

# Processes and Threads

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2025-12-13

# Who am I?

- Self-taught developer
- Started programming with Python in 2009
- Work as a Senior Software Engineer at Endgame Analytics
- Volunteer in the Free and Open Source community
- Organised the Scientific Python Specialist Track at PyCon Australia
- SheCodes mentor since early 2022

# Before I start

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Here be dragons

This talk introduces advanced topics, quickly. The content is designed to stretch your understanding and to challenge you.

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## Questions

I am happy to take questions during the talk, feel free to ask if something doesn't make sense.

# Expanding your technical toolbox

- ① As a programmer, you're continually building up your technical toolbox
- ② This toolbox is the sum total of all the tools that you have available to solve any given problem
- ③ Processes or threads provide another, extremely powerful tool to add to your toolbox
- ④ Helps you understand what happens when a program executes
- ⑤ “Process vs Thread” is also a common interview question

# Today's Analogy

- Processes and Threads can be difficult to understand without context
- So I'll teach by using an analogy
- This analogy is cooking

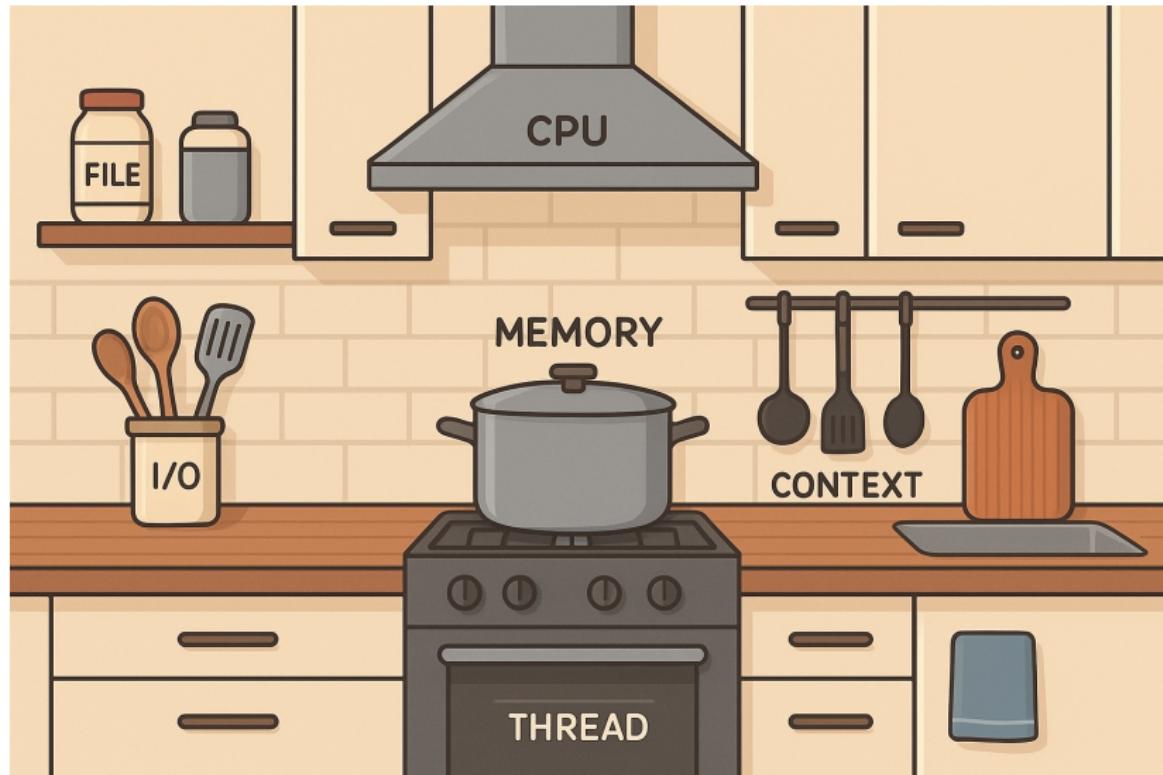
# Why is cooking relevant?

- So far you've learnt to write simple Python programs
- You've learnt to combine data (ingredients) using code (a recipe)
- a.k.a. you've learnt to cook small meals by yourself
- But you need more to cook a meal than just ingredients and a recipe



# Processes

# A process is the kitchen



# A Processes

- A process provides **resources** with which you can cook your meal
  - Memory to store your variables and instructions
  - CPU Time The OS schedules CPU time by processes
  - System Resources give access to things like file handlers and network connections

# A Processes

## Process

An instance of a program in execution, together with its associated resources and execution context.

- A process provides **resources** with which you can cook your meal
  - Memory to store your variables and instructions
  - CPU Time The OS schedules CPU time by processes
  - System Resources give access to things like file handlers and network connections

# Viewing processes

- On Linux/MacOS it is possible to view processes by using the *ps u* command
- This gives us a lot of information:
  - User** Who owns the processes?
  - PID** What is the process ID?
  - %CPU** How much CPU is the process using, as a percentage of total available?
  - %MEM** How much memory is the process using, as a percentage of total available?
  - RSS** resident set size, the non-swapped physical memory that a task has used
  - STAT** process state. What state is the process currently in?

# Creating our own process

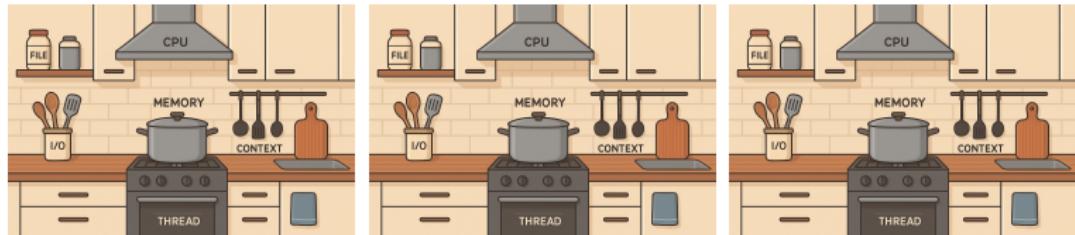
- Let's say we have a very simple Python program:

```
if __name__ == "__main__":
    name = input("Enter your name:")
```

- We can now launch it and see some things:
  - ps u | grep python*

# Processes for parallelism

- So far all your recipies do one thing at a time
- ...but computers can do many things at the same time
- This is analogous to having multiple kitchens to cook in



# Launching multiple processes

- Naively we can launch Python multiple times by launching multiple terminals
- This works but is a hassle
- Instead we can use the inbuilt “multiprocessing” module
- The module allows us to launch a processes from another process

## Creating processes from another process

```
from multiprocessing import Pool
from time import sleep
NAMES = ["Kai", "Tessa", "Jess", "Lucy"]

def say_hello(name):
    sleep(5)
    print(f"Hi {name}!")

def main():
    with Pool(3) as pool:
        pool.map(say_hello, NAMES)

if __name__ == "__main__":
    main()
```

# Check-in quiz

- ① What is the output of this program?
- ② How long does this program take to execute?

# Summary of Processes

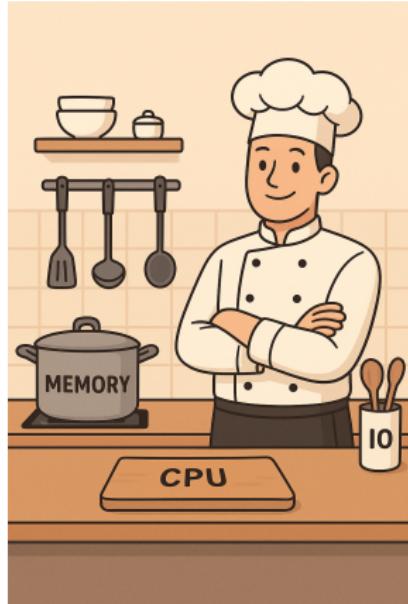
We've covered a lot so far. Let's take a second to revise. We have:

- defined processes as the operating system's representation of a running program
- seen that we can show processes using the ps command
- explained the output of (some) of the ps command's outputs
- shown how to launch multiple processes, both through the terminal and via Python
- shown that using multiple processes can introduce parallelism, allowing us to run many functions at the same time

# Threads

# Threads

- Processes build the whole kitchen
- ...**every time** we want to do parallelism
- This can be highly inefficient
- What about sharing resources within the kitchen?
- Threads are analogous to multiple cooks in the kitchen all utilising the same resources



# Many Threads



# Creating threads from a process

```
from concurrent.futures import ThreadPoolExecutor
from time import sleep
NAMES = ["Kai", "Tessa", "Jess", "Lucy"]

def say_hello(name):
    sleep(3)
    print(f"Hi {name}!")

def main():
    with ThreadPoolExecutor(3) as p:
        p.map(say_hello, NAMES)

if __name__ == "__main__":
    main()
```

# Seeing threads from a process

- Let's run the trusty `ps u | grep python` command again

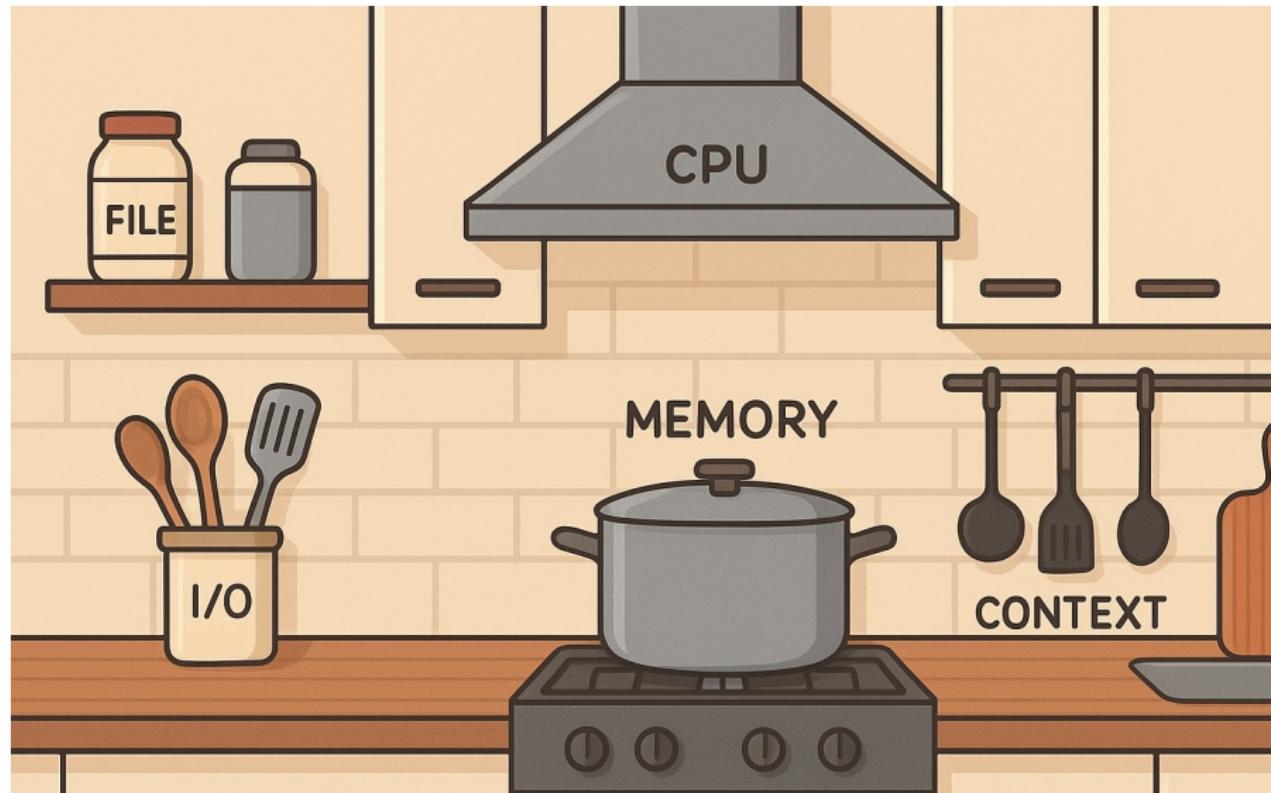
# Seeing threads from a process

- Let's run the trusty `ps u | grep python` command again
- What do we notice here?
  - Only one process appears
  - The amount of virtual memory is much higher

# What do we notice about threads

- We need to use the  $-T$  flag to see threads
- The *PID* of each thread is the same
- This is because the thread runs *inside* the process
- This is significant, threads share the resources provided by the process

# How do threads and processes relate?



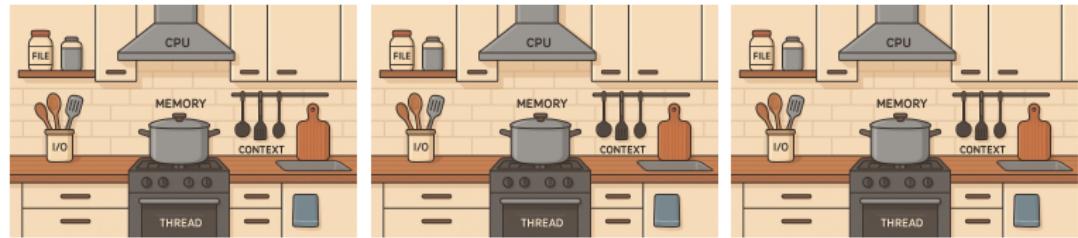
# A kitchen must always have a chef



# You can have multiple chefs per kitchen



# And you can have multiple kitchens



You can even have multiple chefs in multiple kitchens



# Processes vs Threads

- We've talked about processes and threads individually
- Made the analogy of a process as the kitchen and threads as the chef in the kitchen
- But I don't think the example really demonstrates the tradeoffs:
  - Speed
  - Memory
  - Bugs
- I'm going to demonstrate the difference between processes and threads in practice

# Digression: Measuring Performance

- Measuring is nuanced, difficult to get right and is a distinct area of study
- My measurements here are very approximate
- This works because the sizes are massive
- **Don't do this in the real world**

# Threads are much quicker to create

- A process needs to manage its own memory and resources
- $\Rightarrow$  the process of spawning (or creating) a process is much slower than spawning a thread
- Let's test this

# Speed benchmark setup

```
from functools import wraps
from time import time

def timed(f):
    @wraps(f)
    def wrapper(*args, **kwargs):
        start = time() * 1_000
        result = f(*args, **kwargs)
        end = time() * 1_000
        time_ms = end - start
        print(f'{f.__name__}: {time_ms:.2f}ms')
        return result
    return wrapper
```

# Speed benchmark setup

```
from threading import Thread
from timed import timed

@timed
def run_thread():
    t = Thread(target=lambda: None)
    t.start()
    t.join()

if __name__ == "__main__":
    run_thread()
```

# Speed benchmark setup

```
from multiprocessing import Process
from timed import timed

@timed
def run_process():
    p = Process(target=lambda: None)
    p.start()
    p.join()

if __name__ == "__main__":
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```

# Threads use much less memory

- Creating copies of memory requires more memory (*duh!*)
- Threads do not create copies of memory while processes do
- Threads therefore use much less memory, but how much?
- Let's find out!

# Speed benchmark setup

```
from time import sleep
from concurrent.futures import ThreadPoolExecutor
XS = [x for x in range(1_000_000)]

def dummy_work(x):
    sleep(3)
    return x

if __name__ == "__main__":
    with ThreadPoolExecutor(3) as pool:
        pool.map(dummy_work, [XS, XS, XS])
```

# Speed benchmark setup

```
from time import sleep
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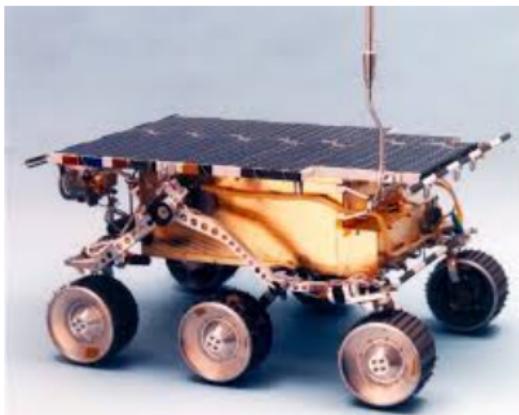
if __name__ == "__main__":
    with Pool(3) as pool:
        pool.map(dummy_work, [XS, XS, XS])
```

# Threads look great! Why would I ever want to use a process?

- If a thread crashes all threads in the process will (usually) also crash
- There are many, very difficult to debug bugs that arise from shared memory
  - Race Conditions
  - Deadlocks
  - Livelocks
  - Thread Starvation
  - Priority Starvation
  - Memory consistency errors
  - Atomicity violations

# Example: Mars Pathfinder Rover (1997)

- Imagine NASA's Mars Pathfinder rover in 1997
- Inside its computer, everything is organised like a *very busy kitchen*.
- The Mars Pathfinder rover kept rebooting because a low-priority logging task held a lock a high-priority system task needed, while medium-priority tasks kept interrupting.

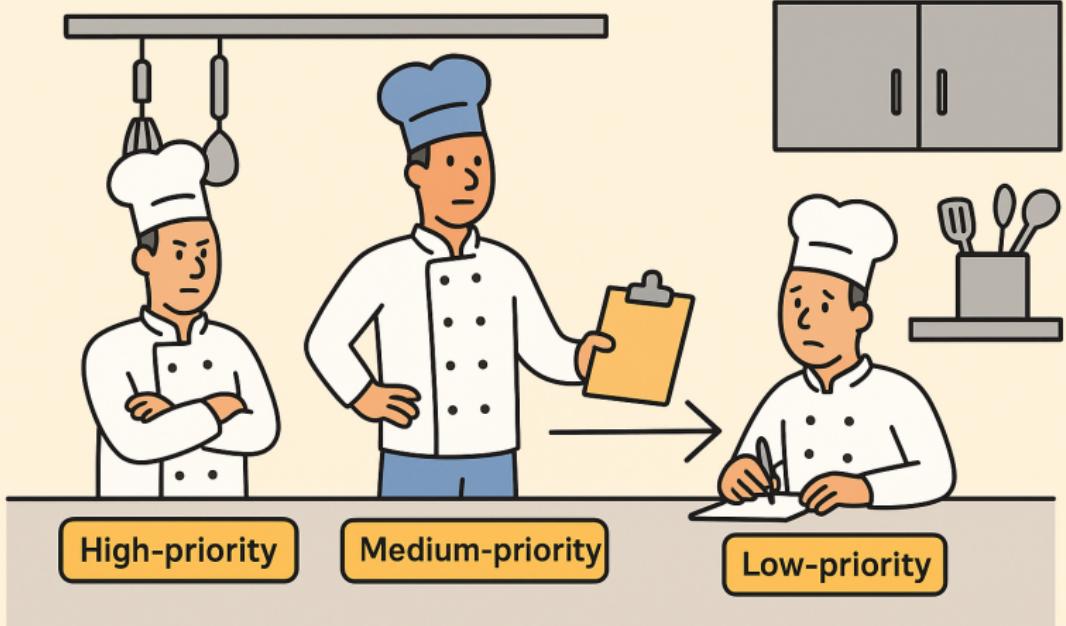


## Example: Mars Pathfinder Rover (1997)

- A low-priority chef in the kitchen grabbed the only mixing bowl
- ...while a high-priority chef urgently needs it.
- But before the low-priority chef can hand it over, another medium-priority chef keeps interrupting them.
- The head chef is stuck waiting
- and is unable to do their *high priority* task

# Example: Mars Pathfinder Rover (1997)

## Priority inversion



# Conclusion

I hope that you:

- enjoyed this session
- learnt something about processes and threads
- remember that you won't be an expert (yet!)