

Processes

CSE 351 Autumn 2018

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REFRESH TYPE	EXAMPLE SHORTCUTS	EFFECT
SOFT REFRESH	EMAIL <input type="button" value="REFRESH"/> BUTTON	REQUESTS UPDATE WITHIN JAVASCRIPT
NORMAL REFRESH	F5, CTRL-R, ⌘R	REFRESHES PAGE
HARD REFRESH	CTRL-F5, CTRL-⇧, ⌘⇧R	REFRESHES PAGE INCLUDING CACHED FILES
HARDER REFRESH	CTRL-⇧-HYPER-ESC-R-F5	REMOTELY CYCLES POWER TO DATACENTER
HARDEST REFRESH	CTRL-⌘-⇧-#-R-F5-F5-ESC-O-O-Ø-▲-SCROLL LOCK	INTERNET STARTS OVER FROM ARPANET

Administrivia

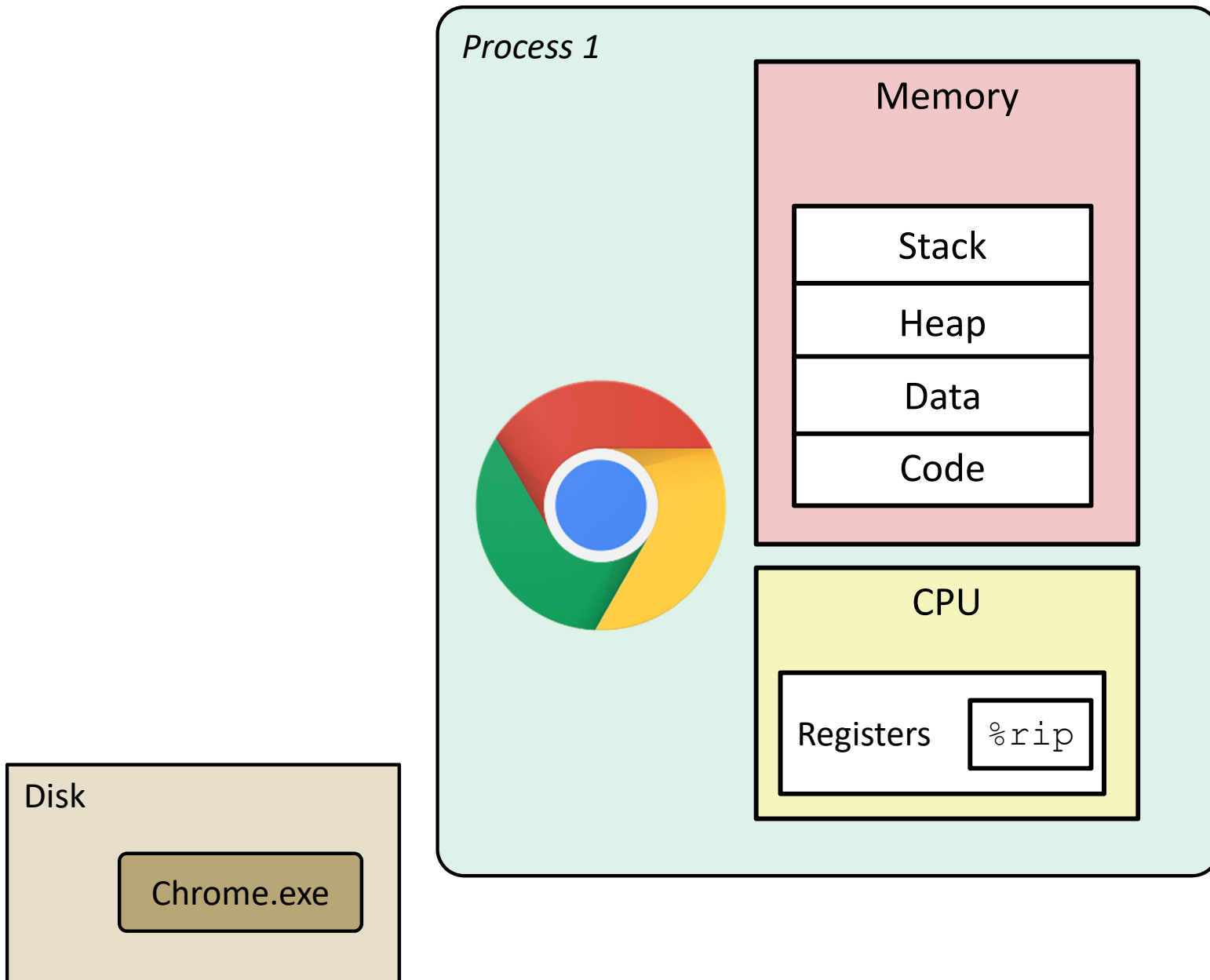
- ❖ Homework 4 due Friday (11/16)
- ❖ Lab 4 due after Thanksgiving (11/26)

Processes

- ❖ **Processes and context switching**
- ❖ Creating new processes
 - `fork()`, `exec*()`, and `wait()`
- ❖ Zombies

What is a process?

It's an illusion!

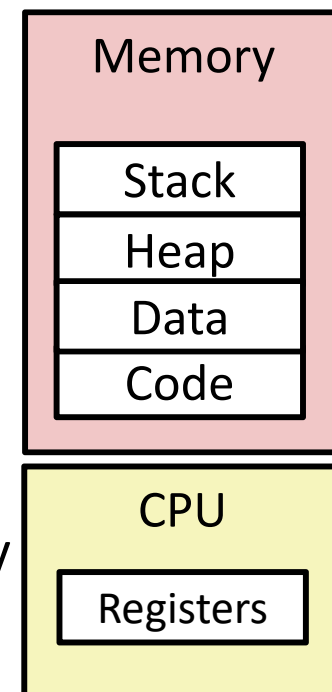


What is a process?

- ❖ Another *abstraction* in our computer system
 - Provided by the OS
 - OS uses a data structure to represent each process
 - Maintains the *interface* between the program and the underlying hardware (CPU + memory)
- ❖ What do *processes* have to do with *exceptional control flow*?
 - Exceptional control flow is the *mechanism* the OS uses to enable **multiple processes** to run on the same system
- ❖ What is the difference between:
 - A processor? A program? A process?

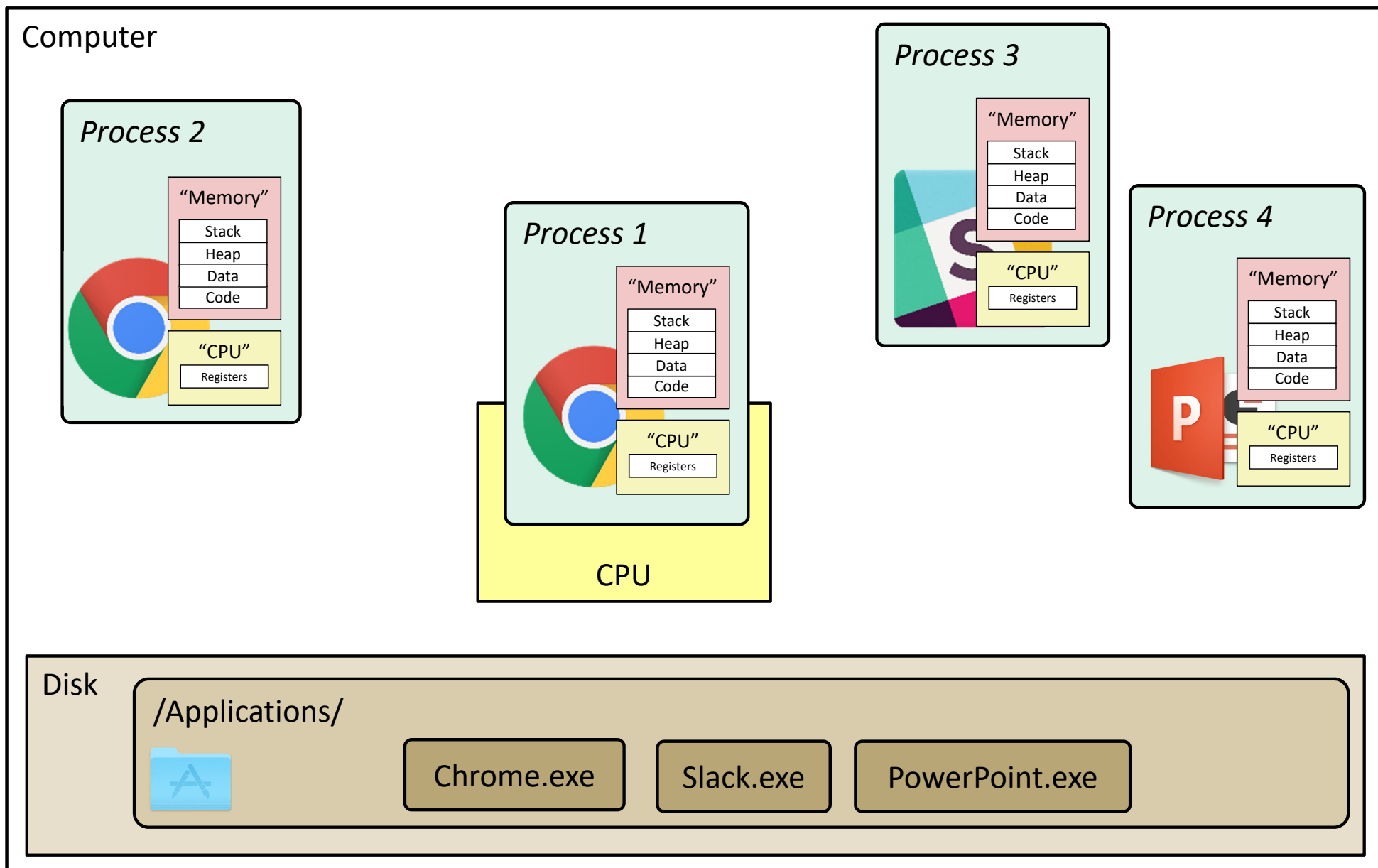
Processes

- ❖ A **process** is an instance of a running program
 - One of the most profound ideas in computer science
 - Not the same as “program” or “processor”
- ❖ Process provides each program with two key abstractions:
 - *Logical control flow*
 - Each program seems to have exclusive use of the CPU
 - Provided by kernel mechanism called **context switching**
 - *Private address space*
 - Each program seems to have exclusive use of main memory
 - Provided by kernel mechanism called **virtual memory**



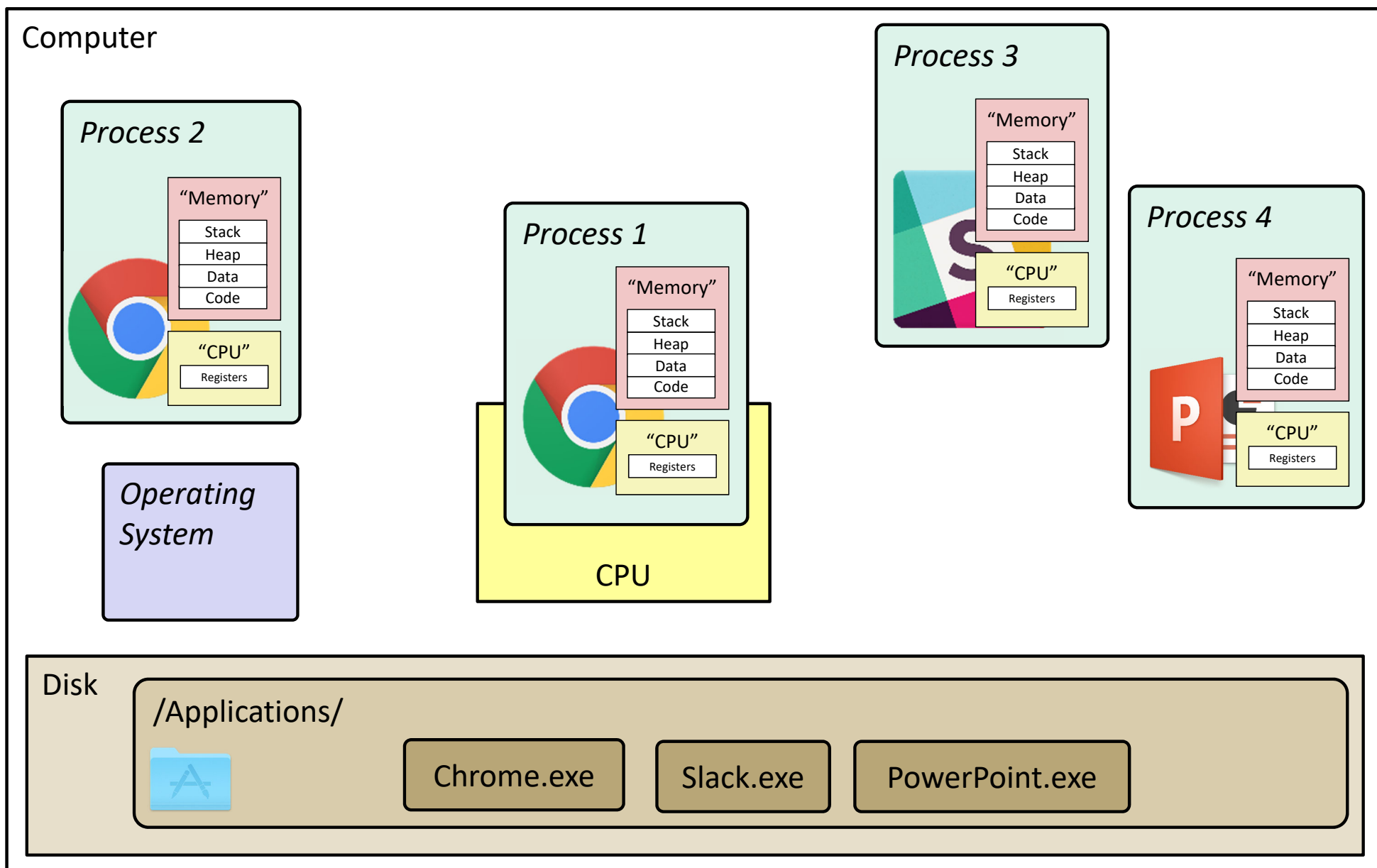
What is a process?

It's an illusion!

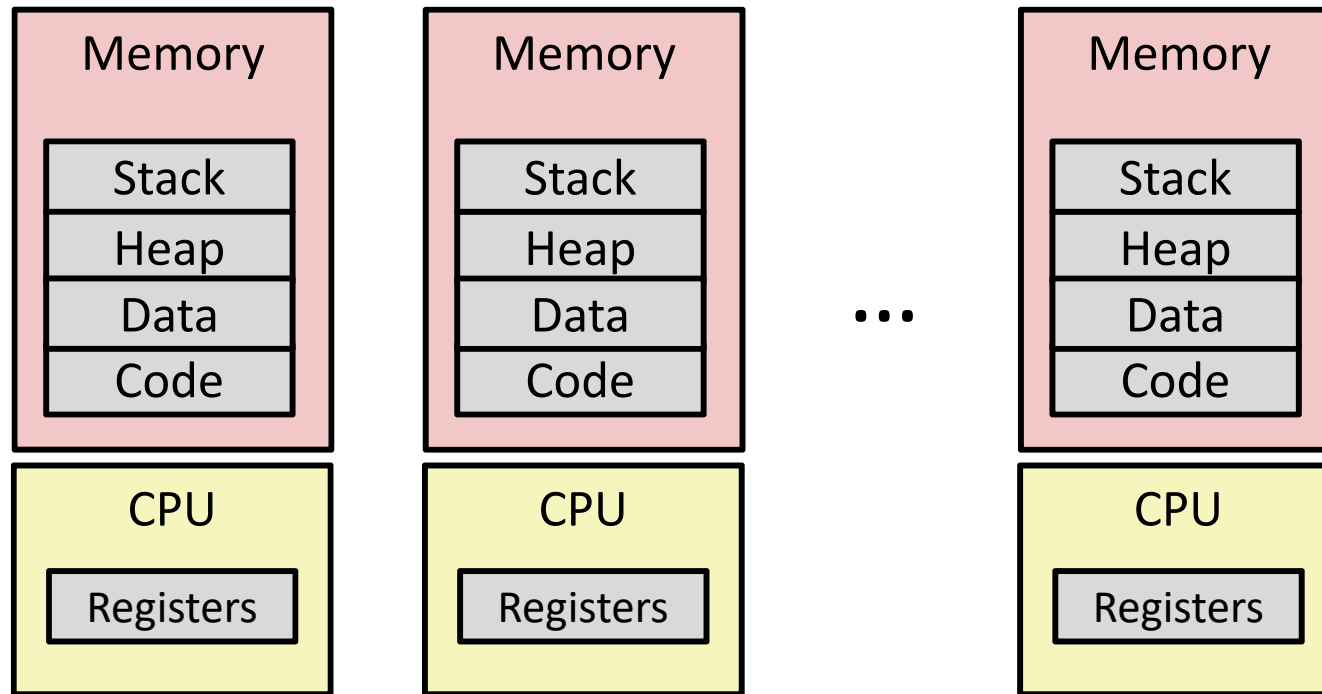


What is a process?

It's an illusion!

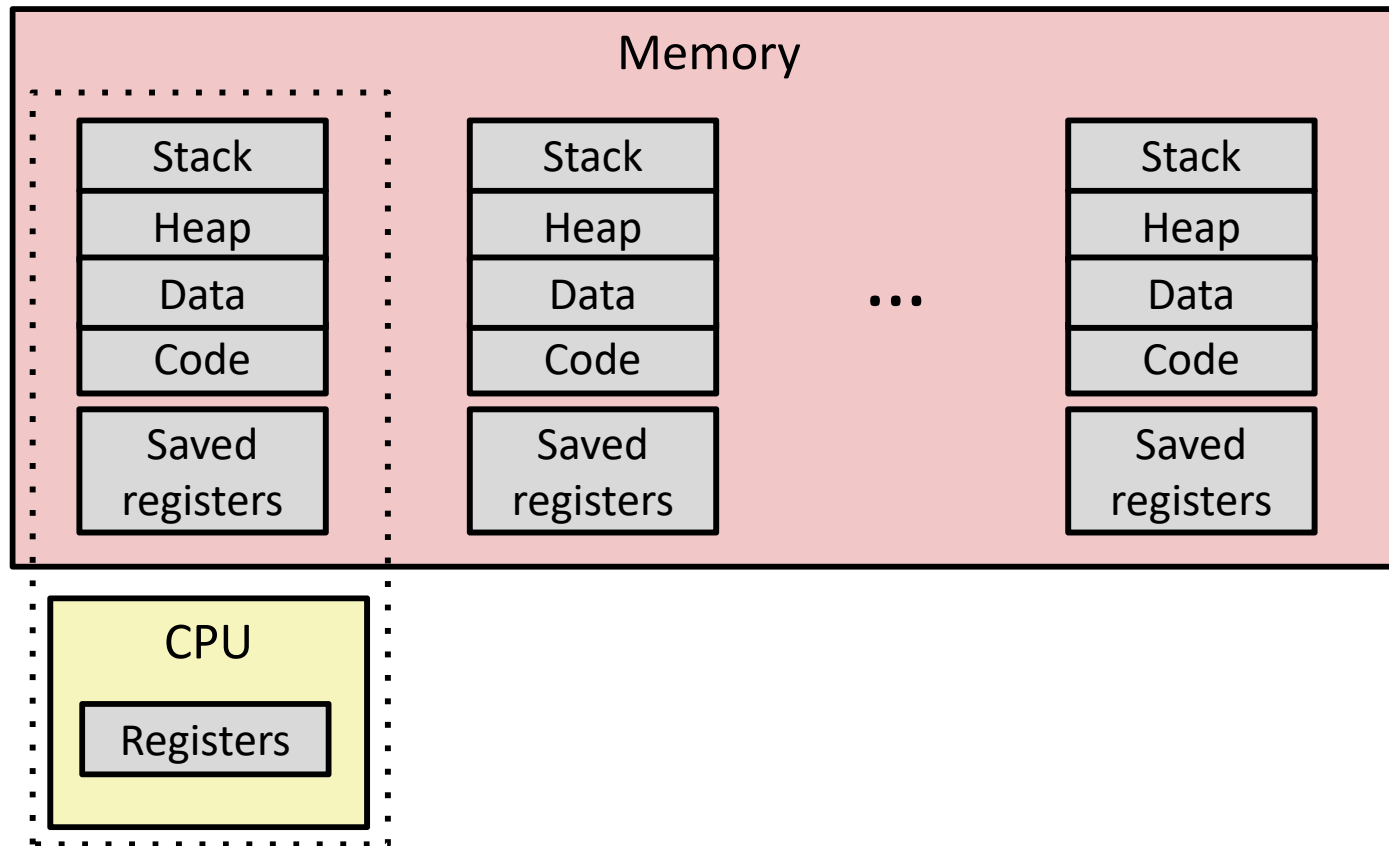


Multiprocessing: The Illusion



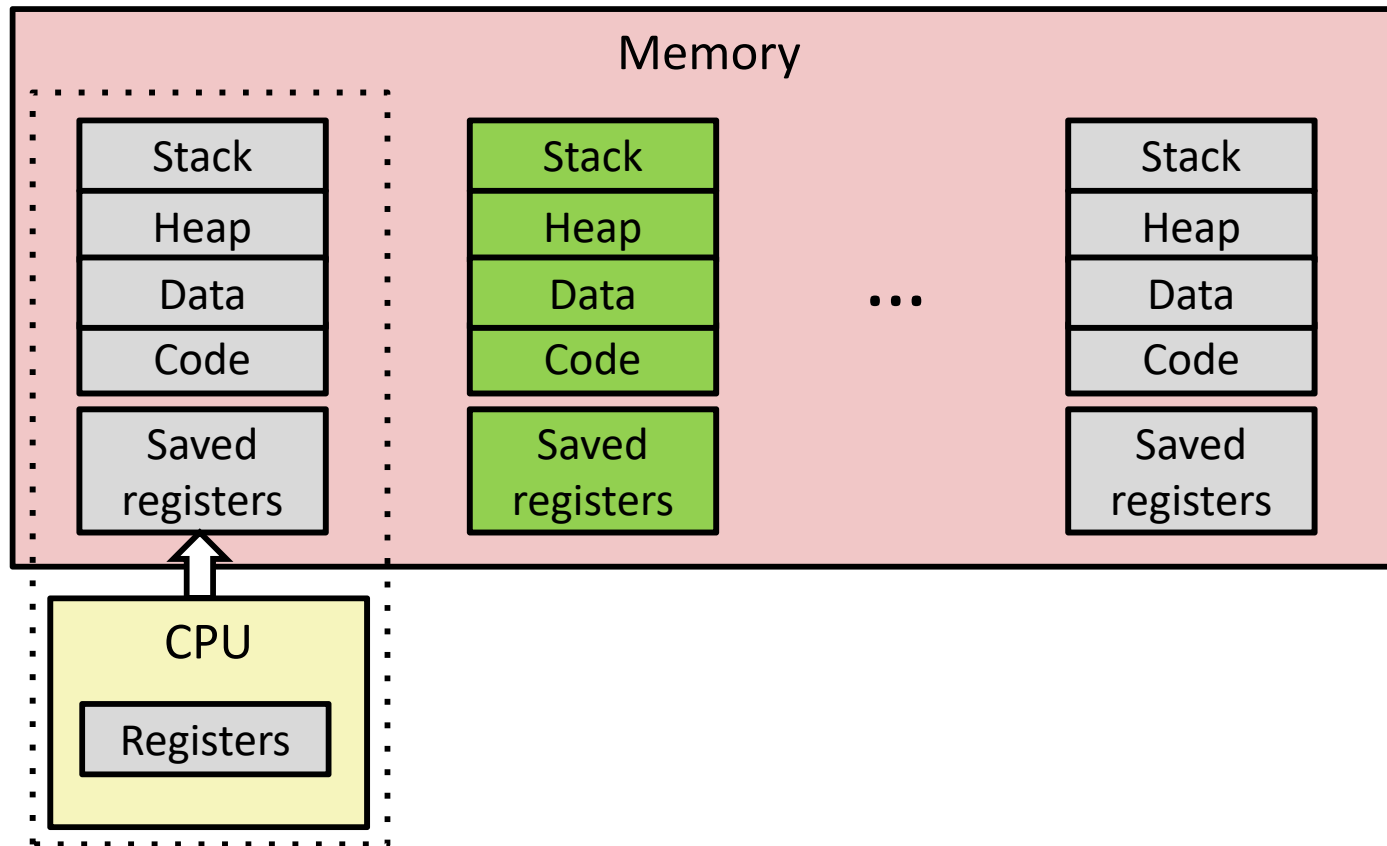
- ❖ Computer runs many processes simultaneously
 - Applications for one or more users
 - Web browsers, email clients, editors, ...
 - Background tasks
 - Monitoring network & I/O devices

Multiprocessing: The Reality



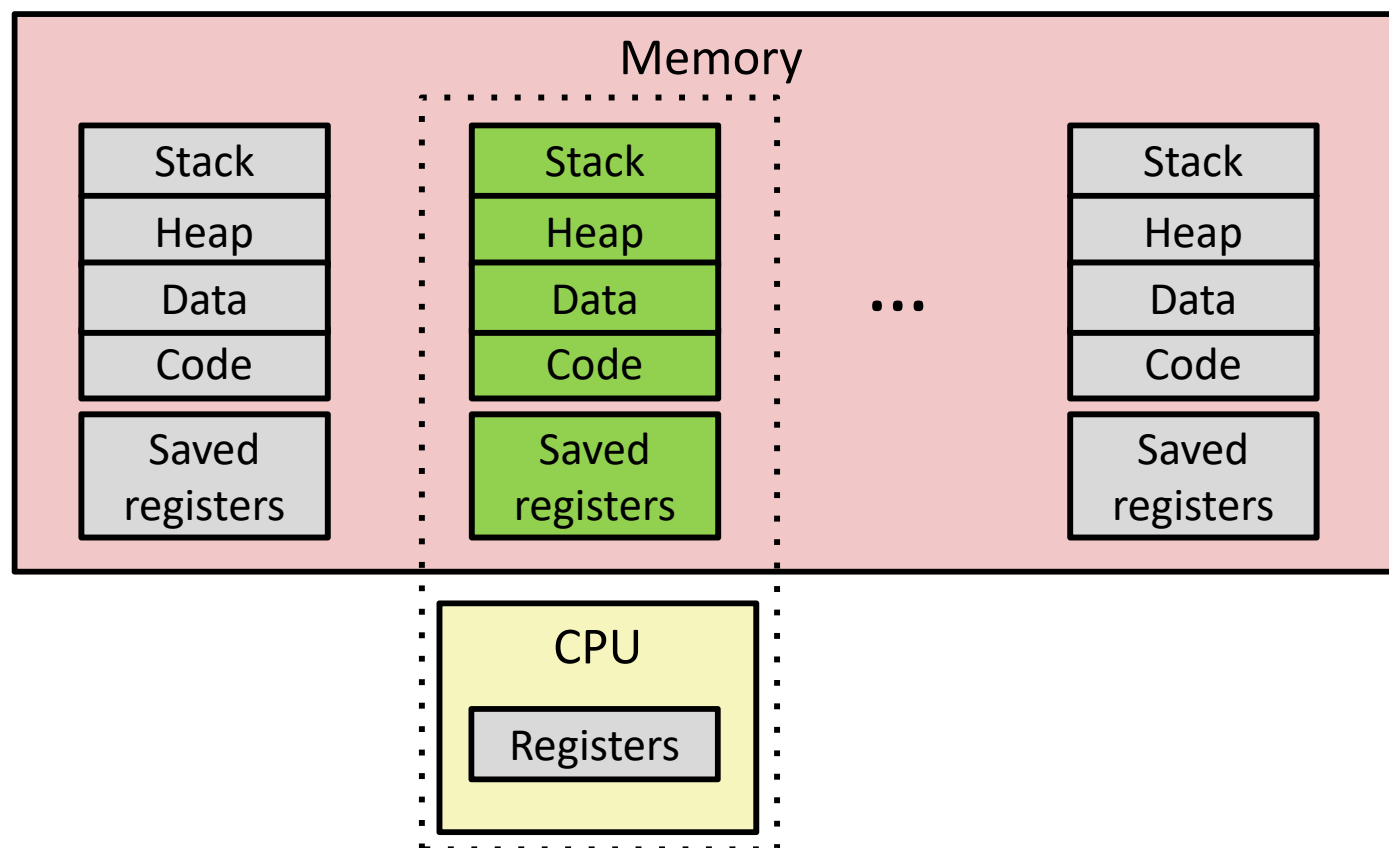
- ❖ Single processor executes multiple processes *concurrently*
 - Process executions interleaved, CPU runs *one at a time*
 - Address spaces managed by virtual memory system (later in course)
 - *Execution context* (register values, stack, ...) for other processes saved in memory

Multiprocessing



- ❖ **Context switch**
 - 1) **Save current registers in memory**

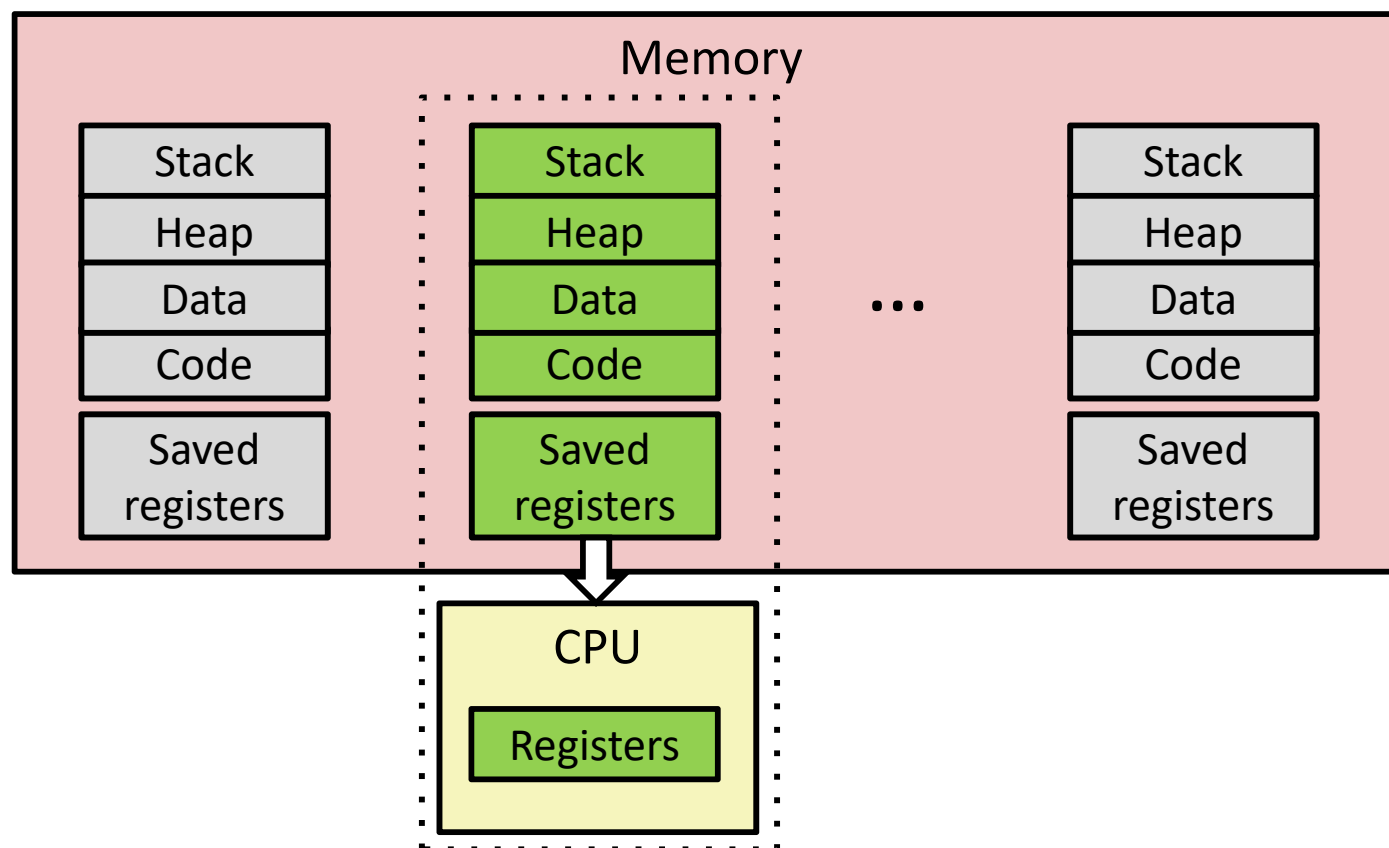
Multiprocessing



❖ Context switch

- 1) Save current registers in memory
- 2) **Schedule next process for execution**

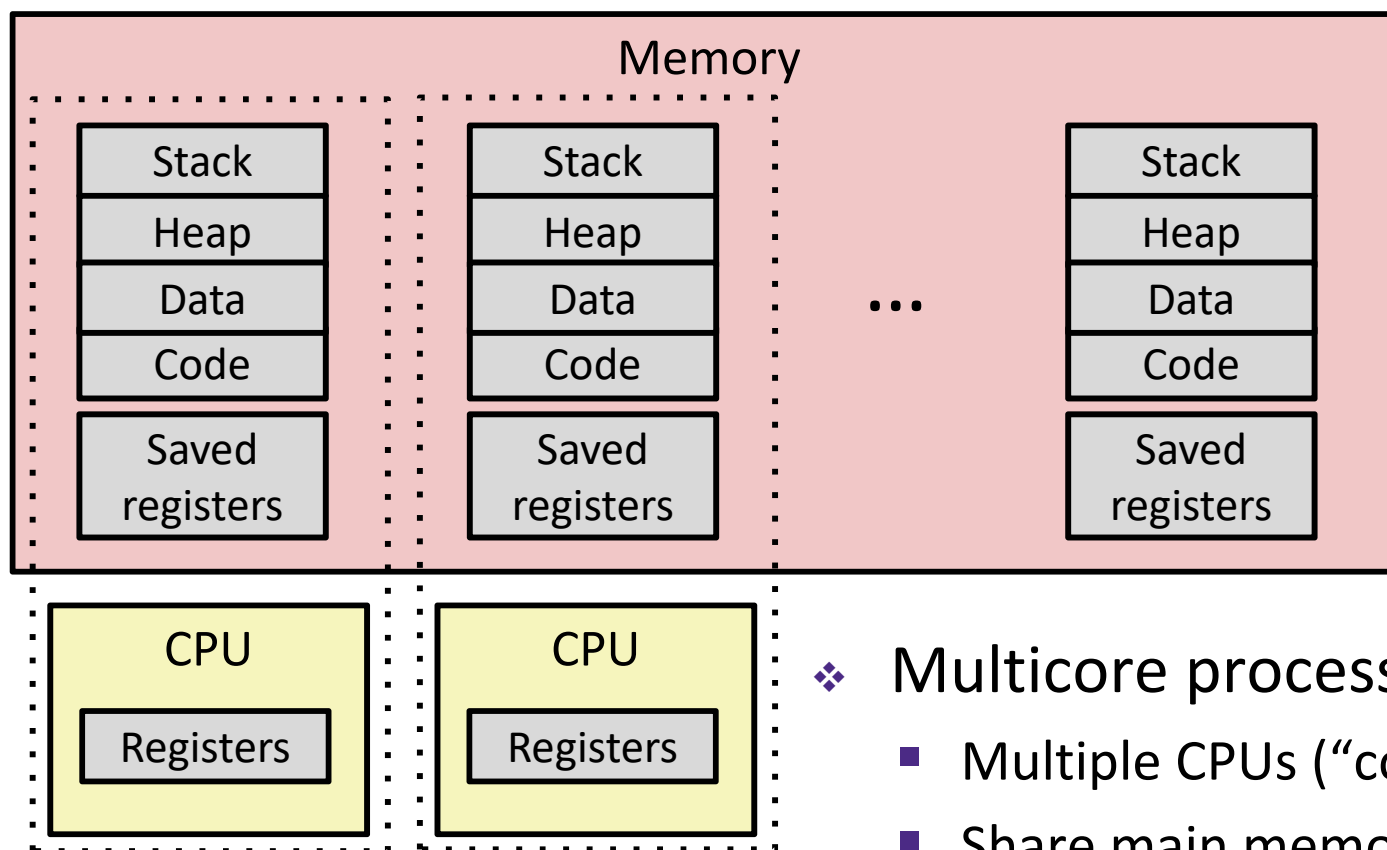
Multiprocessing



❖ Context switch

- 1) Save current registers in memory
- 2) Schedule next process for execution
- 3) **Load saved registers and switch address space**

Multiprocessing: The (Modern) Reality



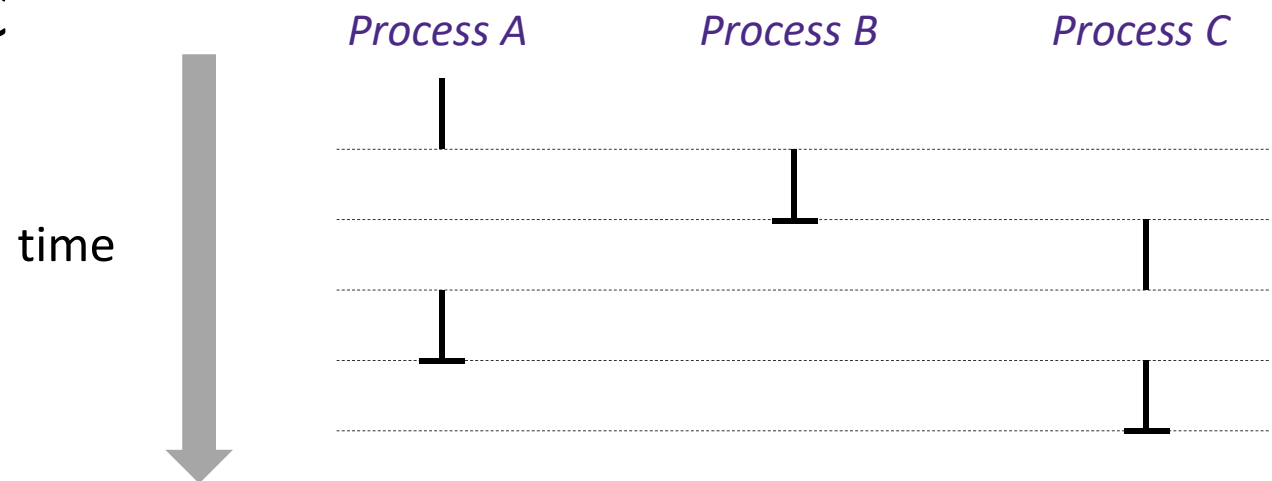
❖ Multicore processors

- Multiple CPUs (“cores”) on single chip
- Share main memory (and some of the caches)
- Each can execute a separate process
 - Kernel schedules processes to cores
 - **Still constantly swapping processes**

Concurrent Processes

Assume only one CPU

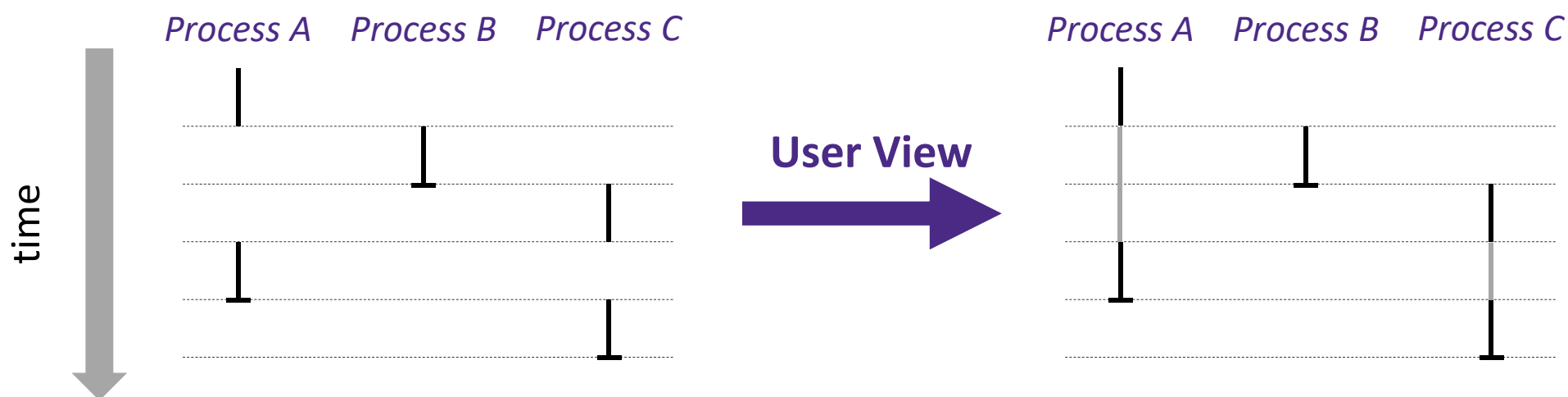
- ❖ Each process is a logical control flow
- ❖ Two processes *run concurrently* (are concurrent) if their instruction executions (flows) overlap in time
 - Otherwise, they are *sequential*
- ❖ Example: (running on single core)
 - Concurrent: A & B, A & C
 - Sequential: B & C



User's View of Concurrency

Assume only one CPU

- ❖ Control flows for concurrent processes are physically disjoint in time
 - CPU only executes instructions for one process at a time
- ❖ However, the user can *think of* concurrent processes as executing at the same time, in *parallel*

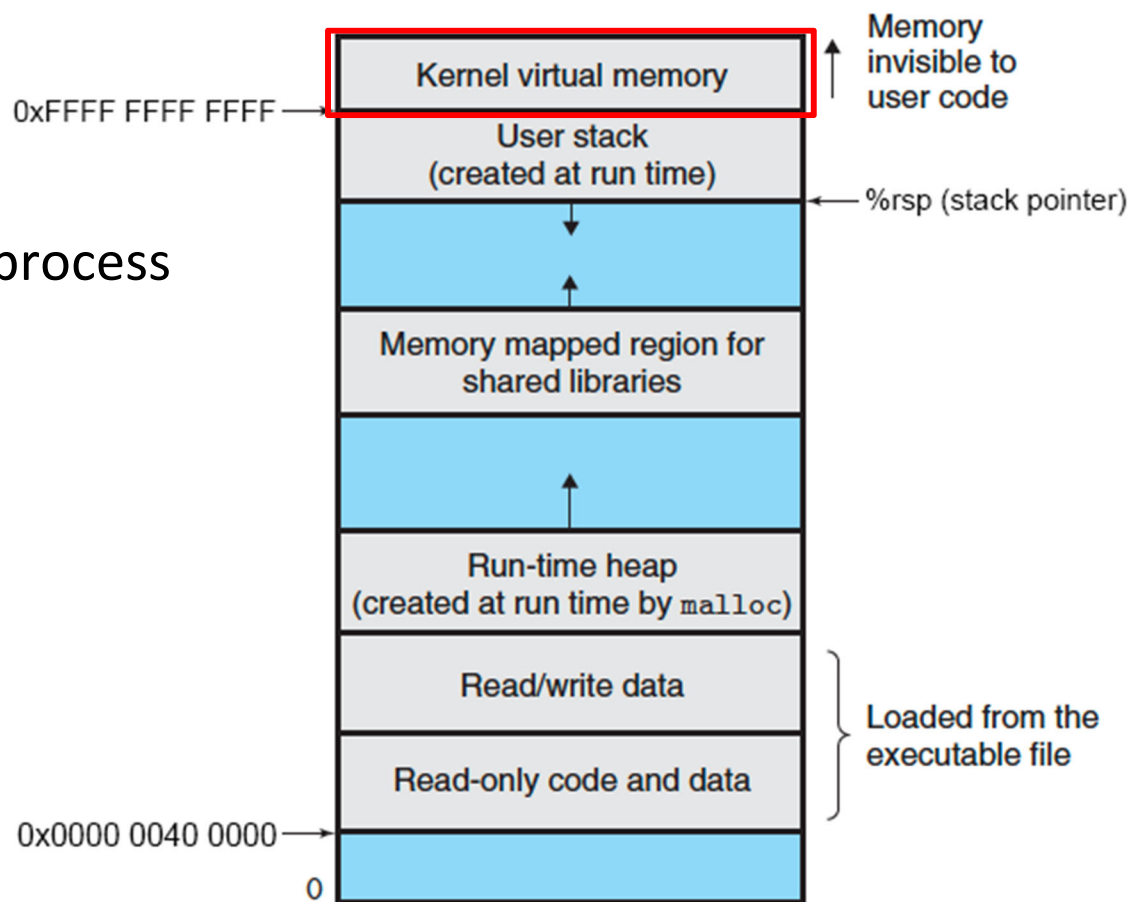


Assume only one CPU

Context Switching

- ❖ Processes are managed by a *shared* chunk of OS code called the **kernel**
 - The kernel is not a separate process, but rather runs as part of a user process

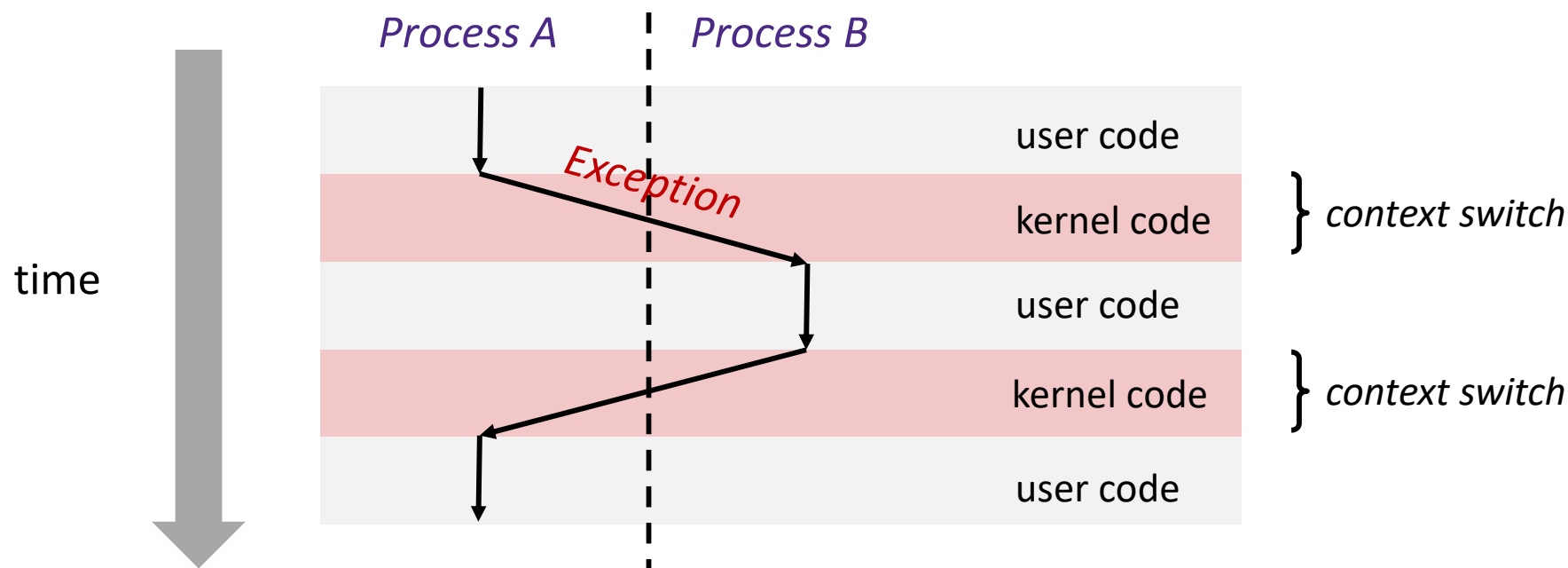
- ❖ In x86-64 Linux:
 - Same address in each process refers to same shared memory location



Context Switching

Assume only one CPU

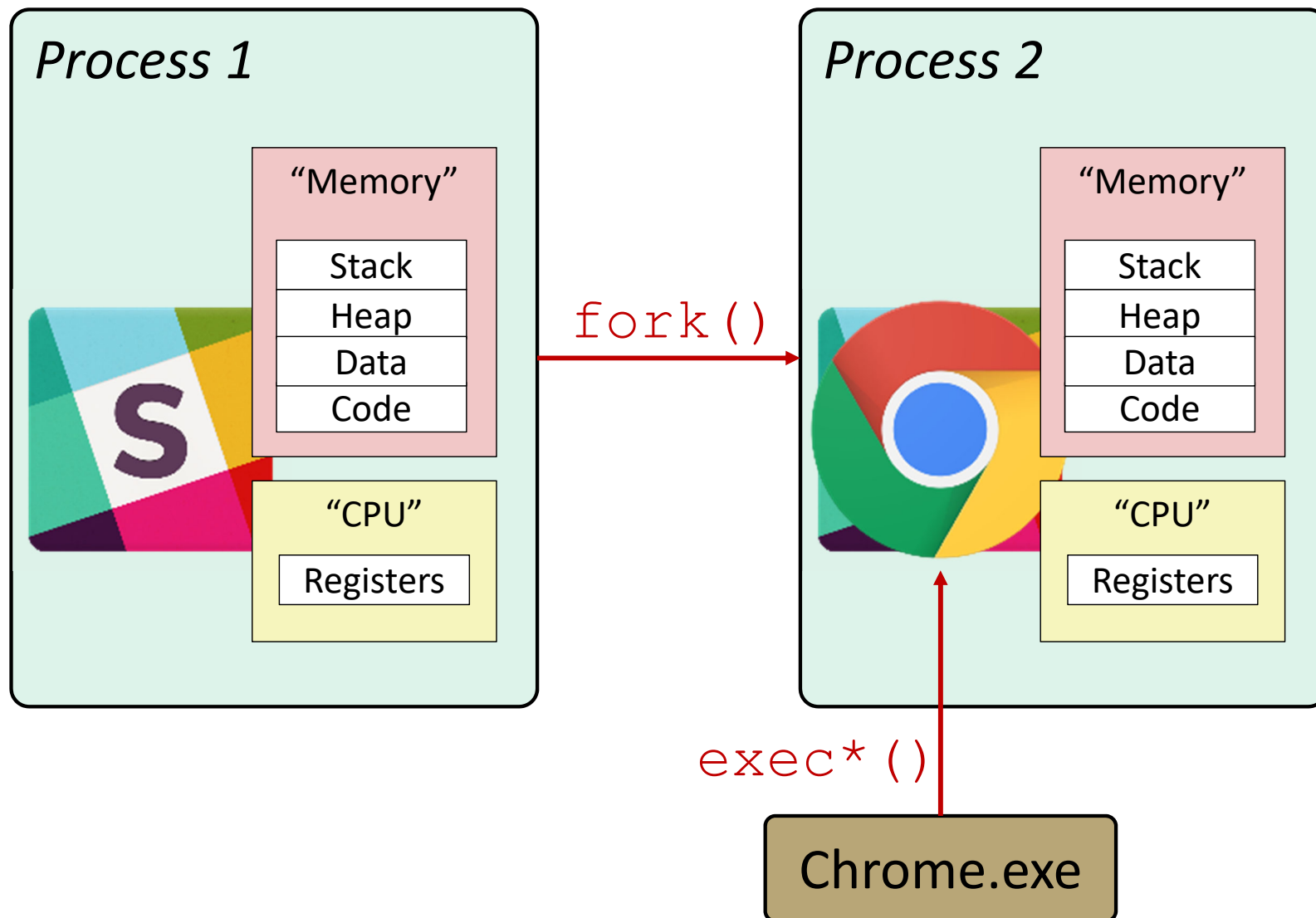
- ❖ Processes are managed by a *shared* chunk of OS code called the **kernel**
 - The kernel is not a separate process, but rather runs as part of a user process
- ❖ Context switch passes control flow from one process to another and is performed using kernel code



Processes

- ❖ Processes and context switching
- ❖ **Creating new processes**
 - `fork()`, `exec*()`, and `wait()`
- ❖ Zombies

Creating New Processes & Programs



Creating New Processes & Programs

- ❖ fork-exec model (Linux):
 - `fork()` creates a copy of the current process
 - `exec*` () replaces the current process' code and address space with the code for a different program
 - Family: `execv`, `execl`, `execve`, `execle`, `execvp`, `execlp`
 - `fork()` and `execve()` are *system calls*

- ❖ Other system calls for process management:
 - `getpid()`
 - `exit()`
 - `wait()`, `waitpid()`

fork: Creating New Processes

❖ `pid_t fork(void)`

- Creates a new “**child**” process that is *identical* to the calling “**parent**” process, including all state (memory, registers, etc.)
- Returns 0 to the **child** process
- Returns child’s **process ID (PID)** to the **parent** process

❖ Child is *almost* identical to parent:

- Child gets an identical (but separate) copy of the parent’s virtual address space
- Child has a different PID than the parent

```
pid_t pid = fork();
if (pid == 0) {
    printf("hello from child\n");
} else {
    printf("hello from parent\n");
}
```

- ❖ `fork` is unique (and often confusing) because it is called **once** but returns “**twice**”

Understanding fork

Process X (parent)



```
pid_t pid = fork();  
if (pid == 0) {  
    printf("hello from child\n");  
} else {  
    printf("hello from parent\n");  
}
```

Process Y (child)



```
pid_t pid = fork();  
if (pid == 0) {  
    printf("hello from child\n");  
} else {  
    printf("hello from parent\n");  
}
```

Understanding fork

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Process Y (child)



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pid_t pid = fork();
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    printf("hello from child\n");
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}
```



```
pid_t pid = fork();
if (pid == 0) {
    printf("hello from child\n");
} else {
    printf("hello from parent\n");
}
```

pid = Y




```
pid_t pid = fork();
if (pid == 0) {
    printf("hello from child\n");
} else {
    printf("hello from parent\n");
}
```

pid = 0


Understanding fork

Process X (parent)




```
pid_t pid = fork();  
if (pid == 0) {  
    printf("hello from child\n");  
} else {  
    printf("hello from parent\n");  
}
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Process Y (child)




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```
pid_t pid = fork();  
if (pid == 0) {  
    printf("hello from child\n");  
} else {  
    printf("hello from parent\n");  
}
```

pid = Y

hello from parent



```
pid_t pid = fork();  
if (pid == 0) {  
    printf("hello from child\n");  
} else {  
    printf("hello from parent\n");  
}
```

pid = 0

hello from child

Which one appears first?

Fork Example

```
void fork1() {
    int x = 1;
    pid_t pid = fork();
    if (pid == 0)
        printf("Child has x = %d\n", ++x);
    else
        printf("Parent has x = %d\n", --x);
    printf("Bye from process %d with x = %d\n", getpid(), x);
}
```

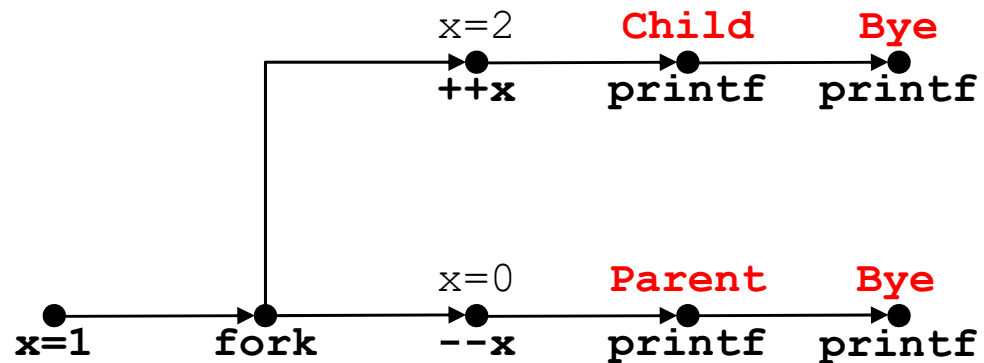
- ❖ Both processes continue/start execution after `fork`
 - Child starts at instruction after the call to `fork` (storing into `pid`)
- ❖ Can't predict execution order of parent and child
- ❖ Both processes start with `x=1`
 - Subsequent changes to `x` are independent
- ❖ Shared open files: `stdout` is the same in both parent and child

Modeling fork with Process Graphs

- ❖ A *process graph* is a useful tool for capturing the partial ordering of statements in a concurrent program
 - Each vertex is the execution of a statement
 - $a \rightarrow b$ means a happens before b
 - Edges can be labeled with current value of variables
 - `printf` vertices can be labeled with output
 - Each graph begins with a vertex with no inedges
- ❖ Any *topological sort* of the graph corresponds to a feasible total ordering
 - Total ordering of vertices where all edges point from left to right

Fork Example: Possible Output

```
void fork1() {  
    int x = 1;  
    pid_t pid = fork();  
    if (pid == 0)  
        printf("Child has x = %d\n", ++x);  
    else  
        printf("Parent has x = %d\n", --x);  
    printf("Bye from process %d with x = %d\n", getpid(), x);  
}
```



Peer Instruction Question

❖ Are the following sequences of outputs possible?

■ Vote at <http://PollEv.com/justinh>

```
void nestedfork() {
    printf("L0\n");
    if (fork() == 0) {
        printf("L1\n");
        if (fork() == 0) {
            printf("L2\n");
        }
    }
    printf("Bye\n");
}
```

Seq 1:

L0

L1

Bye

Bye

Bye

L2

Seq 2:

L0

Bye

L1

L2

Bye

Bye

- | | | |
|-----------|----------------------|------------|
| A. | No | No |
| B. | No | Yes |
| C. | Yes | No |
| D. | Yes | Yes |
| E. | We're lost... | |

Fork-Exec

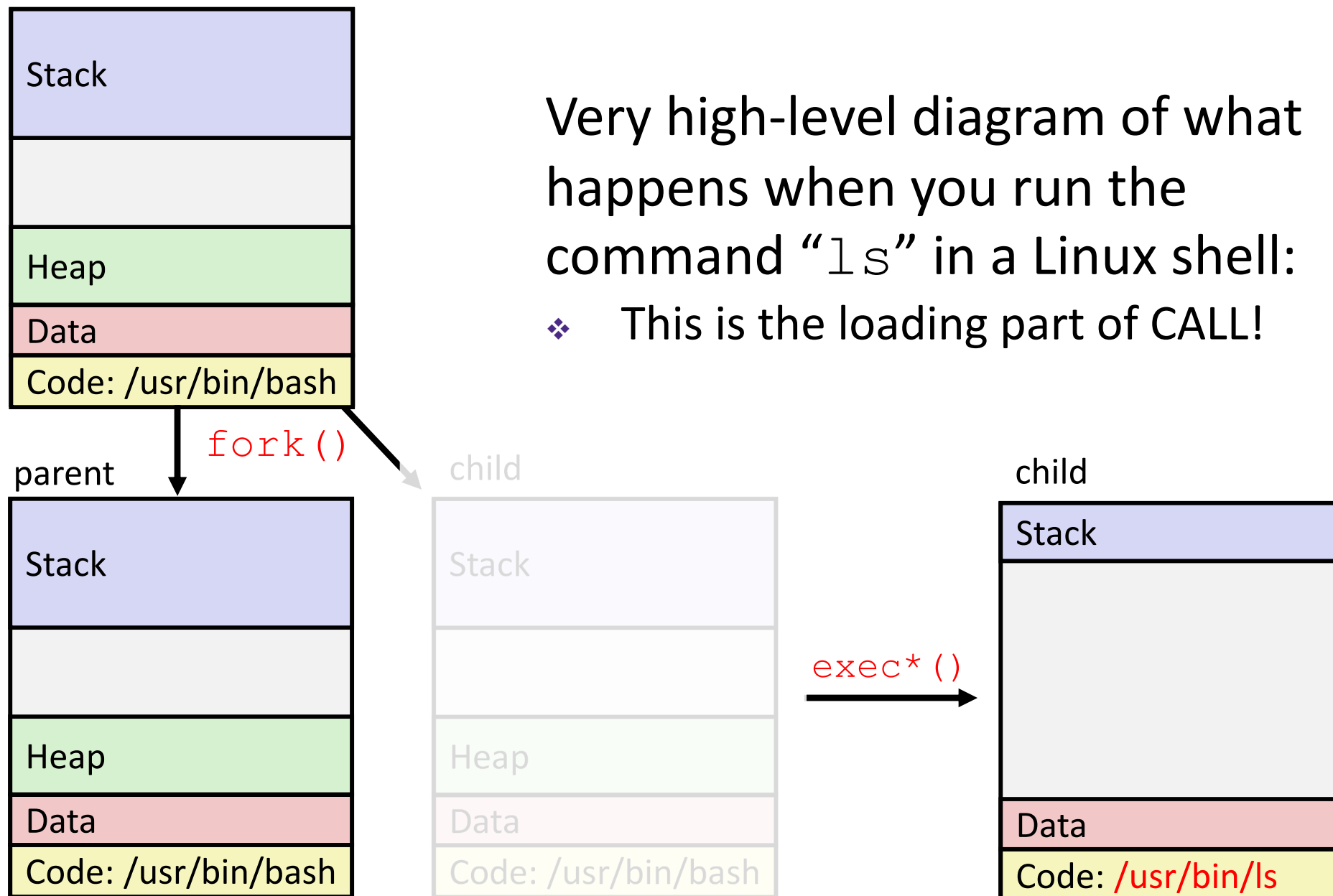
Note: the return values of `fork` and `exec*` should be checked for errors

❖ fork-exec model:

- `fork()` creates a copy of the current process
- `exec*` replaces the current process' code and address space with the code for a different program
 - Whole family of `exec` calls – see **`exec(3)`** and **`execve(2)`**

```
// Example arguments: path="/usr/bin/ls",
//      argv[0]="/usr/bin/ls", argv[1]="-ahl", argv[2]=NULL
void fork_exec(char *path, char *argv[]) {
    pid_t pid = fork();
    if (pid != 0) {
        printf("Parent: created a child %d\n", pid);
    } else {
        printf("Child: about to exec a new program\n");
        execv(path, argv);
    }
    printf("This line printed by parent only!\n");
}
```

Exec-ing a new program



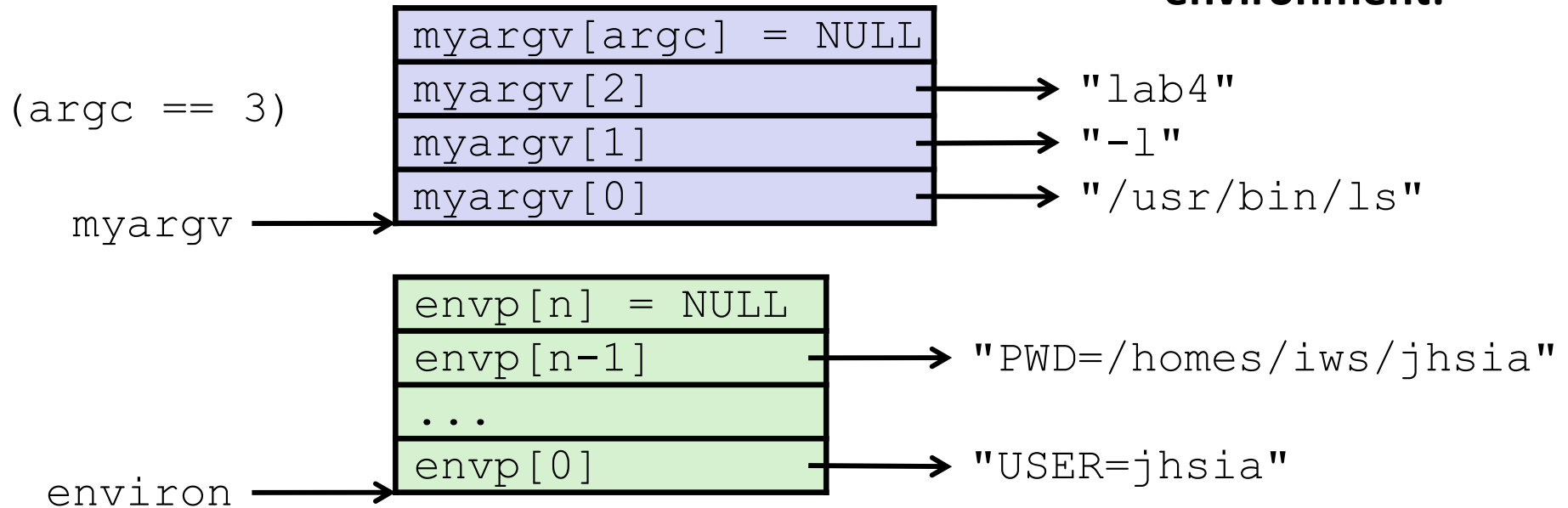
Very high-level diagram of what happens when you run the command “ls” in a Linux shell:

- ❖ This is the loading part of CALL!

execve Example

This is extra
(non-testable)
material

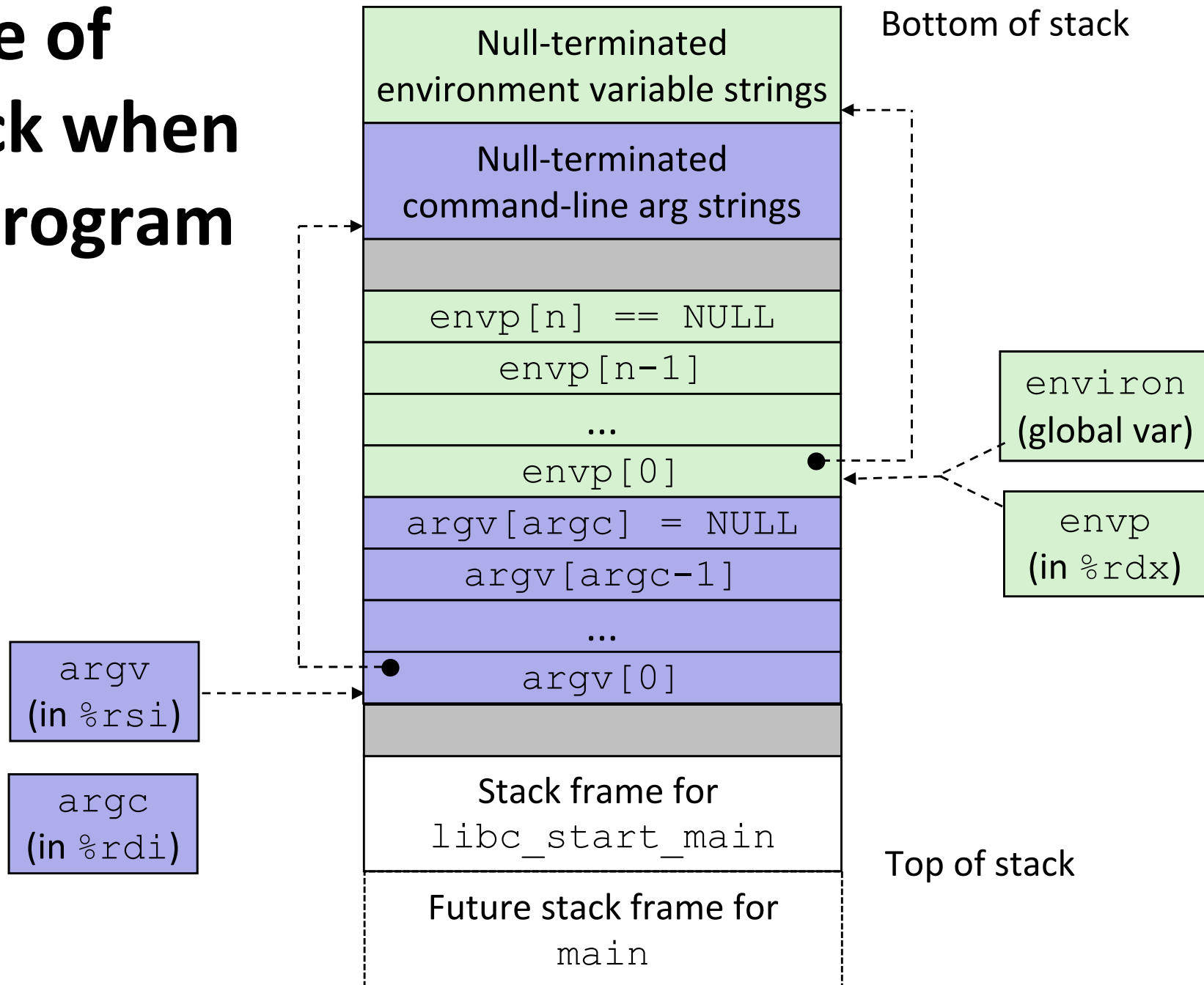
Execute `"/usr/bin/ls -l lab4"` in child process using current environment:



```
if ((pid = fork()) == 0) { /* Child runs program */
    if (execve(myargv[0], myargv, environ) < 0) {
        printf("%s: Command not found.\n", myargv[0]);
        exit(1);
    }
}
```

Run the `printenv` command in a Linux shell to see your own environment variables

Structure of the Stack when a new program starts



This is extra (non-testable) material

exit: Ending a process

- ❖ `void exit(int status)`
 - Explicitly exits a process
 - Status code: 0 is used for a normal exit, nonzero for abnormal exit
- ❖ The `return` statement from `main()` also ends a process in C
 - The return value is the status code

Summary

❖ Processes

- At any given time, system has multiple active processes
- On a one-CPU system, only one can execute at a time, but each process appears to have total control of the processor
- OS periodically “context switches” between active processes
 - Implemented using *exceptional control flow*

❖ Process management

- `fork`: one call, two returns
- `execve`: one call, usually no return
- `wait` or `waitpid`: synchronization
- `exit`: one call, no return

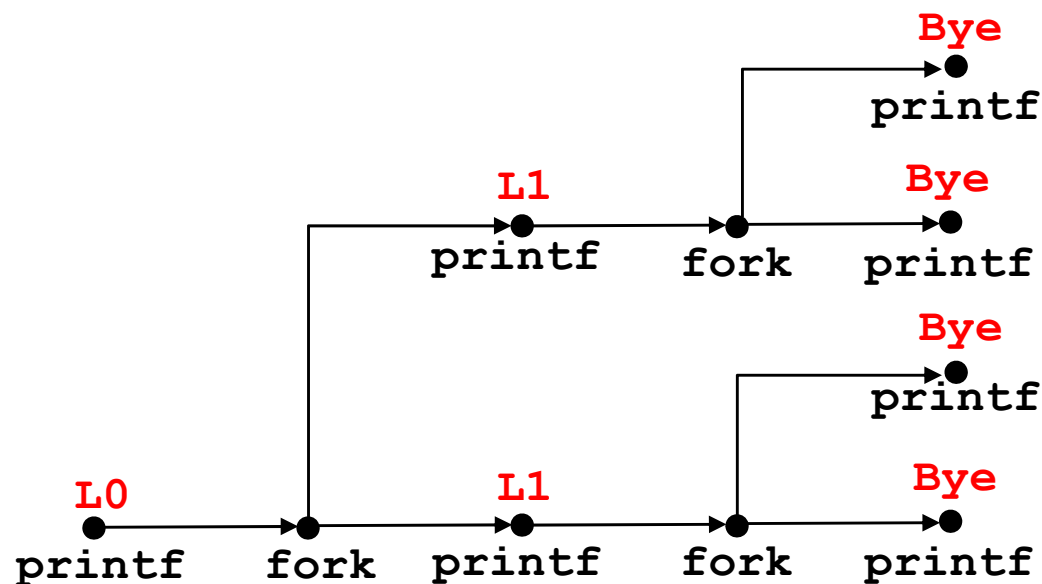
BONUS SLIDES

Detailed examples:

- ❖ Consecutive forks

Example: Two consecutive forks

```
void fork2() {
    printf("L0\n");
    fork();
    printf("L1\n");
    fork();
    printf("Bye\n");
}
```



Feasible output:

L0
L1
Bye
Bye
L1
Bye
Bye

Infeasible output:

L0
Bye
L1
Bye
L1
Bye
Bye

Example: Three consecutive forks

- ❖ Both parent and child can continue forking

```
void fork3() {  
    printf("L0\n");  
    fork();  
    printf("L1\n");  
    fork();  
    printf("L2\n");  
    fork();  
    printf("Bye\n");  
}
```

