Concurrency: Running Together

ECE 650
Methods & Tools for Software Engineering (MTSE)
Fall 2023

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MULTIPROGRAMMING

Multiprogramming

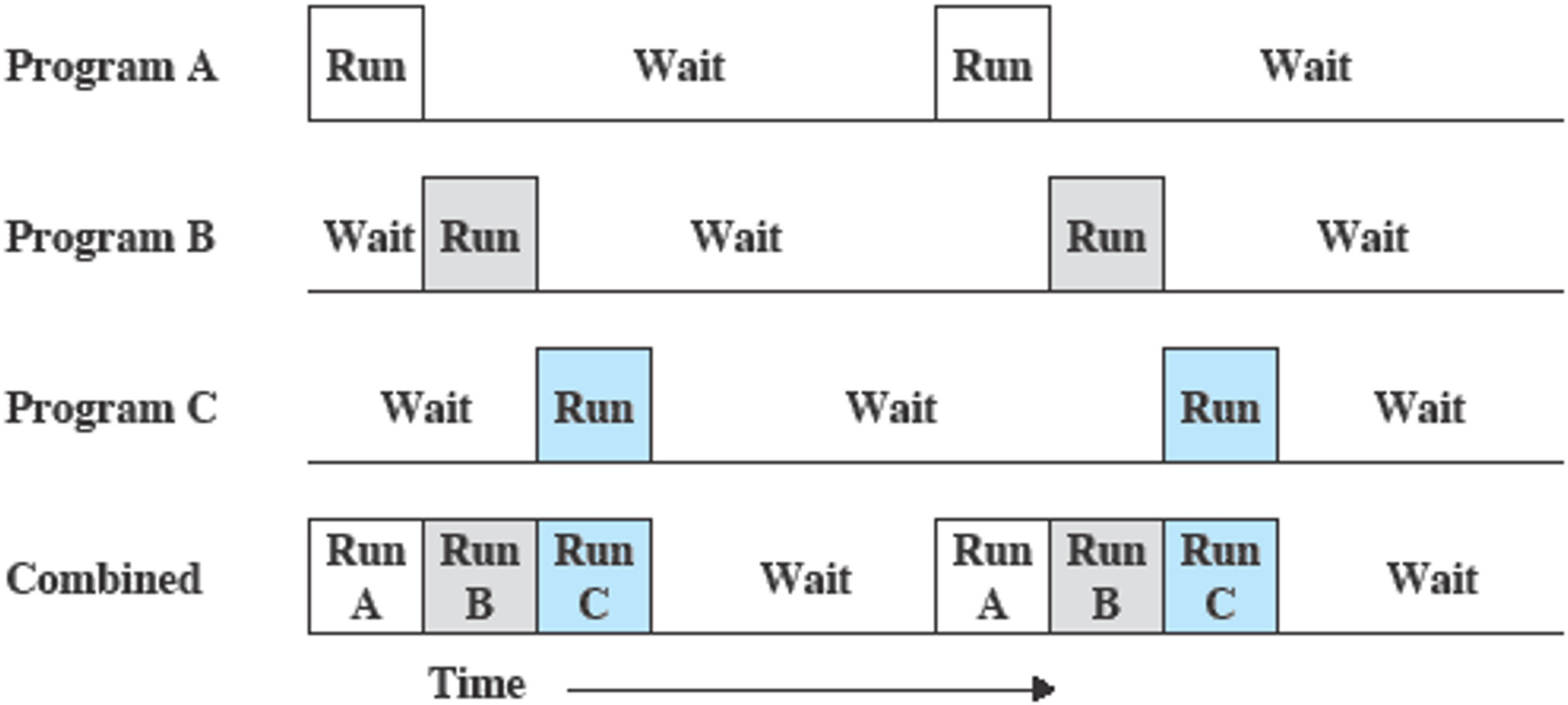
Concurrent execution of multiple tasks (e.g., processes)

- Each task runs as if it was the only task running on the CPU

Benefits:

- When one task needs to wait for I/O, the processor can switch to another task
- (why is this potentially a huge benefit?)

Multiprogramming



(c) Multiprogramming with three programs

Multiprogramming: Example

Web-application

- Python web-server that handles web requests and generates jobs
- Multi-process job-server that processes jobs in parallel

Web-server and Job-server communicate via the file system

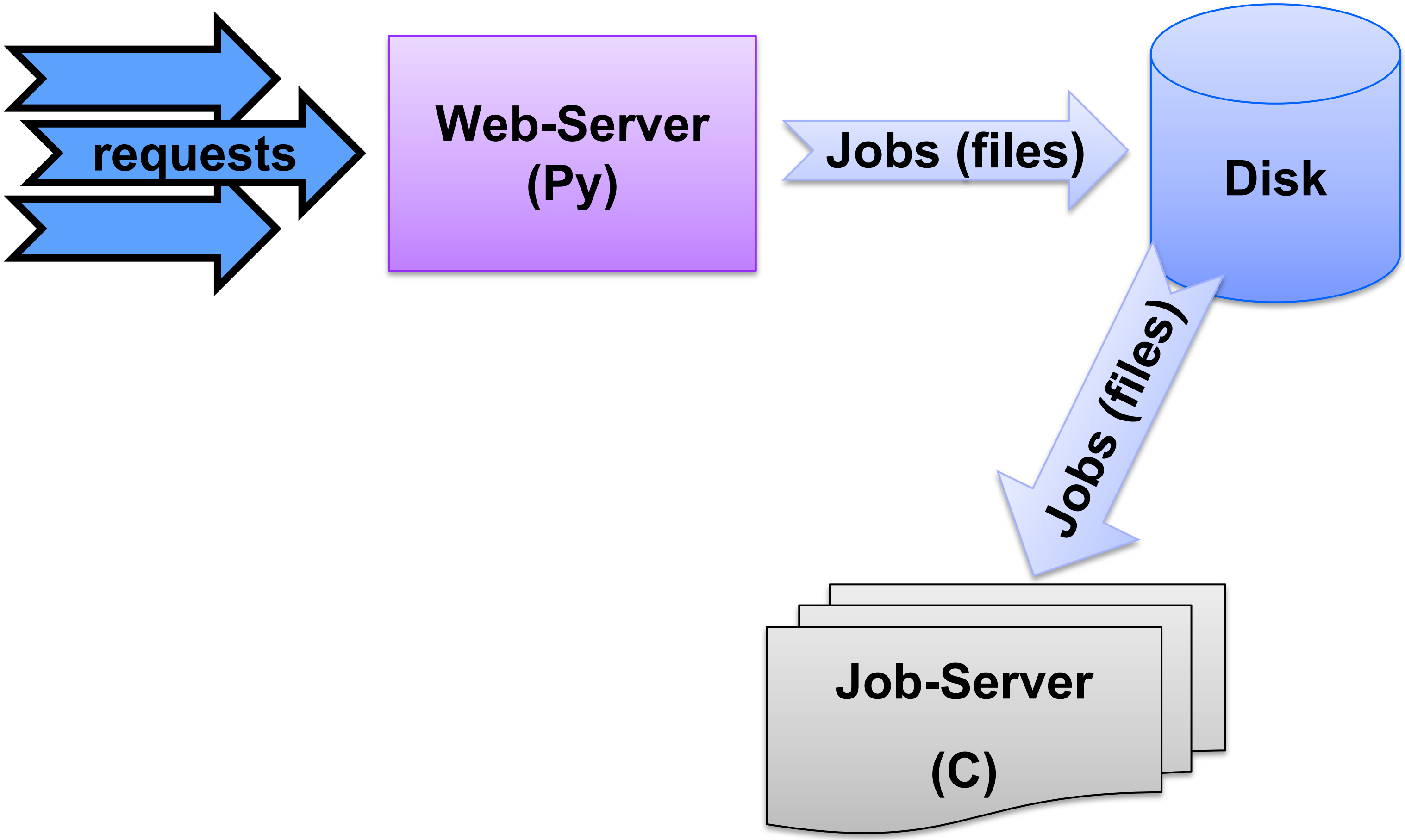
Workers in Job-server compete to acquire jobs to process

Potential problem: Race Condition

- Two workers attempt to acquire the same job to process
- Only one will succeed
  - better than both completing the same job

https://git.uwaterloo.ca/ece650-f23/threads/-/tree/master/webapp

Web-Application: Architecture



Race Condition

A situation where concurrent operations access data in a way that the outcome depends on the order (the timing) in which operations execute.

- **Not** necessarily a **bug**!
- Often is the main source of bugs in concurrent systems
- Programmers assume that order of execution does not influence the result, and/or, implicitly assume that only certain order of operations is possible

In our web-app example, workers are **racing** to rename/lock a job file

- only one succeeds, so the race is not causing a bug
- but it does create unexpected behaviour (disappearing file)

MULTITHREADING

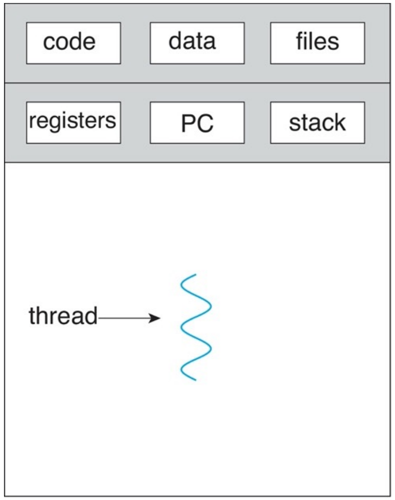
Traditional UNIX Process

Process is OS abstraction of what is needed to run single program

- Often called "heavyweight process"

Processes have two parts

- Sequential program execution stream (active part)
  - Code executed as sequential stream of execution (i.e., thread)
  - Includes state of CPU registers
- Protected resources (passive part)
  - Main memory state (contents of Address Space)
  - I/O state (i.e. file descriptors)



single-threaded process

Modern Process with Threads

Thread: sequential execution stream within process
(sometimes called "lightweight process")

- Process still contains single address space
- No protection between threads

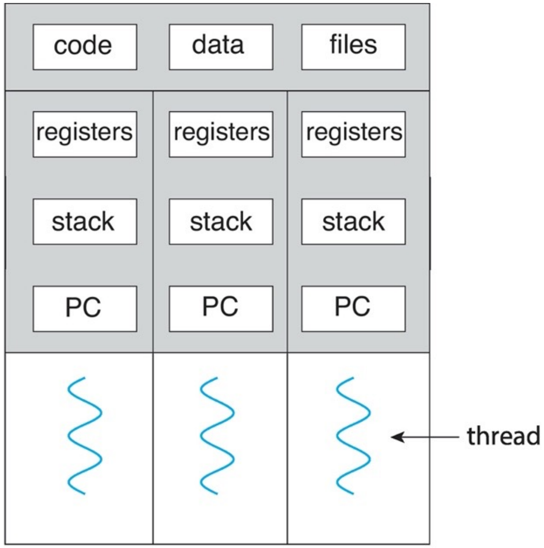
Multithreading: single program made up of different concurrent activities (sometimes called multitasking)

Some states are shared by all threads

- Content of memory (global variables, heap)
- I/O state (file descriptors, network connections, etc.)

Some states "private" to each thread

- CPU registers (including PC) and stack



multithreaded process

Threads Motivation

OS's need to handle multiple things at once (MTAO)

- Processes, interrupts, background system maintenance

Servers need to handle MTAO

- Multiple connections handled simultaneously

Parallel programs need to handle MTAO

- To achieve better performance

Programs with user interfaces often need to handle MTAO

- To achieve user responsiveness while doing computation

Network and disk programs need to handle MTAO

- To hide network/disk latency

Multithreading: Process versus Thread

Process provides an execution context for the program

- **unit of ownership**
- Memory, I/O resources, console, etc.
- Process pretends like it is a single entity controlling the execution environment
- Inter Process Communication (IPC) is “like” communicating between individual machines (but connected with super-fast network)

Thread represent a single execution unit (i.e., CPU)

- unit of scheduling
- ancient time: a process has one thread running on one physical CPU
- old time: a process has many threads sharing one physical CPU
- today: a process has many threads sharing many physical CPUs (multicore)
- all threads of a process share the same memory space!

Threads: Programmer's Perspective

A thread is a function that is ran concurrently with other functions

- It is like `fork()` followed by a call to a child process function
- **Except**: no new process is created. The new thread can access **all** the data of the **current** process

```c
void * foo(void*) {...}
void * bar(void*) {...}

int main(void) {
  pthread_t t1, t2;
  void *data;
  ...
  pthread_create(&t1, NULL, foo, data);
  pthread_create(&t2, NULL, bar, data);

  pthread_join(t1, NULL);
  pthread_join(t2, NULL);
}
```

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Code that will execute concurrently

Start of concurrent execution

Main thread waits for others to finish

Multithreading Example: Compute CRC

CRC – Cyclic Redundancy Check is an error detecting code used to identify error in data

- `CRC(data) = crc_code`,
  - where `crc_code` is a ”small” number summarizing `data`
- CRC computation is expensive, but easy to parallelize

Parallel Computation of CRC

- Divide data into chunks: `data1, data2, data3, …`
- Compute CRC for each chunk
  - `crc1 = CRC(data1), crc2 = CRC(data2), crc3 = CRC(data3), …`
- Combine CRC of chunks into CRC of the data
  - `crc_code = crc1 ++ crc2 ++ crc3 ++ …`
- CRC of each chunk is computed in parallel (using threads)

https://git.uwaterloo.ca/ece650-f23/threads/-/tree/master/checksum

References

Slides & Demo credit:

- Carlos Moreno (cmoreno@uwaterloo.ca)
- Reza Babaee
- Prof. Seyed M. Zahedi (ECE350 UWaterloo)