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)*

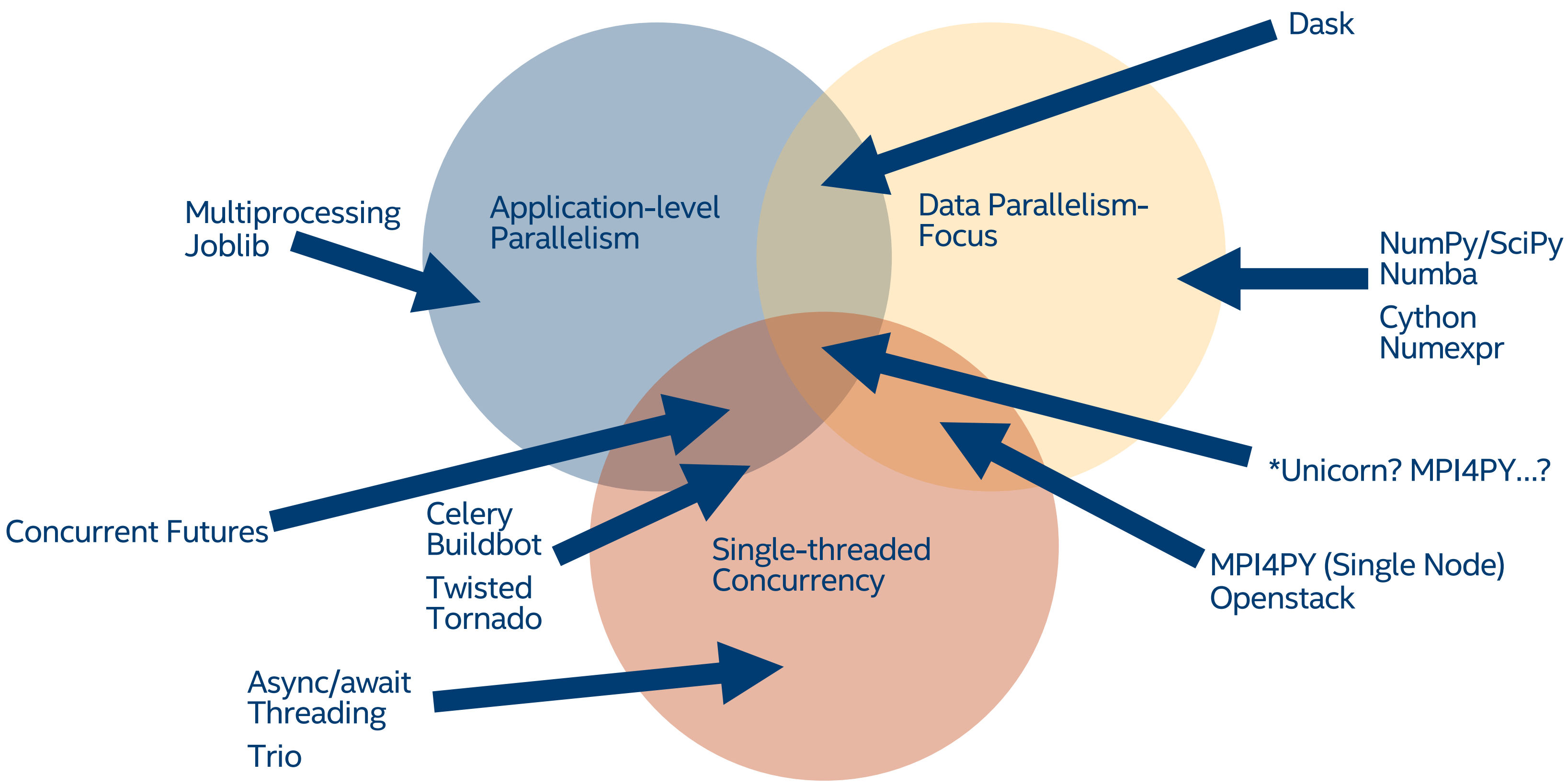
The Safety of the GIL (con't)

- 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



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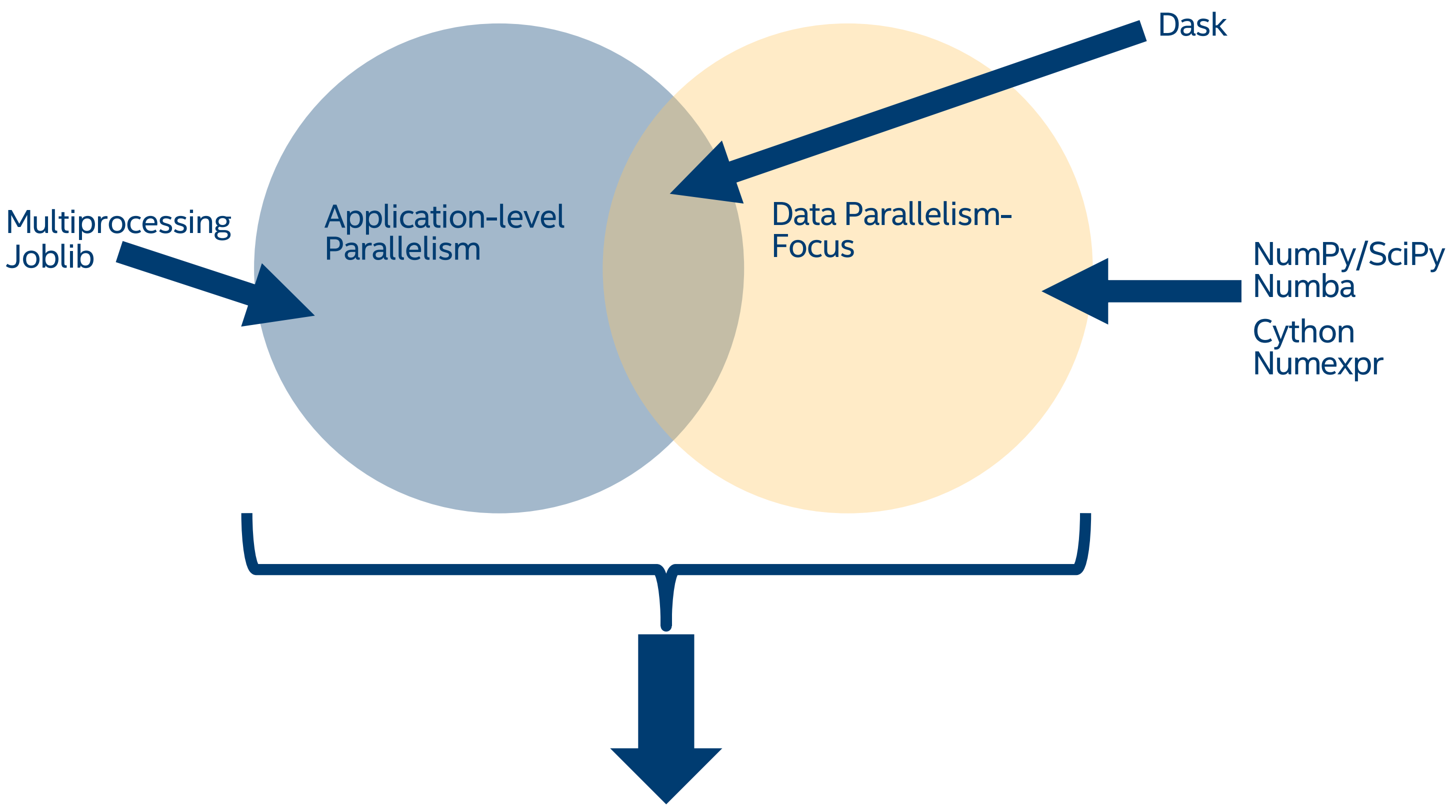

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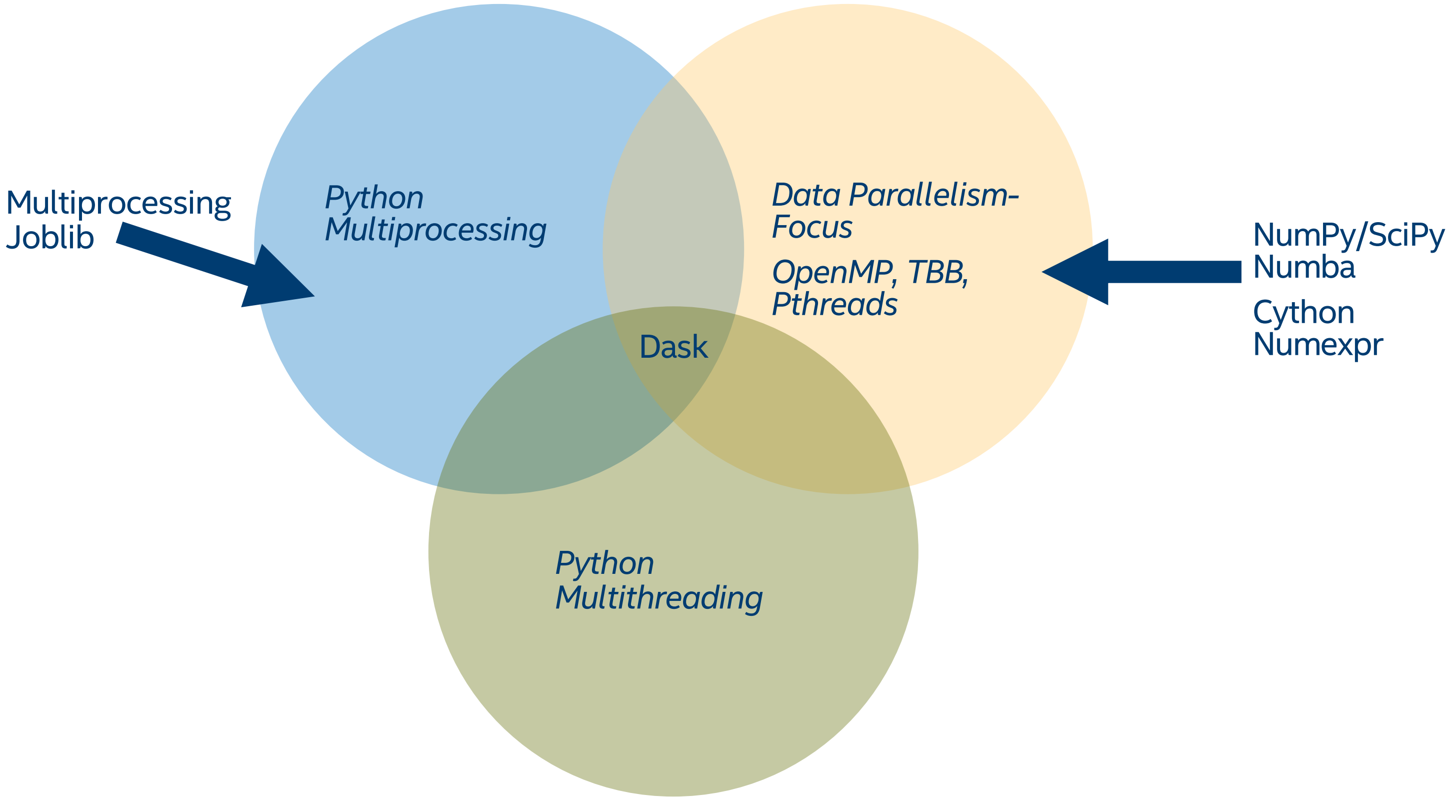

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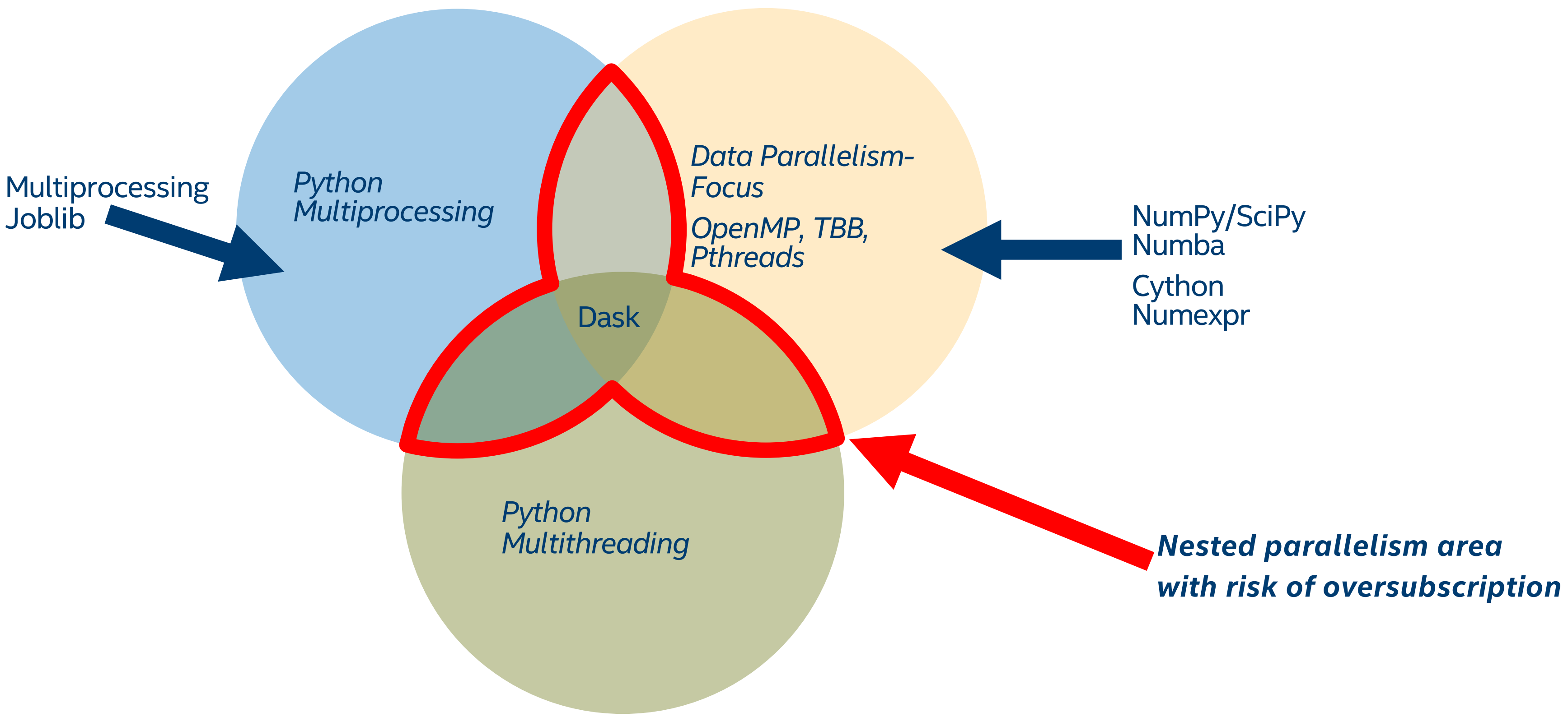


Nested parallelism

```
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 CPUs

*P*P* threads

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

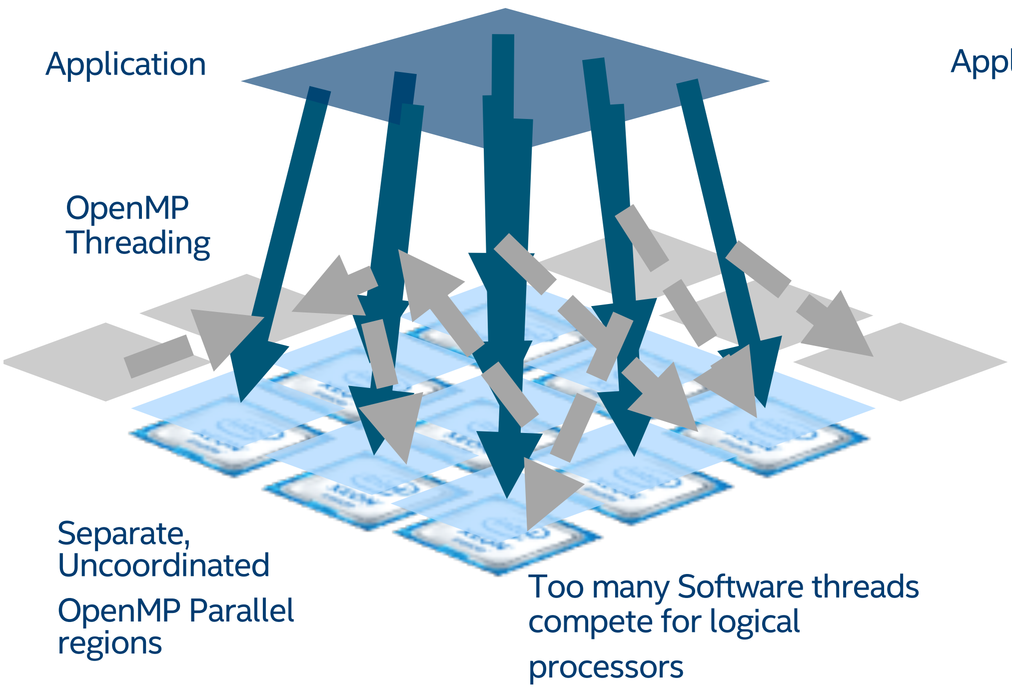
- **smp: Static Multi-Processing**
  - A Pure Python package managing nested parallelism through coarse-grain static settings
  - Instantiates via monkey patching of Python's pools (no code changes required)
  - Utilizes affinity mask + OpenMP settings to statically allocate resources and avoid excessive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

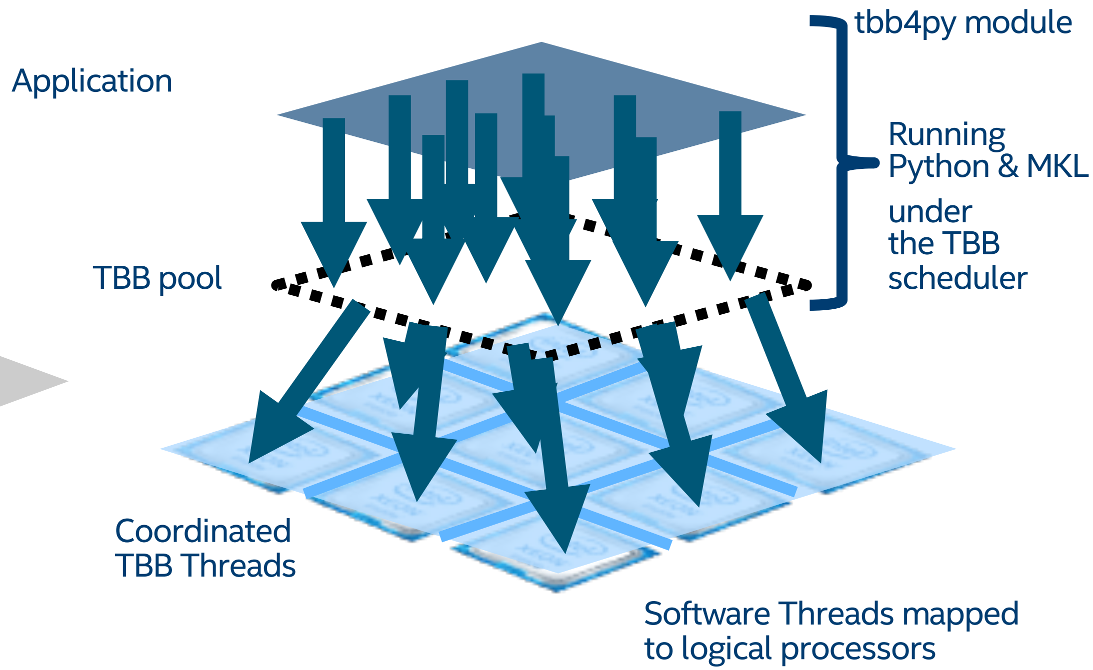
Nested parallelism (again)

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

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

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

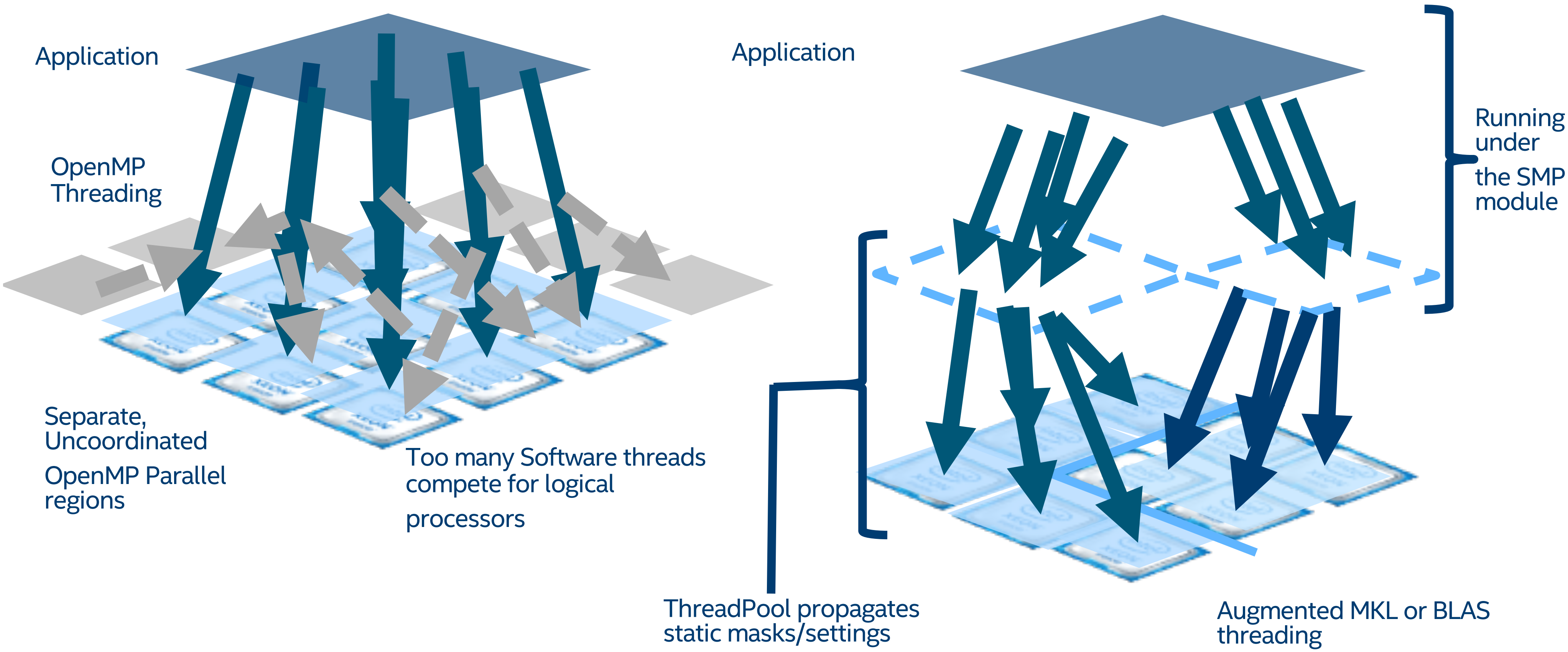
P Python threads ***** *P* NumPy→MKL→OpenMP threads = **P^2** threads total

TBB's Thread coordination system





SMP's total threading affinity system



DEMOS

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)
- ✗ Directly in the Python std library
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Pythonic-ish? (smp)

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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)*

Pythonic-ish 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-ish 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 Pythonic-ish 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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