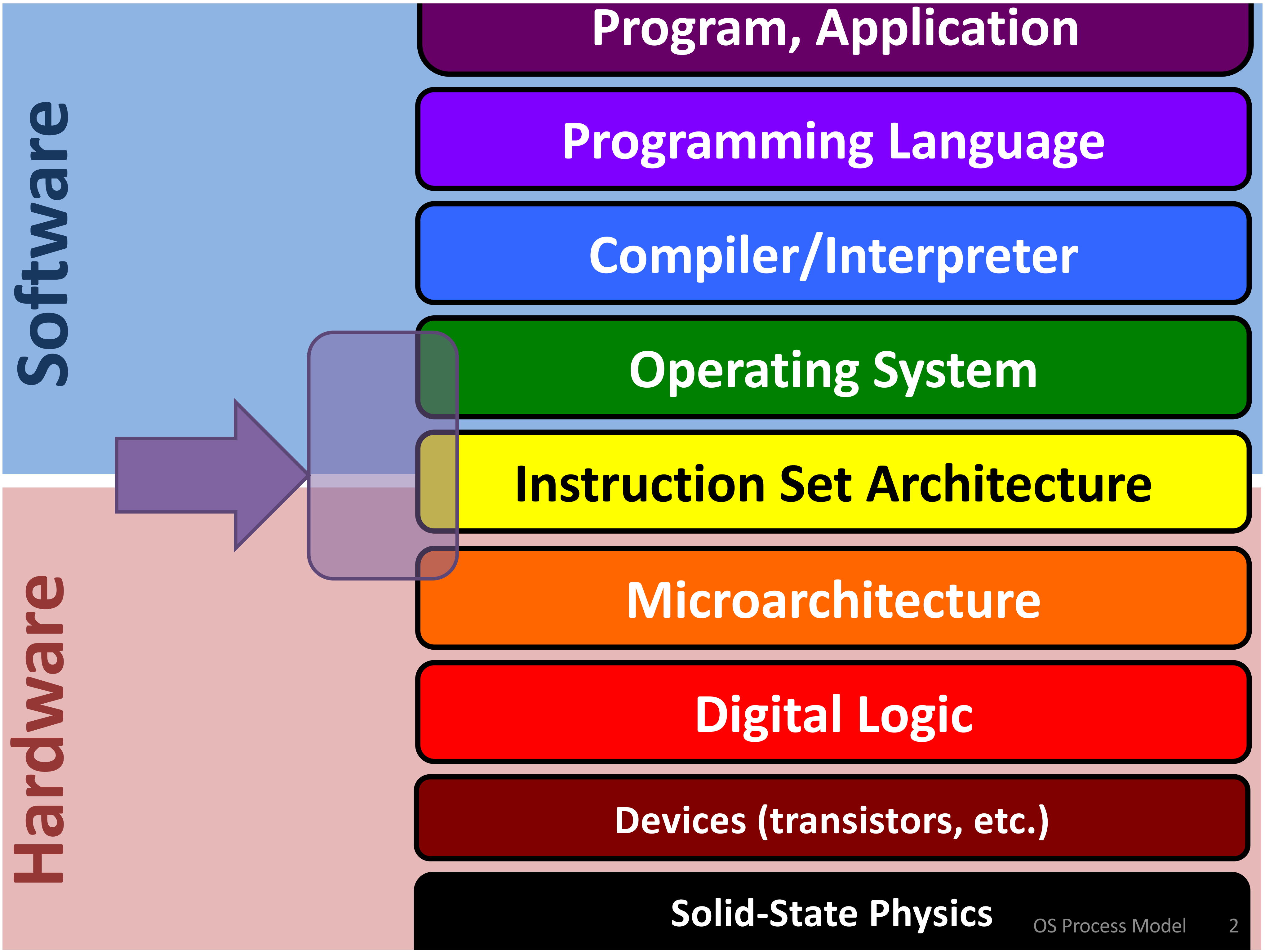
Operating Systems and the Process Model

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

Operating Systems

Problem: unwieldy hardware resources

complex and **varied**

limited

Solution: operating system

Manage, abstract, and virtualize hardware resources

Simpler, common interface to varied hardware

Share limited resources among

Protect

Operating Systems, a 240 view

barely scraping the surface

Key abstractions provided by *kernel*

process

virtual memory

Virtualization mechanisms and hardware support:

context-switching

exceptional control flow

address translation, paging, TLBs

Processes

Program = code (static)

Process = a running program instance (dynamic)

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

Key illusions:

Logical control flow ← Today

Each process seems to have exclusive use of the CPU

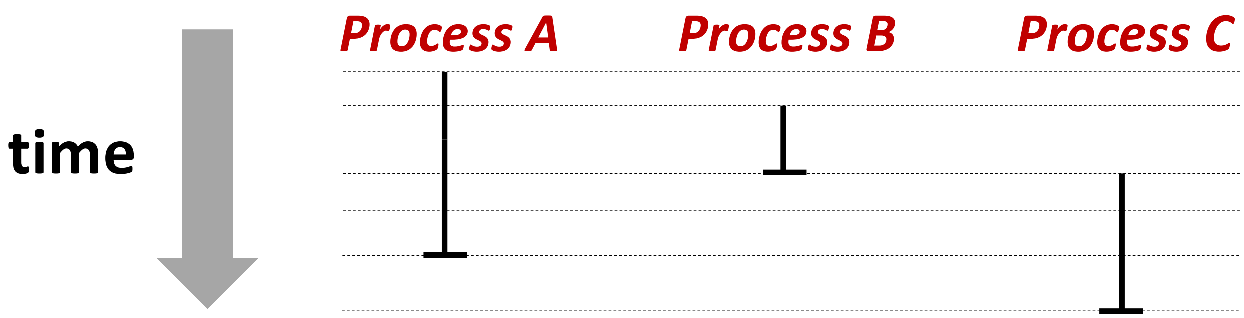
Private address space ← Next Weeks

Each process seems to have exclusive use of full memory

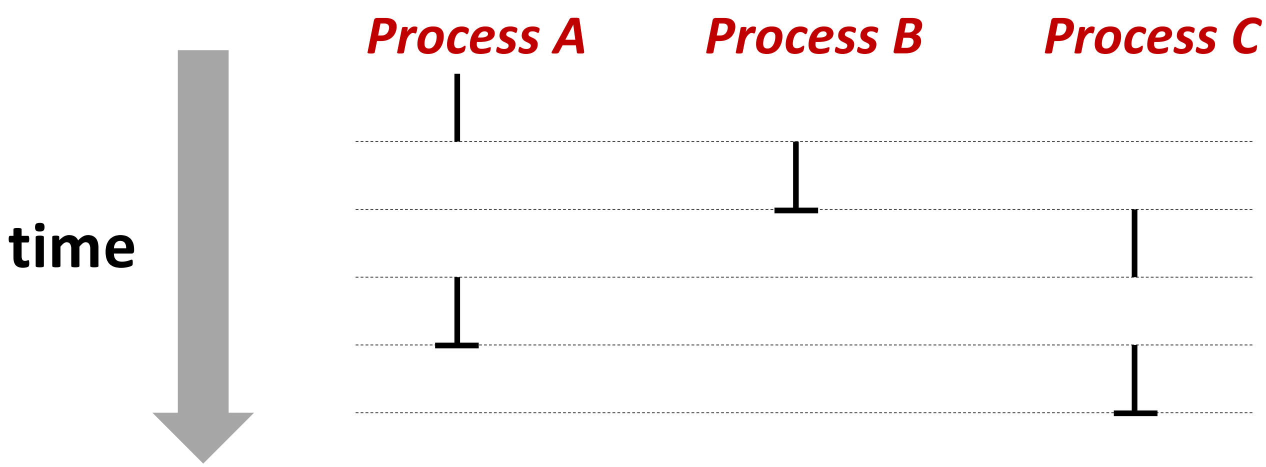
Why? How?

Implementing logical control flow

Abstraction: every process has full control over the CPU



Implementation: time-sharing

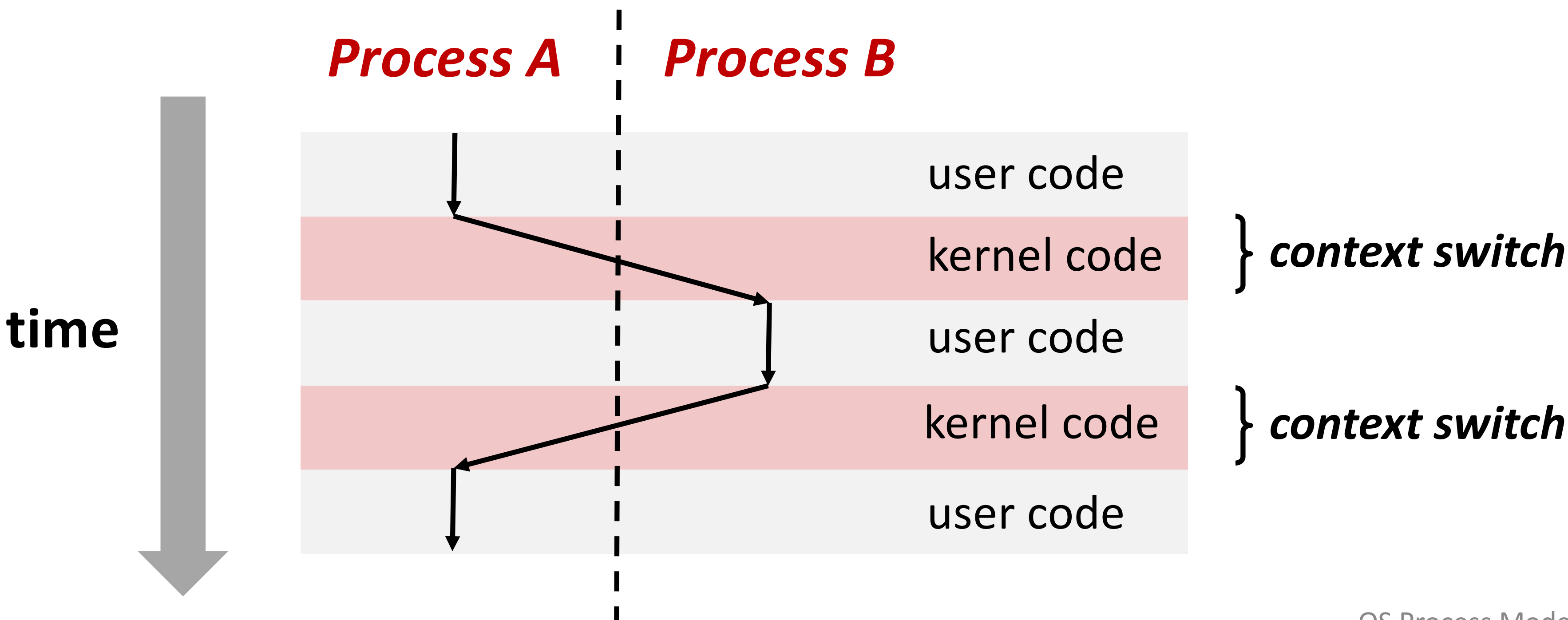


Context Switching

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**

```
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

1

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

Child Process m

2

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

```
pid_t pid = fork(); → 0
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");
}
```

```
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 copes

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

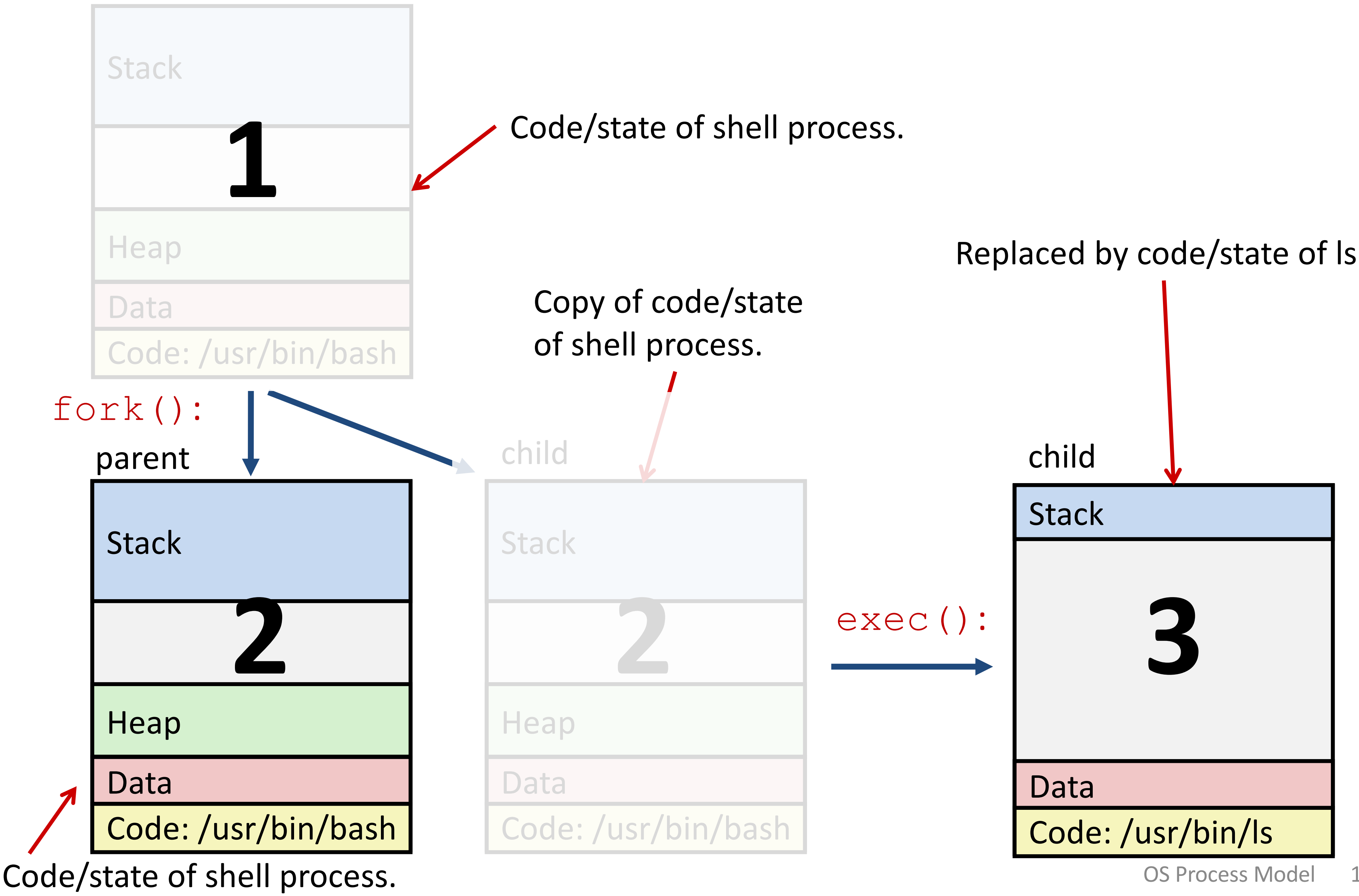
`execv()` replace process code and context (registers, memory) with a fresh program.

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");
}
```

Running the command `ls` in a shell:

Executing a new program



`execv`: load/start a program

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

loads/starts program in current process:

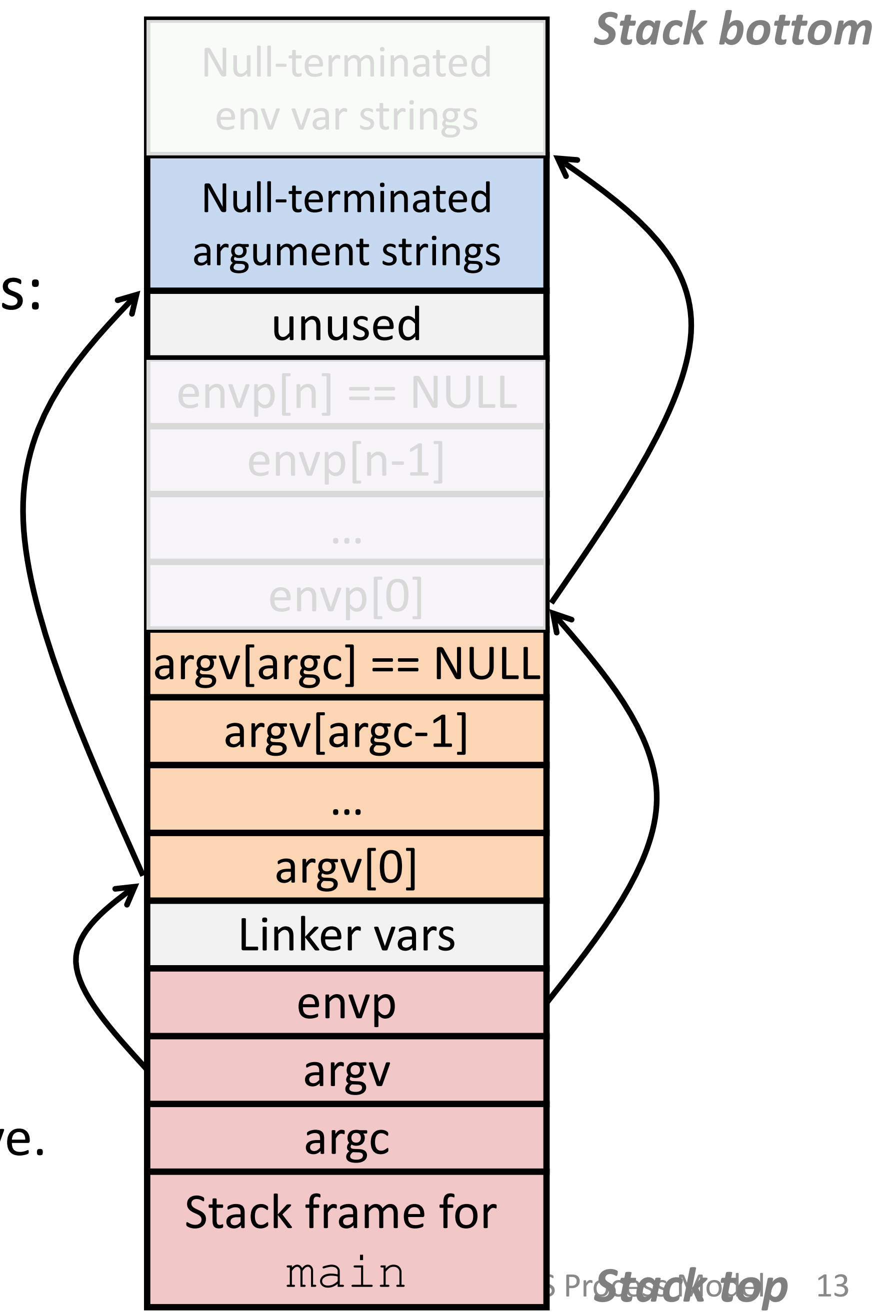
- Executable **`filename`**
- With argument list **`argv`**

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)`

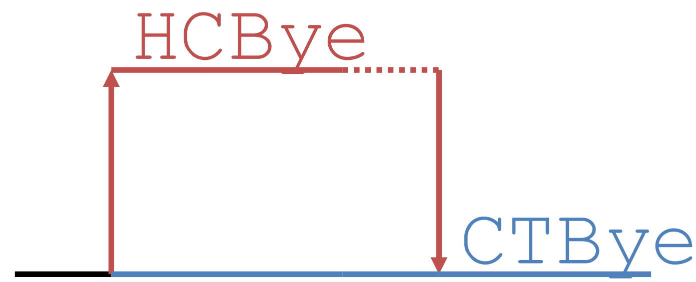
Suspend current process (i.e. parent) until child with **`pid`** ends.

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




```
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);
}
```

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 **`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.>*"

Examining processes on Linux (demo)

ps

pstree

top

/proc