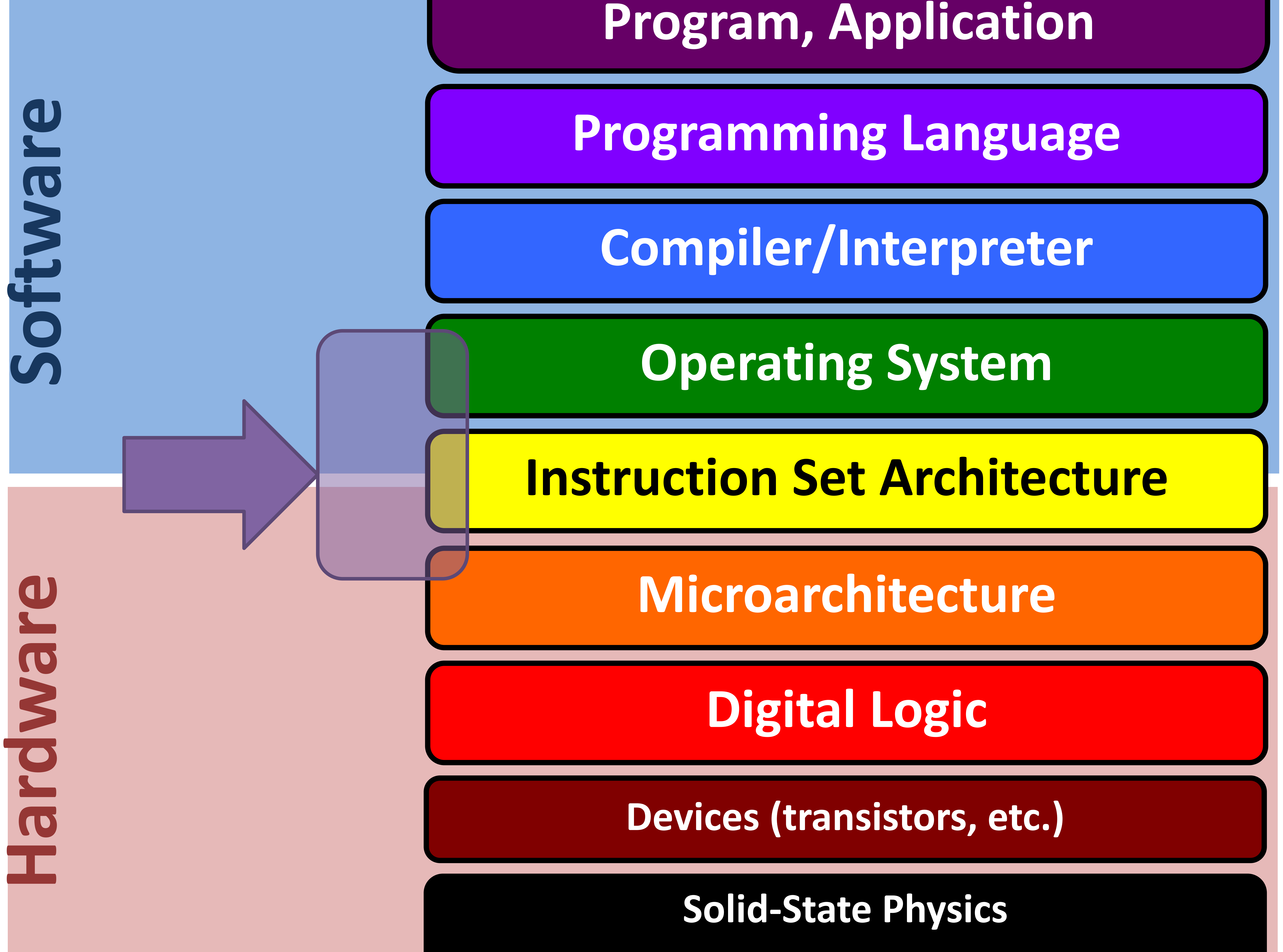
Operating Systems and the Process Model

Process model

Process management

(Unix/Linux/macOS)


Software
Hardware
Program, Application
Programming Language
Compiler/Interpreter
Operating System
Instruction Set Architecture
Microarchitecture
Digital Logic
Devices (transistors, etc.)
Solid-State Physics

Motivation

Why doesn't this program disable my laptop entirely?

```
int main() {
    while (true) {
    }
}
```

Operating Systems

Problems:

- The overall system shouldn't go down for one bad program
- One set of resources, many different software programs!
- The hardware itself varies across computers

Solution: operating system

Manage, abstract, and virtualize hardware resources

Share limited resources among varied software programs

Protect (from both accidental and malicious damage)

Simpler, common interface to varied hardware

Operating Systems, a 240 view

barely scraping the surface!

Key abstractions provided by *kernel*

processes

virtual memory

Virtualization mechanisms and hardware support:

context-switching

exceptional control flow

memory isolation, address translation, paging

Processes

Program = code (static)

Process = a running program instance (dynamic)

code + state (contents of registers, memory, other resources)

Key illusions:

Logical control flow

Each process seems to have exclusive use of the CPU

This unit (parts)

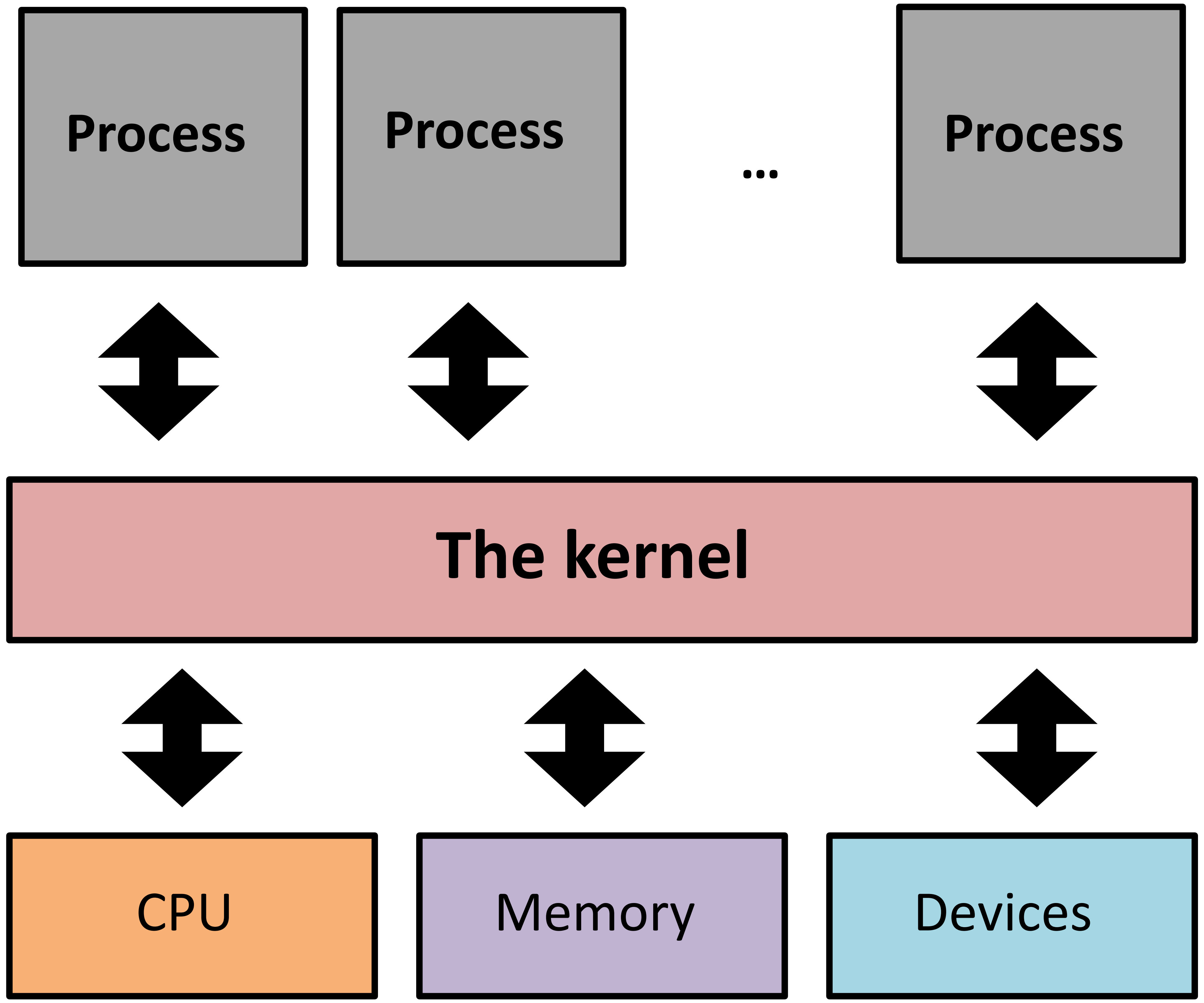
Private address space

Each process seems to have exclusive use of full memory

Not in detail this semester
But read optional slides & CSAPP!

Why? How?

The kernel manages processes



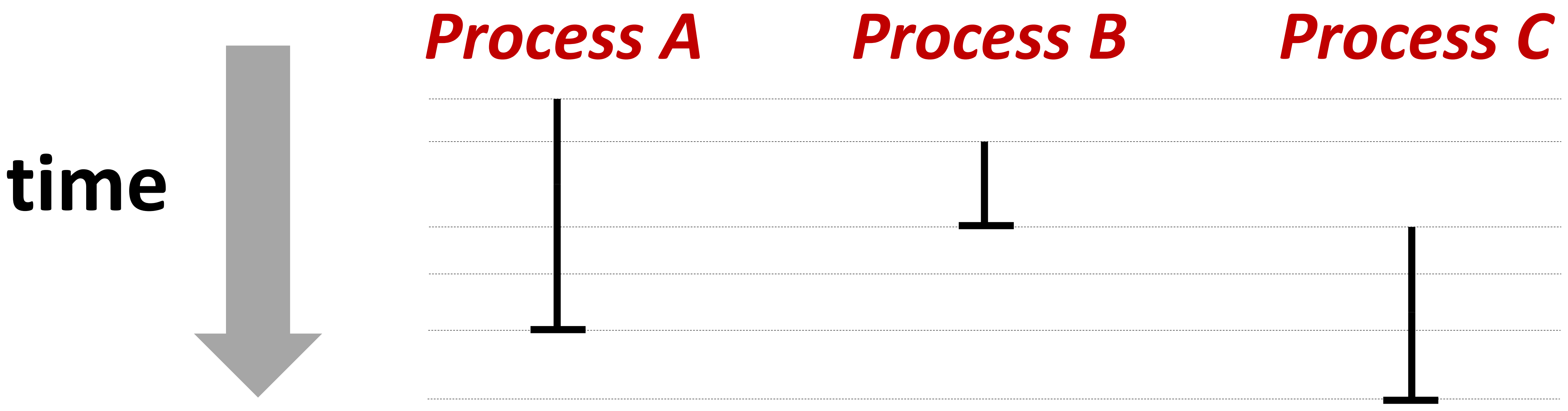
The kernel:

- Runs with full machine privilege
  - On x86: special `%cs` register
- Can interrupt processes
- Manages sharing of resources

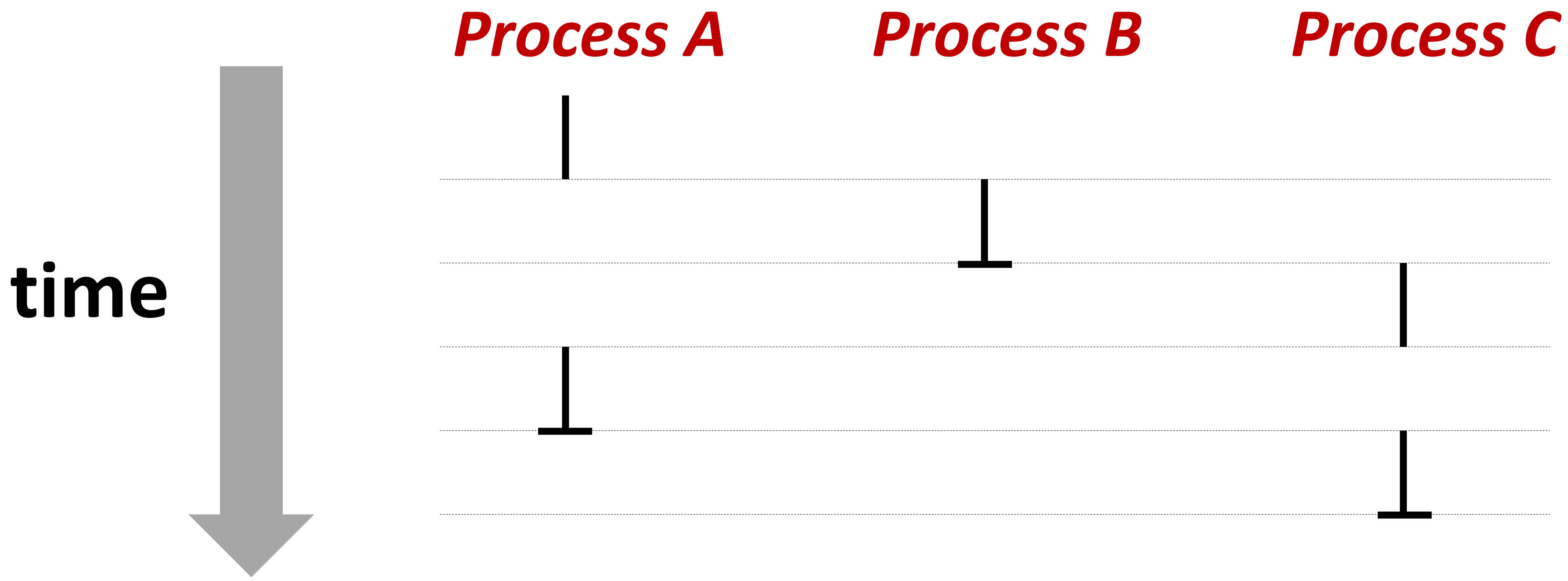
Is a program (almost*) like any other!

Implementing logical control flow

Abstraction: every process has full control over the CPU



Implementation: time-sharing

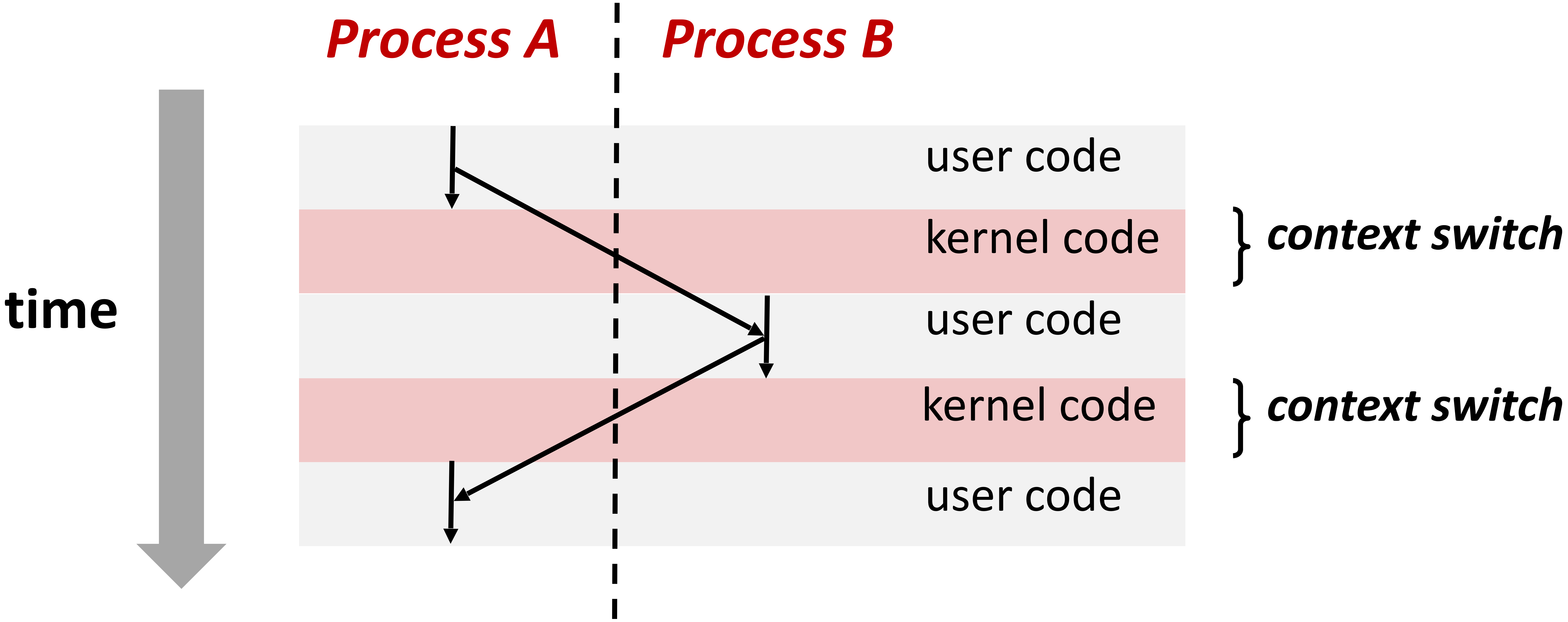


Context Switching

Kernel (shared OS code) switches between processes

Control flow passes between processes via *context switch.*

Context =



`fork`

`pid_t fork()`

1. **Clone** current ***parent*** process to **create** identical* ***child*** process, including all state (memory, registers, **program counter,** …).
2. Continue executing both copies with ***one difference:***
   - **returns 0** to the **child process**
   - **returns child's process ID (`pid`)** to the **parent process**

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

`fork` is unique: called *in one process,* returns *in two processes!*

(once in parent, once in child)

*almost. See `man 3 fork` for exceptions.

Creating a new process with **fork**

Process n

execution

1

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

2

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

3

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

Child Process m

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

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

`hello from parent`

Which prints first?

`hello from child`

`fork` and private copies

Parent and child continue from *private copies* of same state.

Memory contents (**code**, globals, **heap**, **stack**, etc.),
Register contents, **program counter**, file descriptors…

Only difference: return value from `fork()`

Relative execution order of parent/child after `fork()` undefined

```
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);
}
```

fork-exec

fork() clone current process

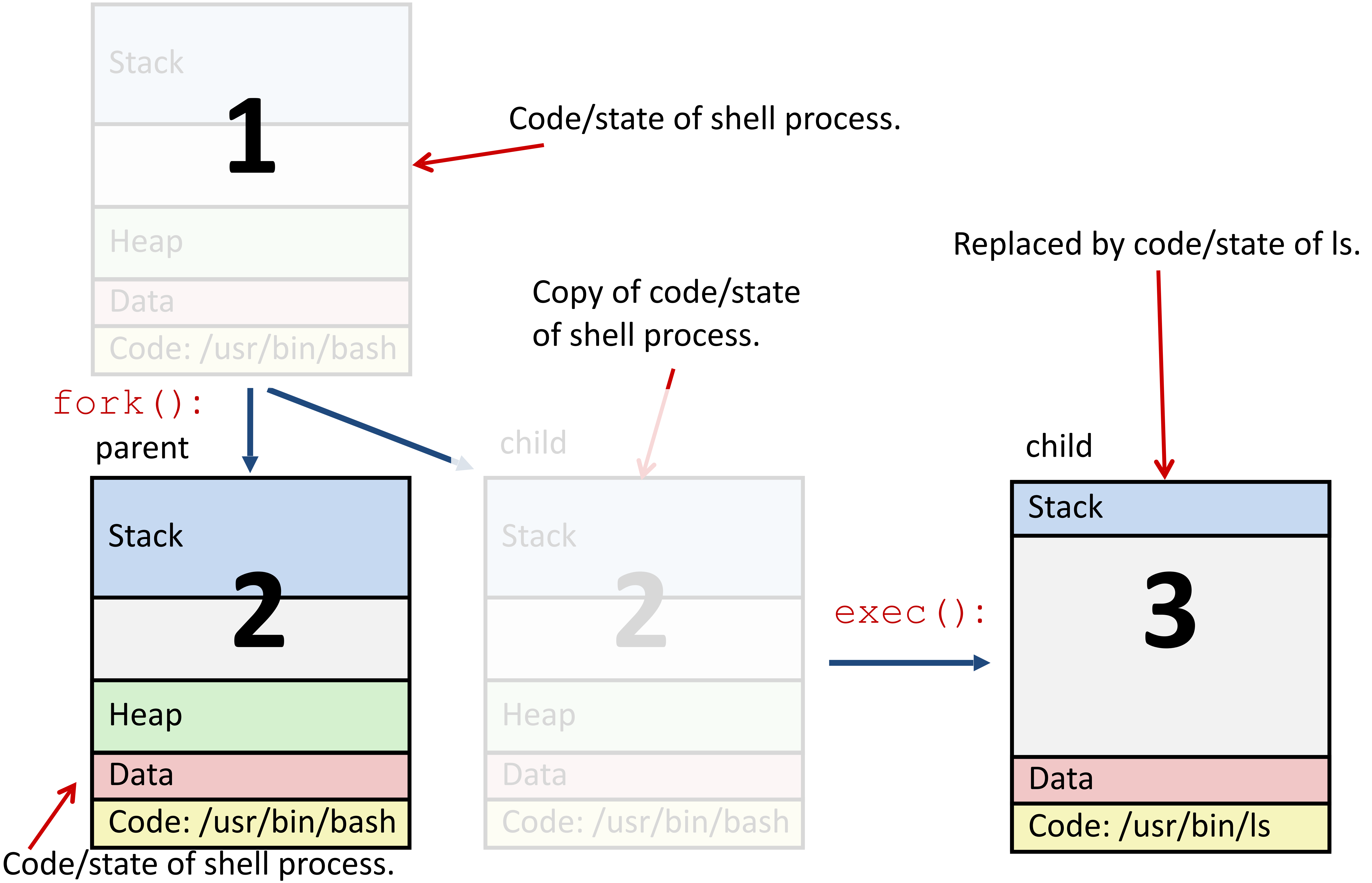
execv() replace process code and context (registers, memory)
with a fresh program.

See **man 3 execv**, man 2 execve

```
// 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: exec-ing new program now\n");
        execv(path, argv);
    }
    printf("This line printed by parent only!\n");
}
```

Executing a new program

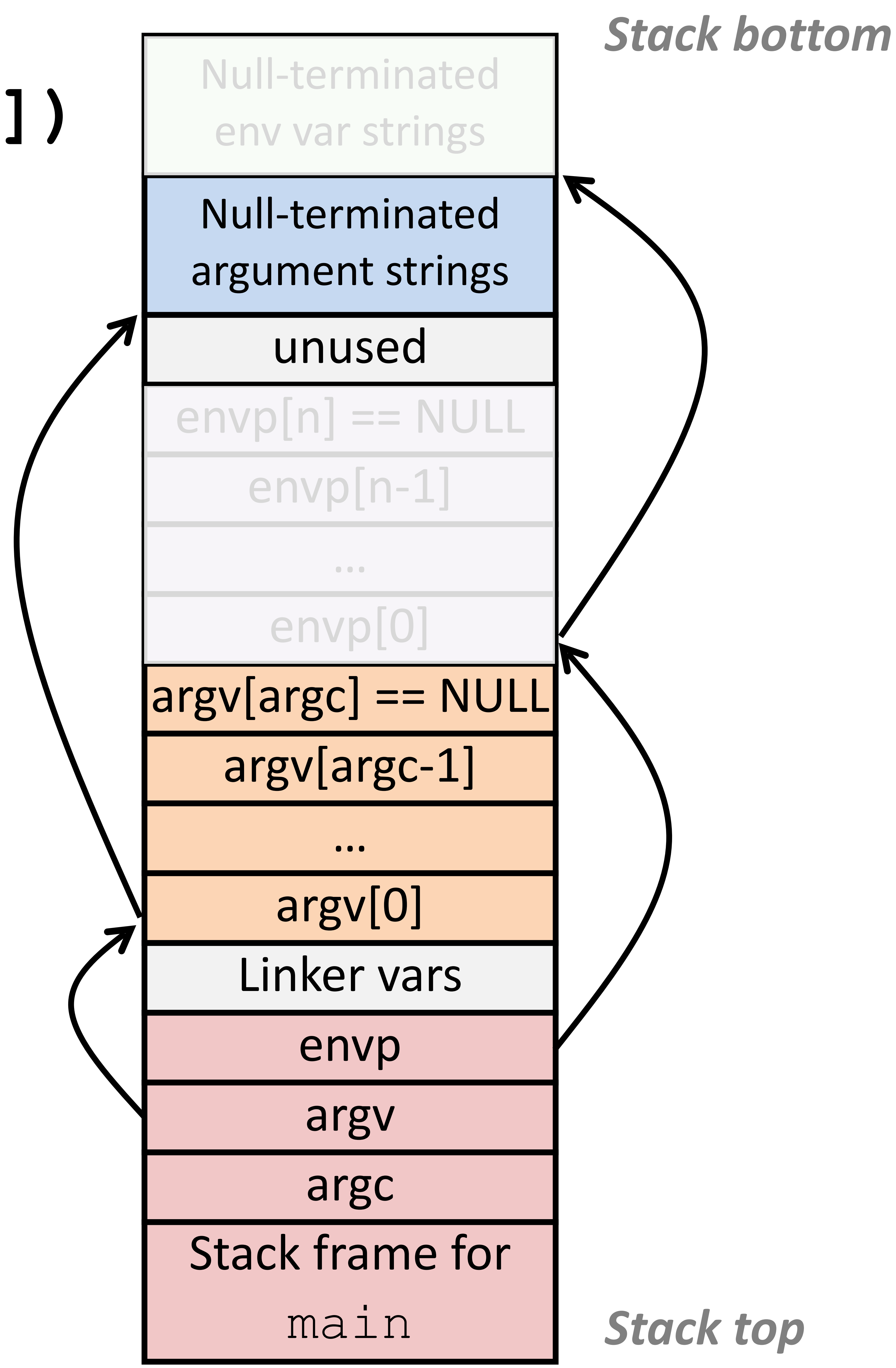
Running the command `ls` in a shell:



`execv`: load/start a program

```
int execv(char* filename,char* argv[])
```

- Loads/starts program in current process:
  - Executable **`filename`**
  - With argument list **`argv`**
- Overwrites code, data, and stack
  - Keeps pid, open files, a few other items
- *Does not return*
  - unless error



Also sets up *environment*. See also: `execve`.

`exit`: end a process

```
void exit(int status)
```

End process with status: 0 = normal, nonzero = error.

`atexit()` registers functions to be executed upon exit

`wait` for child processes to terminate

`pid_t waitpid(pid_t pid, int* stat, int ops)`

Suspend current process (i.e. parent) until child with **`pid`** ends.

On success:

- Return **`pid`** when child terminates.
- Reap child.
- If `stat != NULL`, waitpid saves termination reason where it points.

See also: *`man 3 waitpid`*

`waitpid` example

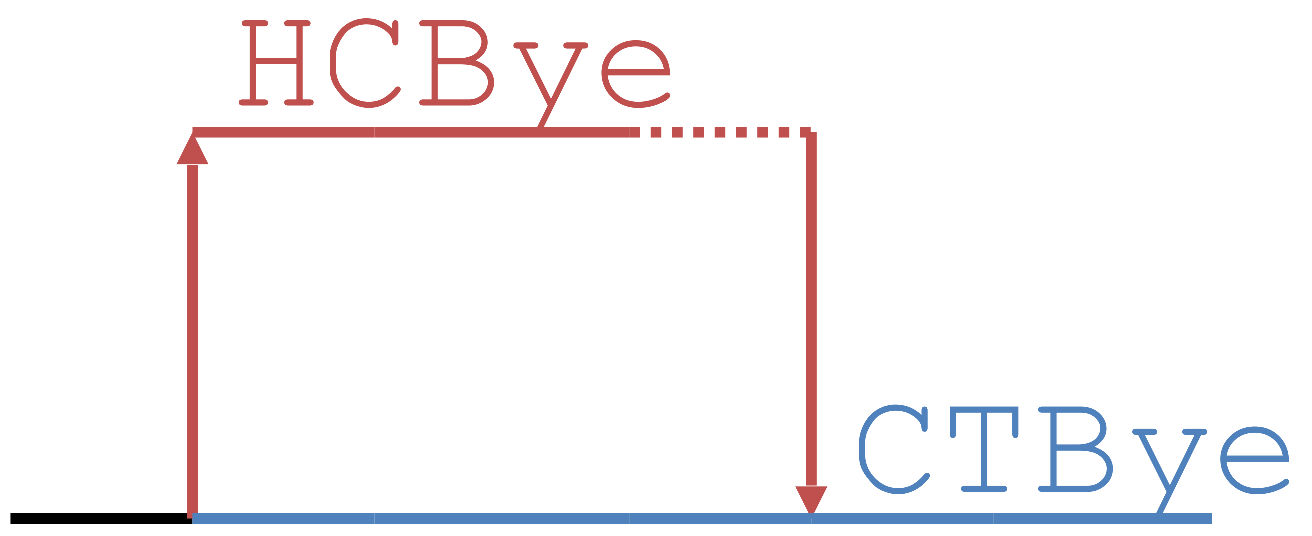
What is printed, in what order?

ex

```
void fork_wait() {
  int child_status;
  pid_t child_pid = fork();

  if (child_pid == 0) {
    printf("HC: hello from child\n");
  } else {
    if (-1 == waitpid(child_pid, &child_status, 0)) {
      perror("waitpid");
      exit(1);
    }
    printf("CT: child %d has terminated\n”, child_pid);
  }
  printf("Bye\n");
  exit(0);
}
```

`waitpid` example



ex

```
void fork_wait() {
  int child_status;
  pid_t child_pid = fork();

  if (child_pid == 0) {
    printf("HC: hello from child\n");
  } else {
    if (-1 == waitpid(child_pid, &child_status, 0)) {
      perror("waitpid");
      exit(1);
    }
    printf("CT: child %d has terminated\n", child_pid);
  }
  printf("Bye\n");
  exit(0);
}
```

Printed:

```
HC: hello from child
Bye
CT: child 1 has terminated
Bye
```

Zombies!

Terminated process still consumes system resources

Reaping with `wait/waitpid`

What if parent doesn't reap?

- If any parent terminates without reaping a child, then child will be reaped by **`systemd/init`** process (pid == 1)
- What if parent runs a long time? *e.g.*, shells and servers

Error-checking

Check return results of system calls for errors! (No exceptions.)

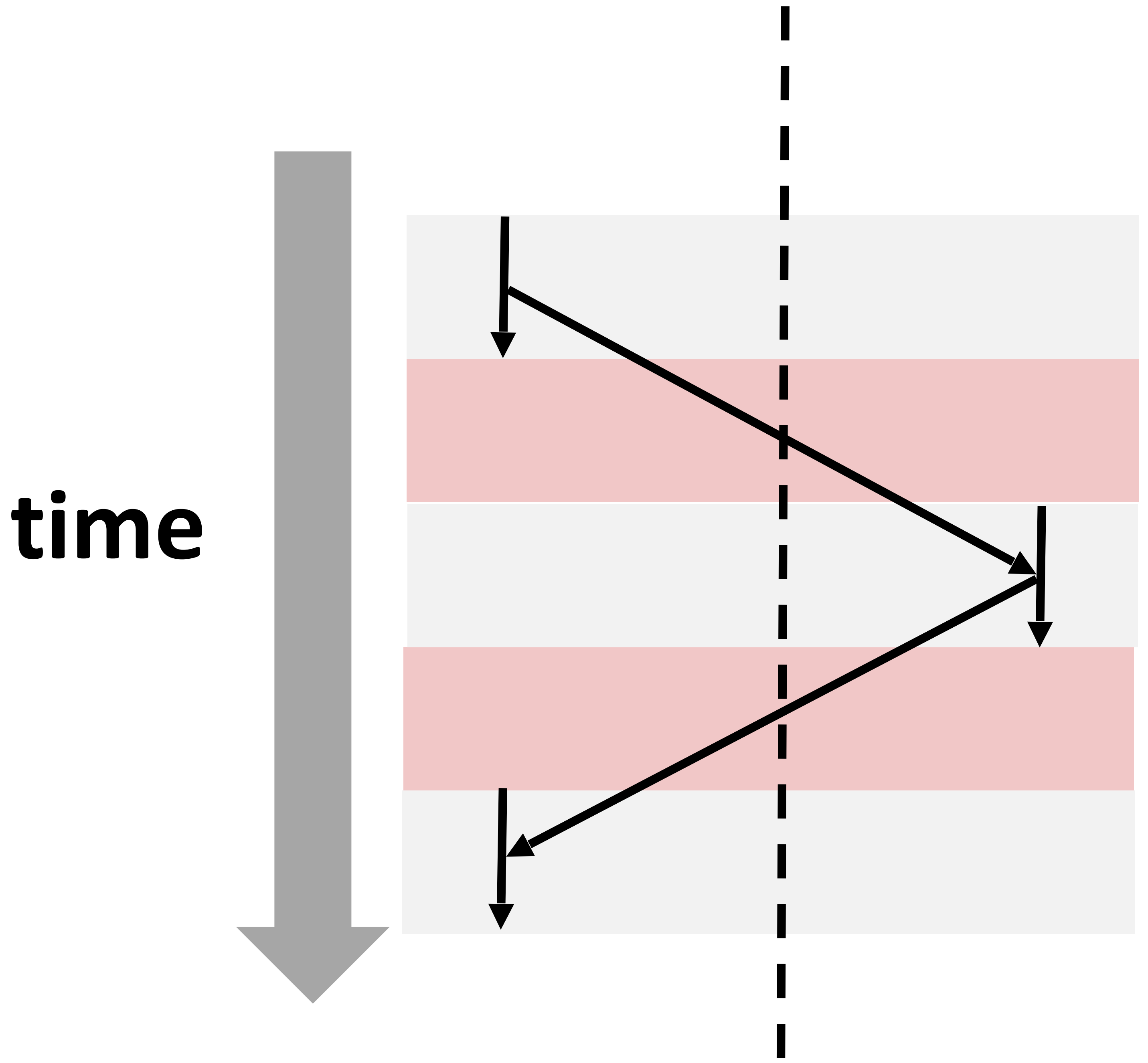
Read documentation for return values.

Use perror to report error, then exit.

```
void perror(char* message)
```

Print "*<message>*: *<reason that last system call failed.>*"

Summary



Processes

System has multiple active processes

Each process:

- Appears to have total control of the processor
- Has isolated access to its own data (usually)

OS periodically “context switches” between active processes

Process management

`fork, execv, waitpid`

Exercise: fork + waitpid

ex

1. Implement the following function using `fork` and `wait`:

```
pid_t fork()
                                        Hint: pass 0 for ops
pid_t waitpid(pid_t pid, int* stat, int ops)
```

```c
/*
    Write a C function that creates a child fork that creates a
    grandchild fork. Make the program print "Hello from grandchild"
    from the grandchild, then "Hello from child" from the child,
    making sure these statements happen in this order.
*/
void wait_for_grandchild() {



}
```

ex

```
void wait_for_grandchild() {
  int status;
  // Fork once to create child
  pid_t child_pid = fork();
  // Only fork again if in the child thread
  if (child_pid == 0) {
    // Fork again to create grandchild
    pid_t grand_child_pid = fork();
    if (grand_child_pid == 0) {
        // Print from inside the grandchild
        printf("Hello from grandchild\n");
    } else {
      // In the child, wait until the grandchild has printed
      if (-1 == waitpid(grand_child_pid, &status, 0)) {
        perror("waitpid");
        exit(1);
      }
      printf("Hello from child\n");
    }
  } else {
     if (-1 = waitpid(child_pid, &status, 0) {… final error check }
}}
```