ADDRESSING MULTITHREADING AND MULTIPROCESSING IN TRANSPARENT AND PYTHONIC METHODS

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Overview

- State of current concurrency and parallelism
- Nested parallelism and oversubscription
- A few composable methods of thread control
- How it works under the hood (*tbb, smp*)
- Pythonic style?
- Future of Pythonic style for parallelism
- Summary
Current State of Python concurrency and parallelism

- The Python ecosystem has had quite a few cool developments over the last few years:
  - Threading library (2008)
  - Multiprocessing (2008)
  - Twisted (2008)
  - Concurrent futures (2009)
  - Cython (2009)
  - Tornado (2010)
  - Numba (2012)
  - Asyncio (2013)
  - Dask (2015)
  - Trio (2017)
Current State of Python concurrency and parallelism

• The options in this space are very good compared to other ecosystems

• Majority do a good job of playing nicely with the Global Interpreter Lock (GIL) or walk around it with distributed or vectorization techniques

• In more domain specific areas, one can rely on high-end C libraries that have threading to harness parallelism (SciPy/NumPy)

• Recent trends have Python accessing increasing core count machines (from 2-4 to over 28 core) as commonplace

  • *Nested parallelism and oversubscription* now quite possible in kernels
The Safety of the GIL

- The GIL has been complained about by many in the Python space
- Many efforts have been made to try to remove the GIL
- As it stands, some of the main tenants of what guarantees the GIL provides are hard to ignore
  - Read/write safety for Python Object access
  - Predictable behavior
  - Ensure reference counting doesn't get hosed
  - Makes extension module development easier (and removes the undue burden on developers)
The Safety of the GIL (con’t)

• In reality, **the GIL is a non-issue** as many have found ways of **stepping around the GIL**.

• *SciPy* and *NumPy* are great examples—once a command is sent to SciPy, it gets dispatched where BLAS implementations like MKL and OpenBLAS are vectorized and parallelized.

• Other frameworks directly access vectorization and exit the Python+GIL layer to utilize threads—*Numba, Numexpr, Cython* do this.

• *Multiprocessing* frameworks can escape it via a separate process, which can also have separate threads.
The Safety of the GIL (con’t)

• Exiting the GIL with a C library is the generally the most Pythonic-ish way of doing things (as it encompasses the abstraction of a known computational flow)

• Composition of abstracted flows also works (splitting off into multiple processes)

• It is quite rare to absolutely necessitate a language to be completely thread safe; many of the advantages of Python would go away
The spaces covered

- Application-level Parallelism
- Data Parallelism-Focus
- Single-threaded Concurrency

Multiprocessing: Joblib
Concurrent Futures: Async/await, Threading
Celery, Buildbot, Twisted, Tornado

Dask
NumPy/SciPy
Numba
Cython
Numexpr

*Unicorn? MPI4PY...?

Multiprocessing: Joblib
Concurrent Futures: Async/await, Threading
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Dask
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- Application-level Parallelism
- Data Parallelism-Focus

Multiprocessing
- Joblib

Dask
- NumPy/SciPy
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- Numexpr
The spaces covered

Python Multiprocessing

Data Parallelism
Focus
OpenMP, TBB, Pthreads

NumPy/SciPy
Numba
Cython
Numexpr

Multiprocessing
Joblib

Dask

Python Multithreading
The spaces covered

- Multiprocessing
  - Joblib

- Python Multiprocessing
  - NumPy/SciPy
  - Numba
  - Cython
  - Numexpr

- Data Parallelism-Focus
  - OpenMP, TBB, Pthreads

- Python Multithreading
  - Dask

Nested parallelism area with risk of oversubscription
Nested parallelism

data = numpy.random.random((256, 256))

pool = multiprocessing.pool.ThreadPool() # creates $P$ threads

pool.map(np.linalg.eig, [data for i in range(1024)])

$P$ Python threads * $P$ NumPy→MKL→OpenMP threads = $P^2$ threads total
Oversubscription

$P$ software threads

$P \times P$ threads

$P$ CPUs

$P$ CPUs
Oversubscription overheads

- Types of impact
  - Direct OS overhead for switching out a thread
  - CPU cache becomes cold: invisible impact
  - Other threads are waiting until the preempted one returns
  - Tensorflow, Scikit-Learn, PyTorch have a recurring battle with these

- How do they solve it?
  - Most use OMP_NUM_THREADS=1... KMP_BLOCKTIME=1...
  - SMP ironically addresses this (more on this later)
Introducing composability modules

- **tbb4py: Intel TBB for Python**
  - A Python C-extension package managing nested parallelism using dynamic task scheduler of Intel® Threading Building Blocks library
  - Instantiates via monkey patching of Python’s pools and enabling TBB threading layer for Intel® MKL (no code changes required)
  - Dynamically maps tasks onto coordinated pool(s) to avoid excessive threads
Introducing composability modules

• **smp: Static Multi-Processing**
  - A Pure Python package managing nested parallelism through coarse-grain static settings
  - Instantiates via monkey patching of Python’s pools (no code changes required)
  - Utilizes affinity mask + OpenMP settings to statically allocate resources and avoid excessive threads
Nested parallelism (again)

```python
data = numpy.random.random((256, 256))

pool = multiprocessing.pool.ThreadPool()  # creates $P$ threads

pool.map(np.linalg.eig, [data for i in range(1024)])
```

$P$ Python threads * $P$ NumPy → MKL → OpenMP threads = $P^2$ threads total
TBB’s Thread coordination system

Application

OpenMP Threading

Separate, Uncoordinated
OpenMP Parallel regions

Too many Software threads compete for logical processors

Application

TBB pool

Coordinated TBB Threads

Software Threads mapped to logical processors

tbb4py module

Running Python & MKL under the TBB scheduler
SMP’s total threading affinity system

- Application
- OpenMP Threading
- Separate, Uncoordinated OpenMP Parallel regions

Running under the SMP module

- ThreadPool propagates static masks/settings
- Augmented MKL or BLAS threading

Too many Software threads compete for logical processors
Repository:

https://github.com/IntelPython/composability_bench/tree/master/scipy2018_demo
Current State of Python concurrency and parallelism (slight return)

- Much of the **concurrency and async areas** are rich with packages that help solve the needs of the majority of Python users
- True Parallelism is a small but strong area, so focus has generally been towards concurrency + async offerings
- Most ways of achieving parallelism in this area rely on **vectorization frameworks** or with multiprocessing or distributed
- How does one do so in a **semi-pythonic** way?
Pythonic-ish?

- Relatively few code changes
- Modify current behavior of a framework to fit one’s needs (or prevent a massive rewrite)
- Directly in the Python std library
- Writable from the Python layer
- Easy interface to understand
- Keeps one in the Python layer (and does not drop to an IR)

*How close can we get?*
Pythonic-ish? (tbb4py)

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- ✔ Modify current behavior of a framework to fit one’s needs (or prevent a massive rewrite)
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Pythonic-ish style for parallelism?

- How realistic is it to have a firm requirement for a Pure Python implementation?
- What is the best way to modify Python code? Monkey patching? New framework?
- At what level should the parallelism be controlled?
- Can an interface be agreed upon to operate on parallelism? (such as concurrency’s concurrent futures)
Python-isyh style for parallelism? (con’t)

• How realistic is it to have a firm requirement for a Pure Python implementation?
  • Not required, but highly recommended
• What is the best way to modify Python code? Monkey patching? New framework?
  • Monkey patching is seeming to be the new normal
Pythonic-lish style for parallelism? (con’t)

- At what level should the parallelism be controlled?
- Python layer-sort of? It should have directives for how additional layers can compose it as the best case
- Can an interface be agreed upon to operate on parallelism? (such as concurrency’s concurrent futures)
- Jury is still out on this one, but with every iteration of attempts (like `smp`) we get a more clear picture
Summary

• **tbb4py** and **smp** attempt to address Python-lish methods by attempting to *augment* the way we use multithreading and multiprocessing (attempting to not change underlying code)

• It is best to leave the two forms of multiprocessing and multithreading at their same levels—Python level and C level, respectively

  • Most multithreading is domain specific it needs to be in C, so it would need to be written or C or generated (like Numba, numexpr, Cython)

  • Perhaps leaving threading and multiprocessing directives as a file or comments might be better... but doesn’t that just sound like #pragma omp?
Summary (con’t)

• Having more “augmentable” threading behavior is more useful, but that means putting the bulk of the responsibility on the users themselves

• Threading for numerical has lots of known frameworks, proper threading from non-numerical may be possible but will require stricter typing than just "Python Object”

• At that point... why are you using Python, right? Flexible vs. Strict

• The Python ecosystem has a critical mass of good frameworks looking to address multithreading and multiprocessing—so for those of you working in it, keep going!
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