Module 2: Concurrency Basics
Topic 1.1: Processes

Processes

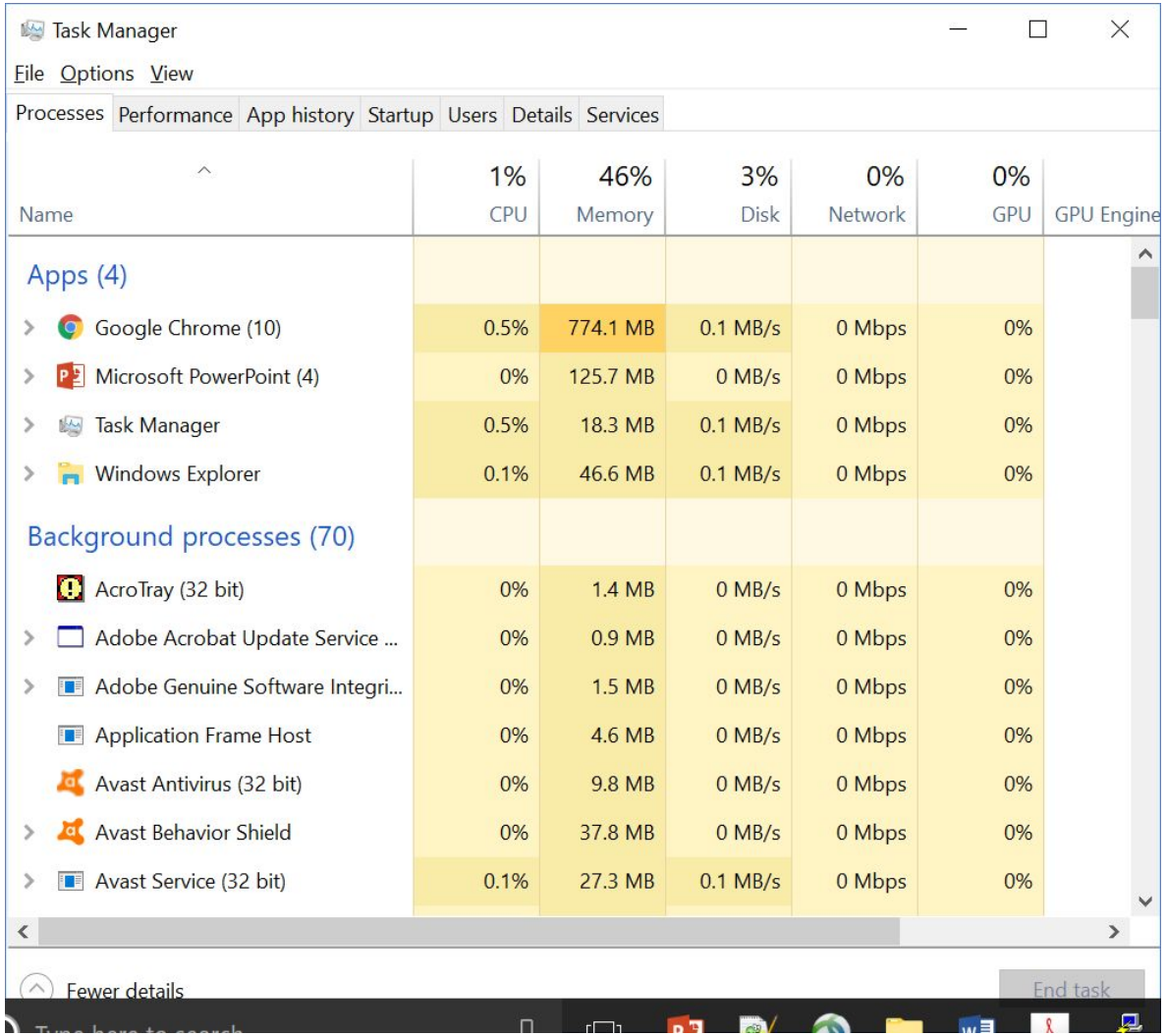
- An instance of a running program
- Things unique to a process

1. Memory
   - Code, stack, heap, shared libraries
   - Virtual address space
2. Registers
   - Program counter, data regs, stack ptr, …

Operating Systems

- Allows many processes to execute concurrently
- Processes are switched quickly
  - 20ms
- User has the impression of parallelism
- Operating system must give processes fair access to resources

Task Manager



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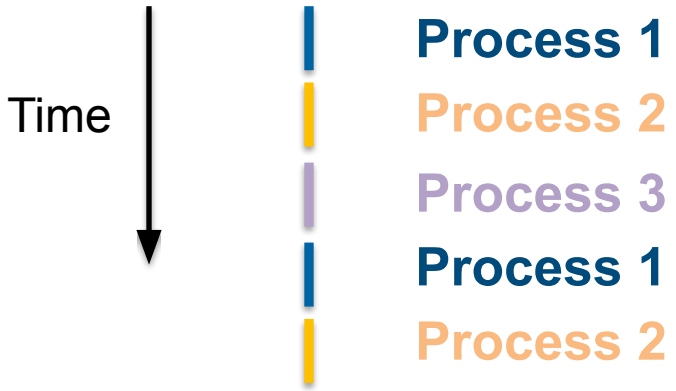
Module 2: Concurrency Basics
Topic 1.2: Scheduling

Scheduling Processes

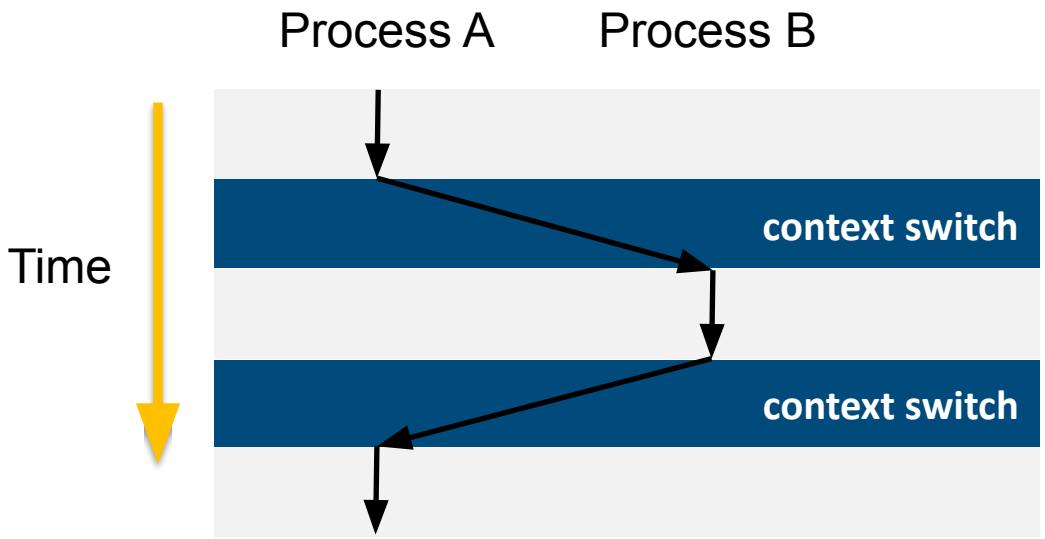
- Operating system schedules processes for execution
- Gives the illusion of parallel execution



- OS gives fair access to CPU, memory, etc.

Context Switch

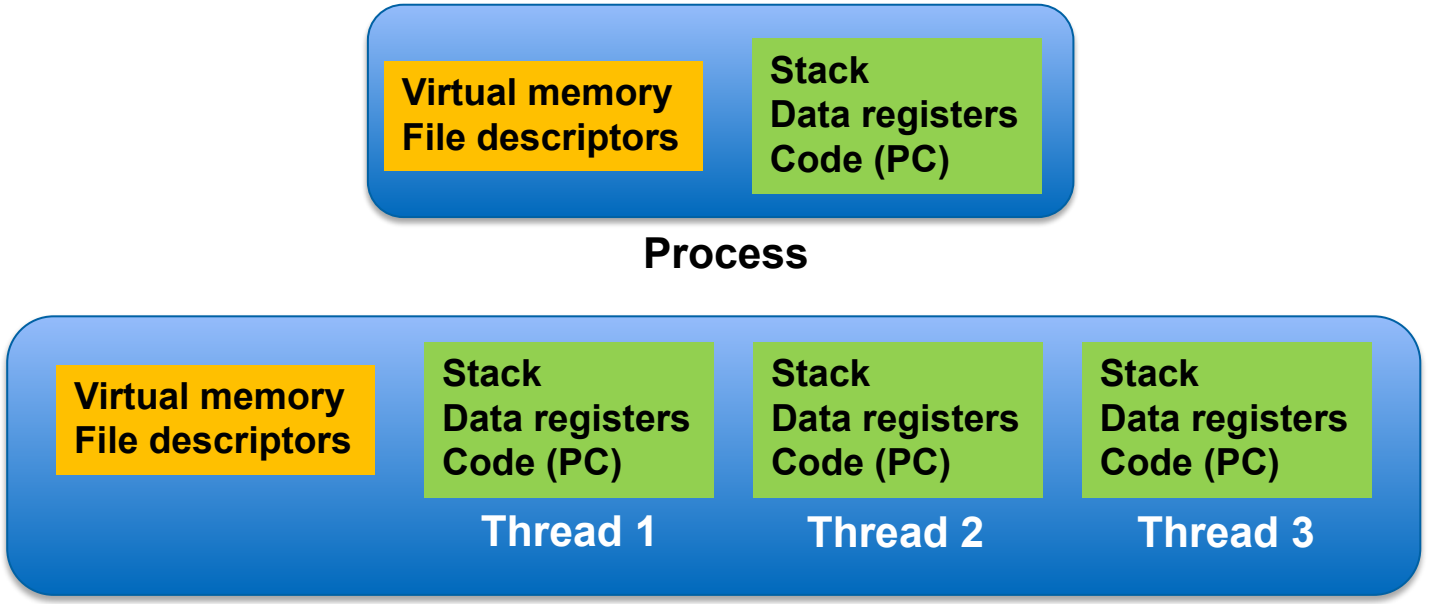
- Control flow changes from one process to another
- Process “context” must be swapped



Module 2: Concurrency Basics
Topic 1.3: Threads and Goroutines

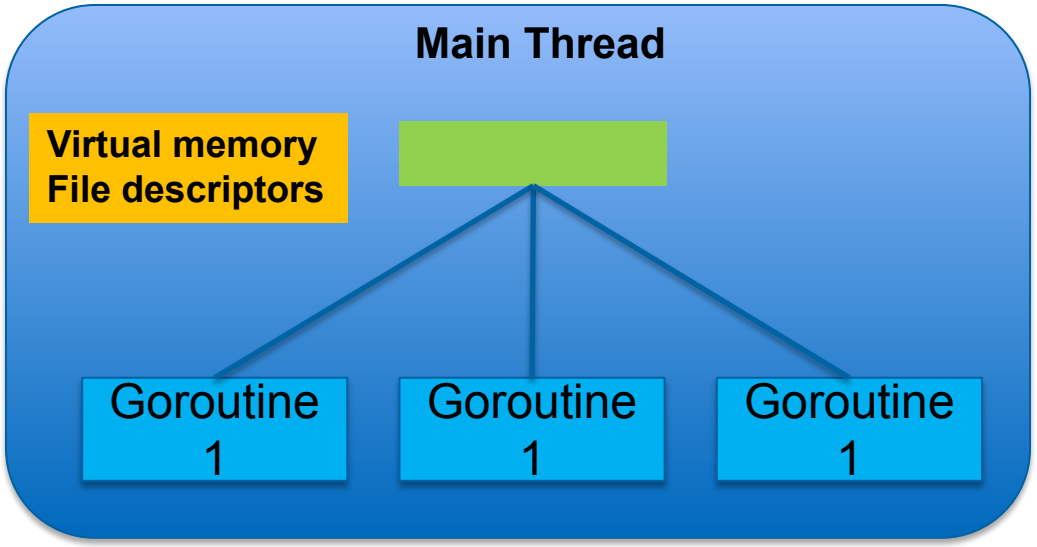
Threads vs. Processes

- Many threads can exist in one process
- Threads share some context
- OS schedules threads rather than processes



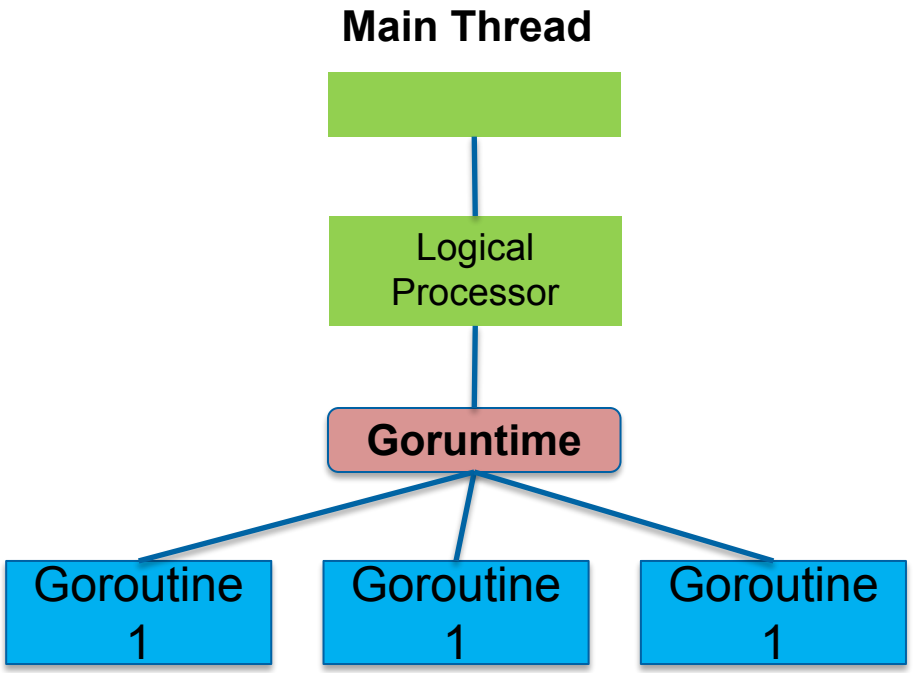
Goroutines

- Like a thread in Go
- Many Goroutines execute within a single OS thread



Go Runtime Scheduler

- Schedules goroutines inside an OS thread
- Like a little OS inside a single OS thread
- **Logical processor** is mapped to a thread



Module 2: Concurrency Basics
Topic 2.1: Interleavings

Interleavings

- Order of execution within a task is known
- Order of execution **between** concurrent tasks is unknown
- Interleaving of instructions between tasks is unknown

Task 1	**Task 2**
1: `a = b + c`	1: `r = s + t`
2: `d = e + f`	2: `u = v + w`
3: `g = h + i`	3: `x = y + z`

Possible Interleavings

1: `a = b + c`	
	1: `r = s + t`
2: `d = e + f`	
	2: `u = v + w`
3: `g = h + i`	
	3: `x = y + z`

1: `a = b + c`	
2: `d = e + f`	
3: `g = h + i`	
	1: `r = s + t`
	2: `u = v + w`
	3: `x = y + z`

- Many interleavings are possible
- Ordering is **non-determininstic**
- Must consider all possibilities

Race Conditions

- Outcome depends on non-deterministic ordering

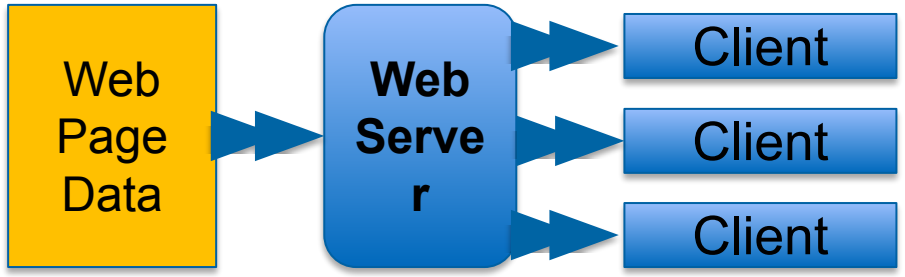
1: `x = 1`	
	1: `print x`
2: `x = x + 1`	

1: `x = 1`	
2: `x = x + 1`	
	1: `print x`

- Races occur due to **communication**

Communication Between Tasks

- Threads are largely independent but not completely independent
- Web server, one thread per client



- Image processing, 1 thread per pixel block