# Programming Principles in Python (CSCI 503/490)

## Structural Pattern Matching

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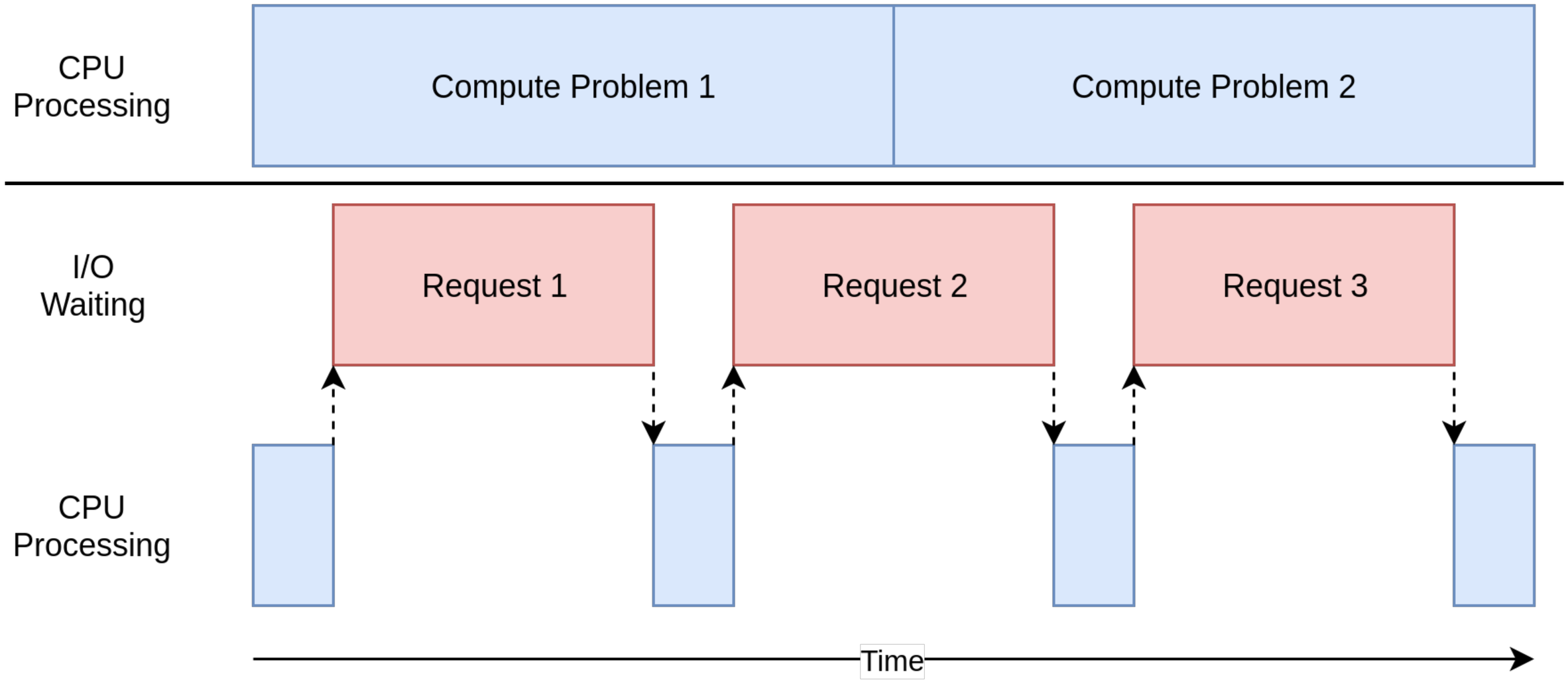
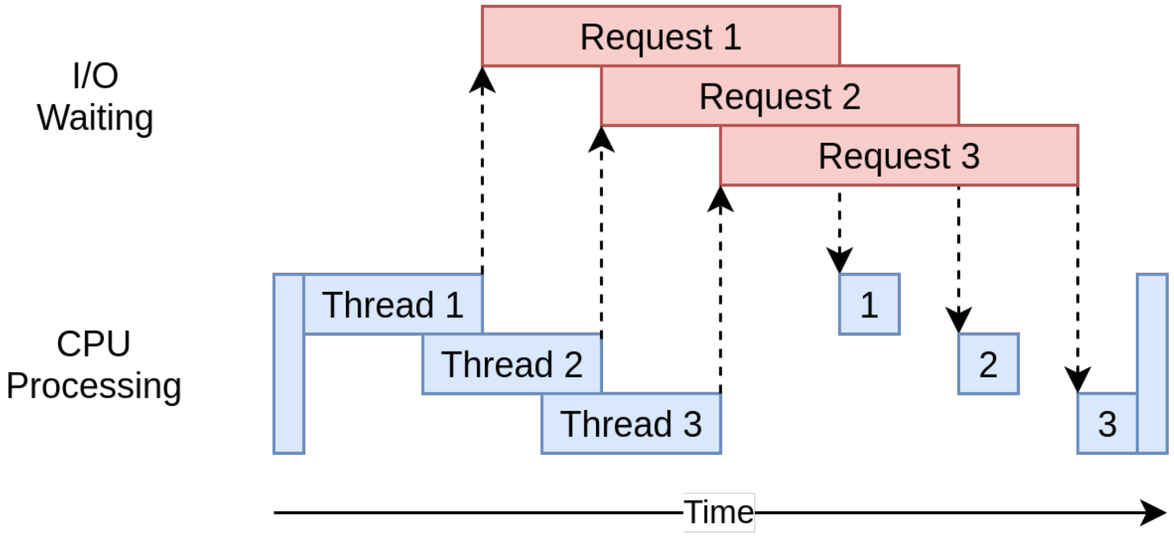
# CPU-Bound vs. I/O-Bound




[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]

# 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

# Python and the GIL

- Solution for reference counting (used for garbage collection)
- 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

# Assignment 6

- Object-Oriented Programming
- Build an online course registration system
- Design classes, use inheritance

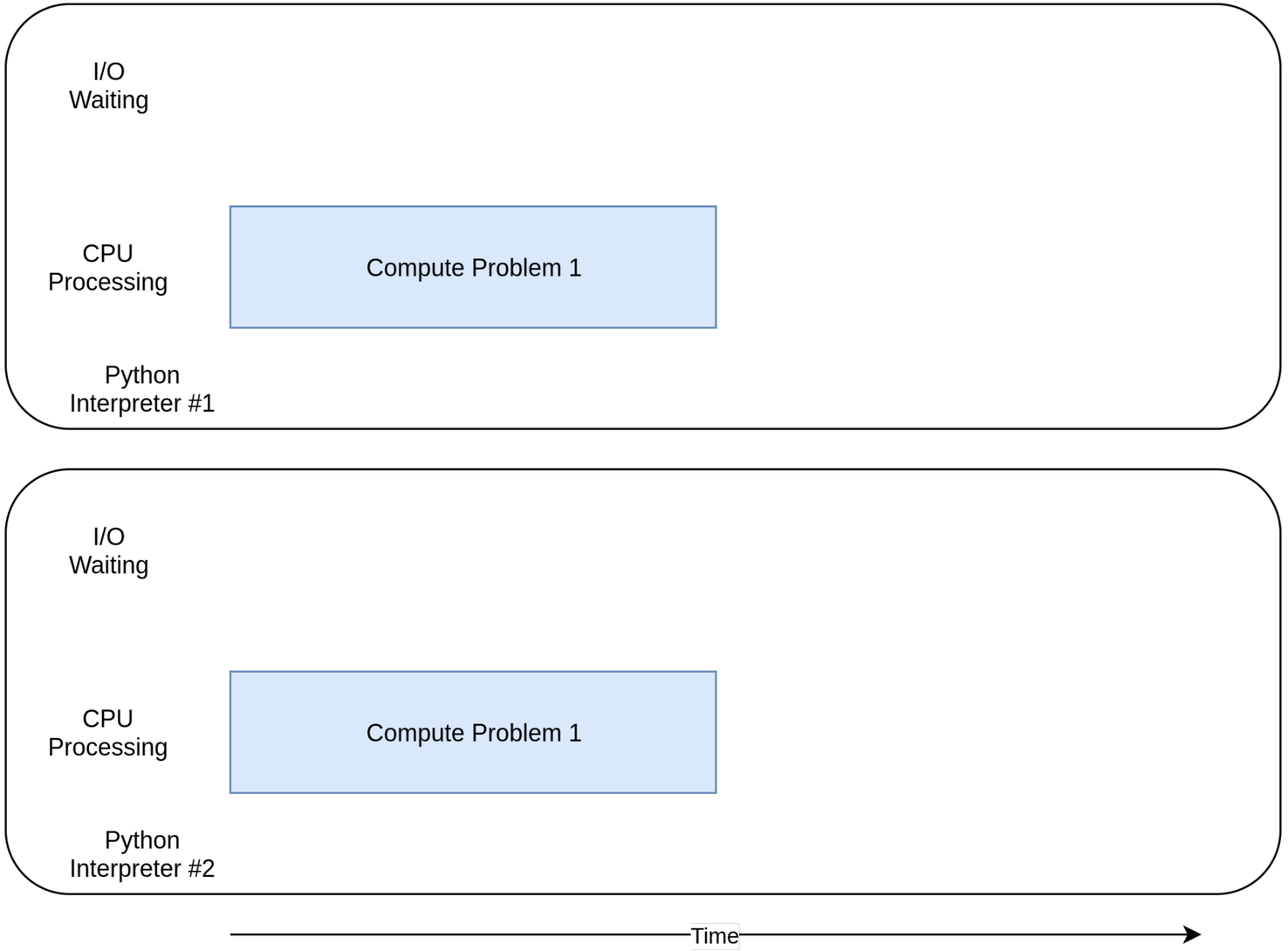
# Test 2

- Monday, November 11, in class from 9:30-10:45am
- 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

# 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

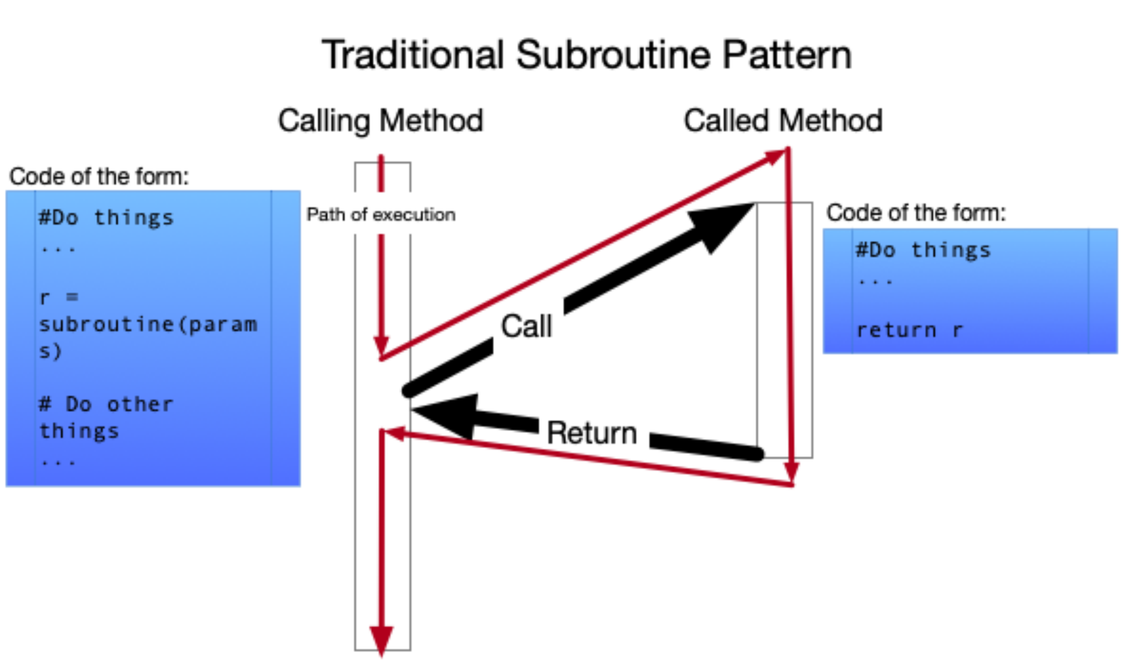
  with concurrent.futures.ProcessPoolExecutor(max_workers=5,
                  mp_context=mp.get_context('fork')) as executor:
      results = executor.map(dummy, range(10))
  ```
- `mp.get_context('fork')` changes from `'spawn'` used by default in MacOS, works in notebook
  ```

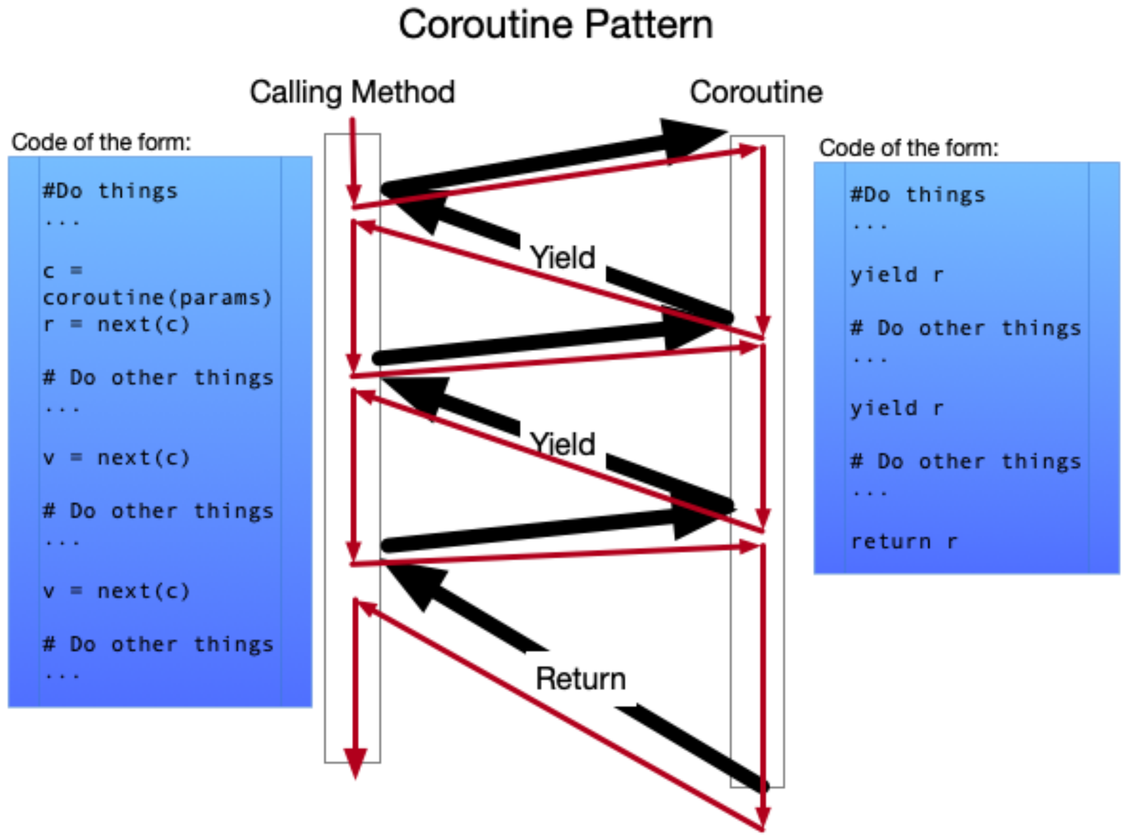
# When to use threading or multiprocessing?

- 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

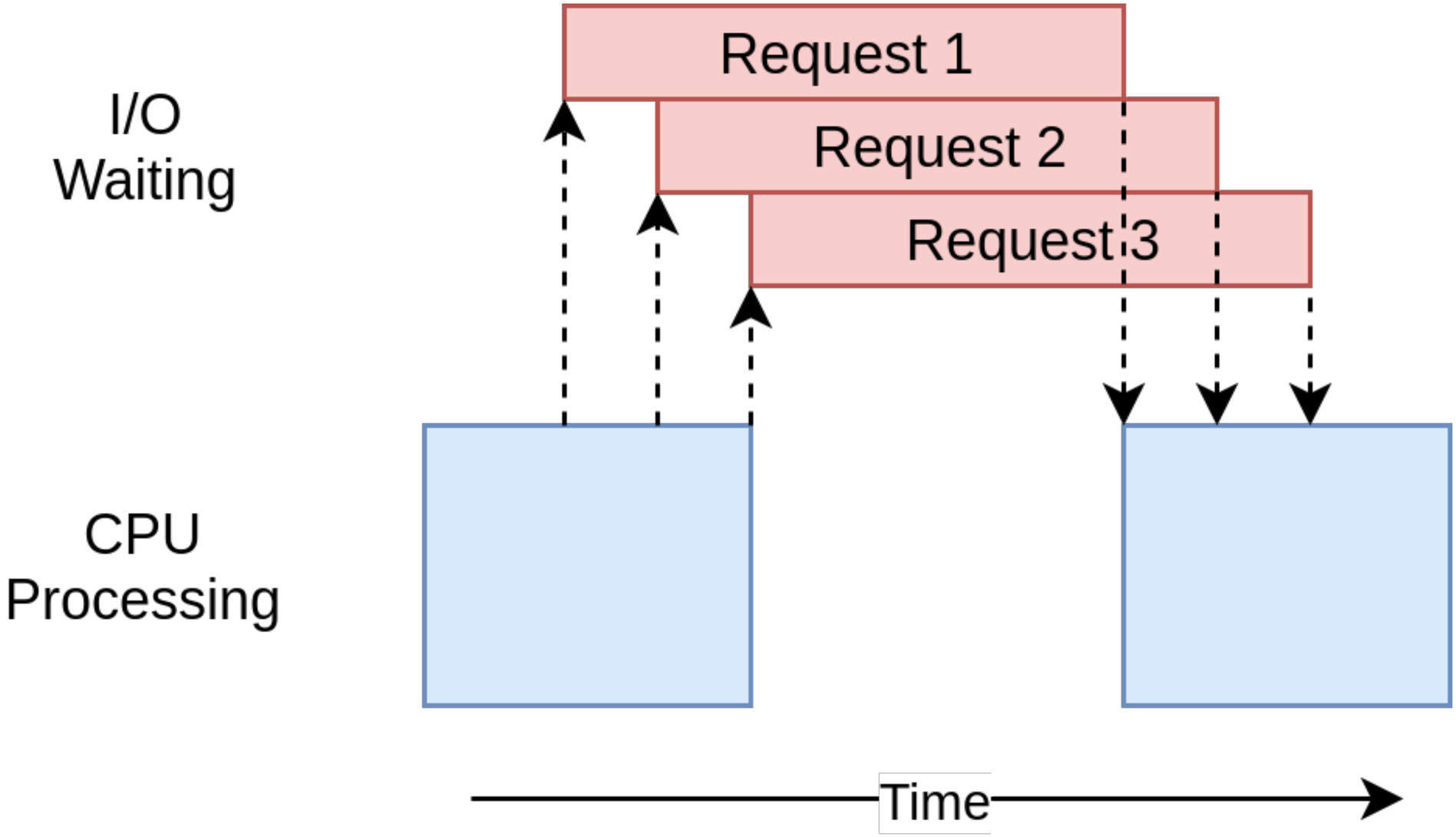
- Single event loop that controls when each task is run
- Tasks can be ready or waiting
- Tasks are **not interrupted** like they are with threading
  - Task controls when control goes back to the main event loop
  - Either waiting or complete
- Event loop keeps track of whether tasks are ready or waiting
  - 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]

# Match Statement

# Conditional Logic

- if/elif/else
- What about a switch statement?
- Exists in C++
- What are the advantages of a switch?

- C++ Example:
  - 
```
switch (val) {
   case 1:
     cout << "1st" << endl;
     break;
   case 2:
     cout << "2nd" << endl;
     break;
   default:
     cout << "???" << endl;
}
```

# Conditional Logic

- if/elif/else
- What about a switch statement?
- Exists in C++
- What are the advantages of a switch?
  - Cleaner and less redundant
  - More efficient than if/elif…

- C++ Example:

```
- switch (val) {
    case 1:
      cout << "1st" << endl;
      break;
    case 2:
      cout << "2nd" << endl;
      break;
    default:
      cout << "???" << endl;
  }
```

# Python

- Python's if/elif structure is pretty similar structure-wise to a switch statement
- If you want the "jump" functionality, remember that dictionaries offer efficient lookup and can store functions!
- Example:

```
- ops = {
        1: lambda: print('1st'),
        2: lambda: print('2nd')
  }
  ops.get(val, lambda: print('???'))()
```

- … so no great need for a standard switch statement

# Match Statement

- But… Python 3.10 added a match statement that can be used like a switch statement
- ```
  match val:
      case 1:
          print('1st')
      case 2:
          print('2nd')
      case _:
          print('???')
  ```
- Why?
  - It can do **more** than a switch statement
  ```

# Structural Pattern Matching

- Besides literal cases, match statements can be used to
  - differentiate structure
  - assign values
  - differentiate class instances
- Example:
- ```
  match sys.argv:
      case [_, "commit"]:
          print("Committing")
      case [_, 'add', fname]:
          print("Adding file", fname)
  ```
  ```

# Evaluation

- Works similar to if/elif/else logic
- Cases are processed **in order**
- Once the first case is matched, it's body is executed and **no** other cases will be matched
- Name bindings (assignments) **can** be used **after** the match statement
  - Like standard conditional logic in Python
  - Differs from some other languages where if/then blocks are scoped…

# Simple Patterns

- Literal patterns:
  - e.g. `2`, `"commit"`, but also `True`, `False`, `None`
- Simple capture pattern:
  - an identifier: `fname`
- Wildcard: matches anything: `_`

[PEP 636]

# Sequence Pattern

- A sequence composed of other patterns: `["add", fname]`
- Any identifiers are assigned when the structure is matched
- Can allow a match of multiple values using * syntax

```
- match sys.argv:
      case [_, "commit"]:
          print("Committing")
      case [_, 'add', *fnames]:
          print("Adding files", fnames)
```

[PEP 636]

# Or Pattern

- May allow multiple patterns to be processed by a single block
- Uses the bar symbol | (**not** the word "or") to connect the patterns
- Example:

```
match command.split():
    ... # Other cases
    case ["north"] | ["go", "north"]:
        current_room = current_room.neighbor("north")
    case ["pick", "up", obj] | ["pick", obj, "up"]:
        ... # Code for picking up the given object
```

[PEP 636]

# Or Pattern

- Problem: Suppose we want to restrict the set of values but don't know which pattern was selected…

- ```
  match command.split():
      case ["go", ("north" | "south" | "east" | "west")]:
          current_room = current_room.neighbor(...)
          # how do I know which direction to go?
  ```

[PEP 636]
  ```

# As Pattern

- Similar to exceptions where we can assign the matched value to an identifier when the patterns are literals
- Can even do this in a more complex pattern:
- ```
  match command.split():
      case ["go", ("north" | "south" | "east" | "west") as d]:
          current_room = current_room.neighbor(d)
  ```

[PEP 636]
  ```

# Guards

- In some cases, we want to add additional logic to check the pattern before allowing the block to be executed
- If the guard is not True, **other cases continue to be checked**
- Example: Suppose certain directions are not allowed in a given room:
- ```
  match command.split():
      case ["go", dir] if dir in current_room.exits:
          current_room = current_room.neighbor(dir)
      case ["go", _]:
          print("Sorry, you can't go that way")
  ```

[PEP 636]
  ```

# Matching Types

- You can match a type in a similar manner, but must put parentheses after it
  - `case str():`
- We can combine this with the as pattern to capture the value
  - `case str() as s:`
- There is also shorthand to do this (useful in more complex expressions)
  - `case str(s):`

# Class Pattern

- We can also match objects…
- ```
  match event:
      case Click() as c:
          print("Click happened", c.x, c.y)
  ```
- but the type shortcut **does not work**
- ```
  match event:
      case Click(c):
          print("Click happened", c)
      …
  ```
- ```
  TypeError: Click() accepts 0 positional sub-patterns (1 given)
  ```
  ```

# Class Pattern

- This hints at something different being allowed for classes
- We can match **instance attributes**!
- ```
  match event:
      case Click(x=x,y=y) if x < y:
          print("Lower-right click happened", x, y)
  ```
  ```

# Class Pattern

- This syntax is a bit clunky and requires keyword-style attributes
- We can use `__match_args__` to specify the order of attributes instead:
- ```
  class Click:
      __match_args__ = ('x','y')
      …

  match event:
      case Click(x,y) if x < y:
          print("Lower-right click happened", x, y)
  ```
- Dataclasses automatically order attributes based on their position
  ```

# Matching Enumerated Values or Constants

- Can use dotted notation to reference the value of an enumerated value or constant (`Button.LEFT`)
- Cannot use bare identifiers (e.g. referencing constants) because they are interpreted as part of the pattern…

# Mapping Pattern

- Just like matching sequences, we can also match mappings (i.e. dictionaries)
- Any unmatched key-value pairs are ignored
  - You don't need to use the multiple match as with sequences
  - But you can use `**rest` if you want to use them

# Mapping Pattern

```
for action in actions:
    match action:
        case {"text": message, "color": c}:
            ui.set_text_color(c)
            ui.display(message)
        case {"sleep": duration}:
            ui.wait(duration)
        case {"sound": url, "format": "mp3"}:
            ui.play(url)
        case {"sound": _, "format": _}:
            warning("Unsupported audio format")
```

[PEP 636]

# Match Statement Guidance

- Zen of Python: "There should be one-- and preferable only one --obvious way to do it."
  - Can use if/elif/else logic
  - Can use checks of sequence length, dictionary structure
- If you're emulating a switch statement, don't use a match statement
- If you're matching structure (sequence, mapping, object), a match statement may be a good idea

# Example

```
def eval_expr(expr):
    """Evaluate an expression and return the result."""
    match expr:
        case BinaryOp('+', left, right):
            return eval_expr(left) + eval_expr(right)
        case BinaryOp('-', left, right):
            return eval_expr(left) - eval_expr(right)
        case BinaryOp('*', left, right):
            return eval_expr(left) * eval_expr(right)
        case BinaryOp('/', left, right):
            return eval_expr(left) / eval_expr(right)
        case UnaryOp('+', arg):
            return eval_expr(arg)
        case UnaryOp('-', arg):
            return -eval_expr(arg)
        case VarExpr(name):
            raise ValueError(f"Unknown value of: {name}")
        case float() | int():
            return expr
        case _:
            raise ValueError(f"Invalid expression value: {repr(expr)}")
```

[G. van Rossum]