Setting Python Threading Free

David Hoese

Who am I?

- Software Developer at UW Space Science and Engineering Center (SSEC)
- Open Source Maintainer and Contributor
- Processing tools and weather instrument data ingest

My experience with parallel processing

- Processing of large image-like arrays
  Chunk data to process in parallel (dask)
- Low-level Cython/C extensions
- Lots of data files - embarrassingly parallel
- Asynchronous event processing (asyncio)
- Communicate with multiple instruments from one command

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- Use C extensions where possible (past talk on Cython)
- Parallel processing → Threads
  - "It's not real threading"
  - "Global Interpreter Lock…blah blah blah"
- Use multiprocessing instead of threading - **no longer necessary**

this talk

Python's simple beginnings

- Scripting language - easier than C
- Performance not the priority
- Over 35 years old
- Performance "speed bumps"
  - Everything is an object
    - Large objects, no primitives
    - Slow to move, hard to cache
  - Reference Counting/Garbage Collection
  - Interpreted
    - Convert Python to bytecode

```c
struct _longobject {
    Py_ssize_t ob_refcnt;
    PyTypeObject *ob_type;
    _PyLongValue long_value;
};
```

Interpreted

```python
def some_func(input):
    result = []
    for row in input:
        weight = get_weight(row)
        avg = mean(row)
        res = avg * weight
        result.append(res)
    return max(result)
```

```
  1     0 RESUME          0

  2     2 BUILD_LIST      0
        4 STORE_FAST      1 (result)

  3     6 LOAD_FAST       0 (input)
        8 GET_ITER
>>     10 FOR_ITER       46 (to 106)
       14 STORE_FAST      2 (row)

  4    16 LOAD_GLOBAL     1 (NULL + get_weight)
       26 LOAD_FAST       2 (row)
       28 CALL            1
       36 STORE_FAST      3 (weight)

  5    38 LOAD_GLOBAL     3 (NULL + mean)
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…
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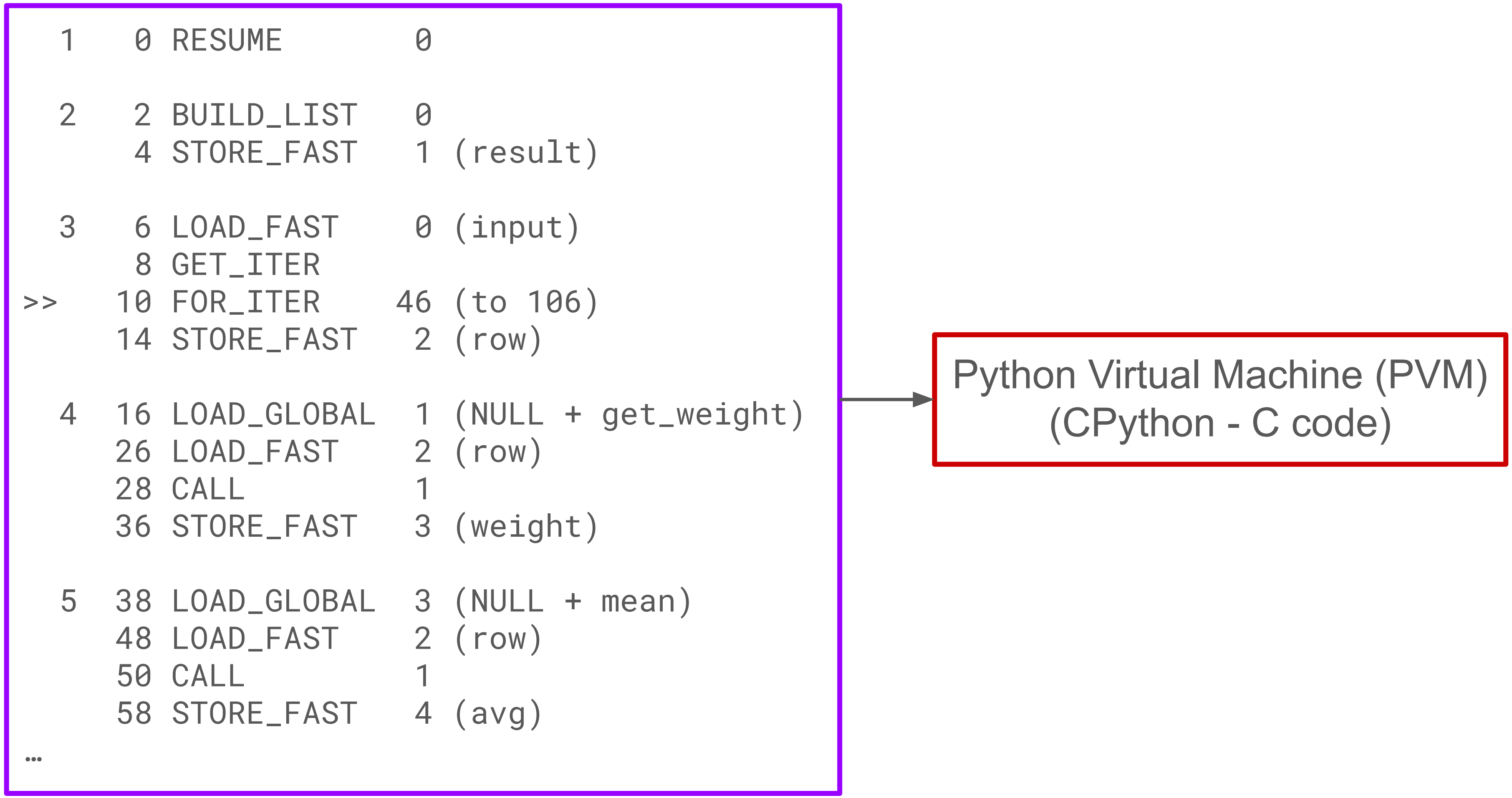

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        - Convert Python to bytecode
        - Hard to specialize instructions
        - Global Interpreter Lock (GIL)

Free-threading to the rescue!

Understanding free-threading

- What is free-threading?
    - Allow Python threads to execute in parallel by removing the GIL
- Concurrency versus Parallelism - "at the same time"
- Threads versus Processes - enable "parallel" work
- How it works now
- Removing the GIL
- What workflows should improve
- Examples

Parallelism versus Concurrency

- Multiple sets of tasks/commands
- Single application (process) versus multiple executions
- Single core versus multiple cores
- Running at the "same time"

Parallelism versus Concurrency

Task A
A1
A2
A3
A4
A5
A6
A7

Task B
B1
B2
B3
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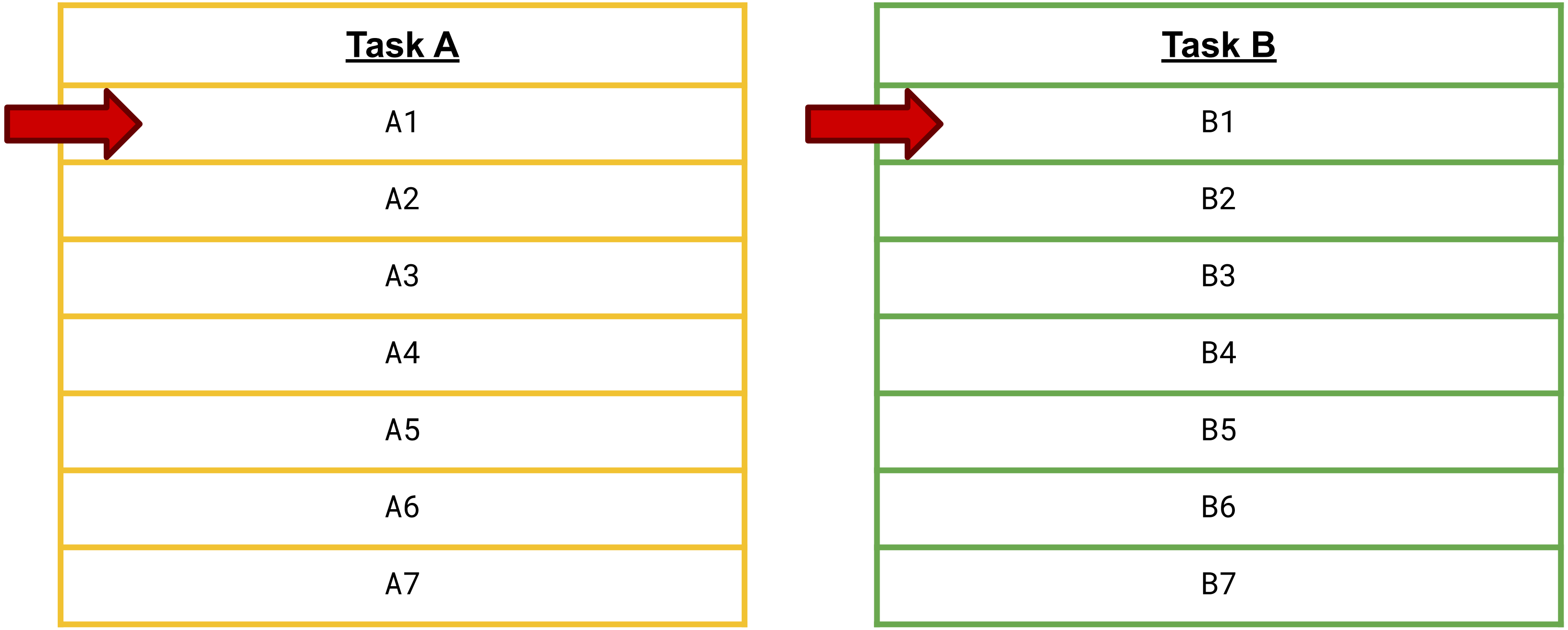
B5
B6
B7

Parallelism - Simultaneous



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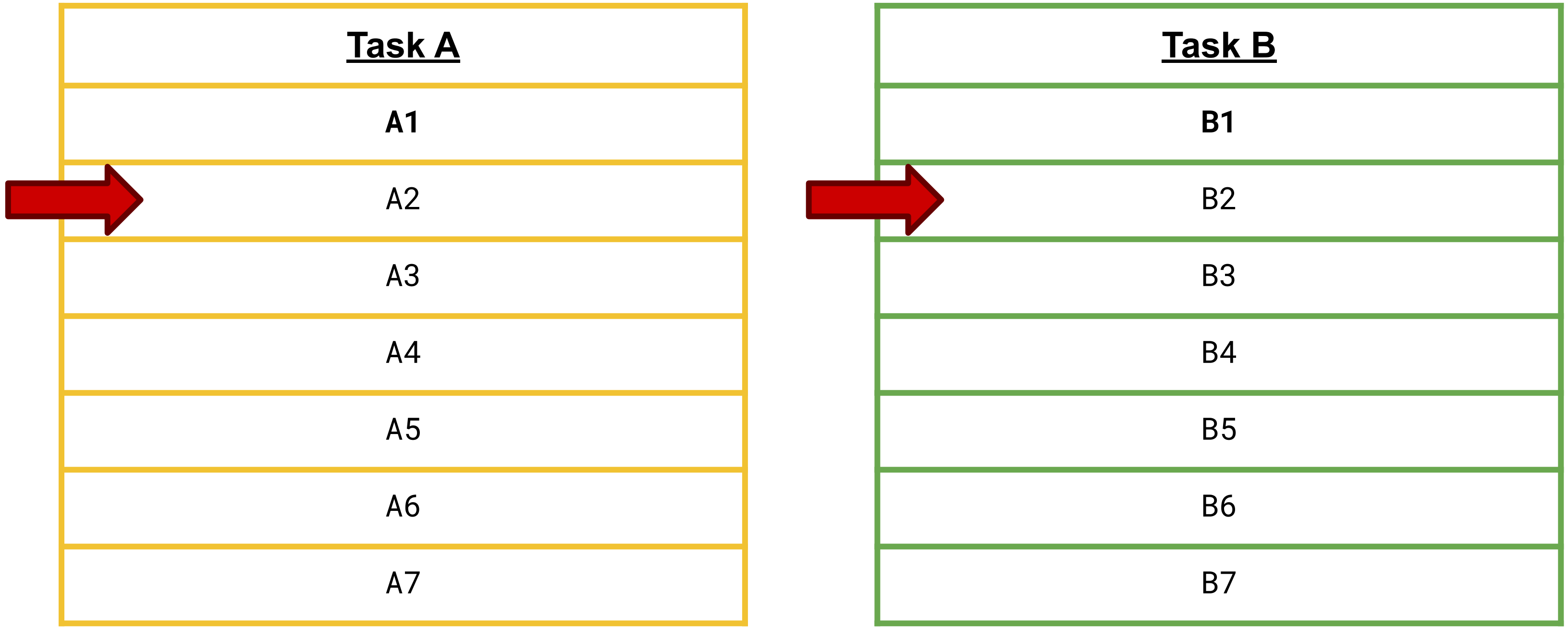

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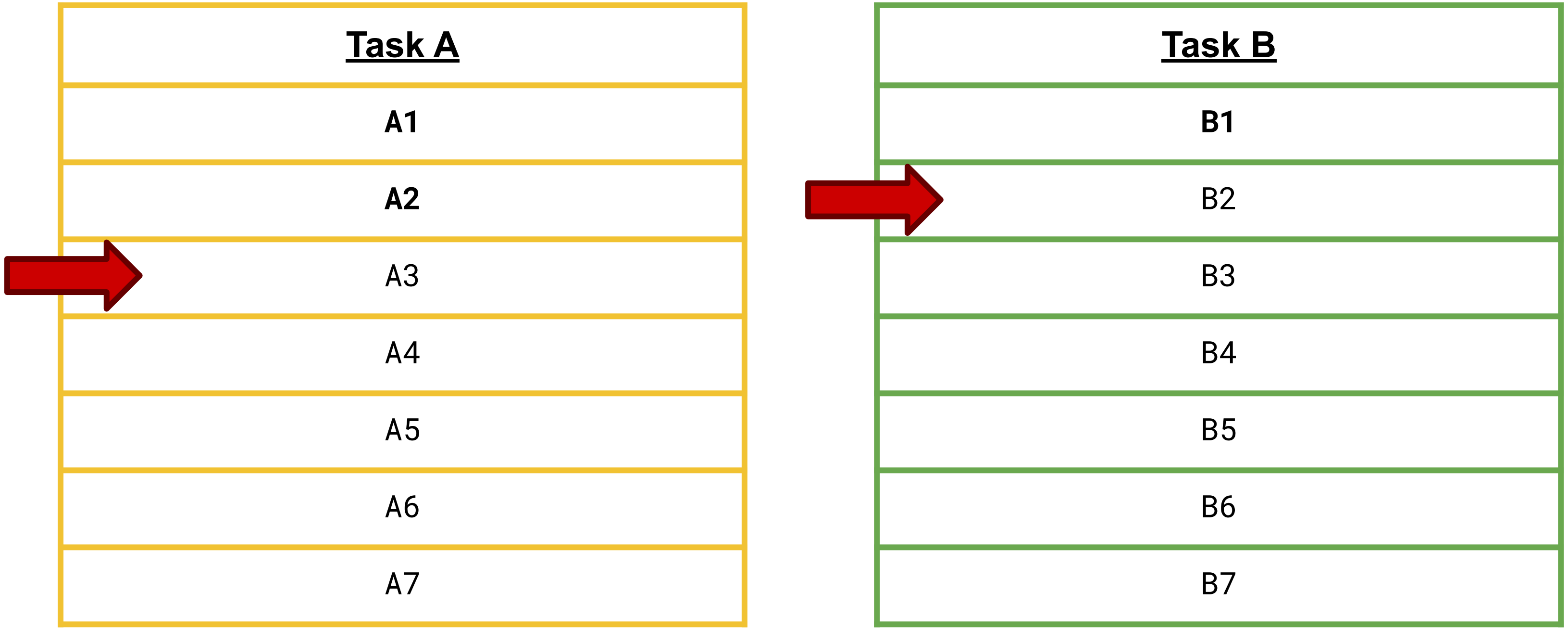

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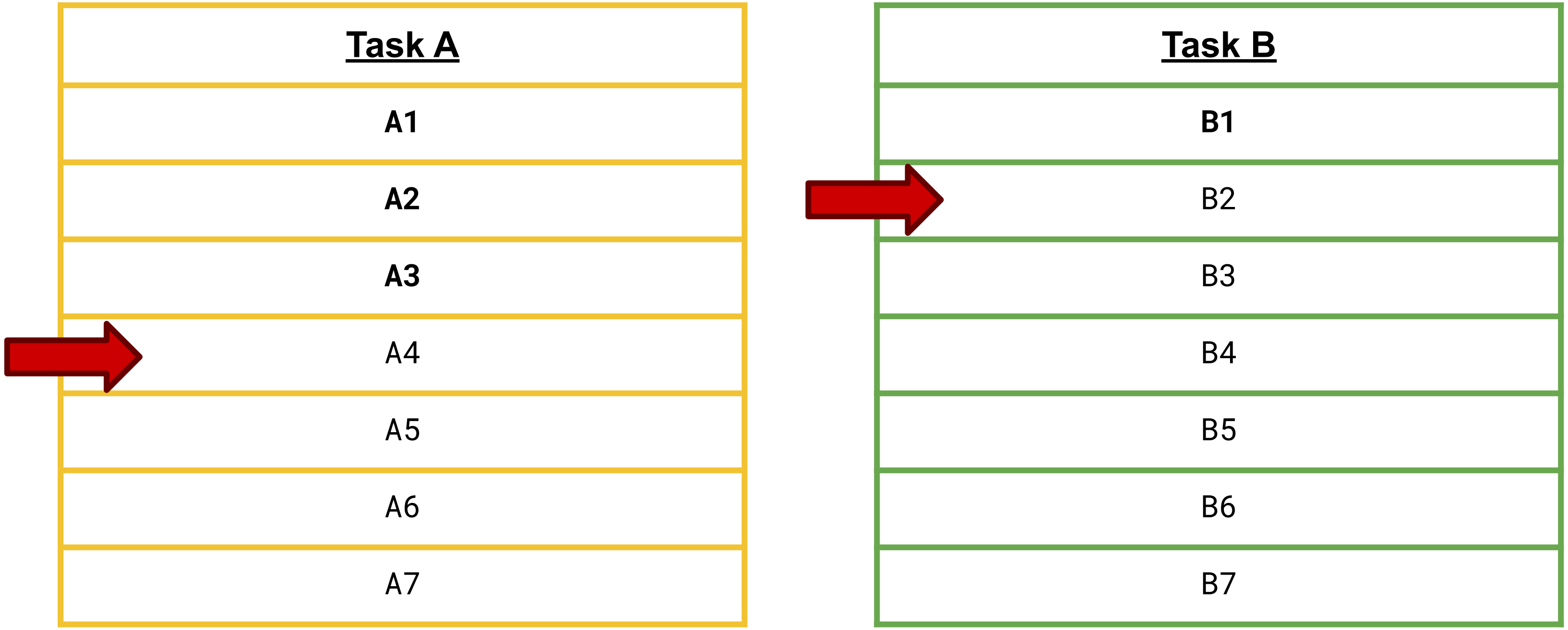

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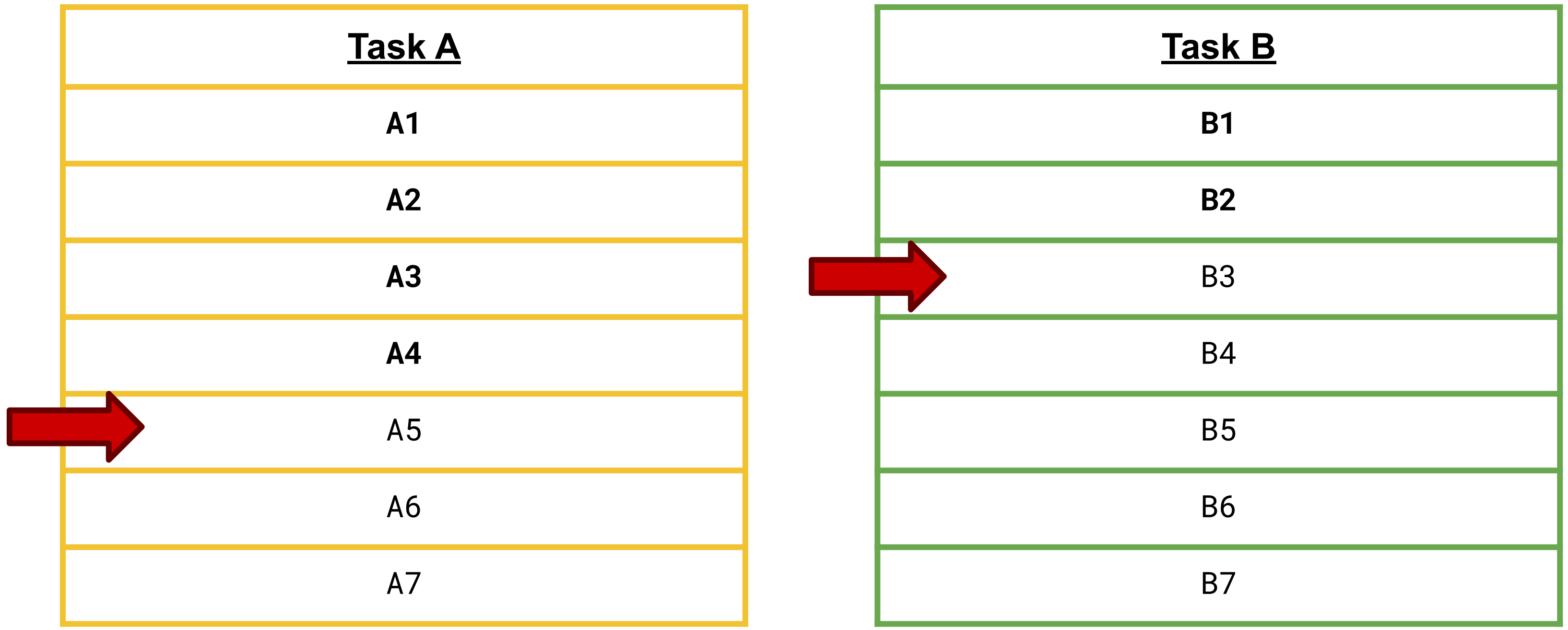

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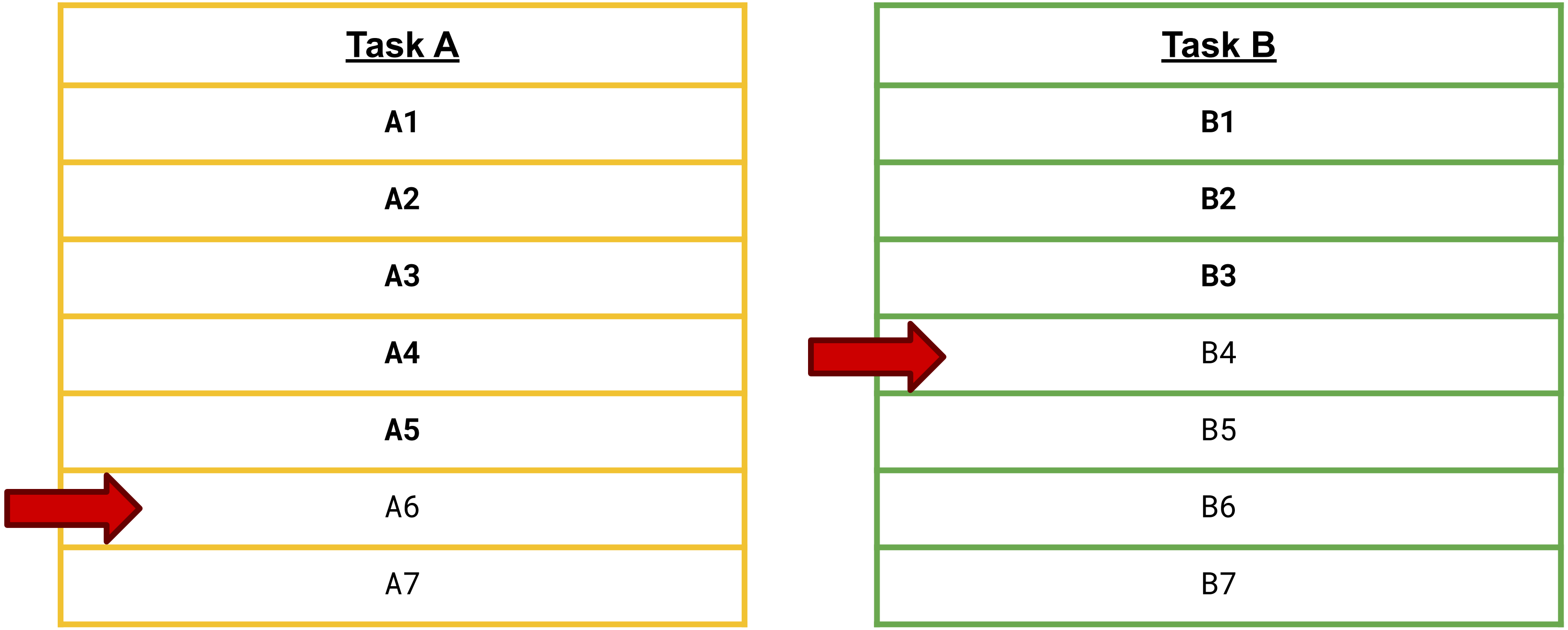

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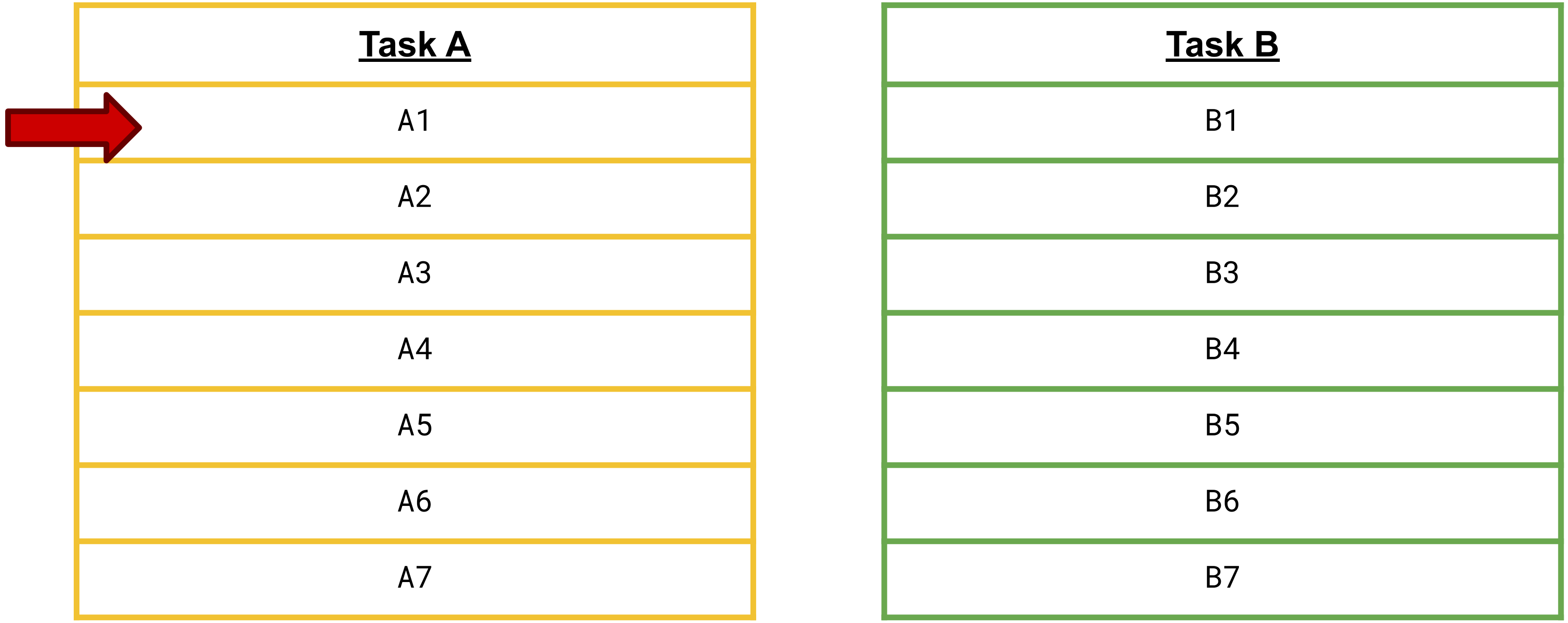

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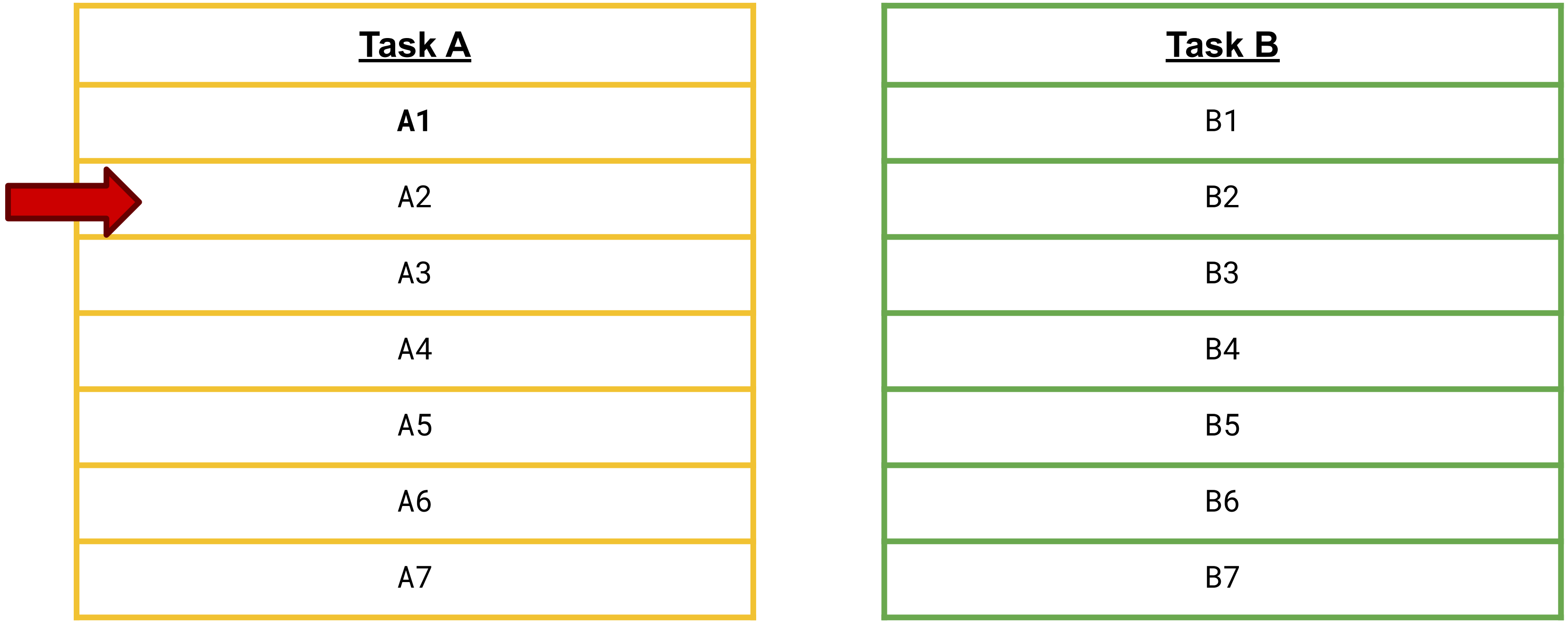

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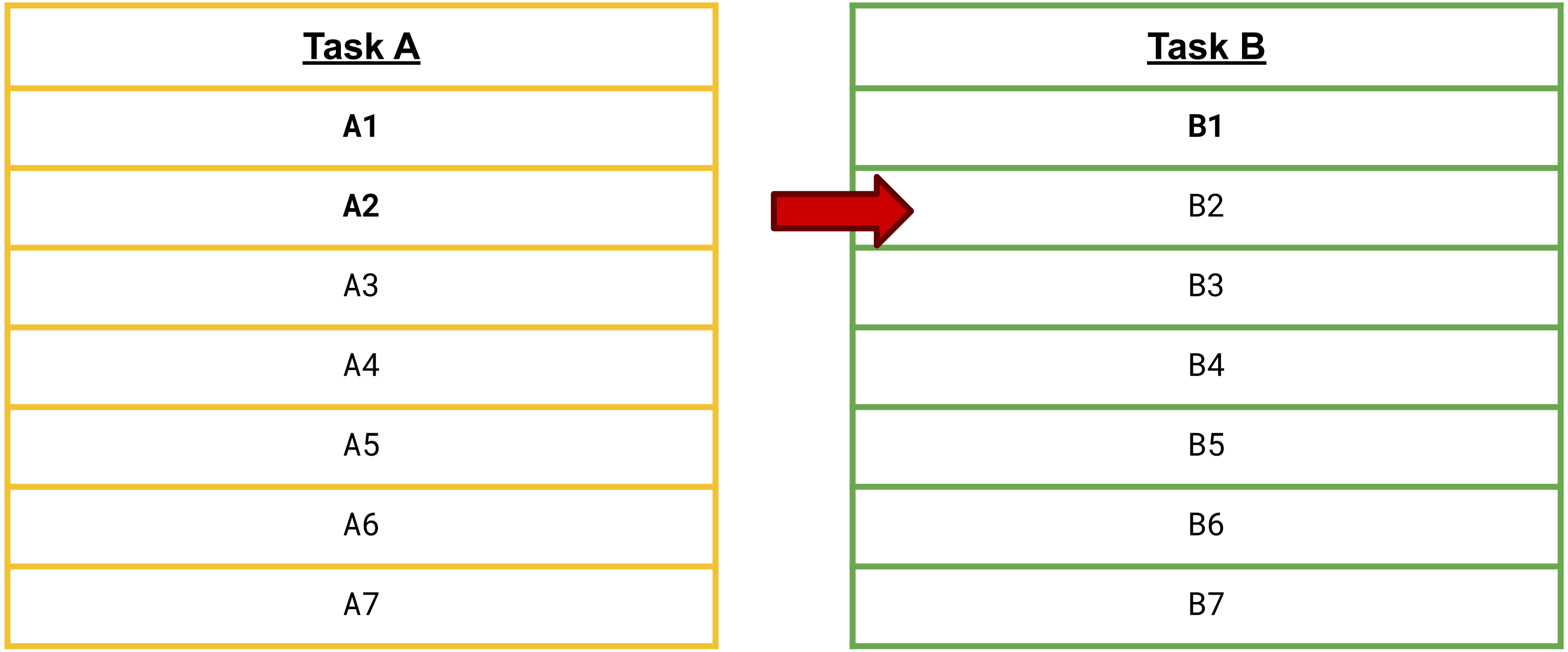

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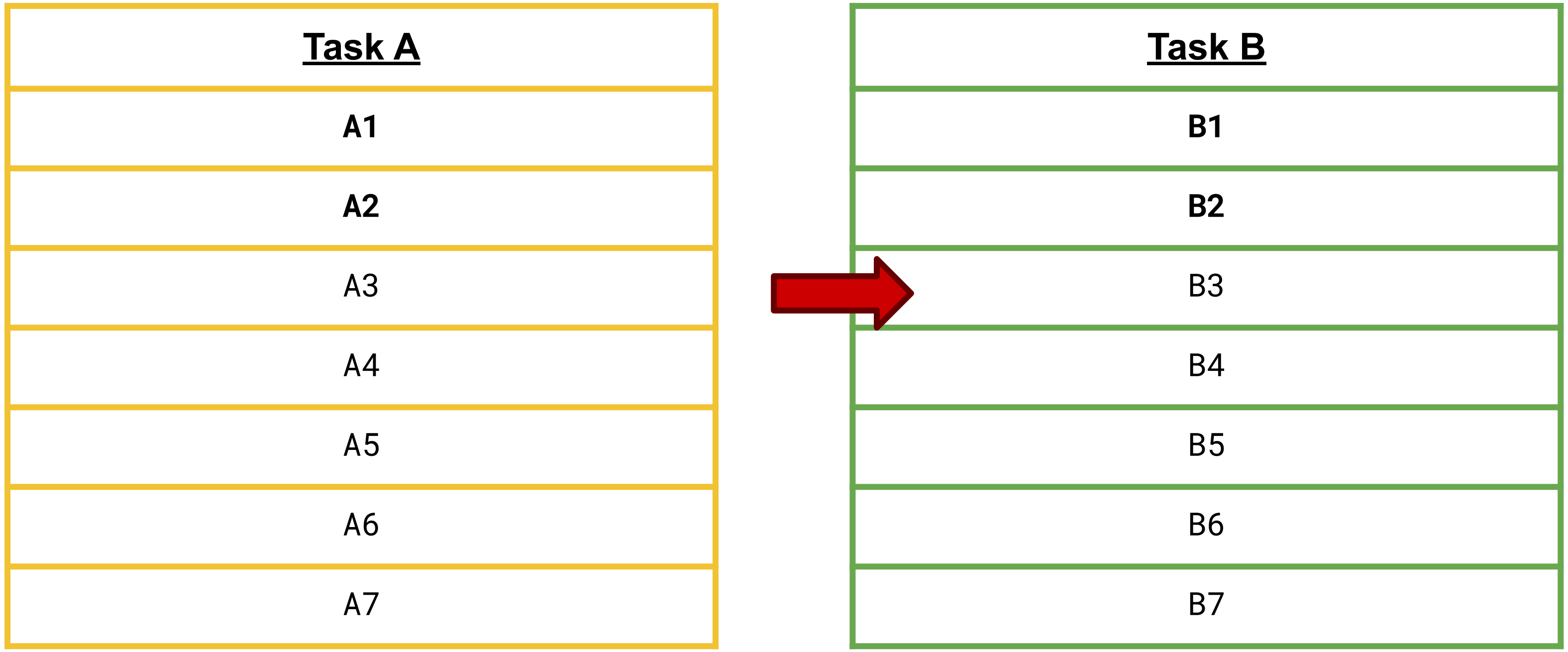

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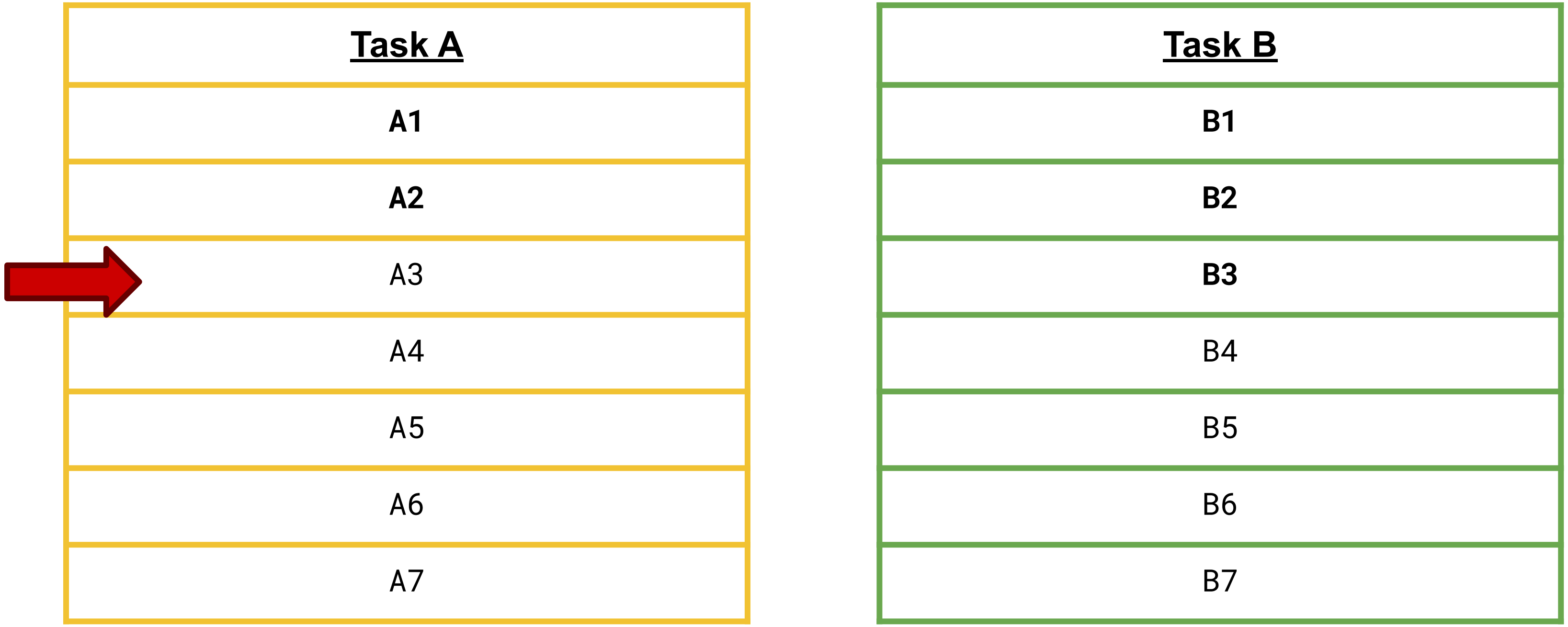

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Parallelism

- Accomplish multiple things at once
- Achieve more with more cores

Examples

- Python multiprocessing
- Linux multiple processes
- Python threading with no GIL (free-threading)

Concurrency

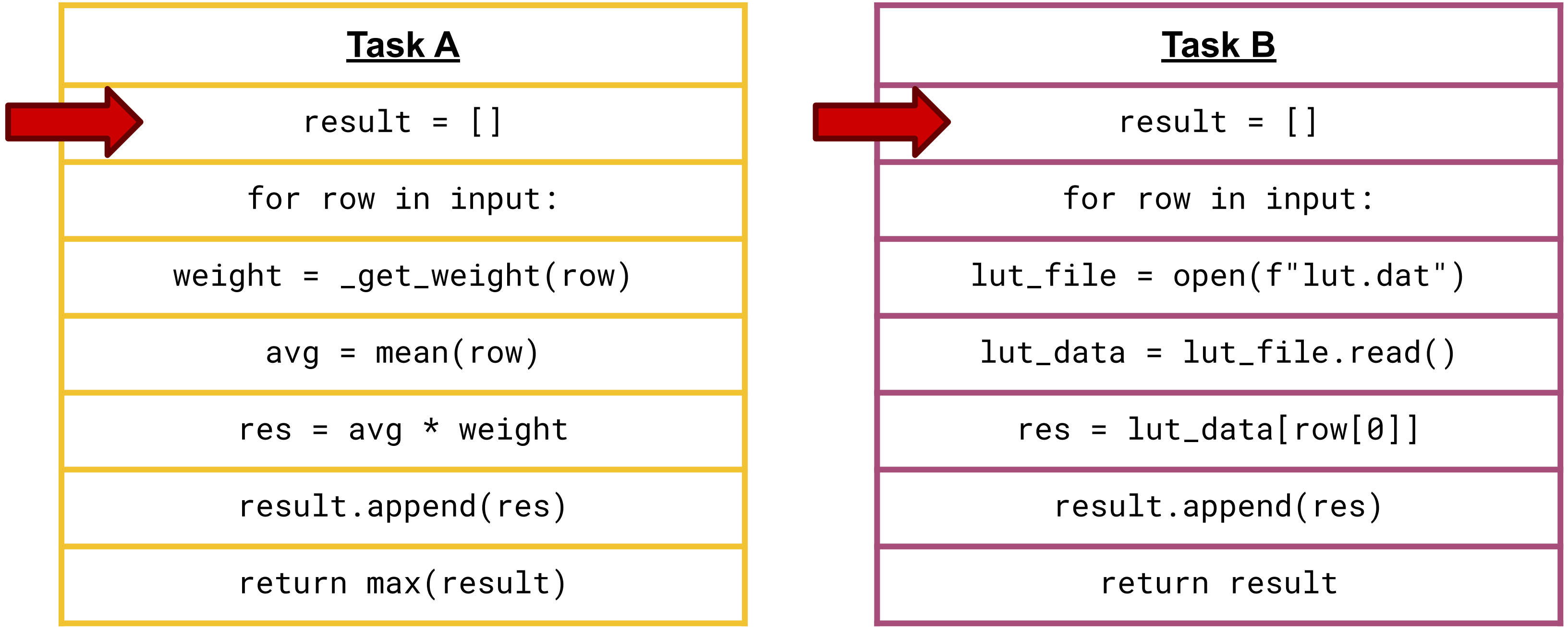
- Accomplish multiple things at once
- Achieve more on limited cores

Examples

- Python threading with GIL - acts as a single executor
- Python's (basic) asyncio
- Linux context switching

Possible to have concurrent and parallel tasks

Global Interpreter Lock (GIL)



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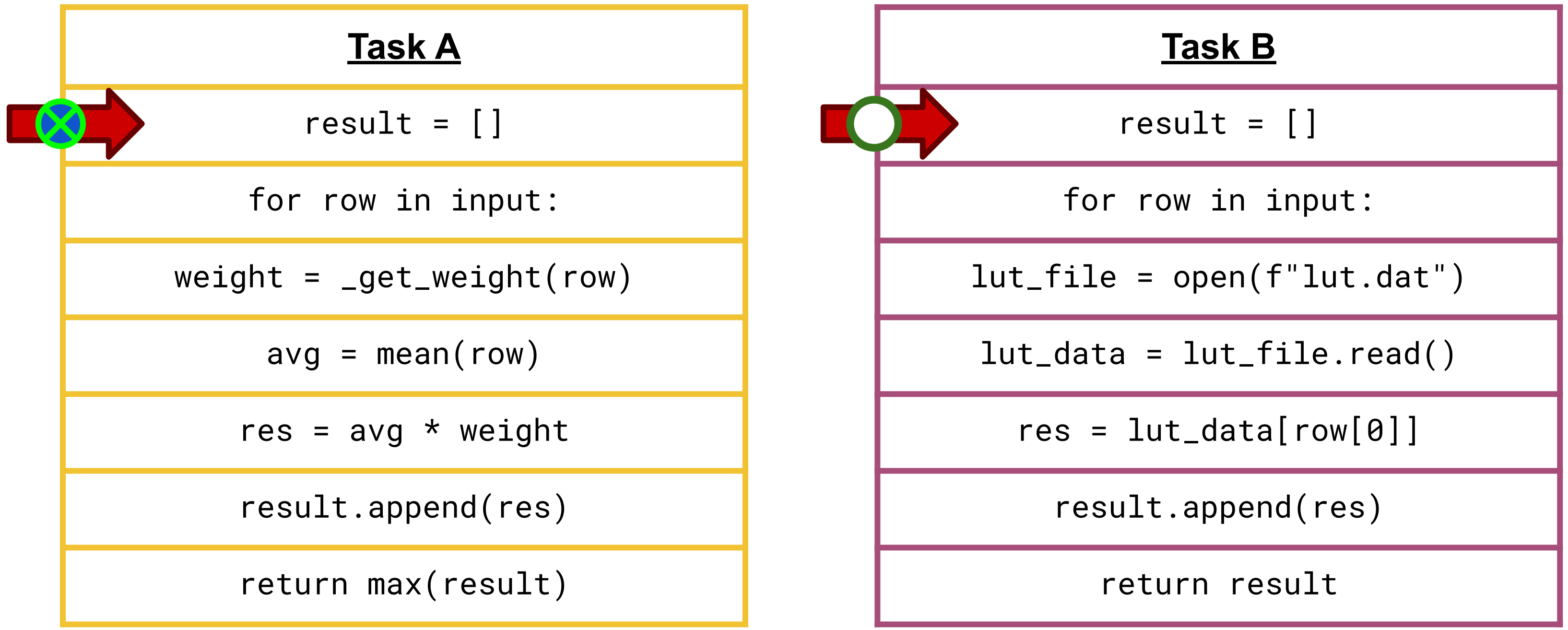

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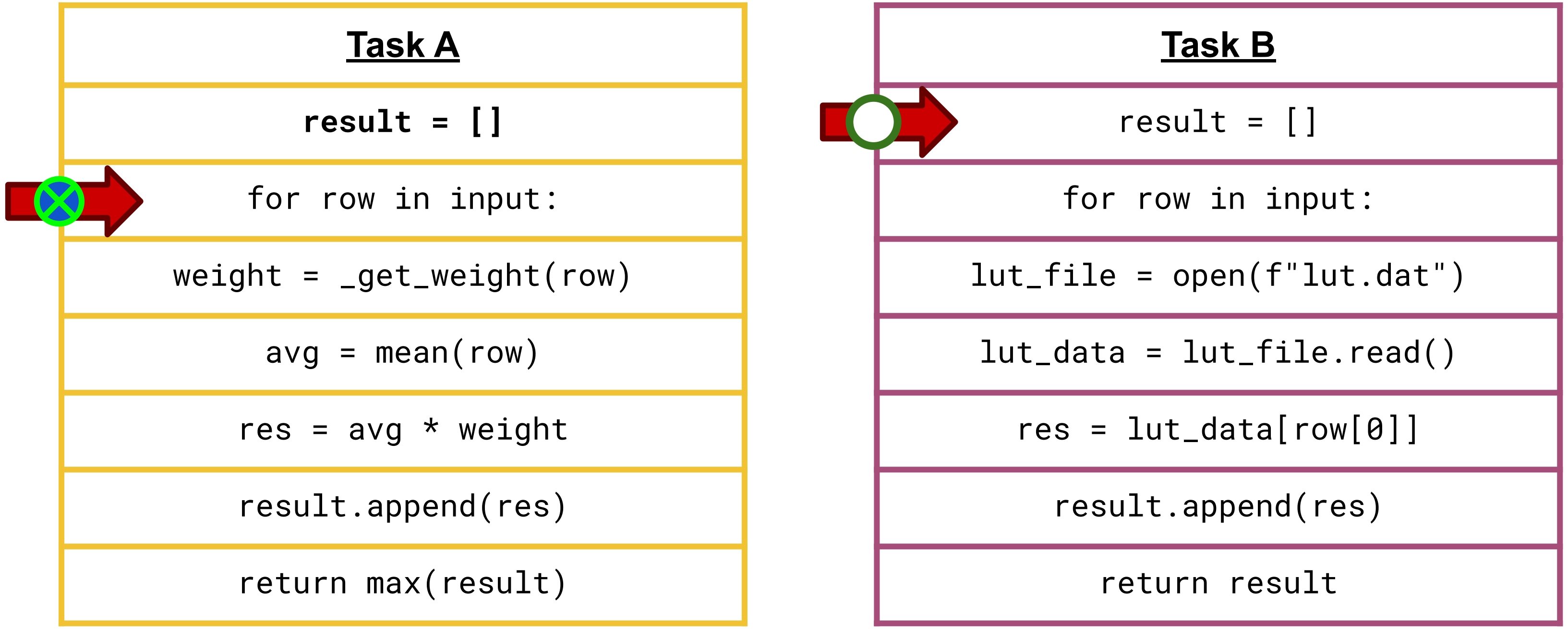

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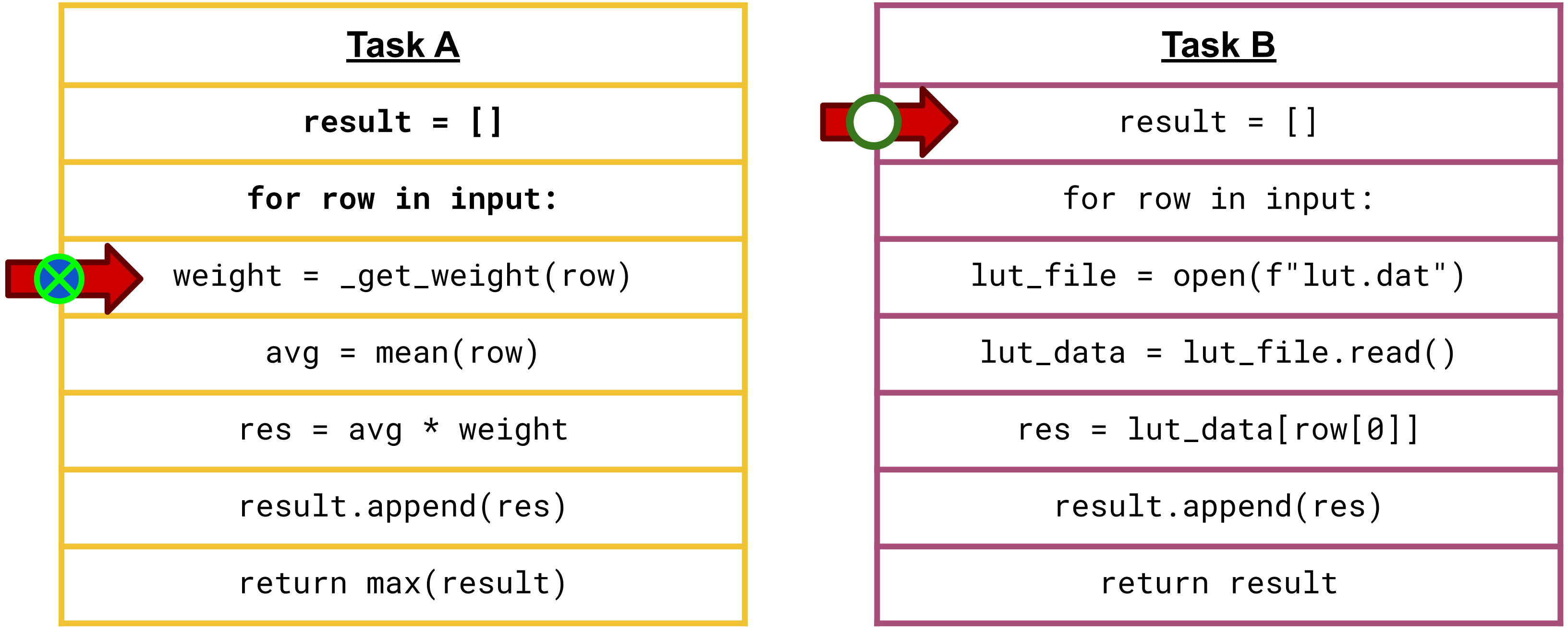

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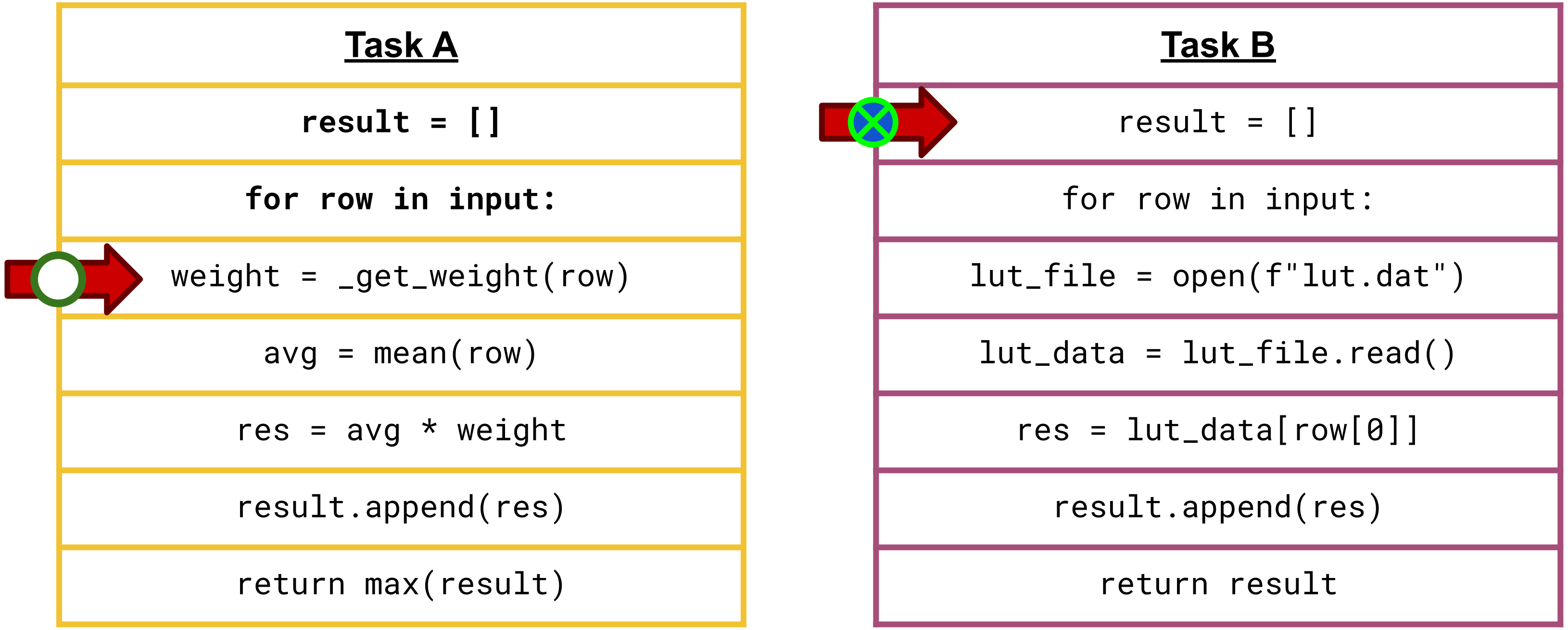

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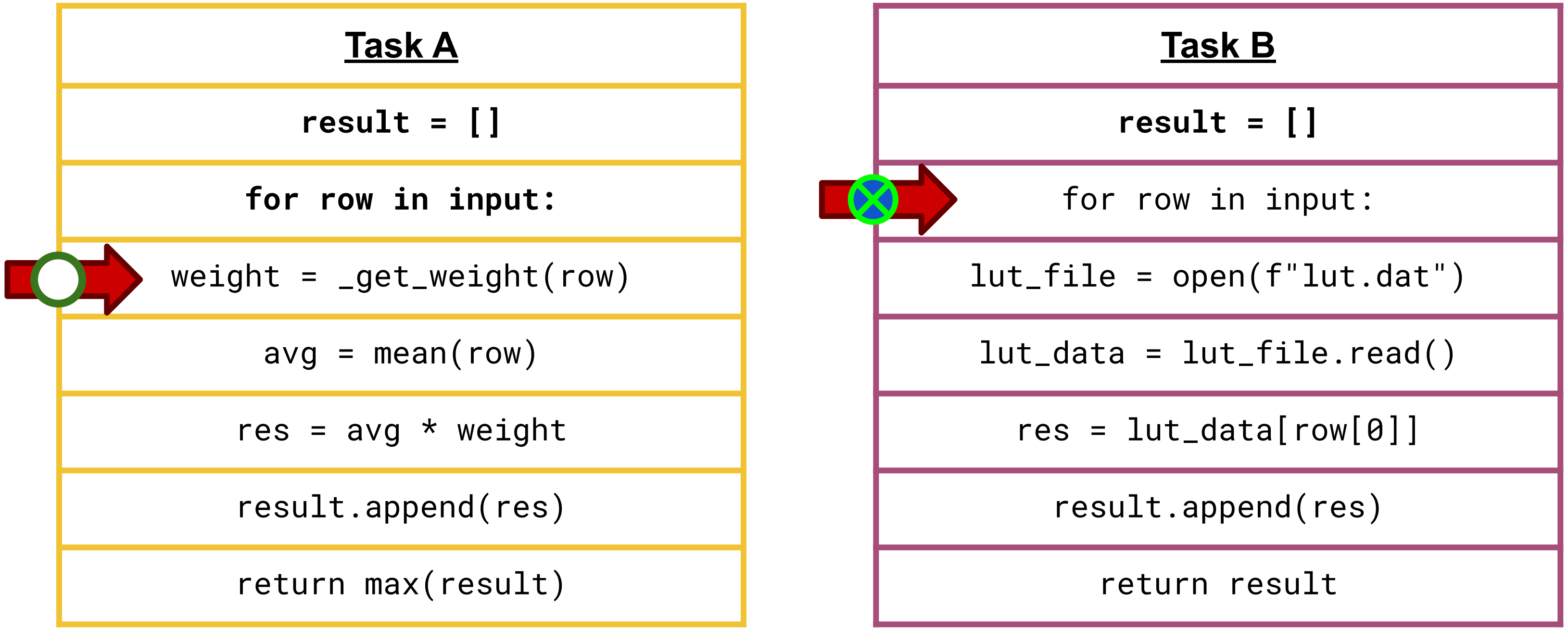

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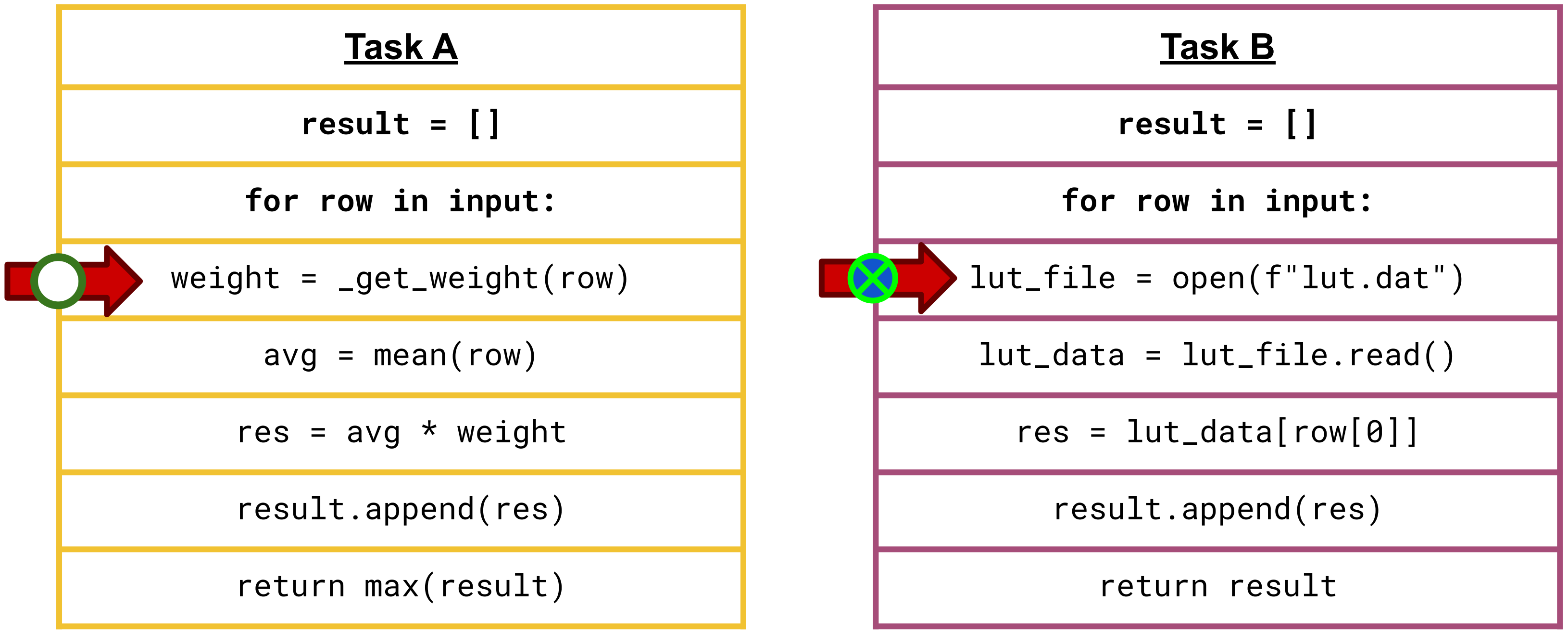

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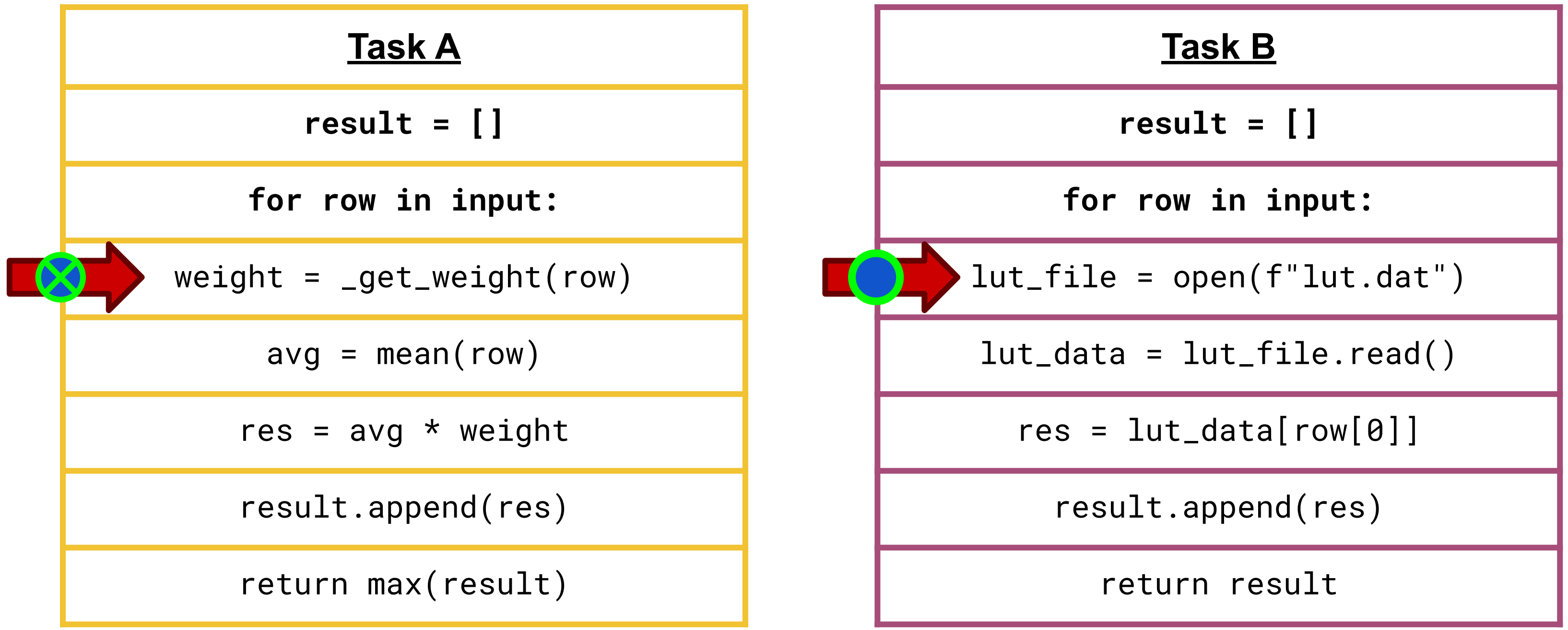

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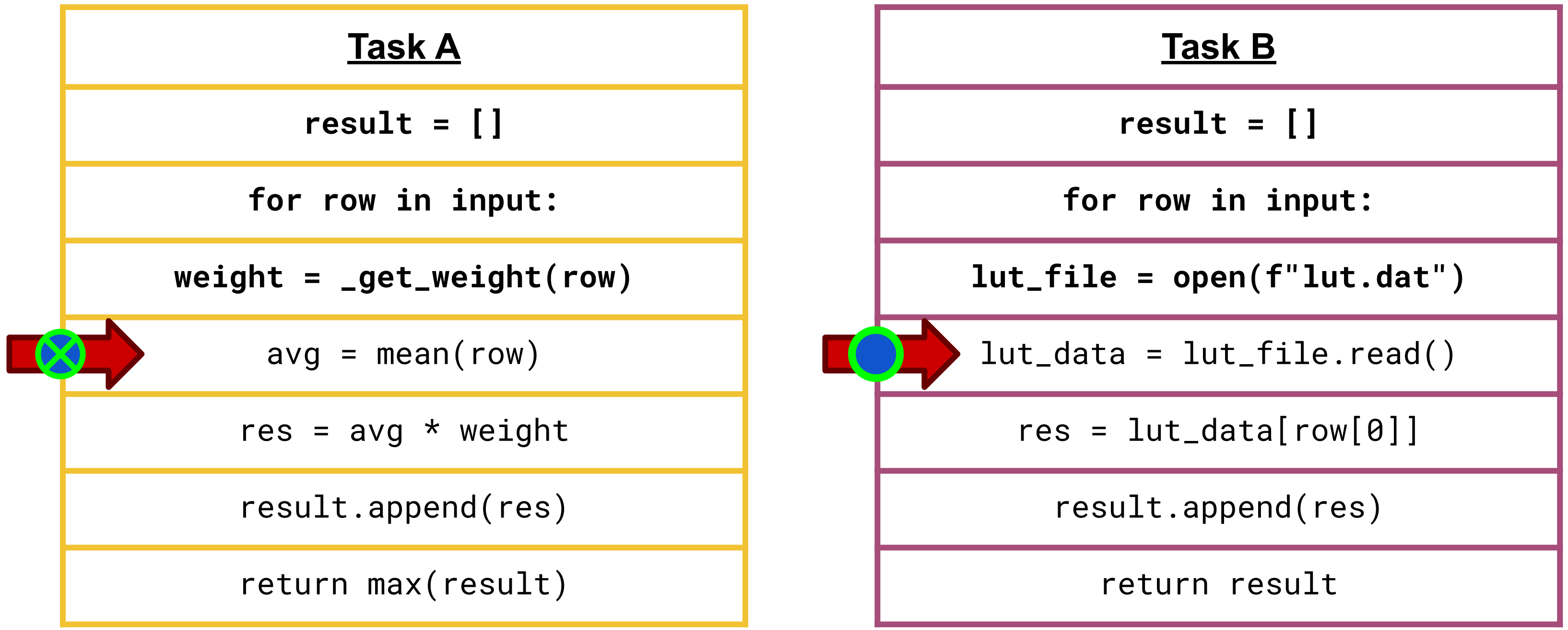

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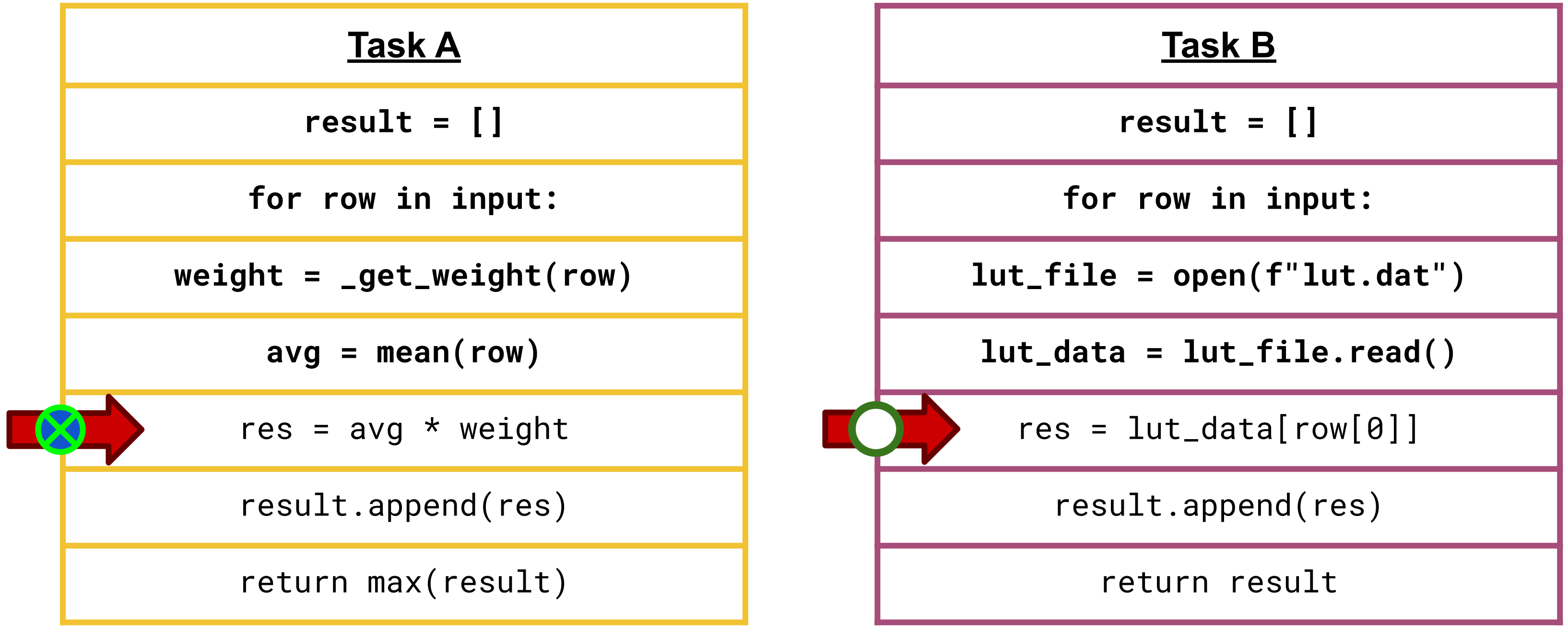

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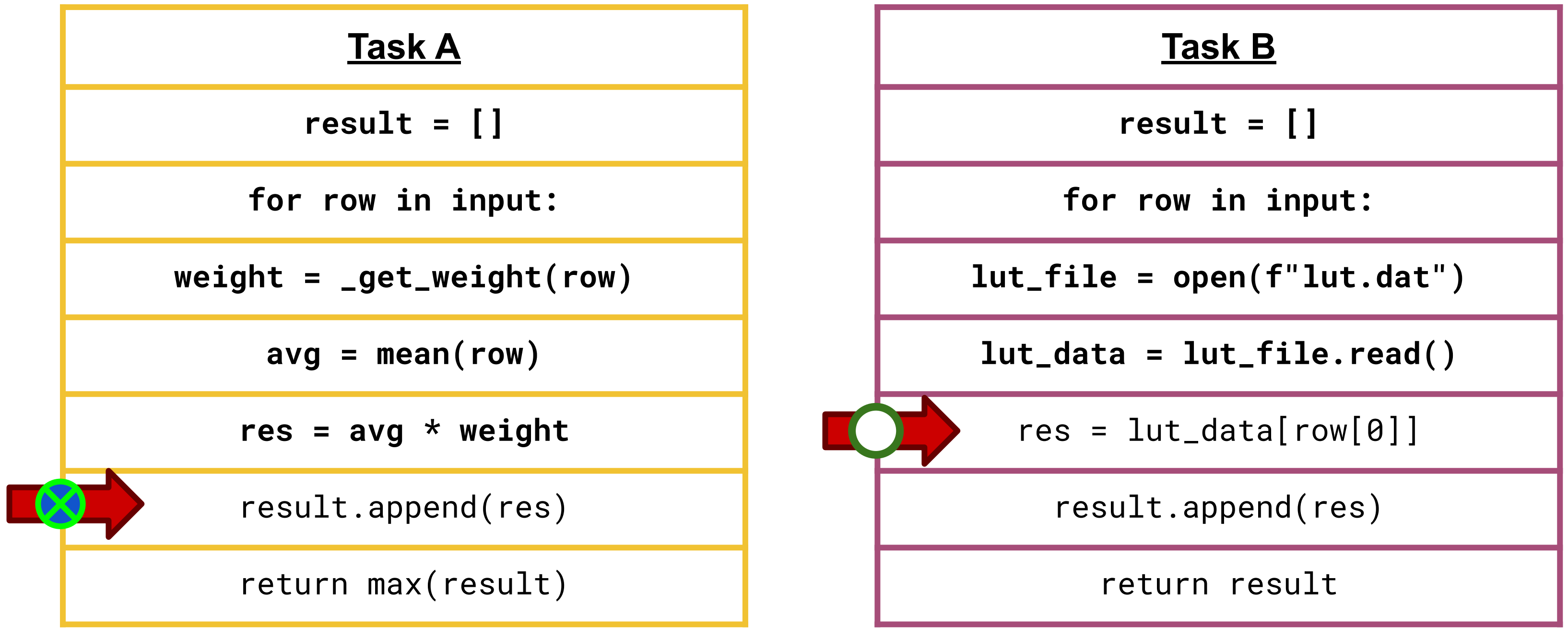

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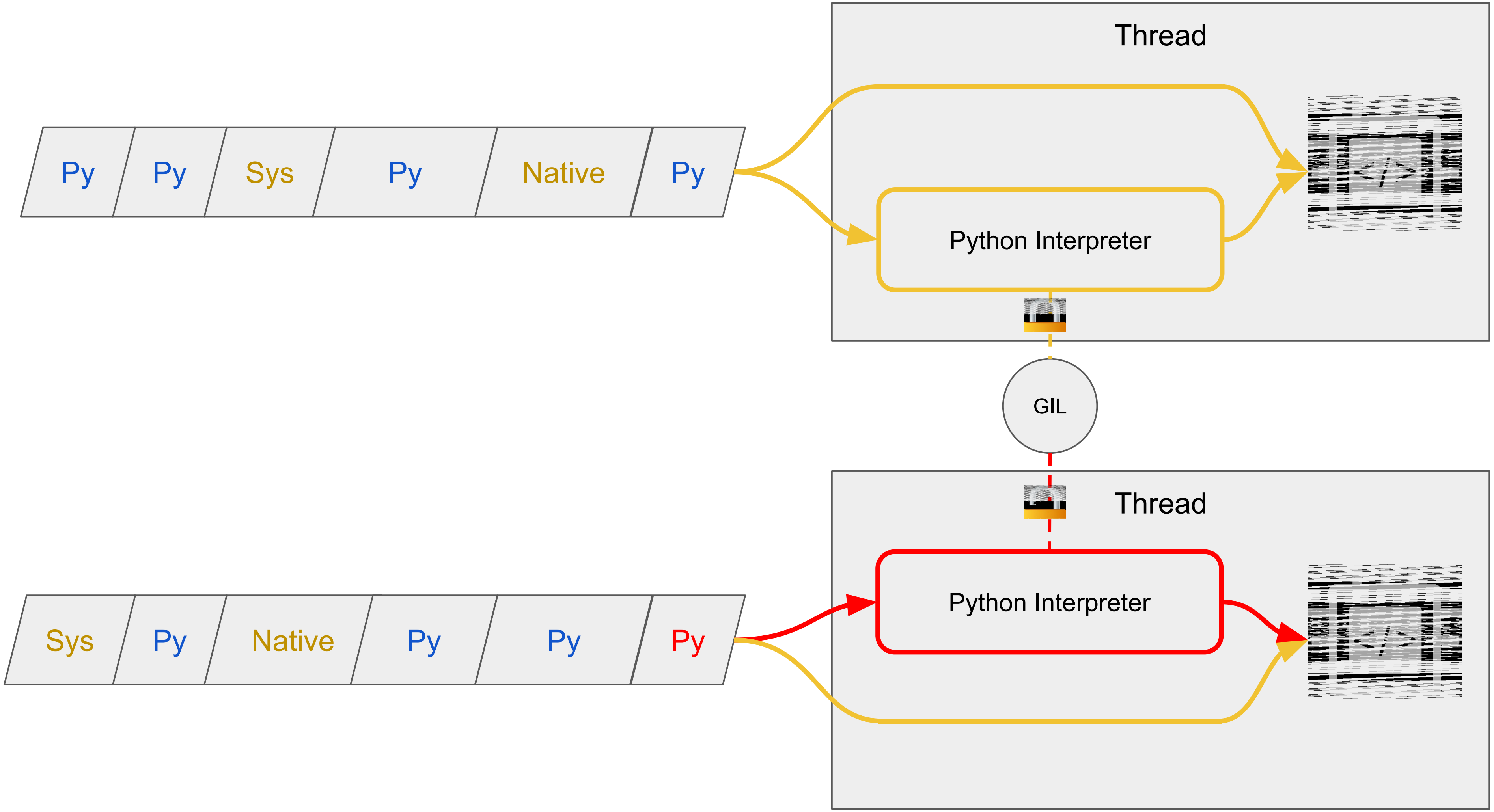
Py
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Python Interpreter
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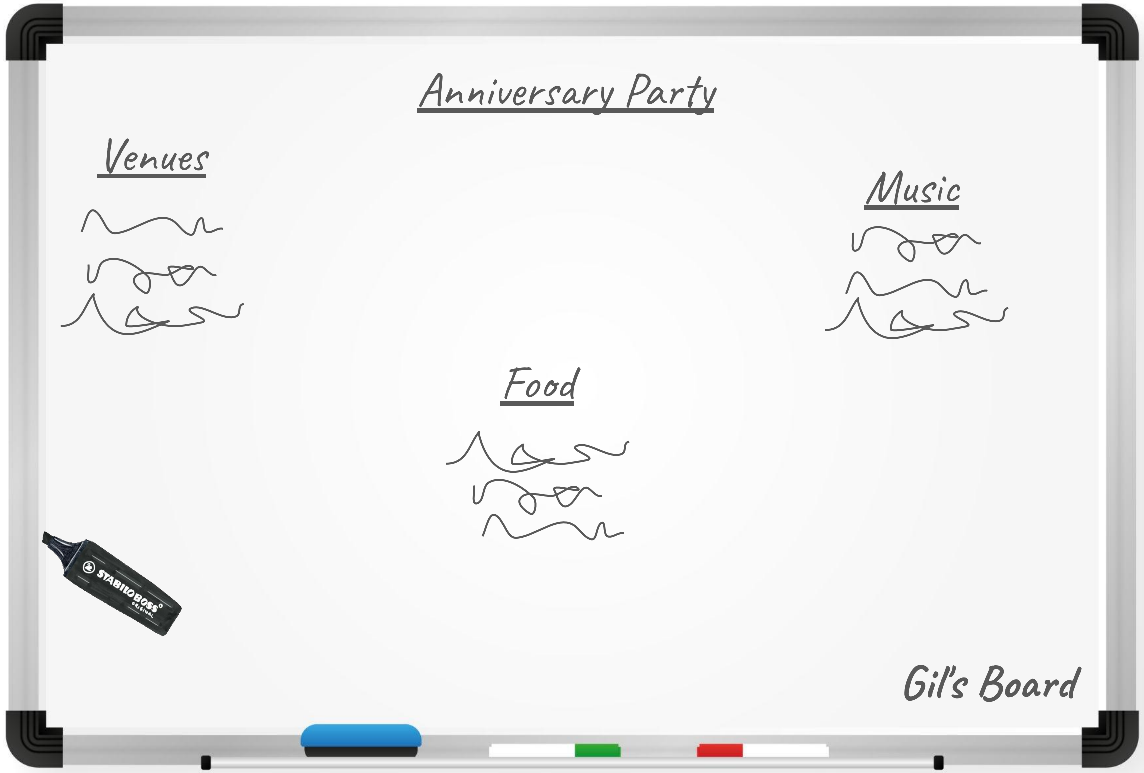

Anniversary Party
Venues
Music
Food
Gil's Board
STABILO BOSS ORIGINAL

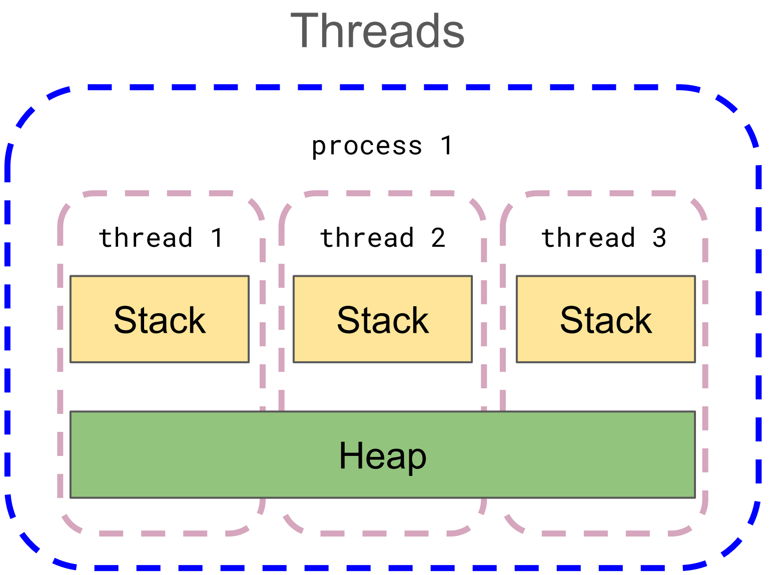
When the GIL isn't a problem

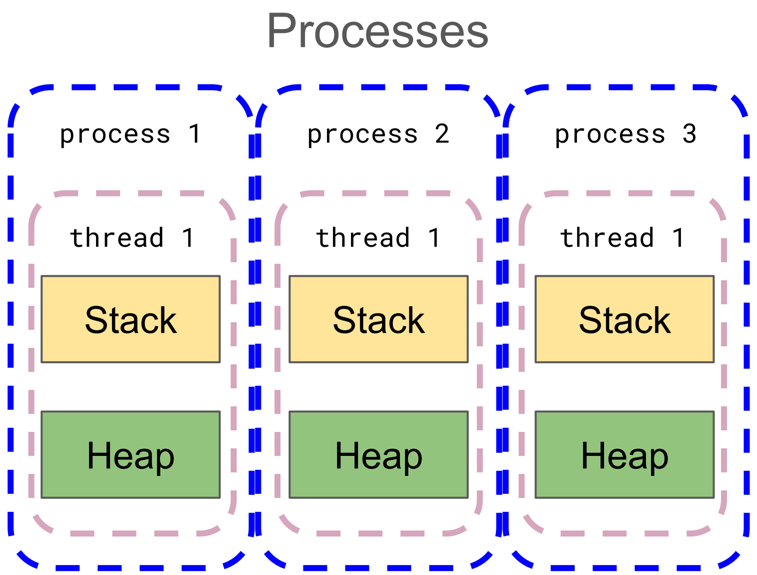
- Input/Output and other system calls
  - Disk
  - Network
  - `time.sleep`
- Explicit releasing of the GIL
  - Cython/C/other extensions
  - Third-party libraries
    - Ex. Numpy
    - "number crunching"
- Non-CPython interpreter
  - Jython
  - IronPython

Threads versus Processes

- Both allow you to accomplish things "at the same time"
- Threads are "lighter", processes are "heavier"
- In non-python languages, threads can be the best of both worlds
    - Easier to share data
    - Easier to context switch
- OS-dependent, version/kernel dependent, etc
- Use "locks" to control access to shared resources/values
    - acquire → release → acquire → release
- Use atomic operations to avoid locking

Threads versus Processes - Memory





Python's threading (traditionally)

- `threading.Thread(target=some_func)`
- Thread Pools
  - `concurrent.futures.ThreadPoolExecutor`
  - `multiprocessing.pool.ThreadPool`
  - third-party library
- "Everything is an object" means everything in the shared heap
- Locks still available for coordinating access to shared resources
- GIL:
  - Pro: Each bytecode operation is "atomic"
  - Con: "To avoid the GIL, use multiple processes"

Threading in Python

```
import threading

def some_func(some_input):
    …

if __name__ == "__main__":
    t = threading.Thread(
        target=some_func,
        args=("my_file.txt",),
    )
    t.start()  # ← start thread 2

    # other stuff - running in thread 1

    t.join()
```

Threading in Python

Questions before free-threading?

Removing the GIL

Changes in CPython 3.13 (PEP 703) - Experimental:

- Reference counting and Immortalization
- Memory management and Garbage Collection
- Container thread-safety (dict, list, etc) - per-object locks
- Locking and atomic APIs
- Turn off some interpreter optimizations

Changes in CPython 3.14:

- Convert temporary workarounds into long-term solutions
- Specializing adaptive interpreter enabled

Python's threading (free-threading)

- Experimental in Python 3.13
- Fully-supported in Python 3.14
- Special ***separate*** build and binary of CPython
    - Optional: Need to explicitly install it
    - Single threaded applications are generally slower
        - 5-10% performance penalty in Python 3.14
        - Even worse in Python 3.13
- No GIL!

What cases does free-threading improve?

- Short answer: Every multi-threaded workflow
- Long answer:
  - I/O bound tasks should see minimal improvement
  - CPU bound pure-python (minimal extensions) will see the greatest improvement

How do I use it?

- `conda install -c conda-forge python-freethreading`
- `python3.13t`
- https://docs.python.org/3/howto/free-threading-python.html
- https://py-free-threading.github.io/ (by Quansight Labs and Meta)
- Re-enable GIL:

```
python3.13t -X gil=1 my_script.py
PYTHONGIL=1 python3.13t
```

- Check if build supports no-GIL:

```
print(sys.version)
'3.13.5 experimental free-threading build | packaged by conda-forge…'
```

- At runtime:

```
sys._is_gil_enabled()
```

Examples

https://github.com/djhoese/free-threading-examples

Free-threading

- Try it out!