Programming Principles in Python (CSCI 503/490)

Concurrency

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Python Modules for Working with the Filesystem

- In general, cross-platform! (Linux, Mac, Windows)
- `os`: translations of operating system commands
- `shutil`: better support for file and directory management
- `fnmatch`, `glob`: match filenames, paths
- `os.path`: path manipulations
- `pathlib`: object-oriented approach to path manipulations, also includes some support for matching paths

Listing Files in a Directory

- Difference between file and directory
- `isfile/is_file` and `isdir/is_dir` methods
  - `os.path.isfile/isdir`
  - `DirEntry.is_file/is_dir`
  - `Path.is_file/is_dir`
- Test while iterating through
  - ```
    from pathlib import Path
    basepath = Path('my_directory/')
    files_in_basepath = basepath.iterdir()
    for item in files_in_basepath:
        if item.is_file():
            print(item.name)
    ```

[V. Ndlovu]
    ```

File Attributes

- Getting information about a file is "stat"-ing it (from the system call name)
- Names are similarly a bit esoteric, use documentation
- `os.stat` or use `.stat` methods on `DirEntry`/`Path`
- Modification time:
  - ```
    from pathlib import Path
    current_dir = Path('my_directory')
    for path in current_dir.iterdir():
        info = path.stat()
        print(info.st_mtime)
    ```
- Also can check existence: `path.exists()`

[V. Ndlovu]
    ```

Filename Pattern Matching

- `string.endswith/startswith`: no wildcards
- `fnmatch`: adds * and ? wildcards to use when matching (**not** just like regex!)
- `glob.glob`: treats filenames starting with . as special
  - can do recursive matchings (e.g. in subdirectories) using `**`
- `pathlib.Path.glob`: object-oriented version of glob
- ```
  from pathlib import Path
  p = Path('.')
  for name in p.glob('*.p*'):
      print(name)
  ```
- Also, can break apart paths:
  - `split/basename/dirname/join ~ parent/name/joinpath`

[V. Ndlovu]
  ```

Deleting/Copying/Moving/Archiving Files/Directories

- Better support in shutil:
  - `shutil.rmtree`, `shutil.copy`, `shutil.move`
- Some support in os/pathlib, too
  - `os.unlink, pathlib.Path.unlink, os.rename`
- Archiving:
  - `zipfile`
  - `tarfile`
  - `shutil.make_archive` and `shutil.unpack_archive`

Assignment 7

- Coming soon…

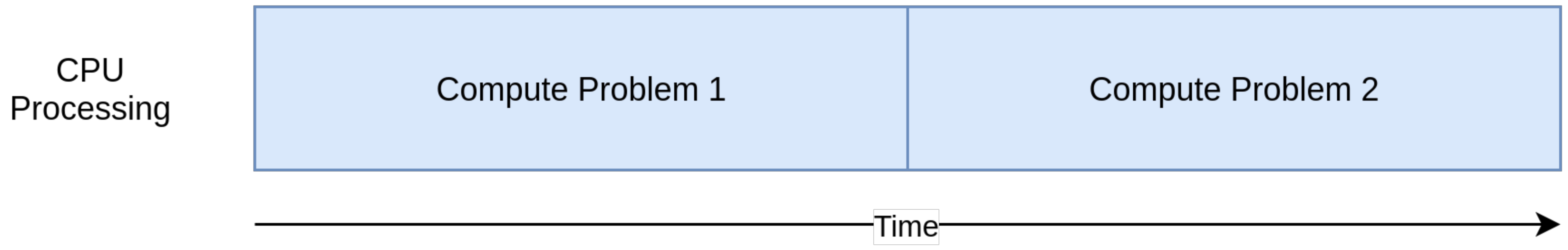
Why do we care about concurrency (threading and multiprocessing)?

Why concurrency?

- Speed:
  - Moore's Law and multiple cores
  - CPU-bound programs can use more cores
- Input/Output
  - Programs often sit waiting for data to load from disk/network

CPU-Bound

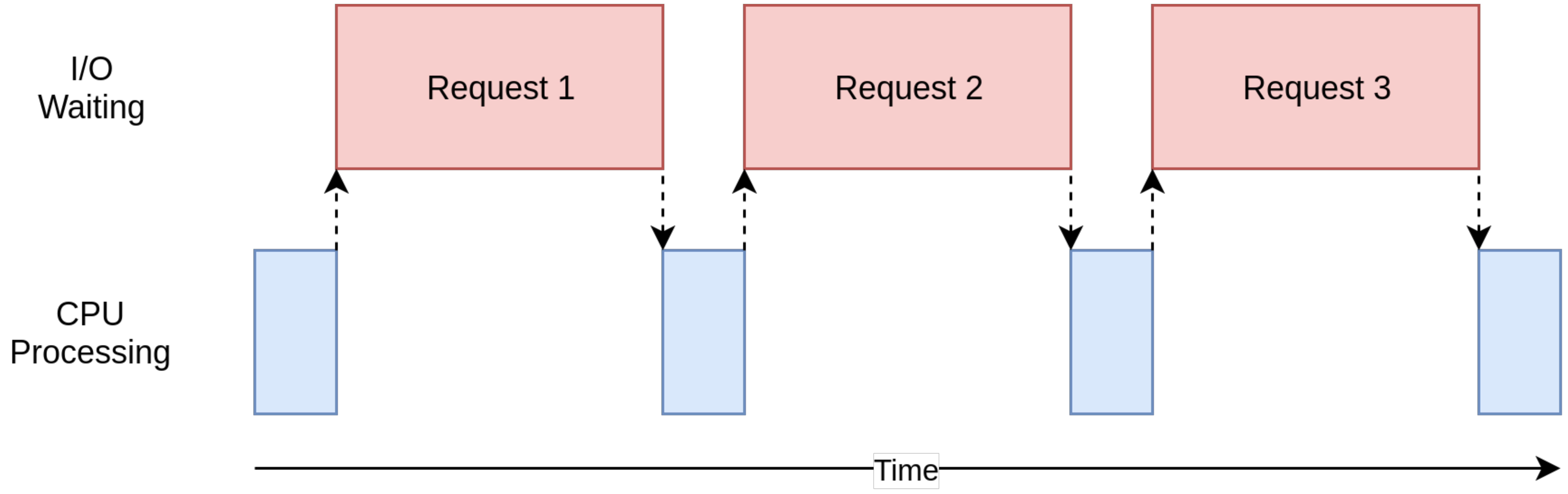
- Have to run each problem in sequence
- Wait for Problem 1 to finish before Problem 2 can start
- …even if they are totally separate problems!
- What if we could use another core for Problem 2?



[J. Anderson]

I/O-Bound

- Waiting for the file system or network to get data
- Nothing else happens while we wait for I/O to finish
- What if we could do something else while waiting for I/O?



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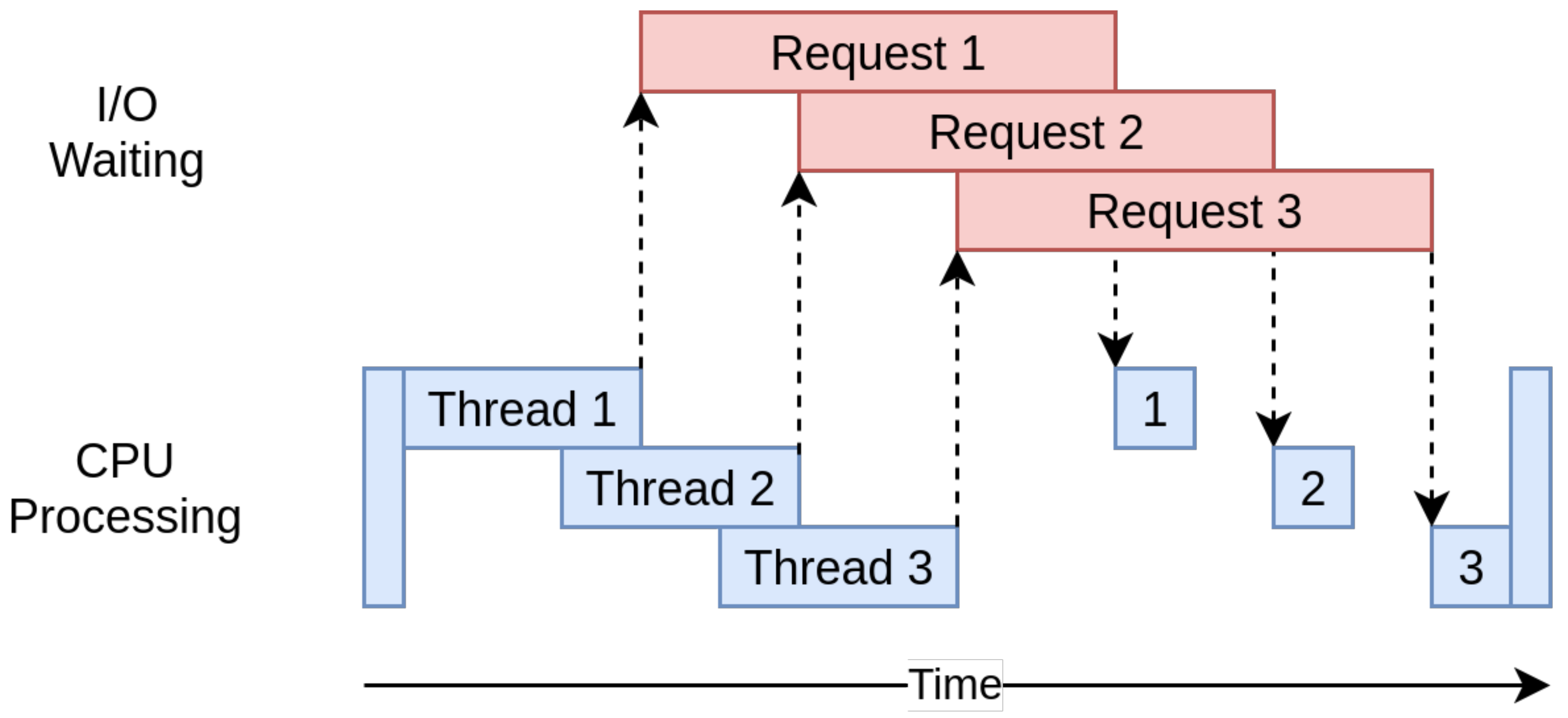
Threading

- Threading address the I/O waits by letting separate pieces of a program run at the same time
- Threads run in the same process
- Threads share the same memory (and global variables)
- Operating system schedules threads; it can manage when each thread runs, e.g. round-robin scheduling
- When blocking for I/O, other threads can run



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Threading Problem: Race Conditions

- Two threads, `T1` and `T2` that increment a variable `a = 42`
- We don't know when these threads will be **interrupted** by the OS
- `T1` reads the value of `a` (`42`)
  `T1` adds one and writes `a` (`43`) # `T1` finished
  `T2` reads the value of `a` (`43`)
  `T2` adds one and writes `a` (`44`) # `T2` finished
- `T1` reads the value of `a` (`42`) # `T1` INTERRUPT
  `T2` reads the value of `a` (`42`) # `T2` INTERRUPT
  `T1` adds one and writes `a` (`43`) # `T1` finished
  `T2` adds one and writes `a` (`43`) # `T2` finished
- Two different answers!

Threading Solution: Locking

- Ensure no two threads can access the same variable at the same time
- `T1` acquires a lock on `a`
  `T1` reads the value of `a` (`42`) # `T1` INTERRUPT
  `T2` waits for a lock on `a` # `T2` BLOCKED, sleeps
  `T1` adds one and writes `a` (`43`)
  `T1` releases lock on `a` # `T1` finished
  `T2` acquires a lock on `a`
  `T2` reads the value of `a` (`43`)
  `T2` adds one and writes `a` (`44`)
  `T2` releases lock on `a` # `T2` finished

Python and Threading

- ```
  import threading
  def printer(num):
      print(num)
  for i in range(5):
      t = threading.Thread(target=printer, args=(i,))
      t.start()
  ```
- Try this: you will likely see out-of-order outputs or weird formatting
- Why?
  ```

Python Locks

- ```
  my_lock = threading.Lock()
  def printer(num):
      with my_lock:
          print(num)

  for i in range(5):
      t = threading.Thread(target=printer, args=(i,))
      t.start()
  ```
- With statement provides context manager to acquire and release the lock
  ```

ThreadPoolExecutor

- Can be difficult to keep track of all threads
- Want to reuse threads instead of creating a new one each time
- Wait until all threads are done executing before next tasks
- `ThreadPoolExecutor` simplifies this
- ```
  from concurrent.futures import ThreadPoolExecutor
  with ThreadPoolExecutor(max_workers=5) as executor:
      executor.map(printer, range(10))
  ```
- `max_workers` specifies the number of threads (can compute multiple times on one thread)
- `map` figures out how to assign the inputs to the threads
  ```

Python Threading Speed

- If I/O bound, threads work great because time spent waiting can now be used by other threads
- Threads **do not** run simultaneously in standard Python, i.e. they cannot take advantage of multiple cores
- Use threads when code is **I/O bound**, otherwise no real speed-up plus some overhead for using threads

Using multiple cores at once

- Python is linear/serial; only one thread executes at a time
- Python has **garbage collection**, releasing memory when not used
  - Requires keeping track of all objects by **reference counting**
  - ```
    a = {'IL','IN','OH'}
    b = {'states': a}
    ```
  - `{'IL','IN',OH'}` has a reference count of 2 (`a` and `b` both reference it)
- Problem: keeping track of references across different threads/processes
    ```

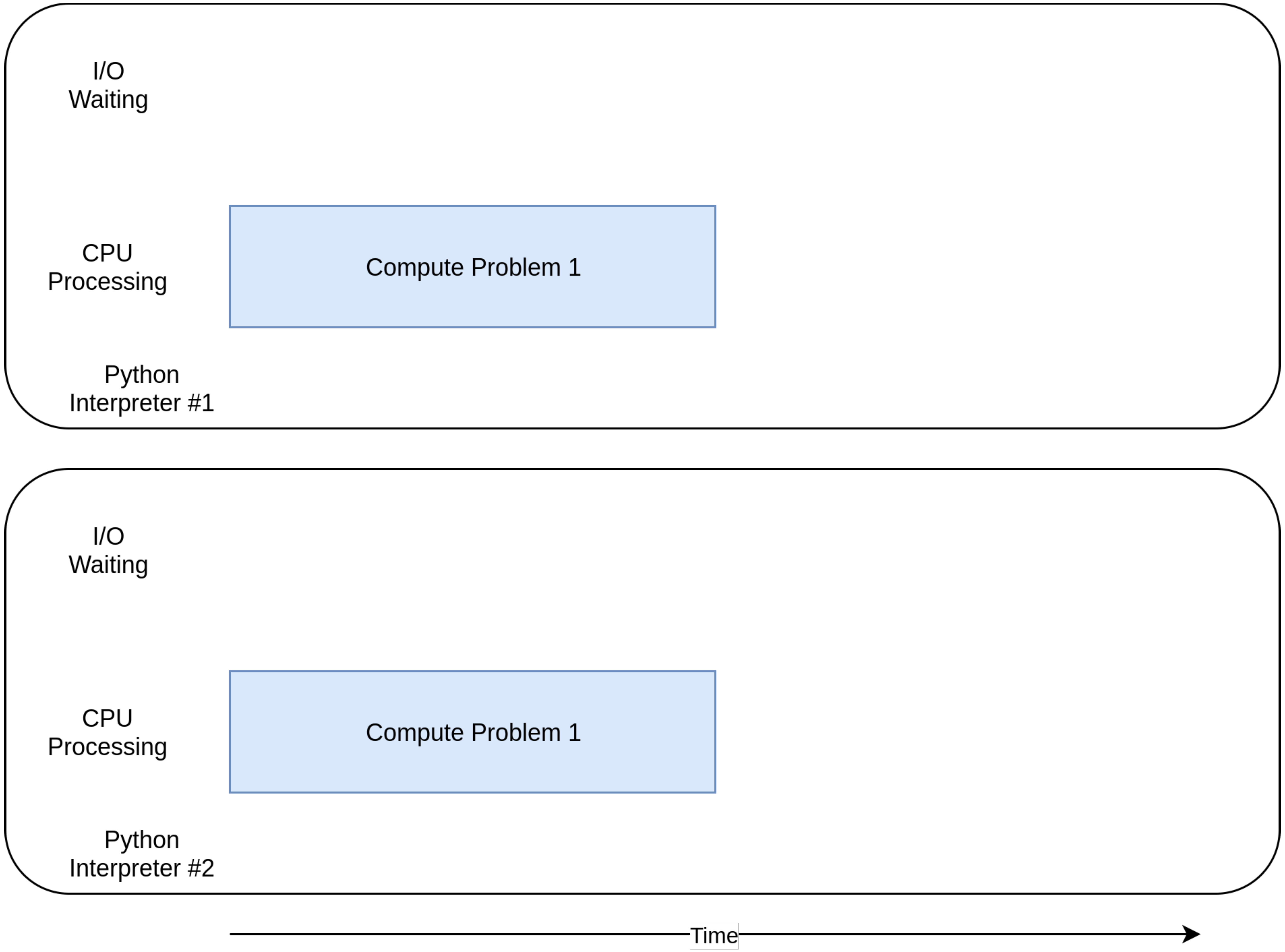
Python and the GIL

- Remember Python integrates other libraries, including those written in C
- Python was designed to have a thread-safe interface for C libraries (which were not necessarily themselves thread-safe)
- Could add locking to every value/data structure, but with multiple locks comes possible **deadlock**
- Python instead has a Global Interpreter Lock (GIL) that must be acquired to execute any Python code
- This effectively makes Python single-threaded (faster execution)
- Python requires threads to give up GIL after certain amount of time
- Python 3 improved allocation of GIL to threads by not allowing a single CPU-bound thread to hog it

Multiprocessing

- Multiple processes do not need to share the same memory, interact less
- Python makes the difference between processes and threads minimal in most cases
- Big win: can take advantage of multiple cores!
- ```
  import multiprocessing
  with multiprocessing.Pool() as pool:
          pool.map(printer, range(5))
  ```
- **Warning**: known issues with running this in the notebook, use in scripts or look for alternate possibilities/library
- Set `__spec__ = None` to use the `%run` command in the notebook with a multiprocessing script
  ```

Multiprocessing address CPU-bound processes



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Multiprocessing using concurrent.futures

- ```
  import concurrent.futures
  import multiprocessing as mp
  import time

  def dummy(num):
      time.sleep(5)
      return num ** 2

  with concurrent.futures.ProcessPoolExecutor(max_workers=5,
               mp_context=mp.get_context('fork')) as executor:
      results = executor.map(dummy, range(10))
  ```
- `mp.get_context('fork')` changes from `'spawn'` used by default in MacOS, works in notebook
  ```

When to use threading or multiprocessing?

- If your code has a lot of I/O or Network usage:
  - Multithreading is your best bet because of its low overhead
- If you have a GUI
  - Multithreading so your UI thread doesn't get locked up
- If your code is CPU bound:
  - You should use multiprocessing (if your machine has multiple cores)

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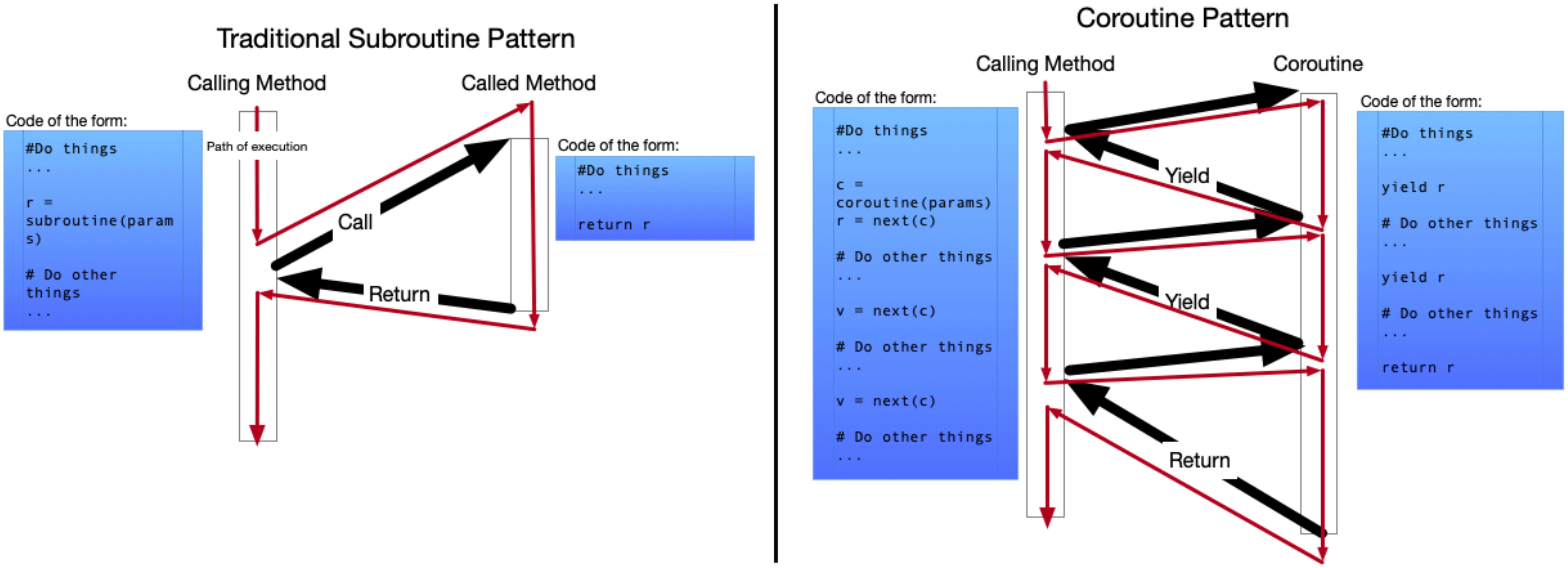
Subroutines vs. Coroutines



[J. Weaver]

Generators basically do this!

- ```
  def random_numbers(start=1, end=1000):
      while True:
          yield random.randint(start, end)
  for x in random_numbers():
      print(x)
  ```
- The `yield` statements pause execution of the function and go back to the main function
- They are almost coroutines except you can't pass anything in
- Hard to have multiple things going on
  ```

asyncio

- Single event loop that controls when each task is run
- Tasks can be ready or waiting
- Tasks are **not interrupted** like they are with threading
  - Task controls when control goes back to the main event loop
  - Either waiting or complete
- Event loop keeps track of whether tasks are ready or waiting
  - Re-checks to see if new tasks are now ready
  - Picks the task that has been waiting the longest

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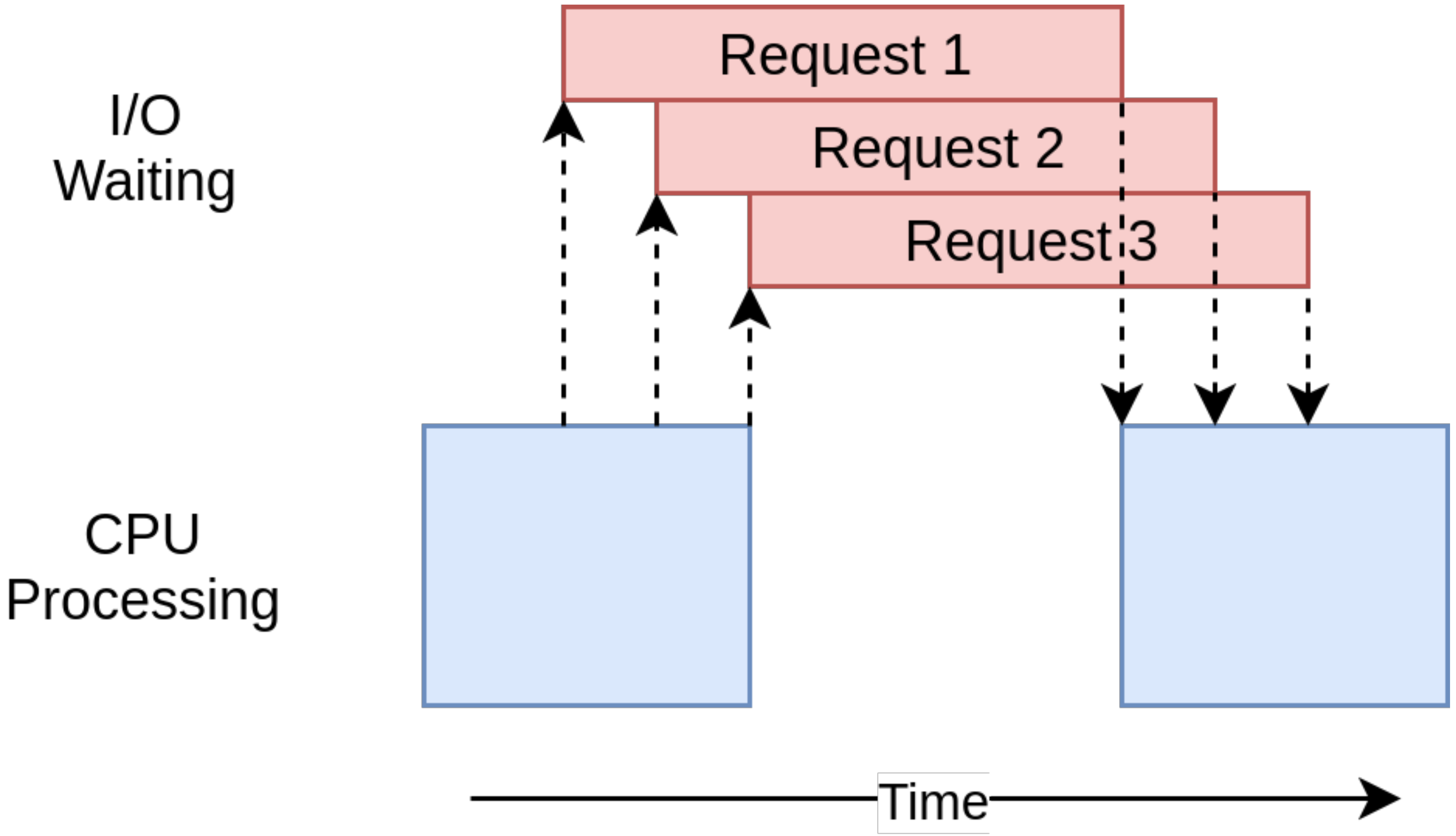
async

- `async` is a keyword that tells Python that the function uses await
- Also `async with` context manager
- ```
  async def download_site(session, url):
      async with session.get(url) as response:
          print("Read {0} from {1}".format(
                       response.content_length, url))
  ```
- `asyncio` uses a single thread
- Requires special libraries (`aiohttp`)
- Tends to have less overhead than multiprocessing
  ```

asyncio


I/O Waiting
CPU Processing
Request 1
Request 2
Request 3
Time