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]
  ```

Moving and Renaming Files/Directories

- Moving files or directories:
  - `shutil.move('dir_1/', 'backup/')`
- Renaming files or directories:
  - `os.rename`
  - `pathlib.Path.rename`
  - ```
    data_file = Path('data_01.txt')
    data_file.rename('data.txt')
    ```

[V. Ndlovu]
    ```

Archives

- `zipfile`: module to deal with zip files
- `tarfile`: module to deal with tar files, can compress (`tar.gz`)
- Easier: `shutil.make_archive`
  - Specify base name, format, and root directory to archive
  - `shutil.make_archive('data/backup', 'tar', 'data/')`
- To extract, use `shutil.unpack_archive`

[V. Ndlovu]

Assignment 6

- Object-Oriented Programming
- Due after the test, but very helpful for Test 2
- Build an online shopping store
- Design classes, use inheritance

Test 2

- Wednesday, April 3, in class from 12:30-1:45pm
- Similar Format to Test 1
- Emphasizes topics covered since Test 1, but still need to know core concepts from the first third of the course

Concurrency

What is concurrency?

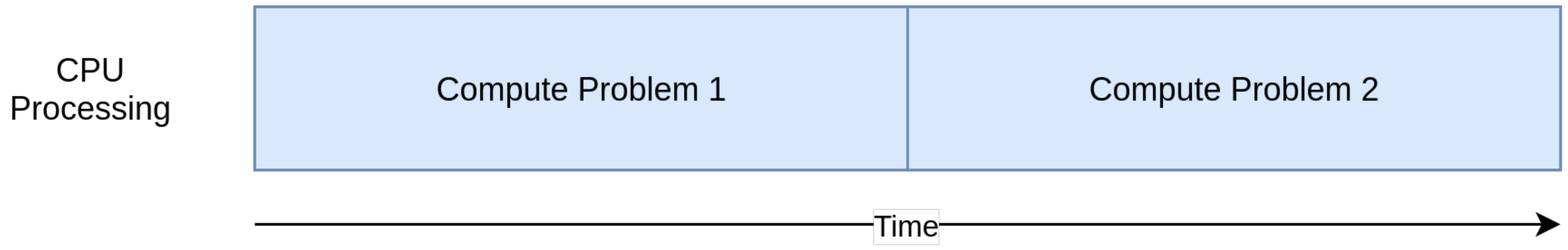
Why do we care about concurrency (multitasking and multiprocessing)?

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

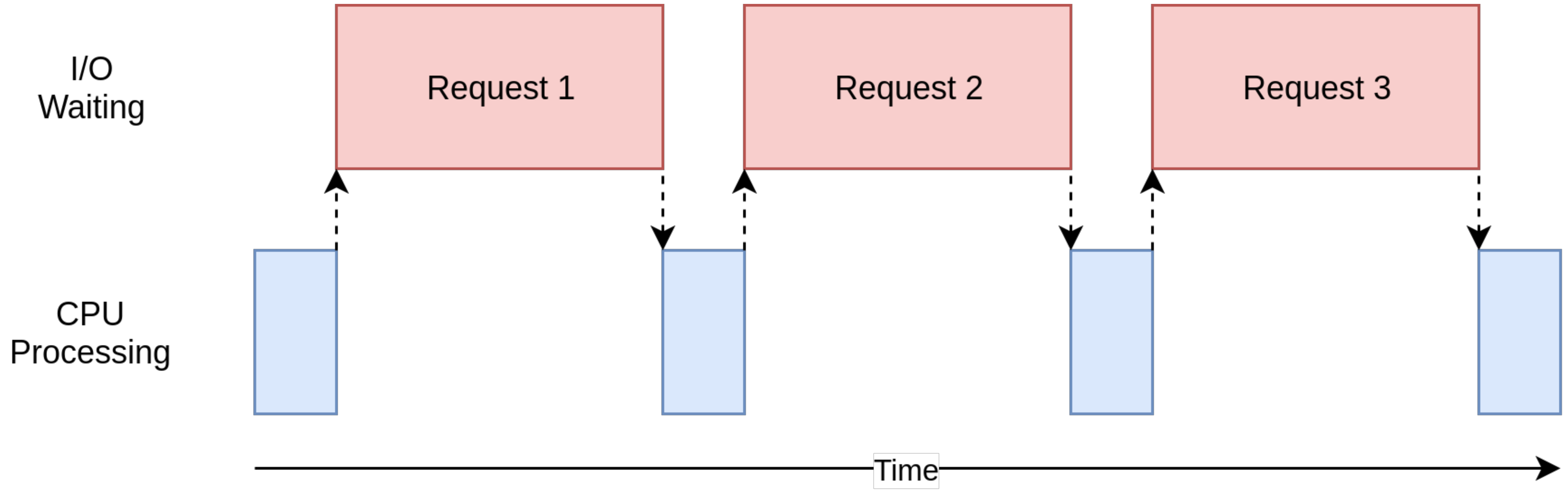
- Have to run each problem in sequence
- Wait for Problem 1 to finish before Problem 2 can start
- …even if they are totally separate problems!
- What if we could use another core for Problem 2?



[J. Anderson]

I/O-Bound

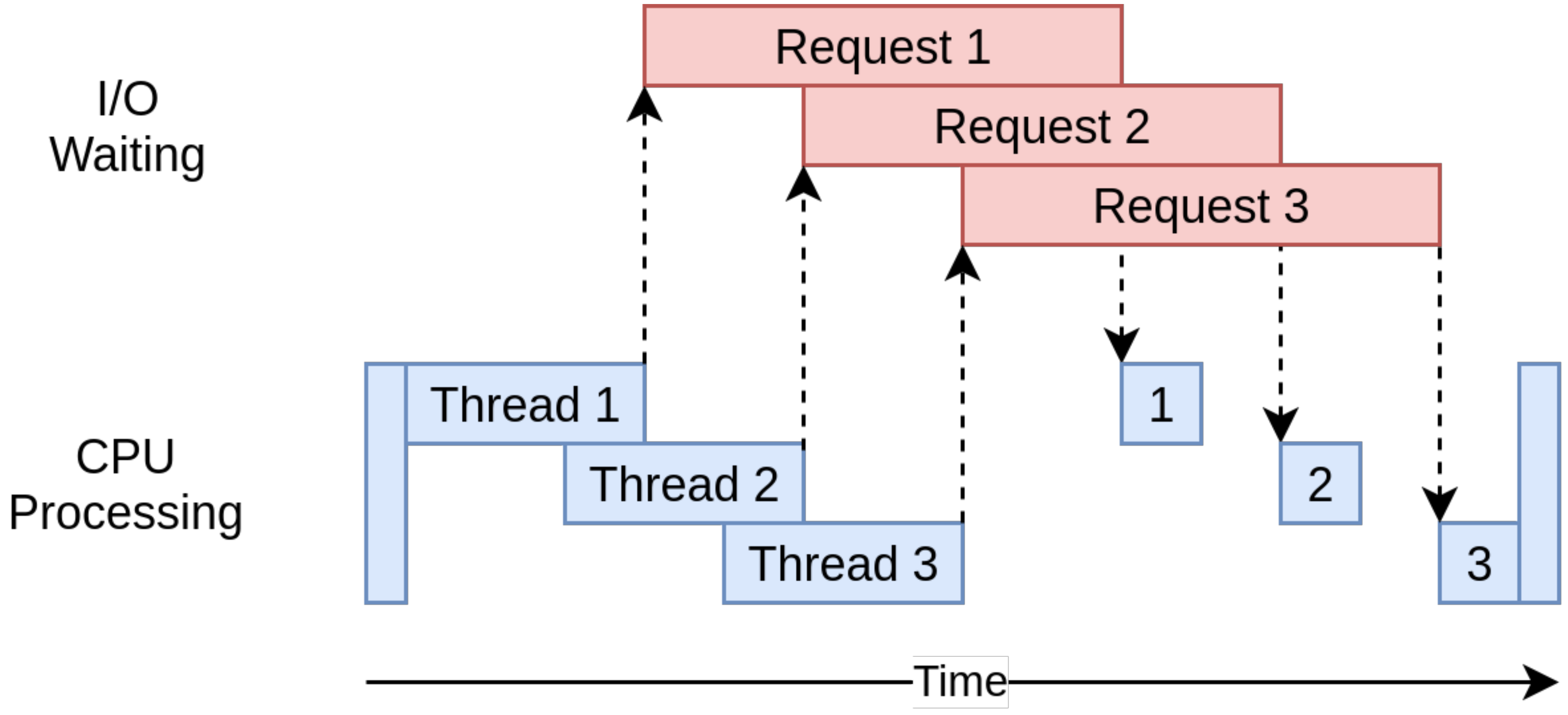
- Waiting for the file system or network to get data
- Nothing else happens while we wait for I/O to finish
- What if we could do something else while waiting for I/O?



[J. Anderson]

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



[J. Anderson]

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

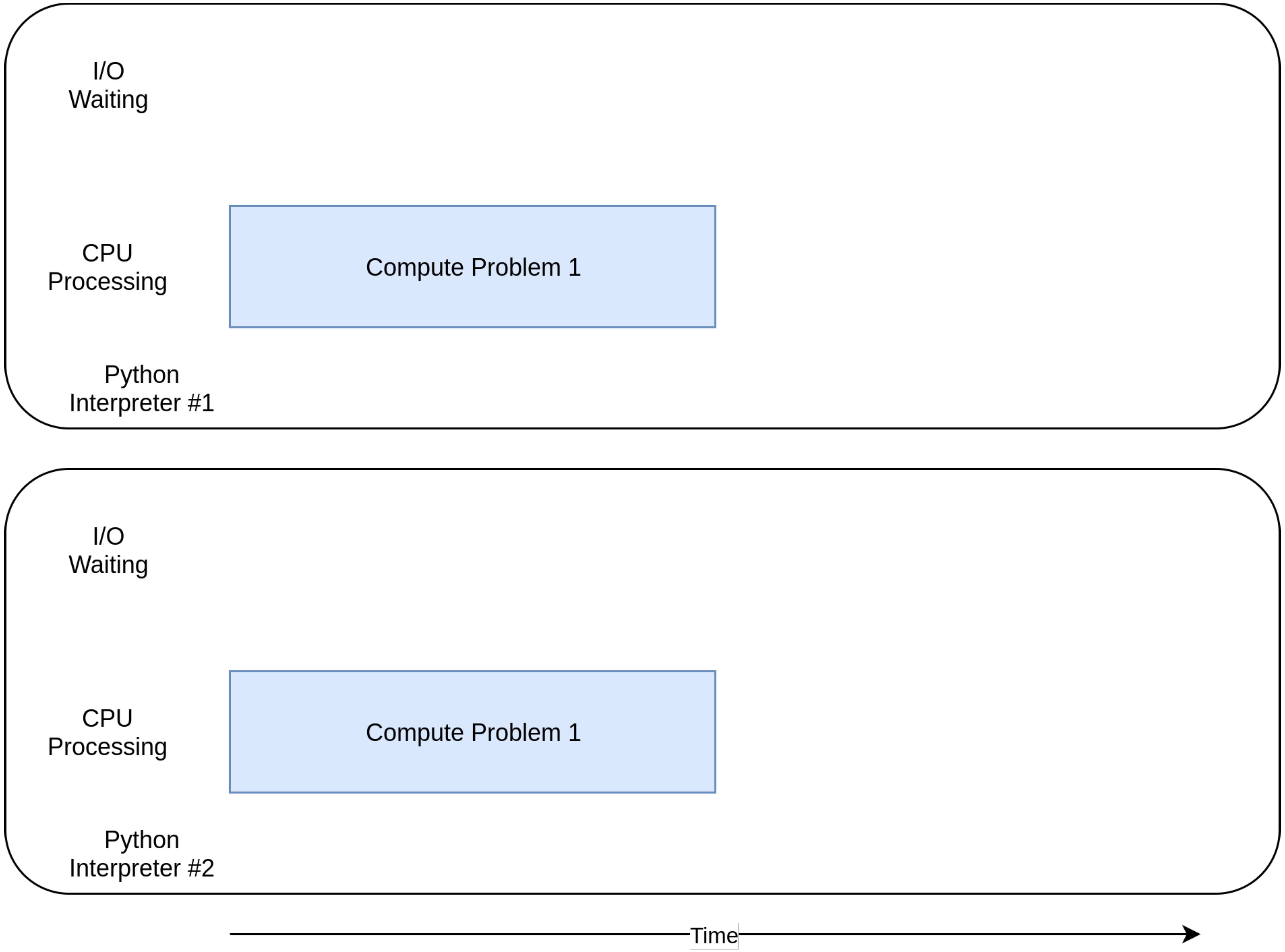
- Remember Python integrates other libraries, including those written in C
- Python was designed to have a thread-safe interface for C libraries (which were not necessarily themselves thread-safe)
- Could add locking to every value/data structure, but with multiple locks comes possible **deadlock**
- 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

--disable-gil (No GIL Python)

- GIL Problems:
  - Difficult to use multi-core CPUs effectively for scientific applications
  - GPU-Heavy workloads (AI) require effective multi-core CPU execution
  - Workarounds are complex, make libraries more difficult to use and maintain
- PEP 703: Making the Global Interpreter Lock Optional in Python
  - Use biased reference counting (most objects used by a single thread)
  - Change memory allocator to one that is thread-safe (pymalloc relies on GIL)
  - Use per-object locking for container thread safety
  - Updates to the garbage collector (non-generational) that also allow "stop-the-world" on threads

[PEP 703]

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



[J. Anderson]

Multiprocessing using concurrent.futures

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

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

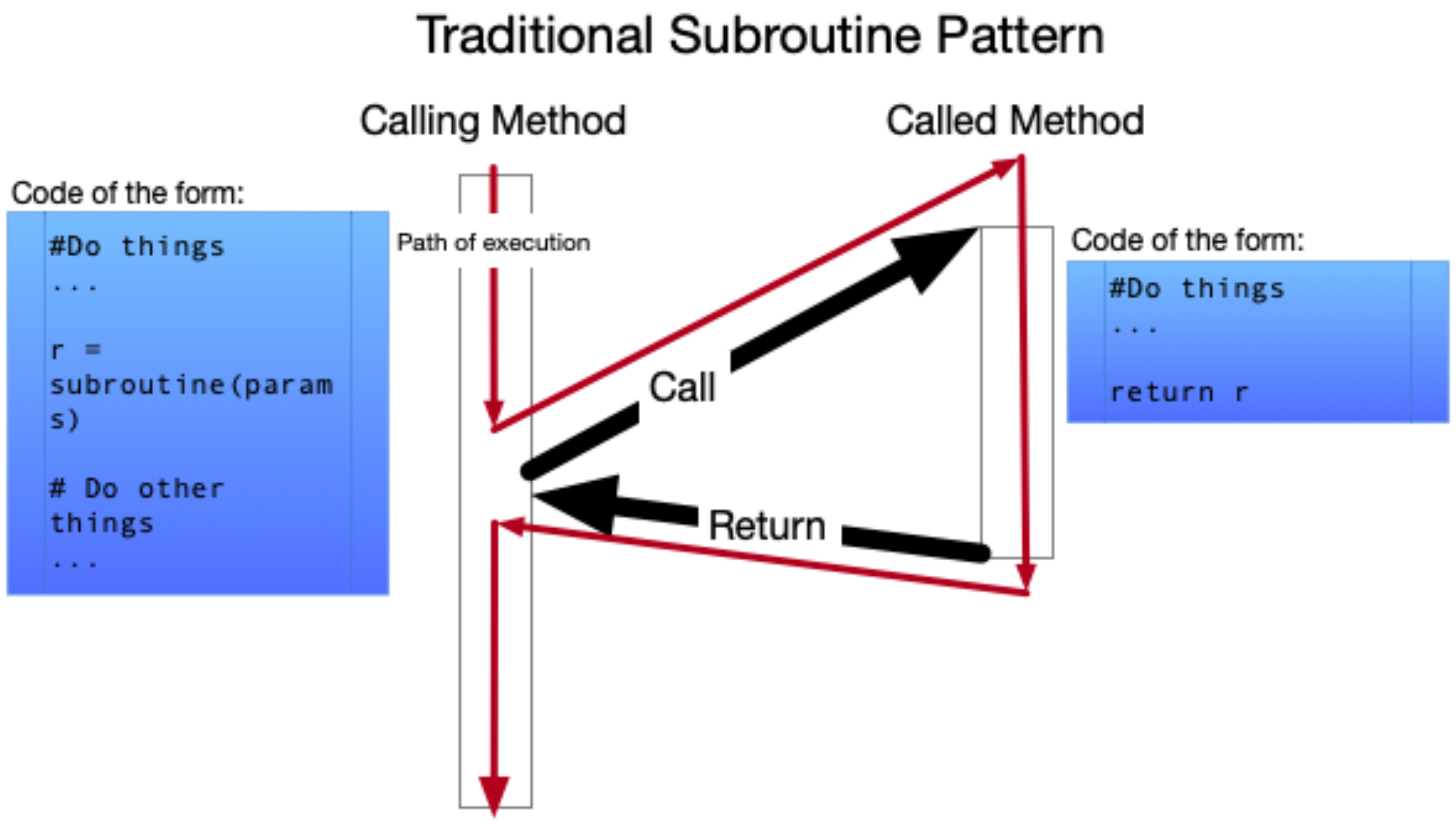
  with concurrent.futures.ProcessPoolExecutor(max_workers=5,
               mp_context=mp.get_context('fork')) as executor:
      results = executor.map(dummy, range(10))
  ```
- `mp.get_context('fork')` changes from `'spawn'` used by default in MacOS, works in notebook
  ```

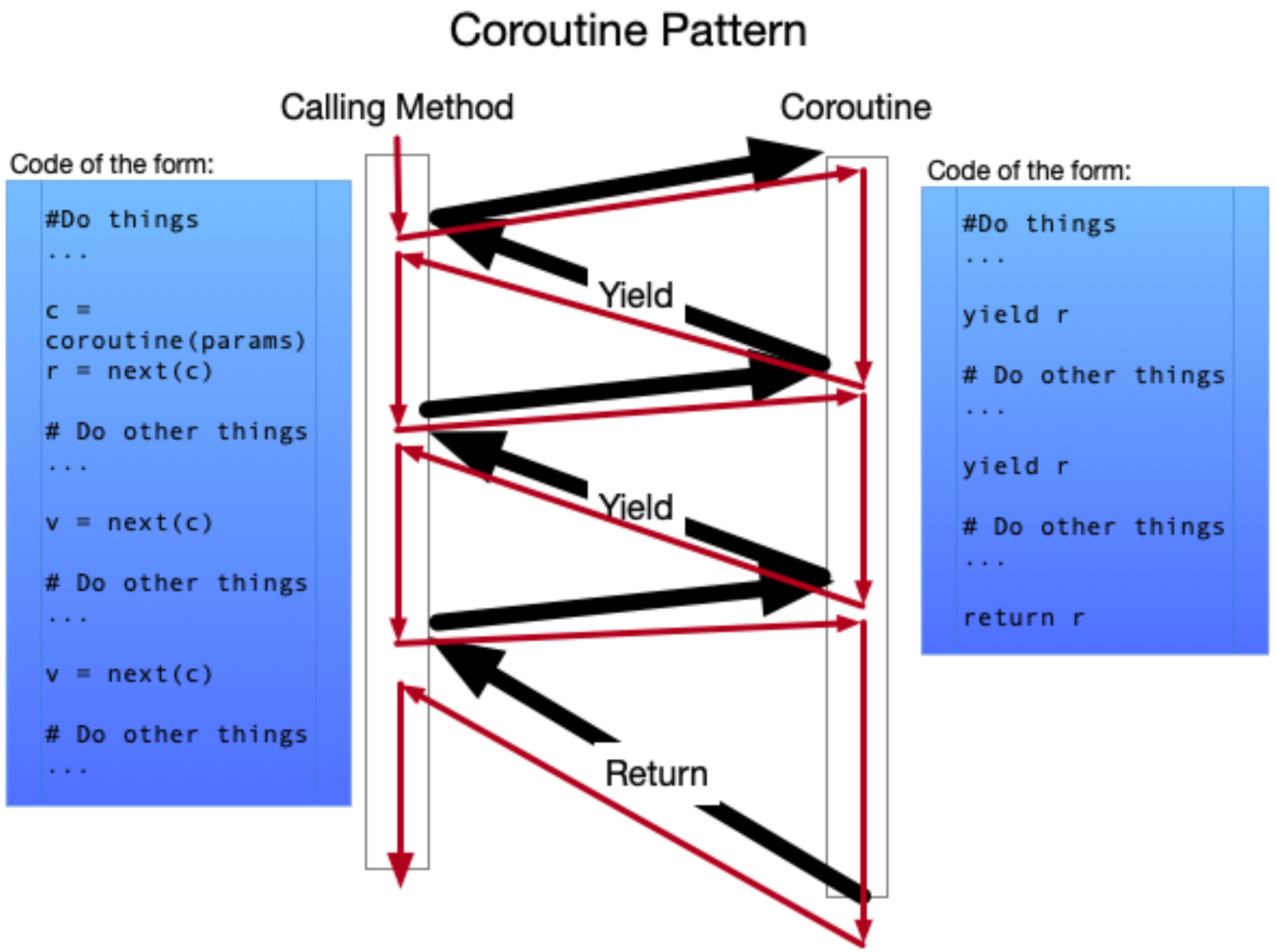
When to use threading or multiprocessing?

- 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)

[J. Anderson]

Subroutines vs. Coroutines



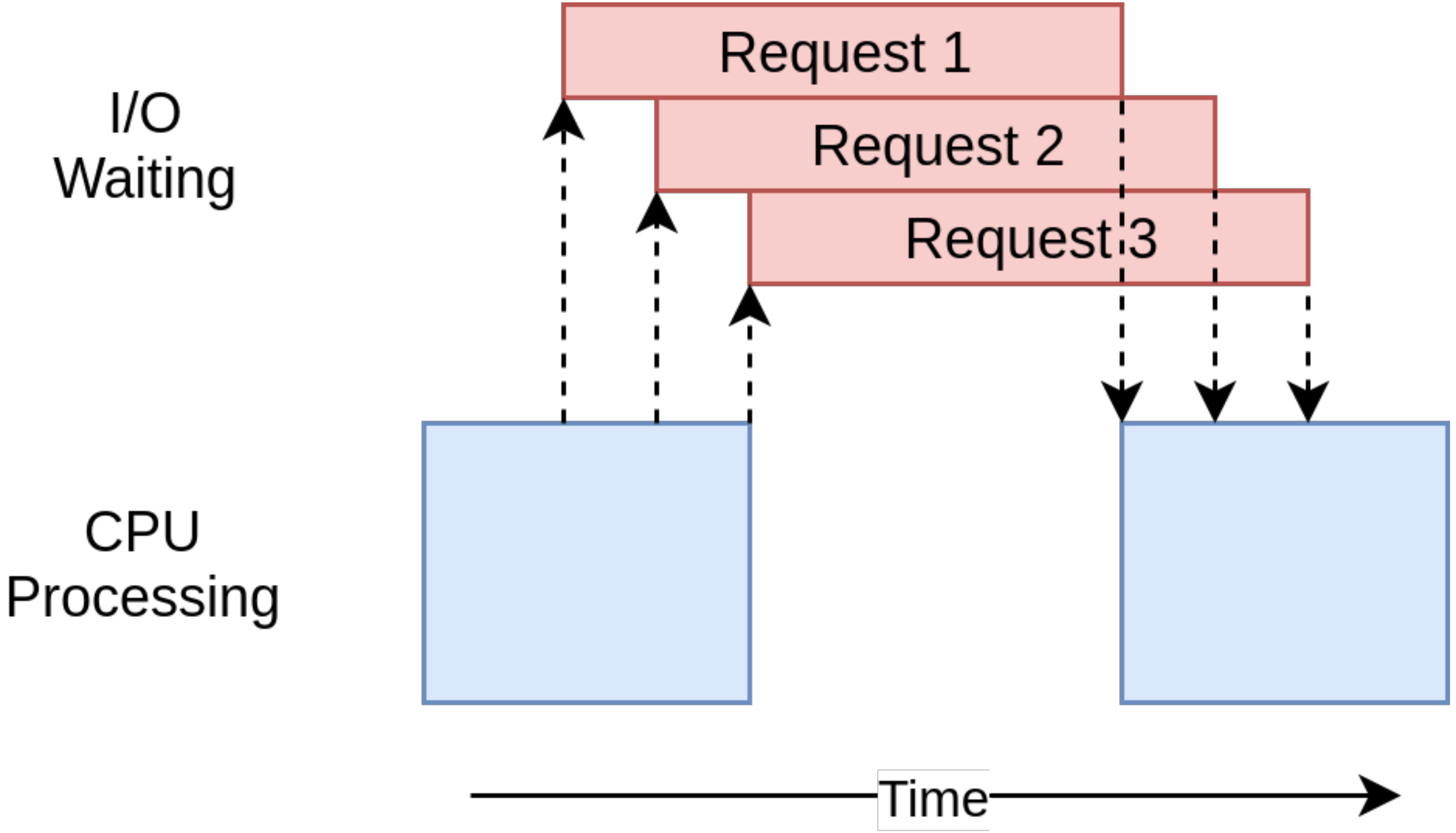


[J. Weaver]

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

[J. Anderson]

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

When to use threading, asyncio, or multiprocessing?

- If your code has a lot of I/O or Network usage:
  - If there is library support, use asyncio
  - Otherwise, multithreading is your best bet (lower 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)

[J. Anderson]

Concurrency Comparison

Concurrency Type	Switching Decision	Number of Processors
Pre-emptive multitasking (`threading`)	The operating system decides when to switch tasks external to Python.	1
Cooperative multitasking (`asyncio`)	The tasks decide when to give up control.	1
Multiprocessing (`multiprocessing`)	The processes all run at the same time on different processors.	Many

[J. Anderson]