, **uint32**, **int64**, **uint64** are fixed-width integers of the corresponding bit width (signed and unsigned)
- **float32** and **float64** are single- and double-precision floating-point numbers, respectively
- **complex64** and **complex128** are single- and double-precision complex numbers, respectively
- array types can be specified by indexing any numeric type, e.g. float32[: ] for a one-dimensional single-precision array or int8[: ,:] for a two-dimensional array of 8-bit integers.

### 1.4.4 Compilation options

A number of keyword-only arguments can be passed to the @jit decorator.

**nopython**

Numba has two compilation modes: **nopython mode** and **object mode**. The former produces much faster code, but has limitations that can force Numba to fall back to the latter. To prevent Numba from falling back, and instead raise an error, pass nopython=True.

```python
@jit(nopython=True)
def f(x, y):
    return x + y
```
See also:

**Troubleshooting and tips**

**nogil**

Whenever Numba optimizes Python code that only works on native types and variables (rather than Python objects), it is not necessary anymore to hold Python’s global interpreter lock (GIL). Numba will release the GIL when entering such a compiled function if you passed `nogil=True`.

```python
@jit(nogil=True)
def f(x, y):
    return x + y
```

Code running with the GIL released runs concurrently with other threads executing Python or Numba code (either the same compiled function, or another one), allowing you to take advantage of multi-core systems. This will not be possible if the function is compiled in object mode.

When using `nogil=True`, you’ll have to be wary of the usual pitfalls of multi-threaded programming (consistency, synchronization, race conditions, etc.).

**cache**

To avoid compilation times each time you invoke a Python program, you can instruct Numba to write the result of function compilation into a file-based cache. This is done by passing `cache=True`:

```python
@jit(cache=True)
def f(x, y):
    return x + y
```

**parallel**

Enables automatic parallelization (and related optimizations) for those operations in the function known to have parallel semantics. For a list of supported operations, see *Automatic parallelization with @jit*. This feature is enabled by passing `parallel=True` and must be used in conjunction with `nopython=True`:

```python
@jit(nopython=True, parallel=True)
def f(x, y):
    return x + y
```

See also:

*Automatic parallelization with @jit*
1.5 Flexible specializations with @generated_jit

While the `jit()` decorator is useful for many situations, sometimes you want to write a function that has different implementations depending on its input types. The `generated_jit()` decorator allows the user to control the selection of a specialization at compile-time, while fully retaining runtime execution speed of a JIT function.

1.5.1 Example

Suppose you want to write a function which returns whether a given value is a “missing” value according to certain conventions. For the sake of the example, let’s adopt the following definition:

- for floating-point arguments, a missing value is a NaN
- for Numpy datetime64 and timedelta64 arguments, a missing value is a NaT
- other types don’t have the concept of a missing value.

That compile-time logic is easily implemented using the `generated_jit()` decorator:

```python
import numpy as np
from numba import generated_jit, types

generated_jit(nopython=True)
def is_missing(x):
    """Return True if the value is missing, False otherwise."
    if isinstance(x, types.Float):
        return lambda x: np.isnan(x)
    elif isinstance(x, (types.NPDatetime, types.NPTimedelta)):
        # The corresponding Not-a-Time value
        missing = x('NaT')
        return lambda x: x == missing
    else:
        return lambda x: False
```

There are several things to note here:

- The decorated function is called with the Numba types of the arguments, not their values.
- The decorated function doesn’t actually compute a result, it returns a callable implementing the actual definition of the function for the given types.
- It is possible to pre-compute some data at compile-time (the missing variable above) to have them reused inside the compiled implementation.
- The function definitions use the same names for arguments as in the decorated function, this is required to ensure passing arguments by name works as expected.
1.5.2 Compilation options

The `generated_jit()` decorator supports the same keyword-only arguments as the `jit()` decorator, for example the `nopython` and `cache` options.

1.6 Creating NumPy universal functions

There are two types of universal functions:

- Those which operate on scalars, these are “universal functions” or `ufuncs` (see `vectorize` below).
- Those which operate on higher dimensional arrays and scalars, these are “generalized universal functions” or `gufuncs` (`guvectorize` below).

1.6.1 The `@vectorize` decorator

Numba’s `vectorize` allows Python functions taking scalar input arguments to be used as NumPy `ufuncs`. Creating a traditional NumPy `ufunc` is not the most straightforward process and involves writing some C code. Numba makes this easy. Using the `vectorize()` decorator, Numba can compile a pure Python function into a ufunc that operates over NumPy arrays as fast as traditional ufuncs written in C.

Using `vectorize()`, you write your function as operating over input scalars, rather than arrays. Numba will generate the surrounding loop (or `kernel`) allowing efficient iteration over the actual inputs.

The `vectorize()` decorator has two modes of operation:

- Eager, or decoration-time, compilation: If you pass one or more type signatures to the decorator, you will be building a Numpy universal function (ufunc). The rest of this subsection describes building ufuncs using decoration-time compilation.
- Lazy, or call-time, compilation: When not given any signatures, the decorator will give you a Numba dynamic universal function (`DUFunc`) that dynamically compiles a new kernel when called with a previously unsupported input type. A later subsection, “Dynamic universal functions”, describes this mode in more depth.

As described above, if you pass a list of signatures to the `vectorize()` decorator, your function will be compiled into a Numpy ufunc. In the basic case, only one signature will be passed:

```python
from numba import vectorize, float64

@vectorize([float64(float64, float64)])
def f(x, y):
    return x + y
```

If you pass several signatures, beware that you have to pass most specific signatures before least specific ones (e.g., single-precision floats before double-precision floats), otherwise type-based dispatching will not work as expected:

```python
@vectorize([int32(int32, int32),
            int64(int64, int64),
            float32(float32, float32),
            float64(float64, float64)])
def f(x, y):
    return x + y
```

The function will work as expected over the specified array types:
but it will fail working on other types:

```python
>>> a = np.linspace(0, 1+1j, 6)
>>> f(a, a)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: ufunc 'ufunc' not supported for the input types, and the inputs could not be safely coerced to any supported types according to the casting rule ''safe''
```

You might ask yourself, “why would I go through this instead of compiling a simple iteration loop using the `@jit` decorator?”. The answer is that NumPy ufuncs automatically get other features such as reduction, accumulation or broadcasting. Using the example above:

```python
>>> a = np.arange(12).reshape(3, 4)
>>> a
array([[ 0,  1,  2,  3],
       [ 4,  5,  6,  7],
       [ 8,  9, 10, 11]])
>>> f.reduce(a, axis=0)
array([12, 15, 18, 21])
>>> f.reduce(a, axis=1)
array([ 6, 22, 38])
>>> f.accumulate(a)
array([[ 0,  1,  3,  6],
       [ 4,  9, 15, 22],
       [ 8, 17, 27, 38]])
```

See also:

Standard features of ufuncs (NumPy documentation).

Note: Only the broadcasting features of ufuncs are supported in compiled code.

The `vectorize()` decorator supports multiple ufunc targets:
<table>
<thead>
<tr>
<th>Target</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cpu</td>
<td>Single-threaded CPU</td>
</tr>
<tr>
<td>parallel</td>
<td>Multi-core CPU</td>
</tr>
<tr>
<td>cuda</td>
<td>CUDA GPU</td>
</tr>
</tbody>
</table>

Note: This creates an *ufunc-like* object. See documentation for CUDA ufunc for detail.

A general guideline is to choose different targets for different data sizes and algorithms. The “cpu” target works well for small data sizes (approx. less than 1KB) and low compute intensity algorithms. It has the least amount of overhead. The “parallel” target works well for medium data sizes (approx. less than 1MB). Threading adds a small delay. The “cuda” target works well for big data sizes (approx. greater than 1MB) and high compute intensity algorithms. Transferring memory to and from the GPU adds significant overhead.

1.6.2 The `@guvectorize` decorator

While `vectorize()` allows you to write ufuncs that work on one element at a time, the `guvectorize()` decorator takes the concept one step further and allows you to write ufuncs that will work on an arbitrary number of elements of input arrays, and take and return arrays of differing dimensions. The typical example is a running median or a convolution filter.

Contrary to `vectorize()` functions, `guvectorize()` functions don’t return their result value: they take it as an array argument, which must be filled in by the function. This is because the array is actually allocated by NumPy’s dispatch mechanism, which calls into the Numba-generated code.

Similar to `vectorize()` decorator, `guvectorize()` also has two modes of operation: Eager, or decoration-time compilation and lazy, or call-time compilation.

Here is a very simple example:

```python
@guvectorize([(int64[:], int64, int64[:])], '(n),()->(n)')
def g(x, y, res):
    for i in range(x.shape[0]):
        res[i] = x[i] + y
```

The underlying Python function simply adds a given scalar (y) to all elements of a 1-dimension array. What’s more interesting is the declaration. There are two things there:

- the declaration of input and output *layouts*, in symbolic form: \((n),()\rightarrow(n)\) tells NumPy that the function takes a \(n\)-element one-dimension array, a scalar (symbolically denoted by the empty tuple \(()\)) and returns a \(n\)-element one-dimension array;
- the list of supported concrete *signatures* as per `@vectorize`; here, as in the above example, we demonstrate `int64` arrays.

Note: 1D array type can also receive scalar arguments (those with shape \(()\)). In the above example, the second argument also could be declared as `int64[:]`. In that case, the value must be read by `y[0]`.

We can now check what the compiled ufunc does, over a simple example:
>>> a = np.arange(5)
>>> a
array([0, 1, 2, 3, 4])
>>> g(a, 2)
array([2, 3, 4, 5, 6])

The nice thing is that NumPy will automatically dispatch over more complicated inputs, depending on their shapes:

```python
>>> a = np.arange(6).reshape(2, 3)
>>> a
array([[0, 1, 2],
       [3, 4, 5]])
>>> g(a, 10)
array([[10, 11, 12],
       [13, 14, 15]])
>>> g(a, np.array([10, 20]))
array([[10, 11, 12],
       [23, 24, 25]])
```

Note: Both `vectorize()` and `guvectorize()` support passing `nopython=True` as in the `@jit` decorator. Use it to ensure the generated code does not fallback to object mode.

### Overwriting input values

In most cases, writing to inputs may also appear to work - however, this behaviour cannot be relied on. Consider the following example function:

```python
@guvectorize([(float64[:], float64[:])], '(O->O)')
def init_values(invals, outvals):
    invals[0] = 6.5
    outvals[0] = 4.2
```

Calling the `init_values` function with an array of `float64` type results in visible changes to the input:

```python
>>> inval = np.zeros(shape=(3, 3), dtype=np.float64)
>>> outval = init_values(inval)
```

This works because NumPy can pass the input data directly into the `init_values` function as the data `dtype` matches that of the declared argument. However, it may also create and pass in a temporary array, in which case changes to the input are lost. For example, this can occur when casting is required. To demonstrate, we can use an array of `float32` with the `init_values` function:
In this case, there is no change to the `invals` array because the temporary casted array was mutated instead.

### 1.6.3 Dynamic universal functions

As described above, if you do not pass any signatures to the `vectorize()` decorator, your Python function will be used to build a dynamic universal function, or `DUFunc`. For example:

```python
from numba import vectorize

@vectorize
def f(x, y):
    return x * y
```

The resulting `f()` is a `DUFunc` instance that starts with no supported input types. As you make calls to `f()`, Numba generates new kernels whenever you pass a previously unsupported input type. Given the example above, the following set of interpreter interactions illustrate how dynamic compilation works:

```bash
>>> f
<numba._DUFunc 'f'>
>>> f.ufunc
<ufunc 'f'>
>>> f.ufunc.types
[]
```

The example above shows that `DUFunc` instances are not ufuncs. Rather than subclass ufunc’s, `DUFunc` instances work by keeping a `ufunc` member, and then delegating ufunc property reads and method calls to this member (also known as type aggregation). When we look at the initial types supported by the ufunc, we can verify there are none.

Let’s try to make a call to `f()`:

```bash
>>> f(3,4)
12
>>> f.types  # shorthand for f.ufunc.types
['ll->l']
```

If this was a normal Numpy ufunc, we would have seen an exception complaining that the ufunc couldn’t handle the input types. When we call `f()` with integer arguments, not only do we receive an answer, but we can verify that Numba created a loop supporting C `long` integers.

We can add additional loops by calling `f()` with different inputs:

```bash
>>> f(1.,2.)
2.0
>>> f.types
['ll->l', 'dd->d']
```

We can now verify that Numba added a second loop for dealing with floating-point inputs, "dd->d".

## 1.6. Creating NumPy universal functions
If we mix input types to `f()`, we can verify that **Numpy ufunc casting rules** are still in effect:

```python
>>> f(1, 2.)
2.0
```

```python
>>> f.types
['ll->l', 'dd->d']
```

This example demonstrates that calling `f()` with mixed types caused Numpy to select the floating-point loop, and cast the integer argument to a floating-point value. Thus, Numba did not create a special "dl->d" kernel.

This **DUFunc** behavior leads us to a point similar to the warning given above in “The @vectorize decorator” subsection, but instead of signature declaration order in the decorator, call order matters. If we had passed in floating-point arguments first, any calls with integer arguments would be cast to double-precision floating-point values. For example:

```python
>>> @vectorize
def g(a, b):
    return a / b...
```

```python
>>> g(2., 3.)
0.66666666666666663
```

```python
g(2, 3)
0.66666666666666663
```

```python
>>> g.types
['dd->d']
```

If you require precise support for various type signatures, you should specify them in the `vectorize()` decorator, and not rely on dynamic compilation.

### 1.6.4 Dynamic generalized universal functions

Similar to a dynamic universal function, if you do not specify any types to the `guvectorize()` decorator, your Python function will be used to build a dynamic generalized universal function, or GUFunc. For example:

```python
from numba import guvectorize

@guvectorize(('n'),()->(n))
def g(x, y, res):
    for i in range(x.shape[0]):
        res[i] = x[i] + y
```

We can verify the resulting function `g()` is a GUFunc instance that starts with no supported input types. For instance:

```python
>>> g
<numba._GUFunc 'g'>
```

```python
>>> g.ufunc
<ufunc 'g'>
```

```python
>>> g.ufunc.types
[]
```

Similar to a **DUFunc**, as one makes calls to `g()`, numba generates new kernels for previously unsupported input types. The following set of interpreter interactions will illustrate how dynamic compilation works for a GUFunc:

```python
>>> x = np.arange(5, dtype=np.int64)
>>> y = 10
>>> res = np.zeros_like(x)
```
If this was a normal `guvectorize()` function, we would have seen an exception complaining that the ufunc could not handle the given input types. When we call `g()` with the input arguments, numba creates a new loop for the input types.

We can add additional loops by calling `g()` with new arguments:

```python
>>> x = np.arange(5, dtype=np.double)
>>> y = 2.2
>>> res = np.zeros_like(x)
>>> g(x, y, res)
```

We can now verify that Numba added a second loop for dealing with floating-point inputs, "dd->d".

```python
>>> g.types  # shorthand for g.ufunc.types
['ll->l', 'dd->d']
```

One can also verify that Numpy ufunc casting rules are working as expected:

```python
>>> x = np.arange(5, dtype=np.int64)
>>> y = 2.2
>>> res = np.zeros_like(x)
>>> g(x, y, res)
```

If you need precise support for various type signatures, you should not rely on dynamic compilation and instead, specify the types them as first argument in the `guvectorize()` decorator.

### 1.7 Compiling Python classes with @jitclass

**Note:** This is a early version of jitclass support. Not all compiling features are exposed or implemented, yet.

Numba supports code generation for classes via the `numba.experimental.jitclass()` decorator. A class can be marked for optimization using this decorator along with a specification of the types of each field. We call the resulting class object a `jitclass`. All methods of a jitclass are compiled into nopython functions. The data of a jitclass instance is allocated on the heap as a C-compatible structure so that any compiled functions can have direct access to the underlying data, bypassing the interpreter.
1.7.1 Basic usage

Here’s an example of a jitclass:

```python
import numpy as np
from numba import int32, float32  # import the types
from numba.experimental import jitclass

spec = [
    ('value', int32),                # a simple scalar field
    ('array', float32[:]),          # an array field
]

@jitclass(spec)
class Bag(object):
    def __init__(self, value):
        self.value = value
        self.array = np.zeros(value, dtype=np.float32)

    @property
def size(self):
        return self.array.size

    def increment(self, val):
        for i in range(self.size):
            self.array[i] += val
        return self.array

    @staticmethod
def add(x, y):
        return x + y

n = 21
mybag = Bag(n)
```

In the above example, a `spec` is provided as a list of 2-tuples. The tuples contain the name of the field and the Numba type of the field. Alternatively, user can use a dictionary (an `OrderedDict` preferably for stable field ordering), which maps field names to types.

The definition of the class requires at least a `__init__` method for initializing each defined fields. Uninitialized fields contains garbage data. Methods and properties (getters and setters only) can be defined. They will be automatically compiled.

1.7.2 Inferred class member types from type annotations with `as_numba_type`

Fields of a `jitclass` can also be inferred from Python type annotations.

```python
from typing import List
from numba.experimental import jitclass
from numba.typed import List as NumbaList

@jitclass
class Counter:
    (continues on next page)
```
value: int

def __init__(self):
    self.value = 0

def get(self) -> int:
    ret = self.value
    self.value += 1
    return ret

@jitclass
class ListLoopIterator:
    counter: Counter
    items: List[float]

    def __init__(self, items: List[float]):
        self.items = items
        self.counter = Counter()

    def get(self) -> float:
        idx = self.counter.get() % len(self.items)
        return self.items[idx]

items = NumbaList([3.14, 2.718, 0.123, -4.])
loop_itr = ListLoopIterator(items)

Any type annotations on the class will be used to extend the spec if that field is not already present. The Numba type corresponding to the given Python type is inferred using as_numba_type. For example, if we have the class

@jitclass([("w", int32), ("y", float64[:])])
class Foo:
    w: int
    x: float
    y: np.ndarray
    z: SomeOtherType

    def __init__(self, w: int, x: float, y: np.ndarray, z: SomeOtherType):
        ...

then the full spec used for Foo will be:

- "w": int32 (specified in the spec)
- "x": float64 (added from type annotation)
- "y": array(float64, 1d, A) (specified in the spec)
- "z": numba.as_numba_type(SomeOtherType) (added from type annotation)

Here SomeOtherType could be any supported Python type (e.g. bool, typing.Dict[int, typing.Tuple[float, float]], or another jitclass).

Note that only type annotations on the class will be used to infer spec elements. Method type annotations (e.g. those of __init__ above) are ignored.

Numba requires knowing the dtype and rank of numpy arrays, which cannot currently be expressed with type annota-
tions. Because of this, numpy arrays need to be included in the spec explicitly.

### 1.7.3 Specifying `numba.typed` containers as class members explicitly

The following patterns demonstrate how to specify a `numba.typed.Dict` or `numba.typed.List` explicitly as part of the spec passed to `jitclass`.

First, using explicit Numba types and explicit construction.

```python
from numba import jitclass, types, typed

# key and value types
kv_ty = (types.int64, types.unicode_type)

# A container class with:
# * member 'd' holding a typed dictionary of int64 -> unicode string (kv_ty)
# * member 'l' holding a typed list of float64
@jitclass([( 'd', types.DictType(*kv_ty)),
          ( 'l', types.ListType(types.float64))])
class ContainerHolder(object):
    def __init__(self):
        # initialize the containers
        self.d = typed.Dict.empty(*kv_ty)
        self.l = typed.List.empty_list(types.float64)

container = ContainerHolder()
container.d[1] = "apple"
container.d[2] = "orange"
container.l.append(123.)
container.l.append(456.)
print(container.d)  # {1: apple, 2: orange}
print(container.l)  # [123.0, 456.0]
```

Another useful pattern is to use the `numba.typed` container attribute `_numba_type_` to find the type of a container, this can be accessed directly from an instance of the container in the Python interpreter. The same information can be obtained by calling `numba.typeof()` on the instance. For example:

```python
from numba import jitclass, typed, typeof

d = typed.Dict()
d[1] = "apple"
d[2] = "orange"
l = typed.List()
l.append(123.)
l.append(456.)

@jitclass([( 'd', typeof(d)), ('l', typeof(l))])
class ContainerInstHolder(object):
    def __init__(self, dict_inst, list_inst):
        self.d = dict_inst
        self.l = list_inst
```

(continues on next page)
container = ContainerInstHolder(d, l)
print(container.d)  # {1: apple, 2: orange}
print(container.l)  # [123.0, 456.0]

It is worth noting that the instance of the container in a jitclass must be initialized before use, for example, this will cause an invalid memory access as self.d is written to without d being initialized as a type.Dict instance of the type specified.

```python
from numba import jitclass, types
dict_ty = types.DictType(types.int64, types.unicode_type)

@jitclass([('d', dict_ty)])
class NotInitialisingContainer(object):
    def __init__(self):
        self.d[10] = "apple"  # this is invalid, `d` is not initialized

NotInitialisingContainer()  # segmentation fault/memory access violation
```

### 1.7.4 Support operations

The following operations of jitclasses work in both the interpreter and Numba compiled functions:

- calling the jitclass class object to construct a new instance (e.g. mybag = Bag(123));
- read/write access to attributes and properties (e.g. mybag.value);
- calling methods (e.g. mybag.increment(3));
- calling static methods as instance attributes (e.g. mybag.add(1, 1));
- calling static methods as class attributes (e.g. Bag.add(1, 2));

Using jitclasses in Numba compiled function is more efficient. Short methods can be inlined (at the discretion of LLVM inliner). Attributes access are simply reading from a C structure. Using jitclasses from the interpreter has the same overhead of calling any Numba compiled function from the interpreter. Arguments and return values must be unboxed or boxed between Python objects and native representation. Values encapsulated by a jitclass does not get boxed into Python object when the jitclass instance is handed to the interpreter. It is during attribute access to the field values that they are boxed. Calling static methods as class attributes is only supported outside of the class definition (i.e. code cannot call Bag.add() from within another method of Bag).

### 1.7.5 Limitations

- A jitclass class object is treated as a function (the constructor) inside a Numba compiled function.
- isinstance() only works in the interpreter.
- Manipulating jitclass instances in the interpreter is not optimized, yet.
- Support for jitclasses are available on CPU only. (Note: Support for GPU devices is planned for a future release.)
1.7.6 The decorator: @jitclass

`numba.experimental.jitclass(cls_or_spec=None, spec=None)`

A function for creating a jitclass. Can be used as a decorator or function.

Different use cases will cause different arguments to be set.

If specified, `spec` gives the types of class fields. It must be a dictionary or sequence. With a dictionary, use collections.OrderedDict for stable ordering. With a sequence, it must contain 2-tuples of (fieldname, fieldtype).

Any class annotations for field names not listed in spec will be added. For class annotation `x: T` we will append `("x", as_numba_type(T))` to the spec if `x` is not already a key in spec.

**Returns**

If used as a decorator, returns a callable that takes a class object and returns a compiled version.

If used as a function, returns the compiled class (an instance of `JitClassType`).

**Examples**

1) `cls_or_spec = None, spec = None`

```python
>>> @jitclass()
... class Foo:
... ...
```

2) `cls_or_spec = None, spec = spec`

```python
>>> @jitclass(spec=spec)
... class Foo:
... ...
```

3) `cls_or_spec = Foo, spec = None`

```python
>>> @jitclass
... class Foo:
... ...
```

4) `cls_or_spec = spec, spec = None` In this case we update `cls_or_spec, spec = None, cls_or_spec`.

```python
>>> @jitclass(spec)
... class Foo:
... ...
```

5) `cls_or_spec = Foo, spec = spec`

```python
>>> JitFoo = jitclass(Foo, spec)
```
1.8 Creating C callbacks with @cfunc

Interfacing with some native libraries (for example written in C or C++) can necessitate writing native callbacks to provide business logic to the library. The `numba.cfunc()` decorator creates a compiled function callable from foreign C code, using the signature of your choice.

### 1.8.1 Basic usage

The `@cfunc` decorator has a similar usage to `@jit`, but with an important difference: passing a single signature is mandatory. It determines the visible signature of the C callback:

```python
from numba import cfunc

@cfunc("float64(float64, float64)")
def add(x, y):
    return x + y
```

The C function object exposes the address of the compiled C callback as the `address` attribute, so that you can pass it to any foreign C or C++ library. It also exposes a `ctypes` callback object pointing to that callback; that object is also callable from Python, making it easy to check the compiled code:

```python
@cfunc("float64(float64, float64)")
def add(x, y):
    return x + y

print(add.ctypes(4.0, 5.0))  # prints "9.0"
```

### 1.8.2 Example

In this example, we are going to be using the `scipy.integrate.quad` function. That function accepts either a regular Python callback or a C callback wrapped in a `ctypes` callback object.

Let’s define a pure Python integrand and compile it as a C callback:

```python
>>> import numpy as np
>>> from numba import cfunc
>>> def integrand(t):
...    return np.exp(-t) / t**2
...:
>>> nb_integrand = cfunc("float64(float64)")(integrand)
```

We can pass the `nb_integrand` object’s `ctypes` callback to `scipy.integrate.quad` and check that the results are the same as with the pure Python function:

```python
>>> import scipy.integrate as si
>>> def do_integrate(func):
...    """
    Integrate the given function from 1.0 to +inf.
    """
    return si.quad(func, 1, np.inf)
...:
>>> do_integrate(integrand)
```

(continues on next page)
Using the compiled callback, the integration function does not invoke the Python interpreter each time it evaluates the integrand. In our case, the integration is made 18 times faster:

```python
>>> %timeit do_integrate(integrand)
1000 loops, best of 3: 242 µs per loop
>>> %timeit do_integrate(nb_integrand.ctypes)
100000 loops, best of 3: 13.5 µs per loop
```

### 1.8.3 Dealing with pointers and array memory

A less trivial use case of C callbacks involves doing operation on some array of data passed by the caller. As C doesn’t have a high-level abstraction similar to Numpy arrays, the C callback’s signature will pass low-level pointer and size arguments. Nevertheless, the Python code for the callback will expect to exploit the power and expressiveness of Numpy arrays.

In the following example, the C callback is expected to operate on 2-d arrays, with the signature `void(double *input, double *output, int m, int n)`. You can implement such a callback thusly:

```python
from numba import cfunc, types, carray
c_sig = types.void(types.CPointer(types.double),
                  types.CPointer(types.double),
                  types.intc, types.intc)
@cfunc(c_sig)
def my_callback(in_, out, m, n):
    in_array = carray(in_, (m, n))
    out_array = carray(out, (m, n))
    for i in range(m):
        for j in range(n):
            out_array[i, j] = 2 * in_array[i, j]
```

The `numba.carray()` function takes as input a data pointer and a shape and returns an array view of the given shape over that data. The data is assumed to be laid out in C order. If the data is laid out in Fortran order, `numba.farray()` should be used instead.

### 1.8.4 Handling C structures

#### With CFFI

For applications that have a lot of state, it is useful to pass data in C structures. To simplify the interoperability with C code, numba can convert a `cffi` type into a numba `Record` type using `numba.core.typing.cffi_utils.map_type`:

```python
from numba.core.typing import cffi_utils
nbtype = cffi_utils.map_type(cffi_type, use_record_dtype=True)
```
Note: use_record_dtype=True is needed otherwise pointers to C structures are returned as void pointers.

Note: From v0.49 the numba.cffi_support module has been phased out in favour of numba.core.typing.cffi_utils

For example:

```python
from cffi import FFI

src = ""
/* Define the C struct */
typedef struct my_struct {
    int i1;
    float f2;
    double d3;
    float af4[7]; // arrays are supported
} my_struct;

/* Define a callback function */
typedef double (*my_func)(my_struct*, size_t);
""

ffi = FFI()
ffi.cdef(src)

# Get the function signature from *my_func*
sig = cffi_utils.map_type(ffi.typeof('my_func'), use_record_dtype=True)

# Make the cfunc
from numba import cfunc, carray
@cfunc(sig)
def foo(ptr, n):
    base = carray(ptr, n)  # view pointer as an array of my_struct
    tmp = 0
    for i in range(n):
        tmp += base[i].i1 * base[i].f2 / base[i].d3
        tmp += base[i].af4.sum()  # nested arrays are like normal numpy array
    return tmp
```

1.8. Creating C callbacks with @cfunc
With `numba.types.Record.make_c_struct`

The `numba.types.Record` type can be created manually to follow a C-structure’s layout. To do that, use `Record.make_c_struct`, for example:

```python
my_struct = types.Record.make_c_struct(
    # Provides a sequence of 2-tuples i.e. (name:str, type:Type)
    ('i1', types.int32),
    ('f2', types.float32),
    ('d3', types.float64),
    ('af4', types.NestedArray(dtype=types.float32, shape=(7,))),
)
```

Due to ABI limitations, structures should be passed as pointers using `types.CPointer(my_struct)` as the argument type. Inside the `cfunc` body, the `my_struct*` can be accessed with `carray`.

**Full example**

See full example in `examples/notebooks/Accessing C Struct Data.ipynb`.

### 1.8.5 Signature specification

The explicit `@cfunc` signature can use any `Numba types`, but only a subset of them make sense for a C callback. You should generally limit yourself to scalar types (such as `int8` or `float64`), pointers to them (for example `types.CPointer(types.int8)`), or pointers to `Record` type.

### 1.8.6 Compilation options

A number of keyword-only arguments can be passed to the `@cfunc` decorator: `nopython` and `cache`. Their meaning is similar to those in the `@jit` decorator.

### 1.9 Compiling code ahead of time

While Numba’s main use case is Just-in-Time compilation, it also provides a facility for Ahead-of-Time compilation (AOT).

#### 1.9.1 Overview

**Benefits**

1. AOT compilation produces a compiled extension module which does not depend on Numba: you can distribute the module on machines which do not have Numba installed (but Numpy is required).

2. There is no compilation overhead at runtime (but see the `@jit cache` option), nor any overhead of importing Numba.

See also:

Compiled extension modules are discussed in the Python packaging user guide.
Limitations

1. AOT compilation only allows for regular functions, not *ufuncs*.
2. You have to specify function signatures explicitly.
3. Each exported function can have only one signature (but you can export several different signatures under different names).
4. AOT compilation produces generic code for your CPU’s architectural family (for example “x86-64”), while JIT compilation produces code optimized for your particular CPU model.

1.9.2 Usage

Standalone example

```python
from numba.pycc import CC

cc = CC('my_module')
# Uncomment the following line to print out the compilation steps
#cc.verbose = True

@cc.export('multf', 'f8(f8, f8)')
@cc.export('multi', 'i4(i4, i4)')
def mult(a, b):
    return a * b

@cc.export('square', 'f8(f8)')
def square(a):
    return a ** 2

if __name__ == '__main__':
    cc.compile()
```

If you run this Python script, it will generate an extension module named `my_module`. Depending on your platform, the actual filename may be `my_module.so`, `my_module.pyd`, `my_module.cpython-34m.so`, etc.

The generated module has three functions: `multf`, `multi` and `square`. `multi` operates on 32-bit integers (i4), while `multf` and `square` operate on double-precision floats (f8):

```none
>>> import my_module
>>> my_module.multi(3, 4)
12
>>> my_module.square(1.414)
1.9993959999999997
```
Distutils integration

You can also integrate the compilation step for your extension modules in your setup.py script, using distutils or setuptools:

```python
from distutils.core import setup
from source_module import cc
setup(...,
    ext_modules=[cc.distutils_extension()])
```

The `source_module` above is the module defining the `cc` object. Extensions compiled like this will be automatically included in the build files for your Python project, so you can distribute them inside binary packages such as wheels or Conda packages. Note that in the case of using conda, the compilers used for AOT need to be those that are available in the Anaconda distribution.

Signature syntax

The syntax for exported signatures is the same as in the `@jit` decorator. You can read more about it in the `types` reference.

Here is an example of exporting an implementation of the second-order centered difference on a 1d array:

```python
@cc.export('centdiff_1d', 'f8[:](f8[:], f8)')
def centdiff_1d(u, dx):
    D = np.empty_like(u)
    D[0] = 0
    D[-1] = 0
    for i in range(1, len(D) - 1):
        D[i] = (u[i+1] - 2 * u[i] + u[i-1]) / dx**2
    return D
```

You can also omit the return type, which will then be inferred by Numba:

```python
@cc.export('centdiff_1d', '(f8[:], f8)')
def centdiff_1d(u, dx):
    # Same code as above
    ...
```

1.10 Automatic parallelization with `@jit`

Setting the `parallel` option for `jit()` enables a Numba transformation pass that attempts to automatically parallelize and perform other optimizations on (part of) a function. At the moment, this feature only works on CPUs.

Some operations inside a user defined function, e.g. adding a scalar value to an array, are known to have parallel semantics. A user program may contain many such operations and while each operation could be parallelized individually, such an approach often has lackluster performance due to poor cache behavior. Instead, with auto-parallelization, Numba attempts to identify such operations in a user program, and fuse adjacent ones together, to form one or more kernels that are automatically run in parallel. The process is fully automated without modifications to the user program, which is in contrast to Numba's `vectorize()` or `guvectorize()` mechanism, where manual effort is required to create parallel kernels.
1.10.1 Supported Operations

In this section, we give a list of all the array operations that have parallel semantics and for which we attempt to parallelize.

1. All numba array operations that are supported by Case study: Array Expressions, which include common arithmetic functions between Numpy arrays, and between arrays and scalars, as well as Numpy ufuncs. They are often called *element-wise* or *point-wise* array operations:
   - unary operators: `+ - ~`
   - binary operators: `+ - * / % | & ^ >> <<` **//**
   - comparison operators: `== != < <= > >=`
   - Numpy ufuncs that are supported in nopython mode.
   - User defined `DUFunc` through `vectorize()`.

2. Numpy reduction functions `sum`, `prod`, `min`, `max`, `argmin`, and `argmax`. Also, array math functions `mean`, `var`, and `std`.

3. Numpy array creation functions `zeros`, `ones`, `arange`, `linspace`, and several random functions (`rand`, `randn`, `ranf`, `random_sample`, `sample`, `random`, `standard_normal`, `chisquare`, `weibull`, `power`, `geometric`, `exponential`, `poisson`, `rayleigh`, `normal`, `uniform`, `beta`, `binomial`, `f`, `gamma`, `lognormal`, `laplace`, `randint`, `triangular`).

4. Numpy `dot` function between a matrix and a vector, or two vectors. In all other cases, Numba's default implementation is used.

5. Multi-dimensional arrays are also supported for the above operations when operands have matching dimension and size. The full semantics of Numpy broadcast between arrays with mixed dimensionality or size is not supported, nor is the reduction across a selected dimension.

6. Array assignment in which the target is an array selection using a slice or a boolean array, and the value being assigned is either a scalar or another selection where the slice range or bitarray are inferred to be compatible.

7. The `reduce` operator of `functools` is supported for specifying parallel reductions on 1D Numpy arrays but the initial value argument is mandatory.

1.10.2 Explicit Parallel Loops

Another feature of the code transformation pass (when parallel=True) is support for explicit parallel loops. One can use Numba's `prange` instead of `range` to specify that a loop can be parallelized. The user is required to make sure that the loop does not have cross iteration dependencies except for supported reductions.

A reduction is inferred automatically if a variable is updated by a binary function/operator using its previous value in the loop body. The initial value of the reduction is inferred automatically for the `+=`, `-=` , `*=` , and `/=` operators. For other functions/operators, the reduction variable should hold the identity value right before entering the `prange` loop. Reductions in this manner are supported for scalars and for arrays of arbitrary dimensions.

The example below demonstrates a parallel loop with a reduction (A is a one-dimensional Numpy array):

```python
from numba import njit, prange

@njit(parallel=True)
def prange_test(A):
    s = 0
    # Without "parallel=True" in the jit-decorator
    # the prange statement is equivalent to range
    (continues on next page)
```
The following example demonstrates a product reduction on a two-dimensional array:

```python
from numba import njit, prange
import numpy as np

@njit(parallel=True)
def two_d_array_reduction_prod(n):
    shp = (13, 17)
    result1 = 2 * np.ones(shp, np.int_)
    tmp = 2 * np.ones_like(result1)
    for i in prange(n):
        result1 *= tmp
    return result1
```

**Note:** When using Python’s `range` to induce a loop, Numba types the induction variable as a signed integer. This is also the case for Numba’s `prange` when `parallel=False`. However, for `parallel=True`, if the range is identifiable as strictly positive, the type of the induction variable will be `uint64`. The impact of a `uint64` induction variable is often most noticeable when undertaking operations involving it and a signed integer. Under Numba’s type coercion rules, such a case will commonly result in the operation producing a floating point result type.

Care should be taken, however, when reducing into slices or elements of an array if the elements specified by the slice or index are written to simultaneously by multiple parallel threads. The compiler may not detect such cases and then a race condition would occur.

The following example demonstrates such a case where a race condition in the execution of the parallel for-loop results in an incorrect return value:

```python
from numba import njit, prange
import numpy as np

@njit(parallel=True)
def prange_wrong_result(x):
    n = x.shape[0]
    y = np.zeros(4)
    for i in prange(n):
        # accumulating into the same element of `y` from different 
        # parallel iterations of the loop results in a race condition
        y[:] += x[i]
    return y
```

as does the following example where the accumulating element is explicitly specified:

```python
from numba import njit, prange
import numpy as np
```

(continues on next page)
@njit(parallel=True)
def prange_wrong_result(x):
    n = x.shape[0]
    y = np.zeros(4)
    for i in prange(n):
        # accumulating into the same element of `y` from different
        # parallel iterations of the loop results in a race condition
        y[i % 4] += x[i]
    return y

whereas performing a whole array reduction is fine:

```
from numba import njit, prange
import numpy as np

@njit(parallel=True)
def prange_ok_result_whole_arr(x):
    n = x.shape[0]
    y = np.zeros(4)
    for i in prange(n):
        y += x[i]
    return y
```

as is creating a slice reference outside of the parallel reduction loop:

```
from numba import njit, prange
import numpy as np

@njit(parallel=True)
def prange_ok_result_outer_slice(x):
    n = x.shape[0]
    y = np.zeros(4)
    z = y[:]
    for i in prange(n):
        z += x[i]
    return y
```

### 1.10.3 Examples

In this section, we give an example of how this feature helps parallelize Logistic Regression:

```
@numba.jit(nopython=True, parallel=True)
def logistic_regression(Y, X, w, iterations):
    for i in range(iterations):
        w -= np.dot(((1.0 / (1.0 + np.exp(-Y * np.dot(X, w))) - 1.0) * Y), X)
    return w
```

We will not discuss details of the algorithm, but instead focus on how this program behaves with auto-parallelization:

1. Input `Y` is a vector of size `N`, `X` is an `N x D` matrix, and `w` is a vector of size `D`.

1.10. Automatic parallelization with `@jit`
2. The function body is an iterative loop that updates variable \( w \). The loop body consists of a sequence of vector and matrix operations.

3. The inner dot operation produces a vector of size \( N \), followed by a sequence of arithmetic operations either between a scalar and vector of size \( N \), or two vectors both of size \( N \).

4. The outer dot produces a vector of size \( D \), followed by an inplace array subtraction on variable \( w \).

5. With auto-parallelization, all operations that produce array of size \( N \) are fused together to become a single parallel kernel. This includes the inner dot operation and all point-wise array operations following it.

6. The outer dot operation produces a result array of different dimension, and is not fused with the above kernel.

Here, the only thing required to take advantage of parallel hardware is to set the \( \text{parallel} \) option for \( \text{jit()} \), with no modifications to the \text{logistic_regression} function itself. If we were to give an equivalence parallel implementation using \( \text{guvectorize()} \), it would require a pervasive change that rewrites the code to extract kernel computation that can be parallelized, which was both tedious and challenging.

### 1.10.4 Unsupported Operations

This section contains a non-exhaustive list of commonly encountered but currently unsupported features:

1. **Mutating a list is not threadsafe**

   Concurrent write operations on container types (i.e. lists, sets and dictionaries) in a \text{prange} parallel region are not threadsafe e.g.:

   
   ```python
   @njit(parallel=True)
   def invalid():
       z = []
       for i in prange(10000):
           z.append(i)
       return z
   ```

   It is highly likely that the above will result in corruption or an access violation as containers require thread-safety under mutation but this feature is not implemented.

2. **Induction variables are not associated with thread ID**

   The use of the induction variable induced by a \text{prange} based loop in conjunction with \text{get_num_threads} as a method of ensuring safe writes into a pre-sized container is not valid e.g.:

   ```python
   @njit(parallel=True)
   def invalid():
       n = get_num_threads()
       z = [0 for _ in range(n)]
       for i in prange(100):
           z[i % n] += i
       return z
   ```

   The above can on occasion appear to work, but it does so by luck. There’s no guarantee about which indexes are assigned to which executing threads or the order in which the loop iterations execute.
1.10.5 Diagnostics

**Note:** At present not all parallel transforms and functions can be tracked through the code generation process. Occasionally diagnostics about some loops or transforms may be missing.

The `parallel` option for `jit()` can produce diagnostic information about the transforms undertaken in automatically parallelizing the decorated code. This information can be accessed in two ways, the first is by setting the environment variable `NUMBA_PARALLEL_DIAGNOSTICS`, the second is by calling `parallel_diagnostics()`, both methods give the same information and print to STDOUT. The level of verbosity in the diagnostic information is controlled by an integer argument of value between 1 and 4 inclusive, 1 being the least verbose and 4 the most. For example:

```python
@njit(parallel=True)
def test(x):
    n = x.shape[0]
    a = np.sin(x)
    b = np.cos(a * a)
    acc = 0
    for i in prange(n - 2):
        for j in prange(n - 1):
            acc += b[i] + b[j + 1]
    return acc
test(np.arange(10))
test.parallel_diagnostics(level=4)
```

produces:

```
==================================================================================================================================================================
======= Parallel Accelerator Optimizing: Function test, example.py (4) =======
==================================================================================================================================================================

Parallel loop listing for Function test, example.py (4)
--------------------------------------------------------|loop #ID
@njit(parallel=True) |
def test(x):
    n = x.shape[0] |
    a = np.sin(x)---------------------| #0
    b = np.cos(a * a)-----------------| #1
    acc = 0 |
    for i in prange(n - 2):-----------| #3
        for j in prange(n - 1):-------| #2
            acc += b[i] + b[j + 1] |
    return acc |
-------------------------------------------------------- Fusing loops ---------------------------------
Attempting fusion of parallel loops (combines loops with similar properties)... Trying to fuse loops #0 and #1:
- fusion succeeded: parallel for-loop #1 is fused into for-loop #0.
Trying to fuse loops #0 and #3:
- fusion failed: loop dimension mismatched in axis 0. slice(0, x_size0.1, 1) != slice(0, $40.4, 1)
```

(continues on next page)
To aid users unfamiliar with the transforms undertaken when the `parallel` option is used, and to assist in the understanding of the subsequent sections, the following definitions are provided:

- **Loop fusion** Loop fusion is a technique whereby loops with equivalent bounds may be combined under certain
conditions to produce a loop with a larger body (aiming to improve data locality).

- **Loop serialization**  Loop serialization occurs when any number of `prange` driven loops are present inside another `prange` driven loop. In this case the outermost of all the `prange` loops executes in parallel and any inner `prange` loops (nested or otherwise) are treated as standard `range` based loops. Essentially, nested parallelism does not occur.

- **Loop invariant code motion**  Loop invariant code motion is an optimization technique that analyses a loop to look for statements that can be moved outside the loop body without changing the result of executing the loop, these statements are then “hoisted” out of the loop to save repeated computation.

- **Allocation hoisting**  Allocation hoisting is a specialized case of loop invariant code motion that is possible due to the design of some common NumPy allocation methods. Explanation of this technique is best driven by an example:

```python
@njit(parallel=True)
def test(n):
    for i in prange(n):
        temp = np.zeros((50, 50))  # <-- Allocate a temporary array with np.
        for j in range(50):
            temp[j, j] = i
        # ...do something with temp
```

internally, this is transformed to approximately the following:

```python
@njit(parallel=True)
def test(n):
    for i in prange(n):
        temp = np.empty((50, 50))  # <-- np.zeros() is rewritten as np.empty()
        temp[:] = 0                 # <-- and then a zero initialisation
        for j in range(50):
            temp[j, j] = i
        # ...do something with temp
```

then after hoisting:

```python
@njit(parallel=True)
def test(n):
    temp = np.empty((50, 50))  # <-- allocation is hoisted as a loop invariant
    # as `np.empty` is considered pure
    for i in prange(n):
        temp[:] = 0               # <-- this remains as assignment is a side effect
    for j in range(50):
        temp[j, j] = i
    # ...do something with temp
```

it can be seen that the `np.zeros` allocation is split into an allocation and an assignment, and then the allocation is hoisted out of the loop in `i`, this producing more efficient code as the allocation only occurs once.
The parallel diagnostics report sections

The report is split into the following sections:

1. **Code annotation** This is the first section and contains the source code of the decorated function with loops that have parallel semantics identified and enumerated. The loop ID column on the right of the source code lines up with identified parallel loops. From the example, #0 is np.sin, #1 is np.cos and #2 and #3 are prange():

```python
from numba import njit
import numpy as np

@njit(parallel=True)
def test(x):
    n = x.shape[0]
    a = np.sin(x)
    b = np.cos(a ** a)
    acc = 0
    for i in prange(n - 2):
        for j in prange(n - 1):
            acc += b[i] + b[j + 1]
    return acc
```

It is worth noting that the loop IDs are enumerated in the order they are discovered which is not necessarily the same order as present in the source. Further, it should also be noted that the parallel transforms use a static counter for loop ID indexing. As a consequence it is possible for the loop ID index to not start at 0 due to use of the same counter for internal optimizations/transforms taking place that are invisible to the user.

2. **Fusing loops** This section describes the attempts made at fusing discovered loops noting which succeeded and which failed. In the case of failure to fuse a reason is given (e.g. dependency on other data). From the example:

```plaintext
Fusing loops

Attempting fusion of parallel loops (combines loops with similar properties)...
Trying to fuse loops #0 and #1:
- fusion succeeded: parallel for-loop #1 is fused into for-loop #0.
Trying to fuse loops #0 and #3:
- fusion failed: loop dimension mismatched in axis 0. slice(0, x_size0.1, 1) != slice(0, $40.4, 1)
```

It can be seen that fusion of loops #0 and #1 was attempted and this succeeded (both are based on the same dimensions of x). Following the successful fusion of #0 and #1, fusion was attempted between #0 (now including the fused #1 loop) and #3. This fusion failed because there is a loop dimension mismatch, #0 is size x.shape whereas #3 is size x.shape[0] - 2.

3. **Before Optimization** This section shows the structure of the parallel regions in the code before any optimization has taken place, but with loops associated with their final parallel region (this is to make before/after optimization output directly comparable). Multiple parallel regions may exist if there are loops which cannot be fused, in this case code within each region will execute in parallel, but each parallel region will run sequentially. From the example:

```
Parallel region 0:
---0 (parallel)
---1 (parallel)
```
As alluded to by the Fusing loops section, there are necessarily two parallel regions in the code. The first contains loops #0 and #1, the second contains #3 and #2, all loops are marked parallel as no optimization has taken place yet.

4. After Optimization This section shows the structure of the parallel regions in the code after optimization has taken place. Again, parallel regions are enumerated with their corresponding loops but this time loops which are fused or serialized are noted and a summary is presented. From the example:

```
Parallel region 0:
---0 (parallel, fused with loop(s): 1)

Parallel region 1:
---3 (parallel)
   ---2 (serial)

Parallel region 0 (loop #0) had 1 loop(s) fused.
Parallel region 1 (loop #3) had 0 loop(s) fused and 1 loop(s) serialized as part of the larger parallel loop (#3).
```

It can be noted that parallel region 0 contains loop #0 and, as seen in the fusing loops section, loop #1 is fused into loop #0. It can also be noted that parallel region 1 contains loop #3 and that loop #2 (the inner prange()) has been serialized for execution in the body of loop #3.

5. Loop invariant code motion This section shows for each loop, after optimization has occurred:

- the instructions that failed to be hoisted and the reason for failure (dependency/impure).
- the instructions that were hoisted.
- any allocation hoisting that may have occurred.

From the example:

```
Instruction hoisting:
loop #0:
Failed to hoist the following:
  dependency: $arg_out_var.10 =getitem(value=x, index=$parfor__index_5.99)
  dependency: $0.6.11 =getattr(value=$0.5, attr=sin)
  dependency: $expr_out_var.9 =call $0.6.11($arg_out_var.10, func=$0.6.11, ...)
  dependency: $arg_out_var.17 = $expr_out_var.9 * $expr_out_var.9
  dependency: $0.10.20 =getattr(value=$0.9, attr=cos)
  dependency: $expr_out_var.16 =call $0.10.20($arg_out_var.17, func=$0.10.20, ...

loop #3:
Has the following hoisted:
  $const58.3 = const(int, 1)
  $58.4 = _n_23 - $const58.3
```
The first thing to note is that this information is for advanced users as it refers to the Numba IR of the function being transformed. As an example, the expression \( a \times a \) in the example source partly translates to the expression $\text{arg\_out\_var.17} = $\text{expr\_out\_var.9} \times $\text{expr\_out\_var.9} in the IR, this clearly cannot be hoisted out of loop #0 because it is not loop invariant! Whereas in loop #3, the expression $\text{const58.3} = \text{const(int, 1)}$ comes from the source \( b[j + 1] \), the number 1 is clearly a constant and so can be hoisted out of the loop.

See also:

parallel, Parallel FAQs

### 1.11 Using the @stencil decorator

Stencils are a common computational pattern in which array elements are updated according to some fixed pattern called the stencil kernel. Numba provides the @stencil decorator so that users may easily specify a stencil kernel and Numba then generates the looping code necessary to apply that kernel to some input array. Thus, the stencil decorator allows clearer, more concise code and in conjunction with the parallel jit option enables higher performance through parallelization of the stencil execution.

#### 1.11.1 Basic usage

An example use of the @stencil decorator:

```python
from numba import stencil

@stencil
def kernel1(a):
    return 0.25 * (a[0, 1] + a[1, 0] + a[0, -1] + a[-1, 0])
```

The stencil kernel is specified by what looks like a standard Python function definition but there are different semantics with respect to array indexing. Stencils produce an output array of the same size and shape as the input array although depending on the kernel definition may have a different type. Conceptually, the stencil kernel is run once for each element in the output array. The return value from the stencil kernel is the value written into the output array for that particular element.

The parameter \( a \) represents the input array over which the kernel is applied. Indexing into this array takes place with respect to the current element of the output array being processed. For example, if element \((x, y)\) is being processed then \(a[0, 0]\) in the stencil kernel corresponds to \(a[x + 0, y + 0]\) in the input array. Similarly, \(a[-1, 1]\) in the stencil kernel corresponds to \(a[x - 1, y + 1]\) in the input array.

Depending on the specified kernel, the kernel may not be applicable to the borders of the output array as this may cause the input array to be accessed out-of-bounds. The way in which the stencil decorator handles this situation is dependent upon which `func_or_mode` is selected. The default mode is for the stencil decorator to set the border elements of the output array to zero.

To invoke a stencil on an input array, call the stencil as if it were a regular function and pass the input array as the argument. For example, using the kernel defined above:

```python
>>> import numpy as np
>>> input_arr = np.arange(100).reshape((10, 10))
array([[ 0,  1,  2,  3,  4,  5,  6,  7,  8,  9],
       [10, 11, 12, 13, 14, 15, 16, 17, 18, 19],
       [20, 21, 22, 23, 24, 25, 26, 27, 28, 29],
       [30, 31, 32, 33, 34, 35, 36, 37, 38, 39],
       [40, 41, 42, 43, 44, 45, 46, 47, 48, 49],
       [50, 51, 52, 53, 54, 55, 56, 57, 58, 59],
       [60, 61, 62, 63, 64, 65, 66, 67, 68, 69],
       [70, 71, 72, 73, 74, 75, 76, 77, 78, 79],
       [80, 81, 82, 83, 84, 85, 86, 87, 88, 89],
       [90, 91, 92, 93, 94, 95, 96, 97, 98, 99]])
```
Note that the stencil decorator has determined that the output type of the specified stencil kernel is \texttt{float64} and has thus created the output array as \texttt{float64} while the input array is of type \texttt{int64}.

### 1.11.2 Stencil Parameters

Stencil kernel definitions may take any number of arguments with the following provisions. The first argument must be an array. The size and shape of the output array will be the same as that of the first argument. Additional arguments may either be scalars or arrays. For array arguments, those arrays must be at least as large as the first argument (array) in each dimension. Array indexing is relative for all such input array arguments.

### 1.11.3 Kernel shape inference and border handling

In the above example and in most cases, the array indexing in the stencil kernel will exclusively use \texttt{Integer} literals. In such cases, the stencil decorator is able to analyze the stencil kernel to determine its size. In the above example, the stencil decorator determines that the kernel is $3 \times 3$ in shape since indices $-1$ to $1$ are used for both the first and second dimensions. Note that the stencil decorator also correctly handles non-symmetric and non-square stencil kernels.

Based on the size of the stencil kernel, the stencil decorator is able to compute the size of the border in the output array. If applying the kernel to some element of input array would cause an index to be out-of-bounds then that element belongs to the border of the output array. In the above example, points $-1$ and $+1$ are accessed in each dimension and thus the output array has a border of size one in all dimensions.

The parallel mode is able to infer kernel indices as constants from simple expressions if possible. For example:

```python
@njit(parallel=True)
def stencil_test(A):
    c = 2
    B = stencil(
```

(continues on next page)
lambda a, c: 0.3 * (a[-c+1] + a[0] + a[c-1]))(A, c)
return B

1.11.4 Stencil decorator options

Note: The stencil decorator may be augmented in the future to provide additional mechanisms for border handling. At present, only one behaviour is implemented, "constant" (see func_or_mode below for details).

neighborhood

Sometimes it may be inconvenient to write the stencil kernel exclusively with Integer literals. For example, let us say we would like to compute the trailing 30-day moving average of a time series of data. One could write 
\[(a[-29] + a[-28] + \ldots + a[-1] + a[0]) / 30\]
but the stencil decorator offers a more concise form using the neighborhood option:

```python
@stencil(neighborhood = ((-29, 0),))
def kernel2(a):
cumul = 0
for i in range(-29, 1):
cumul += a[i]
return cumul / 30
```

The neighborhood option is a tuple of tuples. The outer tuple's length is equal to the number of dimensions of the input array. The inner tuple's lengths are always two because each element of the inner tuple corresponds to minimum and maximum index offsets used in the corresponding dimension.

If a user specifies a neighborhood but the kernel accesses elements outside the specified neighborhood, the behavior is undefined.

func_or_mode

The optional func_or_mode parameter controls how the border of the output array is handled. Currently, there is only one supported value, "constant". In constant mode, the stencil kernel is not applied in cases where the kernel would access elements outside the valid range of the input array. In such cases, those elements in the output array are assigned to a constant value, as specified by the cval parameter.

cval

The optional cval parameter defaults to zero but can be set to any desired value, which is then used for the border of the output array if the func_or_mode parameter is set to constant. The cval parameter is ignored in all other modes. The type of the cval parameter must match the return type of the stencil kernel. If the user wishes the output array to be constructed from a particular type then they should ensure that the stencil kernel returns that type.
standard_indexing

By default, all array accesses in a stencil kernel are processed as relative indices as described above. However, sometimes it may be advantageous to pass an auxiliary array (e.g. an array of weights) to a stencil kernel and have that array use standard Python indexing rather than relative indexing. For this purpose, there is the stencil decorator option `standard_indexing` whose value is a collection of strings whose names match those parameters to the stencil function that are to be accessed with standard Python indexing rather than relative indexing:

```python
@stencil(standard_indexing=("b",))
def kernel3(a, b):
    return a[-1] * b[0] + a[0] + b[1]
```

### 1.11.5 StencilFunc

The stencil decorator returns a callable object of type `StencilFunc`. `StencilFunc` objects contain a number of attributes but the only one of potential interest to users is the `neighborhood` attribute. If the `neighborhood` option was passed to the stencil decorator then the provided neighborhood is stored in this attribute. Else, upon first execution or compilation, the system calculates the neighborhood as described above and then stores the computed neighborhood into this attribute. A user may then inspect the attribute if they wish to verify that the calculated neighborhood is correct.

### 1.11.6 Stencil invocation options

Internally, the stencil decorator transforms the specified stencil kernel into a regular Python function. This function will have the same parameters as specified in the stencil kernel definition but will also include the following optional parameter.

#### out

The optional `out` parameter is added to every stencil function generated by Numba. If specified, the `out` parameter tells Numba that the user is providing their own pre-allocated array to be used for the output of the stencil. In this case, the stencil function will not allocate its own output array. Users should assure that the return type of the stencil kernel can be safely cast to the element-type of the user-specified output array following the Numpy ufunc casting rules.

An example usage is shown below:

```python
>>> import numpy as np
>>> input_arr = np.arange(100).reshape((10, 10))
>>> output_arr = np.full(input_arr.shape, 0.0)
>>> kernel1(input_arr, out=output_arr)
```

### 1.12 Callback into the Python Interpreter from within JIT'ed code

There are rare but real cases when a nopython-mode function needs to callback into the Python interpreter to invoke code that cannot be compiled by Numba. Such cases include:

- logging progress for long running JIT’ed functions;
- use data structures that are not currently supported by Numba;
- debugging inside JIT’ed code using the Python debugger.
When Numba callbacks into the Python interpreter, the following has to happen:

- acquire the GIL;
- convert values in native representation back into Python objects;
- call-back into the Python interpreter;
- convert returned values from the Python-code into native representation;
- release the GIL.

These steps can be expensive. Users should not rely on the feature described here on performance-critical paths.

1.12.1 The objmode context-manager

**Warning:** This feature can be easily mis-used. Users should first consider alternative approaches to achieve their intended goal before using this feature.

```python
numba.objmode(*args, **kwargs)
```

Creates a contextmanager to be used inside jitted functions to enter *object-mode* for using interpreter features. The body of the with-context is lifted into a function that is compiled in *object-mode*. This transformation process is limited and cannot process all possible Python code. However, users can wrap complicated logic in another Python function, which will then be executed by the interpreter.

Use this as a function that takes keyword arguments only. The argument names must correspond to the output variables from the with-block. Their respective values can be:

1. strings representing the expected types; i.e. "float32".
2. compile-time bound global or nonlocal variables referring to the expected type. The variables are read at compile time.

When exiting the with-context, the output variables are converted to the expected nopython types according to the annotation. This process is the same as passing Python objects into arguments of a nopython function.

Example:

```python
import numpy as np
from numba import njit, objmode, types

def bar(x):
    # This code is executed by the interpreter.
    return np.asarray(list(reversed(x.tolist())))

# Output type as global variable
out_ty = types.intp[:]

@njit
def foo():
    x = np.arange(5)
    y = np.zeros_like(x)
    with objmode(y='intp[:]', z=out_ty):
        # annotate return type
        # this region is executed by object-mode.
        y += bar(x)

(continues on next page)
```
z = y

return y, z

**Note:** Known limitations:

- with-block cannot use incoming list objects.
- with-block cannot use incoming function objects.
- with-block cannot yield, break, return or raise such that the execution will leave the with-block immediately.
- with-block cannot contain with statements.
- random number generator states do not synchronize; i.e. no-python-mode and object-mode uses different RNG states.

**Note:** When used outside of no-python mode, the context-manager has no effect.

**Warning:** This feature is experimental. The supported features may change with or without notice.

### 1.13 Automatic module jitting with `jit_module`

A common usage pattern is to have an entire module containing user-defined functions that all need to be jitted. One option to accomplish this is to manually apply the `@jit` decorator to each function definition. This approach works and is great in many cases. However, for large modules with many functions, manually `jit`-wrapping each function definition can be tedious. For these situations, Numba provides another option, the `jit_module` function, to automatically replace functions declared in a module with their `jit`-wrapped equivalents.

It’s important to note the conditions under which `jit_module` will *not* impact a function:

1. Functions which have already been wrapped with a Numba decorator (e.g. `jit`, `vectorize`, `cfunc`, etc.) are not impacted by `jit_module`.
2. Functions which are declared outside the module from which `jit_module` is called are not automatically `jit`-wrapped.
3. Function declarations which occur logically after calling `jit_module` are not impacted.

All other functions in a module will have the `@jit` decorator automatically applied to them. See the following section for an example use case.

**Note:** This feature is for use by module authors. `jit_module` should not be called outside the context of a module containing functions to be jitted.
1.13.1 Example usage

Let’s assume we have a Python module we’ve created, mymodule.py (shown below), which contains several functions. Some of these functions are defined in mymodule.py while others are imported from other modules. We wish to have all the functions which are defined in mymodule.py jitted using jit_module.

```python
# mymodule.py
from numba import jit, jit_module
def inc(x):
    return x + 1
def add(x, y):
    return x + y
import numpy as np
# Use NumPy's mean function
mean = np.mean
@jit(nogil=True)
def mul(a, b):
    return a * b
jit_module(nopython=True, error_model="numpy")
def div(a, b):
    return a / b
```

There are several things to note in the above example:

- Both the inc and add functions will be replaced with their jit-wrapped equivalents with `compilation options` nopython=True and error_model="numpy".
- The mean function, because it’s defined outside of mymodule.py in NumPy, will not be modified.
- mul will not be modified because it has been manually decorated with jit.
- div will not be automatically jit-wrapped because it is declared after jit_module is called.

When the above module is imported, we have:

```shell
>>> import mymodule
>>> mymodule.inc
CPUDispatcher(<function inc at 0x1032f86a8>)
>>> mymodule.mean
<function mean at 0x1096b8950>
```
1.13.2 API

**Warning:** This feature is experimental. The supported features may change with or without notice.

```python
numba.jit_module(**kwargs)
    Automatically jit-wraps functions defined in a Python module

    Note that jit_module should only be called at the end of the module to be jitted. In addition, only functions
    which are defined in the module jit_module is called from are considered for automatic jit-wrapping. See the
    Numba documentation for more information about what can/cannot be jitted.

    Parameters kwargs – Keyword arguments to pass to jit such as nopython or error_model.
```

1.14 Performance Tips

This is a short guide to features present in Numba that can help with obtaining the best performance from code. Two examples are used, both are entirely contrived and exist purely for pedagogical reasons to motivate discussion. The first is the computation of the trigonometric identity \( \cos(x)^2 + \sin(x)^2 \), the second is a simple element wise square root of a vector with reduction over summation. All performance numbers are indicative only and unless otherwise stated were taken from running on an Intel i7-4790 CPU (4 hardware threads) with an input of `np.arange(1.e7)`.

**Note:** A reasonably effective approach to achieving high performance code is to profile the code running with real data and use that to guide performance tuning. The information presented here is to demonstrate features, not to act as canonical guidance!

1.14.1 No Python mode vs Object mode

A common pattern is to decorate functions with `@jit` as this is the most flexible decorator offered by Numba. `@jit` essentially encompasses two modes of compilation, first it will try and compile the decorated function in no Python mode, if this fails it will try again to compile the function using object mode. Whilst the use of looplifting in object mode can enable some performance increase, getting functions to compile under no python mode is really the key to good performance. To make it such that only no python mode is used and if compilation fails an exception is raised the decorators `@njit` and `@jit(nopython=True)` can be used (the first is an alias of the second for convenience).

1.14.2 Loops

Whilst NumPy has developed a strong idiom around the use of vector operations, Numba is perfectly happy with loops too. For users familiar with C or Fortran, writing Python in this style will work fine in Numba (after all, LLVM gets a lot of use in compiling C lineage languages). For example:

```python
@njit
def ident_np(x):
    return np.cos(x) ** 2 + np.sin(x) ** 2

@njit
def ident_loops(x):
    r = np.empty_like(x)
    n = len(x)
```

(continues on next page)
for i in range(n):
    r[i] = np.cos(x[i]) ** 2 + np.sin(x[i]) ** 2
return r

The above run at almost identical speeds when decorated with `@njit`, without the decorator the vectorized function is a couple of orders of magnitude faster.

<table>
<thead>
<tr>
<th>Function Name</th>
<th>@njit</th>
<th>Execution time</th>
</tr>
</thead>
<tbody>
<tr>
<td>ident_np</td>
<td>No</td>
<td>0.581s</td>
</tr>
<tr>
<td>ident_np</td>
<td>Yes</td>
<td>0.659s</td>
</tr>
<tr>
<td>ident_loops</td>
<td>No</td>
<td>25.2s</td>
</tr>
<tr>
<td>ident_loops</td>
<td>Yes</td>
<td>0.670s</td>
</tr>
</tbody>
</table>

### 1.14.3 Fastmath

In certain classes of applications strict IEEE 754 compliance is less important. As a result it is possible to relax some numerical rigour with view of gaining additional performance. The way to achieve this behaviour in Numba is through the use of the `fastmath` keyword argument:

```python
@njit(fastmath=False)
def do_sum(A):
    acc = 0.
    # without fastmath, this loop must accumulate in strict order
    for x in A:
        acc += np.sqrt(x)
    return acc

@njit(fastmath=True)
def do_sum_fast(A):
    acc = 0.
    # with fastmath, the reduction can be vectorized as floating point
    # reassociation is permitted.
    for x in A:
        acc += np.sqrt(x)
    return acc
```

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Execution time</th>
</tr>
</thead>
<tbody>
<tr>
<td>do_sum</td>
<td>35.2 ms</td>
</tr>
<tr>
<td>do_sum_fast</td>
<td>17.8 ms</td>
</tr>
</tbody>
</table>

In some cases you may wish to opt-in to only a subset of possible fast-math optimizations. This can be done by supplying a set of LLVM fast-math flags to `fastmath`:

```python
def add_assoc(x, y):
    return (x - y) + y

print(njit(fastmath=False)(add_assoc)(0, np.inf)) # nan
print(njit(fastmath=True) (add_assoc)(0, np.inf)) # 0.0
print(njit(fastmath={'reassoc', 'nsz'})(add_assoc)(0, np.inf)) # 0.0
```
1.14.4 Parallel=True

If code contains operations that are parallelisable (and supported) Numba can compile a version that will run in parallel on multiple native threads (no GIL!). This parallelisation is performed automatically and is enabled by simply adding the parallel keyword argument:

```python
@njit(parallel=True)
def ident_parallel(x):
    return np.cos(x) ** 2 + np.sin(x) ** 2
```

Executions times are as follows:

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Execution time</th>
</tr>
</thead>
<tbody>
<tr>
<td>ident_parallel</td>
<td>112 ms</td>
</tr>
</tbody>
</table>

The execution speed of this function with parallel=True present is approximately 5x that of the NumPy equivalent and 6x that of standard @njit.

Numba parallel execution also has support for explicit parallel loop declaration similar to that in OpenMP. To indicate that a loop should be executed in parallel the numba.prange function should be used, this function behaves like Python range and if parallel=True is not set it acts simply as an alias of range. Loops induced with prange can be used for embarrassingly parallel computation and also reductions.

Revisiting the reduce over sum example, assuming it is safe for the sum to be accumulated out of order, the loop in n can be parallelised through the use of prange. Further, the fastmath=True keyword argument can be added without concern in this case as the assumption that out of order execution is valid has already been made through the use of parallel=True (as each thread computes a partial sum).

```python
@njit(parallel=True)
def do_sum_parallel(A):
    # each thread can accumulate its own partial sum, and then a cross
    # thread reduction is performed to obtain the result to return
    n = len(A)
    acc = 0.
    for i in prange(n):
        acc += np.sqrt(A[i])
    return acc

@njit(parallel=True, fastmath=True)
def do_sum_parallel_fast(A):
    n = len(A)
    acc = 0.
    for i in prange(n):
        acc += np.sqrt(A[i])
    return acc
```

Execution times are as follows, fastmath again improves performance.
1.14.5 Intel SVML

Intel provides a short vector math library (SVML) that contains a large number of optimised transcendental functions available for use as compiler intrinsics. If the icc_rt package is present in the environment (or the SVML libraries are simply locatable!) then Numba automatically configures the LLVM back end to use the SVML intrinsic functions where ever possible. SVML provides both high and low accuracy versions of each intrinsic and the version that is used is determined through the use of the fastmath keyword. The default is to use high accuracy which is accurate to within 1 ULP, however if fastmath is set to True then the lower accuracy versions of the intrinsics are used (answers to within 4 ULP).

First obtain SVML, using conda for example:

```
conda install -c numba icc_rt
```

Rerunning the identity function example ident_np from above with various combinations of options to @njit and with/without SVML yields the following performance results (input size np.arange(1.e8)). For reference, with just NumPy the function executed in 5.84s:

<table>
<thead>
<tr>
<th>@njit kwargs</th>
<th>SVML</th>
<th>Execution time</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>No</td>
<td>5.95s</td>
</tr>
<tr>
<td>None</td>
<td>Yes</td>
<td>2.26s</td>
</tr>
<tr>
<td>fastmath=True</td>
<td>No</td>
<td>5.97s</td>
</tr>
<tr>
<td>fastmath=True</td>
<td>Yes</td>
<td>1.8s</td>
</tr>
<tr>
<td>parallel=True</td>
<td>No</td>
<td>1.36s</td>
</tr>
<tr>
<td>parallel=True</td>
<td>Yes</td>
<td>0.624s</td>
</tr>
<tr>
<td>parallel=True, fastmath=True</td>
<td>No</td>
<td>1.32s</td>
</tr>
<tr>
<td>parallel=True, fastmath=True</td>
<td>Yes</td>
<td>0.576s</td>
</tr>
</tbody>
</table>

It is evident that SVML significantly increases the performance of this function. The impact of fastmath in the case of SVML not being present is zero, this is expected as there is nothing in the original function that would benefit from relaxing numerical strictness.

1.14.6 Linear algebra

Numba supports most of numpy.linalg in no Python mode. The internal implementation relies on a LAPACK and BLAS library to do the numerical work and it obtains the bindings for the necessary functions from SciPy. Therefore, to achieve good performance in numpy.linalg functions with Numba it is necessary to use a SciPy built against a well optimised LAPACK/BLAS library. In the case of the Anaconda distribution SciPy is built against Intel’s MKL which is highly optimised and as a result Numba makes use of this performance.
1.15 The Threading Layers

This section is about the Numba threading layer, this is the library that is used internally to perform the parallel execution that occurs through the use of the parallel targets for CPUs, namely:

- The use of the parallel=True kwarg in @jit and @njit.
- The use of the target='parallel' kwarg in @vectorize and @guvectorize.

Note: If a code base does not use the threading or multiprocessing modules (or any other sort of parallelism) the defaults for the threading layer that ship with Numba will work well, no further action is required!

1.15.1 Which threading layers are available?

There are three threading layers available and they are named as follows:

- tbb - A threading layer backed by Intel TBB.
- omp - A threading layer backed by OpenMP.
- workqueue - A simple built-in work-sharing task scheduler.

In practice, the only threading layer guaranteed to be present is workqueue. The omp layer requires the presence of a suitable OpenMP runtime library. The tbb layer requires the presence of Intel’s TBB libraries, these can be obtained via the conda command:

```
$ conda install tbb
```

If you installed Numba with pip, TBB can be enabled by running:

```
$ pip install tbb
```

Due to compatibility issues with manylinux1 and other portability concerns, the OpenMP threading layer is disabled in the Numba binary wheels on PyPI.

Note: The default manner in which Numba searches for and loads a threading layer is tolerant of missing libraries, incompatible runtimes etc.

1.15.2 Setting the threading layer

The threading layer is set via the environment variable NUMBA_THREADING_LAYER or through assignment to numba.config.THREADING_LAYER. If the programmatic approach to setting the threading layer is used it must occur logically before any Numba based compilation for a parallel target has occurred. There are two approaches to choosing a threading layer, the first is by selecting a threading layer that is safe under various forms of parallel execution, the second is through explicit selection via the threading layer name (e.g. tbb).
1.15.3 Setting the threading layer selection priority

By default the threading layers are searched in the order of 'tbb', 'omp', then 'workqueue'. To change this search order whilst maintaining the selection of a threading layer based on availability, the environment variable `NUMBA_THREADING_LAYER_PRIORITY` can be used.

Note that it can also be set via `numba.config.THREADING_LAYER_PRIORITY`. Similar to `numba.config.THREADING_LAYER`, it must occur logically before any Numba based compilation for a parallel target has occurred.

For example, to instruct Numba to choose `omp` first if available, then `tbb` and so on, set the environment variable as `NUMBA_THREADING_LAYER_PRIORITY="omp tbb workqueue"`. Or programmatically, `numba.config.THREADING_LAYER_PRIORITY = ["omp", "tbb", "workqueue"]`.

Selecting a threading layer for safe parallel execution

Parallel execution is fundamentally derived from core Python libraries in four forms (the first three also apply to code using parallel execution via other means!):

- threads from the `threading` module.
- spawning processes from the `multiprocessing` module via `spawn` (default on Windows, only available in Python 3.4+ on Unix).
- `forking` processes from the `multiprocessing` module via `fork` (default on Unix).
- `forking` processes from the `multiprocessing` module through the use of a `forkserver` (only available in Python 3 on Unix). Essentially a new process is spawned and then forks are made from this new process on request.

Any library in use with these forms of parallelism must exhibit safe behaviour under the given paradigm. As a result, the threading layer selection methods are designed to provide a way to choose a threading layer library that is safe for a given paradigm in an easy, cross platform and environment tolerant manner. The options that can be supplied to the setting mechanisms are as follows:

- `default` provides no specific safety guarantee and is the default.
- `safe` is both fork and thread safe, this requires the `tbb` package (Intel TBB libraries) to be installed.
- `forksafe` provides a fork safe library.
- `threadsafe` provides a thread safe library.

To discover the threading layer that was selected, the function `numba.threading_layer()` may be called after parallel execution. For example, on a Linux machine with no TBB installed:

```python
from numba import config, njit, threading_layer
import numpy as np

# set the threading layer before any parallel target compilation
config.THREADING_LAYER = 'threadsafe'

@njit(parallel=True)
def foo(a, b):
    return a + b

x = np.arange(10.)
y = x.copy()

# this will force the compilation of the function, select a threading layer
```
# and then execute in parallel
foo(x, y)

# demonstrate the threading layer chosen
print("Threading layer chosen: %s" % threading_layer())

which produces:

Threading layer chosen: omp

and this makes sense as GNU OpenMP, as present on Linux, is thread safe.

Selecting a named threading layer

Advanced users may wish to select a specific threading layer for their use case, this is done by directly supplying the threading layer name to the setting mechanisms. The options and requirements are as follows:

<table>
<thead>
<tr>
<th>Threading Layer Name</th>
<th>Platform</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>tbb</td>
<td>All</td>
<td>The tbb package ($ conda install tbb)</td>
</tr>
<tr>
<td>omp</td>
<td>Linux</td>
<td>GNU OpenMP libraries (very likely this will already exist)</td>
</tr>
<tr>
<td></td>
<td>Windows</td>
<td>MS OpenMP libraries (very likely this will already exist)</td>
</tr>
<tr>
<td></td>
<td>OSX</td>
<td>Either the intel-openmp package or the llvm-openmp package (conda install the package as named).</td>
</tr>
<tr>
<td>workqueue</td>
<td>All</td>
<td>None</td>
</tr>
</tbody>
</table>

Should the threading layer not load correctly Numba will detect this and provide a hint about how to resolve the problem. It should also be noted that the Numba diagnostic command numba -s has a section __Threading Layer Information__ that reports on the availability of threading layers in the current environment.

### 1.15.4 Extra notes

The threading layers have fairly complex interactions with CPython internals and system level libraries, some additional things to note:

- The installation of Intel’s TBB libraries vastly widens the options available in the threading layer selection process.
- On Linux, the omp threading layer is not fork safe due to the GNU OpenMP runtime library (libgomp) not being fork safe. If a fork occurs in a program that is using the omp threading layer, a detection mechanism is present that will try and gracefully terminate the forked child and print an error message to STDERR.
- On systems with the fork(2) system call available, if the TBB backed threading layer is in use and a fork call is made from a thread other than the thread that launched TBB (typically the main thread) then this results in undefined behaviour and a warning will be displayed on STDERR. As spawn is essentially fork followed by exec it is safe to spawn from a non-main thread, but as this cannot be differentiated from just a fork call the warning message will still be displayed.
- On OSX, the intel-openmp package is required to enable the OpenMP based threading layer.
1.15.5 Setting the Number of Threads

The number of threads used by numba is based on the number of CPU cores available (see `numba.config.NUMBA_DEFAULT_NUM_THREADS`), but it can be overridden with the `NUMBA_NUM_THREADS` environment variable.

The total number of threads that numba launches is in the variable `numba.config.NUMBA_NUM_THREADS`.

For some use cases, it may be desirable to set the number of threads to a lower value, so that numba can be used with higher level parallelism.

The number of threads can be set dynamically at runtime using `numba.set_num_threads()`. Note that `set_num_threads()` only allows setting the number of threads to a smaller value than `NUMBA_NUM_THREADS`. Numba always launches `numba.config.NUMBA_NUM_THREADS` threads, but `set_num_threads()` causes it to mask out unused threads so they aren’t used in computations.

The current number of threads used by numba can be accessed with `numba.get_num_threads()`. Both functions work inside of a jitted function.

Example of Limiting the Number of Threads

In this example, suppose the machine we are running on has 8 cores (so `numba.config.NUMBA_NUM_THREADS` would be 8). Suppose we want to run some code with `@njit(parallel=True)`, but we also want to run our code concurrently in 4 different processes. With the default number of threads, each Python process would run 8 threads, for a total in $4 \times 8 = 32$ threads, which is oversubscription for our 8 cores. We should rather limit each process to 2 threads, so that the total will be $4 \times 2 = 8$, which matches our number of physical cores.

There are two ways to do this. One is to set the `NUMBA_NUM_THREADS` environment variable to 2.

```
$ NUMBA_NUM_THREADS=2 python ourcode.py
```

However, there are two downsides to this approach:

1. `NUMBA_NUM_THREADS` must be set before Numba is imported, and ideally before Python is launched. As soon as Numba is imported the environment variable is read and that number of threads is locked in as the number of threads Numba launches.

2. If we want to later increase the number of threads used by the process, we cannot. `NUMBA_NUM_THREADS` sets the maximum number of threads that are launched for a process. Calling `set_num_threads()` with a value greater than `numba.config.NUMBA_NUM_THREADS` results in an error.

The advantage of this approach is that we can do it from outside of the process without changing the code.

Another approach is to use the `numba.set_num_threads()` function in our code.

```python
from numba import njit, set_num_threads

@njit(parallel=True)
def func():
    ...

set_num_threads(2)
func()
```

If we call `set_num_threads(2)` before executing our parallel code, it has the same effect as calling the process with `NUMBA_NUM_THREADS=2`, in that the parallel code will only execute on 2 threads. However, we can later call `set_num_threads(8)` to increase the number of threads back to the default size. And we do not have to worry about setting it before Numba gets imported. It only needs to be called before the parallel function is run.
API Reference

numba.config.NUMBA_NUM_THREADS
The total (maximum) number of threads launched by numba.

Defaults to numba.config.NUMBA_DEFAULT_NUM_THREADS, but can be overridden with the
NUMBA_NUM_THREADS environment variable.

numba.config.NUMBA_DEFAULT_NUM_THREADS
The number of usable CPU cores on the system (as determined by len(os.sched_getaffinity(0)), if sup-
ported by the OS, or multiprocessing.cpu_count() if not). This is the default value for numba.config.
NUMBA_NUM_THREADS unless the NUMBA_NUM_THREADS environment variable is set.

numba.set_num_threads(n)
Set the number of threads to use for parallel execution.

By default, all numba.config.NUMBA_NUM_THREADS threads are used.

This functionality works by masking out threads that are not used. Therefore, the number of threads n must be
less than or equal to NUMBA_NUM_THREADS, the total number of threads that are launched. See its documentation
for more details.

This function can be used inside of a jitted function.

Parameters

n: The number of threads. Must be between 1 and NUMBA_NUM_THREADS.

See also:

get_num_threads, numba.config.NUMBA_NUM_THREADS
numba.config.NUMBA_DEFAULT_NUM_THREADS, NUMBA_NUM_THREADS

numba.get_num_threads()
Get the number of threads used for parallel execution.

By default (if set_num_threads() is never called), all numba.config.NUMBA_NUM_THREADS threads are used.

This number is less than or equal to the total number of threads that are launched, numba.config.
NUMBA_NUM_THREADS.

This function can be used inside of a jitted function.

Returns

The number of threads.

See also:

set_num_threads, numba.config.NUMBA_NUM_THREADS
numba.config.NUMBA_DEFAULT_NUM_THREADS, NUMBA_NUM_THREADS
1.16 Command line interface

Numba is a Python package, usually you import numba from Python and use the Python application programming interface (API). However, Numba also ships with a command line interface (CLI), i.e. a tool numba that is installed when you install Numba.

Currently, the only purpose of the CLI is to allow you to quickly show some information about your system and installation, or to quickly get some debugging information for a Python script using Numba.

1.16.1 Usage

To use the Numba CLI from the terminal, use numba followed by the options and arguments like --help or -s, as explained below.

Sometimes it can happen that you get a “command not found” error when you type numba, because your PATH isn’t configured properly. In that case you can use the equivalent command python -m numba. If that still gives “command not found”, try to import numba as suggested here: Dependency List.

The two versions numba and python -m numba are the same. The first is shorter to type, but if you get a “command not found” error because your PATH doesn’t contain the location where numba is installed, having the python -m numba variant is useful.

To use the Numba CLI from IPython or Jupyter, use !numba, i.e. prefix the command with an exclamation mark. This is a general IPython/Jupyter feature to execute shell commands, it is not available in the regular python terminal.

1.16.2 Help

To see all available options, use numba --help:

```
$ numba --help
            [--dump-assembly] [--dump-cfg] [--dump-ast]
            [--annotate-html ANNOTATE_HTML] [-s]
            [filename]

positional arguments:
  filename  Python source filename

optional arguments:
  -h, --help            show this help message and exit
  --annotate            Annotate source
  --dump-llvm           Print generated llvm assembly
  --dump-optimized      Dump the optimized llvm assembly
  --dump-assembly       Dump the LLVM generated assembly
  --dump-cfg            [Deprecated] Dump the control flow graph
  --dump-ast            [Deprecated] Dump the AST
  --annotate-html ANNOTATE_HTML
                         Output source annotation as html
  -s, --sysinfo         Output system information for bug reporting
```

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1.16.3 System information

The `numba -s` (or the equivalent `numba --sysinfo`) command prints a lot of information about your system and your Numba installation and relevant dependencies.

Remember: you can use `!numba -s` with an exclamation mark to see this information from IPython or Jupyter.

Example output:

```
$ numba -s

System info:

__Time Stamp__
2019-05-07 14:15:39.733994

__Hardware Information__
Machine : x86_64
CPU Name : haswell
CPU count : 8
CPU Features : aes avx avx2 bmi bmi2 cmov cx16 f16c fma fsgsbase invpcid lzcnt mmx movbe pclmul popcnt rdrnd sahf sse sse2 sse3 sse4.1 sse4.2 ssse3 xsave xsaveopt

__OS Information__
Platform : Darwin-18.5.0-x86_64-i386-64bit
Release : 18.5.0
System Name : Darwin
OS specific info : 10.14.4 x86_64

__Python Information__
Python Compiler : Clang 4.0.1 (tags/RELEASE_401/final)
Python Implementation : CPython
Python Version : 3.7.3
Python Locale : en_US UTF-8

__LLVM information__
LLVM version : 7.0.0

__CUDA Information__
CUDA driver library cannot be found or no CUDA enabled devices are present.
Error class: <class 'numba.cuda.cudadrv.error.CudaSupportError'>

__SVML Information__
SVML state, config.USING_SVML : False
SVML library found and loaded : False
llvmmlite using SVML patched LLVM : True
SVML operational : False

__Threading Layer Information__
TBB Threading layer available : False
+++> Disabled due to : Unknown import problem.
```

(continues on next page)
OpenMP Threading layer available : False
+++ Disabled due to : Unknown import problem.
Workqueue Threading layer available : True

__Numba Environment Variable Information__
None set.

__Conda Information__
conda_build_version : 3.17.8
conda_env_version : 4.6.14
platform : osx-64
python_version : 3.7.3.final.0
root_writable : True

__Current Conda Env__
(output truncated due to length)

1.16.4 Debugging

As shown in the help output above, the numba command includes options that can help you to debug Numba compiled code.

To try it out, create an example script called myscript.py:

```python
import numba

@numba.jit
def f(x):
    return 2 * x

f(42)
```

and then execute one of the following commands:

```
$ numba myscript.py --annotate
$ numba myscript.py --annotate-html myscript.html
$ numba myscript.py --dump-llvm
$ numba myscript.py --dump-optimized
$ numba myscript.py --dump-assembly
```

1.17 Troubleshooting and tips

1.17.1 What to compile

The general recommendation is that you should only try to compile the critical paths in your code. If you have a piece of performance-critical computational code amongst some higher-level code, you may factor out the performance-critical code in a separate function and compile the separate function with Numba. Letting Numba focus on that small piece of performance-critical code has several advantages:

- it reduces the risk of hitting unsupported features;
• it reduces the compilation times;
• it allows you to evolve the higher-level code which is outside of the compiled function much easier.

1.17.2 My code doesn’t compile

There can be various reasons why Numba cannot compile your code, and raises an error instead. One common reason is that your code relies on an unsupported Python feature, especially in nopython mode. Please see the list of Supported Python features. If you find something that is listed there and still fails compiling, please report a bug.

When Numba tries to compile your code it first tries to work out the types of all the variables in use, this is so it can generate a type specific implementation of your code that can be compiled down to machine code. A common reason for Numba failing to compile (especially in nopython mode) is a type inference failure, essentially Numba cannot work out what the type of all the variables in your code should be.

For example, let’s consider this trivial function:

```python
@jit(nopython=True)
def f(x, y):
    return x + y
```

If you call it with two numbers, Numba is able to infer the types properly:

```python
>>> f(1, 2)
3
```

If however you call it with a tuple and a number, Numba is unable to say what the result of adding a tuple and number is, and therefore compilation errors out:

```python
>>> f(1, (2,))
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<path>/numba/numba/dispatcher.py", line 339, in _compile_for_args
    raise type(e), e, None
  File "<path>/numba/numba/six.py", line 658, in reraise
    raise value.with_traceback(tb)
numba.errors.TypingError: Failed at nopython (nopython frontend)
Invalid use of + with parameters (int64, tuple(int64 x 1))
Known signatures:
* (int64, int64) -> int64
* (int64, uint64) -> int64
* (uint64, int64) -> int64
* (uint64, uint64) -> uint64
* (float32, float32) -> float32
* (float64, float64) -> float64
* (complex64, complex64) -> complex64
* (complex128, complex128) -> complex128
* (uint16,) -> uint64
* (uint8,) -> uint64
* (uint64,) -> uint64
* (uint32,) -> uint64
* (int16,) -> int64
* (int64,) -> int64
* (int8,) -> int64
```

(continues on next page)
* (int32,) -> int64
* (float32,) -> float32
* (float64,) -> float64
* (complex64,) -> complex64
* (complex128,) -> complex128
* parameterized

[1] During: typing of intrinsic-call at <stdin> (3)

File "<stdin>", line 3:

The error message helps you find out what went wrong: “Invalid use of + with parameters (int64, tuple(int64 x 1))” is to be interpreted as “Numba encountered an addition of variables typed as integer and 1-tuple of integer, respectively, and doesn’t know about any such operation”.

Note that if you allow object mode:

```python
@jit
def g(x, y):
    return x + y
```

compilation will succeed and the compiled function will raise at runtime as Python would do:

```python
>>> g(1, (2,))
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'int' and 'tuple'
```

### 1.17.3 My code has a type unification problem

Another common reason for Numba not being able to compile your code is that it cannot statically determine the return type of a function. The most likely cause of this is the return type depending on a value that is available only at runtime. Again, this is most often problematic when using `nopython mode`. The concept of type unification is simply trying to find a type in which two variables could safely be represented. For example a 64 bit float and a 64 bit complex number could both be represented in a 128 bit complex number.

As an example of type unification failure, this function has a return type that is determined at runtime based on the value of `x`:

```python
In [1]: from numba import jit

In [2]: @jit(nopython=True)
...: def f(x):
...:     if x > 10:
...:         return (1,)
...:     else:
...:         return 1
...:

In [3]: f(10)
```

Trying to execute this function, errors out as follows:
TypingError: Failed at nopython (nopython frontend)
Can't unify return type from the following types: tuple(int64 x 1), int64
Return of: IR name '$8.2', type '(int64 x 1)', location:
File "<ipython-input-2-51ef1cc64bea>", line 4:
def f(x):
    if x > 10:
        return (1,)
    ^
Return of: IR name '$12.2', type 'int64', location:
File "<ipython-input-2-51ef1cc64bea>", line 6:
def f(x):
    else:
        return 1

The error message “Can’t unify return type from the following types: tuple(int64 x 1), int64” should be read as “Numba cannot find a type that can safely represent a 1-tuple of integer and an integer”.

1.17.4 My code has an untyped list problem

As noted previously the first part of Numba compiling your code involves working out what the types of all the variables are. In the case of lists, a list must contain items that are of the same type or can be empty if the type can be inferred from some later operation. What is not possible is to have a list which is defined as empty and has no inferable type (i.e. an untyped list).

For example, this is using a list of a known type:

```python
from numba import jit
@jit(nopython=True)
def f():
    return [1, 2, 3]  # this list is defined on construction with `int` type
```

This is using an empty list, but the type can be inferred:

```python
from numba import jit
@jit(nopython=True)
def f(x):
    tmp = []  # defined empty
    for i in range(x):
        tmp.append(i)  # list type can be inferred from the type of `i`
    return tmp
```

This is using an empty list and the type cannot be inferred:

```python
from numba import jit
@jit(nopython=True)
def f(x):
    tmp = []  # defined empty
    return (tmp, x)  # ERROR: the type of `tmp` is unknown
```

Whilst slightly contrived, if you need an empty list and the type cannot be inferred but you know what type you want the list to be, this “trick” can be used to instruct the typing mechanism:
from numba import jit
import numpy as np
@jit(nopython=True)
def f(x):
    # define empty list, but instruct that the type is np.complex64
    tmp = [np.complex64(x) for x in range(0)]
    return (tmp, x)  # the type of `tmp` is known, but it is still empty

1.17.5 The compiled code is too slow

The most common reason for slowness of a compiled JIT function is that compiling in nopython mode has failed and the Numba compiler has fallen back to object mode. object mode currently provides little to no speedup compared to regular Python interpretation, and its main point is to allow an internal optimization known as loop-lifting: this optimization will allow to compile inner loops in nopython mode regardless of what code surrounds those inner loops.

To find out if type inference succeeded on your function, you can use the inspect_types() method on the compiled function.

For example, let’s take the following function:

```python
@jit
def f(a, b):
    s = a + float(b)
    return s
```

When called with numbers, this function should be fast as Numba is able to convert number types to floating-point numbers. Let’s see:

```python
>>> f(1, 2)
3.0
>>> f.inspect_types()
f (int64, int64)
```

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Without trying to understand too much of the Numba intermediate representation, it is still visible that all variables and temporary values have had their types inferred properly: for example $a$ has the type int64, $0.5$ has the type float64, etc.

However, if $b$ is passed as a string, compilation will fall back on object mode as the float() constructor with a string is currently not supported by Numba:

```python
>>> f(1, "2")
3.0
>>> f.inspect_types()
[... snip annotations for other signatures, see above ...]
================================================================================
  f (int64, str)
  --------------------------------------------------------------------------------
# --- LINE 7 ---
@jit
# --- LINE 8 ---

def f(a, b):

  # --- LINE 9 ---
  # label 0
  # a.1 = a :: pyobject
  # del a
  # b.1 = b :: pyobject
  # del b
  # $0.2 = global(float: <class 'float'>) :: pyobject
  # $0.4 = call $0.2(b.1, ) :: pyobject
  # del b.1
  # del $0.2
  # $0.5 = a.1 + $0.4 :: pyobject
  # del a.1
  # del $0.4
  # s = $0.5 :: pyobject
  # del $0.5
  s = a + float(b)
```

(continues on previous page)
Here we see that all variables end up typed as `pyobject`. This means that the function was compiled in object mode and values are passed around as generic Python objects, without Numba trying to look into them to reason about their raw values. This is a situation you want to avoid when caring about the speed of your code.

If a function fails to compile in `nopython` mode, warnings will be emitted with explanation as to why compilation failed. For example with the `f()` function above (slightly edited for documentation purposes):

```python
>>> f(1, 2)
3.0
>>> f(1, "2")
```

```
example.py:7: NumbaWarning: Compilation is falling back to object mode WITH looplifting enabled because Function "f" failed type inference due to: Invalid use of Function(<class 'float'>) with argument(s) of type(s): (unicode_type) * parameterized
In definition 0:
  TypeError: float() only support for numbers
  raised from <path>/numba/typing/builtins.py:880
In definition 1:
  TypeError: float() only support for numbers
  raised from <path>/numba/typing/builtins.py:880
```

This error is usually caused by passing an argument of a type that is unsupported by the named function.

[1] During: resolving callee type: Function(<class 'float'>)
[2] During: typing of call at example.py (9)

```
File "example.py", line 9:
def f(a, b):
    s = a + float(b)

<path>/numba/compiler.py:722: NumbaWarning: Function "f" was compiled in object mode without forceobj=True.
File "example.py", line 8:
@jit
def f(a, b):
```

```python
3.0
```
1.17.6 Disabling JIT compilation

In order to debug code, it is possible to disable JIT compilation, which makes the `jit` decorator (and the `njit` decorator) act as if they perform no operation, and the invocation of decorated functions calls the original Python function instead of a compiled version. This can be toggled by setting the `NUMBA_DISABLE_JIT` environment variable to 1.

When this mode is enabled, the `vectorize` and `guvectorize` decorators will still result in compilation of a `ufunc`, as there is no straightforward pure Python implementation of these functions.

1.17.7 Debugging JIT compiled code with GDB

Setting the `debug` keyword argument in the `jit` decorator (e.g. `@jit(debug=True)`) enables the emission of debug info in the jitted code. To debug, GDB version 7.0 or above is required. Currently, the following debug info is available:

- Function name will be shown in the backtrace along with type information and values (if available).
- Source location (filename and line number) is available. For example, users can set a break point by the absolute filename and line number; e.g. `break /path/to/myfile.py:6`.
- Arguments to the current function can be show with `info args`
- Local variables in the current function can be shown with `info locals`.
- The type of variables can be shown with `whatis myvar`.
- The value of variables can be shown with `print myvar` or `display myvar`.
  - Simple numeric types, i.e. int, float and double, are shown in their native representation.
  - Other types are shown as a structure based on Numba’s memory model representation of the type.

Known issues:

- Stepping depends heavily on optimization level. At full optimization (equivalent to O3), most of the variables are optimized out. It is often beneficial to use the environment variable `NUMBA_OPT` to adjust the optimization level and `NUMBA_EXTEND_VARIABLE_LIFETIMES` to extend the lifetime of variables to the end of their scope so as to get a debugging experience closer to the semantics of Python execution.
- Memory consumption increases significantly with debug info enabled. The compiler emits extra information (DWARF) along with the instructions. The emitted object code can be 2x bigger with debug info.

Internal details:

- Since Python semantics allow variables to bind to value of different types, Numba internally creates multiple versions of the variable for each type. So for code like:

  ```
x = 1  # type int
x = 2.3  # type float
x = (1, 2, 3)  # type 3-tuple of int
  ```

Each assignments will store to a different variable name. In the debugger, the variables will be `x`, `x$1` and `x$2`. (In the Numba IR, they are `x`, `x.1` and `x.2`.)
- When debug is enabled, inlining of functions at LLVM IR level is disabled.
Example debug usage

The python source:

```python
from numba import njit

@njit(debug=True)
def foo(a):
    b = a + 1
    c = a * 2.34
    d = (a, b, c)
    print(a, b, c, d)

r = foo(123)
print(r)
```

In the terminal:

```
$ NUMBA_OPT=0 NUMBA_EXTEND_VARIABLE_LIFETIMES=1 gdb -q python
Reading symbols from python...
(gdb) break test1.py:5
No source file named test1.py.
Make breakpoint pending on future shared library load? (y or [n]) y
Breakpoint 1 (test1.py:5) pending.
(gdb) run test1.py
Starting program: <path>/bin/python test1.py
... Breakpoint 1, __main__::foo_241[abi:c8tJTC_2fWgEeGLSgydRTQUgiqKEZ6gEoDvQJmaQIA](long␣
˓
long) (a=123) at test1.py:5
  5   b = a + 1
(gdb) info args
a = 123
(gdb) n
  6   c = a * 2.34
(gdb) info locals
b = 124
c = 0
d = {f0 = 0, f1 = 0, f2 = 0}
(gdb) n
  7   d = (a, b, c)
(gdb) info locals
b = 124
c = 287.81999999999999
d = {f0 = 0, f1 = 0, f2 = 0}
(gdb) whatis b
type = int64
(gdb) whatis d
type = Tuple(int64, int64, float64) ({i64, i64, double})
(gdb) n
  8   print(a, b, c, d)
(gdb) print b
$1 = 124
(gdb) print d
$2 = {f0 = 123, f1 = 124, f2 = 287.81999999999999}
```

(continues on next page)
Globally override debug setting

It is possible to enable debug for the full application by setting environment variable `NUMBA_DEBUGINFO=1`. This sets the default value of the debug option in `jit`. Debug can be turned off on individual functions by setting `debug=False`.

Beware that enabling debug info significantly increases the memory consumption for each compiled function. For large application, this may cause out-of-memory error.

1.17.8 Using Numba's direct gdb bindings in nopython mode

Numba (version 0.42.0 and later) has some additional functions relating to gdb support for CPUs that make it easier to debug programs. All the gdb related functions described in the following work in the same manner irrespective of whether they are called from the standard CPython interpreter or code compiled in either nopython mode or object mode.

**Note:** This feature is experimental!

**Warning:** This feature does unexpected things if used from Jupyter or alongside the pdb module. It’s behaviour is harmless, just hard to predict!

Set up

Numba’s gdb related functions make use of a gdb binary, the location and name of this binary can be configured via the `NUMBA_GDB_BINARY` environment variable if desired.

**Note:** Numba’s gdb support requires the ability for gdb to attach to another process. On some systems (notably Ubuntu Linux) default security restrictions placed on ptrace prevent this from being possible. This restriction is enforced at the system level by the Linux security module Yama. Documentation for this module and the security implications of making changes to its behaviour can be found in the Linux Kernel documentation. The Ubuntu Linux security documentation discusses how to adjust the behaviour of Yama on with regards to ptrace_scope so as to permit the required behaviour.
Basic gdb support

**Warning:** Calling `numba.gdb()` and/or `numba.gdb_init()` more than once in the same program is not advisable, unexpected things may happen. If multiple breakpoints are desired within a program, launch `gdb` once via `numba.gdb()` or `numba.gdb_init()` and then use `numba.gdb_breakpoint()` to register additional breakpoint locations.

The most simple function for adding `gdb` support is `numba.gdb()`, which, at the call location, will:

- launch `gdb` and attach it to the running process.
- create a breakpoint at the site of the `numba.gdb()` function call, the attached `gdb` will pause execution here awaiting user input.

use of this functionality is best motivated by example, continuing with the example used above:

```python
from numba import njit, gdb

@njit(debug=True)
def foo(a):
    b = a + 1
    gdb() # instruct Numba to attach gdb at this location and pause execution
    c = a * 2.34
    d = (a, b, c)
    print(a, b, c, d)

r = foo(123)
print(r)
```

In the terminal (... on a line by itself indicates output that is not presented for brevity):

```
$ NUMBA_OPT=0 NUMBA_EXTEND_VARIABLE_LIFETIMES=1 python demo_gdb.py
...
Breakpoint 1, 0x00007fb75238d830 in numba_gdb_breakpoint () from numba/_helperlib.
--> cpython-39-x86_64-linux-gnu.so
(gdb) s
Single stepping until exit from function numba_gdb_breakpoint, which has no line number information.
0x00007fb75233e1cf in numba::misc::gdb_hook::hook_gdb::__3clocals_3e::impl_˓→242[abi:c8tJTeFCjyCbUFRRqOAK_2f6h0phxApMojijRBAAn_3d](StarArgTuple) ()
(gdb) s
Single stepping until exit from function _ZN5numba4misc8gdb_hook8hook_gdb12_3clocals_˓→3e8impl_242B44c8tJTeFCjyCbUFRRqOAK_2f6h0phxApMojijRBAAn_3dE12StarArgTuple, which has no line number information.
__main__::foo_241[abi:c8tJTC_2fWgEeGLSgydRTQUGiqKEZ6gEoDvQJmaQIA](long long) (a=123) at ˓→demo_gdb.py:7
    c = a * 2.34
(gdb) l
```

(continues on next page)
7  c = a * 2.34
8  d = (a, b, c)
9  print(a, b, c, d)
10  r = foo(123)

(gdb) p a
$1 = 123
(gdb) p b
$2 = 124
(gdb) p c
$3 = 0
(gdb) b 9
Breakpoint 2 at 0x7fb73d1f7287: file demo_gdb.py, line 9.
(gdb) c
Continuing.

Breakpoint 2, __main__::foo_241[abi:c8tJTC_2fWgEeGLSgydRTQUgiqKEZ6gEoDvQJmaQIA](long → long) (a=123) at demo_gdb.py:9
9  print(a, b, c, d)

(gdb) info locals
b = 124
c = 287.81999999999999
(d = {f0 = 123, f1 = 124, f2 = 287.81999999999999}

It can be seen in the above example that execution of the code is paused at the location of the gdb() function call at end of the numba_gdb_breakpoint function (this is the Numba internal symbol registered as breakpoint with gdb). Issuing a step twice at this point moves to the stack frame of the compiled Python source. From there, it can be seen that the variables a and b have been evaluated but c has not, as demonstrated by printing their values, this is precisely as expected given the location of the gdb() call. Issuing a break on line 9 and then continuing execution leads to the evaluation of line 7. The variable c is assigned a value as a result of the execution and this can be seen in output of info locals when the breakpoint is hit.

**Running with gdb enabled**

The functionality provided by numba.gdb() (launch and attach gdb to the executing process and pause on a breakpoint) is also available as two separate functions:

- numba.gdb_init() this function injects code at the call site to launch and attach gdb to the executing process but does not pause execution.
- numba.gdb_breakpoint() this function injects code at the call site that will call the special numba_gdb_breakpoint function that is registered as a breakpoint in Numba’s gdb support. This is demonstrated in the next section.

This functionality enables more complex debugging capabilities. Again, motivated by example, debugging a ‘segfault’ (memory access violation signalling SIGSEGV):

```python
from numba import njit, gdb_init
import numpy as np

# NOTE debug=True switches bounds-checking on, but for the purposes of this
# example it is explicitly turned off so that the out of bounds index is
# not caught!
```
@njit(debug=True, boundscheck=False)

def foo(a, index):
    
gdb_init()  # instruct Numba to attach gdb at this location, but not to pause execution
    b = a + 1
    c = a * 2.34
    d = c[index]  # access an address that is a) invalid b) out of the page
    print(a, b, c, d)

bad_index = int(1e9)  # this index is invalid
z = np.arange(10)
r = foo(z, bad_index)
print(r)

In the terminal (... on a line by itself indicates output that is not presented for brevity):

$ NUMBA_OPT=0 python demo_gdb_segfault.py ...
Program received signal SIGSEGV, Segmentation fault.
0x00007f5a4ca655eb in __main__::foo_241[abi:c8tJTC_˓→2fWgEeGLSydRTQUGiqKEXZ6gEoDv01maQIA](Array<long long, 1, C, mutable, aligned>, long␣˓→long) (a=..., index=1000000000) at demo_gdb_segfault.py:12
12 d = c[index]  # access an address that is a) invalid b) out of the page
(gdb) p index
$1 = 1000000000
(gdb) p c
$2 = {meminfo = 0x5586cfb95830 "\001", parent = 0x0, nitems = 10, itemsize = 8, data =˓→0x5586cfb95860, shape = {10}, strides = {8}}
(gdb) whatis c
type = array(float64, 1d, C) ([i8*, i8*, i64, i64, double*, [1 x i64], [1 x i64]])
(gdb) p c.nitems
$3 = 10

In the gdb output it can be noted that a SIGSEGV signal was caught, and the line in which the access violation occurred is printed.

Continuing the example as a debugging session demonstration, first index can be printed, and it is evidently 1e9. Printing c shows that it is a structure, so the type needs looking up and it can be seen that is it an array(float64, 1d, C) type. Given the segfault came from an invalid access it would be informative to check the number of items in the array and compare that to the index requested. Inspecting the nitems member of the structure c shows 10 items. It’s therefore clear that the segfault comes from an invalid access of index 1000000000 in an array containing 10 items.

Adding breakpoints to code

The next example demonstrates using multiple breakpoints that are defined through the invocation of the numba.gdb_breakpoint() function:

from numba import njit, gdb_init, gdb_breakpoint

@njit(debug=True)
def foo(a):
    gdb_init()  # instruct Numba to attach gdb at this location

(continues on next page)
In the terminal (... on a line by itself indicates output that is not presented for brevity):

```
$ NUMBA_OPT=0 python demo_gdb_breakpoints.py
...
Breakpoint 1, 0x000007fb65bb4c830 in numba_gdb_breakpoint () from numba/_helperlib.cpython-39-x86_64-linux-gnu.so
(gdb) step
Single stepping until exit from function numba_gdb_breakpoint, which has no line number information.
__main__::foo_241[abi:c8tJTC_2fWgEeGLSgydRTQUgiqKEZ6gEoDVJmaQIA](long long) (a=123) at ...
__demo_gdb_breakpoints.py:8
8  c = a * 2.34
(gdb) l
3 @njit(debug=True)
4 def foo(a):
5    gdb_init() # instruct Numba to attach gdb at this location
6    b = a + 1
7    gdb_breakpoint() # instruct gdb to break at this location
8    c = a * 2.34
9    d = (a, b, c)
10   gdb_breakpoint() # and to break again at this location
11   print(a, b, c, d)
12
13 r = foo(123)
14 print(r)
```

From the gdb output it can be seen that execution paused at line 8 as a breakpoint was hit, and after a continue was issued, it broke again at line 11 where the next breakpoint was hit.

1.17. Troubleshooting and tips 75
Debugging in parallel regions

The follow example is quite involved, it executes with `gdb` instrumentation from the outset as per the example above, but it also uses threads and makes use of the breakpoint functionality. Further, the last iteration of the parallel section calls the function `work`, which is actually just a binding to `glibc`'s `free(3)` in this case, but could equally be some involved function that is presenting a segfault for unknown reasons.

```python
from numba import njit, prange, gdb_init, gdb_breakpoint
import ctypes

def get_free():
    lib = ctypes.cdll.LoadLibrary('libc.so.6')
    free_binding = lib.free
    free_binding.argtypes = [ctypes.c_void_p,]
    free_binding.restype = None
    return free_binding

work = get_free()

@njit(debug=True, parallel=True)
def foo():
    gdb_init()  # instruct Numba to attach gdb at this location, but not to pause...
    counter = 0
    n = 9
    for i in prange(n):
        if i > 3 and i < 8:  # iterations 4, 5, 6, 7 will break here
            gdb_breakpoint()

        if i == 8:  # last iteration segfaults
            work(0xBADADD)

        counter += 1
    return counter

r = foo()
print(r)
```

In the terminal (... on a line by itself indicates output that is not presented for brevity), note the setting of `NUMBA_NUM_THREADS` to 4 to ensure that there are 4 threads running in the parallel section:

```
$ NUMBA_NUM_THREADS=4 NUMBA_OPT=0 python demo_gdb_threads.py
Attaching to PID: 21462
...
Attaching to process 21462

[New LWP 21467]
[New LWP 21468]
[New LWP 21469]
[New LWP 21470]
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib64/libthread_db.so.1".
0x00007f599ec31756d in nanosleep () at ../sysdeps/unix/syscall-template.S:81
 81 T_PSEUDO (SYSCALL_SYMBOL, SYSCALL_NAME, SYSCALL_NARGS)
Breakpoint 1 at 0x7f59d631e8f0: file numba/_helperlib.c, line 1090.
```

(continues on next page)
Continuing.
[Switching to Thread 0x7f59d1fd1700 (LWP 21470)]

Thread 5 "python" hit Breakpoint 1, numba_gdb_breakpoint () at numba/_helperlib.c:1090
1090 }
(gdb) info threads

<table>
<thead>
<tr>
<th>Id</th>
<th>Target Id</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Thread 0x7f59eca2f740 (LWP 21462) &quot;python&quot; pthread_cond_wait@GLIBC_2.3.2 () at ../nptl/sysdeps/unix/sysv/linux/x86_64/pthread_cond_wait.S:185</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Thread 0x7f59d37d4700 (LWP 21467) &quot;python&quot; pthread_cond_wait@GLIBC_2.3.2 () at ../nptl/sysdeps/unix/sysv/linux/x86_64/pthread_cond_wait.S:185</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Thread 0x7f59d2fd3700 (LWP 21468) &quot;python&quot; pthread_cond_wait@GLIBC_2.3.2 () at ../nptl/sysdeps/unix/sysv/linux/x86_64/pthread_cond_wait.S:185</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Thread 0x7f59d27d2700 (LWP 21469) &quot;python&quot; numba_gdb_breakpoint () at numba/_helperlib.c:1090</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Thread 0x7f59d1fd1700 (LWP 21470) &quot;python&quot; numba_gdb_breakpoint () at numba/_helperlib.c:1090</td>
<td></td>
</tr>
</tbody>
</table>

(gdb) thread apply 2-5 info locals

Thread 2 (Thread 0x7f59d37d4700 (LWP 21467)):
No locals.

Thread 3 (Thread 0x7f59d2fd3700 (LWP 21468)):
No locals.

Thread 4 (Thread 0x7f59d27d2700 (LWP 21469)):
No locals.

Thread 5 (Thread 0x7f59d1fd1700 (LWP 21470)):
sched$35 = '\000' <repeats 55 times>
counter__arr = '\000' <repeats 16 times>, "\001\000\000\000\000\000\000\000\b\000\000\n...\000\000\000\000\000\000\000\000\000\000\000\370B","hU\000\000\001", '\000' <repeats 14 times>
counter = 0
(gdb) continue
Continuing.
[Switching to Thread 0x7f59d27d2700 (LWP 21469)]

Thread 4 "python" hit Breakpoint 1, numba_gdb_breakpoint () at numba/_helperlib.c:1090
1090 }
(gdb) continue
Continuing.
[Switching to Thread 0x7f59d1fd1700 (LWP 21470)]

Thread 5 "python" hit Breakpoint 1, numba_gdb_breakpoint () at numba/_helperlib.c:1090
1090 }
(gdb) continue
Continuing.
[Switching to Thread 0x7f59d27d2700 (LWP 21469)]

Thread 4 "python" hit Breakpoint 1, numba_gdb_breakpoint () at numba/_helperlib.c:1090
1090 }
(gdb) continue

(continues on next page)
Continuing.

Thread 5 "python" received signal SIGSEGV, Segmentation fault.

[Switching to Thread 0x7fffffff80a61ae44 (LWP 21470)]
__GI___libc_free (mem=0xbadadd) at malloc.c:2935
2935 if (chunk_is_mmapped(p)) /* release mmapped memory. */

(gdb) bt
#0 __GI___libc_free (mem=0xbadadd) at malloc.c:2935
#1 0x00007f59d37ded84 in $3cdynamic$3e::__numba_parfor_gufunc__0x7ffff80a61ae3e31
   --> $244(Array<unsigned long long, 1, C, mutable, aligned>, Array<long long, 1, C, mutable, aligned>) () at <string>:24
#2 0x00007f59d17ce326 in __gufunc__._ZN13$3cdynamic$3e45__numba_parfor_gufunc__
   --> _0x7fffffff80a61ae3e31$244E5ArrayIyLi1E1C7mutable7alignedE5ArrayIxLi1E1C7mutable7alignedE() () at <string>:24
#3 0x00007f59d37d7320 in thread_worker ()
   from <path>/numba/numba/npyufunc/workqueue.cpython-37m-x86_64-linux-gnu.so
#4 0x00007f59e626e25 in start_thread (arg=0x7f59d1fd1700) at pthread_create.c:308
#5 0x00007f59e626f25 in clone () at ../sysdeps/unix/sysv/linux/x86_64/clone.S:113

In the output it can be seen that there are 4 threads launched and that they all break at the breakpoint, further that Thread 5 receives a signal SIGSEGV and that back tracing shows that it came from __GI___libc_free with the invalid address in mem, as expected.

**Using the gdb command language**

Both the numba.gdb() and numba.gdb_init() functions accept unlimited string arguments which will be passed directly to gdb as command line arguments when it initializes, this makes it easy to set breakpoints on other functions and perform repeated debugging tasks without having to manually type them every time. For example, this code runs with gdb attached and sets a breakpoint on _dgesdd (say for example the arguments passed to the LAPACK’s double precision divide and conqueror SVD function need debugging).

```python
from numba import njit, gdb
import numpy as np

@njit(debug=True)
def foo(a):
    # instruct Numba to attach gdb at this location and on launch, switch 
    # breakpoint pending on , and then set a breakpoint on the function 
    # _dgesdd, continue execution, and once the breakpoint is hit, backtrace 
    gdb('-ex', 'set breakpoint pending on',
        '-ex', 'b dgesdd_',
        '-ex', 'c',
        '-ex', 'bt')
    b = a + 10
    u, s, vh = np.linalg.svd(b)
    return s # just return singular values
z = np.arange(70.).reshape(10, 7)
r = foo(z)
print(r)
```

In the terminal (... on a line by itself indicates output that is not presented for brevity), note that no interaction is
required to break and backtrace:

```bash
$ NUMBA_OPT=0 python demo_gdb_args.py
Attaching to PID: 22300
GNU gdb (GDB) Red Hat Enterprise Linux 8.0.1-36.el7...
Attaching to process 22300
Reading symbols from <py_env>/bin/python3.7...done.
0x00007f652305a550 in __nanosleep_nocancel () at ../sysdeps/unix/syscall-template.S:81
81     T_PSEUDO (SYSCALL_SYMBOL, SYSCALL_NAME, SYSCALL_NARGS)
Breakpoint 1 at 0x7f650d0618f0: file numa/_helperlib.c, line 1090.
Continuing.
Breakpoint 1, numa_gdb_breakpoint () at numa/_helperlib.c:1090
1090 }
Breakpoint 2 at 0x7f65102322e0 (2 locations)
Continuing.
Breakpoint 2, 0x00007f65182be5f0 in mkl_lapack.dgesdd_ ()
from <py_env>/lib/python3.7/site-packages/numpy/core/../../../../libmkl_rt.so
#0 0x00007f65182be5f0 in mkl_lapack.dgesdd_ ()
from <py_env>/lib/python3.7/site-packages/numpy/core/../../../../libmkl_rt.so
#1 0x00007f650d065b71 in numa_raw_rgesdd (kind=kind@entry=100 'd', jobz=<optimized out>
    →, jobz@entry=65 'A', m=m@entry=10,
    →, n=n@entry=7, a=a@entry=0x561c6fbb20c0, lda=lda@entry=10, s=0x561c6facf3a0,␣
    →, u=u@entry=0x561c6f680e0, ldv=ldv@entry=10, vt=vt@entry=0x561c6fd375c0,␣
    →, ldvt=7, work=work@entry=0x7fff4c926c30, lwork=1, iwork=iwork@entry=0x7fff4c926c40, info=info@entry=0x7fff4c926c20) at␣
    → numa/_lapack.c:1277
#2 0x00007f650d06768f in numa_ez_rgesdd (ldv=ldv@entry=10, vt=vt@entry=0x561c6fd375c0,␣
    →, u=u@entry=0x561c6f680e0, s=s@entry=0x561c6facf3a0, lda=lda@entry=10,␣
    →, a=a@entry=0x561c6fbb20c0, n=n@entry=7, m=m@entry=10, jobz=jobz@entry=65 'A', kind=<optimized out>) at numa/_lapack.
    → c:1307
#3 numa_ez_gesdd (kind=<optimized out>, jobz=<optimized out>, m=m@entry=10, n=n@entry=7,␣
    →, a=a@entry=0x561c6fbb20c0, lda=lda@entry=10, s=s@entry=0x561c6facf3a0,␣
    →, u=u@entry=0x561c6f680e0, ldv=ldv@entry=10, vt=vt@entry=0x561c6fd375c0, ldvt=ldv@entry=10, at numa/_lapack.c:1477
#4 0x00007f650a147a3 in numa::targets::linalg::svd_impl::$3locals$3d1$3e::svd_impl
    → $243(Array<double, 2, C, mutable, aligned>, omitted$28default$3d1$29) ()
#5 0x00007f650a10489 in __main__::foo$241(Array<double, 2, C, mutable, aligned>) () at __
    → demo_gdb_args.py:15
#6 0x00007f650a12110 in cpython::__main__::__main__::foo$241(Array<double, 2, C, mutable,␣
    → aligned>) ()
#7 0x00007f650d096a4 in call_cfunc ()
from <path>/numba/numba/__dispatcher.cpython-37m-x86_64-linux-gnu.so
...```
How does the `gdb` binding work?

For advanced users and debuggers of Numba applications it's important to know some of the internal implementation details of the outlined `gdb` bindings. The `numba.gdb()` and `numba.gdb_init()` functions work by injecting the following into the function’s LLVM IR:

- At the call site of the function first inject a call to `getpid(3)` to get the PID of the executing process and store this for use later, then inject a `fork(3)` call:
  - In the parent:
    - Inject a call `sleep(3)` (hence the pause whilst `gdb` loads).
    - Inject a call to the `numba_gdb_breakpoint` function (only `numba.gdb()` does this).
  - In the child:
    - Inject a call to `exec(3)` with the arguments `numba.config.GDB_BINARY`, the `attach` command and the PID recorded earlier. Numba has a special `gdb` command file that contains instructions to break on the symbol `numba_gdb_breakpoint` and then `finish`, this is to make sure that the program stops on the breakpoint but the frame it stops in is the compiled Python frame (or one step away from, depending on optimisation). This command file is also added to the arguments and finally and any user specified arguments are added.

At the call site of a `numba.gdb_breakpoint()` a call is injected to the special `numba_gdb_breakpoint` symbol, which is already registered and instrumented as a place to break and `finish` immediately.

As a result of this, a e.g. `numba.gdb()` call will cause a fork in the program, the parent will sleep whilst the child launches `gdb` and attaches it to the parent and tells the parent to continue. The launched `gdb` has the `numba_gdb_breakpoint` symbol registered as a breakpoint and when the parent continues and stops sleeping it will immediately call `numba_gdb_breakpoint` on which the child will break. Additional `numba.gdb_breakpoint()` calls create calls to the registered breakpoint hence the program will also break at these locations.

### 1.17.9 Debugging CUDA Python code

#### Using the simulator

CUDA Python code can be run in the Python interpreter using the CUDA Simulator, allowing it to be debugged with the Python debugger or with print statements. To enable the CUDA simulator, set the environment variable `NUMBA_ENABLE_CUDASIM` to 1. For more information on the CUDA Simulator, see the CUDA Simulator documentation.

#### Debug Info

By setting the `debug` argument to `cuda.jit` to `True` (@`cuda.jit(debug=True)`), Numba will emit source location in the compiled CUDA code. Unlike the CPU target, only filename and line information are available, but no variable type information is emitted. The information is sufficient to debug memory error with `cuda-memcheck`.

For example, given the following CUDA python code:

```python
import numppy as np
from numba import cuda

cuda.jit(debug=True)
def foo(arr):
    arr[cuda threadIdx.x] = 1
```

(continues on next page)
```python
arr = np.arange(30)
foo[1, 32](arr)  # more threads than array elements
```

We can use `cuda-memcheck` to find the memory error:

```
$ cuda-memcheck python chk_cuda_debug.py
========= CUDA-MEMCHECK
========= Invalid __global__ write of size 8
========= at 0x00000148 in /home/user/chk_cuda_debug.py:6:cudapy::__main__::foo
---$241(Array<__int64, int=1, C, mutable, aligned>)
========= by thread (31,0,0) in block (0,0,0)
========= Address 0x500a600f8 is out of bounds
...
========= Invalid __global__ write of size 8
========= at 0x00000148 in /home/user/chk_cuda_debug.py:6:cudapy::__main__::foo
---$241(Array<__int64, int=1, C, mutable, aligned>)
========= by thread (30,0,0) in block (0,0,0)
========= Address 0x500a600f0 is out of bounds
...
```

### 1.18 Frequently Asked Questions

#### 1.18.1 Installation

**Numba could not be imported**

If you are seeing an exception on importing Numba with an error message that starts with:

```
ImportError: Numba could not be imported.
```

here are some common issues and things to try to fix it.

1. Your installation has more than one version of Numba a given environment.

   Common ways this occurs include:
   - Installing Numba with `conda` and then installing again with `pip`.
   - Installing Numba with `pip` and then updating to a new version with `pip` (pip re-installations don’t seem to always clean up very well).

   To fix this the best approach is to create an entirely new environment and install a single version of Numba in that environment using a package manager of your choice.

2. Your installation has Numba for Python version X but you are running with Python version Y.

   This occurs due to a variety of Python environment mix-up/mismatch problems. The most common mismatch comes from installing Numba into the site-packages/environment of one version of Python by using a base or system installation of Python that is a different version, this typically happens through the use of the “wrong” `pip` binary. This will obviously cause problems as the C-Extensions on which Numba relies are bound to specific Python versions. A way to check if this likely the problem is to see if the path to the `python` binary at:
matches the path to your installation tool and/or matches the reported installation location and if the Python versions match up across all of these. Note that Python version X.Y.A is compatible with X.Y.B.

To fix this the best approach is to create an entirely new environment and ensure that the installation tool used to install Numba is the one from that environment/the Python versions at install and run time match.

3. Your core system libraries are too old.

This is a somewhat rare occurrence, but there are occasions when a very old (typically out of support) version of Linux is in use it doesn’t have a glibc library with sufficiently new versioned symbols for Numba’s shared libraries to resolve against. The fix for this is to update your OS system libraries/update your OS.

4. You are using an IDE e.g. Spyder.

There are some unknown issues in relation to installing Numba via IDEs, but it would appear that these are likely variations of 1. or 2. with the same suggested fixes. Also, try installation from outside of the IDE with the command line.

If you have an installation problem which is not one of the above problems, please do ask on numba.discourse.group and if possible include the path where Numba is installed and also the output of:

```
python -c 'import sys; print(sys.executable)'
```

1.18.2 Programming

Can I pass a function as an argument to a jitted function?

As of Numba 0.39, you can, so long as the function argument has also been JIT-compiled:

```python
@jit(nopython=True)
def f(g, x):
    return g(x) + g(-x)
result = f(jitted_g_function, 1)
```

However, dispatching with arguments that are functions has extra overhead. If this matters for your application, you can also use a factory function to capture the function argument in a closure:

```python
def make_f(g):
    # Note: a new f() is created each time make_f() is called!
    @jit(nopython=True)
    def f(x):
        return g(x) + g(-x)
    return f

f = make_f(jitted_g_function)
result = f(1)
```

Improving the dispatch performance of functions in Numba is an ongoing task.
Numba doesn’t seem to care when I modify a global variable

Numba considers global variables as compile-time constants. If you want your jitted function to update itself when you have modified a global variable's value, one solution is to recompile it using the `recompile()` method. This is a relatively slow operation, though, so you may instead decide to rearchitect your code and turn the global variable into a function argument.

Can I debug a jitted function?

Calling into `pdb` or other such high-level facilities is currently not supported from Numba-compiled code. However, you can temporarily disable compilation by setting the `NUMBA_DISABLE_JIT` environment variable.

How can I create a Fortran-ordered array?

Numba currently doesn’t support the `order` argument to most Numpy functions such as `numpy.empty()` (because of limitations in the type inference algorithm). You can work around this issue by creating a C-ordered array and then transposing it. For example:

```python
a = np.empty((3, 5), order='F')
b = np.zeros(some_shape, order='F')
```

can be rewritten as:

```python
a = np.empty((5, 3)).T
b = np.zeros(some_shape[::-1]).T
```

How can I increase integer width?

By default, Numba will generally use machine integer width for integer variables. On a 32-bit machine, you may sometimes need the magnitude of 64-bit integers instead. You can simply initialize relevant variables as `np.int64` (for example `np.int64(0)` instead of `0`). It will propagate to all computations involving those variables.

How can I tell if `parallel=True` worked?

If the `parallel=True` transformations failed for a function decorated as such, a warning will be displayed. See also `Diagnostics` for information about parallel diagnostics.

1.18.3 Performance

Does Numba inline functions?

Numba gives enough information to LLVM so that functions short enough can be inlined. This only works in `nopython` mode.
Does Numba vectorize array computations (SIMD)?

Numba doesn’t implement such optimizations by itself, but it lets LLVM apply them.

Why has my loop not vectorized?

Numba enables the loop-vectorize optimization in LLVM by default. While it is a powerful optimization, not all loops are applicable. Sometimes, loop-vectorization may fail due to subtle details like memory access pattern. To see additional diagnostic information from LLVM, add the following lines:

```python
import llvmlite.binding as llvm
llvm.set_option('', '--debug-only=loop-vectorize')
```

This tells LLVM to print debug information from the `loop-vectorize` pass to stderr. Each function entry looks like:

```
LV: Checking a loop in "<low-level symbol name>" from <function name>
LV: Loop hints: force=? width=0 unroll=0
... 
LV: Vectorization is possible but not beneficial.
LV: Interleaving is not beneficial.
```

Each function entry is separated by an empty line. The reason for rejecting the vectorization is usually at the end of the entry. In the example above, LLVM rejected the vectorization because doing so will not speedup the loop. In this case, it can be due to memory access pattern. For instance, the array being looped over may not be in contiguous layout.

When memory access pattern is non-trivial such that it cannot determine the access memory region, LLVM may reject with the following message:

```
LV: Can't vectorize due to memory conflicts
```

Another common reason is:

```
LV: Not vectorizing: loop did not meet vectorization requirements.
```

In this case, vectorization is rejected because the vectorized code may behave differently. This is a case to try turning on `fastmath=True` to allow fastmath instructions.

Why are the typed containers slower when used from the interpreter?

The Numba typed containers found in `numba.typed` e.g. `numba.typed.List` store their data in an efficient form for access from JIT compiled code. When these containers are used from the CPython interpreter, the data involved has to be converted from/to the container format. This process is relatively costly and as a result impacts performance. In JIT compiled code no such penalty exists and so operations on the containers are much quicker and often faster than the pure Python equivalent.
Does Numba automatically parallelize code?

It can, in some cases:

- Ufuncs and gufuncs with the target="parallel" option will run on multiple threads.
- The parallel=True option to @jit will attempt to optimize array operations and run them in parallel. It also adds support for prange() to explicitly parallelize a loop.

You can also manually run computations on multiple threads yourself and use the nogil=True option (see releasing the GIL). Numba can also target parallel execution on GPU architectures using its CUDA and HSA backends.

Can Numba speed up short-running functions?

Not significantly. New users sometimes expect to JIT-compile such functions:

```python
def f(x, y):
    return x + y
```

and get a significant speedup over the Python interpreter. But there isn't much Numba can improve here: most of the time is probably spent in CPython's function call mechanism, rather than the function itself. As a rule of thumb, if a function takes less than 10 \( \mu \text{s} \) to execute: leave it.

The exception is that you should JIT-compile that function if it is called from another jitted function.

There is a delay when JIT-compiling a complicated function, how can I improve it?

Try to pass cache=True to the @jit decorator. It will keep the compiled version on disk for later use.

A more radical alternative is ahead-of-time compilation.

1.18.4 GPU Programming

How do I work around the CUDA initialized before forking error?

On Linux, the multiprocessing module in the Python standard library defaults to using the fork method for creating new processes. Because of the way process forking duplicates state between the parent and child processes, CUDA will not work correctly in the child process if the CUDA runtime was initialized prior to the fork. Numba detects this and raises a CudaDriverError with the message CUDA initialized before forking.

One approach to avoid this error is to make all calls to numba.cuda functions inside the child processes or after the process pool is created. However, this is not always possible, as you might want to query the number of available GPUs before starting the process pool. In Python 3, you can change the process start method, as described in the multiprocessing documentation. Switching from fork to spawn or forkserver will avoid the CUDA initialization issue, although the child processes will not inherit any global variables from their parent.
1.18.5 Integration with other utilities

Can I “freeze” an application which uses Numba?

If you’re using PyInstaller or a similar utility to freeze an application, you may encounter issues with llvmlite. llvmlite needs a non-Python DLL for its working, but it won’t be automatically detected by freezing utilities. You have to inform the freezing utility of the DLL’s location: it will usually be named llvmlite/binding/libllvmlite.so or llvmlite/binding/llvmlite.dll, depending on your system.

I get errors when running a script twice under Spyder

When you run a script in a console under Spyder, Spyder first tries to reload existing modules. This doesn’t work well with Numba, and can produce errors like TypeError: No matching definition for argument type(s).

There is a fix in the Spyder preferences. Open the “Preferences” window, select “Console”, then “Advanced Settings”, click the “Set UMR excluded modules” button, and add numba inside the text box that pops up.

To see the setting take effect, be sure to restart the IPython console or kernel.

Why does Numba complain about the current locale?

If you get an error message such as the following:

```
RuntimeError: Failed at nopython (nopython mode backend)
LLVM will produce incorrect floating-point code in the current locale
```

it means you have hit a LLVM bug which causes incorrect handling of floating-point constants. This is known to happen with certain third-party libraries such as the Qt backend to matplotlib.

To work around the bug, you need to force back the locale to its default value, for example:

```
import locale
locale.setlocale(locale.LC_NUMERIC, 'C')
```

How do I get Numba development builds?

Pre-release versions of Numba can be installed with conda:

```
$ conda install -c numba/label/dev numba
```

1.18.6 Miscellaneous

Where does the project name “Numba” come from?

“Numba” is a combination of “NumPy” and “Mamba”. Mambas are some of the fastest snakes in the world, and Numba makes your Python code fast.
How do I reference/cite/acknowledge Numba in other work?

For academic use, the best option is to cite our ACM Proceedings: Numba: a LLVM-based Python JIT compiler. You can also find the sources on github, including a pre-print pdf, in case you don’t have access to the ACM site but would like to read the paper.

Other related papers

A paper describing ParallelAccelerator technology, that is activated when the `parallel=True` jit option is used, can be found here.

How do I write a minimal working reproducer for a problem with Numba?

A minimal working reproducer for Numba should include:

1. The source code of the function(s) that reproduce the problem.
2. Some example data and a demonstration of calling the reproducing code with that data. As Numba compiles based on type information, unless your problem is numerical, it’s fine to just provide dummy data of the right type, e.g. use `numpy.ones` of the correct `dtype`/size/shape for arrays.
3. Ideally put 1. and 2. into a script with all the correct imports. Make sure your script actually executes and reproduces the problem before submitting it! The target is to make it so that the script can just be copied directly from the issue tracker and run by someone else such that they can see the same problem as you are having.

Having made a reproducer, now remove every part of the code that does not contribute directly to reproducing the problem to create a “minimal” reproducer. This means removing imports that aren’t used, removing variables that aren’t used or have no effect, removing lines of code which have no effect, reducing the complexity of expressions, and shrinking input data to the minimal amount required to trigger the problem.

Doing the above really helps out the Numba issue triage process and will enable a faster response to your problem!

Suggested further reading on writing minimal working reproducers.

1.19 Examples

1.19.1 Mandelbrot

Listing 1: from `test_mandelbrot` of `numba/tests/doc_examples/test_examples.py`

```python
from timeit import default_timer as timer
try:
    from matplotlib.pylab import imshow, show
    have_mpl = True
except ImportError:
    have_mpl = False
import numpy as np
from numba import jit

@jit(nopython=True)
def mandel(x, y, max_iters):
    # (continues on next page)
```

Given the real and imaginary parts of a complex number, determine if it is a candidate for membership in the Mandelbrot set given a fixed number of iterations.

```python
t = 0
c = complex(x, y)
z = 0.0j
for i in range(max_iters):
z = z * z + c
    if (z.real * z.real + z.imag * z.imag) >= 4:
        return i
return 255
```

@jit(nopython=True)
def create_fractal(min_x, max_x, min_y, max_y, image, iters):
    height = image.shape[0]
    width = image.shape[1]
    pixel_size_x = (max_x - min_x) / width
    pixel_size_y = (max_y - min_y) / height
    for x in range(width):
        real = min_x + x * pixel_size_x
        for y in range(height):
            imag = min_y + y * pixel_size_y
            color = mandel(real, imag, iters)
            image[y, x] = color
    return image

image = np.zeros((500 * 2, 750 * 2), dtype=np.uint8)
s = timer()
create_fractal(-2.0, 1.0, -1.0, 1.0, image, 20)
e = timer()
print(e - s)
if have_mpl:
imshow(image)
show()
```

1.19.2 Moving average

Listing 2: from test_moving_average of numba/tests/doc_examples/test_examples.py

```python
import numpy as np
from numba import guvectorize
@guvectorize(['param(float64[:], intp[:], float64[:])'],
```

(continues on next page)
def move_mean(a, window_arr, out):
    window_width = window_arr[0]
    asum = 0.0
    count = 0
    for i in range(window_width):
        asum += a[i]
        count += 1
        out[i] = asum / count
    for i in range(window_width, len(a)):
        asum += a[i] - a[i - window_width]
        out[i] = asum / count

arr = np.arange(20, dtype=np.float64).reshape(2, 10)
print(arr)
print(move_mean(arr, 3))

1.19.3 Multi-threading

The code below showcases the potential performance improvement when using the `nogil` feature. For example, on a 4-core machine, the following results were printed:

<table>
<thead>
<tr>
<th></th>
<th>Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>numpy (1 thread)</td>
<td>145</td>
</tr>
<tr>
<td>numba (1 thread)</td>
<td>128</td>
</tr>
<tr>
<td>numba (4 threads)</td>
<td>35</td>
</tr>
</tbody>
</table>

**Note**: If preferred it’s possible to use the standard `concurrent.futures` module rather than spawn threads and dispatch tasks by hand.

Listing 3: from `test_no_gil` of `numba/tests/doc_examples/test_examples.py`

import math
import threading
from timeit import repeat
import numpy as np
from numba import jit

nthreads = 4
size = 10**6

def func_np(a, b):
    """
    Control function using Numpy.
    """
    return np.exp(2.1 * a + 3.2 * b)

@jit('void(double[:], double[:], double[:])', nopython=True,
def inner_func_nb(result, a, b):
    
    Function under test.
    
    for i in range(len(result)):
        result[i] = math.exp(2.1 * a[i] + 3.2 * b[i])

def timefunc(correct, s, func, *args, **kwargs):
    
    Benchmark *func* and print out its runtime.
    
    print(s.ljust(20), end=" ")
    # Make sure the function is compiled before the benchmark is # started
    res = func(*args, **kwargs)
    if correct is not None:
        assert np.allclose(res, correct), (res, correct)
    # time it
    print('{:>5.0f} ms'.format(min(repeat(
        lambda: func(*args, **kwargs), number=5, repeat=2)) * 1000))
    return res

def make_singlethread(inner_func):
    
    Run the given function inside a single thread.
    
    def func(*args):
        length = len(args[0])
        result = np.empty(length, dtype=np.float64)
        inner_func(result, *args)
        return result
    return func

def make_multithread(inner_func, numthreads):
    
    Run the given function inside *numthreads* threads, splitting # its arguments into equal-sized chunks.
    
    def func_mt(*args):
        length = len(args[0])
        result = np.empty(length, dtype=np.float64)
        args = (result,) + args
        chunklen = (length + numthreads - 1) // numthreads
        # Create argument tuples for each input chunk
        chunks = [[arg[i * chunklen:(i + 1) * chunklen] for arg in
                   args] for i in range(numthreads)]
        # Spawn one thread per chunk
        threads = [threading.Thread(target=inner_func, args=chunk)
                   for chunk in chunks]
        # for thread in threads:
        #     thread.start()
for thread in threads:
    thread.join()
return result

func_nb = make_singlethread(inner_func_nb)
func_nb_mt = make_multithread(inner_func_nb, nthreads)

a = np.random.rand(size)
b = np.random.rand(size)
correct = timefunc(None, "numpy (1 thread)", func_nb, a, b)
timefunc(correct, "numba (1 thread)", func_nb, a, b)
timefunc(correct, "numba (%d threads)" % nthreads, func_nb_mt, a, b)

1.20 Talks and Tutorials

Note: This is a selection of talks and tutorials that have been given by members of the Numba team as well as Numba users. If you know of a Numba-related talk that should be included on this list, please open an issue.

1.20.1 Talks on Numba

- AnacondaCON 2018 - Accelerating Scientific Workloads with Numba - Siu Kwan Lam (Video)
- DIANA-HEP Meeting, 23 April 2018 - Overview of Numba - Stan Seibert

1.20.2 Talks on Applications of Numba

- GPU Technology Conference 2016 - Accelerating a Spectral Algorithm for Plasma Physics with Python/Numba on GPU - Manuel Kirchen & Rémi Lehe (Slides)
- DIANA-HEP Meeting, 23 April 2018 - Use of Numba in XENONnT - Chris Tunnell
- DIANA-HEP Meeting, 23 April 2018 - Extending Numba for HEP data types - Jim Pivarski
- STAC Summit, Nov 1 2017 - Scaling High-Performance Python with Minimal Effort - Ehsan Totoni (Video, Slides)
- SciPy 2018 - UMAP: Uniform Manifold Approximation and Projection for Dimensional Reduction - Leland McInnes (Video, Github)
- PyData Berlin 2018 - Extending Pandas using Apache Arrow and Numba - Uwe L. Korn (Video, Blog)
- FOSDEM 2019 - Extending Numba - Joris Geessels (Video, Slides & Examples)
- PyCon India 2019 - Real World Numba: Taking the Path of Least Resistance - Ankit Mahato (Video)
- SciPy 2019 - How to Accelerate an Existing Codebase with Numba - Siu Kwan Lam & Stanley Seibert (Video)
- SciPy 2019 - Real World Numba: Creating a Skeleton Analysis Library - Juan Nunez-Iglesias (Video)
- SciPy 2019 - Fast Gradient Boosting Decision Trees with PyGBM and Numba - Nicholas Hug (Video)
• PyCon Sweden 2020 - Accelerating Scientific Computing using Numba - Ankit Mahato (Video)

1.20.3 Tutorials

• SciPy 2017 - Numba: Tell those C++ Bullies to Get Lost - Gil Forsyth & Lorena Barba (Video, Notebooks)
• GPU Technology Conference 2018 - GPU Computing in Python with Numba - Stan Seibert (Notebooks)
• PyData Amsterdam 2019 - Create CUDA kernels from Python using Numba and CuPy - Valentin Haenel (Video)
2.1 Types and signatures

2.1.1 Rationale

As an optimizing compiler, Numba needs to decide on the type of each variable to generate efficient machine code. Python’s standard types are not precise enough for that, so we had to develop our own fine-grained type system.

You will encounter Numba types mainly when trying to inspect the results of Numba’s type inference, for debugging or educational purposes. However, you need to use types explicitly if compiling code ahead-of-time.

2.1.2 Signatures

A signature specifies the type of a function. Exactly which kind of signature is allowed depends on the context (AOT or JIT compilation), but signatures always involve some representation of Numba types to specify the concrete types for the function’s arguments and, if required, the function’s return type.

An example function signature would be the string "f8(i4, i4)" (or the equivalent "float64(int32, int32)") which specifies a function taking two 32-bit integers and returning a double-precision float.

2.1.3 Basic types

The most basic types can be expressed through simple expressions. The symbols below refer to attributes of the main numba module (so if you read “boolean”, it means that symbol can be accessed as numba.boolean). Many types are available both as a canonical name and a shorthand alias, following Numpy’s conventions.

**Numbers**

The following table contains the elementary numeric types currently defined by Numba and their aliases.
<table>
<thead>
<tr>
<th>Type name(s)</th>
<th>Shorthand</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean</td>
<td>b1</td>
<td>represented as a byte</td>
</tr>
<tr>
<td>uint8, byte</td>
<td>u1</td>
<td>8-bit unsigned byte</td>
</tr>
<tr>
<td>uint16</td>
<td>u2</td>
<td>16-bit unsigned integer</td>
</tr>
<tr>
<td>uint32</td>
<td>u4</td>
<td>32-bit unsigned integer</td>
</tr>
<tr>
<td>uint64</td>
<td>u8</td>
<td>64-bit unsigned integer</td>
</tr>
<tr>
<td>int8, char</td>
<td>i1</td>
<td>8-bit signed byte</td>
</tr>
<tr>
<td>int16</td>
<td>i2</td>
<td>16-bit signed integer</td>
</tr>
<tr>
<td>int32</td>
<td>i4</td>
<td>32-bit signed integer</td>
</tr>
<tr>
<td>int64</td>
<td>i8</td>
<td>64-bit signed integer</td>
</tr>
<tr>
<td>intc</td>
<td>–</td>
<td>C int-sized integer</td>
</tr>
<tr>
<td>uintc</td>
<td>–</td>
<td>C int-sized unsigned integer</td>
</tr>
<tr>
<td>intp</td>
<td>–</td>
<td>pointer-sized integer</td>
</tr>
<tr>
<td>uintp</td>
<td>–</td>
<td>pointer-sized unsigned integer</td>
</tr>
<tr>
<td>ssize_t</td>
<td>–</td>
<td>C ssize_t</td>
</tr>
<tr>
<td>size_t</td>
<td>–</td>
<td>C size_t</td>
</tr>
<tr>
<td>float32</td>
<td>f4</td>
<td>single-precision floating-point number</td>
</tr>
<tr>
<td>float64, double</td>
<td>f8</td>
<td>double-precision floating-point number</td>
</tr>
<tr>
<td>complex64</td>
<td>c8</td>
<td>single-precision complex number</td>
</tr>
<tr>
<td>complex128</td>
<td>c16</td>
<td>double-precision complex number</td>
</tr>
</tbody>
</table>

**Arrays**

The easy way to declare `Array` types is to subscript an elementary type according to the number of dimensions. For example a 1-dimension single-precision array:

```python
>>> numba.float32[:,:]
array(float32, 1d, A)
```

or a 3-dimension array of the same underlying type:

```python
>>> numba.float32[:, :, :]
array(float32, 3d, A)
```

This syntax defines array types with no particular layout (producing code that accepts both non-contiguous and contiguous arrays), but you can specify a particular contiguity by using the `::1` index either at the beginning or the end of the index specification:

```python
>>> numba.float32[:, :1]
array(float32, 1d, C)

>>> numba.float32[:, :, :1]
array(float32, 3d, C)

>>> numba.float32[:, :1, :]
array(float32, 3d, F)
```
Functions

**Warning:** The feature of considering functions as first-class type objects is under development.

Functions are often considered as certain transformations of input arguments to output values. Within Numba *JIT* compiled functions, the functions can also be considered as objects, that is, functions can be passed around as arguments or return values, or used as items in sequences, in addition to being callable.

First-class function support is enabled for all Numba *JIT* compiled functions and Numba *cfunc* compiled functions except when:

- using a non-CPU compiler,
- the compiled function is a Python generator,
- the compiled function has Omitted arguments,
- or the compiled function returns Optional value.

To disable first-class function support, use `no_cfunc_wrapper=True` decorator option.

For instance, consider an example where the Numba *JIT* compiled function applies user-specified functions as a composition to an input argument:

```python
>>> @numba.njit
... def composition(funcs, x):
...     r = x
...     for f in reversed(funcs):
...         r = f(r)
...     return r
... def a(x):
...     return x + 1.0
... def b(x):
...     return x * 2

>>> composition((a, b), 0.5), composition(b, a, b, a, 0.5))
(1.25, 1.25)
```

Here, *cfunc* compiled functions `a` and `b` are considered as first-class function objects because these are passed in to the Numba *JIT* compiled function `composition` as arguments, that is, the `composition` is *JIT* compiled independently from its argument function objects (that are collected in the input argument `funcs`).

Currently, first-class function objects can be Numba *cfunc* compiled functions, *JIT* compiled functions, and objects that implement the Wrapper Address Protocol (WAP, see below) with the following restrictions:
Wrapper Address Protocol - WAP

Wrapper Address Protocol provides an API for making any Python object a first-class function for Numba JIT compiled functions. This assumes that the Python object represents a compiled function that can be called via its memory address (function pointer value) from Numba JIT compiled functions. The so-called WAP objects must define the following two methods:

```
__wrapper_address__(self) → int
```
Return the memory address of a first-class function. This method is used when a Numba JIT compiled function tries to call the given WAP instance.

```
signature(self) → numba.typing.Signature
```
Return the signature of the given first-class function. This method is used when passing in the given WAP instance to a Numba JIT compiled function.

In addition, the WAP object may implement the `__call__` method. This is necessary when calling WAP objects from Numba JIT compiled functions in *object mode*.

As an example, let us call the standard math library function `cos` within a Numba JIT compiled function. The memory address of `cos` can be established after loading the math library and using the `ctypes` package:

```python
>>> import numba, ctypes, ctypes.util, math
>>> libm = ctypes.cdll.LoadLibrary(ctypes.util.find_library('m'))
>>> class LibMCos(numba.types.WrapperAddressProtocol):
...     def __wrapper_address__(self):
...         return ctypes.cast(libm.cos, ctypes.c_voidp).value
...     def signature(self):
...         return numba.float64(numba.float64)
...
>>> @numba.njit
... def foo(f, x):
...     return f(x)
...
>>> foo(LibMCos(), 0.0)
1.0
>>> foo(LibMCos(), 0.5), math.cos(0.5)
(0.8775825618903728, 0.8775825618903728)
```
Miscellaneous Types

There are some non-numerical types that do not fit into the other categories.

<table>
<thead>
<tr>
<th>Type name(s)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>pyobject</td>
<td>generic Python object</td>
</tr>
<tr>
<td>voidptr</td>
<td>raw pointer, no operations can be performed on it</td>
</tr>
</tbody>
</table>

2.1.4 Advanced types

For more advanced declarations, you have to explicitly call helper functions or classes provided by Numba.

Warning: The APIs documented here are not guaranteed to be stable. Unless necessary, it is recommended to let Numba infer argument types by using the signature-less variant of @jit.

Inference

numba.typeof(value)
Create a Numba type accurately describing the given Python value. ValueError is raised if the value isn't supported in nopython mode.

```python
>>> numba.typeof(np.empty(3))
array(float64, 1d, C)
>>> numba.typeof((1, 2.0))
(int64, float64)
>>> numba.typeof([0])
reflected list(int64)
```

Numpy scalars

Instead of using typeof(), non-trivial scalars such as structured types can also be constructed programmatically.

numba.dtype(dtype)
Create a Numba type corresponding to the given Numpy dtype:

```python
>>> struct_dtype = np.dtype([('row', np.float64), ('col', np.float64)])
>>> ty = numba.from_dtype(struct_dtype)
>>> ty
Record([('row', '<f8'), ('col', '<f8')])
>>> ty[:, :]
unaligned array(Record([('row', '<f8'), ('col', '<f8')]), 2d, A)
```

class numba.types.NPDatetime(unit)
Create a Numba type for Numpy datetimes of the given unit. unit should be a string amongst the codes recognized by Numpy (e.g. Y, M, D, etc.).

class numba.types.NPTimedelta(unit)
Create a Numba type for Numpy timedeltas of the given unit. unit should be a string amongst the codes recognized by Numpy (e.g. Y, M, D, etc.).
See also:
Numpy datetime units.

Arrays

class numba.types.Array(dtype, ndim, layout)
Create an array type. dtype should be a Numba type. ndim is the number of dimensions of the array (a positive integer). layout is a string giving the layout of the array: A means any layout, C means C-contiguous and F means Fortran-contiguous.

Optional types

class numba.optional(typ)
Create an optional type based on the underlying Numba type typ. The optional type will allow any value of either typ or None.

>>> @jit((optional(intp),))
... def f(x):
...     return x is not None
...
>>> f(0)
True
>>> f(None)
False

Type annotations

numba.extending.as_numba_type(py_type)
Create a Numba type corresponding to the given Python type annotation. TypingError is raised if the type annotation can’t be mapped to a Numba type. This function is meant to be used at statically compile time to evaluate Python type annotations. For runtime checking of Python objects see typeof above.

For any numba type, as_numba_type(nb_type) == nb_type.

>>> numba.extending.as_numba_type(int)
int64
>>> import typing  # the Python library, not the Numba one
>>> numba.extending.as_numba_type(typing.List[float])
ListType[float64]
>>> numba.extending.as_numba_type(numba.int32)
int32

as_numba_type is automatically updated to include any @jitclass.

>>> @jitclass
... class Counter:
...     x: int
...     ...
...     __init__(self):
...         self.x = 0
...     ...

(continues on next page)
... def inc(self):
...     old_val = self.x
...     self.x += 1
...     return old_val
...
>>> numba.extending.as_numba_type(Counter)
instance.jitclass.Counter#11bad4278<x:int64>

Currently as_numba_type is only used to infer fields for @jitclass.

2.2 Just-in-Time compilation

2.2.1 JIT functions

@numba.jit(signature=None, nopython=False, nogil=False, cache=False, forceobj=False, parallel=False, error_model='python', fastmath=False, locals={}, boundscheck=False)

Compile the decorated function on-the-fly to produce efficient machine code. All parameters are optional.

If present, the signature is either a single signature or a list of signatures representing the expected Types and signatures of function arguments and return values. Each signature can be given in several forms:

- A tuple of Types and signatures arguments (for example (numba.int32, numba.double)) representing the types of the function’s arguments; Numba will then infer an appropriate return type from the arguments.
- A call signature using Types and signatures, specifying both return type and argument types. This can be given in intuitive form (for example numba.void(numba.int32, numba.double)).
- A string representation of one of the above, for example "void(int32, double)". All type names used in the string are assumed to be defined in the numba.types module.

nopython and nogil are boolean flags. locals is a mapping of local variable names to Types and signatures.

This decorator has several modes of operation:

- If one or more signatures are given in signature, a specialization is compiled for each of them. Calling the decorated function will then try to choose the best matching signature, and raise a TypeError if no appropriate conversion is available for the function arguments. If converting succeeds, the compiled machine code is executed with the converted arguments and the return value is converted back according to the signature.
- If no signature is given, the decorated function implements lazy compilation. Each call to the decorated function will try to re-use an existing specialization if it exists (for example, a call with two integer arguments may re-use a specialization for argument types (numba.int64, numba.int64)). If no suitable specialization exists, a new specialization is compiled on-the-fly, stored for later use, and executed with the converted arguments.

If true, nopython forces the function to be compiled in nopython mode. If not possible, compilation will raise an error.

If true, forceobj forces the function to be compiled in object mode. Since object mode is slower than nopython mode, this is mostly useful for testing purposes.

If true, nogil tries to release the global interpreter lock inside the compiled function. The GIL will only be released if Numba can compile the function in nopython mode, otherwise a compilation warning will be printed.

If true, cache enables a file-based cache to shorten compilation times when the function was already compiled in a previous invocation. The cache is maintained in the __pycache__ subdirectory of the directory containing the
source file; if the current user is not allowed to write to it, though, it falls back to a platform-specific user-wide cache directory (such as $HOME/.cache/numba on Unix platforms).

If true, parallel enables the automatic parallelization of a number of common Numpy constructs as well as the fusion of adjacent parallel operations to maximize cache locality.

The error_model option controls the divide-by-zero behavior. Setting it to 'python' causes divide-by-zero to raise exception like CPython. Setting it to 'numpy' causes divide-by-zero to set the result to +/-inf or nan.

Not all functions can be cached, since some functionality cannot be always persisted to disk. When a function cannot be cached, a warning is emitted.

If true, fastmath enables the use of otherwise unsafe floating point transforms as described in the LLVM documentation. Further, if Intel SVML is installed faster but less accurate versions of some math intrinsics are used (answers to within 4 ULP).

If True, boundscheck enables bounds checking for array indices. Out of bounds accesses will raise IndexError. The default is to not do bounds checking. If bounds checking is disabled, out of bounds accesses can produce garbage results or segfaults. However, enabling bounds checking will slow down typical functions, so it is recommended to only use this flag for debugging. You can also set the NUMBA_BOUNDSCHECK environment variable to 0 or 1 to globally override this flag.

The locals dictionary may be used to force the Types and signatures of particular local variables, for example if you want to force the use of single precision floats at some point. In general, we recommend you let Numba's compiler infer the types of local variables by itself.

Here is an example with two signatures:

```python
@jit(["int32(int32)", "float32(float32)"], nopython=True)
def f(x): ...  
```

Not putting any parentheses after the decorator is equivalent to calling the decorator without any arguments, i.e.:

```python
@jit
def f(x): ...  
```

is equivalent to:

```python
@jit()
def f(x): ...  
```

The decorator returns a Dispatcher object.

**Note:** If no signature is given, compilation errors will be raised when the actual compilation occurs, i.e. when the function is first called with some given argument types.

**Note:** Compilation can be influenced by some dedicated Environment variables.
2.2.2 Generated JIT functions

@numba.generated_jit(nopython=False, nogil=False, cache=False, forceobj=False, locals={})

Like the `jit()` decorator, but calls the decorated function at compile-time, passing the types of the function’s arguments. The decorated function must return a callable which will be compiled as the function’s implementation for those types, allowing flexible kinds of specialization.

The `generated_jit()` decorator returns a `Dispatcher` object.

2.2.3 Dispatcher objects

class Dispatcher

The class of objects created by calling `jit()` or `generated_jit()`. You shouldn’t try to create such an object in any other way. Calling a Dispatcher object calls the compiled specialization for the arguments with which it is called, letting it act as an accelerated replacement for the Python function which was compiled.

In addition, Dispatcher objects have the following methods and attributes:

py_func
The pure Python function which was compiled.

inspect_types(file=None, pretty=False)
Print out a listing of the function source code annotated line-by-line with the corresponding Numba IR, and the inferred types of the various variables. If `file` is specified, printing is done to that file object, otherwise to sys.stdout. If `pretty` is set to True then colored ANSI will be produced in a terminal and HTML in a notebook.

See also:

Numba architecture

inspect_llvm(signature=None)
Return a dictionary keying compiled function signatures to the human readable LLVM IR generated for the function. If the signature keyword is specified a string corresponding to that individual signature is returned.

inspect_asm(signature=None)
Return a dictionary keying compiled function signatures to the human-readable native assembly code for the function. If the signature keyword is specified a string corresponding to that individual signature is returned.

inspect_cfg(signature=None, show_wrapped)
Return a dictionary keying compiled function signatures to the control-flow graph objects for the function. If the signature keyword is specified a string corresponding to that individual signature is returned.

The control-flow graph objects can be stringified (`str` or `repr`) to get the textual representation of the graph in DOT format. Or, use its `.display(filename=None, view=False)` method to plot the graph. The `filename` option can be set to a specific path for the rendered output to write to. If `view` option is True, the plot is opened by the system default application for the image format (PDF). In IPython notebook, the returned object can be plot inlined.

Usage:

```python
@jit
def foo():
    ...
```

(continues on next page)
# opens the CFG in system default application
foo.inspect_cfg(foo.signatures[0]).display(view=True)

inspect_disasm_cfg(signature=None)

Return a dictionary keying compiled function signatures to the control-flow graph of the disassembly of the underlying compiled ELF object. If the signature keyword is specified a control-flow graph corresponding to that individual signature is returned. This function is execution environment aware and will produce SVG output in Jupyter notebooks and ASCII in terminals.

Example:

```python
@njit
def foo(x):
    if x < 3:
        return x + 1
    return x + 2

foo(10)

print(foo.inspect_disasm_cfg(signature=foo.signatures[0]))
```

Gives:

```plaintext
[0x08000040]> # method.__main__.foo_241_long_long (int64_t arg1, int64_t arg3);

0x8000040 ; arg3 ; [02] -r-x section size 279 named .text
;-- section..text:
;-- .text:
;-- __main__::foo$241(long long):
;-- rip:
25: method.__main__.foo_241_long_long (int64_t arg1, int64_t arg3);
; arg int64_t arg1 @ rdi
; arg int64_t arg3 @ rdx
; 2
cmp rdx, 2
jg 0x800004f
```

```
            t
           /|
          /  |
         f   |
            |
            |

0x8000046 ; arg3
inc rdx
; arg3
mov qword [rdi], rdx
xor eax, eax
ret

0x800004f ; arg3
add rdx, 2
; arg3
mov qword [rdi], rdx
xor eax, eax
ret
```
recompile()
Recompile all existing signatures. This can be useful for example if a global or closure variable was frozen by your function and its value in Python has changed. Since compiling isn’t cheap, this is mainly for testing and interactive use.

parallel_diagnostics(signature=None, level=1)
Print parallel diagnostic information for the given signature. If no signature is present it is printed for all known signatures. level is used to adjust the verbosity, level=1 (default) is minimum verbosity, levels 2, 3, and 4 provide increasing levels of verbosity.

get_metadata(signature=None)
Obtain the compilation metadata for a given signature. This is useful for developers of Numba and Numba extensions.

2.2.4 Vectorized functions (ufuncs and DUFuncs)

@numba.vectorize(*, signatures=[], identity=None, nopython=True, target='cpu', forceobj=False, cache=False, locals={})
Compile the decorated function and wrap it either as a Numpy ufunc or a Numba DUFunc. The optional nopython, forceobj and locals arguments have the same meaning as in numba.jit().

signatures is an optional list of signatures expressed in the same form as in the numba.jit() signature argument. If signatures is non-empty, then the decorator will compile the user Python function into a Numpy ufunc. If no signatures are given, then the decorator will wrap the user Python function in a DUFunc instance, which will compile the user function at call time whenever Numpy can not find a matching loop for the input arguments. signatures is required if target is "parallel".

identity is the identity (or unit) value of the function being implemented. Possible values are 0, 1, None, and the string "reorderable". The default is None. Both None and "reorderable" mean the function has no identity value; "reorderable" additionally specifies that reductions along multiple axes can be reordered.

If there are several signatures, they must be ordered from the more specific to the least specific. Otherwise, Numpy’s type-based dispatching may not work as expected. For example, the following is wrong:

```python
@vectorize(\["float64(float64)", "float32(float32)"\])
def f(x): ...
```
as running it over a single-precision array will choose the float64 version of the compiled function, leading to much less efficient execution. The correct invocation is:

```python
@vectorize(\["float32(float32)", "float64(float64)"\])
def f(x): ...
```

target is a string for backend target; Available values are “cpu”, “parallel”, and “cuda”. To use a multithreaded version, change the target to “parallel” (which requires signatures to be specified):

```python
@vectorize(\["float64(float64)", "float32(float32)"\], target='parallel')
def f(x): ...
```

For the CUDA target, use “cuda”:

```python
@vectorize(\["float64(float64)", "float32(float32)"\], target='cuda')
def f(x): ...
```
The compiled function can be cached to reduce future compilation time. It is enabled by setting cache to True. Only the “cpu” and “parallel” targets support caching.
@numba.guvectorize(signatures, layout, *, identity=None, nopython=True, target='cpu', forceobj=False, cache=False, locals={})

Generalized version of numba.vectorize(). While numba.vectorize() will produce a simple ufunc whose core functionality (the function you are decorating) operates on scalar operands and returns a scalar value, numba.guvectorize() allows you to create a Numpy ufunc whose core function takes array arguments of various dimensions.

The additional argument layout is a string specifying, in symbolic form, the dimensionality and size relationship of the argument types and return types. For example, a matrix multiplication will have a layout string of "(m, n), (n, p)\rightarrow(m, p)". Its definition might be (function body omitted):

```python
@guvectorize(['void(float64[:, :], float64[:, :], float64[:, :])'],
            '(m,n),(n,p)\rightarrow(m,p)')
def f(a, b, result):
    """Fill-in *result* matrix such as result := a \times b""
    ...
```

If one of the arguments should be a scalar, the corresponding layout specification is () and the argument will really be given to you as a zero-dimension array (you have to dereference it to get the scalar value). For example, a one-dimension moving average with a parameterable window width may have a layout string of "(n), ()\rightarrow(n)".

Note that any output will be given to you preallocated as an additional function argument: your code has to fill it with the appropriate values for the function you are implementing.

If your function doesn’t take an output array, you should omit the “arrow” in the layout string (e.g. "(n), ()\rightarrow()").

When doing this, it is important to be aware that changes to the input arrays cannot always be relied on to be visible outside the execution of the ufunc, as NumPy may pass in temporary arrays as inputs (for example, if a cast is required).

See also:

Specification of the layout string as supported by Numpy. Note that Numpy uses the term “signature”, which we unfortunately use for something else.

The compiled function can be cached to reduce future compilation time. It is enabled by setting cache to True. Only the “cpu” and “parallel” targets support caching.

class numba.DUFunc

The class of objects created by calling numba.vectorize() with no signatures.

DUFunc instances should behave similarly to Numpy ufunc objects with one important difference: call-time loop generation. When calling a ufunc, Numpy looks at the existing loops registered for that ufunc, and will raise a TypeError if it cannot find a loop that it cannot safely cast the inputs to suit. When calling a DUFunc, Numba delegates the call to Numpy. If the Numpy ufunc call fails, then Numba attempts to build a new loop for the given input types, and calls the ufunc again. If this second call attempt fails or a compilation error occurs, then DUFunc passes along the exception to the caller.

See also:

The “Dynamic universal functions” section in the user’s guide demonstrates the call-time behavior of DUFunc, and discusses the impact of call order on how Numba generates the underlying ufunc.

ufunc

The actual Numpy ufunc object being built by the DUFunc instance. Note that the DUFunc object maintains several important data structures required for proper ufunc functionality (specifically the dynamically compiled loops). Users should not pass the ufunc value around without ensuring the underlying DUFunc will not be garbage collected.

nin

The number of DUFunc (ufunc) inputs. See ufunc.nin.
nout
The number of DUFunc outputs. See ufunc.nout.
nargs
The total number of possible DUFunc arguments (should be \(nin + nout\)). See ufunc.nargs.
ntypes
The number of input types supported by the DUFunc. See ufunc.ntypes.
types
A list of the supported types given as strings. See ufunc.types.
identity
The identity value when using the ufunc as a reduction. See ufunc.identity.
reduce\(A, *\), axis, dtype, out, keepdims\)
Reduces \(A\)'s dimension by one by applying the DUFunc along one axis. See ufunc.reduce.
accumulate\(A, *\), axis, dtype, out\)
Accumulate the result of applying the operator to all elements. See ufunc.accumulate.
reduceat\(A, indices, *\), axis, dtype, out\)
Performs a (local) reduce with specified slices over a single axis. See ufunc.reduceat.
outer\(A, B\)
Apply the ufunc to all pairs \((a, b)\) with \(a\) in \(A\), and \(b\) in \(B\). See ufunc.outer.
at\(A, indices, *, B\)
Performs unbuffered in place operation on operand \(A\) for elements specified by \(indices\). If you are using Numpy 1.7 or earlier, this method will not be present. See ufunc.at.

Note: Vectorized functions can, in rare circumstances, show unexpected warnings or errors.

2.2.5 C callbacks

@numba.cfunc\(\text{signature, nopython=False, cache=False, locals=\{\}}\)
Compile the decorated function on-the-fly to produce efficient machine code. The compiled code is wrapped in a thin C callback that makes it callable using the natural C ABI.

The \text{signature} is a single signature representing the signature of the C callback. It must have the same form as in \text{jit()}. The decorator does not check that the types in the signature have a well-defined representation in C.

\text{nopython} and \text{cache} are boolean flags. \text{locals} is a mapping of local variable names to \text{Types and signatures}. They all have the same meaning as in \text{jit()}. The decorator returns a \text{CFunc} object.

Note: C callbacks currently do not support \text{object mode}.

class \text{CFunc}
The class of objects created by \text{cfunc()}. \text{CFunc} objects expose the following attributes and methods:

address
The address of the compiled C callback, as an integer.
cffi
A cffi function pointer instance, to be passed as an argument to cffi-wrapped functions. The pointer’s type is `void *`, so only minimal type checking will happen when passing it to cffi.

ctypes
A ctypes callback instance, as if it were created using ctypes.CFUNCTYPE().

native_name
The name of the compiled C callback.

inspect_llvm()
Return the human-readable LLVM IR generated for the C callback. native_name is the name under which this callback is defined in the IR.

2.3 Ahead-of-Time compilation

class numba.pycc.CC(extension_name, source_module=None)
An object used to generate compiled extensions from Numba-compiled Python functions. extension_name is the name of the extension to be generated. source_module is the Python module containing the functions; if None, it is inferred by examining the call stack.

CC instances have the following attributes and methods:

name
(read-only attribute) The name of the extension module to be generated.

output_dir
(read-write attribute) The directory the extension module will be written into. By default it is the directory the source_module is located in.

output_file
(read-write attribute) The name of the file the extension module will be written to. By default this follows the Python naming convention for the current platform.

target_cpu
(read-write attribute) The name of the CPU model to generate code for. This will select the appropriate instruction set extensions. By default, a generic CPU is selected in order to produce portable code.

Recognized names for this attribute depend on the current architecture and LLVM version. If you have LLVM installed, llc -mcpu=help will give you a list. Examples on x86-64 are "ivybridge", "haswell", "skylake" or "broadwell". You can also give the value "host" which will select the current host CPU.

verbose
(read-write attribute) If true, print out information while compiling the extension. False by default.

@export(exported_name, sig)
Mark the decorated function for compilation with the signature sig. The compiled function will be exposed as exported_name in the generated extension module.

All exported names within a given CC instance must be distinct, otherwise an exception is raised.

compile()
Compile all exported functions and generate the extension module as specified by output_dir and output_file.

distutils_extension(**kwars)
Return a distutils.core.Extension instance allowing to integrate generation of the extension module in a conventional setup.py-driven build process. The optional kwars let you pass optional parameters to
the \texttt{Extension} constructor.

In this mode of operation, it is not necessary to call \texttt{compile()} yourself. Also, \texttt{output\_dir} and \texttt{output\_file} will be ignored.

### 2.4 Utilities

#### 2.4.1 Dealing with pointers

These functions can be called from pure Python as well as in \textit{nopython mode}.

\begin{verbatim}
numba.carray(ptr, shape, dtype=None)
\end{verbatim}

Return a Numpy array view over the data pointed to by \textit{ptr} with the given \textit{shape}, in C order. If \textit{dtype} is given, it is used as the array’s dtype, otherwise the array’s dtype is inferred from \textit{ptr}’s type. As the returned array is a view, not a copy, writing to it will modify the original data.

- \textit{ptr} should be a ctypes pointer object (either a typed pointer as created using \texttt{POINTER()}, or a \texttt{c\_void\_p}).
- \textit{shape} should be an integer or a tuple of integers.
- \textit{dtype} should be a Numpy dtype or scalar class (i.e. both \texttt{np.dtype('int8')} and \texttt{np.int8} are accepted).

\begin{verbatim}
numba.farray(ptr, shape, dtype=None)
\end{verbatim}

Same as \texttt{carray()}, but the data is assumed to be laid out in Fortran order, and the array view is constructed accordingly.

### 2.5 Environment variables

\underline{Note:} This section relates to environment variables that impact Numba’s runtime, for compile time environment variables see Build time environment variables and configuration of optional components.

Numba allows its behaviour to be changed through the use of environment variables. Unless otherwise mentioned, those variables have integer values and default to zero.

For convenience, Numba also supports the use of a configuration file to persist configuration settings. Note: To use this feature \texttt{pyyaml} must be installed.

The configuration file must be named \texttt{.numba\_config.yaml} and be present in the directory from which the Python interpreter is invoked. The configuration file, if present, is read for configuration settings before the environment variables are searched. This means that the environment variable settings will override the settings obtained from a configuration file (the configuration file is for setting permanent preferences whereas the environment variables are for ephemeral preferences).

The format of the configuration file is a dictionary in YAML format that maps the environment variables below (without the \texttt{NUMBA\_} prefix) to a desired value. For example, to permanently switch on developer mode (\texttt{NUMBA\_DEVELOPER\_MODE} environment variable) and control flow graph printing (\texttt{NUMBA\_DUMP\_CFG} environment variable), create a configuration file with the contents:

\begin{verbatim}
developer_mode: 1
dump_cfg: 1
\end{verbatim}

This can be especially useful in the case of wanting to use a set color scheme based on terminal background color. For example, if the terminal background color is black, the \texttt{dark\_bg} color scheme would be well suited and can be set for permanent use by adding:
2.5.1 Jit flags

These variables globally override flags to the \texttt{jit()} decorator.

\textbf{NUMBA_BOUNDSCHECK}  
If set to 0 or 1, globally disable or enable bounds checking, respectively. The default if the variable is not set or set to an empty string is to use the \texttt{boundscheck} flag passed to the \texttt{jit()} decorator for a given function. See the documentation of \texttt{@jit} for more information.

Note, due to limitations in numba, the bounds checking currently produces exception messages that do not match those from NumPy. If you set \texttt{NUMBA_FULL_TRACEBACKS=1}, the full exception message with the axis, index, and shape information will be printed to the terminal.

2.5.2 Debugging

These variables influence what is printed out during compilation of \textit{JIT functions}.

\textbf{NUMBA_DEVELOPER_MODE}  
If set to non-zero, developer mode produces full tracebacks and disables help instructions. Default is zero.

\textbf{NUMBA_FULL_TRACEBACKS}  
If set to non-zero, enable full tracebacks when an exception occurs. Defaults to the value set by \texttt{NUMBA_DEVELOPER_MODE}.

\textbf{NUMBA_SHOW_HELP}  
If set to non-zero, show resources for getting help. Default is zero.

\textbf{NUMBA_CAPTURED_ERRORS}  
Alters the way in which Numba captures and handles exceptions that do not inherit from \texttt{numba.core.errors.NumbaError} during compilation (e.g. standard Python exceptions). This does not impact runtime exception handling. Valid values are:

- \texttt{"old_style"} (default): this is the exception handling behaviour that is present in Numba versions \textless{}= 0.54.x. Numba will capture and wrap all errors occurring in compilation and depending on the compilation phase they will likely materialize as part of the message in a \texttt{TypingError} or a \texttt{LoweringError}.

- \texttt{"new_style"} this will treat any exception that does not inherit from \texttt{numba.core.errors.NumbaError} and is raised during compilation as a “hard error”, i.e. the exception will propagate and compilation will halt. The purpose of this new style is to differentiate between intentionally raised exceptions and those which occur due to mistakes. For example, if an \texttt{AttributeError} occurs in the typing of an @overload function, under this new behaviour it is assumed that this a mistake in the implementation and compilation will halt due to this exception. This behaviour will eventually become the default.

\textbf{NUMBA_DISABLE_ERROR_MESSAGE_HIGHLIGHTING}  
If set to non-zero error message highlighting is disabled. This is useful for running the test suite on CI systems.

\textbf{NUMBA_COLOR_SCHEME}  
Alters the color scheme used in error reporting (requires the \texttt{colorama} package to be installed to work). Valid values are:

- \texttt{no_color} No color added, just bold font weighting.
- \texttt{dark_bg} Suitable for terminals with a dark background.
- \texttt{light_bg} Suitable for terminals with a light background.
• blue_bg Suitable for terminals with a blue background.
• jupyter_nb Suitable for use in Jupyter Notebooks.

Default value: no_color. The type of the value is string.

NUMBA_HIGHLIGHT_DUMPS
If set to non-zero and pygments is installed, syntax highlighting is applied to Numba IR, LLVM IR and assembly dumps. Default is zero.

NUMBA_DISABLE_PERFORMANCE_WARNINGS
If set to non-zero the issuing of performance warnings is disabled. Default is zero.

NUMBA_DEBUG
If set to non-zero, print out all possible debugging information during function compilation. Finer-grained control can be obtained using other variables below.

NUMBA_DEBUG_FRONTEND
If set to non-zero, print out debugging information during operation of the compiler frontend, up to and including generation of the Numba Intermediate Representation.

NUMBA_DEBUGINFO
If set to non-zero, enable debug for the full application by setting the default value of the debug option in jit. Beware that enabling debug info significantly increases the memory consumption for each compiled function. Default value equals to the value of NUMBA_ENABLE_PROFILING.

NUMBA_EXTEND_VARIABLE_LIFETIMES
If set to non-zero, extend the lifetime of variables to the end of the block in which their lifetime ends. This is particularly useful in conjunction with NUMBA_DEBUGINFO as it helps with introspection of values. Default is zero.

NUMBA_GDB_BINARY
Set the gdb binary for use in Numba’s gdb support, this takes the form of a path and full name of the binary, for example: /path/from/root/to/binary/name_of_gdb_binary This is to permit the use of a gdb from a non-default location with a non-default name. If not set gdb is assumed to reside at /usr/bin/gdb.

NUMBA_DEBUG_TYPEINFER
If set to non-zero, print out debugging information about type inference.

NUMBA_ENABLE_PROFILING
Enables JIT events of LLVM in order to support profiling of jitted functions. This option is automatically enabled under certain profilers.

NUMBA_TRACE
If set to non-zero, trace certain function calls (function entry and exit events, including arguments and return values).

NUMBA_DUMP_BYTECODE
If set to non-zero, print out the Python bytecode of compiled functions.

NUMBA_DUMP_CFG
If set to non-zero, print out information about the Control Flow Graph of compiled functions.

NUMBA_DUMP_IR
If set to non-zero, print out the Numba Intermediate Representation of compiled functions.

NUMBA_DUMP_SSA
If set to non-zero, print out the Numba Intermediate Representation of compiled functions after conversion to Static Single Assignment (SSA) form.
NUMBA_DEBUG_PRINT_AFTER
Dump the Numba IR after declared pass(es). This is useful for debugging IR changes made by given passes.
Accepted values are:

- Any pass name (as given by the .name() method on the class)
- Multiple pass names as a comma separated list, i.e. "foo_pass,bar_pass"
- The token "all", which will print after all passes.

The default value is "none" so as to prevent output.

NUMBA_DUMP_ANNOTATION
If set to non-zero, print out types annotations for compiled functions.

NUMBA_DUMP_LLVM
Dump the unoptimized LLVM assembly source of compiled functions. Unoptimized code is usually very verbose; therefore, NUMBA_DUMP_OPTIMIZED is recommended instead.

NUMBA_DUMP_FUNC_OPT
Dump the LLVM assembly source after the LLVM “function optimization” pass, but before the “module optimization” pass. This is useful mostly when developing Numba itself, otherwise use NUMBA_DUMP_OPTIMIZED.

NUMBA_DUMP_OPTIMIZED
Dump the LLVM assembly source of compiled functions after all optimization passes. The output includes the raw function as well as its CPython-compatible wrapper (whose name begins with wrapper.). Note that the function is often inlined inside the wrapper, as well.

NUMBA_DEBUG_ARRAY_OPT
Dump debugging information related to the processing associated with the parallel=True jit decorator option.

NUMBA_DEBUG_ARRAY_OPT_RUNTIME
Dump debugging information related to the runtime scheduler associated with the parallel=True jit decorator option.

NUMBA_DEBUG_ARRAY_OPT_STATS
Dump statistics about how many operators/calls are converted to parallel for-loops and how many are fused together, which are associated with the parallel=True jit decorator option.

NUMBA_PARALLEL_DIAGNOSTICS
If set to an integer value between 1 and 4 (inclusive) diagnostic information about parallel transforms undertaken by Numba will be written to STDOUT. The higher the value set the more detailed the information produced.

NUMBA_DUMP_ASSEMBLY
Dump the native assembly code of compiled functions.

NUMBA_LLVM_PASS_TIMINGS
Set to 1 to enable recording of pass timings in LLVM; e.g. NUMBA_LLVM_PASS_TIMINGS=1. See Notes on timing LLVM.

Default value: 0 (Off)

See also:
Troubleshooting and tips and Numba architecture.
2.5.3 Compilation options

**NUMBA_OPT**
The optimization level; this option is passed straight to LLVM.

*Default value:* 3

**NUMBA_LOOP_VECTORIZE**
If set to non-zero, enable LLVM loop vectorization.

*Default value:* 1 (except on 32-bit Windows)

**NUMBA_SLP_VECTORIZE**
If set to non-zero, enable LLVM superword-level parallelism vectorization.

*Default value:* 1

**NUMBA_ENABLE_AVX**
If set to non-zero, enable AVX optimizations in LLVM. This is disabled by default on Sandy Bridge and Ivy Bridge architectures as it can sometimes result in slower code on those platforms.

**NUMBA_DISABLE_INTEL_SVML**
If set to non-zero and Intel SVML is available, the use of SVML will be disabled.

**NUMBA_DISABLE_JIT**
Disable JIT compilation entirely. The `jit()` decorator acts as if it performs no operation, and the invocation of decorated functions calls the original Python function instead of a compiled version. This can be useful if you want to run the Python debugger over your code.

**NUMBA_CPU_NAME**
**NUMBA_CPU_FEATURES**
Override CPU and CPU features detection. By setting `NUMBA_CPU_NAME=generic`, a generic CPU model is picked for the CPU architecture and the feature list (`NUMBA_CPU_FEATURES`) defaults to empty. CPU features must be listed with the format `+feature1,-feature2` where `+` indicates enable and `-` indicates disable. For example, `+sse,+sse2,-avx,-avx2` enables SSE and SSE2, and disables AVX and AVX2.

These settings are passed to LLVM for configuring the compilation target. To get a list of available options, use the `llc` commandline tool from LLVM, for example:

```
llc -march=x86 -mattr=help
```

*Tip:* To force all caching functions (@jit(cache=True)) to emit portable code (portable within the same architecture and OS), simply set `NUMBA_CPU_NAME=generic`.

**NUMBA_FUNCTION_CACHE_SIZE**
Override the size of the function cache for retaining recently deserialized functions in memory. In systems like Dask, it is common for functions to be deserialized multiple times. Numba will cache functions as long as there is a reference somewhere in the interpreter. This cache size variable controls how many functions that are no longer referenced will also be retained, just in case they show up in the future. The implementation of this is not a true LRU, but the large size of the cache should be sufficient for most situations.

*Note:* this is unrelated to the compilation cache.

*Default value:* 128

**NUMBA_LLVM_REFPRUNE_PASS**
Turns on the LLVM pass level reference-count pruning pass and disables the regex based implementation in Numba.
Default value: 1 (On)

**NUMBA_LLVM_REFPRUNE_FLAGS**

When **NUMBA_LLVM_REFPRUNE_PASS** is on, this allows configuration of subpasses in the reference-count pruning LLVM pass.

Valid values are any combinations of the below separated by , (case-insensitive):

- `all`: enable all subpasses.
- `per_bb`: enable per-basic-block level pruning, which is same as the old regex based implementation.
- `diamond`: enable inter-basic-block pruning that is a diamond shape pattern, i.e. a single-entry single-exit CFG subgraph where has an incref in the entry and a corresponding decref in the exit.
- `fanout`: enable inter-basic-block pruning that has a fanout pattern, i.e. a single-entry multiple-exit CFG subgraph where the entry has an incref and every exit has a corresponding decref.
- `fanout_raise`: same as `fanout` but allow subgraph exit nodes to be raising an exception and not have a corresponding decref.

For example, `all` is the same as `per_bb, diamond, fanout, fanout_raise`

Default value: “all”

### 2.5.4 Caching options

Options for the compilation cache.

**NUMBA_DEBUG_CACHE**

If set to non-zero, print out information about operation of the JIT compilation cache.

**NUMBA_CACHE_DIR**

Override the location of the cache directory. If defined, this should be a valid directory path.

If not defined, Numba picks the cache directory in the following order:

1. In-tree cache. Put the cache next to the corresponding source file under a `__pycache__` directory following how `.pyc` files are stored.
2. User-wide cache. Put the cache in the user’s application directory using `appdirs.user_cache_dir` from the Appdirs package.
3. IPython cache. Put the cache in an IPython specific application directory. Stores are made under the `numba_cache` in the directory returned by `IPython.paths.get_ipython_cache_dir()`.

Also see docs on cache sharing and docs on cache clearing

### 2.5.5 GPU support

**NUMBA_DISABLE_CUDA**

If set to non-zero, disable CUDA support.

**NUMBA_FORCE_CUDA_CC**

If set, force the CUDA compute capability to the given version (a string of the type `major.minor`), regardless of attached devices.

**NUMBA_CUDA_DEFAULT_PTX_CC**

The default compute capability (a string of the type `major.minor`) to target when compiling to PTX using `cuda.compile_ptx`. The default is 5.2, which is the lowest non-deprecated compute capability in the most recent version of the CUDA toolkit supported (10.2 at present).
NUMBA_ENABLE_CUDASIM
    If set, don’t compile and execute code for the GPU, but use the CUDA Simulator instead. For debugging purposes.

NUMBA_CUDA_ARRAY_INTERFACE_SYNC
    Whether to synchronize on streams provided by objects imported using the CUDA Array Interface. This defaults
to 1. If set to 0, then no synchronization takes place, and the user of Numba (and other CUDA libraries) is
responsible for ensuring correctness with respect to synchronization on streams.

NUMBA_CUDA_LOG_LEVEL
    For debugging purposes. If no other logging is configured, the value of this variable is the logging level for
CUDA API calls. The default value is CRITICAL - to trace all API calls on standard error, set this to DEBUG.

NUMBA_CUDA_LOG_API_ARGS
    By default the CUDA API call logs only give the names of functions called. Setting this variable to 1 also
includes the values of arguments to Driver API calls in the logs.

NUMBA_CUDA_DRIVER
    Path of the directory in which the CUDA driver libraries are to be found. Normally this should not need to be
set as Numba can locate the driver in standard locations. However, this variable can be used if the driver is in a
non-standard location.

NUMBA_CUDA_LOG_SIZE
    Buffer size for logs produced by CUDA driver API operations. This defaults to 1024 and should not normally
need to be modified - however, if an error in an API call produces a large amount of output that appears to be
truncated (perhaps due to multiple long function names, for example) then this variable can be used to increase
the buffer size and view the full error message.

NUMBA_CUDA_VERBOSE_JIT_LOG
    Whether the CUDA driver should produce verbose log messages. Defaults to 1, indicating that verbose messaging
is enabled. This should not need to be modified under normal circumstances.

NUMBA_CUDA_PER_THREAD_DEFAULT_STREAM
    When set to 1, the default stream is the per-thread default stream. When set to 0, the default stream is the legacy
default stream. This defaults to 0, for the legacy default stream. See Stream Synchronization Behavior for an
explanation of the legacy and per-thread default streams.

    This variable only takes effect when using Numba’s internal CUDA bindings; when using the NVIDIA bindings,
use the environment variable CUDA_PYTHON_CUDA_PER_THREAD_DEFAULT_STREAM instead.

    See also:
    The Default Stream section in the NVIDIA Bindings documentation.

NUMBA_CUDA_LOW_OCCUPANCY_WARNINGS
    Enable warnings if the grid size is too small relative to the number of streaming multiprocessors (SM). This
option is on by default (default value is 1).

    The heuristic checked is whether gridsize < 2 * (number of SMs). NOTE: The absence of a warning
does not imply a good gridsize relative to the number of SMs. Disabling this warning will reduce the number of
CUDA API calls (during JIT compilation), as the heuristic needs to check the number of SMs available on the
device in the current context.

NUMBA_CUDA_WARN_ON_IMPLICIT_COPY
    Enable warnings if a kernel is launched with host memory which forces a copy to and from the device. This
option is on by default (default value is 1).

NUMBA_CUDA_USE_NVIDIA_BINDING
    When set to 1, Numba will attempt to use the NVIDIA CUDA Python binding to make calls to the driver API
instead of using its own ctypes binding. This defaults to 0 (off), as the NVIDIA binding is currently missing
support for Per-Thread Default Streams and the profiler APIs.

2.5. Environment variables  113
2.5.6 Threading Control

**NUMBA_NUM_THREADS**
If set, the number of threads in the thread pool for the parallel CPU target will take this value. Must be greater than zero. This value is independent of `OMP_NUM_THREADS` and `MKL_NUM_THREADS`.

*Default value:* The number of CPU cores on the system as determined at run time. This can be accessed via `numba.config.NUMBA_DEFAULT_NUM_THREADS`.

See also the section on *Setting the Number of Threads* for information on how to set the number of threads at runtime.

**NUMBA_THREADING_LAYER**
This environment variable controls the library used for concurrent execution for the CPU parallel targets (`@vectorize(target='parallel'), @guvectorize(target='parallel')` and `@njit(parallel=True)`). The variable type is string and by default is `default` which will select a threading layer based on what is available in the runtime. The valid values are (for more information about these see the threading layer documentation):

- default - select a threading layer based on what is available in the current runtime.
- safe - select a threading layer that is both fork and thread safe (requires the TBB package).
- forksafe - select a threading layer that is fork safe.
- threadsafe - select a threading layer that is thread safe.
- tbb - A threading layer backed by Intel TBB.
- omp - A threading layer backed by OpenMP.
- workqueue - A simple built-in work-sharing task scheduler.

**NUMBA_THREADING_LAYER_PRIORITY**
This environment variable controls the order in which the libraries used for concurrent execution, for the CPU parallel targets (`@vectorize(target='parallel'), @guvectorize(target='parallel')` and `@njit(parallel=True)`), are prioritized for use. The variable type is string and by default is `tbb omp workqueue`, with the priority taken based on position from the left of the string, left most being the highest. Valid values are any permutation of the three choices (for more information about these see the threading layer documentation.)

2.6 Supported Python features

Apart from the Language part below, which applies to both object mode and nopython mode, this page only lists the features supported in nopython mode.

**Warning:** Numba behavior differs from Python semantics in some situations. We strongly advise reviewing Deviations from Python Semantics to become familiar with these differences.
2.6.1 Language

Constructs

Numba strives to support as much of the Python language as possible, but some language features are not available inside Numba-compiled functions. Below is a quick reference for the support level of Python constructs.

**Supported** constructs:
- conditional branch: `if .. elif .. else`
- loops: `while`, `for .. in`, `break`, `continue`
- basic generator: `yield`
- assertion: `assert`

**Partially supported** constructs:
- exceptions: `try .. except, raise, else and finally` (See details in this section)
- context manager: `with` (only support `numba.objmode()`)
- list comprehension (see details in this section)

**Unsupported** constructs:
- async features: `async with`, `async for` and `async def`
- class definition: `class` (except for `@jitclass`)
- set, dict and generator comprehensions
- generator delegation: `yield from`

Functions

Function calls

Numba supports function calls using positional and named arguments, as well as arguments with default values and `*args` (note the argument for `*args` can only be a tuple, not a list). Explicit `**kwargs` are not supported.

Function calls to locally defined inner functions are supported as long as they can be fully inlined.

Functions as arguments

Functions can be passed as argument into another function. But, they cannot be returned. For example:

```python
from numba import jit

@jit
def add1(x):
    return x + 1

@jit
def bar(fn, x):
    return fn(x)
```

(continues on next page)
def foo(x):
    return bar(add1, x)

# Passing add1 within numba compiled code.
print(foo(1))
# Passing add1 into bar from interpreted code
print(bar(add1, 1))

Note: Numba does not handle function objects as real objects. Once a function is assigned to a variable, the variable cannot be re-assigned to a different function.

Inner function and closure

Numba now supports inner functions as long as they are non-recursive and only called locally, but not passed as argument or returned as result. The use of closure variables (variables defined in outer scopes) within an inner function is also supported.

Recursive calls

Most recursive call patterns are supported. The only restriction is that the recursive callee must have a control-flow path that returns without recursing. Numba is able to type-infer recursive functions without specifying the function type signature (which is required in numba 0.28 and earlier). Recursive calls can even call into a different overload of the function.

Generators

Numba supports generator functions and is able to compile them in object mode and nopython mode. The returned generator can be used both from Numba-compiled code and from regular Python code.

Coroutine features of generators are not supported (i.e. the generator.send(), generator.throw(), generator.close() methods).

Exception handling

raise statement

The raise statement is only supported in the following forms:

- raise SomeException
- raise SomeException(<arguments>): in nopython mode, constructor arguments must be compile-time constants

It is currently unsupported to re-raise an exception created in compiled code.
try .. except

The `try .. except` construct is partially supported. The following forms of are supported:

- the *bare* except that captures all exceptions:

```python
try:
 ...
except:
 ...
```

- using exactly the `Exception` class in the `except` clause:

```python
try:
 ...
except Exception:
 ...
```

This will match any exception that is a subclass of `Exception` as expected. Currently, instances of `Exception` and its subclasses are the only kind of exception that can be raised in compiled code.

---

**Warning:** Numba currently masks signals like `KeyboardInterrupt` and `SystemExit`. These signaling exceptions are ignored during the execution of Numba compiled code. The Python interpreter will handle them as soon as the control is returned to it.

Currently, exception objects are not materialized inside compiled functions. As a result, it is not possible to store an exception object into a user variable or to re-raise an exception. With this limitation, the only realistic use-case would look like:

```python
try:
    do_work()
except Exception:
    handle_error_case()
    return error_code
```

---

try .. except .. else .. finally

The `else` block and the `finally` block of a `try .. except` are supported:

```python
>>> @jit(nopython=True)
... def foo():
...     try:
...         print('main block')
...     except Exception:
...         print('handler block')
...     else:
...         print('else block')
...     finally:
...         print('final block')
... >>> foo()
```

(continues on next page)
The `try .. finally` construct without the `except` clause is also supported.

### 2.6.2 Built-in types

#### int, bool

Arithmetic operations as well as truth values are supported.

The following attributes and methods are supported:

- `.conjugate()`
- `.real`
- `.imag`

#### float, complex

Arithmetic operations as well as truth values are supported.

The following attributes and methods are supported:

- `.conjugate()`
- `.real`
- `.imag`

#### str

Numba supports (Unicode) strings in Python 3. Strings can be passed into `nopython mode` as arguments, as well as constructed and returned from `nopython mode`. As in Python, slices (even of length 1) return a new, reference counted string. Optimized code paths for efficiently accessing single characters may be introduced in the future.

The in-memory representation is the same as was introduced in Python 3.4, with each string having a tag to indicate whether the string is using a 1, 2, or 4 byte character width in memory. When strings of different encodings are combined (as in concatenation), the resulting string automatically uses the larger character width of the two input strings. String slices also use the same character width as the original string, even if the slice could be represented with a narrower character width. (These details are invisible to the user, of course.)

The following constructors, functions, attributes and methods are currently supported:

- `str(int)`
- `len()`
- `+` (concatenation of strings)
- `*` (repetition of strings)
- `.in`, `.contains()`
- `==`, `<`, `<=`, `>`, `>=` (comparison)
- `.capitalize()`
• `casefold()`
• `center()`
• `count()`
• `endswith()`
• `expandtabs()`
• `find()`
• `index()`
• `isalnum()`
• `isalpha()`
• `isdecimal()`
• `isdigit()`
• `isidentifier()`
• `islower()`
• `isnumeric()`
• `isprintable()`
• `isspace()`
• `istitle()`
• `isupper()`
• `join()`
• `ljust()`
• `lower()`
• `lstrip()`
• `partition()`
• `replace()`
• `rfind()`
• `rindex()`
• `rjust()`
• `rpartition()`
• `rsplit()`
• `rstrip()`
• `split()`
• `splitlines()`
• `startswith()`
• `strip()`
• `swapcase()`
• `.title()`
• `.upper()`
• `.zfill()`

Regular string literals (e.g. "ABC") as well as f-strings without format specs (e.g. "ABC_{a+1}") that only use string and integer variables (types with `str()` overload) are supported in `nopython mode`.

Additional operations as well as support for Python 2 strings / Python 3 bytes will be added in a future version of Numba. Python 2 Unicode objects will likely never be supported.

**Warning:** The performance of some operations is known to be slower than the CPython implementation. These include substring search (in, `.contains()` and `find()`) and string creation (like `.split()`). Improving the string performance is an ongoing task, but the speed of CPython is unlikely to be surpassed for basic string operation in isolation. Numba is most successfully used for larger algorithms that happen to involve strings, where basic string operations are not the bottleneck.

### tuple

Tuple support is categorised into two categories based on the contents of a tuple. The first category is homogeneous tuples, these are tuples where the type of all the values in the tuple are the same, the second is heterogeneous tuples, these are tuples where the types of the values are different.

**Note:** The `tuple()` constructor itself is NOT supported.

### homogeneous tuples

An example of a homogeneous tuple:

```python
homogeneous_tuple = (1, 2, 3, 4)
```

The following operations are supported on homogeneous tuples:

- Tuple construction.
- Tuple unpacking.
- Comparison between tuples.
- Iteration and indexing.
- Addition (concatenation) between tuples.
- Slicing tuples with a constant slice.
- The index method on tuples.
heterogeneous tuples

An example of a heterogeneous tuple:

```python
heterogeneous_tuple = (1, 2j, 3.0, "a")
```

The following operations are supported on heterogeneous tuples:

- Comparison between tuples.
- Indexing using an index value that is a compile time constant e.g. `mytuple[7]`, where 7 is evidently a constant.
- Iteration over a tuple (requires experimental `literal_unroll()` feature, see below).

**Warning:** The following feature (`literal_unroll()`) is experimental and was added in version 0.47.

To permit iteration over a heterogeneous tuple the special function `numba.literal_unroll()` must be used. This function has no effect other than to act as a token to permit the use of this feature. Example use:

```python
from numba import njit, literal_unroll

@njit
def foo():
    heterogeneous_tuple = (1, 2j, 3.0, "a")
    for i in literal_unroll(heterogeneous_tuple):
        print(i)
```

**Warning:** The following restrictions apply to the use of `literal_unroll()`:

- `literal_unroll()` can only be used on tuples and constant lists of compile time constants, e.g. `[1, 2j, 3, "a"]` and the list not being mutated.
- The only supported use pattern for `literal_unroll()` is loop iteration.
- Only one `literal_unroll()` call is permitted per loop nest (i.e. nested heterogeneous tuple iteration loops are forbidden).
- The usual type inference/stability rules still apply.

A more involved use of `literal_unroll()` might be type specific dispatch, recall that string and integer literal values are considered their own type, for example:

```python
from numba import njit, types, literal_unroll
from numba.extending import overload

def dt(x):
    # dummy function to overload
    pass

@overload(dt, inline='always')
def ol_dt(li):
    if isinstance(li, types.StringLiteral):
        value = li.literal_value
        if value == "apple":
```

(continues on next page)
def impl(li):
    return 1
elif value == "orange":
    def impl(li):
        return 2
elif value == "banana":
    def impl(li):
        return 3
return impl
elif isinstance(li, types.IntegerLiteral):
    value = li.literal_value
    if value == 0xca11ab1e:
        def impl(li):
            # capture the dispatcher literal value
            return @x5calable + value
        return impl

@njit
def foo():
    acc = 0
    for t in literal_unroll(('apple', 'orange', 'banana', 3390155550)):
        acc += dt(t)
    return acc

print(foo())

Warning: As of version 0.45.x the internal implementation for the list datatype in Numba is changing. Until recently, only a single implementation of the list datatype was available, the so-called reflected-list (see below). However, it was scheduled for deprecation from version 0.44.0 onwards due to its limitations. As of version 0.45.0 a new implementation, the so-called typed-list (see below), is available as an experimental feature. For more information, please see: Deprecation Notices.

Creating and returning lists from JIT-compiled functions is supported, as well as all methods and operations. Lists must be strictly homogeneous: Numba will reject any list containing objects of different types, even if the types are compatible (for example, [1, 2.5] is rejected as it contains an int and a float).

For example, to create a list of arrays:

In [1]: from numba import njit
In [2]: import numpy as np
In [3]: @njit
   ...: def foo(x):
   ...:     lst = []
   ...:     for i in range(x):
   ...:         lst.append(np.arange(i))
   ...:     return lst

(continues on next page)
...:

In [4]: foo(4)
Out[4]: [array([], dtype=int64), array([0]), array([0, 1]), array([0, 1, 2])]

List Reflection

In nopython mode, Numba does not operate on Python objects. `list` are compiled into an internal representation. Any `list` arguments must be converted into this representation on the way in to nopython mode and their contained elements must be restored in the original Python objects via a process called `reflection`. Reflection is required to maintain the same semantics as found in regular Python code. However, the reflection process can be expensive for large lists and it is not supported for lists that contain reflected data types. Users cannot use list-of-list as an argument because of this limitation.

**Note:** When passing a list into a JIT-compiled function, any modifications made to the list will not be visible to the Python interpreter until the function returns. (A limitation of the reflection process.)

**Warning:** List sorting currently uses a quicksort algorithm, which has different performance characteristics than the algorithm used by Python.

Initial Values

**Warning:** This is an experimental feature!

Lists that:

- Are constructed using the square braces syntax
- Have values of a literal type

will have their initial value stored in the `.initial_value` property on the type so as to permit inspection of these values at compile time. If required, to force value based dispatch the `literally` function will accept such a list.

Example:

```python
from numba import njit, literally
from numba.extending import overload

# overload this function
def specialize(x):
    pass

@overload(specialize)
```

(continues on next page)
```python
def ol_specialize(x):
    iv = x.initial_value
    if iv is None:
        return lambda x: literally(x)  # Force literal dispatch
    assert iv == [1, 2, 3]  # INITIAL VALUE
    return lambda x: x

@njit
def foo():
    l = [1, 2, 3]
    l[2] = 20  # no impact on .initial_value
    l.append(30)  # no impact on .initial_value
    return specialize(l)

result = foo()
print(result)  # [1, 2, 20, 30] # NOT INITIAL VALUE!
```

## Typed List

**Note:** `numba.typed.List` is an experimental feature, if you encounter any bugs in functionality or suffer from unexpectedly bad performance, please report this, ideally by opening an issue on the Numba issue tracker.

As of version 0.45.0 a new implementation of the list data type is available, the so-called *typed-list*. This is compiled library backed, type-homogeneous list data type that is an improvement over the *reflected-list* mentioned above. Additionally, lists can now be arbitrarily nested. Since the implementation is considered experimental, you will need to import it explicitly from the `numba.typed` module:

```
In [1]: from numba.typed import List

In [2]: from numba import njit

In [3]: @njit
    ...: def foo(l):
    ...:     l.append(23)
    ...:     return l
    ...:

In [4]: mylist = List()

In [5]: mylist.append(1)

In [6]: foo(mylist)
Out[6]: ListType[int64](1, 23)
```

**Note:** As the typed-list stabilizes it will fully replace the reflected-list and the constructors `[]` and `list()` will create a typed-list instead of a reflected one.

Here's an example using `List()` to create `numba.typed.List` inside a JIT-compiled function and letting the compiler
infer the item type:

```python
from numba import njit
from numba.typed import List

@njit
def foo():
    # Instantiate a typed-list
    l = List()
    # Append a value to it, this will set the type to int32/int64
    # (depending on platform)
    l.append(42)
    # The usual list operations, getitem, pop and length are
    # supported
    print(l[0])  # 42
    l[0] = 23
    print(l[0])  # 23
    print(len(l))  # 1
    l.pop()
    print(len(l))  # 0
    return l

foo()
```

Here’s an example of using `List()` to create a `numba.typed.List` outside of a jit-compiled function and then using it as an argument to a jit-compiled function:

```python
from numba import njit
from numba.typed import List

@njit
def foo(mylist):
    for i in range(10, 20):
        mylist.append(i)
    return mylist

# Instantiate a typed-list, outside of a jit context
l = List()
# Append a value to it, this will set the type to int32/int64
# (depending on platform)
l.append(42)
# The usual list operations, getitem, pop and length are supported
print(l[0])  # 42
l[0] = 23
print(l[0])  # 23
print(len(l))  # 1
l.pop()
```

(continues on next page)
print(len(l)) # 0

# And you can use the typed-list as an argument for a jit compiled
# function
l = foo(l)
print(len(l)) # 10

# You can also directly construct a typed-list from an existing
# Python list
py_list = [2, 3, 5]
numba_list = List(py_list)
print(len(numba_list)) # 3

Finally, here’s an example of using a nested List():

```
from numba.typed import List

mylist = List()
for i in range(10):
    l = List()
    for i in range(10):
        l.append(i)
    mylist.append(l)
# mylist is now a list of 10 lists, each containing 10 integers
print(mylist)
```

**Literal List**

**Warning:** This is an experimental feature!

Numba supports the use of literal lists containing any values, for example:

```
l = ['a', 1, 2j, np.zeros(5,)]
```

the predominant use of these lists is for use as a configuration object. The lists appear as a LiteralList type which inherits from Literal, as a result the literal values of the list items are available at compile time. For example:

```
from numba import njit
from numba.extending import overload

# overload this function
```
```python
5
def specialize(x):
    pass

@overload(specialize)
def ol_specialize(x):
    l = x.literal_value
    const_expr = []
    for v in l:
        const_expr.append(str(v))
    const_strings = tuple(const_expr)

    def impl(x):
        return const_strings
    return impl

@njit
def foo():
    const_list = ['a', 10, 1j, ['another', 'list']]
    return specialize(const_list)

result = foo()
print(result)  # ('Literal[str](a)', 'Literal[int](10)', 'complex128', 'list(unicode_type)') #˓
˓noqa E501
```

Important things to note about these kinds of lists:

1. They are immutable, use of mutating methods e.g. `.pop()` will result in compilation failure. Read-only static
   access and read only methods are supported e.g. `len()`.

2. Dynamic access of items is not possible, e.g. `some_list[x]`, for a value `x` which is not a compile time constant.
   This is because it’s impossible to statically determine the type of the item being accessed.

3. Inside the compiler, these lists are actually just tuples with some extra things added to make them look like they
   are lists.

4. They cannot be returned to the interpreter from a compiled function.

**List comprehension**

Numba supports list comprehension. For example:

```
In [1]: from numba import njit

In [2]: @njit
   ...: def foo(x):
   ...:     return [[i for i in range(n)] for n in range(x)]
   ...:

In [3]: foo(3)
Out[3]: [[], [0], [0, 1]]
```

**Note:** Prior to version 0.39.0, Numba did not support the creation of nested lists.
Numba also supports “array comprehension” that is a list comprehension followed immediately by a call to `numpy.array()`. The following is an example that produces a 2D Numpy array:

```python
from numba import jit
import numpy as np

@jit(nopython=True)
def f(n):
    return np.array([[x * y for x in range(n)] for y in range(n)])
```

In this case, Numba is able to optimize the program to allocate and initialize the result array directly without allocating intermediate list objects. Therefore, the nesting of list comprehension here is not a problem since a multi-dimensional array is being created here instead of a nested list.

Additionally, Numba supports parallel array comprehension when combined with the `parallel` option on CPUs.

**set**

All methods and operations on sets are supported in JIT-compiled functions.

Sets must be strictly homogeneous: Numba will reject any set containing objects of different types, even if the types are compatible (for example, `{1, 2.5}` is rejected as it contains an `int` and a `float`). The use of reference counted types, e.g. strings, in sets is unsupported.

**Note:** When passing a set into a JIT-compiled function, any modifications made to the set will not be visible to the Python interpreter until the function returns.

**Typed Dict**

**Warning:** `numba.typed.Dict` is an experimental feature. The API may change in the future releases.

**Note:** `dict()` was not supported in versions prior to 0.44. Currently, calling `dict()` translates to calling `numba.typed.Dict()`.

Numba only supports the use of `dict()` without any arguments. Such use is semantically equivalent to `{}` and `numba.typed.Dict()`. It will create an instance of `numba.typed.Dict` where the key-value types will be later inferred by usage.

Numba does not fully support the Python `dict` because it is an untyped container that can have any Python types as members. To generate efficient machine code, Numba needs the keys and the values of the dictionary to have fixed types, declared in advance. To achieve this, Numba has a typed dictionary, `numba.typed.Dict`, for which the type-inference mechanism must be able to infer the key-value types by use, or the user must explicitly declare the key-value type using the `Dict.empty()` constructor method. This typed dictionary has the same API as the Python `dict`, it implements the `collections.MutableMapping` interface and is usable in both interpreted Python code and JIT-compiled Numba functions. Because the typed dictionary stores keys and values in Numba’s native, unboxed data layout, passing a Numba dictionary into nopython mode has very low overhead. However, this means that using a typed dictionary from the Python interpreter is slower than a regular dictionary because Numba has to box and unbox key and value objects when getting or setting items.
An important difference of the typed dictionary in comparison to Python’s `dict` is that **implicit casting** occurs when a key or value is stored. As a result the `setitem` operation may fail should the type-casting fail.

It should be noted that the Numba typed dictionary is implemented using the same algorithm as the CPython 3.7 dictionary. As a consequence, the typed dictionary is ordered and has the same collision resolution as the CPython implementation.

Further to the above in relation to type specification, there are limitations placed on the types that can be used as keys and/or values in the typed dictionary, most notably the Numba `Set` and `List` types are currently unsupported. Acceptable key/value types include but are not limited to: unicode strings, arrays (value only), scalars, tuples. It is expected that these limitations will be relaxed as Numba continues to improve.

Here’s an example of using `dict()` and `{}` to create `numba.typed.Dict` instances and letting the compiler infer the key-value types:

```python
from numba import njit
import numpy as np

@njit
def foo():
    d = dict()
    k = {1: np.arange(1), 2: np.arange(2)}
    # The following tells the compiler what the key type and the
    # value
    # type are for `d`.
    d[3] = np.arange(3)
    d[5] = np.arange(5)
    return d, k

(d, k) = foo()
print(d)  # {3: [0 1 2], 5: [0 1 2 3 4]}
print(k)  # {1: [0], 2: [0 1]}
```

Here’s an example of creating a `numba.typed.Dict` instance from interpreted code and using the dictionary in jit code:

```python
import numpy as np
from numba import njit
from numba.core import types
from numba.typed import Dict

# The Dict.empty() constructs a typed dictionary.
# The key and value typed must be explicitly declared.
d = Dict.empty(
    key_type=types.unicode_type,
    value_type=types.float64[:],
)

# The typed-dict can be used from the interpreter.
```

(continues on next page)
Here's an example of creating a `numba.typed.Dict` instance from jit code and using the dictionary in interpreted code:

```python
import numpy as np
from numba import njit
from numba.core import types
from numba.typed import Dict

# Make array type. Type-expression is not supported in jit # functions.
float_array = types.float64[:]

@njit
def foo():
    # Make dictionary
    d = Dict.empty(
        key_type=types.unicode_type,
        value_type=float_array,
    )
    # Fill the dictionary
    d['posx'] = np.arange(3).astype(np.float64)
    d['posy'] = np.arange(3, 6).astype(np.float64)
    return d

d = foo()
# Print the dictionary
print(d)  # Out: {posx: [0. 1. 2.], posy: [3. 4. 5.]}  
```

It should be noted that `numba.typed.Dict` is not thread-safe. Specifically, functions which modify a dictionary from
multiple threads will potentially corrupt memory, causing a range of possible failures. However, the dictionary can be safely read from multiple threads as long as the contents of the dictionary do not change during the parallel access.

**Dictionary comprehension**

Numba supports dictionary comprehension under the assumption that a `numba.typed.Dict` instance can be created from the comprehension. For example:

```python
In [1]: from numba import njit

In [2]: @njit
   ...: def foo(n):
   ...:     return {i: i**2 for i in range(n)}
   ...:

In [3]: foo(3)
Out[3]: DictType[int64,int64]<iv=None>({0: 0, 1: 1, 2: 4})
```

**Initial Values**

**Warning:** This is an experimental feature!

Typed dictionaries that:

- Are constructed using the curly braces syntax
- Have literal string keys
- Have values of a literal type

will have their initial value stored in the `.initial_value` property on the type so as to permit inspection of these values at compile time. If required, to force value based dispatch the `literally` function will accept a typed dictionary.

Example:

```python
Listing 9: from test_ex_initial_value_dict_compile_time_const
of numba/tests/doc_examples/test_literal_container_usage.py

from numba import njit, literally
from numba.extending import overload

# overload this function
@overload(specialize)
def ol_specialize(x):
    iv = x.initial_value
    if iv is None:
        return lambda x: literally(x) # Force literal dispatch
    assert iv == {'a': 1, 'b': 2, 'c': 3} # INITIAL VALUE
```

(continues on next page)
return lambda x: literally(x)

@njit
def foo():
    d = {'a': 1, 'b': 2, 'c': 3}
    d['c'] = 20 # no impact on .initial_value
    d['d'] = 30 # no impact on .initial_value
    return specialize(d)

result = foo()
print(result) # {a: 1, b: 2, c: 20, d: 30} # NOT INITIAL VALUE!

Heterogeneous Literal String Key Dictionary

**Warning**: This is an experimental feature!

Numba supports the use of statically declared string key to any value dictionaries, for example:

```
d = {'a': 1, 'b': 'data', 'c': 2j}
```

the predominant use of these dictionaries is to orchestrate advanced compilation dispatch or as a container for use as a configuration object. The dictionaries appear as a `LiteralStrKeyDict` type which inherits from `Literal`, as a result the literal values of the keys and the types of the items are available at compile time. For example:

```
Listing 10: from test_ex_literal_dict_compile_time_consts of numba/tests/doc_examples/test_literal_container_usage.py

import numpy as np
from numba import njit, types
from numba.extending import overload

# overload this function
def specialize(x):
    pass

@overload(specialize)
def ol_specialize(x):
    ld = x.literal_value
    const_expr = []
    for k, v in ld.items():
        if isinstance(v, types.Literal):
            lv = v.literal_value
            if lv == 'cat':
                const_expr.append("Meow!")
            elif lv == 'dog':
                const_expr.append("Woof!")
            elif isinstance(lv, int):
                const_expr.append(k.literal_value * lv)
```
else: # it's an array
    const_expr.append("Array(dim=\{dim\})".format(dim=v.ndim))
const_strings = tuple(const_expr)

def impl(x):
    return const_strings
return impl

@njit
def foo():
    pets_ints_and_array = {
        'a': 1,
        'b': 2,
        'c': 'cat',
        'd': 'dog',
        'e': np.ones(5,)}
    return specialize(pets_ints_and_array)

result = foo()
print(result) # ('a', 'bb', 'Meow!', 'Woof!', 'Array(dim=1)')

Important things to note about these kinds of dictionaries:

1. They are immutable, use of mutating methods e.g. .pop() will result in compilation failure. Read-only static access and read only methods are supported e.g. len().

2. Dynamic access of items is not possible, e.g. some_dictionary[x], for a value x which is not a compile time constant. This is because it’s impossible statically determine the type of the item being accessed.

3. Inside the compiler, these dictionaries are actually just named tuples with some extra things added to make them look like they are dictionaries.

4. They cannot be returned to the interpreter from a compiled function.

5. The .keys(), .values() and .items() methods all functionally operate but return tuples opposed to iterables.

None

The None value is supported for identity testing (when using an optional type).

bytes, bytearray, memoryview

The bytearray type and, on Python 3, the bytes type support indexing, iteration and retrieving the len().

The memoryview type supports indexing, slicing, iteration, retrieving the len(), and also the following attributes:

- contiguous
- c_contiguous
- f_contiguous
- itemsize
- nbytes
- ndim
- readonly

2.6. Supported Python features
• shape
• strides

2.6.3 Built-in functions

The following built-in functions are supported:

**Warning:** Support for `isinstance` is an experimental feature. This feature is automatically enabled by simply using `isinstance` in JIT compiled code.

• `abs()`
• `bool`
• `chr()`
• `complex`
• `divmod()`
• `enumerate()`
• `filter()`
• `float`
• `hash()` (see Hashing below)
• `int`: only the one-argument form
• `iter()`: only the one-argument form
• `isinstance()` (experimental support only)
• `len()`
• `min()`
• `map()`
• `max()`
• `next()`: only the one-argument form
• `ord()`
• `print()`: only numbers and strings; no `file` or `sep` argument
• `range`: The only permitted use of range is as a callable function (cannot pass range as an argument to a jitted function or return a range from a jitted function).
• `round()`
• `sorted()`: the `key` argument is not supported
• `sum()`
• `type()`: only the one-argument form, and only on some types (e.g. numbers and named tuples)
• `zip()`
Hashing

The `hash()` built-in is supported and produces hash values for all supported hashable types with the following Python version specific behavior:

Under Python 3, hash values computed by Numba will exactly match those computed in CPython under the condition that the `sys.hash_info.algorithm` is `siphash24` (default).

The `PYTHONHASHSEED` environment variable influences the hashing behavior in precisely the manner described in the CPython documentation.

2.6.4 Standard library modules

array

Limited support for the `array.array` type is provided through the buffer protocol. Indexing, iteration and taking the `len()` is supported. All type codes are supported except for “u”.

cmath

The following functions from the `cmath` module are supported:

- `cmath.acos()`
- `cmath.acosh()`
- `cmath.asin()`
- `cmath.asinh()`
- `cmath.atan()`
- `cmath.atanh()`
- `cmath.cos()`
- `cmath.cosh()`
- `cmath.exp()`
- `cmath.isfinite()`
- `cmath.isinf()`
- `cmath.isnan()`
- `cmath.log()`
- `cmath.log10()`
- `cmath.phase()`
- `cmath.polar()`
- `cmath.rect()`
- `cmath.sin()`
- `cmath.sinh()`
- `cmath.sqrt()`
- `cmath.tan()`
collections

Named tuple classes, as returned by `collections.namedtuple()`, are supported in the same way regular tuples are supported. Attribute access and named parameters in the constructor are also supported.

Creating a named tuple class inside Numba code is not supported; the class must be created at the global level.

ctypes

Numba is able to call ctypes-declared functions with the following argument and return types:

- `ctypes.c_int8`
- `ctypes.c_int16`
- `ctypes.c_int32`
- `ctypes.c_int64`
- `ctypes.c_uint8`
- `ctypes.c_uint16`
- `ctypes.c_uint32`
- `ctypes.c_uint64`
- `ctypes.c_float`
- `ctypes.c_double`
- `ctypes.c_void_p`

enum

Both `enum.Enum` and `enum.IntEnum` subclasses are supported.

math

The following functions from the `math` module are supported:

- `math.acos()`
- `math.acosh()`
- `math.asin()`
- `math.asinh()`
- `math.atan()`
- `math.atan2()`
- `math.atanh()`
- `math.ceil()`
- `math.copysign()`
- `math.cos()`
• math.cosh()
• math.degrees()
• math.erf()
• math.erfc()
• math.exp()
• math.expm1()
• math.fabs()
• math.floor()
• math.frexp()
• math.gamma()
• math.gcd()
• math.hypot()
• math.isfinite()
• math.isinf()
• math.isnan()
• math.ldexp()
• math.lgamma()
• math.log()
• math.log10()
• math.log1p()
• math.pow()
• math.radians()
• math.sin()
• math.sinh()
• math.sqrt()
• math.tan()
• math.tanh()
• math.trunc()

operator

The following functions from the operator module are supported:

• operator.add()
• operator.and_()
• operator.eq()
• operator.floordiv()
• operator.ge()
• operator.gt()
• operator.iadd()
• operator.iand()
• operator.ifloordiv()
• operator.ilshift()
• operator.imatmul() (Python 3.5 and above)
• operator.imod()
• operator.imul()
• operator.invert()
• operator.iord()
• operator.ipow()
• operator.irshift()
• operator.isub()
• operator.itruediv()
• operator.ixor()
• operator.le()
• operator.lshift()
• operator.lt()
• operator.matmul() (Python 3.5 and above)
• operator.mod()
• operator.mul()
• operator.ne()
• operator.neg()
• operator.not_()
• operator.or_()
• operator.pos()
• operator.pow()
• operator.rshift()
• operator.sub()
• operator.truediv()
• operator.xor()
functools

The `functools.reduce()` function is supported but the `initializer` argument is required.

random

Numba supports top-level functions from the `random` module, but does not allow you to create individual `Random` instances. A Mersenne-Twister generator is used, with a dedicated internal state. It is initialized at startup with entropy drawn from the operating system.

- `random.betavariate()`
- `random.expovariate()`
- `random.gammavariate()`
- `random.gauss()`
- `random.getrandbits()`: number of bits must not be greater than 64
- `random.lognormvariate()`
- `random.normalvariate()`
- `random.paretovariate()`
- `random.randint()`
- `random.random()`
- `random.randrange()`
- `random.seed()`: with an integer argument only
- `random.shuffle()`: the sequence argument must be a one-dimension Numpy array or buffer-providing object (such as a `bytearray` or `array.array`); the second (optional) argument is not supported
- `random.uniform()`
- `random.triangular()`
- `random.vonmisesvariate()`
- `random.weibullvariate()`

**Warning:** Calling `random.seed()` from non-Numba code (or from `object mode` code) will seed the Python random generator, not the Numba random generator. To seed the Numba random generator, see the example below.

```python
from numba import njit
import random

@njit
def seed(a):
    random.seed(a)

@njit
def rand():
    return random.random()
```

(continues on next page)
# Incorrect seeding
random.seed(1234)
print(rand())
random.seed(1234)
print(rand())

# Correct seeding
seed(1234)
print(rand())
seed(1234)
print(rand())

Note: Since version 0.28.0, the generator is thread-safe and fork-safe. Each thread and each process will produce independent streams of random numbers.

See also:
Numba also supports most additional distributions from the *Numpy random module*.

heapq

The following functions from the `heapq` module are supported:

- `heapq.heapify()`
- `heapq.heappop()`
- `heapq.heappush()`
- `heapq.heappushpop()`
- `heapq.heapreplace()`
- `heapq.nlargest()`: first two arguments only
- `heapq.nsmallest()`: first two arguments only

Note: the heap must be seeded with at least one value to allow its type to be inferred; heap items are assumed to be homogeneous in type.

2.6.5 Third-party modules

cffi

Similarly to ctypes, Numba is able to call into cffi-declared external functions, using the following C types and any derived pointer types:

- `char`
- `short`
- `int`
• long
• long long
• unsigned char
• unsigned short
• unsigned int
• unsigned long
• unsigned long long
• int8_t
• uint8_t
• int16_t
• uint16_t
• int32_t
• uint32_t
• int64_t
• uint64_t
• float
• double
• ssize_t
• size_t
• void

The `from_buffer()` method of `cffi.FFI` and `CompiledFFI` objects is supported for passing Numpy arrays and other buffer-like objects. Only contiguous arguments are accepted. The argument to `from_buffer()` is converted to a raw pointer of the appropriate C type (for example a `double *` for a `float64` array).

Additional type mappings for the conversion from a buffer to the appropriate C type may be registered with Numba. This may include struct types, though it is only permitted to call functions that accept pointers to structs - passing a struct by value is unsupported. For registering a mapping, use:

```python
numba.core.typing.cffi_utils.register_type(cffi_type, numba_type)
```

Out-of-line cffi modules must be registered with Numba prior to the use of any of their functions from within Numba-compiled functions:

```python
numba.core.typing.cffi_utils.register_module(mod)
```

Register the cffi out-of-line module `mod` with Numba.

Inline cffi modules require no registration.
2.7 Supported NumPy features

One objective of Numba is having a seamless integration with NumPy. NumPy arrays provide an efficient storage method for homogeneous sets of data. NumPy dtypes provide type information useful when compiling, and the regular, structured storage of potentially large amounts of data in memory provides an ideal memory layout for code generation. Numba excels at generating code that executes on top of NumPy arrays.

NumPy support in Numba comes in many forms:

• Numba understands calls to NumPy ufuncs and is able to generate equivalent native code for many of them.
• NumPy arrays are directly supported in Numba. Access to Numpy arrays is very efficient, as indexing is lowered to direct memory accesses when possible.
• Numba is able to generate ufuncs and gufuncs. This means that it is possible to implement ufuncs and gufuncs within Python, getting speeds comparable to that of ufuncs/gufuncs implemented in C extension modules using the NumPy C API.

The following sections focus on the Numpy features supported in nopython mode, unless otherwise stated.

2.7.1 Scalar types

Numba supports the following Numpy scalar types:

• **Integers**: all integers of either signedness, and any width up to 64 bits
• **Booleans**
• **Real numbers**: single-precision (32-bit) and double-precision (64-bit) reals
• **Complex numbers**: single-precision (2x32-bit) and double-precision (2x64-bit) complex numbers
• **Dtimes and timestamps**: of any unit
• **Character sequences** (but no operations are available on them)
• **Structured scalars**: structured scalars made of any of the types above and arrays of the types above

The following scalar types and features are not supported:

• **Arbitrary Python objects**
• **Half-precision and extended-precision** real and complex numbers
• **Nested structured scalars** the fields of structured scalars may not contain other structured scalars

The operations supported on NumPy scalars are almost the same as on the equivalent built-in types such as int or float. You can use a type’s constructor to convert from a different type or width. In addition you can use the view(np.<dtype>) method to bitcast all int and float types within the same width. However, you must define the scalar using a NumPy constructor within a jitted function. For example, the following will work:

```python
>>> import numpy as np
>>> from numba import njit
>>> @njit
... def bitcast():
...    i = np.int64(-1)
...    print(i.view(np.uint64))
...    return

>>> bitcast()
18446744073709551615
```
Whereas the following will not work:

```python
>>> import numpy as np
>>> from numba import njit
>>> @njit
... def bitcast(i):
...     print(i.view(np.uint64))
>>> bitcast(np.int64(-1))
---------------------------------------------------------------------------
TypingError          Traceback (most recent call last)
                     ...                              
TypingError: Failed in nopython mode pipeline (step: ensure IR is legal prior to →
    lowering)
'view' can only be called on NumPy dtypes, try wrapping the variable with 'np.<dtype>()'

File "<ipython-input-3-fc40aaab84c4>", line 3:
def bitcast(i):
    print(i.view(np.uint64))
```

Structured scalars support attribute getting and setting, as well as member lookup using constant strings. Strings stored in a local or global tuple are considered constant strings and can be used for member lookup.

```python
import numpy as np
from numba import njit

arr = np.array([(1, 2)], dtype=[('a1', 'f8'), ('a2', 'f8')])
fields_gl = ('a1', 'a2')

@njit
def get_field_sum(rec):
    fields_lc = ('a1', 'a2')
    field_name1 = fields_lc[0]
    field_name2 = fields_gl[1]
    return rec[field_name1] + rec[field_name2]

get_field_sum(arr[0])  # returns 3
```

It is also possible to use local or global tuples together with `literal_unroll`:

```python
import numpy as np
from numba import njit, literal_unroll

arr = np.array([(1, 2)], dtype=[('a1', 'f8'), ('a2', 'f8')])
fields_gl = ('a1', 'a2')

@njit
def get_field_sum(rec):
    out = 0
    for f in literal_unroll(fields_gl):
        out += rec[f]
    return out

get_field_sum(arr[0])  # returns 3
```
Record subtyping

**Warning:** This is an experimental feature.

Numba allows **width subtyping** of structured scalars. For example, `dtype([[a, f8], [b, i8]])` will be considered a subtype of `dtype([[a, f8]])`, because the second is a strict subset of the first, i.e. field `a` is of the same type and is in the same position in both types. The subtyping relationship will matter in cases where compilation for a certain input is not allowed, but the input is a subtype of another, allowed type.

```python
import numpy as np
from numba import njit, typeof
from numba.core import types
record1 = np.array([[1], dtype=[(a, 'f8')]][0]
record2 = np.array([[2,3], dtype=[(a, 'f8'), (b, 'f8')]][0]

@njit(types.float64(typeof(record1)))
def foo(rec):
    return rec[a]

foo(record1)
foo(record2)
```

Without subtyping the last line would fail. With subtyping, no new compilation will be triggered, but the compiled function for `record1` will be used for `record2`.

**See also:**
Numpy scalars reference.

### 2.7.2 Array types

Numpy arrays of any of the scalar types above are supported, regardless of the shape or layout.

**Array access**

Arrays support normal iteration. Full basic indexing and slicing is supported. A subset of advanced indexing is also supported: only one advanced index is allowed, and it has to be a one-dimensional array (it can be combined with an arbitrary number of basic indices as well).

**See also:**
Numpy indexing reference.
Structured array access

Numba presently supports accessing fields of individual elements in structured arrays by attribute as well as by getting and setting. This goes slightly beyond the NumPy API, which only allows accessing fields by getting and setting. For example:

```python
from numba import njit
import numpy as np

record_type = np.dtype([('ival', np.int32), ('fval', np.float64)], align=True)

def f(rec):
    value = 2.5
    rec[0].ival = int(value)
    rec[0].fval = value
    return rec

arr = np.ones(1, dtype=record_type)
cfunc = njit(f)

# Works
print(cfunc(arr))

# Does not work
print(f(arr))
```

The above code results in the output:

```
[(2, 2.5)]
```

Traceback (most recent call last):
  File "repro.py", line 22, in <module>
    print(cfunc(arr))
  File "repro.py", line 9, in f
    rec[0].ival = int(value)
AttributeError: 'numpy.void' object has no attribute 'ival'

The Numba-compiled version of the function executes, but the pure Python version raises an error because of the unsupported use of attribute access.

Note: This behavior will eventually be deprecated and removed.

Attributes

The following attributes of Numpy arrays are supported:

- `dtype`
- `flags`
- `flat`
- `itemsize`
- `ndim`
• shape
• size
• strides
• T
• real
• imag

The flags object

The object returned by the flags attribute supports the contiguous, c_contiguous and f_contiguous attributes.

The flat object

The object returned by the flat attribute supports iteration and indexing, but be careful: indexing is very slow on non-C-contiguous arrays.

The real and imag attributes

Numpy supports these attributes regardless of the dtype but Numba chooses to limit their support to avoid potential user error. For numeric dtypes, Numba follows Numpy’s behavior. The real attribute returns a view of the real part of the complex array and it behaves as an identity function for other numeric dtypes. The imag attribute returns a view of the imaginary part of the complex array and it returns a zero array with the same shape and dtype for other numeric dtypes. For non-numeric dtypes, including all structured/record dtypes, using these attributes will result in a compile-time (TypingError) error. This behavior differs from Numpy’s but it is chosen to avoid the potential confusion with field names that overlap these attributes.

Calculation

The following methods of Numpy arrays are supported in their basic form (without any optional arguments):
• all()
• any()
• clip()
• conj()
• conjugate()
• cumprod()
• cumsum()
• max()
• mean()
• min()
• nonzero()
• prod()
The corresponding top-level Numpy functions (such as `numpy.prod()`) are similarly supported.

**Other methods**

The following methods of Numpy arrays are supported:

- `argmax()` (axis keyword argument supported).
- `argmin()` (axis keyword argument supported).
- `argsort()` (kind keyword argument supported for values 'quicksort' and 'mergesort')
- `astype()` (only the 1-argument form)
- `copy()` (without arguments)
- `dot()` (only the 1-argument form)
- `flatten()` (no order argument; ‘C’ order only)
- `item()` (without arguments)
- `itemset()` (only the 1-argument form)
- `ptp()` (without arguments)
- `ravel()` (no order argument; ‘C’ order only)
- `repeat()` (no axis argument)
- `reshape()` (only the 1-argument form)
- `sort()` (without arguments)
- `sum()` (with or without the axis and/or dtype arguments.)
  - axis only supports integer values.
  - If the axis argument is a compile-time constant, all valid values are supported. An out-of-range value will result in a `LoweringError` at compile-time.
  - If the axis argument is not a compile-time constant, only values from 0 to 3 are supported. An out-of-range value will result in a runtime exception.
  - All numeric dtypes are supported in the dtype parameter. `timedelta` arrays can be used as input arrays but `timedelta` is not supported as dtype parameter.
  - When a dtype is given, it determines the type of the internal accumulator. When it is not, the selection is made automatically based on the input array’s dtype, mostly following the same rules as NumPy. However, on 64-bit Windows, Numba uses a 64-bit accumulator for integer inputs (int64 for int32 inputs and uint64 for uint32 inputs), while NumPy would use a 32-bit accumulator in those cases.
- `transpose()`
- `view()` (only the 1-argument form)
- `__contains__()`

Where applicable, the corresponding top-level NumPy functions (such as `numpy.argmax()`) are similarly supported.
Warning: Sorting may be slightly slower than Numpy’s implementation.

### 2.7.3 Functions

#### Linear algebra

Basic linear algebra is supported on 1-D and 2-D contiguous arrays of floating-point and complex numbers:

- `numpy.dot()`
- `numpy.kron()` ('C' and 'F' order only)
- `numpy.outer()`
- `numpy.trace()` (only the first argument).
- `numpy.vdot()`
- On Python 3.5 and above, the matrix multiplication operator from PEP 465 (i.e. `a @ b` where `a` and `b` are 1-D or 2-D arrays).
- `numpy.linalg.cholesky()`
- `numpy.linalg.cond()` (only non string values in `p`).
- `numpy.linalg.det()`
- `numpy.linalg.eig()` (only running with data that does not cause a domain change is supported e.g. real input -> real output, complex input -> complex output).
- `numpy.linalg.eigh()` (only the first argument).
- `numpy.linalg.eigvals()` (only running with data that does not cause a domain change is supported e.g. real input -> real output, complex input -> complex output).
- `numpy.linalg.eigvalsh()` (only the first argument).
- `numpy.linalg.inv()`
- `numpy.linalg.lstsq()`
- `numpy.linalg.matrix_power()`
- `numpy.linalg.matrix_rank()`
- `numpy.linalg.norm()` (only the 2 first arguments and only non string values in `ord`).
- `numpy.linalg.pinv()`
- `numpy.linalg.qr()` (only the first argument).
- `numpy.linalg.slogdet()`
- `numpy.linalg.solve()`
- `numpy.linalg.svd()` (only the 2 first arguments).

**Note:** The implementation of these functions needs SciPy to be installed.
Reductions

The following reduction functions are supported:

- `numpy.diff()` (only the 2 first arguments)
- `numpy.median()` (only the first argument)
- `numpy.nancumprod()` (only the first argument)
- `numpy.nancumsum()` (only the first argument)
- `numpy.nanmax()` (only the first argument)
- `numpy.nanmean()` (only the first argument)
- `numpy.nanmedian()` (only the first argument)
- `numpy.nanmin()` (only the first argument)
- `numpy.nanpercentile()` (only the 2 first arguments, complex dtypes unsupported)
- `numpy.nanquantile()` (only the 2 first arguments, complex dtypes unsupported)
- `numpy.nanprod()` (only the first argument)
- `numpy.nanstd()` (only the first argument)
- `numpy.nansum()` (only the first argument)
- `numpy.nanvar()` (only the first argument)
- `numpy.percentile()` (only the 2 first arguments, complex dtypes unsupported)
- `numpy.quantile()` (only the 2 first arguments, complex dtypes unsupported)

Other functions

The following top-level functions are supported:

- `numpy.append()`
- `numpy.arange()`
- `numpy.argsort()` (kind key word argument supported for values 'quicksort' and 'mergesort')
- `numpy.argwhere()`
- `numpy.array()` (only the 2 first arguments)
- `numpy.array_equal()`
- `numpy.array_split()`
- `numpy.asarray()` (only the 2 first arguments)
- `numpy.asarray_chkfinite()` (only the 2 first arguments)
- `numpy.asfarray()`
- `numpy.asfortranarray()` (only the first argument)
- `numpy.atleast_1d()`
- `numpy.atleast_2d()`
- `numpy.atleast_3d()`
- `numpy.bartlett()`
- `numpy.bincount()`
- `numpy.blackman()`
- `numpy.broadcast_to()` (only the 2 first arguments)
- `numpy.column_stack()`
- `numpy.concatenate()`
- `numpy.convolve()` (only the 2 first arguments)
- `numpy.copy()` (only the first argument)
- `numpy.corrcoef()` (only the 3 first arguments, requires SciPy)
- `numpy.correlate()` (only the 2 first arguments)
- `numpy.count_nonzero()` (axis only supports scalar values)
- `numpy.cov()` (only the 5 first arguments)
- `numpy.cross()` (only the 2 first arguments; at least one of the input arrays should have shape[-1] == 3)
  - If shape[-1] == 2 for both inputs, please replace your `numpy.cross()` call with `numba.np.extensions.cross2d()`.
- `numpy.delete()` (only the 2 first arguments)
- `numpy.diag()`
- `numpy.digitize()`
- `numpy.dstack()`
- `numpy.dtype()` (only the first argument)
- `numpy.ediff1d()`
- `numpy.empty()` (only the 2 first arguments)
- `numpy.empty_like()` (only the 2 first arguments)
- `numpy.expand_dims()`
- `numpy.extract()`
- `numpy.eye()`
- `numpy.fill_diagonal()`
- `numpy.flatten()` (no order argument; ‘C’ order only)
- `numpy.flatnonzero()`
- `numpy.flip()` (no axis argument)
- `numpy.fliplr()`
- `numpy.flipud()`
- `numpy.frombuffer()` (only the 2 first arguments)
- `numpy.full()` (only the 3 first arguments)
- `numpy.full_like()` (only the 3 first arguments)
- `numpy.hamming()`
- `numpy.hanning()`
- `numpy.histogram()` (only the 3 first arguments)
- `numpy.hstack()`
- `numpy.identity()`
- `numpy.kaiser()`
- `numpy.iscomplex()`
- `numpy.iscomplexobj()`
- `numpy.isneginf()`
- `numpy.isposinf()`
- `numpy.isreal()`
- `numpy.isrealobj()`
- `numpy.isscalar()`
- `numpy.interp()` (only the 3 first arguments)
- `numpy.intersect1d()` (only first 2 arguments, ar1 and ar2)
- `numpy.linspace()` (only the 3-argument form)
- `numpy.logspace()` (only the 3 first arguments)
- `numpy.ndenumerate`
- `numpy.ndindex`
- `numpy.nditer` (only the first argument)
- `numpy.ones()` (only the 2 first arguments)
- `numpy.ones_like()` (only the 2 first arguments)
- `numpy.partition()` (only the 2 first arguments)
- `numpy.ptp()` (only the first argument)
- `numpy.ravel()` (no order argument; ‘C’ order only)
- `numpy.repeat()` (no axis argument)
- `numpy.reshape()` (no order argument; ‘C’ order only)
- `numpy.roll()` (only the 2 first arguments; second argument shift must be an integer)
- `numpy.roots()`
- `numpy.rot90()` (only the 2 first arguments)
- `numpy.round_()`
- `numpy.searchsorted()` (only the 3 first arguments)
- `numpy.select()` (only using homogeneous lists or tuples for the first two arguments, condlist and choicelist). Additionally, these two arguments can only contain arrays (unlike Numpy that also accepts tuples).
- `numpy.shape()`
- `numpy.sinc()`
- `numpy.sort()` (no optional arguments)
- `numpy.split()`
• `numpy.stack()`
• `numpy.swapaxes()`
• `numpy.take()` (only the 2 first arguments)
• `numpy.take_along_axis()` (the axis argument must be a literal value)
• `numpy.transpose()`
• `numpy.trapz()` (only the 3 first arguments)
• `numpy.tri()` (only the 3 first arguments; third argument `k` must be an integer)
• `numpy.tril()` (second argument `k` must be an integer)
• `numpy.tril_indices()` (all arguments must be integer)
• `numpy.tril_indices_from()` (second argument `k` must be an integer)
• `numpy.triu()` (second argument `k` must be an integer)
• `numpy.triu_indices()` (all arguments must be integer)
• `numpy.triu_indices_from()` (second argument `k` must be an integer)
• `numpy.unique()` (only the first argument)
• `numpy.vander()`
• `numpy.vstack()`
• `numpy.where()`
• `numpy.zeros()` (only the 2 first arguments)
• `numpy.zeros_like()` (only the 2 first arguments)

The following constructors are supported, both with a numeric input (to construct a scalar) or a sequence (to construct an array):

• `numpy.bool_`
• `numpy.complex64`
• `numpy.complex128`
• `numpy.float32`
• `numpy.float64`
• `numpy.int8`
• `numpy.int16`
• `numpy.int32`
• `numpy.int64`
• `numpy.intc`
• `numpy.intp`
• `numpy.uint8`
• `numpy.uint16`
• `numpy.uint32`
• `numpy.uint64`
- `numpy.uintc`
- `numpy.uintp`

The following machine parameter classes are supported, with all purely numerical attributes:

- `numpy.iinfo`
- `numpy.finfo` (*machar* attribute not supported)
- `numpy.MachAr` (with no arguments to the constructor)

### Literal arrays

Neither Python nor Numba has actual array literals, but you can construct arbitrary arrays by calling `numpy.array()` on a nested tuple:

```python
a = numpy.array(((a, b, c), (d, e, f)))
```

(nested lists are not yet supported by Numba)

### 2.7.4 Modules

**random**

Numba supports top-level functions from the `numpy.random` module, but does not allow you to create individual RandomState instances. The same algorithms are used as for the standard random module (and therefore the same notes apply), but with an independent internal state: seeding or drawing numbers from one generator won’t affect the other.

The following functions are supported.

#### Initialization

- `numpy.random.seed()`: with an integer argument only

**Warning:** Calling `numpy.random.seed()` from interpreted code (including from `object mode` code) will seed the NumPy random generator, not the Numba random generator. To seed the Numba random generator, see the example below.

```python
from numba import njit
import numpy as np

@njit
def seed(a):
    np.random.seed(a)

@njit
def rand():
    return np.random.rand()

# Incorrect seeding
```

(continues on next page)
np.random.seed(1234)
print(rand())

np.random.seed(1234)
print(rand())

# Correct seeding
seed(1234)
print(rand())

seed(1234)
print(rand())

Simple random data

- `numpy.random.rand()`
- `numpy.random.randint()` (only the first two arguments)
- `numpy.random.randn()`
- `numpy.random.random()`
- `numpy.random.random_sample()`
- `numpy.random.ranf()`
- `numpy.random.sample()`

Permutations

- `numpy.random.choice()`: the optional `p` argument (probabilities array) is not supported
- `numpy.random.permutation()`
- `numpy.random.shuffle()`: the sequence argument must be a one-dimension Numpy array or buffer-providing object (such as a `bytearray` or `array.array`)

Distributions

**Warning**: The `size` argument is not supported in the following functions.

- `numpy.random.beta()`
- `numpy.random.binomial()`
- `numpy.random.chisquare()`
- `numpy.random.dirichlet()`
- `numpy.random.exponential()`
- `numpy.random.f()`
• numpy.random.gamma()
• numpy.random.geometric()
• numpy.random.gumbel()
• numpy.random.hypergeometric()
• numpy.random.laplace()
• numpy.random.logistic()
• numpy.random.lognormal()
• numpy.random.logseries()
• numpy.random.multinomial()
• numpy.random.negative_binomial()
• numpy.random.normal()
• numpy.random.pareto()
• numpy.random.poisson()
• numpy.random.power()
• numpy.random.rayleigh()
• numpy.random.standard_cauchy()
• numpy.random.standard_exponential()
• numpy.random.standard_gamma()
• numpy.random.standard_normal()
• numpy.random.standard_t()
• numpy.random.triangular()
• numpy.random.uniform()
• numpy.random.vonmises()
• numpy.random.wald()
• numpy.random.weibull()
• numpy.random.zipf()

**Note:** Calling `numpy.random.seed()` from non-Numba code (or from *object mode* code) will seed the Numpy random generator, not the Numba random generator.

**Note:** Since version 0.28.0, the generator is thread-safe and fork-safe. Each thread and each process will produce independent streams of random numbers.
The following function from the `numpy.lib.stride_tricks` module is supported:

- `as_strided()` (the `strides` argument is mandatory, the `subok` argument is not supported)

### 2.7.5 Standard ufuncs

One objective of Numba is having all the standard ufuncs in NumPy understood by Numba. When a supported ufunc is found when compiling a function, Numba maps the ufunc to equivalent native code. This allows the use of those ufuncs in Numba code that gets compiled in `nopython mode`.

**Limitations**

Right now, only a selection of the standard ufuncs work in `nopython mode`. Following is a list of the different standard ufuncs that Numba is aware of, sorted in the same way as in the NumPy documentation.

**Math operations**

<table>
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<tr>
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(*) not supported on timedelta types

**Trigonometric functions**

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**Bit-twiddling functions**

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### Comparison functions

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### Floating functions

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</table>

(*) not supported on windows 32 bit

### Datetime functions

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</tr>
<tr>
<td>isnat</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
2.8 Deviations from Python Semantics

2.8.1 Bounds Checking

By default, instead of causing an `IndexError`, accessing an out-of-bound index of an array in a Numba-compiled function will return invalid values or lead to an access violation error (it’s reading from invalid memory locations). Bounds checking can be enabled on a specific function via the `boundscheck` option of the jit decorator. Additionally, the `NUMBA_BOUNDSCHECK` can be set to 0 or 1 to globally override this flag.

**Note:** Bounds checking will slow down typical functions so it is recommended to only use this flag for debugging purposes.

2.8.2 Exceptions and Memory Allocation

Due to limitations in the current compiler when handling exceptions, memory allocated (almost always NumPy arrays) within a function that raises an exception will leak. This is a known issue that will be fixed, but in the meantime, it is best to do memory allocation outside of functions that can also raise exceptions.

2.8.3 Integer width

While Python has arbitrary-sized integers, integers in Numba-compiled functions get a fixed size through type inference (usually, the size of a machine integer). This means that arithmetic operations can wrap round or produce undefined results or overflow.

Type inference can be overridden by an explicit type specification, if fine-grained control of integer width is desired.

**See also:**

*Enhancement proposal 1: Changes in integer typing*

2.8.4 Boolean inversion

Calling the bitwise complement operator (the ~ operator) on a Python boolean returns an integer, while the same operator on a Numpy boolean returns another boolean:

```python
>>> ~True
-2
>>> ~np.bool_(True)
False
```

Numba follows the Numpy semantics.
2.8.5 Global and closure variables

In `nopython mode`, global and closure variables are `frozen` by Numba: a Numba-compiled function sees the value of those variables at the time the function was compiled. Also, it is not possible to change their values from the function.

Numba `may or may not` copy global variables referenced inside a compiled function. Small global arrays are copied for potential compiler optimization with immutability assumption. However, large global arrays are not copied to conserve memory. The definition of “small” and “large” may change.

2.8.6 Zero initialization of variables

Numba does not track variable liveness at runtime. For simplicity of implementation, all variables are zero-initialized.

Example:

```python
from numba import njit

@njit
def foo():
    for i in range(0):
        pass
    print(i)  # will print 0 and not raise UnboundLocalError

foo()
```

2.9 Floating-point pitfalls

2.9.1 Precision and accuracy

For some operations, Numba may use a different algorithm than Python or Numpy. The results may not be bit-by-bit compatible. The difference should generally be small and within reasonable expectations. However, small accumulated differences might produce large differences at the end, especially if a divergent function is involved.

Math library implementations

Numba supports a variety of platforms and operating systems, each of which has its own math library implementation (referred to as `libm` from here in). The majority of math functions included in `libm` have specific requirements as set out by the IEEE 754 standard (like `sin()`, `exp()` etc.), but each implementation may have bugs. Thus, on some platforms Numba has to exercise special care in order to workaround known `libm` issues.

Another typical problem is when an operating system’s `libm` function set is incomplete and needs to be supplemented by additional functions. These are provided with reference to the IEEE 754 and C99 standards and are often implemented in Numba in a manner similar to equivalent CPython functions.
Linear algebra

Numpy forces some linear algebra operations to run in double-precision mode even when a float32 input is given. Numba will always observe the input's precision, and invoke single-precision linear algebra routines when all inputs are float32 or complex64.

The implementations of the numpy.linalg routines in Numba only support the floating point types that are used in the LAPACK functions that provide the underlying core functionality. As a result only float32, float64, complex64 and complex128 types are supported. If a user has e.g. an int32 type, an appropriate type conversion must be performed to a floating point type prior to its use in these routines. The reason for this decision is to essentially avoid having to replicate type conversion choices made in Numpy and to also encourage the user to choose the optimal floating point type for the operation they are undertaking.

Mixed-types operations

Numpy will most often return a float64 as a result of a computation with mixed integer and floating-point operands (a typical example is the power operator **). Numba by contrast will select the highest precision amongst the floating-point operands, so for example float32 ** int32 will return a float32, regardless of the input values. This makes performance characteristics easier to predict, but you should explicitly cast the input to float64 if you need the extra precision.

2.9.2 Warnings and errors

When calling a ufunc created with vectorize(), Numpy will determine whether an error occurred by examining the FPU error word. It may then print out a warning or raise an exception (such as RuntimeWarning: divide by zero encountered), depending on the current error handling settings.

Depending on how LLVM optimized the ufunc’s code, however, some spurious warnings or errors may appear. If you get caught by this issue, we recommend you call numpy.seterr() to change Numpy’s error handling settings, or the numpy.errstate context manager to switch them temporarily:

```python
with np.errstate(all='ignore'):
    x = my_ufunc(y)
```

2.10 Deprecation Notices

This section contains information about deprecation of behaviours, features and APIs that have become undesirable/obsolete. Any information about the schedule for their deprecation and reasoning behind the changes, along with examples, is provided. However, first is a small section on how to suppress deprecation warnings that may be raised from Numba so as to prevent warnings propagating into code that is consuming Numba.
2.10.1 Suppressing Deprecation warnings

All Numba deprecations are issued via `NumbaDeprecationWarning` or `NumbaPendingDeprecationWarning` warnings, to suppress the reporting of these the following code snippet can be used:

```python
from numba.core.errors import NumbaDeprecationWarning, NumbaPendingDeprecationWarning
import warnings

warnings.simplefilter('ignore', category=NumbaDeprecationWarning)
warnings.simplefilter('ignore', category=NumbaPendingDeprecationWarning)
```

The action used above is 'ignore', other actions are available, see The Warnings Filter documentation for more information.

**Note:** It is strongly recommended that applications and libraries which choose to suppress these warnings should pin their Numba dependency to a suitable version because their users will no longer be aware of the coming incompatibility.

2.10.2 Deprecation of reflection for List and Set types

Reflection (reflection) is the jargon used in Numba to describe the process of ensuring that changes made by compiled code to arguments that are mutable Python container data types are visible in the Python interpreter when the compiled function returns. Numba has for some time supported reflection of `list` and `set` data types and it is support for this reflection that is scheduled for deprecation with view to replace with a better implementation.

**Reason for deprecation**

First recall that for Numba to be able to compile a function in `nopython` mode all the variables must have a concrete type ascertained through type inference. In simple cases, it is clear how to reflect changes to containers inside `nopython` mode back to the original Python containers. However, reflecting changes to complex data structures with nested container types (for example, lists of lists of integers) quickly becomes impossible to do efficiently and consistently. After a number of years of experience with this problem, it is clear that providing this behaviour is both fraught with difficulty and often leads to code which does not have good performance (all reflected data has to go through special APIs to convert the data to native formats at call time and then back to CPython formats at return time). As a result of this, the sheer number of reported problems in the issue tracker, and how well a new approach that was taken with `typed.Dict` (typed dictionaries) has gone, the core developers have decided to deprecate the noted reflection behaviour.

**Example(s) of the impact**

At present only a warning of the upcoming change is issued. In future code such as:

```python
from numba import njit

@njit
def foo(x):
    x.append(10)

a = [1, 2, 3]
foo(a)
```
will require adjustment to use a `typed.List` instance, this typed container is synonymous to the `Typed Dict`. An example of translating the above is:

```python
from numba import njit
from numba.typed import List

@njit
def foo(x):
    x.append(10)

a = [1, 2, 3]
typed_a = List()
[typed_a.append(x) for x in a]
foo(typed_a)
```

For more information about `typed.List` see `Typed List`. Further usability enhancements for this feature were made in the 0.47.0 release cycle.

**Schedule**

This feature will be removed with respect to this schedule:

- Pending-deprecation warnings will be issued in version 0.44.0
- Prominent notice will be given for a minimum of two releases prior to full removal.

**Recommendations**

Projects that need/rely on the deprecated behaviour should pin their dependency on Numba to a version prior to removal of this behaviour, or consider following replacement instructions that will be issued outlining how to adjust to the change.

**Expected Replacement**

As noted above `typed.List` will be used to permit similar functionality to reflection in the case of `list`s, a `typed.Set` will provide the equivalent for `set` (not implemented yet!). The advantages to this approach are:

- That the containers are typed means type inference has to work less hard.
- Nested containers (containers of containers of ...) are more easily supported.
- Performance penalties currently incurred translating data to/from native formats are largely avoided.
- Numba’s `typed.Dict` will be able to use these containers as values.
2.10.3 Deprecation of object mode fall-back behaviour when using @jit

The `numba.jit` decorator has for a long time followed the behaviour of first attempting to compile the decorated function in `nopython mode` and should this compilation fail it will `fall-back` and try again to compile but this time in `object mode`. It it this `fall-back` behaviour which is being deprecated, the result of which will be that `numba.jit` will by default compile in `nopython mode` and `object mode` compilation will become `opt-in` only.

Reason for deprecation

The `fall-back` has repeatedly caused confusion for users as seemingly innocuous changes in user code can lead to drastic performance changes as code which may have once compiled in `nopython mode` mode may silently switch to compiling in `object mode` e.g:

```python
from numba import jit

@jit
def foo():
    l = []
    for x in range(10):
        l.append(x)
    return l

foo()

assert foo.nopython_signatures # this was compiled in nopython mode

@jit
def bar():
    l = []
    for x in range(10):
        l.append(x)
    return reversed(l) # innocuous change, but no reversed support in nopython mode

bar()

assert not bar.nopython_signatures # this was not compiled in nopython mode
```

Another reason to remove the `fall-back` is that it is confusing for the compiler engineers developing Numba as it causes internal state problems that are really hard to debug and it makes manipulating the compiler pipelines incredibly challenging.

Further, it has long been considered best practice that the `nopython mode` keyword argument in the `numba.jit` decorator is set to `True` and that any user effort spent should go into making code work in this mode as there’s very little gain if it does not. The result is that, as Numba has evolved, the amount of use `object mode` gets in practice and its general utility has decreased. It can be noted that there are some minor improvements available through the notion of `loop-lifting`, the cases of this being used in practice are, however, rare and often a legacy from use of less-recent Numba whereby such behaviour was better accommodated/the use of `@jit` with `full-back` was recommended.
Example(s) of the impact

At present a warning of the upcoming change is issued if @jit decorated code uses the fall-back compilation path. In future code such as:

```python
@jit
def bar():
    l = []
    for x in range(10):
        l.append(x)
    return reversed(l)

bar()
```

will simply not compile, a TypingError would be raised.

Schedule

This feature will be removed with respect to this schedule:

- Deprecation warnings will be issued in version 0.44.0
- Prominent notice will be given for a minimum of two releases prior to full removal.

Recommendations

Projects that need/rely on the deprecated behaviour should pin their dependency on Numba to a version prior to removal of this behaviour. Alternatively, to accommodate the scheduled deprecations, users with code compiled at present with @jit can supply the nopython=True keyword argument, if the code continues to compile then the code is already ready for this change. If the code does not compile, continue using the @jit decorator without nopython=True and profile the performance of the function. Then remove the decorator and again check the performance of the function. If there is no benefit to having the @jit decorator present consider removing it! If there is benefit to having the @jit decorator present, then to be future proof supply the keyword argument forceobj=True to ensure the function is always compiled in object mode.

2.10.4 Deprecation of the inspect_ptx() method

The undocumented inspect_ptx() method of functions decorated with @cuda.jit(device=True) is sometimes used to compile a Python function to PTX for use outside of Numba. An interface for this specific purpose is provided in the compile_ptx() function. inspect_ptx() has one or two longstanding issues and presents a maintenance burden for upcoming changes in the CUDA target, so it is deprecated and will be removed in favor of the use of compile_ptx().
Recommendations

Replace any code that compiles device functions to PTX using the following pattern:

```python
@cuda.jit(signature, device=True)
def func(args):
    ...

ptx_code = func.inspect_ptx(nvvm_options=nvvm_options).decode()
```

with:

```python
def func(args):
    ...

ptx_code, return_type = compile_ptx(func, signature, device=True, nvvm_options=nvvm_options)
```

Schedule

- In Numba 0.54: `inspect_ptx()` was deprecated.
- In Numba 0.55: `inspect_ptx()` was removed.

2.10.5 Deprecation of eager compilation of CUDA device functions

In future versions of Numba, the `device` kwarg to the `@cuda.jit` decorator will be obviated, and whether a device function or global kernel is compiled will be inferred from the context. With respect to kernel / device functions and lazy / eager compilation, four cases were handled:

1. `device=True`, eager compilation with a signature provided
2. `device=False`, eager compilation with a signature provided
3. `device=True`, lazy compilation with no signature
4. `device=False`, lazy compilation with no signature

The latter two cases can be differentiated without the `device` kwarg, because it can be inferred from the calling context - if the call is from the host, then a global kernel should be compiled, and if the call is from a kernel or another device function, then a device function should be compiled.

The first two cases cannot be differentiated in the absence of the `device` kwarg - without it, it will not be clear from a signature alone whether a device function or global kernel should be compiled. In order to resolve this, device functions will no longer be eagerly compiled. When a signature is provided to a device function, it will only be used to enforce the types of arguments that the function accepts.

Note: In previous releases this notice stated that support for providing signatures to device functions would be removed completely - however, this precludes the common use case of enforcing the types that can be passed to a device function (and the automatic insertion of casts that it implies) so this notice has been updated to retain support for passing signatures.
Schedule

- In Numba 0.54: Eager compilation of device functions will be deprecated.
- In Numba 0.55: Eager compilation of device functions will be unsupported and the provision of signatures for device functions will only enforce casting.

2.10.6 Deprecation of `numba.core.base.BaseContext.add_user_function()`

`add_user_function()` offers the same functionality as `insert_user_function()`, only with a check that the function has already been inserted at least once. It is now deprecated as it is no longer used internally and it is expected that it is not used externally.

Recommendations

Replace any uses of `add_user_function()` with `insert_user_function()`.

Schedule

- In Numba 0.55: `add_user_function()` will be deprecated.
- In Numba 0.56: `add_user_function()` will be removed.

2.10.7 Deprecation of CUDA Toolkits < 10.2 and devices with CC < 5.3

Support for:

- Devices with Compute Capability < 5.3, and
- CUDA toolkits less than 10.2

is deprecated and will be removed in future.

Recommendations

- For devices of Compute Capability 3.0 - 5.2, Numba 0.55.1 or earlier will be required.
- CUDA toolkit 10.2 or later (ideally 11.2 or later) should be installed.

Schedule

- In Numba 0.55.1: support for CC < 5.3 and CUDA toolkits < 10.2 are deprecated.
- In Numba 0.56: support for CC < 5.3 and CUDA toolkits < 10.2 will be removed.
3.1 Overview

Numba supports CUDA GPU programming by directly compiling a restricted subset of Python code into CUDA kernels and device functions following the CUDA execution model. Kernels written in Numba appear to have direct access to NumPy arrays. NumPy arrays are transferred between the CPU and the GPU automatically.

3.1.1 Terminology

Several important terms in the topic of CUDA programming are listed here:

- **host**: the CPU
- **device**: the GPU
- **host memory**: the system main memory
- **device memory**: onboard memory on a GPU card
- **kernels**: a GPU function launched by the host and executed on the device
- **device function**: a GPU function executed on the device which can only be called from the device (i.e. from a kernel or another device function)

3.1.2 Programming model

Most CUDA programming facilities exposed by Numba map directly to the CUDA C language offered by NVidia. Therefore, it is recommended you read the official CUDA C programming guide.

3.1.3 Requirements

**Supported GPUs**

Numba supports CUDA-enabled GPUs with Compute Capability 3.0 or greater. Support for devices with Compute Capability less than 5.3 is deprecated, and will be removed in the next Numba release (0.56).

Devices with Compute Capability 5.3 or greater include (but are not limited to):

- **Embedded platforms**: NVIDIA Jetson Nano, TX1, TX2, Xavier NX, AGX Xavier.
- **Desktop / Server GPUs**: All GPUs with Pascal microarchitecture or later. E.g. GTX 10 / 16 series, RTX 20 / 30 series, Quadro P / V / RTX series, RTX A series.
• Laptop GPUs: All GPUs with Pascal microarchitecture or later. E.g. MX series, Quadro P / T series (mobile), RTX 20 / 30 series (mobile), RTX A series (mobile).

Software

Numba aims to support CUDA Toolkit versions released within the last 3 years. An NVIDIA driver sufficient for the toolkit version is also required. Presently:

• 9.2 is the minimum required toolkit version.
• Support for versions less than 10.2 is deprecated, and will be removed in the next Numba release (0.56).
• 11.2 or later is recommended, as it uses an NVVM version based on LLVM 7 (as opposed to 3.4 in earlier releases).

CUDA is supported on 64-bit Linux and Windows.

If you are using Conda, you can install the CUDA toolkit with:

```bash
$ conda install cudatoolkit
```

If you are not using Conda or if you want to use a different version of CUDA toolkit, the following describes how Numba searches for a CUDA toolkit installation.

CUDA Bindings

Numba supports interacting with the CUDA Driver API via the NVIDIA CUDA Python bindings and its own ctypes-based bindings. Functionality is equivalent between the two bindings. The ctypes-based bindings are presently the default, but the NVIDIA bindings will be used by default (if they are available in the environment) in a future Numba release.

You can install the NVIDIA bindings with:

```bash
$ conda install nvidia::cuda-python
```

if you are using Conda, or:

```bash
$ pip install cuda-python
```

if you are using pip.

The use of the NVIDIA bindings is enabled by setting the environment variable `NUMBA_CUDA_USE_NVIDIA_BINDING` to "1".

Setting CUDA Installation Path

Numba searches for a CUDA toolkit installation in the following order:

1. Conda installed `cudatoolkit` package.
2. Environment variable `CUDA_HOME`, which points to the directory of the installed CUDA toolkit (i.e. `/home/user/cuda-10`)
3. System-wide installation at exactly `/usr/local/cuda` on Linux platforms. Versioned installation paths (i.e. `/usr/local/cuda-10.0`) are intentionally ignored. Users can use `CUDA_HOME` to select specific versions.
In addition to the CUDA toolkit libraries, which can be installed by conda into an environment or installed system-wide by the CUDA SDK installer, the CUDA target in Numba also requires an up-to-date NVIDIA graphics driver. Updated graphics drivers are also installed by the CUDA SDK installer, so there is no need to do both. Note that on macOS, the CUDA SDK must be installed to get the required driver, and the driver is only supported on macOS prior to 10.14 (Mojave). If the libcuda library is in a non-standard location, users can set environment variable `NUMBA_CUDA_DRIVER` to the file path (not the directory path) of the shared library file.

### 3.1.4 Missing CUDA Features

Numba does not implement all features of CUDA, yet. Some missing features are listed below:

- dynamic parallelism
- texture memory

### 3.2 Writing CUDA Kernels

#### 3.2.1 Introduction

CUDA has an execution model unlike the traditional sequential model used for programming CPUs. In CUDA, the code you write will be executed by multiple threads at once (often hundreds or thousands). Your solution will be modeled by defining a thread hierarchy of grid, blocks and threads.

Numba’s CUDA support exposes facilities to declare and manage this hierarchy of threads. The facilities are largely similar to those exposed by Nvidia’s CUDA C language.

Numba also exposes three kinds of GPU memory: global device memory (the large, relatively slow off-chip memory that’s connected to the GPU itself), on-chip shared memory and local memory. For all but the simplest algorithms, it is important that you carefully consider how to use and access memory in order to minimize bandwidth requirements and contention.

#### 3.2.2 Kernel declaration

A kernel function is a GPU function that is meant to be called from CPU code (*). It gives it two fundamental characteristics:

- kernels cannot explicitly return a value; all result data must be written to an array passed to the function (if computing a scalar, you will probably pass a one-element array);
- kernels explicitly declare their thread hierarchy when called: i.e. the number of thread blocks and the number of threads per block (note that while a kernel is compiled once, it can be called multiple times with different block sizes or grid sizes).

At first sight, writing a CUDA kernel with Numba looks very much like writing a JIT function for the CPU:

```python
@cuda.jit
def increment_by_one(an_array):
    
    """
    Increment all array elements by one.
    """

    # code elided here; read further for different implementations
```

(*) Note: newer CUDA devices support device-side kernel launching; this feature is called dynamic parallelism but Numba does not support it currently)
### 3.2.3 Kernel invocation

A kernel is typically launched in the following way:

```python
threadsperblock = 32
blockspergrid = (an_array.size + (threadsperblock - 1)) // threadsperblock
increment_by_one[blockspergrid, threadsperblock](an_array)
```

We notice two steps here:

- Instantiate the kernel proper, by specifying a number of blocks (or “blocks per grid”), and a number of threads per block. The product of the two will give the total number of threads launched. Kernel instantiation is done by taking the compiled kernel function (here `increment_by_one`) and indexing it with a tuple of integers.

- Running the kernel, by passing it the input array (and any separate output arrays if necessary). Kernels run asynchronously: launches queue their execution on the device and then return immediately. You can use `cuda.synchronize()` to wait for all previous kernel launches to finish executing.

**Note:** Passing an array that resides in host memory will implicitly cause a copy back to the host, which will be synchronous. In this case, the kernel launch will not return until the data is copied back, and therefore appears to execute synchronously.

### Choosing the block size

It might seem curious to have a two-level hierarchy when declaring the number of threads needed by a kernel. The block size (i.e. number of threads per block) is often crucial:

- On the software side, the block size determines how many threads share a given area of shared memory.
- On the hardware side, the block size must be large enough for full occupation of execution units; recommendations can be found in the CUDA C Programming Guide.

### Multi-dimensional blocks and grids

To help deal with multi-dimensional arrays, CUDA allows you to specify multi-dimensional blocks and grids. In the example above, you could make `blockspergrid` and `threadsperblock` tuples of one, two or three integers. Compared to 1D declarations of equivalent sizes, this doesn’t change anything to the efficiency or behaviour of generated code, but can help you write your algorithms in a more natural way.

### 3.2.4 Thread positioning

When running a kernel, the kernel function’s code is executed by every thread once. It therefore has to know which thread it is in, in order to know which array element(s) it is responsible for (complex algorithms may define more complex responsibilities, but the underlying principle is the same).

One way is for the thread to determine its position in the grid and block and manually compute the corresponding array position:
# Block id in a 1D grid
ty = cuda.blockIdx.x

# Block width, i.e. number of threads per block
bw = cuda.blockDim.x

# Compute flattened index inside the array
pos = tx + ty * bw
if pos < an_array.size:
    # Check array boundaries
    an_array[pos] += 1

**Note:** Unless you are sure the block size and grid size is a divisor of your array size, you **must** check boundaries as shown above.

*threadIdx*, *blockIdx*, *blockDim* and *gridDim* are special objects provided by the CUDA backend for the sole purpose of knowing the geometry of the thread hierarchy and the position of the current thread within that geometry. These objects can be 1D, 2D or 3D, depending on how the kernel was invoked. To access the value at each dimension, use the *x*, *y* and *z* attributes of these objects, respectively.

numba.cuda.threadIdx
The thread indices in the current thread block. For 1D blocks, the index (given by the *x* attribute) is an integer spanning the range from 0 inclusive to *numba.cuda.blockDim* exclusive. A similar rule exists for each dimension when more than one dimension is used.

numba.cuda blockDim
The shape of the block of threads, as declared when instantiating the kernel. This value is the same for all threads in a given kernel, even if they belong to different blocks (i.e. each block is “full”).

numba.cuda blockIdx
The block indices in the grid of threads launched a kernel. For a 1D grid, the index (given by the *x* attribute) is an integer spanning the range from 0 inclusive to *numba.cuda.gridDim* exclusive. A similar rule exists for each dimension when more than one dimension is used.

numba.cuda gridDim
The shape of the grid of blocks, i.e. the total number of blocks launched by this kernel invocation, as declared when instantiating the kernel.

**Absolute positions**

Simple algorithms will tend to always use thread indices in the same way as shown in the example above. Numba provides additional facilities to automate such calculations:

numba.cuda.grid(*ndim*)
Return the absolute position of the current thread in the entire grid of blocks. *ndim* should correspond to the number of dimensions declared when instantiating the kernel. If *ndim* is 1, a single integer is returned. If *ndim* is 2 or 3, a tuple of the given number of integers is returned.

numba.cuda gridSize(*ndim*)
Return the absolute size (or shape) in threads of the entire grid of blocks. *ndim* has the same meaning as in *grid()* above.

With these functions, the incrementation example can become:

```python
@cuda.jit
def increment_by_one(an_array):
    # (continues on next page)
```
The same example for a 2D array and grid of threads would be:

```python
@cuda.jit
def increment_a_2D_array(an_array):
    x, y = cuda.grid(2)
    if x < an_array.shape[0] and y < an_array.shape[1]:
        an_array[x, y] += 1
```

Note the grid computation when instantiating the kernel must still be done manually, for example:

```python
threadsperblock = (16, 16)
blockspergrid_x = math.ceil(an_array.shape[0] / threadsperblock[0])
blockspergrid_y = math.ceil(an_array.shape[1] / threadsperblock[1])
blockspergrid = (blockspergrid_x, blockspergrid_y)
increment_a_2D_array[blockspergrid, threadsperblock](an_array)
```

Further Reading

Please refer to the CUDA C Programming Guide for a detailed discussion of CUDA programming.

### 3.3 Memory management

#### 3.3.1 Data transfer

Even though Numba can automatically transfer NumPy arrays to the device, it can only do so conservatively by always transferring device memory back to the host when a kernel finishes. To avoid the unnecessary transfer for read-only arrays, you can use the following APIs to manually control the transfer:

```python
numba.cuda.device_array(shape, dtype=np.float_, strides=None, order='C', stream=0)
Allocate an empty device ndarray. Similar to numpy.empty().

numba.cuda.device_array_like(ary, stream=0)
Call device_array() with information from the array.

numba.cuda.to_device(obj, stream=0, copy=True, to=None)
Allocate and transfer a numpy ndarray or structured scalar to the device.

To copy host->device a numpy array:

```python
ary = np.arange(10)
d_ary = cuda.to_device(ary)
```

To enqueue the transfer to a stream:

```python
stream = cuda.stream()
d_ary = cuda.to_device(ary, stream=stream)
```
The resulting \texttt{d_ary} is a \texttt{DeviceNDArray}.

To copy device->host:

\begin{verbatim}
ary = d_ary.copy_to_host()
\end{verbatim}

To copy device->host to an existing array:

\begin{verbatim}
ary = np.empty(shape=d_ary.shape, dtype=d_ary.dtype)
d_ary.copy_to_host(ary)
\end{verbatim}

To enqueue the transfer to a stream:

\begin{verbatim}
ary = d_ary.copy_to_host(stream=stream)
\end{verbatim}

In addition to the device arrays, Numba can consume any object that implements \textit{cuda array interface}. These objects also can be manually converted into a Numba device array by creating a view of the GPU buffer using the following APIs:

\begin{verbatim}
numba.cuda.as_cuda_array(obj, sync=True)
\end{verbatim}

Create a \texttt{DeviceNDArray} from any object that implements the \textit{cuda array interface}.

A view of the underlying GPU buffer is created. No copying of the data is done. The resulting \texttt{DeviceNDArray} will acquire a reference from \texttt{obj}.

If \texttt{sync} is True, then the imported stream (if present) will be synchronized.

\begin{verbatim}
numba.cuda.is_cuda_array(obj)
\end{verbatim}

Test if the object has defined the \texttt{__cuda_array_interface__} attribute.

Does not verify the validity of the interface.

**Device arrays**

Device array references have the following methods. These methods are to be called in host code, not within CUDA-jitted functions.

\begin{verbatim}
class numba.cuda.cudadrv.devicearray.DeviceNDArray(shape, strides, dtype, stream=0, gpu_data=None)
An on-GPU array type

\texttt{copy_to_host(ary=None, stream=0)}
Copy self to ary or create a new Numpy ndarray if ary is None.

If a CUDA stream is given, then the transfer will be made asynchronously as part as the given stream. Otherwise, the transfer is synchronous: the function returns after the copy is finished.

Always returns the host array.

Example:

\begin{verbatim}
import numpy as np
from numba import cuda

arr = np.arange(1000)
d_arr = cuda.to_device(arr)

my_kernel[100, 100](d_arr)
result_array = d_arr.copy_to_host()
\end{verbatim}
\end{verbatim}

3.3. Memory management
is_c_contiguous()
Return true if the array is C-contiguous.

is_f_contiguous()
Return true if the array is Fortran-contiguous.

ravel(order='C', stream=0)
Flatten the array without changing its contents, similar to numpy.ndarray.ravel().

reshape(*newshape, **kws)
Reshape the array without changing its contents, similarly to numpy.ndarray.reshape(). Example:

```
d_arr = d_arr.reshape(20, 50, order='F')
```

Note: DeviceNDArray defines the cuda array interface.

### 3.3.2 Pinned memory

numba.cuda.pinned(*arylist)
A context manager for temporary pinning a sequence of host ndarrays.

numba.cuda.pinned_array(shape, dtype=np.float_, strides=None, order='C')
Allocate an ndarray with a buffer that is pinned (pagelocked). Similar to np.empty().

numba.cuda.pinned_array_like(ary)
Call pinned_array() with the information from the array.

### 3.3.3 Mapped memory

numba.cuda.mapped(*arylist, **kws)
A context manager for temporarily mapping a sequence of host ndarrays.

numba.cuda.mapped_array(shape, dtype=np.float_, strides=None, order='C', stream=0, portable=False, wc=False)
Allocate a mapped ndarray with a buffer that is pinned and mapped on to the device. Similar to np.empty()

**Parameters**

- **portable** – a boolean flag to allow the allocated device memory to be usable in multiple devices.
- **wc** – a boolean flag to enable writecombined allocation which is faster to write by the host and to read by the device, but slower to write by the host and slower to write by the device.

numba.cuda.mapped_array_like(ary, stream=0, portable=False, wc=False)
Call mapped_array() with the information from the array.
3.3.4 Managed memory

```python
numba.cuda.managed_array(shape, dtype=np.float_, strides=None, order='C', stream=0, attach_global=True)
```
Allocate a np.ndarray with a buffer that is managed. Similar to np.empty().

Managed memory is supported on Linux / x86 and PowerPC, and is considered experimental on Windows and Linux / AArch64.

**Parameters**
- **attach_global** – A flag indicating whether to attach globally. Global attachment implies that the memory is accessible from any stream on any device. If `False`, attachment is `host`, and memory is only accessible by devices with Compute Capability 6.0 and later.

3.3.5 Streams

Streams can be passed to functions that accept them (e.g. copies between the host and device) and into kernel launch configurations so that the operations are executed asynchronously.

```python
numba.cuda.stream()
```
Create a CUDA stream that represents a command queue for the device.

```python
numba.cuda.default_stream()
```
Get the default CUDA stream. CUDA semantics in general are that the default stream is either the legacy default stream or the per-thread default stream depending on which CUDA APIs are in use. In Numba, the APIs for the legacy default stream are always the ones in use, but an option to use APIs for the per-thread default stream may be provided in future.

```python
numba.cuda.legacy_default_stream()
```
Get the legacy default CUDA stream.

```python
numba.cuda.per_thread_default_stream()
```
Get the per-thread default CUDA stream.

```python
numba.cuda.external_stream(ptr)
```
Create a Numba stream object for a stream allocated outside Numba.

**Parameters**
- **ptr** (`int`) – Pointer to the external stream to wrap in a Numba Stream

CUDA streams have the following methods:

```python
class numba.cuda.cudadrv.driver.Stream(context, handle, finalizer, external=False)
```

- **auto_synchronize()**
  A context manager that waits for all commands in this stream to execute and commits any pending memory transfers upon exiting the context.

- **synchronize()**
  Wait for all commands in this stream to execute. This will commit any pending memory transfers.

3.3.6 Shared memory and thread synchronization

A limited amount of shared memory can be allocated on the device to speed up access to data, when necessary. That memory will be shared (i.e. both readable and writable) amongst all threads belonging to a given block and has faster access times than regular device memory. It also allows threads to cooperate on a given solution. You can think of it as a manually-managed data cache.

The memory is allocated once for the duration of the kernel, unlike traditional dynamic memory management.
numba.cuda.shared.array(shape, type)
Allocate a shared array of the given shape and type on the device. This function must be called on the device (i.e. from a kernel or device function). shape is either an integer or a tuple of integers representing the array’s dimensions and must be a simple constant expression. type is a Numba type of the elements needing to be stored in the array.

The returned array-like object can be read and written to like any normal device array (e.g. through indexing).

A common pattern is to have each thread populate one element in the shared array and then wait for all threads to finish using syncthreads().

numba.cuda.syncthreads()
Synchronize all threads in the same thread block. This function implements the same pattern as barriers in traditional multi-threaded programming: this function waits until all threads in the block call it, at which point it returns control to all its callers.

See also:
Matrix multiplication example.

3.3.7 Local memory
Local memory is an area of memory private to each thread. Using local memory helps allocate some scratchpad area when scalar local variables are not enough. The memory is allocated once for the duration of the kernel, unlike traditional dynamic memory management.

numba.cuda.local.array(shape, type)
Allocate a local array of the given shape and type on the device. shape is either an integer or a tuple of integers representing the array’s dimensions and must be a simple constant expression. type is a Numba type of the elements needing to be stored in the array. The array is private to the current thread. An array-like object is returned which can be read and written to like any standard array (e.g. through indexing).

See also:
The Local Memory section of Device Memory Accesses in the CUDA programming guide.

3.3.8 Constant memory
Constant memory is an area of memory that is read only, cached and off-chip, it is accessible by all threads and is host allocated. A method of creating an array in constant memory is through the use of:

numba.cuda.const.array_like(arr)
Allocate and make accessible an array in constant memory based on array-like arr.

3.3.9 Deallocation Behavior
This section describes the deallocation behaviour of Numba’s internal memory management. If an External Memory Management Plugin is in use (see External Memory Management (EMM) Plugin interface), then deallocation behaviour may differ; you may refer to the documentation for the EMM Plugin to understand its deallocation behaviour.

Deallocation of all CUDA resources are tracked on a per-context basis. When the last reference to a device memory is dropped, the underlying memory is scheduled to be deallocated. The deallocation does not occur immediately. It is added to a queue of pending deallocations. This design has two benefits:

1. Resource deallocation API may cause the device to synchronize; thus, breaking any asynchronous execution. Deferring the deallocation could avoid latency in performance critical code section.
2. Some deallocation errors may cause all the remaining deallocations to fail. Continued deallocation errors can cause critical errors at the CUDA driver level. In some cases, this could mean a segmentation fault in the CUDA driver. In the worst case, this could cause the system GUI to freeze and could only recover with a system reset. When an error occurs during a deallocation, the remaining pending deallocations are cancelled. Any deallocation error will be reported. When the process is terminated, the CUDA driver is able to release all allocated resources by the terminated process.

The deallocation queue is flushed automatically as soon as the following events occur:

- An allocation failed due to out-of-memory error. Allocation is retried after flushing all deallocations.
- The deallocation queue has reached its maximum size, which is default to 10. User can override by setting the environment variable `NUMBA_CUDA_MAX_PENDING_DEALLOCS_COUNT`. For example, `NUMBA_CUDA_MAX_PENDING_DEALLOCS_COUNT=20`, increases the limit to 20.
- The maximum accumulated byte size of resources that are pending deallocation is reached. This is default to 20% of the device memory capacity. User can override by setting the environment variable `NUMBA_CUDA_MAX_PENDING_DEALLOCS_RATIO`. For example, `NUMBA_CUDA_MAX_PENDING_DEALLOCS_RATIO=0.5` sets the limit to 50% of the capacity.

Sometimes, it is desired to defer resource deallocation until a code section ends. Most often, users want to avoid any implicit synchronization due to deallocation. This can be done by using the following context manager:

```python
numba.cuda.defer_cleanup()
```

Temporarily disable memory deallocation. Use this to prevent resource deallocation breaking asynchronous execution.

For example:

```python
with defer_cleanup():
    # all cleanup is deferred in here
    do_speed_critical_code()
    # cleanup can occur here
```

Note: this context manager can be nested.

### 3.4 Writing Device Functions

CUDA device functions can only be invoked from within the device (by a kernel or another device function). To define a device function:

```python
from numba import cuda

@cuda.jit(device=True)
def a_device_function(a, b):
    return a + b
```

Unlike a kernel function, a device function can return a value like normal functions.
3.5 Supported Python features in CUDA Python

This page lists the Python features supported in the CUDA Python. This includes all kernel and device functions compiled with @cuda.jit and other higher level Numba decorators that targets the CUDA GPU.

3.5.1 Language

Execution Model

CUDA Python maps directly to the single-instruction multiple-thread execution (SIMT) model of CUDA. Each instruction is implicitly executed by multiple threads in parallel. With this execution model, array expressions are less useful because we don’t want multiple threads to perform the same task. Instead, we want threads to perform a task in a cooperative fashion.

For details please consult the CUDA Programming Guide.

Constructs

The following Python constructs are not supported:

- Exception handling (try .. except, try .. finally)
- Context management (the with statement)
- Comprehensions (either list, dict, set or generator comprehensions)
- Generator (any yield statements)

The raise statement is supported.

The assert statement is supported, but only has an effect when debug=True is passed to the numba.cuda.jit() decorator. This is similar to the behavior of the assert keyword in CUDA C/C++, which is ignored unless compiling with device debug turned on.

Printing of strings, integers, and floats is supported, but printing is an asynchronous operation - in order to ensure that all output is printed after a kernel launch, it is necessary to call numba.cuda.synchronize(). Eliding the call to synchronize is acceptable, but output from a kernel may appear during other later driver operations (e.g. subsequent kernel launches, memory transfers, etc.), or fail to appear before the program execution completes. Up to 32 arguments may be passed to the print function - if more are passed then a format string will be emitted instead and a warning will be produced. This is due to a general limitation in CUDA printing, as outlined in the section on limitations in printing in the CUDA C++ Programming Guide.

3.5.2 Built-in types

The following built-in types support are inherited from CPU nopython mode.

- int
- float
- complex
- bool
- None
- tuple
See `nopython built-in types`.

There is also some very limited support for character sequences (bytes and unicode strings) used in NumPy arrays. Note that this support can only be used with CUDA 11.2 onwards.

### 3.5.3 Built-in functions

The following built-in functions are supported:

- `abs()`
- `bool`
- `complex`
- `enumerate()`
- `float`
- `int`: only the one-argument form
- `len()`
- `min()`: only the multiple-argument form
- `max()`: only the multiple-argument form
- `pow()`
- `range`
- `round()`
- `zip()`

### 3.5.4 Standard library modules

#### cmath

The following functions from the `cmath` module are supported:

- `cmath.acos()`
- `cmath.acosh()`
- `cmath.asin()`
- `cmath.asinh()`
- `cmath.atan()`
- `cmath.atanh()`
- `cmath.cos()`
- `cmath.cosh()`
- `cmath.exp()`
- `cmath.isfinite()`
- `cmath.isinf()`
- `cmath.isnan()`
- \texttt{cmath.log()}
- \texttt{cmath.log10()}
- \texttt{cmath.phase()}
- \texttt{cmath.polar()}
- \texttt{cmath.rect()}
- \texttt{cmath.sin()}
- \texttt{cmath.sinh()}
- \texttt{cmath.sqrt()}
- \texttt{cmath.tan()}
- \texttt{cmath.tanh()}

\texttt{math}

The following functions from the \texttt{math} module are supported:

- \texttt{math.acos()}
- \texttt{math.asin()}
- \texttt{math.atan()}
- \texttt{math.acosh()}
- \texttt{math.asinh()}
- \texttt{math.atanh()}
- \texttt{math.cos()}
- \texttt{math.sin()}
- \texttt{math.tan()}
- \texttt{math.hypot()}
- \texttt{math.cosh()}
- \texttt{math.sinh()}
- \texttt{math.tanh()}
- \texttt{math.atan2()}
- \texttt{math.erf()}
- \texttt{math.erfc()}
- \texttt{math.exp()}
- \texttt{math.expm1()}
- \texttt{math.fabs()}
- \texttt{math.frexp()}
- \texttt{math.ldexp()}
- \texttt{math.gamma()}
- \texttt{math.lgamma()}
math.log()
math.log2()
math.log10()
math.log1p()
math.sqrt()
math.remainder(): Python 3.7+
math.pow()
math.ceil()
math.floor()
math.copysign()
math.fmod()
math.modf()
math.isnan()
math.isinf()
math.isfinite()

**operator**

The following functions from the `operator` module are supported:

- operator.add()
- operator.and_()
- operator.eq()
- operator.floordiv()
- operator.ge()
- operator.gt()
- operator.iadd()
- operator.iand()
- operator.ifloordiv()
- operator.ilshift()
- operator.imod()
- operator.imul()
- operator.invert()
- operator.ior()
- operator.ipow()
- operator.irshift()
- operator.isub()
- operator.itruediv()
• operator.ixor()
• operator.le()
• operator.lshift()
• operator.lt()
• operator.mod()
• operator.mul()
• operator.ne()
• operator.neg()
• operator.not_()
• operator.or_()
• operator.pos()
• operator.pow()
• operator.rshift()
• operator.sub()
• operator.truediv()
• operator.xor()

### 3.5.5 Numpy support

Due to the CUDA programming model, dynamic memory allocation inside a kernel is inefficient and is often not needed. Numba disallows any memory allocating features. This disables a large number of NumPy APIs. For best performance, users should write code such that each thread is dealing with a single element at a time.

Supported numpy features:
- accessing *ndarray* attributes `.shape`, `.strides`, `.ndim`, `.size`, etc..
- scalar ufuncs that have equivalents in the *math* module; i.e. `np.sin(x[0])`, where `x` is a 1D array.
- indexing and slicing works.

Unsupported numpy features:
- array creation APIs.
- array methods.
- functions that returns a new array.
3.6 CUDA Fast Math

As noted in *Fastmath*, for certain classes of applications that utilize floating point, strict IEEE-754 conformance is not required. For this subset of applications, performance speedups may be possible.

The CUDA target implements *Fastmath* behavior with two differences.

- First, the `fastmath` argument to the `@jit` decorator is limited to the values `True` and `False`. When `True`, the following optimizations are enabled:
  - Flushing of denormals to zero.
  - Use of a fast approximation to the square root function.
  - Use of a fast approximation to the division operation.
  - Contraction of multiply and add operations into single fused multiply-add operations.

See the documentation for `nvvmCompileProgram` for more details of these optimizations.

- Secondly, calls to a subset of math module functions on `float32` operands will be implemented using fast approximate implementations from the libdevice library.
  - `math.cos()`: Implemented using `__nv_fast_cosf`.
  - `math.sin()`: Implemented using `__nv_fast_sinf`.
  - `math.tan()`: Implemented using `__nv_fast_tanf`.
  - `math.exp()`: Implemented using `__nv_fast_expf`.
  - `math.log2()`: Implemented using `__nv_fast_log2f`.
  - `math.log10()`: Implemented using `__nv_fast_log10f`.
  - `math.log()`: Implemented using `__nv_fast_logf`.
  - `math.pow()`: Implemented using `__nv_fast_powf`.

3.7 Supported Atomic Operations

Numba provides access to some of the atomic operations supported in CUDA. Those that are presently implemented are as follows:

```python
class numba.cuda.atomic
    Namespace for atomic operations

    class add(ary, idx, val)
        Perform atomic ary[idx] += val. Supported on int32, float32, and float64 operands only.
        Returns the old value at the index location as if it is loaded atomically.

    class and_(ary, idx, val)
        Perform atomic ary[idx] &= val. Supported on int32, int64, uint32 and uint64 operands only.
        Returns the old value at the index location as if it is loaded atomically.

    class compare_and_swap(ary, old, val)
        Conditionally assign val to the first element of an 1D array ary if the current value matches old.
        Returns the current value as if it is loaded atomically.
```

class **dec**(ary, idx, val)
Perform ary[idx] = (value if (array[idx] == 0) or (array[idx] > value) else array[idx] - 1).
Supported on uint32, and uint64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **exch**(ary, idx, val)
Perform atomic ary[idx] = val. Supported on int32, int64, uint32 and uint64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **inc**(ary, idx, val)
Perform atomic ary[idx] += 1 up to val, then reset to 0. Supported on uint32, and uint64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **max**(ary, idx, val)
Perform atomic ary[idx] = max(ary[idx], val).
Supported on int32, int64, uint32, uint64, float32, float64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **min**(ary, idx, val)
Perform atomic ary[idx] = min(ary[idx], val).
Supported on int32, int64, uint32, uint64, float32, float64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **nanmax**(ary, idx, val)
Perform atomic ary[idx] = max(ary[idx], val).
NOTE: NaN is treated as a missing value such that: nanmax(NaN, n) == n, nanmax(n, NaN) == n
Supported on int32, int64, uint32, uint64, float32, float64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **nanmin**(ary, idx, val)
Perform atomic ary[idx] = min(ary[idx], val).
NOTE: NaN is treated as a missing value, such that: nanmin(NaN, n) == n, nanmin(n, NaN) == n
Supported on int32, int64, uint32, uint64, float32, float64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **or_**(ary, idx, val)
Perform atomic ary[idx] |= val. Supported on int32, int64, uint32 and uint64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **sub**(ary, idx, val)
Perform atomic ary[idx] -= val. Supported on int32, float32, and float64 operands only.
Returns the old value at the index location as if it is loaded atomically.

class **xor**(ary, idx, val)
Perform atomic ary[idx] ^= val. Supported on int32, int64, uint32 and uint64 operands only.
Returns the old value at the index location as if it is loaded atomically.
3.7.1 Example

The following code demonstrates the use of `numba.cuda.atomic.max` to find the maximum value in an array. Note that this is not the most efficient way of finding a maximum in this case, but that it serves as an example:

```python
from numba import cuda
import numpy as np

def max_example(result, values):
    t0 = cuda.threadIdx.x
    b0 = cuda.blockIdx.x
    bd0 = cuda.blockDim.x
    i = (b0 * bd0) + t0
    cuda.atomic.max(result, 0, values[i])

arr = np.random.rand(16384)
result = np.zeros(1, dtype=np.float64)
max_example[256,64](result, arr)
print(result[0])  # Found using cuda.atomic.max
print(max(arr))  # Print max(arr) for comparison (should be equal!)
```

Multiple dimension arrays are supported by using a tuple of ints for the index:

```python
@cuda.jit
def max_example_3d(result, values):
    i, j, k = cuda.grid(3)
    cuda.atomic.max(result, (0, 1, 2), values[i, j, k])

arr = np.random.rand(1000).reshape(10,10,10)
result = np.zeros((3, 3, 3), dtype=np.float64)
max_example_3d[(2, 2, 2), (5, 5, 5)](result, arr)
print(result[0, 1, 2], '==', np.max(arr))
```

3.8 Cooperative Groups

3.8.1 Supported features

Numba’s Cooperative Groups support presently provides grid groups and grid synchronization, along with cooperative kernel launches.

Cooperative groups are supported on Linux, and Windows for devices in **TCC mode**. Cooperative Groups also require the CUDA Device Runtime library, `cudadevrt`, to be available - for conda default channel-installed CUDA toolkit
packages, it is only available in versions 10.2 onwards. System-installed toolkits (e.g. from NVIDIA distribution packages or runfiles) all include cudadevrt.

### 3.8.2 Using Grid Groups

To get the current grid group, use the `cg.this_grid()` function:
```python
g = cuda.cg.this_grid()
```

Synchronizing the grid is done with the `sync()` method of the grid group:
```python
g.sync()
```

### 3.8.3 Cooperative Launches

Unlike the CUDA C/C++ API, a cooperative launch is invoked using the same syntax as a normal kernel launch - Numba automatically determines whether a cooperative launch is required based on whether a grid group is synchronized in the kernel.

The grid size limit for a cooperative launch is more restrictive than for a normal launch - the grid must be no larger than the maximum number of active blocks on the device on which it is launched. To get maximum grid size for a cooperative launch of a kernel with a given block size and dynamic shared memory requirement, use the `max_cooperative_grid_blocks()` method of kernel overloads:

```python
_kernel.max_cooperative_grid_blocks(blockdim, dynsmemsize=0)
```

Calculates the maximum number of blocks that can be launched for this kernel in a cooperative grid in the current context, for the given block and dynamic shared memory sizes.

**Parameters**

- `blockdim` – Block dimensions, either as a scalar for a 1D block, or a tuple for 2D or 3D blocks.

- `dynsmemsize` – Dynamic shared memory size in bytes.

**Returns** The maximum number of blocks in the grid.

This can be used to ensure that the kernel is launched with no more than the maximum number of blocks. Exceeding the maximum number of blocks for the cooperative launch will result in a CUDA_ERROR_COOPERATIVE_LAUNCH_TOO_LARGE error.

### 3.8.4 Applications and Example

Grid group synchronization can be used to implement a global barrier across all threads in the grid - applications of this include a global reduction to a single value, or looping over rows of a large matrix sequentially using the entire grid to operate on column elements in parallel.

In the following example, rows are written sequentially by the grid. Each thread in the grid reads a value from the previous row written by it’s opposite thread. A grid sync is needed to ensure that threads in the grid don’t run ahead of threads in other blocks, or fail to see updates from their opposite thread.

First we’ll define our kernel:
from numba import cuda, int32
import numpy as np

sig = (int32[:,:1],)

@cuda.jit(sig)
def sequential_rows(M):
    col = cuda.grid(1)
    g = cuda.cg.this_grid()

    rows = M.shape[0]
    cols = M.shape[1]

    for row in range(1, rows):
        opposite = cols - col - 1
        # Each row's elements are one greater than the previous row
        M[row, col] = M[row - 1, opposite] + 1
        # Wait until all threads have written their column element,
        # and that the write is visible to all other threads
        g.sync()

Then create some empty input data and determine the grid and block sizes:

# Empty input data
A = np.zeros((1024, 1024), dtype=np.int32)
# A somewhat arbitrary choice (one warp), but generally smaller block sizes
# allow more blocks to be launched (noting that other limitations on
# occupancy apply such as shared memory size)
blockdim = 32
griddim = A.shape[1] // blockdim

Finally we launch the kernel and print the result:

# Kernel launch - this is implicitly a cooperative launch
sequential_rows[griddim, blockdim](A)

# What do the results look like?
print(A)

# [[  0   0   0 ...   0   0   0]
#  [  1   1   1 ...   1   1   1]
#  [  2   2   2 ...   2   2   2]
#  ...]
# [1021 1021 1021 ... 1021 1021 1021]
The maximum grid size for `sequential_rows` can be enquired using:

```python
overload = sequential_rows.overloads[(int32[:,::1),)
max_blocks = overload.max_cooperative_grid_blocks(blockdim)
print(max_blocks)
# 1152 (e.g. on Quadro RTX 8000 with Numba 0.52.1 and CUDA 11.0)
```

## 3.9 Random Number Generation

Numba provides a random number generation algorithm that can be executed on the GPU. Due to technical issues with how NVIDIA implemented cuRAND, however, Numba’s GPU random number generator is not based on cuRAND. Instead, Numba’s GPU RNG is an implementation of the xoroshiro128+ algorithm. The xoroshiro128+ algorithm has a period of $2^{128} - 1$, which is shorter than the period of the XORWOW algorithm used by default in cuRAND, but xoroshiro128+ still passes the BigCrush tests of random number generator quality.

When using any RNG on the GPU, it is important to make sure that each thread has its own RNG state, and they have been initialized to produce non-overlapping sequences. The `numba.cuda.random` module provides a host function to do this, as well as CUDA device functions to obtain uniformly or normally distributed random numbers.

**Note:** Numba (like cuRAND) uses the Box-Muller transform (<https://en.wikipedia.org/wiki/Box%E2%80%93Muller_transform>) to generate normally distributed random numbers from a uniform generator. However, Box-Muller generates pairs of random numbers, and the current implementation only returns one of them. As a result, generating normally distributed values is half the speed of uniformly distributed values.

```
numba.cuda.random.create_xoroshiro128p_states(n, seed, subsequence_start=0, stream=0)
```

Returns a new device array initialized for n random number generators.

This initializes the RNG states so that each state in the array corresponds subsequences in the separated by $2^{64}$ steps from each other in the main sequence. Therefore, as long no CUDA thread requests more than $2^{64}$ random numbers, all of the RNG states produced by this function are guaranteed to be independent.

The subsequence_start parameter can be used to advance the first RNG state by a multiple of $2^{64}$ steps.

**Parameters**

- `n (int)` – number of RNG states to create
- `seed (uint64)` – starting seed for list of generators
- `subsequence_start (uint64)` –
- `stream (CUDA stream)` – stream to run initialization kernel on

```
numba.cuda.random.init_xoroshiro128p_states(states, seed, subsequence_start=0, stream=0)
```

Initialize RNG states on the GPU for parallel generators.

This initializes the RNG states so that each state in the array corresponds subsequences in the separated by $2^{64}$ steps from each other in the main sequence. Therefore, as long no CUDA thread requests more than $2^{64}$ random numbers, all of the RNG states produced by this function are guaranteed to be independent.

The subsequence_start parameter can be used to advance the first RNG state by a multiple of $2^{64}$ steps.

**Parameters**
• states (1D DeviceNDArray, dtype=xoroshiro128p_dtype) – array of RNG states
• seed (uint64) – starting seed for list of generators

numba.cuda.random.xoroshiro128p_normal_float32(states, index)
Return a normally distributed float32 and advance states[index].

The return value is drawn from a Gaussian of mean=0 and sigma=1 using the Box-Muller transform. This advances the RNG sequence by two steps.

Parameters
• states (1D array, dtype=xoroshiro128p_dtype) – array of RNG states
• index (int64) – offset in states to update

Return type float32

numba.cuda.random.xoroshiro128p_normal_float64(states, index)
Return a normally distributed float64 and advance states[index].

The return value is drawn from a Gaussian of mean=0 and sigma=1 using the Box-Muller transform. This advances the RNG sequence by two steps.

Parameters
• states (1D array, dtype=xoroshiro128p_dtype) – array of RNG states
• index (int64) – offset in states to update

Return type float64

numba.cuda.random.xoroshiro128p_uniform_float32(states, index)
Return a float32 in range [0.0, 1.0) and advance states[index].

Parameters
• states (1D array, dtype=xoroshiro128p_dtype) – array of RNG states
• index (int64) – offset in states to update

Return type float32

numba.cuda.random.xoroshiro128p_uniform_float64(states, index)
Return a float64 in range [0.0, 1.0) and advance states[index].

Parameters
• states (1D array, dtype=xoroshiro128p_dtype) – array of RNG states
• index (int64) – offset in states to update

Return type float64

3.9.1 A simple example

Here is a sample program that uses the random number generator:

```
from __future__ import print_function, absolute_import
from numba import cuda
from numba.cuda.random import create_xoroshiro128p_states, xoroshiro128p_uniform_float32
import numpy as np
```

(continues on next page)
@cuda.jit
def compute_pi(rng_states, iterations, out):
    """Find the maximum value in values and store in result[0]""
    thread_id = cuda.grid(1)

    # Compute pi by drawing random \((x, y)\) points and finding what
    # fraction lie inside a unit circle
    inside = 0
    for i in range(iterations):
        x = xoroshiro128p_uniform_float32(rng_states, thread_id)
        y = xoroshiro128p_uniform_float32(rng_states, thread_id)
        if x**2 + y**2 <= 1.0:
            inside += 1

    out[thread_id] = 4.0 * inside / iterations

threads_per_block = 64
blocks = 24
rng_states = create_xoroshiro128p_states(threads_per_block * blocks, seed=1)
out = np.zeros(threads_per_block * blocks, dtype=np.float32)
compute_pi[blocks, threads_per_block](rng_states, 10000, out)
print('pi:', out.mean())

3.9.2 An example of managing RNG state size and using a 3D grid

The number of RNG states scales with the number of threads using the RNG, so it is often better to use strided loops
in conjunction with the RNG in order to keep the state size manageable.

In the following example, which initializes a large 3D array with random numbers, using one thread per output element
would result in 453,617,100 RNG states. This would take a long time to initialize and poorly utilize the GPU. Instead,
it uses a fixed size 3D grid with a total of 2,097,152 \((16 ** 3) \times (8 ** 3)\) threads striding over the output array.
The 3D thread indices startx, starty, and startz are linearized into a 1D index, tid, to index into the 2,097,152
RNG states.

Listing 4: from test_ex_3d_grid of `numba/cuda/tests/doc_example/test_random.py

from numba import cuda
from numba.cuda.random import (create_xoroshiro128p_states,
xoroshiro128p_uniform_float32)
import numpy as np

@cuda.jit
def random_3d(arr, rng_states):
    # Per-dimension thread indices and strides
    startx, starty, startz = cuda.grid(3)
    stridex, stridey, stridex = cuda.gridsize(3)

    # Linearized thread index
    tid = (startz * stridey * stridex) + (starty * stridex) + startx

    # A fixed size 3D grid with a number of threads specified in the
    # gridsize() of random_3d.py, which can be set from the host
    sample = xoroshiro128p_uniform_float32(rng_states, tid)
    arr[tid] = sample

    return arr

print('pi:', out.mean())

# Use strided loops over the array to assign a random value to each entry
    for i in range(startz, arr.shape[0], stridez):
        for j in range(starty, arr.shape[1], stridey):
            for k in range(startx, arr.shape[2], stridex):
                arr[i, j, k] = xoroshiro128p_uniform_float32(rng_states, tid)

# Array dimensions
X, Y, Z = 701, 900, 719

# Block and grid dimensions
bx, by, bz = 8, 8, 8
gx, gy, gz = 16, 16, 16

# Total number of threads
nthreads = bx * by * bz * gx * gy * gz

# Initialize a state for each thread
rng_states = create_xoroshiro128p_states(nthreads, seed=1)

# Generate random numbers
arr = cuda.device_array((X, Y, Z), dtype=np.float32)
random_3d[(gx, gy, gz), (bx, by, bz)](arr, rng_states)

## 3.10 Device management

For multi-GPU machines, users may want to select which GPU to use. By default the CUDA driver selects the fastest
GPU as the device 0, which is the default device used by Numba.

The features introduced on this page are generally not of interest unless working with systems hosting/offering more
than one CUDA-capable GPU.

### 3.10.1 Device Selection

If at all required, device selection must be done before any CUDA feature is used.

```python
from numba import cuda

cuda.select_device(0)
```

The device can be closed by:

```python
cuda.close()
```

Users can then create a new context with another device.

```python
cuda.select_device(1)  # assuming we have 2 GPUs
```

```python
numba.cuda.select_device(device_id)
```

Create a new CUDA context for the selected `device_id`. `device_id` should be the number of the device (starting
from 0; the device order is determined by the CUDA libraries). The context is associated with the current thread.
Numba currently allows only one context per thread.
If successful, this function returns a device instance.

```python
numba.cuda.close()
```

Explicitly close all contexts in the current thread.

**Note:** Compiled functions are associated with the CUDA context. This makes it not very useful to close and create new devices, though it is certainly useful for choosing which device to use when the machine has multiple GPUs.

### 3.11 The Device List

The Device List is a list of all the GPUs in the system, and can be indexed to obtain a context manager that ensures execution on the selected GPU.

```python
numba.cuda.gpus
c numa.cuda.cudadrv.devices.gpus
```

`numba.cuda.gpus` is an instance of the `_DeviceList` class, from which the current GPU context can also be retrieved:

```python
class numba.cuda.cudadrv.devices._DeviceList

    property current
        Returns the active device or None if there’s no active device
```

### 3.12 Device UUIDs

The UUID of a device (equal to that returned by `nvidia-smi -L`) is available in the `uuid` attribute of a CUDA device object.

For example, to obtain the UUID of the current device:

```python
dev = cuda.current_context().device
# prints e.g. "GPU-e6489c45-5b68-3b03-bab7-0e7c8e809643"
print(dev.uuid)
```

### 3.13 Examples

#### 3.13.1 Matrix multiplication

First, import the modules needed for this example:

```python
from numba import cuda, float32
import numpy as np
import math
```

Here is a naïve implementation of matrix multiplication using a CUDA kernel:
This implementation is straightforward and intuitive but performs poorly, because the same matrix elements will be loaded multiple times from device memory, which is slow (some devices may have transparent data caches, but they may not be large enough to hold the entire inputs at once).

It will be faster if we use a blocked algorithm to reduce accesses to the device memory. CUDA provides a fast shared memory for threads in a block to cooperatively compute on a task. The following implements a faster version of the square matrix multiplication using shared memory:

```
# Controls threads per block and shared memory usage.
# The computation will be done on blocks of TPBxTPB elements.
# TPB should not be larger than 32 in this example
TPB = 16

@cuda.jit
def fast_matmul(A, B, C):
    
    """Perform matrix multiplication of C = A * B using CUDA shared memory."
    
    Reference: https://stackoverflow.com/a/64198479/13697228 by @RobertCrovella
    
    # Define an array in the shared memory
    # The size and type of the arrays must be known at compile time
    sA = cuda.shared.array(shape=(TPB, TPB), dtype=float32)
    sB = cuda.shared.array(shape=(TPB, TPB), dtype=float32)

    x, y = cuda.grid(2)

    tx = cuda.threadIdx.x
    ty = cuda.threadIdx.y
    bpg = cuda.gridDim.x  # blocks per grid

    # Each thread computes one element in the result matrix.
    # The dot product is chunked into dot products of TPB-long vectors.
    tmp = float32(0.)
    for i in range(bpg):
        # Preload data into shared memory

    C[ty, tx] += tmp
```

(continues on next page)
sB[ty, tx] = 0
if y < A.shape[0] and (tx + i * TPB) < A.shape[1]:
    sA[ty, tx] = A[y, tx + i * TPB]
if x < B.shape[1] and (ty + i * TPB) < B.shape[0]:
    sB[ty, tx] = B[ty + i * TPB, x]

# Wait until all threads finish preloading
cuda.syncthreads()

# Computes partial product on the shared memory
for j in range(TPB):
    tmp += sA[ty, j] * sB[j, tx]

# Wait until all threads finish computing
cuda.syncthreads()
if y < C.shape[0] and x < C.shape[1]:
    C[y, x] = tmp

Because the shared memory is a limited resource, the code preloads a small block at a time from the input arrays. Then, it calls `syncthreads()` to wait until all threads have finished preloading and before doing the computation on the shared memory. It synchronizes again after the computation to ensure all threads have finished with the data in shared memory before overwriting it in the next loop iteration.

An example usage of this function is as follows:

Listing 8: from test_ex_matmul in numba/cuda/tests/doc_examples/test_matmul.py

```python
x_h = np.arange(16).reshape([4, 4])
y_h = np.ones([4, 4])
z_h = np.zeros([4, 4])

x_d = cuda.to_device(x_h)
y_d = cuda.to_device(y_h)
z_d = cuda.to_device(z_h)

threadsperblock = (TPB, TPB)
blockspergrid_x = math.ceil(z_h.shape[0] / threadsperblock[0])
blockspergrid_y = math.ceil(z_h.shape[1] / threadsperblock[1])
blockspergrid = (blockspergrid_x, blockspergrid_y)

fast_matmul[blockspergrid, threadsperblock](x_d, y_d, z_d)
z_h = z_d.copy_to_host()
print(z_h)
print(x_h @ y_h)
```

This passes a CUDA memory check test, which can help with debugging. Running the code above produces the following output:

```
$ python fast_matmul.py
[[ 6.  6.  6.  6.]
 [22. 22. 22. 22.]
 [38. 38. 38. 38.]]
```
Note: For high performance matrix multiplication in CUDA, see also the CuPy implementation.

The approach outlined here generalizes to non-square matrix multiplication as follows by adjusting the `blockspergrid` variable:

Again, here is an example usage:

```python
Listing 9: from test_ex_matmul in numba/cuda/tests/doc_examples/test_matmul.py

1 x_h = np.arange(115).reshape([5, 23])
2 y_h = np.ones([23, 7])
3 z_h = np.zeros([5, 7])

4 x_d = cuda.to_device(x_h)
5 y_d = cuda.to_device(y_h)
6 z_d = cuda.to_device(z_h)

7 threadsperblock = (TPB, TPB)
8 grid_y_max = max(x_h.shape[0], y_h.shape[0])
9 grid_x_max = max(x_h.shape[1], y_h.shape[1])
10 blockspergrid_x = math.ceil(grid_x_max / threadsperblock[0])
11 blockspergrid_y = math.ceil(grid_y_max / threadsperblock[1])
12 blockspergrid = (blockspergrid_x, blockspergrid_y)

13 fast_matmul[blockspergrid, threadsperblock](x_d, y_d, z_d)
14 z_h = z_d.copy_to_host()
15 print(z_h)
16 print(x_h @ y_h)
```

and the corresponding output:

```
$ python nonsquare_matmul.py
 [ 782.  782.  782.  782.  782.  782.  782.]
[1311. 1311. 1311. 1311. 1311. 1311. 1311.]
[1840. 1840. 1840. 1840. 1840. 1840. 1840.]
[2369. 2369. 2369. 2369. 2369. 2369. 2369.]
[[ 782.  782.  782.  782.  782.  782.  782.]]
[1311. 1311. 1311. 1311. 1311. 1311. 1311.]
[1840. 1840. 1840. 1840. 1840. 1840. 1840.]
[2369. 2369. 2369. 2369. 2369. 2369. 2369.]]
```
3.14 Debugging CUDA Python with the CUDA Simulator

Numba includes a CUDA Simulator that implements most of the semantics in CUDA Python using the Python interpreter and some additional Python code. This can be used to debug CUDA Python code, either by adding print statements to your code, or by using the debugger to step through the execution of an individual thread.

The simulator deliberately allows running non-CUDA code like starting a debugger and printing arbitrary expressions for debugging purposes. Therefore, it is best to start from code that compiles for the CUDA target, and then move over to the simulator to investigate issues.

Execution of kernels is performed by the simulator one block at a time. One thread is spawned for each thread in the block, and scheduling of the execution of these threads is left up to the operating system.

3.14.1 Using the simulator

The simulator is enabled by setting the environment variable NUMBA_ENABLE_CUDASIM to 1 prior to importing Numba. CUDA Python code may then be executed as normal. The easiest way to use the debugger inside a kernel is to only stop a single thread, otherwise the interaction with the debugger is difficult to handle. For example, the kernel below will stop in the thread <<<(3, 0, 0), (1, 0, 0)>>:

```python
@cuda.jit
def vec_add(A, B, out):
    x = cuda.threadIdx.x
    bx = cuda blockIdx.x
    bdx = cuda blockDim.x
    if x == 1 and bx == 3:
        from pdb import set_trace; set_trace()
    i = bx * bdx + x
    out[i] = A[i] + B[i]
```

when invoked with a one-dimensional grid and one-dimensional blocks.

3.14.2 Supported features

The simulator aims to provide as complete a simulation of execution on a real GPU as possible - in particular, the following are supported:

- Atomic operations
- Constant memory
- Local memory
- Shared memory: declarations of shared memory arrays must be on separate source lines, since the simulator uses source line information to keep track of allocations of shared memory across threads.
- Mapped arrays.
- Host and device memory operations: copying and setting memory.
- `syncthreads()` is supported - however, in the case where divergent threads enter different `syncthreads()` calls, the launch will not fail, but unexpected behaviour will occur. A future version of the simulator may detect this condition.
- The stream API is supported, but all operations occur sequentially and synchronously, unlike on a real device. Synchronising on a stream is therefore a no-op.
• The event API is also supported, but provides no meaningful timing information.

• Data transfer to and from the GPU - in particular, creating array objects with \texttt{device\_array()} and \texttt{device\_array\_like()}. The APIs for pinned memory \texttt{pinned()} and \texttt{pinned\_array()} are also supported, but no pinning takes place.

• The driver API implementation of the list of GPU contexts (\texttt{cuda.gpus} and \texttt{cuda.cudadrv.devices.gpus}) is supported, and reports a single GPU context. This context can be closed and reset as the real one would.

• The \texttt{detect()} function is supported, and reports one device called \texttt{SIMULATOR}.

• Cooperative grids: A cooperative kernel can be launched, but with only one block - the simulator always returns 1 from a kernel overload’s \texttt{max\_cooperative\_grid\_blocks()} method.

Some limitations of the simulator include:

• It does not perform type checking/type inference. If any argument types to a jitted function are incorrect, or if the specification of the type of any local variables are incorrect, this will not be detected by the simulator.

• Only one GPU is simulated.

• Multithreaded accesses to a single GPU are not supported, and will result in unexpected behaviour.

• Most of the driver API is unimplemented.

• It is not possible to link PTX code with CUDA Python functions.

• Warps and warp-level operations are not yet implemented.

• Because the simulator executes kernels using the Python interpreter, structured array access by attribute that works with the hardware target may fail in the simulator - see \texttt{Structured array access}.

• Operations directly against device arrays are only partially supported, that is, testing equality, less than, greater than, and basic mathematical operations are supported, but many other operations, such as the in-place operators and bit operators are not.

• The \texttt{ffs()} function only works correctly for values that can be represented using 32-bit integers.

Obviously, the speed of the simulator is also much lower than that of a real device. It may be necessary to reduce the size of input data and the size of the CUDA grid in order to make debugging with the simulator tractable.

### 3.15 GPU Reduction

Writing a reduction algorithm for CUDA GPU can be tricky. Numba provides a \texttt{@reduce} decorator for converting a simple binary operation into a reduction kernel. An example follows:

```python
import numpy
from numba import cuda

@cuda.reduce
def sum_reduce(a, b):
    return a + b

A = (numpy.arange(1234, dtype=numpy.float64)) + 1
expect = A.sum()  # numpy sum reduction
got = sum_reduce(A)  # cuda sum reduction
assert expect == got
```

Lambda functions can also be used here:
The `reduce` decorator creates an instance of the `Reduce` class. Currently, `reduce` is an alias to `Reduce`, but this behavior is not guaranteed.

```python
def reduce(func):
    return Reduce(func)
```

```python
class Reduce:
    def __init__(self, func):
        self._func = func
        self._compiled = False

    def __call__(self, arr, size=None, res=None, init=0, stream=0):
        return self.reduce(arr, size, res, init, stream)
```

3.15.1 The Reduce class

This page describes the CUDA ufunc-like object.

To support the programming pattern of CUDA programs, CUDA Vectorize and GUVectorize cannot produce a conventional ufunc. Instead, a ufunc-like object is returned. This object is a close analog but not fully compatible with a regular NumPy ufunc. The CUDA ufunc adds support for passing intra-device arrays (already on the GPU device) to reduce traffic over the PCI-express bus. It also accepts a `stream` keyword for launching in asynchronous mode.
3.16.1 Example: Basic Example

```python
import math
from numba import vectorize, cuda
import numpy as np

@vectorize(['float32(float32, float32, float32)
            ',
            'float64(float64, float64, float64)'],
            target='cuda')
def cu_discriminant(a, b, c):
    return math.sqrt(b ** 2 - 4 * a * c)

N = 10000
dtype = np.float32

# prepare the input
A = np.array(np.random.sample(N), dtype=dtype)
B = np.array(np.random.sample(N) + 10, dtype=dtype)
C = np.array(np.random.sample(N), dtype=dtype)

D = cu_discriminant(A, B, C)

print(D)  # print result
```

3.16.2 Example: Calling Device Functions

All CUDA ufunc kernels have the ability to call other CUDA device functions:

```python
from numba import vectorize, cuda

# define a device function
@cuda.jit('float32(float32, float32, float32)', device=True, inline=True)
def cu_device_fn(x, y, z):
    return x ** y / z

# define a ufunc that calls our device function
@vectorize(['float32(float32, float32, float32)'], target='cuda')
def cu_ufunc(x, y, z):
    return cu_device_fn(x, y, z)
```

3.16.3 Generalized CUDA ufuncs

Generalized ufuncs may be executed on the GPU using CUDA, analogous to the CUDA ufunc functionality. This may be accomplished as follows:

```python
from numba import guvectorize

@guvectorize([void(float32[:, :], float32[:, :], float32[:, :])],
              '(m,n),(n,p)->(m,p)', target='cuda')
def matmulcore(A, B, C):
    ...
```

3.16. CUDA Ufuncs and Generalized Ufuncs
There are times when the gufunc kernel uses too many of a GPU’s resources, which can cause the kernel launch to fail. The user can explicitly control the maximum size of the thread block by setting the `max_blocksize` attribute on the compiled gufunc object.

```python
from numba import guvectorize

guvectorize(..., target='cuda')
def very_complex_kernel(A, B, C):
    ...

very_complex_kernel.max_blocksize = 32  # limits to 32 threads per block
```

### 3.17 Sharing CUDA Memory

#### 3.17.1 Sharing between process

**Export device array to another process**

A device array can be shared with another process in the same machine using the CUDA IPC API. To do so, use the `.get_ipc_handle()` method on the device array to get a `IpcArrayHandle` object, which can be transferred to another process.

```python
DeviceNDArray.get_ipc_handle()
```

Returns a `IpcArrayHandle` object that is safe to serialize and transfer to another process to share the local allocation.

Note: this feature is only available on Linux.

```python
class numba.cuda.cudadrv.devicearray.IpcArrayHandle(ipc_handle, array_desc)
An IPC array handle that can be serialized and transfer to another process in the same machine for share a GPU allocation.

On the destination process, use the `.open()` method to creates a new `DeviceNDArray` object that shares the allocation from the original process. To release the resources, call the `.close()` method. After that, the destination can no longer use the shared array object. (Note: the underlying weakref to the resource is now dead.)

This object implements the context-manager interface that calls the `.open()` and `.close()` method automatically:

```python
with the_ipc_array_handle as ipc_array:
    # use ipc_array here as a normal gpu array object
    some_code(ipc_array)

# ipc_array is dead at this point
```

**close()**

Closes the IPC handle to the array.

**open()**

Returns a new `DeviceNDArray` that shares the allocation from the original process. Must not be used on the original process.
Import IPC memory from another process

The following function is used to open IPC handle from another process as a device array.

```python
cuda.open_ipc_array(shape, dtype, strides=None, offset=0)
```

A context manager that opens a IPC handle (CUipcMemHandle) that is represented as a sequence of bytes (e.g. bytes, tuple of int) and represent it as an array of the given `shape`, `strides` and `dtype`. The `strides` can be omitted. In that case, it is assumed to be a 1D C contiguous array.

Yields a device array.

The IPC handle is closed automatically when context manager exits.

### 3.18 CUDA Array Interface (Version 3)

The *CUDA Array Interface* (or CAI) is created for interoperability between different implementations of CUDA array-like objects in various projects. The idea is borrowed from the NumPy array interface.

#### 3.18.1 Python Interface Specification

The `__cuda_array_interface__` attribute returns a dictionary (dict) that must contain the following entries:

- **shape**: (integer, ...)
  
  A tuple of `int` (or `long`) representing the size of each dimension.

- **typestr**: str
  
  The type string. This has the same definition as `typestr` in the NumPy array interface.

- **data**: (integer, boolean)
  
  The `data` is a 2-tuple. The first element is the data pointer as a Python `int` (or `long`). The data must be device-accessible. For zero-size arrays, use `0` here. The second element is the read-only flag as a Python `bool`.

  Because the user of the interface may or may not be in the same context, the most common case is to use `cuPointerGetAttribute` with `CU_POINTER_ATTRIBUTE_DEVICE_POINTER` in the CUDA driver API (or the equivalent CUDA Runtime API) to retrieve a device pointer that is usable in the currently active context.

- **version**: integer
  
  An integer for the version of the interface being exported. The current version is `3`.

The following are optional entries:

- **strides**: `None` or (integer, ...)
  
  If `strides` is not given, or it is `None`, the array is in C-contiguous layout. Otherwise, a tuple of `int` (or `long`) is explicitly given for representing the number of bytes to skip to access the next element at each dimension.
• **descr**
  This is for describing more complicated types. This follows the same specification as in the `numpy array interface`.

• **mask**: `None` or object exposing the `__cuda_array_interface__`
  If `None` then all values in `data` are valid. All elements of the mask array should be interpreted only as true or not true indicating which elements of this array are valid. This has the same definition as `mask` in the `numpy array interface`.

**Note:** Numba does not currently support working with masked CUDA arrays and will raise a `NotImplementedError` exception if one is passed to a GPU function.

• **stream**: `None` or integer
  An optional stream upon which synchronization must take place at the point of consumption, either by synchronizing on the stream or enqueuing operations on the data on the given stream. Integer values in this entry are as follows:
  - 0: This is disallowed as it would be ambiguous between `None` and the default stream, and also between the legacy and per-thread default streams. Any use case where 0 might be given should either use `None`, 1, or 2 instead for clarity.
  - 1: The legacy default stream.
  - 2: The per-thread default stream.
  - Any other integer: a `cudaStream_t` represented as a Python integer.

When `None`, no synchronization is required. See the `Synchronization` section below for further details.

In a future revision of the interface, this entry may be expanded (or another entry added) so that an event to synchronize on can be specified instead of a stream.

**Synchronization**

**Definitions**

When discussing synchronization, the following definitions are used:

- **Producer**: The library / object on which `__cuda_array_interface__` is accessed.
- **Consumer**: The library / function that accesses the `__cuda_array_interface__` of the Producer.
- **User Code**: Code that induces a Producer and Consumer to share data through the CAI.
- **User**: The person writing or maintaining the User Code. The User may implement User Code without knowledge of the CAI, since the CAI accesses can be hidden from their view.

In the following example:

```python
import cupy
from numba import cuda

cuda.jit
def add(x, y, out):
    start = cuda.grid(1)
    stride = cuda.gridsize(1)
    for i in range(start, x.shape[0], stride):
```

(continues on next page)
```python
out[i] = x[i] + y[i]

a = cupy.arange(10)
b = a * 2
out = cupy.zeros_like(a)
add[1, 32](a, b, out)
```

When the `add` kernel is launched:

- `a`, `b`, `out` are Producers.
- The `add` kernel is the Consumer.
- The User Code is specifically `add[1, 32](a, b, out)`.
- The author of the code is the User.

### Design Motivations

Elements of the CAI design related to synchronization seek to fulfill these requirements:

1. Producers and Consumers that exchange data through the CAI must be able to do so without data races.

2. Requirement 1 should be met without requiring the user to be aware of any particulars of the CAI - in other words, exchanging data between Producers and Consumers that operate on data asynchronously should be correct by default.
   - An exception to this requirement is made for Producers and Consumers that explicitly document that the User is required to take additional steps to ensure correctness with respect to synchronization. In this case, Users are required to understand the details of the CUDA Array Interface, and the Producer/Consumer library documentation must specify the steps that Users are required to take.

   Use of this exception should be avoided where possible, as it is provided for libraries that cannot implement the synchronization semantics without the involvement of the User - for example, those interfacing with third-party libraries oblivious to the CUDA Array Interface.

3. Where the User is aware of the particulars of the CAI and implementation details of the Producer and Consumer, they should be able to, at their discretion, override some of the synchronization semantics of the interface to reduce the synchronization overhead. Overriding synchronization semantics implies that:
   - The CAI design, and the design and implementation of the Producer and Consumer do not specify or guarantee correctness with respect to data races.
   - Instead, the User is responsible for ensuring correctness with respect to data races.

### Interface Requirements

The `stream` entry enables Producers and Consumers to avoid hazards when exchanging data. Expected behaviour of the Consumer is as follows:

- When `stream` is not present or is `None`:
  - No synchronization is required on the part of the Consumer.
  - The Consumer may enqueue operations on the underlying data immediately on any stream.
When stream is an integer, its value indicates the stream on which the Producer may have in-progress operations on the data, and which the Consumer is expected to either:

- Synchronize on before accessing the data, or
- Enqueue operations in when accessing the data.

The Consumer can choose which mechanism to use, with the following considerations:

- If the Consumer synchronizes on the provided stream prior to accessing the data, then it must ensure that no computation can take place in the provided stream until its operations in its own choice of stream have taken place. This could be achieved by either:
  * Placing a wait on an event in the provided stream that occurs once all of the Consumer’s operations on the data are completed, or
  * Avoiding returning control to the user code until after its operations on its own stream have completed.

- If the consumer chooses to only enqueue operations on the data in the provided stream, then it may return control to the User code immediately after enqueuing its work, as the work will all be serialized on the exported array’s stream. This is sufficient to ensure correctness even if the User code were to induce the Producer to subsequently start enqueuing more work on the same stream.

If the User has set the Consumer to ignore CAI synchronization semantics, the Consumer may assume it can operate on the data immediately in any stream with no further synchronization, even if the stream member has an integer value.

When exporting an array through the CAI, Producers must ensure that:

- If there is work on the data enqueued in one or more streams, then synchronization on the provided stream is sufficient to ensure synchronization with all pending work.
  - If the Producer has no enqueued work, or work only enqueued on the stream identified by stream, then this condition is met.
  - If the Producer has enqueued work on the data on multiple streams, then it must enqueue events on those streams that follow the enqueued work, and then wait on those events in the provided stream. For example:
    1. Work is enqueued by the Producer on streams 7, 9, and 15.
    2. Events are then enqueued on each of streams 7, 9, and 15.
    3. Producer then tells stream 3 to wait on the events from Step 2, and the stream entry is set to 3.

- If there is no work enqueued on the data, then the stream entry may be either None, or not provided.

Optionally, to facilitate the User relaxing conformance to synchronization semantics:

- Producers may provide a configuration option to always set stream to None.
- Consumers may provide a configuration option to ignore the value of stream and act as if it were None or not provided. This elides synchronization on the Producer-provided streams, and allows enqueuing work on streams other than that provided by the Producer.

These options should not be set by default in either a Producer or a Consumer. The CAI specification does not prescribe the exact mechanism by which these options are set, or related options that Producers or Consumers might provide to allow the user further control over synchronization behavior.
Synchronization in Numba

Numba is neither strictly a Producer nor a Consumer - it may be used to implement either by a User. In order to facilitate the correct implementation of synchronization semantics, Numba exhibits the following behaviors related to synchronization of the interface:

- When Numba acts as a Consumer (for example when an array-like object is passed to a kernel launch): If \texttt{stream} is an integer, then Numba will immediately synchronize on the provided \texttt{stream}. A Numba Device Array created from an array-like object has its default \texttt{stream} set to the provided stream.

- When Numba acts as a Producer (when the \texttt{__cuda_array_interface__} property of a Numba CUDA Array is accessed): If the exported CUDA Array has a default \texttt{stream}, then it is given as the \texttt{stream} entry. Otherwise, \texttt{stream} is set to \texttt{None}.

\textbf{Note:} In Numba's terminology, an array’s default \texttt{stream} is a property specifying the stream that Numba will enqueue asynchronous transfers in if no other stream is provided as an argument to the function invoking the transfer. It is not the same as the Default Stream in normal CUDA terminology.

Numba’s synchronization behavior results in the following intended consequences:

- Exchanging data either as a Producer or a Consumer will be correct without the need for any further action from the User, provided that the other side of the interaction also follows the CAI synchronization semantics.

- The User is expected to either:
  - Avoid launching kernels or other operations on streams that are not the default stream for their parameters, or
  - When launching operations on a stream that is not the default stream for a given parameter, they should then insert an event into the stream that they are operating in, and wait on that event in the default stream for the parameter. For an example of this, see below.

The User may override Numba’s synchronization behavior by setting the environment variable \texttt{NUMBA_CUDA_ARRAY_INTERFACE_SYNC} or the config variable \texttt{CUDA_ARRAY_INTERFACE_SYNC} to 0 (see GPU Support Environment Variables). When set, Numba will not synchronize on the streams of imported arrays, and it is the responsibility of the user to ensure correctness with respect to stream synchronization. Synchronization when creating a Numba CUDA Array from an object exporting the CUDA Array Interface may also be elided by passing \texttt{sync=False} when creating the Numba CUDA Array with \texttt{numba.cuda.as_cuda_array()} or \texttt{numba.cuda.from_cuda_array_interface()}.

There is scope for Numba’s synchronization implementation to be optimized in the future, by eliding synchronizations when a kernel or driver API operation (e.g. a memcpy or memset) is launched on the same stream as an imported array.

\textbf{An example launching on an array’s non-default stream}

This example shows how to ensure that a Consumer can safely consume an array with a default stream when it is passed to a kernel launched in a different stream.

First we need to import Numba and a consumer library (a fictitious library named \texttt{other_cai_library} for this example):

\begin{verbatim}
from numba import cuda, int32, void
import other_cai_library
\end{verbatim}

Now we’ll define a kernel - this initializes the elements of the array, setting each entry to its index:
```python
@cuda.jit(void, int32[:])
def initialize_array(x):
    i = cuda.grid(1)
    if i < len(x):
        x[i] = i
```

Next we will create two streams:

```python
array_stream = cuda.stream()
kernel_stream = cuda.stream()
```

Then create an array with one of the streams as its default stream:

```python
N = 16384
x = cuda.device_array(N, stream=array_stream)
```

Now we launch the kernel in the other stream:

```python
nthreads = 256
nblocks = N // nthreads
initialize_array[nthreads, nblocks, kernel_stream](x)
```

If we were to pass `x` to a Consumer now, there is a risk that it may operate on it in `array_stream` whilst the kernel is still running in `kernel_stream`. To prevent operations in `array_stream` starting before the kernel launch is finished, we create an event and wait on it:

```python
# Create event
evt = cuda.event()
# Record the event after the kernel launch in kernel_stream
evt.record(kernel_stream)
# Wait for the event in array_stream
evt.wait(array_stream)
```

It is now safe for `other_cai_library` to consume `x`:

```python
other_cai_library.consume(x)
```

**Lifetime management**

**Data**

Obtaining the value of the `__cuda_array_interface__` property of any object has no effect on the lifetime of the object from which it was created. In particular, note that the interface has no slot for the owner of the data.

The User code must preserve the lifetime of the object owning the data for as long as the Consumer might use it.
Streams

Like data, CUDA streams also have a finite lifetime. It is therefore required that a Producer exporting data on the interface with an associated stream ensures that the exported stream’s lifetime is equal to or surpasses the lifetime of the object from which the interface was exported.

Lifetime management in Numba

Producing Arrays

Numba takes no steps to maintain the lifetime of an object from which the interface is exported - it is the user’s responsibility to ensure that the underlying object is kept alive for the duration that the exported interface might be used.

The lifetime of any Numba-managed stream exported on the interface is guaranteed to equal or surpass the lifetime of the underlying object, because the underlying object holds a reference to the stream.

Note: Numba-managed streams are those created with `cuda.default_stream()`, `cuda.legacy_default_stream()`, or `cuda.per_thread_default_stream()`. Streams not managed by Numba are created from an external stream with `cuda.external_stream()`.

Consuming Arrays

Numba provides two mechanisms for creating device arrays from objects exporting the CUDA Array Interface. Which to use depends on whether the created device array should maintain the life of the object from which it is created:

- **as_cuda_array**: This creates a device array that holds a reference to the owning object. As long as a reference to the device array is held, its underlying data will also be kept alive, even if all other references to the original owning object have been dropped.

- **from_cuda_array_interface**: This creates a device array with no reference to the owning object by default. The owning object, or some other object to be considered the owner can be passed in the `owner` parameter.

The interfaces of these functions are:

```python
cuda.as_cuda_array(sync=True)
Create a DeviceNDArray from any object that implements the cuda array interface.
A view of the underlying GPU buffer is created. No copying of the data is done. The resulting DeviceNDArray will acquire a reference from obj.
If sync is True, then the imported stream (if present) will be synchronized.
```

```python
cuda.from_cuda_array_interface(owner=None, sync=True)
Create a DeviceNDArray from a cuda-array-interface description. The owner is the owner of the underlying memory. The resulting DeviceNDArray will acquire a reference from it.
If sync is True, then the imported stream (if present) will be synchronized.
```
Pointer Attributes

Additional information about the data pointer can be retrieved using `cuPointerGetAttribute` or `cudaPointerGetAttributes`. Such information include:

- the CUDA context that owns the pointer;
- is the pointer host-accessible?
- is the pointer a managed memory?

Differences with CUDA Array Interface (Version 0)

Version 0 of the CUDA Array Interface did not have the optional `mask` attribute to support masked arrays.

Differences with CUDA Array Interface (Version 1)

Versions 0 and 1 of the CUDA Array Interface neither clarified the `strides` attribute for C-contiguous arrays nor specified the treatment for zero-size arrays.

Differences with CUDA Array Interface (Version 2)

Prior versions of the CUDA Array Interface made no statement about synchronization.

Interoperability

The following Python libraries have adopted the CUDA Array Interface:

- Numba
- CuPy
- PyTorch
- PyArrow
- mpi4py
- ArrayViews
- JAX
- PyCUDA
- DALI: the NVIDIA Data Loading Library:
  - TensorGPU objects expose the CUDA Array Interface.
  - The External Source operator consumes objects exporting the CUDA Array Interface.
- The RAPIDS stack:
  - cuDF
  - cuML
  - cuSignal
  - RMM

If your project is not on this list, please feel free to report it on the Numba issue tracker.
3.19 External Memory Management (EMM) Plugin interface

The **CUDA Array Interface** enables sharing of data between different Python libraries that access CUDA devices. However, each library manages its own memory distinctly from the others. For example:

- By default, Numba allocates memory on CUDA devices by interacting with the CUDA driver API to call functions such as `cuMemAlloc` and `cuMemFree`, which is suitable for many use cases.
- The RAPIDS libraries (cuDF, cuML, etc.) use the **RAPIDS Memory Manager (RMM)** for allocating device memory.
- CuPy includes a memory pool implementation for both device and pinned memory.

When multiple CUDA-aware libraries are used together, it may be preferable for Numba to defer to another library for memory management. The EMM Plugin interface facilitates this, by enabling Numba to use another CUDA-aware library for all allocations and deallocations.

An EMM Plugin is used to facilitate the use of an external library for memory management. An EMM Plugin can be a part of an external library, or could be implemented as a separate library.

### 3.19.1 Overview of External Memory Management

When an EMM Plugin is in use (see **Setting the EMM Plugin**), Numba will make memory allocations and deallocations through the Plugin. It will never directly call functions such as `cuMemAlloc`, `cuMemFree`, etc.

EMM Plugins always take responsibility for the management of device memory. However, not all CUDA-aware libraries also support managing host memory, so a facility for Numba to continue the management of host memory whilst ceding control of device memory to the EMM is provided (see **The Host-Only CUDA Memory Manager**).

**Effects on Deallocation Strategies**

Numba’s internal **Deallocation Behavior** is designed to increase efficiency by deferring deallocations until a significant quantity are pending. It also provides a mechanism for preventing deallocations entirely during critical sections, using the `defer_cleanup()` context manager.

When an EMM Plugin is in use, the deallocation strategy is implemented by the EMM, and Numba’s internal deallocation mechanism is not used. The EMM Plugin could implement:

- A similar strategy to the Numba deallocation behaviour, or
- Something more appropriate to the plugin - for example, deallocated memory might immediately be returned to a memory pool.

The `defer_cleanup` context manager may behave differently with an EMM Plugin - an EMM Plugin should be accompanied by documentation of the behaviour of the `defer_cleanup` context manager when it is in use. For example, a pool allocator could always immediately return memory to a pool even when the context manager is in use, but could choose not to free empty pools until `defer_cleanup` is not in use.
Management of other objects

In addition to memory, Numba manages the allocation and deallocation of *events*, *streams*, and modules (a module is a compiled object, which is generated from `@cuda.jit`-ted functions). The management of events, streams, and modules is unchanged by the use of an EMM Plugin.

Asynchronous allocation and deallocation

The present EMM Plugin interface does not provide support for asynchronous allocation and deallocation. This may be added to a future version of the interface.

3.19.2 Implementing an EMM Plugin

An EMM Plugin is implemented by deriving from `BaseCUDAMemoryManager`. A summary of considerations for the implementation follows:

- Numba instantiates one instance of the EMM Plugin class per context. The context that owns an EMM Plugin object is accessible through `self.context`, if required.
- The EMM Plugin is transparent to any code that uses Numba - all its methods are invoked by Numba, and never need to be called by code that uses Numba.
- The allocation methods `memalloc`, `memhostalloc`, and `mempin`, should use the underlying library to allocate and/or pin device or host memory, and construct an instance of a *memory pointer* representing the memory to return back to Numba. These methods are always called when the current CUDA context is the context that owns the EMM Plugin instance.
- The `initialize` method is called by Numba prior to the first use of the EMM Plugin object for a context. This method should do anything required to prepare the underlying library for allocations in the current context. This method may be called multiple times, and must not invalidate previous state when it is called.
- The `reset` method is called when all allocations in the context are to be cleaned up. It may be called even prior to `initialize`, and an EMM Plugin implementation needs to guard against this.
- To support inter-GPU communication, the `get_ipc_handle` method should provide an *IpcHandle* for a given *MemoryPointer* instance. This method is part of the EMM interface (rather than being handled within Numba) because the base address of the allocation is only known by the underlying library. Closing an IPC handle is handled internally within Numba.
- It is optional to provide memory info from the `get_memory_info` method, which provides a count of the total and free memory on the device for the context. It is preferable to implement the method, but this may not be practical for all allocators. If memory info is not provided, this method should raise a `RuntimeError`.
- The `defer_cleanup` method should return a context manager that ensures that expensive cleanup operations are avoided whilst it is active. The nuances of this will vary between plugins, so the plugin documentation should include an explanation of how deferring cleanup affects deallocations, and performance in general.
- The `interface_version` property is used to ensure that the plugin version matches the interface provided by the version of Numba. At present, this should always be 1.

Full documentation for the base class follows:

```python
class numba.cuda.BaseCUDAMemoryManager(*args, **kwargs)
    Abstract base class for External Memory Management (EMM) Plugins.
    
    abstract memalloc(size)
        Allocate on-device memory in the current context.

        Parameters size (int) -- Size of allocation in bytes
```
Returns A memory pointer instance that owns the allocated memory

Return type MemoryPointer

abstract memhostalloc(size, mapped, portable, wc)
Allocate pinned host memory.

Parameters

- **size**(int) – Size of the allocation in bytes
- **mapped**(bool) – Whether the allocated memory should be mapped into the CUDA address space.
- **portable**(bool) – Whether the memory will be considered pinned by all contexts, and not just the calling context.
- **wc**(bool) – Whether to allocate the memory as write-combined.

Returns A memory pointer instance that owns the allocated memory. The return type depends on whether the region was mapped into device memory.

Return type MappedMemory or PinnedMemory

abstract mempin(owner, pointer, size, mapped)
Pin a region of host memory that is already allocated.

Parameters

- **owner** – The object that owns the memory.
- **pointer**(int) – The pointer to the beginning of the region to pin.
- **size**(int) – The size of the region in bytes.
- **mapped**(bool) – Whether the region should also be mapped into device memory.

Returns A memory pointer instance that refers to the allocated memory.

Return type MappedMemory or PinnedMemory

abstract initialize()
Perform any initialization required for the EMM plugin instance to be ready to use.

Returns None

abstract get_ipc_handle(memory)
Return an IPC handle from a GPU allocation.

Parameters memory (MemoryPointer) – Memory for which the IPC handle should be created.

Returns IPC handle for the allocation

Return type IpcHandle

abstract get_memory_info()
Returns (free, total) memory in bytes in the context. May raise NotImplemented, if returning such information is not practical (e.g. for a pool allocator).

Returns Memory info

Return type MemoryInfo

abstract reset()
Clears up all memory allocated in this context.

Returns None
abstract defer_cleanup()
Returns a context manager that ensures the implementation of deferred cleanup whilst it is active.

abstract property interface_version
Returns an integer specifying the version of the EMM Plugin interface supported by the plugin implementation. Should always return 1 for implementations of this version of the specification.

The Host-Only CUDA Memory Manager

Some external memory managers will support management of on-device memory but not host memory. For implementing EMM Plugins using one of these memory managers, a partial implementation of a plugin that implements host-side allocation and pinning is provided. To use it, derive from HostOnlyCUDAMemoryManager instead of BaseCUDAMemoryManager. Guidelines for using this class are:

- The host-only memory manager implements memhostalloc and mempin - the EMM Plugin should still implement memalloc.
- If reset is overridden, it must also call super().reset() to allow the host allocations to be cleaned up.
- If defer_cleanup is overridden, it must hold an active context manager from super().defer_cleanup() to ensure that host-side cleanup is also deferred.

Documentation for the methods of HostOnlyCUDAMemoryManager follows:

class numba.cuda.HostOnlyCUDAMemoryManager(*args, **kwargs)
Base class for External Memory Management (EMM) Plugins that only implement on-device allocation. A subclass need not implement the memhostalloc and mempin methods.

This class also implements reset and defer_cleanup (see numba.cuda.BaseCUDAMemoryManager) for its own internal state management. If an EMM Plugin based on this class also implements these methods, then its implementations of these must also call the method from super() to give HostOnlyCUDAMemoryManager an opportunity to do the necessary work for the host allocations it is managing.

This class does not implement interface_version, as it will always be consistent with the version of Numba in which it is implemented. An EMM Plugin subclassing this class should implement interface_version instead.

memhostalloc(size, mapped=False, portable=False, wc=False)
Implements the allocation of pinned host memory.
It is recommended that this method is not overridden by EMM Plugin implementations - instead, use the BaseCUDAMemoryManager.

mempin(owner, pointer, size, mapped=False)
Implements the pinning of host memory.
It is recommended that this method is not overridden by EMM Plugin implementations - instead, use the BaseCUDAMemoryManager.

reset()
Clears up all host memory (mapped and/or pinned) in the current context.
EMM Plugins that override this method must call super().reset() to ensure that host allocations are also cleaned up.

defer_cleanup()
Returns a context manager that disables cleanup of mapped or pinned host memory in the current context whilst it is active.
EMM Plugins that override this method must obtain the context manager from this method before yielding to ensure that cleanup of host allocations is also deferred.

The IPC Handle Mixin

An implementation of the `get_ipc_handle()` function is provided in the `GetIpcHandleMixin` class. This uses the driver API to determine the base address of an allocation for opening an IPC handle. If this implementation is appropriate for an EMM plugin, it can be added by mixing in the `GetIpcHandleMixin` class:

```python
class numba.cuda.GetIpcHandleMixin:
    A class that provides a default implementation of `get_ipc_handle()`.
    
    `get_ipc_handle(memory)`
    Open an IPC memory handle by using `cuMemGetAddressRange` to determine the base pointer of the allocation. An IPC handle of type `cu_ipc_mem_handle` is constructed and initialized with `cuIpcGetMemHandle`. A `numba.cuda.IpcHandle` is returned, populated with the underlying `ipc_mem_handle`.
```

3.19.3 Classes and structures of returned objects

This section provides an overview of the classes and structures that need to be constructed by an EMM Plugin.

Memory Pointers

EMM Plugins should construct memory pointer instances that represent their allocations, for return to Numba. The appropriate memory pointer class to use in each method is:

- `MemoryPointer`: returned from `memalloc`
- `MappedMemory`: returned from `memhostalloc` or `mempin` when the host memory is mapped into the device memory space.
- `PinnedMemory`: return from `memhostalloc` or `mempin` when the host memory is not mapped into the device memory space.

Memory pointers can take a finalizer, which is a function that is called when the buffer is no longer needed. Usually the finalizer will make a call to the memory management library (either internal to Numba, or external if allocated by an EMM Plugin) to inform it that the memory is no longer required, and that it could potentially be freed and/or unpinned. The memory manager may choose to defer actually cleaning up the memory to any later time after the finalizer runs - it is not required to free the buffer immediately.

Documentation for the memory pointer classes follows.

```python
class numba.cuda.MemoryPointer(context, pointer, size, owner=None, finalizer=None)
A memory pointer that owns a buffer, with an optional finalizer. Memory pointers provide reference counting, and instances are initialized with a reference count of 1.

The base `MemoryPointer` class does not use the reference count for managing the buffer lifetime. Instead, the buffer lifetime is tied to the memory pointer instance’s lifetime:

- When the instance is deleted, the finalizer will be called.
- When the reference count drops to 0, no action is taken.

Subclasses of `MemoryPointer` may modify these semantics, for example to tie the buffer lifetime to the reference count, so that the buffer is freed when there are no more references.
```

Parameters
• **context** (*Context*) – The context in which the pointer was allocated.
• **pointer** (*ctypes.c_void_p*) – The address of the buffer.
• **size** (*int*) – The size of the allocation in bytes.
• **owner** (*NoneType*) – The owner is sometimes set by the internals of this class, or used for Numba’s internal memory management. It should not be provided by an external user of the MemoryPointer class (e.g. from within an EMM Plugin); the default of *None* should always suffice.
• **finalizer** (*function*) – A function that is called when the buffer is to be freed.

The AutoFreePointer class need not be used directly, but is documented here as it is subclassed by *numba.cuda.*

**MappedMemory:**

class numba.cuda.cudaddrv.driver.AutoFreePointer(*args, **kwargs)

Modifies the ownership semantic of the MemoryPointer so that the instance lifetime is directly tied to the number of references.

When the reference count reaches zero, the finalizer is invoked.

Constructor arguments are the same as for MemoryPointer.

class numba.cuda.MappedMemory(context, pointer, size, owner=None, finalizer=None)

A memory pointer that refers to a buffer on the host that is mapped into device memory.

**Parameters**

• **context** (*Context*) – The context in which the pointer was mapped.
• **pointer** (*ctypes.c_void_p*) – The address of the buffer.
• **size** (*int*) – The size of the buffer in bytes.
• **owner** (*NoneType*) – The owner is sometimes set by the internals of this class, or used for Numba’s internal memory management. It should not be provided by an external user of the MappedMemory class (e.g. from within an EMM Plugin); the default of *None* should always suffice.
• **finalizer** (*function*) – A function that is called when the buffer is to be freed.

class numba.cuda.PinnedMemory(context, pointer, size, owner=None, finalizer=None)

A pointer to a pinned buffer on the host.

**Parameters**

• **context** (*Context*) – The context in which the pointer was mapped.
• **owner** – The object owning the memory. For EMM plugin implementation, this ca
• **pointer** (*ctypes.c_void_p*) – The address of the buffer.
• **size** (*int*) – The size of the buffer in bytes.
• **owner** – An object owning the buffer that has been pinned. For EMM plugin implementation, the default of *None* suffices for memory allocated in memhostalloc - for mempin, it should be the owner passed in to the mempin method.
• **finalizer** (*function*) – A function that is called when the buffer is to be freed.
Memory Info

If an implementation of `get_memory_info()` is to provide a result, then it should return an instance of the `MemoryInfo` named tuple:

```python
class numba.cuda.MemoryInfo(free, total)
    Free and total memory for a device.
    free
        Free device memory in bytes.
    total
        Total device memory in bytes.
```

IPC

An instance of `IpcHandle` is required to be returned from an implementation of `get_ipc_handle()`:

```python
class numba.cuda.IpcHandle(base, handle, size, source_info=None, offset=0)
    CUDA IPC handle. Serialization of the CUDA IPC handle object is implemented here.
    Parameters
        • base (MemoryPointer) – A reference to the original allocation to keep it alive
        • handle – The CUDA IPC handle, as a ctypes array of bytes.
        • size (int) – Size of the original allocation
        • source_info (dict) – The identity of the device on which the IPC handle was opened.
        • offset (int) – The offset into the underlying allocation of the memory referred to by this
          IPC handle.
```

Guidance for constructing an IPC handle in the context of implementing an EMM Plugin:

- The `memory` parameter passed to the `get_ipc_handle` method of an EMM Plugin can be passed as the `base` parameter.
- A suitable type for the `handle` can be constructed as `ctypes.c_byte * 64`. The data for `handle` must be populated using a method for obtaining a CUDA IPC handle appropriate to the underlying library.
- `size` should match the size of the original allocation, which can be obtained with `memory.size` in `get_ipc_handle`.
- An appropriate value for `source_info` can be created by calling `self.context.device.get_device_identity()`.
- If the underlying memory does not point to the base of an allocation returned by the CUDA driver or runtime API (e.g. if a pool allocator is in use) then the `offset` from the base must be provided.
3.19.4 Setting the EMM Plugin

By default, Numba uses its internal memory management - if an EMM Plugin is to be used, it must be configured. There are two mechanisms for configuring the use of an EMM Plugin: an environment variable, and a function.

Environment variable

A module name can be provided in the environment variable, NUMBA_CUDA_MEMORY_MANAGER. If this environment variable is set, Numba will attempt to import the module, and use its _numba_memory_manager global variable as the memory manager class. This is primarily useful for running the Numba test suite with an EMM Plugin, e.g.:

```
$ NUMBA_CUDA_MEMORY_MANAGER=rmm python -m numba.runtests numba.cuda.tests
```

Function

The set_memory_manager() function can be used to set the memory manager at runtime. This should be called prior to the initialization of any contexts, as EMM Plugin instances are instantiated along with contexts.

```
numba.cuda.set_memory_manager(mm_plugin)
```

Configure Numba to use an External Memory Management (EMM) Plugin. If the EMM Plugin version does not match one supported by this version of Numba, a RuntimeError will be raised.

Parameters mm_plugin (BaseCUDAMemoryManager) – The class implementing the EMM Plugin.

Returns None

Resetting the memory manager

It is recommended that the memory manager is set once prior to using any CUDA functionality, and left unchanged for the remainder of execution. It is possible to set the memory manager multiple times, noting the following:

- At the time of their creation, contexts are bound to an instance of a memory manager for their lifetime.
- Changing the memory manager will have no effect on existing contexts - only contexts created after the memory manager was updated will use instances of the new memory manager.
- numba.cuda.close() can be used to destroy contexts after setting the memory manager so that they get re-created with the new memory manager.
  - This will invalidate any arrays, streams, events, and modules owned by the context.
  - Attempting to use invalid arrays, streams, or events will likely fail with an exception being raised due to a CUDA_ERROR_INVALID_CONTEXT or CUDA_ERROR_CONTEXT_IS_DESTROYED return code from a Driver API function.
  - Attempting to use an invalid module will result in similar, or in some cases a segmentation fault / access violation.

Note: The invalidation of modules means that all functions compiled with @cuda.jit prior to context destruction will need to be redefined, as the code underlying them will also have been unloaded from the GPU.
3.20 CUDA Bindings

Numba supports two bindings to the CUDA Driver APIs: its own internal bindings based on ctypes, and the official NVIDIA CUDA Python bindings. Functionality is equivalent between the two bindings.

The internal bindings are used by default. If the NVIDIA bindings are installed, then they can be used by setting the environment variable `NUMBA_CUDA_USE_NVIDIA_BINDING` to 1 prior to the import of Numba. Once Numba has been imported, the selected binding cannot be changed.

3.20.1 Per-Thread Default Streams

Responsibility for handling Per-Thread Default Streams (PTDS) is delegated to the NVIDIA bindings when they are in use. To use PTDS with the NVIDIA bindings, set the environment variable `CUDA_PYTHON_CUDA_PER_THREAD_DEFAULT_STREAM` to 1 instead of Numba’s environment variable `NUMBA_CUDA_PER_THREAD_DEFAULT_STREAM`.

See also:
The Default Stream section in the NVIDIA Bindings documentation.

3.20.2 Roadmap

In Numba 0.56, the NVIDIA Bindings will be used by default, if they are installed.

In future versions of Numba:

- The internal bindings will be deprecated.
- The internal bindings will be removed.

At present, no specific release is planned for the deprecation or removal of the internal bindings.

3.21 CUDA Frequently Asked Questions

3.21.1 nvprof reports “No kernels were profiled”

When using the `nvprof` tool to profile Numba jitted code for the CUDA target, the output contains No kernels were profiled but there are clearly running kernels present, what is going on?

This is quite likely due to the profiling data not being flushed on program exit, see the NVIDIA CUDA documentation for details. To fix this simply add a call to `numba.cuda.profile_stop()` prior to the exit point in your program (or wherever you want to stop profiling). For more on CUDA profiling support in Numba, see Profiling.
4.1 CUDA Host API

4.1.1 Device Management

Device detection and enquiry

The following functions are available for querying the available hardware:

numba.cuda.is_available()

Returns a boolean to indicate the availability of a CUDA GPU.

This will initialize the driver if it hasn’t been initialized.

numba.cuda.detect()

Detect supported CUDA hardware and print a summary of the detected hardware.

Returns a boolean indicating whether any supported devices were detected.

Context management

CUDA Python functions execute within a CUDA context. Each CUDA device in a system has an associated CUDA context, and Numba presently allows only one context per thread. For further details on CUDA Contexts, refer to the CUDA Driver API Documentation on Context Management and the CUDA C Programming Guide Context Documentation. CUDA Contexts are instances of the Context class:

class numba.cuda.cudadrv.driver.Context(device, handle)

This object wraps a CUDA Context resource.

Contexts should not be constructed directly by user code.

get_memory_info()

Returns (free, total) memory in bytes in the context.

pop()

Pops this context off the current CPU thread. Note that this context must be at the top of the context stack, otherwise an error will occur.

push()

Pushes this context on the current CPU Thread.

reset()

Clean up all owned resources in this context.

The following functions can be used to get or select the context:
numba.cuda.current_context(devnum=None)
    Get the current device or use a device by device number, and return the CUDA context.

numba.cuda.require_context(fn)
    A decorator that ensures a CUDA context is available when fn is executed.

    Note: The function fn cannot switch CUDA-context.

The following functions affect the current context:

numba.cuda.synchronize()
    Synchronize the current context.

numba.cuda.close()
    Explicitly clears all contexts in the current thread, and destroys all contexts if the current thread is the main thread.

Device management

Numba maintains a list of supported CUDA-capable devices:

numba.cuda.gpus
    An indexable list of supported CUDA devices. This list is indexed by integer device ID.

Alternatively, the current device can be obtained:

numba.cuda.gpus.current()
    Return the currently-selected device.

Getting a device through numba.cuda.gpus always provides an instance of numba.cuda.cudadrv.devices._DeviceContextManager, which acts as a context manager for the selected device:

class numba.cuda.cudadrv.devices._DeviceContextManager(device)
    Provides a context manager for executing in the context of the chosen device. The normal use of instances of this type is from numba.cuda.gpus. For example, to execute on device 2:

    with numba.cuda.gpus[2]:
        d_a = numba.cuda.to_device(a)

    to copy the array a onto device 2, referred to by d_a.

One may also select a context and device or get the current device using the following three functions:

numba.cuda.select_device(device_id)
    Make the context associated with device device_id the current context.

    Returns a Device instance.

    Raises exception on error.

numba.cuda.get_current_device()
    Get current device associated with the current thread

numba.cuda.list_devices()
    Return a list of all detected devices

The numba.cuda.cudadrv.driver.Device class can be used to enquire about the functionality of the selected device:

class numba.cuda.cudadrv.driver.Device
    The device associated with a particular context.
compute_capability
A tuple, (major, minor) indicating the supported compute capability.

id
The integer ID of the device.

name
The name of the device (e.g. “GeForce GTX 970”).

uuid
The UUID of the device (e.g. “GPU-e6489c45-5b68-3b03-bab7-0e7c8e809643”).

reset()
Delete the context for the device. This will destroy all memory allocations, events, and streams created within the context.

4.1.2 Compilation

Numba provides an entry point for compiling a Python function to PTX without invoking any of the driver API. This can be useful for:

- Generating PTX that is to be inlined into other PTX code (e.g. from outside the Numba / Python ecosystem).
- Generating code when there is no device present.
- Generating code prior to a fork without initializing CUDA.

Note: It is the user’s responsibility to manage any ABI issues arising from the use of compilation to PTX.

numba.cuda.compile_ptx(pyfunc, args, debug=False, lineinfo=False, device=False, fastmath=False, cc=None, opt=True)

Compile a Python function to PTX for a given set of argument types.

Parameters

- pyfunc – The Python function to compile.
- args – A tuple of argument types to compile for.
- debug (bool) – Whether to include debug info in the generated PTX.
- lineinfo (bool) – Whether to include a line mapping from the generated PTX to the source code. Usually this is used with optimized code (since debug mode would automatically include this), so we want debug info in the LLVM but only the line mapping in the final PTX.
- device (bool) – Whether to compile a device function. Defaults to False, to compile global kernel functions.
- fastmath (bool) – Whether to enable fast math flags (ftz=1, prec_sqrt=0, prec_div=, and fma=1)
- cc (tuple) – Compute capability to compile for, as a tuple (MAJOR, MINOR). Defaults to (5, 2).
- opt (bool) – Enable optimizations. Defaults to True.

Returns (ptx, resty): The PTX code and inferred return type

Return type tuple
The environment variable `NUMBA_CUDA_DEFAULT_PTX_CC` can be set to control the default compute capability targeted by `compile_ptx` - see GPU support. If PTX for the compute capability of the current device is required, the `compile_ptx_for_current_device` function can be used:

```python
c numa.cuda.compile_ptx_for_current_device(pyfunc, args, debug=False, lineinfo=False, device=False, fastmath=False, opt=True)
```

Compile a Python function to PTX for a given set of argument types for the current device’s compute capability. This calls `compile_ptx()` with an appropriate `cc` value for the current device.

### 4.1.3 Measurement

#### Profiling

The NVidia Visual Profiler can be used directly on executing CUDA Python code - it is not a requirement to insert calls to these functions into user code. However, these functions can be used to allow profiling to be performed selectively on specific portions of the code. For further information on profiling, see the NVidia Profiler User’s Guide.

```python
c numa.cuda.profile_start()
```

Enable profile collection in the current context.

```python
c numa.cuda.profile_stop()
```

Disable profile collection in the current context.

```python
c numa.cuda.profiling()
```

Context manager that enables profiling on entry and disables profiling on exit.

#### Events

Events can be used to monitor the progress of execution and to record the timestamps of specific points being reached. Event creation returns immediately, and the created event can be queried to determine if it has been reached. For further information, see the CUDA C Programming Guide Events section.

The following functions are used for creating and measuring the time between events:

```python
c numa.cuda.event(timing=True)
```

Create a CUDA event. Timing data is only recorded by the event if it is created with `timing=True`.

```python
c numa.cuda.event_elapsed_time(evtstart, evtend)
```

Compute the elapsed time between two events in milliseconds.

Events are instances of the `numba.cuda.cudadrv.driver.Event` class:

```python
class numa.cuda.cudadrv.driver.Event(context, handle, finalizer=None)
```

- `query()`
  - Returns True if all work before the most recent record has completed; otherwise, returns False.
- `record(stream=0)`
  - Set the record point of the event to the current point in the given stream.
  - The event will be considered to have occurred when all work that was queued in the stream at the time of the call to `record()` has been completed.
- `synchronize()`
  - Synchronize the host thread for the completion of the event.
- `wait(stream=0)`
  - All future works submitted to stream will wait until the event completes.
4.1.4 Stream Management

Streams allow concurrency of execution on a single device within a given context. Queued work items in the same stream execute sequentially, but work items in different streams may execute concurrently. Most operations involving a CUDA device can be performed asynchronously using streams, including data transfers and kernel execution. For further details on streams, see the CUDA C Programming Guide Streams section.

Numba defaults to using the legacy default stream as the default stream. The per-thread default stream can be made the default stream by setting the environment variable NUMBA_CUDA_PER_THREAD_DEFAULT_STREAM to 1 (see the CUDA Environment Variables section). Regardless of this setting, the objects representing the legacy and per-thread default streams can be constructed using the functions below.

Streams are instances of `numba.cuda.cudadrv.driver.Stream`:

```python
class numba.cuda.cudadrv.driver.Stream(context, handle, finalizer, external=False)
```

- `add_callback(callback, arg)`
  Add a callback to a compute stream. The user provided function is called from a driver thread once all preceding stream operations are complete.
  
  Callback functions are called from a CUDA driver thread, not from the thread that invoked `add_callback`. No CUDA API functions may be called from within the callback function.
  
  The duration of a callback function should be kept short, as the callback will block later work in the stream and may block other callbacks from being executed.
  
  Note: The driver function underlying this method is marked for eventual deprecation and may be replaced in a future CUDA release.

- `async_done()` ➞ `asyncio.Future`
  Return an awaitable that resolves once all preceding stream operations are complete. The result of the awaitable is the current stream.

- `auto_synchronize()`
  A context manager that waits for all commands in this stream to execute and commits any pending memory transfers upon exiting the context.

- `synchronize()`
  Wait for all commands in this stream to execute. This will commit any pending memory transfers.

To create a new stream:

```python
numba.cuda.stream()
```

Create a CUDA stream that represents a command queue for the device.

To get the default stream:

```python
numba.cuda.default_stream()
```

Get the default CUDA stream. CUDA semantics in general are that the default stream is either the legacy default stream or the per-thread default stream depending on which CUDA APIs are in use. In Numba, the APIs for the legacy default stream are always the ones in use, but an option to use APIs for the per-thread default stream may be provided in future.

To get the default stream with an explicit choice of whether it is the legacy or per-thread default stream:

```python
numba.cuda.legacy_default_stream()
```

Get the legacy default CUDA stream.
numba.cuda.per_thread_default_stream()

Get the per-thread default CUDA stream.

To construct a Numba Stream object using a stream allocated elsewhere, the external_stream function is provided. Note that the lifetime of external streams must be managed by the user - Numba will not deallocate an external stream, and the stream must remain valid whilst the Numba Stream object is in use.

numba.cuda.external_stream(ptr)

Create a Numba stream object for a stream allocated outside Numba.

Parameters

ptr (int) – Pointer to the external stream to wrap in a Numba Stream

4.1.5 Runtime

Numba generally uses the Driver API, but it provides a simple wrapper to the Runtime API so that the version of the runtime in use can be queried. This is accessed through cuda.runtime, which is an instance of the numba.cuda.cudadrv.runtime.Runtime class:

class numba.cuda.cudadrv.runtime.Runtime

Runtime object that lazily binds runtime API functions.

get_version()

Returns the CUDA Runtime version as a tuple (major, minor).

is_supported_version()

Returns True if the CUDA Runtime is a supported version.

property supported_versions

A tuple of all supported CUDA toolkit versions. Versions are given in the form (major_version, minor_version).

Whether the current runtime is officially supported and tested with the current version of Numba can also be queried:

numba.cuda.is_supported_version()

Returns True if the CUDA Runtime is a supported version.

Unsupported versions (e.g. newer versions than those known to Numba) may still work; this function provides a facility to check whether the current Numba version is tested and known to work with the current runtime version. If the current version is unsupported, the caller can decide how to act. Options include:

• Continuing silently,
• Emitting a warning,
• Generating an error or otherwise preventing the use of CUDA.

4.2 CUDA Kernel API

4.2.1 Kernel declaration

The @cuda.jit decorator is used to create a CUDA dispatcher object that can be configured and launched:

numba.cuda.jit(func_or_sig=None, device=False, inline=False, link=[], debug=None, opt=True, **kws)

JIT compile a python function conforming to the CUDA Python specification. If a signature is supplied, then a function is returned that takes a function to compile.

Parameters


func_or_sig – A function to JIT compile, or a signature of a function to compile. If a function is supplied, then a numba.cuda.compiler.AutoJitCUDAKernel is returned. If a signature is supplied, then a function is returned. The returned function accepts another function, which it will compile and then return a numba.cuda.compiler.AutoJitCUDAKernel.

Note: A kernel cannot have any return value.

device (bool) – Indicates whether this is a device function.

link (list) – A list of files containing PTX source to link with the function

debug – If True, check for exceptions thrown when executing the kernel. Since this degrades performance, this should only be used for debugging purposes. If set to True, then opt should be set to False. Defaults to False. (The default value can be overridden by setting environment variable NUMBA_CUDA_DEBUGINFO=1.)

fastmath – When True, enables fastmath optimizations as outlined in the CUDA Fast Math documentation.

max_registers – Request that the kernel is limited to using at most this number of registers per thread. The limit may not be respected if the ABI requires a greater number of registers than that requested. Useful for increasing occupancy.

opt (bool) – Whether to compile from LLVM IR to PTX with optimization enabled. When True, -opt=3 is passed to NVVM. When False, -opt=0 is passed to NVVM. Defaults to True.

lineinfo (bool) – If True, generate a line mapping between source code and assembly code. This enables inspection of the source code in NVIDIA profiling tools and correlation with program counter sampling.

4.2.2 Dispatcher objects

The usual syntax for configuring a Dispatcher with a launch configuration uses subcripting, with the arguments being as in the following:

```python
# func is some function decorated with @cuda.jit
func[griddim, blockdim, stream, sharedmem]
```

The griddim and blockdim arguments specify the size of the grid and thread blocks, and may be either integers or tuples of length up to 3. The stream parameter is an optional stream on which the kernel will be launched, and the sharedmem parameter specifies the size of dynamic shared memory in bytes.

Subscripting the Dispatcher returns a configuration object that can be called with the kernel arguments:

```python
configured = func[griddim, blockdim, stream, sharedmem]
configured(x, y, z)
```

However, it is more idiomatic to configure and call the kernel within a single statement:

```python
func[griddim, blockdim, stream, sharedmem](x, y, z)
```

This is similar to launch configuration in CUDA C/C++:
func<<<griddim, blockdim, sharedmem, stream>>>(x, y, z)

**Note:** The order of stream and sharedmem are reversed in Numba compared to in CUDA C/C++.

Dispatcher objects also provide several utility methods for inspection and creating a specialized instance:

```python
class numba.cuda.compiler.Dispatcher(py_func, sigs, targetoptions)
```

CUDA Dispatcher object. When configured and called, the dispatcher will specialize itself for the given arguments (if no suitable specialized version already exists) & compute capability, and launch on the device associated with the current context.

Dispatcher objects are not to be constructed by the user, but instead are created using the `numba.cuda.jit()` decorator.

**property extensions**

A list of objects that must have a `prepare_args` function. When a specialized kernel is called, each argument will be passed through to the `prepare_args` (from the last object in this list to the first). The arguments to `prepare_args` are:

- `ty` the numba type of the argument
- `val` the argument value itself
- `stream` the CUDA stream used for the current call to the kernel
- `retr` a list of zero-arg functions that you may want to append post-call cleanup work to.

The `prepare_args` function must return a tuple `(ty, val)`, which will be passed in turn to the next right-most extension. After all the extensions have been called, the resulting `(ty, val)` will be passed into Numba’s default argument marshalling logic.

```python
forall(ntasks, tpb=0, stream=0, sharedmem=0)
```

Returns a 1D-configured kernel for a given number of tasks.

This assumes that:

- the kernel maps the Global Thread ID `cuda.grid(1)` to tasks on a 1-1 basis.
- the kernel checks that the Global Thread ID is upper-bounded by `ntasks`, and does nothing if it is not.

**Parameters**

- `ntasks` – The number of tasks.
- `tpb` – The size of a block. An appropriate value is chosen if this parameter is not supplied.
- `stream` – The stream on which the configured kernel will be launched.
- `sharedmem` – The number of bytes of dynamic shared memory required by the kernel.

**Returns** A configured kernel, ready to launch on a set of arguments.

```python
get_regs_per_thread(signature=None)
```

Returns the number of registers used by each thread in this kernel for the device in the current context.

**Parameters** `signature` – The signature of the compiled kernel to get register usage for. This may be omitted for a specialized kernel.

**Returns** The number of registers used by the compiled variant of the kernel for the given signature and current device.


**inspect_asm**(*signature=None*)
Return this kernel’s PTX assembly code for the device in the current context.

Parameters **signature** – A tuple of argument types.

Returns The PTX code for the given signature, or a dict of PTX codes for all previously-encountered signatures.

**inspect_llvm**(*signature=None*)
Return the LLVM IR for this kernel.

Parameters **signature** – A tuple of argument types.

Returns The LLVM IR for the given signature, or a dict of LLVM IR for all previously-encountered signatures.

**inspect_sass**(*signature=None*)
Return this kernel’s SASS assembly code for the device in the current context.

Parameters **signature** – A tuple of argument types.

Returns The SASS code for the given signature, or a dict of SASS codes for all previously-encountered signatures.

SASS for the device in the current context is returned.
Requires nvdisasm to be available on the PATH.

**inspect_types**(*file=None*)
Produce a dump of the Python source of this function annotated with the corresponding Numba IR and type information. The dump is written to `file`, or `sys.stdout` if `file` is `None`.

**specialize**(*^*args*)
Create a new instance of this dispatcher specialized for the given `args`.

property **specialized**
True if the Dispatcher has been specialized.

### 4.2.3 Intrinsic Attributes and Functions

The remainder of the attributes and functions in this section may only be called from within a CUDA Kernel.

#### Thread Indexing

**numba.cuda.threadIdx**
The thread indices in the current thread block, accessed through the attributes `x`, `y`, and `z`. Each index is an integer spanning the range from 0 inclusive to the corresponding value of the attribute in `numba.cuda.blockDim` exclusive.

**numba.cuda.blockIdx**
The block indices in the grid of thread blocks, accessed through the attributes `x`, `y`, and `z`. Each index is an integer spanning the range from 0 inclusive to the corresponding value of the attribute in `numba.cuda.gridDim` exclusive.

**numba.cuda blockDim**
The shape of a block of threads, as declared when instantiating the kernel. This value is the same for all threads in a given kernel, even if they belong to different blocks (i.e. each block is “full”).

**numba.cuda.gridDim**
The shape of the grid of blocks, accessed through the attributes `x`, `y`, and `z`. 
numba.cuda.laneid
The thread index in the current warp, as an integer spanning the range from 0 inclusive to the numba.cuda.warpsize exclusive.

numba.cuda.warpsize
The size in threads of a warp on the GPU. Currently this is always 32.

numba.cuda.grid(ndim)
Return the absolute position of the current thread in the entire grid of blocks. ndim should correspond to the number of dimensions declared when instantiating the kernel. If ndim is 1, a single integer is returned. If ndim is 2 or 3, a tuple of the given number of integers is returned.

Computation of the first integer is as follows:
\[
\text{cuda.threadIdx.x + cuda.blockIdx.x} \times \text{cuda.blockDim.x}
\]
and is similar for the other two indices, but using the y and z attributes.

numba.cuda.gridsize(ndim)
Return the absolute size (or shape) in threads of the entire grid of blocks. ndim should correspond to the number of dimensions declared when instantiating the kernel.

Computation of the first integer is as follows:
\[
\text{cuda.blockDim.x} \times \text{cuda.gridDim.x}
\]
and is similar for the other two indices, but using the y and z attributes.

Memory Management

numba.cuda.shared.array(shape, dtype)
Creates an array in the local memory space of the CUDA kernel with the given shape and dtype.

Returns an array with its content uninitialized.

**Note:** All threads in the same thread block sees the same array.

numba.cuda.local.array(shape, dtype)
Creates an array in the local memory space of the CUDA kernel with the given shape and dtype.

Returns an array with its content uninitialized.

**Note:** Each thread sees a unique array.

numba.cuda.const.array_like(ary)
Copies the ary into constant memory space on the CUDA kernel at compile time.

Returns an array like the ary argument.

**Note:** All threads and blocks see the same array.
Synchronization and Atomic Operations

numba.cuda.atomic.add(array, idx, value)
Perform array[idx] += value. Support int32, int64, float32 and float64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multiple dimensional arrays. The number of element in idx must match the number of dimension of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.sub(array, idx, value)
Perform array[idx] -= value. Support int32, int64, float32 and float64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multi-dimensional arrays. The number of elements in idx must match the number of dimensions of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.and_(array, idx, value)
Perform array[idx] &= value. Support int32, uint32, int64, and uint64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multi-dimensional arrays. The number of elements in idx must match the number of dimensions of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.or_(array, idx, value)
Perform array[idx] |= value. Support int32, uint32, int64, and uint64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multi-dimensional arrays. The number of elements in idx must match the number of dimensions of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.xor(array, idx, value)
Perform array[idx] ^= value. Support int32, uint32, int64, and uint64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multi-dimensional arrays. The number of elements in idx must match the number of dimensions of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.exch(array, idx, value)
Perform array[idx] = value. Support int32, uint32, int64, and uint64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multi-dimensional arrays. The number of elements in idx must match the number of dimensions of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.inc(array, idx, value)
Perform array[idx] = (0 if array[idx] >= value else array[idx] + 1). Support uint32, and uint64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multi-dimensional arrays. The number of elements in idx must match the number of dimensions of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.dec(array, idx, value)
Perform array[idx] = (value if (array[idx] == 0) or (array[idx] > value) else array[idx] - 1). Support uint32, and uint64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multi-dimensional arrays. The number of elements in idx must match the number of dimensions of array.

Returns the value of array[idx] before the storing the new value. Behaves like an atomic load.

numba.cuda.atomic.max(array, idx, value)
Perform array[idx] = max(array[idx], value). Support int32, int64, float32 and float64 only. The idx argument can be an integer or a tuple of integer indices for indexing into multiple dimensional arrays. The number
of element in `idx` must match the number of dimension of `array`.

Returns the value of `array[idx]` before the storing the new value. Behaves like an atomic load.

```python
def numba.cuda.synchronize()
    Synchronize all threads in the same thread block. This function implements the same pattern as barriers in traditional multi-threaded programming: this function waits until all threads in the block call it, at which point it returns control to all its callers.
```

```python
def numba.cuda.syncthreads_count(predicate)
    An extension to `numba.cuda.syncthreads` where the return value is a count of the threads where `predicate` is true.
```

```python
def numba.cuda.syncthreads_and(predicate)
    An extension to `numba.cuda.syncthreads` where 1 is returned if `predicate` is true for all threads or 0 otherwise.
```

```python
def numba.cuda.syncthreads_or(predicate)
    An extension to `numba.cuda.syncthreads` where 1 is returned if `predicate` is true for any thread or 0 otherwise.
```

**Warning:** All syncthreads functions must be called by every thread in the thread-block. Falling to do so may result in undefined behavior.

### Cooperative Groups

```python
def numba.cuda.cg.this_grid()
    Get the current grid group.
```

**Returns** The current grid group

**Return type** `numba.cuda.cg.GridGroup`

```python
class numba.cuda.cg.GridGroup
    A grid group. Users should not construct a GridGroup directly - instead, get the current grid group using `cg.this_grid()`.
```

```python
def sync()
    Synchronize the current grid group.
```

#### Memory Fences

The memory fences are used to guarantee the effect of memory operations are visible by other threads within the same thread-block, the same GPU device, and the same system (across GPUs on global memory). Memory loads and stores are guaranteed to not move across the memory fences by optimization passes.

**Warning:** The memory fences are considered to be advanced API and most usercases should use the thread barrier (e.g. `syncthreads()`).

```python
def numba.cuda.threadfence()
    A memory fence at device level (within the GPU).
```

```python
def numba.cuda.threadfence_block()
    A memory fence at thread block level.
```
numba.cuda.threadfence_system()
A memory fence at system level (across GPUs).

**Warp Intrinsics**

The argument `membermask` is a 32 bit integer mask with each bit corresponding to a thread in the warp, with 1 meaning the thread is in the subset of threads within the function call. The `membermask` must be all 1 if the GPU compute capability is below 7.x.

```python
numba.cuda.syncwarp(membermask)
Synchronize a masked subset of the threads in a warp.
```

```python
numba.cuda.all_sync(membermask, predicate)
If the `predicate` is true for all threads in the masked warp, then a non-zero value is returned, otherwise 0 is returned.
```

```python
numba.cuda.any_sync(membermask, predicate)
If the `predicate` is true for any thread in the masked warp, then a non-zero value is returned, otherwise 0 is returned.
```

```python
numba.cuda.eq_sync(membermask, predicate)
If the boolean `predicate` is the same for all threads in the masked warp, then a non-zero value is returned, otherwise 0 is returned.
```

```python
numba.cuda.ballot_sync(membermask, predicate)
Returns a mask of all threads in the warp whose `predicate` is true, and are within the given mask.
```

```python
numba.cuda.shfl_sync(membermask, value, src_lane)
Shuffles `value` across the masked warp and returns the `value` from `src_lane`. If this is outside the warp, then the given `value` is returned.
```

```python
numba.cuda.shfl_up_sync(membermask, value, delta)
Shuffles `value` across the masked warp and returns the `value` from `laneid - delta`. If this is outside the warp, then the given `value` is returned.
```

```python
numba.cuda.shfl_down_sync(membermask, value, delta)
Shuffles `value` across the masked warp and returns the `value` from `laneid + delta`. If this is outside the warp, then the given `value` is returned.
```

```python
numba.cuda.shfl_xor_sync(membermask, value, lane_mask)
Shuffles `value` across the masked warp and returns the `value` from `laneid ^ lane_mask`.
```

```python
numba.cuda.match_any_sync(membermask, value, lane_mask)
Returns a mask of threads that have same `value` as the given `value` from within the masked warp.
```

```python
numba.cuda.match_all_sync(membermask, value, lane_mask)
Returns a tuple of (mask, pred), where mask is a mask of threads that have same `value` as the given `value` from within the masked warp, if they all have the same value, otherwise it is 0. And `pred` is a boolean of whether or not all threads in the mask warp have the same value.
```

```python
numba.cuda.activemask()
Returns a 32-bit integer mask of all currently active threads in the calling warp. The Nth bit is set if the Nth lane in the warp is active when activemask() is called. Inactive threads are represented by 0 bits in the returned mask. Threads which have exited the kernel are always marked as inactive.
```

```python
numba.cuda.lanemask_lt()
Returns a 32-bit integer mask of all lanes (including inactive ones) with ID less than the current lane.
```
Integer Intrinsics

A subset of the CUDA Math API’s integer intrinsics are available. For further documentation, including semantics, please refer to the CUDA Toolkit documentation.

numba.cuda.popc(x)
    Returns the number of bits set in x.

numba.cuda.brev(x)
    Returns the reverse of the bit pattern of x. For example, 0b10110110 becomes 0b01101101.

numba.cuda.clz(x)
    Returns the number of leading zeros in x.

numba.cuda.ffs(x)
    Returns the position of the first (least significant) bit set to 1 in x, where the least significant bit position is 1. ffs(0) returns 0.

Floating Point Intrinsics

A subset of the CUDA Math API’s floating point intrinsics are available. For further documentation, including semantics, please refer to the single and double precision parts of the CUDA Toolkit documentation.

numba.cuda.fma()
    Perform the fused multiply-add operation. Named after the fma and fmaf in the C api, but maps to the fma.rn.f32 and fma.rn.f64 (round-to-nearest-even) PTX instructions.

numba.cuda.cbrt(x)
    Perform the cube root operation, x ** (1/3). Named after the functions cbrt and cbrtf in the C api. Supports float32, and float64 arguments only.

16-bit Floating Point Intrinsics

The following functions are used to operate on 16-bit floating point operands. These functions return a 16-bit floating point result.

numba.cuda.fp16.hfma(a, b, c)
    Perform the fused multiply-add operation (a * b) + c on 16-bit floating point arguments in round to nearest mode. Maps to the fma.rn.f16 PTX instruction.
    Returns the 16-bit floating point result of the fused multiply-add.

numba.cuda.fp16.hadd(a, b)
    Perform the add operation a + b on 16-bit floating point arguments in round to nearest mode. Maps to the add.f16 PTX instruction.
    Returns the 16-bit floating point result of the addition.

numba.cuda.fp16.hsub(a, b)
    Perform the subtract operation a - b on 16-bit floating point arguments in round to nearest mode. Maps to the sub.f16 PTX instruction.
    Returns the 16-bit floating point result of the subtraction.

numba.cuda.fp16.hmul(a, b)
    Perform the multiply operation a * b on 16-bit floating point arguments in round to nearest mode. Maps to the mul.f16 PTX instruction.
    Returns the 16-bit floating point result of the multiplication.
numba.cuda.fp16.hneg(a)

Perform the negation operation \(-a\) on the 16-bit floating point argument. Maps to the \texttt{neg.f16} PTX instruction.

Returns the 16-bit floating point result of the negation.

numba.cuda.fp16.habs(a)

Perform the absolute value operation \(|a|\) on the 16-bit floating point argument. Maps to the \texttt{abs.f16} PTX instruction.

Returns the 16-bit floating point result of the absolute value operation.

### Control Flow Instructions

A subset of the CUDA’s control flow instructions are directly available as intrinsics. Avoiding branches is a key way to improve CUDA performance, and using these intrinsics mean you don’t have to rely on the \texttt{nvcc} optimizer identifying and removing branches. For further documentation, including semantics, please refer to the relevant CUDA Toolkit documentation.

numba.cuda.selp()

Select between two expressions, depending on the value of the first argument. Similar to LLVM’s \texttt{select} instruction.

### Timer Intrinsics

numba.cuda.nanosleep(ns)

Suspends the thread for a sleep duration approximately close to the delay \(ns\), specified in nanoseconds.

### 4.3 Memory Management

numba.cuda.to_device(obj, stream=0, copy=True, to=None)

Allocate and transfer a numpy ndarray or structured scalar to the device.

To copy host->device a numpy array:

```python
ary = np.arange(10)
d_ary = cuda.to_device(ary)
```

To enqueue the transfer to a stream:

```python
stream = cuda.stream()
d_ary = cuda.to_device(ary, stream=stream)
```

The resulting \texttt{d_ary} is a \texttt{DeviceNDArray}.

To copy device->host:

```python
hary = d_ary.copy_to_host()
```

To copy device->host to an existing array:

```python
ary = np.empty(shape=d_ary.shape, dtype=d_ary.dtype)
d_ary.copy_to_host(ary)
```

To enqueue the transfer to a stream:
nary = d_ary.copy_to_host(stream=stream)

numba.cuda.device_array(shape, dtype=np.float_, strides=None, order='C', stream=0)
Allocate an empty device ndarray. Similar to numpy.empty().

numba.cuda.device_array_like(ary, stream=0)
Call device_array() with information from the array.

numba.cuda.pinned_array(shape, dtype=np.float_, strides=None, order='C')
Allocate an ndarray with a buffer that is pinned (pagelocked). Similar to np.empty().

numba.cuda.pinned_array_like(ary)
Call pinned_array() with the information from the array.

numba.cuda.mapped_array(shape, dtype=np.float_, strides=None, order='C', stream=0, portable=False, wc=False)
Allocate a mapped ndarray with a buffer that is pinned and mapped on to the device. Similar to np.empty()

Parameters
- portable – a boolean flag to allow the allocated device memory to be usable in multiple devices.
- wc – a boolean flag to enable writecombined allocation which is faster to write by the host and to read by the device, but slower to write by the host and slower to write by the device.

numba.cuda.mapped_array_like(ary, stream=0, portable=False, wc=False)
Call mapped_array() with the information from the array.

numba.cuda.managed_array(shape, dtype=np.float_, strides=None, order='C', stream=0, portable=False, wc=False)
Allocate a np.ndarray with a buffer that is managed. Similar to np.empty().

Managed memory is supported on Linux / x86 and PowerPC, and is considered experimental on Windows and Linux / AArch64.

Parameters attach_global – A flag indicating whether to attach globally. Global attachment implies that the memory is accessible from any stream on any device. If False, attachment is host, and memory is only accessible by devices with Compute Capability 6.0 and later.

numba.cuda.pinned(*arylist)
A context manager for temporary pinning a sequence of host ndarrays.

numba.cuda.mapped(*arylist, **kws)
A context manager for temporarily mapping a sequence of host ndarrays.

4.3.1 Device Objects

class numba.cuda.cudadevicedarray.DeviceNDArray(shape, strides, dtype, stream=0, gpu_data=None)
An on-GPU array type

copy_to_device(ary, stream=0)
Copy ary to self.

If ary is a CUDA memory, perform a device-to-device transfer. Otherwise, perform a a host-to-device transfer.

copy_to_host(ary=None, stream=0)
Copy self to ary or create a new Numpy ndarray if ary is None.

If a CUDA stream is given, then the transfer will be made asynchronously as part as the given stream. Otherwise, the transfer is synchronous: the function returns after the copy is finished.
Always returns the host array.

Example:

```python
import numpy as np
from numba import cuda

arr = np.arange(1000)
d_arr = cuda.to_device(arr)

my_kernel[100, 100](d_arr)

result_array = d_arr.copy_to_host()
```

```python
is_c_contiguous()
Return true if the array is C-contiguous.
```

```python
is_f_contiguous()
Return true if the array is Fortran-contiguous.
```

```python
ravel(order='C', stream=0)
Flatten the array without changing its contents, similar to numpy.ndarray.ravel().
```

```python
reshape(*newshape, **kws)
Reshape the array without changing its contents, similarly to numpy.ndarray.reshape(). Example:
```

```python
d_arr = d_arr.reshape(20, 50, order='F')
```

```python
split(section, stream=0)
Split the array into equal partition of the section size. If the array cannot be equally divided, the last section will be smaller.
```

```python
class numba.cuda.cudadrv.devicearray.DeviceRecord(dtype, stream=0, gpu_data=None)
An on-GPU record type
```

```python
copy_to_device(ary, stream=0)
Copy ary to self.

If ary is a CUDA memory, perform a device-to-device transfer. Otherwise, perform a host-to-device transfer.
```

```python
copy_to_host(ary=None, stream=0)
Copy self to ary or create a new Numpy ndarray if ary is None.

If a CUDA stream is given, then the transfer will be made asynchronously as part as the given stream. Otherwise, the transfer is synchronous: the function returns after the copy is finished.

Always returns the host array.
```

Example:

```python
import numpy as np
from numba import cuda

arr = np.arange(1000)
d_arr = cuda.to_device(arr)

my_kernel[100, 100](d_arr)

result_array = d_arr.copy_to_host()
```

4.3. Memory Management
class numba.cuda.cudadriv.devicearray.MappedNDArray(shape, strides, dtype, stream=0, gpu_data=None)
A host array that uses CUDA mapped memory.

copy_to_device(ary, stream=0)
Copy ary to self.
If ary is a CUDA memory, perform a device-to-device transfer. Otherwise, perform a host-to-device transfer.

copy_to_host(ary=None, stream=0)
Copy self to ary or create a new Numpy ndarray if ary is None.
If a CUDA stream is given, then the transfer will be made asynchronously as part of the given stream. Otherwise, the transfer is synchronous: the function returns after the copy is finished.
Always returns the host array.

Example:

```python
import numpy as np
from numba import cuda
arr = np.arange(1000)
d_arr = cuda.to_device(arr)
my_kernel[100, 100](d_arr)
result_array = d_arr.copy_to_host()
```

split(section, stream=0)
Split the array into equal partition of the section size. If the array cannot be equally divided, the last section will be smaller.

4.4 Libdevice functions

All wrapped libdevice functions are listed in this section. All functions in libdevice are wrapped, with the exception of __nv_nan and __nv_nanf. These functions return a representation of a quiet NaN, but the argument they take (a pointer to an object specifying the representation) is undocumented, and follows an unusual form compared to the rest of libdevice - it is not an output like every other pointer argument. If a NaN is required, one can be obtained in CUDA Python by other means, e.g. math.nan.

4.4.1 Wrapped functions

numba.cuda.libdevice.abs(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_abs.html

Parameters x (int32) – Argument.

Return type int32

numba.cuda.libdevice.acos(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_acos.html

Parameters x (float64) – Argument.

Return type float64
numba.cuda.libdevice.acosf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_acosf.html
    Parameters  x (float32) – Argument.
    Return type  float32

numba.cuda.libdevice.acosh(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_acosh.html
    Parameters  x (float64) – Argument.
    Return type  float64

numba.cuda.libdevice.acoshf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_acoshf.html
    Parameters  x (float32) – Argument.
    Return type  float32

numba.cuda.libdevice.asin(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_asin.html
    Parameters  x (float64) – Argument.
    Return type  float64

numba.cuda.libdevice.asinf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_asinf.html
    Parameters  x (float32) – Argument.
    Return type  float32

numba.cuda.libdevice.asinh(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_asinh.html
    Parameters  x (float64) – Argument.
    Return type  float64

numba.cuda.libdevice.asinhf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_asinhf.html
    Parameters  x (float32) – Argument.
    Return type  float32

numba.cuda.libdevice.atan(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_atan.html
    Parameters  x (float64) – Argument.
    Return type  float64

numba.cuda.libdevice.atan2(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_atan2.html
    Parameters
        •  x (float64) – Argument.
        •  y (float64) – Argument.
    Return type  float64
numba.cuda.libdevice.atan2f(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_atan2f.html

    Parameters
    • x(float32) – Argument.
    • y(float32) – Argument.

    Return type float32

numba.cuda.libdevice.atanf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_atanf.html

    Parameters x(float32) – Argument.

    Return type float32

numba.cuda.libdevice.atanh(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_atanh.html

    Parameters x(float64) – Argument.

    Return type float64

numba.cuda.libdevice.atanhf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_atanhf.html

    Parameters x(float32) – Argument.

    Return type float32

numba.cuda.libdevice.brev(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_brev.html

    Parameters x(int32) – Argument.

    Return type int32

numba.cuda.libdevice.brevll(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_brevll.html

    Parameters x(int64) – Argument.

    Return type int64

numba.cuda.libdevice.byte_perm(x, y, z)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_byte_perm.html

    Parameters
    • x(int32) – Argument.
    • y(int32) – Argument.
    • z(int32) – Argument.

    Return type int32

numba.cuda.libdevice.cbrt(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_cbrt.html

    Parameters x(float64) – Argument.

    Return type float64

numba.cuda.libdevice.cbrtf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_cbrtf.html
Parameters \( x \) (float32) – Argument.
Return type float32
numba.cuda.libdevice.ceil(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv ceil.html
Parameters \( x \) (float64) – Argument.
Return type float64
numba.cuda.libdevice.ceilf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv ceilf.html
Parameters \( x \) (float32) – Argument.
Return type float32
numba.cuda.libdevice.clz(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv clz.html
Parameters \( x \) (int32) – Argument.
Return type int32
numba.cuda.libdevice.clzll(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv clzll.html
Parameters \( x \) (int64) – Argument.
Return type int32
numba.cuda.libdevice.copysign(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv copysign.html
Parameters
• \( x \) (float64) – Argument.
• \( y \) (float64) – Argument.
Return type float64
numba.cuda.libdevice.copysignf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv copysignf.html
Parameters
• \( x \) (float32) – Argument.
• \( y \) (float32) – Argument.
Return type float32
numba.cuda.libdevice.cos(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv cos.html
Parameters \( x \) (float64) – Argument.
Return type float64
numba.cuda.libdevice.cosf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv cosf.html
Parameters \( x \) (float32) – Argument.
Return type float32
numba.cuda.libdevice.cosh(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_cosh.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.coshf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_coshf.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.cospi(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_cospi.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.cospi(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_cospi.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.dadd_rd(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dadd_rd.html
    Parameters
        • x (float64) – Argument.
        • y (float64) – Argument.
    Return type float64

numba.cuda.libdevice.dadd_rn(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dadd_rn.html
    Parameters
        • x (float64) – Argument.
        • y (float64) – Argument.
    Return type float64

numba.cuda.libdevice.dadd_ru(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dadd_ru.html
    Parameters
        • x (float64) – Argument.
        • y (float64) – Argument.
    Return type float64

numba.cuda.libdevice.dadd_rz(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dadd_rz.html
    Parameters
        • x (float64) – Argument.
        • y (float64) – Argument.
numba.cuda.libdevice.ddiv_rd(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ddiv_rd.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64

numba.cuda.libdevice.ddiv_rn(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ddiv_rn.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64

numba.cuda.libdevice.ddiv_ru(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ddiv_ru.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64

numba.cuda.libdevice.ddiv_rz(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ddiv_rz.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64

numba.cuda.libdevice.dmul_rd(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dmul_rd.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64

numba.cuda.libdevice.dmul_rn(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dmul_rn.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64
numba.cuda.libdevice.dmul_ru(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dmul_ru.html

    Parameters
    • x (float64) – Argument.
    • y (float64) – Argument.

    Return type  float64

numba.cuda.libdevice.dmul_rz(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dmul_rz.html

    Parameters
    • x (float64) – Argument.
    • y (float64) – Argument.

    Return type  float64

numba.cuda.libdevice.double2float_rd(d)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2float_rd.html

    Parameters  d (float64) – Argument.

    Return type  float32

numba.cuda.libdevice.double2float_rn(d)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2float_rn.html

    Parameters  d (float64) – Argument.

    Return type  float32

numba.cuda.libdevice.double2float_ru(d)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2float_ru.html

    Parameters  d (float64) – Argument.

    Return type  float32

numba.cuda.libdevice.double2float_rz(d)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2float_rz.html

    Parameters  d (float64) – Argument.

    Return type  float32

numba.cuda.libdevice.double2hiint(d)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2hiint.html

    Parameters  d (float64) – Argument.

    Return type  int32

numba.cuda.libdevice.double2int_rd(d)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2int_rd.html

    Parameters  d (float64) – Argument.

    Return type  int32

numba.cuda.libdevice.double2int_rn(d)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2int_rn.html

    Parameters  d (float64) – Argument.
Return type  int32
numba.cuda.libdevice.double2int_ru(d)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2int_ru.html
Parameters  d(float64) – Argument.
Return type  int32
numba.cuda.libdevice.double2int_rz(d)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2int_rz.html
Parameters  d(float64) – Argument.
Return type  int32
numba.cuda.libdevice.double2ll_rd(f)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2ll_rd.html
Parameters  f(float64) – Argument.
Return type  int64
numba.cuda.libdevice.double2ll_rn(f)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2ll_rn.html
Parameters  f(float64) – Argument.
Return type  int64
numba.cuda.libdevice.double2ll_ru(f)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2ll_ru.html
Parameters  f(float64) – Argument.
Return type  int64
numba.cuda.libdevice.double2loint(d)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2loint.html
Parameters  d(float64) – Argument.
Return type  int32
numba.cuda.libdevice.double2uint_rd(d)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2uint_rd.html
Parameters  d(float64) – Argument.
Return type  int32
numba.cuda.libdevice.double2uint_rn(d)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2uint_rn.html
Parameters  d(float64) – Argument.
Return type  int32
numba.cuda.libdevice.double2uint_ru(d)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_double2uint_ru.html
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Parameters \( d (\text{float64}) \) – Argument.

Return type \( \text{int32} \)

\[
\text{numba.cuda.libdevice.double2uint} \_\_\_r(z(d))
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_double2uint_rz.html

Parameters \( d (\text{float64}) \) – Argument.

Return type \( \text{int32} \)

\[
\text{numba.cuda.libdevice.double2ull} \_\_\_rd(f)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_double2ull_rd.html

Parameters \( f (\text{float64}) \) – Argument.

Return type \( \text{int64} \)

\[
\text{numba.cuda.libdevice.double2ull} \_\_\_rn(f)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_double2ull rn.html

Parameters \( f (\text{float64}) \) – Argument.

Return type \( \text{int64} \)

\[
\text{numba.cuda.libdevice.double2ull} \_\_\_ru(f)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_double2ull ru.html

Parameters \( f (\text{float64}) \) – Argument.

Return type \( \text{int64} \)

\[
\text{numba.cuda.libdevice.double2ull} \_\_\_rz(f)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_double2ull rz.html

Parameters \( f (\text{float64}) \) – Argument.

Return type \( \text{int64} \)

\[
\text{numba.cuda.libdevice.double_as_longlong}(x)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_double_as_longlong.html

Parameters \( x (\text{float64}) \) – Argument.

Return type \( \text{int64} \)

\[
\text{numba.cuda.libdevice.drcp} \_\_\_rd(x)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_drcp rd.html

Parameters \( x (\text{float64}) \) – Argument.

Return type \( \text{float64} \)

\[
\text{numba.cuda.libdevice.drcp} \_\_\_rn(x)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_drcp rn.html

Parameters \( x (\text{float64}) \) – Argument.

Return type \( \text{float64} \)

\[
\text{numba.cuda.libdevice.drcp} \_\_\_ru(x)
\]
See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_drcp ru.html

Parameters \( x (\text{float64}) \) – Argument.

Return type \( \text{float64} \)
numba.cuda.libdevice.drcp_rz(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_drcp_rz.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.dsqrt_rd(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dsqrt_rd.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.dsqrt_rn(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dsqrt_rn.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.dsqrt_ru(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dsqrt_ru.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.dsqrt_rz(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_dsqrt_rz.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.erf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erf.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.erfc(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erfc.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.erfcf(x)
Parameters x (float32) – Argument.
Return type float32

numba.cuda.libdevice.erfcinv(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erfcinv.html

Parameters x (float64) – Argument.
Return type float64

numba.cuda.libdevice.erfcinvf(x)
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.erfcx(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erfcx.html
Parameters x (float64) – Argument.
Return type float64
numba.cuda.libdevice.erfcxf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erfcxf.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.erff(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erff.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.erfinv(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erfinv.html
Parameters x (float64) – Argument.
Return type float64
numba.cuda.libdevice.erfinvf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_erfinvf.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.exp(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_exp.html
Parameters x (float64) – Argument.
Return type float64
numba.cuda.libdevice.exp10(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_exp10.html
Parameters x (float64) – Argument.
Return type float64
numba.cuda.libdevice.exp10f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_exp10f.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.exp2(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_exp2.html
Parameters x (float64) – Argument.
Return type float64
numba.cuda.libdevice.exp2f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_exp2f.html
Parameters  \( x \) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.expf(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_expf.html

Parameters  \( x \) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.expml(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_expml.html

Parameters  \( x \) (float64) – Argument.

Return type  float64

numba.cuda.libdevice.expmlf(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_expmlf.html

Parameters  \( x \) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.fabs(f)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fabs.html

Parameters  \( f \) (float64) – Argument.

Return type  float64

numba.cuda.libdevice.fabsf(f)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fabsf.html

Parameters  \( f \) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.fadd_rd(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fadd_rd.html

Parameters

-  \( x \) (float32) – Argument.
-  \( y \) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.fadd_rn(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fadd_rn.html

Parameters

-  \( x \) (float32) – Argument.
-  \( y \) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.fadd_ru(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fadd_ru.html

Parameters

-  \( x \) (float32) – Argument.
-  \( y \) (float32) – Argument.
Return type float32
numba.cuda.libdevice.fadd_rz(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fadd_rz.html
Parameters
• x (float32) – Argument.
• y (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_cosf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_cosf.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_exp10f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_exp10f.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_expf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_expf.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_fdividef(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_fdividef.html
Parameters
• x (float32) – Argument.
• y (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_log10f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_log10f.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_log2f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_log2f.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_logf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_logf.html
Parameters x (float32) – Argument.
Return type float32
numba.cuda.libdevice.fast_powf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_powf.html
Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fast_sincosf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_sincosf.html

Parameters
- \(x\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fast_sinf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_sinf.html

Parameters
- \(x\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fast_tanf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fast_tanf.html

Parameters
- \(x\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fdim(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fdim.html

Parameters

- \(x\) (float64) – Argument.
- \(y\) (float64) – Argument.

Return type float64

numba.cuda.libdevice.fdimf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fdimf.html

Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fdiv_rd(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fdiv_rd.html

Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fdiv_rn(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fdiv_rn.html

Parameters

- \(x\) (float32) – Argument.
• *y* (*float32*) – Argument.

**Return type**  
*float32*

**numba.cuda.libdevice.fdiv_ru**(*x, y*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fdiv_ru.html

**Parameters**

• *x* (*float32*) – Argument.

• *y* (*float32*) – Argument.

**Return type**  
*float32*

**numba.cuda.libdevice.fdiv_rz**(*x, y*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fdiv_rz.html

**Parameters**

• *x* (*float32*) – Argument.

• *y* (*float32*) – Argument.

**Return type**  
*float32*

**numba.cuda.libdevice.ffs**(*x*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ffs.html

**Parameters**  
*x* (*int32*) – Argument.

**Return type**  
*int32*

**numba.cuda.libdevice.ffsll**(*x*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ffsll.html

**Parameters**  
*x* (*int64*) – Argument.

**Return type**  
*int32*

**numba.cuda.libdevice.finitef**(*x*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_finitef.html

**Parameters**  
*x* (*float32*) – Argument.

**Return type**  
*int32*

**numba.cuda.libdevice.float2half_rn**(*f*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float2half_rn.html

**Parameters**  
*f* (*float32*) – Argument.

**Return type**  
*int16*

**numba.cuda.libdevice.float2int_rd**(*x*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float2int_rd.html

**Parameters**  
*x* (*float32*) – Argument.

**Return type**  
*int32*

**numba.cuda.libdevice.float2int_rn**(*x*)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float2int_rn.html

**Parameters**  
*x* (*float32*) – Argument.

**Return type**  
*int32*
numba.cuda.libdevice<Float2Int_RU>(x)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2int_ru.html
   Parameters in (float32) – Argument.
   Return type int32

numba.cuda.libdevice<Float2Int_RZ>(x)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2int_rz.html
   Parameters in (float32) – Argument.
   Return type int32

numba.cuda.libdevice<Float2Int_RD>(f)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2int_rd.html
   Parameters f (float32) – Argument.
   Return type int64

numba.cuda.libdevice<Float2Int_RN>(f)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2int_rn.html
   Parameters f (float32) – Argument.
   Return type int64

numba.cuda.libdevice<Float2Int_RU>(f)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2int_ru.html
   Parameters f (float32) – Argument.
   Return type int64

numba.cuda.libdevice<Float2Int_RZ>(f)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2int_rz.html
   Parameters f (float32) – Argument.
   Return type int64

numba.cuda.libdevice<Float2Uint_RD>(x)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2uint_rd.html
   Parameters in (float32) – Argument.
   Return type int32

numba.cuda.libdevice<Float2Uint_RN>(x)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2uint_rn.html
   Parameters in (float32) – Argument.
   Return type int32

numba.cuda.libdevice<Float2Uint_RU>(x)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2uint_ru.html
   Parameters in (float32) – Argument.
   Return type int32

numba.cuda.libdevice<Float2Uint_RZ>(x)
   See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_float2uint_rz.html
   Parameters in (float32) – Argument.
Return type int32
numba.cuda.libdevice.float2ull_rd(f)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float2ull_rd.html
    Parameters f(float32) – Argument.
    Return type int64
numba.cuda.libdevice.float2ull_rn(f)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float2ull_rn.html
    Parameters f(float32) – Argument.
    Return type int64
numba.cuda.libdevice.float2ull_ru(f)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float2ull_ru.html
    Parameters f(float32) – Argument.
    Return type int64
numba.cuda.libdevice.float2ull_rz(f)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float2ull_rz.html
    Parameters f(float32) – Argument.
    Return type int64
numba.cuda.libdevice.float_as_int(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_float_as_int.html
    Parameters x(float32) – Argument.
    Return type int32
numba.cuda.libdevice.floor(f)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_floor.html
    Parameters f(float64) – Argument.
    Return type float64
numba.cuda.libdevice.floorf(f)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_floorf.html
    Parameters f(float32) – Argument.
    Return type float32
numba.cuda.libdevice.fma(x, y, z)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fma.html
    Parameters
        • x(float64) – Argument.
        • y(float64) – Argument.
        • z(float64) – Argument.
    Return type float64
numba.cuda.libdevice.fma_rd(x, y, z)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fma_rd.html
    Parameters
• \( x (\text{float64}) \) – Argument.
• \( y (\text{float64}) \) – Argument.
• \( z (\text{float64}) \) – Argument.

**Return type** float64

numba.cuda.libdevice.fma_rn(x, y, z)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fma_rn.html

**Parameters**

• \( x (\text{float64}) \) – Argument.
• \( y (\text{float64}) \) – Argument.
• \( z (\text{float64}) \) – Argument.

**Return type** float64

numba.cuda.libdevice.fma_ru(x, y, z)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fma_ru.html

**Parameters**

• \( x (\text{float64}) \) – Argument.
• \( y (\text{float64}) \) – Argument.
• \( z (\text{float64}) \) – Argument.

**Return type** float64

numba.cuda.libdevice.fma_rz(x, y, z)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fma_rz.html

**Parameters**

• \( x (\text{float64}) \) – Argument.
• \( y (\text{float64}) \) – Argument.
• \( z (\text{float64}) \) – Argument.

**Return type** float64

numba.cuda.libdevice.fmaf(x, y, z)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmaf.html

**Parameters**

• \( x (\text{float32}) \) – Argument.
• \( y (\text{float32}) \) – Argument.
• \( z (\text{float32}) \) – Argument.

**Return type** float32

numba.cuda.libdevice.fmaf_rd(x, y, z)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmaf_rd.html

**Parameters**

• \( x (\text{float32}) \) – Argument.
• \( y (\text{float32}) \) – Argument.
• \( z (\text{float32}) \) – Argument.
numba.cuda.libdevice.fmaf_rn(x, y, z)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmaf_rn.html

Parameters
• x (float32) – Argument.
• y (float32) – Argument.
• z (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmaf_ru(x, y, z)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmaf_ru.html

Parameters
• x (float32) – Argument.
• y (float32) – Argument.
• z (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmaf_rz(x, y, z)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmaf_rz.html

Parameters
• x (float32) – Argument.
• y (float32) – Argument.
• z (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmax(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmax.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64

numba.cuda.libdevice.fmaxf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmaxf.html

Parameters
• x (float32) – Argument.
• y (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmin(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmin.html

Parameters
• x (float64) – Argument.
numba.cuda.libdevice.fminf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fminf.html

Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmod(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmod.html

Parameters

- \(x\) (float64) – Argument.
- \(y\) (float64) – Argument.

Return type float64

numba.cuda.libdevice.fmodf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmodf.html

Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmul_rd(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmul_rd.html

Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmul_rn(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmul_rn.html

Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

numba.cuda.libdevice.fmul_ru(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmul_ru.html

Parameters

- \(x\) (float32) – Argument.
- \(y\) (float32) – Argument.

Return type float32

4.4. Libdevice functions
numba.cuda.libdevice.fmul_rz(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fmul_rz.html

Parameters

• \(x\) (float32) – Argument.
• \(y\) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.frcp_rd(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_frcp_rd.html

Parameters \(x\) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.frcp_rn(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_frcp_rn.html

Parameters \(x\) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.frcp_ru(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_frcp_ru.html

Parameters \(x\) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.frcp_rz(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_frcp_rz.html

Parameters \(x\) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.frexp(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_frexp.html

Parameters \(x\) (float64) – Argument.

Return type  Tuple(float64, int32)

numba.cuda.libdevice.frexpf(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_frexpf.html

Parameters \(x\) (float32) – Argument.

Return type  Tuple(float32, int32)

numba.cuda.libdevice.frsqrt_rn(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_frsqrt_rn.html

Parameters \(x\) (float32) – Argument.

Return type  float32

numba.cuda.libdevice.fsqrt_rd(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fsqrt_rd.html

Parameters \(x\) (float32) – Argument.

Return type  float32
numba.cuda.libdevice.fsqrt_rn(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fsqrt_rn.html
    Parameters  x (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.fsqrt_ru(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fsqrt_ru.html
    Parameters  x (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.fsqrt_rz(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fsqrt_rz.html
    Parameters  x (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.fsub_rn(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fsub_rn.html
    Parameters
        •  x (float32) – Argument.
        •  y (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.fsub_ru(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fsub_ru.html
    Parameters
        •  x (float32) – Argument.
        •  y (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.fsub_rz(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_fsub_rz.html
    Parameters
        •  x (float32) – Argument.
        •  y (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.hadd(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_hadd.html
    Parameters
• x (int32) – Argument.
• y (int32) – Argument.

Return type  int32
numba.cuda.libdevice.half2float(h)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_half2float.html

Parameters  h (int16) – Argument.
Return type  float32
numba.cuda.libdevice.hioint2double(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_hioint2double.html

Parameters
• x (int32) – Argument.
• y (int32) – Argument.

Return type  float64
numba.cuda.libdevice.hypot(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_hypot.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type  float64
numba.cuda.libdevice.hypotf(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_hypotf.html

Parameters
• x (float32) – Argument.
• y (float32) – Argument.

Return type  float32
numba.cuda.libdevice.ilogb(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ilogb.html

Parameters  x (float64) – Argument.
Return type  int32
numba.cuda.libdevice.ilogbf(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ilogbf.html

Parameters  x (float32) – Argument.
Return type  int32
numba.cuda.libdevice.int2double_rn(i)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_int2double_rn.html

Parameters  i (int32) – Argument.
Return type  float64
numba.cuda.libdevice.int2float_rd(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_int2float_rd.html
Parameters \texttt{in} (\texttt{int32}) – Argument.

Return type \texttt{float32}

\texttt{numba.cuda.libdevice.int2float_rn(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_int2float_rn.html

Parameters \texttt{in} (\texttt{int32}) – Argument.

Return type \texttt{float32}

\texttt{numba.cuda.libdevice.int2float_ru(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_int2float_ru.html

Parameters \texttt{in} (\texttt{int32}) – Argument.

Return type \texttt{float32}

\texttt{numba.cuda.libdevice.int2float_rz(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_int2float_rz.html

Parameters \texttt{in} (\texttt{int32}) – Argument.

Return type \texttt{float32}

\texttt{numba.cuda.libdevice.int_as_float(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_int_as_float.html

Parameters \texttt{x (int32)} – Argument.

Return type \texttt{float32}

\texttt{numba.cuda.libdevice.isfinated(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_isfinated.html

Parameters \texttt{x (float64)} – Argument.

Return type \texttt{int32}

\texttt{numba.cuda.libdevice.isinf(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_isinf.html

Parameters \texttt{x (float64)} – Argument.

Return type \texttt{int32}

\texttt{numba.cuda.libdevice.isinff(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_isinff.html

Parameters \texttt{x (float32)} – Argument.

Return type \texttt{int32}

\texttt{numba.cuda.libdevice.isnand(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_isnand.html

Parameters \texttt{x (float64)} – Argument.

Return type \texttt{int32}

\texttt{numba.cuda.libdevice.isnanf(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_isnanf.html

Parameters \texttt{x (float32)} – Argument.

Return type \texttt{int32}
numba.cuda.libdevice.j0f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_j0f.html

Parameters
x (float32) – Argument.

Return type float32

numba.cuda.libdevice.j1f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_j1f.html

Parameters
x (float32) – Argument.

Return type float32

numba.cuda.libdevice.jn(n, x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_jn.html

Parameters
• n (int32) – Argument.
• x (float64) – Argument.

Return type float64

numba.cuda.libdevice.ldexpf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ldexpf.html

Parameters
• x (float32) – Argument.
• y (int32) – Argument.

Return type float32
numba.cuda.libdevice.lgamma(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_lgamma.html
    Parameters x (float64) – Argument.
    Return type float64

def numba.cuda.libdevice.lgammaf(x):
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_lgammaf.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.ll2double_rd(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2double_rd.html
    Parameters l (int64) – Argument.
    Return type float64

numba.cuda.libdevice.ll2double_rn(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2double_rn.html
    Parameters l (int64) – Argument.
    Return type float64

numba.cuda.libdevice.ll2double_ru(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2double_ru.html
    Parameters l (int64) – Argument.
    Return type float64

numba.cuda.libdevice.ll2double_rz(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2double_rz.html
    Parameters l (int64) – Argument.
    Return type float64

numba.cuda.libdevice.ll2float_rd(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2float_rd.html
    Parameters l (int64) – Argument.
    Return type float32

numba.cuda.libdevice.ll2float_rn(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2float_rn.html
    Parameters l (int64) – Argument.
    Return type float32

numba.cuda.libdevice.ll2float_ru(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2float_ru.html
    Parameters l (int64) – Argument.
    Return type float32

numba.cuda.libdevice.ll2float_rz(l)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ll2float_rz.html

4.4. Libdevice functions
Parameters l (int64) – Argument.

Return type  float32

dnumba.cuda.libdevice.llabs(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_llabs.html

Parameters x (int64) – Argument.

Return type  int64

dnumba.cuda.libdevice.llmax(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_llmax.html

Parameters
• x (int64) – Argument.
• y (int64) – Argument.

Return type  int64

dnumba.cuda.libdevice.llmin(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_llmin.html

Parameters
• x (int64) – Argument.
• y (int64) – Argument.

Return type  int64

dnumba.cuda.libdevice.llrint(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_llrint.html

Parameters x (float64) – Argument.

Return type  int64

dnumba.cuda.libdevice.llrintf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_llrintf.html

Parameters x (float32) – Argument.

Return type  int64

dnumba.cuda.libdevice.llround(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_llround.html

Parameters x (float64) – Argument.

Return type  int64

dnumba.cuda.libdevice.llroundf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_llroundf.html

Parameters x (float32) – Argument.

Return type  int64

dnumba.cuda.libdevice.log(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_log.html

Parameters x (float64) – Argument.

Return type  float64
numba.cuda.libdevice.log10(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_log10.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.log10f(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_log10f.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.log1p(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_log1p.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.log1pf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_log1pf.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.log2(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_log2.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.log2f(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_log2f.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.logb(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_logb.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.logbf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_logbf.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.logf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_logf.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.longlong_as_double(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_longlong_as_double.html
    Parameters x (int64) – Argument.

4.4. Libdevice functions 265
Return type  float64
numba.cuda.libdevice.max(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_max.html
Parameters
    • x (int32) – Argument.
    • y (int32) – Argument.
Return type  int32
numba.cuda.libdevice.min(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_min.html
Parameters
    • x (int32) – Argument.
    • y (int32) – Argument.
Return type  int32
numba.cuda.libdevice.modf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_modf.html
Parameters
    x (float64) – Argument.
Return type  UniTuple(float64 x 2)
numba.cuda.libdevice.modff(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_modff.html
Parameters
    x (float32) – Argument.
Return type  UniTuple(float32 x 2)
numba.cuda.libdevice.mul24(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_mul24.html
Parameters
    • x (int32) – Argument.
    • y (int32) – Argument.
Return type  int32
numba.cuda.libdevice.mul64hi(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_mul64hi.html
Parameters
    • x (int64) – Argument.
    • y (int64) – Argument.
Return type  int64
numba.cuda.libdevice.mulhi(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/_nv_mulhi.html
Parameters
    • x (int32) – Argument.
    • y (int32) – Argument.
Return type int32

numba.cuda.libdevice.nearbyint(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_nearbyint.html

Parameters x (float64) – Argument.

Return type float64

numba.cuda.libdevice.nearbyintf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_nearbyintf.html

Parameters x (float32) – Argument.

Return type float32

numba.cuda.libdevice.nextafter(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_nextafter.html

Parameters
• x (float64) – Argument.
• y (float64) – Argument.

Return type float64

numba.cuda.libdevice.nextafterf(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_nextafterf.html

Parameters
• x (float32) – Argument.
• y (float32) – Argument.

Return type float32

numba.cuda.libdevice.normcdf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_normcdf.html

Parameters x (float64) – Argument.

Return type float64

numba.cuda.libdevice.normcdff(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_normcdff.html

Parameters x (float32) – Argument.

Return type float32

numba.cuda.libdevice.normcdfinv(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_normcdfinv.html

Parameters x (float64) – Argument.

Return type float64

numba.cuda.libdevice.normcdfinvf(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_normcdfinvf.html

Parameters x (float32) – Argument.

Return type float32

numba.cuda.libdevice.popc(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_popc.html

4.4. Libdevice functions
Parameters `x` (*int32*) – Argument.

Return type `int32`

`numba.cuda.libdevice.popcll(x)`

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_popcll.html

Parameters `x` (*int64*) – Argument.

Return type `int32`

`numba.cuda.libdevice.pow(x, y)`

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_pow.html

Parameters

- `x` (*float64*) – Argument.
- `y` (*float64*) – Argument.

Return type `float64`

`numba.cuda.libdevice.powf(x, y)`

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_powf.html

Parameters

- `x` (*float32*) – Argument.
- `y` (*float32*) – Argument.

Return type `float32`

`numba.cuda.libdevice.powi(x, y)`

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_powi.html

Parameters

- `x` (*float64*) – Argument.
- `y` (*int32*) – Argument.

Return type `float64`

`numba.cuda.libdevice.powif(x, y)`

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_powif.html

Parameters

- `x` (*float32*) – Argument.
- `y` (*int32*) – Argument.

Return type `float32`

`numba.cuda.libdevice.rcbrt(x)`

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_rcbrt.html

Parameters `x` (*float64*) – Argument.

Return type `float64`

`numba.cuda.libdevice.rcbrtf(x)`

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_rcbrtf.html

Parameters `x` (*float32*) – Argument.

Return type `float32`
numba.cuda.libdevice.**remainder**(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_remainder.html

**Parameters**

- **x** (*float64*) – Argument.
- **y** (*float64*) – Argument.

**Return type**  float64

numba.cuda.libdevice.**remainderf**(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_remainderf.html

**Parameters**

- **x** (*float32*) – Argument.
- **y** (*float32*) – Argument.

**Return type**  float32

numba.cuda.libdevice.**remquo**(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_remquo.html

**Parameters**

- **x** (*float64*) – Argument.
- **y** (*float64*) – Argument.

**Return type**  Tuple(float64, int32)

numba.cuda.libdevice.**remquof**(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_remquof.html

**Parameters**

- **x** (*float32*) – Argument.
- **y** (*float32*) – Argument.

**Return type**  Tuple(float32, int32)

numba.cuda.libdevice.**rhadd**(x, y)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_rhadd.html

**Parameters**

- **x** (*int32*) – Argument.
- **y** (*int32*) – Argument.

**Return type**  int32

numba.cuda.libdevice.**rint**(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_rint.html

**Parameters**

- **x** (*float64*) – Argument.

**Return type**  float64

numba.cuda.libdevice.**rintf**(x)

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_rintf.html

**Parameters**

- **x** (*float32*) – Argument.

**Return type**  float32

4.4. Libdevice functions
numba.cuda.libdevice.round(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_round.html
    **Parameters**
    - x (float64) – Argument.
    **Return type**
    float64

numba.cuda.libdevice.roundf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_roundf.html
    **Parameters**
    - x (float32) – Argument.
    **Return type**
    float32

numba.cuda.libdevice.rsqrt(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_rsqrt.html
    **Parameters**
    - x (float64) – Argument.
    **Return type**
    float64

numba.cuda.libdevice.rsqrtf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_rsqrtf.html
    **Parameters**
    - x (float32) – Argument.
    **Return type**
    float32

numba.cuda.libdevice.sad(x, y, z)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sad.html
    **Parameters**
    - x (int32) – Argument.
    - y (int32) – Argument.
    - z (int32) – Argument.
    **Return type**
    int32

numba.cuda.libdevice.saturatef(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_saturatef.html
    **Parameters**
    - x (float32) – Argument.
    **Return type**
    float32

numba.cuda.libdevice.scalbn(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_scalbn.html
    **Parameters**
    - x (float64) – Argument.
    - y (int32) – Argument.
    **Return type**
    float64

numba.cuda.libdevice.scalbnf(x, y)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_scalbnf.html
    **Parameters**
    - x (float32) – Argument.
    - y (int32) – Argument.
    **Return type**
    float32
numba.cuda.libdevice.signbitd(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_signbitd.html
    Parameters x (float64) – Argument.
    Return type int32

numba.cuda.libdevice.signbitf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_signbitf.html
    Parameters x (float32) – Argument.
    Return type int32

numba.cuda.libdevice.sin(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sin.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.sincos(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sincos.html
    Parameters x (float64) – Argument.
    Return type UniTuple(float64 x 2)

numba.cuda.libdevice.sincosf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sincosf.html
    Parameters x (float32) – Argument.
    Return type UniTuple(float32 x 2)

numba.cuda.libdevice.sincospif(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sincospif.html
    Parameters x (float32) – Argument.
    Return type UniTuple(float32 x 2)

numba.cuda.libdevice.sinf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sinf.html
    Parameters x (float32) – Argument.
    Return type float32

numba.cuda.libdevice.sinh(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sinh.html
    Parameters x (float64) – Argument.
    Return type float64

numba.cuda.libdevice.sinhf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sinhf.html
    Parameters x (float32) – Argument.

4.4. Libdevice functions
Return type  float32
numba.cuda.libdevice.sinpi(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sinpi.html
    Parameters x (float64) – Argument.
    Return type  float64
numba.cuda.libdevice.sinpif(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sinpif.html
    Parameters x (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.sqrt(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sqrt.html
    Parameters x (float64) – Argument.
    Return type  float64
numba.cuda.libdevice.sqrtf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_sqrtf.html
    Parameters x (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.tan(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_tan.html
    Parameters x (float64) – Argument.
    Return type  float64
numba.cuda.libdevice.tanf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_tanf.html
    Parameters x (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.tanh(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_tanh.html
    Parameters x (float64) – Argument.
    Return type  float64
numba.cuda.libdevice.tanhf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_tanhf.html
    Parameters x (float32) – Argument.
    Return type  float32
numba.cuda.libdevice.tgamma(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_tgamma.html
    Parameters x (float64) – Argument.
    Return type  float64
numba.cuda.libdevice.tgammaf(x)
    See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_tgammaf.html
Parameters \( x \) (float32) – Argument.

Return type float32

\texttt{numba.cuda.libdevice.trunc(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_trunc.html

Parameters \( x \) (float64) – Argument.

Return type float64

\texttt{numba.cuda.libdevice.truncf(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_truncf.html

Parameters \( x \) (float32) – Argument.

Return type float32

\texttt{numba.cuda.libdevice.uhadd(x, y)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_uhadd.html

\textbf{Parameters}

- \( x \) (int32) – Argument.
- \( y \) (int32) – Argument.

Return type int32

\texttt{numba.cuda.libdevice.uint2double_rn(i)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_uint2double_rn.html

Parameters \( i \) (int32) – Argument.

Return type float64

\texttt{numba.cuda.libdevice.uint2float_rd(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_uint2float_rd.html

Parameters \( x \) (int32) – Argument.

Return type float32

\texttt{numba.cuda.libdevice.uint2float_rn(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_uint2float_rn.html

Parameters \( x \) (int32) – Argument.

Return type float32

\texttt{numba.cuda.libdevice.uint2float_ru(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_uint2float_ru.html

Parameters \( x \) (int32) – Argument.

Return type float32

\texttt{numba.cuda.libdevice.uint2float_rz(x)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_uint2float_rz.html

Parameters \( x \) (int32) – Argument.

Return type float32

\texttt{numba.cuda.libdevice.ull2double_rd(l)}

See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2double_rd.html

Parameters \( l \) (int64) – Argument.

Return type float64
Return type  float64
numba.cuda.libdevice.ull2double_rn(l)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2double_rn.html
 Parameters  l (int64) – Argument.
 Return type  float64
numba.cuda.libdevice.ull2double_ru(l)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2double_ru.html
 Parameters  l (int64) – Argument.
 Return type  float64
numba.cuda.libdevice.ull2double_rz(l)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2double_rz.html
 Parameters  l (int64) – Argument.
 Return type  float64
numba.cuda.libdevice.ull2float_rd(l)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2float_rd.html
 Parameters  l (int64) – Argument.
 Return type  float32
numba.cuda.libdevice.ull2float_rn(l)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2float_rn.html
 Parameters  l (int64) – Argument.
 Return type  float32
numba.cuda.libdevice.ull2float_ru(l)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2float_ru.html
 Parameters  l (int64) – Argument.
 Return type  float32
numba.cuda.libdevice.ull2float_rz(l)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ull2float_rz.html
 Parameters  l (int64) – Argument.
 Return type  float32
numba.cuda.libdevice.ullmax(x, y)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ullmax.html
 Parameters
 •  x (int64) – Argument.
 •  y (int64) – Argument.
 Return type  int64
numba.cuda.libdevice.ullmin(x, y)
 See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ullmin.html
 Parameters
 •  x (int64) – Argument.
• y (int64) – Argument.

Return type int64

numba.cuda.libdevice.umax(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_umax.html

Parameters
• x (int32) – Argument.
• y (int32) – Argument.

Return type int32

numba.cuda.libdevice.umin(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_umin.html

Parameters
• x (int32) – Argument.
• y (int32) – Argument.

Return type int32

numba.cuda.libdevice.umul24(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_umul24.html

Parameters
• x (int32) – Argument.
• y (int32) – Argument.

Return type int32

numba.cuda.libdevice.umul64hi(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_umul64hi.html

Parameters
• x (int64) – Argument.
• y (int64) – Argument.

Return type int64

numba.cuda.libdevice.umulhi(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_umulhi.html

Parameters
• x (int32) – Argument.
• y (int32) – Argument.

Return type int32

numba.cuda.libdevice.urhadd(x, y)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_urhadd.html

Parameters
• x (int32) – Argument.
• y (int32) – Argument.

Return type int32
numba.cuda.libdevice.usad(x, y, z)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_usad.html

Parameters
• x (int32) – Argument.
• y (int32) – Argument.
• z (int32) – Argument.

Return type  int32

numba.cuda.libdevice.y0(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_y0.html

Parameters  x (float64) – Argument.

Return type  float64

numba.cuda.libdevice.y0f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_y0f.html

Parameters  x (float32) – Argument.

Return type  float32

numba.cuda.libdevice.y1(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_y1.html

Parameters  x (float64) – Argument.

Return type  float64

numba.cuda.libdevice.y1f(x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_y1f.html

Parameters  x (float32) – Argument.

Return type  float32

numba.cuda.libdevice.yn(n, x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_yn.html

Parameters
• n (int32) – Argument.
• x (float64) – Argument.

Return type  float64

numba.cuda.libdevice.ynf(n, x)
See https://docs.nvidia.com/cuda/libdevice-users-guide/__nv_ynf.html

Parameters
• n (int32) – Argument.
• x (float32) – Argument.

Return type  float32
This chapter describes how to extend Numba to make it recognize and support additional operations, functions or types. Numba provides two categories of APIs to this end:

- The high-level APIs provide abstracted entry points which are sufficient for simple uses. They require little knowledge of Numba’s internal compilation chain.
- The low-level APIs reflect Numba’s internal compilation chain and allow flexible interaction with its various layers, but require more effort and experience with Numba internals.

It may be helpful for readers of this chapter to also read some of the documents in the developer manual, especially the architecture document.

5.1 High-level extension API

This extension API is exposed through the numba.extending module.

To aid debugging extensions to Numba, it’s recommended to set the following environment variable:

```
NUMBA_CAPTURED_ERRORS="new_style"
```

this makes it easy to differentiate between errors in implementation and acceptable errors that can take part in e.g. type inference. For more information see NUMBA_CAPTURED_ERRORS.

5.1.1 Implementing functions

The @overload decorator allows you to implement arbitrary functions for use in nopython mode functions. The function decorated with @overload is called at compile-time with the types of the function’s runtime arguments. It should return a callable representing the implementation of the function for the given types. The returned implementation is compiled by Numba as if it were a normal function decorated with @jit. Additional options to @jit can be passed as dictionary using the jit_options argument.

For example, let’s pretend Numba doesn’t support the len() function on tuples yet. Here is how to implement it using @overload:

```python
from numba import types
from numba.extending import overload

@overload(len)
def tuple_len(seq):
    if isinstance(seq, types.BaseTuple):
        n = len(seq)
```

(continues on next page)
You might wonder, what happens if `len()` is called with something else than a tuple? If a function decorated with `@overload` doesn't return anything (i.e. returns None), other definitions are tried until one succeeds. Therefore, multiple libraries may overload `len()` for different types without conflicting with each other.

### 5.1.2 Implementing methods

The `@overload_method` decorator similarly allows implementing a method on a type well-known to Numba.

```python
def len_impl(seq):
    return n
return len_impl
```

5.1.2 Implementing methods

The `@overload_method` decorator similarly allows implementing a method on a type well-known to Numba.

```python
def array_take(arr, indices):
    if isinstance(indices, types.Array):
        def take_impl(arr, indices):
            n = indices.shape[0]
            res = np.empty(n, arr.dtype)
            for i in range(n):
                res[i] = arr[indices[i]]
            return res
        return take_impl
```

### 5.1.3 Implementing classmethods

The `@overload_classmethod` decorator similarly allows implementing a classmethod on a type well-known to Numba.

```python
@overload_classmethod(types.Array, "make")
def ov_make(cls, nitems):
    def impl(cls, nitems):
        return np.arange(nitems)
    return impl
```

The above code will allow the following to work in jit-compiled code:
@njit
def foo(n):
    return types.Array.make(n)

5.1.4 Implementing attributes

The @overload_attribute decorator allows implementing a data attribute (or property) on a type. Only reading the attribute is possible; writable attributes are only supported through the low-level API.

The following example implements the nbytes attribute on Numpy arrays:

@overload_attribute(types.Array, 'nbytes')
def array_nbytes(arr):
    def get(arr):
        return arr.size * arr.itemsize
    return get

5.1.5 Importing Cython Functions

The function get_cython_function_address obtains the address of a C function in a Cython extension module. The address can be used to access the C function via a ctypes.CFUNCTYPE() callback, thus allowing use of the C function inside a Numba jitted function. For example, suppose that you have the file foo.pyx:

```python
from libc.math cimport exp
cdef api double myexp(double x):
    return exp(x)
```

You can access myexp from Numba in the following way:

```python
import ctypes
from numba.extending import get_cython_function_address

addr = get_cython_function_address("foo", "myexp")
functype = ctypes.CFUNCTYPE(ctypes.c_double, ctypes.c_double)
myexp = functype(addr)
```

The function myexp can now be used inside jitted functions, for example:

```python
@njit
def double_myexp(x):
    return 2*myexp(x)
```

One caveat is that if your function uses Cython’s fused types, then the function’s name will be mangled. To find out the mangled name of your function you can check the extension module’s __pyx_capi__ attribute.
5.1.6 Implementing intrinsics

The `@intrinsic` decorator is used for marking a function `func` as typing and implementing the function in nopython mode using the llvmlite IRBuilder API. This is an escape hatch for expert users to build custom LLVM IR that will be inlined into the caller, there is no safety net!

The first argument to `func` is the typing context. The rest of the arguments corresponds to the type of arguments of the decorated function. These arguments are also used as the formal argument of the decorated function. If `func` has the signature `foo(typing_context, arg0, arg1)`, the decorated function will have the signature `foo(arg0, arg1)`. The return values of `func` should be a 2-tuple of expected type signature, and a code-generation function that will passed to `lower_builtin()`. For an unsupported operation, return `None`.

Here is an example that cast any integer to a byte pointer:

```python
from numba import types
from numba.extending import intrinsic

@intrinsic
def cast_int_to_byte_ptr(typingctx, src):
    # check for accepted types
    if isinstance(src, types.Integer):
        # create the expected type signature
        result_type = types.CPointer(types.uint8)
        sig = result_type(types.uintp)
        # defines the custom code generation
        def codegen(context, builder, signature, args):
            # llvm IRBuilder code here
            [src] = args
            rtype = signature.return_type
            llrtype = context.get_value_type(rtype)
            return builder.inttoptr(src, llrtype)
        return sig, codegen
```

It may be used as follows:

```python
from numba import njit

@njit('void(int64)')
def foo(x):
    y = cast_int_to_byte_ptr(x)

foo.inspect_types()
```

And the output of `.inspect_types()` demonstrates the cast (note the `uint8*`):

```python
def foo(x):
    # x = arg(0, name=x) :: int64
    # $0.1 = global(cast_int_to_byte_ptr: <intrinsic cast_int_to_byte_ptr>) ::
    # Function(<intrinsic cast_int_to_byte_ptr>)
    # $0.3 = call $0.1(x, func=$0.1, args=[Var(x, check_intrin.py (24))], kws={},
    # vararg=None) :: (uint64,) -> uint8*
    # del x
    # del $0.1
```

(continues on next page)
Warning: This is an experimental feature, the API may change without warning.

The `numba.experimental.structref` module provides utilities for defining mutable pass-by-reference structures, a StructRef. The following example demonstrates how to define a basic mutable structure:

**Defining a StructRef**

```python
import numpy as np

from numba import njit
from numba.core import types
from numba.experimental import structref

from numba.tests.support import skip_unless_scipy

# Define a StructRef.
# `structref.register` associates the type with the default data model.
# This will also install getters and setters to the fields of
# the StructRef.
@structref.register
class MyStructType(types.StructRef):
    def preprocess_fields(self, fields):
        # This method is called by the type constructor for additional
        # preprocessing on the fields.
        # Here, we don't want the struct to take Literal types.
        return tuple((name, types.unliteral(typ)) for name, typ in fields)

# Define a Python type that can be use as a proxy to the StructRef
# allocated inside Numba. Users can construct the StructRef via
# the constructor for this type in python code and jit-code.
class MyStruct(structref.StructRefProxy):
```

(continues on next page)
def __new__(cls, name, vector):
    # Overriding the __new__ method is optional, doing so
    # allows Python code to use keyword arguments,
    # or add other customized behavior.
    # The default __new__ takes `*args`.
    # IMPORTANT: Users should not override __init__.
    return structref.StructRefProxy.__new__(cls, name, vector)

    # By default, the proxy type does not reflect the attributes or
    # methods to the Python side. It is up to users to define
    # these. (This may be automated in the future.)

@property
def name(self):
    # To access a field, we can define a function that simply
    # return the field in jit-code.
    # The definition of MyStruct_get_name is shown later.
    return MyStruct_get_name(self)

@property
def vector(self):
    # The definition of MyStruct_get_vector is shown later.
    return MyStruct_get_vector(self)

@njit
def MyStruct_get_name(self):
    # In jit-code, the StructRef's attribute is exposed via
    # structref.register
    return self.name

@njit
def MyStruct_get_vector(self):
    return self.vector

# This associates the proxy with MyStructType for the given set of
# fields. Notice how we are not constring the type of each field.
# Field types remain generic.
structref.define_proxy(MyStruct, MyStructType, ['name', 'vector'])

The following demonstrates using the above mutable struct definition:

Listing 2: from test_type_definition of numba/tests/doc_examples/test_structref_usage.py

# Let's test our new StructRef.
# Define one in Python
alice = MyStruct("Alice", vector=np.random.random(3))
# Define one in jit-code
@njit
def make_bob():
    bob = MyStruct("unnamed", vector=np.zeros(3))
    # Mutate the attributes
    bob.name = "Bob"
    bob.vector = np.random.random(3)
    return bob

bob = make_bob()

# Out: Alice: [0.5488135 0.71518937 0.60276338]
print(f"{alice.name}: {alice.vector}"
# Out: Bob: [0.88325739 0.73527629 0.87746707]
print(f"{bob.name}: {bob.vector}"

# Define a jit function to operate on the structs.
@njit
def distance(a, b):
    return np.linalg.norm(a.vector - b.vector)

# Out: 0.4332647200356598
print(distance(alice, bob))

---

**Defining a method on StructRef**

Methods and attributes can be attached using `@overload_*` as shown in the previous sections.

The following demonstrates the use of `@overload_method` to insert a method for instances of `MyStructType`:

```python
from numba.core.extending import overload_method
from numba.core.errors import TypingError

# Use @overload_method to add a method for
# MyStructType.distance(other)
# where *other* is an instance of MyStructType.
@overload_method(MyStructType, "distance")
def ol_distance(self, other):
    # Guard that *other* is an instance of MyStructType
    if not isinstance(other, MyStructType):
        raise TypingError(f"*other* must be a {MyStructType}; got {other}"
    
    def impl(self, other):
        return np.linalg.norm(self.vector - other.vector)

    return impl
```

(continues on next page)
```python
# Test
@njit
def test():
    alice = MyStruct("Alice", vector=np.random.random(3))
    bob = MyStruct("Bob", vector=np.random.random(3))
    # Use the method
    return alice.distance(bob)
```

### numba.experimental.structref API Reference

Utilities for defining a mutable struct.

A mutable struct is passed by reference; hence, structref (a reference to a struct).

```python
class numba.experimental.structref.StructRefProxy(*args)
    A PyObject proxy to the Numba allocated structref data structure.
```

**Notes**

- Subclasses should not define `__init__`.
- Subclasses can override `__new__`.

```python
numba.experimental.structref.define_attributes(struct_typeclass)
    Define attributes on `struct_typeclass`.
    Defines both setters and getters in jit-code.
    This is called directly in `register()`.
```

```python
numba.experimental.structref.define_boxing(struct_type, obj_class)
    Define the boxing & unboxing logic for `struct_type` to `obj_class`.
    Defines both boxing and unboxing.
    - boxing turns an instance of `struct_type` into a PyObject of `obj_class`
    - unboxing turns an instance of `obj_class` into an instance of `struct_type` in jit-code.
    Use this directly instead of `define_proxy()` when the user does not want any constructor to be defined.
```

```python
numba.experimental.structref.define_constructor(py_class, struct_typeclass, fields)
    Define the jit-code constructor for `struct_typeclass` using the Python type `py_class` and the required `fields`.
    Use this instead of `define_proxy()` if the user does not want boxing logic defined.
```

```python
numba.experimental.structref.define_proxy(py_class, struct_typeclass, fields)
    Defines a PyObject proxy for a structref.
    This makes `py_class` a valid constructor for creating an instance of `struct_typeclass` that contains the members as defined by `fields`.
```

**Parameters**

- `py_class` [type] The Python class for constructing an instance of `struct_typeclass`.
- `struct_typeclass` [numba.core.types.Type] The structref type class to bind to.
- `fields` [Sequence[str]] A sequence of field names.
Returns

None

`numba.experimental.structref.register(struct_type)`
Register a `numba.core.types.StructRef` for use in jit-code.

This defines the data-model for lowering an instance of `struct_type`. This defines attributes accessor and mutator for an instance of `struct_type`.

Parameters

`struct_type` [type] A subclass of `numba.core.types.StructRef`.

Returns

`struct_type` [type] Returns the input argument so this can act like a decorator.

Examples

```python
class MyStruct(numba.core.types.StructRef):
    ...  # the simplest subclass can be empty

numba.experimental.structref.register(MyStruct)
```

### 5.1.8 Determining if a function is already wrapped by a jit family decorator

The following function is provided for this purpose.

`extending.is_jitted()`

Returns True if a function is wrapped by one of the Numba @jit decorators, for example: numba.jit, numba.njit

The purpose of this function is to provide a means to check if a function is already JIT decorated.

### 5.2 Low-level extension API

This extension API is available through the `numba.extending` module. It allows you to hook directly into the Numba compilation chain. As such, it distinguished between several compilation phases:

- The **typing** phase deduces the types of variables in a compiled function by looking at the operations performed.
- The **lowering** phase converts high-level Python operations into low-level LLVM code. This phase exploits the typing information derived by the typing phase.
- **Boxing** and **unboxing** convert Python objects into native values, and vice-versa. They occur at the boundaries of calling a Numba function from the Python interpreter.
5.2.1 Typing

Type inference – or simply typing – is the process of assigning Numba types to all values involved in a function, so as to enable efficient code generation. Broadly speaking, typing comes in two flavours: typing plain Python values (e.g. function arguments or global variables) and typing operations (or functions) on known value types.

@typeof_impl.register(cls)
Register the decorated function as typing Python values of class cls. The decorated function will be called with the signature \((\text{val}, c)\) where \(\text{val}\) is the Python value being typed and \(c\) is a context object.

@type_callable(func)
Register the decorated function as typing the callable \(\text{func}\). \(\text{func}\) can be either an actual Python callable or a string denoting a operation internally known to Numba (for example 'getitem'). The decorated function is called with a single context argument and must return a typer function. The typer function should have the same signature as the function being typed, and it is called with the Numba types of the function arguments; it should return either the Numba type of the function's return value, or None if inference failed.

as_numba_type.register(py_type, numba_type)
Register that the Python type \(\text{py\_type}\) corresponds with the Numba type \(\text{numba\_type}\). This can be used to register a new type or overwrite the existing default (e.g. to treat float as numba.float32 instead of numba.float64).

@as_numba_type.register
Register the decorated function as a type inference function used by as_numba_type when trying to infer the Numba type of a Python type. The decorated function is called with a single \(\text{py\_type}\) argument and returns either a corresponding Numba type, or None if it cannot infer that \(\text{py\_type}\).

5.2.2 Lowering

The following decorators all take a type specification of some kind. A type specification is usually a type class (such as types.Float) or a specific type instance (such as types.float64). Some values have a special meaning:

- types.Any matches any type; this allows doing your own dispatching inside the implementation
- types.VarArg(<some type>) matches any number of arguments of the given type; it can only appear as the last type specification when describing a function’s arguments.

A context argument in the following APIs is a target context providing various utility methods for code generation (such as creating a constant, converting from a type to another, looking up the implementation of a specific function, etc.). A builder argument is a llvmlite.ir.IRBuilder instance for the LLVM code being generated.

A signature is an object specifying the concrete type of an operation. The args attribute of the signature is a tuple of the argument types. The return_type attribute of the signature is the type that the operation should return.

Note: Numba always reasons on Numba types, but the values being passed around during lowering are LLVM values: they don’t hold the required type information, which is why Numba types are passed explicitly too.

LLVM has its own, very low-level type system: you can access the LLVM type of a value by looking up its .type attribute.
Native operations

@lower_builtin(func, typespec, ...)
Register the decorated function as implementing the callable func for the arguments described by the given Numba typespec. As with type_callable(), func can be either an actual Python callable or a string denoting a operation internally known to Numba (for example 'getitem').

The decorated function is called with four arguments (context, builder, sig, args). sig is the concrete signature the callable is being invoked with. args is a tuple of the values of the arguments the callable is being invoked with; each value in args corresponds to a type in sig.args. The function must return a value compatible with the type sig.return_type.

@lower_getattr(typespec, name)
Register the decorated function as implementing the attribute name of the given typespec. The decorated function is called with four arguments (context, builder, typ, value). typ is the concrete type the attribute is being looked up on. value is the value the attribute is being looked up on.

@lower_getattr_generic(typespec)
Register the decorated function as a fallback for attribute lookup on a given typespec. Any attribute that does not have a corresponding lower_getattr() declaration will go through lower_getattr_generic(). The decorated function is called with five arguments (context, builder, typ, value, name). typ and value are as in lower_getattr(). name is the name of the attribute being looked up.

@lower_cast(fromspec, tospec)
Register the decorated function as converting from types described by fromspec to types described by tospec. The decorated function is called with five arguments (context, builder, fromty, toty, value). fromty and toty are the concrete types being converted from and to, respectively. value is the value being converted. The function must return a value compatible with the type toty.

Constants

@lower_constant(typespec)
Register the decorated function as implementing the creation of constants for the Numba typespec. The decorated function is called with four arguments (context, builder, ty, pyval). ty is the concrete type to create a constant for. pyval is the Python value to convert into a LLVM constant. The function must return a value compatible with the type ty.

Boxing and unboxing

In these functions, c is a convenience object with several attributes:

- its context attribute is a target context as above
- its builder attribute is a llvmlite.ir.IRBuilder as above
- its pyapi attribute is an object giving access to a subset of the Python interpreter's C API

An object, as opposed to a native value, is a PyObject * pointer. Such pointers can be produced or processed by the methods in the pyapi object.

@box(typespec)
Register the decorated function as boxing values matching the typespec. The decorated function is called with three arguments (typ, val, c). typ is the concrete type being boxed. val is the value being boxed. The function should return a Python object, or NULL to signal an error.

@unbox(typespec)
Register the decorated function as unboxing values matching the typespec. The decorated function is called with three arguments (typ, obj, c). typ is the concrete type being unboxed. obj is the Python object (a PyObject
* pointer, in C terms) being unboxed. The function should return a `NativeValue` object giving the unboxing result value and an optional error bit.

## 5.3 Example: an interval type

We will extend the Numba frontend to support a class that it does not currently support so as to allow:

- Passing an instance of the class to a Numba function
- Accessing attributes of the class in a Numba function
- Constructing and returning a new instance of the class from a Numba function

(all the above in `nopython mode`)

We will mix APIs from the *high-level extension API* and the *low-level extension API*, depending on what is available for a given task.

The starting point for our example is the following pure Python class:

```python
class Interval(object):
    
    """
    A half-open interval on the real number line.
    """

    def __init__(self, lo, hi):
        self.lo = lo
        self.hi = hi

    def __repr__(self):
        return 'Interval(%f, %f)' % (self.lo, self.hi)

    @property
    def width(self):
        return self.hi - self.lo

```

### 5.3.1 Extending the typing layer

#### Creating a new Numba type

As the `Interval` class is not known to Numba, we must create a new Numba type to represent instances of it. Numba does not deal with Python types directly: it has its own type system that allows a different level of granularity as well as various meta-information not available with regular Python types.

We first create a type class `IntervalType` and, since we don’t need the type to be parametric, we instantiate a single type instance `interval_type`:

```python
from numba import types

class IntervalType(types.Type):
    def __init__(self):
        super(IntervalType, self).__init__(name='Interval')

interval_type = IntervalType()
```
Type inference for Python values

In itself, creating a Numba type doesn’t do anything. We must teach Numba how to infer some Python values as instances of that type. In this example, it is trivial: any instance of the Interval class should be treated as belonging to the type interval_type:

```python
from numba.extending import typeof_impl
@typeof_impl.register(Interval)
def typeof_index(val, c):
    return interval_type
```

Function arguments and global values will thusly be recognized as belonging to interval_type whenever they are instances of Interval.

Type inference for Python annotations

While typeof is used to infer the Numba type of Python objects, as_numba_type is used to infer the Numba type of Python types. For simple cases, we can simply register that the Python type Interval corresponds with the Numba type interval_type:

```python
from numba.extending import as_numba_type
as_numba_type.register(Interval, interval_type)
```

Note that as_numba_type is only used to infer types from type annotations at compile time. The typeof registry above is used to infer the type of objects at runtime.

Type inference for operations

We want to be able to construct interval objects from Numba functions, so we must teach Numba to recognize the two-argument Interval(lo, hi) constructor. The arguments should be floating-point numbers:

```python
from numba.extending import type_callable
@type_callable(Interval)
def type_interval(context):
    def typer(lo, hi):
        if isinstance(lo, types.Float) and isinstance(hi, types.Float):
            return interval_type
    return typer
```

The type callable() decorator specifies that the decorated function should be invoked when running type inference for the given callable object (here the Interval class itself). The decorated function must simply return a typer function that will be called with the argument types. The reason for this seemingly convoluted setup is for the typer function to have exactly the same signature as the typed callable. This allows handling keyword arguments correctly.

The context argument received by the decorated function is useful in more sophisticated cases where computing the callable’s return type requires resolving other types.

5.3. Example: an interval type 289
5.3.2 Extending the lowering layer

We have finished teaching Numba about our type inference additions. We must now teach Numba how to actually generate code and data for the new operations.

Defining the data model for native intervals

As a general rule, *nopython mode* does not work on Python objects as they are generated by the CPython interpreter. The representations used by the interpreter are far too inefficient for fast native code. Each type supported in *nopython mode* therefore has to define a tailored native representation, also called a data model.

A common case of data model is an immutable struct-like data model, that is akin to a C struct. Our interval datatype conveniently falls in that category, and here is a possible data model for it:

```python
from numba.extending import models, register_model

@register_model(IntervalType)
class IntervalModel(models.StructModel):
    def __init__(self, dmm, fe_type):
        members = [
            ('lo', types.float64),
            ('hi', types.float64),
        ]
        models.StructModel.__init__(self, dmm, fe_type, members)
```

This instructs Numba that values of type `IntervalType` (or any instance thereof) are represented as a structure of two fields `lo` and `hi`, each of them a double-precision floating-point number (`types.float64`).

**Note:** Mutable types need more sophisticated data models to be able to persist their values after modification. They typically cannot be stored and passed on the stack or in registers like immutable types do.

Exposing data model attributes

We want the data model attributes `lo` and `hi` to be exposed under the same names for use in Numba functions. Numba provides a convenience function to do exactly that:

```python
from numba.extending import make_attribute_wrapper

make_attribute_wrapper(IntervalType, 'lo', 'lo')
mak_attribute_wrapper(IntervalType, 'hi', 'hi')
```

This will expose the attributes in read-only mode. As mentioned above, writable attributes don't fit in this model.
Exposing a property

As the width property is computed rather than stored in the structure, we cannot simply expose it like we did for lo and hi. We have to re-implement it explicitly:

```python
from numba.extending import overload_attribute

@overload_attribute(IntervalType, "width")
def get_width(interval):
    def getter(interval):
        return interval.hi - interval.lo
    return getter
```

You might ask why we didn’t need to expose a type inference hook for this attribute? The answer is that @overload_attribute is part of the high-level API: it combines type inference and code generation in a single API.

Implementing the constructor

Now we want to implement the two-argument Interval constructor:

```python
from numba.extending import lower_builtin
from numba.core import cgutils

@lower_builtin(Interval, types.Float, types.Float)
def impl_interval(context, builder, sig, args):
    typ = sig.return_type
    lo, hi = args
    interval = cgutils.create_struct_proxy(typ)(context, builder)
    interval.lo = lo
    interval.hi = hi
    return interval._getvalue()
```

There is a bit more going on here. @lower_builtin decorates the implementation of the given callable or operation (here the Interval constructor) for some specific argument types. This allows defining type-specific implementations of a given operation, which is important for heavily overloaded functions such as `len()`.

types.Float is the class of all floating-point types (types.float64 is an instance of types.Float). It is generally more future-proof to match argument types on their class rather than on specific instances (however, when returning a type – chiefly during the type inference phase –, you must usually return a type instance).

cgutils.create_struct_proxy() and interval._getvalue() are a bit of boilerplate due to how Numba passes values around. Values are passed as instances of `llvmlite.ir.Value`, which can be too limited: LLVM structure values especially are quite low-level. A struct proxy is a temporary wrapper around a LLVM structure value allowing to easily get or set members of the structure. The _getvalue() call simply gets the LLVM value out of the wrapper.
Boxing and unboxing

If you try to use an `Interval` instance at this point, you'll certainly get the error "cannot convert Interval to native value". This is because Numba doesn't yet know how to make a native interval value from a Python `Interval` instance. Let's teach it how to do it:

```python
from numba.extending import unbox, NativeValue

@unbox(IntervalType)
def unbox_interval(typ, obj, c):
    ""
    Convert a Interval object to a native interval structure.
    ""
    lo_obj = c.pyapi.object_getattr_string(obj, "lo")
    hi_obj = c.pyapi.object_getattr_string(obj, "hi")
    interval = cgutils.create_struct_proxy(typ)(c.context, c.builder)
    interval.lo = c.pyapi.float_as_double(lo_obj)
    interval.hi = c.pyapi.float_as_double(hi_obj)
    c.pyapi.decref(lo_obj)
    c.pyapi.decref(hi_obj)
    is_error = cgutils.is_not_null(c.builder, c.pyapi.err_occurred())
    return NativeValue(interval._getvalue(), is_error=is_error)
```

Unbox is the other name for "convert a Python object to a native value" (it fits the idea of a Python object as a sophisticated box containing a simple native value). The function returns a `NativeValue` object which gives its caller access to the computed native value, the error bit and possibly other information.

The snippet above makes abundant use of the `c.pyapi` object, which gives access to a subset of the Python interpreter’s C API. Note the use of `c.pyapi.err_occurred()` to detect any errors that may have happened when unboxing the object (try passing `Interval('a', 'b')` for example).

We also want to do the reverse operation, called boxing, so as to return interval values from Numba functions:

```python
from numba.extending import box

@box(IntervalType)
def box_interval(typ, val, c):
    ""
    Convert a native interval structure to an Interval object.
    ""
    interval = cgutils.create_struct_proxy(typ)(c.context, c.builder, value=val)
    lo_obj = c.pyapi.float_from_double(interval.lo)
    hi_obj = c.pyapi.float_from_double(interval.hi)
    class_obj = c.pyapi.unserialize(c.pyapi.serialize_object(Interval))
    res = c.pyapi.call_function_objargs(class_obj, (lo_obj, hi_obj))
    c.pyapi.decref(lo_obj)
    c.pyapi.decref(hi_obj)
    c.pyapi.decref(class_obj)
    return res
```
5.3.3 Using it

*nopython mode* functions are now able to make use of Interval objects and the various operations you have defined on them. You can try for example the following functions:

```python
from numba import jit

@jit(nopython=True)
def inside_interval(interval, x):
    return interval.lo <= x < interval.hi

@jit(nopython=True)
def interval_width(interval):
    return interval.width

@jit(nopython=True)
def sum_intervals(i, j):
    return Interval(i.lo + j.lo, i.hi + j.hi)
```

5.3.4 Conclusion

We have shown how to do the following tasks:

- Define a new Numba type class by subclassing the `Type` class
- Define a singleton Numba type instance for a non-parametric type
- Teach Numba how to infer the Numba type of Python values of a certain class, using `typeof_impl.register`
- Teach Numba how to infer the Numba type of the Python type itself, using `as_numba_type.register`
- Define the data model for a Numba type using `StructModel` and `register_model`
- Implementing a boxing function for a Numba type using the `@box` decorator
- Implementing an unboxing function for a Numba type using the `@unbox` decorator and the `NativeValue` class
- Type and implement a callable using the `@type_callable` and `@lower_builtin` decorators
- Expose a read-only structure attribute using the `make_attribute_wrapper` convenience function
- Implement a read-only property using the `@overload_attribute` decorator

5.4 A guide to using @overload

As mentioned in the *high-level extension API*, you can use the `@overload` decorator to create a Numba implementation of a function that can be used in *nopython mode* functions. A common use case is to re-implement NumPy functions so that they can be called in `@jit` decorated code. This section discusses how and when to use the `@overload` decorator and what contributing such a function to the Numba code base might entail. This should help you get started when needing to use the `@overload` decorator or when attempting to contribute new functions to Numba itself.

The `@overload` decorator and its variants are useful when you have a third-party library that you do not control and you wish to provide Numba compatible implementations for specific functions from that library.
5.4.1 Concrete Example

Let’s assume that you are working on a minimization algorithm that makes use of `scipy.linalg.norm` to find different vector norms and the `frobenius norm` for matrices. You know that only integer and real numbers will be involved. (While this may sound like an artificial example, especially because a Numba implementation of `numpy.linalg.norm` exists, it is largely pedagogical and serves to illustrate how and when to use `@overload`).

The skeleton might look something like this:

```python
def algorithm():
    # setup
    v = ...
    while True:
        # take a step
        d = scipy.linalg.norm(v)
        if d < tolerance:
            break
```

Now, let’s further assume, that you have heard of Numba and you now wish to use it to accelerate your function. However, after adding the `jit(nopython=True)` decorator, Numba complains that `scipy.linalg.norm` isn’t supported.

From looking at the documentation, you realize that a norm is probably fairly easy to implement using NumPy. A good starting point is the following template.

```python
# Declare that function `myfunc` is going to be overloaded (have a
# substitutable Numba implementation)
@overload(myfunc)
# Define the overload function with formal arguments
# these arguments must be matched in the inner function implementation
def jit_myfunc(arg0, arg1, arg2, ...):
    # This scope is for typing, access is available to the *type* of all
    # arguments. This information can be used to change the behaviour of the
    # implementing function and check that the types are actually supported
    # by the implementation.
    print(arg0)  # this will show the Numba type of arg0

    # This is the definition of the function that implements the `myfunc` work.
    # It does whatever algorithm is needed to implement myfunc.
def myfunc_impl(arg0, arg1, arg2, ...):  # match arguments to jit_myfunc
    # < Implementation goes here >
    return  # whatever needs to be returned by the algorithm

    # return the implementation
    return myfunc_impl
```

After some deliberation and tinkering, you end up with the following code:

```python
import numpy as np
from numba import njit, types
from numba.extending import overload, register_jitable
from numba.core.errors import TypingError

import scipy.linalg
```

(continues on next page)
@register_jitable
def _oneD_norm_2(a):
    # re-usable implementation of the 2-norm
    val = np.abs(a)
    return np.sqrt(np.sum(val * val))

@overload(scipy.linalg.norm)
def jit_norm(a, ord=None):
    if isinstance(ord, types.Optional):
        ord = ord.type
    # Reject non integer, floating-point or None types for ord
    if not isinstance(ord, (types.Integer, types.Float, types.NoneType)):
        raise TypingError("'ord' must be either integer or floating-point")
    # Reject non-narray types
    if not isinstance(a, types.Array):
        raise TypingError("Only accepts NumPy ndarray")
    # Reject ndarrays with non integer or floating-point dtype
    if not isinstance(a.dtype, (types.Integer, types.Float)):
        raise TypingError("Only integer and floating point types accepted")
    # Reject ndarrays with unsupported dimensionality
    if not (0 <= a.ndim <= 2):
        raise TypingError("3D and beyond are not allowed")
    # Implementation for scalars/0d-arrays
    elif a.ndim == 0:
        return a.item()
    # Implementation for vectors
    elif a.ndim == 1:
        def _oneD_norm_x(a, ord=None):
            if ord == 2 or ord is None:
                return _oneD_norm_2(a)
            elif ord == np.inf:
                return np.max(np.abs(a))
            elif ord == -np.inf:
                return np.min(np.abs(a))
            elif ord == 0:
                return np.sum(a != 0)
            elif ord == 1:
                return np.sum(np.abs(a))
            else:
                return np.sum(np.abs(a) ** ord)**(1. / ord)
        return _oneD_norm_x
    # Implementation for matrices
    elif a.ndim == 2:
        def _two_D_norm_2(a, ord=None):
            return _oneD_norm_2(a.ravel())
        return _two_D_norm_2

if __name__ == "__main__":
    @njit
def use(a, ord=None):
    # simple test function to check that the overload works
    return scipy.linalg.norm(a, ord)

# spot check for vectors
a = np.arange(10)
print(use(a))
print(scipy.linalg.norm(a))

# spot check for matrices
b = np.arange(9).reshape((3, 3))
print(use(b))
print(scipy.linalg.norm(b))

As you can see, the implementation only supports what you need right now:

- Only supports integer and floating-point types
- All vector norms
- Only the Frobenius norm for matrices
- Code sharing between vector and matrix implementations using @register_jitable.
- Norms are implemented using NumPy syntax. (This is possible because Numba is very aware of NumPy and many functions are supported.)

So what actually happens here? The overload decorator registers a suitable implementation for scipy.linalg.norm in case a call to this is encountered in code that is being JIT-compiled, for example when you decorate your algorithm function with @jit(nopython=True). In that case, the function jit_norm will be called with the currently encountered types and will then return either _oneD_norm_x in the vector case and _two_D_norm_2.

You can download the example code here: mynorm.py

5.4.2 Implementing @overload for NumPy functions

Numba supports NumPy through the provision of @jit compatible re-implementations of NumPy functions. In such cases @overload is a very convenient option for writing such implementations, however there are a few additional things to watch out for.

- The Numba implementation should match the NumPy implementation as closely as feasible with respect to accepted types, arguments, raised exceptions and algorithmic complexity (Big-O / Landau order).
- When implementing supported argument types, bear in mind that, due to duck typing, NumPy does tend to accept a multitude of argument types beyond NumPy arrays such as scalar, list, tuple, set, iterator, generator etc. You will need to account for that during type inference and subsequently as part of the tests.
- A NumPy function may return a scalar, array or a data structure which matches one of its inputs, you need to be aware of type unification problems and dispatch to appropriate implementations. For example, np.corrcoef may return an array or a scalar depending on its inputs.
- If you are implementing a new function, you should always update the documentation. The sources can be found in docs/source/reference/numpysupported.rst. Be sure to mention any limitations that your implementation has, e.g. no support for the axis keyword.
- When writing tests for the functionality itself, it’s useful to include handling of non-finite values, arrays with different shapes and layouts, complex inputs, scalar inputs, inputs with types for which support is not documented
(e.g. a function which the NumPy docs say requires a float or int input might also ‘work’ if given a bool or complex input).

- When writing tests for exceptions, for example if adding tests to `numba/tests/test_np_functions.py`, you may encounter the following error message:

```
FAIL: test_foo (numba.tests.test_np_functions.TestNPFunctions)
Traceback (most recent call last):
  File "<path>/numba/numba/tests/support.py", line 645, in tearDown
    self.memory_leak_teardown()
  File "<path>/numba/numba/tests/support.py", line 619, in memory_leak_teardown
    self.assert_no_memory_leak()
  File "<path>/numba/numba/tests/support.py", line 628, in assert_no_memory_leak
    self.assertEqual(total_alloc, total_free)
AssertionError: 36 != 35
```

This occurs because raising exceptions from jitted code leads to reference leaks. Ideally, you will place all exception testing in a separate test method and then add a call in each test to `self.disable_leak_check()` to disable the leak-check (inherit from `numba.tests.support.TestCase` to make that available).

- For many of the functions that are available in NumPy, there are corresponding methods defined on the NumPy `ndarray` type. For example, the function `repeat` is available as a NumPy module level function and a member function on the `ndarray` class.

```python
import numpy as np
da = np.arange(10)
# function
np.repeat(a, 10)
# method
da.repeat(10)
```

Once you have written the function implementation, you can easily use `@overload_method` and reuse it. Just be sure to check that NumPy doesn’t diverge in the implementations of its function/method.

As an example, the `repeat` function/method:

```python
@extending.overload_method(types.Array, 'repeat')
def array_repeat(a, repeats):
    def array_repeat_impl(a, repeat):
        # np.repeat has already been overloaded
        return np.repeat(a, repeat)
    return array_repeat_impl
```

- If you need to create ancillary functions, for example to re-use a small utility function or to split your implementation across functions for the sake of readability, you can make use of the `@register_jitable` decorator. This will make those functions available from within your `@jit` and `@overload` decorated functions.

- The Numba continuous integration (CI) set up tests a wide variety of NumPy versions, you’ll sometimes be alerted to a change in behaviour from some previous NumPy version. If you can find supporting evidence in the NumPy change log / repository, then you’ll need to decide whether to create branches and attempt to replicate the logic across versions, or use a version gate (with associated wording in the documentation) to advertise that Numba replicates NumPy from some particular version onwards.

- You can look at the Numba source code for inspiration, many of the overloaded NumPy functions and methods

### 5.4. A guide to using `@overload`
are in numba/targets/arrayobj.py. Below, you will find a list of implementations to look at that are well implemented in terms of accepted types and test coverage.

- np.repeat

## 5.5 Registering Extensions with Entry Points

Often, third party packages will have a user-facing API as well as define extensions to the Numba compiler. In those situations, the new types and overloads can registered with Numba when the package is imported by the user. However, there are situations where a Numba extension would not normally be imported directly by the user, but must still be registered with the Numba compiler. An example of this is the numba-scipy package, which adds support for some SciPy functions to Numba. The end user does not need to import numba_scipy to enable compiler support for SciPy, the extension only needs to be installed in the Python environment.

Numba discovers extensions using the entry points feature of setuptools. This allows a Python package to register an initializer function that will be called before numba compiles for the first time. The delay ensures that the cost of importing extensions is deferred until it is necessary.

### 5.5.1 Adding Support for the “Init” Entry Point

A package can register an initialization function with Numba by adding the entry_points argument to the setup() function call in setup.py:

```python
setup(
    ..., 
    entry_points={
        "numba_extensions": [
            "init = numba_scipy:_init_extension",
        ],
        ...
    }
)
```

Numba currently only looks for the init entry point in the numba_extensions group. The entry point should be a function (any name, as long as it matches what is listed in setup.py) that takes no arguments, and the return value is ignored. This function should register types, overloads, or call other Numba extension APIs. The order of initialization of extensions is undefined.

### 5.5.2 Testing your Entry Point

Numba loads all entry points when the first function is compiled. To test your entry point, it is not sufficient to just import numba: you have to define and run a small function, like this:

```python
import numba; numba.njit(lambda x: x + 1)(123)
```

It is not necessary to import your module: entry points are identified by the entry_points.txt file in your library’s *.egg-info directory.

The setup.py build command does not create eggs, but setup.py sdist (for testing in a local directory) and setup.py install do. All entry points registered in eggs that are on the Python path are loaded. Be sure to check for stale entry_points.txt when debugging.
6.1 Contributing to Numba

We welcome people who want to make contributions to Numba, big or small! Even simple documentation improvements are encouraged. If you have questions, don't hesitate to ask them (see below).

6.1.1 Communication

Real-time Chat

Numba uses Gitter for public real-time chat. To help improve the signal-to-noise ratio, we have two channels:

- numba/numba: General Numba discussion, questions, and debugging help.
- numba/numba-dev: Discussion of PRs, planning, release coordination, etc.

Both channels are public, but we may ask that discussions on numba-dev move to the numba channel. This is simply to ensure that numba-dev is easy for core developers to keep up with.

Note that the Github issue tracker is the best place to report bugs. Bug reports in chat are difficult to track and likely to be lost.

Forum

Numba uses Discourse as a forum for longer running threads such as design discussions and roadmap planning. There are various categories available and it can be reached at: numba.discourse.group.

Weekly Meetings

The core Numba developers have a weekly video conference to discuss roadmap, feature planning, and outstanding issues. These meetings are entirely public, details are posted on numba.discourse.group Announcements and everyone is welcome to join the discussion. Minutes will be taken and will be posted to the Numba wiki.
Bug tracker

We use the Github issue tracker to track both bug reports and feature requests. If you report an issue, please include specifics:

- what you are trying to do;
- which operating system you have and which version of Numba you are running;
- how Numba is misbehaving, e.g. the full error traceback, or the unexpected results you are getting;
- as far as possible, a code snippet that allows full reproduction of your problem.

6.1.2 Getting set up

If you want to contribute, we recommend you fork our Github repository, then create a branch representing your work. When your work is ready, you should submit it as a pull request from the Github interface.

If you want, you can submit a pull request even when you haven’t finished working. This can be useful to gather feedback, or to stress your changes against the continuous integration platform. In this case, please prepend [WIP] to your pull request’s title.

Build environment

Numba has a number of dependencies (mostly NumPy and llvmlite) with non-trivial build instructions. Unless you want to build those dependencies yourself, we recommend you use conda to create a dedicated development environment and install precompiled versions of those dependencies there.

First add the Anaconda Cloud numba channel so as to get development builds of the llvmlite library:

$ conda config --add channels numba

Then create an environment with the right dependencies:

$ conda create -n numbaenv python=3.8 llvmlite numpy scipy jinja2 cffi

Note: This installs an environment based on Python 3.8, but you can of course choose another version supported by Numba. To test additional features, you may also need to install tbb and/or llvm-openmp.

To activate the environment for the current shell session:

$ conda activate numbaenv

Note: These instructions are for a standard Linux shell. You may need to adapt them for other platforms.

Once the environment is activated, you have a dedicated Python with the required dependencies:

$ python
Python 3.8.5 (default, Sep 4 2020, 07:30:14)
[GCC 7.3.0] :: Anaconda, Inc. on linux
Type "help", "copyright", "credits" or "license" for more information.

(continues on next page)
>>> import llvmlite
>>> llvmlite.__version__
'0.35.0'

Building Numba

For a convenient development workflow, we recommend you build Numba inside its source checkout:

```bash
$ git clone git://github.com/numba/numba.git
$ cd numba
$ python setup.py build_ext --inplace
```

This assumes you have a working C compiler and runtime on your development system. You will have to run this command again whenever you modify C files inside the Numba source tree.

The `build_ext` command in Numba’s setup also accepts the following arguments:

- `--noopt`: This disables optimization when compiling Numba’s CPython extensions, which makes debugging them much easier. Recommended in conjunction with the standard `build_ext` option `--debug`.
- `--werror`: Compiles Numba’s CPython extensions with the `-Werror` flag.
- `--wall`: Compiles Numba’s CPython extensions with the `-Wall` flag.

Note that Numba’s CI and the conda recipe for Linux build with the `--werror` and `--wall` flags, so any contributions that change the CPython extensions should be tested with these flags too.

Running tests

Numba is validated using a test suite comprised of various kind of tests (unit tests, functional tests). The test suite is written using the standard `unittest` framework.

The tests can be executed via `python -m numba.runtests`. If you are running Numba from a source checkout, you can type `./runtests.py` as a shortcut. Various options are supported to influence test running and reporting. Pass `--h` or `--help` to get a glimpse at those options. Examples:

- to list all available tests:
  ```bash
  $ python -m numba.runtests -l
  ```

- to list tests from a specific (sub-)suite:
  ```bash
  $ python -m numba.runtests -l numba.tests.test_usecases
  ```

- to run those tests:
  ```bash
  $ python -m numba.runtests numba.tests.test_usecases
  ```

- to run all tests in parallel, using multiple sub-processes:
  ```bash
  $ python -m numba.runtests -m
  ```

For a detailed list of all options:

6.1. Contributing to Numba
The numba test suite can take a long time to complete. When you want to avoid the long wait, it is useful to focus on the failing tests first with the following test runner options:

- The `--failed-first` option is added to capture the list of failed tests and to re-execute them first:

  ```shell
  $ python -m numba.runtests --failed-first -m -v -b
  ```

- The `--last-failed` option is used with `--failed-first` to execute the previously failed tests only:

  ```shell
  $ python -m numba.runtests --last-failed -m -v -b
  ```

When debugging, it is useful to turn on logging. Numba logs using the standard logging module. One can use the standard ways (i.e. `logging.basicConfig`) to configure the logging behavior. To enable logging in the test runner, there is a `--log` flag for convenience:

```shell
$ python -m numba.runtests --log
```

To enable runtime type-checking, set the environment variable `NUMBA_USE_TYPEGUARD=1` and use `runtests.py` from the source root instead. For example:

```shell
$ NUMBA_USE_TYPEGUARD=1 python runtests.py
```

### 6.1.3 Development rules

#### Code reviews

Any non-trivial change should go through a code review by one or several of the core developers. The recommended process is to submit a pull request on github.

A code review should try to assess the following criteria:

- general design and correctness
- code structure and maintainability
- coding conventions
- docstrings, comments
- test coverage

#### Coding conventions

All Python code should follow PEP 8. Our C code doesn’t have a well-defined coding style (would it be nice to follow PEP 7?). Code and documentation should generally fit within 80 columns, for maximum readability with all existing tools (such as code review UIs).

Numba uses Flake8 to ensure a consistent Python code format throughout the project. `flake8` can be installed with pip or conda and then run from the root of the Numba repository:

```bash
flake8 numba
```

Optionally, you may wish to setup pre-commit hooks to automatically run `flake8` when you make a git commit. This can be done by installing pre-commit:
pip install pre-commit

and then running:

pre-commit install

from the root of the Numba repository. Now flake8 will be run each time you commit changes. You can skip this check with git commit --no-verify.

Numba has started the process of using type hints in its code base. This will be a gradual process of extending the number of files that use type hints, as well as going from voluntary to mandatory type hints for new features. Mypy is used for automated static checking.

At the moment, only certain files are checked by mypy. The list can be found in mypy.ini. When making changes to those files, it is necessary to add the required type hints such that mypy tests will pass. Only in exceptional circumstances should type: ignore comments be used.

If you are contributing a new feature, we encourage you to use type hints, even if the file is not currently in the checklist. If you want to contribute type hints to enable a new file to be in the checklist, please add the file to the files variable in mypy.ini, and decide what level of compliance you are targeting. Level 3 is basic static checks, while levels 2 and 1 represent stricter checking. The levels are described in details in mypy.ini.

There is potential for confusion between the Numba module typing and Python built-in module typing used for type hints, as well as between Numba types—such as Dict or Literal—and typing types of the same name. To mitigate the risk of confusion we use a naming convention by which objects of the built-in typing module are imported with an pt prefix. For example, typing.Dict is imported as from typing import Dict as ptDict.

### Stability

The repository’s main branch is expected to be stable at all times. This translates into the fact that the test suite passes without errors on all supported platforms (see below). This also means that a pull request also needs to pass the test suite before it is merged in.

### Platform support

Every commit to the main branch is automatically tested on all of the platforms Numba supports. This includes ARMv8, POWER8, and NVIDIA GPUs. The build system however is internal to Anaconda, so we also use Azure to provide public continuous integration information for as many combinations as can be supported by the service. Azure CI automatically tests all pull requests on Windows, OS X and Linux, as well as a sampling of different Python and NumPy versions. If you see problems on platforms you are unfamiliar with, feel free to ask for help in your pull request. The Numba core developers can help diagnose cross-platform compatibility issues. Also see the continuous integration section on how public CI is implemented.

### Continuous integration testing

The Numba test suite causes CI systems a lot of grief:

1. It’s huge, 9000+ tests.
2. In part because of 1. and that compilers are pretty involved, the test suite takes a long time to run.
3. There’s sections of the test suite that are deliberately designed to stress systems almost to the point of failure (tests which concurrently compile and execute with threads and fork processes etc).
4. The combination of things that Numba has to test well exceeds the capacity of any public CI system, (Python versions x NumPy versions x Operating systems x Architectures x feature libraries (e.g. SVML) x threading backends (e.g. OpenMP, TBB)) and then there’s CUDA too and all its version variants.

As a result of the above, public CI is implemented as follows:

1. The combination of OS x Python x NumPy x Various Features in the testing matrix is designed to give a good indicative result for whether “this pull request is probably ok”.

2. When public CI runs it:
   1. Looks for files that contain tests that have been altered by the proposed change and runs these on the whole testing matrix.
   2. Runs a subset of the test suite on each part of the testing matrix. i.e. slice the test suite up by the number of combinations in the testing matrix and each combination runs one chunk. This is done for speed, because public CI cannot cope with the load else.

If a Pull Request (PR) changes CUDA code or will affect the CUDA target, it needs to be run on gpuCI. This can be triggered by one of the Numba maintainers commenting run gpuCI tests on the PR discussion. This runs the CUDA testsuite with various CUDA toolkit versions on Linux, to provide some initial confidence in the correctness of the changes with respect to CUDA. Following approval, the PR will also be run on Numba’s build farm to test other configurations with CUDA (including Windows, which is not tested by gpuCI).

If the PR is not CUDA-related but makes changes to something that the core developers consider risky, then it will also be run on the Numbafarm just to make sure. The Numba project’s private build and test farm will actually exercise all the applicable tests on all the combinations noted above on real hardware!

**Type annotation and runtime type checking**

Numba is slowly gaining type annotations. To facilitate the review of pull requests that are incrementally adding type annotations, the test suite uses typeguard to perform runtime type checking. This helps verify the validity of type annotations.

To enable runtime type checking in the test suite, users can use runtests.py in the source root as the test runner and set environment variable NUMBA_USE_TYPEGUARD=1. For example:

```
$ NUMBA_USE_TYPEGUARD=1 python runtests.py numba.tests
```

**Things that help with pull requests**

Even with the mitigating design above public CI can get overloaded which causes a backlog of builds. It’s therefore really helpful when opening pull requests if you can limit the frequency of pushing changes. Ideally, please squash commits to reduce the number of patches and/or push as infrequently as possible. Also, once a pull request review has started, please don’t rebase/force push/squash or do anything that rewrites history of the reviewed code as GitHub cannot track this and it makes it very hard for reviewers to see what has changed.

The core developers thank everyone for their cooperation with the above!
Why is my pull request/issue seemingly being ignored?

Numba is an open source project and like many similar projects it has limited resources. As a result, it is unfortunately necessary for the core developers to associate a priority with issues/pull requests (PR). A great way to move your issue/PR up the priority queue is to help out somewhere else in the project so as to free up core developer time. Examples of ways to help:

- Perform an initial review on a PR. This often doesn’t require compiler engineering knowledge and just involves checking that the proposed patch is of good quality, fixes the problem/implements the feature, is well tested and documented.
- Debug an issue, there are numerous issues which “need triage” which essentially involves debugging the reported problem. Even if you cannot get right to the bottom of a problem, leaving notes about what was discovered for someone else is also helpful.
- Answer questions/provide help for users on discourse and/or gitter.im.

The core developers thank everyone for their understanding with the above!

6.1.4 Documentation

The Numba documentation is split over two repositories:

- This documentation is in the docs directory inside the Numba repository.
- The Numba homepage has its sources in a separate repository at https://github.com/numba/numba-webpage

Main documentation

This documentation is under the docs directory of the Numba repository. It is built with Sphinx and numpydoc, which are available using conda or pip; i.e. conda install sphinx numpydoc.

To build the documentation, you need the bootstrap theme:

```
$ pip install sphinx_bootstrap_theme
```

You can edit the source files under docs/source/, after which you can build and check the documentation:

```
$ make html
$ open _build/html/index.html
```

Core developers can upload this documentation to the Numba website at https://numba.pydata.org by using the gh-pages.py script under docs:

```
$ python gh-pages.py version # version can be 'dev' or '0.16' etc
```

then verify the repository under the gh-pages directory and use git push.
Web site homepage

The Numba homepage on https://numba.pydata.org can be fetched from here: https://github.com/numba/numba-webpage

After pushing documentation to a new version, core developers will want to update the website. Some notable files:

- index.rst # Update main page
- _templates/sidebar_versions.html # Update sidebar links
- doc.rst # Update after adding a new version for numba docs
- download.rst # Update after uploading new numba version to pypi

After updating run:

```bash
$ make html
```

and check out _build/html/index.html. To push updates to the Web site:

```bash
$ python _scripts/gh-pages.py
```

then verify the repository under the gh-pages directory. Make sure the CNAME file is present and contains a single line for numba.pydata.org. Finally, use git push to update the website.

### 6.2 Numba Release Process

The goal of the Numba release process – from a high level perspective – is to publish source and binary artifacts that correspond to a given version number. This usually involves a sequence of individual tasks that must be performed in the correct order and with diligence. Numba and llvmlite are commonly released in lockstep since there is usually a one-to-one mapping between a Numba version and a corresponding llvmlite version.

This section contains various notes and templates that can be used to create a Numba release checklist on the Numba Github issue tracker. This is an aid for the maintainers during the release process and helps to ensure that all tasks are completed in the correct order and that no tasks are accidentally omitted.

If new or additional items do appear during release, please do remember to add them to the checklist templates. Also note that the release process itself is always a work in progress. This means that some of the information here may be outdated. If you notice this please do remember to submit a pull-request to update this document.

All release checklists are available as Gitub issue templates. To create a new release checklist simply open a new issue and select the correct template.

#### 6.2.1 Primary Release Candidate Checklist

This is for the first/primary release candidate for minor release i.e. the first release of every series. It is special, because during this release, the release branch will have to be created. Release candidate indexing begins at 1.

```markdown
# Numba X.Y.Z

* [ ] Merge to main.
  - [ ] "remaining Pull-Requests from milestone".
* [ ] Merge change log changes.
  - [ ] "PR with changelog entries".
* [ ] Create X.Y release branch.
```

(continues on next page)
### Post Release:

* [ ] Tag X.Y+1.0dev0 to start new development cycle on `main`.
* [ ] Update llvmmlite dependency spec to match next version via PR to `main`.
* [ ] Update release checklist template with any additional bullet points that may have arisen during the release.
* [ ] Close milestone (and then close this release issue).

### Post release

* [ ] Update release checklist template.
* [ ] Ping Anaconda Distro team to trigger a build for `defaults` (FINAL ONLY).
* [ ] Create a release on Github at https://github.com/numba/numba/releases (FINAL ONLY).
* [ ] Close milestone (and then close this release issue).
Open a subsequent release checklist.

6.3 A Map of the Numba Repository

The Numba repository is quite large, and due to age has functionality spread around many locations. To help orient developers, this document will try to summarize where different categories of functionality can be found.

6.3.1 Support Files

Build and Packaging

- `setup.py` - Standard Python distutils/setuptools script
- `MANIFEST.in` - Distutils packaging instructions
- `requirements.txt` - Pip package requirements, not used by conda
- `versioneer.py` - Handles automatic setting of version in installed package from git tags
- `.flake8` - Preferences for code formatting. Files should be fixed and removed from the exception list as time allows.
- `.pre-commit-config.yaml` - Configuration file for pre-commit hooks.
- `.readthedocs.yml` - Configuration file for Read the Docs.
- `buildscripts/condarecipe.local` - Conda build recipe
- `buildscripts/condarecipe_clone_icc_rt` - Recipe to build a standalone icc_rt package.

Continuous Integration

- `azure-pipelines.yml` - Azure Pipelines CI config (active: Win/Mac/Linux)
- `buildscripts/azure/` - Azure Pipeline configuration for specific platforms
- `buildscripts/appveyor/` - Appveyor build scripts
- `buildscripts/incremental/` - Generic scripts for building Numba on various CI systems
- `codecov.yml` - Codecov.io coverage reporting

Documentation

- `LICENSE` - License for Numba
- `LICENSES.third-party` - License for third party code vendored into Numba
- `README.rst` - README for repo, also uploaded to PyPI
- `CONTRIBUTING.md` - Documentation on how to contribute to project (out of date, should be updated to point to Sphinx docs)
- `CHANGE_LOG` - History of Numba releases, also directly embedded into Sphinx documentation
- `docs/` - Documentation source
- `docs/_templates/` - Directory for templates (to override defaults with Sphinx theme)
Numba ships with both the source code and tests in one package.

- numba/ - all of the source code and tests

**Public API**

These define aspects of the public Numba interface.

- numba/core/decorators.py - User-facing decorators for compiling regular functions on the CPU
- numba/core/extending.py - Public decorators for extending Numba (overload, intrinsic, etc) - numba/experimental/structref.py - Public API for defining a mutable struct
- numba/core/ccallback.py - @cfunc decorator for compiling functions to a fixed C signature. Used to make callbacks.
- numba/np/ufunc/decorators.py - ufunc/gufunc compilation decorators
- numba/core/config.py - Numba global config options and environment variable handling
- numba/core/annotations - Gathering and printing type annotations of Numba IR
- numba/core/annotations/pretty_annotate.py - Code highlighting of Numba functions and types (both ANSI terminal and HTML)
- numba/core/event.py - A simple event system for applications to listen to specific compiler events.

**Dispatching**

- numba/core/dispatcher.py - Dispatcher objects are compiled functions produced by @jit. A dispatcher has different implementations for different type signatures.
- numba/_dispatcher.cpp - C++ dispatcher implementation (for speed on common data types)
- numba/core/retarget.py - Support for dispatcher objects to switch target via a specific with-context.
Compiler Pipeline

- numba/core/compiler.py - Compiler pipelines and flags
- numba/core/errors.py - Numba exception and warning classes
- numba/core/ir.py - Numba IR data structure objects
- numba/core/bytecode.py - Bytecode parsing and function identity (??)
- numba/core/interpreter.py - Translate Python interpreter bytecode to Numba IR
- numba/core/analysis.py - Utility functions to analyze Numba IR (variable lifetime, prune branches, etc)
- numba/core/dataflow.py - Dataflow analysis for Python bytecode (used in analysis.py)
- numba/core/controlflow.py - Control flow analysis of Numba IR and Python bytecode
- numba/core/typeinfer.py - Type inference algorithm
- numba/core/transforms.py - Numba IR transformations
- numba/core/rewrites - Rewrite passes used by compiler
  - numba/core/rewrites/__init__.py - Loads all rewrite passes so they are put into the registry
  - numba/core/rewrites/registry.py - Registry object for collecting rewrite passes
  - numba/core/rewrites/ir_print.py - Write print() calls into special print nodes in the IR
  - numba/core/rewrites/static_raise.py - Converts exceptions with static arguments into a special form that can be lowered
  - numba/core/rewrites/static_getitem.py - Rewrites getitem and setitem with constant arguments to allow type inference
  - numba/core/rewrites/static_binop.py - Rewrites binary operations (specifically **) with constant arguments so faster code can be generated
  - numba/core/inline_closurecall.py - Inlines body of closure functions to call site. Support for array comprehensions, reduction inlining, and stencil inlining.
  - numba/core/postproc.py - Postprocessor for Numba IR that computes variable lifetime, inserts del operations, and handles generators
  - numba/core/lowering.py - General implementation of lowering Numba IR to LLVM
  - numba/core/environment.py - Runtime environment object
  - numba/core/withcontexts.py - General scaffolding for implementing context managers in nopython mode, and the objectmode context manager
  - numba/core/pylowering.py - Lowering of Numba IR in object mode
  - numba/core/pythonapi.py - LLVM IR code generation to interface with CPython API
  - numba/core/targetconfig.py - Utils for target configurations such as compiler flags.
Type Management

• numba/core/typeconv/ - Implementation of type casting and type signature matching in both C++ and Python
• numba/capsulethunk.h - Used by typeconv
• numba/core/types/ - definition of the Numba type hierarchy, used everywhere in compiler to select implementations
• numba/core/consts.py - Constant inference (used to make constant values available during codegen when possible)
• numba/core/datamodel - LLVM IR representations of data types in different contexts
• numba/core/datamodel/models.py - Models for most standard types
• numba/core/datamodel/registry.py - Decorator to register new data models
• numba/core/datamodel/packer.py - Pack typed values into a data structure
• numba/core/datamodel/testing.py - Data model tests (this should move??)
• numba/core/datamodel/manager.py - Map types to data models

Compiled Extensions

Numba uses a small amount of compiled C/C++ code for core functionality, like dispatching and type matching where performance matters, and it is more convenient to encapsulate direct interaction with CPython APIs.

• numba/_arraystruct.h - Struct for holding NumPy array attributes. Used in helperlib and the Numba Runtime.
• numba/_helperlib.c - C functions required by Numba compiled code at runtime. Linked into ahead-of-time compiled modules
• numba/_helpermod.c - Python extension module with pointers to functions from _helperlib.c and _npymath_exports.c
• numba/_npymath_exports.c - Export function pointer table to NumPy C math functions
• numba/_dynfuncmod.c - Python extension module exporting _dynfunc.c functionality
• numba/_dynfunc.c - C level Environment and Closure objects (keep in sync with numba/target/base.py)
• numba/mathnames.h - Macros for defining names of math functions
• numba/_pymodule.h - C macros for Python 2/3 portable naming of C API functions
• numba/mviewbuf.c - Handles Python memoryviews
• numba/_typeof.h | numba/_typeof.c - C implementation of type fingerprinting, used by dispatcher
• numba/_numba_common.h - Portable C macro for marking symbols that can be shared between object files, but not outside the library.
Misc Support

- numba/_version.py - Updated by versioneer
- numba/core/runtime - Language runtime. Currently manages reference-counted memory allocated on the heap by Numba-compiled functions
- numba/core/ir_utils.py - Utility functions for working with Numba IR data structures
- numba/core/cgutils.py - Utility functions for generating common code patterns in LLVM IR
- numba/core/utils.py - Python 2 backports of Python 3 functionality (also imports local copy of six)
- numba/core/overload_glue.py - Functions for wrapping split typing and lowering API use cases into overloads.
- numba/misc/appdirs.py - Vendored package for determining application config directories on every platform
- numba/core/compiler_lock.py - Global compiler lock because Numba’s usage of LLVM is not thread-safe
- numba/misc/special.py - Python stub implementations of special Numba functions (prange, gdb*)
- numba/core/itanium_mangler.py - Python implementation of Itanium C++ name mangling
- numba/misc/findlib.py - Helper function for locating shared libraries on all platforms
- numba/core/debuginfo.py - Helper functions to construct LLVM IR debug info
- numba/core/unsafe/refcount.py - Read reference count of object
- numba/core/unsafe/eh.py - Exception handling helpers
- numba/core/unsafe/nrt.py - Numba runtime (NRT) helpers
- numba/cpython/unsafe/tuple.py - Replace a value in a tuple slot
- numba/np/unsafe/ndarray.py - NumPy array helpers
- numba/core/unsafe/bytes.py - Copying and dereferencing data from void pointers
- numba/misc/dummyarray.py - Used by GPU backends to hold array information on the host, but not the data.
- numba/core/callwrapper.py - Handles argument unboxing and releasing the GIL when moving from Python to nopython mode
- numba/np/numpy_support.py - Helper functions for working with NumPy and translating Numba types to and from NumPy dtypes.
- numba/core/tracing.py - Decorator for tracing Python calls and emitting log messages
- numba/core/funcdesc.py - Classes for describing function metadata (used in the compiler)
- numba/core/sigutils.py - Helper functions for parsing and normalizing Numba type signatures
- numba/core/serialize.py - Support for pickling compiled functions
- numba/core/caching.py - Disk cache for compiled functions
- numba/np/npdatetime.py - Helper functions for implementing NumPy datetime64 support
- numba/misc/llvm_pass_timings.py - Helper to record timings of LLVM passes.
- numba/cloudpickle - Vendored cloudpickle subpackage
Core Python Data Types

- `numba/_hashtable.h | numba/_hashtable.c` - Adaptation of the Python 3.7 hash table implementation
- `numba/cext/dictobject.h | numba/cext/dictobject.c` - C level implementation of typed dictionary
- `numba/typed/dictobject.py` - Nopython mode wrapper for typed dictionary
- `numba/cext/listobject.h | numba/cext/listobject.c` - C level implementation of typed list
- `numba/typed/listobject.py` - Nopython mode wrapper for typed list
- `numba/typed/typedobjectutils.py` - Common utilities for typed dictionary and list
- `numba/cpython/unicode.py` - Unicode strings (Python 3.5 and later)
- `numba/typed` - Python interfaces to statically typed containers
- `numba/typed/typeddict.py` - Python interface to typed dictionary
- `numba/typed/typedlist.py` - Python interface to typed list
- `numba/experimental/jitclass` - Implementation of experimental JIT compilation of Python classes
- `numba/core/generators.py` - Support for lowering Python generators

Math

- `numba/_random.c` - Reimplementation of NumPy / CPython random number generator
- `numba/_lapack.c` - Wrappers for calling BLAS and LAPACK functions (requires SciPy)

ParallelAccelerator

Code transformation passes that extract parallelizable code from a function and convert it into multithreaded gufunc calls.

- `numba/parfors/parfor.py` - General ParallelAccelerator
- `numba/parfors/parfor_lowering.py` - gufunc lowering for ParallelAccelerator
- `numba/parfors/array_analysis.py` - Array analysis passes used in ParallelAccelerator

Stencil

Implementation of `@stencil`:

- `numba/stencils/stencil.py` - Stencil function decorator (implemented without ParallelAccelerator)
- `numba/stencils/stencilparfor.py` - ParallelAccelerator implementation of stencil
Debugging Support

- numba/misc/gdb_hook.py - Hooks to jump into GDB from nopython mode
- numba/misc/cmdlang.gdb - Commands to setup GDB for setting explicit breakpoints from Python

Type Signatures (CPU)

Some (usually older) Numba supported functionality separates the declaration of allowed type signatures from the definition of implementations. This package contains registries of type signatures that must be matched during type inference.

- numba/core/typing - Type signature module
- numba/core/typing/templates.py - Base classes for type signature templates
- numba/core/typing/cmathdecl.py - Python complex math (cmath) module
- numba/core/typing/bufproto.py - Interpreting objects supporting the buffer protocol
- numba/core/typing/mathdecl.py - Python math module
- numba/core/typing/listdecl.py - Python lists
- numba/core/typing/builtins.py - Python builtin global functions and operators
- numba/core/typing/randomdecl.py - Python and NumPy random modules
- numba/core/typing/setdecl.py - Python sets
- numba/core/typing/npydecl.py - NumPy ndarray (and operators), NumPy functions
- numba/core/typing/arraydecl.py - Python array module
- numba/core/typing/context.py - Implementation of typing context (class that collects methods used in type inference)
- numba/core/typing/collections.py - Generic container operations and namedtuples
- numba/core/typing/ctypes_utils.py - Typing ctypes-wrapped function pointers
- numba/core/typing/enumdecl.py - Enum types
- numba/core/typing/cffi_utils.py - Typing of CFFI objects
- numba/core/typing/typeof.py - Implementation of typeof operations (maps Python object to Numba type)
- numba/core/typing/asnumbatype.py - Implementation of as_numba_type operations (maps Python types to Numba type)
- numba/core/typing/npdatetime.py - Datetime dtype support for NumPy arrays

Target Implementations (CPU)

Implementations of Python / NumPy functions and some data models. These modules are responsible for generating LLVM IR during lowering. Note that some of these modules do not have counterparts in the typing package because newer Numba extension APIs (like overload) allow typing and implementation to be specified together.

- numba/core/cpu.py - Context for code gen on CPU
- numba/core/base.py - Base class for all target contexts
- numba/core/codegen.py - Driver for code generation
• numba/core/boxing.py - Boxing and unboxing for most data types
• numba/core/intrinsics.py - Utilities for converting LLVM intrinsics to other math calls
• numba/core/callconv.py - Implements different calling conventions for Numba-compiled functions
• numba/core/options.py - Container for options that control lowering
• numba/core/optional.py - Special type representing value or None
• numba/core/registry.py - Registry object for collecting implementations for a specific target
• numba/core/imputils.py - Helper functions for lowering
• numba/core/externals.py - Registers external C functions needed to link generated code
• numba/core/fastmathpass.py - Rewrite pass to add fastmath attributes to function call sites and binary operations
• numba/core/removerefcptpass.py - Rewrite pass to remove unnecessary incref/decref pairs
• numba/core/descriptors.py - empty base class for all target descriptors (is this needed?)
• numba/cpython/builtins.py - Python builtin functions and operators
• numba/cpython/cmathimpl.py - Python complex math module
• numba/cpython/enumimpl.py - Enum objects
• numba/cpython/hashing.py - Hashing algorithms
• numba/cpython/heapq.py - Python heapq module
• numba/cpython/iterators.py - Iterable data types and iterators
• numba/cpython/listobj.py - Python lists
• numba/cpython/mathimpl.py - Python math module
• numba/cpython/numbers.py - Numeric values (int, float, etc)
• numba/cpython/printimpl.py - Print function
• numba/cpython/randomimpl.py - Python and NumPy random modules
• numba/cpython/rangeobj.py - Python range objects
• numba/cpython/slicing.py - Slice objects, and index calculations used in slicing
• numba/cpython/setobj.py - Python set type
• numba/cpython/tupleobj.py - Tuples (statically typed as immutable struct)
• numba/misc/cffiimpl.py - CFFI functions
• numba/misc/quicksort.py - Quicksort implementation used with list and array objects
• numba/misc/mergesort.py - Mergesort implementation used with array objects
• numba/np/arraymath.py - Math operations on arrays (both Python and NumPy)
• numba/np/arrayobj.py - Array operations (both NumPy and buffer protocol)
• numba/np/linalg.py - NumPy linear algebra operations
• numba/np/npdatetime.py - NumPy datetime operations
• numba/np/npyfuncs.py - Kernels used in generating some NumPy ufuncs
• numba/np/npyimpl.py - Implementations of most NumPy ufuncs
• numba/np/polynomial.py - numpy.roots function
• **numba/np/ufunc_db.py** - Big table mapping types to ufunc implementations

**Ufunc Compiler and Runtime**

• **numba/np/ufunc** - ufunc compiler implementation
• **numba/np/ufunc/_internal.h | numba/np/ufunc/_internal.c** - Python extension module with helper functions that use CPython & NumPy C API
• **numba/np/ufunc/_ufunc.c** - Used by _internal.c
• **numba/np/ufunc/deviceufunc.py** - Custom ufunc dispatch for non-CPU targets
• **numba/np/ufunc/gufunc_scheduler.h | numba/np/ufunc/gufunc_scheduler.cpp** - Schedule work chunks to threads
• **numba/np/ufunc/ufunc.py** - Special ufunc that can compile new implementations at call time
• **numba/np/ufunc/ufuncbuilder.py** - Top-level orchestration of ufunc/gufunc compiler pipeline
• **numba/np/ufunc/sigparse.py** - Parser for generalized ufunc indexing signatures
• **numba/np/ufunc/parallel.py** - Codegen for parallel target
• **numba/np/ufunc/array_exprs.py** - Rewrite pass for turning array expressions in regular functions into ufuncs
• **numba/np/ufunc/wrappers.py** - Wrap scalar function kernel with loops
• **numba/np/ufunc/workqueue.h | numba/np/ufunc/workqueue.c** - Threading backend based on pthreads/Windows threads and queues
• **numba/np/ufunc/omppool.cpp** - Threading backend based on OpenMP
• **numba/np/ufunc/tbbpool.cpp** - Threading backend based on TBB

**Unit Tests (CPU)**

CPU unit tests (GPU target unit tests listed in later sections

• **runtests.py** - Convenience script that launches test runner and turns on full compiler tracebacks
• **run_coverage.py** - Runs test suite with coverage tracking enabled
• **.coveragerc** - Coverage.py configuration
• **numba/runtests.py** - Entry point to unitest runner
• **numba/testing/_runtests.py** - Implementation of custom test runner command line interface
• **numba/tests/test_*** - Test cases
• **numba/tests/*.usecases.py** - Python functions compiled by some unit tests
• **numba/tests/support.py** - Helper functions for testing and special TestCase implementation
• **numba/tests/dummy_module.py** - Module used in test_dispatcher.py
• **numba/tests/npyufunc** - ufunc / gufunc compiler tests
• **numba/testing** - Support code for testing
• **numba/testing/loader.py** - Find tests on disk
• **numba/testing/notebook.py** - Support for testing notebooks
• **numba/testing/main.py** - Numba test runner
Command Line Utilities

- bin/numba - Command line stub, delegates to main in numba_entry.py
- numba/misc/numba_entry.py - Main function for numba command line tool
- numba/pycc - Ahead of time compilation of functions to shared library extension
- numba/pycc/__init__.py - Main function for pycc command line tool
- numba/pycc/cc.py - User-facing API for tagging functions to compile ahead of time
- numba/pycc/compiler.py - Compiler pipeline for creating standalone Python extension modules
- numba/pycc/llvm_types.py - Aliases to LLVM data types used by compiler.py
- numba/pycc/pycc - Stub to call main function. Is this still used?
- numba/pycc/modulemixin.c - C file compiled into every compiled extension. Pulls in C source from Numba core that is needed to make extension standalone
- numba/pycc/platform.py - Portable interface to platform-specific compiler toolchains
- numba/pycc/decorators.py - Deprecated decorators for tagging functions to compile. Use cc.py instead.

CUDA GPU Target

Note that the CUDA target does reuse some parts of the CPU target.

- numba/cuda/ - The implementation of the CUDA (NVIDIA GPU) target and associated unit tests
- numba/cuda/decorators.py - Compiler decorators for CUDA kernels and device functions
- numba/cuda/dispatcher.py - Dispatcher for CUDA JIT functions
- numba/cuda/printimpl.py - Special implementation of device printing
- numba/cuda/libdevice.py - Registers libdevice functions
- numba/cuda/kernels/ - Custom kernels for reduction and transpose
- numba/cuda/device_init.py - Initializes the CUDA target when imported
- numba/cuda/compiler.py - Compiler pipeline for CUDA target
- numba/cuda/intrinsic_wrapper.py - CUDA device intrinsics (shuffle, ballot, etc)
- numba/cuda/initialize.py - Deferset initialization of the CUDA device and subsystem. Called only when user imports numba.cuda
- numba/cuda/simulator_init.py - Initializes the CUDA simulator subsystem (only when user requests it with env var)
- numba/cuda/random.py - Implementation of random number generator
- numba/cuda/api.py - User facing APIs imported into numba.cuda.*
- numba/cuda/stubs.py - Python placeholders for functions that only can be used in GPU device code
- numba/cuda/simulator/ - Simulate execution of CUDA kernels in Python interpreter
- numba/cuda/vectorizers.py - Subclasses of ufunc/gufunc compilers for CUDA
- numba/cuda/args.py - Management of kernel arguments, including host<->device transfers
- numba/cuda/target.py - Typing and target contexts for GPU
- numba/cuda/cudamath.py - Type signatures for math functions in CUDA Python
• numba/cuda/errors.py - Validation of kernel launch configuration
• numba/cuda/nvvmutils.py - Helper functions for generating NVVM-specific IR
• numba/cuda/testing.py - Support code for creating CUDA unit tests and capturing standard out
• numba/cuda/cudadecl.py - Type signatures of CUDA API (threadIdx, blockIdx, atomics) in Python on GPU
• numba/cuda/cudaimpl.py - Implementations of CUDA API functions on GPU
• numba/cuda/codegen.py - Code generator object for CUDA target
• numba/cuda/cudadrv/ - Wrapper around CUDA driver API
• numba/cuda/tests/ - CUDA unit tests, skipped when CUDA is not detected
• numba/cuda/tests/cudasim/ - Tests of CUDA simulator
• numba/cuda/tests/nocuda/ - Tests for NVVM functionality when CUDA not present
• numba/cuda/tests/cudapy/ - Tests of compiling Python functions for GPU
• numba/cuda/tests/cudadrv/ - Tests of Python wrapper around CUDA API

6.4 Numba architecture

6.4.1 Introduction

Numba is a compiler for Python bytecode with optional type-specialization.

Suppose you enter a function like this into the standard Python interpreter (henceforward referred to as “CPython”):

```python
def add(a, b):
    return a + b
```

The interpreter will immediately parse the function and convert it into a bytecode representation that describes how the CPython interpreter should execute the function at a low level. For the example above, it looks something like this:

```python
>>> import dis
>>> dis.dis(add)
  2 0 LOAD_FAST 0 (a)
  3 LOAD_FAST 1 (b)
  6 BINARY_ADD
  7 RETURN_VALUE
```

CPython uses a stack-based interpreter (much like an HP calculator), so the code first pushes two local variables onto the stack. The BINARY_ADD opcode pops the top two arguments off the stack and makes a Python C API function call that is equivalent to calling `a.__add__(b)` . The result is then pushed onto the top of the interpreter stack. Finally, the RETURN_VALUE opcode returns value on the top of the stack as the result of the function call.

Numba can take this bytecode and compile it to machine code that performs the same operations as the CPython interpreter, treating `a` and `b` as generic Python objects. The full semantics of Python are preserved, and the compiled function can be used with any kind of objects that have the add operator defined. When a Numba function is compiled this way, we say that it has been compiled in object mode, because the code still manipulates Python objects.

Numba code compiled in object mode is not much faster than executing the original Python function in the CPython interpreter. However, if we specialize the function to only run with certain data types, Numba can generate much shorter and more efficient code that manipulates the data natively without any calls into the Python C API. When code has been compiled for specific data types so that the function body no longer relies on the Python runtime, we say the...
function has been compiled in \textit{nopython mode}. Numeric code compiled in nopython mode can be hundreds of times faster than the original Python.

6.4.2 Compiler architecture

Like many compilers, Numba can be conceptually divided into a \textit{frontend} and a \textit{backend}.

The Numba \textit{frontend} comprises the stages which analyze the Python bytecode, translate it to \textit{Numba IR} and perform various transformations and analysis steps on the IR. One of the key steps is \textit{type inference}. The frontend must succeed in typing all variables unambiguously in order for the backend to generate code in \textit{nopython mode}, because the backend uses type information to match appropriate code generators with the values they operate on.

The Numba \textit{backend} walks the Numba IR resulting from the frontend analyses and exploits the type information deduced by the type inference phase to produce the right LLVM code for each encountered operation. After LLVM code is produced, the LLVM library is asked to optimize it and generate native processor code for the final, native function.

There are other pieces besides the compiler frontend and backend, such as the caching machinery for JIT functions. Those pieces are not considered in this document.

6.4.3 Contexts

Numba is quite flexible, allowing it to generate code for different hardware architectures like CPUs and GPUs. In order to support these different applications, Numba uses a \textit{typing context} and a \textit{target context}.

A \textit{typing context} is used in the compiler frontend to perform type inference on operations and values in the function. Similar typing contexts could be used for many architectures because for nearly all cases, typing inference is hardware-independent. However, Numba currently has a different typing context for each target.

A \textit{target context} is used to generate the specific instruction sequence required to operate on the Numba types identified during type inference. Target contexts are architecture-specific and are flexible in defining the execution model and available Python APIs. For example, Numba has a “cpu” and a “cuda” context for those two kinds of architecture, and a “parallel” context which produces multithreaded CPU code.

6.4.4 Compiler stages

The \textit{jit()} \index{Numba!jit()} decorator in Numba ultimately calls \texttt{numba.compiler.compile\_extra()} which compiles the Python function in a multi-stage process, described below.

\textbf{Stage 1: Analyze bytecode}

At the start of compilation, the function bytecode is passed to an instance of the Numba interpreter (\texttt{numba.interpreter}). The interpreter object analyzes the bytecode to find the control flow graph (\texttt{numba.controlflow}). The control flow graph (CFG) describes the ways that execution can move from one block to the next inside the function as a result of loops and branches.

The data flow analysis (\texttt{numba.dataflow}) takes the control flow graph and traces how values get pushed and popped off the Python interpreter stack for different code paths. This is important to understand the lifetimes of variables on the stack, which are needed in Stage 2.

If you set the environment variable \texttt{NUMBA\_DUMP\_CFG} to 1, Numba will dump the results of the control flow graph analysis to the screen. Our \texttt{add()} example is pretty boring, since there is only one statement block:
A function with more complex flow control will have a more interesting control flow graph. This function:

```python
def doloops(n):
    acc = 0
    for i in range(n):
        acc += 1
        if n == 10:
            break
    return acc
```

compiles to this bytecode:

```
9  0  LOAD_CONST       1  (0)
  3  STORE_FAST       1  (acc)

10  6  SETUP_LOOP     46  (to  55)
  9  LOAD_GLOBAL      0  (range)
 12  LOAD_FAST        0  (n)
 15  CALL_FUNCTION    1
 18  GET_ITER
   >> 19  FOR_ITER     32  (to  54)
 22  STORE_FAST       2  (i)

11  25  LOAD_FAST       1  (acc)
 28  LOAD_CONST       2  (1)
 31  INPLACE_ADD
 32  STORE_FAST       1  (acc)

12  35  LOAD_FAST       0  (n)
 38  LOAD_CONST       3  (10)
 41  COMPARE_OP       2  (==)
 44  POP_JUMP_IF_FALSE 19

13  47  BREAK_LOOP
 48  JUMP_ABSOLUTE    19
   >> 51  JUMP_ABSOLUTE  19
   >> 54  POP_BLOCK

14  >> 55  LOAD_FAST       1  (acc)
 58  RETURN_VALUE
```

The corresponding CFG for this bytecode is:

CFG adjacency lists:
{0: []}
CFG dominators:
{0: set([0])}
CFG post-dominators:
{0: set([0])}
CFG back edges: []
CFG loops:
{}
CFG node-to-loops:
{0: []}
The numbers in the CFG refer to the bytecode offsets shown just to the left of the opcode names above.

Stage 2: Generate the Numba IR

Once the control flow and data analyses are complete, the Numba interpreter can step through the bytecode and translate it into an Numba-internal intermediate representation. This translation process changes the function from a stack machine representation (used by the Python interpreter) to a register machine representation (used by LLVM).

Although the IR is stored in memory as a tree of objects, it can be serialized to a string for debugging. If you set the environment variable `NUMBA_DUMP_IR` equal to 1, the Numba IR will be dumped to the screen. For the add() function described above, the Numba IR looks like:

```
label 0:
    a = arg(0, name=a)           ['a']
    b = arg(1, name=b)           ['b']
    $0.3 = a + b                 ['$0.3', 'a', 'b']
    del b
    del a
    $0.4 = cast(value=$0.3)      ['$0.3', '$0.4']
    del $0.3
    return $0.4                 ['$0.4']
```

The `del` instructions are produced by Live Variable Analysis. Those instructions ensure references are not leaked. In nopython mode, some objects are tracked by the Numba runtime and some are not. For tracked objects, a dereference operation is emitted; otherwise, the instruction is an no-op. In object mode each variable contains an owned reference to a PyObject.
Stage 3: Rewrite untyped IR

Before running type inference, it may be desired to run certain transformations on the Numba IR. One such example is to detect raise statements which have an implicitly constant argument, so as to support them in nopython mode. Let’s say you compile the following function with Numba:

```python
def f(x):
    if x == 0:
        raise ValueError("x cannot be zero")
```

If you set the `NUMBA_DUMP_IR` environment variable to 1, you’ll see the IR being rewritten before the type inference phase:

```
REWRITING:
    del $0.3 []
    $12.1 = global(ValueError: <class 'ValueError'>) ['$12.1']
    $const12.2 = const(str, x cannot be zero) ['$const12.2']
    $12.3 = call $12.1($const12.2) ['$12.1', '$12.3', '$const12.2']
    del $const12.2 []
    del $12.1 []
    raise $12.3 ['$12.3']
```

```
REWRITING:
    del $0.3 []
    $12.1 = global(ValueError: <class 'ValueError'>) ['$12.1']
    $const12.2 = const(str, x cannot be zero) ['$const12.2']
    $12.3 = call $12.1($const12.2) ['$12.1', '$12.3', '$const12.2']
    del $const12.2 []
    del $12.1 []
    raise <class 'ValueError'>('x cannot be zero') []
```

Stage 4: Infer types

Now that the Numba IR has been generated, type analysis can be performed. The types of the function arguments can be taken either from the explicit function signature given in the @jit decorator (such as @jit('float64(float64, float64)')), or they can be taken from the types of the actual function arguments if compilation is happening when the function is first called.

The type inference engine is found in numba.typeinfer. Its job is to assign a type to every intermediate variable in the Numba IR. The result of this pass can be seen by setting the `NUMBA_DUMP_ANNOTATION` environment variable to 1:

```
-----------------------------------ANNOTATION-----------------------------------
# File: archex.py
# --- LINE 4 ---
@jit(nopython=True)
# --- LINE 5 ---
def add(a, b):
    # --- LINE 6 ---
    # label 0
```

(continues on next page)
If type inference fails to find a consistent type assignment for all the intermediate variables, it will label every variable as type `pyobject` and fall back to object mode. Type inference can fail when unsupported Python types, language features, or functions are used in the function body.

### Stage 5a: Rewrite typed IR

This pass’s purpose is to perform any high-level optimizations that still require, or could at least benefit from, Numba IR type information.

One example of a problem domain that isn’t as easily optimized once lowered is the domain of multidimensional array operations. When Numba lowers an array operation, Numba treats the operation like a full ufunc kernel. During lowering a single array operation, Numba generates an inline broadcasting loop that creates a new result array. Then Numba generates an application loop that applies the operator over the array inputs. Recognizing and rewriting these loops once they are lowered into LLVM is hard, if not impossible.

An example pair of optimizations in the domain of array operators is loop fusion and shortcut deforestation. When the optimizer recognizes that the output of one array operator is being fed into another array operator, and only to that array operator, it can fuse the two loops into a single loop. The optimizer can further eliminate the temporary array allocated for the initial operation by directly feeding the result of the first operation into the second, skipping the store and load to the intermediate array. This elimination is known as shortcut deforestation. Numba currently uses the rewrite pass to implement these array optimizations. For more information, please consult the “Case study: Array Expressions” subsection, later in this document.

One can see the result of rewriting by setting the `NUMBA_DUMP_IR` environment variable to a non-zero value (such as 1). The following example shows the output of the rewrite pass as it recognizes an array expression consisting of a multiply and add, and outputs a fused kernel as a special operator, `arrayexpr()`:

---

REWRITING:

<table>
<thead>
<tr>
<th>Expression</th>
<th>IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>a0 = arg(0, name=a0)</td>
<td>['a0']</td>
</tr>
<tr>
<td>a1 = arg(1, name=a1)</td>
<td>['a1']</td>
</tr>
<tr>
<td>a2 = arg(2, name=a2)</td>
<td>['a2']</td>
</tr>
<tr>
<td>$0.3 = a0 * a1</td>
<td>['$0.3', 'a0', 'a1']</td>
</tr>
<tr>
<td>del a1</td>
<td>[]</td>
</tr>
<tr>
<td>del a0</td>
<td>[]</td>
</tr>
<tr>
<td>$0.5 = $0.3 + a2</td>
<td>['$0.3', '$0.5', 'a2']</td>
</tr>
<tr>
<td>del a2</td>
<td>[]</td>
</tr>
<tr>
<td>del $0.3</td>
<td>[]</td>
</tr>
<tr>
<td>$0.6 = cast(value=$0.5)</td>
<td>['$0.5', '$0.6']</td>
</tr>
<tr>
<td>del $0.5</td>
<td>[]</td>
</tr>
<tr>
<td>return $0.6</td>
<td>['$0.6']</td>
</tr>
</tbody>
</table>

---

(continues on next page)
Following this rewrite, Numba lowers the array expression into a new ufunc-like function that is inlined into a single loop that only allocates a single result array.

**Stage 5b: Perform Automatic Parallelization**

This pass is only performed if the `parallel` option in the `jit()` decorator is set to `True`. This pass finds parallelism implicit in the semantics of operations in the Numba IR and replaces those operations with explicitly parallel representations of those operations using a special `parfor` operator. Then, optimizations are performed to maximize the number of parfors that are adjacent to each other such that they can then be fused together into one parfor that takes only one pass over the data and will thus typically have better cache performance. Finally, during lowering, these parfor operators are converted to a form similar to guvectorize to implement the actual parallelism.

The automatic parallelization pass has a number of sub-passes, many of which are controllable using a dictionary of options passed via the `parallel` keyword argument to `jit()`:

```python
{
    'comprehension': True/False, # parallel comprehension
    'prange': True/False, # parallel for-loop
    'numpy': True/False, # parallel numpycalls
    'reduction': True/False, # parallel reduce calls
    'setitem': True/False, # parallel setitem
    'stencil': True/False, # parallel stencils
    'fusion': True/False, # enable fusion or not
}
```

The default is set to `True` for all of them. The sub-passes are described in more detail in the following paragraphs.

1. **CFG Simplification** Sometimes Numba IR will contain chains of blocks containing no loops which are merged in this sub-pass into single blocks. This sub-pass simplifies subsequent analysis of the IR.

2. **Numpy canonicalization** Some Numpy operations can be written as operations on Numpy objects (e.g. `arr.sum()`), or as calls to Numpy taking those objects (e.g. `numpy.sum(arr)`). This sub-pass converts all such operations to the latter form for cleaner subsequent analysis.

3. **Array analysis** A critical requirement for later parfor fusion is that parfors have identical iteration spaces and these iteration spaces typically correspond to the sizes of the dimensions of Numpy arrays. In this sub-pass, the IR is analyzed to determine equivalence classes for the dimensions of Numpy arrays. Consider the example, `a = b + 1`, where `a` and `b` are both Numpy arrays. Here, we know that each dimension of `a` must have the same equivalence class as the corresponding dimension of `b`. Typically, routines rich in Numpy operations will enable equivalence classes to be fully known for all arrays created within a function.

Array analysis will also reason about size equivalence for slice selection, and boolean array masking (one dimensional only). For example, it is able to infer that `a[1 : n-1]` is of the same size as `b[0 : n-2]`. 

---

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Array analysis may also insert safety assumptions to ensure pre-conditions related to array sizes are met before an operation can be parallelized. For example, \( \text{np.dot}(X, w) \) between a 2-D matrix \( X \) and a 1-D vector \( w \) requires that the second dimension of \( X \) is of the same size as \( w \). Usually this kind of runtime check is automatically inserted, but if array analysis can infer such equivalence, it will skip them.

Users can even help array analysis by turning implicit knowledge about array sizes into explicit assertions. For example, in the code below:

```python
@numba.njit(parallel=True)
def logistic_regression(Y, X, w, iterations):
    assert (X.shape == (Y.shape[0], w.shape[0]))
    for i in range(iterations):
        w -= np.dot(((1.0 / (1.0 + np.exp(-Y * np.dot(X, w))) - 1.0) * Y), X)
    return w
```

Making the explicit assertion helps eliminate all bounds checks in the rest of the function.

4. **prange() to parfor** The use of prange (Explicit Parallel Loops) in a for loop is an explicit indication from the programmer that all iterations of the for loop can execute in parallel. In this sub-pass, we analyze the CFG to locate loops and to convert those loops controlled by a prange object to the explicit `parfor` operator. Each explicit parfor operator consists of:

- a. A list of loop nest information that describes the iteration space of the parfor. Each entry in the loop nest list contains an indexing variable, the start of the range, the end of the range, and the step value for each iteration.

- b. An initialization (init) block which contains instructions to be executed one time before the parfor begins executing.

- c. A loop body comprising a set of basic blocks that correspond to the body of the loop and compute one point in the iteration space.

- d. The index variables used for each dimension of the iteration space.

For parfor pranges, the loop nest is a single entry where the start, stop, and step fields come from the specified `prange`. The init block is empty for `prange` parfors and the loop body is the set of blocks in the loop minus the loop header.

With parallelization on, array comprehensions (List comprehension) will also be translated to prange so as to run in parallel. This behavior can be disabled by setting `parallel={'comprehension': False}`.

Likewise, the overall `prange` to parfor translation can be disabled by setting `parallel={'prange': False}`, in which case `prange` is treated the same as `range`.

5. **Numpy to parfor** In this sub-pass, Numpy functions such as `ones`, `zeros`, `dot`, most of the random number generating functions, arrayexprs (from Section *Stage 5a: Rewrite typed IR*), and Numpy reductions are converted to parfors. Generally, this conversion creates the loop nest list, whose length is equal to the number of dimensions of the left-hand side of the assignment instruction in the IR. The number and size of the dimensions of the left-hand-side array is taken from the array analysis information generated in sub-pass 3 above. An instruction to create the result Numpy array is generated and stored in the new parfor’s init block. A basic block is created for the loop body and an instruction is generated and added to the end of that block to store the result of the computation into the array at the current point in the iteration space. The result stored into the array depends on the operation that is being converted. For example, for `ones`, the value stored is a constant 1. For calls to generate a random array, the value comes from a call to the same random number function but with the `size` parameter dropped and therefore returning a scalar. For arrayexpr operators, the arrayexpr tree is converted to Numba IR and the value at the root of that expression tree is used to write into the output array. The translation from Numpy functions and arrayexpr operators to parfor can be disabled by setting `parallel={'numpy': False}`.
For reductions, the loop nest list is similarly created using the array analysis information for the array being reduced. In the init block, the initial value is assigned to the reduction variable. The loop body consists of a single block in which the next value in the iteration space is fetched and the reduction operation is applied to that value and the current reduction value and the result stored back into the reduction value.

The translation of reduction functions to `parfor` can be disabled by setting `parallel={"reduction": False}`.

Setting the `NUMBA_DEBUG_ARRAY_OPT_STATS` environment variable to 1 will show some statistics about parfor conversions in general.

6. **Setitem to parfor** Setting a range of array elements using a slice or boolean array selection can also run in parallel. Statement such as `A[P] = B[Q]` (or a simpler case `A[P] = c`, where `c` is a scalar) is translated to `parfor` if one of the following conditions is met:
   a. `P` and `Q` are slices or multi-dimensional selector involving scalar and slices, and `A[P]` and `B[Q]` are considered size equivalent by array analysis. Only 2-value slice/range is supported, 3-value with a step will not be translated to `parfor`.
   b. `P` and `Q` are the same boolean array.

This translation can be disabled by setting `parallel={"setitem": False}`.

7. **Simplification** Performs a copy propagation and dead code elimination pass.

8. **Fusion** This sub-pass first processes each basic block and does a reordering of the instructions within the block with the goal of pushing parfors lower in the block and lifting non-parfors towards the start of the block. In practice, this approach does a good job of getting parfors adjacent to each other in the IR, which enables more parfors to then be fused. During parfor fusion, each basic block is repeatedly scanned until no further fusion is possible. During this scan, each set of adjacent instructions are considered. Adjacent instructions are fused together if:
   a. they are both parfors
   b. the parfors’ loop nests are the same size and the array equivalence classes for each dimension of the loop nests are the same, and
   c. the first parfor does not create a reduction variable used by the second parfor.

The two parfors are fused together by adding the second parfor’s init block to the first’s, merging the two parfors’ loop bodies together and replacing the instances of the second parfor’s loop index variables in the second parfor’s body with the loop index variables for the first parfor. Fusion can be disabled by setting `parallel={"fusion": False}`.

Setting the `NUMBA_DEBUG_ARRAY_OPT_STATS` environment variable to 1 will show some statistics about parfor fusions.

9. **Push call objects and compute parfor parameters** In the lowering phase described in Section *Stage 6a: Generate nopython LLVM IR*, each parfor becomes a separate function executed in parallel in `guvectorize` (*The @guvectorize decorator* style. Since parfors may use variables defined previously in a function, when those parfors become separate functions, those variables must be passed to the parfor function as parameters. In this sub-pass, a use-def scan is made over each parfor body and liveness information is used to determine which variables are used but not defined by the parfor. That list of variables is stored here in the parfor for use during lowering. Function variables are a special case in this process since function variables cannot be passed to functions compiled in nopython mode. Instead, for function variables, this sub-pass pushes the assignment instruction to the function variable into the parfor body so that those do not need to be passed as parameters.

To see the intermediate IR between the above sub-passes and other debugging information, set the `NUMBA_DEBUG_ARRAY_OPT` environment variable to 1. For the example in Section *Stage 5a: Rewrite typed IR*, the following IR with a parfor is generated during this stage:
label 0:
    a0 = arg(0, name=a0)  ['a0']
    a0_sh_attr0.0 = getattr(attr=shape, value=a0) ['a0', 'a0_sh_attr0.0']
    $consta00.1 = \text{const}($int, 0) ['$consta00.1']
    a0size0.2 = static_getitem(value=a0_sh_attr0.0, index_var=$consta00.1, index=0) ['$consta00.1', 'a0_sh_attr0.0', 'a0size0.2']
    a1 = arg(1, name=a1) ['a1']
    a1_sh_attr0.3 = getattr(attr=shape, value=a1) ['a1', 'a1_sh_attr0.3']
    $consta10.4 = \text{const}($int, 0) ['$consta10.4']
    a1size0.5 = static_getitem(value=a1_sh_attr0.3, index_var=$consta10.4, index=0) ['$consta10.4', 'a1_sh_attr0.3', 'a1size0.5']
    a2 = arg(2, name=a2) ['a2']
    a2_sh_attr0.6 = getattr(attr=shape, value=a2) ['a2', 'a2_sh_attr0.6']
    $consta20.7 = \text{const}($int, 0) ['$consta20.7']
    a2size0.8 = static_getitem(value=a2_sh_attr0.6, index_var=$consta20.7, index=0) ['$consta20.7', 'a2_sh_attr0.6', 'a2size0.8']

---begin parfor 0---
    index_var = parfor_index.9
    LoopNest(index_variable=parfor_index.9, range=0,a0size0.2,1 correlation=5)
    init block:
        $np_g_var.10 = \text{global}($np: <module 'numpy' from '/usr/local/lib/python3.5/dist-packages/numpy/__init__.py'>) ['$np_g_var.10']
        $empty_attr_attr.11 = getattr(attr=empty, value=$np_g_var.10) ['$empty_attr_attr.11', '$np_g_var.10']
        $np_typ_var.12 = getattr(attr=float64, value=$np_g_var.10) ['$np_g_var.10', '$np_typ_var.12']
        $0.5 = \text{call} $empty_attr_attr.11(a0size0.2, $np_typ_var.12, kws=(), func=\text{empty_attr_attr.11}, vararg=None, args=[Var(a0size0.2, test2.py (7)), Var($np_typ_var.12, test2.py (7))]) ['$0.5', '$empty_attr_attr.11', '$np_typ_var.12', '$0.5']
    label 1:
        $arg_out_var.15 = \text{getitem}(value=a0, index=parfor_index.9) ['$arg_out_var.15', 'a0', 'parfor_index.9']
        $arg_out_var.16 = \text{getitem}(value=a1, index=parfor_index.9) ['$arg_out_var.16', 'a1', 'parfor_index.9']
        $arg_out_var.14 = $arg_out_var.15 * $arg_out_var.16 ['$arg_out_var.14', '$arg_out_var.15', '$arg_out_var.16']
        $arg_out_var.17 = \text{getitem}(value=a2, index=parfor_index.9) ['$arg_out_var.17', 'a2', 'parfor_index.9']
        $expr_out_var.13 = $arg_out_var.14 + $arg_out_var.17 ['$arg_out_var.14', '$arg_out_var.17', '$expr_out_var.13']
        $0.5[parfor_index.9] = $expr_out_var.13 ['$0.5', '$expr_out_var.13', 'parfor_index.9']
    ----end parfor 0----
    $0.6 = \text{cast}(value=$0.5) ['$0.6']
    return $0.6 ['$0.6']
Stage 6a: Generate nopython LLVM IR

If type inference succeeds in finding a Numba type for every intermediate variable, then Numba can (potentially) generate specialized native code. This process is called *lowering*. The Numba IR tree is translated into LLVM IR by using helper classes from *llvmlite*. The machine-generated LLVM IR can seem unnecessarily verbose, but the LLVM toolchain is able to optimize it quite easily into compact, efficient code.

The basic lowering algorithm is generic, but the specifics of how particular Numba IR nodes are translated to LLVM instructions is handled by the target context selected for compilation. The default target context is the “cpu” context, defined in `numba.targets.cpu`.

The LLVM IR can be displayed by setting the `NUMBA_DUMP_LLVM` environment variable to 1. For the “cpu” context, our `add()` example would look like:

```c
define i32 @"__main__.add$1.int64.int64"(i64* %"retptr",
    {i8*, i32}** %"excinfo",
    i8* %"env",
    i64 %"arg.a", i64 %"arg.b")
{
    entry:
    %"a" = alloca i64
    %"b" = alloca i64
    %"$0.3" = alloca i64
    %"$0.4" = alloca i64
    br label %"B0"

B0:
    store i64 %"arg.a", i64* %"a"
    store i64 %"arg.b", i64* %"b"
    %".8" = load i64* %"a"
    %".9" = load i64* %"b"
    %".10" = add i64 %".8", %".9"
    store i64 %".10", i64* %"$0.3"
    %".12" = load i64* %"$0.3"
    store i64 %".12", i64* %"$0.4"
    %".14" = load i64* %"$0.4"
    store i64 %".14", i64* %"retptr"
    ret i32 0
}
```

The post-optimization LLVM IR can be output by setting `NUMBA_DUMP_OPTIMIZED` to 1. The optimizer shortens the code generated above quite significantly:

```c
define i32 @"__main__.add$1.int64.int64"(i64* nocapture %retptr,
    {i8*, i32}** nocapture readnone %excinfo,
    i8* nocapture readnone %env,
    i64 %arg.a, i64 %arg.b)
{
    entry:
    %.10 = add i64 %arg.b, %arg.a
    store i64 %.10, i64* %retptr, align 8
    ret i32 0
}
```

If created during *Stage 5b: Perform Automatic Parallelization*, parfor operations are lowered in the following manner. First, instructions in the parfor’s init block are lowered into the existing function using the normal lowering code.
Second, the loop body of the parfor is turned into a separate GUFunc. Third, code is emitted for the current function to call the parallel GUFunc.

To create a GUFunc from the parfor body, the signature of the GUFunc is created by taking the parfor parameters as identified in step 9 of Stage 5b: Perform Automatic Parallelization and adding to that a special schedule parameter, across which the GUFunc will be parallelized. The schedule parameter is in effect a static schedule mapping portions of the parfor iteration space to Numba threads and so the length of the schedule array is the same as the number of configured Numba threads. To make this process easier and somewhat less dependent on changes to Numba IR, this stage creates a Python function as text that contains the parameters to the GUFunc and iteration code that takes the current schedule entry and loops through the specified portion of the iteration space. In the body of that loop, a special sentinel is inserted for subsequent easy location. This code that handles the processing of the iteration space is then eval’ed into existence and the Numba compiler’s run_frontend function is called to generate IR. That IR is scanned to locate the sentinel and the sentinel is replaced with the loop body of the parfor. Then, the process of creating the parallel GUFunc is completed by compiling this merged IR with the Numba compiler’s compile_ir function.

To call the parallel GUFunc, the static schedule must be created. Code is inserted to call a function named do_scheduling. This function is called with the size of each of the parfor’s dimensions and the number $N$ of configured Numba threads ($NUMBA_NUM_THREADS$). The do_scheduling function will divide the iteration space into $N$ approximately equal sized regions (linear for 1D, rectangular for 2D, or hyperrectangles for 3+D) and the resulting schedule is passed to the parallel GUFunc. The number of threads dedicated to a given dimension of the full iteration space is roughly proportional to the ratio of the size of the given dimension to the sum of the sizes of all the dimensions of the iteration space.

Parallel reductions are not natively provided by GUFuncs but the parfor lowering strategy allows us to use GUFuncs in a way that reductions can be performed in parallel. To accomplish this, for each reduction variable computed by a parfor, the parallel GUFunc and the code that calls it are modified to make the scalar reduction variable into an array of reduction variables whose length is equal to the number of Numba threads. In addition, the GUFunc still contains a scalar version of the reduction variable that is updated by the parfor body during each iteration. One time at the end of the GUFunc this local reduction variable is copied into the reduction array. In this way, false sharing of the reduction array is prevented. Code is also inserted into the main function after the parallel GUFunc has returned that does a reduction across this smaller reduction array and this final reduction value is then stored into the original scalar reduction variable.

The GUFunc corresponding to the example from Section 5b: Perform Automatic Parallelization can be seen below:

```
label 0:
    sched.29 = arg(0, name=sched)   ['sched.29']
    a0 = arg(1, name=a0)          ['a0']
    a1 = arg(2, name=a1)          ['a1']
    a2 = arg(3, name=a2)          ['a2']
    _0_5 = arg(4, name=_0_5)     ['_0_5']
    $3.1.24 = global(range: <class 'range'>) ['$3.1.24']
    $const3.3.21 = const(int, 0)     ['$const3.3.21']
    $3.4.23 = getitem(value=sched.29, index=$const3.3.21) ['$3.4.23', '$const3.3.21',
               'sched.29']
    $const3.6.28 = const(int, 1)     ['$const3.6.28']
    $3.7.27 = getitem(value=sched.29, index=$const3.6.28) ['$3.7.27', '$const3.6.28',
               'sched.29']
    $const3.8.32 = const(int, 1)     ['$const3.8.32']
    $3.9.31 = $3.7.27 + $const3.8.32  ['$3.7.27', '$3.9.31', '$const3.8.32']
    $3.10.36 = call $3.1.24($3.4.23, $3.9.31, kws=[], func=$3.1.24, vararg=None,
               args=[Var($3.4.23, <string> (2)), Var($3.9.31, <string> (2))]) ['$3.1.24', '$3.10.36',
               '$3.4.23', '$3.9.31']
```
Stage 6b: Generate object mode LLVM IR

If type inference fails to find Numba types for all values inside a function, the function will be compiled in object mode. The generated LLVM will be significantly longer, as the compiled code will need to make calls to the Python C API to perform basically all operations. The optimized LLVM for our example add() function is:

```c
@PyExc_SystemError = external global i8 
".const.Numba_internal_error:object_mode_function_called_without_an_environment" = internal constant [73 x i8] c"Numba internal error: object mode function called without an environment\00"
@".const.name_\"a\"_is_not_defined" = internal constant [24 x i8] c"name \"a\" is not defined\00"
@PyExc_NameError = external global i8 
".const.name_\"b\"_is_not_defined" = internal constant [24 x i8] c"name \"b\" is not defined\00"

define i32 @"__main__.add$1.pyobject.pyobject"(i8** nocapture %retptr, { i8*, i32 }** nocapture readnone %excinfo, i8* readnone %env, i8* %arg.a, i8* %arg.b) {
  entry:
    %6 = icmp eq i8* %env, null
    br i1 %6, label %entry.if, label %entry.endif, !prof !0

  entry.if: ; preds = %entry
    tail call void @PyErr_SetString(i8* @PyExc_SystemError, i8* getelementptr inbounds ([73 x i8]* @".const.Numba_internal_error:object_mode_function_called_without_an_environment\", i64 0, i64 0))
```

(continues on next page)


```
ret i32 -1

entry.endif: ; preds = %entry
  tail call void @Py_IncRef(i8* %arg.a)
  tail call void @Py_IncRef(i8* %arg.b)
  %.21 = icmp eq i8* %arg.a, null
  br i1 %.21, label %B0.if, label %B0 endif, !prof !0

B0.if: ; preds = %entry.endif
  tail call void @PyErr_SetString(i8* @PyExc_NameError, i8* getelementptr inbounds ([24, 8 x i8]* @".const.name_"a"_is_not_defined", i64 0, i64 0))
  tail call void @Py_DecRef(i8* null)
  tail call void @Py_DecRef(i8* %arg.b)
  ret i32 -1

B0 endif: ; preds = %entry.endif
  %.30 = icmp eq i8* %arg.b, null
  br i1 %.30, label %B0 endif1, label %B0 endif1.1, !prof !0

B0 endif1: ; preds = %B0 endif
  tail call void @PyErr_SetString(i8* @PyExc_NameError, i8* getelementptr inbounds ([24, 8 x i8]* @".const.name_"b"_is_not_defined", i64 0, i64 0))
  tail call void @Py_DecRef(i8* %arg.a)
  tail call void @Py_DecRef(i8* null)
  ret i32 -1

B0 endif1.1: ; preds = %B0 endif
  %.38 = tail call i8* @PyNumber_Add(i8* %arg.a, i8* %arg.b)
  %.39 = icmp eq i8* %.38, null
  br i1 %.39, label %B0 endif1.1 if, label %B0 endif1.1 endif, !prof !0

B0 endif1.1 if: ; preds = %B0 endif1.1
  tail call void @Py_DecRef(i8* %arg.a)
  tail call void @Py_DecRef(i8* %arg.b)
  ret i32 -1

B0 endif1.1 endif: ; preds = %B0 endif1.1
  tail call void @Py_DecRef(i8* %arg.b)
  tail call void @Py_DecRef(i8* %arg.a)
  tail call void @Py_IncRef(i8* %.38)
  tail call void @Py_DecRef(i8* %.38)
  store i8* %.38, i8** %retptr, align 8
  ret i32 0
}
```

```
declare void @_PyErr_SetString(i8*, i8*)

declare void @Py_IncRef(i8*)

declare void @Py_DecRef(i8*)

declare i8* @PyNumber_Add(i8*, i8*)
```

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The careful reader might notice several unnecessary calls to `Py_IncRef` and `Py_DecRef` in the generated code. Currently Numba isn’t able to optimize those away.

Object mode compilation will also attempt to identify loops which can be extracted and statically-typed for “nopython” compilation. This process is called *loop-lifting*, and results in the creation of a hidden nopython mode function just containing the loop which is then called from the original function. Loop-lifting helps improve the performance of functions that need to access uncompileable code (such as I/O or plotting code) but still contain a time-intensive section of compilable code.

**Stage 7: Compile LLVM IR to machine code**

In both *object mode* and *nopython mode*, the generated LLVM IR is compiled by the LLVM JIT compiler and the machine code is loaded into memory. A Python wrapper is also created (defined in `numba.dispatcher.Dispatcher`) which can do the dynamic dispatch to the correct version of the compiled function if multiple type specializations were generated (for example, for both `float32` and `float64` versions of the same function).

The machine assembly code generated by LLVM can be dumped to the screen by setting the `NUMBA_DUMP_ASSEMBLY` environment variable to 1:

```
.globl __main__.add$1.int64.int64
.align 16, 0x90
.type __main__.add$1.int64.int64, @function
__main__.add$1.int64.int64:
    addq %r8, %rcx
    movq %rcx, (%rdi)
    xorl %eax, %eax
    retq
```

The assembly output will also include the generated wrapper function that translates the Python arguments to native data types.

### 6.5 Polymorphic dispatching

Functions compiled using `jit()` or `vectorize()` are open-ended: they can be called with many different input types and have to select (possibly compile on-the-fly) the right low-level specialization. We hereby explain how this mechanism is implemented.

#### 6.5.1 Requirements

JIT-compiled functions can take several arguments and each of them is taken into account when selecting a specialization. Thus it is a form of multiple dispatch, more complex than single dispatch.

Each argument weighs in the selection based on its *Numba type*. Numba types are often more granular than Python types: for example, Numba types Numpy arrays differently depending on their dimensionality and their layout (C-contiguous, etc.).

Once a Numba type is inferred for each argument, a specialization must be chosen amongst the available ones; or, if not suitable specialization is found, a new one must be compiled. This is not a trivial decision: there can be multiple specializations compatible with a given concrete signature (for example, say a two-argument function has compiled specializations for (float64, float64) and (complex64, complex64), and it is called with (float32, float32)).

Therefore, there are two crucial steps in the dispatch mechanism:
1. infer the Numba types of the concrete arguments
2. select the best available specialization (or choose to compile a new one) for the inferred Numba types

**Compile-time vs. run-time**

This document discusses dispatching when it is done at runtime, i.e. when a JIT-compiled function is called from pure Python. In that context, performance is important. To stay in the realm of normal function call overhead in Python, the overhead of dispatching should stay under a microsecond. Of course, the faster the better...

When a JIT-compiled function is called from another JIT-compiled function (in *nopython mode*), the polymorphism is resolved at compile-time, using a non-performance critical mechanism, bearing zero runtime performance overhead.

---

**Note:** In practice, the performance-critical parts described here are coded in C.

### 6.5.2 Type resolution

The first step is therefore to infer, at call-time, a Numba type for each of the function's concrete arguments. Given the finer granularity of Numba types compared to Python types, one cannot simply lookup an object’s class and key a dictionary with it to obtain the corresponding Numba type.

Instead, there is a machinery to inspect the object and, based on its Python type, query various properties to infer the appropriate Numba type. This can be more or less complex: for example, a Python `int` argument will always infer to a Numba `intp` (a pointer-sized integer), but a Python `tuple` argument can infer to multiple Numba types (depending on the tuple’s size and the concrete type of each of its elements).

The Numba type system is high-level and written in pure Python; there is a pure Python machinery, based on a generic function, to do said inference (in `numba.typing.typeof`). That machinery is used for compile-time inference, e.g. on constants. Unfortunately, it is too slow for run-time value-based dispatching. It is only used as a fallback for rarely used (or difficult to infer) types, and exhibits multiple-microsecond overhead.

**Typecodes**

The Numba type system is really too high-level to be manipulated efficiently from C code. Therefore, the C dispatching layer uses another representation based on integer typecodes. Each Numba type gets a unique integer typecode when constructed; also, an interning system ensure no two instances of same type are created. The dispatching layer is therefore able to eschew the overhead of the Numba type system by working with simple integer typecodes, amenable to well-known optimizations (fast hash tables, etc.).

The goal of the type resolution step becomes: infer a Numba *typecode* for each of the function’s concrete arguments. Ideally, it doesn’t deal with Numba types anymore...

**Hard-coded fast paths**

While eschewing the abstraction and object-orientation overhead of the type system, the integer typecodes still have the same conceptual complexity. Therefore, an important technique to speed up inference is to first go through checks for the most important types, and hard-code a fast resolution for each of them.

Several types benefit from such an optimization, notably:

- basic Python scalars (`bool`, `int`, `float`, `complex`);
- basic Numpy scalars (the various kinds of integer, floating-point, complex numbers);
• Numpy arrays of certain dimensionalities and basic element types.

Each of those fast paths ideally uses a hard-coded result value or a direct table lookup after a few simple checks. However, we can’t apply that technique to all argument types; there would be an explosion of ad-hoc internal caches, and it would become difficult to maintain. Besides, the recursive application of hard-coded fast paths would not necessarily combine into a low overhead (in the nested tuple case, for example).

**Fingerprint-based typecode cache**

For non-so-trivial types (imagine a tuple, or a Numpy `datetime64` array, for example), the hard-coded fast paths don’t match. Another mechanism then kicks in, more generic.

The principle here is to examine each argument value, as the pure Python machinery would do, and to describe its Numba type unambiguously. The difference is that *we don’t actually compute a Numba type*. Instead, we compute a simple bytestring, a low-level possible denotation of that Numba type: a fingerprint. The fingerprint format is designed to be short and extremely simple to compute from C code (in practice, it has a bytecode-like format).

Once the fingerprint is computed, it is looked up in a cache mapping fingerprints to typecodes. The cache is a hash table, and the lookup is fast thanks to the fingerprints being generally very short (rarely more than 20 bytes).

If the cache lookup fails, the typecode must first be computed using the slow pure Python machinery. Luckily, this would only happen once: on subsequent calls, the cached typecode would be returned for the given fingerprint.

In rare cases, a fingerprint cannot be computed efficiently. This is the case for some types which cannot be easily inspected from C: for example `cffi` function pointers. Then, the slow Pure Python machinery is invoked at each function call with such an argument.

**Note:** Two fingerprints may denote a single Numba type. This does not make the mechanism incorrect; it only creates more cache entries.

**Summary**

Type resolution of a function argument involves the following mechanisms in order:

• Try a few hard-coded fast paths, for common simple types.

• If the above failed, compute a fingerprint for the argument and lookup its typecode in a cache.

• If all the above failed, invoke the pure Python machinery which will determine a Numba type for the argument (and look up its typecode).

**6.5.3 Specialization selection**

At the previous step, an integer typecode has been determined for each concrete argument to the JIT-compiled function. Now it remains to match that concrete signature against each of the available specializations for the function. There can be three outcomes:

• There is a satisfying best match: the corresponding specialization is then invoked (it will handle argument un-boxing and other details).

• There is a tie between two or more “best matches”: an exception is raised, refusing to solve the ambiguity.

• There is no satisfying match: a new specialization is compiled tailored for the concrete argument types that were inferred.
The selection works by looping over all available specializations, and computing the compatibility of each concrete argument type with the corresponding type in the specialization’s intended signature. Specifically, we are interested in:

1. Whether the concrete argument type is allowed to convert implicitly to the specialization’s argument type;
2. If so, at what semantic (user-visible) cost the conversion comes.

**Implicit conversion rules**

There are five possible kinds of implicit conversion from a source type to a destination type (note this is an asymmetric relationship):

1. **exact match**: the two types are identical; this is the ideal case, since the specialization would behave exactly as intended;
2. **same-kind promotion**: the two types belong to the same “kind” (for example int32 and int64 are two integer types), and the source type can be converted losslessly to the destination type (e.g. from int32 to int64, but not the reverse);
3. **safe conversion**: the two types belong to different kinds, but the source type can be reasonably converted to the destination type (e.g. from int32 to float64, but not the reverse);
4. **unsafe conversion**: a conversion is available from the source type to the destination type, but it may lose precision, magnitude, or another desirable quality.
5. **no conversion**: there is no correct or reasonably efficient way to convert between the two types (for example between an int64 and a datetime64, or a C-contiguous array and a Fortran-contiguous array).

When a specialization is examined, the latter two cases eliminate it from the final choice: i.e. when at least one argument has no conversion or only an unsafe conversion to the signature’s argument type.

**Note:** However, if the function is compiled with explicit signatures in the `jit()` call (and therefore it is not allowed to compile new specializations), unsafe conversion is allowed.

**Candidates and best match**

If a specialization is not eliminated by the rule above, it enters the list of candidates for the final choice. Those candidates are ranked by an ordered 4-uple of integers: (number of unsafe conversions, number of safe conversions, number of same-kind promotions, number of exact matches) (note the sum of the tuple’s elements is equal to the number of arguments). The best match is then the #1 result in sorted ascending order, thereby preferring exact matches over promotions, promotions over safe conversions, safe conversions over unsafe conversions.

**Implementation**

The above-described mechanism works on integer typecodes, not on Numba types. It uses an internal hash table storing the possible conversion kind for each pair of compatible types. The internal hash table is in part built at startup (for built-in trivial types such as int32, int64 etc.), in part filled dynamically (for arbitrarily complex types such as array types: for example to allow using a C-contiguous 2D array where a function expects a non-contiguous 2D array).
Summary

Selecting the right specialization involves the following steps:

- Examine each available specialization and match it against the concrete argument types.
- Eliminate any specialization where at least one argument doesn’t offer sufficient compatibility.
- If there are remaining candidates, choose the best one in terms of preserving the types’ semantics.

6.5.4 Miscellaneous

Some benchmarks of dispatch performance exist in the Numba benchmarks repository.

Some unit tests of specific aspects of the machinery are available in `numba.tests.test_typeinfer` and `numba.tests.test_typeof`. Higher-level dispatching tests are in `numba.tests.test_dispatcher`.

6.6 Notes on generators

Numba recently gained support for compiling generator functions. This document explains some of the implementation choices.

6.6.1 Terminology

For clarity, we distinguish between generator functions and generators. A generator function is a function containing one or several yield statements. A generator (sometimes also called “generator iterator”) is the return value of a generator function; it resumes execution inside its frame each time `next()` is called.

A yield point is the place where a yield statement is called. A resumption point is the place just after a yield point where execution is resumed when `next()` is called again.

6.6.2 Function analysis

Suppose we have the following simple generator function:

```python
def gen(x, y):
    yield x + y
    yield x - y
```

Here is its CPython bytecode, as printed out using `dis.dis()`:

```
7 0 LOAD_FAST 0 (x)
3 0 LOAD_FAST 1 (y)
6 BINARY_ADD
7 YIELD_VALUE
8 POP_TOP

8 0 LOAD_FAST 0 (x)
12 0 LOAD_FAST 1 (y)
15 BINARY_SUBTRACT
16 YIELD_VALUE
17 POP_TOP
```

(continues on next page)
When compiling this function with `NUMBA_DUMP_IR` set to 1, the following information is printed out:

```
----------------------------------IR DUMP: gen----------------------------------
label 0:
  x = arg(0, name=x)  ['x']
  y = arg(1, name=y)  ['y']
  $0.3 = x + y       ['$0.3', 'x', 'y']
  $0.4 = yield $0.3  ['$0.3', '$0.4']
  del $0.4          []
  del $0.3          []
  $0.3 = x - y      ['$0.3', 'x', 'y']
  del y             []
  del x             []
  $0.8 = yield $0.7  ['$0.7', '$0.8']
  del $0.8          []
  del $0.7          []
  $const0.9 = const(NoneType, None)  ['$const0.9']
  $0.10 = cast(value=$const0.9)  ['$0.10', '$const0.9']
  del $const0.9     []
  return $0.10      ['$0.10']
```

What does it mean? The first part is the Numba IR, as already seen in `Stage 2: Generate the Numba IR`. We can see the two yield points (`yield $0.3` and `yield $0.7`).

The second part shows generator-specific information. To understand it we have to understand what suspending and resuming a generator means.

When suspending a generator, we are not merely returning a value to the caller (the operand of the `yield` statement). We also have to save the generator's current state in order to resume execution. In trivial use cases, perhaps the CPU’s register values or stack slots would be preserved until the next call to `next()`. However, any non-trivial case will hopelessly clobber those values, so we have to save them in a well-defined place.

What are the values we need to save? Well, in the context of the Numba Intermediate Representation, we must save all live variables at each yield point. These live variables are computed thanks to the control flow graph.

Once live variables are saved and the generator is suspended, resuming the generator simply involves the inverse operation: the live variables are restored from the saved generator state.

**Note:** It is the same analysis which helps insert Numba `del` instructions where appropriate.

Let’s go over the generator info again:

```
generator state variables: ['$0.3', '$0.7', 'x', 'y']
yield point #1: live variables = ['x', 'y'], weak live variables = ['$0.3']
yield point #2: live variables = [], weak live variables = ['$0.7']
```
Numba has computed the union of all live variables (denoted as “state variables”). This will help define the layout of the generator structure. Also, for each yield point, we have computed two sets of variables:

- the live variables are the variables which are used by code following the resumption point (i.e. after the yield statement)
- the weak live variables are variables which are del’ed immediately after the resumption point; they have to be saved in object mode, to ensure proper reference cleanup

### 6.6.3 The generator structure

#### Layout

Function analysis helps us gather enough information to define the layout of the generator structure, which will store the entire execution state of a generator. Here is a sketch of the generator structure’s layout, in pseudo-code:

```c
struct gen_struct_t {
    int32_t resume_index;
    struct gen_args_t {
        arg_0_t arg0;
        arg_1_t arg1;
        ...
        arg_N_t argN;
    }
    struct gen_state_t {
        state_0_t state_var0;
        state_1_t state_var1;
        ...
        state_N_t state_varN;
    }
}
```

Let’s describe those fields in order.

- The first member, the resume index, is an integer telling the generator at which resumption point execution must resume. By convention, it can have two special values: 0 means execution must start at the beginning of the generator (i.e. the first time next() is called); -1 means the generator is exhausted and resumption must immediately raise StopIteration. Other values indicate the yield point’s index starting from 1 (corresponding to the indices shown in the generator info above).

- The second member, the arguments structure is read-only after it is first initialized. It stores the values of the arguments the generator function was called with. In our example, these are the values of x and y.

- The third member, the state structure, stores the live variables as computed above.

Concretely, our example’s generator structure (assuming the generator function is called with floating-point numbers) is then:

```c
struct gen_struct_t {
    int32_t resume_index;
    struct gen_args_t {
        double arg0;
        double arg1;
    }
    struct gen_state_t {
```

(continues on next page)
double $0.3;
double $0.7;
double x;
double y;
}
}

Note that here, saving \( x \) and \( y \) is redundant: Numba isn’t able to recognize that the state variables \( x \) and \( y \) have the same value as \( \text{arg0} \) and \( \text{arg1} \).

**Allocation**

How does Numba ensure the generator structure is preserved long enough? There are two cases:

- When a Numba-compiled generator function is called from a Numba-compiled function, the structure is allocated on the stack by the callee. In this case, generator instantiation is practically costless.
- When a Numba-compiled generator function is called from regular Python code, a CPython-compatible wrapper is instantiated that has the right amount of allocated space to store the structure, and whose `tp_iternext` slot is a wrapper around the generator’s native code.

### 6.6.4 Compiling to native code

When compiling a generator function, three native functions are actually generated by Numba:

- An initialization function. This is the function corresponding to the generator function itself: it receives the function arguments and stores them inside the generator structure (which is passed by pointer). It also initialized the `resume index` to 0, indicating that the generator hasn’t started yet.
- A `next()` function. This is the function called to resume execution inside the generator. Its single argument is a pointer to the generator structure and it returns the next yielded value (or a special exit code is used if the generator is exhausted, for quick checking when called from Numba-compiled functions).
- An optional finalizer. In object mode, this function ensures that all live variables stored in the generator state are decref’ed, even if the generator is destroyed without having been exhausted.

**The `next()` function**

The `next()` function is the least straightforward of the three native functions. It starts with a trampoline which dispatches execution to the right resume point depending on the `resume index` stored in the generator structure. Here is how the function start may look like in our example:

```c
#define i32 /*_main__.gen.next*/
  double* nocapture %retptr,
  { 18*, i32 }** nocapture readnone %excinfo,
  i8* nocapture readnone %excinfo,
  { i32, { double, double }, { double, double, double, double } }* nocapture %arg.gen)
{
  %gen.resume_index = getelementptr { i32, { double, double }, { double, double, double, double }, i32, double, double }* %arg.gen, i64 0, i32 0
  %_.47 = load i32* %gen.resume_index, align 4
```
We recognize the pointer to the generator structure in %arg.gen. The trampoline switch has three targets (one for each resume index 0, 1 and 2), and a fallback target label named stop_iteration. Label B0 represents the function’s start, generator_resume1 (resp. generator_resume2) is the resumption point after the first (resp. second) yield point.

After generation by LLVM, the whole native assembly code for this function may look like this (on x86-64):

```
.globl __main__.gen.next
.align 16, 0x90
__main__.gen.next:
movl (%rcx), %eax
cmpl $2, %eax
je .LBB1_5
cmpl $1, %eax
jne .LBB1_2
movsd 40(%rcx), %xmm0
subsd 48(%rcx), %xmm0
movl $2, (%rcx)
movsd %xmm0, (%rdi)
xorl %eax, %eax
retq
.LBB1_5:
movl $-1, (%rcx)
jmp .LBB1_6
.LBB1_2:
testl %eax, %eax
jne .LBB1_6
movsd 8(%rcx), %xmm0
movsd 16(%rcx), %xmm1
movaps %xmm0, %xmm2
addsd %xmm1, %xmm2
movsd %xmm1, 48(%rcx)
movsd %xmm0, 48(%rcx)
movl $1, (%rcx)
movsd %xmm2, (%rdi)
xorl %eax, %eax
retq
.LBB1_6:
movl $-3, %eax
retq
```

Note the function returns 0 to indicate a value is yielded, -3 to indicate StopIteration. %rcx points to the start of the generator structure, where the resume index is stored.
6.7 Notes on Numba Runtime

The Numba Runtime (NRT) provides the language runtime to the nopython mode Python subset. NRT is a standalone C library with a Python binding. This allows NPM runtime feature to be used without the GIL. Currently, the only language feature implemented in NRT is memory management.

6.7.1 Memory Management

NRT implements memory management for NPM code. It uses atomic reference count for threadsafe, deterministic memory management. NRT maintains a separate MemInfo structure for storing information about each allocation.

Cooperating with CPython

For NRT to cooperate with CPython, the NRT python binding provides adaptors for converting python objects that export a memory region. When such an object is used as an argument to a NPM function, a new MemInfo is created and it acquires a reference to the Python object. When a NPM value is returned to the Python interpreter, the associated MemInfo (if any) is checked. If the MemInfo references a Python object, the underlying Python object is released and returned instead. Otherwise, the MemInfo is wrapped in a Python object and returned. Additional process maybe required depending on the type.

The current implementation supports Numpy array and any buffer-exporting types.

Compiler-side Cooperation

NRT reference counting requires the compiler to emit incref/decref operations according to the usage. When the reference count drops to zero, the compiler must call the destructor routine in NRT.

Optimizations

The compiler is allowed to emit incref/decref operations naively. It relies on an optimization pass to remove redundant reference count operations.

A new optimization pass is implemented in version 0.52.0 to remove reference count operations that fall into the following four categories of control-flow structure—per basic-block, diamond, fanout, fanout+raise. See the documentation for NUMBA_LLVM_REFPRUNE_FLAGS for their descriptions.

The old optimization pass runs at block level to avoid control flow analysis. It depends on LLVM function optimization pass to simplify the control flow, stack-to-register, and simplify instructions. It works by matching and removing incref and decref pairs within each block. The old pass can be enabled by setting NUMBA_LLVM_REFPRUNE_PASS to 0.

Important assumptions

Both the old (pre-0.52.0) and the new (post-0.52.0) optimization passes assume that the only function that can consume a reference is NRT_decref. It is important that there are no other functions that will consume references. Since the passes operate on LLVM IR, the “functions” here are referring to any callee in a LLVM call instruction.

To summarize, all functions exposed to the refcount optimization pass must not consume counted references unless done so via NRT_decref.
Quirks of the old optimization pass

Since the pre-0.52.0 refcount optimization pass requires the LLVM function optimization pass, the pass works on the LLVM IR as text. The optimized IR is then materialized again as a new LLVM in-memory bitcode object.

Debugging Leaks

To debug reference leaks in NRT MemInfo, each MemInfo python object has a .refcount attribute for inspection. To get the MemInfo from a ndarray allocated by NRT, use the .base attribute.

To debug memory leaks in NRT, the numba.core.runtime.rtsys defines .get_allocation_stats(). It returns a namedtuple containing the number of allocation and deallocation since the start of the program. Checking that the allocation and deallocation counters are matching is the simplest way to know if the NRT is leaking.

Debugging Leaks in C

The start of numba/core/runtime/nrt.h has these lines:

```c
/* Debugging facilities - enabled at compile-time */
/* #undef NDEBUG */
#if 0
#define NRT_Debug(X) X
#else
#define NRT_Debug(X) if (0) { X; }
#endif
```

Undefining NDEBUG (uncomment the #undef NDEBUG line) enables the assertion check in NRT.

Enabling the NRT_Debug (replace #if 0 with #if 1) turns on debug print inside NRT.

6.7.2 Recursion Support

During the compilation of a pair of mutually recursive functions, one of the functions will contain unresolved symbol references since the compiler handles one function at a time. The memory for the unresolved symbols is allocated and initialized to the address of the unresolved symbol abort function (nrt_unresolved_abort) just before the machine code is generated by LLVM. These symbols are tracked and resolved as new functions are compiled. If a bug prevents the resolution of these symbols, the abort function will be called, raising a RuntimeError exception.

The unresolved symbol abort function is defined in the NRT with a zero-argument signature. The caller is safe to call it with arbitrary number of arguments. Therefore, it is safe to be used in place of the intended callee.

6.7.3 Using the NRT from C code

Externally compiled C code should use the NRT_api_functions struct as a function table to access the NRT API. The struct is defined in numba/core/runtime/nrt_external.h. Users can use the utility function numba.extending.include_path() to determine the include directory for Numba provided C headers.

Listing 1: numba/core/runtime/nrt_external.h

```c
#ifndef NUMBA_NRT_EXTERNAL_H_
#define NUMBA_NRT_EXTERNAL_H_
```

(continues on next page)
#include <stdlib.h>

typedef struct MemInfo NRT_MemInfo;

typedef void NRT_managed_dtor(void *data);

typedef void *(*NRT_external_malloc_func)(size_t size, void *opaque_data);

typedef void *(*NRT_external_realloc_func)(void *ptr, size_t new_size, void *opaque_data);

typedef void *(*NRT_external_free_func)(void *ptr, void *opaque_data);

struct ExternalMemAllocator {
    NRT_external_malloc_func malloc;
    NRT_external_realloc_func realloc;
    NRT_external_free_func free;
    void *opaque_data;
};

typedef struct ExternalMemAllocator NRT_ExternalAllocator;

typedef struct {
    /* Methods to create MemInfos.
       MemInfos are like smart pointers for objects that are managed by the Numba. */
    /* Allocate memory
       *nbytes* is the number of bytes to be allocated
       Returning a new reference.
       */
    NRT_MemInfo* (*allocate)(size_t nbytes);
    /* Allocates memory using an external allocator but still using Numba's MemInfo.
       */
    NRT_MemInfo* (*allocate_external)(size_t nbytes, NRT_ExternalAllocator *allocator);
    /* Convert externally allocated memory into a MemInfo.
       *data* is the memory pointer
       *dtor* is the deallocator of the memory
       */
    NRT_MemInfo* (*manage_memory)(void *data, NRT_managed_dtor dtor);
    /* Acquire a reference */
    void (*acquire)(NRT_MemInfo* mi);
    /* Release a reference */
    void (*release)(NRT_MemInfo* mi);
    /* Get MemInfo data pointer */
};
Inside Numba compiled code, the `numba.core.unsafe.nrt.NRT_get_api()` intrinsic can be used to obtain a pointer to the `NRT_api_functions`.

Here is an example that uses the `nrt_external.h`:

```c
#include <stdio.h>
#include "numba/core/runtime/nrt_external.h"

void my_dtor(void *ptr) {
    free(ptr);
}

NRT_MemInfo* my_allocate(NRT_api_functions *nrt) {
    /* heap allocate some memory */
    void *data = malloc(10);
    /* wrap the allocated memory; yield a new reference */
    NRT_MemInfo *mi = nrt->manage_memory(data, my_dtor);
    /* acquire reference */
    nrt->acquire(mi);
    /* release reference */
    nrt->release(mi);
    return mi;
}
```

It is important to ensure that the NRT is initialized prior to making calls to it, calling `numba.core.runtime.nrt.rtsys.initialize(context)` from Python will have the desired effect. Similarly the code snippet:

```python
from numba.core.registry import cpu_target  # Get the CPU target singleton
cpu_target.target_context  # Access the target_context property to initialize
```

will achieve the same specifically for Numba’s CPU target (the default). Failure to initialize the NRT will result in access violations as function pointers for various internal atomic operations will be missing in the `NRT_MemSys` struct.

### 6.7.4 Future Plan

The plan for NRT is to make a standalone shared library that can be linked to Numba compiled code, including use within the Python interpreter and without the Python interpreter. To make that work, we will be doing some refactoring:

- `numba NPM` code references statically compiled code in “helperlib.c”. Those functions should be moved to NRT.
6.8 Using the Numba Rewrite Pass for Fun and Optimization

6.8.1 Overview

This section introduces intermediate representation (IR) rewrites, and how they can be used to implement optimizations. As discussed earlier in “Stage 5a: Rewrite typed IR”, rewriting the Numba IR allows us to perform optimizations that would be much more difficult to perform at the lower LLVM level. Similar to the Numba type and lowering subsystems, the rewrite subsystem is user extensible. This extensibility affords Numba the possibility of supporting a wide variety of domain-specific optimizations (DSO’s).

The remaining subsections detail the mechanics of implementing a rewrite, registering a rewrite with the rewrite registry, and provide examples of adding new rewrites, as well as internals of the array expression optimization pass. We conclude by reviewing some use cases exposed in the examples, as well as reviewing any points where developers should take care.

6.8.2 Rewriting Passes

Rewriting passes have a simple `match()` and `apply()` interface. The division between matching and rewriting follows how one would define a term rewrite in a declarative domain-specific languages (DSL’s). In such DSL’s, one may write a rewrite as follows:

```
<match> => <replacement>
```

The `<match>` and `<replacement>` symbols represent IR term expressions, where the left-hand side presents a pattern to match, and the right-hand side an IR term constructor to build upon matching. Whenever the rewrite matches an IR pattern, any free variables in the left-hand side are bound within a custom environment. When applied, the rewrite uses the pattern matching environment to bind any free variables in the right-hand side.

As Python is not commonly used in a declarative capacity, Numba uses object state to handle the transfer of information between the matching and application steps.

The Rewrite Base Class

```python
class Rewrite
    The Rewrite class simply defines an abstract base class for Numba rewrites. Developers should define rewrites as subclasses of this base type, overloading the `match()` and `apply()` methods.

    pipeline
        The pipeline attribute contains the numba.compiler.Pipeline instance that is currently compiling the function under consideration for rewriting.

    __init__(self, pipeline, *args, **kws)
        The base constructor for rewrites simply stashes its arguments into attributes of the same name. Unless being used in debugging or testing, rewrites should only be constructed by the RewriteRegistry in the RewriteRegistry.apply() method, and the construction interface should remain stable (though the pipeline will commonly contain just about everything there is to know).

    match(self, block, typemap, callmap)
        The `match()` method takes four arguments other than `self`:
        - `func_ir`: This is an instance of numba.ir.FunctionIR for the function being rewritten.
        - `block`: This is an instance of numba.ir.Block. The matching method should iterate over the instructions contained in the numba.ir.Block.body member.
```
• typemap: This is a Python \texttt{dict} instance mapping from symbol names in the IR, represented as strings, to Numba types.

• callmap: This is another \texttt{dict} instance mapping from calls, represented as \texttt{numba.ir.Expr} instances, to their corresponding call site type signatures, represented as a \texttt{numba.typing.templates.Signature} instance.

The \texttt{match()} method should return a \texttt{bool} result. A \texttt{True} result should indicate that one or more matches were found, and the \texttt{apply()} method will return a new replacement \texttt{numba.ir.Block} instance. A \texttt{False} result should indicate that no matches were found, and subsequent calls to \texttt{apply()} will return undefined or invalid results.

\texttt{apply(self)}

The \texttt{apply()} method should only be invoked following a successful call to \texttt{match()}. This method takes no additional parameters other than \texttt{self}, and should return a replacement \texttt{numba.ir.Block} instance.

As mentioned above, the behavior of calling \texttt{apply()} is undefined unless \texttt{match()} has already been called and returned \texttt{True}.

\section*{Subclassing Rewrite}

Before going into the expectations for the overloaded methods any \texttt{Rewrite} subclass must have, let’s step back a minute to review what is taking place here. By providing an extensible compiler, Numba opens itself to user-defined code generators which may be incomplete, or worse, incorrect. When a code generator goes awry, it can cause abnormal program behavior or early termination. User-defined rewrites add a new level of complexity because they must not only generate correct code, but the code they generate should ensure that the compiler does not get stuck in a match/apply loop. Non-termination by the compiler will directly lead to non-termination of user function calls.

There are several ways to help ensure that a rewrite terminates:

• \textit{Typing}: A rewrite should generally attempt to decompose composite types, and avoid composing new types. If the rewrite is matching a specific type, changing expression types to a lower-level type will ensure they will no long match after the rewrite is applied.

• \textit{Special instructions}: A rewrite may synthesize custom operators or use special functions in the target IR. This technique again generates code that is no longer within the domain of the original match, and the rewrite will terminate.

In the “\textit{Case study: Array Expressions}” subsection, below, we’ll see how the array expression rewriter uses both of these techniques.

\section*{Overloading Rewrite.match()}

Every rewrite developer should seek to have their implementation of \texttt{match()} return a \texttt{False} value as quickly as possible. Numba is a just-in-time compiler, and adding compilation time ultimately adds to the user’s run time. When a rewrite returns \texttt{False} for a given block, the registry will no longer process that block with that rewrite, and the compiler is that much closer to proceeding to lowering.

This need for timeliness has to be balanced against collecting the necessary information to make a match for a rewrite. Rewrite developers should be comfortable adding dynamic attributes to their subclasses, and then having these new attributes guide construction of the replacement basic block.
Overloading Rewrite\texttt{.apply()}

The \texttt{apply()} method should return a replacement \texttt{numba.ir.Block} instance to replace the basic block that contained a match for the rewrite. As mentioned above, the IR built by \texttt{apply()} methods should preserve the semantics of the user’s code, but also seek to avoid generating another match for the same rewrite or set of rewrites.

### 6.8.3 The Rewrite Registry

When you want to include a rewrite in the rewrite pass, you should register it with the rewrite registry. The \texttt{numba.rewrites} module provides both the abstract base class and a class decorator for hooking into the Numba rewrite subsystem. The following illustrates a stub definition of a new rewrite:

```python
from numba import rewrites

@rewrites.register_rewrite
class MyRewrite(rewrites.Rewrite):
    def match(self, block, typemap, calltypes):
        raise NotImplementedError("FIXME")

    def apply(self):
        raise NotImplementedError("FIXME")
```

Developers should note that using the class decorator as shown above will register a rewrite at import time. It is the developer’s responsibility to ensure their extensions are loaded before compilation starts.

### 6.8.4 Case study: Array Expressions

This subsection looks at the array expression rewriter in more depth. The array expression rewriter, and most of its support functionality, are found in the \texttt{numba.npyufunc.array_exprs} module. The rewriting pass itself is implemented in the \texttt{RewriteArrayExprs} class. In addition to the rewriter, the \texttt{array_exprs} module includes a function for lowering array expressions, \texttt{\_\_\_lower_array_expr()}. The overall optimization process is as follows:

- \texttt{RewriteArrayExprs.match()}: The rewrite pass looks for two or more array operations that form an array expression.
- \texttt{RewriteArrayExprs.apply()}: Once an array expression is found, the rewriter replaces the individual array operations with a new kind of IR expression, the \texttt{arrayexpr}.
- \texttt{numba.npyufunc.array_exprs.\_\_\_lower_array_expr()}: During lowering, the code generator calls \texttt{\_\_\_lower_array_expr()} whenever it finds an \texttt{arrayexpr} IR expression.

More details on each step of the optimization are given below.
The RewriteArrayExprs.match() method

The array expression optimization pass starts by looking for array operations, including calls to supported ufunc's and user-defined DUFunc's. Numba IR follows the conventions of a static single assignment (SSA) language, meaning that the search for array operators begins with looking for assignment instructions.

When the rewriting pass calls the RewriteArrayExprs.match() method, it first checks to see if it can trivially reject the basic block. If the method determines the block to be a candidate for matching, it sets up the following state variables in the rewrite object:

- **crnt_block**: The current basic block being matched.
- **typemap**: The typemap for the function being matched.
- **matches**: A list of variable names that reference array expressions.
- **array_assigns**: A map from assignment variable names to the actual assignment instructions that define the given variable.
- **const_assigns**: A map from assignment variable names to the constant valued expression that defines the constant variable.

At this point, the match method iterates over the assignment instructions in the input basic block. For each assignment instruction, the matcher looks for one of two things:

- Array operations: If the right-hand side of the assignment instruction is an expression, and the result of that expression is an array type, the matcher checks to see if the expression is either a known array operation, or a call to a universal function. If an array operator is found, the matcher stores the left-hand variable name and the whole instruction in the **array_assigns** member. Finally, the matcher tests to see if any operands of the array operation have also been identified as targets of other array operations. If one or more operands are also targets of array operations, then the matcher will also append the left-hand side variable name to the **matches** member.
- Constants: Constants (even scalars) can be operands to array operations. Without worrying about the constant being apart of an array expression, the matcher stores constant names and values in the **const_assigns** member.

The end of the matching method simply checks for a non-empty **matches** list, returning True if there were one or more matches, and False when **matches** is empty.

The RewriteArrayExprs.apply() method

When one or matching array expressions are found by RewriteArrayExprs.match(), the rewriting pass will call RewriteArrayExprs.apply(). The apply method works in two passes. The first pass iterates over the matches found, and builds a map from instructions in the old basic block to new instructions in the new basic block. The second pass iterates over the instructions in the old basic block, copying instructions that are not changed by the rewrite, and replacing or deleting instructions that were identified by the first pass.

The RewriteArrayExprs._handle_matches() implements the first pass of the code generation portion of the rewrite. For each match, this method builds a special IR expression that contains an expression tree for the array expression. To compute the leaves of the expression tree, the _handle_matches() method iterates over the operands of the identified root operation. If the operand is another array operation, it is translated into an expression sub-tree. If the operand is a constant, _handle_matches() copies the constant value. Otherwise, the operand is marked as being used by an array expression. As the method builds array expression nodes, it builds a map from old instructions to new instructions (replace_map), as well as sets of variables that may have moved (used_vars), and variables that should be removed altogether (dead_vars). These three data structures are returned back to the calling RewriteArrayExprs.apply() method.

The remaining part of the RewriteArrayExprs.apply() method iterates over the instructions in the old basic block. For each instruction, this method either replaces, deletes, or duplicates that instruction based on the results
of `RewriteArrayExprs._handle_matches()`. The following list describes how the optimization handles individual instructions:

- When an instruction is an assignment, `apply()` checks to see if it is in the replacement instruction map. When an assignment instruction is found in the instruction map, `apply()` must then check to see if the replacement instruction is also in the replacement map. The optimizer continues this check until it either arrives at a `None` value or an instruction that isn't in the replacement map. Instructions that have a replacement that is `None` are deleted. Instructions that have a non-`None` replacement are replaced. Assignment instructions not in the replacement map are appended to the new basic block with no changes made.

- When the instruction is a delete instruction, the rewrite checks to see if it deletes a variable that may still be used by a later array expression, or if it deletes a dead variable. Delete instructions for used variables are added to a map of deferred delete instructions that `apply()` uses to move them past any uses of that variable. The loop copies delete instructions for non-dead variables, and ignores delete instructions for dead variables (effectively removing them from the basic block).

- All other instructions are appended to the new basic block.

Finally, the `apply()` method returns the new basic block for lowering.

### The `_lower_array_expr()` function

If we left things at just the rewrite, then the lowering stage of the compiler would fail, complaining it doesn’t know how to lower `arrayexpr` operations. We start by hooking a lowering function into the target context whenever the `RewriteArrayExprs` class is instantiated by the compiler. This hook causes the lowering pass to call `_lower_array_expr()` whenever it encounters an `arrayexpr` operator.

This function has two steps:

- Synthesize a Python function that implements the array expression: This new Python function essentially behaves like a Numpy `ufunc`, returning the result of the expression on scalar values in the broadcasted array arguments. The lowering function accomplishes this by translating from the array expression tree into a Python AST.

- Compile the synthetic Python function into a kernel: At this point, the lowering function relies on existing code for lowering `ufunc` and DUFunc kernels, calling `numba.targets.numpyimpl.numpy_ufunc_kernel()` after defining how to lower calls to the synthetic function.

The end result is similar to loop lifting in Numba’s object mode.

### 6.8.5 Conclusions and Caveats

We have seen how to implement rewrites in Numba, starting with the interface, and ending with an actual optimization. The key points of this section are:

- When writing a good plug-in, the matcher should try to get a go/no-go result as soon as possible.

- The rewrite application portion can be more computationally expensive, but should still generate code that won’t cause infinite loops in the compiler.

- We use object state to communicate any results of matching to the rewrite application pass.
6.9 Live Variable Analysis

(Related issue https://github.com/numba/numba/pull/1611)

Numba uses reference-counting for garbage collection, a technique that requires cooperation by the compiler. The Numba IR encodes the location where a decref must be inserted. These locations are determined by live variable analysis. The corresponding source code is the `_insert_var_dels()` method in https://github.com/numba/numba/blob/main/numba/interpreter.py.

In Python semantic, once a variable is defined inside a function, it is alive until the variable is explicitly deleted or the function scope is ended. However, Numba analyzes the code to determine the minimum bound of the lifetime of each variable by its definition and usages during compilation. As soon as a variable is unreachable, a `del` instruction is inserted at the closest basic-block (either at the start of the next block(s) or at the end of the current block). This means variables can be released earlier than in regular Python code.

The behavior of the live variable analysis affects memory usage of the compiled code. Internally, Numba does not differentiate temporary variables and user variables. Since each operation generates at least one temporary variable, a function can accumulate a high number of temporary variables if they are not released as soon as possible. Our generator implementation can benefit from early releasing of variables, which reduces the size of the state to suspend at each yield point.

6.9.1 Notes on behavior of the live variable analysis

Variable deleted before definition

(Related issue: https://github.com/numba/numba/pull/1738)

When a variable lifetime is confined within the loop body (its definition and usage does not escape the loop body), like:

```python
def f(arr):
    # BB 0
    res = 0
    # BB 1
    for i in (0, 1):
        # BB 2
        t = arr[i]
        if t[i] > 1:
            # BB 3
            res += t[i]
        # BB 4
    return res
```

Variable `t` is never referenced outside of the loop. A `del` instruction is emitted for `t` at the head of the loop (BB 1) before a variable is defined. The reason is obvious once we know the control flow graph:

```
+-----------------------------------> BB4
|                                      |
|                                      |
| BB 0 -- BB 1 -- BB 2 -- BB 3 |
|   ^   |   |    |
|   V   V   |
+---------------------+
```

Variable `t` is defined in BB 1. In BB 2, the evaluation of `t[i] > 1` uses `t`, which is the last use if execution takes the false branch and goto BB 1. In BB 3, `t` is only used in `res += t[i]`, which is the last use if execution takes the true
branch. Because BB 3, an outgoing branch of BB 2 uses t, t must be deleted at the common predecessor. The closest point is BB 1, which does not have t defined from the incoming edge of BB 0.

Alternatively, if t is deleted at BB 4, we will still have to delete the variable before its definition because BB4 can be executed without executing the loop body (BB 2 and BB 3), where the variable is defined.

6.10 Listings

This shows listings from compiler internal registries (e.g. lowering definitions). The information is provided as developer reference. When possible, links to source code are provided via github links.

6.10.1 New style listings

The following listings are generated from numba.help.inspector.write_listings(). Users can run python -m numba.help.inspector --format=rst <package> to recreate the documentation.

Listings for builtins

**builtins**

builtins.abs()

- defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

builtinschr()

- defined by ol_chr(i) at numba/cpython/unicode.py:2386-2391

builtins.divmod()

- defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

builtins.hash()

- defined by hash_overload(obj) at numba/cpython/hashing.py:49-53

builtins.isinstance()

- defined by ol_isinstance(var, typs) at numba/cpython/builtins.py:682-779

builtins.iter()

- defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

builtins.len()

- defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>
• defined by unicode_len(s) at numba/cpython/unicode.py:442-447
• defined by charseq_len(s) at numba/cpython/charseq.py:348-369
• defined by literal_list_len(lst) at numba/cpython/listobj.py:1228-1233
• defined by impl_len(d) at numba/typed/dictobject.py:661-671
• defined by literalstrkeydict_impl_len(d) at numba/typed/dictobject.py:1255-1260
• defined by impl_len(l) at numba/typed/listobject.py:402-410
• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorator.<locals>.Template'>

builtins.max()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorator.<locals>.Template'>
• defined by indval_max(indval1, indval2) at numba/cpython/builtins.py:549-557
• defined by iterable_max(iterable) at numba/cpython/builtins.py:582-584

builtins.min()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorator.<locals>.Template'>
• defined by indval_min(indval1, indval2) at numba/cpython/builtins.py:538-546
• defined by iterable_min(iterable) at numba/cpython/builtins.py:577-579

builtins.next()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorator.<locals>.Template'>

builtins.ord()

• defined by ol_ord(c) at numba/cpython/unicode.py:2346-2355

builtins.pow()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorator.<locals>.Template'>

builtins.print()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorator.<locals>.Template'>

builtins.round()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorator.<locals>.Template'>

builtins.sorted()

• defined by ol_sorted(iterable, key=None, reverse=False) at numba/cpython/listobj.py:1110-1123

builtins.sum()
• defined by \texttt{ol\_sum(iterable, start=0)} at numba/cpython/builtins.py:619-652

Not showing 25 unsupported functions.
supported $= \frac{16}{41} = 39.02\%$

\textbf{Listings for math}

\texttt{math}

\texttt{math.acos()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.acosh()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.asin()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.asinh()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.atan()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.atan2()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.atanh()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.ceil()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.copysign()}

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

\texttt{math.cos()}
math.cosh()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.degrees()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.erf()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.erfc()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.exp()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.expm1()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.fabs()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.floor()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.frexp()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.gamma()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.gcd()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.hypot()
• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.isfinite()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.isinf()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.isnan()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.ldexp()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.lgamma()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.log()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.log10()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.log1p()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.pow()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.radians()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.sin()

• defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

math.sinh()
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- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

math.sqrt()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

math.tan()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

math.tanh()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

math.trunc()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

Not showing 7 unsupported functions.
supported = 38 / 45 = 84.44%

Listings for cmath

cmath

cmath.acos()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

cmath.acosh()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

cmath.asin()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

cmath.asinh()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

cmath.atan()  
- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

cmath.atanh()
• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.cos()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.cosh()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.exp()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.isfinite()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.isinf()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.isnan()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.log()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.log10()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.phase()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.polar()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.rect()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>

cmath.sin()
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- Defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

`cmath.sinh()`

- Defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

`cmath.sqrt()`

- Defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

`cmath.tan()`

- Defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

`cmath.tanh()`

- Defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

Not showing 1 unsupported functions.
supported = 22 / 23 = 95.65%

**Listings for numpy**

`numpy`

`numpy.all()`

- Defined by `np_all(a)` at numba/np/arraymath.py:857-866

`numpy.amax()`

- Defined by `<class 'abc.Numpy_redirect_max'>`

`numpy.amin()`

- Defined by `<class 'abc.Numpy_redirect_min'>`

`numpy.angle()`

- Defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

- Defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.any()`

- Defined by `np_any(a)` at numba/np/arraymath.py:869-878

`numpy.append()`

- Defined by `np_append(arr, values, axis=None)` at numba/np/arrayobj.py:1832-1855
numpy.arange()

• defined by np.arange(start, stop=None, step=None, dtype=None) at numba/np/arrayobj.py:4111-4176

numpy.argmax()

• defined by array.argmax(arr, axis=None) at numba/np/arraymath.py:837-854

numpy.argmin()

• defined by array.argmin(arr, axis=None) at numba/np/arraymath.py:707-724

numpy.argsort()

• defined by <class 'abc.Numpy_redirect_argsort'>

numpy.argwhere()

• defined by np.argwhere(a) at numba/np/arraymath.py:2985-3017

numpy.around()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.array()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.array_equal()

• defined by np.array_equal(a, b) at numba/np/arraymath.py:3630-3649

numpy.array_split()

• defined by np.array_split(ary, indices_or_sections, axis=0) at numba/np/arrayobj.py:5252-5310

numpy.asarray()

• defined by np.asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpy.asarray_chkfinite()

• defined by np.asarray_chkfinite(a, dtype=None) at numba/np/arraymath.py:4432-4454

numpy.ascontiguousarray()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
numpy.asfarray()

- defined by np_asfarray(a, dtype=<class 'numpy.float64'>) at numba/np/arraymath.py:4340-4352

numpy.asfortranarray()

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.atleast_1d()

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.atleast_2d()

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.atleast_3d()

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.average()

- defined by np_average(arr, axis=None, weights=None) at numba/np/arraymath.py:881-915

numpy.bartlett()

- defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.bincount()

- defined by np_bincount(a, weights=None, minlength=0) at numba/np/arraymath.py:3685-3740

numpy.blackman()

- defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.broadcast_to()

- defined by numpy_broadcast_to(array, shape) at numba/np/arrayobj.py:1360-1382

numpy.clip()
• defined by `np_clip(a, a_min, a_max, out=None)` at numba/np/arrayobj.py:1900-1940

`numpy.column_stack()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.concatenate()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.correlate()`

• defined by `np_correlate(a, v)` at numba/np/arraymath.py:4213-4258

`numpy.count_nonzero()`

• defined by `np_count_nonzero(arr, axis=None)` at numba/np/arraymath.py:3523-3537

`numpy.cov()`

• defined by `np_cov(m, y=None, rowvar=True, bias=False, ddof=None)` at numba/np/arraymath.py:2889-2945

`numpy.cross()`

• defined by `np_cross(a, b)` at numba/np/arraymath.py:4690-4712

`numpy.cumprod()`

• defined by `<class 'abc.Numpy_redirect_cumprod'>`

`numpy.cumsum()`

• defined by `<class 'abc.Numpy_redirect_cumsum'>`

`numpy.delete()`
• defined by np_delete(arr, obj) at numba/numpy/arraymath.py:3544-3588

numpy.diag()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.diff()

• defined by np_diff_impl(a, n=1) at numba/numpy/arraymath.py:3591-3627

numpy.digitize()

• defined by np_digitize(x, bins, right=False) at numba/numpy/arraymath.py:3808-3934

numpy.dot()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.dstack()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.ediff1d()

• defined by np_ediff1d(ary, to_end=None, to_begin=None) at numba/numpy/arraymath.py:1937-1992

numpy.empty()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.empty_like()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.expand_dims()
numpy.extract()
    • defined by `np_extract(condition, arr)` at `numba/numpy/arraymath.py:4355-4378`

numpy.eye()
    • defined by `numpy.eye(N, M=None, k=0, dtype=class 'float')` at `numba/numpy/arrayobj.py:3948-3971`

numpy.fill_diagonal()
    • defined by `np_fill_diagonal(a, val, wrap=False)` at `numba/numpy/arraymath.py:3122-3152`

numpy.flatnonzero()
    • defined by `np_flatnonzero(a)` at `numba/numpy/arraymath.py:3020-3035`

numpy.flip()
    • defined by `np_flip(a)` at `numba/numpy/arrayobj.py:5238-5249`

numpy.fliplr()
    • defined by `np_flip_lr(a)` at `numba/numpy/arrayobj.py:5174-5188`

numpy.flipud()
    • defined by `np_flip_ud(a)` at `numba/numpy/arrayobj.py:5191-5205`

numpy.frombuffer()
    • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
    • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

numpy.full()
    • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
    • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

numpy.full_like()
    • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
    • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

numpy.hamming()
    • defined by `window_generator.<locals>.window_overload(M)` at `numba/numpy/arraymath.py:4509-4521`

numpy.hanning()
• defined by \texttt{window_generator.<locals>.window_overload(M)} at numba/np/arraymath.py:4509-4521

\texttt{numpy.histogram()}

• defined by \texttt{np_histogram(a, bins=10, range=None)} at numba/np/arraymath.py:3940-4020

\texttt{numpy.hstack()}

• defined by \texttt{._OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)} at numba/core/overload_glue.py:131-181

\texttt{numpy.identity()}

• defined by \texttt{._OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)} at numba/core/overload_glue.py:131-181

\texttt{numpy.imag()}

• defined by \texttt{np_imag(a)} at numba/np/arraymath.py:3498-3503

\texttt{numpy.interp()}

• defined by \texttt{np_interp(x, xp, fp)} at numba/np/arraymath.py:2640-2701

\texttt{numpy.intersect1d()}

• defined by \texttt{jit_np_intersect1d(ar1, ar2)} at numba/np/arraymath.py:3652-3672

\texttt{numpy.iscomplex()}

• defined by \texttt{np_iscomplex(x)} at numba/np/arraymath.py:931-936

\texttt{numpy.iscomplexobj()}

• defined by \texttt{iscomplexobj(x)} at numba/np/arraymath.py:947-964

\texttt{numpy.isneginf()}

• defined by \texttt{isneginf(x, out=None)} at numba/np/arraymath.py:999-1002

\texttt{numpy.isposinf()}

• defined by \texttt{isposinf(x, out=None)} at numba/np/arraymath.py:1005-1008

\texttt{numpy.isreal()}

• defined by \texttt{np_isreal(x)} at numba/np/arraymath.py:939-944

\texttt{numpy.isrealobj()}

• defined by \texttt{isrealobj(x)} at numba/np/arraymath.py:967-974

\texttt{numpy.isscalar()}

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• defined by \texttt{np.isscalar}(\texttt{num}) at 
  \texttt{numba/np/arrmath.py:977-983}

\texttt{numpy.kaiser()}

• defined by \texttt{np.kaiser}(M, beta) at 
  \texttt{numba/np/arrmath.py:4627-4646}

\texttt{numpy.kron()}

• defined by \texttt{kron_impl}(a, b) at 
  \texttt{numba/np/linalg.py:2709-2763}

\texttt{numpy.linspace()}

• defined by \texttt{numpy.linspace}(\texttt{start}, \texttt{stop}, \texttt{num}=50) at 
  \texttt{numba/np/arrobj.py:1645-1658}

\texttt{numpy.max()}

  Alias to: \texttt{numpy.amax}

  • defined by \texttt{<class 'abc.Numpy_redirect_max'>}

\texttt{numpy.mean()}

• defined by \texttt{<class 'abc.Numpy_redirect_mean'>}

\texttt{numpy.median()}

• defined by \texttt{np.median}(\texttt{a}) at 
  \texttt{numba/np/arrmath.py:1448-1460}

\texttt{numpy.min()}

  Alias to: \texttt{numpy.amin}

  • defined by \texttt{<class 'abc.Numpy_redirect_min'>}

\texttt{numpy.nancumprod()}

• defined by \texttt{np.nancumprod}(\texttt{a}) at 
  \texttt{numba/np/arrmath.py:1193-1215}

\texttt{numpy.nancumsum()}

• defined by \texttt{np.nancumsum}(\texttt{a}) at 
  \texttt{numba/np/arrmath.py:1218-1240}

\texttt{numpy.nanmax()}

• defined by \texttt{np.nanmax}(\texttt{a}) at 
  \texttt{numba/np/arrmath.py:1084-1090}

\texttt{numpy.nanmean()}

• defined by \texttt{np.nanmean}(\texttt{a}) at 
  \texttt{numba/np/arrmath.py:1093-1110}

\texttt{numpy.nanmedian()}

• defined by \texttt{np.nanmedian}(\texttt{a}) at 
  \texttt{numba/np/arrmath.py:1634-1656}

\texttt{numpy.nanmin()}

\newpage
• defined by np_nanmin(a) at numba/np/arraymath.py:1075-1081

numpy.nanpercentile()

• defined by np_nanpercentile(a, q) at numba/np/arraymath.py:1613-1617

numpy.nanprod()

• defined by np_nanprod(a) at numba/np/arraymath.py:1171-1190

numpy.nanquantile()

• defined by np_nanquantile(a, q) at numba/np/arraymath.py:1627-1631

numpy.nanstd()

• defined by np_nanstd(a) at numba/np/arraymath.py:1138-1146

numpy.nansum()

• defined by np_nansum(a) at numba/np/arraymath.py:1149-1168

numpy.nanvar()

• defined by np_nanvar(a) at numba/np/arraymath.py:1113-1135

numpy.nonzero()

• defined by <class 'abc.Numpy_redirect_nonzero'>

numpy.ones()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.ones_like()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.outer()

• defined by outer_impl(a, b, out=none) at numba/np/linalg.py:2632-2643

numpy.partition()

• defined by np_partition(a, kth) at numba/np/arraymath.py:1715-1737

numpy.percentile()

• defined by np_percentile(a, q) at numba/np/arraymath.py:1606-1610

numpy.prod()

• defined by <class 'abc.Numpy_redirect_prod'>
numpy.ptp()
  • defined by np_ptp(a) at numba/numpy/np/arraymath.py:1302-1328

numpy.quantile()
  • defined by np_quantile(a, q) at numba/numpy/np/arraymath.py:1620-1624

numpy.ravel()
  • defined by <class 'abc.Numpy_redirect_ravel'>

numpy.real()
  • defined by np_real(a) at numba/numpy/np/arraymath.py:3490-3495

numpy.repeat()
  • defined by np_repeat(a, repeats) at numba/numpy/np/arrayobj.py:2098-2140

numpy.reshape()
  • defined by np_reshape(a, shape) at numba/numpy/np/arrayobj.py:1825-1829

numpy.roll()
  • defined by np_roll(a, shift) at numba/numpy/np/arraymath.py:2127-2147

numpy.roots()
  • defined by roots_impl(p) at numba/numpy/np/polynomial.py:14-59

numpy.rot90()
  • defined by numpy_rot90(arr, k=1) at numba/numpy/np/arrayobj.py:1661-1685

numpy.round()
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload Glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload Glue.py:131-181

numpy.round_()
  Alias to: numpy.round
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload Glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload Glue.py:131-181

numpy.row_stack()
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload Glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload Glue.py:131-181

numpy.searchsorted()
• defined by `searchsorted(a, v, side='left')` at numba/np/arraysmath.py:3773-3805

`numpy.select()`

• defined by `np_select(condlist, choicelist, default=0)` at numba/np/arraysmath.py:4381-4429

`numpy.shape()`

• defined by `np_shape(a)` at numba/np/arrayobj.py:2076-2083

`numpy.sinc()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.sort()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.split()`

• defined by `np_split(ary, indices_or_sections, axis=0)` at numba/np/arrayobj.py:5313-5337

`numpy.stack()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.std()`

• defined by `<class 'abc.Numpy_redirect_std'>`

`numpy.sum()`

• defined by `<class 'abc.Numpy_redirect_sum'>`

`numpy.swapaxes()`

• defined by `numpy_swapaxes(arr, axis1, axis2)` at numba/np/arrayobj.py:5544-5577

`numpy.take()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.take_along_axis()`

• defined by `arr_take_along_axis(arr, indices, axis)` at numba/np/arrayobj.py:5641-5682
numpy.trace()
  • defined by matrix_trace_impl(a, offset=0) at numba/np/linalg.py:2566-2594

numpy.transpose()
  • defined by numpy_transpose(a, axes=None) at numba/np/arrayobj.py:1610-1622

numpy.trapz()
  • defined by np_trapz(y, x=None, dx=1.0) at numba/np/arraymath.py:2029-2048

numpy.tri()
  • defined by np_tri(N, M=None, k=0) at numba/np/arraymath.py:1756-1767

numpy.tril()
  • defined by my_tril(m, k=0) at numba/np/arraysmath.py:1793-1817

numpy.tril_indices()
  • defined by np_tril_indices(n, k=0, m=None) at numba/np/arraysmath.py:1820-1831

numpy.tril_indices_from()
  • defined by np_tril_indices_from(arr, k=0) at numba/np/arraysmath.py:1834-1845

numpy.triu()
  • defined by my_triu(m, k=0) at numba/np/arraysmath.py:1854-1877

numpy.triu_indices()
  • defined by np_triu_indices(n, k=0, m=None) at numba/np/arraysmath.py:1880-1891

numpy.triu_indices_from()
  • defined by np_triu_indices_from(arr, k=0) at numba/np/arraysmath.py:1894-1905

numpy.unique()
  • defined by np_unique(a) at numba/np/arrayobj.py:2088-2095

numpy.vander()
  • defined by np_vander(x, N=None, increasing=False) at numba/np/arraysmath.py:2087-2124

numpy.var()
  • defined by <class 'abc.Numpy_redirect_var'>

numpy.vdot()
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.vstack()

Alias to: numpy.row_stack

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.where()

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.zeros()

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.zeros_like()

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 166 unsupported functions.
supported = 144 / 310 = 46.45%

numpy.compat

This module is not supported.

numpy.compat.py3k

This module is not supported.

numpy.compat.setup

This module is not supported.
numpy.core

numpy.core.all()
   Alias to: numpy.all
       • defined by np_all(a) at numba/np/arraymath.py:857-866

numpy.core.amax()
   Alias to: numpy.amax
       • defined by <class 'abc.Numpy_redirect_max'>

numpy.core.amin()
   Alias to: numpy.amin
       • defined by <class 'abc.Numpy_redirect_min'>

numpy.core.any()
   Alias to: numpy.any
       • defined by np_any(a) at numba/np/arraymath.py:869-878

numpy.core.arange()
   Alias to: numpy.arange
       • defined by np_arange(start, stop=None, step=None, dtype=None) at numba/np/arrayobj.py:4111-4176

numpy.core.argmax()
   Alias to: numpy.argmax
       • defined by array_argmax(arr, axis=None) at numba/np/arraymath.py:837-854

numpy.core.argmin()
   Alias to: numpy.argmin
       • defined by array_argmin(arr, axis=None) at numba/np/arraymath.py:707-724

numpy.core.argsort()
   Alias to: numpy.argsort
       • defined by <class 'abc.Numpy_redirect_argsort'>

numpy.core.argwhere()
   Alias to: numpy.argwhere
       • defined by np_argwhere(a) at numba/np/arraymath.py:2985-3017

numpy.core.around()
   Alias to: numpy.around
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.array()
   Alias to: numpy.array
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.core.array_equal()
   Alias to: numpy.array_equal
   • defined by np.array_equal(a, b) at numba/np/arraymath.py:3630-3649

numpy.core.asarray()
   Alias to: numpy.asarray
   • defined by np.asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpy.core.ascontiguousarray()
   Alias to: numpy.ascontiguousarray
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.asfortranarray()
   Alias to: numpy.asfortranarray
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.atleast_1d()
   Alias to: numpy.atleast_1d
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.atleast_2d()
   Alias to: numpy.atleast_2d
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.atleast_3d()
   Alias to: numpy.atleast_3d
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.clip()
   Alias to: numpy.clip
   • defined by np.clip(a, a_min, a_max, out=None) at numba/np/arrayobj.py:1900-1940

numpy.core.concatenate()
   Alias to: numpy.concatenate
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwags) at numba/core/overload_glue.py:131-181

```
numba.core.convolve()
  Alias to: numba.convolve
  - defined by np.convolve(a, v) at numba/np/arraymath.py:4261-4282
```

```
numba.core.correlate()
  Alias to: numba.correlate
  - defined by _np_correlate(a, v) at numba/np/arraymath.py:4213-4258
```

```
numba.core.count_nonzero()
  Alias to: numba.count_nonzero
  - defined by np.count_nonzero(arr, axis=None) at numba/np/arraymath.py:3523-3537
```

```
numba.core.cross()
  Alias to: numba.cross
  - defined by np.cross(a, b) at numba/np/arraymath.py:4690-4712
```

```
numba.core.cumprod()
  Alias to: numba.cumprod
  - defined by <class 'abc.Numpy_redirect_cumprod'>
```

```
numba.core.cumsum()
  Alias to: numba.cumsum
  - defined by <class 'abc.Numpy_redirect_cumsum'>
```

```
numba.core.dot()
  Alias to: numba.dot
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
```

```
numba.core.empty()
  Alias to: numba.empty
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
```

```
numba.core.empty_like()
  Alias to: numba.empty_like
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
```

```
numba.core.flatnonzero()
  Alias to: numba.flatnonzero
  - defined by np.flatnonzero(a) at numba/np/arraymath.py:3020-3035
```
numpy.core.frombuffer()
    Alias to: numpy.frombuffer
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.full()
    Alias to: numpy.full
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.full_like()
    Alias to: numpy.full_like
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.hstack()
    Alias to: numpy.hstack
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.identity()
    Alias to: numpy.identity
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.isscalar()
    Alias to: numpy.isscalar
    • defined by np.isscalar(num) at numba/numpyarraymath.py:977-983

numpy.core.linspace()
    Alias to: numpy.linspace
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.logspace()
    Alias to: numpy.logspace
    • defined by numpy.logspace(start, stop, num=50) at numba/numpyarrayobj.py:1645-1658
numpy.core.max()
    Alias to: numpy.amax
    • defined by <class 'abc.Numpy_redirect_max'>

numpy.core.mean()
    Alias to: numpy.mean
    • defined by <class 'abc.Numpy_redirect_mean'>

numpy.core.min()
    Alias to: numpy.amin
    • defined by <class 'abc.Numpy_redirect_min'>

numpy.core.nonzero()
    Alias to: numpy.nonzero
    • defined by <class 'abc.Numpy_redirect_nonzero'>

numpy.core.ones()
    Alias to: numpy.ones
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.core.ones_like()
    Alias to: numpy.ones_like
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.core.outer()
    Alias to: numpy.outer
    • defined by outer_impl(a, b, out=None) at numba/np/linalg.py:2632-2643

numpy.core.partition()
    Alias to: numpy.partition
    • defined by np.partition(a, kth) at numba/np/arraymath.py:1715-1737

numpy.core.prod()
    Alias to: numpy.prod
    • defined by <class 'abc.Numpy_redirect_prod'>

numpy.core.ptp()
    Alias to: numpy.ptp
    • defined by np.ptp(a) at numba/np/arraymath.py:1302-1328

numpy.core.ravel()
    Alias to: numpy.ravel
    • defined by <class 'abc.Numpy_redirect_ravel'>

numpy.core.repeat()
    Alias to: numpy.repeat
• defined by np_repeat(a, repeats) at numba/np/arrayobj.py:2098-2140

numpy.core.reshape()
   Alias to: numpy.reshape
   • defined by npreshape(a, shape) at numba/np/arrayobj.py:1825-1829

numpy.core.roll()
   Alias to: numpy.roll
   • defined by np_roll(a, shift) at numba/np/arraymath.py:2127-2147

numpy.core.round()
   Alias to: numpy.round
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.rounded()
   Alias to: numpy.rounded
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.searchsorted()
   Alias to: numpy.searchsorted
   • defined by searchsorted(a, v, side='left') at numba/np/arraymath.py:3773-3805

numpy.core.shape()
   Alias to: numpy.shape
   • defined by np_shape(a) at numba/np/arrayobj.py:2076-2083

numpy.core.sort()
   Alias to: numpy.sort
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.stack()
   Alias to: numpy.stack
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.std()
   Alias to: numpy.std
   • defined by <class 'abc.Numpy_redirect_std'>

numpy.core.sum()
   Alias to: numpy.sum
• defined by `<class 'abc.Numpy_redirect_sum'>`

`numpy.core.swapaxes()`

Alias to: `numpy.swapaxes`

• defined by `numpy_swapaxes(arr, axis1, axis2)` at `numba/np/arrayobj.py:5544-5577`

`numpy.core.take()`

Alias to: `numpy.take`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.core.trace()`

Alias to: `numpy.trace`

• defined by `matrix_trace_impl(a, offset=0)` at `numba/np/linalg.py:2566-2594`

`numpy.core.transpose()`

Alias to: `numpy.transpose`

• defined by `numpytranspose(a, axes=None)` at `numba/np/arrayobj.py:1610-1622`

`numpy.core.var()`

Alias to: `numpy.var`

• defined by `<class 'abc.Numpy_redirect_var'>`

`numpy.core.vdot()`

Alias to: `numpy.vdot`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.core.vstack()`

Alias to: `numpy.row_stack`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.core.where()`

Alias to: `numpy.where`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.core.zeros()`

Alias to: `numpy.zeros`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

```
numpy.core.zeros_like()
```

Alias to: `numpy.zeros_like`

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 77 unsupported functions.
supported = 70 / 147 = 47.62%

```
numpy.core.arrayprint
```

```
numpy.core.arrayprint.any()
```

Alias to: `numpy.any`

- defined by np.any(a) at numba/numpy/arraymath.py:869-878

```
numpy.core.arrayprint.array()
```

Alias to: `numpy.array`

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

```
numpy.core.arrayprint.asarray()
```

Alias to: `numpy.asarray`

- defined by np.asarray(a, dtype=None) at numba/numpy/arraymath.py:4285-4337

```
numpy.core.arrayprint.concatenate()
```

Alias to: `numpy.concatenate`

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 21 unsupported functions.
supported = 4 / 25 = 16.00%

```
numpy.core.defchararray
```

```
numpy.core.defchararray.narray()
```

Alias to: `numpy.array`

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Chapter 6. Developer Manual
Not showing 54 unsupported functions.
supported = 1 / 55 = 1.82%

**numpy.core.einsumfunc**

This module is not supported.

**numpy.core.fromnumeric**

numpy.core.fromnumeric.all()
   Alias to: numpy.all
      • defined by np_all(a) at numba/numpy/arraymath.py:857-866

numpy.core.fromnumeric.amax()
   Alias to: numpy.amax
      • defined by <class 'abc.Numpy_redirect_max'>

numpy.core.fromnumeric.amin()
   Alias to: numpy.amin
      • defined by <class 'abc.Numpy_redirect_min'>

numpy.core.fromnumeric.any()
   Alias to: numpy.any
      • defined by np_any(a) at numba/numpy/arraymath.py:869-878

numpy.core.fromnumeric.argmax()
   Alias to: numpy.argmax
      • defined by array_argmax(arr, axis=None) at numba/numpy/arraymath.py:837-854

numpy.core.fromnumeric.argmin()
   Alias to: numpy.argmin
      • defined by array_argmin(arr, axis=None) at numba/numpy/arraymath.py:707-724

numpy.core.fromnumeric.argsort()
   Alias to: numpy.argsort
      • defined by <class 'abc.Numpy_redirect_argsort'>

numpy.core.fromnumeric.around()
   Alias to: numpy.around
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.fromnumeric.array()
   Alias to: numpy.array
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpyp.core.fromnumeric.asarray()  
   Alias to: numpyp.asarray  
      • defined by np_asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpyp.core.fromnumeric.clip()  
   Alias to: numpyp.clip  
      • defined by np_clip(a, a_min, a_max, out=None) at numba/np/arrayobj.py:1900-1940

numpyp.core.fromnumeric.concatenate()  
   Alias to: numpyp.concatenate  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpyp.core.fromnumeric.cumprod()  
   Alias to: numpyp.cumprod  
      • defined by <class 'abc.Numpy_redirect_cumprod'>

numpyp.core.fromnumeric.cumsum()  
   Alias to: numpyp.cumsum  
      • defined by <class 'abc.Numpy_redirect_cumsum'>

numpyp.core.fromnumeric.mean()  
   Alias to: numpyp.mean  
      • defined by <class 'abc.Numpy_redirect_mean'>

numpyp.core.fromnumeric.nonzero()  
   Alias to: numpyp.nonzero  
      • defined by <class 'abc.Numpy_redirect_nonzero'>

numpyp.core.fromnumeric.partition()  
   Alias to: numpyp.partition  
      • defined by np_partition(a, kth) at numba/np/arraymath.py:1715-1737

numpyp.core.fromnumeric.prod()  
   Alias to: numpyp.prod  
      • defined by <class 'abc.Numpy_redirect_prod'>

numpyp.core.fromnumeric.ptp()  
   Alias to: numpyp.ptp  
      • defined by np_ptp(a) at numba/np/arraymath.py:1302-1328

numpyp.core.fromnumeric.ravel()  
   Alias to: numpyp.ravel  
      • defined by <class 'abc.Numpy_redirect_ravel'>

numpyp.core.fromnumeric.repeat()  
   Alias to: numpyp.repeat  
      • defined by np_repeat(a, repeats) at numba/np/arrayobj.py:2098-2140

numpyp.core.fromnumeric.reshape()  
   Alias to: numpyp.reshape
• defined by `np_reshape(a, shape)` at numba/np/arrayobj.py:1825-1829

`numpy.core.fromnumeric.round()`
Alias to: `numpy.round`
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args)` at numba/core/overload_glue.py:131-181
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args)` at numba/core/overload_glue.py:131-181

`numpy.core.fromnumeric.searchsorted()`
Alias to: `numpy.searchsorted`
- defined by `searchsorted(a, v, side='left')` at numba/np/arrmath.py:3773-3805

`numpy.core.fromnumeric.shape()`
Alias to: `numpy.shape`
- defined by `np_shape(a)` at numba/np/arrayobj.py:2076-2083

`numpy.core.fromnumeric.sort()`
Alias to: `numpy.sort`
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args)` at numba/core/overload_glue.py:131-181
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args)` at numba/core/overload_glue.py:131-181

`numpy.core.fromnumeric.std()`
Alias to: `numpy.std`
- defined by `<class 'abc.Numpy_redirect_std'>`

`numpy.core.fromnumeric.sum()`
Alias to: `numpy.sum`
- defined by `<class 'abc.Numpy_redirect_sum'>`

`numpy.core.fromnumeric.swapaxes()`
Alias to: `numpy.swapaxes`
- defined by `numpy_swapaxes(arr, axis1, axis2)` at numba/np/arrayobj.py:5544-5577

`numpy.core.fromnumeric.take()`
Alias to: `numpy.take`
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args)` at numba/core/overload_glue.py:131-181
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args)` at numba/core/overload_glue.py:131-181

`numpy.core.fromnumeric.trace()`
Alias to: `numpy.trace`
- defined by `matrix_trace_impl(a, offset=0)` at numba/np/linalg.py:2566-2594

`numpy.core.fromnumeric.transpose()`
Alias to: `numpy.transpose`
- defined by `numpy_transpose(a, axes=None)` at numba/np/arrayobj.py:1610-1622

`numpy.core.fromnumeric.var()`
Alias to: `numpy.var`
• defined by <class 'abc.Numpy_redirect_var'>
Not showing 15 unsupported functions.
supported = 33 / 48 = 68.75%

**numpy.core.function_base**

defined by_
    _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 6 unsupported functions.
supported = 2 / 8 = 25.00%

**numpy.core.getlimits**

defined by_
    _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 1 unsupported functions.
supported = 1 / 2 = 50.00%

**numpy.core.machar**

defined by np.any(a) at numba/np/arraymath.py:869-878
Not showing 1 unsupported functions.
supported = 1 / 2 = 50.00%
numpy.core.multiarray

numpy.core.multiarray.arange()
  Alias to: numpy.arange
  • defined by np.arange(start, stop=None, step=None, dtype=None) at numba/numpy/arrayobj.py:4111-4176

numpy.core.multiarray.array()
  Alias to: numpy.array
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.asarray()
  Alias to: numpy.asarray
  • defined by np.asarray(a, dtype=None) at numba/numpy/arraymath.py:4285-4337

numpy.core.multiarray.ascontiguousarray()
  Alias to: numpy.ascontiguousarray
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.asfortranarray()
  Alias to: numpy.asfortranarray
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.bincount()
  Alias to: numpy.bincount
  • defined by np.bincount(a, weights=None, minlength=0) at numba/numpy/arraymath.py:3685-3740

numpy.core.multiarray.concatenate()
  Alias to: numpy.concatenate
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.dot()
  Alias to: numpy.dot
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.core.multiarray.empty()
Alias to: numpy.empty
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.empty_like()
Alias to: numpy.empty_like
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.frombuffer()
Alias to: numpy.frombuffer
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.vdot()
Alias to: numpy.vdot
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.where()
Alias to: numpy.where
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.multiarray.zeros()
Alias to: numpy.zeros
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 46 unsupported functions.
supported = 14 / 60 = 23.33%
numpy.core.numeric

numpy.core.numeric.all()
   Alias to: numpy.all
       • defined by np_all(a) at numba/np/arraysmath.py:857-866

numpy.core.numeric.amax()
   Alias to: numpy.amax
       • defined by <class 'abc.Numpy_redirect_max'>

numpy.core.numeric.amin()
   Alias to: numpy.amin
       • defined by <class 'abc.Numpy_redirect_min'>

numpy.core.numeric.any()
   Alias to: numpy.any
       • defined by np_any(a) at numba/np/arraysmath.py:869-878

numpy.core.numeric.arange()
   Alias to: numpy.arange
       • defined by np.arange(start, stop=None, step=None, dtype=None) at numba/np/arraysobj.py:4111-4176

numpy.core.numeric.argmax()
   Alias to: numpy.argmax
       • defined by array_argmax(arr, axis=None) at numba/np/arraysmath.py:837-854

numpy.core.numeric.argmin()
   Alias to: numpy.argmin
       • defined by array_argmin(arr, axis=None) at numba/np/arraysmath.py:707-724

numpy.core.numeric.argsort()
   Alias to: numpy.argsort
       • defined by <class 'abc.Numpy_redirect_argsort'>

numpy.core.numeric.argwhere()
   Alias to: numpy.argwhere
       • defined by np_argwhere(a) at numba/np/arraysmath.py:2985-3017

numpy.core.numeric.around()
   Alias to: numpy.around
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.array()
   Alias to: numpy.array
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.core.numeric.array_equal()  
   Alias to: numpy.array_equal  
   • defined by np_array_equal(a, b) at numba/numpy/arraymath.py:3630-3649

numpy.core.numeric.asarray()  
   Alias to: numpy.asarray  
   • defined by np_asarray(a, dtype=None) at numba/numpy/arraymath.py:4285-4337

numpy.core.numeric.ascontiguousarray()  
   Alias to: numpy.ascontiguousarray  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181

numpy.core.numeric.asfortranarray()  
   Alias to: numpy.asfortranarray  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181

numpy.core.numeric.clip()  
   Alias to: numpy.clip  
   • defined by np_clip(a, a_min, a_max, out=None) at numba/numpy/arrayobj.py:1900-1940

numpy.core.numeric.concatenate()  
   Alias to: numpy.concatenate  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181

numpy.core.numeric.convolve()  
   Alias to: numpy.convolve  
   • defined by np_convolve(a, v) at numba/numpy/arraymath.py:4261-4282

numpy.core.numeric.correlate()  
   Alias to: numpy.correlate  
   • defined by _np_correlate(a, v) at numba/numpy/arraymath.py:4213-4258

numpy.core.numeric.count_nonzero()  
   Alias to: numpy.count_nonzero  
   • defined by np_count_nonzero(arr, axis=None) at numba/numpy/arraymath.py:3523-3537

numpy.core.numeric.cross()  
   Alias to: numpy.cross  
   • defined by np_cross(a, b) at numba/numpy/arraymath.py:4690-4712

numpy.core.numeric.cumprod()  
   Alias to: numpy.cumprod  
   • defined by <class 'abc.Numpy_redirect_cumprod'>
numpy.core.numeric.cumsum()
  Alias to: numpy.cumsum
  • defined by <class 'abc.Numpy_redirect_cumsum'>

numpy.core.numeric.dot()
  Alias to: numpy.dot
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.empty()
  Alias to: numpy.empty
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.empty_like()
  Alias to: numpy.empty_like
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.flatnonzero()
  Alias to: numpy.flatnonzero
  • defined by np_flatnonzero(a) at numba/numpyarraymath.py:3020-3035

numpy.core.numeric.frombuffer()
  Alias to: numpy.frombuffer
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.full()
  Alias to: numpy.full
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.full_like()
  Alias to: numpy.full_like
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.core.numeric.identity()  
   Alias to: numpy.identity  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.isscalar()  
   Alias to: numpy.isscalar  
   • defined by np_isscalar(num) at numba/numpy/numarraymath.py:977-983

numpy.core.numeric.mean()  
   Alias to: numpy.mean  
   • defined by <class 'abc.Numpy_redirect_mean'>

numpy.core.numeric.nonzero()  
   Alias to: numpy.nonzero  
   • defined by <class 'abc.Numpy_redirect_nonzero'>

numpy.core.numeric.ones()  
   Alias to: numpy.ones  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.ones_like()  
   Alias to: numpy.ones_like  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.outer()  
   Alias to: numpy.outer  
   • defined by outer_impl(a, b, out=None) at numba/numpy/linalg.py:2632-2643

numpy.core.numeric.partition()  
   Alias to: numpy.partition  
   • defined by np_partition(a, kth) at numba/numpy/arraymath.py:1715-1737

numpy.core.numeric.prod()  
   Alias to: numpy.prod  
   • defined by <class 'abc.Numpy_redirect_prod'>

numpy.core.numeric.ptp()  
   Alias to: numpy.ptp  
   • defined by np_ptp(a) at numba/numpy/arraymath.py:1302-1328

numpy.core.numeric.ravel()  
   Alias to: numpy.ravel  
   • defined by <class 'abc.Numpy_redirect_ravel'>
numpy.core.numeric.repeat()
   Alias to: numpy.repeat
   • defined by np_repeat(a, repeats) at numba/np/arrayobj.py:2098-2140

numpy.core.numeric.reshape()
   Alias to: numpy.reshape
   • defined by np_reshape(a, shape) at numba/np/arrayobj.py:1825-1829

numpy.core.numeric.roll()
   Alias to: numpy.roll
   • defined by np_roll(a, shift) at numba/np/arraymath.py:2127-2147

numpy.core.numeric.round_
   Alias to: numpy.round
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.searchsorted()
   Alias to: numpy.searchsorted
   • defined by searchsorted(a, v, side='left') at numba/np/arraymath.py:3773-3805

numpy.core.numeric.shape()
   Alias to: numpy.shape
   • defined by np_shape(a) at numba/np/arrayobj.py:2076-2083

numpy.core.numeric.sort()
   Alias to: numpy.sort
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numeric.std()
   Alias to: numpy.std
   • defined by <class 'abc.Numpy_redirect_std'>

numpy.core.numeric.sum()
   Alias to: numpy.sum
   • defined by <class 'abc.Numpy_redirect_sum'>

numpy.core.numeric.swapaxes()
   Alias to: numpy.swapaxes
   • defined by numpy_swapaxes(arr, axis1, axis2) at numba/np/arrayobj.py:5544-5577

numpy.core.numeric.take()
   Alias to: numpy.take
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

numpy.core.numeric.trace()

Alias to: numpy.trace

- defined by matrix_trace_impl(a, offset=0) at numba/np/linalg.py:2566-2594

numpy.core.numeric.transpose()

Alias to: numpy.transpose

- defined by numpy_transpose(a, axes=None) at numba/np/arrayobj.py:1610-1622

numpy.core.numeric.var()

Alias to: numpy.var

- defined by <class 'abc.Numpy_redirect_var'>

numpy.core.numeric.vdot()

Alias to: numpy.vdot

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.core.numeric.where()

Alias to: numpy.where

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.core.numeric.zeros()

Alias to: numpy.zeros

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.core.numeric.zeros_like()

Alias to: numpy.zeros_like

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

Not showing 78 unsupported functions.

supported = 59 / 137 = 43.07%
numpy.core.numerictypes

numpy.core.numerictypes.array()
  Alias to: numpy.array
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.numerictypes.empty()
  Alias to: numpy.empty
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 18 unsupported functions.
supported = 2 / 20 = 10.00%

numpy.core.overrides

This module is not supported.

numpy.core.records

This module is not supported.

numpy.core.setup_common

This module is not supported.

numpy.core.shape_base

numpy.core.shape_base.array()
  Alias to: numpy.array
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.shape_base.atleast_1d()
  Alias to: numpy.atleast_1d
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

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numpy.core.shape_base.atleast_2d()
    Alias to: numpy.atleast_2d
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.shape_base.atleast_3d()
    Alias to: numpy.atleast_3d
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.shape_base.hstack()
    Alias to: numpy.hstack
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.shape_base.stack()
    Alias to: numpy.stack
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.core.shape_base.vstack()
    Alias to: numpy.row_stack
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 3 unsupported functions.
supported = 7 / 10 = 70.00%

numpy.core.umath

numpy.core.umath.arange()
    Alias to: numpy.arange
    • defined by np.arange(start=None, stop=None, step=None, dtype=None) at numba/np/arrayobj.py:4111-4176

numpy.core.umath.array()
    Alias to: numpy.array
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
* defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwags)` at numba/core/overload_glue.py:131-181

```python
numpy.core.umath.asarray()
```

Alias to: `numpy.asarray`

* defined by `np_asarray(a, dtype=None)` at numba/np/umathmath.py:4285-4337

```python
numpy.core.umath.ascontiguousarray()
```

Alias to: `numpy.ascontiguousarray`

* defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwags)` at numba/core/overload_glue.py:131-181

```python
numpy.core.umath.asfortranarray()
```

Alias to: `numpy.asfortranarray`

* defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwags)` at numba/core/overload_glue.py:131-181

```python
numpy.core.umath.empty()
```

Alias to: `numpy.empty`

* defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwags)` at numba/core/overload_glue.py:131-181

```python
numpy.core.umath.frombuffer()
```

Alias to: `numpy.frombuffer`

* defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwags)` at numba/core/overload_glue.py:131-181

```python
numpy.core.umath.zeros()
```

Alias to: `numpy.zeros`

* defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwags)` at numba/core/overload_glue.py:131-181

Not showing 52 unsupported functions.

supported = 8 / 60 = 13.33%
numpy.core.umath_tests

This module is not supported.

numpy.ctypeslib

numpy.ctypeslib.asarray()
   Alias to: numpy.asarray
      • defined by np_asarray(a, dtype=None) at numba/np/ arraymath.py:4285-4337

numpy.ctypeslib.frombuffer()
   Alias to: numpy.frombuffer
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 5 unsupported functions.
supported = 2 / 7 = 28.57%

numpy.distutils

This module is not supported.

numpy.distutils.ccompiler

This module is not supported.

numpy.distutils.ccompiler_opt

This module is not supported.

numpy.distutils.command

This module is not supported.

numpy.distutils.command.autodist

This module is not supported.
nump.distutils.command.bdist_rpm

This module is not supported.

nump.distutils.command.build

This module is not supported.

nump.distutils.command.build_clib

This module is not supported.

nump.distutils.command.build_ext

This module is not supported.

nump.distutils.command.build_py

This module is not supported.

nump.distutils.command.build_scripts

This module is not supported.

nump.distutils.command.build_src

This module is not supported.

nump.distutils.command.config

This module is not supported.

nump.distutils.command.config_compiler

This module is not supported.
numpy.distutils.command.develop

This module is not supported.

numpy.distutils.command.egg_info

This module is not supported.

numpy.distutils.command.install

This module is not supported.

numpy.distutils.command.install_clib

This module is not supported.

numpy.distutils.command.install_data

This module is not supported.

numpy.distutils.command.install_headers

This module is not supported.

numpy.distutils.command.sdist

This module is not supported.

numpy.distutils.conv_template

This module is not supported.

numpy.distutils.core

This module is not supported.
numpy.distutils.cpuinfo

This module is not supported.

numpy.distutils.exec_command

This module is not supported.

numpy.distutils.extension

This module is not supported.

numpy.distutils.fcompiler

This module is not supported.

numpy.distutils.fcompiler.absoft

This module is not supported.

numpy.distutils.fcompiler.compaq

This module is not supported.

numpy.distutils.fcompiler.environment

This module is not supported.

numpy.distutils.fcompiler.fujitsu

This module is not supported.

numpy.distutils.fcompiler.g95

This module is not supported.
This module is not supported.

This module is not supported.

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This module is not supported.
This module is not supported.

.npy_pkg_config

This module is not supported.

.numpy_distribution

This module is not supported.

.pathccompiler

This module is not supported.

.setup

This module is not supported.

system_info

```
numpy.distutils.system_info.reduce()
```

- defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>._decorate.<locals>.Template'>`

Not showing 16 unsupported functions.
supported = \(1 / 17 = 5.88\%\)
numpy.distutils.unixccompiler

This module is not supported.

numpy.doc

This module is not supported.

numpy.doc.constants

This module is not supported.

numpy.doc.ufuncs

This module is not supported.

numpy.dual

numpy.dual.cholesky()

• defined by cho_impl(a) at numba/np/linalg.py:900-942

numpy.dual.det()

• defined by det_impl(a) at numba/np/linalg.py:2017-2028

numpy.dual.eig()

• defined by eig_impl(a) at numba/np/linalg.py:944-1057

numpy.dual.eigh()

• defined by eigh_impl(a) at numba/np/linalg.py:1178-1225

numpy.dual.eigvals()

• defined by eigvals_impl(a) at numba/np/linalg.py:1059-1176

numpy.dual.eigvalsh()

• defined by eigvalsh_impl(a) at numba/np/linalg.py:1227-1274

numpy.dual.inv()

• defined by inv_impl(a) at numba/np/linalg.py:832-869

numpy.dual.lstsq()

• defined by lstsq_impl(a, b, rcond=-1.0) at numba/np/linalg.py:1582-1674

numpy.dual.norm()

• defined by norm_impl(a, ord=None) at numba/np/linalg.py:2351-2357
numpy.dual.pinv()
• defined by pinv_impl(a, rcond=1e-15) at numba/np/linalg.py:1758-1919

numpy.dual.solve()
• defined by solve_impl(a, b) at numba/np/linalg.py:1697-1755

numpy.dual.svd()
• defined by svd_impl(a, full_matrices=1) at numba/np/linalg.py:1276-1339

Not showing 10 unsupported functions.
supported = 12 / 22 = 54.55%

**numpy.f2py**

This module is not supported.

**numpy.f2py.auxfuncs**

**numpy.f2py.auxfuncs.reduce()**

Alias to: numpy.distutils.system_info.reduce
• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.<locals>.Template'>

Not showing 103 unsupported functions.
supported = 1 / 104 = 0.96%

**numpy.f2py.capi_maps**

This module is not supported.

**numpy.f2py.cb_rules**

This module is not supported.

**numpy.f2py.cfuncs**

This module is not supported.
This module is not supported.

This module is not supported.

This module is not supported.

This module is not supported.

This module is not supported.

This module is not supported.

This module is not supported.
numpy.fft

This module is not supported.

numpy.fft.helper

numpy.fft.helper.arrange()
   Alias to: numpy.arange
   • defined by np.arange(start, stop=None, step=None, dtype=None) at numba/numpyarrayobj.py:4111-4176

numpy.fft.helper.asarray()
   Alias to: numpy.asarray
   • defined by np.asarray(a, dtype=None) at numba/numpyarraymath.py:4285-4337

numpy.fft.helper.empty()
   Alias to: numpy.empty
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.fft.helper.roll()
   Alias to: numpy.roll
   • defined by np.roll(a, shift) at numba/numpyarraymath.py:2127-2147

Not showing 6 unsupported functions.
supported = 4 / 10 = 40.00%

numpy.fft.setup

This module is not supported.

numpy.lib

numpy.lib.angle()
   Alias to: numpy.angle
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.append()
   Alias to: numpy.append
   • defined by np.append(arr, values, axis=None) at numba/numpyarrayobj.py:1832-1855

numpy.lib.array_split()
   Alias to: numpy.array_split
• defined by np_array_split(ary, indices_or_sections, axis=0) at numba/np/arrayobj.py:5252-5310

numpy.lib.asarray_chkfinite()
   Alias to: numpy.asarray_chkfinite
   • defined by np_asarray_chkfinite(a, dtype=None) at numba/np/arraymath.py:4432-4454

numpy.lib.asfarray()
   Alias to: numpy.asfarray
   • defined by np ASFarray(a, dtype=<class 'numpy.float64'>) at numba/np/ arraymath.py:4340-4352

numpy.lib.average()
   Alias to: numpy.average
   • defined by np_average(arr, axis=None, weights=None) at numba/np/ arraymath.py:881-915

numpy.lib.bartlett()
   Alias to: numpy.bartlett
   • defined by window_generator.<locals>.window_overload(M) at numba/np/ arraymath.py:4509-4521

numpy.lib.bincount()
   Alias to: numpy.bincount
   • defined by np_bincount(a, weights=None, minlength=0) at numba/np/ arraymath.py:3685-3740

numpy.lib.blackman()
   Alias to: numpy.blackman
   • defined by window_generator.<locals>.window_overload(M) at numba/np/ arraymath.py:4509-4521

numpy.lib.broadcast_to()
   Alias to: numpy.broadcast_to
   • defined by numpy_broadcast_to(array, shape) at numba/np/arrayobj.py:1360-1382

numpy.lib.column_stack()
   Alias to: numpy.column_stack
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.copy()
   Alias to: numpy.copy
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.corrcoef()
   Alias to: numpy.corrcoef
   • defined by np_corrcoef(x, y=None, rowvar=True) at numba/np/ arraymath.py:2948-2978
numpy.lib.cov()
    Alias to: numpy.cov
    • defined by np_cov(m, y=None, rowvar=True, bias=False, ddof=None) at numba/numpy/arraymath.py:2889-2945

numpy.lib.delete()
    Alias to: numpy.delete
    • defined by np_delete(arr, obj) at numba/numpy/arraymath.py:3544-3588

numpy.lib.diag()
    Alias to: numpy.diag
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.lib.diff()
    Alias to: numpy.diff
    • defined by np_diff_impl(a, n=1) at numba/numpy/arraymath.py:3591-3627

numpy.lib.digitize()
    Alias to: numpy.digitize
    • defined by np_digitize(x, bins, right=False) at numba/numpy/arraymath.py:3808-3934

numpy.lib.dstack()
    Alias to: numpy.dstack
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.lib.ediff1d()
    Alias to: numpy.ediff1d
    • defined by np_eddiff1d(ary, to_end=None, to_begin=None) at numba/numpy/arraymath.py:1937-1992

numpy.lib.expand_dims()
    Alias to: numpy.expand_dims
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.lib.extract()
    Alias to: numpy.extract
    • defined by np_extract(condition, arr) at numba/numpy/arraymath.py:4355-4378

numpy.lib.eye()
    Alias to: numpy.eye
    • defined by numpy_eye(N, M=None, k=0, dtype=<class 'float'>) at numba/numpy/arrayobj.py:3948-3971
numpy.lib.fill_diagonal()
  Alias to: numpy.fill_diagonal
  • defined by np_fill_diagonal(a, val, wrap=False) at numba/np/arraymath.py:3122-3152

numpy.lib.flip()
  Alias to: numpy.flip
  • defined by np_flip(a) at numba/np/arrayobj.py:5238-5249

numpy.lib.fliplr()
  Alias to: numpy.fliplr
  • defined by np_flip_lr(a) at numba/np/arrayobj.py:5174-5188

numpy.lib.flipud()
  Alias to: numpy.flipud
  • defined by np_flip_ud(a) at numba/np/arrayobj.py:5191-5205

numpy.lib.hamming()
  Alias to: numpy.hamming
  • defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.lib.hanning()
  Alias to: numpy.hanning
  • defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.lib.histogram()
  Alias to: numpy.histogram
  • defined by np_histogram(a, bins=10, range=None) at numba/np/arraymath.py:3940-4020

numpy.lib.imag()
  Alias to: numpy.imag
  • defined by np_imag(a) at numba/np/arraymath.py:3498-3503

numpy.lib.interp()
  Alias to: numpy.interp
  • defined by np_interpol(x, xp, fp) at numba/np/arraymath.py:2640-2701

numpy.lib.intersect1d()
  Alias to: numpy.intersect1d
  • defined by jit_np_intersect1d(ar1, ar2) at numba/np/arraymath.py:3652-3672

numpy.lib.iscomplex()
  Alias to: numpy.iscomplex
  • defined by np_iscomplex(x) at numba/np/arraymath.py:931-936

numpy.lib.iscomplexobj()
  Alias to: numpy.iscomplexobj
  • defined by iscomplexobj(x) at numba/np/arraymath.py:947-964

numpy.lib.isneginf()
  Alias to: numpy.isneginf
  • defined by isneginf(x, out=None) at numba/np/arraymath.py:999-1002
Numpy Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

numpy.lib.isposinf()
    Alias to: numpy.isposinf
    • defined by isposinf(x, out=None) at numba/np/arraymath.py:1005-1008

numpy.lib.isreal()
    Alias to: numpy.isreal
    • defined by np_isreal(x) at numba/np/arraymath.py:939-944

numpy.lib.isrealobj()
    Alias to: numpy.isrealobj
    • defined by isrealobj(x) at numba/np/arraymath.py:967-974

numpy.lib.kaiser()
    Alias to: numpy.kaiser
    • defined by np_kaiser(M, beta) at numba/np/arraymath.py:4627-4646

numpy.lib.kron()
    Alias to: numpy.kron
    • defined by kron_impl(a, b) at numba/np/linalg.py:2709-2763

numpy.lib.median()
    Alias to: numpy.median
    • defined by np_median(a) at numba/np/arraymath.py:1448-1460

numpy.lib.nancumprod()
    Alias to: numpy.nancumprod
    • defined by np_nancumprod(a) at numba/np/arraymath.py:1193-1215

numpy.lib.nancumsum()
    Alias to: numpy.nancumsum
    • defined by np_nancumsum(a) at numba/np/arraymath.py:1218-1240

numpy.lib.nanmax()
    Alias to: numpy.nanmax
    • defined by np_nanmax(a) at numba/np/arraymath.py:1084-1090

numpy.lib.nanmean()
    Alias to: numpy.nanmean
    • defined by np_nanmean(a) at numba/np/arraymath.py:1093-1110

numpy.lib.nanmedian()
    Alias to: numpy.nanmedian
    • defined by np_nanmedian(a) at numba/np/arraymath.py:1634-1656

numpy.lib.nanmin()
    Alias to: numpy.nanmin
    • defined by np_nanmin(a) at numba/np/arraymath.py:1075-1081

numpy.lib.nanpercentile()
    Alias to: numpy.nanpercentile
    • defined by np_nanpercentile(a, q) at numba/np/arraymath.py:1613-1617

numpy.lib.nanprod()
    Alias to: numpy.nanprod
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- defined by np_nanprod(a) at numba/numpy/np/arraymath.py:1171-1190

numpy.lib.nanquantile()
    Alias to: numpy.nanquantile
    • defined by np_nanquantile(a, q) at numba/numpy/np/arraymath.py:1627-1631

numpy.lib.nanstd()
    Alias to: numpy.nanstd
    • defined by np_nanstd(a) at numba/numpy/np/arraymath.py:1138-1146

numpy.lib.nansum()
    Alias to: numpy.nansum
    • defined by np_nansum(a) at numba/numpy/np/arraymath.py:1149-1168

numpy.lib.nanvar()
    Alias to: numpy.nanvar
    • defined by np_nanvar(a) at numba/numpy/np/arraymath.py:1113-1135

numpy.lib.percentile()
    Alias to: numpy.percentile
    • defined by np_percentile(a, q) at numba/numpy/np/arraymath.py:1606-1610

numpy.lib.quantile()
    Alias to: numpy.quantile
    • defined by np_quantile(a, q) at numba/numpy/np/arraymath.py:1620-1624

numpy.lib.real()
    Alias to: numpy.real
    • defined by np_real(a) at numba/numpy/np/arraymath.py:3490-3495

numpy.lib.roots()
    Alias to: numpy.roots
    • defined by roots_impl(p) at numba/numpy/polynomial.py:14-59

numpy.lib.rot90()
    Alias to: numpy.rot90
    • defined by numpy_rot90(arr, k=1) at numba/numpy/np/arrayobj.py:1661-1685

numpy.lib.row_stack()
    Alias to: numpy.row_stack
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.select()
    Alias to: numpy.select
    • defined by np_select(condlist, choicelist, default=0) at numba/numpy/np/arraymath.py:4381-4429

numpy.lib.sinc()
    Alias to: numpy.sinc
    • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

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• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.split()
  Alias to: numpy.split
    • defined by np_split(ary, indices_or_sections, axis=0) at numba/np/arrayobj.py:5313-5337

numpy.lib.take_along_axis()
  Alias to: numpy.take_along_axis
    • defined by arr_take_along_axis(arr, indices, axis) at numba/np/arrayobj.py:5641-5682

numpy.lib.trapz()
  Alias to: numpy.trapz
    • defined by np_trapz(y, x=None, dx=1.0) at numba/np/arraymath.py:2029-2048

numpy.lib.tri()
  Alias to: numpy.tri
    • defined by np_tri(N, M=None, k=0) at numba/np/arraymath.py:1756-1767

numpy.lib.tril()
  Alias to: numpy.tril
    • defined by my_tril(m, k=0) at numba/np/arraymath.py:1793-1817

numpy.lib.tril_indices()
  Alias to: numpy.tril_indices
    • defined by np_tril_indices(n, k=0, m=None) at numba/np/arraymath.py:1820-1831

numpy.lib.tril_indices_from()
  Alias to: numpy.tril_indices_from
    • defined by np_tril_indices_from(arr, k=0) at numba/np/arraymath.py:1834-1845

numpy.lib.triu()
  Alias to: numpy.triu
    • defined by my_triu(m, k=0) at numba/np/arraymath.py:1854-1877

numpy.lib.triu_indices()
  Alias to: numpy.triu_indices
    • defined by np_triu_indices(n, k=0, m=None) at numba/np/arraymath.py:1880-1891

numpy.lib.triu_indices_from()
  Alias to: numpy.triu_indices_from
    • defined by np_triu_indices_from(arr, k=0) at numba/np/arraymath.py:1894-1905

numpy.lib.unique()
  Alias to: numpy.unique
    • defined by np_unique(a) at numba/np/arrayobj.py:2088-2095

numpy.lib.vander()
  Alias to: numpy.vander
    • defined by np_vander(x, N=None, increasing=False) at numba/np/arraymath.py:2087-2124

Not showing 86 unsupported functions.
supported = 74 / 160 = 46.25%
numpy.lib.arraypad

This module is not supported.

numpy.lib.arraysetops

numpy.lib.arraysetops.ediff1d()
Alias to: numpy.ediff1d

• defined by np_ediff1d(ary, to_end=None, to_begin=None) at numba/np/arraymath.py:1937-1992

numpy.lib.arraysetops.intersect1d()
Alias to: numpy.intersect1d

• defined by jit_np_intersect1d(ar1, ar2) at numba/np/arraymath.py:3652-3672

numpy.lib.arraysetops.unique()
Alias to: numpy.unique

• defined by np_unique(a) at numba/np/arrayobj.py:2088-2095

Not showing 5 unsupported functions.
supported = 3 / 8 = 37.50%

numpy.lib.arrayterator

numpy.lib.arrayterator.mul()

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>..decorate.<locals>..Template'>

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>..decorate.<locals>..Template'>

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>..decorate.<locals>..Template'>

• defined by unicode_repeat(a, b) at numba/cpython/unicode.py:1764-1773

• defined by charseq_repeat(a, b) at numba/cpython/charseq.py:399-416

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>..decorate.<locals>..Template'>

numpy.lib.arrayterator.reduce()
Alias to: numpy.distutils.system_info.reduce

• defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>..decorate.<locals>..Template'>

Not showing 0 unsupported functions.
supported = 2 / 2 = 100.00%
numpy.lib.format

This module is not supported.

numpy.lib.function_base

numpy.lib.function_base.angle()
Alias to: numpy.angle
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.any()
Alias to: numpy.any
• defined by np_any(a) at numba/np/arraymath.py:869-878

numpy.lib.function_base.append()
Alias to: numpy.append
• defined by np_append(arr, values, axis=None) at numba/np/arrayobj.py:1832-1855

numpy.lib.function_base.arange()
Alias to: numpy.arange
• defined by np_arange(start, stop=None, step=None, dtype=None) at numba/np/arrayobj.py:4111-4176

numpy.lib.function_base.around()
Alias to: numpy.around
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.array()
Alias to: numpy.array
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.asarray()
Alias to: numpy.asarray
• defined by np_asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpy.lib.function_base.asarray_chkfinite()
Alias to: numpy.asarray_chkfinite
• defined by np_asarray_chkfinite(a, dtype=None) at numba/np/arraymath.py:4432-4454

numpy.lib.function_base.average()
Alias to: numpy.average
• defined by np_average(arr, axis=None, weights=None) at numba/np/arraymath.py:881-915
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numpy.lib.function_base.digitize()  
Alias to: numpy.digitize  
• defined by np_digitize(x, bins, right=False) at numba/numpy/np/arraymath.py:3808-3934

numpy.lib.function_base.dot()  
Alias to: numpy.dot  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.empty()  
Alias to: numpy.empty  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.extract()  
Alias to: numpy.extract  
• defined by np_extract(condition, arr) at numba/numpy/np/arraymath.py:4355-4378

numpy.lib.function_base.flip()  
Alias to: numpy.flip  
• defined by np_flip(a) at numba/numpy/np/arrayobj.py:5238-5249

numpy.lib.function_base.hamming()  
Alias to: numpy.hamming  
• defined by window_generator.<locals>.window_overload(M) at numba/numpy/np/arraymath.py:4509-4521

numpy.lib.function_base.hanning()  
Alias to: numpy.hanning  
• defined by window_generator.<locals>.window_overload(M) at numba/numpy/np/arraymath.py:4509-4521

numpy.lib.function_base.histogram()  
Alias to: numpy.histogram  
• defined by np_histogram(a, bins=10, range=None) at numba/numpy/np/arraymath.py:3940-4020

numpy.lib.function_base.interp()  
Alias to: numpy.interp  
• defined by np_interp(x, xp, fp) at numba/numpy/np/arraymath.py:2640-2701

numpy.lib.function_base.isscalar()  
Alias to: numpy.isscalar  
• defined by np_isscalar(num) at numba/numpy/np/arraymath.py:977-983

numpy.lib.function_base.kaiser()  
Alias to: numpy.kaiser  
• defined by np_kaiser(M, beta) at numba/numpy/np/arraymath.py:4627-4646
numpy.lib.function_base.mean()
   Alias to: numpy.mean
   • defined by <class 'abc.Numpy_redirect_mean'>

numpy.lib.function_base.median()
   Alias to: numpy.median
   • defined by np_median(a) at numba/numpy/arraymath.py:1448-1460

numpy.lib.function_base.nonzero()
   Alias to: numpy.nonzero
   • defined by <class 'abc.Numpy_redirect_nonzero'>

numpy.lib.function_base.ones()
   Alias to: numpy.ones
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.partition()
   Alias to: numpy.partition
   • defined by np_partition(a, kth) at numba/numpy/arraymath.py:1715-1737

numpy.lib.function_base.percentile()
   Alias to: numpy.percentile
   • defined by np_percentile(a, q) at numba/numpy/arraymath.py:1606-1610

numpy.lib.function_base.quantile()
   Alias to: numpy.quantile
   • defined by np_quantile(a, q) at numba/numpy/arraymath.py:1620-1624

numpy.lib.function_base.ravel()
   Alias to: numpy.ravel
   • defined by <class 'abc.Numpy_redirect_ravel'>

numpy.lib.function_base.rot90()
   Alias to: numpy.rot90
   • defined by numpy_rot90(arr, k=1) at numba/numpy/arrays.py:1661-1685

numpy.lib.function_base.select()
   Alias to: numpy.select
   • defined by np_select(condlist, choicelist, default=0) at numba/numpy/arraymath.py:4381-4429

numpy.lib.function_base.sinc()
   Alias to: numpy.sinc
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.sum()
   Alias to: numpy.sum
• defined by <class 'abc.Numpy_redirect_sum'>

numpy.lib.function_base.take()
   Alias to: numpy.take
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.transpose()
   Alias to: numpy.transpose
   • defined by numpy.transpose(a, axes=None) at numba/numpy/np/arrays.py:1610-1622

numpy.lib.function_base.trapz()
   Alias to: numpy.trapz
   • defined by np_trapz(y, x=None, dx=1.0) at numba/numpy/np/arrays.py:2029-2048

numpy.lib.function_base.where()
   Alias to: numpy.where
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.function_base.zeros_like()
   Alias to: numpy.zeros_like
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 22 unsupported functions.
supported = 47 / 69 = 68.12%

numpy.lib.histograms

numpy.lib.histograms.histogram()
   Alias to: numpy.histogram
   • defined by np_histogram(a, bins=10, range=None) at numba/numpy/arrays.py:3940-4020

Not showing 2 unsupported functions.
supported = 1 / 3 = 33.33%
numpy.lib.index_tricks

numpy.lib.index_tricks.arange()
   Alias to: numpy.arange
       • defined by np.arange(start, stop=None, step=None, dtype=None) at numba/np/arrayobj.py:4111-4176

numpy.lib.index_tricks.array()
   Alias to: numpy.array
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.index_tricks.as_strided()
       • defined by as_strided(x, shape=None, strides=None) at numba/np/arrayobj.py:5500-5526

numpy.lib.index_tricks.asarray()
   Alias to: numpy.asarray
       • defined by np.asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpy.lib.index_tricks.cumprod()
   Alias to: numpy.cumprod
       • defined by <class 'abc.Numpy_redirect_cumprod'>

numpy.lib.index_tricks.diff()
   Alias to: numpy.diff
       • defined by np.diff_impl(a, n=1) at numba/np/arraymath.py:3591-3627

numpy.lib.index_tricks.fill_diagonal()
   Alias to: numpy.fill_diagonal
       • defined by np_fill_diagonal(a, val, wrap=False) at numba/np/arraymath.py:3122-3152

numpy.lib.index_tricks.linspace()
   Alias to: numpy.linspace
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 10 unsupported functions.
supported = 8 / 18 = 44.44%

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numpy.lib.mixins

This module is not supported.

numpy.lib.nanfunctions

numpy.lib.nanfunctions.nancumprod()
   Alias to: numpy.nancumprod
      • defined by np_nancumprod(a) at numba/numpy/arrays.py:1193-1215

numpy.lib.nanfunctions.nancumsum()
   Alias to: numpy.nancumsum
      • defined by np_nancumsum(a) at numba/numpy/arrays.py:1218-1240

numpy.lib.nanfunctions.nanmax()
   Alias to: numpy.nanmax
      • defined by np_nanmax(a) at numba/numpy/arrays.py:1084-1090

numpy.lib.nanfunctions.nanmean()
   Alias to: numpy.nanmean
      • defined by np_nanmean(a) at numba/numpy/arrays.py:1093-1110

numpy.lib.nanfunctions.nanmedian()
   Alias to: numpy.nanmedian
      • defined by np_nanmedian(a) at numba/numpy/arrays.py:1634-1656

numpy.lib.nanfunctions.nanmin()
   Alias to: numpy.nanmin
      • defined by np_nanmin(a) at numba/numpy/arrays.py:1075-1081

numpy.lib.nanfunctions.nanpercentile()
   Alias to: numpy.nanpercentile
      • defined by np_nanpercentile(a, q) at numba/numpy/arrays.py:1613-1617

numpy.lib.nanfunctions.nanprod()
   Alias to: numpy.nanprod
      • defined by np_nanprod(a) at numba/numpy/arrays.py:1171-1190

numpy.lib.nanfunctions.nanquantile()
   Alias to: numpy.nanquantile
      • defined by np_nanquantile(a, q) at numba/numpy/arrays.py:1627-1631

numpy.lib.nanfunctions.nanstd()
   Alias to: numpy.nanstd
      • defined by np_nanstd(a) at numba/numpy/arrays.py:1138-1146

numpy.lib.nanfunctions.nansum()
   Alias to: numpy.nansum
      • defined by np_nansum(a) at numba/numpy/arrays.py:1149-1168

numpy.lib.nanfunctions.nanvar()
   Alias to: numpy.nanvar
• defined by `np_nanvar(a)` at numba/np/arraymath.py:1113-1135

Not showing 2 unsupported functions.
supported = 12 / 14 = 85.71%

```
numpy.lib.npyio

This module is not supported.
```

```
numpy.lib.polynomial

numpy.lib.polynomial.array()
   Alias to: numpy.array
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.polynomial.atleast_1d()
   Alias to: numpy.atleast_1d
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.polynomial.diag()
   Alias to: numpy.diag
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.polynomial.dot()
   Alias to: numpy.dot
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.polynomial.eigvals()
   Alias to: numpy.dual.eigvals
      • defined by eigvals_impl(a) at numba/np/linalg.py:1059-1176

numpy.lib.polynomial.hstack()
   Alias to: numpy.hstack
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
```
numpy.lib.polynomial.imag()
   Alias to: numpy.imag
   • defined by np_imag(a) at numba/numpy/np/arraymath.py:3498-3503

numpy.lib.polynomial.inv()
   Alias to: numpy.linalg.inv
   • defined by inv_impl(a) at numba/numpy/linalg.py:832-869

numpy.lib.polynomial.iscomplex()
   Alias to: numpy.iscomplex
   • defined by np_iscomplex(x) at numba/numpy/np/arraymath.py:931-936

numpy.lib.polynomial.isscalar()
   Alias to: numpy.isscalar
   • defined by np_isscalar(num) at numba/numpy/np/arraymath.py:977-983

numpy.lib.polynomial.lstsq()
   Alias to: numpy.linalg.lstsq
   • defined by lstsq_impl(a, b, rcond=-1.0) at numba/numpy/linalg.py:1582-1674

numpy.lib.polynomial.ones()
   Alias to: numpy.ones
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.polynomial.real()
   Alias to: numpy.real
   • defined by np_real(a) at numba/numpy/np/arraymath.py:3490-3495

numpy.lib.polynomial.roots()
   Alias to: numpy.roots
   • defined by roots_impl(p) at numba/numpy/np/polynomial.py:14-59

numpy.lib.polynomial.vander()
   Alias to: numpy.vander
   • defined by np_vander(x, N=None, increasing=False) at numba/numpy/np/arraymath.py:2087-2124

Not showing 12 unsupported functions.

supported = 15 / 27 = 55.56%

**numpy.lib.recfunctions**

This module is not supported.
numpy.lib.scimath

numpy.lib.scimath.any()
   Alias to: numpy.any
       • defined by np_any(a) at numba/numpy/arraymath.py:869-878

numpy.lib.scimath.asarray()
   Alias to: numpy.asarray
       • defined by np_asarray(a, dtype=None) at numba/numpy/arraymath.py:4285-4337

numpy.lib.scimath.isreal()
   Alias to: numpy.isreal
       • defined by np_isreal(x) at numba/numpy/arraymath.py:939-944

Not showing 10 unsupported functions.
supported = 3 / 13 = 23.08%

numpy.lib.setup

This module is not supported.

numpy.lib.shape_base

numpy.lib.shape_base.array()
   Alias to: numpy.array
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.array_split()
   Alias to: numpy.array_split
       • defined by np_array_split(ary, indices_or_sections, axis=0) at numba/numpy/arrayobj.py:5252-5310

numpy.lib.shape_base.asarray()
   Alias to: numpy.asarray
       • defined by np_asarray(a, dtype=None) at numba/numpy/arraymath.py:4285-4337

numpy.lib.shape_base.atleast_3d()
   Alias to: numpy.atleast_3d
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.column_stack()
   Alias to: numpy.column_stack
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars) at numba/core/overload_glue.py:131-181
Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

- defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.concatenate()
  Alias to: numpy.concatenate
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.dstack()
  Alias to: numpy.dstack
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.expand_dims()
  Alias to: numpy.expand_dims
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.kron()
  Alias to: numpy.kron
  - defined by kron_impl(a, b) at numba/nplinalg.py:2709-2763

numpy.lib.shape_base.outer()
  Alias to: numpy.outer
  - defined by outer_impl(a, b, out=None) at numba/nplinalg.py:2632-2643

numpy.lib.shape_base.reshape()
  Alias to: numpy.reshape
  - defined by np_reshape(a, shape) at numba/numpyarrayobj.py:1825-1829

numpy.lib.shape_base.row_stack()
  Alias to: numpy.row_stack
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
  - defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.split()
  Alias to: numpy.split
  - defined by np_split(ary, indices_or_sections, axis=0) at numba/numpyarrayobj.py:5313-5337

numpy.lib.shape_base.take_along_axis()
  Alias to: numpy.take_along_axis
  - defined by arr_take_along_axis(arr, indices, axis) at numba/numpyarrayobj.py:5641-5682

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numpy.lib.shape_base.\texttt{transpose}()
   Alias to: \texttt{numpy.transpose}
   • defined by \texttt{numpy.transpose(a, axes=None)} at numba/np/arrayobj.py:1610-1622

numpy.lib.shape_base.\texttt{vstack}()
   Alias to: \texttt{numpy.row_stack}
   • defined by \_OverloadWrapper._\texttt{build}.\_\texttt{locals}.\_\texttt{generated}(*\texttt{ol Args}, **\texttt{ol Keywords}) at numba/core/overload_glue.py:131-181
   • defined by \_OverloadWrapper._\texttt{build}.\_\texttt{locals}.\_\texttt{generated}(*\texttt{ol Args}, **\texttt{ol Keywords}) at numba/core/overload_glue.py:131-181

numpy.lib.shape_base.\texttt{zeros}()
   Alias to: \texttt{numpy.zeros}
   • defined by \_OverloadWrapper._\texttt{build}.\_\texttt{locals}.\_\texttt{generated}(*\texttt{ol Args}, **\texttt{ol Keywords}) at numba/core/overload_glue.py:131-181
   • defined by \_OverloadWrapper._\texttt{build}.\_\texttt{locals}.\_\texttt{generated}(*\texttt{ol Args}, **\texttt{ol Keywords}) at numba/core/overload_glue.py:131-181

Not showing 12 unsupported functions.
supported = 17 / 29 = 58.62%

\texttt{numpy.lib.stride_tricks}

numpy.lib.stride_tricks.\texttt{as_strided}()
   Alias to: \texttt{numpy.lib.index_tricks.as_strided}
   • defined by \texttt{as_strided(x, shape=None, strides=None)} at numba/np/arrayobj.py:5500-5526

numpy.lib.stride_tricks.\texttt{broadcast_to}()
   Alias to: \texttt{numpy.broadcast_to}
   • defined by \texttt{numpy_broadcast_to(array, shape)} at numba/np/arrayobj.py:1360-1382

Not showing 6 unsupported functions.
supported = 2 / 8 = 25.00%

\texttt{numpy.lib.twodim_base}

numpy.lib.twodim_base.\texttt{arange}()
   Alias to: \texttt{numpy.arange}
   • defined by \texttt{np.arange(start, stop=None, step=None, dtype=None)} at numba/np/arrayobj.py:4111-4176

numpy.lib.twodim_base.\texttt{asarray}()
   Alias to: \texttt{numpy.asarray}
   • defined by \texttt{np.asarray(a, dtype=None)} at numba/np/arraysmath.py:4285-4337

numpy.lib.twodim_base.\texttt{broadcast_to}()
   Alias to: \texttt{numpy.broadcast_to}
   • defined by \texttt{numpy_broadcast_to(array, shape)} at numba/np/arrayobj.py:1360-1382
numpy.lib.twodim_base.diag()
Alias to: numpy.diag
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.twodim_base.empty()
Alias to: numpy.empty
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.twodim_base.eye()
Alias to: numpy.eye
  • defined by numpy_eye(N, M=None, k=0, dtype=<class 'float'>) at numba/np/arrayobj.py:3948-3971

numpy.lib.twodim_base.fliplr()
Alias to: numpy.fliplr
  • defined by np_flip_lr(a) at numba/np/arrayobj.py:5174-5188

numpy.lib.twodim_base.flipud()
Alias to: numpy.flipud
  • defined by np_flip_ud(a) at numba/np/arrayobj.py:5191-5205

numpy.lib.twodim_base.nonzero()
Alias to: numpy.nonzero
  • defined by <class 'abc.Numpy_redirect_nonzero'>

numpy.lib.twodim_base.ones()
Alias to: numpy.ones
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.twodim_base.tri()
Alias to: numpy.tri
  • defined by np_tri(N, M=None, k=0) at numba/np/arraymath.py:1756-1767

numpy.lib.twodim_base.tril()
Alias to: numpy.tril
  • defined by my_tril(m, k=0) at numba/np/arraymath.py:1793-1817

numpy.lib.twodim_base.tril_indices()
Alias to: numpy.tril_indices
  • defined by np_tril_indices(n, k=0, m=None) at numba/np/arraymath.py:1820-1831

numpy.lib.twodim_base.tril_indices_from()
Alias to: numpy.tril_indices_from
• defined by np_tril_indices_from(arr, k=0) at numba/np/arraymath.py:1834-1845

numpy.lib.twodim_base.triu()
   Alias to: numpy.triu
   • defined by my_triu(m, k=0) at numba/np/arraymath.py:1854-1877

numpy.lib.twodim_base.triu_indices()
   Alias to: numpy.triu_indices
   • defined by np_triu_indices(n, k=0, m=None) at numba/np/arraymath.py:1880-1891

numpy.lib.twodim_base.triu_indices_from()
   Alias to: numpy.triu_indices_from
   • defined by np_triu_indices_from(arr, k=0) at numba/np/arraymath.py:1894-1905

numpy.lib.twodim_base.vander()
   Alias to: numpy.vander
   • defined by np_vander(x, N=None, increasing=False) at numba/np/arraymath.py:2087-2124

numpy.lib.twodim_base.where()
   Alias to: numpy.where
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.twodim_base.zeros()
   Alias to: numpy.zeros
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 9 unsupported functions.

supported = 20 / 29 = 68.97%

**numpy.lib.type_check**

numpy.lib.type_check.asarray()
   Alias to: numpy.asarray
   • defined by np_asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpy.lib.type_check.asfarray()
   Alias to: numpy.asfarray
   • defined by np_asfarray(a, dtype=<class 'numpy.float64'>) at numba/np/arraymath.py:4340-4352

numpy.lib.type_check.imag()
   Alias to: numpy.imag
   • defined by np_imag(a) at numba/np/arraymath.py:3498-3503

numpy.lib.type_check.iscomplex()
   Alias to: numpy.iscomplex
• defined by np_iscomplex(x) at numba/np/arraymath.py:931-936

```
numpy.lib.type_check.iscomplexobj()
   Alias to: numpy.iscomplexobj

• defined by iscomplexobj(x) at numba/np/arraymath.py:947-964
```

```
numpy.lib.type_check.isneginf()
   Alias to: numpy.isneginf

• defined by isneginf(x, out=None) at numba/np/arraymath.py:999-1002
```

```
numpy.lib.type_check.isposinf()
   Alias to: numpy.isposinf

• defined by isposinf(x, out=None) at numba/np/arraymath.py:1005-1008
```

```
numpy.lib.type_check.isreal()
   Alias to: numpy.isreal

• defined by np_isreal(x) at numba/np/arraymath.py:939-944
```

```
numpy.lib.type_check.isrealobj()
   Alias to: numpy.isrealobj

• defined by isrealobj(x) at numba/np/arraymath.py:967-974
```

```
numpy.lib.type_check.real()
   Alias to: numpy.real

• defined by np_real(a) at numba/np/arraymath.py:3490-3495
```

```
numpy.lib.type_check.zeros()
   Alias to: numpy.zeros

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
```

Not showing 8 unsupported functions.

supported = 11 / 19 = 57.89%

```
numpy.lib.ufunclike
```

```
numpy.lib.ufunclike.isneginf()
   Alias to: numpy.isneginf

• defined by isneginf(x, out=None) at numba/np/arraymath.py:999-1002
```

```
numpy.lib.ufunclike.isposinf()
   Alias to: numpy.isposinf

• defined by isposinf(x, out=None) at numba/np/arraymath.py:1005-1008
```

Not showing 2 unsupported functions.

supported = 2 / 4 = 50.00%
numpy.lib.user_array

numpy.lib.user_array.arange()
  Alias to: numpy.arange
  • defined by np.arange(start, stop=None, step=None, dtype=None) at numba/np/arrayobj.py:4111-4176

numpy.lib.user_array.array()
  Alias to: numpy.array
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.lib.user_array.asarray()
  Alias to: numpy.asarray
  • defined by np_asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpy.lib.user_array.reshape()
  Alias to: numpy.reshape
  • defined by np.reshape(a, shape) at numba/np/arrayobj.py:1825-1829

numpy.lib.user_array.shape()
  Alias to: numpy.shape
  • defined by np_shape(a) at numba/np/arrayobj.py:2076-2083

numpy.lib.user_array.transpose()
  Alias to: numpy.transpose
  • defined by numpy_transpose(a, axes=None) at numba/np/arrayobj.py:1610-1622

Not showing 0 unsupported functions.
supported = 6 / 6 = 100.00%

numpy.lib.utils

numpy.lib.utils.asarray()
  Alias to: numpy.asarray
  • defined by np_asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

Not showing 13 unsupported functions.
supported = 1 / 14 = 7.14%
numpy.linalg

numpy.linalg.cholesky()
    Alias to: numpy.dual.cholesky
    • defined by cho_impl(a) at numba/np/linalg.py:900-942

numpy.linalg.cond()
    • defined by cond_impl(a, p=None) at numba/np/linalg.py:2360-2402

numpy.linalg.det()
    Alias to: numpy.dual.det
    • defined by det_impl(a) at numba/np/linalg.py:2017-2028

numpy.linalg.eig()
    Alias to: numpy.dual.eig
    • defined by eig_impl(a) at numba/np/linalg.py:944-1057

numpy.linalg.eigh()
    Alias to: numpy.dual.eigh
    • defined by eigh_impl(a) at numba/np/linalg.py:1178-1225

numpy.linalg.eigvals()
    Alias to: numpy.dual.eigvals
    • defined by eigvals_impl(a) at numba/np/linalg.py:1059-1176

numpy.linalg.eigvalsh()
    Alias to: numpy.dual.eigvalsh
    • defined by eigvalsh_impl(a) at numba/np/linalg.py:1227-1274

numpy.linalg.inv()
    Alias to: numpy.dual.inv
    • defined by inv_impl(a) at numba/np/linalg.py:832-869

numpy.linalg.lstsq()
    Alias to: numpy.dual.lstsq
    • defined by lstsq_impl(a, b, rcond=-1.0) at numba/np/linalg.py:1582-1674

numpy.linalg.matrix_power()
    • defined by matrix_power_impl(a, n) at numba/np/linalg.py:2485-2561

numpy.linalg.matrix_rank()
    • defined by matrix_rank_impl(a, tol=None) at numba/np/linalg.py:2419-2482

numpy.linalg.norm()
    Alias to: numpy.dual.norm
    • defined by norm_impl(a, ord=None) at numba/np/linalg.py:2351-2357

numpy.linalg.pinv()
    Alias to: numpy.dual.pinv
    • defined by pinv_impl(a, rcond=1e-15) at numba/np/linalg.py:1758-1919

numpy.linalg.qr()
• defined by qr_impl(a) at numba/np/linalg.py:1342-1416

numpy.linalg.slogdet()

• defined by slogdet_impl(a) at numba/np/linalg.py:1958-2014

numpy.linalg.solve()
   Alias to: numpy.dual.solve
      • defined by solve_impl(a, b) at numba/np/linalg.py:1697-1755

numpy.linalg.svd()
   Alias to: numpy.dual.svd
      • defined by svd_impl(a, full_matrices=1) at numba/np/linalg.py:1276-1339

Not showing 3 unsupported functions.

supported = 17 / 20 = 85.00%

**numpy.linalg.lapack_lite**

This module is not supported.

**numpy.linalg.linalg**

numpy.linalg.linalg.all()
   Alias to: numpy.all
      • defined by np_all(a) at numba/np/arraymath.py:857-866

numpy.linalg.linalg.amax()
   Alias to: numpy.amax
      • defined by <class 'abc.Numpy_redirect_max'>

numpy.linalg.linalg.amin()
   Alias to: numpy.amin
      • defined by <class 'abc.Numpy_redirect_min'>

numpy.linalg.linalg.argsort()
   Alias to: numpy.argsort
      • defined by <class 'abc.Numpy_redirect_argsort'>

numpy.linalg.linalg.array()
   Alias to: numpy.array
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.linalg.linalg.asarray()
   Alias to: numpy.asarray
      • defined by np_asarray(a, dtype=None) at numba/np/arraymath.py:4285-4337

numpy.linalg.linalg.atleast_2d()
   Alias to: numpy.atleast_2d
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

numpy.linalg.linalg.cholesky()
   Alias to: numpy.dual.cholesky
      • defined by cho_impl(a) at numba/np/linalg.py:900-942

numpy.linalg.linalg.cond()
   Alias to: numpy.linalg.cond
      • defined by cond_impl(a, p=None) at numba/np/linalg.py:2360-2402

numpy.linalg.linalg.count_nonzero()
   Alias to: numpy.count_nonzero
      • defined by np_count_nonzero(arr, axis=None) at numba/np/arraymath.py:3523-3537

numpy.linalg.linalg.det()
   Alias to: numpy.dual.det
      • defined by det_impl(a) at numba/np/linalg.py:2017-2028

numpy.linalg.linalg.dot()
   Alias to: numpy.dot
      • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
      • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

numpy.linalg.linalg.eig()
   Alias to: numpy.dual.eig
      • defined by eig_impl(a) at numba/np/linalg.py:944-1057

numpy.linalg.linalg.eigh()
   Alias to: numpy.dual.eigh
      • defined by eigh_impl(a) at numba/np/linalg.py:1178-1225

numpy.linalg.linalg.eigvals()
   Alias to: numpy.dual.eigvals
      • defined by eigvals_impl(a) at numba/np/linalg.py:1059-1176

numpy.linalg.linalg.eigvalsh()
   Alias to: numpy.dual.eigvalsh
      • defined by eigvalsh_impl(a) at numba/np/linalg.py:1227-1274

numpy.linalg.linalg.empty()
   Alias to: numpy.empty
      • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
      • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

numpy.linalg.linalg.empty_like()
   Alias to: numpy.empty_like
**defined by** _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

**defined by** _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.linalg.linalg.eye()
   Alias to: numpy.eye
       • **defined by** numpy.eye(N, M=None, k=0, dtype=<class 'float'>) at numba/np/arrayobj.py:3948-3971

numpy.linalg.linalg.inv()
   Alias to: numpy.linalg.inv
       • **defined by** inv_impl(a) at numba/np/linalg.py:832-869

numpy.linalg.linalg.lstsq()
   Alias to: numpy.linalg.lstsq
       • **defined by** lstsq_impl(a, b, rcond=-1.0) at numba/np/linalg.py:1582-1674

numpy.linalg.linalg.matrix_power()
   Alias to: numpy.linalg.matrix_power
       • **defined by** matrix_power_impl(a, n) at numba/np/linalg.py:2485-2561

numpy.linalg.linalg.matrix_rank()
   Alias to: numpy.linalg.matrix_rank
       • **defined by** matrix_rank_impl(a, tol=None) at numba/np/linalg.py:2419-2482

numpy.linalg.linalg.norm()
   Alias to: numpy.linalg.norm
       • **defined by** norm_impl(a, ord=None) at numba/np/linalg.py:2351-2357

numpy.linalg.linalg.pinv()
   Alias to: numpy.linalg.pinv
       • **defined by** pinv_impl(a, rcond=1e-15) at numba/np/linalg.py:1758-1919

numpy.linalg.linalg.qr()
  Alias to: numpy.linalg.qr
       • **defined by** qr_impl(a) at numba/np/linalg.py:1342-1416

numpy.linalg.linalg.slogdet()
   Alias to: numpy.linalg.slogdet
       • **defined by** slogdet_impl(a) at numba/np/linalg.py:1958-2014

numpy.linalg.linalg.solve()
   Alias to: numpy.linalg.solve
       • **defined by** solve_impl(a, b) at numba/np/linalg.py:1697-1755

numpy.linalg.linalg.sort()
   Alias to: numpy.sort
       • **defined by** _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
       • **defined by** _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
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```
numpy.linalg.linalg.\texttt{sum}()
   Alias to: numpy.\texttt{sum}
   • defined by \texttt{<class 'abc.Numpy_redirect_sum'>}

numpy.linalg.linalg.\texttt{svd}()
   Alias to: numpy.dual.\texttt{svd}
   • defined by \texttt{svd_impl(a, full_matrices=1)} at numba/np/linalg.py:1276-1339

numpy.linalg.linalg.\texttt{swapaxes}()
   Alias to: numpy.swapaxes
   • defined by numpy_swapaxes(arr, axis1, axis2) at numba/np/arrayobj.py:5544-5577

numpy.linalg.linalg.\texttt{triu}()
   Alias to: numpy.triu
   • defined by \texttt{my_triu(m, k=0)} at numba/np/arraymath.py:1854-1877

numpy.linalg.linalg.\texttt{zeros}()
   Alias to: numpy.zeros
   • defined by _OverloadWrapper._build.<locals>.\texttt{ol_generated}(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.\texttt{ol_generated}(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 13 unsupported functions.
supported = 34 / 47 = 72.34%

\texttt{numpy.linalg.setup}

This module is not supported.

\texttt{numpy.ma}

\texttt{numpy.ma.\texttt{amax}()}
   Alias to: numpy.\texttt{amax}
   • defined by \texttt{<class 'abc.Numpy_redirect_max'>}

\texttt{numpy.ma.\texttt{amin}()}
   Alias to: numpy.\texttt{amin}
   • defined by \texttt{<class 'abc.Numpy_redirect_min'>}

\texttt{numpy.ma.\texttt{clip}()}
   Alias to: numpy.\texttt{clip}
   • defined by np_clip(a, a_min, a_max, out=None) at numba/np/arrayobj.py:1900-1940

\texttt{numpy.ma.\texttt{diff}()}
   Alias to: numpy.\texttt{diff}
   • defined by np_diff_impl(a, n=1) at numba/np/arraymath.py:3591-3627

\texttt{numpy.ma.\texttt{expand_dims}()}
   Alias to: numpy.\texttt{expand_dims}
```

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• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at
  numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at
  numba/core/overload_glue.py:131-181

Not showing 105 unsupported functions.
supported = 5 / 110 = 4.55%

**numpy.ma.bench**

This module is not supported.

**numpy.ma.core**

numpy.ma.core.amax()
  Alias to: numpy.amax
  • defined by <class 'abc.Numpy_redirect_max'>

numpy.ma.core.amin()
  Alias to: numpy.amin
  • defined by <class 'abc.Numpy_redirect_min'>

numpy.ma.core.clip()
  Alias to: numpy.clip
  • defined by np.clip(a, a_min, a_max, out=None) at numba/np/arrayobj.py:1900-1940

numpy.ma.core.diff()
  Alias to: numpy.diff
  • defined by np_diff_impl(a, n=1) at numba/np/arraymath.py:3591-3627

numpy.ma.core.expand_dims()
  Alias to: numpy.expand_dims
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at
    numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at
    numba/core/overload_glue.py:131-181

numpy.ma.core.iscomplexobj()
  Alias to: numpy.iscomplexobj
  • defined by iscomplexobj(x) at numba/np/arraymath.py:947-964

numpy.ma.core.narray()
  Alias to: numpy.array
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at
    numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at
    numba/core/overload_glue.py:131-181

numpy.ma.core.ones_like()
  Alias to: numpy.ones_like
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars)` at numba/core/overload_glue.py:131-181

numpy.ma.core.reduce()

  Alias to: `numpy.distutils.system_info.reduce`

  • defined by `<class 'numba.core.typing.templates.Registry.register_global.<locals>.decorate.<locals>.Template'>`

numpy.ma.core.zeros_like()

  Alias to: `numpy.zeros_like`

  • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars)` at numba/core/overload_glue.py:131-181

  • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars)` at numba/core/overload_glue.py:131-181

Not showing 85 unsupported functions.
supported = 10 / 95 = 10.53%

**numpy.ma.extras**

numpy.ma.extras.nxarray()

  Alias to: `numpy.array`

  • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars)` at numba/core/overload_glue.py:131-181

  • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars)` at numba/core/overload_glue.py:131-181

Not showing 48 unsupported functions.
supported = 1 / 49 = 2.04%

**numpy.ma.mrecords**

numpy.ma.mrecords.narray()

  Alias to: `numpy.array`

  • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars)` at numba/core/overload_glue.py:131-181

  • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwars)` at numba/core/overload_glue.py:131-181

Not showing 10 unsupported functions.
supported = 1 / 11 = 9.09%
numpma.setup

This module is not supported.

numpma.tesutil

This module is not supported.

numpma.timer comparison

numpma.timer.comparison.reduce()

Alias to: numpa.distutils.system_info.reduce

· defined by <class 'numba.core.typing.templates.Registry.register_global.<locals>.decorates.<locals>.Template'>

Not showing 1 unsupported functions.
supported = 1 / 2 = 50.00%

numpma.matlib

numpma.matlib.all()

Alias to: numpma.all

· defined by np_all(a) at numba/numparraymath.py:857-866

numpma.matlib.amax()

Alias to: numpma.amax

· defined by <class 'abc.Numpy_redirect_max'>

numpma.matlib.amin()

Alias to: numpma.amin

· defined by <class 'abc.Numpy_redirect_min'>

numpma.matlib.angle()

Alias to: numpma.angle

· defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181

· defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwarg) at numba/core/overload_glue.py:131-181

numpma.matlib.any()

Alias to: numpma.any

· defined by np.any(a) at numba/numparraymath.py:869-878

numpma.matlib.append()

Alias to: numpma.append

· defined by np.append(arr, values, axis=None) at numba/numparrayobj.py:1832-1855

numpma.matlib.arange()

Alias to: numpma.arange

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• defined by np_arange(start, stop=None, step=None, dtype=None) at `numba/np/arrayobj.py:4111-4176`

`numpy.matlib.argmax()`
   Alias to: `numpy.argmax`  
   • defined by `array_argmax(arr, axis=None)` at `numba/np/arraymath.py:837-854`

`numpy.matlib.argmin()`
   Alias to: `numpy.argmin`  
   • defined by `array_argmin(arr, axis=None)` at `numba/np/arraymath.py:707-724`

`numpy.matlib.argsort()`
   Alias to: `numpy.argsort`  
   • defined by `<class 'abc.Numpy_redirect_argsort'>`

`numpy.matlib.argwhere()`
   Alias to: `numpy.argwhere`  
   • defined by `np_argwhere(a)` at `numba/np/arraymath.py:2985-3017`

`numpy.matlib.around()`
   Alias to: `numpy.around`  
   • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
   • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.matlib.array()`
   Alias to: `numpy.array`  
   • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
   • defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.matlib.array_equal()`
   Alias to: `numpy.array_equal`  
   • defined by `np_array_equal(a, b)` at `numba/np/arraymath.py:3630-3649`

`numpy.matlib.array_split()`
   Alias to: `numpy.array_split`  
   • defined by `np_array_split(ary, indices_or_sections, axis=0)` at `numba/np/arrayobj.py:5252-5310`

`numpy.matlib.asarray()`
   Alias to: `numpy.asarray`  
   • defined by `np_asarray(a, dtype=None)` at `numba/np/arraymath.py:4285-4337`

`numpy.matlib.asarray_chkfinite()`
   Alias to: `numpy.asarray_chkfinite`  
   • defined by `np_asarray_chkfinite(a, dtype=None)` at `numba/np/arraymath.py:4432-4454`

`numpy.matlib.ascontiguousarray()`
   Alias to: `numpy.ascontiguousarray`
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181

numpy.matlib.asfarray()
   Alias to: numpy.asfarray
     • defined by np_asfarray(a, dtype=<class 'numpy.float64'>) at numba/np/arraymath.py:4340-4352

numpy.matlib.asfortranarray()
   Alias to: numpy.asfortranarray
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181

numpy.matlib.atleast_1d()
   Alias to: numpy.atleast_1d
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181

numpy.matlib.atleast_2d()
   Alias to: numpy.atleast_2d
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181

numpy.matlib.atleast_3d()
   Alias to: numpy.atleast_3d
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181
     • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwangs) at numba/core/overload_glue.py:131-181

numpy.matlib.average()
   Alias to: numpy.average
     • defined by np_average(arr, axis=None, weights=None) at numba/np/arraymath.py:881-915

numpy.matlib.bartlett()
   Alias to: numpy.bartlett
     • defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.matlib.bincount()
   Alias to: numpy.bincount
     • defined by np_bincount(a, weights=None, minlength=0) at numba/np/arraymath.py:3685-3740

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numpy.matlib.blackman()
   Alias to: numpy.blackman
   • defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.matlib.broadcast_to()
   Alias to: numpy.broadcast_to
   • defined by numpy_broadcast_to(array, shape) at numba/np/arrayobj.py:1360-1382

numpy.matlib.clip()
   Alias to: numpy.clip
   • defined by np_clip(a, a_min, a_max, out=None) at numba/np/arrayobj.py:1900-1940

numpy.matlib.column_stack()
   Alias to: numpy.column_stack
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.concatenate()
   Alias to: numpy.concatenate
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.correlate()
   Alias to: numpy.correlate
   • defined by _np_correlate(a, v) at numba/np/arraymath.py:4213-4258

numpy.matlib.count_nonzero()
   Alias to: numpy.count_nonzero
   • defined by np_count_nonzero(arr, axis=None) at numba/np/arraymath.py:3523-3537

numpy.matlib.cov()
• defined by np_cov(m, y=None, rowvar=True, bias=False, ddof=None) at numba/np/arraymath.py:2889-2945

numpy.matlib.cross()
   Alias to: numpy.cross
      • defined by np_cross(a, b) at numba/np/arraymath.py:4690-4712

numpy.matlib.cumprod()
   Alias to: numpy.cumprod
      • defined by <class 'abc.Numpy_redirect_cumprod'>

numpy.matlib.cumsum()
   Alias to: numpy.cumsum
      • defined by <class 'abc.Numpy_redirect_cumsum'>

numpy.matlib.delete()
   Alias to: numpy.delete
      • defined by np_delete(arr, obj) at numba/np/arraymath.py:3544-3588

numpy.matlib.diag()
   Alias to: numpy.diag
      • defined by __OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by __OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.diff()
   Alias to: numpy.diff
      • defined by np_diff_impl(a, n=1) at numba/np/arraymath.py:3591-3627

numpy.matlib.digitize()
   Alias to: numpy.digitize
      • defined by np_digitize(x, bins, right=False) at numba/np/arraymath.py:3808-3934

numpy.matlib.dot()
   Alias to: numpy.dot
      • defined by __OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by __OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.hstack()
   Alias to: numpy.hstack
      • defined by __OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by __OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.ediff1d()
   Alias to: numpy.ediff1d
      • defined by np_ediff1d(ary, to_end=None, to_begin=None) at numba/np/arraymath.py:1937-1992
numpy.matlib.empty_like()
   Alias to: numpy.empty_like
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.expand_dims()
   Alias to: numpy.expand_dims
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.extract()
   Alias to: numpy.extract
   • defined by np_extract(condition, arr) at numba/numpy/arraymath.py:4355-4378

numpy.matlib.fill_diagonal()
   Alias to: numpy.fill_diagonal
   • defined by np_fill_diagonal(a, val, wrap=False) at numba/numpy/arraymath.py:3122-3152

numpy.matlib.flatten()
   Alias to: numpy.flatten
   • defined by np.flatten() at numba/numpy/arrayobj.py:5238-5249

numpy.matlib.flip()
   Alias to: numpy.flip
   • defined by np.flip(a) at numba/numpy/arrayobj.py:5174-5188

numpy.matlib.flipud()
   Alias to: numpy.flipud
   • defined by np.flipud(a) at numba/numpy/arrayobj.py:5191-5205

numpy.matlib.frombuffer()
   Alias to: numpy.frombuffer
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.full()
   Alias to: numpy.full
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.matlib.full_like()  
Alias to: numpy.full_like  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.hamming()  
Alias to: numpy.hamming  
• defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.matlib.hanning()  
Alias to: numpy.hanning  
• defined by window_generator.<locals>.window_overload(M) at numba/np/arraymath.py:4509-4521

numpy.matlib.histogram()  
Alias to: numpy.histogram  
• defined by np_histogram(a, bins=10, range=None) at numba/np/arraymath.py:3940-4020

numpy.matlib.hstack()  
Alias to: numpy.hstack  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.imag()  
Alias to: numpy.imag  
• defined by np_imag(a) at numba/np/arraymath.py:3498-3503

numpy.matlib.interp()  
Alias to: numpy.interp  
• defined by np_interp(x, xp, fp) at numba/np/arraymath.py:2640-2701

numpy.matlib.intersect1d()  
Alias to: numpy.intersect1d  
• defined by jit_np_intersect1d(ar1, ar2) at numba/np/arraymath.py:3652-3672

numpy.matlib.iscomplex()  
Alias to: numpy.iscomplex  
• defined by np_iscomplex(x) at numba/np/arraymath.py:931-936

numpy.matlib.iscomplexobj()  
Alias to: numpy.iscomplexobj  
• defined by iscomplexobj(x) at numba/np/arraymath.py:947-964

numpy.matlib.isneginf()  
Alias to: numpy.isneginf  
• defined by isneginf(x, out=None) at numba/np/arraymath.py:999-1002
numpy.matlib.isposinf()
   Alias to: numpy.isposinf
   • defined by isposinf(x, out=None) at numba/np/arraymath.py:1005-1008

numpy.matlib.isreal()
   Alias to: numpy.isreal
   • defined by np.isreal(x) at numba/np/arraymath.py:939-944

numpy.matlib.isrealobj()
   Alias to: numpy.isrealobj
   • defined by isrealobj(x) at numba/np/arraymath.py:967-974

numpy.matlib.isscalar()
   Alias to: numpy.isscalar
   • defined by np.isscalar(num) at numba/np/arraymath.py:977-983

numpy.matlib.kaiser()
   Alias to: numpy.kaiser
   • defined by np.kaiser(M, beta) at numba/np/arraymath.py:4627-4646

numpy.matlib.kron()
   Alias to: numpy.kron
   • defined by kron_impl(a, b) at numba/np/linalg.py:2709-2763

numpy.matlib.linspace()
   Alias to: numpy.linspace
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.logspace()
   Alias to: numpy.logspace
   • defined by numpy.logspace(start, stop, num=50) at numba/np/arrayobj.py:1645-1658

numpy.matlib.mean()
   Alias to: numpy.mean
   • defined by <class 'abc.Numpy_redirect_mean'>

numpy.matlib.median()
   Alias to: numpy.median
   • defined by np.median(a) at numba/np/arraymath.py:1448-1460

numpy.matlib.nancumprod()
   Alias to: numpy.nancumprod
   • defined by np.nancumprod(a) at numba/np/arraymath.py:1193-1215

numpy.matlib.nancumsum()
   Alias to: numpy.nancumsum
   • defined by np.nancumsum(a) at numba/np/arraymath.py:1218-1240

numpy.matlib.nanmax()
   Alias to: numpy.nanmax
• defined by np_nanmax(a) at numba/numpy/arith/math.py:1084-1090

numpy.matlib.nanmean()
  Alias to: numpy.nanmean

• defined by np_nanmean(a) at numba/numpy/arith/math.py:1093-1110

numpy.matlib.nanmedian()
  Alias to: numpy.nanmedian

• defined by np_nanmedian(a) at numba/numpy/arith/math.py:1634-1656

numpy.matlib.nanmin()
  Alias to: numpy.nanmin

• defined by np_nanmin(a) at numba/numpy/arith/math.py:1075-1081

numpy.matlib.nanpercentile()
  Alias to: numpy.nanpercentile

• defined by np_nanpercentile(a, q) at numba/numpy/arith/math.py:1613-1617

numpy.matlib.nanprod()
  Alias to: numpy.nanprod

• defined by np_nanprod(a) at numba/numpy/arith/math.py:1171-1190

numpy.matlib.nanquantile()
  Alias to: numpy.nanquantile

• defined by np_nanquantile(a, q) at numba/numpy/arith/math.py:1627-1631

numpy.matlib.nanstd()
  Alias to: numpy.nanstd

• defined by np_nanstd(a) at numba/numpy/arith/math.py:1138-1146

numpy.matlib.nansum()
  Alias to: numpy.nansum

• defined by np_nansum(a) at numba/numpy/arith/math.py:1149-1168

numpy.matlib.nanvar()
  Alias to: numpy.nanvar

• defined by np_nanvar(a) at numba/numpy/arith/math.py:1113-1135

numpy.matlib.nonzero()
  Alias to: numpy.nonzero

• defined by <class 'abc.Numpy_redirect_nonzero'>

numpy.matlib.ones_like()
  Alias to: numpy.ones_like

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.outer()
  Alias to: numpy.outer

• defined by outer_impl(a, b, out=None) at numba/numpy/linalg.py:2632-2643
**numpy.matlib.partition()**

- Defined by `np_partition(a, kth)` at `numba/numpy/arraymath.py:1715-1737`

**numpy.matlib.percentile()**

- Defined by `np_percentile(a, q)` at `numba/numpy/arraymath.py:1606-1610`

**numpy.matlib.prod()**

- Defined by `<class 'abc.Numpy_redirect_prod'>`

**numpy.matlib.ptp()**

- Defined by `np_ptp(a)` at `numba/numpy/arraymath.py:1302-1328`

**numpy.matlib.quantile()**

- Defined by `np_quantile(a, q)` at `numba/numpy/arraymath.py:1620-1624`

**numpy.matlib.ravel()**

- Defined by `<class 'abc.Numpy_redirect_ravel'>`

**numpy.matlib.real()**

- Defined by `np_real(a)` at `numba/numpy/arraymath.py:3490-3495`

**numpy.matlib.repeat()**

- Defined by `np_repeat(a, repeats)` at `numba/numpy/arrays.py:2098-2140`

**numpy.matlib.reshape()**

- Defined by `np_reshape(a, shape)` at `numba/numpy/arrays.py:1825-1829`

**numpy.matlib.roll()**

- Defined by `np_roll(a, shift)` at `numba/numpy/arraymath.py:2127-2147`

**numpy.matlib.roots()**

- Defined by `roots_impl(p)` at `numba/numpy/polynomials.py:14-59`

**numpy.matlib.rot90()**

- Defined by `numpy_rot90(arr, k=1)` at `numba/numpy/arrays.py:1661-1685`

**numpy.matlib.round_()**

- Defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

numpy.matlib.row_stack()
Alias to: numpy.row_stack

- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

numpy.matlib.searchsorted()
Alias to: numpy.searchsorted

- defined by searchsorted(a, v, side='left') at numba/np/arraymath.py:3773-3805

numpy.matlib.select()
Alias to: numpy.select

- defined by np_select(condlist, choicelist, default=0) at numba/np/arraymath.py:4381-4429

numpy.matlib.shape()
Alias to: numpy.shape

- defined by np_shape(a) at numba/np/arrayobj.py:2076-2083

numpy.matlib.sinc()
Alias to: numpy.sinc

- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

numpy.matlib.sort()
Alias to: numpy.sort

- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

numpy.matlib.split()
Alias to: numpy.split

- defined by np_split(ary, indices_or_sections, axis=0) at numba/np/arrayobj.py:5313-5337

numpy.matlib.stack()
Alias to: numpy.stack

- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
- defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

numpy.matlib.std()
Alias to: numpy.std

- defined by `<class 'abc.Numpy_redirect_std'>`
numpy.matlib.sum()
Alias to: numpy.sum
  • defined by <class 'abc.Numpy_redirect_sum'>

numpy.matlib.swapaxes()
Alias to: numpy.swapaxes
  • defined by numpy_swapaxes(arr, axis1, axis2) at numba/np/arrayobj.py:5544-5577

numpy.matlib.take()
Alias to: numpy.take
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.take_along_axis()
Alias to: numpy.take_along_axis
  • defined by arr_take_along_axis(arr, indices, axis) at numba/np/arrayobj.py:5641-5682

numpy.matlib.trace()
Alias to: numpy.trace
  • defined by matrix_trace_impl(a, offset=0) at numba/nplinalg.py:2566-2594

numpy.matlib.transpose()
Alias to: numpy.transpose
  • defined by numpytranspose(a, axes=None) at numba/np/arrayobj.py:1610-1622

numpy.matlib.trapz()
Alias to: numpy.trapz
  • defined by np_trapz(y, x=None, dx=1.0) at numba/np/arraymath.py:2029-2048

numpy.matlib.tri()
Alias to: numpy.tri
  • defined by np_tri(N, M=None, k=0) at numba/np/arraymath.py:1756-1767

numpy.matlib.tril()
Alias to: numpy.tril
  • defined by my_tril(m, k=0) at numba/np/arraymath.py:1793-1817

numpy.matlib.tril_indices()
Alias to: numpy.tril_indices
  • defined by np_tril_indices(n, k=0, m=None) at numba/np/arraymath.py:1820-1831

numpy.matlib.tril_indices_from()
Alias to: numpy.tril_indices_from
  • defined by np_tril_indices_from(arr, k=0) at numba/np/arraymath.py:1834-1845

numpy.matlib.triu()
Alias to: numpy.triu
  • defined by my_triu(m, k=0) at numba/np/arraymath.py:1854-1877

numpy.matlib.triu_indices()
Alias to: numpy.triu_indices
• defined by np_triu_indices(n, k=0, m=None) at numba/np/arraymath.py:1880-1891

numpy.matlib.triu_indices_from()
    Alias to: numpy.triu_indices_from
        • defined by np_triu_indices_from(arr, k=0) at numba/np/arraymath.py:1894-1905

numpy.matlib.unique()
    Alias to: numpy.unique
        • defined by np_unique(a) at numba/np/arrayobj.py:2088-2095

numpy.matlib.vander()
    Alias to: numpy.vander
        • defined by np_vander(x, N=None, increasing=False) at numba/np/arraymath.py:2087-2124

numpy.matlib.var()
    Alias to: numpy.var
        • defined by <class 'abc.Numpy_redirect_var'>

numpy.matlib.vdot()
    Alias to: numpy.vdot
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.vstack()
    Alias to: numpy.row_stack
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.where()
    Alias to: numpy.where
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.matlib.zeros_like()
    Alias to: numpy.zeros_like
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
        • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 174 unsupported functions.
supported = 136 / 310 = 43.87%
numpy.matrixlib

This module is not supported.

numpy.matrixlib.defmatrix

numpy.matrixlib.defmatrix.concatenate()
   Alias to: numpy.concatenate
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181
       • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at numba/core/overload_glue.py:131-181

numpy.matrixlib.defmatrix.isscalar()
   Alias to: numpy.isscalar
       • defined by np_isscalar(num) at numba/numpymath.py:977-983

numpy.matrixlib.defmatrix.matrix_power()
   Alias to: numpy.linalg.matrix_power
       • defined by matrix_power_impl(a, n) at numba/numpy.linalg.py:2485-2561

Not showing 4 unsupported functions.
supported = 3 / 7 = 42.86%

numpy.matrixlib.setup

This module is not supported.

numpy.polynomial

This module is not supported.

numpy.polynomial.chebyshev

This module is not supported.

numpy.polynomial.hermite

This module is not supported.
numpypolynomial.hermite_e

This module is not supported.

numpypolynomial.laguerre

This module is not supported.

numpypolynomial.legendre

This module is not supported.

numpypolynomial.polynomial

This module is not supported.

numpypolynomial.polyutils

This module is not supported.

numpypolynomial.setup

This module is not supported.

numpypolynomial

numpypolynomial.beta()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpypolynomial.binomial()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpypolynomial.chisquare()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpypolynomial.choice()
• defined by `choice(a, size=None, replace=True)` at `numba/cpython/randomimpl.py:1360-1441`

`numpy.random.dirichlet()`

• defined by `dirichlet(alpha, size=None)` at `numba/cpython/randomimpl.py:1527-1588`

`numpy.random.exponential()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.random.f()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.random.gamma()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.random.geometric()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.random.gumbel()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.random.hypergeometric()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`

`numpy.random.laplace()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at `numba/core/overload_glue.py:131-181`
Numpy.random.logistic()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.lognormal()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.logseries()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.multinomial()

• defined by multinomial(n, pvals, size=None) at numba/cpython/randomimpl.py:1447-1522

numpy.random.negative_binomial()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.normal()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.pareto()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.permutation()

• defined by permutation_impl(x) at numba/cpython/randomimpl.py:1238-1252

numpy.random.poisson()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.power()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.rand()

• defined by rand(*size) at numba/cpython/randomimpl.py:1328-1340

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.randint()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.randn()

• defined by randn(*size) at numba/cpython/randomimpl.py:1342-1354

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.random()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.random_sample()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.ranf()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.rayleigh()

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

• defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.sample()
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.seed()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.shuffle()`

• defined by `shuffle_impl(arr)` at numba/cpython/randomimpl.py:1234-1236

`numpy.random.standard_cauchy()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.standard_exponential()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.standard_gamma()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.standard_normal()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.standard_t()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.triangular()`
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.uniform()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.vonmises()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.wald()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.weibull()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

`numpy.random.zipf()`

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs)` at numba/core/overload_glue.py:131-181

Not showing 8 unsupported functions.
supported = 43 / 51 = 84.31%
nump.random.bit_generator

This module is not supported.

nump.random.mtrand

nump.random.mtrand.beta()
   Alias to: nump.random.beta
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

nump.random.mtrand.binomial()
   Alias to: nump.random.binomial
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

nump.random.mtrand.chisquare()
   Alias to: nump.random.chisquare
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

nump.random.mtrand.choice()
   Alias to: nump.random.choice
      • defined by choice(a, size=None, replace=True) at numba/cpython/randomimpl.py:1360-1441

nump.random.mtrand.dirichlet()
   Alias to: nump.random.dirichlet
      • defined by dirichlet(alpha, size=None) at numba/cpython/randomimpl.py:1527-1588

nump.random.mtrand.exponential()
   Alias to: nump.random.exponential
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

nump.random.mtrand.f()
   Alias to: nump.random.f
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.random.mtrand.gamma()
   Alias to: numpy.random.gamma
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.geometric()
   Alias to: numpy.random.geometric
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.gumbel()
   Alias to: numpy.random.gumbel
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.hypergeometric()
   Alias to: numpy.random.hypergeometric
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.laplace()
   Alias to: numpy.random.laplace
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.logistic()
   Alias to: numpy.random.logistic
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.lognormal()
   Alias to: numpy.random.lognormal
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.random.mtrand.logseries()  
Alias to: numpy.random.logseries
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.multinomial()  
Alias to: numpy.random.multinomial
  • defined by multinomial(n, pvals, size=None) at numba/cpython/randomimpl.py:1447-1522

numpy.random.mtrand.negative_binomial()  
Alias to: numpy.random.negative_binomial
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.normal()  
Alias to: numpy.random.normal
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.pareto()  
Alias to: numpy.random.pareto
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.permutation()  
Alias to: numpy.random.permutation
  • defined by permutation_impl(x) at numba/cpython/randomimpl.py:1238-1252

numpy.random.mtrand.poisson()  
Alias to: numpy.random.poisson
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.power()  
Alias to: numpy.random.power
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
  • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

6.10. Listings
numpy.random.mtrand.rand()  
   Alias to: numpy.random.rand  
      • defined by rand(*size) at numba/cpython/randomimpl.py:1328-1340

numpy.random.mtrand.randint()  
   Alias to: numpy.random.randint  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.randn()  
   Alias to: numpy.random.randn  
      • defined by randn(*size) at numba/cpython/randomimpl.py:1342-1354

numpy.random.mtrand.random()  
   Alias to: numpy.random.random  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.random_sample()  
   Alias to: numpy.random.random_sample  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.ranf()  
   Alias to: numpy.random.ranf  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.rayleigh()  
   Alias to: numpy.random.rayleigh  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.sample()  
   Alias to: numpy.random.sample  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181  
      • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
numpy.random.mtrand.seed()
   Alias to: numpy.random.seed
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181

numpy.random.mtrand.shuffle()
   Alias to: numpy.random.shuffle
   • defined by shuffle_impl(arr) at numba/cpython/randomimpl.py:1234-1236

numpy.random.mtrand.standard_cauchy()
   Alias to: numpy.random.standard_cauchy
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181

numpy.random.mtrand.standard_exponential()
   Alias to: numpy.random.standard_exponential
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181

numpy.random.mtrand.standard_gamma()
   Alias to: numpy.random.standard_gamma
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181

numpy.random.mtrand.standard_normal()
   Alias to: numpy.random.standard_normal
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181

numpy.random.mtrand.standard_t()
   Alias to: numpy.random.standard_t
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181

numpy.random.mtrand.triangular()
   Alias to: numpy.random.triangular
   • defined by _OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kw_args) at
     numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.uniform()
Alias to: numpy.random.uniform

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.vonmises()
Alias to: numpy.random.vonmises

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.wald()
Alias to: numpy.random.wald

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.weibull()
Alias to: numpy.random.weibull

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

numpy.random.mtrand.zipf()
Alias to: numpy.random.zipf

• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181
• defined by `_OverloadWrapper._build.<locals>.ol_generated(*ol_args, **ol_kwargs) at numba/core/overload_glue.py:131-181

Not showing 7 unsupported functions.
supported = 43 / 50 = 86.00%
numpy.random.setup

This module is not supported.

numpy.setup

This module is not supported.

numpy.testing

This module is not supported.

numpy.testing.print_coercion_tables

This module is not supported.

numpy.testing.setup

This module is not supported.

numpy.testing.utils

This module is not supported.

numpy.typing

This module is not supported.

numpy.typing.mypy_plugin

This module is not supported.

numpy.typing.setup

This module is not supported.
numpy.version

This module is not supported.

6.10.2 Old style listings

Lowering Listing

This lists all lowering definition registered to the CPU target. Each subsection corresponds to a Python function that is supported by numba nopython mode. These functions have one or more lower implementation with different signatures. The compiler chooses the most specific implementation from all overloads.

'array.argsort'

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array, StringLiteral)</td>
<td>array_argsort numba/np/arrayobj.py lines 5396-5410</td>
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'array.astype'

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<th>Signature</th>
<th>Definition</th>
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<tbody>
<tr>
<td>(Array, DTypeSpec)</td>
<td>array_astype numba/np/arrayobj.py lines 4343-4371</td>
</tr>
<tr>
<td>(Array, StringLiteral)</td>
<td>array_astype numba/np/arrayobj.py lines 4343-4371</td>
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'array.copy'

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<tr>
<td>(Array)</td>
<td>array_copy numba/np/arrayobj.py lines 4258-4260</td>
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'array.cumprod'

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<th>Definition</th>
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<tr>
<td>(Array)</td>
<td>array_cumprod numba/np/arraymath.py lines 390-406</td>
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'array.cumsum'

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<tr>
<td>(Array)</td>
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'array.flatten'

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<td>numba/np/arrayobj.py lines 1889-1897</td>
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'array.item'

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'array.itemset'

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<td>(Array, any)</td>
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'array.max'

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'array.mean'

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'array.min'

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'array.nonzero'

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'array.prod'

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<td>(Array)</td>
<td>array_prod numba/np/arraymath.py lines 355-367</td>
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'array.ravel'

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<td>(Array)</td>
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'array.reshape'

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<tr>
<td>(Array, *any)</td>
<td>array_reshape_vararg numba/np/arrayobj.py lines 1819-1822</td>
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<tr>
<td>(Array, BaseTuple)</td>
<td>array_reshape numba/np/arrayobj.py lines 1754-1816</td>
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'array.sort'

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<td>array_sort numba/np/arrayobj.py lines 5372-5382</td>
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'array.std'

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'array.sum'

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<td>array_sum numba/np/arraymath.py lines 166-179</td>
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<td>(Array, DTypeSpec)</td>
<td>array_sum_dtype numba/np/arraymath.py lines 295-308</td>
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<td>(Array, IntegerLiteral)</td>
<td>array_sum_axis numba/np/arraymath.py lines 311-352</td>
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<tr>
<td>(Array, IntegerLiteral, DTypeSpec)</td>
<td>array_sum_axis_dtype numba/np/arraymath.py lines 252-292</td>
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<tr>
<td>(Array, int64)</td>
<td>array_sum_axis numba/np/arraymath.py lines 311-352</td>
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<tr>
<td>(Array, int64, DTypeSpec)</td>
<td>array_sum_axis_dtype numba/np/arraymath.py lines 252-292</td>
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'array.take'

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<tr>
<td>(Array, Array)</td>
<td>numpy_take_2</td>
<td>numba/np/arrayobj.py lines 4036-4059</td>
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<tr>
<td>(Array, BaseTuple)</td>
<td>numpy_take_3</td>
<td>numba/np/arrayobj.py lines 4062-4082</td>
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<tr>
<td>(Array, Integer)</td>
<td>numpy_take_1</td>
<td>numba/np/arrayobj.py lines 4023-4033</td>
</tr>
<tr>
<td>(Array, List)</td>
<td>numpy_take_3</td>
<td>numba/np/arrayobj.py lines 4062-4082</td>
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'array.transpose'

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<td>array_transpose</td>
<td>numba/np/arrayobj.py lines 1529-1531</td>
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<tr>
<td>(Array, *any)</td>
<td>array_transpose_vararg</td>
<td>numba/np/arrayobj.py lines 1604-1607</td>
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<tr>
<td>(Array, BaseTuple)</td>
<td>array_transpose_tuple</td>
<td>numba/np/arrayobj.py lines 1549-1601</td>
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<td>(Array)</td>
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<td>numba/np/arraymath.py lines 427-442</td>
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'array.view'

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<td>(Array, DTypeSpec)</td>
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<td>numba/np/arrayobj.py lines 2169-2194</td>
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'complex.conjugate'

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<td>(Complex)</td>
<td>complex_conjugate_impl</td>
<td>numba/cpython/numbers.py lines 936-942</td>
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<tr>
<td>(Float)</td>
<td>real_conjugate_impl</td>
<td>numba/cpython/numbers.py lines 951-952</td>
</tr>
<tr>
<td>(Integer)</td>
<td>real_conjugate_impl</td>
<td>numba/cpython/numbers.py lines 951-952</td>
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'ffi.from_buffer'

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<th>Location</th>
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</thead>
<tbody>
<tr>
<td>(Buffer)</td>
<td>from_buffer</td>
<td>numba/misc/cffiimpl.py lines 12-22</td>
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</table>
'getiter'

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<tr>
<th>Signature</th>
<th>Definition</th>
<th>Definition</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Buffer)</td>
<td>getiter_array</td>
<td>numba/numpy/numbaarray.py lines 256-277</td>
<td></td>
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<tr>
<td>(DictItemsIterable-</td>
<td>impl_iterable_getiter</td>
<td>numba/typed/dictobject.py lines 935-966</td>
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<tr>
<td>Type)</td>
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<tr>
<td>(DictKeysIterable-</td>
<td>impl_iterable_getiter</td>
<td>numba/typed/dictobject.py lines 935-966</td>
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<td>Type)</td>
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<td>(DictType)</td>
<td>impl_dict_getiter</td>
<td>numba/typed/dictobject.py lines 969-1000</td>
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<td>(DictValuesIterable-</td>
<td>impl_iterable_getiter</td>
<td>numba/typed/dictobject.py lines 935-966</td>
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<tr>
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<td>(range_state_int32)</td>
<td>make_range_impl.&lt;locals&gt;.getiter_range32_impl</td>
<td>numba/cpython/rangeobject.py lines 91-99</td>
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'list.append'

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'list.reverse'

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'not in'

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<td>(any, any)</td>
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<td>(Boolean)</td>
<td>number_item_impl numba/cpython/numbers.py lines 1167-1173</td>
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<td>(Number)</td>
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'print_item'

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<td>(any)</td>
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'set.add'

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<td>(Set, any)</td>
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<td>(Set, Set)</td>
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'set.issuperset'

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'set.symmetric_difference'

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<td>(Array, StringLiteral)</td>
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<td>(BaseTuple, IntegerLiteral)</td>
<td>static_getitem_tuple</td>
<td>numba/np/arrayobj.py lines 348-373</td>
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<td>static_getitem_tuple</td>
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<td>(EnumClass, StringLiteral)</td>
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<td>record_static_getitem_int</td>
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<td>(BaseTuple, any)</td>
<td>getitemtyped numba/cpython/tupleobj.py lines 208-290</td>
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(<class 'numba.core.types.containers.BaseTuple'>, '__hash__')

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<td>(BaseTuple, *any)</td>
<td>_OverloadMethodTemplate._init_once.&lt;locals&gt;.method_impl numba/core/typing/templates.py lines 1111-1120</td>
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(<class 'numba.core.types.containers.BaseTuple'>, 'index')

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(<class 'numba.core.types.containers.Bytes'>, '__to_str__')

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(<class 'numba.core.types.containers.Bytes'>, 'center')

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(<class 'numba.core.types.containers.Bytes'>, 'endswith')

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<td>join</td>
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<td>Bytes</td>
<td>ljust</td>
</tr>
<tr>
<td>Bytes</td>
<td>lstrip</td>
</tr>
<tr>
<td>Bytes</td>
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ROADCAST Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

(<class 'numba.core.types.containers.Bytes'>, 'find')

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(<class 'numba.core.types.containers.Bytes'>, 'isascii')

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(<class 'numba.core.types.containers.Bytes'>, 'join')

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(<class 'numba.core.types.containers.Bytes'>, 'lstrip')

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(<class 'numba.core.types.containers.Bytes'>, 'rfind')

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6.10. Listings 475
(<class 'numba.core.types.containers.DictType'>, '__setitem__')

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(<class 'numba.core.types.containers.DictType'>, 'clear')

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(<class 'numba.core.types.containers.DictType'>, 'copy')

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(<class 'numba.core.types.containers.DictType'>, 'get')

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(<class 'numba.core.types.containers.DictType'>, 'items')

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(<class 'numba.core.types.containers.DictType'>, 'keys')

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<td>:class:<code>numba.core.types.containers.ListType</code>, '_allocated'</td>
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The documentation shows several methods defined for two different classes: `numba.core.types.containers.ListType` and `numba.core.types.containers.LiteralList`. Here's a brief overview of each:

### ListType
- **Signature**: `(ListType, *any)`
- **Definition**: `_OverloadMethodTemplate._init_once.<locals>.method_impl` from `numba/core/typing/templates.py` lines 1111-1120

#### Methods
- **remove**
- **reverse**
- **sort**

### LiteralList
- **Signature**: `(LiteralList, *any)`
- **Definition**: `_OverloadMethodTemplate._init_once.<locals>.method_impl` from `numba/core/typing/templates.py` lines 1111-1120

#### Methods
- **append**
- **clear**
- **copy**
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## Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

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tumba/core/typing/templates.py lines 1111-1120`

### Signature | Definition
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(Array, *any) | `_OverloadMethodTemplate._init_once.<locals>.method_impl`  
numba/core/typing/templates.py lines 1111-1120

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(Array, *any) | `_OverloadMethodTemplate._init_once.<locals>.method_impl`  
numba/core/typing/templates.py lines 1111-1120
(<class 'numba.core.types.npytypes.Array'>, 'dot')

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</thead>
<tbody>
<tr>
<td>(Array, *any)</td>
<td>_OverloadMethodTemplate._init_once.&lt;locals&gt;.method_impl</td>
</tr>
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<td></td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
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</table>

(<class 'numba.core.types.npytypes.Array'>, 'fill')

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(<class 'numba.core.types.npytypes.Array'>, 'ptp')

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(<class 'numba.core.types.npytypes.Array'>, 'repeat')

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<td>(Array, *any)</td>
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<td></td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
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</tbody>
</table>

(<class 'numba.core.types.npytypes.CharSeq'>, '__hash__')

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<tr>
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<tbody>
<tr>
<td>(CharSeq, *any)</td>
<td>_OverloadMethodTemplate._init_once.&lt;locals&gt;.method_impl</td>
</tr>
<tr>
<td></td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
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</table>

(<class 'numba.core.types.npytypes.CharSeq'>, '__get_kind__')

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<tr>
<td>(CharSeq, *any)</td>
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</table>
(<<class 'numba.core.types.npytypes.CharSeq'>, '_to_str')

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<tr>
<td>(CharSeq,</td>
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<td>*any)</td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
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(<<class 'numba.core.types.npytypes.CharSeq'>, 'center')

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<tbody>
<tr>
<td>(CharSeq,</td>
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<td>numba/core/typing/templates.py lines 1111-1120</td>
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(<<class 'numba.core.types.npytypes.CharSeq'>, 'endswith')

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<tr>
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(<<class 'numba.core.types.npytypes.CharSeq'>, 'find')

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<td>(CharSeq,</td>
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(<<class 'numba.core.types.npytypes.CharSeq'>, 'isascii')

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<tr>
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<td>*any)</td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
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(<<class 'numba.core.types.npytypes.CharSeq'>, 'isupper')

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<tr>
<td>(CharSeq,</td>
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<td>*any)</td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
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</table>
(<class 'numba.core.types.npytypes.CharSeq'>, 'join')

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| (CharSeq, *any) | _OverloadMethodTemplate._init_once.<locals>.method_impl  
numba/core/typing/templates.py lines 1111-1120 |

(<class 'numba.core.types.npytypes.CharSeq'>, 'ljust')

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| (CharSeq, *any) | _OverloadMethodTemplate._init_once.<locals>.method_impl  
numba/core/typing/templates.py lines 1111-1120 |

(<class 'numba.core.types.npytypes.CharSeq'>, 'lstrip')

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| (CharSeq, *any) | _OverloadMethodTemplate._init_once.<locals>.method_impl  
numba/core/typing/templates.py lines 1111-1120 |

(<class 'numba.core.types.npytypes.CharSeq'>, 'rfind')

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(<class 'numba.core.types.npytypes.CharSeq'>, 'rjust')

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(<class 'numba.core.types.npytypes.CharSeq'>, 'rstrip')

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### Listings

6.10.
### Signature | Definition
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Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

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<td>Signature</td>
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<tr>
<td>(Complex, *any)</td>
<td><code>_OverloadMethodTemplate._init_once.&lt;locals&gt;.method_impl</code></td>
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<td>numba/core/typing/templates.py lines 1111-1120</td>
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<tr>
<td>(Float, *any)</td>
<td><code>_OverloadMethodTemplate._init_once.&lt;locals&gt;.method_impl</code></td>
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<tr>
<td></td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
</tr>
<tr>
<td>(Float, *any)</td>
<td><code>_OverloadMethodTemplate._init_once.&lt;locals&gt;.method_impl</code></td>
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<td></td>
<td>numba/core/typing/templates.py lines 1111-1120</td>
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<tr>
<td>(IntEnumMember, *any)</td>
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<tr>
<td>(Integer, *any)</td>
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(\texttt{<class 'numba.core.types.scalars.NPDatetime'>}, '\texttt{__hash__}')

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\text{typeof}[\texttt{<class 'numba.core.types.containers.DictType'>}], '\texttt{empty}')

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<td>\texttt{(typeof&lt;class 'numba.core.types.containers.DictType'&gt;, any)}</td>
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\text{typeof}[\texttt{<class 'numba.core.types.containers.ListType'>}], '\texttt{empty_list}')

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\text{typeof}[\texttt{<class 'numba.core.types.npytypes.Array'>}], '\texttt{allocate}')

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<td>\texttt{(typeof&lt;class 'numba.core.types.npytypes.Array'&gt;, any)}</td>
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\text{ufunc 'absolute'}

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\text{ufunc 'add'}

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### <ufunc 'bitwise_or'>

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### <ufunc 'bitwise_xor'>

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Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

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**<ufunc 'conjugate'>**

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**<ufunc 'degrees'>**

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**<ufunc 'equal'>**

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**<ufunc 'expm1'>**

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### <ufunc 'fabs'>

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### <ufunc 'float_power'>

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### <ufunc 'floor'>

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### <ufunc 'floor_divide'>

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### <ufunc 'fmax'>

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### <ufunc 'isinf'>

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### <ufunc 'isnan'>

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### <ufunc 'isnat'>

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### <ufunc 'lcm'>

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### <ufunc 'ldexp'>

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### Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

<ufunc 'left_shift'>

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<ufunc 'less'>

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<ufunc 'less_equal'>

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<ufunc 'log'>

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<ufunc 'log10'>

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<ufunc 'log1p'>

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<ufunc 'log2'>

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<ufunc 'logaddexp'>

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<ufunc 'logaddexp2'>

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<ufunc 'logical_and'>

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<ufunc 'logical_not'>

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<ufunc 'logical_or'>

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<ufunc 'logical_xor'>

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<ufunc 'maximum'>

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<ufunc 'minimum'>

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<ufunc 'multiply'>

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<ufunc 'negative'>

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<ufunc 'nextafter'>

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<ufunc 'not_equal'>

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<ufunc 'positive'>

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<ufunc 'power'>

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<ufunc 'rad2deg'>

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<ufunc 'radians'>

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<ufunc 'reciprocal'>

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### <ufunc 'remainder'>

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### <ufunc 'right_shift'>

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### <ufunc 'rint'>

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### <ufunc 'sign'>

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### <ufunc 'signbit'>

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### <ufunc 'sin'>

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<ufunc 'sinh'>

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<ufunc 'spacing'>

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<ufunc 'sqrt'>

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<tr>
<td>(any, Array)</td>
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<td>numba/np/npyimpl.py lines 482-483</td>
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<ufunc 'square'>

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<td>numba/np/npyimpl.py lines 482-483</td>
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<tr>
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<td>numba/np/npyimpl.py lines 482-483</td>
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<ufunc 'subtract'>

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<td></td>
<td>numba/np/npyimpl.py lines 482-483</td>
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<tr>
<td>(any, any, Array)</td>
<td>register_ufunc_kernel.&lt;locals&gt;.do_ufunc</td>
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<td>numba/np/npyimpl.py lines 482-483</td>
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<ufunc 'tan'>

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### <ufunc 'true_divide'>

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<td>(any, any)</td>
<td>register_ufunc_kernel.&lt;locals&gt;.do_ufunc numba/npyimpl.py lines 482-483</td>
</tr>
<tr>
<td>(any, any, Array)</td>
<td>register_ufunc_kernel.&lt;locals&gt;.do_ufunc numba/npyimpl.py lines 482-483</td>
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### <ufunc 'trunc'>

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<tr>
<td>(any, Array)</td>
<td>register_ufunc_kernel.&lt;locals&gt;.do_ufunc numba/npyimpl.py lines 482-483</td>
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### _operator.add_

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<tr>
<td>(Array, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</td>
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<tr>
<td></td>
<td>numba/npyimpl.py lines 505-506</td>
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<tr>
<td>(Array, any)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</td>
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<tr>
<td></td>
<td>numba/npyimpl.py lines 505-506</td>
</tr>
<tr>
<td>(BaseTuple, BaseTuple)</td>
<td>tuple_add numba/cpython/tupleobj.py lines 31-36</td>
</tr>
<tr>
<td>(Complex, Complex)</td>
<td>complex_add_impl numba/cpython/numbers.py lines 1004-1017</td>
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<tr>
<td>(Float, Float)</td>
<td>real_add_impl numba/cpython/numbers.py lines 583-585</td>
</tr>
<tr>
<td>(Integer, Integer)</td>
<td>int_add_impl numba/cpython/numbers.py lines 36-42</td>
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<tr>
<td>(List, List)</td>
<td>list_add numba/cpython/listobj.py lines 686-706</td>
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<tr>
<td>(NPDatetime, NPTimedelta)</td>
<td>datetime_plus_timedelta numba/npydatetime.py lines 606-615</td>
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<td>(NPTimedelta, NPDatetime)</td>
<td>timedelta_plus_datetime numba/npydatetime.py lines 618-627</td>
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<tr>
<td>(NPTimedelta, NPTimedelta)</td>
<td>timedelta_add_impl numba/npydatetime.py lines 183-194</td>
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<tr>
<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</td>
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<td>numba/npyimpl.py lines 505-506</td>
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_operator.and_

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<td>(Array, any)</td>
<td><code>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</code> numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Boolean, Boolean)</td>
<td><code>int_and_impl</code> numba/cpython/numbers.py lines 400-406</td>
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<tr>
<td>(Integer, Integer)</td>
<td><code>int_and_impl</code> numba/cpython/numbers.py lines 400-406</td>
</tr>
<tr>
<td>(Set, Set)</td>
<td><code>set_intersection</code> numba/cpython/setobj.py lines 1358-1371</td>
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<tr>
<td>(any, Array)</td>
<td><code>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</code> numba/np/npyimpl.py lines 505-506</td>
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_operator.contains

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<tr>
<td>(Sequence, any)</td>
<td><code>in_seq</code>         numba/cpython/listobj.py lines 660-668</td>
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<tr>
<td>(Set, any)</td>
<td><code>in_set</code>         numba/cpython/setobj.py lines 1207-1210</td>
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_operator.delitem

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<tr>
<td>(List, Integer)</td>
<td><code>delitem_list_index</code> numba/cpython/listobj.py lines 616-622</td>
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<tr>
<td>(List, SliceType)</td>
<td><code>delitem_list</code> numba/cpython/listobj.py lines 625-655</td>
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### _operator.eq

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<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Array, any)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(BaseTuple, BaseTuple)</td>
<td>tuple_eq numba/cpython/typetuple.py lines 60-73</td>
</tr>
<tr>
<td>(Complex, Complex)</td>
<td>complex_eq_impl numba/cpython/numbers.py lines 1110-1119</td>
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<td>(EnumMember, EnumMember)</td>
<td>enum_eq numba/cpython/enumimpl.py lines 13-19</td>
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<tr>
<td>(Float, Float)</td>
<td>real_eq_impl numba/cpython/numbers.py lines 831-833</td>
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<tr>
<td>(Integer, Integer)</td>
<td>int_eq_impl numba/cpython/numbers.py lines 355-357</td>
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<tr>
<td>(IntegerLiteral, IntegerLiteral)</td>
<td>const_eq_impl numba/cpython/builtins.py lines 105-113</td>
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<tr>
<td>(List, List)</td>
<td>list_eq numba/cpython/listobj.py lines 767-789</td>
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<td>(Literal, Literal)</td>
<td>const_eq_impl numba/cpython/builtins.py lines 105-113</td>
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<td>(LiteralStrKeyDict, LiteralStrKeyDict)</td>
<td>literalstrkeydict_impl_equals numba/typed/dictobject.py lines 1173-1179</td>
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<td>(NPDatetime, NPDatetime)</td>
<td>_create_datetime_comparison_impl.&lt;locals&gt;.impl numba/np/npdatetime.py lines 666-692</td>
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<tr>
<td>(NPTimedelta, NPTimedelta)</td>
<td>_create_timedelta_comparison_impl.&lt;locals&gt;.impl numba/np/npdatetime.py lines 377-403</td>
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<td>(Set, Set)</td>
<td>set_isdisjoint numba/cpython/setobj.py lines 1430-1435</td>
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<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(bool, bool)</td>
<td>int_eq_impl numba/cpython/numbers.py lines 355-357</td>
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### _operator.floordiv

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<tr>
<td>(Array, Array)</td>
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<td>(Float, Float)</td>
<td>real_floordiv_impl numba/cpython/numbers.py lines 780-796</td>
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<tr>
<td>(Integer, Integer)</td>
<td>int_floordiv_impl numba/cpython/numbers.py lines 169-174</td>
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<td>(NPTimedelta, Float)</td>
<td>timedelta_over_number numba/np/npdatetime.py lines 250-278</td>
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<tr>
<td>(NPTimedelta, Integer)</td>
<td>timedelta_over_number numba/np/npdatetime.py lines 250-278</td>
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<td>(NPTimedelta, NPTimedelta)</td>
<td>timedelta_floor_div_timedelta numba/np/npdatetime.py lines 304-337</td>
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<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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### _operator.ge

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<td>(Array, any)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numpa/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(BaseTuple, BaseTuple)</td>
<td>tuple_ge numpa/cpython/tupleobj.py lines 95-98</td>
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<tr>
<td>(Float, Float)</td>
<td>real_ge_impl numpa/cpython/numbers.py lines 826-828</td>
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<tr>
<td>(IntegerLiteral, IntegerLiteral)</td>
<td>int_slt_impl numpa/cpython/numbers.py lines 315-317</td>
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<tr>
<td>(List, List)</td>
<td>list_ge numpa/cpython/listobj.py lines 829-835</td>
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<td>(NPDatetime, NPDatetime)</td>
<td>_create_datetime_comparison_impl.&lt;locals&gt;.impl numpa/np/npdatetime.py lines 666-692</td>
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<tr>
<td>(NPTimedelta, NPTimedelta)</td>
<td>_create_timedelta_ordering_impl.&lt;locals&gt;.impl numpa/np/npdatetime.py lines 409-428</td>
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<tr>
<td>(Set, Set)</td>
<td>set_issuperset numpa/cpython/setobj.py lines 1422-1428</td>
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<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numpa/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(bool, bool)</td>
<td>int_uge_impl numpa/cpython/numbers.py lines 350-352</td>
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<tr>
<td>(int16, int16)</td>
<td>int_sge_impl numpa/cpython/numbers.py lines 330-332</td>
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<td>(int32, int32)</td>
<td>int_sge_impl numpa/cpython/numbers.py lines 330-332</td>
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<td>(int64, int64)</td>
<td>int_sge_impl numpa/cpython/numbers.py lines 330-332</td>
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<td>(uint8, uint8)</td>
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### _operator.getitem

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<tr>
<td>(Buffer, Array)</td>
<td>fancy_getitem_array numpa/np/arrayobj.py lines 1065-1082</td>
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<td>(Buffer, BaseTuple)</td>
<td>getitem_array_tuple numpa/np/arrayobj.py lines 445-467</td>
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<td>(Buffer, Integer)</td>
<td>getitem_arraynd_intp numpa/np/arrayobj.py lines 428-442</td>
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<tr>
<td>(Buffer, SliceType)</td>
<td>getitem_arraynd_intp numpa/np/arrayobj.py lines 428-442</td>
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<tr>
<td>(CPointer, Integer)</td>
<td>getitem_cpointer numpa/cpython/builtins.py lines 176-181</td>
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<tr>
<td>(List, Integer)</td>
<td>getitem_list numpa/cpython/listobj.py lines 509-518</td>
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<tr>
<td>(List, SliceType)</td>
<td>getslice_list numpa/cpython/listobj.py lines 532-553</td>
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<tr>
<td>(NamedUniTuple, int64)</td>
<td>getitem_unituple numpa/cpython/tupleobj.py lines 293-345</td>
</tr>
<tr>
<td>(NamedUniTuple, uint64)</td>
<td>getitem_unituple numpa/cpython/tupleobj.py lines 293-345</td>
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<tr>
<td>(NumpyFlatType, Integer)</td>
<td>iternext_numpy_getitem numpa/np/arrayobj.py lines 3412-3425</td>
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<td>(UniTuple, int64)</td>
<td>getitem_unituple numpa/cpython/tupleobj.py lines 293-345</td>
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<tr>
<td>(UniTuple, uint64)</td>
<td>getitem_unituple numpa/cpython/tupleobj.py lines 293-345</td>
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## _operator.gt

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<td></td>
<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Array, any)</td>
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<tr>
<td></td>
<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(BaseTuple, BaseTuple)</td>
<td>tuple_gt numba/cpython/tupleobj.py lines 90-93</td>
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<td>(Float, Float)</td>
<td>real_gt_impl numba/cpython/numbers.py lines 821-823</td>
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<td>(IntegerLiteral, IntegerLiteral)</td>
<td>int_slt_impl numba/cpython/numbers.py lines 315-317</td>
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<td>(List, List)</td>
<td>list_gt numba/cpython/listobj.py lines 837-843</td>
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<td>(NPDateTime, NPDateTime)</td>
<td>_create_datetime_comparison_impl.&lt;locals&gt;.impl</td>
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<td>numba/np/npdatetime.py lines 666-692</td>
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<td>(NPTimedelta, NPTimedelta)</td>
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<tr>
<td></td>
<td>numba/np/npdatetime.py lines 409-428</td>
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<tr>
<td>(Set, Set)</td>
<td>set_gt numba/cpython/setobj.py lines 1451-1456</td>
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<td>(any, Array)</td>
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<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(bool, bool)</td>
<td>int_ugt_impl numba/cpython/numbers.py lines 345-347</td>
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<td>(int16, int16)</td>
<td>int_sgt_impl numba/cpython/numbers.py lines 325-327</td>
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<td>int_sgt_impl numba/cpython/numbers.py lines 325-327</td>
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<td>(int64, int64)</td>
<td>int_sgt_impl numba/cpython/numbers.py lines 325-327</td>
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<td>(int8, int8)</td>
<td>int_sgt_impl numba/cpython/numbers.py lines 325-327</td>
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<td>(uint8, uint8)</td>
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## _operator.iadd

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<td></td>
<td>numba/np/npyimpl.py lines 508-514</td>
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<tr>
<td></td>
<td>numba/np/npyimpl.py lines 508-514</td>
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<tr>
<td>(Complex, Complex)</td>
<td>complex_add_impl numba/cpython/numbers.py lines 1004-1017</td>
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<td>(Float, Float)</td>
<td>real_add_impl numba/cpython/numbers.py lines 583-585</td>
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<td>(Integer, Integer)</td>
<td>int_add_impl numba/cpython/numbers.py lines 36-42</td>
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<tr>
<td>(List, List)</td>
<td>list_add_inplace numba/cpython/listobj.py lines 708-713</td>
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<td>(NPDateTime, NPTimedelta)</td>
<td>datetime_plus_timedelta numba/np/npdatetime.py lines 606-615</td>
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<td>(NPTimedelta, NPDateTime)</td>
<td>timedelta_plus_datetime numba/np/npdatetime.py lines 618-627</td>
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<td>(NPTimedelta, NPTimedelta)</td>
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<td>numba/np/npyimpl.py lines 508-514</td>
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_operator.iand

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<td>(any, Array)</td>
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<td><code>numba/np/npyimpl.py lines 508-514</code></td>
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<td>(Float, IntegerLiteral)</td>
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<td>(Float, int16)</td>
<td><code>int_power_impl numba/cpython/numbers.py lines 207-247</code></td>
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| (Array, Array) | register_binary_operator_kernel.<locals>.lower_inplace_operator
numba/np/npyimpl.py lines 508-514 |
| (Array, any) | register_binary_operator_kernel.<locals>.lower_inplace_operator
numba/np/npyimpl.py lines 508-514 |
| (Integer, Integer) | int_shr_impl numba/cpython/numbers.py lines 388-397 |
| (any, Array) | register_binary_operator_kernel.<locals>.lower_inplace_operator
numba/np/npyimpl.py lines 508-514 |

### _operator.is_

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<td>(Boolean, Boolean)</td>
<td>bool_is_impl numba/cpython/builtins.py lines 86-101</td>
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<td>(EnumMember, EnumMember)</td>
<td>enum_is numba/cpython/enumimpl.py lines 22-31</td>
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<td>(List, List)</td>
<td>list_is numba/cpython/listobj.py lines 759-765</td>
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<td>(ListType, ListType)</td>
<td>list_is numba/typed/listobject.py lines 217-223</td>
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<td>(Opaque, Opaque)</td>
<td>opaque_is numba/cpython/builtins.py lines 70-83</td>
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<td>(Optional, none)</td>
<td>optional_is_none numba/core/optional.py lines 18-35</td>
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<td>(Set, Set)</td>
<td>set_is numba/cpython/setobj.py lines 1458-1464</td>
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<td>generic_is numba/cpython/builtins.py lines 44-67</td>
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### _operator.lshift

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<tr>
<td>(Array, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Array, any)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Integer, Integer)</td>
<td>int_shl_impl numba/cpython/numbers.py lines 379-385</td>
</tr>
<tr>
<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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### _operator.lt

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<tr>
<td>(Array, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Array, any)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(BaseTuple, BaseTuple)</td>
<td>tuple_lt numba/cpython/tupleobj.py lines 80-83</td>
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<tr>
<td>(Float, Float)</td>
<td>real_lt_impl numba/cpython/numbers.py lines 811-813</td>
</tr>
<tr>
<td>(IntegerLiteral, IntegerLiteral)</td>
<td>int_slt_impl numba/cpython/numbers.py lines 315-317</td>
</tr>
<tr>
<td>(List, List)</td>
<td>list_lt numba/cpython/listobj.py lines 814-827</td>
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<td>(NPDatetime, NPDatetime)</td>
<td>_create_datetime_comparison_impl.&lt;locals&gt;.impl numba/np/npdatetime.py lines 666-692</td>
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<tr>
<td>(NPTimedelta, NPTimedelta)</td>
<td>_create_timedelta_ordering_impl.&lt;locals&gt;.impl numba/np/npdatetime.py lines 409-428</td>
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<tr>
<td>(Set, Set)</td>
<td>set_lt numba/cpython/setobj.py lines 1444-1449</td>
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<tr>
<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/np/npyimpl.py lines 505-506</td>
</tr>
<tr>
<td>(bool, bool)</td>
<td>int_ult_impl numba/cpython/numbers.py lines 335-337</td>
</tr>
<tr>
<td>(int16, int16)</td>
<td>int_slt_impl numba/cpython/numbers.py lines 315-317</td>
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<tr>
<td>(int32, int32)</td>
<td>int_slt_impl numba/cpython/numbers.py lines 315-317</td>
</tr>
<tr>
<td>(int64, int64)</td>
<td>int_slt_impl numba/cpython/numbers.py lines 315-317</td>
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<tr>
<td>(int8, int8)</td>
<td>int_slt_impl numba/cpython/numbers.py lines 315-317</td>
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<tr>
<td>(uint16, uint16)</td>
<td>int_ult_impl numba/cpython/numbers.py lines 335-337</td>
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<tr>
<td>(uint32, uint32)</td>
<td>int_ult_impl numba/cpython/numbers.py lines 335-337</td>
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<td>(uint64, uint64)</td>
<td>int_ult_impl numba/cpython/numbers.py lines 335-337</td>
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<td>(uint8, uint8)</td>
<td>int_ult_impl numba/cpython/numbers.py lines 335-337</td>
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_operator.matmul

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<tr>
<td>(Array, Array)</td>
<td>dot_2 numba/nplinalg.py lines 524-543</td>
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_operator.mod

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| (Array, Array)| register_binary_operator_kernel.<locals>.
               | lower_binary_operator                          |
|               | numba/npyimpl.py lines 505-506                  |
| (Array, any)  | register_binary_operator_kernel.<locals>.
               | lower_binary_operator                          |
|               | numba/npyimpl.py lines 505-506                  |
| (Float, Float)| real_mod_impl numba/cpython/numbers.py lines
               | 761-777                                        |
| (Integer, Integer)| int_rem_impl numba/cpython/numbers.py lines
               | 190-195                                        |
| (any, Array)  | register_binary_operator_kernel.<locals>.
               | lower_binary_operator                          |
|               | numba/npyimpl.py lines 505-506                  |

_operator.mul

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| (Array, Array)| register_binary_operator_kernel.<locals>.
               | lower_binary_operator                          |
|               | numba/npyimpl.py lines 505-506                  |
| (Array, any)  | register_binary_operator_kernel.<locals>.
               | lower_binary_operator                          |
|               | numba/npyimpl.py lines 505-506                  |
| (Complex, Complex)| complex_mul_impl numba/cpython/numbers.py
               | lines 1036-1056                                 |
| (Float, Float)| real_mul_impl numba/cpython/numbers.py lines
               | 593-595                                        |
| (Float, NPTimedelta)| number_times_timedelta numba/np
               | npdatetime.py lines 239-247                    |
| (Integer, Integer)| int_mul_impl numba/cpython/numbers.py lines
               | 54-60                                          |
| (Integer, NPTimedelta)| number_times_timedelta numba/np
               | npdatetime.py lines 239-247                    |
| (List, Integer)| list_mul numba/cpython/listobj.py lines 716-734|
| (NPTimedelta, Float)| timedelta_times_number numba/np
               | npdatetime.py lines 228-236                    |
| (NPTimedelta, Integer)| timedelta_times_number numba/np
               | npdatetime.py lines 228-236                    |
| (any, Array)  | register_binary_operator_kernel.<locals>.
               | lower_binary_operator                          |
|               | numba/npyimpl.py lines 505-506                  |
### _operator.ne

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<tr>
<td>(Array, any)</td>
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<td></td>
<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(BaseTuple, BaseTu-</td>
<td>tuple_ne numba/cpython/tupleobj.py lines 75-78</td>
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<td>ple)</td>
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<td>(Complex, Complex)</td>
<td>complex_ne_impl numba/cpython/numbers.py lines 1122-1131</td>
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<td>(EnumMember, Enum-</td>
<td>enum_ne numba/cpython/enumimpl.py lines 34-40</td>
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<tr>
<td>Member)</td>
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<tr>
<td>(Float, Float)</td>
<td>real_ne_impl numba/cpython/numbers.py lines 836-838</td>
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<tr>
<td>(Integer, Integer)</td>
<td>int_ne_impl numba/cpython/numbers.py lines 360-362</td>
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<td>(IntegerLiteral,</td>
<td>const_ne_impl numba/cpython/builtins.py lines 117-125</td>
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<tr>
<td>IntegerLiteral)</td>
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<td>(List, List)</td>
<td>list_ne numba/cpython/listobj.py lines 791-797</td>
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<tr>
<td>(Literal, Literal)</td>
<td>const_ne_impl numba/cpython/builtins.py lines 117-125</td>
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<td>(NPDatetime, NPDa-</td>
<td>_create_datetime_comparison_impl.&lt;locals&gt;.impl numba/np/npdatetime.py</td>
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<tr>
<td>tetime)</td>
<td>lines 666-692</td>
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<td>(NPTimedelta, NPTi-</td>
<td>_create_timedelta_comparison_impl.&lt;locals&gt;.impl numba/np/npdatetime.py</td>
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<td>medelta)</td>
<td>lines 377-403</td>
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<tr>
<td>(Set, Set)</td>
<td>set_ne numba/cpython/setobj.py lines 1437-1442</td>
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<tr>
<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</td>
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<td></td>
<td>numba/np/npimpl.py lines 505-506</td>
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<tr>
<td>(bool, bool)</td>
<td>int_ne_impl numba/cpython/numbers.py lines 360-362</td>
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### _operator.neg

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<tr>
<td>(Array)</td>
<td>register_unary_operator_kernel.&lt;locals&gt;.lower_unary_operator</td>
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<tr>
<td></td>
<td>numba/np/npyimpl.py lines 498-499</td>
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<tr>
<td>(Complex)</td>
<td>complex_negate_impl numba/cpython/numbers.py lines 1093-1102</td>
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<tr>
<td>(Float)</td>
<td>real_negate_impl numba/cpython/numbers.py lines 848-851</td>
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<tr>
<td>(Integer)</td>
<td>int_negate_impl numba/cpython/numbers.py lines 427-433</td>
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<td>(NPTimedelta)</td>
<td>timedelta_neg_impl numba/np/npdatetime.py lines 142-145</td>
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<td>(bool)</td>
<td>bool_negate_impl numba/cpython/numbers.py lines 494-499</td>
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### _operator.not_

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<tr>
<td>(Complex)</td>
<td>number_not_impl numba/cpython/numbers.py lines 1179-1184</td>
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<tr>
<td>(Float)</td>
<td>number_not_impl numba/cpython/numbers.py lines 1179-1184</td>
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<tr>
<td>(Integer)</td>
<td>number_not_impl numba/cpython/numbers.py lines 1179-1184</td>
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<tr>
<td>(bool)</td>
<td>number_not_impl numba/cpython/numbers.py lines 1179-1184</td>
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### _operator.or_

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<td>(Array, Array)</td>
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<tr>
<td></td>
<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Array, any)</td>
<td><code>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</code></td>
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<tr>
<td></td>
<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Boolean, Boolean)</td>
<td><code>int_or_impl</code> numba/cpython/numbers.py lines 409-415</td>
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<tr>
<td>(Integer, Integer)</td>
<td><code>int_or_impl</code> numba/cpython/numbers.py lines 409-415</td>
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<td>(Set, Set)</td>
<td><code>set_union</code> numba/cpython/setobj.py lines 1389-1402</td>
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<td>numba/np/npyimpl.py lines 505-506</td>
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### _operator.pos_

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<td>(Array)</td>
<td><code>array_positive_impl</code> numba/np/npyimpl.py lines 529-541</td>
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<tr>
<td>(Array)</td>
<td><code>register_unary_operator_kernel.&lt;locals&gt;.lower_unary_operator</code></td>
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<td></td>
<td>numba/np/npyimpl.py lines 498-499</td>
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<tr>
<td>(Complex)</td>
<td><code>complex_positive_impl</code> numba/cpython/numbers.py lines 1105-1107</td>
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<td>(Float)</td>
<td><code>real_positive_impl</code> numba/cpython/numbers.py lines 854-858</td>
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<td>(Integer)</td>
<td><code>int_positive_impl</code> numba/cpython/numbers.py lines 436-440</td>
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<td>(NPTimedelta)</td>
<td><code>timedelta_pos_impl</code> numba/np/npdatetime.py lines 136-139</td>
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<td>(bool)</td>
<td><code>bool_unary_positive_impl</code> numba/cpython/numbers.py lines 502-506</td>
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### _operator.pow

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<td>numba/np/npyimpl.py lines 505-506</td>
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<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Complex, Complex)</td>
<td>complex_power_impl numba/cpython/numbers.py lines 960-1002</td>
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<tr>
<td>(Float, Float)</td>
<td>real_power_impl numba/cpython/numbers.py lines 799-808</td>
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<tr>
<td>(Float, IntegerLiteral)</td>
<td>static_power_impl numba/cpython/numbers.py lines 250-312</td>
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<tr>
<td>(Float, int16)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
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<tr>
<td>(Float, int32)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
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<td>(Float, int64)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
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<td>(Float, int8)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
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<tr>
<td>(Float, uint16)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
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<td>(Float, uint32)</td>
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<td>(Float, uint64)</td>
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<td>(Integer, Integer)</td>
<td>static_power_impl numba/cpython/numbers.py lines 250-312</td>
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<tr>
<td>(Integer, IntegerLiteral)</td>
<td>static_power_impl numba/cpython/numbers.py lines 250-312</td>
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<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</td>
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<td>numba/np/npyimpl.py lines 505-506</td>
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### _operator.rshift

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<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
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<td>numba/np/npyimpl.py lines 505-506</td>
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### _operator.setitem

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<th>Definition</th>
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<tbody>
<tr>
<td>(Buffer, any, any)</td>
<td>setitem_array numba/np/arrayobj.py lines 470-508</td>
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<tr>
<td>(CPointer, Integer, any)</td>
<td>setitem_cpointer numba/cpython/builtins.py lines 184-188</td>
</tr>
<tr>
<td>(List, Integer, any)</td>
<td>setitem_list numba/cpython/listobj.py lines 520-529</td>
</tr>
<tr>
<td>(List, SliceType, any)</td>
<td>setitem_list numba/cpython/listobj.py lines 553-612</td>
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<tr>
<td>(NumpyFlatType, Integer, any)</td>
<td>iternext_numpy_getitem_any numba/np/arrayobj.py lines 3428-3442</td>
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### _operator.sub

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<td>numba/np/npyimpl.py lines 505-506</td>
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<tr>
<td>(Array, any)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator</td>
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<tr>
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<td>numba/np/npyimpl.py lines 505-506</td>
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<td>(Complex, Complex)</td>
<td>complex_sub_impl numba/cpython/numbers.py lines 1020-1033</td>
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<tr>
<td>(Float, Float)</td>
<td>real_sub_impl numba/cpython/numbers.py lines 588-590</td>
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<tr>
<td>(Integer, Integer)</td>
<td>int_sub_impl numba/cpython/numbers.py lines 45-51</td>
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<td>datetime_minus_datetime numba/np/npdatetime.py lines 646-660</td>
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<td>(NPDatetime, NPTimedelta)</td>
<td>datetime_minus_timedelta numba/np/npdatetime.py lines 632-641</td>
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<td>(NPTimedelta, NPTimedelta)</td>
<td>timedelta_sub_impl numba/np/npdatetime.py lines 197-208</td>
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<td>(Set, Set)</td>
<td>set_difference numba/cpython/setobj.py lines 1348-1356</td>
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<td>(any, Array)</td>
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<td>numba/np/npyimpl.py lines 505-506</td>
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### _operator.truediv

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<td>numba/np/npyimpl.py lines 505-506</td>
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<td>timedelta_over_number numba/np/npdatetime.py lines 250-278</td>
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<td>(NPTimedelta, NPTimedelta)</td>
<td>timedelta_over_timedelta numba/np/npdatetime.py lines 281-296</td>
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### _operator.xor

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<td>(Array, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/ap/npyimpl.py lines 505-506</td>
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<tr>
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<tr>
<td>(Boolean, Boolean)</td>
<td>int_xor_impl numba/cpython/numbers.py lines 418-424</td>
</tr>
<tr>
<td>(Integer, Integer)</td>
<td>int_xor_impl numba/cpython/numbers.py lines 418-424</td>
</tr>
<tr>
<td>(Set, Set)</td>
<td>set_symmetric_difference numba/cpython/setobj.py lines 1373-1387</td>
</tr>
<tr>
<td>(any, Array)</td>
<td>register_binary_operator_kernel.&lt;locals&gt;.lower_binary_operator numba/ap/npyimpl.py lines 505-506</td>
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### builtins.abs

<table>
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<tr>
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<th>Definition</th>
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<tbody>
<tr>
<td>(Complex)</td>
<td>complex_abs_impl numba/cpython/numbers.py lines 1134-1142</td>
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<tr>
<td>(Float)</td>
<td>real_abs_impl numba/cpython/numbers.py lines 841-845</td>
</tr>
<tr>
<td>(NPTimedelta)</td>
<td>timedelta_abs_impl numba/ap/npdatetime.py lines 148-158</td>
</tr>
<tr>
<td>(int16)</td>
<td>int_abs_impl numba/cpython/numbers.py lines 365-371</td>
</tr>
<tr>
<td>(int32)</td>
<td>int_abs_impl numba/cpython/numbers.py lines 365-371</td>
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<tr>
<td>(int64)</td>
<td>int_abs_impl numba/cpython/numbers.py lines 365-371</td>
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<tr>
<td>(int8)</td>
<td>int_abs_impl numba/cpython/numbers.py lines 365-371</td>
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<tr>
<td>(uint16)</td>
<td>uint_abs_impl numba/cpython/numbers.py lines 374-376</td>
</tr>
<tr>
<td>(uint32)</td>
<td>uint_abs_impl numba/cpython/numbers.py lines 374-376</td>
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<tr>
<td>(uint64)</td>
<td>uint_abs_impl numba/cpython/numbers.py lines 374-376</td>
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<tr>
<td>(uint8)</td>
<td>uint_abs_impl numba/cpython/numbers.py lines 374-376</td>
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### builtins.bool

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<tbody>
<tr>
<td>(Boolean)</td>
<td>bool_as_bool numba/cpython/numbers.py lines 1186-1189</td>
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<tr>
<td>(Complex)</td>
<td>complex_as_bool numba/cpython/numbers.py lines 1201-1210</td>
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<tr>
<td>(Float)</td>
<td>float_as_bool numba/cpython/numbers.py lines 1196-1199</td>
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<tr>
<td>(Integer)</td>
<td>int_as_bool numba/cpython/numbers.py lines 1191-1194</td>
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<tr>
<td>(Sequence)</td>
<td>sequence_bool numba/cpython/listobj.py lines 670-675</td>
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<tr>
<td>(Sized)</td>
<td>sized_bool numba/cpython/builtins.py lines 424-430</td>
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### builtins.complex

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<tr>
<td>(*any)</td>
<td>complex_impl numba/cpython/builtins.py lines 301-326</td>
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### builtins.dict

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<td>()</td>
<td>impl_dict numba/typed/dictimpl.py lines 7-20</td>
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### builtins.divmod

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<tr>
<td>(Float, Float)</td>
<td>real_divmod_impl numba/cpython/numbers.py lines 735-758</td>
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<tr>
<td>(Integer, Integer)</td>
<td>int_divmod_impl numba/cpython/numbers.py lines 160-166</td>
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### builtins.enumerate

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<th>Definition</th>
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<tbody>
<tr>
<td>(IterableType)</td>
<td>make_enumerate_object numba/cpython/iterators.py lines 20-44</td>
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<tr>
<td>(IterableType, Integer)</td>
<td>make_enumerate_object numba/cpython/iterators.py lines 20-44</td>
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### builtins.float

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<th>Definition</th>
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<tr>
<td>(any)</td>
<td>int_impl numba/cpython/builtins.py lines 292-298</td>
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### builtins.int

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<th>Definition</th>
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<tr>
<td>(any)</td>
<td>int_impl numba/cpython/builtins.py lines 292-298</td>
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**builtins.iter**

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<tr>
<td>(IterableType)</td>
<td>iter_impl numba/cpython/builtins.py lines 382-387</td>
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**builtins.len**

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<tbody>
<tr>
<td>(Buffer)</td>
<td>array_len numba/np/arrayobj.py lines 511-519</td>
</tr>
<tr>
<td>(ConstSized)</td>
<td>constsize_len numba/cpython/builtins.py lines 416-421</td>
</tr>
<tr>
<td>(List)</td>
<td>list_len numba/cpython/listobj.py lines 484-487</td>
</tr>
<tr>
<td>(NumpyFlatType)</td>
<td>iternext_numpy_getitem_flat numba/np/arrayobj.py lines 3445-3453</td>
</tr>
<tr>
<td>(Set)</td>
<td>set_len numba/cpython/setobj.py lines 1202-1205</td>
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<tr>
<td>(range_state_int32)</td>
<td>make_range_impl.&lt;locals&gt;.range_len numba/cpython/rangeobj.py lines 81-89</td>
</tr>
<tr>
<td>(range_state_uint64)</td>
<td>make_range_impl.&lt;locals&gt;.range_len numba/cpython/rangeobj.py lines 81-89</td>
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**builtins.list**

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<tr>
<td>()</td>
<td>list_constructor numba/cpython/listobj.py lines 474-479</td>
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<tr>
<td>(IterableType)</td>
<td>list_constructor numba/cpython/listobj.py lines 464-472</td>
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**builtins.max**

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<tbody>
<tr>
<td>(*any)</td>
<td>max_vararg numba/cpython/builtins.py lines 223-225</td>
</tr>
<tr>
<td>(BaseTuple)</td>
<td>max_iterable numba/cpython/builtins.py lines 217-221</td>
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**builtins.min**

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<tbody>
<tr>
<td>(*any)</td>
<td>min_vararg numba/cpython/builtins.py lines 233-235</td>
</tr>
<tr>
<td>(BaseTuple)</td>
<td>min_iterable numba/cpython/builtins.py lines 227-231</td>
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**builtins.next**

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<tr>
<td>(IteratorType)</td>
<td>next_impl numba/cpython/builtins.py lines 390-400</td>
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**builtins.pow**

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<th>Definition</th>
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<tbody>
<tr>
<td>(Complex, Complex)</td>
<td>complex_power_impl numba/cpython/numbers.py lines 960-1002</td>
</tr>
<tr>
<td>(Float, Float)</td>
<td>real_power_impl numba/cpython/numbers.py lines 799-808</td>
</tr>
<tr>
<td>(Float, int16)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Float, int32)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Float, int64)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Float, int8)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Float, uint16)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Float, uint32)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Float, uint64)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Float, uint8)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
</tr>
<tr>
<td>(Integer, Integer)</td>
<td>int_power_impl numba/cpython/numbers.py lines 207-247</td>
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**builtins.print**

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<th>Definition</th>
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<tr>
<td>(*any)</td>
<td>print_varargs_impl numba/cpython/printimpl.py lines 65-83</td>
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**builtins.range**

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<th>Definition</th>
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<tbody>
<tr>
<td>(int32)</td>
<td>make_range_impl.&lt;locals&gt;.rangel1_impl numba/cpython/rangeobj.py lines 30-45</td>
</tr>
<tr>
<td>(int32, int32)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
</tr>
<tr>
<td>(int32, int32, int32)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
</tr>
<tr>
<td>(int64)</td>
<td>make_range_impl.&lt;locals&gt;.rangel1_impl numba/cpython/rangeobj.py lines 30-45</td>
</tr>
<tr>
<td>(int64, int64)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
</tr>
<tr>
<td>(int64, int64, int64)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
</tr>
<tr>
<td>(uint64)</td>
<td>make_range_impl.&lt;locals&gt;.rangel1_impl numba/cpython/rangeobj.py lines 30-45</td>
</tr>
<tr>
<td>(uint64, uint64)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
</tr>
<tr>
<td>(uint64, uint64, uint64)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
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### builtins.round

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<th>Definition</th>
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<tbody>
<tr>
<td>(Float)</td>
<td><code>round_impl_unary</code> lines 242-252</td>
</tr>
<tr>
<td>(Float, Integer)</td>
<td><code>round_impl_binary</code> lines 254-286</td>
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### builtins.set

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<tr>
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<th>Definition</th>
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<tbody>
<tr>
<td>()</td>
<td><code>set_empty_constructor</code> lines 1177-1181</td>
</tr>
<tr>
<td>(IterableType)</td>
<td><code>set_constructor</code> lines 1183-1196</td>
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### builtins.slice

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<th>Definition</th>
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<tbody>
<tr>
<td>(*any)</td>
<td><code>slice_constructor_impl</code> lines 151-196</td>
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### builtins.tuple

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<tr>
<td>()</td>
<td><code>lower_empty_tuple</code> lines 432-436</td>
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<tr>
<td>(BaseTuple)</td>
<td><code>lower_tuple</code> lines 438-441</td>
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### builtins.type

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<th>Definition</th>
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<tbody>
<tr>
<td>(any)</td>
<td><code>type_impl</code> lines 374-379</td>
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### builtins.zip

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<tr>
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<th>Definition</th>
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<tbody>
<tr>
<td>(*any)</td>
<td><code>make_zip_object</code> lines 71-83</td>
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</table>
### cmath.acos

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Complex)</td>
<td><code>acos_impl</code> numba/cpython/cmathimpl.py lines 379-403</td>
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### cmath.acosh

<table>
<thead>
<tr>
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<th>Definition</th>
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<tbody>
<tr>
<td>(Complex)</td>
<td><code>acosh_impl</code> numba/cpython/cmathimpl.py lines 405-429</td>
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### cmath.asin

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<tr>
<td>(Complex)</td>
<td><code>asin_impl</code> numba/cpython/cmathimpl.py lines 455-463</td>
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### cmath.asinh

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<tr>
<td>(Complex)</td>
<td><code>asinh_impl</code> numba/cpython/cmathimpl.py lines 431-453</td>
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### cmath.atan

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<th>Definition</th>
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<tbody>
<tr>
<td>(Complex)</td>
<td><code>atan_impl</code> numba/cpython/cmathimpl.py lines 465-477</td>
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### cmath.atanh

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<th>Definition</th>
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<tr>
<td>(Complex)</td>
<td><code>atanh_impl</code> numba/cpython/cmathimpl.py lines 479-531</td>
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### cmath.cos

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<th>Definition</th>
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<tr>
<td>(Complex)</td>
<td><code>cos_impl</code> numba/cpython/cmathimpl.py lines 267-274</td>
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cmath.cosh

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<th>Definition</th>
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<tbody>
<tr>
<td>(Complex)</td>
<td>cosh_impl</td>
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<td></td>
<td>numba/cpython/cmathimpl.py lines 276-302</td>
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cmath.exp

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<th>Definition</th>
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<tbody>
<tr>
<td>(Complex)</td>
<td>intrinsic_complex_unary.&lt;locals&gt;.wrapper</td>
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<td></td>
<td>numba/cpython/cmathimpl.py lines 94-108</td>
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cmath.isfinite

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<th>Definition</th>
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<tr>
<td>(Complex)</td>
<td>isfinite_float_impl</td>
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<td>numba/cpython/cmathimpl.py lines 50-56</td>
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cmath.isnan

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<td>(Complex)</td>
<td>isnan_float_impl</td>
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cmath.log

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<td>intrinsic_complex_unary.&lt;locals&gt;.wrapper</td>
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<tr>
<td></td>
<td>numba/cpython/cmathimpl.py lines 94-108</td>
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<tr>
<td>(Complex, complex)</td>
<td>log_base_impl</td>
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<td></td>
<td>numba/cpython/cmathimpl.py lines 166-175</td>
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cmath.log10

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<tr>
<td>(Complex)</td>
<td>log10_impl numba/cpython/cmathimpl.py lines 178-190</td>
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cmath.phase

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<td>(Complex)</td>
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cmath.polar

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cmath.rect

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<th>Definition</th>
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<tr>
<td>(Float, Float)</td>
<td>rect_impl numba/cpython/cmathimpl.py lines 59-91</td>
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cmath.sin

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<tbody>
<tr>
<td>(Complex)</td>
<td>sin_impl numba/cpython/cmathimpl.py lines 305-313</td>
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cmath.sinh

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<td>(Complex)</td>
<td>sinh_impl numba/cpython/cmathimpl.py lines 315-338</td>
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cmath.sqrt

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<tr>
<td>(Complex)</td>
<td>sqrt_impl numba/cpython/cmathimpl.py lines 206-264</td>
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cmath.tan

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<th>Definition</th>
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<td>(Complex)</td>
<td>tan_impl numba/cpython/cmathimpl.py lines 341-349</td>
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cmath.tanh

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<tbody>
<tr>
<td>(Complex)</td>
<td>tanh_impl numba/cpython/cmathimpl.py lines 351-376</td>
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math.acos

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<tr>
<th>Signature</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>(Float)</td>
<td>unary_mathExtern.&lt;locals&gt;.float_impl numba/cpython/mathimpl.py lines 149-165</td>
</tr>
<tr>
<td>(Integer)</td>
<td>_unary_int_input_wrapper_impl.&lt;locals&gt;.implementer numba/cpython/mathimpl.py lines 113-119</td>
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math.acosh

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<tr>
<td>(Float)</td>
<td>unary_mathExtern.&lt;locals&gt;.float_impl numba/cpython/mathimpl.py lines 149-165</td>
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<tr>
<td>(Integer)</td>
<td>_unary_int_input_wrapper_impl.&lt;locals&gt;.implementer numba/cpython/mathimpl.py lines 113-119</td>
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math.asin

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<td>(Float)</td>
<td>unary_mathExtern.&lt;locals&gt;.float_impl numba/cpython/mathimpl.py lines 149-165</td>
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**math.asinh**

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**math.atan**

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**math.atan2**

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<tr>
<td>(Float, Float)</td>
<td>atan2_float_impl numba/cpython/mathimpl.py lines 313-326</td>
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<td>(int64, int64)</td>
<td>atan2_s64_impl numba/cpython/mathimpl.py lines 297-303</td>
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<td>(uint64, uint64)</td>
<td>atan2_u64_impl numba/cpython/mathimpl.py lines 305-311</td>
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**math.atanh**

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**math.ceil**

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math.copysign

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<tr>
<td>(Float, Float)</td>
<td>copysign_float_impl numba/cpython/mathimpl.py lines 250-257</td>
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math.cos

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math.cosh

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math.degrees

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<td>(Float)</td>
<td>degrees_float_impl numba/cpython/mathimpl.py lines 394-399</td>
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math.erf

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### math.erfc

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### math.exp

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### math.expm1

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### math.fabs

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### math.floor

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### math.frexp

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<td>(Float)</td>
<td>frexp_impl numba/cpython/mathimpl.py lines 263-277</td>
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### math.gamma

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### math.gcd

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<tr>
<td>(Integer, Integer)</td>
<td>gcdImpl numba/cpython/mathimpl.py lines 427-454</td>
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### math.hypot

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<tr>
<td>(Float, Float)</td>
<td>hypotFloatImpl numba/cpython/mathimpl.py lines 352-378</td>
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<td>(int64, int64)</td>
<td>hypotS64Impl numba/cpython/mathimpl.py lines 332-339</td>
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<tr>
<td>(uint64, uint64)</td>
<td>hypotU64Impl numba/cpython/mathimpl.py lines 342-349</td>
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### math.isfinite

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<tr>
<td>(Float)</td>
<td>isfiniteFloatImpl numba/cpython/mathimpl.py lines 237-241</td>
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<td>(Integer)</td>
<td>isfiniteIntImpl numba/cpython/mathimpl.py lines 244-247</td>
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### math.isinf

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<tr>
<td>(Float)</td>
<td>isinfFloatImpl numba/cpython/mathimpl.py lines 225-229</td>
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<td>(Integer)</td>
<td>isinfIntImpl numba/cpython/mathimpl.py lines 231-234</td>
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### math.isnan

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<tr>
<td>(Float)</td>
<td>isnan_float_impl numba/cpython/mathimpl.py lines 213-217</td>
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<td>(Integer)</td>
<td>isnan_int_impl numba/cpython/mathimpl.py lines 219-222</td>
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### math.ldexp

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<tbody>
<tr>
<td>(Float, int32)</td>
<td>ldexp_impl numba/cpython/mathimpl.py lines 280-291</td>
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### math.lgamma

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### math.log

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### math.log10

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### `math.log1p`

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### `math.log2`

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<td>_unary_int_input_wrapper_impl.&lt;locals&gt;.implementer numba/cpython/mathimpl.py lines 113-119</td>
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### `math.pow`

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<tr>
<td>(Float, Float)</td>
<td>powImpl numba/cpython/mathimpl.py lines 405-409</td>
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<tr>
<td>(Float, Integer)</td>
<td>powImpl numba/cpython/mathimpl.py lines 405-409</td>
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### `math.radians`

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<tr>
<td>(Float)</td>
<td>radians_floatImpl numba/cpython/mathimpl.py lines 383-388</td>
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### `math.sin`

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### math.sinh

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### math.sqrt

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### math.trunc

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<td>_unaryIntInputWrapperExtern.&lt;locals&gt;.implementer numba/cpython/mathimpl.py lines 113-119</td>
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numba.core.types.abstract.TypeRef

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<tbody>
<tr>
<td>(*any)</td>
<td>redirect_typector numba/cpython/builtins.py lines 587-616</td>
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numba.core.types.functions.NamedTupleClass

<table>
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<tbody>
<tr>
<td>(*any)</td>
<td>namedtuple_constructor numba/cpython/tupleobj.py lines 17-29</td>
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numba.core.types.functions.NumberClass

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<tr>
<td>(any)</td>
<td>number_constructor numba/cpython/builtins.py lines 329-345</td>
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numba.core.types.misc.ClassType

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<tr>
<td>(*any)</td>
<td>ctor_impl numba/experimental/jitclass/base.py lines 544-586</td>
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numba.core.typing.builtins.IndexValue

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<tr>
<td>(int64, Type)</td>
<td>impl_index_value numba/cpython/builtins.py lines 527-535</td>
</tr>
<tr>
<td>(uint64, Type)</td>
<td>impl_index_value numba/cpython/builtins.py lines 527-535</td>
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numba.cpython.builtins.get_type_max_value

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<td>(DType)</td>
<td>lower_get_type_max_value numba/cpython/builtins.py lines 501-520</td>
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<td>(NumberClass)</td>
<td>lower_get_type_max_value numba/cpython/builtins.py lines 501-520</td>
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numba.cpython.builtins.get_type_min_value

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<tr>
<td>(DType)</td>
<td>lower_get_type_min_value numba/cpython/builtins.py lines 480-499</td>
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<td>lower_get_type_min_value numba/cpython/builtins.py lines 480-499</td>
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numba.misc.special.pndindex

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<tbody>
<tr>
<td>(*&lt;class 'numba.core.types.scalars.Integer'&gt;)</td>
<td>make_array_ndindex numba/np/arrayobj.py lines 3490-3502</td>
</tr>
<tr>
<td>(BaseTuple)</td>
<td>make_array_ndindex_tuple numba/np/arrayobj.py lines 3505-3525</td>
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numba.misc.special.prange

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<td>(int32)</td>
<td>make_range_impl.&lt;locals&gt;.rangel_impl numba/cpython/rangeobj.py lines 30-45</td>
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<td>(int32, int32)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
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<tr>
<td>(int32, int32, int32)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
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<td>(int64)</td>
<td>make_range_impl.&lt;locals&gt;.rangel_impl numba/cpython/rangeobj.py lines 30-45</td>
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<td>(int64, int64)</td>
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<tr>
<td>(uint64)</td>
<td>make_range_impl.&lt;locals&gt;.rangel_impl numba/cpython/rangeobj.py lines 30-45</td>
</tr>
<tr>
<td>(uint64, uint64)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
</tr>
<tr>
<td>(uint64, uint64, uint64)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
</tr>
</tbody>
</table>

numba.np.arrayobj.reshape_unchecked

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array, BaseTuple, BaseTuple)</td>
<td>impl_shape_unchecked numba/np/arrayobj.py lines 5478-5497</td>
</tr>
</tbody>
</table>

numba.parfors.parfor.internal_prange

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(int32)</td>
<td>make_range_impl.&lt;locals&gt;.rangel_impl numba/cpython/rangeobj.py lines 30-45</td>
</tr>
<tr>
<td>(int32, int32)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
</tr>
<tr>
<td>(int32, int32, int32)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
</tr>
<tr>
<td>(int64)</td>
<td>make_range_impl.&lt;locals&gt;.rangel_impl numba/cpython/rangeobj.py lines 30-45</td>
</tr>
<tr>
<td>(int64, int64)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
</tr>
<tr>
<td>(int64, int64, int64)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
</tr>
<tr>
<td>(uint64)</td>
<td>make_range_impl.&lt;locals&gt;.rangel_impl numba/cpython/rangeobj.py lines 30-45</td>
</tr>
<tr>
<td>(uint64, uint64)</td>
<td>make_range_impl.&lt;locals&gt;.range2_impl numba/cpython/rangeobj.py lines 47-62</td>
</tr>
<tr>
<td>(uint64, uint64, uint64)</td>
<td>make_range_impl.&lt;locals&gt;.range3_impl numba/cpython/rangeobj.py lines 64-79</td>
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</tbody>
</table>
numba.stencils.stencil

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>()</td>
<td>stencil_dummy_lower</td>
<td>numba/stencils/stencil.py lines 827-830</td>
</tr>
</tbody>
</table>

numpy.amax

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_max</td>
</tr>
</tbody>
</table>

numpy.amin

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_min</td>
</tr>
</tbody>
</table>

numpy.argsort

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array, StringLiteral)</td>
<td>array_argsort</td>
</tr>
</tbody>
</table>

numpy.cumprod

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_cumprod</td>
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numpy.cumsum

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<tr>
<th>Signature</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_cumsum</td>
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numpy.mean

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<tr>
<th>Signature</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_mean</td>
</tr>
</tbody>
</table>
### numpy.ndenumerate

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>make_array_ndenumerate numba/np/arrayobj.py lines 3456-3471</td>
</tr>
</tbody>
</table>

### numpy.ndindex

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(*&lt;class 'numba.core.types.scalars.Integer'&gt;)</td>
<td>make_array_ndindex numba/np/arrayobj.py lines 3490-3502</td>
</tr>
<tr>
<td>(BaseTuple)</td>
<td>make_array_ndindex_tuple numba/np/arrayobj.py lines 3505-3525</td>
</tr>
</tbody>
</table>

### numpy.nditer

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(any)</td>
<td>make_array_nditer numba/np/arrayobj.py lines 3540-3557</td>
</tr>
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### numpy.nonzero

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_nonzero numba/np/arraymath.py lines 3315-3371</td>
</tr>
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</table>

### numpy.prod

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_prod numba/np/arraymath.py lines 355-367</td>
</tr>
</tbody>
</table>

### numpy.ravel

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>np_ravel numba/np/arrayobj.py lines 1881-1886</td>
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</table>

### numpy.std

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_std numba/np/arraymath.py lines 445-451</td>
</tr>
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</table>
### numpy.sum

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_sum numba/np/arraymath.py lines 166-179</td>
</tr>
<tr>
<td>(Array, DTypeSpec)</td>
<td>array_sum_dtype numba/np/arraymath.py lines 295-308</td>
</tr>
<tr>
<td>(Array, IntegerLiteral)</td>
<td>array_sum_axis numba/np/arraymath.py lines 311-352</td>
</tr>
<tr>
<td>(Array, IntegerLiteral, DTypeSpec)</td>
<td>array_sum_axis_dtype numba/np/arraymath.py lines 252-292</td>
</tr>
<tr>
<td>(Array, int64)</td>
<td>array_sum_axis numba/np/arraymath.py lines 311-352</td>
</tr>
<tr>
<td>(Array, int64, DTypeSpec)</td>
<td>array_sum_axis_dtype numba/np/arraymath.py lines 252-292</td>
</tr>
</tbody>
</table>

### numpy.var

<table>
<thead>
<tr>
<th>Signature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Array)</td>
<td>array_var numba/np/arraymath.py lines 427-442</td>
</tr>
</tbody>
</table>

### 6.11 Notes on stencils

Numba provides the `@stencil decorator` to represent stencil computations. This document explains how this feature is implemented in the several different modes available in Numba. Currently, calls to the stencil from non-jitted code is supported as well as calls from jitted code, either with or without the `parallel=True` option.

#### 6.11.1 The stencil decorator

The stencil decorator itself just returns a `StencilFunc` object. This object encapsulates the original stencil kernel function as specified in the program and the options passed to the stencil decorator. Also of note is that after the first compilation of the stencil, the computed neighborhood of the stencil is stored in the `StencilFunc` object in the `neighborhood` attribute.

#### 6.11.2 Handling the three modes

As mentioned above, Numba supports the calling of stencils from inside or outside a `@jit` compiled function, with or without the `parallel=True` option.

**Outside jit context**

`StencilFunc` overrides the `__call__` method so that calls to `StencilFunc` objects execute the stencil:

```python
def __call__(self, *args, **kwargs):
    result = kwargs.get('out')

    new_stencil_func = self._stencil_wrapper(result, None, *args)

    if result is None:
        return new_stencil_func.entry_point(*args)
    else:
        return new_stencil_func.entry_point(*args, result)
```

### 6.11. Notes on stencils
First, the presence of the optional `out` parameter is checked. If it is present then the output array is stored in `result`. Then, the call to `_stencil_wrapper` generates the stencil function given the result and argument types and finally the generated stencil function is executed and its result returned.

### Jit without `parallel=True`

When constructed, a `StencilFunc` inserts itself into the typing context’s set of user functions and provides the `_type_me` callback. In this way, the standard Numba compiler is able to determine the output type and signature of a `StencilFunc`. Each `StencilFunc` maintains a cache of previously seen combinations of input argument types and keyword types. If previously seen, the `StencilFunc` returns the computed signature. If not previously computed, the `StencilFunc` computes the return type of the stencil by running the Numba compiler frontend on the stencil kernel and then performing type inference on the Numba IR (IR) to get the scalar return type of the kernel. From that, a Numpy array type is constructed whose element type matches that scalar return type.

After computing the signature of the stencil for a previously unseen combination of input and keyword types, the `StencilFunc` then creates the stencil function itself. `StencilFunc` then installs the new stencil function’s definition in the target context so that jitted code is able to call it.

Thus, in this mode, the generated stencil function is a stand-alone function called like a normal function from within jitted code.

### Jit with `parallel=True`

When calling a `StencilFunc` from a jitted context with `parallel=True`, a separate stencil function as generated by Creating the stencil function is not used. Instead, `parfors` (Stage 5b: Perform Automatic Parallelization) are created within the current function that implements the stencil. This code again starts with the stencil kernel and does a similar kernel size computation but then rather than standard Python looping syntax, corresponding `parfors` are created so that the execution of the stencil will take place in parallel.

The stencil to `parfor` translations can also be selectively disabled by setting `parallel={'stencil': False}`, among other sub-options described in Stage 5b: Perform Automatic Parallelization.

### 6.11.3 Creating the stencil function

Conceptually, a stencil function is created from the user-specified stencil kernel by adding looping code around the kernel, transforming the relative kernel indices into absolute array indices based on the loop indices, and replacing the kernel’s `return` statement with a statement to assign the computed value into the output array.

To accomplish this transformation, first, a copy of the stencil kernel IR is created so that subsequent modifications of the IR for different stencil signatures will not effect each other.

Then, an approach similar to how GUFunc’s are created for `parfors` is employed. In a text buffer, a Python function is created with a unique name. The input array parameter is added to the function definition and if the `out` argument type is present then an `out` parameter is added to the stencil function definition. If the `out` argument is not present then first an output array is created with `numpy.zeros` having the same shape as the input array.

The kernel is then analyzed to compute the stencil size and the shape of the boundary (or the `neighborhood` stencil decorator argument is used for this purpose if present). Then, one for loop for each dimension of the input array is added to the stencil function definition. The range of each loop is controlled by the stencil kernel size previously computed so that the boundary of the output image is not modified but instead left as is. The body of the innermost for loop is a single `sentinel` statement that is easily recognized in the IR. A call to `exec` with the text buffer is used to force the stencil function into existence and an `eval` is used to get access to the corresponding function on which `run_frontend` is used to get the stencil function IR.
Various renaming and relabeling is performed on the stencil function IR and the kernel IR so that the two can be combined without conflict. The relative indices in the kernel IR (i.e., `getitem` calls) are replaced with expressions where the corresponding loop index variables are added to the relative indices. The `return` statement in the kernel IR is replaced with a `setitem` for the corresponding element in the output array. The stencil function IR is then scanned for the sentinel and the sentinel replaced with the modified kernel IR.

Next, `compile_ir` is used to compile the combined stencil function IR. The resulting compile result is cached in the `StencilFunc` so that other calls to the same stencil do not need to undertake this process again.

### 6.11.4 Exceptions raised

Various checks are performed during stencil compilation to make sure that user-specified options do not conflict with each other or with other runtime parameters. For example, if the user has manually specified a `neighborhood` to the stencil decorator, the length of that neighborhood must match the dimensionality of the input array. If this is not the case, a `ValueError` is raised.

If the neighborhood has not been specified then it must be inferred and a requirement to infer the kernel is that all indices are constant integers. If they are not, a `ValueError` is raised indicating that kernel indices may not be non-constant.

Finally, the stencil implementation detects the output array type by running Numba type inference on the stencil kernel. If the return type of this kernel does not match the type of the value passed to the `cval` stencil decorator option then a `ValueError` is raised.

### 6.12 Customizing the Compiler

**Warning:** The custom pipeline feature is for expert use only. Modifying the compiler behavior can invalidate internal assumptions in the numba source code.

For library developers looking for a way to extend or modify the compiler behavior, you can do so by defining a custom compiler by inheriting from `numba.compiler.CompilerBase`. The default Numba compiler is defined as `numba.compiler.Compiler`, implementing the `.define_pipelines()` method, which adds the `nopython-mode`, `object-mode` and `interpreted-mode` pipelines. For convenience these three pipelines are defined in `numba.compiler.DefaultPassBuilder` by the methods:

- `.define_nopython_pipeline()`
- `.define_objectmode_pipeline()`
- `.define_interpreted_pipeline()`

respectively.

To use a custom subclass of `CompilerBase`, supply it as the `pipeline_class` keyword argument to the `@jit` and `@generated_jit` decorators. By doing so, the effect of the custom pipeline is limited to the function being decorated.
6.12.1 Implementing a compiler pass

Numba makes it possible to implement a new compiler pass and does so through the use of an API similar to that of LLVM. The following demonstrates the basic process involved.

Compiler pass classes

All passes must inherit from `numba.compiler_machinery.CompilerPass`, commonly used subclasses are:

- `numba.compiler_machinery.FunctionPass` for describing a pass that operates on a function-at-once level and may mutate the IR state.
- `numba.compiler_machinery.AnalysisPass` for describing a pass that performs analysis only.
- `numba.compiler_machinery.LoweringPass` for describing a pass that performs lowering only.

In this example a new compiler pass will be implemented that will rewrite all `ir.Const(x)` nodes, where `x` is a subclass of `numbers.Number`, such that the value of `x` is incremented by one. There is no use for this pass other than to serve as a pedagogical vehicle!

The `numba.compiler_machinery.FunctionPass` is appropriate for the suggested pass behavior and so is the base class of the new pass. Further, a `run_pass` method is defined to do the work (this method is abstract, all compiler passes must implement it).

First the new class:

```python
from numba import njit
from numba.core import ir
from numba.core.compiler import CompilerBase, DefaultPassBuilder
from numba.core.compiler_machinery import FunctionPass, register_pass
from numba.core.untyped_passes import IRProcessing
from numbers import Number

# Register this pass with the compiler framework, declare that it will not
# mutate the control flow graph and that it is not an analysis_only pass (it
# potentially mutates the IR).
@register_pass(mutates_CFG=False, analysis_only=False)
class ConstsAddOne(FunctionPass):
    _name = "consts_add_one" # the common name for the pass

    def __init__(self):
        FunctionPass.__init__(self)

        # implement method to do the work, "state" is the internal compiler
        # state from the CompilerBase instance.
        def run_pass(self, state):
            func_ir = state.func_ir # get the FunctionIR object
            mutated = False # used to record whether this pass mutates the IR
            # walk the blocks
            for blk in func_ir.blocks.values():
                # find the assignment nodes in the block and walk them
                for assgn in blk.find_insts(ir.Assign):
                    # if an assignment value is a ir.Const
                    if isinstance(assgn.value, ir.Const):
                        const_val = assgn.value
                        # if the value of the ir.Const is a Number
                        if isinstance(const_val, Number):
                            # increment the value
                            const_val += 1
        # Flattening
        def _flat_pass(state):
            func_ir = state.func_ir # get the FunctionIR object
            mutated = False # used to record whether this pass mutates the IR
            # walk the blocks
            for blk in func_ir.blocks.values():
                # find the assignment nodes in the block and walk them
                for assgn in blk.find_insts(ir.Assign):
                    # if an assignment value is a ir.Const
                    if isinstance(assgn.value, ir.Const):
                        const_val = assgn.value
                        # if the value of the ir.Const is a Number
                        if isinstance(const_val, Number):
                            # increment the value
                            const_val += 1
```

(continues on next page)
if isinstance(const_val.value, Number):
    # then add one!
    const_val.value += 1
    mutated |= True

return mutated # return True if the IR was mutated, False if not.

Note also that the class must be registered with Numba’s compiler machinery using @register_pass. This in part is to allow the declaration of whether the pass mutates the control flow graph and whether it is an analysis only pass.

Next, define a new compiler based on the existing numba.compiler.CompilerBase. The compiler pipeline is defined through the use of an existing pipeline and the new pass declared above is added to be run after the IRProcessing pass.

class MyCompiler(CompilerBase): # custom compiler extends from CompilerBase
    def define_pipelines(self):
        # define a new set of pipelines (just one in this case) and for ease
        # base it on an existing pipeline from the DefaultPassBuilder,
        # namely the "nopython" pipeline
        pm = DefaultPassBuilder.define_nopython_pipeline(self.state)
        # Add the new pass to run after IRProcessing
        pm.add_pass_after(ConstsAddOne, IRProcessing)
        # finalize
        pm.finalize()
        # return as an iterable, any number of pipelines may be defined!
        return [pm]

Finally update the @njit decorator at the call site to make use of the newly defined compilation pipeline.

@njit(pipeline_class=MyCompiler) # JIT compile using the custom compiler
def foo(x):
    a = 10
    b = 20.2
    c = x + a + b
    return c

print(foo(100)) # 100 + 10 + 20.2 (+ 1 + 1), extra + 1 + 1 from the rewrite!

---

### 6.12.2 Debugging compiler passes

#### Observing IR Changes

It is often useful to be able to see the changes a pass makes to the IR. Numba conveniently permits this through the use of the environment variable NUMBA_DEBUG_PRINT_AFTER. In the case of the above pass, running the example code with NUMBA_DEBUG_PRINT_AFTER="ir_processing,consts_add_one" gives:

```markdown
label 0:
  x = arg(0, name=x) ['x']
  $const0.1 = const(int, 10) ['$const0.1']
  a = $const0.1 ['$const0.1', 'a']
```

(continues on next page)
Note the change in the values in the const nodes.

### Pass execution times

Numba has built-in support for timing all compiler passes, the execution times are stored in the metadata associated with a compilation result. This demonstrates one way of accessing this information based on the previously defined function, `foo`:

```python
code_result = foo.overloads[foo.signatures[0]]
nopython_times = code_result.metadata['pipeline_times'][nopython]
for k in nopython_times.keys():
    if ConstsAddOne._name in k:
        print(nopython_times[k])
```

the output of which is, for example:
pass_timings(init=1.914000677061267e-06, run=4.308700044930447e-05, finalize=1.7400006981915794e-06)

this displaying the pass initialization, run and finalization times in seconds.

6.13 Notes on Inlining

There are occasions where it is useful to be able to inline a function at its call site, at the Numba IR level of representation. The decorators such as `numba.jit()`, `numba.extending.overload()` and `register_jitable()` support the keyword argument `inline`, to facilitate this behaviour.

When attempting to inline at this level, it is important to understand what purpose this serves and what effect this will have. In contrast to the inlining performed by LLVM, which is aimed at improving performance, the main reason to inline at the Numba IR level is to allow type inference to cross function boundaries.

As an example, consider the following snippet:

```python
from numba import njit

@njit
def bar(a):
    a.append(10)

@njit
def foo():
    z = []
    bar(z)

foo()
```

This will fail to compile and run, because the type of `z` can not be inferred as it will only be refined within `bar`. If we now add `inline=True` to the decorator for `bar` the snippet will compile and run. This is because inlining the call to `a.append(10)` will mean that `z` will be refined to hold integers and so type inference will succeed.

So, to recap, inlining at the Numba IR level is unlikely to have a performance benefit. Whereas inlining at the LLVM level stands a better chance.

The `inline` keyword argument can be one of three values:

- The string ‘never’, this is the default and results in the function not being inlined under any circumstances.
- The string ‘always’, this results in the function being inlined at all call sites.
- A python function that takes three arguments. The first argument is always the `ir.Expr` node that is the call requesting the inline, this is present to allow the function to make call contextually aware decisions. The second and third arguments are:
  - In the case of an untyped inline, i.e. that which occurs when using the `numba.jit()` family of decorators, both arguments are `numba.ir.FunctionIR` instances. The second argument corresponding to the IR of the caller, the third argument corresponding to the IR of the callee.
  - In the case of a typed inline, i.e. that which occurs when using `numba.extending.overload()`, both arguments are instances of a `namedtuple` with fields (corresponding to their standard use in the compiler
internals):

* **func_ir** - the function’s Numba IR.
* **typemap** - the function’s type map.
* **calltypes** - the call types of any calls in the function.
* **signature** - the function’s signature.

The second argument holds the information from the caller, the third holds the information from the callee.

In all cases the function should return True to inline and return False to not inline, this essentially permitting custom inlining rules (typical use might be cost models).

- Recursive functions with `inline='always'` will result in a non-terminating compilation. If you wish to avoid this, supply a function to limit the recursion depth (see below).

**Note:** No guarantee is made about the order in which functions are assessed for inlining or about the order in which they are inlined.

### 6.13.1 Example using `numba.jit()`

An example of using all three options to inline in the `numba.njit()` decorator:

```python
from numba import njit
import numba
from numba.core import ir

@njit(inline='never')
def never_inline():
    return 100

@njit(inline='always')
def always_inline():
    return 200

def sentinel_cost_model(expr, caller_info, callee_info):
    # this cost model will return True (i.e. do inlining) if either:
    # a) the callee IR contains an `ir.Const(37)`
    # b) the caller IR contains an `ir.Const(13)` logically prior to the call
    
    # check the callee
    for blk in callee_info.blocks.values():
        for stmt in blk.body:
            if isinstance(stmt, ir.Assign):
                if isinstance(stmt.value, ir.Const):
                    if stmt.value.value == 37:
                        return True

(continues on next page)
# check the caller
before_expr = True
for blk in caller_info.blocks.values():
    for stmt in blk.body:
        if isinstance(stmt, ir.Assign):
            if isinstance(stmt.value, ir.Expr):
                if stmt.value == expr:
                    before_expr = False
            if isinstance(stmt.value, ir.Const):
                if stmt.value.value == 13:
                    return True & before_expr
    return False

@njit(inline=sentinel_cost_model)
def maybe_inline1():
    # Will not inline based on the callee IR with the declared cost model
    # The following is ir.Const(300).
    return 300

@njit(inline=sentinel_cost_model)
def maybe_inline2():
    # Will inline based on the callee IR with the declared cost model
    # The following is ir.Const(37).
    return 37

@njit
def foo():
    a = never_inline()  # will never inline
    b = always_inline()  # will always inline

    # will not inline as the function does not contain a magic constant known to
    # the cost model, and the IR up to the call site does not contain a magic
    # constant either
    d = maybe_inline1()

    # declare this magic constant to trigger inlining of maybe_inline1 in a
    # subsequent call
    magic const = 13

    # will inline due to above constant declaration
    e = maybe_inline1()

    # will inline as the maybe_inline2 function contains a magic constant known
    # to the cost model
    c = maybe_inline2()

    return a + b + c + d + e + magic const

6.13. Notes on Inlining
foo()

which produces the following when executed (with a print of the IR after the legalization pass, enabled via the environment variable NUMBA_DEBUG_PRINT_AFTER="ir_legalization"):

```python
label 0:
  $0.1 = global(never_inline: CPUDispatcher(<function never_inline at 0x7f890ccf9048>) ['$0.1'])
  $0.2 = call $0.1(func=$0.1, args=[], kws=(), vararg=None) ['$0.1', '$0.2']
  del $0.1 []
  a = $0.2 ['$0.2', 'a']
  del $0.2 []
  $0.3 = global(always_inline: CPUDispatcher(<function always_inline at 0x7f890ccf9598>) ['$0.3'])
  del $0.3 []
  $const0.1.0 = const(int, 200) ['$const0.1.0']
  $0.2.1 = $const0.1.0 ['$0.2.1', '$const0.1.0']
  del $const0.1.0 []
  $0.4 = $0.2.1 ['$0.2.1', '$0.4']
  del $0.2.1 []
  b = $0.4 ['$0.4', 'b']
  del $0.4 []
  $0.5 = global(maybe_inline1: CPUDispatcher(<function maybe_inline1 at 0x7f890ccf9ae8>) ['$0.5'])
  $0.6 = call $0.5(func=$0.5, args=[], kws=(), vararg=None) ['$0.5', '$0.6']
  del $0.5 []
  d = $0.6 ['$0.6', 'd']
  del $0.6 []
  $const0.7 = const(int, 13) ['$const0.7']
  magic_const = $const0.7 ['$const0.7', 'magic_const']
  del $const0.7 []
  $0.8 = global(maybe_inline1: CPUDispatcher(<function maybe_inline1 at 0x7f890ccf9ae8>) ['$0.8'])
  del $0.8 []
  $const0.1.2 = const(int, 300) ['$const0.1.2']
  $0.2.3 = $const0.1.2 ['$0.2.3', '$const0.1.2']
  del $const0.1.2 []
  $0.9 = $0.2.3 ['$0.2.3', '$0.9']
  del $0.2.3 []
  e = $0.9 ['$0.9', 'e']
  del $0.9 []
  $0.10 = global(maybe_inline2: CPUDispatcher(<function maybe_inline2 at 0x7f890ccf9b70>) ['$0.10'])
  del $0.10 []
  $const0.1.4 = const(int, 37) ['$const0.1.4']
  $0.2.5 = $const0.1.4 ['$0.2.5', '$const0.1.4']
  del $const0.1.4 []
  $0.11 = $0.2.5 ['$0.11', '$0.2.5']
  del $0.2.5 []
  c = $0.11 ['$0.11', 'c']
  del $0.11 []
  $0.14 = a + b ['$0.14', 'a', 'b']
```

(continues on next page)
Things to note in the above:

1. The call to the function never_inline remains as a call.

2. The always_inline function has been inlined, note its const(int, 200) in the caller body.

3. There is a call to maybe_inline1 before the const(int, 13) declaration, the cost model prevented this from being inlined.

4. After the const(int, 13) the subsequent call to maybe_inline1 has been inlined as shown by the const(int, 300) in the caller body.

5. The function maybe_inline2 has been inlined as demonstrated by const(int, 37) in the caller body.

6. That dead code elimination has not been performed and as a result there are superfluous statements present in the IR.

### 6.13.2 Example using numba.extending.overload()

An example of using inlining with the numba.extending.overload() decorator. It is most interesting to note that if a function is supplied as the argument to inline a lot more information is available via the supplied function arguments for use in decision making. Also that different @overload s can have different inlining behaviours, with multiple ways to achieve this:

```python
import numba
from numba.extending import overload
from numba import njit, types

def bar(x):
    
    
    
    pass

@overload(bar, inline='always')
def ol_bar_tuple(x):
```

(continues on next page)
# An overload that will always inline, there is a type guard so that this
# only applies to UniTuples.
if isinstance(x, types.UniTuple):
def impl(x):
    return x[0]
return impl

def cost_model(expr, caller, callee):
    # Only inline if the type of the argument is an Integer
    return isinstance(caller.typemap[expr.args[0].name], types.Integer)

@overload(bar, inline=cost_model)
def ol_bar_scalar(x):
    # An overload that will inline based on a cost model, it only applies to
    # scalar values in the numerical domain as per the type guard on Number
    if isinstance(x, types.Number):
def impl(x):
        return x + 1
    return impl

@njit
def foo():
    # This will resolve via `ol_bar_tuple` as the argument is a types.UniTuple
    # instance. It will always be inlined as specified in the decorator for this
    # overload.
a = bar((1, 2, 3))

    # This will resolve via `ol_bar_scalar` as the argument is a types.Number
    # instance, hence the cost_model will be used to determine whether to
    # inline.
    # The function will be inlined as the value 100 is an IntegerLiteral which
    # is an instance of a types.Integer as required by the cost_model function.
b = bar(100)

    # This will also resolve via `ol_bar_scalar` as the argument is a
    # types.Number instance, again the cost_model will be used to determine
    # whether to inline.
    # The function will not be inlined as the complex value is not an instance
    # of a types.Integer as required by the cost_model function.
c = bar(300j)

    return a + b + c

foo()

which produces the following when executed (with a print of the IR after the legalization pass, enabled via the envi-
ronment variable NUMBA_DEBUG_PRINT_AFTER="ir_legalization"):
label 0:

```python
const0.2 = const(tuple, (1, 2, 3)) ['const0.2']
x.0 = const0.2 ['const0.2', 'x.0']
del const0.2 []
const0.2.2 = const(int, 0) ['const0.2.2']
0.3.3 = getitem(value=x.0, index=const0.2.2) ['0.3.3', 'const0.2.2', 'x.0']
del x.0 []
del const0.2.2 []
const0.5 = const(int, 100) ['const0.5']
x.5 = const0.5 ['const0.5', 'x.5']
del const0.5 []
const0.2.7 = const(int, 1) ['const0.2.7']
0.3.8 = x.5 + const0.2.7 ['0.3.8', 'const0.2.7', 'x.5']
del x.5 []
del const0.2.7 []
const0.8 = const(complex, 300j) ['const0.8']
0.9 = call const0.8(func=const0.8, args=[Var(const0.8), inline_overload_example.py (56)], kws=(), vararg=None) ['0.7', '0.9', 'const0.8']
del const0.8 []
del 0.7 []
c = 0.9 ['0.9', 'c']
del 0.9 []
0.12 = a + b ['0.12', 'a', 'b']
del b []
del a []
0.14 = 0.12 + c ['0.12', '0.14', 'c']
del c []
del 0.12 []
0.15 = cast(value=0.14) ['0.14', '0.15']
del 0.14 []
return 0.15 ['0.15']
```

Things to note in the above:

1. The first highlighted section is the always inlined overload for the UniTuple argument type.
2. The second highlighted section is the overload for the Number argument type that has been inlined as the cost model function decided to do so as the argument was an Integer type instance.
3. The third highlighted section is the overload for the Number argument type that has not inlined as the cost model function decided to reject it as the argument was a Complex type instance.
4. That dead code elimination has not been performed and as a result there are superfluous statements present in the IR.

### 6.13.3 Using a function to limit the inlining depth of a recursive function

When using recursive inlines, you can terminate the compilation by using a cost model.

```python
from numba import njit
import numpy as np

class CostModel(object):
    def __init__(self, max_inlines):
        self._count = 0
        self._max_inlines = max_inlines

    def __call__(self, expr, caller, callee):
        ret = self._count < self._max_inlines
        self._count += 1
        return ret

@njit(inline=CostModel(3))
def factorial(n):
    if n <= 0:
        return 1
    return n * factorial(n - 1)

factorial(5)
```

### 6.14 Environment Object

The Environment object (Env) is used to maintain references to python objects that are needed to support compiled functions for both object-mode and nopython-mode.

In nopython-mode, the Env is used for:

- Storing pyobjects for reconstruction from native values, such as:
  - for printing native values of NumPy arrays;
  - for returning or yielding native values back to the interpreter.

In object-mode, the Env is used for:

- storing constant values referenced in the code.
- storing a reference to the function’s global dictionary to load global values.
6.14.1 The Implementation

The Env is implemented in two parts. In _dynfunc.c, the Env is defined as EnvironmentObject as a Python C-extension type. In lowering.py, the EnvironmentObject (exported as _dynfunc.Environment) is extended to support necessary operations needed at lowering.

Serialization

The Env supports being pickled. Compilation cache files and ahead-of-time compiled modules serialize all the used Envs for recreation at the runtime.

Usage

At the start of the lowering for a function or a generator, an Env is created. Throughout the compilation, the Env is mutated to attach additional information. The compiled code references an Env via a global variable in the emitted LLVM IR. The global variable is zero-initialized with “common” linkage, which is the default linkage for C global values. The use of this linkage allows multiple definitions of the global variable to be merged into a single definition when the modules are linked together. The name of the global variable is computed from the name of the function (see FunctionDescriptor.env_name and .get_env_name() of the target context).

The Env is initialized when the compiled-function is loaded. The JIT engine finds the address of the associated global variable for the Env and stores the address of the Env into it. For cached functions, the same process applies. For ahead-of-time compiled functions, the module initializer in the generated library is responsible for initializing the global variables of all the Envs in the module.

6.15 Notes on Hashing

Numba supports the built-in hash() and does so by simply calling the __hash__() member function on the supplied argument. This makes it trivial to add hash support for new types as all that is required is the application of the extension API overload_method() decorator to overload a function for computing the hash value for the new type registered to the type’s __hash__() method. For example:

```
from numba.extending import overload_method

@overload_method(myType, '__hash__')
def myType_hash_overload(obj):
    # implementation details
```

6.15.1 The Implementation

The implementation of the Numba hashing functions strictly follows that of Python 3. The only exception to this is that for hashing Unicode and bytes (for content longer than sys.hash_info.cutoff) the only supported algorithm is siphash24 (default in CPython 3). As a result Numba will match Python 3 hash values for all supported types under the default conditions described.
Unicode hash cache differences

Both Numba and CPython Unicode string internal representations have a hash member for the purposes of caching the string’s hash value. This member is always checked ahead of computing a hash value with the view of simply providing a value from cache as it is considerably cheaper to do so. The Numba Unicode string hash caching implementation behaves in a similar way to that of CPython’s. The only notable behavioral change (and its only impact is a minor potential change in performance) is that Numba always computes and caches the hash for Unicode strings created in npython mode at the time they are boxed for reuse in Python, this is too eager in some cases in comparison to CPython which may delay hashing a new Unicode string depending on creation method. It should also be noted that Numba copies in the hash member of the CPython internal representation for Unicode strings when unboxing them to its own representation so as to not recompute the hash of a string that already has a hash value associated with it.

The accommodation of PYTHONHASHSEED

The PYTHONHASHSEED environment variable can be used to seed the CPython hashing algorithms for e.g. the purposes of reproducibility. The Numba hashing implementation directly reads the CPython hashing algorithms’ internal state and as a result the influence of PYTHONHASHSEED is replicated in Numba’s hashing implementations.

6.16 Notes on Caching

Numba supports caching of compiled functions into the filesystem for future use of the same functions.

6.16.1 The Implementation

Caching is done by saving the compiled object code, the ELF object of the executable code. By using the object code, cached functions have minimal overhead because no compilation is needed. The cached data is saved under the cache directory (see NUMBA_CACHE_DIR). The index of the cache is stored in a .nbi file, with one index per function, and it lists all the overloaded signatures compiled for the function. The object code is stored in files with an .nbc extension, one file per overload. The data in both files is serialized with pickle.

Note: On Python <=3.7, Numba extends pickle using the pure-Python pickler. To use the faster C Pickler, install pickle5 from pip. pickle5 backports Python 3.8 pickler features.

Requirements for Cacheability

Developers should note the requirements of a function to permit it to be cached to ensure that the features they are working on are compatible with caching.

Requirements for cacheable function:

- The LLVM module must be self-contained, meaning that it cannot rely on other compiled units without linking to them.
- The only allowed external symbols are from the NRT or other common symbols from system libraries (i.e. libc and libm).

Debugging note:

- Look for the usage of inttoptr in the LLVM IR or target_context.add_dynamic_add() in the lowering code in Python. They indicate potential usage of runtime address. Not all uses are problematic and some are necessary. Only the conversion of constant integers into pointers will affect caching.
• Misuse of dynamic address or dynamic symbols will likely result in a segfault.
• Linking order matters because unused symbols are dropped after linking. Linking should start from the leaf nodes of the dependency graph.

Features Compatible with Caching

The following features are explicitly verified to work with caching.
• ufuncs and gufuncs for the cpu and parallel target
• parallel accelerator features (i.e. parallel=True)

Caching Limitations

This is a list of known limitation of the cache:
• Cache invalidation fails to recognize changes in symbols defined in a different file.
• Global variables are treated as constants. The cache will remember the value in the global variable used at compilation. On cache load, the cached function will not rebind to the new value of the global variable.

Cache Sharing

It is safe to share and reuse the contents in the cache directory on a different machine. The cache remembers the CPU model and the available CPU features during compilation. If the CPU model and the CPU features do not match exactly, the cache contents will not be considered. (Also see NUMBA_CPU_NAME)

If the cache directory is shared on a network filesystem, concurrent read/write of the cache is safe only if file replacement operation is atomic for the filesystem. Numba always writes to a unique temporary file first, it then replaces the target cache file path with the temporary file. Numba is tolerant against lost cache files and lost cache entries.

Cache Clearing

The cache is invalidated when the corresponding source file is modified. However, it is necessary sometimes to clear the cache directory manually. For instance, changes in the compiler will not be recognized because the source files are not modified.

To clear the cache, the cache directory can be simply removed.

Removing the cache directory when a Numba application is running may cause an OSError exception to be raised at the compilation site.

Related Environment Variables

See env-vars for caching.
6.17 Notes on Numba’s threading implementation

The execution of the work presented by the Numba parallel targets is undertaken by the Numba threading layer. Practically, the “threading layer” is a Numba built-in library that can perform the required concurrent execution. At the time of writing there are three threading layers available, each implemented via a different lower level native threading library. More information on the threading layers and appropriate selection of a threading layer for a given application/system can be found in the threading layer documentation.

The pertinent information to note for the following sections is that the function in the threading library that performs the parallel execution is the parallel_for function. The job of this function is to both orchestrate and execute the parallel tasks.

The relevant source files referenced in this document are

- numba/np/ufunc/tbbpool.cpp
- numba/np/ufunc/omppool.cpp
- numba/np/ufunc/workqueue.c

These files contain the TBB, OpenMP, and workqueue threadpool implementations, respectively. Each includes the functions set_num_threads(), get_num_threads(), and get_thread_id(), as well as the relevant logic for thread masking in their respective schedulers. Note that the basic thread local variable logic is duplicated in each of these files, and not shared between them.

- numba/np/ufunc/parallel.py

This file contains the Python and JIT compatible wrappers for set_num_threads(), get_num_threads(), and get_thread_id(), as well as the code that loads the above libraries into Python and launches the threadpool.

- numba/parfors/parfor_lowering.py

This file contains the main logic for generating code for the parallel backend. The thread mask is accessed in this file in the code that generates scheduler code, and passed to the relevant backend scheduler function (see below).

6.17.1 Thread masking

As part of its design, Numba never launches new threads beyond the threads that are launched initially with numba.np.ufunc.parallel._launch_threads() when the first parallel execution is run. This is due to the way threads were already implemented in Numba prior to thread masking being implemented. This restriction was kept to keep the design simple, although it could be removed in the future. Consequently, it’s possible to programmatically set the number of threads, but only to less than or equal to the total number that have already been launched. This is done by “masking” out unused threads, causing them to do no work. For example, on a 16 core machine, if the user were to call set_num_threads(4), Numba would always have 16 threads present, but 12 of them would sit idle for parallel computations. A further call to set_num_threads(16) would cause those same threads to do work in later computations.

Thread masking was added to make it possible for a user to programmatically alter the number of threads performing work in the threading layer. Thread masking proved challenging to implement as it required the development of a programming model that is suitable for users, easy to reason about, and could be implemented safely, with consistent behavior across the various threading layers.
Programming model

The programming model chosen is similar to that found in OpenMP. The reasons for this choice were that it is familiar to a lot of users, restricted in scope and also simple. The number of threads in use is specified by calling `set_num_threads` and the number of threads in use can be queried by calling `get_num_threads`. These two functions are synonymous with their OpenMP counterparts (with the above restriction that the mask must be less than or equal to the number of launched threads). The execution semantics are also similar to OpenMP in that once a parallel region is launched, altering the thread mask has no impact on the currently executing region, but will have an impact on parallel regions executed subsequently.

The Implementation

So as to place no further restrictions on user code other than those that already existed in the threading layer libraries, careful consideration of the design of thread masking was required. The “thread mask” cannot be stored in a global value as concurrent use of the threading layer may result in classic forms of race conditions on the value itself. Numerous designs were discussed involving various types of mutex on such a global value, all of which were eventually broken through thought experiment alone. It eventually transpired that, following some OpenMP implementations, the “thread mask” is best implemented as a thread local. This means each thread that executes a Numba parallel function will have a thread local storage (TLS) slot that contains the value of the thread mask to use when scheduling threads in the `parallel_for` function.

The above notion of TLS use for a thread mask is relatively easy to implement, `get_num_threads` and `set_num_threads` simply need to address the TLS slot in a given threading layer. This also means that the execution schedule for a parallel region can be derived from a run time call to `get_num_threads`. This is achieved via a well known and relatively easy to implement pattern of a C library function registration and wrapping it in the internal Numba implementation.

In addition to satisfying the original upfront thread masking requirements, a few more complicated scenarios needed consideration as follows.

Nested parallelism

In all threading layers a “main thread” will invoke the `parallel_for` function and then in the parallel region, depending on the threading layer, some number of additional threads will assist in doing the actual work. If the work contains a call to another parallel function (i.e. nested parallelism) it is necessary for the thread making the call to know what the “thread mask” of the main thread is so that it can propagate it into the `parallel_for` call it makes when executing the nested parallel function. The implementation of this behavior is threading layer specific but the general principle is for the “main thread” to always “send” the value of the thread mask from its TLS slot to all threads in the threading layer that are active in the parallel region. These active threads then update their TLS slots with this value prior to performing any work. The net result of this implementation detail is that:

- thread masks correctly propagate into nested functions
- it’s still possible for each thread in a parallel region to safely have a different mask with which to call nested functions, if it’s not set explicitly then the inherited mask from the “main thread” is used
- threading layers which have dynamic scheduling with threads potentially joining and leaving the active pool during a `parallel_for` execution are successfully accommodated
- any “main thread” thread mask is entirely decoupled from the in-flux nature of the thread masks of the threads in the active thread pool
Python threads independently invoking parallel functions

The threading layer launch sequence is heavily guarded to ensure that the launch is both thread and process safe and run once per process. In a system with numerous Python threading module threads all using Numba, the first thread through the launch sequence will get its thread mask set appropriately, but no further threads can run the launch sequence. This means that other threads will need their initial thread mask set some other way. This is achieved when `get_num_threads` is called and no thread mask is present, in this case the thread mask will be set to the default. In the implementation, “no thread mask is present” is represented by the value -1 and the “default thread mask” (unset) is represented by the value 0. The implementation also immediately calls `set_num_threads(NUMBA_NUM_THREADS)` after doing this, so if either -1 or 0 is encountered as a result from `get_num_threads()` it indicates a bug in the above processes.

OS fork() calls

The use of TLS was also in part driven by the Linux (the most popular platform for Numba use by far) having a `fork(2, 3P)` call that will do TLS propagation into child processes, see `clone(2)`’s `CLONE_SETTLS`.

Thread ID

A private `get_thread_id()` function was added to each threading backend, which returns a unique ID for each thread. This can be accessed from Python by `numba.np.ufunc.parallel._get_thread_id()` (it can also be used inside a JIT compiled function). The thread ID function is useful for testing that the thread masking behavior is correct, but it should not be used outside of the tests. For example, one can call `set_num_threads(4)` and then collect all unique `_get_thread_id()`s in a parallel region to verify that only 4 threads are run.

Caveats

Some caveats to be aware of when testing thread masking:

- The TBB backend may choose to schedule fewer than the given mask number of threads. Thus a test such as the one described above may return fewer than 4 unique threads.
- The workqueue backend is not threadsafe, so attempts to do multithreading nested parallelism with it may result in deadlocks or other undefined behavior. The workqueue backend will raise a SIGABRT signal if it detects nested parallelism.
- Certain backends may reuse the main thread for computation, but this behavior shouldn’t be relied upon (for instance, if propagating exceptions).

Use in Code Generation

The general pattern for using `get_num_threads` in code generation is

```python
import llvmlite.llvmpy.core as lc

g = cgutils.get_or_insert_function(builder.module, 
    lc.Type.function(lc.Type.int(types.intp.bitwidth), []), 
    name="get_num_threads")

num_threads = builder.call(g, [])[0]
```

(continues on next page)
with cgutils.if_unlikely(builder, builder.icmp_signed('<=', num_threads, num_threads.type(0))):
    cgutils.printf(builder, "num_threads: %d\n", num_threads)
context.call_conv.return_user_exc(builder, RuntimeError,
    ("Invalid number of threads. "
    "This likely indicates a bug in Numba.",))

# Pass num_threads through to the appropriate backend function here

See the code in numba/parfors/parfor_lowering.py.

The guard against num_threads being <= 0 is not strictly necessary, but it can protect against accidentally incorrect behavior in case the thread masking logic contains a bug.

The num_threads variable should be passed through to the appropriate backend function, such as do_scheduling or parallel_for. If it’s used in some way other than passing it through to the backend function, the above considerations should be taken into account to ensure the use of the num_threads variable is safe. It would probably be better to keep such logic in the threading backends, rather than trying to do it in code generation.

## 6.18 Notes on Literal Types

**Note:** This document describes an advanced feature designed to overcome some limitations of the compilation mechanism relating to types.

Some features need to specialize based on the literal value during compilation to produce type stable code necessary for successful compilation in Numba. This can be achieved by propagating the literal value through the type system. Numba recognizes inline literal values as numba.types.Literal. For example:

```python
def foo(x):
    a = 123
    return bar(x, a)
```

Numba will infer the type of `a` as Literal[int](123). The definition of `bar()` can subsequently specialize its implementation knowing that the second argument is an `int` with the value 123.

### 6.18.1 Literal Type

Classes and methods related to the Literal type.

```python
class numba.types.Literal(*args, **kwargs):
    Base class for Literal types. Literal types contain the original Python value in the type.
    A literal type should always be constructed from the literal(val) function.

numba.types.literal(value)
    Returns a Literal instance or raise LiteralTypingError

numba.types.unliteral(lit_type)
    Get base type from Literal type.

numba.types.maybe_literal(value)
    Get a Literal type for the value or None.
```
To specify a value as a `Literal` type in code scheduled for JIT compilation, use the following function:

```python
numba.literally(obj)
```

Forces Numba to interpret `obj` as an `Literal` value.

`obj` must be either a literal or an argument of the caller function, where the argument must be bound to a literal. The literal requirement propagates up the call stack.

This function is intercepted by the compiler to alter the compilation behavior to wrap the corresponding function parameters as `Literal`. It has **no effect** outside of nopython-mode (interpreter, and objectmode).

The current implementation detects literal arguments in two ways:

1. Scans for uses of `literally` via a compiler pass.
2. `literally` is overloaded to raise `numba.errors.ForceLiteralArg` to signal the dispatcher to treat the corresponding parameter differently. This mode is to support indirect use (via a function call).

The execution semantic of this function is equivalent to an identity function.

See `numba/tests/test_literal_dispatch.py` for examples.

### Code Example

Listing 2: from `test_literally_usage` of `numba/tests/doc_examples/test_literally_usage.py`

```python
import numba

def power(x, n):
    raise NotImplementedError

@numba.extending.overload(power)
def ov_power(x, n):
    if isinstance(n, numba.types.Literal):
        # only if `n` is a literal
        if n.literal_value == 2:
            # special case: square
            print("square")
            return lambda x, n: x * x
        elif n.literal_value == 3:
            # special case: cubic
            print("cubic")
            return lambda x, n: x * x * x
    else:
        # If `n` is not literal, request literal dispatch
        return lambda x, n: numba.literally(n)

    print("generic")
    return lambda x, n: x ** n

@numba.njit
def test_power(x, n):
    return power(x, n)
```

(continues on next page)
```python
# should print "square" and "9"
print(test_power(3, 2))

# should print "cubic" and "27"
print(test_power(3, 3))

# should print "generic" and "81"
print(test_power(3, 4))
```

**Internal Details**

Internally, the compiler raises a `ForceLiteralArgs` exception to signal the dispatcher to wrap specified arguments using the `Literal` type.

```python
class numba.errors.ForceLiteralArg(arg_indices, fold_arguments=None, loc=None)
```

A Pseudo-exception to signal the dispatcher to type an argument literally.

**Attributes**

- `requested_args` [frozenset[int]] requested positions of the arguments.

**__init__**(arg_indices, fold_arguments=None, loc=None)

**Parameters**

- `arg_indices` [Sequence[int]] requested positions of the arguments.
- `fold_arguments`: callable A function (tuple, dict) -> tuple that binds and flattens the args and kwargs.
- `loc` [numba.ir.Loc or None]

**__or__**(other)

Same as self.combine(other)

**combine**(other)

Returns a new instance by or’ing the `requested_args`.

### 6.18.3 Inside Extensions

@overload extensions can use literally inside the implementation body like in normal jit-code.

Explicit handling of literal requirements is possible through use of the following:

```python
class numba.extending.SentryLiteralArgs(literal_args)
```

**Parameters**

- `literal_args` [Sequence[str]] A sequence of names for literal arguments
Examples

The following line:

```python
>>> SentryLiteralArgs(literal_args).for_pysig(pysig).bind(*args, **kwargs)
```  
is equivalent to:

```python
>>> sentry_literal_args(pysig, literal_args, args, kwargs)
```

```python
for_function(func)
```

Bind the sentry to the signature of `func`.

Parameters

- **func**: [Function] A python function.

Returns

- obj [BoundLiteralArgs]

```python
for_pysig(pysig)
```

Bind the sentry to the given signature `pysig`.

Parameters

- **pysig**: [inspect.Signature]

Returns

- obj [BoundLiteralArgs]

```python
class numba.extending.BoundLiteralArgs(pysig, literal_args)
```

This class is usually created by SentryLiteralArgs.

```python
bind(*args, **kwargs)
```

Bind to argument types.

```python
numba.extending.sentry_literal_args(pysig, literal_args, args, kwargs)
```

Ensures that the given argument types (in `args` and `kwargs`) are literally typed for a function with the python signature `pysig` and the list of literal argument names in `literal_args`.

Alternatively, this is the same as:

```python
SentryLiteralArgs(literal_args).for_pysig(pysig).bind(*args, **kwargs)
```

6.19 Notes on timing LLVM

6.19.1 Getting LLVM Pass Timings

The dispatcher stores LLVM pass timings in the dispatcher object metadata under the `llvm_pass_timings` key when `NUMBA_LLVM_PASS_TIMINGS` is enabled or `numba.config.LLVM_PASS_TIMINGS` is set to truthy. The timings information contains details on how much time has been spent in each pass. The pass timings are also grouped by their purpose. For example, there will be pass timings for function-level pre-optimizations, module-level optimizations, and object code generation.
Code Example

Listing 3: from test_pass_timings of numba/tests/doc_examples/test_llvm_pass_timings.py

```python
import numba

@numba.njit
def foo(n):
    c = 0
    for i in range(n):
        for j in range(i):
            c += j
    return c

foo(10)
md = foo.get_metadata(foo.signatures[0])
print(md['llvm_pass_timings'])
```

Example output:

```
Printing pass timings for JITCodeLibrary('DocsLLVMPassTimings.test_pass_timings.<locals>.foo')
Total time: 0.0376
== #0 Function passes on '_ZN5numba5tests12doc_examples22test_llvm_pass...
Percent: 4.8%
Total 0.0018s
Top timings:
  0.0015s (81.6%) SROA #3
  0.0002s (9.3%) Early CSE #2
  0.0001s (4.0%) Simplify the CFG #9
  0.0000s (1.5%) Prune NRT refops #4
  0.0000s (1.1%) Post-Dominator Tree Construction #5
== #1 Function passes on '_ZN7cpython5numba5tests12doc_examples22test_llvm_pass...
Percent: 0.8%
Total 0.0003s
Top timings:
  0.0001s (30.4%) Simplify the CFG #10
  0.0001s (24.1%) Early CSE #3
  0.0001s (17.8%) SROA #4
  0.0000s (8.8%) Prune NRT refops #5
  0.0000s (5.6%) Post-Dominator Tree Construction #6
== #2 Function passes on 'cfunc._ZN5numba5tests12doc_examples22test_llvm_pass...
Percent: 0.5%
Total 0.0002s
Top timings:
  0.0001s (27.7%) Early CSE #4
  0.0001s (26.8%) Simplify the CFG #11
  0.0000s (13.8%) Prune NRT refops #6
  0.0000s (7.4%) Post-Dominator Tree Construction #7
```

6.19. Notes on timing LLVM
API for custom analysis

It is possible to get more details than the summary text in the above example. The pass timings are stored in a numba.misco.llvm_pass_timings.PassTimingsCollection, which contains methods for accessing individual record for each pass.

class numba.misco.llvm_pass_timings.PassTimingsCollection(name)

A collection of pass timings.

   This class implements the Sequence protocol for accessing the individual timing records.

   __getitem__(i)
     Get the i-th timing record.

   Returns
     res: (name, timings) A named tuple with two fields:
     • name: str
     • timings: ProcessedPassTimings

   __len__()
     Length of this collection.

   get_total_time()
     Computes the sum of the total time across all contained timings.

Returns

res: float or None  Returns the total number of seconds or None if no timings were recorded

list_longest_first()
Returns the timings in descending order of total time duration.

Returns

res: List[ProcessedPassTimings]

summary(topn=5)
Return a string representing the summary of the timings.

Parameters

topn: int; optional, default=5. This limits the maximum number of items to show. This function will show the topn most time-consuming passes.

Returns

res: str

See also ProcessedPassTimings.summary()

class numba.misc.llvm_pass_timings.ProcessedPassTimings(raw_data)
A class for processing raw timing report from LLVM.
The processing is done lazily so we don’t waste time processing unused timing information.

get_raw_data()
Returns the raw string data.

Returns

res: str

get_total_time()
Compute the total time spend in all passes.

Returns

res: float

list_records()
Get the processed data for the timing report.

Returns

res: List[PassTimingRecord]

list_top(n)
Returns the top(n) most time-consuming (by wall-time) passes.

Parameters

n: int  This limits the maximum number of items to show. This function will show the n most time-consuming passes.

Returns

res: List[PassTimingRecord]  Returns the top(n) most time-consuming passes in descending order.

summary(topn=5, indent=0)
Return a string summarizing the timing information.

Parameters

6.19. Notes on timing LLVM
### 6.20 Notes on Debugging

This section describes techniques that can be useful in debugging the compilation and execution of generated code.

See also:

*Debugging JIT compiled code with GDB*

#### 6.20.1 Memcheck

Memcheck is a memory error detector implemented using Valgrind. It is useful for detecting memory errors in compiled code, particularly out-of-bounds accesses and use-after-free errors. Buggy or miscompiled native code can generate these kinds of errors. The Memcheck documentation explains its usage; here, we discuss only the specifics of using it with Numba.

The Python interpreter and some of the libraries used by Numba can generate false positives with Memcheck - see this section of the manual for more information on why false positives occur. The false positives can make it difficult to determine when an actual error has occurred, so it is helpful to suppress known false positives. This can be done by supplying a suppressions file, which instructs Memcheck to ignore errors that match the suppressions defined in it.

The CPython source distribution includes a suppressions file, in the file `Misc/valgrind-python.supp`. Using this file prevents a lot of spurious errors generated by Python's memory allocation implementation. Additionally, the Numba repository includes a suppressions file in `contrib/valgrind-numba.supp`.

**Note:** It is important to use the suppressions files from the versions of the Python interpreter and Numba that you are using - these files evolve over time, so non-current versions can fail to suppress some errors, or erroneously suppress actual errors.

To run the Python interpreter under Memcheck with both suppressions files, it is invoked with the following command:

```
valgrind --tool=memcheck \
  --suppressions=${CPYTHON_SRC_DIR}/Misc/valgrind-python.supp \
  --suppressions=${NUMBA_SRC_DIR}/contrib/valgrind-numba.supp \
  python ${{PYTHON_ARGS}}
```

where `${CPYTHON_SRC_DIR}` is set to the location of the CPython source distribution, `${NUMBA_SRC_DIR}` is the location of the Numba source dir, and `${PYTHON_ARGS}` are the arguments to the Python interpreter.

If there are errors, then messages describing them will be printed to standard error. An example of an error is:
Use of uninitialised value of size 8

The traceback provided only outlines the C call stack, which can make it difficult to determine what the Python interpreter was doing at the time of the error. One can learn more about the state of the stack by looking at the backtrace in the GNU Debugger (GDB). Launch valgrind with an additional argument, `--vgdb-error=0` and attach to the process using GDB as instructed by the output. Once an error is encountered, GDB will stop at the error and the stack can be inspected.

GDB does provide support for backtracing through the Python stack, but this requires symbols which may not be easily available in your Python distribution. In this case, it is still possible to determine some information about what was happening in Python, but this depends on examining the backtrace closely. For example, in a backtrace corresponding to the above error, we see items such as:

```c
#18 0x0000000002722da in sot_tp_call (self=<_wrap_impl(_callable=<_wrap_missing_loc(func=<function at remote 0x1cf66c20>) at remote 0x1d200bd0>, _imp=<function at remote 0x1d0e7440>, _context=<CUDATargetContext(address_size=64, typing_context=<CUDATypingContext(_registries=<Registry(functions=[<type at remote 0x65be5e0>, <type at remote 0x65be9d0>, <type at remote 0x65bedc0>, <type at remote 0x65bf1b0>, <type at remote 0x8b78000>, <type at remote 0x8b783f0>, <type at remote 0x8b787e0>, <type at remote 0x8b78bd0>, <type at remote 0x8b78fc0>, <type at remote 0x8b793b0>, <type at remote 0x8b797a0>, <type at remote 0x8b79b90>, <type at remote 0x8b79f80>, <type at remote 0x8b7a370>, <type at remote 0x8b7a60>, <type at remote 0x8b7ab50>, <type at remote 0x8b7af40>, <type at remote 0x8b7b330>, <type at remote 0x8b7b720>, <type at remote 0x8b7bf00>, <type at remote 0x8b7c2f0>, <type at remote 0x8b7c60>, attributes=[<type at remote 0x8b77cd0>, <type at remote 0x8b77ce0>, <type at remote 0x8b7d20>, <type at remote 0x8b7da0>, <type at remote 0x8b7da0>, <type at remote 0x8b7da0>, <type at remote 0x8b7d20>, <type at remote 0x8b7da0], ...], args=<Builder(_block=Block(parent=Function(parent=<Module(context=<Context(scope=<NameScope(_useset=''

(continues on next page)
We can see some of the arguments, in particular the names of the compiled functions, e.g:

```
ZN5numba4cuda5tests6cuda19cuconstRecAlign$247(A

We can run this through `c++filt` to see a more human-readable representation:

```
numba::cuda::tests::cuda::test_constmem::cuconstRecAlign$247(
  Array<double, 1, C, mutable, aligned>,
  Array<double, 1, C, mutable, aligned>,
  Array<double, 1, C, mutable, aligned>,
  Array<double, 1, C, mutable, aligned>,
  Array<double, 1, C, mutable, aligned>)
```

which is the fully qualified name of a jitted function and the types with which it was called.

### 6.21 Event API

The `numba.core.event` module provides a simple event system for applications to register callbacks to listen to specific compiler events.

The following events are built in:

- "numba:compile" is broadcast when a dispatcher is compiling. Events of this kind have data defined to be a dict with the following key-values:
  - "dispatcher": the dispatcher object that is compiling.
  - "args": the argument types.
  - "return_type": the return type.
- "numba:compiler_lock" is broadcast when the internal compiler-lock is acquired. This is mostly used internally to measure time spent with the lock acquired.
- "numba:llvm_lock" is broadcast when the internal LLVM-lock is acquired. This is used internally to measure time spent with the lock acquired.

Applications can register callbacks that are listening for specific events using `register(kind: str, listener: Listener)`, where `listener` is an instance of `Listener` that defines custom actions on occurrence of the specific event.

```
class numba.core.event.Event(kind, status, data=None, exc_details=None)
An event.
```
Parameters

    kind [str]
    status [EventStatus]
    data [any; optional] Additional data for the event.
    exc_details [3-tuple; optional] Same 3-tuple for __exit__.

property data
    Event data

    Returns
    res [object]

property is_end
    Is it an END event?

    Returns
    res [bool]

property is_failed
    Is the event carrying an exception?

    This is used for END event. This method will never return True in a START event.

    Returns
    res [bool]

property is_start
    Is it a START event?

    Returns
    res [bool]

property kind
    Event kind

    Returns
    res [str]

property status
    Event status

    Returns
    res [EventStatus]

class numba.core.event.EventStatus(value)
    Status of an event.

class numba.core.event.Listener
    Base class for all event listeners.

    notify(event)
    Notify this Listener with the given Event.

    Parameters

    event [Event]
abstract on_end(event)
    Called when there is a END event.

    Parameters
    event [Event]

abstract on_start(event)
    Called when there is a START event.

    Parameters
    event [Event]

class numba.core.event.RecordingListener
    A listener that records all events and stores them in the .buffer attribute as a list of 2-tuple (float, Event), where the first element is the time the event occurred as returned by time.time() and the second element is the event.

on_end(event)
    Called when there is a END event.

    Parameters
    event [Event]

on_start(event)
    Called when there is a START event.

    Parameters
    event [Event]

class numba.core.event.TimingListener
    A listener that measures the total time spent between START and END events during the time this listener is active.

    property done
        Returns a bool indicating whether a measurement has been made.

        When this returns False, the matching event has never fired. If and only if this returns True, .duration can be read without error.

    property duration
        Returns the measured duration.

        This may raise AttributeError. Users can use .done to check that a measurement has been made.

on_end(event)
    Called when there is a END event.

    Parameters
    event [Event]

on_start(event)
    Called when there is a START event.

    Parameters
    event [Event]

numba.core.event.broadcast(event)
    Broadcast an event to all registered listeners.

    Parameters
event [Event]

```python
numba.core.event.end_event(kind, data=None, exc_details=None)
```

Trigger the end of an event of `kind`, `exc_details`.

**Parameters**

- `kind` [str] Event kind.
- `data` [any; optional] Extra event data.
- `exc_details` [3-tuple; optional] Same 3-tuple for `__exit__`. Or, `None` if no error.

**Examples**

```python
>>> with install_listener("numba:compile", listener):
    some_code()  # listener will be active here.
    other_code()  # listener will be unregistered by this point.
```

```python
numba.core.event.install_listener(kind, listener)
```

Install a listener for event “kind” temporarily within the duration of the context.

**Returns**

- `res` [Listener] The `listener` provided.

**Examples**

This is equivalent to:

```python
>>> with install_listener(kind, RecordingListener()) as res:
    ...
```

```python
numba.core.event.install_recorder(kind)
```

Install a RecordingListener temporarily to record all events.

Once the context is closed, users can use `RecordingListener.buffer` to access the recorded events.

**Returns**

- `res` [RecordingListener]

**Examples**

```python
>>> with install_listener(kind, RecordingListener()) as res:
    ...
```

```python
numba.core.event.install_timer(kind, callback)
```

Install a TimingListener temporarily to measure the duration of an event.

If the context completes successfully, the `callback` function is executed. The `callback` function is expected to take a float argument for the duration in seconds.

**Returns**

- `res` [TimingListener]
Examples

This is equivalent to:

```python
>>> with install_listener(kind, TimingListener()) as res:
>>>     ...
```

```
numba.core.event.register(kind, listener)
```

Register a listener for a given event kind.

**Parameters**

- `kind` [str]
- `listener` [Listener]

```
numba.core.event.start_event(kind, data=None)
```

Trigger the start of an event of `kind` with `data`.

**Parameters**

- `kind` [str] Event kind.
- `data` [any; optional] Extra event data.

```
numba.core.event.trigger_event(kind, data=None)
```

A context manager to trigger the start and end events of `kind` with `data`. The start event is triggered when entering the context. The end event is triggered when exiting the context.

**Parameters**

- `kind` [str] Event kind.
- `data` [any; optional] Extra event data.

```
numba.core.event.unregister(kind, listener)
```

Unregister a listener for a given event kind.

**Parameters**

- `kind` [str]
- `listener` [Listener]

### 6.22 Notes on Target Extensions

**Warning:** All features and APIs described in this page are in-development and may change at any time without deprecation notices being issued.

#### 6.22.1 Inheriting compiler flags from the caller

Compiler flags, i.e. options such as `fastmath`, `nrt` in `@jit(nrt=True, fastmath=True)`) are specified per-function but their effects are not well-defined—some flags affect the entire callgraph, some flags affect only the current function. Sometimes it is necessary for callees to inherit flags from the caller; for example the `fastmath` flag should be infectious.

To address the problem, the following are needed:
1. Better definitions for the semantics of compiler flags. Preferably, all flags should limit their effect to the current function. (TODO)

2. Allow compiler flags to be inherited from the caller. (Done)

3. Consider compiler flags in function resolution. (TODO)

numba.core.targetconfig.ConfigStack is used to propagate the compiler flags throughout the compiler. At the start of the compilation, the flags are pushed into the ConfigStack, which maintains a thread-local stack for the compilation. Thus, callees can check the flags in the caller.

```python
class numba.core.targetconfig.ConfigStack
    A stack for tracking target configurations in the compiler.
    It stores the stack in a thread-local class attribute. All instances in the same thread will see the same stack.

    enter(flags)
        Returns a contextmanager that performs push(flags) on enter and pop() on exit.

    classmethod top_or_none()
        Get the TOS or return None if no config is set.
```

**Compiler flags**

Compiler flags are defined as a subclass of TargetConfig:

```python
class numba.core.targetconfig.TargetConfig(copy_from=None)
    Base class for TargetConfig.
    Subclass should fill class members with Option. For example:

    >>> class MyTargetConfig(TargetConfig):
    >>>     a_bool_option = Option(type=bool, default=False, doc="a bool")
    >>>     an_int_option = Option(type=int, default=0, doc="an int")
```

The metaclass will insert properties for each Option. For example:

```python
>>> tc = MyTargetConfig()
>>> tc.a_bool_option = True  # invokes the setter
>>> print(tc.an_int_option)  # print the default
```

- `copy()`  
  Clone this instance.

- `classmethod demangle(mangled: str) → str`
  Returns the demangled result from .get_mangle_string()

- `discard(name)`
  Remove the option by name if it is defined.
  After this, the value for the option will be set to its default value.

- `get_mangle_string() → str`
  Return a string suitable for symbol mangling.

- `inherit_if_not_set(name, default=<NotSet>)`
  Inherit flag from ConfigStack.

  **Parameters**
  
  - `name` [str] Option name.

6.22. Notes on Target Extensions
default [optional] When given, it overrides the default value. It is only used when the flag is not defined locally and there is no entry in the ConfigStack.

is_set(name)
Is the option set?

summary() → str
Returns a str that summarizes this instance.
In contrast to __repr__, only options that are explicitly set will be shown.

values() Returns a dict of all the values

These are internal compiler flags and they are different from the user-facing options used in the jit decorators.

Internally, the user-facing options are mapped to the internal compiler flags by numba.core.options. TargetOptions. Each target can override the default compiler flags and control the flag inheritance in TargetOptions.finalize. The CPU target overrides it.

class numba.core.options.TargetOptions
Target options maps user options from decorators to the numba.core.compiler.Flags used by lowering and target context.

finalize(flags, options)
Subclasses can override this method to make target specific customizations of default flags.

Parameters
flags [Flags]
options [dict]

In numba.core.options.TargetOptions.finalize(), use numba.core.targetconfig.TargetConfig.inherit_if_not_set() to request a compiler flag from the caller if it is not set for the current function.

6.23 Numba Project Roadmap

Note: This page was last revised in December 2018.

This roadmap is for informational purposes only. Priorities and resources change, so we may choose to reorder or abandon things on this list. Additionally, the further out items are, the less concrete they will be. If you have an interest in working on one of these items, please open an issue where we can discuss the design and approach first.

6.23.1 Short Term: 2019H1

- Container improvements:
  - Numba dictionary support
  - Refactor lists to follow new container best practices. See the discussion in issue 3546.
- Deprecate Python 2.7 support
- Improve caching:
  - Full support for functions compiled with ParallelAccelerator
  - Safe caching of generated functions (eval of strings)
– Expire cache when any function in call chain (even in other files) changes
– Process for distributing pre-populated cache

• Continue to improve usability and debugging:
  – Trap more unsupported features earlier in pipeline (especially things that parfors can’t handle)
  – Error messages
  – Diagnostic tools for debugging and understanding performance
  – Better on-boarding for new users and contributors (revise docs, more examples)

• Begin refactoring existing features that cause common bug reports:
  – Enhance description of interfaces provided by Numba functions to give more type information
  – Convert older Numba function implementations to use public extension mechanisms
  – More unit testing and modularization of ParallelAccelerator passes

6.23.2 Medium Term: 2019H2

• Unify dispatch of regular functions, ufuncs, and gufuncs
• Declare Numba 1.0 with stable interfaces
• Continue to improve usability and debugging (see above)
• Continue refactoring Numba internals to solve common bug reports (see above)
• JIT class review and improvement
• Improve compilation speed
• Improve memory management of Numba-allocated memory
• Better support for writing code transformation passes
• Make caching and parallel execution features opt-out instead of opt-in
  – add heuristic to determine if parfor passes will be beneficial

6.23.3 Long Term: 2020 and beyond

• Unify GPU backends (share more code and interfaces)
• Improve ahead of time compilation (for low powered devices)
• Improve cross language connections (C++, JVM?, Julia?, R?)
  – Call Numba from other languages,
  – Call from Numba into other languages
• Better support for “hybrid” CPU/GPU/TPU/etc programming
• Partial / deferred compilation of functions
• Foster integration of Numba into core PyData packages:
  – scipy/scikit-learn/scikit-image/pandas
• More support for efforts to put Numba into other applications (databases, etc) for compiling user-defined functions
• More support for usage of Numba as a “compiler toolkit” to create custom compilers (like HPAT, automatic differentiation of functions, etc)
• Investigate AST-based Numba frontend in addition to existing bytecode-based frontend
CHAPTER
SEVEN

NUMBA ENHANCEMENT PROPOSALS

Numba Enhancement Proposals (not really abbreviated “NEPs”, since “NEP” is already taken by the Numpy project) describe proposed changes to Numba. They are modeled on Python Enhancement Proposals (PEPs) and Numpy Enhancement Proposals, and are typically written up when important changes (behavioural changes, feature additions…) to Numba are proposed.

This page provides an overview of all proposals, making only a distinction between the ones that have been implemented and those that have not been implemented.

7.1 Implemented proposals

7.1.1 NBEP 1: Changes in integer typing

Author  Antoine Pitrou
Date    July 2015
Status  Final

Current semantics

Type inference of integers in Numba currently has some subtleties and some corner cases. The simple case is when some variable has an obvious Numba type (for example because it is the result of a constructor call to a Numpy scalar type such as np.int64). That case suffers no ambiguity.

The less simple case is when a variable doesn’t bear such explicit information. This can happen because it is inferred from a built-in Python int value, or from an arithmetic operation between two integers, or other cases yet. Then Numba has a number of rules to infer the resulting Numba type, especially its signedness and bitwidth.

Currently, the generic case could be summarized as: start small, grow bigger as required. Concretely:

1. Each constant or pseudo-constant is inferred using the smallest signed integer type that can correctly represent it (or, possibly, uint64 for positive integers between 2**63 and 2**64 - 1).
2. The result of an operation is typed so as to ensure safe representation in the face of overflow and other magnitude increases (for example, int32 + int32 would be typed int64).
3. As an exception, a Python int used as function argument is always typed intp, a pointer-size integer. This is to avoid the proliferation of compiled specializations, as otherwise various integer bitwidths in input arguments may produce multiple signatures.

Note: The second rule above (the “respect magnitude increases” rule) reproduces Numpy’s behaviour with arithmetic on scalar values. Numba, however, has different implementation and performance constraints than Numpy scalars.
It is worth nothing, by the way, that Numpy arrays do not implement said rule (i.e. `array(int32) + array(int32)` is typed `array(int32)`, not `array(int64)`). Probably because this makes performance more controllable.

This has several non-obvious side-effects:

1. It is difficult to predict the precise type of a value inside a function, after several operations. The basic operands in an expression tree may for example be `int8` but the end result may be `int64`. Whether this is desirable or not is an open question; it is good for correctness, but potentially bad for performance.

2. In trying to follow the correctness over predictability rule, some values can actually leave the integer realm. For example, `int64 + uint64` is typed `float64` in order to avoid magnitude losses (but incidentally will lose precision on large integer values...), again following Numpy’s semantics for scalars. This is usually not intended by the user.

3. More complicated scenarios can produce unexpected errors at the type unification stage. An example is at Github issue 1299, the gist of which is reproduced here:

```python
@jit(nopython=True)
def f():
    variable = 0
    for i in range(1):
        variable = variable + 1
    return np.arange(variable)
```

At the time of this writing, this fails compiling, on a 64-bit system, with the error:

```
numba.errors.TypingError: Failed at nopython (nopython frontend)
Can't unify types of variable '$48.4': $48.4 := {array(int32, 1d, C), array(int64, ...
˓→1d, C)}
```

People expert with Numba’s type unification system can understand why. But the user is caught in mystery.

**Proposal: predictable width-conserving typing**

We propose to turn the current typing philosophy on its head. Instead of “*start small and grow as required*”, we propose “*start big and keep the width unchanged*”.

Concretely:

1. The typing of Python `int` values used as function arguments doesn’t change, as it works satisfyingly and doesn’t surprise the user.

2. The typing of integer constants (and pseudo-constants) changes to match the typing of integer arguments. That is, every non-explicitly typed integer constant is typed `intptr`, the pointer-sized integer; except for the rare cases where `int64` (on 32-bit systems) or `uint64` is required.

3. Operations on integers promote bitwidth to `intptr`, if smaller, otherwise they don’t promote. For example, on a 32-bit machine, `int8 + int8` is typed `int32`, as is `int32 + int32`. However, `int64 + int64` is typed `int64`.

4. Furthermore, mixed operations between signed and unsigned fall back to signed, while following the same bitwidth rule. For example, on a 32-bit machine, `int8 + uint16` is typed `int32`, as is `uint32 + int32`.

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Proposal impact

Semantics

With this proposal, the semantics become clearer. Regardless of whether the arguments and constants of a function were explicitly typed or not, the results of various expressions at any point in the function have easily predictable types.

When using built-in Python \texttt{int}, the user gets acceptable magnitude (32 or 64 bits depending on the system’s bitness), and the type remains the same across all computations.

When explicitly using smaller bitwidths, intermediate results don’t suffer from magnitude loss, since their bitwidth is promoted to \texttt{intp}.

There is also less potential for annoyances with the type unification system as demonstrated above. The user would have to force several different types to be faced with such an error.

One potential cause for concern is the discrepancy with Numpy’s scalar semantics; but at the same time this brings Numba scalar semantics closer to array semantics (both Numba’s and Numpy’s), which seems a desirable outcome as well.

It is worth pointing out that some sources of integer numbers, such as the \texttt{range()} built-in, always yield 32-bit integers or larger. This proposal could be an opportunity to standardize them on \texttt{intp}.

Performance

Except in trivial cases, it seems unlikely that the current “best fit” behaviour for integer constants really brings a performance benefit. After all, most integers in Numba code would either be stored in arrays (with well-known types, chosen by the user) or be used as indices, where a \texttt{int8} is highly unlikely to fare better than a \texttt{intp} (actually, it may be worse, if LLVM isn’t able to optimize away the required sign-extension).

As a side note, the default use of \texttt{intp} rather than \texttt{int64} ensures that 32-bit systems won’t suffer from poor arithmetic performance.

Implementation

Optimistically, this proposal may simplify some Numba internals a bit. Or, at least, it doesn’t threaten to make them significantly more complicated.

Limitations

This proposal doesn’t really solve the combination of signed and unsigned integers. It is geared mostly at solving the bitwidth issues, which are a somewhat common cause of pain for users. Unsigned integers are in practice very uncommon in Numba-compiled code, except when explicitly asked for, and therefore much less of a pain point.

On the bitwidth front, 32-bit systems could still show discrepancies based on the values of constants: if a constant is too large to fit in 32 bits, it is typed \texttt{int64}, which propagates through other computations. This would be a reminiscence of the current behaviour, but rarer and much more controlled still.
Long-term horizon

While we believe this proposal makes Numba's behaviour more regular and more predictable, it also pulls it further from general compatibility with pure Python semantics, where users can assume arbitrary-precision integers without any truncation issues.

7.1.2 NBEP 7: CUDA External Memory Management Plugins

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Background and goals

The **CUDA Array Interface** enables sharing of data between different Python libraries that access CUDA devices. However, each library manages its own memory distinctly from the others. For example:

- Numba internally manages memory for the creation of device and mapped host arrays.
- The RAPIDS libraries (cuDF, cuML, etc.) use the Rapids Memory Manager for allocating device memory.
- CuPy includes a memory pool implementation for both device and pinned memory.

The goal of this NBEP is to describe a plugin interface that enables Numba's internal memory management to be replaced with an external memory manager by the user. When the plugin interface is in use, Numba no longer directly allocates or frees any memory when creating arrays, but instead requests allocations and frees through the external manager.

Requirements

Provide an **External Memory Manager (EMM)** interface in Numba.

- When the EMM is in use, Numba will make all memory allocation using the EMM. It will never directly call functions such as `CuMemAlloc`, `cuMemFree`, etc.
- When not using an **External Memory Manager (EMM)**, Numba's present behaviour is unchanged (at the time of writing, the current version is the 0.48 release).

If an EMM is to be used, it will entirely replace Numba's internal memory management for the duration of program execution. An interface for setting the memory manager will be provided.

Device vs. Host memory

An EMM will always take responsibility for the management of device memory. However, not all CUDA memory management libraries also support managing host memory, so a facility for Numba to continue the management of host memory whilst ceding control of device memory to the EMM will be provided.
Deallocation strategies

Numba’s internal memory management uses a deallocation strategy designed to increase efficiency by deferring deallocations until a significant quantity are pending. It also provides a mechanism for preventing deallocations entirely during critical sections, using the `defer_cleanup()` context manager.

- When the EMM is not in use, the deallocation strategy and operation of `defer_cleanup` remain unchanged.
- When the EMM is in use, the deallocation strategy is implemented by the EMM, and Numba’s internal deallocation mechanism is not used. For example:
  - A similar strategy to Numba’s could be implemented by the EMM, or
  - Deallocated memory might immediately be returned to a memory pool.
- The `defer_cleanup` context manager may behave differently with an EMM - an EMM should be accompanied by documentation of the behaviour of the `defer_cleanup` context manager when it is in use.
  - For example, a pool allocator could always immediately return memory to a pool even when the context manager is in use, but could choose not to free empty pools until `defer_cleanup` is not in use.

Management of other objects

In addition to memory, Numba manages the allocation and deallocation of events, streams, and modules (a module is a compiled object, which is generated from `@cuda.jit`-ted functions). The management of streams, events, and modules should be unchanged by the presence or absence of an EMM.

Asynchronous allocation / deallocation

An asynchronous memory manager might provide the facility for an allocation or free to take a CUDA stream and execute asynchronously. For freeing, this is unlikely to cause issues since it operates at a layer beneath Python, but for allocations this could be problematic if the user tries to then launch a kernel on the default stream from this asynchronous memory allocation.

The interface described in this proposal will not be required to support asynchronous allocation and deallocation, and as such these use cases will not be considered further. However, nothing in this proposal should preclude the straightforward addition of asynchronous operations in future versions of the interface.

Non-requirements

In order to minimise complexity and constrain this proposal to a reasonable scope, the following will not be supported:

- Using different memory manager implementations for different contexts. All contexts will use the same memory manager implementation - either the Numba internal implementation or an external implementation.
- Changing the memory manager once execution has begun. It is not practical to change the memory manager and retain all allocations. Cleaning up the entire state and then changing to a different memory allocator (rather than starting a new process) appears to be a rather niche use case.
- Any changes to the `__cuda_array_interface__` to further define its semantics, e.g. for acquiring / releasing memory as discussed in Numba Issue #4886 - these are independent, and can be addressed as part of separate proposals.
- Managed memory / UVM is not supported. At present Numba does not support UVM - see Numba Issue #4362 for discussion of support.
Interface for Plugin developers

New classes and functions will be added to `numba.cuda.cudadrv.driver`:

- **BaseCUDAMemoryManager** and **HostOnlyCUDAMemoryManager**: base classes for EMM plugin implementations.
- **set_memory_manager**: a method for registering an external memory manager with Numba.

These will be exposed through the public API, in the `numba.cuda` module. Additionally, some classes that are already part of the `driver` module will be exposed as part of the public API:

- **MemoryPointer**: used to encapsulate information about a pointer to device memory.
- **MappedMemory**: used to hold information about host memory that is mapped into the device address space (a subclass of `MemoryPointer`).
- **PinnedMemory**: used to hold information about host memory that is pinned (a subclass of `mviewbuf.MemAlloc`, a class internal to Numba).

As an alternative to calling the `set_memory_manager` function, an environment variable can be used to set the memory manager. The value of the environment variable should be the name of the module containing the memory manager in its global scope, named `_numba_memory_manager`:

```
export NUMBA_CUDA_MEMORY_MANAGER="<module>"
```

When this variable is set, Numba will automatically use the memory manager from the specified module. Calls to `set_memory_manager` will issue a warning, but otherwise be ignored.

Plugin Base Classes

An EMM plugin is implemented by inheriting from the **BaseCUDAMemoryManager** class, which is defined as:

```python
class BaseCUDAMemoryManager(object, metaclass=ABCMeta):
    @abstractmethod
def memalloc(self, size):
        ""
        Allocate on-device memory in the current context. Arguments:
        - `size`: Size of allocation in bytes
        Returns: a `MemoryPointer` to the allocated memory.
        ""

    @abstractmethod
def memhostalloc(self, size, mapped, portable, wc):
        ""
        Allocate pinned host memory. Arguments:
        - `size`: Size of the allocation in bytes
        - `mapped`: Whether the allocated memory should be mapped into the CUDA address space.
        - `portable`: Whether the memory will be considered pinned by all contexts, and not just the calling context.
        - `wc`: Whether to allocate the memory as write-combined.
```
Returns a `MappedMemory` or `PinnedMemory` instance that owns the allocated memory, depending on whether the region was mapped into device memory.

```
@abstractmethod
def mempin(self, owner, pointer, size, mapped):
    
    Pin a region of host memory that is already allocated. Arguments:
    - `owner`: An object owning the memory - e.g. a `DeviceNDArray`.
    - `pointer`: The pointer to the beginning of the region to pin.
    - `size`: The size of the region to pin.
    - `mapped`: Whether the region should also be mapped into device memory.

    Returns a `MappedMemory` or `PinnedMemory` instance that refers to the allocated memory, depending on whether the region was mapped into device memory.
```

```
@abstractmethod
def initialize(self):
    
    Perform any initialization required for the EMM plugin to be ready to use.
```

```
@abstractmethod
def get_memory_info(self):
    
    Returns (free, total) memory in bytes in the context
```

```
@abstractmethod
def get_ipc_handle(self, memory):
    
    Return an `IpcHandle` from a GPU allocation. Arguments:
    - `memory`: A `MemoryPointer` for which the IPC handle should be created.
```

```
@abstractmethod
def reset(self):
    
    Clear up all memory allocated in this context.
```

```
@abstractmethod
def defer_cleanup(self):
    
    Returns a context manager that ensures the implementation of deferred cleanup whilst it is active.
```

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@property
@abstractmethod
def interface_version(self):
    
    Returns an integer specifying the version of the EMM Plugin interface
    supported by the plugin implementation. Should always return 1 for
    implementations described in this proposal.

All of the methods of an EMM plugin are called from within Numba - they never need to be invoked directly by a
Numba user.

The initialize method is called by Numba prior to any memory allocations being requested. This gives the EMM
an opportunity to initialize any data structures, etc., that it needs for its normal operations. The method may be called
multiple times during the lifetime of the program - subsequent calls should not invalidate or reset the state of the EMM.

The memalloc, memhostalloc, and mempin methods are called when Numba requires an allocation of device or host
memory, or pinning of host memory. Device memory should always be allocated in the current context.

get_ipc_handle is called when an IPC handle for an array is required. Note that there is no method for closing an
IPC handle - this is because the IpcHandle object constructed by get_ipc_handle contains a close() method as
part of its definition in Numba, which closes the handle by calling cuIpcCloseMemHandle. It is expected that this
is sufficient for general use cases, so no facility for customising the closing of IPC handles is provided by the EMM
Plugin interface.

get_memory_info may be called at any time after initialize.

reset is called as part of resetting a context. Numba does not normally call reset spontaneously, but it may be called
at the behest of the user. Calls to reset may even occur before initialize is called, so the plugin should be robust
against this occurrence.

defer_cleanup is called when the numba.cuda.defer_cleanup context manager is used from user code.

interface_version is called by Numba when the memory manager is set, to ensure that the version of the interface
implemented by the plugin is compatible with the version of Numba in use.

**Representing pointers**

**Device Memory**

The MemoryPointer class is used to represent a pointer to memory. Whilst there are various details of its implementa-
tion, the only aspect relevant to EMM plugin development is its initialization. The __init__ method has the following
interface:

```python
class MemoryPointer:
    def __init__(self, context, pointer, size, owner=None, finalizer=None):
```

- **context**: The context in which the pointer was allocated.
- **pointer**: A ctypes pointer (e.g. ctypes.c_uint64) holding the address of the memory.
- **size**: The size of the allocation in bytes.
- **owner**: The owner is sometimes set by the internals of the class, or used for Numba’s internal memory manage-
  ment, but need not be provided by the writer of an EMM plugin - the default of None should always suffice.
• **finalizer**: A method that is called when the last reference to the `MemoryPointer` object is released. Usually this will make a call to the external memory management library to inform it that the memory is no longer required, and that it could potentially be freed (though the EMM is not required to free it immediately).

### Host Memory

Memory mapped into the CUDA address space (which is created when the `memhostalloc` or `mempin` methods are called with `mapped=True`) is managed using the `MappedMemory` class:

```python
class MappedMemory(AutoFreePointer):
    def __init__(self, context, pointer, size, owner, finalizer=None):
        # context: The context in which the pointer was allocated.
        # pointer: A ctypes pointer (e.g. ctypes.c_void_p) holding the address of the allocated memory.
        # size: The size of the allocated memory in bytes.
        # owner: A Python object that owns the memory, e.g. a DeviceNDArray instance.
        # finalizer: A method that is called when the last reference to the MappedMemory object is released. For example, this method could call `cuMemFreeHost` on the pointer to deallocate the memory immediately.
```

Note that the inheritance from `AutoFreePointer` is an implementation detail and need not concern the developer of an EMM plugin - `MemoryPointer` is higher in the MRO of `MappedMemory`.

Memory that is only in the host address space and has been pinned is represented with the `PinnedMemory` class:

```python
class PinnedMemory(mviewbuf.MemAlloc):
    def __init__(self, context, pointer, size, owner, finalizer=None):
        # context: The context in which the pointer was allocated.
        # pointer: A ctypes pointer (e.g. ctypes.c_void_p) holding the address of the pinned memory.
        # size: The size of the pinned region in bytes.
        # owner: A Python object that owns the memory, e.g. a DeviceNDArray instance.
        # finalizer: A method that is called when the last reference to the PinnedMemory object is released. This method could e.g. call `cuMemHostUnregister` on the pointer to unpin the memory immediately.
```

### Providing device memory management only

Some external memory managers will support management of on-device memory but not host memory. To make it easy to implement an EMM plugin using one of these managers, Numba will provide a memory manager class with implementations of the `memhostalloc` and `mempin` methods. An abridged definition of this class follows:

```python
class HostOnlyCUDAMemoryManager(BaseCUDAMemoryManager):
    # Unimplemented methods:
    #
    # - memalloc
    # - get_memory_info

    def memhostalloc(self, size, mapped, portable, wc):
        # Implemented.
```

(continues on next page)
A class can subclass the `HostOnlyCUDAMemoryManager` and then it only needs to add implementations of methods for on-device memory. Any subclass must observe the following rules:

- If the subclass implements `__init__`, then it must also call `HostOnlyCUDAMemoryManager.__init__`, as this is used to initialize some of its data structures (`self.allocations` and `self.deallocations`).
- The subclass must implement `memalloc` and `get_memory_info`.
- The `initialize` and `reset` methods perform initialisation of structures used by the `HostOnlyCUDAMemoryManager`.
  - If the subclass has nothing to do on initialisation (possibly) or reset (unlikely) then it need not implement these methods.
  - However, if it does implement these methods then it must also call the methods from `HostOnlyCUDAMemoryManager` in its own implementations.
- Similarly if `defer_cleanup` is implemented, it should enter the context provided by `HostOnlyCUDAManager.defer_cleanup()` prior to yielding (or in the `__enter__` method) and release it prior to exiting (or in the `__exit__` method).

**Import order**

The order in which Numba and the library implementing an EMM Plugin should not matter. For example, if `rmm` were to implement and register an EMM Plugin, then:

```python
from numba import cuda
import rmm
```

and

```python
import rmm
from numba import cuda
```
are equivalent - this is because Numba does not initialize CUDA or allocate any memory until the first call to a CUDA function - neither instantiating and registering an EMM plugin, nor importing numba.cuda causes a call to a CUDA function.

Numba as a Dependency

Adding the implementation of an EMM Plugin to a library naturally makes Numba a dependency of the library where it may not have been previously. In order to make the dependency optional, if this is desired, one might conditionally instantiate and register the EMM Plugin like:

```python
try:
    import numba
    from mylib.numba_utils import MyNumbaMemoryManager
    numba.cuda.cudadrv.driver.set_memory_manager(MyNumbaMemoryManager)
except:
    print("Numba not importable - not registering EMM Plugin")
```

so that mylib.numba_utils, which contains the implementation of the EMM Plugin, is only imported if Numba is already present. If Numba is not available, then mylib.numba_utils (which necessarily imports numba), will never be imported.

It is recommended that any library with an EMM Plugin includes at least some environments with Numba for testing with the EMM Plugin in use, as well as some environments without Numba, to avoid introducing an accidental Numba dependency.

Example implementation - A RAPIDS Memory Manager (RMM) Plugin

An implementation of an EMM plugin within the Rapids Memory Manager (RMM) is sketched out in this section. This is intended to show an overview of the implementation in order to support the descriptions above and to illustrate how the plugin interface can be used - different choices may be made for a production-ready implementation.

The plugin implementation consists of additions to python/rmm/rmm.py:

```python
# New imports:
from contextlib import context_manager
# RMM already has Numba as a dependency, so these imports need not be guarded
# by a check for the presence of numba.
from numba.cuda import (HostOnlyCUDAMemoryManager, MemoryPointer, IpcHandle, set_memory_manager)

# New class implementing the EMM Plugin:
class RMMNumbaManager(HostOnlyCUDAMemoryManager):
    def memalloc(self, size):
        # Allocates device memory using RMM functions. The finalizer for the
        # allocated memory calls back to RMM to free the memory.
        addr = librmm.rmm_alloc(bytesize, 0)
        ctx = cuda.current_context()
        ptr = ctypes.c_uint64(int(addr))
        finalizer = _make_finalizer(addr, stream)
        return MemoryPointer(ctx, ptr, size, finalizer=finalizer)

    def get_ipc_handle(self, memory):
```

(continues on next page)
Get an IPC handle for the memory with offset modified by the RMM memory pool.

This implementation provides a functional implementation and illustrates what get_ipc_handle needs to do, but it is not a very "clean" implementation, and it relies on borrowing bits of Numba internals to initialise ipchandle.

A more polished implementation might make use of additional functions in the RMM C++ layer for initialising IPC handles, and not use any Numba internals.

```python
ipchandle = (ctypes.c_byte * 64)()  # IPC handle is 64 bytes
cuda.cudadrv.memory.driver_funcs.cuIpcMemGetHandle(
    ctypes.byref(ipchandle),
    memory.owner.handle,
)
source_info = cuda.current_context().device.get_device_identity()
ptr = memory.device_ctypes_pointer.value
offset = librmm.rmm_get_allocation_offset(ptr, 0)
return IpcHandle(memory, ipchandle, memory.size, source_info,
                  offset=offset)
```

```python
def get_memory_info(self):
    # Returns a tuple of (free, total) using RMM functionality.
    return get_info()  # Function defined in rmm.py

def initialize(self):
    # Nothing required to initialize RMM here, but this method is added
    # to illustrate that the super() method should also be called.
    super().initialize()

@contextmanager
def defer_cleanup(self):
    # Does nothing to defer cleanup - a full implementation may choose to
    # implement a different policy.
    with super().defer_cleanup():
        yield

@property
def interface_version(self):
    # As required by the specification
    return 1
```

The existing _make_finalizer function is used by RMMNumbaManager:

```python
def _make_finalizer(handle, stream):
    """
    Factory to make the finalizer function.
    We need to bind "handle" and "stream" into the actual finalizer, which
takes no args.
    """
```
def finalizer():
    
    Invoked when the MemoryPointer is freed
    
    librmm.rmm_free(handle, stream)

    return finalizer

# Utility function register `RMMNumbaManager` as an EMM:
def use_rmm_for_numba():
    set_memory_manager(RMMNumbaManager)

# To support `NUMBA_CUDA_MEMORY_MANAGER=rmm`:
_numba_memory_manager = RMMNumbaManager

Example usage

A simple example that configures Numba to use RMM for memory management and creates a device array is as follows:

```python
# example.py
import rmm
import numpy as np
from numba import cuda
rmm.use_rmm_for_numba()
a = np.zeros(10)
d_a = cuda.to_device(a)
del(d_a)
print(rmm.csv_log())
```

Running this should result in output similar to the following:

```
Event Type,Device ID,Address,Stream,Size (bytes),Free Memory,Total Memory,Current Allocs,Start,End,Elapsed,Location
Alloc,0,0x7fae06600000,0,80,0,0,1,1.10549,1.1074,0.00191666,<path>/numba/numba/cuda/__cudadrv/driver.py:683
Free,0,0x7fae06600000,0,0,0,0,0,1.10798,1.10921,0.00122238,<path>/numba/numba/utils.py:678
```

Note that there is some scope for improvement in RMM for detecting the line number at which the allocation / free occurred, but this is outside the scope of the example in this proposal.

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Setting the memory manager through the environment

Rather than calling `rmm.use_rmm_for_numba()` in the example above, the memory manager could also be set to use RMM globally with an environment variable, so the Python interpreter is invoked to run the example as:

```
NUMBA_CUDA_MEMORY_MANAGER="rmm.RMMNumbaManager" python example.py
```

Numba internal changes

This section is intended primarily for Numba developers - those with an interest in the external interface for implementing EMM plugins may choose to skip over this section.

Current model / implementation

At present, memory management is implemented in the `Context` class. It maintains lists of allocations and deallocations:

- `allocations` is a `numba.core.utils.UniqueDict`, created at context creation time.
- `deallocations` is an instance of the `_PendingDeallocs` class, and is created when `Context.prepare_for_use()` is called.

These are used to track allocations and deallocations of:

- Device memory
- Pinned memory
- Mapped memory
- Streams
- Events
- Modules

The `_PendingDeallocs` class implements the deferred deallocation strategy - cleanup functions (such as `cuMemFree`) for the items above are added to its list of pending deallocations by the finalizers of objects representing allocations. These finalizers are run when the objects owning them are garbage-collected by the Python interpreter. When the addition of a new cleanup function to the deallocation list causes the number or size of pending deallocations to exceed a configured ratio, the `_PendingDeallocs` object runs deallocators for all items it knows about and then clears its internal pending list.

See `Deallocation Behavior` for more details of this implementation.

Proposed changes

This section outlines the major changes that will be made to support the EMM plugin interface - there will be various small changes to other parts of Numba that will be required in order to adapt to these changes; an exhaustive list of these is not provided.
Context changes

The `numba.cuda.cudadrv.driver.Context` class will no longer directly allocate and free memory. Instead, the context will hold a reference to a memory manager instance, and its memory allocation methods will call into the memory manager, e.g.:

```python
def memalloc(self, size):
    return self.memory_manager.memalloc(size)

def memhostalloc(self, size, mapped=False, portable=False, wc=False):
    return self.memory_manager.memhostalloc(size, mapped, portable, wc)

def mempin(self, owner, pointer, size, mapped=False):
    if mapped and not self.device.CAN_MAP_HOST_MEMORY:
        raise CudaDriverError("%s cannot map host memory" % self.device)
    return self.memory_manager.mempin(owner, pointer, size, mapped)

def prepare_for_use(self):
    self.memory_manager.initialize()

def get_memory_info(self):
    self.memory_manager.get_memory_info()

def get_ipc_handle(self, memory):
    return self.memory_manager.get_ipc_handle(memory)

def reset(self):
    # ... Already-extant reset logic, plus:
    self._memory_manager.reset()
```

The `memory_manager` member is initialised when the context is created.

The `mempin` method (not shown above but currently exists in the `Context` class) has never been implemented - it presently raises a `NotImplementedError`. This method arguably un-needed - pinned memory is immediately unpinned by its finalizer, and unpinning before a finalizer runs would invalidate the state of `PinnedMemory` objects for which references are still held. It is proposed that this is removed when making the other changes to the `Context` class.

The `Context` class will still instantiate `self.allocations` and `self.deallocations` as before - these will still be used by the context to manage the allocations and deallocations of events, streams, and modules, which are not handled by the EMM plugin.

New components of the driver module

- `BaseCUDAMemoryManager`: An abstract class, as defined in the plugin interface above.
- `HostOnlyCUDAMemoryManager`: A subclass of `BaseCUDAMemoryManager`, with the logic from `Context`. `memhostalloc` and `Context.mempin` moved into it. This class will also create its own `allocations` and `deallocations` members, similarly to how the `Context` class creates them. These are used to manage the allocations and deallocations of pinned and mapped host memory.
- `NumbaCUDAMemoryManager`: A subclass of `HostOnlyCUDAMemoryManager`, which also contains an implementation of `memalloc` based on that presently existing in the `Context` class. This is the default memory manager, and its use preserves the behaviour of Numba prior to the addition of the EMM plugin interface - that is, all memory allocation and deallocation for Numba arrays is handled within Numba.
This class shares the allocations and deallocations members with its parent class HostOnlyCUDAMemoryManager, and it uses these for the management of device memory that it allocates.

- The set_memory_manager function, which sets a global pointing to the memory manager class. This global initially holds NumbaCUDAMemoryManager (the default).

### Staged IPC

Staged IPC should not take ownership of the memory that it allocates. When the default internal memory manager is in use, the memory allocated for the staging array is already owned. When an EMM plugin is in use, it is not legitimate to take ownership of the memory.

This change can be made by applying the following small patch, which has been tested to have no effect on the CUDA test suite:

```diff
diff --git a/numba/cuda/cudadrv/driver.py b/numba/cuda/cudadrv/driver.py
index 7832955..f2c1352 100644
--- a/numba/cuda/cudadrv/driver.py
+++ b/numba/cuda/cudadrv/driver.py
@@ -922,7 +922,11 @@ class _StagedIpcImpl(object):
     with cuda.gpus[srcdev.id]:
         impl.close()
-    return newmem.own()
+    return newmem
```

### Testing

Alongside the addition of appropriate tests for new functionality, there will be some refactoring of existing tests required, but these changes are not substantial. Tests of the deallocation strategy (e.g. TestDeallocation, TestDeferCleanup) will need to be modified to ensure that they are examining the correct set of deallocations. When an EMM plugin is in use, they will need to be skipped.

### Prototyping / experimental implementation

Some prototype / experimental implementations have been produced to guide the designs presented in this document. The current implementations can be found in:

  - See CuPy memory management docs.
Current implementation status

RMM Plugin

For a minimal example, a simple allocation and free using RMM works as expected. For the example code (similar to the RMM example above):

```python
import rmm
import numpy as np
from numba import cuda
rmm.use_rmm_for_numba()
a = np.zeros(10)
d_a = cuda.to_device(a)
deleted
print(rmm.csv_log())
```

We see the following output:

```
Event Type,Device ID,Address,Stream,Size (bytes),Free Memory,Total Memory,Current Allocs,Start,End,Elapsed,Location
Alloc,0,0x7f96c7400000,0,80,0,0,1,1.13396,1.13576,0.00180059,<path>/numba/numba/cuda/
cudadrv/driver.py:686
Free,0,0x7f96c7400000,0,0,0,0,1.13628,1.13723,0.000956004,<path>/numba/numba/utils.
py:678
```

This output is similar to the expected output from the example usage presented above (though note that the pointer addresses and timestamps vary compared to the example), and provides some validation of the example use case.

CuPy Plugin

```python
from nbep7.cupy_mempool import use_cupy_mm_for_numba
import numpy as np
from numba import cuda
use_cupy_mm_for_numba()
a = np.zeros(10)
d_a = cuda.to_device(a)
deleted
```

The prototype CuPy plugin has somewhat primitive logging, so we see the output:

```
Allocated 80 bytes at 7f004d400000
Freeing 80 bytes at 7f004d400000
```
Numba CUDA Unit tests

As well as providing correct execution of a simple example, all relevant Numba CUDA unit tests also pass with the prototype branch, for both the internal memory manager and the RMM EMM Plugin.

**RMM**

The unit test suite can be run with the RMM EMM Plugin with:

```
NUMBA_CUDA_MEMORY_MANAGER=rmm python -m numba.runtests numba.cuda.tests
```

A summary of the unit test suite output is:

```
Ran 564 tests in 142.211s
OK (skipped=11)
```

When running with the built-in Numba memory management, the output is:

```
Ran 564 tests in 133.396s
OK (skipped=5)
```

i.e. the changes for using an external memory manager do not break the built-in Numba memory management. There are an additional 6 skipped tests, from:

- TestDeallocation: skipped as it specifically tests Numba's internal deallocation strategy.
- TestDeferCleanup: skipped as it specifically tests Numba's implementation of deferred cleanup.
- TestCudaArrayInterface.test_ownership: skipped as Numba does not own memory when an EMM Plugin is used, but ownership is assumed by this test case.

**CuPy**

The test suite can be run with the CuPy plugin using:

```
NUMBA_CUDA_MEMORY_MANAGER=nbep7.cupy_mempool python -m numba.runtests numba.cuda.tests
```

This plugin implementation is presently more primitive than the RMM implementation, and results in some errors with the unit test suite:

```
Ran 564 tests in 111.699s
FAILED (errors=8, skipped=11)
```

The 8 errors are due to a lack of implementation of `get_ipc_handle` in the CuPy EMM Plugin implementation. It is expected that this implementation will be re-visited and completed so that CuPy can be used stably as an allocator for Numba in the future.
7.2 Other proposals

7.2.1 NBEP 2: Extension points

Author Antoine Pitrou
Date July 2015
Status Draft

Implementing new types or functions in Numba requires hooking into various mechanisms along the compilation chain (and potentially outside of it). This document aims, first, at examining the current ways of doing so and, second, at making proposals to make extending easier.

If some of the proposals are implemented, we should first strive to use and exercise them internally, before exposing the APIs to the public.

Note: This document doesn’t cover CUDA or any other non-CPU backend.

High-level API

There is currently no high-level API, making some use cases more complicated than they should be.

Proposed changes

Dedicated module

We propose the addition of a `numba.extending` module exposing the main APIs useful for extending Numba.

Implementing a function

We propose the addition of a `@overload` decorator allowing the implementation of a given function for use in `nopython mode`. The overloading function has the same formal signature as the implemented function, and receives the actual argument types. It should return a Python function implementing the overloaded function for the given types.

The following example implements `numpy.where()` with this approach.

```python
import numpy as np

from numba.core import types
from numba.extending import overload

@overload(np.where)
def where(cond, x, y):
    """
    Implement np.where().
    """
    # Choose implementation based on argument types.
    if isinstance(cond, types.Array):
        # Array where() => return an array of the same shape
```

(continues on next page)
if all(ty.layout == 'C' for ty in (cond, x, y)):
def where_impl(cond, x, y):
    
    Fast implementation for C-contiguous arrays
    
    shape = cond.shape
    if x.shape != shape or y.shape != shape:
        raise ValueError("all inputs should have the same shape")
    res = np.empty_like(x)
    cf = cond.flat
    xf = x.flat
    yf = y.flat
    rf = res.flat
    for i in range(cond.size):
        rf[i] = xf[i] if cf[i] else yf[i]
    return res
else:
def where_impl(cond, x, y):
    
    Generic implementation for other arrays
    
    shape = cond.shape
    if x.shape != shape or y.shape != shape:
        raise ValueError("all inputs should have the same shape")
    res = np.empty_like(x)
    for idx, c in np.ndenumerate(cond):
        res[idx] = x[idx] if c else y[idx]
    return res
else:
def where_impl(cond, x, y):
    
    Scalar where() => return a 0-dim array
    
    scal = x if cond else y
    return np.full_like(scal, scal)

return where_impl

It is also possible to implement functions already known to Numba, to support additional types. The following example implements the built-in function `len()` for tuples with this approach:

```python
@overload(len)
def tuple_len(x):
    if isinstance(x, types.BaseTuple):
        # The tuple length is known at compile-time, so simply reify it
        # as a constant.
        n = len(x)
        def len_impl(x):
            return n
        return len_impl
```
Implementing an attribute

We propose the addition of a `@overload_attribute` decorator allowing the implementation of an attribute getter for use in `nopython mode`.

The following example implements the `.nbytes` attribute on Numpy arrays:

```python
@overload_attribute(types.Array, 'nbytes')
def array_nbytes(arr):
    def get(arr):
        return arr.size * arr.itemsize
    return get
```

Note: The overload_attribute() signature allows for expansion to also define setters and deleters, by letting the decorated function return a `getter, setter, deleter` tuple instead of a single `getter`.

Implementing a method

We propose the addition of a `@overload_method` decorator allowing the implementation of an instance method for use in `nopython mode`.

The following example implements the `.take()` method on Numpy arrays:

```python
@overload_method(types.Array, 'take')
def array_take(arr, indices):
    if isinstance(indices, types.Array):
        def take_impl(arr, indices):
            n = indices.shape[0]
            res = np.empty(n, arr.dtype)
            for i in range(n):
                res[i] = arr[indices[i]]
            return res
        return take_impl
    return take
```

Exposing a structure member

We propose the addition of a `make_attribute_wrapper()` function exposing an internal field as a visible read-only attribute, for those types backed by a `StructModel` data model.

For example, assuming `PdIndexType` is the Numba type of pandas indices, here is how to expose the underlying Numpy array as a `.data` attribute:

```python
@register_model(PdIndexType)
class PdIndexModel(models.StructModel):
    def __init__(self, dmm, fe_type):
        members = [
            ('values', fe_type.as_array),
        ]
        models.StructModel.__init__(self, dmm, fe_type, members)

make_attribute_wrapper(PdIndexType, 'values', '_data')
```
Typing

Numba types

Numba’s standard types are declared in `numba.types`. To declare a new type, one subclasses the base `Type` class or one of its existing abstract subclasses, and implements the required functionality.

Proposed changes

No change required.

Type inference on values

Values of a new type need to be type-inferred if they can appear as function arguments or constants. The core machinery is in `numba.typing.typeof`.

In the common case where some Python class or classes map exclusively to the new type, one can extend a generic function to dispatch on said classes, e.g.:

```python
from numba.typing.typeof import typeof_impl

@typeof_impl(MyClass)
def _typeof_myclass(val, c):
  if "some condition":
    return MyType(...)
```

The `typeof_impl` specialization must return a Numba type instance, or None if the value failed typing.

(when one controls the class being type-inferred, an alternative to `typeof_impl` is to define a `_numba_type_` property on the class)

In the rarer case where the new type can denote various Python classes that are impossible to enumerate, one must insert a manual check in the fallback implementation of the `typeof_impl` generic function.

Proposed changes

Allow people to define a generic hook without monkeypatching the fallback implementation.

Fast path for type inference on function arguments

Optionally, one may want to allow a new type to participate in the fast type resolution (written in C code) to minimize function call overhead when a JIT-compiled function is called with the new type. One must then insert the required checks and implementation in the `_typeof.c` file, presumably inside the `compute_fingerprint()` function.
Proposed changes

None. Adding generic hooks to C code embedded in a C Python extension is too delicate a change.

Type inference on operations

Values resulting from various operations (function calls, operators, etc.) are typed using a set of helpers called “templates”. One can define a new template by subclassing one of the existing base classes and implement the desired inference mechanism. The template is explicitly registered with the type inference machinery using a decorator.

The `ConcreteTemplate` base class allows one to define inference as a set of supported signatures for a given operation. The following example types the modulo operator:

```python
@builtin
class BinOpMod(ConcreteTemplate):
    key = "%"
    cases = [signature(op, op, op)
             for op in sorted(types.signed_domain)]
    cases += [signature(op, op, op)
              for op in sorted(types.unsigned_domain)]
    cases += [signature(op, op, op) for op in sorted(types.real_domain)]
```

(note that type instances are used in the signatures, severely limiting the amount of genericity that can be expressed)

The `AbstractTemplate` base class allows to define inference programmatically, giving it full flexibility. Here is a simplistic example of how tuple indexing (i.e. the `__getitem__` operator) can be expressed:

```python
@builtin
class GetItemUniTuple(AbstractTemplate):
    key = "getitem"
    def generic(self, args, kws):
        tup, idx = args
        if isinstance(tup, types.UniTuple) and isinstance(idx, types.Integer):
            return signature(tup.dtype, tup, idx)
```

The `AttributeTemplate` base class allows to type the attributes and methods of a given type. Here is an example, typing the `.real` and `.imag` attributes of complex numbers:

```python
@builtin_attr
class ComplexAttribute(AttributeTemplate):
    key = types.Complex
    def resolve_real(self, ty):
        return ty.underlying_float
    def resolve_imag(self, ty):
        return ty.underlying_float
```

Note: `AttributeTemplate` only works for getting attributes. Setting an attribute’s value is hardcoded in `numba.typeinfer`.

7.2. Other proposals 611
The CallableTemplate base class offers an easier way to parse flexible function signatures, by letting one define a callable that has the same definition as the function being typed. For example, here is how one could hypothetically type Python's `sorted` function if Numba supported lists:

```python
@builtin
class Sorted(CallableTemplate):
    key = sorted

    def generic(self):
        def typer(iterable, key=None, reverse=None):
            if reverse is not None and not isinstance(reverse, types.Boolean):
                return
            if key is not None and not isinstance(key, types.Callable):
                return
            if not isinstance(iterable, types.Iterable):
                return
            return types.List(iterable.iterator_type.yield_type)

        return typer
```

(note you can return just the function's return type instead of the full signature)

### Proposed changes

Naming of the various decorators is quite vague and confusing. We propose renaming `@builtin` to `@infer`, `@builtin_attr` to `@infer_getattr` and `builtin_global` to `infer_global`.

The two-step declaration for global values is a bit verbose, we propose simplifying it by allowing the use of `infer_global` as a decorator:

```python
@infer_global(len)
class Len(AbstractTemplate):
    key = len

    def generic(self, args, kws):
        assert not kws
        (val,) = args
        if isinstance(val, (types.Buffer, types.BaseTuple)):
            return signature(types.intp, val)
```

The class-based API can feel clumsy, we can add a functional API for some of the template kinds:

```python
@type_callable(sorted)
def type_sorted(context):
    def typer(iterable, key=None, reverse=None):
        # [same function as above]

        return typer
```
Code generation

Concrete representation of values of a Numba type

Any concrete Numba type must be able to be represented in LLVM form (for variable storage, argument passing, etc.). One defines that representation by implementing a datamodel class and registering it with a decorator. Datamodel classes for standard types are defined in numba.datamodel.models.

Proposed changes

No change required.

Conversion between types

Implicit conversion between Numba types is currently implemented as a monolithic sequence of choices and type checks in theBaseContext.cast() method. To add a new implicit conversion, one appends a type-specific check in that method.

Boolean evaluation is a special case of implicit conversion (the destination type being types.Boolean).

Note: Explicit conversion is seen as a regular operation, e.g. a constructor call.

Proposed changes

Add a generic function for implicit conversion, with multiple dispatch based on the source and destination types. Here is an example showing how to write a float-to-integer conversion:

```python
@lower_cast(types.Float, types.Integer)
def float_to_integer(context, builder, fromty, toty, val):
    lty = context.get_value_type(toty)
    if toty.signed:
        return builder.fptosi(val, lty)
    else:
        return builder.fptoui(val, lty)
```

Implementation of an operation

Other operations are implemented and registered using a set of generic functions and decorators. For example, here is how lookup for the .ndim attribute on Numpy arrays is implemented:

```python
@builtin_attr
@impl_attribute(types.Kind(types.Array), "ndim", types.intp)
def array_ndim(context, builder, typ, value):
    return context.get_constant(types.intp, typ.ndim)
```

And here is how calling len() on a tuple value is implemented:
@builtin  
@implement(types.len_type, types.Kind(types.BaseTuple))  
def tuple_len(context, builder, sig, args):
    tupty, = sig.args  
    retty = sig.return_type  
    return context.get_constant(retty, len(tupty.types))

**Proposed changes**

Review and streamline the API. Drop the requirement to write `types.Kind(...)` explicitly. Remove the separate `@implement` decorator and rename `@builtin` to `@lower_builtin`, `@builtin_attr` to `@lower_getattr`, etc.

Add decorators to implement `setattr()` operations, named `@lower_setattr` and `@lower_setattr_generic`.

**Conversion from / to Python objects**

Some types need to be converted from or to Python objects, if they can be passed as function arguments or returned from a function. The corresponding boxing and unboxing operations are implemented using a generic function. The implementations for standard Numba types are in `numba.targets.boxing`. For example, here is the boxing implementation for a boolean value:

@box(types.Boolean)
def box_bool(c, typ, val):
    longval = c.builder.zext(val, c.pyapi.long)
    return c.pyapi.bool_from_long(longval)

**Proposed changes**

Change the implementation signature from `(c, typ, val)` to `(typ, val, c)`, to match the one chosen for the `typeof_impl` generic function.

### 7.2.2 NBEP 3: JIT Classes

**Author**  Siu Kwan Lam  
**Date**  Dec 2015  
**Status**  Draft

**Introduction**

Numba does not yet support user-defined classes. Classes provide useful abstraction and promote modularity when used right. In the simplest sense, a class specifies the set of data and operations as attributes and methods, respectively. A class instance is an instantiation of that class. This proposal will focus on supporting this simple usecase of classes—with just attributes and methods. Other features, such as class methods, static methods, and inheritance are deferred to another proposal, but we believe these features can be easily implemented given the foundation described here.
Proposal: jit-classes

A JIT-classes is more restricted than a Python class. We will focus on the following operations on a class and its instance:

- Instantiation: create an instance of a class using the class object as the constructor: `cls(*args, **kwargs)`
- Destruction: remove resources allocated during instantiation and release all references to other objects.
- Attribute access: loading and storing attributes using `instance.attr` syntax.

With these operations, a class object (not the instance) does not need to be materialize. Using the class object as a constructor is fully resolved (a runtime implementation is picked) during the typing phase in the compiler. This means a class object will not be first class. On the other hand, implementing a first-class class object will require an “interface” type, or the type of class.

The instantiation of a class will allocate resources for storing the data attributes. This is described in the “Storage model” section. Methods are never stored in the instance. They are information attached to the class. Since a class object only exists in the type domain, the methods will also be fully resolved at the typing phase. Again, numba do not have first-class function value and each function type maps uniquely to each function implementation (this needs to be changed to support function value as argument).

A class instance can contain other NRT reference-counted object as attributes. To properly clean up an instance, a destructor is called when the reference count of the instance is dropped to zero. This is described in the “Reference count and destructor” section.

Storage model

For compatibility with C, attributes are stored in a simple plain-old-data structure. Each attribute are stored in a user-defined order in a padded (for proper alignment), contiguous memory region. An instance that contains three fields of int32, float32, complex64 will be compatible with the following C structure:

```c
struct {
    int32   field0;
    float32 field1;
    complex64 field2;
};
```

This will also be comptabile with an aligned numpy structure dtype.

Methods

Methods are regular function that can be bounded to an instance. They can be compiled as regular function by numba. The operation `getattr(instance, name)` (getting an attribute `name` from instance) binds the instance to the requested method at runtime.

The special `__init__` method is also handled like regular functions.

`__del__` is not supported at this time.
Reference count and destructor

An instance of jit-class is reference-counted by NRT. Since it may contain other NRT tracked object, it must call a destructor when its reference count dropped to zero. The destructor will decrement the reference count of all attributes by one.

At this time, there is no support for user defined `__del__` method.

Proper cleanup for cyclic reference is not handled at this time. Cycles will cause memory leak.

Type inference

So far we have not described the type of the attributes or the methods. Type information is necessary to materialize the instance (e.g. allocate the storage). The simplest way is to let user provide the type of each attributes as well as the ordering; for instance:

```python
dct = OrderedDict()
dct['x'] = int32
dct['y'] = float32
```

Allowing user to supply an ordered dictionary will provide the name, ordering and types of the attributes. However, this statically typed semantic is not as flexible as the Python semantic which behaves like a generic class.

Inferring the type of attributes is difficult. In a previous attempt to implement JIT classes, the `__init__` method is specialized to capture the type stored into the attributes. Since the method can contain arbitrary logic, the problem can become a dependent typing problem if types are assigned conditionally depending on the value. (Very few languages implement dependent typing and those that does are mostly theorem provers.)

Example: typing function using an OrderedDict

```python
spec = OrderedDict()
spec['x'] = numba.int32
spec['y'] = numba.float32

@jitclass(spec)
class Vec(object):
    def __init__(self, x, y):
        self.x = x
        self.y = y

    def add(self, dx, dy):
        self.x += dx
        self.y += dy
```
## Example: typing function using a list of 2-tuples

```python
spec = [('x', numba.int32),
        ('y', numba.float32)]

@jitclass(spec)
class Vec(object):
    ...
```

### Creating multiple jitclasses from a single class object

The `jitclass(spec)` decorator creates a new jitclass type even when applied to the same class object and the same type specification.

```python
class Vec(object):
    ...
Vec1 = jitclass(spec)(Vec)
Vec2 = jitclass(spec)(Vec)
# Vec1 and Vec2 are two different jitclass types
```

### Usage from the Interpreter

When constructing a new instance of a jitclass, a “box” is created that wraps the underlying jitclass instance from numba. Attributes and methods are accessible from the interpreter. The actual implementation will be in numba compiled code. Any Python object is converted to its native representation for consumption in numba. Similarly, the returned value is converted to its Python representation. As a result, there may be overhead in manipulating jitclass instances in the interpreter. This overhead is minimal and should be easily amortized by more efficient computation in the compiled methods.

### Support for property, staticmethod and classmethod

The use of `property` is accepted for getter and setter only. Deleter is not supported.

The use of `staticmethod` is not supported.

The use of `classmethod` is not supported.

### Inheritance

Class inheritance is not considered in this proposal. The only accepted base class for a jitclass is `object`.  

---

7.2. Other proposals
Supported targets

Only the CPU target (including the parallel target) is supported. GPUs (e.g. CUDA and HSA) targets are supported via an immutable version of the jitclass instance, which will be described in a separate NBEP.

Other properties

Given:

```python
def spec
    [('x', numba.int32),
     ('y', numba.float32)]

@jitclass(spec)
class Vec(object):
    ...

    * isinstance(Vec(1, 2), Vec) is True.
    * type(Vec(1, 2)) may not be Vec.
```

Future enhancements

This proposal has only described the basic semantic and functionality of a jitclass. Additional features will be described in future enhancement proposals.

7.2.3 NBEP 4: Defining C callbacks

**Author**  Antoine Pitrou
**Date**  April 2016
**Status**  Draft

Interfacing with some native libraries (for example written in C or C++) can necessitate writing native callbacks to provide business logic to the library. Some Python-facing libraries may also provide the alternative of passing a ctypes-wrapped native callback instead of a Python callback for better performance. A simple example is the scipy.integrate package where the user passes the function to be integrated as a callback.

Users of those libraries may want to benefit from the performance advantage of running purely native code, while writing their code in Python. This proposal outlines a scheme to provide such a functionality in Numba.

Basic usage

We propose adding a new decorator, @cfunc, importable from the main package. This decorator allows defining a callback as in the following example:

```python
from numba import cfunc
from numba.types import float64

# A callback with the C signature `double(double)`
@cfunc(float64(float64), nopython=True)
```
def integrand(x):
    return 1 / x

The @cfunc decorator returns a “C function” object holding the resources necessary to run the given compiled function (for example its LLVM module). This object has several attributes and methods:

- the ctypes attribute is a ctypes function object representing the native function.
- the address attribute is the address of the native function code, as an integer (note this can also be computed from the ctypes attribute).
- the native_name attribute is the symbol under which the function can be looked up inside the current process.
- the inspect_llvm() method returns the IR for the LLVM module in which the function is compiled. It is expected that the native_name attribute corresponds to the function’s name in the LLVM IR.

The general signature of the decorator is cfunc(signature, **options).

The signature must specify the argument types and return type of the function using Numba types. In contrary to @jit, the return type cannot be omitted.

The options are keyword-only parameters specifying compilation options. We are expecting that the standard @jit options (nopython, forceobj, cache) can be made to work with @cfunc.

### Calling from Numba-compiled functions

While the intended use is to pass a callback’s address to foreign C code expecting a function pointer, it should be made possible to call the C callback from a Numba-compiled function.

### Passing array data

Native platform ABIs as used by C or C++ don’t have the notion of a shaped array as in Numpy. One common solution is to pass a raw data pointer and one or several size arguments (depending on dimensionality). Numba must provide a way to rebuild an array view of this data inside the callback.

```python
from numba import cfunc, carray
from numba.types import float64, CPointer, void, intp

# A callback with the C signature `void(double *, double *, size_t)`
@cfunc(void(CPointer(float64), CPointer(float64), intp))
def invert(in_ptr, out_ptr, n):
    in_ = carray(in_ptr, (n,))
    out = carray(out_ptr, (n,))
    for i in range(n):
        out[i] = 1 / in_[i]
```

The carray function takes (pointer, shape, dtype) arguments (dtype being optional) and returns a C-layout array view over the data pointer, with the given shape and dtype. pointer must be a ctypes pointer object (not a Python integer). The array’s dimensionality corresponds to the shape tuple’s length. If dtype is not given, the array’s dtype corresponds to the pointer’s pointee type.

The farray function is similar except that it returns a F-layout array view.

### 7.2. Other proposals
Error handling

There is no standard mechanism in C for error reporting. Unfortunately, Numba currently doesn’t handle try . except blocks, which makes it more difficult for the user to implement the required error reporting scheme. The current stance of this proposal is to let users guard against invalid arguments where necessary, and do whatever is required to inform the caller of the error.

Based on user feedback, we can later add support for some error reporting schemes, such as returning an integer error code depending on whether an exception was raised, or setting errno.

Deferred topics

Ahead-of-Time compilation

This proposal doesn’t make any provision for AOT compilation of C callbacks. It would probably necessitate a separate API (a new method on the numba . pycc . CC object), and the implementation would require exposing a subset of the C function object’s functionality from the compiled C extension module.

Opaque data pointers

Some libraries allow passing an opaque data pointer (void *) to a user-provided callback, to provide any required context for execution of the callback. Taking advantage of this functionality would require adding specific support in Numba, for example the ability to do generic conversion from types . voidptr and to take the address of a Python-facing jitclass instance.

7.2.4 NBEP 5: Type Inference

- Author Siu Kwan Lam
- Date Sept 2016
- Status Draft

This document describes the current type inference implementation in numba.

Introduction

Numba uses type information to ensure that every variable in the user code can be correctly lowered (translated into a low-level representation). The type of a variable describes the set of valid operations and available attributes. Resolving this information during compilation avoids the overhead of type checking and dispatching at runtime. However, Python is dynamically typed and the user does not declare variable types. Since type information is absent, we use type inference to reconstruct the missing information.
Numba Type Semantic

Type inference operates on Numba IR, a mostly static-single-assignment (SSA) encoding of the Python bytecode. Conceptually, all intermediate values in the Python code are explicitly assigned to a variable in the IR. Numba enforces that each IR variable to have one type only. A user variable (from the Python source code) can be mapped to multiple variables in the IR. They are versions of a variable. Each time a user variable is assigned to, a new version is created. From that point, all subsequent references will use the new version. The user variable evolves as the function logic updates its type. Merge points (e.g. subsequent block to an if-else, the loop body, etc.) in the control flow need extra care. At each merge point, a new version is implicitly created to merge the different variable versions from the incoming paths. The merging of the variable versions may translate into an implicit cast.

Numba uses function overloading to emulate Python duck-typing. The type of a function can contain multiple call signatures that accept different argument types and yield different return types. The process to decide the best signature for an overloaded function is called overload resolution. Numba partially implements the C++ overload resolution scheme (ISO/IEC 13.3 Overload Resolution). The scheme uses a “best fit” algorithm by ranking each argument symmetrically. The five possible rankings in increasing order of penalty are:

- **Exact**: the expected type is the same as the actual type.
- **Promotion**: the actual type can be upcast to the expected type by extending the precision without changing the behavior.
- **Safe conversion**: the actual type can be cast to the expected type by changing the type without losing information.
- **Unsafe conversion**: the actual type can be cast to the expected type by changing the type or downcasting the type even if it is imprecise.
- **No match**: no valid operation can convert the actual type to the expected type.

It is possible to have an ambiguous resolution. For example, a function with signatures `(int16, int32)` and `(int32, int16)` can become ambiguous if presented with the argument types `(int32, int32)`, because demoting either argument to `int16` is equally “fit”. Fortunately, numba can usually resolve such ambiguity by compiling a new version with the exact signature `(int32, int32)`. When compilation is disabled and there are multiple signatures with equal fit, an exception is raised.

Type Inference

The type inference in numba has three important components—type variable, constraint network, and typing context.

- The **typing context** provides all the type information and typing related operations, including the logic for type unification, and the logic for typing of global and constant values. It defines the semantic of the language that can be compiled by numba.
- A **type variable** holds the type of each variable (in the Numba IR). Conceptually, it is initialized to the universal type and, as it is re-assigned, it stores a common type by unifying the new type with the existing type. The common type must be able to represent values of the new type and the existing type. Type conversion is applied as necessary and precision loss is accepted for usability reason.
- The **constraint network** is a dependency graph built from the IR. Each node represents an operation in the Numba IR and updates at least one type variable. There may be cycles due to loops in user code.

The type inference process starts by seeding the argument types. These initial types are propagated in the constraint network, which eventually fills all the type variables. Due to cycles in the network, the process repeats until all type variables converge or it fails with undecidable types.

Type unification always returns a more “general” (quoted because unsafe conversion is allowed) type. Types will converge to the least “general” type that can represent all possible values that the variable can hold. Since unification will never move down the type hierarchy and there is a single top type, the universal type—object, the type inference is guaranteed to converge.
A failure in type inference can be caused by two reasons. The first reason is user error due to incorrect use of a type. This type of error will also trigger an exception in regular python execution. The second reason is due to the use of an unsupported feature, but the code is otherwise valid in regular python execution. Upon an error, the type inference will set all types to the object type. As a result, numba will fallback to object-mode.

Since functions can be overloaded, the type inference needs to decide the type signature used at each call site. The overload resolution is applied to all known overload versions of the callee function described in call-templates. A call-template can either be concrete or abstract. A concrete call-template defines a fixed list of all possible signatures. An abstract call-template defines the logic to compute the accepted signature and it is used to implement generic functions.

Numba-compiled functions are generic functions due to their ability to compile new versions. When it sees a new set of argument types, it triggers type inference to validate and determine the return type. When there are nested calls for numba-compiled functions, each call-site triggers type inference. This poses a problem to recursive functions because the type inference will also be triggered recursively. Currently, simple single recursion is supported if the signature is user-annotated by the user, which avoids unbound recursion in type inference that will never terminate.

### 7.2.5 NBEP 6: Typing Recursion

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**Date**  Sept 2016

**Status**  Draft

#### Introduction

This document proposes an enhancement to the type inference algorithm to support recursion without explicitly annotating the function signature. As a result, the proposal enables numba to type-infer both self-recursive and mutual-recursive functions under some limitations. In practice, these limitations can be easily overcome by specifying a compilation order.

#### The Current State

Recursion support in numba is currently limited to self-recursion with explicit type annotation for the function. This limitation comes from the inability to determine the return type of a recursive call. This is because the callee is either the current function (for self-recursion) or a parent function (mutual-recursion) and its type inference process has been suspended while waiting for the function-type of its callee. This results in the formation of a cyclic dependency. For example, given a function `foo()` that calls `bar()`, which in turns call `foo()`:

```python
def foo(x):
    if x > 0:
        return bar(x)
    else:
        return 1

def bar(x):
    return foo(x - 1)
```

The type inference process of `foo()` depends on that of `bar()`, which depends on `foo()`. Therefore `foo()` depends on itself and the type inference algorithm cannot terminate.
The Solution

The proposed solution has two components:

1. The introduction of a compile-time callstack that tracks the compiling functions.
2. The allowance of a partial type inference on functions by leveraging the return type on non-recursive control-flow paths.

The compile-time callstack stores typing information of the functions being compiled. Like an ordinary callstack, it pushes a new record every time a function is “called”. Since this occurs at compile-time, a “call” triggers a compilation of the callee.

To detect recursion, the compile-time callstack is searched bottom-up (stack grows downward) for a record that matches the callee. As the record contains a reference to the type inference state, the type inference process can be resumed to determine the return type.

Recall that the type inference process cannot be resumed normally because of the cyclic dependency of the return type. In practice, we can assume that a useful program must have a terminating condition, a path that does not recurse. So, the type inference process can make an initial guess for the return-type at the recursive call by using the return-type determined by the non-recursive paths. This allows type information to propagate on the recursive paths to generate the final return type, which is used to refine the type information by the subsequent iteration in the type inference process.

The following figure illustrates the compile-time callstack when the compiler reaches the recursive call to foo() from bar():

At this time, the type inference process of foo() is suspended and that of bar() is active. The compiler can see that the callee is already compiling by searching the callstack. Knowing that it is a recursive call, the compiler can resume the type-inference on foo() by ignoring the paths that contain recursive calls. This means only the else branch is considered and we can easily tell that foo() returns an int in this case. The compiler will then set the initial return type of foo() and bar() to int. The subsequent type propagation can use this information to complete the type inference of both functions, unifying the return-type of all returning paths.

Limitations

For the proposed type inference algorithm to terminate, it assumes that at least one of the control path leads to a return-statement without undertaking a recursive call. Should this not be the case, the algorithm will raise an exception indicating a potential runaway recursion.

For example:

```python
@jit
def first(x):
    # The recursing call must have a path that is non-recursing.
    if x > 0:
        return second(x)
    else:
        return 1

@jit
def second(x):
    return third(x)

@jit
```

(continues on next page)
def third(x):
    return first(x - 1)

The `first()` function must be the compiled first for the type inference algorithm to complete successfully. Compiling any other function first will lead to a failure in type inference. The type inference algorithm will treat it as a runaway recursion due to the lack of a non-recursive exit in the recursive callee.

For example, compiling `second()` first will move the recursive call to `first()`. When the compiler tries to resume the type inference process of `second()`, it will fail to find a non-recursive path.

This is a small limitation and can be overcome easily by code restructuring or precompiling in a specific order.
ahead-of-time compilation

AOT compilation

AOT  Compilation of a function in a separate step before running the program code, producing an on-disk binary object which can be distributed independently. This is the traditional kind of compilation known in languages such as C, C++ or Fortran.

bytecode

Python bytecode  The original form in which Python functions are executed. Python bytecode describes a stack-machine executing abstract (untyped) operations using operands from both the function stack and the execution environment (e.g. global variables).

compile-time constant  An expression whose value Numba can infer and freeze at compile-time. Global variables and closure variables are compile-time constants.

just-in-time compilation

JIT compilation

JIT  Compilation of a function at execution time, as opposed to ahead-of-time compilation.

JIT function  Shorthand for “a function JIT-compiled with Numba using the @jit decorator.”

loop-lifting

loop-jitting  A feature of compilation in object mode where a loop can be automatically extracted and compiled in nopython mode. This allows functions with operations unsupported in nopython mode to see significant performance improvements if they contain loops with only nopython-supported operations.

lowering  The act of translating Numba IR into LLVM IR. The term “lowering” stems from the fact that LLVM IR is low-level and machine-specific while Numba IR is high-level and abstract.

NPM

nopython mode  A Numba compilation mode that generates code that does not access the Python C API. This compilation mode produces the highest performance code, but requires that the native types of all values in the function can be inferred. Unless otherwise instructed, the @jit decorator will automatically fall back to object mode if nopython mode cannot be used.

Numba IR

Numba intermediate representation  A representation of a piece of Python code which is more amenable to analysis and transformations than the original Python bytecode.

object mode  A Numba compilation mode that generates code that handles all values as Python objects and uses the Python C API to perform all operations on those objects. Code compiled in object mode will often run no faster than Python interpreted code, unless the Numba compiler can take advantage of loop-jitting.
OptionalType  An OptionalType is effectively a type union of a type and None. They typically occur in practice due to a variable being set to None and then in a branch the variable being set to some other value. It’s often not possible at compile time to determine if the branch will execute so to permit type inference to complete, the type of the variable becomes the union of a type (from the value) and None, i.e. OptionalType(type).

type inference  The process by which Numba determines the specialized types of all values within a function being compiled. Type inference can fail if arguments or globals have Python types unknown to Numba, or if functions are used that are not recognized by Numba. Successful type inference is a prerequisite for compilation in nopython mode.

typing  The act of running type inference on a value or operation.

ufunc  A NumPy universal function. Numba can create new compiled ufuncs with the @vectorize decorator.

reflection  In numba, when a mutable container is passed as argument to a nopython function from the Python interpreter, the container object and all its contained elements are converted into nopython values. To match the semantics of Python, any mutation on the container inside the nopython function must be visible in the Python interpreter. To do so, Numba must update the container and its elements and convert them back into Python objects during the transition back into the interpreter.

Not to be confused with Python’s “reflection” in the context of binary operators (see https://docs.python.org/3.5/reference/datamodel.html).
CHAPTER NINE

RELEASE NOTES

9.1 Version 0.55.2 (25 May, 2022)

This is a maintenance release to support NumPy 1.22 and Apple M1.

Pull-Requests:

- PR #8067: Backport #8027: Support for NumPy 1.22 (stuartarchibald)
- PR #8069: Install llvmlite 0.38 for Numba 0.55.* (esc)
- PR #8075: update max NumPy for 0.55.2 (esc)
- PR #8078: Backport #7804: update local references from master -> main (esc)
- PR #8082: Backport #8080: fix windows failure due to timeout (Siu Kwan Lam)
- PR #8084: Pin meta.yaml to llvmlite 0.38 series (Siu Kwan Lam)
- PR #8093: Backport #7904: Support m1 (esc)
- PR #8094: Backport #8052 Ensure pthread is linked in when building for ppc64le. (Siu Kwan Lam)
- PR #8098: Backport #8097: Exclude libopenblas 0.3.20 on osx-arm64 (esc)
- PR #8100: Backport #7786 for 0.55.2: Remove dependency on intel-openmp for OSX (stuartarchibald)
- PR #8103: Backport #8102 to fix numpy requirements (Siu Kwan Lam)
- PR #8114: Backport #8109 Pin TBB support with respect to incompatible 2021.6 API. (stuartarchibald)

Total PRs: 12

Authors:

- esc
- Siu Kwan Lam
- stuartarchibald

Total authors: 3
9.2 Version 0.55.1 (27 January, 2022)

This is a bugfix release that closes all the remaining issues from the accelerated release of 0.55.0 and also any release critical regressions discovered since then.

CUDA target deprecation notices:

- Support for CUDA toolkits < 10.2 is deprecated and will be removed in Numba 0.56.
- Support for devices with Compute Capability < 5.3 is deprecated and will be removed in Numba 0.56.

Pull-Requests:

- PR #7755: CUDA: Deprecate support for CC < 5.3 and CTK < 10.2 (Graham Markall)
- PR #7749: Refactor threading layer priority tests to not use stdout/stderr (stuartarchibald)
- PR #7744: Fix issues with locating/parsing source during DebugInfo emission. (stuartarchibald)
- PR #7712: Fixing issue 7693 (Graham Markall luk-f-a stuartarchibald)
- PR #7729: Handle Omitted/OmittedArgDataModel in DI generation. (stuartarchibald)
- PR #7788: Avoid issue with DI gen for arrayexprs. (stuartarchibald)
- PR #7752: Fix #7751: Use original filename for array exprs (Graham Markall)
- PR #7748: Fix #7713: Ensure _prng_random_hash return has correct bitwidth (Graham Markall)
- PR #7745: Fix the release year for Numba 0.55 change log entry. (stuartarchibald)
- PR #7740: CUDA Python 11.6 support (Graham Markall)
- PR #7724: Update URLs in error messages to refer to RTD docs. (stuartarchibald)
- PR #7709: CUDA: Fixes missing type annotation pass following #7704 (stuartarchibald)
- PR #7704: Move the type annotation pass to post legalization. (stuartarchibald)
- PR #7619: CUDA: Fix linking with PTX when compiling lazily (Graham Markall)

Authors:

- Graham Markall
- luk-f-a
- stuartarchibald

9.3 Version 0.55.0 (13 January, 2022)

This release includes a significant number important dependency upgrades along with a number of new features and bug fixes.

NOTE: Due to NumPy CVE-2021-33430 this release has bypassed the usual release process so as to promptly provide a Numba release that supports NumPy 1.21. A single release candidate (RC1) was made and a few issues were reported, these are summarised as follows and will be fixed in a subsequent 0.55.1 release.

Known issues with this release:

- Incorrect result copying array-typed field of structured array (#7693)
- Two issues in DebugInfo generation (#7726, #7730)
- Compilation failure for hash of floating point values on 32 bit Windows when using Python 3.10 (#7713).
Highlights of core dependency upgrades:

- Support for Python 3.10
- Support for NumPy 1.21

Python language support enhancements:

- Experimental support for `isinstance`.

NumPy features/enhancements:

The following functions are now supported:

- `np.broadcast_to`
- `np.float_power`
- `np.cbrt`
- `np.logspace`
- `np.take_along_axis`
- `np.average`
- `np.argmax` gains support for the `axis` kwarg.
- `np.ndarray.astype` gains support for types expressed as literal strings.

Highlights of core changes:

- For users of the Numba extension API, Numba now has a new error handling mode whereby it will treat all exceptions that do not inherit from `numba.errors.NumbaException` as a “hard error” and immediately unwind the stack. This makes it much easier to debug when writing @overloads etc from the extension API as there’s now no confusion between Python errors and Numba errors. This feature can be enabled by setting the environment variable: `NUMBA_CAPTURED_ERRORS='new_style'`.

- The threading layer selection priority can now be changed via the environment variable `NUMBA_THREADING_LAYER_PRIORITY`.

Highlights of changes for the CUDA target:

- Support for NVIDIA's CUDA Python bindings.
- Support for 16-bit floating point numbers and their basic operations via intrinsics.
- Streams are provided in the `Stream.async_done` result, making it easier to implement asynchronous work queues.
- Support for structured types in device arrays, character sequences in NumPy arrays, and some array operations on nested arrays.
- Much underlying refactoring to align the CUDA target more closely with the CPU target, which lays the groundwork for supporting the high level extension API in CUDA in future releases.

Intel also kindly sponsored research and development into native debug (DWARF) support and handling per-function compilation flags:

- Line number/location tracking is much improved.
- Numba’s internal representation of containers (e.g. tuples, arrays) are now encoded as structures.
- Numba’s per-function compilation flags are encoded into the ABI field of the mangled name of the function such that it’s possible to compile and differentiate between versions of the same function with different flags set.

General deprecation notices:
• There are no new general deprecations.

CUDA target deprecation notices:
• There are no new CUDA target deprecations.

Version support/dependency changes:
• Python 3.10 is supported.
• NumPy version 1.21 is supported.
• The minimum supported NumPy version is raised to 1.18 for runtime (compilation however remains compatible with NumPy 1.11).

Pull-Requests:
• PR #6075: add np.float_power and np.cbrt (Guilherme Leobas)
• PR #7047: Support __hash__ for numpy.datetime64 (Guilherme Leobas stuartarchibald)
• PR #7057: Fix #7041: Add charseq registry to CUDA target (Graham Markall stuartarchibald)
• PR #7082: Added Add/Sub between datetime64 array and timedelta64 scalar (Nick Riasanovsky stuartarchibald)
• PR #7119: Add support for np.broadcast_to (Guilherme Leobas)
• PR #7129: Add support for axis keyword argument to np.argmin() (Itamar Turner-Trauring)
• PR #7132: gh #7131 Support for astype with literal strings (Nick Riasanovsky)
• PR #7177: Add debug information support based on datamodel. (stuartarchibald)
• PR #7185: Add get_impl_key as abstract method to types.Callable (Alexey Kozlov)
• PR #7186: Add support for np.logspace. (Guoqiang Qi)
• PR #7189: CUDA: Skip IPC tests on ARM (Graham Markall)
• PR #7190: CUDA: Fix test_pinned on Jetson (Graham Markall)
• PR #7192: Fix missing import in array.argsort impl and add more tests. (stuartarchibald)
• PR #7196: Fixes for lineinfo emission (stuartarchibald)
• PR #7197: don’t post to python announce on the first RC (esc)
• PR #7202: Initial implementation of np.take_along_axis (Itamar Turner-Trauring)
• PR #7203: remove duplicate changelog entries (esc)
• PR #7216: Update CHANGE_LOG for 0.54.0rc2 (stuartarchibald)
• PR #7219: bump llvmlite dependency to 0.38.0dev0 for Numba 0.55.0dev0 (esc)
• PR #7220: update release checklist post 0.54rc1+2 (esc)
• PR #7221: Show GPU UUIDs in cuda.detect() output (Graham Markall)
• PR #7222: CUDA: Warn when debug=True and opt=True (Graham Markall)
• PR #7223: Replace assertion errors on IR assumption violation (Siu Kwan Lam)
• PR #7226: Add support for structured types in Device Arrays (Michael Collison)
• PR #7227: FIX: Typo (Srinath Kailasa)
• PR #7230: PR #7171 bugfix only (stuartarchibald Todd A. Anderson)
• PR #7234: add THREADING_LAYER_PRIORITY & NUMBA_THREADING_LAYER_PRIORITY (Kolen Cheung)
- PR #7235: replace wordings of WIP by draft PR (Kolen Cheung)
- PR #7236: CUDA: Skip managed alloc tests on ARM (Graham Markall)
- PR #7237: fix a typo in a string (Kolen Cheung)
- PR #7241: Set aliasing information for inplace_binops.. (Todd A. Anderson)
- PR #7242: FIX: typo (Srinath Kailasa)
- PR #7244: Implement partial literal propagation pass (support ‘isinstance’) (Guilherme Leobas stuartarchibald)
- PR #7247: Solve memory leak to fix issue #7210 (Siu Kwan Lam Graham Markall ysheffer)
- PR #7251: Fix #6001: typed.List ignores ctor arguments with JIT disabled (Graham Markall)
- PR #7256: Fix link to the discourse forum in README (Kenichi Maehashi)
- PR #7257: Use normal list constructor in List.__new__() (Graham Markall)
- PR #7260: Support typed lists in heapq (Graham Markall)
- PR #7263: Updated issue URL for error messages #7261 (DeviousLab)
- PR #7265: Fix linspace to use np.divide and clamp to stop. (stuartarchibald)
- PR #7266: CUDA: Skip multi-GPU copy test with peer access disabled (Graham Markall)
- PR #7267: Fix #7258. Bug in SROA optimization (Siu Kwan Lam)
- PR #7271: Update 3rd party license text. (stuartarchibald)
- PR #7272: Allow annotations in njit-ed functions (LunarLanding)
- PR #7273: Update CHANGE_LOG for 0.54.0rc3. (stuartarchibald)
- PR #7283: Added NPM to Glossary and linked to mentions (Nihal Shetty)
- PR #7285: CUDA: Fix OOB in test_kernel_arg (Graham Markall)
- PR #7288: Handle cval as a np attr in stencil generation. (stuartarchibald)
- PR #7294: Continuation of PR #7280, fixing lifetime of TBB task_scheduler_handle (Sergey Pokhodenko stuartarchibald)
- PR #7296: Fix generator lowering not casting to the actual yielded type (Siu Kwan Lam)
- PR #7298: Use CBC to pin GCC to 7 on most linux and 9 on aarch64. (stuartarchibald)
- PR #7304: Continue PR#3655: add support for np.average (Hadia Ahmed slnguyen)
- PR #7307: Prevent mutation of arrays in global tuples. (stuartarchibald)
- PR #7309: Update MapConstraint to handle type coercion for typed.Dict correctly. (stuartarchibald)
- PR #7312: Fix #7302. Workaround missing pthread problem on ppc64le (Siu Kwan Lam)
- PR #7315: Link ELF obj as DSO for radare2 disassembly CFG (stuartarchibald)
- PR #7316: Use float64 for consistent typing in heapq tests. (stuartarchibald)
- PR #7317: In TBB tsh test switch os.fork for mp fork ctx (stuartarchibald)
- PR #7319: Update CHANGE_LOG for 0.54.0 final. (stuartarchibald)
- PR #7329: Improve documentation in reference to CUDA local memory (Sterling Baird)
- PR #7330: Cuda matmul docs (Sterling Baird)
- PR #7340: Add size_t and ssize_t types (Bruce Merry)
• PR #7345: Add check for ipykernel file in IPython cache locator (Sahil Gupta)
• PR #7347: fix:updated url for error report and feature request using issue template (DEBARGHA SAHA)
• PR #7349: Allow arbitrary walk-back in reduction nodes to find inplace_binop. (Todd A. Anderson)
• PR #7359: Extend support for nested arrays inside numpy records (Graham Markall luk-f-a)
• PR #7375: CUDA: Run doctests as part of numba.cuda.tests and fix test_cg (Graham Markall)
• PR #7395: Fix #7394 and #6550 & Added test & improved error message (Megalng)
• PR #7397: Add option to catch only Numba numba.core.errors derived exceptions. (stuartarchibald)
• PR #7398: Add support for arrayanalysis of tuple args. (Todd A. Anderson)
• PR #7403: Fix for issue 7402: implement missing numpy ufunc interface (Guilherme Leobas)
• PR #7404: fix typo in literal_unroll docs (esc)
• PR #7419: insert missing backtick in comment (esc)
• PR #7422: Update Omitted Type to use Hashable Values as Keys for Caching (Nick Riasanovsky)
• PR #7429: Update CHANGE_LOG for 0.54.1 (stuartarchibald)
• PR #7432: add github release task to checklist (esc)
• PR #7440: Refactor TargetConfig naming. (stuartarchibald)
• PR #7441: Permit any string as a key in literalstrkeydict type. (stuartarchibald)
• PR #7442: Add some diagnostics to SVML test failures. (stuartarchibald)
• PR #7443: Refactor template selection logic for targets. (stuartarchibald)
• PR #7444: use correct variable name in closure (esc)
• PR #7447: cleanup Numba metadata (esc)
• PR #7453: CUDA: Provide stream in async_done result (Graham Markall)
• PR #7456: Fix invalid codegen for #7451. (stuartarchibald)
• PR #7457: Factor out target registry selection logic (stuartarchibald)
• PR #7459: Include compiler flags in symbol mangling (Siu Kwan Lam)
• PR #7460: Add FP16 support for CUDA (Michael Collison Graham Markall)
• PR #7461: Support NVIDIA’s CUDA Python bindings (Graham Markall)
• PR #7465: Update changelog for 0.54.1 release (Siu Kwan Lam)
• PR #7477: Fix unicode operator.eq handling of Optional types. (stuartarchibald)
• PR #7479: CUDA: Print format string and warn for > 32 print() args (Graham Markall)
• PR #7483: NumPy 1.21 support (Sebastian Berg stuartarchibald)
• PR #7484: Fixed outgoing link to nvidia documentation. (Dhruv Patel)
• PR #7493: Consolidate TLS stacks in target configuration (Siu Kwan Lam)
• PR #7496: CUDA: Use a single dispatcher class for all kinds of functions (Graham Markall)
• PR #7498: refactor with-detection logic (stuartarchibald esc)
• PR #7499: Add build scripts for CUDA testing on gpuCI (Charles Blackmon-Luca Graham Markall)
• PR #7500: Update parallel.rst (Julius Bier Kirkegaard)
• PR #7506: Enhance Flags mangling/demangling (Siu Kwan Lam)
• PR #7514: Fixup cuda debuginfo emission for 7177 (Siu Kwan Lam)
• PR #7525: Make sure `demangle()` returns `str` type. (Siu Kwan Lam)
• PR #7538: Fix `@overload_glue` performance regression. (stuartarchibald)
• PR #7539: Fix str decode issue from merge #7525/#7506 (stuartarchibald)
• PR #7546: Fix handling of missing const key in LiteralStrKeyDict (Siu Kwan Lam stuartarchibald)
• PR #7547: Remove 32bit linux scipy installation. (stuartarchibald)
• PR #7548: Correct evaluation order in assert statement (Graham Markall)
• PR #7552: Prepend the inlined function name to inlined variables. (stuartarchibald)
• PR #7557: Python3.10 v2 (stuartarchibald esc)
• PR #7560: Refactor with detection py310 (Siu Kwan Lam esc)
• PR #7561: fix a typo (Kolen Cheung)
• PR #7567: Update docs to note meetings are public. (stuartarchibald)
• PR #7570: Update the docs and error message for errors when importing Numba. (stuartarchibald)
• PR #7580: Fix #7507. catch `NotImplementedError` in `.get_function()` (Siu Kwan Lam)
• PR #7581: Add support for casting from int enums (Michael Collison)
• PR #7583: Make numba.types.Optional __str__ less verbose. (stuartarchibald)
• PR #7588: Fix casting of start/stop in linspace (stuartarchibald)
• PR #7591: Remove deprecations (Graham Markall)
• PR #7596: Fix max symbol match length for r2 (stuartarchibald)
• PR #7597: Update gdb docs for new DWARF enhancements. (stuartarchibald)
• PR #7603: Fix list.insert() for refcounted values (Ehsan Totoni)
• PR #7605: Fix TBB 2021 DSO names on OSX/Win and make TBB reporting consistent (stuartarchibald)
• PR #7606: Ensure a prescribed threading layer can load in CI. (stuartarchibald)
• PR #7610: Fix #7609. Type should not be mutated. (Siu Kwan Lam)
• PR #7618: Fix the doc build: docutils 0.18 not compatible with pinned sphinx (stuartarchibald)
• PR #7626: Fix issues with package dependencies. (stuartarchibald esc)
• PR #7627: PR 7321 continued (stuartarchibald Eric Wieser)
• PR #7628: Move to using windows-2019 images in Azure (stuartarchibald)
• PR #7632: Capture output in CUDA matmul doctest (Graham Markall)
• PR #7636: Copy prange loop header to after the parfor. (Todd A. Anderson)
• PR #7637: Increase the timeout on the SVML tests for loaded machines. (stuartarchibald)
• PR #7645: In debuginfo, do not add noinline to functions marked alwaysinline (stuartarchibald)
• PR #7650: Move Azure builds to OSX 10.15 (stuartarchibald esc Siu Kwan Lam)

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9.4 Version 0.54.1 (7 October, 2021)

This is a bugfix release for 0.54.0. It fixes a regression in structured array type handling, a potential leak on initialization failure in the CUDA target, a regression caused by Numba’s vendored cloudpickle module resetting dynamic classes and a few minor testing/infrastructure related problems.

- PR #7348: test_inspect_cli: Decode exception with default (utf-8) codec (Graham Markall)
- PR #7360: CUDA: Fix potential leaks when initialization fails (Graham Markall)
- PR #7386: Ensure the NRT is initialized prior to use in external NRT tests. (stuartarchibald)
- PR #7388: Patch cloudpickle to not reset dynamic class each time it is unpickled (Siu Kwan Lam)
- PR #7393: skip azure pipeline test if file not present (esc)
- PR #7428: Fix regression #7355: cannot set items in structured array data types (Siu Kwan Lam)

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9.5 Version 0.54.0 (19 August, 2021)

This release includes a significant number of new features, important refactoring, critical bug fixes and a number of dependency upgrades.

Python language support enhancements:
- Basic support for f-strings.
- dict comprehensions are now supported.
- The sum built-in function is implemented.

NumPy features/enhancements:

The following functions are now supported:
- np.clip
- np.iscomplex
- np.iscomplexobj
- np.isneginf
- np.isposinf
- np.isreal
- np.isrealobj
- np.isscalar
- np.random.dirichlet
- np.rot90
- np.swapaxes
Also np.argmax has gained support for the axis keyword argument and it’s now possible to use 0d NumPy arrays as scalars in __setitem__ calls.

Internal changes:

- Debugging support through DWARF has been fixed and enhanced.
- Numba now optimises the way in which locals are emitted to help reduce time spent in LLVM’s SROA passes.

CUDA target changes:

- Support for emitting lineinfo to be consumed by profiling tools such as Nsight Compute
- Improved fastmath code generation for various trig, division, and other functions
- Faster compilation using lazy addition of libdevice to compiled units
- Support for IPC on Windows
- Support for passing tuples to CUDA ufuncs
- Performance warnings:
  - When making implicit copies by calling a kernel on arrays in host memory
  - When occupancy is poor due to kernel or ufunc/gufunc configuration
- Support for implementing warp-aggregated intrinsics:
  - Using support for more CUDA functions: activemask(), lanemask_lt()
  - The ffs() function now works correctly!
- Support for @overload in the CUDA target

Intel kindly sponsored research and development that lead to a number of new features and internal support changes:

- Dispatchers can now be retargetted to a new target via a user defined context manager.
- Support for custom NumPy array subclasses has been added (including an overloadable memory allocator).
- An inheritance based model for targets that permits targets to share @overload implementations.
- Per function compiler flags with inheritance behaviours.
- The extension API now has support for overloading class methods via the @overload_classmethod decorator.

Deprecations:

- The ROCm target (for AMD ROC GPUs) has been moved to an “unmaintained” status and a sepaerate repository stub has been created for it at: https://github.com/numba/numba-rocm

CUDA target deprecations and breaking changes:

- Relaxed strides checking is now the default when computing the contiguity of device arrays.
- The inspect_ptx() method is deprecated. For use cases that obtain PTX for further compilation outside of Numba, use compile_ptx() instead.
- Eager compilation of device functions (the case when device=True and a signature is provided) is deprecated.

Version support/dependency changes:

- LLVM 11 is now supported on all platforms via llvmlite.
- The minimum supported Python version is raised to 3.7.
- NumPy version 1.20 is supported.
• The minimum supported NumPy version is raised to 1.17 for runtime (compilation however remains compatible with NumPy 1.11).
• Vendor cloudpickle v1.6.0 – now used for all pickle operations.
• TBB >= 2021 is now supported and all prior versions are unsupported (not easily possible to maintain the ABI breaking changes).

Pull-Requests:

• PR #4516: Make setitem accept 0d np-arrays (Guilherme Leobas)
• PR #4610: Implement np.is* functions (Guilherme Leobas)
• PR #5984: Handle idx and size unification in wrap_index manually. (Todd A. Anderson)
• PR #6468: Access replace_functions_map via PreParforPass instance (Sergey Pokhodenko Reazul Hoque)
• PR #6469: Add address space in pointer type (Sergey Pokhodenko Reazul Hoque)
• PR #6608: Support f-strings for common cases (Ehsan Totoni)
• PR #6619: Improved fastmath code generation for trig, log, and exp/pow. (Graham Markall Michael Collison)
• PR #6681: Explicitly catch with ..as and raise error. (stuartarchibald)
• PR #6689: Fix setup.py build command detection (Hannes Pahl)
• PR #6695: Enable negative indexing for cuda atomic operations (Ashutosh Varma)
• PR #6696: flake8: made more files flake8 compliant (Ashutosh Varma)
• PR #6698: Fix #6697: Wrong dtype when using np.asarray on DeviceNDArray (Ashutosh Varma)
• PR #6700: Add UUID to CUDA devices (Graham Markall)
• PR #6709: Block matplotlib in test examples (Graham Markall)
• PR #6718: doc: fix typo in rewrites.rst (extra iterates) (Alexander-Makaryev)
• PR #6720: Faster compile (Siu Kwan Lam)
• PR #6730: Fix Typeguard error (Graham Markall)
• PR #6731: Add CUDA-specific pipeline (Graham Markall)
• PR #6735: CUDA: Don’t parse IR for modules with llvmlite (Graham Markall)
• PR #6736: Support for dict comprehension (stuartarchibald)
• PR #6742: Do not add overload function definitions to index. (stuartarchibald)
• PR #6750: Bump to llvmlite 0.37 series (Siu Kwan Lam)
• PR #6751: Suppress typeguard warnings that affect testing. (Siu Kwan Lam)
• PR #6753: The check for internal types in RewriteArrayExprs (Alexander-Makaryev)
• PR #6755: install llvmlite from numba/label/dev (esc)
• PR #6758: patch to compile _devicearray.cpp with c++11 (esc)
• PR #6760: Fix scheduler bug where it rounds to 0 divisions for a chunk. (Todd A. Anderson)
• PR #6762: Glue wrappers to create @overload from split typing and lowering. (stuartarchibald Siu Kwan Lam)
• PR #6766: Fix DeviceNDArray null shape issue (Michael Collison)
• PR #6769: CUDA: Replace CachedPTX and CachedCUDAFUNCTION with CUDACodeLibrary functionality (Graham Markall)
• PR #6776: Fix issue with TBB interface causing warnings and parfors counting them (stuartarchibald)
• PR #6779: Fix wrap_index type unification. (Todd A. Anderson)
• PR #6786: Fix gufunc kwargs support (Siu Kwan Lam)
• PR #6788: Add support for fastmath 32-bit floating point divide (Michael Collison)
• PR #6789: Fix warnings struct ref typeguard (stuartarchibald Siu Kwan Lam esc)
• PR #6794: refactor and move create_temp_module into numba.tests.support (Alexander-Makaryev)
• PR #6795: CUDA: Lazily add libdevice to compilation units (Graham Markall)
• PR #6798: CUDA: Add optional Driver API argument logging (Graham Markall)
• PR #6799: Print Numba and llvmlite versions in sysinfo (Graham Markall)
• PR #6800: Make a common standard API for querying ufunc impl (Sergey Pokhodenko Siu Kwan Lam)
• PR #6801: ParallelAccelerator no long will convert StaticSetItem to SetItem because record arrays require StaticSetItems. (Todd A. Anderson)
• PR #6802: Add lineinfo flag to PTX and SASS compilation (Graham Markall Max Katz)
• PR #6804: added runtime version to numba -s (Kalyan)
• PR #6808: #3468 continued: Add support for np.clip (Graham Markall Aaron Russell Voelker)
• PR #6809: #3203 additional info in cuda detect (Kalyan)
• PR #6810: Fix tiny formatting error in ROC kernel docs (Felix Divo)
• PR #6811: CUDA: Remove test of runtime being a supported version (Graham Markall)
• PR #6813: Mostly CUDA: Replace llvmpy API usage with llvmlite APIs (Graham Markall)
• PR #6814: Improving context stack (stuartarchibald Siu Kwan Lam)
• PR #6818: CUDA: Support IPC on Windows (Graham Markall)
• PR #6822: Add support for np.rot90 (stuartarchibald Daniel Nagel)
• PR #6829: Fix accuracy of np.arange and np.linspace (stuartarchibald)
• PR #6830: CUDA: Use relaxed strides checking to compute contiguity (Graham Markall)
• PR #6833: Raise TypeError exception if numpy array is cast to scalar (Michael Collison)
• PR #6834: Remove illegal “debug” kw argument (Shaun Cutts)
• PR #6836: CUDA: Documentation updates (Graham Markall)
• PR #6840: CUDA: Remove items deprecated in 0.53 + simulator test fixes (Graham Markall)
• PR #6841: CUDA: Fix source location on kernel entry and enable breakpoints to be set on kernels by mangled name (Graham Markall)
• PR #6843: cross-referenced Array type in docs (Kalyan)
• PR #6844: CUDA: Remove NUMBAPRO env var warnings, envvars.py + other small tidy-ups (Graham Markall)
• PR #6848: Ignore .ycm_extra_conf.py (Graham Markall)
• PR #6849: Add __hash__ for IntEnum (Hannes Pahl)
• PR #6850: Fix up more internal warnings (stuartarchibald)
• PR #6854: PR 6096 continued (stuartarchibald Ivan Butygin)
• PR #6861: updated reference to hsa with roc (Kalyan)
• PR #6867: Update changelog for 0.53.1 (esc)
• PR #6869: Implement builtin sum() (stuartarchibald)
• PR #6870: Add support for dispatcher retargeting using with-context (stuartarchibald Siu Kwan Lam)
• PR #6871: Force text-align: left when using Annotate (Guilherme Leobas)
• PR #6873: docs: Update reference to @jitclass location (David Nadlinger)
• PR #6876: Add trailing slashes to dir paths in CODEOWNERS (Graham Markall)
• PR #6877: Add doc for recent target extension features (Siu Kwan Lam)
• PR #6878: CUDA: Support passing tuples to ufuncs (Graham Markall)
• PR #6879: CUDA: NumPy and string dtypes for local and shared arrays (Graham Markall)
• PR #6880: Add attribute lower_extension to CPUContext (Reazul Hoque)
• PR #6883: Add support of np.swapaxes #4074 (Daniel Nagel)
• PR #6885: CUDA: Explicitly specify objmode + looplifting for jit functions in cuda.random (Graham Markall)
• PR #6886: CUDA: Fix parallel testing for all testsuite submodules (Graham Markall)
• PR #6888: Get overload to consider compiler flags in cache lookup (Siu Kwan Lam)
• PR #6889: Address guvectorize too slow for cuda target (Michael Collison)
• PR #6890: fixes #6884 (Kalyan)
• PR #6898: Work on overloading by hardware target. (stuartarchibald)
• PR #6911: CUDA: Add support for activemask(), lanemask_lt(), and nanosleep() (Graham Markall)
• PR #6912: Prevent use of varargs in closure calls. (stuartarchibald)
• PR #6913: Add runtests option to gitdiff on the common ancestor (Siu Kwan Lam)
• PR #6915: Update _Intrinsic for sphinx to capture the inner docstring (Guilherme Leobas)
• PR #6917: Add type conversion for StringLiteral to unicode_type and test. (stuartarchibald)
• PR #6918: Start section on commonly encountered unsupported parfors code. (stuartarchibald)
• PR #6924: CUDA: Fix ffs (Graham Markall)
• PR #6928: Add support for axis keyword arg to numpy.argmax() (stuartarchibald Itamar Turner-Trauring)
• PR #6929: Fix CI failure when gitpython is missing. (Siu Kwan Lam)
• PR #6935: fixes broken link in numba-runtime.rst (Kalyan)
• PR #6936: CUDA: Implement support for PTDS globally (Graham Markall)
• PR #6937: Fix memory leak in bytes boxing (stuartarchibald)
• PR #6940: Fix function resolution for intrinsics across hardware. (stuartarchibald)
• PR #6941: ABC the target descriptor and make consistent throughout. (stuartarchibald)
• PR #6944: CUDA: Support for @overload (Graham Markall)
• PR #6945: Fix issue with array analysis tests needing scipy. (stuartarchibald)
• PR #6948: Refactor registry init. (stuartarchibald Graham Markall Siu Kwan Lam)
• PR #6953: CUDA: Fix and deprecate inspect_ptx(), fix NVVM option setup for device functions (Graham Markall)
• PR #6958: Inconsistent behavior of reshape between numpy and numba/cuda device array (Lauren Arnett)
• PR #6961: Update overload glue to deal with typing_key (stuartarchibald)
• PR #6964: Move minimum supported Python version to 3.7 (stuartarchibald)
• PR #6966: Fix issue with TBB test detecting forks from incorrect state. (stuartarchibald)
• PR #6971: Fix CUDA @intrinsic use (stuartarchibald)
• PR #6977: Vendor cloudpickle (Siu Kwan Lam)
• PR #6978: Implement operator.contains for empty Tuples (Brandon T. Willard)
• PR #6981: Fix LLVM IR parsing error on use of np.bool_ in globals (stuartarchibald)
• PR #6983: Support Optional types in ufuncs. (stuartarchibald)
• PR #6985: Implement static set/get items on records with integer index (stuartarchibald)
• PR #6986: document release checklist (esc)
• PR #6989: update threading docs for function loading (esc)
• PR #6990: Refactor hardware extension API to refer to “target” instead. (stuartarchibald)
• PR #6991: Move ROCm target status to “unmaintained”. (stuartarchibald)
• PR #6995: Resolve issue where nan was being assigned to int type numpy array (Michael Collison)
• PR #6996: Add constant lowering support for SliceType’s (Brandon T. Willard)
• PR #6997: CUDA: Remove catch of NotImplementedError in target.py (Graham Markall)
• PR #6999: Fix errors introduced by the cloudpickle patch (Siu Kwan Lam)
• PR #7003: More mainline fixes (stuartarchibald Graham Markall Siu Kwan Lam)
• PR #7004: Test extending the CUDA target (Graham Markall)
• PR #7007: Made stencil compilation not fail for arrays of conflicting types. (MegaIng)
• PR #7008: Added support for np.random.dirichlet with all size arguments (Rishi Kulkarni)
• PR #7016: Docs: Add DALI to list of CAI-supporting libraries (Graham Markall)
• PR #7018: Remove cu{blas,sparse,rand,fft} from library checks (Graham Markall)
• PR #7019: Support NumPy 1.20 (stuartarchibald)
• PR #7020: Fix #7017. Adds util class PickleCallableByPath (Siu Kwan Lam)
• PR #7024: fixed llvmir usage in create_module method (stuartarchibald Kalyan)
• PR #7027: Fix nrt debug print (MegaIng)
• PR #7031: Fix inliner to use a single scope for all blocks (Alexey Kozlov Siu Kwan Lam)
• PR #7040: Add Github action to mark issues as stale (Graham Markall)
• PR #7044: Fixes for LLVM 11 (stuartarchibald)
• PR #7049: Make NumPy random module use @overload_glue (stuartarchibald)
• PR #7050: Add overload_classmethod (Siu Kwan Lam)
• PR #7052: Fix string support in CUDA target (Graham Markall)
• PR #7056: Change prange conversion approach to reuse header block. (Todd A. Anderson)
• PR #7061: Add ndarray allocator classmethod (stuartarchibald Siu Kwan Lam)
• PR #7064: Testhound/host array performance warning (Michael Collison)
• PR #7066: Fix #7065: Add expected exception messages for NumPy 1.20 to tests (Graham Markall)
• PR #7068: Enhancing docs about PRNG seeding (Jérome Eertmans)
• PR #7070: Improve the issue templates and pull request template. (Guoqiang QI)
• PR #7080: Fix __eq__ for Flags and cpu_options classes (Siu Kwan Lam)
• PR #7087: Add note to docs about zero-initialization of variables. (stuartarchibald)
• PR #7088: Initialize NUMBA_DEFAULT_NUM_THREADS with a batch scheduler aware value (Thomas VINCENT)
• PR #7100: Replace deprecated call to cuDeviceComputeCapability (Graham Markall)
• PR #7113: Temporarily disable debug env export. (stuartarchibald)
• PR #7114: CUDA: Deprecate eager compilation of device functions (Graham Markall)
• PR #7116: Fix various issues with dwarf emission: (stuartarchibald vlad-perevezentsev)
• PR #7118: Remove print to stdout (stuartarchibald)
• PR #7121: Continue work on numpy subclasses (Todd A. Anderson Siu Kwan Lam)
• PR #7122: Rtd/sphinx compat (esc)
• PR #7134: Move minimum LLVM version to 11. (stuartarchibald)
• PR #7137: skip pycc test on Python 3.7 + macOS because of distutils issue (esc)
• PR #7138: Update the Azure default linux image to Ubuntu 18.04 (stuartarchibald)
• PR #7141: Require llvmlite 0.37 as minimum supported. (stuartarchibald)
• PR #7143: Update version checks in __init__ for np 1.17 (stuartarchibald)
• PR #7145: Fix mainline (stuartarchibald)
• PR #7146: Fix inline_closurecall may not be imported (Siu Kwan Lam)
• PR #7147: Revert “Workaround gitpython 3.1.18 dependency issue” (stuartarchibald)
• PR #7149: Fix issue in bytecode analysis where target and next are same. (stuartarchibald)
• PR #7152: Fix iterators in CUDA (Graham Markall)
• PR #7156: Fix ir_utils._max_label being updated incorrectly (Siu Kwan Lam)
• PR #7160: Split parfors tests (stuartarchibald)
• PR #7161: Update README for 0.54 (stuartarchibald)
• PR #7162: CUDA: Fix linkage of device functions when compiling for debug (Graham Markall)
• PR #7163: Split legalization pass to consider IR and features separately. (stuartarchibald)
• PR #7165: Fix use of np.clip where out is not provided. (stuartarchibald)
• PR #7189: CUDA: Skip IPC tests on ARM (Graham Markall)
• PR #7190: CUDA: Fix test_pinned on Jetson (Graham Markall)
• PR #7192: Fix missing import in array.argsort impl and add more tests. (stuartarchibald)
• PR #7196: Fixes for lineinfo emission. (stuartarchibald)
• PR #7203: remove duplicate changelog entries (esc)
• PR #7209: Clamp numpy (esc)
• PR #7216: Update CHANGE_LOG for 0.54.0rc2. (stuartarchibald)
• PR #7223: Replace assertion errors on IR assumption violation (Siu Kwan Lam)
• PR #7230: PR #7171 bugfix only (Todd A. Anderson stuartarchibald)
• PR #7236: CUDA: Skip managed alloc tests on ARM (Graham Markall)
• PR #7267: Fix #7258. Bug in SROA optimization (Siu Kwan Lam)
• PR #7271: Update 3rd party license text. (stuartarchibald)
• PR #7272: Allow annotations in njit-ed functions (LunarLanding)
• PR #7273: Update CHANGE_LOG for 0.54.0rc3. (stuartarchibald)
• PR #7285: CUDA: Fix OOB in test_kernel_arg (Graham Markall)
• PR #7294: Continuation of PR #7280, fixing lifetime of TBB task_scheduler_handle (Sergey Pokhodenko stuartarchibald)
• PR #7298: Use CBC to pin GCC to 7 on most linux and 9 on aarch64. (stuartarchibald)
• PR #7312: Fix #7302. Workaround missing pthread problem on ppc64le (Siu Kwan Lam)
• PR #7317: In TBB tsh test switch os.fork for mp fork ctx (stuartarchibald)
• PR #7319: Update CHANGE_LOG for 0.54.0 final. (stuartarchibald)

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9.6 Version 0.53.1 (25 March, 2021)

This is a bugfix release for 0.53.0. It contains the following four pull-requests which fix two critical regressions and two build failures reported by the openSuSe team:

- PR #6826 Fix regression on gufunc serialization
- PR #6828 Fix regression in CUDA: Set stream in mapped and managed array device_setup
- PR #6837 Ignore warnings from packaging module when testing import behaviour.
- PR #6851 set non-reported llvm timing values to 0.0

Authors:

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- Siu Kwan Lam
- Stuart Archibald

9.7 Version 0.53.0 (11 March, 2021)

This release continues to add new features, bug fixes and stability improvements to Numba.

Highlights of core changes:

- Support for Python 3.9 (Stuart Archibald).
- Function sub-typing (Lucio Fernandez-Arjona).
- Initial support for dynamic gufuncs (i.e. from @guvectorize) (Guilherme Leobas).
• Parallel Accelerator (@njit(parallel=True)) now supports Fortran ordered arrays (Todd A. Anderson and Siu Kwan Lam).

Intel also kindly sponsored research and development that lead to two new features:
• Exposing LLVM compilation pass timings for diagnostic purposes (Siu Kwan Lam).
• An event system for broadcasting compiler events (Siu Kwan Lam).

Highlights of changes for the CUDA target:
• CUDA 11.2 onwards (versions of the toolkit using NVVM IR 1.6 / LLVM IR 7.0.1) are now supported (Graham Markall).
• A fast cube root function is added (Michael Collison).
• Support for atomic xor, increment, decrement, exchange, are added, and compare-and-swap is extended to support 64-bit integers (Michael Collison).
• Addition of cuda.is_supported_version() to check if the CUDA runtime version is supported (Graham Markall).
• The CUDA dispatcher now shares infrastructure with the CPU dispatcher, improving launch times for lazily-compiled kernels (Graham Markall).
• The CUDA Array Interface is updated to version 3, with support for streams added (Graham Markall).
• Tuples and namedtuples can now be passed to kernels (Graham Markall).
• Initial support for Cooperative Groups is added, with support for Grid Groups and Grid Sync (Graham Markall and Nick White).
• Support for math.log2 and math.remainder is added (Guilherme Leobas).

General deprecation notices:
• There are no new general deprecations.

CUDA target deprecation notices:
• CUDA support on macOS is deprecated with this release (it still works, it is just unsupported).
• The argtypes, restypes, and bind keyword arguments to the cuda.jit decorator, deprecated since 0.51.0, are removed
• The Device.COMPUTE_CAPABILITY property, deprecated since 2014, has been removed (use compute_capability instead).
• The to_host method of device arrays is removed (use copy_to_host instead).

General Enhancements:
• PR #4769: objmode complex type spelling (Siu Kwan Lam)
• PR #5579: Function subtyping (Lucio Fernandez-Arjona)
• PR #5659: Add support for parfors creating ‘Fortran layout Numpy arrays. (Todd A. Anderson)
• PR #5936: Improve array analysis for user-defined data types. (Todd A. Anderson)
• PR #5938: Initial support for dynamic gufuncs (Guilherme Leobas)
• PR #5958: Making typed.List a typing Generic (Lucio Fernandez-Arjona)
• PR #6334: Support attribute access from other modules (Farah Hariri)
• PR #6373: Allow Dispatchers to be cached (Eric Wieser)
• PR #6519: Avoid unnecessary ir.Del generation and removal (Ehsan Totoni)
• PR #6545: Refactoring ParforDiagnostics (Elena Totmenina)
• PR #6560: Add LLVM pass timer (Siu Kwan Lam)
• PR #6573: Improve __str__ for typed.List when invoked from IPython shell (Amin Sadeghi)
• PR #6575: Avoid temp variable assignments (Ehsan Totoni)
• PR #6578: Add support for numpy intersect1d and basic test cases (@caljrobe)
• PR #6579: Python 3.9 support. (Stuart Archibald)
• PR #6580: Store partial typing errors in compiler state (Ehsan Totoni)
• PR #6626: A simple event system to broadcast compiler events (Siu Kwan Lam)
• PR #6635: Try to resolve dynamic getitems as static post unroll transform. (Stuart Archibald)
• PR #6636: Adds llvm_lock event (Siu Kwan Lam)
• PR #6664: Adds tests for PR 5659 (Siu Kwan Lam)
• PR #6680: Allow getattr to work in objmode output type spec (Siu Kwan Lam)

Fixes:
• PR #6176: Remove references to deprecated numpy globals (Eric Wieser)
• PR #6374: Use Python 3 style OSError handling (Eric Wieser)
• PR #6402: Fix typed.Dict and typed.List crashing on parametrized types (Andreas Sodeur)
• PR #6403: Add types.ListType.key (Andreas Sodeur)
• PR #6410: Fixes issue #6386 (Danny Weitekamp)
• PR #6425: Fix unicode join for issue #6405 (Teugea Ioan-Teodor)
• PR #6437: Don’t pass reduction variables known in an outer parfor to inner parfors when analyzing reductions. (Todd A. Anderson)
• PR #6453: Keep original variable names in metadata to improve diagnostics (Ehsan Totoni)
• PR #6454: FIX: Fixes for literals (Eric Larson)
• PR #6463: Bump llvmlite to 0.36 series (Stuart Archibald)
• PR #6466: Remove the misspelling of finalize_dynamic Globals (Sergey Pokhodenko)
• PR #6489: Improve the error message for unsupported Buffer in Buffer situation. (Stuart Archibald)
• PR #6503: Add test to ensure Numba imports without warnings. (Stuart Archibald)
• PR #6508: Defer requirements to setup.py (Siu Kwan Lam)
• PR #6521: Skip annotated jitclass test if typeguard is running. (Stuart Archibald)
• PR #6524: Fix typed.List return value (Lucio Fernandez-Arjona)
• PR #6562: Correcting typo in numba sysinfo output (Nick Sutcliffe)
• PR #6574: Run parfor fusion if 2 or more parfors (Ehsan Totoni)
• PR #6582: Fix typed dict error with uninitialized padding bytes (Siu Kwan Lam)
• PR #6584: Remove jitclass from __init__ __all___. (Stuart Archibald)
• PR #6586: Run closure inlining ahead of branch pruning in case of nonlocal (Stuart Archibald)
• PR #6591: Fix inlineasm test failure. (Siu Kwan Lam)
• PR #6622: Fix 6534, handle unpack of assign-like tuples. (Stuart Archibald)
• PR #6652: Simplify PR-6334 (Siu Kwan Lam)
• PR #6653: Fix get_numba_envvar (Siu Kwan Lam)
• PR #6654: Fix #6632 support alternative dtype string spellings (Stuart Archibald)
• PR #6685: Add Python 3.9 to classifiers. (Stuart Archibald)
• PR #6693: patch to compile _devicearray.cpp with c++11 (Valentin Haenel)
• PR #6716: Consider assignment lhs live if used in rhs (Fixes #6715) (Ehsan Totoni)
• PR #6727: Avoid errors in array analysis for global tuples with non-int (Ehsan Totoni)
• PR #6733: Fix segfault and errors in #6668 (Siu Kwan Lam)
• PR #6741: Enable SSA in IR inliner (Ehsan Totoni)
• PR #6763: use an alternative constraint for the conda packages (Valentin Haenel)
• PR #6786: Fix gufunc kwargs support (Siu Kwan Lam)

CUDA Enhancements/Fixes:

• PR #5162: Specify synchronization semantics of CUDA Array Interface (Graham Markall)
• PR #6245: CUDA Cooperative grid groups (Graham Markall and Nick White)
• PR #6333: Remove dead _Kernel.__call__ (Graham Markall)
• PR #6343: CUDA: Add support for passing tuples and namedtuples to kernels (Graham Markall)
• PR #6349: Refactor Dispatcher to remove unnecessary indirection (Graham Markall)
• PR #6358: Add log2 and remainder implementations for cuda (Guilherme Leobas)
• PR #6376: Added a fixed seed in test_atomics.py for issue #6370 (Teugea Ioan-Teodor)
• PR #6377: CUDA: Fix various issues in test suite (Graham Markall)
• PR #6409: Implement cuda atomic xor (Michael Collison)
• PR #6422: CUDA: Remove deprecated items, expect CUDA 11.1 (Graham Markall)
• PR #6427: Remove duplicate repeated definition of gufunc (Amit Kumar)
• PR #6432: CUDA: Use _dispatcher.Dispatcher as base Dispatcher class (Graham Markall)
• PR #6447: CUDA: Add get_regs_per_thread method to Dispatcher (Graham Markall)
• PR #6499: CUDA atomic increment, decrement, exchange and compare and swap (Michael Collison)
• PR #6510: CUDA: Make device array assignment synchronous where necessary (Graham Markall)
• PR #6517: CUDA: Add NVVM test of all 8-bit characters (Graham Markall)
• PR #6567: Refactor llvm replacement code into separate function (Michael Collison)
• PR #6624: Testhound/cuda cuberoot (Michael Collison)
• PR #6661: CUDA: Support NVVM70 / CUDA 11.2 (Graham Markall)
• PR #6663: Fix error caused by missing “-static” libraries defined for some platforms (Siu Kwan Lam)
• PR #6666: CUDA: Add a function to query whether the runtime version is supported. (Graham Markall)
• PR #6725: CUDA: Fix compile to PTX with debug for CUDA 11.2 (Graham Markall)

Documentation Updates:
• PR #5740: Add FAQ entry on how to create a MWR. (Stuart Archibald)
• PR #6346: DOC: add where to get dev builds from to FAQ (Eyal Trabelsi)
• PR #6418: docs: use https for homepage (@imba-tjd)
• PR #6430: CUDA docs: Add RNG example with 3D grid and strided loops (Graham Markall)
• PR #6436: docs: remove typo in Deprecation Notices (Thibault Ballier)
• PR #6440: Add note about performance of typed containers from the interpreter. (Stuart Archibald)
• PR #6457: Link to read the docs instead of numba homepage (Hannes Pahl)
• PR #6470: Adding PyCon Sweden 2020 talk on numba (Ankit Mahato)
• PR #6472: Document numba.extending.is_jitted (Stuart Archibald)
• PR #6495: Fix typo in literal list docs. (Stuart Archibald)
• PR #6501: Add doc entry on Numba’s limited resources and how to help. (Stuart Archibald)
• PR #6502: Add CODEOWNERS file. (Stuart Archibald)
• PR #6531: Update canonical URL. (Stuart Archibald)
• PR #6544: Minor typo / grammar fixes to 5 minute guide (Ollin Boer Bohan)
• PR #6599: docs: fix simple typo, conservatively -> conservatively (Tim Gates)
• PR #6609: Recommend miniforge instead of c4aarch64 (Isuru Fernando)
• PR #6671: Update environment creation example to python 3.8 (Lucio Fernandez-Arjona)
• PR #6676: Update hardware and software versions in various docs. (Stuart Archibald)
• PR #6682: Update deprecation notices for 0.53 (Stuart Archibald)

CI/Infrastructure Updates:
• PR #6458: Enable typeguard in CI (Siu Kwan Lam)
• PR #6500: Update bug and feature request templates. (Stuart Archibald)
• PR #6516: Fix RTD build by using conda. (Stuart Archibald)
• PR #6587: Add zenodo badge (Siu Kwan Lam)

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• Eric Wieser
• Eyal Trabelsi
• Farah Hariri

9.7. Version 0.53.0 (11 March, 2021)
This release focuses on performance improvements, but also adds some new features and contains numerous bug fixes and stability improvements.

Highlights of core performance improvements include:

• Intel kindly sponsored research and development into producing a new reference count pruning pass. This pass operates at the LLVM level and can prune a number of common reference counting patterns. This will improve performance for two primary reasons:
  – There will be less pressure on the atomic locks used to do the reference counting.
  – Removal of reference counting operations permits more inlining and the optimisation passes can in general do more with what is present.
(Siu Kwan Lam).

• Intel also sponsored work to improve the performance of the numba.typed.List container, particularly in the case of __getitem__ and iteration (Stuart Archibald).

• Superword-level parallelism vectorization is now switched on and the optimisation pipeline has been lightly analysed and tuned so as to be able to vectorize more and more often (Stuart Archibald).

Highlights of core feature changes include:

• The inspect_cfg method on the JIT dispatcher object has been significantly enhanced and now includes highlighted output and interleaved line markers and Python source (Stuart Archibald).
• The BSD operating system is now unofficially supported (Stuart Archibald).

• Numerous features/functionality improvements to NumPy support, including support for:
  – np.asfarray (Guilherme Leobas)
  – “subtyping” in record arrays (Lucio Fernandez-Arjona)
  – np.split and np.array_split (Isaac Virshup)
  – operator.contains with ndarray (@mugoh).
  – np.asarray_chkfinite (Rishabh Varshney).
  – NumPy 1.19 (Stuart Archibald).
  – the ndarray allocators, empty, ones and zeros, accepting a dtype specified as a string literal (Stuart Archibald).

• Booleans are now supported as literal types (Alexey Kozlov).

• On the CUDA target:
  – CUDA 9.0 is now the minimum supported version (Graham Markall).
  – Support for Unified Memory has been added (Max Katz).
  – Kernel launch overhead is reduced (Graham Markall).
  – Cudasim support for mapped array, memcopies and memset has been added (Mike Williams).
  – Access has been wired in to all libdevice functions (Graham Markall).
  – Additional CUDA atomic operations have been added (Michael Collison).
  – Additional math library functions (frexp, ldexp, isfinite) (Zhihao Yuan).
  – Support for power on complex numbers (Graham Markall).

Deprecations to note:

There are no new deprecations. However, note that “compatibility” mode, which was added some 40 releases ago to help transition from 0.11 to 0.12+, has been removed! Also, the shim to permit the import of jitclass from Numba’s top level namespace has now been removed as per the deprecation schedule.

General Enhancements:

• PR #5418: Add np.asarray impl (Guilherme Leobas)
• PR #5560: Record subtyping (Lucio Fernandez-Arjona)
• PR #5609: Jitclass Infer Spec from Type Annotations (Ethan Pronovost)
• PR #5699: Implement np.split and np.array_split (Isaac Virshup)
• PR #6015: Adding BooleanLiteral type (Alexey Kozlov)
• PR #6027: Support operators inlining in InlineOverloads (Alexey Kozlov)
• PR #6038: Closes #6037, fixing FreeBSD compilation (László Károlyi)
• PR #6086: Add more accessible version information (Stuart Archibald)
• PR #6157: Add pipeline_class argument to @cfunc as supported by @jit. (Arthur Peters)
• PR #6262: Support dtype from str literal. (Stuart Archibald)
• PR #6271: Support ndarray contains (@mugoh)
• PR #6295: Enhance inspect_cfg (Stuart Archibald)
• PR #6304: Support NumPy 1.19 (Stuart Archibald)
• PR #6309: Add suitable file search path for BSDs. (Stuart Archibald)
• PR #6341: Re roll 6279 (Rishabh Varshney and Valentin Haenel)

Performance Enhancements:
• PR #6145: Patch to fingerprint namedtuples. (Stuart Archibald)
• PR #6202: Speed up str(int) (Stuart Archibald)
• PR #6261: Add np.ndarray.ptp() support. (Stuart Archibald)
• PR #6266: Use custom LLVM refcount pruning pass (Siu Kwan Lam)
• PR #6275: Switch on SLP vectorize. (Stuart Archibald)
• PR #6278: Improve typed list performance. (Stuart Archibald)
• PR #6335: Split optimisation passes. (Stuart Archibald)
• PR #6455: Fix refprune on obfuscated refs and stabilize optimisation WRT wrappers. (Stuart Archibald)

Fixes:
• PR #5639: Make UnicodeType inherit from Hashable (Stuart Archibald)
• PR #6006: Resolves incorrectly hoisted list in parfor. (Todd A. Anderson)
• PR #6126: fix version_info if version can not be determined (Valentin Haenel)
• PR #6137: Remove references to Python 2’s long (Eric Wieser)
• PR #6139: Use direct syntax instead of the add_metaclass decorator (Eric Wieser)
• PR #6140: Replace calls to utils.iteritems(d) with d.items() (Eric Wieser)
• PR #6141: Fix #6130 objmode cache segfault (Siu Kwan Lam)
• PR #6156: Remove callers of reraise in favor of using with_traceback directly (Eric Wieser)
• PR #6162: Move charseq support out of init (Stuart Archibald)
• PR #6165: #5425 continued (Amos Bird and Stuart Archibald)
• PR #6166: Remove Python 2 compatibility from numba.core.utils (Eric Wieser)
• PR #6185: Better error message on NotDefinedError (Luiz Almeida)
• PR #6194: Remove recursion from traverse_types (Radu Popovici)
• PR #6200: Workaround #5973 (Stuart Archibald)
• PR #6203: Make find_callname only lookup functions that are likely part of NumPy. (Stuart Archibald)
• PR #6204: Fix unicode kind selection for getitem. (Stuart Archibald)
• PR #6206: Build all extension modules with -g -Wall -Werror on Linux x86, provide -O0 flag option (Graham Markall)
• PR #6212: Fix for objmode recompilation issue (Alexey Kozlov)
• PR #6213: Fix #6177. Remove AOT dependency on the Numba package (Siu Kwan Lam)
• PR #6224: Add support for tuple concatenation to array analysis. (#5396 continued) (Todd A. Anderson)
• PR #6231: Remove compatibility mode (Graham Markall)
• PR #6254: Fix win-32 hashing bug (from Stuart Archibald) (Ray Donnelly)
• PR #6265: Fix #6260 (Stuart Archibald)
• PR #6267: speed up a couple of really slow unitests (Stuart Archibald)
• PR #6281: Remove numba.jitclass shim as per deprecation schedule. (Stuart Archibald)
• PR #6294: Make return type propagate to all return variables (Andreas Sodeur)
• PR #6300: Un-skip tests that were skipped because of #4026. (Owen Anderson)
• PR #6307: Remove restrictions on SVML version due to bug in LLVM SVML CC (Stuart Archibald)
• PR #6316: Make IR inliner tests not self mutating. (Stuart Archibald)
• PR #6318: PR #5892 continued (Todd A. Anderson, via Stuart Archibald)
• PR #6319: Permit switching off boundschecking when debug is on. (Stuart Archibald)
• PR #6324: PR 6208 continued (Ivan Butygin and Stuart Archibald)
• PR #6337: Implements key on types.TypeRef (Andreas Sodeur)
• PR #6354: Bump llvmlite to 0.35. series. (Stuart Archibald)
• PR #6357: Fix enumerate invalid decref (Siu Kwan Lam)
• PR #6359: Fixes typed list indexing on 32bit (Stuart Archibald)
• PR #6378: Fix incorrect CPU override in vectorization test. (Stuart Archibald)
• PR #6379: Use O0 to enable inline and not affect loop-vectorization by later O3… (Siu Kwan Lam)
• PR #6384: Fix failing tests to match on platform invariant int spelling. (Stuart Archibald)
• PR #6390: Updates inspect_cfg (Stuart Archibald)
• PR #6396: Remove hard dependency on tbb package. (Stuart Archibald)
• PR #6408: Don’t do array analysis for tuples that contain arrays. (Todd A. Anderson)
• PR #6441: Fix ASCII flag in Unicode slicing (0.52.0rc2 regression) (Ehsan Totoni)
• PR #6442: Fix array analysis regression in 0.52 RC2 for tuple of 1D arrays (Ehsan Totoni)
• PR #6446: Fix #6444: pruner issues with reference stealing functions (Siu Kwan Lam)
• PR #6450: Fix asarray kwarg default handling. (Stuart Archibald)
• PR #6486: fix abstract base class import (Valentin Haenel)
• PR #6487: Restrict maximum version of python (Siu Kwan Lam)
• PR #6527: setup.py: fix py version guard (Chris Barnes)

CUDA Enhancements/Fixes:
• PR #5465: Remove macro expansion and replace uses with FE typing + BE lowering (Graham Markall)
• PR #5741: CUDA: Add two-argument implementation of round() (Graham Markall)
• PR #5900: Enable CUDA Unified Memory (Max Katz)
• PR #6042: CUDA: Lower launch overhead by launching kernel directly (Graham Markall)
• PR #6064: Lower math.frexp and math.ldexp in numba.cuda (Zhihao Yuan)
• PR #6066: Lower math.isfinite in numba.cuda (Zhihao Yuan)
• PR #6092: CUDA: Add mapped_array_like and pinned_array_like (Graham Markall)
• PR #6127: Fix race in reduction kernels on Volta, require CUDA 9, add syncwarp with default mask (Graham Markall)
• PR #6129: Extend Cudasim to support most of the memory functionality. (Mike Williams)
• PR #6150: CUDA: Turn on flake8 for cudadriv and fix errors (Graham Markall)
• PR #6152: CUDA: Provide wrappers for all libdevice functions, and fix typing of math function (#4618) (Graham Markall)
• PR #6227: Raise exception when no supported architectures are found (Jacob Tomlinson)
• PR #6244: CUDA Docs: Make workflow using simulator more explicit (Graham Markall)
• PR #6248: Add support for CUDA atomic subtract operations (Michael Collison)
• PR #6289: Refactor atomic test cases to reduce code duplication (Michael Collison)
• PR #6290: CUDA: Add support for complex power (Graham Markall)
• PR #6296: Fix flake8 violations in numba.cuda module (Graham Markall)
• PR #6297: Fix flake8 violations in numba.cuda.tests.cudapy module (Graham Markall)
• PR #6298: Fix flake8 violations in numba.cuda.tests.cudadriv (Graham Markall)
• PR #6299: Fix flake8 violations in numba.cuda.simulator (Graham Markall)
• PR #6306: Fix flake8 in cuda atomic test from merge. (Stuart Archibald)
• PR #6325: Refactor code for atomic operations (Michael Collison)
• PR #6329: Flake8 fix for a CUDA test (Stuart Archibald)
• PR #6331: Explicitly state that NUMBA_ENABLE_CUDASIM needs to be set before import (Graham Markall)
• PR #6340: CUDA: Fix #6339, performance regression launching specialized kernels (Graham Markall)
• PR #6380: Only test managed allocations on Linux (Graham Markall)

Documentation Updates:
• PR #6090: doc: Add doc on direct creation of Numba typed-list (@rht)
• PR #6110: Update CONTRIBUTING.md (Stuart Archibald)
• PR #6128: CUDA Docs: Restore Dispatcher.forall() docs (Graham Markall)
• PR #6277: fix: cross2d wrong doc. reference (issue #6276) (@jeertmans)
• PR #6282: Remove docs on Python 2.7. EOL. (Stuart Archibald)
• PR #6283: Add note on how public CI is impl and what users can do to help. (Stuart Archibald)
• PR #6292: Document support for structured array attribute access (Graham Markall)
• PR #6310: Declare unofficial *BSD support (Stuart Archibald)
• PR #6342: Fix docs on literally usage. (Stuart Archibald)
• PR #6348: doc: fix typo in jitclass.rst ("initilising" -> "initialising") (@muxator)
• PR #6362: Move llvmlite support in README to 0.35 (Stuart Archibald)
• PR #6363: Note that reference counted types are not permitted in set(). (Stuart Archibald)
• PR #6364: Move deprecation schedules for 0.52 (Stuart Archibald)

CI/Infrastructure Updates:
• PR #6252: Show channel URLs (Siu Kwan Lam)
• PR #6338: Direct user questions to Discourse instead of the Google Group. (Stan Seibert)

• PR #6474: Add skip on PPC64LE for tests causing SIGABRT in LLVM. (Stuart Archibald)

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9.9 Version 0.51.2 (September 2, 2020)

This is a bugfix release for 0.51.1. It fixes a critical performance bug in the CFG back edge computation algorithm that leads to exponential time complexity arising in compilation for use cases with certain pathological properties.

- PR #6195: PR 6187 Continue. Don’t visit already checked successors

Authors:
- Graham Markall
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9.10 Version 0.51.1 (August 26, 2020)

This is a bugfix release for 0.51.0, it fixes a critical bug in caching, another critical bug in the CUDA target initialisation sequence and also fixes some compile time performance regressions:

- PR #6141: Fix #6130 objmode cache segfault
- PR #6146: Fix compilation slowdown due to controlflow analysis
- PR #6147: CUDA: Don’t make a runtime call on import
- PR #6153: Fix for #6151. Make UnicodeCharSeq into str for comparison.
- PR #6168: Fix Issue #6167: Failure in test_cuda_submodules

Authors:
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9.11 Version 0.51.0 (August 12, 2020)

This release continues to add new features to Numba and also contains a significant number of bug fixes and stability improvements.

Highlights of core feature changes include:

- The compilation chain is now based on LLVM 10 (Valentin Haenel).
- Numba has internally switched to prefer non-literal types over literal ones so as to reduce function over-specialisation, this with view of speeding up compile times (Siu Kwan Lam).
- On the CUDA target: Support for CUDA Toolkit 11, Ampere, and Compute Capability 8.0; Printing of SASS code for kernels; Callbacks to Python functions can be inserted into CUDA streams, and streams are async awaitable; Atomic nanmin and nanmax functions are added; Fixes for various miscompilations and segfaults. (mostly Graham Markall; call backs on streams by Peter Würtz).

Intel also kindly sponsored research and development that lead to some exciting new features:

- Support for heterogeneous immutable lists and heterogeneous immutable string key dictionaries. Also optional initial/construction value capturing for all lists and dictionaries containing literal values (Stuart Archibald).
- A new pass-by-reference mutable structure extension type StructRef (Siu Kwan Lam).
Object mode blocks are now cacheable, with the side effect of numerous bug fixes and performance improvements in caching. This also permits caching of functions defined in closures (Siu Kwan Lam).

Deprecations to note:
To align with other targets, the argtypes and restypes kwargs to @cuda.jit are now deprecated, the bind kwarg is also deprecated. Further the target kwarg to the numba.jit decorator family is deprecated.

General Enhancements:
- PR #5463: Add str(int) impl
- PR #5526: Impl. np.asarray(literal)
- PR #5619: Add support for multi-output ufuncs
- PR #5711: Division with timedelta input
- PR #5763: Support minlength argument to np.bincount
- PR #5779: Return zero array from np.dot when the arguments are empty.
- PR #5796: Add implementation for np.positive
- PR #5849: Setitem for records when index is StringLiteral, including literal unroll
- PR #5856: Add support for conversion of inplace_binop to parfor.
- PR #5893: Allocate 1D iteration space one at a time for more even distribution.
- PR #5922: Reduce objmode and unpickling overhead
- PR #5944: re-enable OpenMP in wheels
- PR #5946: Implement literal dictionaries and lists.
- PR #5956: Update numba_sysinfo.py
- PR #5978: Add structref as a mutable struct that is pass-by-ref
- PR #5980: Deprecate target kwarg for numba.jit.
- PR #6058: Add prefer_literal option to overload API

Fixes:
- PR #5674: Fix #3955. Allow with objmode to be cached
- PR #5724: Initialize process lock lazily to prevent multiprocessing issue
- PR #5783: Make np.divide and np.remainder code more similar
- PR #5808: Fix 5665 Block jit(nopython=True, forceobj=True) and suppress njit(forceobj=True)
- PR #5834: Fix the is operator on Ellipsis
- PR #5838: Ensure Dispatcher.__eq__ always returns a bool
- PR #5841: cleanup: Use PythonAPI.bool_from_bool in more places
- PR #5862: Do not leak loop iteration variables into the numba.np.npyimpl namespace
- PR #5869: Update repomap
- PR #5879: Fix erroneous input mutation in linalg routines
- PR #5882: Type check function in jit decorator
- PR #5925: Use np.inf and -np.inf for max and min float values respectively.
- PR #5935: Fix default arguments with multiprocessing
• PR #5952: Fix “Internal error ... local variable ‘errstr’ referenced before assignment during BoundFunc-
tection(...)”
• PR #5962: Fix SVML tests with LLVM 10 and AVX512
• PR #5972: fix flake8 for numba/runtests.py
• PR #5995: Update setup.py with new llvmlite versions
• PR #5996: Set lower bound for llvmlite to 0.33
• PR #6004: Fix problem in branch pruning with LiteralStrKeyDict
• PR #6017: Fixing up numba_do_raise
• PR #6028: Fix #6023
• PR #6031: Continue 5821
• PR #6035: Fix overspecialize of literal
• PR #6046: Fixes statement reordering bug in maximize fusion step.
• PR #6056: Fix issue on invalid inlining of non-empty build_list by inline_arraycall
• PR #6057: fix aarch64/python_3.8 failure on master
• PR #6070: Fix overspecialized containers
• PR #6071: Remove f-strings in setup.py
• PR #6072: Fix for #6005
• PR #6073: Fixes invalid C prototype in helper function.
• PR #6078: Duplicate NumPy’s PyArray_DescrCheck macro
• PR #6081: Fix issue with cross drive use and relpath.
• PR #6083: Fix bug in initial value unify.
• PR #6087: remove invalid sanity check from randrange tests
• PR #6089: Fix invalid reference to TypingError
• PR #6097: Add function code and closure bytes into cache key
• PR #6099: Restrict upper limit of TBB version due to ABI changes.
• PR #6101: Restrict lower limit of icc_rt version due to assumed SVML bug.
• PR #6107: Fix and test #6095
• PR #6109: Fixes an issue reported in #6094
• PR #6111: Decouple LiteralList and LiteralStrKeyDict from tuple
• PR #6116: Fix #6102. Problem with non-unique label.

CUDA Enhancements/Fixes:
• PR #5359: Remove special-casing of 0d arrays
• PR #5709: CUDA: Refactoring of cuda.jit and kernel / dispatcher abstractions
• PR #5732: CUDA Docs: document forall method of kernels
• PR #5745: CUDA stream callbacks and async awaitable streams
• PR #5761: Add implemtation for int types for isnan and isinf for CUDA
Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

- PR #5819: Add support for CUDA 11 and Ampere / CC 8.0
- PR #5826: CUDA: Add function to get SASS for kernels
- PR #5846: CUDA: Allow disabling NVVM optimizations, and fix debug issues
- PR #5851: CUDA EMM enhancements - add default get_ipc_handle implementation, skip a test conditionally
- PR #5852: CUDA: Fix cuda.test()
- PR #5857: CUDA docs: Add notes on resetting the EMM plugin
- PR #5859: CUDA: Fix reduce docs and style improvements
- PR #6016: Fixes change of list spelling in a cuda test.
- PR #6020: CUDA: Fix #5820, adding atomic nanmin / nanmax
- PR #6030: CUDA: Don’t optimize IR before sending it to NVVM
- PR #6052: Fix dtype for atomic_add_double testsuite
- PR #6080: CUDA: Prevent auto-upgrade of atomic intrinsics
- PR #6123: Fix #6121

Documentation Updates:
- PR #5782: Host docs on Read the Docs
- PR #5830: doc: Mention that caching uses pickle
- PR #5963: Fix broken link to numpy ufunc signature docs
- PR #5975: restructure communication section
- PR #5981: Document bounds-checking behavior in python deviations page
- PR #5993: Docs for structref
- PR #6008: Small fix so bullet points are rendered by sphinx
- PR #6013: emphasize cuda kernel functions are asynchronous
- PR #6036: Update deprecation doc from numba.errors to numba.core.errors
- PR #6062: Change references to numba.pydata.org to https

CI updates:
- PR #5850: Updates the “New Issue” behaviour to better redirect users.
- PR #5940: Add discourse badge
- PR #5960: Setting mypy on CI

Enhancements from user contributed PRs (with thanks!):
- Aisha Tammy added the ability to switch off TBB support at compile time in #5821 (continued in #6031 by Stuart Archibald).
- Alexander Stiebing fixed a reference before assignment bug in #5952.
- Alexey Kozlov fixed a bug in tuple getitem for literals in #6028.
- Andrew Eckart updated the repomap in #5869, added support for Read the Docs in #5782, fixed a bug in the np.dot implementation to correctly handle empty arrays in #5779 and added support for minlength to np.bincount in #5763.
- @bitsisbits updated numba_sysinfo.py to handle HSA agents correctly in #5956.
• Daichi Suzuo Fixed a bug in the threading backend initialisation sequence such that it is now correctly a lazy lock in #5724.

• Eric Wieser contributed a number of patches, particularly in enhancing and improving the ufunc capabilities:
  – #5359: Remove special-casing of 0d arrays
  – #5834: Fix the is operator on Ellipsis
  – #5619: Add support for multi-output ufuns
  – #5841: cleanup: Use PythonAPI.bool_from_bool in more places
  – #5862: Do not leak loop iteration variables into the numba.np.npyimpl namespace
  – #5838: Ensure Dispatcher.__eq__ always returns a bool
  – #5830: doc: Mention that caching uses pickle
  – #5783: Make np.divide and np.remainder code more similar

• Ethan Pronovost added a guard to prevent the common mistake of applying a jit decorator to the same function twice in #5881.

• Graham Markall contributed many patches to the CUDA target, as follows:
  – #6052: Fix dtype for atomic_add_double tests
  – #6030: CUDA: Don’t optimize IR before sending it to NVVM
  – #5846: CUDA: Allow disabling NVVM optimizations, and fix debug issues
  – #5826: CUDA: Add function to get SASS for kernels
  – #5851: CUDA EMM enhancements - add default get_ipc_handle implementation, skip a test conditionally
  – #5709: CUDA: Refactoring of cuda.jit and kernel / dispatcher abstractions
  – #5819: Add support for CUDA 11 and Ampere / CC 8.0
  – #6020: CUDA: Fix #5820, adding atomic nanmin / nanmax
  – #5857: CUDA docs: Add notes on resetting the EMM plugin
  – #5859: CUDA: Fix reduce docs and style improvements
  – #5852: CUDA: Fix cuda.test()
  – #5732: CUDA Docs: document forall method of kernels

• Guilherme Leobas added support for str(int) in #5463 and np.asarray(literal value)` in #5526.

• Hameer Abbasi deprecated the target kwarg for numba.jit in #5980.

• Hannes Pahl added a badge to the Numba github page linking to the new discourse forum in #5940 and also fixed a bug that permitted illegal combinations of flags to be passed into @jit in #5808.

• Kayran Schmidt emphasized that CUDA kernel functions are asynchronous in the documentation in #6013.

• Leonardo Uieda fixed a broken link to the NumPy ufunc signature docs in #5963.

• Lucio Fernandez-Arjona added mypy to CI and started adding type annotations to the code base in #5960, also fixed a (de)serialization problem on the dispatcher in #5935, improved the undefined variable error message in #5876, added support for division with timedelta input in #5711 and implemented setitem for records when the index is a StringLiteral in #5849.

• Ludovic Tiako documented Numba’s bounds-checking behavior in the python deviations page in #5981.

• Matt Roeschke changed all http references https in #6062.
• @niteya-shah implemented isnan and isinf for integer types on the CUDA target in #5761 and implemented np.positive in #5796.
• Peter Würtz added CUDA stream callbacks and async awaitable streams in #5745.
• @rht fixed an invalid import referred to in the deprecation documentation in #6036.
• Sergey Pokhodenko updated the SVML tests for LLVM 10 in #5962.
• Shyam Saladi fixed a Sphinx rendering bug in #6008.

Authors:
• Aisha Tammy
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• Alexey Kozlov
• Andrew Eckart
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• Daichi Suzuo
• Eric Wieser
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• Guilherme Leobas
• Hameer Abbasi
• Hannes Pahl
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• Leonardo Uieda
• Lucio Fernandez-Arjona
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• Stuart Archibald (core dev)
• Todd A. Anderson (core dev)
• Valentin Haenel (core dev)
9.12 Version 0.50.1 (Jun 24, 2020)

This is a bugfix release for 0.50.0, it fixes a critical bug in error reporting and a number of other smaller issues:

- PR #5861: Added except for possible Windows get_terminal_size exception
- PR #5876: Improve undefined variable error message
- PR #5884: Update the deprecation notices for 0.50.1
- PR #5889: Fixes literally not forcing re-dispatch for inline='always'
- PR #5912: Fix bad attr access on certain typing templates breaking exceptions.
- PR #5918: Fix cuda test due to #5876

Authors:

- @pepping_dore
- Lucio Fernandez-Arjona
- Siu Kwan Lam (core dev)
- Stuart Archibald (core dev)

9.13 Version 0.50.0 (Jun 10, 2020)

This is a more usual release in comparison to the others that have been made in the last six months. It comprises the result of a number of maintenance tasks along with some new features and a lot of bug fixes.

Highlights of core feature changes include:

- The compilation chain is now based on LLVM 9.
- The error handling and reporting system has been improved to reduce the size of error messages, and also improve quality and specificity.
- The CUDA target has more stream constructors available and a new function for compiling to PTX without linking and loading the code to a device. Further, the macro-based system for describing CUDA threads and blocks has been replaced with standard typing and lowering implementations, for improved debugging and extensibility.

IMPORTANT: The backwards compatibility shim, that was present in 0.49.x to accommodate the refactoring of Numba’s internals, has been removed. If a module is imported from a moved location an `ImportError` will occur.

General Enhancements:

- PR #5060: Enables np.sum for timedelta64
- PR #5225: Adjust interpreter to make conditionals predicates via bool() call.
- PR #5506: Jitclass static methods
- PR #5580: Revert shim
- PR #5591: Fix #5525 Add figure for total memory to `numba -s` output.
- PR #5616: Simplify the ufunc kernel registration
- PR #5617: Remove /examples from the Numba repo.
- PR #5673: Fix inliners to run all passes on IR and clean up correctly.
- PR #5700: Make it easier to understand type inference: add SSA dump, use for DEBUG_TYPEINFER
• PR #5702: Fixes for LLVM 9
• PR #5722: Improve error messages.
• PR #5758: Support NumPy 1.18

Fixes:
• PR #5390: add error handling for lookup_module
• PR #5464: Jitclass drops annotations to avoid error
• PR #5478: Fix #5471. Issue with omitted type not recognized as literal value.
• PR #5517: Fix numba.typed.List extend for singleton and empty iterable
• PR #5549: Check type getitem
• PR #5568: Add skip to entrypoint test on windows
• PR #5581: Revert #5568
• PR #5602: Fix segfault caused by pop from numba.typed.List
• PR #5645: Fix SSA redundant CFG computation
• PR #5686: Fix issue with SSA not minimal
• PR #5689: Fix bug in unified_function_type (issue 5685)
• PR #5694: Skip part of slice array analysis if any part is not analyzable.
• PR #5697: Fix usedef issue with parfor loopnest variables.
• PR #5705: A fix for cases where SSA looks like a reduction variable.
• PR #5714: Fix bug in test
• PR #5717: Initialise Numba extensions ahead of any compilation starting.
• PR #5721: Fix array iterator layout.
• PR #5738: Unbreak master on buildfarm
• PR #5757: Force LLVM to use ZMM registers for vectorization.
• PR #5764: fix flake8 errors
• PR #5768: Interval example: fix import
• PR #5781: Moving record array examples to a test module
• PR #5791: Fix up no cgroups problem
• PR #5795: Restore refct removal pass and make it strict
• PR #5807: Skip failing test on POWER8 due to PPC CTR Loop problem.
• PR #5812: Fix side issue from #5792, @overload inliner cached IR being mutated.
• PR #5815: Pin llvmlite to 0.33
• PR #5833: Fixes the source location appearing incorrectly in error messages.

CUDA Enhancements/Fixes:
• PR #5347: CUDA: Provide more stream constructors
• PR #5388: CUDA: Fix OOB write in test_round[f4,f8]
• PR #5437: Fix #5429: Exception using .get_ipc_handle(...) on array from as_cuda_array(...)
• PR #5481: CUDA: Replace macros with typing and lowering implementations
• PR #5556: CUDA: Make atomic semantics match Python / NumPy, and fix #5458
• PR #5558: CUDA: Only release primary ctx if retained
• PR #5561: CUDA: Add function for compiling to PTX (+ other small fixes)
• PR #5573: CUDA: Skip tests under cuda-memcheck that hang it
• PR #5578: Implement math.modf for CUDA target
• PR #5704: CUDA Eager compilation: Fix max_registers kwarg
• PR #5718: CUDA lib path tests: unset CUDA_PATH when CUDA_HOME unset
• PR #5800: Fix LLVM 9 IR for NVVM
• PR #5803: CUDA Update expected error messages to fix #5797

Documentation Updates:
• PR #5546: DOC: Add documentation about cost model to inlining notes.
• PR #5653: Update doc with respect to try-finally case

Enhancements from user contributed PRs (with thanks!):
• Elias Kuthe fixed in issue with imports in the Interval example in #5768
• Eric Wieser Simplified the ufunc kernel registration mechanism in #5616
• Ethan Pronovost patched a problem with __annotations__ in jitclass in #5464, fixed a bug that lead to infinite loops in Numba's Type.__getitem__ in #5549, fixed a bug in np.arange testing in #5714 and added support for @staticmethod to jitclass in #5506.
• Gabriele Gemmi implemented math.modf for the CUDA target in #5578
• Graham Markall contributed many patches, largely to the CUDA target, as follows:
  – #5347: CUDA: Provide more stream constructors
  – #5388: CUDA: Fix OOB write in test_round{f4,f8}
  – #5437: Fix #5429: Exception using .get_ipc_handle(...) on array from as_cuda_array(...)
  – #5481: CUDA: Replace macros with typing and lowering implementations
  – #5556: CUDA: Make atomic semantics match Python / NumPy, and fix #5458
  – #5558: CUDA: Only release primary ctx if retained
  – #5561: CUDA: Add function for compiling to PTX (+ other small fixes)
  – #5573: CUDA: Skip tests under cuda-memcheck that hang it
  – #5648: Unset the memory manager after EMM Plugin tests
  – #5700: Make it easier to understand type inference: add SSA dump, use for DEBUG_TYPEINFER
  – #5704: CUDA Eager compilation: Fix max_registers kwarg
  – #5718: CUDA lib path tests: unset CUDA_PATH when CUDA_HOME unset
  – #5800: Fix LLVM 9 IR for NVVM
  – #5803: CUDA Update expected error messages to fix #5797
• Guilherme Leobas updated the documentation surrounding try-finally in #5653
• Hameer Abbasi added documentation about the cost model to the notes on inlining in #5546
• Jacques Gaudin rewrote numba -s to produce and consume a dictionary of output about the current system in #5591
• James Bourbeau Updated min/argmin and max/argmax to handle non-leading nans (via #5758)
• Lucio Fernandez-Arjona moved the record array examples to a test module in #5781 and added np.timedelta64 handling to np.sum in #5060
• Pearu Peterson Fixed a bug in unified_function_type in #5689
• Sergey Pokhodenko fixed an issue impacting LLVM 10 regarding vectorization widths on Intel SkyLake processors in #5757
• Shan Sikdar added error handling for lookup_module in #5390
• @toddrme2178 add CI testing for NumPy 1.18 (via #5758)

Authors:

• Elias Kuthe
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• Ethan Pronovost
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9.14 Version 0.49.1 (May 7, 2020)

This is a bugfix release for 0.49.0, it fixes some residual issues with SSA form, a critical bug in the branch pruning logic and a number of other smaller issues:

• PR #5587: Fixed #5586 Threading Implementation Typos
• PR #5592: Fixes #5583 Remove references to cffi_support from docs and examples
• PR #5614: Fix invalid type in resolve for comparison expr in parfors.
• PR #5624: Fix erroneous rewrite of predicate to bit const on prune.
Numba Documentation, Release 0.55.2+0.g2298ad618.dirty-py3.7-linux-x86_64.egg

- PR #5627: Fixes #5623, SSA local def scan based on invalid equality assumption.
- PR #5629: Fixes naming error in array_exprs
- PR #5630: Fix #5570. Incorrect race variable detection due to SSA naming.
- PR #5638: Make literal_unroll function work as a freevar.
- PR #5648: Unset the memory manager after EMM Plugin tests
- PR #5651: Fix some SSA issues
- PR #5652: Pin to sphinx=2.4.4 to avoid problem with C declaration
- PR #5658: Fix unifying undefined first class function types issue
- PR #5669: Update example in 5m guide WRT SSA type stability.
- PR #5676: Restore numba.types as public API

Authors:
- Graham Markall
- Juan Manuel Cruz Martinez
- Pearu Peterson
- Sean Law
- Stuart Archibald (core dev)
- Siu Kwan Lam (core dev)

9.15 Version 0.49.0 (Apr 16, 2020)

This release is very large in terms of code changes. Large scale removal of unsupported Python and NumPy versions has taken place along with a significant amount of refactoring to simplify the Numba code base to make it easier for contributors. Numba's intermediate representation has also undergone some important changes to solve a number of long standing issues. In addition some new features have been added and a large number of bugs have been fixed!

IMPORTANT: In this release Numba's internals have moved about a lot. A backwards compatibility "shim" is provided for this release so as to not immediately break projects using Numba's internals. If a module is imported from a moved location the shim will issue a deprecation warning and suggest how to update the import statement for the new location. The shim will be removed in 0.50.0!

Highlights of core feature changes include:
- Removal of all Python 2 related code and also updating the minimum supported Python version to 3.6, the minimum supported NumPy version to 1.15 and the minimum supported SciPy version to 1.0. (Stuart Archibald).
- Refactoring of the Numba code base. The code is now organised into submodules by functionality. This cleans up Numba's top level namespace. (Stuart Archibald).
- Introduction of an ir.Del free static single assignment form for Numba's intermediate representation (Siu Kwan Lam and Stuart Archibald).
- An OpenMP-like thread masking API has been added for use with code using the parallel CPU backends (Aaron Meurer and Stuart Archibald).
- For the CUDA target, all kernel launches now require a configuration, this preventing accidental launches of kernels with the old default of a single thread in a single block. The hard-coded autotuner is also now removed, such tuning is deferred to CUDA API calls that provide the same functionality (Graham Markall).
• The CUDA target also gained an External Memory Management plugin interface to allow Numba to use another CUDA-aware library for all memory allocations and deallocations (Graham Markall).
• The Numba Typed List container gained support for construction from iterables (Valentin Haenel).
• Experimental support was added for first-class function types (Pearu Peterson).

Enhancements from user contributed PRs (with thanks!):
• Aaron Meurer added support for thread masking at runtime in #4615.
• Andreas Sodeur fixed a long standing bug that was preventing cProfile from working with Numba JIT compiled functions in #4476.
• Arik Funke fixed error messages in test_array_reductions (#5278), fixed an issue with test discovery (#5239), made it so the documentation would build again on windows (#5453) and fixed a nested list problem in the docs in #5489.
• Antonio Russo fixed a SyntaxWarning in #5252.
• Eric Wieser added support for inferring the types of object arrays (#5348) and iterating over 2D arrays (#5115), also fixed some compiler warnings due to missing (void) in #5222. Also helped improved the “shim” and associated warnings in #5485, #5488, #5498 and partly #5532.
• Ethan Pronovost fixed a problem with the shim erroneously warning for jitclass use in #5454 and also prevented illegal return values in jitclass __init__ in #5505.
• Gabriel Majeri added SciPy 2019 talks to the docs in #5106.
• Graham Markall changed the Numba HTML documentation theme to resolve a number of long standing issues in #5346. Also contributed were a large number of CUDA enhancements and fixes, namely:
  – #5519: CUDA: Silence the test suite - Fix #4809, remove autojit, delete prints
  – #5443: Fix #5196: Docs: assert in CUDA only enabled for debug
  – #5436: Fix #5408: test_set_registers_57 fails on Maxwell
  – #5423: Fix #5421: Add notes on printing in CUDA kernels
  – #5400: Fix #4954, and some other small CUDA testsuite fixes
  – #5328: NBEP 7: External Memory Management Plugin Interface
  – #5144: Fix #4875: Make #2655 test with debug expect to pass
  – #5323: Document lifetime semantics of CUDA Array Interface
  – #5061: Prevent kernel launch with no configuration, remove autotuner
  – #5099: Fix #5073: Slices of dynamic shared memory all alias
  – #5136: CUDA: Enable asynchronous operations on the default stream
  – #5085: Support other itemsizes with view
  – #5059: Docs: Explain how to use Memcheck with Numba, fixups in CUDA documentation
  – #4957: Add notes on overwriting gufunc inputs to docs
• Greg Jennings fixed an issue with np.random.choice not acknowledging the RNG seed correctly in #3897/#5310.
• Guilherme Leobas added support for np.isnat in #5293.
• Henry Schreiner made the llvmlite requirements more explicit in requirements.txt in #5150.
• Ivan Butygin helped fix an issue with parfors sequential lowering in #5114/#5250.
• Jacques Gaudin fixed a bug for Python >= 3.8 in numba -s in #5548.
• Jim Pivarski added some hints for debugging entry points in #5280.
• John Kirkham added numpy.dtype coercion for the dtype argument to CUDA device arrays in #5252.
• Leo Fang added a list of libraries that support __cuda_array_interface__ in #5104.
• Lucio Fernandez-Arjona added getitem for the NumPy record type when the index is a StringLiteral type in #5182 and improved the documentation rendering via additions to the TOC and removal of numbering in #5450.
• Mads R. B. Kristensen fixed an issue with __cuda_array_interface__ not requiring the context in #5189.
• Marcin Tolysz added support for nested modules in AOT compilation in #5174.
• Mike Williams fixed some issues with NumPy records and getitem in the CUDA simulator in #5343.
• Pearu Peterson added experimental support for first-class function types in #5287 (and fixes in #5459, #5473/#5429, and #5557).
• Ravi Teja Gutta added support for np.flip in #4376/#5313.
• Rohit Sanjay fixed an issue with type refinement for unicode input supplied to typed-list extend() (#5295) and fixed unicode .strip() to strip all whitespace characters in #5213.
• Vladimir Lukyanov fixed an awkward bug in typed.dict in #5361, added a fix to ensure the LLVM and assembly dumps are highlighted correctly in #5357 and implemented a Numba IR Lexer and added highlighting to Numba IR dumps in #5333.
• hdf fixed an issue with the boundscheck flag in the CUDA jit target in #5257.

General Enhancements:
• PR #4615: Allow masking threads out at runtime
• PR #4798: Add branch pruning based on raw predicates.
• PR #5115: Add support for iterating over 2D arrays
• PR #5117: Implement ord()/chr()
• PR #5122: Remove Python 2.
• PR #5127: Calling convention adaptor for boxer/unboxer to call jitcode
• PR #5151: implement None-typed typed-list
• PR #5174: Nested modules https://github.com/numba/numba/issues/4739
• PR #5182: Add getitem for Record type when index is StringLiteral
• PR #5185: extract code-gen utilities from closures
• PR #5197: Refactor Numba, part I
• PR #5210: Remove more unsupported Python versions from build tooling.
• PR #5212: Adds support for viewing the CFG of the ELF disassembly.
• PR #5227: Immutable typed-list
• PR #5231: Added support for np.asarray to be used with numba.typed.List
• PR #5235: Added property dtype to numba.typed.List
• PR #5272: Refactor parfor: split up ParforPass
• PR #5281: Make IR ir.Del free until legalized.
• PR #5287: First-class function type
• PR #5293: np.isnat
• PR #5294: Create typed-list from iterable
• PR #5295: refine typed-list on unicode input to extend
• PR #5296: Refactor parfor: better exception from passes
• PR #5308: Provide numba.extending.is_jitted
• PR #5320: refactor array_analysis
• PR #5325: Let literal_unroll accept types.Named*Tuple
• PR #5330: refactor common operation in parfor lowering into a new util
• PR #5333: Add: highlight Numba IR dump
• PR #5342: Support for tuples passed to parfors.
• PR #5348: Add support for inferring the types of object arrays
• PR #5351: SSA again
• PR #5352: Add shim to accommodate refactoring.
• PR #5356: implement allocated parameter in njit
• PR #5369: Make test ordering more consistent across feature availability
• PR #5428: Wip/deprecate jitclass location
• PR #5441: Additional changes to first class function
• PR #5455: Move to llvmlite 0.32.*
• PR #5457: implement repr for untyped lists

Fixes:
• PR #4476: Another attempt at fixing frame injection in the dispatcher tracing path
• PR #4942: Prevent some parfor aliasing. Rename copied function var to prevent recursive type locking.
• PR #5092: Fix 5087
• PR #5150: More explicit llvmlite requirement in requirements.txt
• PR #5172: fix version spec for llvmlite
• PR #5176: Normalize kws going into fold_arguments.
• PR #5183: pass ‘inline’ explicitly to overload
• PR #5193: Fix CI failure due to missing files when installed
• PR #5213: Fix .strip() to strip all whitespace characters
• PR #5216: Fix namedtuple mistreated by dispatcher as simple tuple
• PR #5222: Fix compiler warnings due to missing (void)
• PR #5232: Fixes a bad import that breaks master
• PR #5239: fix test discovery for unittest
• PR #5247: Continue PR #5126
• PR #5250: Part fix/5098
• PR #5252: Trivially fix SyntaxWarning
• PR #5276: Add prange variant to has_no_side_effect.
• PR #5278: fix error messages in test_array_reductions
• PR #5310: PR #3897 continued
• PR #5313: Continues PR #4376
• PR #5318: Remove AUTHORS file reference from MANIFEST.in
• PR #5327: Add warning if FNV hashing is found as the default for CPython.
• PR #5338: Remove refcount pruning pass
• PR #5345: Disable test failing due to removed pass.
• PR #5357: Small fix to have llvm and asm highlighted properly
• PR #5361: 5081 typed.dict
• PR #5431: Add tolerance to numba extension module entrypoints.
• PR #5432: Fix code causing compiler warnings.
• PR #5445: Remove undefined variable
• PR #5454: Don’t warn for numba.experimental.jitclass
• PR #5459: Fixes issue 5448
• PR #5480: Fix for #5477, literal_unroll KeyError searching for getitems
• PR #5485: Show the offending module in “no direct replacement” error message
• PR #5488: Add missing numba.config shim
• PR #5495: Fix missing null initializer for variable after phi strip
• PR #5498: Make the shim deprecation warnings work on python 3.6 too
• PR #5505: Better error message if __init__ returns value
• PR #5527: Attempt to fix #5518
• PR #5529: PR #5473 continued
• PR #5532: Make numba.<mod> available without an import
• PR #5542: Fixes RC2 module shim bug
• PR #5548: Fix #5537 Removed reference to platform.linux_distribution
• PR #5555: Fix #5515 by reverting changes to ArrayAnalysis
• PR #5557: First-class function call cannot use keyword arguments
• PR #5569: Fix RewriteConstGetitems not registering calltype for new expr
• PR #5571: Pin down llvmlite requirement

CUDA Enhancements/Fixes:
• PR #5061: Prevent kernel launch with no configuration, remove autotuner
• PR #5085: Support other itemsizes with view
• PR #5099: Fix #5073: Slices of dynamic shared memory all alias
• PR #5104: Add a list of libraries that support __cuda_array_interface__
• PR #5136: CUDA: Enable asynchronous operations on the default stream
• PR #5144: Fix #4875: Make #2655 test with debug expect to pass
• PR #5189: __cuda_array_interface__ not requiring context
• PR #5253: Coerce dtype to numpy.dtype
• PR #5257: boundscheck fix
• PR #5319: Make user facing error string use abs path not rel.
• PR #5323: Document lifetime semantics of CUDA Array Interface
• PR #5328: NBEP 7: External Memory Management Plugin Interface
• PR #5343: Fix cuda spoof
• PR #5400: Fix #4954, and some other small CUDA testsuite fixes
• PR #5436: Fix #5408: test_set_registers_57 fails on Maxwell
• PR #5519: CUDA: Silence the test suite - Fix #4809, remove autojit, delete prints

Documentation Updates:
• PR #4957: Add notes on overwriting gufunc inputs to docs
• PR #5059: Docs: Explain how to use Memcheck with Numba, fixups in CUDA documentation
• PR #5106: Add SciPy 2019 talks to docs
• PR #5147: Update master for 0.48.0 updates
• PR #5155: Explain what inlining at Numba IR level will do
• PR #5161: Fix README.rst formatting
• PR #5207: Remove AUTHORS list
• PR #5249: fix target path for See also
• PR #5262: fix typo in inlining docs
• PR #5270: fix ‘see also’ in typeddict docs
• PR #5280: Added some hints for debugging entry points.
• PR #5297: Update docs with intro to {g,}ufuncs.
• PR #5326: Update installation docs with OpenMP requirements.
• PR #5346: Docs: use sphinx_rtd_theme
• PR #5366: Remove reference to Python 2.7 in install check output
• PR #5423: Fix #5421: Add notes on printing in CUDA kernels
• PR #5438: Update package deps for doc building.
• PR #5440: Bump deprecation notices.
• PR #5443: Fix #5196: Docs: assert in CUDA only enabled for debug
• PR #5450: Docs: remove numbers and add titles to TOC
• PR #5453: fix building docs on windows
• PR #5489: docs: fix rendering of nested bulleted list

CI updates:
• PR #5314: Update the image used in Azure CI for OSX.
• PR #5360: Remove Travis CI badge.

Authors:
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9.16 Version 0.48.0 (Jan 27, 2020)

This release is particularly small as it was present to catch anything that missed the 0.47.0 deadline (the deadline deliberately coincided with the end of support for Python 2.7). The next release will be considerably larger.

The core changes in this release are dominated by the start of the clean up needed for the end of Python 2.7 support, improvements to the CUDA target and support for numerous additional unicode string methods.

Enhancements from user contributed PRs (with thanks!):

- Brian Wignall fixed more spelling typos in #4998.
- Denis Smirnov added support for string methods capitalize (#4823), casefold (#4824), swapcase (#4825), rsplit (#4834), partition (#4845) and splitlines (#4849).
- Elena Totmenina extended support for string methods startswith (#4867) and added endswith (#4868).
- Eric Wieser made type_callable return the decorated function itself in #4760
- Ethan Pronovost added support for np.argmax in #4617
- Graham Markall contributed a large number of CUDA enhancements and fixes, namely:
  - #5068: Remove Python 3.4 backports from utils
  - #4975: Make device_array_like create contiguous arrays (Fixes #4832)
  - #5023: Don’t launch ForAll kernels with 0 elements (Fixes #5017)
  - #5016: Fix various issues in CUDA library search (Fixes #4979)
  - #5014: Enable use of records and bools for shared memory, remove ddt, add additional transpose tests
  - #4964: Fix #4628: Add more appropriate typing for CUDA device arrays
  - #5007: test_consuming_strides: Keep dev array alive
  - #4997: State that CUDA Toolkit 8.0 required in docs
- James Bourbeau added the Python 3.8 classifier to setup.py in #5027.
- John Kirkham added a clarification to the __cuda_array_interface__ documentation in #5049.
- Leo Fang fixed an indexing problem in dummyarray in #5012.
- Marcel Bargull fixed a build and test issue for Python 3.8 in #5029.
- Maria Rubtsov added support for string methods is decimal (#4842), is digit (#4843), is numeric (#4844) and replace (#4865).

General Enhancements:

- PR #4760: Make type_callable return the decorated function
- PR #5010: merge string prs

This merge PR included the following:

- PR #4823: Implement str.capitalize() based on CPython
- PR #4824: Implement str.casefold() based on CPython
- PR #4825: Implement str.swapcase() based on CPython
- PR #4834: Implement str.rsplit() based on CPython
- PR #4842: Implement str.isdecimal
- PR #4843: Implement str.isdigit
PR #4844: Implement str.isnumeric
PR #4845: Implement str.partition() based on CPython
PR #4849: Implement str.splitlines() based on CPython
PR #4865: Implement str.replace
PR #4867: Functionality extension str.startswith() based on CPython
PR #4868: Add functionality for str.endswith()

• PR #5039: Disable help messages.
• PR #4617: Add coverage for np.argwhere

Fixes:
• PR #4724: Only use lives (and not aliases) to create post parfor live set.
• PR #4998: Fix more spelling typos
• PR #5024: Propagate semantic constants ahead of static rewrites.
• PR #5027: Add Python 3.8 classifier to setup.py
• PR #5046: Update setup.py and buildscripts for dependency requirements
• PR #5053: Convert from arrays to names in define() and don’t invalidate for multiple consistent defines.
• PR #5058: Permit mixed int types in wrap_index
• PR #5078: Catch the use of global typed-list in JITed functions
• PR #5092: Fix #5087, bug in bytecode analysis.

CUDA Enhancements/Fixes:
• PR #4964: Fix #4628: Add more appropriate typing for CUDA device arrays
• PR #4975: Make device_array_like create contiguous arrays (Fixes #4832)
• PR #4997: State that CUDA Toolkit 8.0 required in docs
• PR #5007: test_consuming_strides: Keep dev array alive
• PR #5012: Fix IndexError when accessing the “-1” element of dummyarray
• PR #5014: Enable use of records and bools for shared memory, remove ddt, add additional transpose tests
• PR #5016: Fix various issues in CUDA library search (Fixes #4979)
• PR #5023: Don’t launch ForAll kernels with 0 elements (Fixes #5017)
• PR #5068: Remove Python 3.4 backports from utils

Documentation Updates:
• PR #5049: Clarify what dictionary means
• PR #5062: Update docs for updated version requirements
• PR #5090: Update deprecation notices for 0.48.0

CI updates:
• PR #5029: Install optional dependencies for Python 3.8 tests
• PR #5040: Drop Py2.7 and Py3.5 from public CI
• PR #5048: Fix CI py38
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9.17 Version 0.47.0 (Jan 2, 2020)

This release expands the capability of Numba in a number of important areas and is also significant as it is the last major point release with support for Python 2 and Python 3.5 included. The next release (0.48.0) will be for Python 3.6+ only! (This follows NumPy’s deprecation schedule as specified in NEP 29.)

Highlights of core feature changes include:

- Full support for Python 3.8 (Siu Kwan Lam)
- Opt-in bounds checking (Aaron Meurer)
- Support for map, filter and reduce (Stuart Archibald)

Intel also kindly sponsored research and development that lead to some exciting new features:

- Initial support for basic try/except use (Siu Kwan Lam)
- The ability to pass functions created from closures/lambdas as arguments (Stuart Archibald)
- sorted and list.sort() now accept the key argument (Stuart Archibald and Siu Kwan Lam)
- A new compiler pass triggered through the use of the function numba.literal_unroll which permits iteration over heterogeneous tuples and constant lists of constants. (Stuart Archibald)

Enhancements from user contributed PRs (with thanks!):

- Ankit Mahato added a reference to a new talk on Numba at PyCon India 2019 in #4862
- Brian Wignall kindly fixed some spelling mistakes and typos in #4909
- Denis Smirnov wrote numerous methods to considerable enhance string support including:
• Elena Totmenina implemented both `str.isalnum()`, `str.isalpha()` and `str.isascii` in #4839, #4840 and #4847 respectively.

• Eric Larson fixed a bug in literal comparison in #4710

• Ethan Pronovost updated the `np.arange` implementation in #4770 to allow the use of the `dtype` key word argument and also added bool implementations for several types in #4715.

• Graham Markall fixed some issues with the CUDA target, namely:
  – #4931: Added physical limits for CC 7.0 / 7.5 to CUDA autotune
  – #4934: Fixed bugs in TestCudaWarpOperations
  – #4938: Improved errors / warnings for the CUDA vectorize decorator

• Guilherme Leobas fixed a typo in the `urem` implementation in #4667

• Isaac Virshup contributed a number of patches that fixed bugs, added support for more NumPy functions and enhanced Python feature support. These contributions included:
  – #4729: Allow array construction with mixed type shape tuples
  – #4904: Implementing `np.lcm`
  – #4780: Implement `np.gcd` and `math.gcd`
  – #4779: Make slice constructor more similar to python.
  – #4707: Added support for slice.indices
  – #4578: Clarify numba ufunc supported features

• James Bourbeau fixed some issues with tooling, #4794 add `setuptools` as a dependency and #4501 add pre-commit hooks for `flake8` compliance.

• Leo Fang made `numbadummyarray.Array` iterable in #4629

• Marc Garcia fixed the `numba.jit` parameter name signature_or_function in #4703

• Marcelo Duarte Trevisani patched the llvmlite requirement to `>=0.30.0` in #4725

• Matt Cooper fixed a long standing CI problem in #4737 by remove maxParallel

• Matti Picus fixed an issue with `collections.abc` in #4734 from Azure Pipelines.

• Rob Ennis patched a bug in `np.interp float32` handling in #4911

• VDimir fixed a bug in array transposition layouts in #4777 and re-enabled and fixed some idle tests in #4776.

• Vyacheslav Smirnov Enable support for `str.istitle()` in #4645

General Enhancements:
• PR #4432: Bounds checking
• PR #4501: Add pre-commit hooks
• PR #4536: Handle kw args in inliner when callee is a function
• PR #4599: Permits closures to become functions, enables map(), filter()
• PR #4611: Implement method title() for unicode based on Cpython
• PR #4645: Enable support for istitle() method for unicode string
• PR #4651: Implement str.lower() and str.islower()
• PR #4652: Implement str.rfind()
• PR #4695: Refactor overload* and support jit_options and inline
• PR #4707: Added support for slice.indices
• PR #4715: Add bool overload for several types
• PR #4729: Allow array construction with mixed type shape tuples
• PR #4755: Python3.8 support
• PR #4756: Add parfor support for ndarray.fill.
• PR #4768: Update typeconv error message to ask for sys.executable.
• PR #4770: Update np.arange implementation with @overload
• PR #4779: Make slice constructor more similar to python.
• PR #4780: Implement np.gcd and math.gcd
• PR #4794: Add setuptools as a dependency
• PR #4802: put git hash into build string
• PR #4803: Better compiler error messages for improperly used reduction variables.
• PR #4817: Typed list implement and expose allocation
• PR #4818: Typed list faster copy
• PR #4835: Implement str.isspace() based on CPython
• PR #4836: Implement str.isprintable() based on CPython
• PR #4837: Implement str.isidentifier() based on CPython
• PR #4839: Implement str.isalnum() based on CPython
• PR #4840: Implement str.isalpha() based on CPython
• PR #4841: Implement str.rpartition() based on CPython
• PR #4847: Implement str.isascii() based on CPython
• PR #4851: Add graphviz output for FunctionIR
• PR #4854: Python3.8 loopleveling
• PR #4858: Implement str.expandtabs() based on CPython
• PR #4860: Implement str.index() based on CPython
• PR #4861: Implement str.rindex() based on CPython
• PR #4866: Support params start/end for str.find()
• PR #4874: Bump to llvmlite 0.31
• PR #4896: Specialise arange dtype on arch + python version.
• PR #4902: basic support for try except
• PR #4904: Implement np.lcm
• PR #4910: loop canonicalisation and type aware tuple unroller/loop body versioning passes
• PR #4961: Update hash(tuple) for Python 3.8.
• PR #4977: Implement sort/sorted with key.
• PR #4987: Add is_internal property to all Type classes.

Fixes:
• PR #4090: Update to LLVM8 memset/memcpy intrinsic
• PR #4582: Convert sub to add and div to mul when doing the reduction across the per-thread reduction array.
• PR #4648: Handle 0 correctly as slice parameter.
• PR #4660: Remove multiply defined variables from all blocks’ equivalence sets.
• PR #4672: Fix pickling of dufunc
• PR #4710: BUG: Comparison for literal
• PR #4718: Change get_call_table to support intermediate Vars.
• PR #4725: Requires llvmlite >=0.30.0
• PR #4734: prefer to import from collections.abc
• PR #4736: fix flake8 errors
• PR #4776: Fix and enable idle tests from test_array_manipulation
• PR #4777: Fix transpose output array layout
• PR #4782: Fix issue with SVML (and knock-on function resolution effects).
• PR #4785: Treat 0d arrays like scalars.
• PR #4787: fix missing incref on flags
• PR #4789: fix typos in numba/targets/base.py
• PR #4791: fix typos
• PR #4811: fix spelling in now-failing tests
• PR #4852: windowing test should check equality only up to double precision errors
• PR #4881: fix refining list by using extend on an iterator
• PR #4882: Fix return type in arange and zero step size handling.
• PR #4885: suppress spurious RuntimeWarning about ufunc sizes
• PR #4891: skip the xfail test for now. Py3.8 CFG refactor seems to have changed the test case
• PR #4892: regex needs to accept singular form of “argument”
• PR #4901: fix typed list equals
• PR #4909: Fix some spelling typos
• PR #4911: np.interp bugfix for float32 handling
• PR #4920: fix creating list with JIT disabled
• PR #4921: fix creating dict with JIT disabled
• PR #4935: Better handling of prange with multiple reductions on the same variable.
• PR #4946: Improve the error message for `raise <string>`.
• PR #4955: Move overload of literal_unroll to avoid circular dependency that breaks Python 2.7
• PR #4962: Fix test error on windows
• PR #4973: Fixes a bug in the relabelling logic in literal_unroll.
• PR #4978: Fix overload_method problem with stararg
• PR #4981: Add ind_to_const to enable fewer equivalence classes.
• PR #4991: Continuation of #4588 (Let dead code removal handle removing more of the unneeded code after prange conversion to parfor)
• PR #4994: Remove xfail for test which has since had underlying issue fixed.
• PR #5018: Fix #5011.
• PR #5019: skip pycc test on Python 3.8 + macOS because of distutils issue

CUDA Enhancements/Fixes:
• PR #4629: Make numba.dummyarray.Array iterable
• PR #4675: Bump cuda array interface to version 2
• PR #4741: Update choosing the “CUDA_PATH” for windows
• PR #4838: Permit ravel('A') for contig device arrays in CUDA target
• PR #4931: Add physical limits for CC 7.0 / 7.5 to autotune
• PR #4934: Fix fails in TestCudaWarpOperations
• PR #4938: Improve errors / warnings for cuda vectorize decorator

Documentation Updates:
• PR #4418: Directed graph task roadmap
• PR #4578: Clarify numba ufunc supported features
• PR #4655: fix sphinx build warning
• PR #4667: Fix typo on urem implementation
• PR #4669: Add link to ParallelAccelerator paper.
• PR #4703: Fix numba.jit parameter name signature_or_function
• PR #4862: Addition of PyCon India 2019 talk on Numba
• PR #4947: Document jitclass with numba.typed use.
• PR #4958: Add docs for `try..except`
• PR #4993: Update deprecations for 0.47

CI Updates:
• PR #4737: remove maxParallel from Azure Pipelines
• PR #4767: pin to 2.7.16 for py27 on osx
• PR #4781: WIP/runtest cf pytest

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This release significantly reworked one of the main parts of Numba, the compiler pipeline, to make it more extensible and easier to use. The purpose of this was to continue enhancing Numba's ability for use as a compiler toolkit. In a similar vein, Numba now has an extension registration mechanism to allow other Numba-using projects to automatically have their Numba JIT compilable functions discovered. There were also a number of other related compiler toolkit enhancement added along with some more NumPy features and a lot of bug fixes.

This release has updated the CUDA Array Interface specification to version 2, which clarifies the strides attribute for C-contiguous arrays and specifies the treatment for zero-size arrays. The implementation in Numba has been changed and may affect downstream packages relying on the old behavior (see issue #4661).

Enhancements from user contributed PRs (with thanks!):

- Aaron Meurer fixed some Python issues in the code base in #4345 and #4341.
- Ashwin Srinath fixed a CUDA performance bug via #4576.
- Ethan Pronovost added support for triangular indices functions in #4601 (the NumPy functions tril_indices, tril_indices_from, triu_indices, and triu_indices_from).
- Gerald Dalley fixed a tear down race occurring in Python 2.
- Gregory R. Lee fixed the use of deprecated inspect.getargspec.
- Guilherme Leobas contributed five PRs, adding support for np.append and np.count_nonzero in #4518 and #4386. The typed List was fixed to accept unsigned integers in #4510. #4463 made a fix to NamedTuple internals and #4397 updated the docs for np.sum.
- James Bourbeau added a new feature to permit the automatic application of the jit decorator to a whole module in #4331. Also some small fixes to the docs and the code base were made in #4447 and #4433, and a fix to inplace array operation in #4228.
- Jim Crist fixed a bug in the rendering of patched errors in #4464.
- Leo Fang updated the CUDA Array Interface contract in #4609.
- Pearu Peterson added support for Unicode based NumPy arrays in #4425.
- Peter Andreas Entschev fixed a CUDA concurrency bug in #4581.
- Lucio Fernandez-Arjona extended Numba's np.sum support to now accept the dtype kwarg in #4472.
- Pedro A. Morales Maries added support for np.cross in #4128 and also added the necessary extension numba.numpy_extensions.cross2d in #4595.
- David Hoese, Eric Firing, Joshua Adelman, and Juan Nunez-Iglesias all made documentation fixes in #4565, #4482, #4455, #4375 respectively.
- Vyacheslav Smirnov and Rujal Desai enabled support for count() on unicode strings in #4606.

General Enhancements:

- PR #4113: Add rewrite for semantic constants.
- PR #4128: Add np.cross support
- PR #4162: Make IR comparable and legalize it.
- PR #4208: R&D inlining, jitted and overloaded.
- PR #4331: Automatic JIT of called functions
- PR #4353: Inspection tool to check what numba supports
- PR #4386: Implement np.count_nonzero
• PR #4425: Unicode array support
• PR #4427: Entrypoints for numba extensions
• PR #4467: Literal dispatch
• PR #4472: Allow dtype input argument in np.sum
• PR #4513: New compiler.
• PR #4518: add support for np.append
• PR #4554: Refactor NRT C-API
• PR #4556: 0.46 scheduled deprecations
• PR #4567: Add env var to disable performance warnings.
• PR #4568: add np.array_equal support
• PR #4595: Implement numba.cross2d
• PR #4601: Add triangular indices functions
• PR #4606: Enable support for count() method for unicode string

Fixes:
• PR #4228: Fix inplace operator error for arrays
• PR #4282: Detect and raise unsupported on generator expressions
• PR #4305: Don’t allow the allocation of mutable objects written into a container to be hoisted.
• PR #4311: Avoid deprecated use of inspect.getargspec
• PR #4328: Replace GC macro with function call
• PR #4330: Loosen up typed container casting checks
• PR #4341: Fix some coding lines at the top of some files (utf8 -> utf-8)
• PR #4345: Replace “import *” with explicit imports in numba/types
• PR #4346: Fix incorrect alg in isupper for ascii strings.
• PR #4349: test using jitclass in typed-list
• PR #4361: Add allocation hoisting info to LICM section at diagnostic L4
• PR #4366: Offset search box to avoid wrapping on some pages with Safari. Fixes #4365.
• PR #4372: Replace all “except BaseException” with “except Exception”.
• PR #4407: Restore the “free” conda channel for NumPy 1.10 support.
• PR #4408: Add lowering for constant bytes.
• PR #4409: Add exception chaining for better error context
• PR #4411: Name of type should not contain user facing description for debug.
• PR #4412: Fix #4387. Limit the number of return types for recursive functions
• PR #4426: Fixed two module teardown races in py2.
• PR #4431: Fix and test numpy.random.random_sample(n) for np117
• PR #4463: NamedTuple - Raises an error on non-iterable elements
• PR #4464: Add a newline in patched errors
• PR #4474: Fix liveness for remove dead of parfors (and other IR extensions)
• PR #4510: Make List.__getitem__ accept unsigned parameters
• PR #4512: Raise specific error at typing time for iteration on >1D array.
• PR #4532: Fix static_getitem with Literal type as index
• PR #4547: Update to inliner cost model information.
• PR #4557: Use specific random number seed when generating arbitrary test data
• PR #4559: Adjust test timeouts
• PR #4564: Skip unicode array tests on ppc64le that trigger an LLVM bug
• PR #4621: Fix packaging issue due to missing numba/cext
• PR #4623: Fix issue 4520 due to storage model mismatch
• PR #4644: Updates for llvmlite 0.30.0

CUDA Enhancements/Fixes:
• PR #4410: Fix #4111. cudasim mishandling recarray
• PR #4576: Replace use of np.prod with functools.reduce for computing size from shape
• PR #4581: Prevent taking the GIL in ForAll
• PR #4592: Fix #4589. Just pass NULL for b2d_func for constant dynamic sharedmem
• PR #4609: Update CUDA Array Interface & Enforce Numba compliance
• PR #4619: Implement math.{degrees, radians} for the CUDA target.
• PR #4675: Bump cuda array interface to version 2

Documentation Updates:
• PR #4317: Add docs for ARMv8/AArch64
• PR #4318: Add supported platforms to the docs. Closes #4316
• PR #4375: Add docstrings to inspect methods
• PR #4388: Update Python 2.7 EOL statement
• PR #4397: Add note about np.sum
• PR #4447: Minor parallel performance tips edits
• PR #4455: Clarify docs for typed dict with regard to arrays
• PR #4482: Fix example in guvectorize docstring.
• PR #4541: fix two typos in architecture.rst
• PR #4548: Document numba.extending.intrinsic and inlining.
• PR #4565: Fix typo in jit-compilation docs
• PR #4607: add dependency list to docs
• PR #4614: Add documentation for implementing new compiler passes.

CI Updates:
• PR #4415: Make 32bit incremental builds on linux not use free channel
• PR #4433: Removes stale azure comment
• PR #4493: Fix Overload Inliner wrt CUDA Intrinsics
• PR #4593: Enable Azure CI batching

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9.19 Version 0.45.1

This patch release addresses some regressions reported in the 0.45.0 release and adds support for NumPy 1.17:
• PR #4325: accept scalar/0d-arrays
• PR #4338: Fix #4299. Parfors reduction vars not deleted.
• PR #4350: Use process level locks for fork() only.
• PR #4354: Try to fix #4352.
• PR #4357: Fix np1.17 isnan, isinf, isnfinite ufuncs
• PR #4363: Fix np.interp for np1.17 nan handling
• PR #4371: Fix nump1.17 random function non-aliasing

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9.20 Version 0.45.0

In this release, Numba gained an experimental `numba.typed.List` container as a future replacement of the reflected list. In addition, functions decorated with `parallel=True` can now be cached to reduce compilation overhead associated with the auto-parallelization.

Enhancements from user contributed PRs (with thanks!):
• James Bourbeau added the Numba version to reportable error messages in #4227, added the signature parameter to `inspect_types` in #4200, improved the docstring of `normalize_signature` in #4205, and fixed #3658 by adding reference counting to `register_dispatcher` in #4254
• Guilherme Leobas implemented the dominator tree and dominance frontier algorithms in #4216 and #4149, respectively.
• Nick White fixed the issue with `round` in the CUDA target in #4137.
• Joshua Adelman added support for determining if a value is in a range (i.e. `x in range(...)`) in #4129, and added windowing functions (`np.bartlett`, `np.hamming`, `np.blackman`, `np.hanning`, `np.kaiser`) from NumPy in #4076.
• Lucio Fernandez-Arjona added support for `np.select` in #4077
• Rob Ennis added support for `np.flatnonzero` in #4157
• Keith Kraus extended the `__cuda_array_interface__` with an optional mask attribute in #4199.
• Gregory R. Lee replaced deprecated use of `inspect.getargspec` in #4311.

General Enhancements:
• PR #4328: Replace GC macro with function call
• PR #4311: Avoid deprecated use of `inspect.getargspec`
• PR #4296: Slacken window function testing tol on ppc64le
• PR #4254: Add reference counting to `register_dispatcher`
• PR #4239: Support len() of multi-dim arrays in array analysis
• PR #4234: Raise informative error for `np.kron` array order
• PR #4232: Add unicodetype db, low level str functions and examples.
• PR #4229: Make hashing cacheable
• PR #4227: Include numba version in reportable error message
• PR #4216: Add dominator tree
• PR #4200: Add signature parameter to `inspect_types`
• PR #4196: Catch missing imports of internal functions.
• PR #4180: Update use of unlowerable global message.
• PR #4166: Add tests for PR #4149
• PR #4157: Support for np.flatnonzero
• PR #4149: Implement dominance frontier for SSA for the Numba IR
• PR #4148: Call branch pruning in inline_closure_call()
• PR #4132: Reduce usage of inttoptr
• PR #4129: Support contains for range
• PR #4112: better error messages for np.transpose and tuples
• PR #4110: Add range attrs, start, stop, step
• PR #4077: Add np select
• PR #4076: Add numpy windowing functions support (np.bartlett, np.hamming, np.blackman, np.hanning, np.kaiser)
• PR #4095: Support ir.Global/FreeVar in find_const()
• PR #3691: Make TypingError abort compiling earlier
• PR #3646: Log internal errors encountered in typeinfer

Fixes:
• PR #4303: Work around scipy bug 10206
• PR #4302: Fix flake8 issue on master
• PR #4301: Fix integer literal bug in np.select impl
• PR #4291: Fix pickling of jitclass type
• PR #4262: Resolves #4251 - Fix bug in reshape analysis.
• PR #4233: Fixes issue revealed by #4215
• PR #4224: Fix #4223. Looplifting error due to StaticSetItem in objectmode
• PR #4222: Fix bad python path.
• PR #4178: Fix unary operator overload, check with unicode impl
• PR #4173: Fix return type in np.bincount with weights
• PR #4153: Fix slice shape assignment in array analysis
• PR #4152: fix status check in dict lookup
• PR #4145: Use callable instead of checking __module__
• PR #4118: Fix inline assembly support on CPU.
• PR #4088: Resolves #4075 - parfors array_analysis bug.
• PR #4085: Resolves #3314 - parfors array_analysis bug with reshape.

CUDA Enhancements/Fixes:
• PR #4199: Extend __cuda_array_interface__ with optional mask attribute, bump version to 1
• PR #4137: CUDA - Fix round Builtin
• PR #4114: Support 3rd party activated CUDA context

Documentation Updates:
  • PR #4317: Add docs for ARMv8/AArch64
  • PR #4318: Add supported platforms to the docs. Closes #4316
  • PR #4295: Alter deprecation schedules
  • PR #4253: fix typo in pysupported docs
  • PR #4252: fix typo on repomap
  • PR #4241: remove unused import
  • PR #4240: fix typo in jitclass docs
  • PR #4205: Update return value order in normalize_signature docstring
  • PR #4237: Update doc links to point to latest not dev docs.
  • PR #4197: hyperlink repomap
  • PR #4170: Clarify docs on accumulating into arrays in prange
  • PR #4147: fix docstring for DictType iterables
  • PR #3951: A guide to overloading

CI Updates:
  • PR #4300: AArch64 has no faulthandler package
  • PR #4273: pin to MKL BLAS for testing to get consistent results
  • PR #4209: Revert previous network tol patch and try with conda config
  • PR #4138: Remove tbb before Azure test only on Python 3, since it was already removed for Python 2

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9.21 Version 0.44.1

This patch release addresses some regressions reported in the 0.44.0 release:

- PR #4165: Fix #4164 issue with NUMBAPRO_NVVM.
- PR #4172: Abandon branch pruning if an arg name is redefined. (Fixes #4163)
- PR #4183: Fix #4156. Problem with defining in-loop variables.

9.22 Version 0.44.0

IMPORTANT: In this release a few significant deprecations (and some less significant ones) are being made, users are encouraged to read the related documentation.

General enhancements in this release include:

- Numba is backed by LLVM 8 on all platforms apart from ppc64le, which, due to bugs, remains on the LLVM 7.x series.
- Numba’s dictionary support now includes type inference for keys and values.
- The .view() method now works for NumPy scalar types.
- Newly supported NumPy functions added: np.delete, np.nanquantile, np.quantile, np.repeat, np.shape.

In addition considerable effort has been made to fix some long standing bugs and a large number of other bugs, the “Fixes” section is very large this time!

Enhancements from user contributed PRs (with thanks!):

- Max Bolingbroke added support for the selective use of fastmath flags in #3847.
- Rob Ennis made min() and max() work on iterables in #3820 and added np.quantile and np.nanquantile in #3899.
- Sergey Shalnov added numerous unicode string related features, zfill in #3978, ljust in #4001, rjust and center in #4044 and strip, lstrip and rstrip in #4048.
- Guilherme Leobas added support for np.delete in #3890.
- Christoph Deil exposed the Numba CLI via python -m numba in #4066 and made numerous documentation fixes.
- Leo Schwarz wrote the bulk of the code for jitclass default constructor arguments in #3852.
- Nick White enhanced the CUDA backend to use min/max PTX instructions where possible in #4054.
- Lucio Fernandez-Arjona implemented the unicode string __mul__ function in #3952.
- Dimitri Vorona wrote the bulk of the code to implement getitem and setitem for jitclass in #3861.

General Enhancements:

- PR #3820: Min max on iterables
- PR #3842: Unicode type iteration
- PR #3847: Allow fine-grained control of fastmath flags to partially address #2923
- PR #3852: Continuation of PR #2894
- PR #3861: Continuation of PR #3730
- PR #3890: Add support for np.delete
• PR #3899: Support for np.quantile and np.nanquantile
• PR #3900: Fix 3457 :: Implements np.repeat
• PR #3928: Add .view() method for NumPy scalars
• PR #3939: Update icc_rt clone recipe.
• PR #3952: __mul__ for strings, initial implementation and tests
• PR #3956: Type-inferred dictionary
• PR #3959: Create a view for string slicing to avoid extra allocations
• PR #3978: zfill operation implementation
• PR #4001: ljust operation implementation
• PR #4010: Support dict() and {}
• PR #4022: Support for llvm 8
• PR #4034: Make type.Optional str more representative
• PR #4041: Deprecation warnings
• PR #4044: rjust and center operations implementation
• PR #4048: strip, lstrip and rstrip operations implementation
• PR #4066: Expose numba CLI via python -m numba
• PR #4081: Impl np.shape and support function for asarray.
• PR #4091: Deprecate the use of iternext_impl without RefType

CUDA Enhancements/Fixes:
• PR #3933: Adds .nbytes property to CUDA device array objects.
• PR #4011: Add .inspect_ptx() to cuda device function
• PR #4054: CUDA: Use min/max PTX Instructions
• PR #4096: Update env-vars for CUDA libraries lookup

Documentation Updates:
• PR #3867: Code repository map
• PR #3918: adding Joris’ Fosdem 2019 presentation
• PR #3926: order talks on applications of Numba by date
• PR #3943: fix two small typos in vectorize docs
• PR #3944: Fixup jitclass docs
• PR #3990: mention preprint repo in FAQ. Fixes #3981
• PR #4012: Correct runtests command in contributing.rst
• PR #4043: fix typo
• PR #4047: Ambiguous Documentation fix for guvectorize.
• PR #4060: Remove remaining mentions of autojit in docs
• PR #4063: Fix annotate example in docstring
• PR #4065: Add FAQ entry explaining Numba project name
• PR #4079: Add Documentation for atomicity of typed.Dict
• PR #4105: Remove info about CUDA ENVVAR potential replacement

Fixes:
• PR #3719: Resolves issue #3528. Adds support for slices when not using parallel=True.
• PR #3727: Remove dels for known dead vars.
• PR #3845: Fix mutable flag transmission in .astype
• PR #3853: Fix some minor issues in the C source.
• PR #3862: Correct boolean reinterpretation of data
• PR #3863: Comments out the appveyor badge
• PR #3869: fixes flake8 after merge
• PR #3871: Add assert to ir.py to help enforce correct structuring
• PR #3881: fix preparfor dtype transform for datetime64
• PR #3884: Prevent mutation of objmode fallback IR.
• PR #3885: Updates for llvmlite 0.29
• PR #3886: Use safe_load from pyyaml.
• PR #3887: Add tolerance to network errors by permitting conda to retry
• PR #3893: Fix casting in namedtuple ctor.
• PR #3894: Fix array inliner for multiple array definition.
• PR #3905: Cherrypick #3903 to main
• PR #3920: Raise better error if unsupported jump opcode found.
• PR #3927: Apply flake8 to the numpy related files
• PR #3935: Silence DeprecationWarning
• PR #3938: Better error message for unknown opcode
• PR #3941: Fix typing of ufuncs in parfor conversion
• PR #3946: Return variable renaming dict from inline_closurecall
• PR #3962: Fix bug in alignment computation of Record.make_c_struct
• PR #3967: Fix error with pickling unicode
• PR #3964: Unicode split algo versioning
• PR #3975: Add handler for unknown locale to numba -s
• PR #3991: Permit Optionals in ufunc machinery
• PR #3995: Remove assert in type inference causing poor error message.
• PR #3996: add is_ascii flag to UnicodeType
• PR #4009: Prevent zero division error in np.linalg.cond
• PR #4014: Resolves #4007.
• PR #4021: Add a more specific error message for invalid write to a global.
• PR #4023: Fix handling of titles in record dtype
• PR #4024: Do a check if a call is const before saying that an object is multiply defined.
• PR #4027: Fix issue #4020. Turn off no_cpython_wrapper flag when compiling for...
• PR #4033: [WIP] Fixing wrong dtype of array inside reflected list #4028
• PR #4061: Change IPython cache dir name to numba_cache
• PR #4067: Delete examples/notebooks/LinearRegr.py
• PR #4070: Catch writes to global typed.Dict and raise.
• PR #4078: Check tuple length
• PR #4084: Fix missing incref on optional return None
• PR #4089: Make the warnings fixer flush work for warning comparing on type.
• PR #4094: Fix function definition finding logic for commented def
• PR #4100: Fix alignment check on 32-bit.
• PR #4104: Use PEP 508 compliant env markers for install deps

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9.23 Version 0.43.1

This is a bugfix release that provides minor changes to fix: a bug in branch pruning, bugs in `np.interp` functionality, and also fully accommodate the NumPy 1.16 release series.

- PR #3826: NumPy 1.16 support
- PR #3850: Refactor np.interp
- PR #3883: Rewrite pruned conditionals as their evaluated constants.

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9.24 Version 0.43.0

In this release, the major new features are:

- Initial support for statically typed dictionaries
- Improvements to `hash()` to match Python 3 behavior
- Support for the `heapq` module
- Ability to pass C structs to Numba
- More NumPy functions: asarray, trapz, roll, ptp, extract

NOTE:

The vast majority of NumPy 1.16 behaviour is supported, however `datetime` and `timedelta` use involving NaT matches the behaviour present in earlier release. The ufunc suite has not been extending to accommodate the two new time computation related additions present in NumPy 1.16. In addition the functions `ediff1d` and `interp` have known minor issues in replicating outputs exactly when NaN's occur in certain input patterns.

General Enhancements:

- PR #3563: Support for np.roll
- PR #3572: Support for np.ptp
- PR #3592: Add dead branch prune before type inference.
- PR #3598: Implement np.asarray()
- PR #3604: Support for np.interp
- PR #3607: Some simplication to lowering
- PR #3612: Exact match flag in dispatcher
- PR #3627: Support for np.trapz
- PR #3630: np.where with broadcasting
- PR #3633: Support for np.extract
- PR #3657: np.max, np.min, np.nanmax, np.nanmin - support for complex dtypes
- PR #3661: Access C Struct as Numpy Structured Array
• PR #3678: Support for str.split and str.join
• PR #3684: Support C array in C struct
• PR #3696: Add intrinsic to help debug refcount
• PR #3703: Implementations of type hashing.
• PR #3715: Port CPython3.7 dictionary for numba internal use
• PR #3716: Support inplace concat of strings
• PR #3718: Add location to ConstantInferenceError exceptions.
• PR #3720: improve error msg about invalid signature
• PR #3731: Support for heapq
• PR #3754: Updates for llvmlite 0.28
• PR #3760: Overloadable operator.setitem
• PR #3775: Support overloading operator.delitem
• PR #3777: Implement compiler support for dictionary
• PR #3791: Implement interpreter-side interface for numba dict
• PR #3799: Support refcount’ed types in numba dict

CUDA Enhancements/Fixes:
• PR #3713: Fix the NvvmSupportError message when CC too low
• PR #3722: Fix #3705: slicing error with negative strides
• PR #3755: Make cuda.to_device accept readonly host array
• PR #3773: Adapt library search to accommodate multiple locations

Documentation Updates:
• PR #3651: fix link to berrycond in docs
• PR #3668: Add Azure Pipelines build badge
• PR #3749: DOC: Clarify when prange is different from range
• PR #3771: fix a few typos
• PR #3785: Clarify use of range as function only.
• PR #3829: Add docs for typed-dict

Fixes:
• PR #3614: Resolve #3586
• PR #3618: Skip gdb tests on ARM.
• PR #3643: Remove support_literals usage
• PR #3645: Enforce and fix that AbstractTemplate.generic must be returning a Signature
• PR #3648: Fail on @overload signature mismatch.
• PR #3660: Added Ignore message to test numba.tests.test_lists.TestLists.test_mul_error
• PR #3662: Replace six with numba.six
• PR #3663: Removes coverage computation from travisci builds
• PR #3672: Avoid leaking memory when iterating over uniform tuple
• PR #3676: Fixes constant string lowering inside tuples
• PR #3677: Ensure all referenced compiled functions are linked properly
• PR #3692: Fix test failure due to overly strict test on floating point values.
• PR #3693: Intercept failed import to help users.
• PR #3694: Fix memory leak in enumerate iterator
• PR #3695: Convert return of None from intrinsic implementation to dummy value
• PR #3697: Fix for issue #3687
• PR #3701: Fix array.T analysis (fixes #3700)
• PR #3704: Fixes for overload_method
• PR #3706: Don’t push call vars recursively into nested parfors. Resolves #3686.
• PR #3710: Set as non-hoistable if a mutable variable is passed to a function in a loop. Resolves #3699.
• PR #3712: parallel=True to use better builtin mechanism to resolve call types. Resolves issue #3671
• PR #3725: Fix invalid removal of dead empty list
• PR #3740: add uintp as a valid type to the tuple operator.getitem
• PR #3758: Fix target definition update in inlining
• PR #3782: Raise typing error on yield optional.
• PR #3792: Fix non-module object used as the module of a function.
• PR #3800: Bugfix for np.interp
• PR #3808: Bump macro to include VS2014 to fix py3.5 build
• PR #3809: Add debug guard to debug only C function.
• PR #3816: Fix array.sum(axis) 1d input return type.
• PR #3821: Replace PySys_WriteStdout with PySys_FormatStdout to ensure no truncation.
• PR #3830: Getitem should not return optional type
• PR #3832: Handle single string as path in find_file()

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9.25 Version 0.42.1

Bugfix release to fix the incorrect hash in OSX wheel packages. No change in source code.

9.26 Version 0.42.0

In this release the major features are:

- The capability to launch and attach the GDB debugger from within a jitted function.
- The upgrading of LLVM to version 7.0.0.

We added a draft of the project roadmap to the developer manual. The roadmap is for informational purposes only as priorities and resources may change.

Here are some enhancements from contributed PRs:

- #3532. Daniel Wennberg improved the `cuda.{pinned, mapped}` API so that the associated memory is released immediately at the exit of the context manager.
- #3531. Dimitri Vorona enabled the inlining of jitclass methods.
- #3516. Simon Perkins added the support for passing numpy dtypes (i.e. `np.dtype("int32")`) and their type constructor (i.e. `np.int32`) into a jitted function.
- #3509. Rob Ennis added support for `np.corrcoef`.

A regression issue (#3554, #3461) relating to making an empty slice in parallel mode is resolved by #3558.

General Enhancements:

- PR #3392: Launch and attach gdb directly from Numba.
- PR #3437: Changes to accommodate LLVM 7.0.x
- PR #3509: Support for `np.corrcoef`
- PR #3516: Typeof dtype values
- PR #3520: Fix `@stencil` ignoring cval if out kwarg supplied.
- PR #3531: Fix jitclass method inlining and avoid unnecessary increfs
- PR #3538: Avoid future C-level assertion error due to invalid visibility
- PR #3543: Avoid implementation error being hidden by the try-except
- PR #3544: Add `long_running` test flag and feature to exclude tests.
- PR #3549: ParallelAccelerator caching improvements
- PR #3558: Fixes array analysis for inplace binary operators.
• PR #3566: Skip alignment tests on armv7l.
• PR #3567: Fix unifying literal types in namedtuple
• PR #3576: Add special copy routine for NumPy out arrays
• PR #3577: Fix example and docs typos for objmode context manager. reorder statements.
• PR #3580: Use alias information when determining whether it is safe to
• PR #3583: Use ir.unknown_loc for unknown Loc, as #3390 with tests
• PR #3587: Fix llvm.memset usage changes in llvm7
• PR #3596: Fix Array Analysis for Global Namedtuples
• PR #3597: Warn users if threading backend init unsafe.
• PR #3605: Add guard for writing to read only arrays from ufunc calls
• PR #3606: Improve the accuracy of error message wording for undefined type.
• PR #3611: gdb test guard needs to ack ptrace permissions
• PR #3616: Skip gdb tests on ARM.

CUDA Enhancements:
• PR #3532: Unregister temporarily pinned host arrays at once
• PR #3552: Handle broadcast arrays correctly in host->device transfer.
• PR #3578: Align cuda and cuda simulator kwarg names.

Documentation Updates:
• PR #3545: Fix @njit description in 5 min guide
• PR #3570: Minor documentation fixes for numba.cuda
• PR #3581: Fixing minor typo in reference/types.rst
• PR #3594: Changing @stencil docs to correctly reflect func_or_mode param
• PR #3617: Draft roadmap as of Dec 2018

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9.27 Version 0.41.0

This release adds the following major features:

- Diagnostics showing the optimizations done by ParallelAccelerator
- Support for profiling Numba-compiled functions in Intel VTune
- Additional NumPy functions: partition, nancumsum, nancumprod, ediff1d, cov, conj, conjugate, tri, tril, triu
- Initial support for Python 3 Unicode strings

General Enhancements:

- PR #1968: armv7 support
- PR #2983: invert mapping b/w binop operators and the operator module #2297
- PR #3160: First attempt at parallel diagnostics
- PR #3307: Adding NUMBA_ENABLE_PROFILING envvar, enabling jit event
- PR #3320: Support for np.partition
- PR #3324: Support for np.nancumsum and np.nancumprod
- PR #3325: Add location information to exceptions.
- PR #3337: Support for np.ediff1d
- PR #3345: Support for np.cov
- PR #3348: Support user pipeline class in with lifting
- PR #3363: string support
- PR #3373: Improve error message for empty imprecise lists.
- PR #3375: Enable overload(operator.getitem)
- PR #3402: Support negative indexing in tuple.
- PR #3414: Refactor Const type
- PR #3416: Optimized usage of alloca out of the loop
- PR #3424: Updates for llvmlite 0.26
- PR #3462: Add support for np.conj/np.conjugate.
- PR #3480: np.tri, np.tril, np.triu - default optional args
- PR #3481: Permit dtype argument as sole kwarg in np.eye

CUDA Enhancements:

- PR #3399: Add max_registers Option to cuda.jit

Continuous Integration / Testing:

- PR #3303: CI with Azure Pipelines
- PR #3309: Workaround race condition with apt
- PR #3371: Fix issues with Azure Pipelines
• PR #3362: Fix #3360: RuntimeWarning: 'numba.runtests' found in sys.modules
• PR #3374: Disable openmp in wheel building
• PR #3404: Azure Pipelines templates
• PR #3419: Fix cuda tests and error reporting in test discovery
• PR #3491: Prevent faulthandler installation on armv7l
• PR #3493: Fix CUDA test that used negative indexing behaviour that’s fixed.
• PR #3495: Start Flake8 checking of Numba source

Fixes:
• PR #2950: Fix dispatcher to only consider contiguous-ness.
• PR #3124: Fix 3119, raise for 0d arrays in reductions
• PR #3228: Reduce redundant module linking
• PR #3329: Fix AOT on windows.
• PR #3335: Fix memory management of __cuda_array_interface__ views.
• PR #3340: Fix typo in error name.
• PR #3365: Fix the default unboxing logic
• PR #3367: Allow non-global reference to objmode() context-manager
• PR #3381: Fix global reference in objmode for dynamically created function
• PR #3382: CUDA_ERROR_MISALIGNED_ADDRESS Using Multiple Const Arrays
• PR #3384: Correctly handle very old versions of colorama
• PR #3394: Add 32bit package guard for non-32bit installs
• PR #3397: Fix with-objmode warning
• PR #3403 Fix label offset in call inline after parfor pass
• PR #3429: Fixes raising of user defined exceptions for exec(<string>).
• PR #3432: Fix error due to function naming in CI in py2.7
• PR #3444: Fixed TBB’s single thread execution and test added for #3440
• PR #3449: Allow matching non-array objects in find_callname()
• PR #3455: Change getiter and iternext to not be pure. Resolves #3425
• PR #3467: Make ir.UndefinendType singleton class.
• PR #3478: Fix np.random.shuffle sideeffect
• PR #3487: Raise unsupported for kwargs given to print()
• PR #3488: Remove dead script.
• PR #3498: Fix stencil support for boolean as return type
• PR #3511: Fix handling make_function literals (regression of #3414)
• PR #3514: Add missing unicode != unicode
• PR #3527: Fix complex math sqrt implementation for large -ve values
• PR #3530: This adds arg an check for the pattern supplied to Parfors.
• PR #3536: Sets list dtor linkage to `linkonce_odr` to fix visibility in AOT

Documentation Updates:
• PR #3316: Update 0.40 changelog with additional PRs
• PR #3318: Tweak spacing to avoid search box wrapping onto second line
• PR #3321: Add note about memory leaks with exceptions to docs. Fixes #3263
• PR #3322: Add FAQ on CUDA + fork issue. Fixes #3315.
• PR #3343: Update docs for argsort, kind kwarg partially supported.
• PR #3357: Added mention of njit in `5minguide.rst`
• PR #3434: Fix parallel reduction example in docs.
• PR #3452: Fix broken link and mark up problem.
• PR #3484: Size Numba logo in docs in em units. Fixes #3313
• PR #3502: just two typos
• PR #3506: Document string support
• PR #3513: Documentation for parallel diagnostics.
• PR #3526: Fix 5 min guide with respect to @njit decl

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9.28 Version 0.40.1

This is a PyPI-only patch release to ensure that PyPI wheels can enable the TBB threading backend, and to disable the OpenMP backend in the wheels. Limitations of manylinux1 and variation in user environments can cause segfaults when OpenMP is enabled on wheel builds. Note that this release has no functional changes for users who obtained Numba 0.40.0 via conda.

Patches:

• PR #3338: Accidentally left Anton off contributor list for 0.40.0
• PR #3374: Disable OpenMP in wheel building
• PR #3376: Update 0.40.1 changelog and docs on OpenMP backend

9.29 Version 0.40.0

This release adds a number of major features:

• A new GPU backend: kernels for AMD GPUs can now be compiled using the ROCm driver on Linux.
• The thread pool implementation used by Numba for automatic multithreading is configurable to use TBB, OpenMP, or the old “workqueue” implementation. (TBB is likely to become the preferred default in a future release.)
• New documentation on thread and fork-safety with Numba, along with overall improvements in thread-safety.
• Experimental support for executing a block of code inside a nopython mode function in object mode.
• Parallel loops now allow arrays as reduction variables
• CUDA improvements: FMA, faster float64 atomics on supporting hardware, records in const memory, and improved datetime dtype support
• More NumPy functions: vander, tri, triu, tril, fill_diagonal

General Enhancements:

• PR #3017: Add facility to support with-contexts
• PR #3033: Add support for multidimensional CFFI arrays
• PR #3122: Add inliner to object mode pipeline
• PR #3127: Support for reductions on arrays.
• PR #3145: Support for np.fill_diagonal
• PR #3151: Keep a queue of references to last N deserialized functions. Fixes #3026
• PR #3154: Support use of list() if typeable.
• PR #3166: Objmode with-block
• PR #3179: Updates for llvmlite 0.25
• PR #3181: Support function extension in alias analysis
• PR #3189: Support literal constants in typing of object methods
• PR #3190: Support passing closures as literal values in typing
• PR #3199: Support inferring stencil index as constant in simple unary expressions
• PR #3202: Threading layer backend refactor/rewrite/reinvention!
• PR #3209: Support for np.tri, np.tril and np.triu
• PR #3211: Handle unpacking in building tuple (BUILD_TUPLE_UNPACK opcode)
• PR #3212: Support for np.vander
• PR #3227: Add MemInfo_data to runtime._nrt_python.c_helpers
• PR #3273: Refactor. Removing thread-local-storage based context nesting.
• PR #3278: compiler thread safety lockdown
• PR #3291: Add CPU count and CFS restrictions info to numba -s.

CUDA Enhancements:
• PR #3152: Use cuda driver api to get best blocksize for best occupancy
• PR #3165: Add FMA intrinsic support
• PR #3172: Use float64 add Atomics, Where Available
• PR #3186: Support Records in CUDA Const Memory
• PR #3191: CUDA: fix log size
• PR #3198: Fix GPU datetime timedelta types usage
• PR #3221: Support datetime/timedelta scalar argument to a CUDA kernel.
• PR #3259: Add DeviceNDArray.view method to reinterpret data as a different type.
• PR #3310: Fix IPC handling of sliced cuda array.

ROCm Enhancements:
• PR #3023: Support for AMDGCN/ROCm.
• PR #3108: Add ROC info to numba -s output.
• PR #3176: Move ROC vectorize init to npyufunc
• PR #3177: Add auto_synchronize support to ROC stream
• PR #3178: Update ROC target documentation.
• PR #3294: Add compiler lock to ROC compilation path.
• PR #3280: Add wavebits property to the HSA Agent.
• PR #3281: Fix ds_permute types and add tests

Continuous Integration / Testing:
• PR #3091: Remove old recipes, switch to test config based on env var.
• PR #3094: Add higher ULP tolerance for products in complex space.
• PR #3096: Set exit on error in incremental scripts
• PR #3109: Add skip to test needing jinja2 if no jinja2.
• PR #3125: Skip cudasim only tests
• PR #3126: add slack, drop flowdock
• PR #3147: Improve error message for arg type unsupported during typing.
• PR #3128: Fix recipe/build for jetson tx2/ARM
• PR #3167: In build script activate env before installing.
• PR #3180: Add skip to broken test.
• PR #3216: Fix libcuda.so loading in some container setup
• PR #3224: Switch to new Gitter notification webhook URL and encrypt it
• PR #3235: Add 32bit Travis CI jobs
• PR #3257: This adds scipy/ipython back into windows conda test phase.

Fixes:
• PR #3038: Fix random integer generation to match results from NumPy.
• PR #3045: Fix #3027 - Numba reassigns sys.stdout
• PR #3059: Handler for known LoweringErrors.
• PR #3060: Adjust attribute error for NumPy functions.
• PR #3067: Abort simulator threads on exception in thread block.
• PR #3079: Implement +/-(types.boolean) Fix #2624
• PR #3080: Compute np.var and np.std correctly for complex types.
• PR #3088: Fix #3066 (array.dtype.type in prange)
• PR #3089: Fix invalid ParallelAccelerator hoisting issue.
• PR #3136: Fix #3135 (lowering error)
• PR #3137: Fix for issue3103 (race condition detection)
• PR #3142: Fix Issue #3139 (parfors reuse of reduction variable across prange blocks)
• PR #3148: Remove dead array equal @infer code
• PR #3153: Fix canonicalize_array_math typing for calls with kw args
• PR #3156: Fixes issue with missing pygments in testing and adds guards.
• PR #3168: Py37 bytes output fix.
• PR #3171: Fix #3146. Fix CFUNCTYPE void* return-type handling
• PR #3193: Fix setitem/getitem resolvers
• PR #3222: Fix #3214. Mishandling of POP_BLOCK in while True loop.
• PR #3230: Fixes liveness analysis issue in loollifting
• PR #3233: Fix return type difference for 32bit ctypes.c_void_p
• PR #3234: Fix types and layout for np.where.
• PR #3237: Fix DeprecationWarning about imp module
• PR #3241: Fix #3225. Normalize 0nd array to scalar in typing of indexing code.
• PR #3256: Fix #3251: Move imports of ABCs to collections.abc for Python >= 3.3
• PR #3292: Fix issue3279.
• PR #3302: Fix error due to mismatching dtype

Documentation Updates:
• PR #3104: Workaround for #3098 (test_optional_unpack Heisenbug)
• PR #3132: Adds an ~5 minute guide to Numba.
• PR #3194: Fix docs RE: np.random generator fork/thread safety
• PR #3242: Page with Numba talks and tutorial links
• PR #3258: Allow users to choose the type of issue they are reporting.
• PR #3260: Fixed broken link
• PR #3266: Fix cuda pointer ownership problem with user/externally allocated pointer
• PR #3269: Tweak typography with CSS
• PR #3270: Update FAQ for functions passed as arguments
• PR #3274: Update installation instructions
• PR #3275: Note Pyobject and voidptr are types in docs
• PR #3288: Do not need to call parallel optimizations “experimental” anymore
• PR #3318: Tweak spacing to avoid search box wrapping onto second line

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9.30 Version 0.39.0

Here are the highlights for the Numba 0.39.0 release.
• This is the first version that supports Python 3.7.
• With help from Intel, we have fixed the issues with SVML support (related issues #2938, #2998, #3006).
• List has gained support for containing reference-counted types like NumPy arrays and list. Note, list still cannot hold heterogeneous types.
We have made a significant change to the internal calling-convention, which should be transparent to most users, to allow for a future feature that will permitting jumping back into python-mode from a nopython-mode function. This also fixes a limitation to `print` that disabled its use from nopython functions that were deep in the call-stack.

For CUDA GPU support, we added a `__cuda_array_interface__` following the NumPy array interface specification to allow Numba to consume externally defined device arrays. We have opened a corresponding pull request to CuPy to test out the concept and be able to use a CuPy GPU array.

The Numba dispatcher `inspect_types()` method now supports the kwarg `pretty` which if set to `True` will produce ANSI/HTML output, showing the annotated types, when invoked from ipython/jupyter-notebook respectively.

The NumPy functions `ndarray.dot`, `np.percentile` and `np.nanpercentile`, and `np.unique` are now supported.

Numba now supports the use of a per-project configuration file to permanently set behaviours typically set via `NUMBA_*` family environment variables.

Support for the `ppc64le` architecture has been added.

Enhancements:

- PR #2793: Simplify and remove javascript from html_annotate templates.
- PR #2840: Support list of refcounted types
- PR #2902: Support for `np.unique`
- PR #2926: Enable fence for all architecture and add developer notes
- PR #2928: Making error about untyped list more informative.
- PR #2930: Add configuration file and color schemes.
- PR #2932: Fix encoding to ‘UTF-8’ in `check_output` decode.
- PR #2938: Python 3.7 compat: `_Py_Finalizing` becomes `_Py_IsFinalizing()`
- PR #2939: Comprehensive SVML unit test
- PR #2946: Add support for `ndarray.dot` method and tests.
- PR #2953: percentile and nanpercentile
- PR #2957: Add new 3.7 opcode support.
- PR #2963: Improve alias analysis to be more comprehensive
- PR #2984: Support for namedtuples in array analysis
- PR #2986: Fix environment propagation
- PR #2990: Improve function call matching for intrinsics
- PR #3002: Second pass at error rewrites (interpreter errors).
- PR #3004: Add `numpy.empty` to the list of pure functions.
- PR #3008: Augment SVML detection with llvmlite SVML patch detection.
- PR #3012: Make use of the common spelling of heterogeneous/homogeneous.
- PR #3032: Fix `pycc` ctypes test due to mismatch in calling-convention
- PR #3039: Add SVML detection to Numba environment diagnostic tool.
- PR #3041: This adds `@needs_blas` to tests that use BLAS
- PR #3056: Require llvmlite>=0.24.0

CUDA Enhancements:
• PR #2860: __cuda_array_interface__
• PR #2910: More CUDA intrinsics
• PR #2929: Add Flag To Prevent Unneccessary D->H Copies
• PR #3037: Add CUDA IPC support on non-peer-accessible devices

CI Enhancements:
• PR #3021: Update appveyor config.
• PR #3040: Add fault handler to all builds
• PR #3042: Add catchsegv
• PR #3077: Adds optional number of processes for -m in testing

Fixes:
• PR #2897: Fix line position of delete statement in numba ir
• PR #2905: Fix for #2862
• PR #3009: Fix optional type returning in recursive call
• PR #3019: workaround and unittest for issue #3016
• PR #3035: [TESTING] Attempt delayed removal of Env
• PR #3048: [WIP] Fix cuda tests failure on buildfarm
• PR #3054: Make test work on 32-bit
• PR #3062: Fix cuda.In freeing devary before the kernel launch
• PR #3073: Workaround #3072
• PR #3076: Avoid ignored exception due to missing globals at interpreter teardown

Documentation Updates:
• PR #2966: Fix syntax in env var docs.
• PR #2967: Fix typo in CUDA kernel layout example.
• PR #2970: Fix docstring copy paste error.

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9.31 Version 0.38.1

This is a critical bug fix release addressing: https://github.com/numba/numba/issues/3006

The bug does not impact users using conda packages from Anaconda or Intel Python Distribution (but it does impact conda-forge). It does not impact users of pip using wheels from PyPI.

This only impacts a small number of users where:

• The ICC runtime (specifically libsvml) is present in the user’s environment.
• The user is using an llvmlite statically linked against a version of LLVM that has not been patched with SVML support.
• The platform is 64-bit.

The release fixes a code generation path that could lead to the production of incorrect results under the above situation.

Fixes:

• PR #3007: Augment SVML detection with llvmlite SVML patch detection.

Contributors:

The following people contributed to this release.

• Stuart Archibald (core dev)

9.32 Version 0.38.0

Following on from the bug fix focus of the last release, this release swings back towards the addition of new features and usability improvements based on community feedback. This release is comparatively large! Three key features/changes to note are:

• Numba (via llvmlite) is now backed by LLVM 6.0, general vectorization is improved as a result. A significant long standing LLVM bug that was causing corruption was also found and fixed.
• Further considerable improvements in vectorization are made available as Numba now supports Intel’s short vector math library (SVML). Try it out with conda install -c numba icc_rt.
• CUDA 8.0 is now the minimum supported CUDA version.

Other highlights include:

• Bug fixes to parallel=True have enabled more vectorization opportunities when using the ParallelAccelerator technology.
• Much effort has gone into improving error reporting and the general usability of Numba. This includes highlighted error messages and performance tips documentation. Try it out with conda install colorama.
• A number of new NumPy functions are supported, np.convolve, np.correlate np.reshape, np.transpose, np.permutation, np.real, np.imag, and np.searchsorted now supports the side` kwarg. Further, np.argsort now supports the kind kwarg with quicksort and mergesort available.
• The Numba extension API has gained the ability to operate more easily with functions from Cython modules through the use of numba.extending.get_cython_function_address to obtain function addresses for direct use in ctypes.CFUNCTYPE.
• Numba now allows the passing of jitted functions (and containers of jitted functions) as arguments to other jitted functions.

• The CUDA functionality has gained support for a larger selection of bit manipulation intrinsics, also SELP, and has had a number of bugs fixed.

• Initial work to support the PPC64LE platform has been added, full support is however waiting on the LLVM 6.0.1 release as it contains critical patches not present in 6.0.0. It is hoped that any remaining issues will be fixed in the next release.

• The capacity for advanced users/compiler engineers to define their own compilation pipelines.

Enhancements:

• PR #2660: Support bools from cffi in nopython.

• PR #2741: Enhance error message for undefined variables.

• PR #2744: Add diagnostic error message to test suite discovery failure.

• PR #2748: Added Intel SVML optimizations as opt-out choice working by default

• PR #2762: Support transpose with axes arguments.

• PR #2777: Add support for np.correlate and np.convolve

• PR #2779: Implement np.random.permutation

• PR #2801: Passing jitted functions as args

• PR #2802: Support np.real() and np.imag()

• PR #2807: Expose import_cython_function

• PR #2821: Add kwarg ‘side’ to np.searchsorted

• PR #2822: Adds stable argsort

• PR #2832: Fixups for llvmlite 0.23/llvm 6

• PR #2836: Support index method on tuples

• PR #2839: Support for np.transpose and np.reshape.

• PR #2843: Custom pipeline

• PR #2847: Replace signed array access indices in unsiged prange loop body

• PR #2859: Add support for improved error reporting.

• PR #2880: This adds a github issue template.

• PR #2881: Build recipe to clone Intel ICC runtime.

• PR #2882: Update TravisCI to test SVML

• PR #2893: Add reference to the data buffer in array.ctypes object

• PR #2895: Move to CUDA 8.0

Fixes:

• PR #2737: Fix #2007 (part 1). Empty array handling in np.linalg.

• PR #2738: Fix install_requires to allow pip getting pre-release version

• PR #2740: Fix 2208. Generate better error message.

• PR #2765: Fix Bit-ness
• PR #2780: PowerPC reference counting memory fences
• PR #2805: Fix six imports.
• PR #2813: Fix #2812: gufunc scalar output bug.
• PR #2814: Fix the build post #2727
• PR #2831: Attempt to fix #2473
• PR #2842: Fix issue with test discovery and broken CUDA drivers.
• PR #2850: Add rtsys init guard and test.
• PR #2852: Skip vectorization test with targets that are not x86
• PR #2856: Prevent printing to stdout in test_extending.py
• PR #2864: Correct C code to prevent compiler warnings.
• PR #2889: Attempt to fix #2386.
• PR #2891: Removed test skipping for inspect_cfg
• PR #2898: Add guard to parallel test on unsupported platforms
• PR #2907: Update change log for PPC64LE LLVM dependency.
• PR #2911: Move build requirement to llvmlite>=0.23.0dev0
• PR #2912: Fix random permutation test.
• PR #2914: Fix MD list syntax in issue template.

Documentation Updates:
• PR #2739: Explicitly state default value of error_model in docstring
• PR #2803: DOC: parallel vectorize requires signatures
• PR #2829: Add Python 2.7 EOL plan to docs
• PR #2838: Use automatic numbering syntax in list.
• PR #2877: Add performance tips documentation.
• PR #2883: Fix #2872: update rng doc about thread/fork-safety
• PR #2908: Add missing link and ref to docs.
• PR #2909: Tiny typo correction

ParallelAccelerator enhancements/fixes:
• PR #2727: Changes to enable vectorization in ParallelAccelerator.
• PR #2816: Array analysis for transpose with arbitrary arguments
• PR #2874: Fix dead code eliminator not to remove a call with side-effect
• PR #2886: Fix ParallelAccelerator arrayexpr repr

CUDA enhancements:
• PR #2734: More Constants From cuda.h
• PR #2767: Add len(...) Support to DeviceNDArray
• PR #2778: Add More Device Array API Functions to CUDA Simulator
• PR #2824: Add CUDA Primitives for Population Count
• PR #2835: Emit selp Instructions to Avoid Branching
• PR #2867: Full support for CUDA device attributes

CUDA fixes: * PR #2768: Don’t Compile Code on Every Assignment * PR #2878: Fixes a Win64 issue with the test in Pr/2865

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9.33 Version 0.37.0

This release focuses on bug fixing and stability but also adds a few new features including support for Numpy 1.14. The key change for Numba core was the long awaited addition of the final tranche of thread safety improvements that allow Numba to be run concurrently on multiple threads without hitting known thread safety issues inside LLVM itself. Further, a number of fixes and enhancements went into the CUDA implementation and ParallelAccelerator gained some new features and underwent some internal refactoring.

Misc enhancements:
• PR #2627: Remove hacks to make llvm-lite threadsafe
• PR #2672: Add ascontiguousarray
• PR #2678: Add Gitter badge
• PR #2691: Fix #2690: add intrinsic to convert array to tuple
• PR #2703: Test runner feature: failed-first and last-failed
• PR #2708: Patch for issue #1907
• PR #2732: Add support for array.fill

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Misc Fixes:
- PR #2610: Fix #2606 lowering of optional.setattr
- PR #2650: Remove skip for win32 cosine test
- PR #2668: Fix empty_like from readonly arrays.
- PR #2682: Fixes 2210, remove _DisableJitWrapper
- PR #2684: Fix #2340, generator error yielding bool
- PR #2693: Add travis-ci testing of NumPy 1.14, and also check on Python 2.7
- PR #2694: Avoid type inference failure due to a typing template rejection
- PR #2695: Update llvmmlite version dependency.
- PR #2696: Fix tuple indexing codegeneration for empty tuple
- PR #2698: Fix #2697 by deferring deletion in the simplify_CFG loop.
- PR #2701: Small fix to avoid tempfiles being created in the current directory
- PR #2725: Fix 2481, LLVM IR parsing error due to mutated IR
- PR #2726: Fix #2673: incorrect fork error msg.
- PR #2728: Alternative to #2620. Remove dead code ByteCodeInst.get.
- PR #2730: Add guard for test needing SciPy/BLAS

Documentation updates:
- PR #2670: Update communication channels
- PR #2671: Add docs about diagnosing loop vectorizer
- PR #2683: Add docs on const arg requirements and on const mem alloc
- PR #2722: Add docs on numpy support in cuda
- PR #2724: Update doc: warning about unsupported arguments

ParallelAccelerator enhancements/fixtures:
Parallel support for np.arange and np.linspace, also np.mean, np.std and np.var are added. This was performed as part of a general refactor and cleanup of the core ParallelAccelerator code.
- PR #2674: Core pa
- PR #2704: Generate Dels after parfor sequential lowering
- PR #2716: Handle matching directly supported functions

CUDA enhancements:
- PR #2665: CUDA DeviceNDArray: Support numpy transpose API
- PR #2681: Allow Assigning to DeviceNDArrays
- PR #2702: Make DummyArray do High Dimensional Reshapes
- PR #2714: Use CFFI to Reuse Code

CUDA fixes:
- PR #2667: Fix CUDA DeviceNDArray slicing
- PR #2686: Fix #2663: incorrect offset when indexing cuda array.
- PR #2687: Ensure Constructed Stream Bound
- PR #2706: Workaround for unexpected warp divergence due to exception raising code
- PR #2707: Fix regression: cuda test submodules not loading properly in runtests
- PR #2731: Use more challenging values in slice tests.
- PR #2720: A quick testsuite fix to not run the new cuda testcase in the multiprocess pool

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### 9.34 Version 0.36.2

This is a bugfix release that provides minor changes to address:
- PR #2645: Avoid CPython bug with `exec` in older 2.7.x.
- PR #2652: Add support for CUDA 9.

### 9.35 Version 0.36.1

This release continues to add new features to the work undertaken in partnership with Intel on ParallelAccelerator technology. Other changes of note include the compilation chain being updated to use LLVM 5.0 and the production of conda packages using conda-build 3 and the new compilers that ship with it.

NOTE: A version 0.36.0 was tagged for internal use but not released.

ParallelAccelerator:

NOTE: The ParallelAccelerator technology is under active development and should be considered experimental.

New features relating to ParallelAccelerator, from work undertaken with Intel, include the addition of the `@stencil` decorator for ease of implementation of stencil-like computations, support for general reductions, and slice and range fusion for parallel slice/bit-array assignments. Documentation on both the use and implementation of the above has been added. Further, a new debug environment variable `NUMBA_DEBUG_ARRAY_OPT_STATS` is made available to give information about which operators/calls are converted to parallel for-loops.

ParallelAccelerator features:
- PR #2457: Stencil Computations in ParallelAccelerator
- PR #2548: Slice and range fusion, parallelizing bitarray and slice assignment
• PR #2516: Support general reductions in ParallelAccelerator

ParallelAccelerator fixes:
• PR #2540: Fix bug #2537
• PR #2566: Fix issue #2564.
• PR #2599: Fix nested multi-dimensional parfor type inference issue
• PR #2604: Fixes for stencil tests and cmath sin().
• PR #2605: Fixes issue #2603.

Additional features of note:
This release of Numba (and llvmlite) is updated to use LLVM version 5.0 as the compiler back end, the main change to Numba to support this was the addition of a custom symbol tracker to avoid the calls to LLVM’s ExecutionEngine that was crashing when asking for non-existent symbol addresses. Further, the conda packages for this release of Numba are built using conda build version 3 and the new compilers/recipe grammar that are present in that release.
• PR #2568: Update for LLVM 5
• PR #2607: Fixes abort when getting address to “nrt_unresolved_abort”
• PR #2615: Working towards conda build 3

Thanks to community feedback and bug reports, the following fixes were also made.

Misc fixes/enhancements:
• PR #2534: Add tuple support to np.take.
• PR #2551: Rebranding fix
• PR #2552: relative doc links
• PR #2570: Fix issue #2561, handle missing successor on loop exit
• PR #2588: Fix #2555. Disable libpython.so linking on linux
• PR #2601: Update llvmlite version dependency.
• PR #2608: Fix potential cache file collision
• PR #2612: Fix NRT test failure due to increased overhead when running in coverage
• PR #2619: Fix dubious pthread_cond_signal not in lock
• PR #2622: Fix np.nanmedian for all NaN case.
• PR #2633: Fix markdown in CONTRIBUTING.md
• PR #2635: Make the dependency on compilers for AOT optional.

CUDA support fixes:
• PR #2523: Fix invalid cuda context in memory transfer calls in another thread
• PR #2575: Use CPU to initialize xoroshiro states for GPU RNG. Fixes #2573
• PR #2581: Fix cuda gufunc mishandling of scalar arg as array and out argument
9.36 Version 0.35.0

This release includes some exciting new features as part of the work performed in partnership with Intel on ParallelAccelerator technology. There are also some additions made to Numpy support and small but significant fixes made as a result of considerable effort spent chasing bugs and implementing stability improvements.

ParallelAccelerator:

NOTE: The ParallelAccelerator technology is under active development and should be considered experimental.

New features relating to ParallelAccelerator, from work undertaken with Intel, include support for a larger range of np.random functions in parallel mode, printing Numpy arrays in no Python mode, the capacity to initialize Numpy arrays directly from list comprehensions, and the axis argument to .sum(). Documentation on the ParallelAccelerator technology implementation has also been added. Further, a large amount of work on equivalence relations was undertaken to enable runtime checks of broadcasting behaviours in parallel mode.

ParallelAccelerator features:

• PR #2400: Array comprehension
• PR #2405: Support printing Numpy arrays
• PR #2438: from Support more np.random functions in ParallelAccelerator
• PR #2482: Support for sum with axis in nopython mode.
• PR #2487: Adding developer documentation for ParallelAccelerator technology.
• PR #2492: Core PA refactor adds assertions for broadcast semantics

ParallelAccelerator fixes:

• PR #2478: Rename cfg before parfor translation (#2477)
• PR #2479: Fix broken array comprehension tests on unsupported platforms
• PR #2484: Fix array comprehension test on win64
• PR #2506: Fix for 32-bit machines.

Additional features of note:

Support for np.take, np.finfo, np.iinfo and np.MachAr in no Python mode is added. Further, three new environment variables are added, two for overriding CPU target/features and another to warn if parallel=True was set no such transform was possible.

• PR #2490: Implement np.take and ndarray.take
• PR #2493: Display a warning if parallel=True is set but not possible.
• PR #2513: Add np.MachAr, np.finfo, np.iinfo
• PR #2515: Allow environ overriding of cpu target and cpu features.

Due to expansion of the test farm and a focus on fixing bugs, the following fixes were also made.

Misc fixes/enhancements:

• PR #2455: add contextual information to runtime errors
• PR #2470: Fixes #2458, poor performance in np.median
• PR #2471: Ensure LLVM thread safety in {g,}ufunc building.
• PR #2494: Update doc theme
• PR #2503: Remove hacky code added in 2482 and feature enhancement
• PR #2505: Serialise env mutation tests during multithreaded testing.
• PR #2520: Fix failing cpu-target override tests

CUDA support fixes:
• PR #2504: Enable CUDA toolkit version testing
• PR #2509: Disable tests generating code unavailable in lower CC versions.
• PR #2511: Fix Windows 64 bit CUDA tests.

9.37 Version 0.34.0

This release adds a significant set of new features arising from combined work with Intel on ParallelAccelerator technology. It also adds list comprehension and closure support, support for Numpy 1.13 and a new, faster, CUDA reduction algorithm. For Linux users this release is the first to be built on Centos 6, which will be the new base platform for future releases. Finally a number of thread-safety, type inference and other smaller enhancements and bugs have been fixed.

ParallelAccelerator features:
NOTE: The ParallelAccelerator technology is under active development and should be considered experimental.

The ParallelAccelerator technology is accessed via a new “nopython” mode option “parallel”. The ParallelAccelerator technology attempts to identify operations which have parallel semantics (for instance adding a scalar to a vector), fuse together adjacent such operations, and then parallelize their execution across a number of CPU cores. This is essentially auto-parallelization.

In addition to the auto-parallelization feature, explicit loop based parallelism is made available through the use of prange in place of range as a loop iterator.

More information and examples on both auto-parallelization and prange are available in the documentation and examples directory respectively.

As part of the necessary work for ParallelAccelerator, support for closures and list comprehensions is added:
• PR #2318: Transfer ParallelAccelerator technology to Numba
• PR #2379: ParallelAccelerator Core Improvements
• PR #2367: Add support for len(range(...))
• PR #2369: List comprehension
• PR #2391: Explicit Parallel Loop Support (prange)

The ParallelAccelerator features are available on all supported platforms and Python versions with the exceptions of (with view of supporting in a future release):
• The combination of Windows operating systems with Python 2.7.
• Systems running 32 bit Python.

CUDA support enhancements:
• PR #2377: New GPU reduction algorithm

CUDA support fixes:
• PR #2397: Fix #2393, always set alignment of cuda static memory regions

Misc Fixes:
• PR #2373, Issue #2372: 32-bit compatibility fix for parfor related code
• PR #2376: Fix #2375 missing stdint.h for py2.7 vc9
• PR #2378: Fix deadlock in parallel gufunc when kernel acquires the GIL.
• PR #2382: Forbid unsafe casting in bitwise operation
• PR #2385: docs: fix Sphinx errors
• PR #2396: Use 64-bit RHS operand for shift
• PR #2404: Fix threadsafety logic issue in ufunc compilation cache.
• PR #2424: Ensure consistent iteration order of blocks for type inference.
• PR #2425: Guard code to prevent the use of ‘parallel’ on win32 + py27
• PR #2426: Basic test for Enum member type recovery.
• PR #2433: Fix up the parfors tests with respect to windows py2.7
• PR #2442: Skip tests that need BLAS/LAPACK if scipy is not available.
• PR #2444: Add test for invalid array setitem
• PR #2449: Make the runtime initialiser threadsafe
• PR #2452: Skip CFG test on 64bit windows

Misc Enhancements:
• PR #2366: Improvements to IR utils
• PR #2388: Update README.rst to indicate the proper version of LLVM
• PR #2394: Upgrade to llvmlite 0.19.*
• PR #2395: Update llvmlite version to 0.19
• PR #2406: Expose environment object to ufuncs
• PR #2407: Expose environment object to target-context inside lowerer
• PR #2413: Add flags to pass through to conda build for buildbot
• PR #2414: Add cross compile flags to local recipe
• PR #2415: A few cleanups for rewrites
• PR #2418: Add getitem support for Enum classes
• PR #2419: Add support for returning enums in vectorize
• PR #2421: Add copyright notice for Intel contributed files.
• PR #2422: Patch code base to work with np 1.13 release
• PR #2448: Adds in warning message when using ‘parallel’ if cache=True
• PR #2450: Add test for keyword arg on .sum-like and .cumsum-like array methods
9.38 Version 0.33.0

This release resolved several performance issues caused by atomic reference counting operations inside loop bodies. New optimization passes have been added to reduce the impact of these operations. We observe speed improvements between 2x-10x in affected programs due to the removal of unnecessary reference counting operations.

There are also several enhancements to the CUDA GPU support:

- A GPU random number generator based on xoroshiro128+ algorithm is added. See details and examples in documentation.
- @cuda.jit CUDA kernels can now call @jit and @njit CPU functions and they will automatically be compiled as CUDA device functions.
- CUDA IPC memory API is exposed for sharing memory between processes. See usage details in documentation.

Reference counting enhancements:

- PR #2346, Issue #2345, #2248: Add extra refcount pruning after inlining
- PR #2349: Fix refct pruning not removing refct op with tail call.
- PR #2352, Issue #2350: Add refcount pruning pass for function that does not need refcount

CUDA support enhancements:

- PR #2023: Supports CUDA IPC for device array
- PR #2343, Issue #2335: Allow CPU jit decorated function to be used as cuda device function
- PR #2347: Add random number generator support for CUDA device code
- PR #2361: Update autotune table for CC: 5.3, 6.0, 6.1, 6.2

Misc fixes:

- PR #2362: Avoid test failure due to typing to int32 on 32-bit platforms
- PR #2359: Fixed nogil example that threw a TypeError when executed.
- PR #2357, Issue #2356: Fix fragile test that depends on how the script is executed.
- PR #2355: Fix cpu dispatcher referenced as attribute of another module
- PR #2354: Fixes an issue with caching when function needs NRT and refcount pruning
- PR #2342, Issue #2339: Add warnings to inspection when it is used on unserialized cached code
- PR #2329, Issue #2250: Better handling of missing op codes

Misc enhancements:

- PR #2360: Adds missing values in error message interp.
- PR #2353: Handle when get_host_cpu_features() raises RuntimeError
- PR #2351: Enable SVML for erf/erfc/gamma/lgamma/log2
- PR #2344: Expose error_model setting in jit decorator
- PR #2337: Align blocking terminate support for fork() with new TBB version
- PR #2336: Bump llvmlite version to 0.18
- PR #2330: Core changes in PR #2318
9.39 Version 0.32.0

In this release, we are upgrading to LLVM 4.0. A lot of work has been done to fix many race-condition issues inside LLVM when the compiler is used concurrently, which is likely when Numba is used with Dask.

Improvements:

- PR #2322: Suppress test error due to unknown but consistent error with tgamma
- PR #2320: Update llvmlite dependency to 0.17
- PR #2308: Add details to error message on why cuda support is disabled.
- PR #2302: Add os x to travis
- PR #2294: Disable remove_module on MCJIT due to memory leak inside LLVM
- PR #2291: Split parallel tests and recycle workers to tame memory usage
- PR #2253: Remove the pointer-stuffing hack for storing meminfos in lists

Fixes:

- PR #2331: Fix a bug in the GPU array indexing
- PR #2326: Fix #2321 docs referring to non-existing function.
- PR #2316: Fixing more race-condition problems
- PR #2315: Fix #2314. Relax strict type check to allow optional type.
- PR #2310: Fix race condition due to concurrent compilation and cache loading
- PR #2304: Fix intrinsic 1st arg not a typing.Context as stated by the docs.
- PR #2287: Fix int64 atomic min-max
- PR #2286: Fix #2285 @overload_method not linking dependent libs
- PR #2303: Missing import statements to interval-example.rst

9.40 Version 0.31.0

In this release, we added preliminary support for debugging with GDB version >= 7.0. The feature is enabled by setting the debug=True compiler option, which causes GDB compatible debug info to be generated. The CUDA backend also gained limited debugging support so that source locations are showed in memory-checking and profiling tools. For details, see Troubleshooting and tips.

Also, we added the fastmath=True compiler option to enable unsafe floating-point transformations, which allows LLVM to auto-vectorize more code.

Other important changes include upgrading to LLVM 3.9.1 and adding support for Numpy 1.12.

Improvements:

- PR #2281: Update for numpy1.12
- PR #2278: Add CUDA atomic.{max, min, compare_and_swap}
- PR #2277: Add about section to conda recipies to identify license and other metadata in Anaconda Cloud
- PR #2271: Adopt itanium C++-style mangling for CPU and CUDA targets
- PR #2267: Add fastmath flags
• PR #2261: Support dtype.type
• PR #2249: Changes for llvm3.9
• PR #2234: Bump llvmlite requirement to 0.16 and add install_name_tool_fixer to mviewbuf for OS X
• PR #2230: Add python3.6 to TravisCi
• PR #2227: Enable caching for gufunc wrapper
• PR #2170: Add debugging support
• PR #2037: inspect_cfg() for easier visualization of the function operation

Fixes:
• PR #2274: Fix nvvm ir patch in mishandling “load”
• PR #2272: Fix breakage to cuda7.5
• PR #2269: Fix caching of copy_strides kernel in cuda.reduce
• PR #2265: Fix #2263: error when linking two modules with dynamic globals
• PR #2252: Fix path separator in test
• PR #2246: Fix overuse of memory in some system with fork
• PR #2241: Fix #2240: __module__ in dynamically created function not a str
• PR #2239: Fix fingerprint computation failure preventing fallback

9.41 Version 0.30.1

This is a bug-fix release to enable Python 3.6 support. In addition, there is now early Intel TBB support for parallel ufuncs when building from source with TBBROOT defined. The TBB feature is not enabled in our official builds.

Fixes:
• PR #2232: Fix name clashes with _Py_hashtable_xxx in Python 3.6.

Improvements:
• PR #2217: Add Intel TBB threadpool implementation for parallel ufunc.

9.42 Version 0.30.0

This release adds preliminary support for Python 3.6, but no official build is available yet. A new system reporting tool (numba --sysinfo) is added to provide system information to help core developers in replication and debugging. See below for other improvements and bug fixes.

Improvements:
• PR #2209: Support Python 3.6.
• PR #2175: Support np.trace(), np.outer() and np.kron().
• PR #2197: Support np.nanprod().
• PR #2190: Support caching for ufunc.
• PR #2186: Add system reporting tool.

Fixes:
• PR #2214, Issue #2212: Fix memory error with ndenumerate and flat iterators.
• PR #2206, Issue #2163: Fix `zip()` consuming extra elements in early exhaustion.
• PR #2185, Issue #2159, #2169: Fix rewrite pass affecting objmode fallback.
• PR #2204, Issue #2178: Fix annotation for liftedloop.
• PR #2203: Fix Appveyor segfault with Python 3.5.
• PR #2202, Issue #2198: Fix target context not initialized when loading from ufunc cache.
• PR #2172, Issue #2171: Fix optional type unpacking.
• PR #2189, Issue #2188: Disable freezing of big (>1MB) global arrays.
• PR #2180, Issue #2179: Fix invalid variable version in looplifting.
• PR #2156, Issue #2155: Fix divmod, floordiv segfault on CUDA.

9.43 Version 0.29.0

This release extends the support of recursive functions to include direct and indirect recursion without explicit function type annotations. See new example in `examples/mergesort.py`. Newly supported numpy features include array stacking functions, `np.linalg.eig*` functions, `np.linalg.matrix_power`, `np.roots` and array to array broadcasting in assignments.

This release depends on llvmlite 0.14.0 and supports CUDA 8 but it is not required.

Improvements:
• PR #2130, #2137: Add type-inferred recursion with docs and examples.
• PR #2134: Add `np.linalg.matrix_power`.
• PR #2125: Add `np.roots`.
• PR #2129: Add `np.linalg.{eigvals,eigh,eigvalsh}`.
• PR #2126: Add array-to-array broadcasting.
• PR #2069: Add hstack and related functions.
• PR #2128: Allow for vectorizing a jitted function. (thanks to @dhirschfeld)
• PR #2117: Update examples and make them test-able.
• PR #2127: Refactor interpreter class and its results.

Fixes:
• PR #2149: Workaround MSVC9.0 SP1 fmod bug kb982107.
• PR #2145, Issue #2009: Fixes kwargs for jitclass __init__ method.
• PR #2150: Fix slowdown in objmode fallback.
• PR #2050, Issue #1259: Fix liveness problem with some generator loops.
• PR #2072, Issue #1995: Right shift of unsigned LHS should be logical.
• PR #2115, Issue #1466: Fix inspect_types() error due to mangled variable name.
• PR #2119, Issue #2118: Fix array type created from record-dtype.
• PR #2122, Issue #1808: Fix returning a generator due to datamodel error.
9.44 Version 0.28.1

This is a bug-fix release to resolve packaging issues with setuptools dependency.

9.45 Version 0.28.0

Amongst other improvements, this version improves again the level of support for linear algebra – functions from the `numpy.linalg` module. Also, our random generator is now guaranteed to be thread-safe and fork-safe.

Improvements:

- PR #2019: Add the `@intrinsic` decorator to define low-level subroutines callable from JIT functions (this is considered a private API for now).
- PR #2059: Implement `np.concatenate` and `np.stack`.
- PR #2048: Make random generation fork-safe and thread-safe, producing independent streams of random numbers for each thread or process.
- PR #2031: Add documentation of floating-point pitfalls.
- Issue #2053: Avoid polling in parallel CPU target (fixes severe performance regression on Windows).
- Issue #2029: Make default arguments fast.
- PR #2052: Add logging to the CUDA driver.
- PR #2049: Implement the built-in `divmod()` function.
- PR #2036: Implement the `argsort()` method on arrays.
- PR #2046: Improving CUDA memory management by deferring deallocations until certain thresholds are reached, so as to avoid breaking asynchronous execution.
- PR #2040: Switch the CUDA driver implementation to use CUDA’s “primary context” API.
- PR #2017: Allow `min(tuple)` and `max(tuple)`.
- PR #2039: Reduce fork() detection overhead in CUDA.
- PR #2021: Handle structured dtypes with titles.
- PR #1996: Rewrite looPlifting as a transformation on Numba IR.
- PR #2014: Implement `np.linalg.matrix_rank`.
- PR #2012: Implement `np.linalg.cond`.
- PR #1985: Rewrite even trivial array expressions, which opens the door for other optimizations (for example, `array ** 2` can be converted into `array * array`).
- PR #1950: Have `typeof()` always raise `ValueError` on failure. Previously, it would either raise or return None, depending on the input.
- Issue #1979: Document integer width inference and how to workaround.
- PR #1938: Numba is now compatible with LLVM 3.8.
- PR #1967: Restrict `np.linalg` functions to homogeneous dtypes. Users wanting to pass mixed-typed inputs have to convert explicitly, which makes the performance implications more obvious.
Fixes:

- PR #2006: array(float32) ** int should return array(float32).
- PR #2044: Allow reshaping empty arrays.
- Issue #2051: Fix refcounting issue when concatenating tuples.
- Issue #2000: Make Numpy optional for setup.py, to allow pip install to work without Numpy pre-installed.
- PR #1989: Fix assertion in Dispatcher.disable_compile().
- Issue #2028: Ignore filesystem errors when caching from multiple processes.
- Issue #2003: Allow unicode variable and function names (on Python 3).
- Issue #1998: Fix deadlock in parallel ufuncs that reacquire the GIL.
- PR #1997: Fix random crashes when AOT compiling on certain Windows platforms.
- Issue #1933: Ensure array constants are emitted with the right alignment.

9.46 Version 0.27.0

Improvements:

- Issue #1976: improve error message when non-integral dimensions are given to a CUDA kernel.
- PR #1970: Optimize the power operator with a static exponent.
- PR #1710: Improve contextual information for compiler errors.
- PR #1961: Support printing constant strings.
- PR #1959: Support more types in the print() function.
- PR #1823: Support compute_50 in CUDA backend.
- PR #1896: Improve the SmartArray API.
- Issue #1943: Improve error message when an argument fails typing.
- PR #1927: Support np.linalg.lstsq.
- PR #1934: Use system functions for hypot() where possible, instead of our own implementation.
- PR #1929: Add cffi support to @cfunc objects.
- PR #1932: Add user-controllable thread pool limits for parallel CPU target.
- PR #1928: Support self-recursion when the signature is explicit.
- PR #1890: List all lowering implementations in the developer docs.
- Issue #1884: Support np.lib.stride_tricks.as_strided().

Fixes:

- Issue #1960: Fix sliced assignment when source and destination areas are overlapping.
- PR #1963: Make CUDA print() atomic.
• PR #1956: Allow 0d array constants.
• Issue #1945: Allow using Numpy ufuncs in AOT compiled code.
• Issue #1916: Fix documentation example for @generated_jit.
• Issue #1926: Fix regression when caching functions in an IPython session.
• Issue #1923: Allow non-intp integer arguments to carray() and farray().
• Issue #1908: Accept non-ASCII unicode docstrings on Python 2.
• Issue #1874: Allow del container[key] in object mode.
• Issue #1913: Fix set insertion bug when the lookup chain contains deleted entries.
• Issue #1911: Allow function annotations on jitclass methods.

9.47 Version 0.26.0

This release adds support for cfunc decorator for exporting numba jitted functions to 3rd party API that takes C callbacks. Most of the overhead of using jitclasses inside the interpreter are eliminated. Support for decompositions in numpy.linalg are added. Finally, Numpy 1.11 is supported.

Improvements:
• PR #1889: Export BLAS and LAPACK wrappers for pycc.
• PR #1888: Faster array power.
• Issue #1867: Allow “out” keyword arg for dufuncs.
• PR #1871: carray() and farray() for creating arrays from pointers.
• PR #1855: @cfunc decorator for exporting as ctypes function.
• PR #1862: Add support for numpy.linalg.qr.
• PR #1851: jitclass support for ‘_’ and ‘__’ prefixed attributes.
• PR #1842: Optimize jitclass in Python interpreter.
• Issue #1837: Fix CUDA simulator issues with device function.
• PR #1839: Add support for decompositions from numpy.linalg.
• PR #1829: Support Python enums.
• PR #1828: Add support for numpy.random.rand() and numpy.random.randn() 
• Issue #1825: Use of 0-darray in place of scalar index.
• Issue #1824: Scalar arguments to object mode gufuncs.
• Issue #1813: Let bitwise bool operators return booleans, not integers.
• Issue #1760: Optional arguments in generators.
• PR #1780: Numpy 1.11 support.
9.48 Version 0.25.0

This release adds support for set objects in nopython mode. It also adds support for many missing Numpy features and functions. It improves Numba’s compatibility and performance when using a distributed execution framework such as dask, distributed or Spark. Finally, it removes compatibility with Python 2.6, Python 3.3 and Numpy 1.6.

Improvements:

- Issue #1800: Add erf(), erfc(), gamma() and lgamma() to CUDA targets.
- PR #1793: Implement more Numpy functions: np.bincount(), np.diff(), np.digitize(), np.histogram(), np.searchsorted() as well as NaN-aware reduction functions (np.nansum(), np.nanmedian(), etc.)
- PR #1789: Optimize some reduction functions such as np.sum(), np.prod(), np.median(), etc.
- PR #1752: Make CUDA features work in dask, distributed and Spark.
- PR #1787: Support np.nditer() for fast multi-array indexing with broadcasting.
- PR #1799: Report JIT-compiled functions as regular Python functions when profiling (allowing to see the file-name and line number where a function is defined).
- PR #1782: Support np.any() and np.all().
- Issue #1788: Support the iter() and next() built-in functions.
- PR #1778: Support array.astype().
- Issue #1775: Allow the user to set the target CPU model for AOT compilation.
- PR #1758: Support creating random arrays using the size parameter to the np.random APIs.
- PR #1757: Support len() on array.flat objects.
- PR #1749: Remove Numpy 1.6 compatibility.
- PR #1748: Remove Python 2.6 and 3.3 compatibility.
- PR #1735: Support the not in operator as well as operator.contains() in nopython mode.
- Issue #875: make compilation of array constants faster.

Fixes:

- PR #1795: Fix a massive performance issue when calling Numba functions with distributed, Spark or a similar mechanism using serialization.
- Issue #1784: Make jitclasses usable with NUMBA_DISABLE_JIT=1.
- Issue #1786: Allow using linear algebra functions when profiling.
- Issue #1796: Fix np.dot() memory leak on non-contiguous inputs.
- PR #1792: Fix static negative indexing of tuples.
- Issue #1771: Use fallback cache directory when __pycache__ isn’t writable, such as when user code is installed in a system location.
- Issue #1223: Use Numpy error model in array expressions (e.g. division by zero returns inf or nan instead of raising an error).
- Issue #1640: Fix np.random.binomial() for large n values.
- Issue #1643: Improve error reporting when passing an invalid spec to @jitclass.
- PR #1756: Fix slicing with a negative step and an omitted start.
9.49 Version 0.24.0

This release introduces several major changes, including the @generated_jit decorator for flexible specializations as with Julia’s "@generated" macro, or the SmartArray array wrapper type that allows seamless transfer of array data between the CPU and the GPU.

This will be the last version to support Python 2.6, Python 3.3 and Numpy 1.6.

Improvements:

- PR #1723: Improve compatibility of JIT functions with the Python profiler.
- PR #1509: Support array.ravel() and array.flatten().
- PR #1676: Add SmartArray type to support transparent data management in multiple address spaces (host & GPU).
- PR #1689: Reduce startup overhead of importing Numba.
- PR #1705: Support registration of CFFI types as corresponding to known Numba types.
- PR #1686: Document the extension API.
- PR #1698: Improve warnings raised during type inference.
- PR #1697: Support np.dot() and friends on non-contiguous arrays.
- PR #1692: cffi.from_buffer() improvements (allow more pointer types, allow non-Numpy buffer objects).
- PR #1648: Add the @generated_jit decorator.
- PR #1651: Implementation of np.linalg.inv using LAPACK. Thanks to Matthieu Dartiailh.
- PR #1674: Support np.diag().
- PR #1673: Improve error message when looking up an attribute on an unknown global.
- Issue #1569: Implement runtime check for the LLVM locale bug.
- PR #1612: Switch to LLVM 3.7 in sync with llvmlite.
- PR #1624: Allow slice assignment of sequence to array.
- PR #1622: Support slicing tuples with a constant slice.

Fixes:

- Issue #1722: Fix returning an optional boolean (bool or None).
- Issue #1734: NRT decref bug when variable is del’ed before being defined, leading to a possible memory leak.
- PR #1732: Fix tuple getitem regression for CUDA target.
- PR #1718: Mishandling of optional to optional casting.
- PR #1714: Fix .compile() on a JIT function not respecting ._can_compile.
- Issue #1667: Fix np.angle() on arrays.
- Issue #1690: Fix slicing with an omitted stop and a negative step value.
- PR #1693: Fix gufunc bug in handling scalar formal arg with non-scalar input value.
- PR #1683: Fix parallel testing under Windows.
- Issue #1616: Use system-provided versions of C99 math where possible.
- Issue #1652: Reductions of bool arrays (e.g. sum() or mean()) should return integers or floats, not bools.
• Issue #1664: Fix regression when indexing a record array with a constant index.
• PR #1661: Disable AVX on old Linux kernels.
• Issue #1636: Allow raising an exception looked up on a module.

9.50 Version 0.23.1

This is a bug-fix release to address several regressions introduced in the 0.23.0 release, and a couple other issues.

Fixes:
• Issue #1645: CUDA ufuncs were broken in 0.23.0.
• Issue #1638: Check tuple sizes when passing a list of tuples.
• Issue #1630: Parallel ufunc would keep eating CPU even after finishing under Windows.
• Issue #1628: Fix ctypes and cffi tests under Windows with Python 3.5.
• Issue #1627: Fix xrange() support.
• PR #1611: Rewrite variable liveness analysis.
• Issue #1610: Allow nested calls between explicitly-typed ufuncs.
• Issue #1593: Fix *args in object mode.

9.51 Version 0.23.0

This release introduces JIT classes using the new @jitclass decorator, allowing user-defined structures for nopython mode. Other improvements and bug fixes are listed below.

Improvements:
• PR #1609: Speed up some simple math functions by inlining them in their caller
• PR #1571: Implement JIT classes
• PR #1584: Improve typing of array indexing
• PR #1583: Allow printing booleans
• PR #1542: Allow negative values in np.reshape()
• PR #1560: Support vector and matrix dot product, including np.dot() and the @ operator in Python 3.5
• PR #1546: Support field lookup on record arrays and scalars (i.e. array['field'] in addition to array.
• field)
• PR #1440: Support the HSA wavebarrier() and activelanepermute_wavewidth() intrinsicsics
• PR #1540: Support np.angle()
• PR #1543: Implement CPU multithreaded gufuncs (target="parallel")
• PR #1551: Allow scalar arguments in np.where(), np.empty_like().
• PR #1516: Add some more examples from NumbaPro
• PR #1517: Support np.sinc()
• Issue #1603: Fix calling a non-cached function from a cached function
• Issue #1594: Ensure a list is homogeneous when unboxing
• Issue #1595: Replace deprecated use of get_pointer_to_function()
• Issue #1586: Allow tests to be run by different users on the same machine
• Issue #1587: Make CudaAPIError picklable
• Issue #1568: Fix using Numba from inside Visual Studio 2015
• Issue #1559: Fix serializing a jit function referring a renamed module
• PR #1508: Let reshape() accept integer argument(s), not just a tuple
• Issue #1545: Improve error checking when unboxing list objects
• Issue #1538: Fix array broadcasting in CUDA gufuncs
• Issue #1526: Fix a reference count handling bug

9.52 Version 0.22.1

This is a bug-fix release to resolve some packaging issues and other problems found in the 0.22.0 release.

Fixes:

- PR #1515: Include MANIFEST.in in MANIFEST.in so that sdist still works from source tar files.
- PR #1518: Fix reference counting bug caused by hidden alias
- PR #1519: Fix erroneous assert when passing nopython=True to guvectorize.
- PR #1521: Fix cuda.test()

9.53 Version 0.22.0

This release features several highlights: Python 3.5 support, Numpy 1.10 support, Ahead-of-Time compilation of extension modules, additional vectorization features that were previously only available with the proprietary extension NumbaPro, improvements in array indexing.

Improvements:

- PR #1497: Allow scalar input type instead of size-1 array to @guvectorize
- PR #1480: Add distutils support for AOT compilation
- PR #1460: Create a new API for Ahead-of-Time (AOT) compilation
- PR #1451: Allow passing Python lists to JIT-compiled functions, and reflect mutations on function return
- PR #1387: Numpy 1.10 support
- PR #1464: Support cffi.FFI.from_buffer()
- PR #1437: Propagate errors raised from Numba-compiled ufuncs; also, let “division by zero” and other math errors produce a warning instead of exiting the function early
- PR #1445: Support a subset of fancy indexing
- PR #1454: Support “out-of-line” CFFI modules
- PR #1442: Improve array indexing to support more kinds of basic slicing
• PR #1409: Support explicit CUDA memory fences
• PR #1435: Add support for vectorize() and guvectorize() with HSA
• PR #1432: Implement numpy.nonzero() and numpy.where()
• PR #1416: Add support for vectorize() and guvectorize() with CUDA, as originally provided in NumbaPro
• PR #1424: Support in-place array operators
• PR #1414: Python 3.5 support
• PR #1404: Add the parallel ufunc functionality originally provided in NumbaPro
• PR #1393: Implement sorting on arrays and lists
• PR #1415: Add functions to estimate the occupancy of a CUDA kernel
• PR #1360: The JIT cache now stores the compiled object code, yielding even larger speedups.
• PR #1402: Fixes for the ARMv7 (armv7l) architecture under Linux
• PR #1400: Add the cuda.reduce() decorator originally provided in NumbaPro

Fixes:
• PR #1483: Allow np.empty_like() and friends on non-contiguous arrays
• Issue #1471: Allow caching JIT functions defined in IPython
• PR #1457: Fix flat indexing of boolean arrays
• PR #1421: Allow calling Numpy ufuncs, without an explicit output, on non-contiguous arrays
• Issue #1411: Fix crash when unpacking a tuple containing a Numba-allocated array
• Issue #1394: Allow unifying range_state32 and range_state64
• Issue #1373: Fix code generation error on lists of bools

9.54 Version 0.21.0

This release introduces support for AMD’s Heterogeneous System Architecture, which allows memory to be shared directly between the CPU and the GPU. Other major enhancements are support for lists and the introduction of an opt-in compilation cache.

Improvements:
• PR #1391: Implement print() for CUDA code
• PR #1366: Implement integer typing enhancement proposal (NBEP 1)
• PR #1380: Support the one-argument type() builtin
• PR #1375: Allow boolean evaluation of lists and tuples
• PR #1371: Support array.view() in CUDA mode
• PR #1369: Support named tuples in nopython mode
• PR #1250: Implement numpymedian().
• PR #1289: Make dispatching faster when calling a JIT-compiled function from regular Python
• Issue #1226: Improve performance of integer power
• PR #1321: Document features supported with CUDA
• PR #1345: HSA support
• PR #1343: Support lists in nopython mode
• PR #1356: Make Numba-allocated memory visible to tracemalloc
• PR #1363: Add an environment variable NUMBA_DEBUG_TYPEINFERENCE
• PR #1051: Add an opt-in, per-function compilation cache

Fixes:

• Issue #1372: Some array expressions would fail rewriting when involved the same variable more than once, or a unary operator
• Issue #1385: Allow CUDA local arrays to be declared anywhere in a function
• Issue #1285: Support datetime64 and timedelta64 in Numpy reduction functions
• Issue #1332: Handle the EXTENDED_ARG opcode.
• PR #1329: Handle the in operator in object mode
• Issue #1322: Fix augmented slice assignment on Python 2
• PR #1357: Fix slicing with some negative bounds or step values.

9.55 Version 0.20.0

This release updates Numba to use LLVM 3.6 and CUDA 7 for CUDA support. Following the platform deprecation in CUDA 7, Numba's CUDA feature is no longer supported on 32-bit platforms. The oldest supported version of Windows is Windows 7.

Improvements:

• Issue #1203: Support indexing ndarray.flat
• PR #1200: Migrate cgutils to llvmlite
• PR #1190: Support more array methods: .transpose(), .T, .copy(), .reshape(), .view()
• PR #1214: Simplify setup.py and avoid manual maintenance
• PR #1217: Support datetime64 and timedelta64 constants
• PR #1236: Reload environment variables when compiling
• PR #1225: Various speed improvements in generated code
• PR #1252: Support cmath module in CUDA
• PR #1238: Use 32-byte aligned allocator to optimize for AVX
• PR #1258: Support numpy.frombuffer()
• PR #1274: Use TravisCI container infrastructure for lower wait time
• PR #1279: Micro-optimize overload resolution in call dispatch
• Issue #1248: Improve error message when return type unification fails

Fixes:

• Issue #1131: Handling of negative zeros in np.conjugate() and np.arccos()
• Issue #1188: Fix slow array return
• Issue #1164: Avoid warnings from CUDA context at shutdown
• Issue #1229: Respect the writeable flag in arrays
• Issue #1244: Fix bug in refcount pruning pass
• Issue #1251: Fix partial left-indexing of Fortran contiguous array
• Issue #1264: Fix compilation error in array expression
• Issue #1254: Fix error when yielding array objects
• Issue #1276: Fix nested generator use

9.56 Version 0.19.2

This release fixes the source distribution on pypi. The only change is in the setup.py file. We do not plan to provide a conda package as this release is essentially the same as 0.19.1 for conda users.

9.57 Version 0.19.1

• Issue #1196:
  – fix double-free segfault due to redundant variable deletion in the Numba IR (#1195)
  – fix use-after-delete in array expression rewrite pass

9.58 Version 0.19.0

This version introduces memory management in the Numba runtime, allowing to allocate new arrays inside Numba-compiled functions. There is also a rework of the ufunc infrastructure, and an optimization pass to collapse cascading array operations into a single efficient loop.

Warning: Support for Windows XP and Vista with all compiler targets and support for 32-bit platforms (Win/Mac/Linux) with the CUDA compiler target are deprecated. In the next release of Numba, the oldest version of Windows supported will be Windows 7. CPU compilation will remain supported on 32-bit Linux and Windows platforms.

Known issues:
• There are some performance regressions in very short running nopython functions due to the additional overhead incurred by memory management. We will work to reduce this overhead in future releases.

Features:
• Issue #1181: Add a Frequently Asked Questions section to the documentation.
• Issue #1162: Support the cumsum() and cumprod() methods on Numpy arrays.
• Issue #1152: Support the *args argument-passing style.
• Issue #1147: Allow passing character sequences as arguments to JIT-compiled functions.
• Issue #1110: Shortcut deforestation and loop fusion for array expressions.
• Issue #1136: Support various Numpy array constructors, for example numpy.zeros() and numpy.zeros_like().
• Issue #1127: Add a CUDA simulator running on the CPU, enabled with the NUMBA_ENABLE_CUDASIM environment variable.
• Issue #1086: Allow calling standard Numpy ufuncs without an explicit output array from nopython functions.
• Issue #1113: Support keyword arguments when calling numpy.empty() and related functions.
• Issue #1108: Support the ctypes.data attribute of Numpy arrays.
• Issue #1077: Memory management for array allocations in nopython mode.
• Issue #1105: Support calling a ctypes function that takes ctypes.py_object parameters.
• Issue #1084: Environment variable NUMBA_DISABLE_JIT disables compilation of @jit functions, instead calling into the Python interpreter when called. This allows easier debugging of multiple jitted functions.
• Issue #927: Allow gufuncs with no output array.
• Issue #1097: Support comparisons between tuples.
• Issue #1075: Numba-generated ufuncs can now be called from nopython functions.
• Issue #1062: @vectorize now allows omitting the signatures, and will compile the required specializations on the fly (like @jit does).
• Issue #1027: Support numpy.round().
• Issue #1085: Allow returning a character sequence (as fetched from a structured array) from a JIT-compiled function.

Fixes:
• Issue #1170: Ensure ndindex(), ndenumerate() and ndarray.flat work properly inside generators.
• Issue #1151: Disallow unpacking of tuples with the wrong size.
• Issue #1141: Specify install dependencies in setup.py.
• Issue #1106: Loop-lifting would fail when the lifted loop does not produce any output values for the function tail.
• Issue #1103: Fix mishandling of some inputs when a JIT-compiled function is called with multiple array layouts.
• Issue #1089: Fix range() with large unsigned integers.
• Issue #1088: Install entry-point scripts (numba, pycc) from the conda build recipe.
• Issue #1081: Constant structured scalars now work properly.
• Issue #1080: Fix automatic promotion of booleans to integers.

9.59 Version 0.18.2

Bug fixes:
• Issue #1073: Fixes missing template file for HTML annotation
• Issue #1074: Fixes CUDA support on Windows machine due to NVVM API mismatch
**9.60 Version 0.18.1**

Version 0.18.0 is not officially released.

This version removes the old deprecated and undocumented argtypes and restype arguments to the @jit decorator. Function signatures should always be passed as the first argument to @jit.

Features:

- Issue #960: Add inspect_llvm() and inspect_asm() methods to JIT-compiled functions: they output the LLVM IR and the native assembler source of the compiled function, respectively.
- Issue #990: Allow passing tuples as arguments to JIT-compiled functions in nopython mode.
- Issue #774: Support two-argument round() in nopython mode.
- Issue #987: Support missing functions from the math module in nopython mode: frexp(), ldexp(), gamma(), lgamma(), erf(), erfc().
- Issue #995: Improve code generation for round() on Python 3.
- Issue #981: Support functions from the random and numpy.random modules in nopython mode.
- Issue #979: Add cuda.atomic.max().
- Issue #1006: Improve exception raising and reporting. It is now allowed to raise an exception with an error message in nopython mode.
- Issue #821: Allow ctypes- and cffi-defined functions as arguments to nopython functions.
- Issue #901: Allow multiple explicit signatures with @jit. The signatures must be passed in a list, as with @vectorize.
- Issue #884: Better error message when a JIT-compiled function is called with the wrong types.
- Issue #1010: Simpler and faster CUDA argument marshalling thanks to a refactoring of the data model.
- Issue #1018: Support arrays of scalars inside Numpy structured types.
- Issue #808: Reduce Numba import time by half.
- Issue #1021: Support the buffer protocol in nopython mode. Buffer-providing objects, such as bytearray, array.array or memoryview support array-like operations such as indexing and iterating. Furthermore, some standard attributes on the memoryview object are supported.
- Issue #1030: Support nested arrays in Numpy structured arrays.
- Issue #1033: Implement the inspect_types(), inspect_llvm() and inspect_asm() methods for CUDA kernels.
- Issue #1029: Support Numpy structured arrays with CUDA as well.
- Issue #1034: Support for generators in nopython and object mode.
- Issue #1044: Support default argument values when calling Numba-compiled functions.
- Issue #1048: Allow calling Numpy scalar constructors from CUDA functions.
- Issue #1047: Allow indexing a multi-dimensional array with a single integer, to take a view.
- Issue #1050: Support len() on tuples.
- Issue #1011: Revive HTML annotation.

Fixes:

- Issue #977: Assignment optimization was too aggressive.
- Issue #561: One-argument round() now returns an int on Python 3.
• Issue #1001: Fix an unlikely bug where two closures with the same name and id() would compile to the same LLVM function name, despite different closure values.
• Issue #1006: Fix reference leak when a JIT-compiled function is disposed of.
• Issue #1017: Update instructions for CUDA in the README.
• Issue #1008: Generate shorter LLVM type names to avoid segfaults with CUDA.
• Issue #1005: Properly clean up references when raising an exception from object mode.
• Issue #1041: Fix incompatibility between Numba and the third-party library “future”.
• Issue #1053: Fix the size attribute of CUDA shared arrays.

9.61 Version 0.17.0

The major focus in this release has been a rewrite of the documentation. The new documentation is better structured and has more detailed coverage of Numba features and APIs. It can be found online at https://numba.pydata.org/numba-doc/dev/index.html

Features:
• Issue #895: LLVM can now inline nested function calls in nopython mode.
• Issue #863: CUDA kernels can now infer the types of their arguments (“autojit”-like).
• Issue #833: Support numpy.{min,max,argmin,argmax,sum,mean,var,std} in nopython mode.
• Issue #905: Add a nogil argument to the @jit decorator, to release the GIL in nopython mode.
• Issue #829: Add a identity argument to @vectorize and @guvectorize, to set the identity value of the ufunc.
• Issue #843: Allow indexing 0-d arrays with the empty tuple.
• Issue #933: Allow named arguments, not only positional arguments, when calling a Numba-compiled function.
• Issue #902: Support numpy.ndenumerate() in nopython mode.
• Issue #950: AVX is now enabled by default except on Sandy Bridge and Ivy Bridge CPUs, where it can produce slower code than SSE.
• Issue #956: Support constant arrays of structured type.
• Issue #959: Indexing arrays with floating-point numbers isn’t allowed anymore.
• Issue #955: Add support for 3D CUDA grids and thread blocks.
• Issue #902: Support numpy.ndindex() in nopython mode.
• Issue #951: Numpy number types (numpy.int8, etc.) can be used as constructors for type conversion in nopython mode.

Fixes:
• Issue #889: Fix NUMBA_DUMP_ASSEMBLY for the CUDA backend.
• Issue #903: Fix calling of stdcall functions with ctypes under Windows.
• Issue #908: Allow lazy-compiling from several threads at once.
• Issue #868: Wrong error message when multiplying a scalar by a non-scalar.
• Issue #917: Allow vectorizing with datetime64 and timedelta64 in the signature (only with unit-less values, though, because of a Numpy limitation).
• Issue #431: Allow overloading of cuda device function.
• Issue #917: Print out errors occurred in object mode ufuncs.
• Issue #923: Numba-compiled ufuncs now inherit the name and doc of the original Python function.
• Issue #928: Fix boolean return value in nested calls.
• Issue #915: @jit called with an explicit signature with a mismatching type of arguments now raises an error.
• Issue #784: Fix the truth value of NaNs.
• Issue #953: Fix using shared memory in more than one function (kernel or device).
• Issue #970: Fix an uncommon double to uint64 conversion bug on CentOS5 32-bit (C compiler issue).

9.62 Version 0.16.0

This release contains a major refactor to switch from llvmpy to llvmlite as our code generation backend. The switch is necessary to reconcile different compiler requirements for LLVM 3.5 (needs C++11) and Python extensions (need specific compiler versions on Windows). As a bonus, we have found the use of llvmlite speeds up compilation by a factor of 2!

Other Major Changes:
• Faster dispatch for numpy structured arrays
• Optimized array.flat()
• Improved CPU feature selection
• Fix constant tuple regression in macro expansion code

Known Issues:
• AVX code generation is still disabled by default due to performance regressions when operating on misaligned NumPy arrays. We hope to have a workaround in the future.
• In extremely rare circumstances, a known issue with LLVM 3.5 code generation can cause an ELF relocation error on 64-bit Linux systems.

9.63 Version 0.15.1

(This was a bug-fix release that superceded version 0.15 before it was announced.)

Fixes:
• Workaround for missing __ftol2 on Windows XP.
• Do not lift loops for compilation that contain break statements.
• Fix a bug in loop-lifting when multiple values need to be returned to the enclosing scope.
• Handle the loop-lifting case where an accumulator needs to be updated when the loop count is zero.
9.64 Version 0.15

Features:

- Support for the Python `cmath` module. (NumPy complex functions were already supported.)
- Support for `.real`, `.imag`, and `.conjugate()` on non-complex numbers.
- Add support for `math.isfinite()` and `math.copysign()`.
- Compatibility mode: If enabled (off by default), a failure to compile in object mode will fall back to using the pure Python implementation of the function.
- Experimental support for serializing JIT functions with cloudpickle.
- Loop-jitting in object mode now works with loops that modify scalars that are accessed after the loop, such as accumulators.
- `@vectorize` functions can be compiled in object mode.
- Numba can now be built using the Visual C++ Compiler for Python 2.7 on Windows platforms.
- CUDA JIT functions can be returned by factory functions with variables in the closure frozen as constants.
- Support for “optional” types in nopython mode, which allow `None` to be a valid value.

Fixes:

- If nopython mode compilation fails for any reason, automatically fall back to object mode (unless nopython=True is passed to @jit) rather than raise an exception.
- Allow function objects to be returned from a function compiled in object mode.
- Fix a linking problem that caused slower platform math functions (such as `exp()` to be used on Windows, leading to performance regressions against NumPy.
- `min()` and `max()` no longer accept scalars arguments in nopython mode.
- Fix handling of ambiguous type promotion among several compiled versions of a JIT function. The dispatcher will now compile a new version to resolve the problem. (issue #776)
- Fix `float32` to `uint64` casting bug on 32-bit Linux.
- Fix type inference to allow forced casting of return types.
- Allow the shape of a 1D `cuda.shared.array` and `cuda.local.array` to be a one-element tuple.
- More correct handling of signed zeros.
- Add custom implementation of `atan2()` on Windows to handle special cases properly.
- Eliminated race condition in the handling of the pagelocked staging area used when transferring CUDA arrays.
- Fix non-deterministic type unification leading to varying performance. (issue #797)
9.65 Version 0.14

Features:

- Support for nearly all the Numpy math functions (including comparison, logical, bitwise and some previously missing float functions) in nopython mode.
- The Numpy datetime64 and timedelta64 dtypes are supported in nopython mode with Numpy 1.7 and later.
- Support for Numpy math functions on complex numbers in nopython mode.
- ndarray.sum() is supported in nopython mode.
- Better error messages when unsupported types are used in Numpy math functions.
- Set NUMBA_WARNINGS=1 in the environment to see which functions are compiled in object mode vs. nopython mode.
- Add support for the two-argument pow() builtin function in nopython mode.
- New developer documentation describing how Numba works, and how to add new types.
- Support for Numpy record arrays on the GPU. (Note: Improper alignment of dtype fields will cause an exception to be raised.)
- Slices on GPU device arrays.
- GPU objects can be used as Python context managers to select the active device in a block.
- GPU device arrays can be bound to a CUDA stream. All subsequent operations (such as memory copies) will be queued on that stream instead of the default. This can prevent unnecessary synchronization with other streams.

Fixes:

- Generation of AVX instructions has been disabled to avoid performance bugs when calling external math functions that may use SSE instructions, especially on OS X.
- JIT functions can be removed by the garbage collector when they are no longer accessible.
- Various other reference counting fixes to prevent memory leaks.
- Fixed handling of exception when input argument is out of range.
- Prevent autojit functions from making unsafe numeric conversions when called with different numeric types.
- Fix a compilation error when an unhashable global value is accessed.
- Gracefully handle failure to enable faulthandler in the IPython Notebook.
- Fix a bug that caused loop lifting to fail if the loop was inside an else block.
- Fixed a problem with selecting CUDA devices in multithreaded programs on Linux.
- The pow() function (and ** operation) applied to two integers now returns an integer rather than a float.
- Numpy arrays using the object dtype no longer cause an exception in the autojit.
- Attempts to write to a global array will cause compilation to fall back to object mode, rather than attempt and fail at nopython mode.
- range() works with all negative arguments (ex: range(−10, −12, −1))
9.66 Version 0.13.4

Features:
- Setting and deleting attributes in object mode
- Added documentation of supported and currently unsupported numpy ufuncs
- Assignment to 1-D numpy array slices
- Closure variables and functions can be used in object mode
- All numeric global values in modules can be used as constants in JIT compiled code
- Support for the start argument in enumerate()
- Inplace arithmetic operations (+=, -=, etc.)
- Direct iteration over a 1D numpy array (e.g. “for x in array: …”) in nopython mode

Fixes:
- Support for NVIDIA compute capability 5.0 devices (such as the GTX 750)
- Vectorize no longer crashes/gives an error when bool_ is used as return type
- Return the correct dictionary when globals() is used in JIT functions
- Fix crash bug when creating dictionary literals in object
- Report more informative error message on import if llvmpy is too old
- Temporarily disable pycc –header, which generates incorrect function signatures.

9.67 Version 0.13.3

Features:
- Support for enumerate() and zip() in nopython mode
- Increased LLVM optimization of JIT functions to -O1, enabling automatic vectorization of compiled code in some cases
- Iteration over tuples and unpacking of tuples in nopython mode
- Support for dict and set (Python >= 2.7) literals in object mode

Fixes:
- JIT functions have the same __name__ and __doc__ as the original function.
- Numerous improvements to better match the data types and behavior of Python math functions in JIT compiled code on different platforms.
- Importing Numba will no longer throw an exception if the CUDA driver is present, but cannot be initialized.
- guvectorize now properly supports functions with scalar arguments.
- CUDA driver is lazily initialized
9.68 Version 0.13.2

Features:

- @vectorize ufunc now can generate SIMD fast path for unit strided array
- Added cuda.gridsize
- Added preliminary exception handling (raise exception class)

Fixes:

- UNARY_POSITIVE
- Handling of closures and dynamically generated functions
- Global None value

9.69 Version 0.13.1

Features:

- Initial support for CUDA array slicing

Fixes:

- Indirectly fixes numbapro when the system has a incompatible CUDA driver
- Fix numba.cuda.detect
- Export numba.intp and numba.intc

9.70 Version 0.13

Features:

- Opensourcing NumbaPro CUDA python support in numba.cuda
- Add support for ufunc array broadcasting
- Add support for mixed input types for ufuncs
- Add support for returning tuple from jitted function

Fixes:

- Fix store slice bytecode handling for Python2
- Fix inplace subtract
- Fix pycc so that correct header is emitted
- Allow vectorize to work on functions with jit decorator
9.71 Version 0.12.2

Fixes:
- Improved NumPy ufunc support in nopython mode
- Misc bug fixes

9.72 Version 0.12.1

This version fixed many regressions reported by user for the 0.12 release. This release contains a new loop-lifting mechanism that specializes certain loop patterns for nopython mode compilation. This avoids direct support for heap-allocating and other very dynamic operations.

Improvements:
- Add loop-lifting–jit-ing loops in nopython for object mode code. This allows functions to allocate NumPy arrays and use Python objects, while the tight loops in the function can still be compiled in nopython mode. Any arrays that the tight loop uses should be created before the loop is entered.

Fixes:
- Add support for majority of “math” module functions
- Fix for...else handling
- Add support for builtin round()
- Fix ternary if...else support
- Revive “numba” script
- Fix problems with some boolean expressions
- Add support for more NumPy ufuncs

9.73 Version 0.12

Version 0.12 contains a big refactor of the compiler. The main objective for this refactor was to simplify the code base to create a better foundation for further work. A secondary objective was to improve the worst case performance to ensure that compiled functions in object mode never run slower than pure Python code (this was a problem in several cases with the old code base). This refactor is still a work in progress and further testing is needed.

Main improvements:
- Major refactor of compiler for performance and maintenance reasons
- Better fallback to object mode when native mode fails
- Improved worst case performance in object mode

The public interface of numba has been slightly changed. The idea is to make it cleaner and more rational:
- jit decorator has been modified, so that it can be called without a signature. When called without a signature, it behaves as the old autojit. Autojit has been deprecated in favour of this approach.
- Jitted functions can now be overloaded.
- Added a “njit” decorator that behaves like “jit” decorator with nopython=True.
• The numba.vectorize namespace is gone. The vectorize decorator will be in the main numba namespace.
• Added a guvectorize decorator in the main numba namespace. It is similar to numba.vectorize, but takes a
dimension signature. It generates gufuncs. This is a replacement for the GUVectorize gufunc factory which has
been deprecated.

Main regressions (will be fixed in a future release):
• Creating new NumPy arrays is not supported in nopython mode
• Returning NumPy arrays is not supported in nopython mode
• NumPy array slicing is not supported in nopython mode
• lists and tuples are not supported in nopython mode
• string, datet ime, cdecimal, and struct types are not implemented yet
• Extension types (classes) are not supported in nopython mode
• Closures are not supported
• Raise keyword is not supported
• Recursion is not support in nopython mode

9.74 Version 0.11

• Experimental support for NumPy datet ime type

9.75 Version 0.10

• Annotation tool (/bin/numba –annotate –fancy) (thanks to Jay Bourque)
• Open sourced prange
• Support for raise statement
• Pluggable array representation
• Support for enumerate and zip (thanks to Eugene Toder)
• Better string formatting support (thanks to Eugene Toder)
• Builtin s min(), max() and bool() (thanks to Eugene Toder)
• Fix some code reloading issues (thanks to Björn Linse)
• Recognize NumPy scalar objects (thanks to Björn Linse)
9.76 Version 0.9

- Improved math support
- Open sourced generalized ufuncs
- Improved array expressions

9.77 Version 0.8

- Support for autojit classes
  - Inheritance not yet supported
- Python 3 support for pycc
- Allow retrieval of ctypes function wrapper
  - And hence support retrieval of a pointer to the function
- Fixed a memory leak of array slicing views

9.78 Version 0.7.2

- Official Python 3 support (python 3.2 and 3.3)
- Support for intrinsics and instructions
- Various bug fixes (see https://github.com/numba/numba/issues?milestone=7&state=closed)

9.79 Version 0.7.1

- Various bug fixes

9.80 Version 0.7

- Open sourced single-threaded ufunc vectorizer
- Open sourced NumPy array expression compilation
- Open sourced fast NumPy array slicing
- Experimental Python 3 support
- Support for typed containers
  - typed lists and tuples
- Support for iteration over objects
- Support object comparisons
- Preliminary CFFI support
  - Jit calls to CFFI functions (passed into autojit functions)
— TODO: Recognize ffi_lib.my_func attributes

• Improved support for ctypes
• Allow declaring extension attribute types as through class attributes

• Support for type casting in Python
  — Get the same semantics with or without numba compilation

• Support for recursion
  — For jit methods and extension classes
• Allow jit functions as C callbacks
• Friendlier error reporting
• Internal improvements
• A variety of bug fixes

9.81 Version 0.6.1

• Support for bitwise operations

9.82 Version 0.6

• Python 2.6 support

• Programmable typing
  — Allow users to add type inference for external code

• Better NumPy type inference
  — outer, inner, dot, vdot, tensordot, nonzero, where, binary ufuncs + methods (reduce, accumulate, reduceat, outer)

• Type based alias analysis
  — Support for strict aliasing
• Much faster autojit dispatch when calling from Python
• Faster numerical loops through data and stride pre-loading
• Integral overflow and underflow checking for conversions from objects
• Make Meta dependency optional
9.83 Version 0.5

- SSA-based type inference
  - Allows variable reuse
  - Allow referring to variables before lexical definition
- Support multiple comparisons
- Support for template types
- List comprehensions
- Support for pointers
- Many bug fixes
- Added user documentation

9.84 Version 0.4

9.85 Version 0.3.2

- Add support for object arithmetic (issue 56).
- Bug fixes (issue 55).

9.86 Version 0.3

- Changed default compilation approach to ast
- Added support for cross-module linking
- Added support for closures (can jit inner functions and return them) (see examples/closure.py)
- Added support for dtype structures (can access elements of structure with attribute access) (see examples/structures.py)
- Added support for extension types (numba classes) (see examples/numbaclasses.py)
- Added support for general Python code (use nopython to raise an error if Python C-API is used to avoid unexpected slowness because of lack of implementation defaulting to generic Python)
- Fixed many bugs
- Added support to detect math operations.
- Added with python and with nopython contexts
- Added more examples

Many features need to be documented still. Look at examples and tests for more information.
9.87 Version 0.2

- Added an ast approach to compilation
- Removed d, f, i, b from numba namespace (use f8, f4, i4, b1)
- Changed function to autojit2
- Added autojit function to decorate calls to the function and use types of the variable to create compiled versions.
- changed keyword arguments to jit and autojit functions to restype and argtypes to be consistent with ctypes module.
- Added pycc – a python to shared library compiler
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