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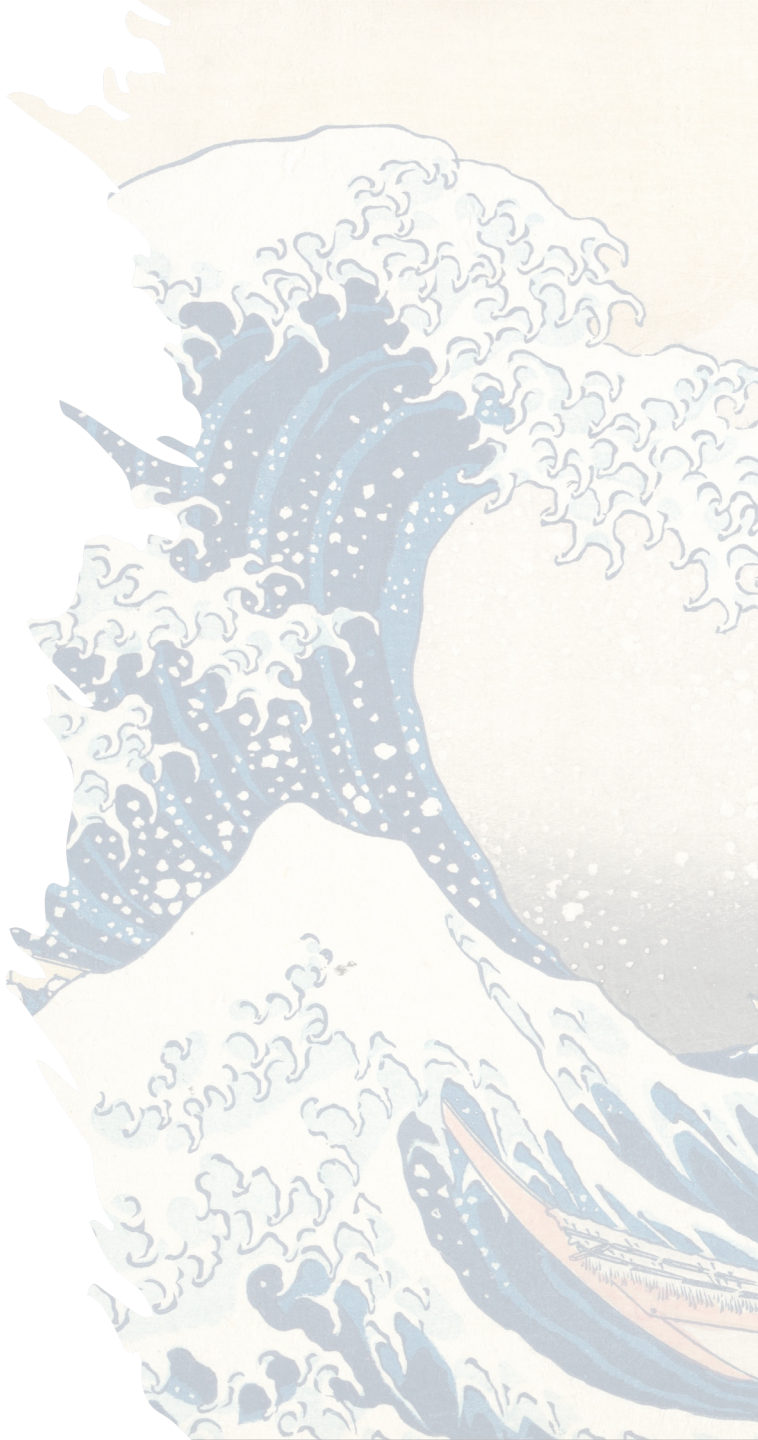
3. Multiprocessing with Python

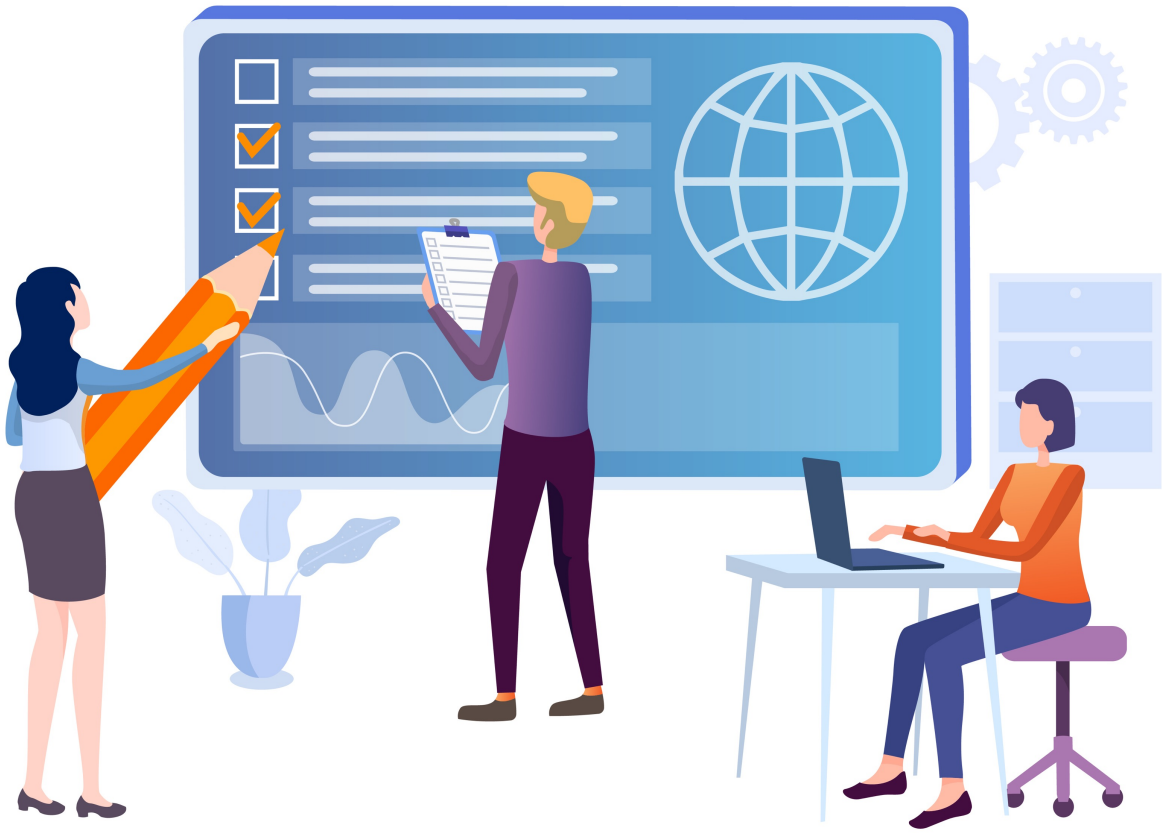
Agenda

- Finalise complexity: Dynamic programming
- Introduction to multiprocessing with Python
  - Serial vs Parallel processing
  - When to use?
  - Processes and Threads
  - Tutorial
- Lab 3 – using the `multiprocessing` library



Quiz of the day

Get ready!



Complexity!

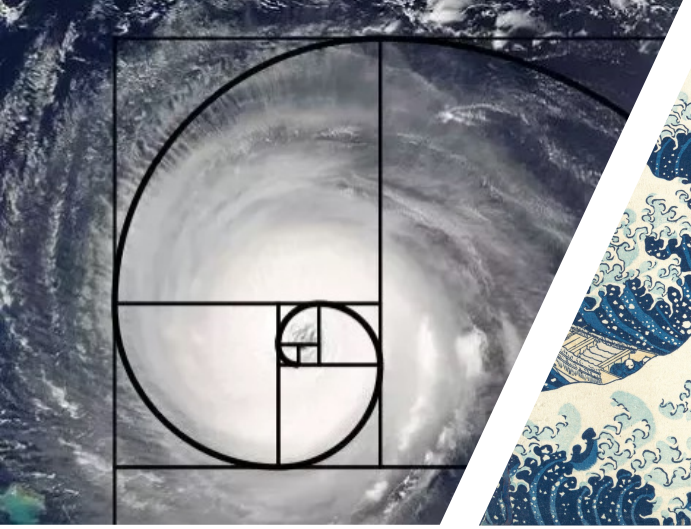
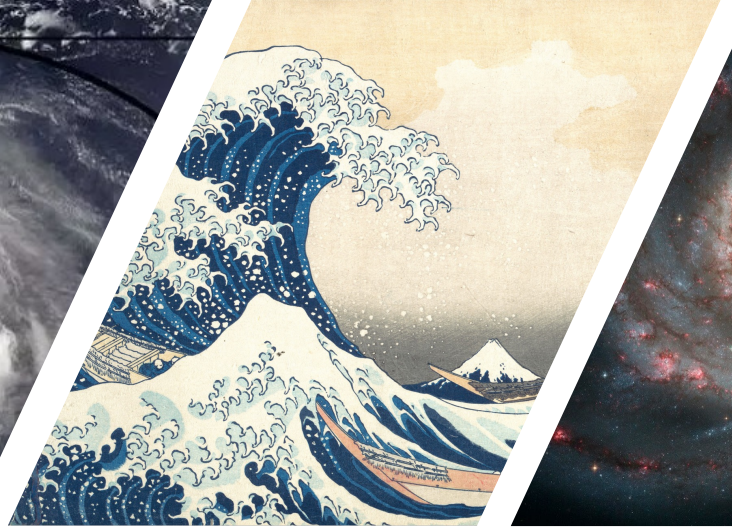
Algorithm	Time	Space
Linear search	O(n)	O(1)
Binary search	O(logn)	O(1)
Bubble sort	O(n^2)	O(1)
Insertion sort	O(n^2)	O(1)
Merge sort	O(nlogn)	O(n)
Tim sort	O(nlogn)	O(n)
Knapsack fractional	O(nlogn)	O(n)

We can still do better!

Dynamic programming

The Romanesco flower!

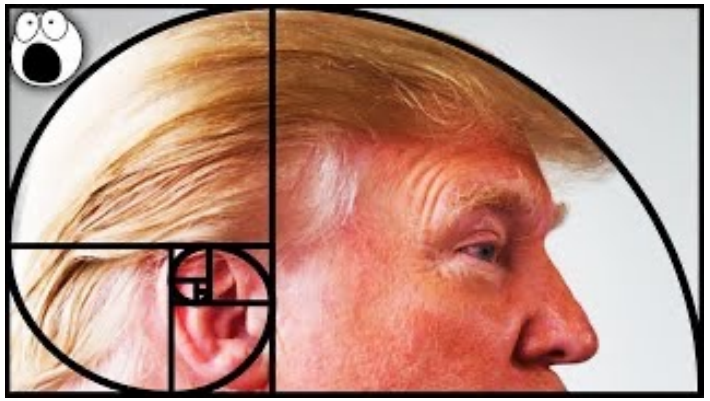
- Romanesco has flowers that form perfect geometric spiral patterns that repeat.
- Each spiral bud is composed of a series of smaller buds
  - All buds are arranged in yet another spiral that continues at smaller levels
- The number of spirals on Romanesco's head follows the **Fibonacci sequence**!

Other examples

Fibonacci symmetry algorithm underlies our perception of attractiveness


Reflects the growth processes in nature



What is the Fibonacci sequence?

- The Fibonacci Sequence is a series of numbers:

  `0, 1, 1, 2, 3, 5, 8, 13, 21, ?, ...`

  34

- The sequence starts with **zero** and **one** and is a steadily increasing series where each number equals the sum of the preceding two numbers.

- Example: Fibonacci F_3 is found by adding $F_2 + F_1$

$$F_3 = F_2 + F_1 = 1+1 = 2$$

$$F_2 = F_1 + F_0 = 1+0 = 1$$

$$F_1 = 1 \quad F_0 = 0$$

Quiz!

- What is the Fibonacci of 7?
  - Can you do it without pen and paper? ☺

$$F_3 = F_2 + F_1 = 1+1 = 2$$

$$F_2 = F_1 + F_0 = 1+0 = 1$$

$$F_1 = 1 \quad F_0 = 0$$

$$F_0 = 0$$

$$F_1 = 1$$

$$F_2 = 1$$

$$F_3 = 2$$

$$F_4 = 3$$

$$F_5 = 5$$

$$F_6 = 8$$

$$\mathbf{F_7 = 13}$$

How to calculate the Fibonacci sequence?

script

```
function fibo(n)
    if n <= 1:
     return n
    else:
     return fibo(n-1) + fibo(n-2)
```

How to calculate the Fibonacci sequence?

```
function fibo(n)
    if n <= 1:
        return n
    else:
        return fibo(n-1) + fibo(n-2)
```

- If `n = 0`, then what is the `fibo(0)`?
  - Answer: `0`
- If `n = 1`, then what is the `fibo(1)`?
  - Answer: `1`

How to calculate the Fibonacci sequence?

script

```
function fibo(n)
    if n <= 1:
        return n
    else:
        return fibo(n-1) + fibo(n-2)
```

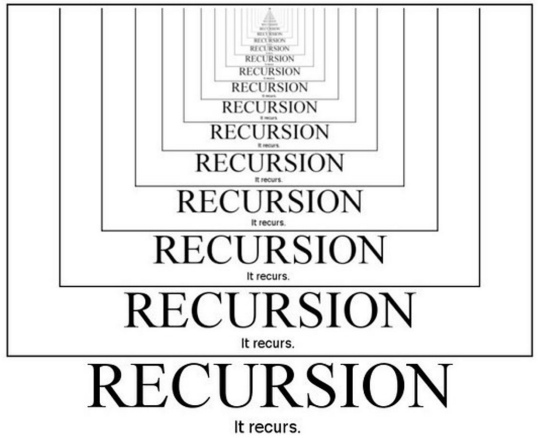
- If `n = 2`, then what is the `fibo(2)`?
  - Answer: `fibo(1) + fibo(0)`

    `= 1 + 0 = 1`
- If `n = 3`, then what is the `fibo(3)`?
  - Answer: `fibo(2) + fibo(1)`

    `= 1 + 1 = 2`

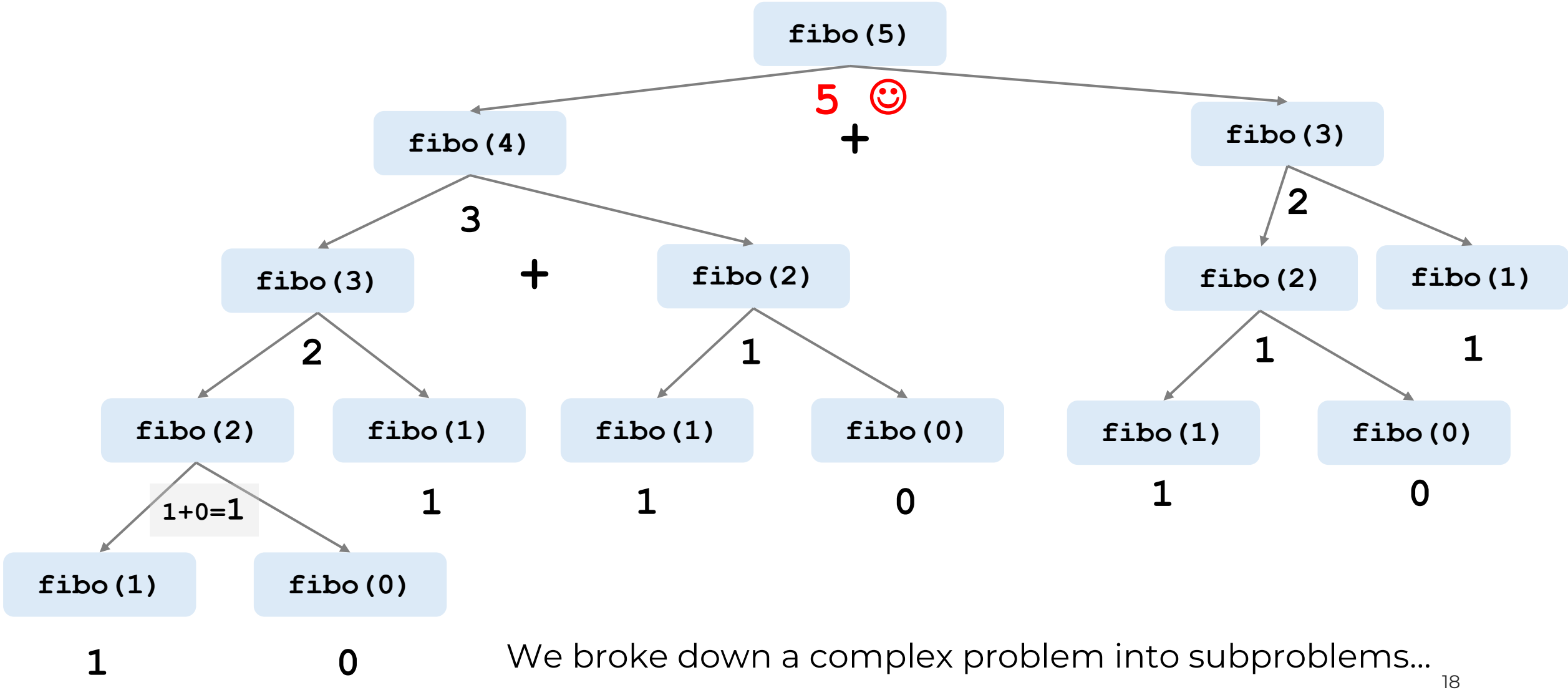
What is recursion in programming?

- Recursion is the technique of making a function call itself.
- This technique provides a way to break complicated problems down into simple problems which are easier to solve.



Let's see in practice!

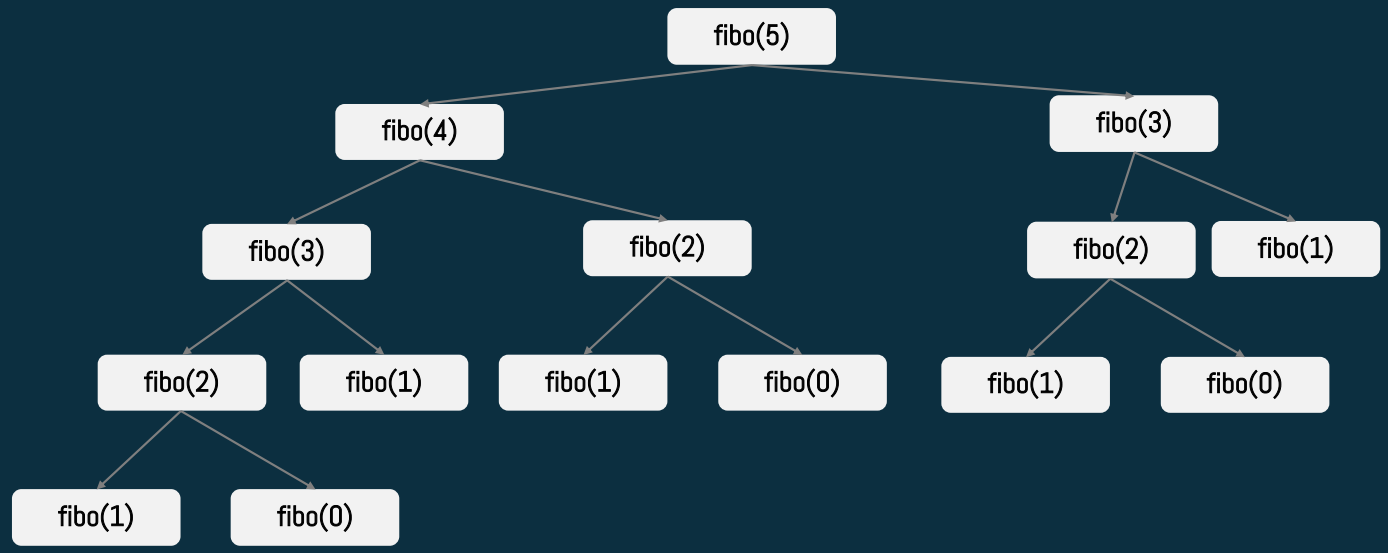
We solve it recursively!



We broke down a complex problem into subproblems...

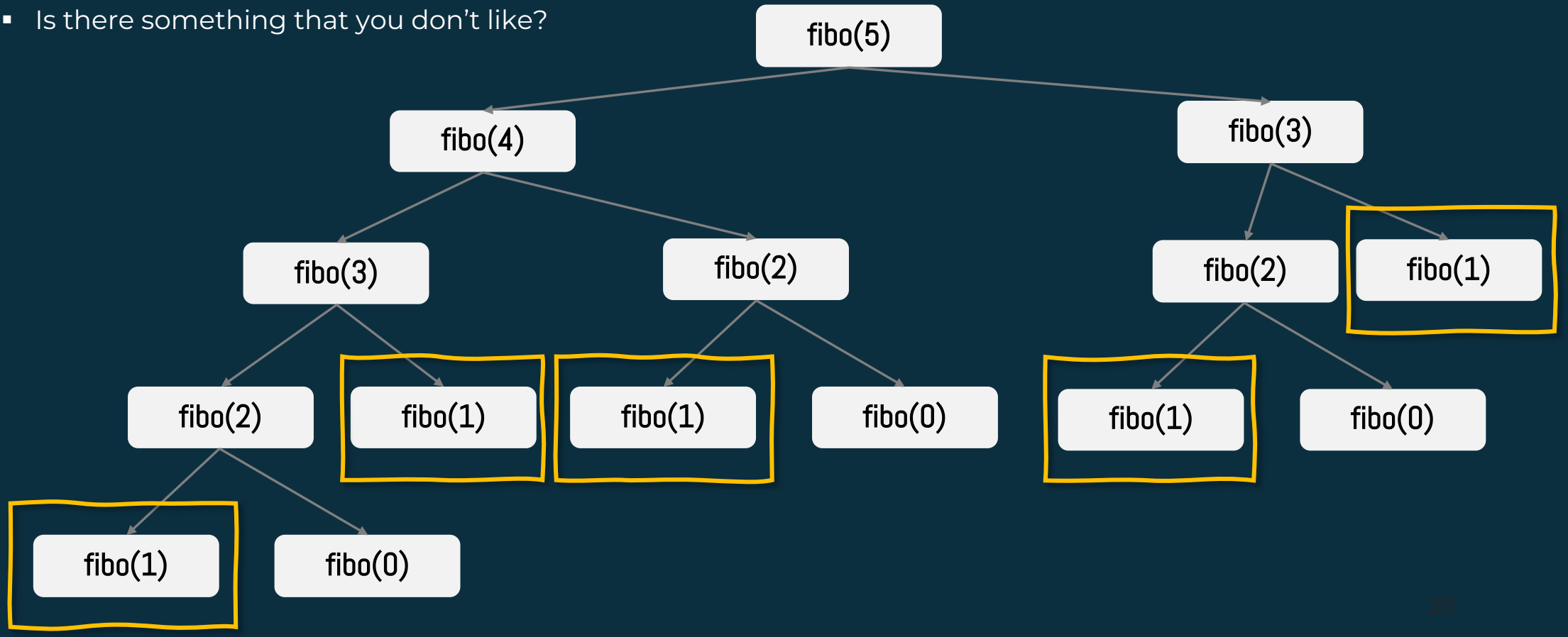
Quiz!

- What about computational complexity?
  - What is the time complexity of the Fibonacci method with recursion we just explored?
  - Answer: $O(2^n)$ (exponential)
    - Space is O(n)
- Is this good?
  - Answer: O(No!)



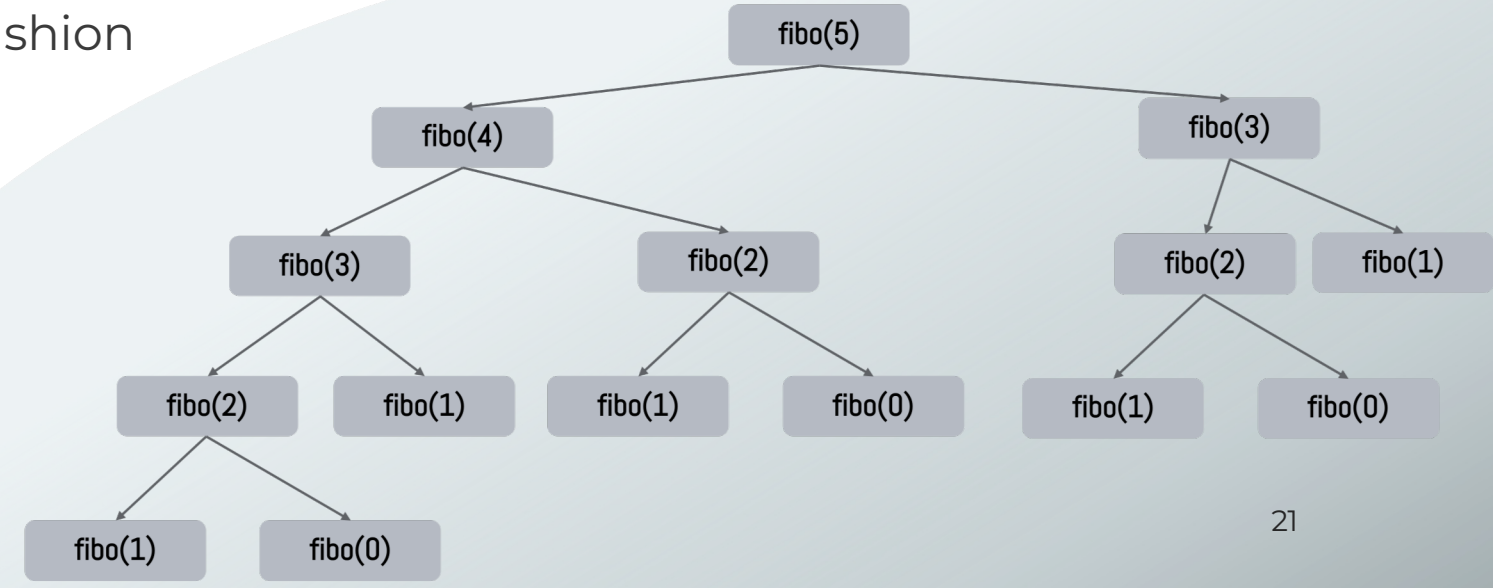
Quiz!

- Can you do better?
  - Is there something that you don't like?



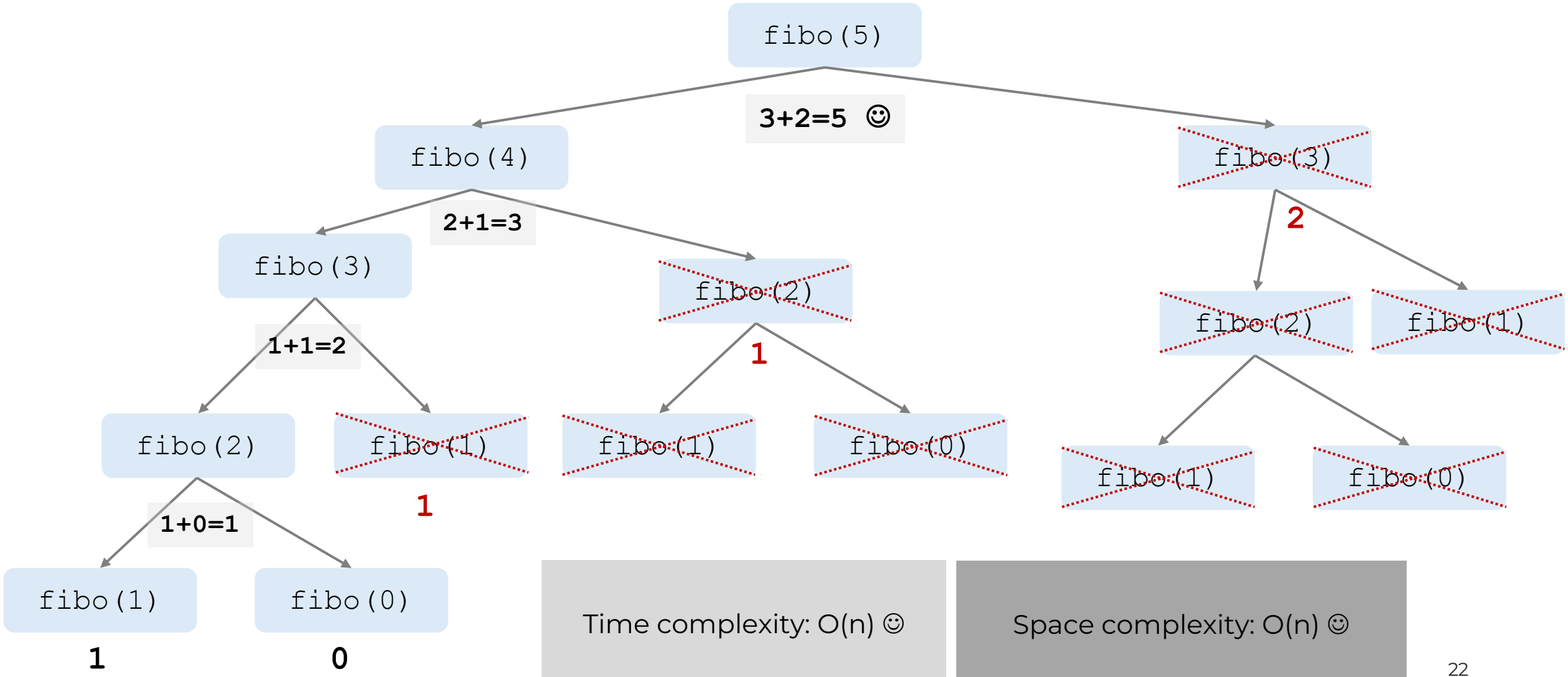
Can we do it better?

- **What if we avoid calculating the same Fibonacci numbers again and again?**
- What if we memorise the results of an existing calculation and use it in the next iteration?
  - Let's solve it in a **bottom-up** fashion



Let's use dynamic programming!

0	1	1	2	3	5
0	1	2	3	4	5



Time complexity: O(n) ☺

Space complexity: O(n) ☺

Using dynamic programming

script

```
def memoized_fibonacci(n, memo={}):
    if n in memo:
        return memo[n]
    if n <= 0:
        return 0
    elif n == 1:
        return 1
    else:
        memo[n] = memoized_fibonacci(n-1, memo) + memoized_fibonacci(n-2, memo)
        return memo[n]
```

Summary

- **Divide and conquer** breaks down a problem into two or more sub-problems
  - Until these become simple enough to be solved directly.

- **Greedy methods** (top-down) solve a problem as quickly as possible.
  - Make whatever choice seems best now and then solve the sub-problems arising after.

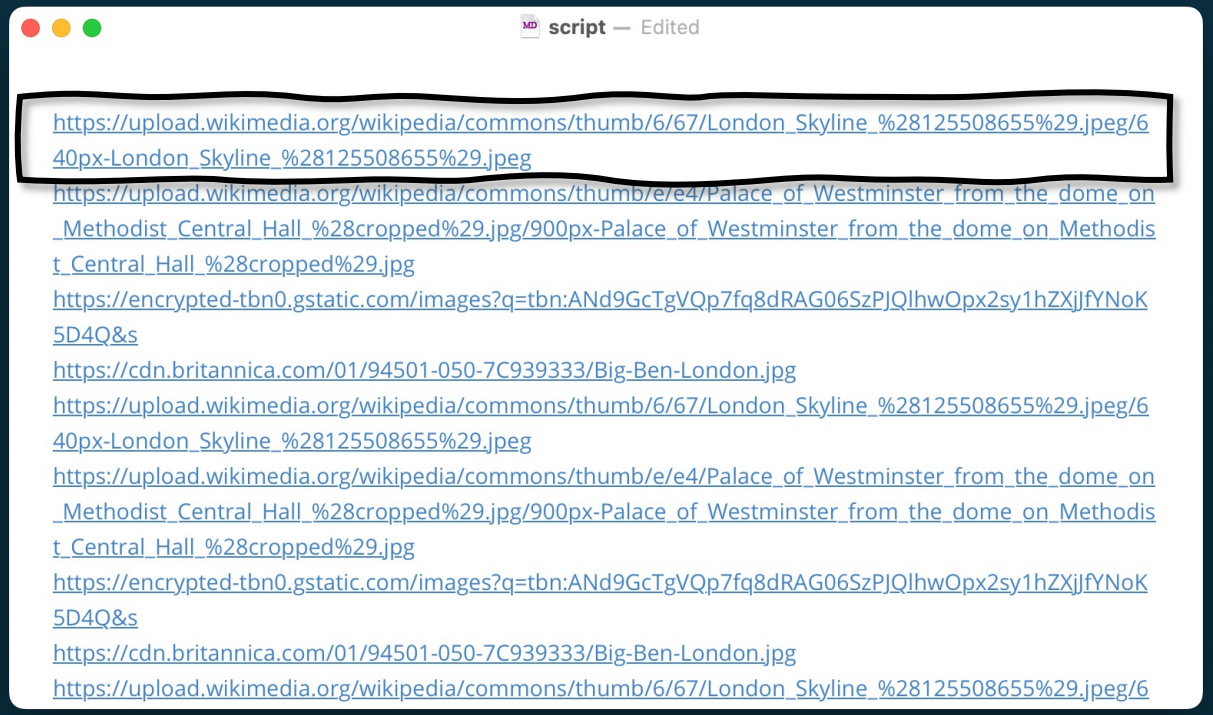
- **Dynamic programming** (bottom-up) solves a problem as efficiently as possible.
  - Store the result for future purposes so you do not need to compute it again.

How do you avoid the complexity wall?

YouTube example

- Each video on YouTube is analysed on user upload for classifying its content.
- Imagine an **`"analyse_video()"`** function that you must run for each of the 3.7 million videos uploaded daily!
  - Each video analysis takes around 2 minutes
  - For a daily analysis, YouTube has to wait 14 years!

What is your plan?



- A text file with URLs of photos
- Task: Download the photos.
- What is your strategy to approach this problem?

Solutions

Serial

- Write a function to load text into a list:

  `load_data(afile)`

- Write a function that downloads a photo from a given URL.

  `get_img(aurl)`

- For each URL in the list, call the

  `get_img(img)`

Parallel

- Write a function to load data into a list:

  `load_data(afile)`

- Write a function that downloads a photo from a given URL.

  `get_img(aurl)`

- Create a set of processes to call the `get_img` using each `url`

What is your plan?

- A folder with 1000 YouTube videos...
- Task:
  - Analyse each video and determine if the content is suitable for children.
- What is your strategy to approach this problem?

- Write a function to load a video

  `load_video(video_file)`

- Write a function to process a video.

  `process_video(video)`

- Create a set of processes to run the `load_video()` in parallel.
  - How many processes?
    - >= CPU cores
- Create a second set of processes to run the `process_video()` parallel.
  - CPU bound task

Intro to multiprocessing

Central Processing Unit (CPU)

The brain of a computer

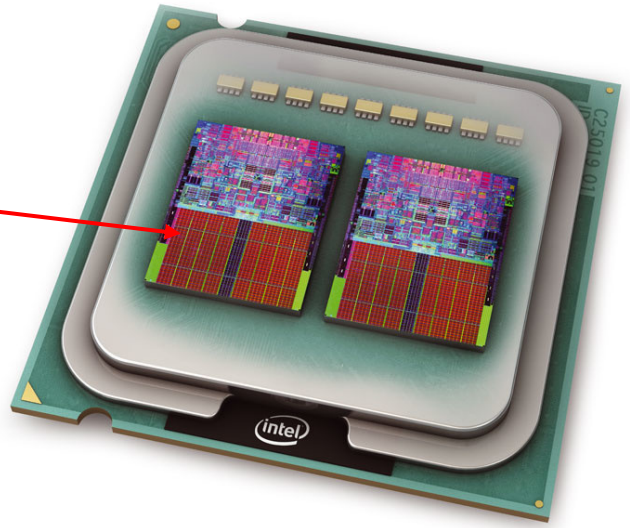
Hard Disk (HD) memory

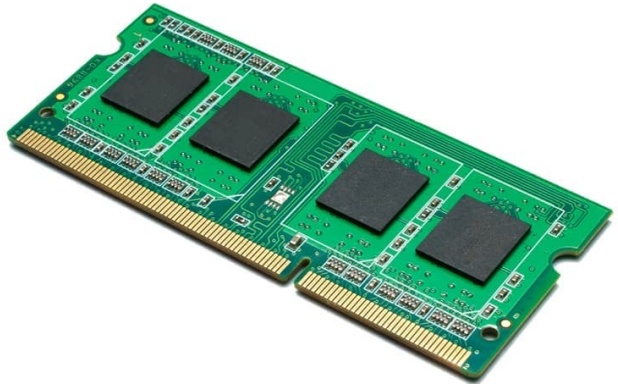
(Secondary memory)
Permanent storage

I run in the CPU

```
print(10+20)
```

Using one of the cores





I live in the RAM

```
num=10
```

Random Access Memory (RAM)

(Main memory)
Temporary storage

Multicore processor

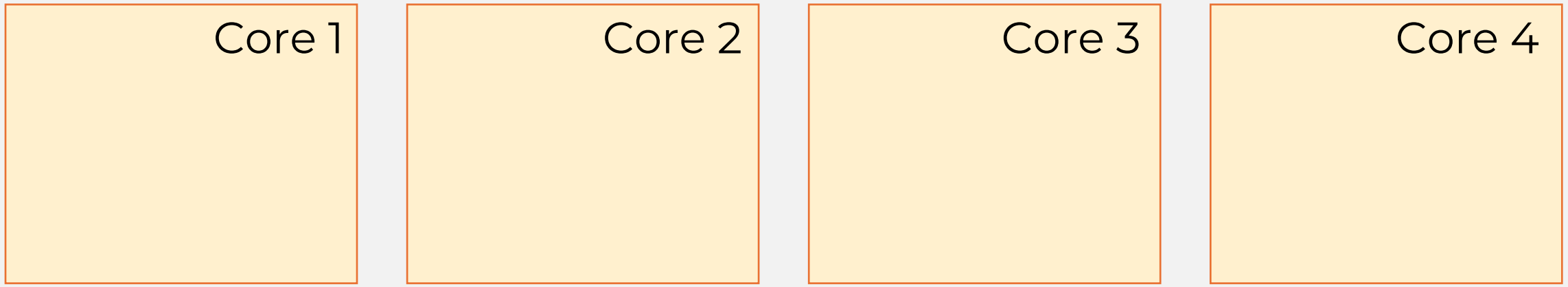
A CPU core is a single processing unit in the CPU that can execute instructions.

CPU

Inputs 5 3 6 2

2
6
3
5

```
def foo(n):
    return n*n
```



Outputs 25 9 36 4

Example of serial processing

CPU

Inputs 5 3 6 2

2

5

3

6

Core 1

```
def foo(n):
    return n*n
```

Core 2

```
def foo(n):
    return n*n
```

Core 3

```
def foo(n):
    return n*n
```

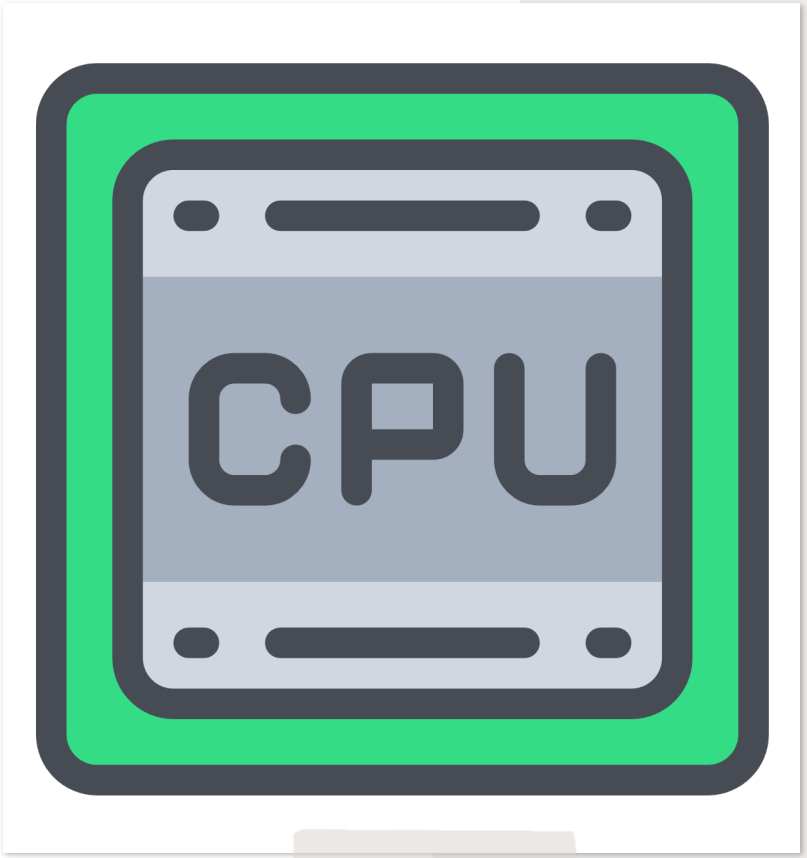
Core 4

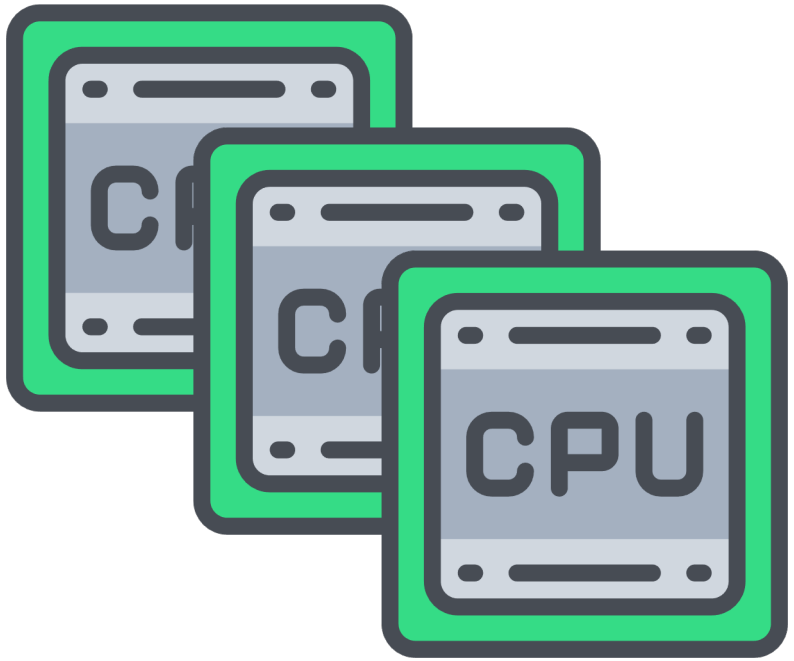
Outputs 25 9 36 4

Example of parallel processing

Serial processing

- Executing instructions sequentially, one after another (linear).
  - Single processor use (1 core).
  - It is easier to implement and debug – tasks are completed in a strict order.
  - It may be slower for large tasks – it doesn't utilize multi-core processors.
- When to use?
  - Tasks must be done in a specific order – a task depends on the previous one.
  - The overhead of managing parallel tasks outweighs its benefits.





Parallel processing

- Executing multiple tasks simultaneously (concurrently) across different processors or cores (same or different machine).
  - More complex to implement and debug due to concurrency issues:
    - Two or more processes access the same data.
  - Faster for large-scale processing tasks

When to use parallel?

- Large-scale data processing tasks
  - Big data analysis, scientific computing, and real-time processing.
- CPU-intensive applications like video encoding, large-scale simulations, or complex computations in physics and engineering.
- Applications that need to handle high volumes of simultaneous requests, such as web servers and database management systems.

How long does this script take to run?

script

```
import time
def do_something():
    time.sleep(1)


start = time.time()
do_something()
do_something()
end = time.time()
print(end-start)
```

2 seconds!

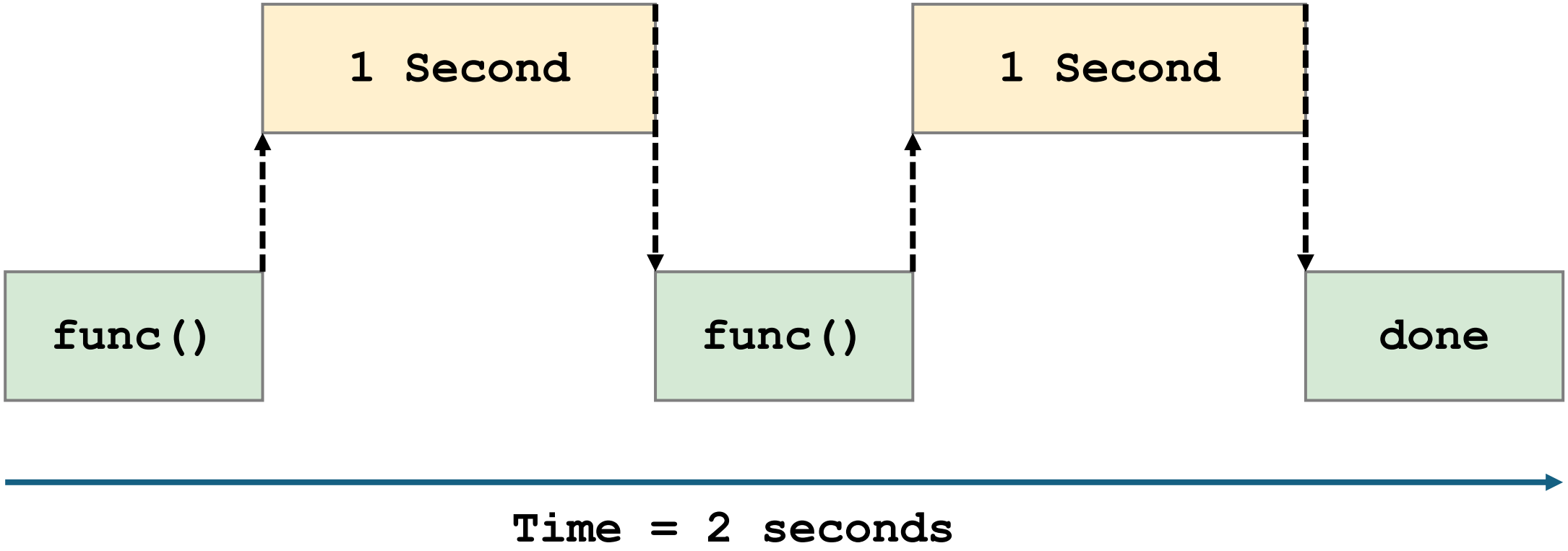
What about this one?

script

```
import time
def do_something(sec):
    time.sleep(sec)


start = time.time()
do_something(2)
do_something(4)
end = time.time()
print(end-start)
```

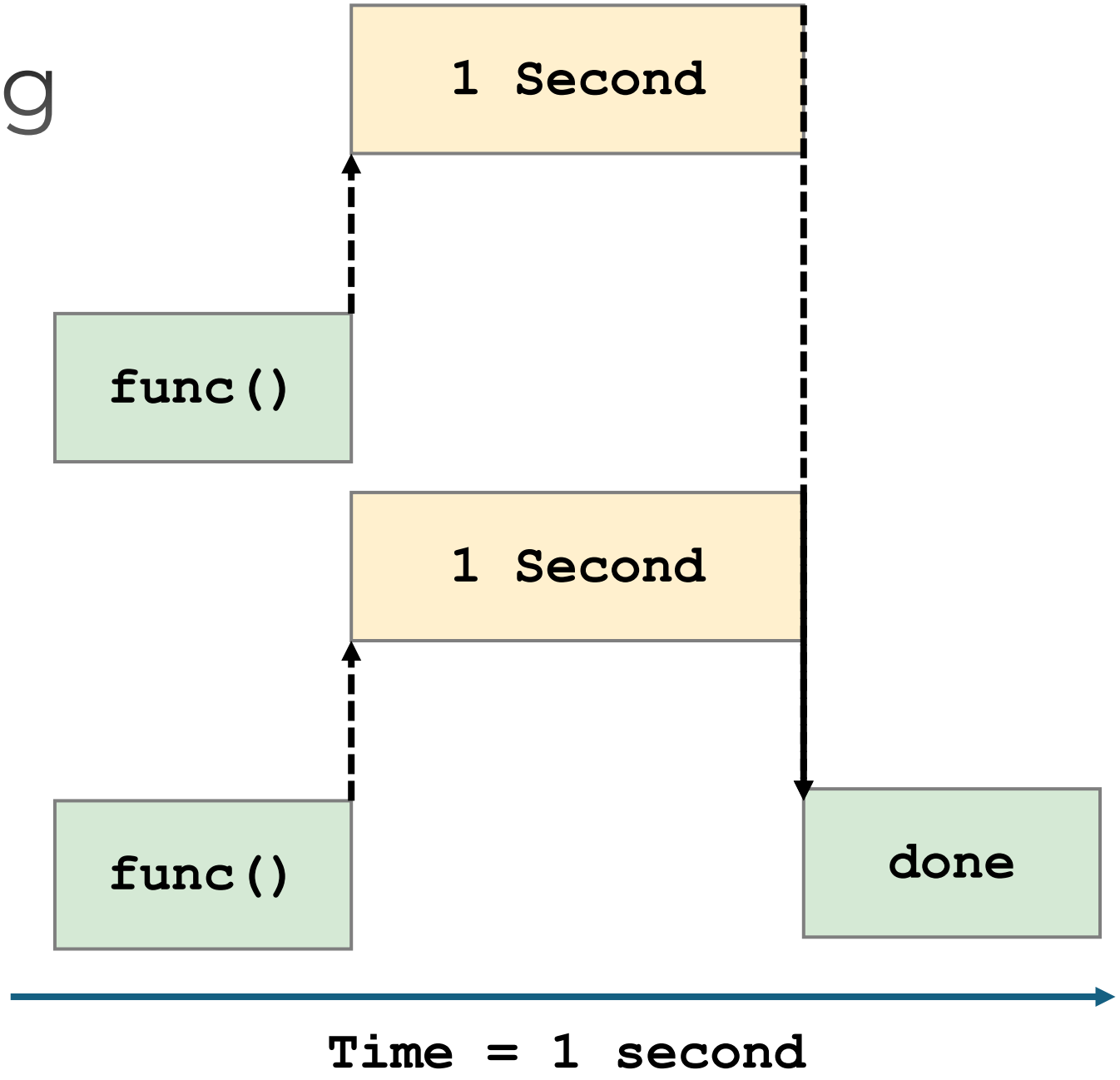
6 seconds!

Up until now, we have been inefficient!



Parallel processing

- “Processes” can run the operations on the data
- One piece at a time, then combine the results at the end to get the complete result.



Serial vs multi-processing vs multi-threading

- Serial processing:

  `1 problem = 1 python program = 1 process = 1 task`

- Multi-processing:

  `1 problem = 1 python program = n processes = n tasks`

- Multi-threading:

  `1 problem = 1 python program = 1 process = n threads = n tasks`

  (threads share memory)

What is a process?

- **A process refers to an instance of a running program.**
  - It is a self-contained execution environment with its own memory space, meaning it runs independently of other processes.
- Python **multiprocessing** module allows you to create and manage new processes.

  Library:

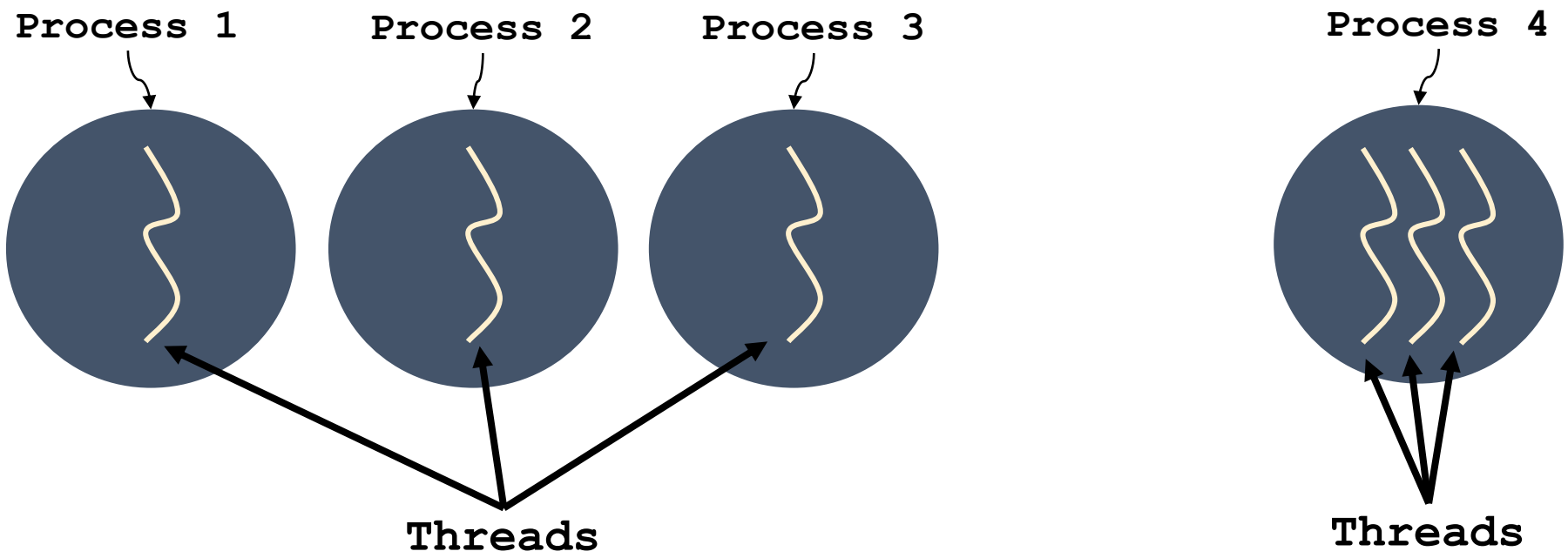
```
import multiprocessing
```

Process types

- **CPU-bound**
  - Requiring significant computation – spends most of its time utilizing the CPU.
    - Processing videos.
  - Reduce computation time or distribute the load across multiple CPU cores.
- **Input/Output (I/O)-bound**
  - Requiring significant computation – spends most of its time utilizing the disk.
    - Downloading YouTube videos from the web.
  - The bottleneck is the speed at which the data is received or sent.

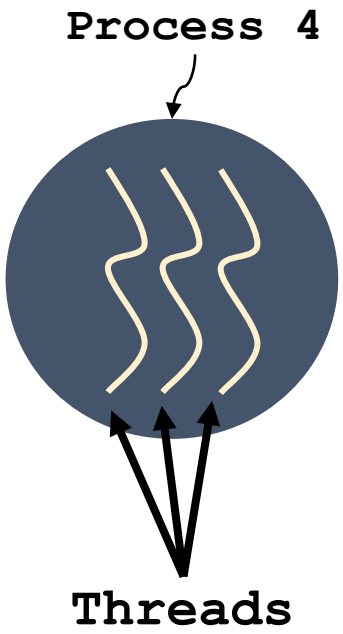
Processes and threads...

- Threads live inside “processes” and share memory!



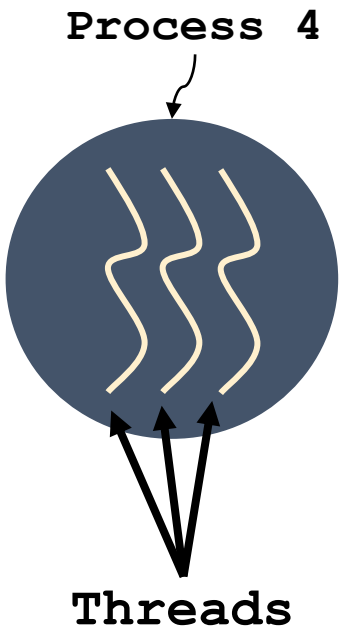
Why to use threads?

- Allow a single application to do many things at once
- Example
  - Watching YouTube videos
  - ...while typing in Word
  - ...while facetime rings.
- Ideal for I/O operations!



Threads

- Threads are components of a process that can run in parallel.
- Multiple threads can be in a process and share the same memory space.
  - All threads share the variables declared within the program.



Processes vs Threads

Processes

- An instance of a program that is being executed
- Processes operate independently
- They do not share memory space with other processes directly
- **Ideal for CPU-bound tasks**

Threads

- The smallest unit of processing
- Threads live in the same process and share the same memory
- Less resource-intensive than creating a process
- **Ideal for I/O bound tasks**

Serial

script — Edited

```
import time

start = time.perf_counter()

def do_something():
    time.sleep(1)

do_something()
do_something()

finish = time.perf_counter()

print(f'Finished in {finish-start} se
```

Float value of time in seconds

Parallel

script — Edited

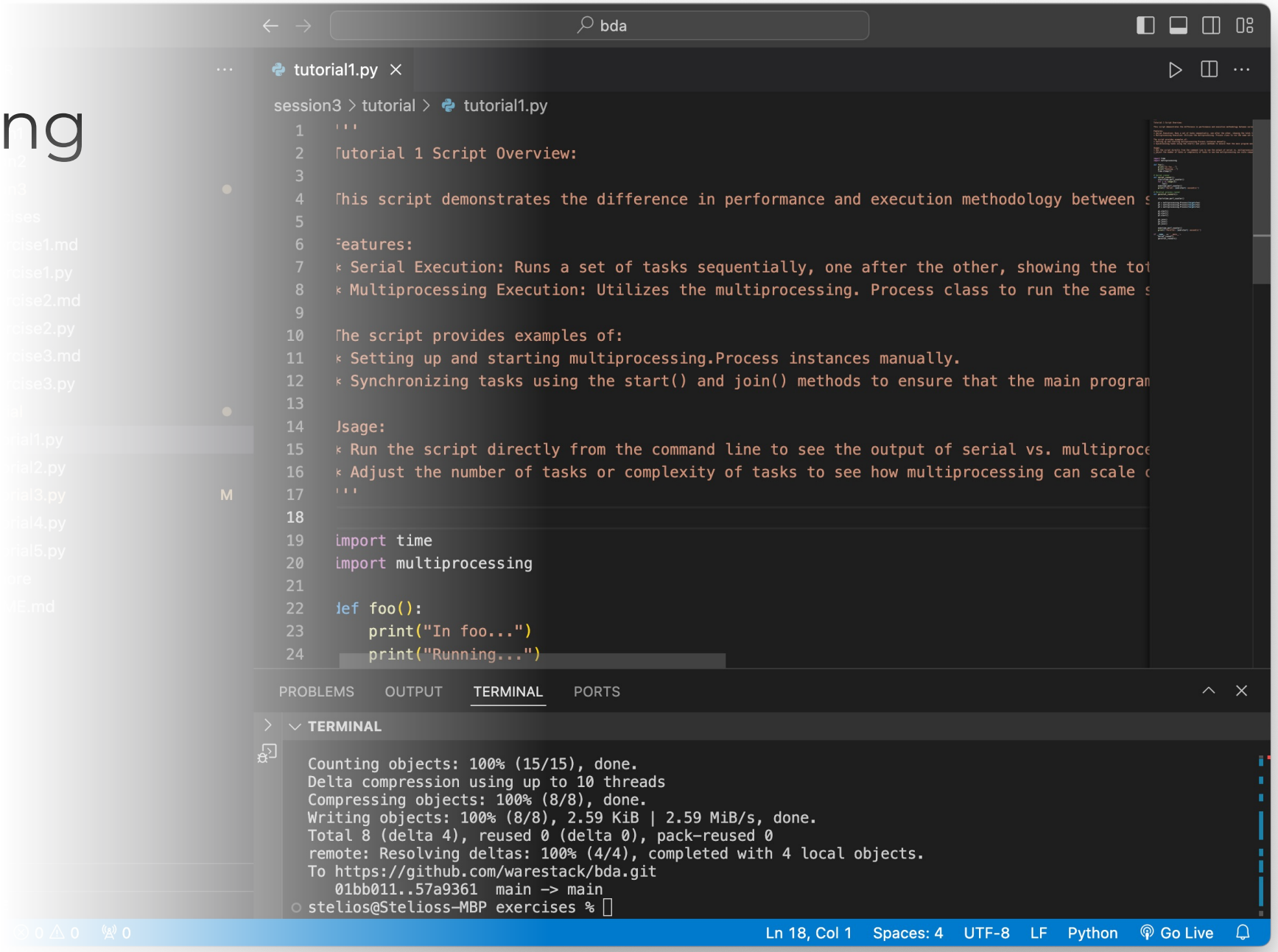
```
import multiprocessing
import time

start = time.perf_counter()

def do_something():
    time.sleep(1)

p1 = multiprocessing.Process(target=do_something)
p2 = multiprocessing.Process(target=do_something)

p1.start()
p2.start()

p1.join()
p2.join()

finish = time.perf_counter()

print(f'Finished in {finish-start} seconds(s)')
```

Start the processes

Wait for p1, p2 to complete

Multiprocessing tutorial

- Let’s run it together!
  - Using the Visual Studio Code…



Multiprocessing library

`multiprocessing.Process`

What is it?

- The **`multiprocessing.Process`** class allows you to create, launch, and manage new processes in parallel.
- Each **`Process`** object runs in its memory space, operating independently of other processes.

When to use it?

- Large-scale data processing:
  - Tasks can be easily parallelized and executed concurrently as batch jobs on chunks of data.
- Simulations:
  - Simulations or models that are computationally intensive and independent from each other.
- Batch Image or Video Processing:
  - Processing large sets of media files where each file can be processed independently.

```
from multiprocessing import Process

def my_function(args):
    print("Doing something with:", args)

if __name__ == '__main__':
    # Create a Process object that will run my_function
    p = Process(target=my_function, args=('some data',))
    p.start()  # Start the process
    p.join()   # Wait for the process to finish
```

Concurrent futures library

`concurrent.futures.ProcessPoolExecutor`

What is it?

- The **`ProcessPoolExecutor`** uses a pool of processes to execute function calls asynchronously and is designed to handle tasks that are CPU-bound.
- This approach is useful for parallel execution of tasks that can run independently and benefit from multiple cores.

When to use it?

- CPU-intensive Tasks:
  - Ideal for tasks that require heavy computation and can be distributed over multiple cores.
- Parallel Data Processing:
  - Useful in scenarios where a large amount of data needs to be processed in parallel, such as in data analysis or scientific computing.
- Complex Operations in Web Servers:
  - Can be used to handle CPU-heavy requests in web applications, running them in a background process pool to avoid blocking web server threads.

script

```
import concurrent.futures

import math


def compute_sqrt(number):

    result = math.sqrt(number)

    print(f"The square root of {number} is {result}")

    return result


if __name__ == "__main__":

    numbers = [25, 36, 49, 64, 81]

    with concurrent.futures.ProcessPoolExecutor() as executor:

        results = list(executor.map(compute_sqrt, numbers))
```

Pool library

`pool`

What is it?

- A powerful tool for parallel programming, enabling you to distribute tasks across multiple processors for concurrent execution.
- This is particularly useful for CPU-intensive operations that can benefit significantly from parallelization.
- The Pool class is designed to manage multiple worker processes, handling the dispatching of tasks and the collection of results seamlessly.

When to use it?

- Data Processing:
  - When you have a large dataset and need to perform computation-intensive operations on each element, multiprocessing.Pool() can significantly speed up processing by distributing the work across multiple CPUs.
- Simulations and Modeling:
  - For simulations that require a lot of independent computations, using Pool can reduce overall runtime.
- Batch Jobs:
  - Useful in scenarios where tasks are independent and can be completed in parallel, such as batch processing of files, images, or logs.

script

```
from multiprocessing import Pool


def square(n):
    return n * n


if __name__ == "__main__":
    numbers = [1, 2, 3, 4, 5]
    with Pool(5) as p:
        results = p.map(square, numbers)
    print(results)
```

Thank you!

- The lab starts soon!

  (404-405)

O(no!)

Lab 3

Big Data Analytics

How to complete lab 3?

1. Start with the tutorial. Study, adapt and run the scripts!
2. Complete the exercises using your tutorial notes.
3. Complete the homework (in class or at home).

* Use your preferred Python IDE – I suggest using VSC.