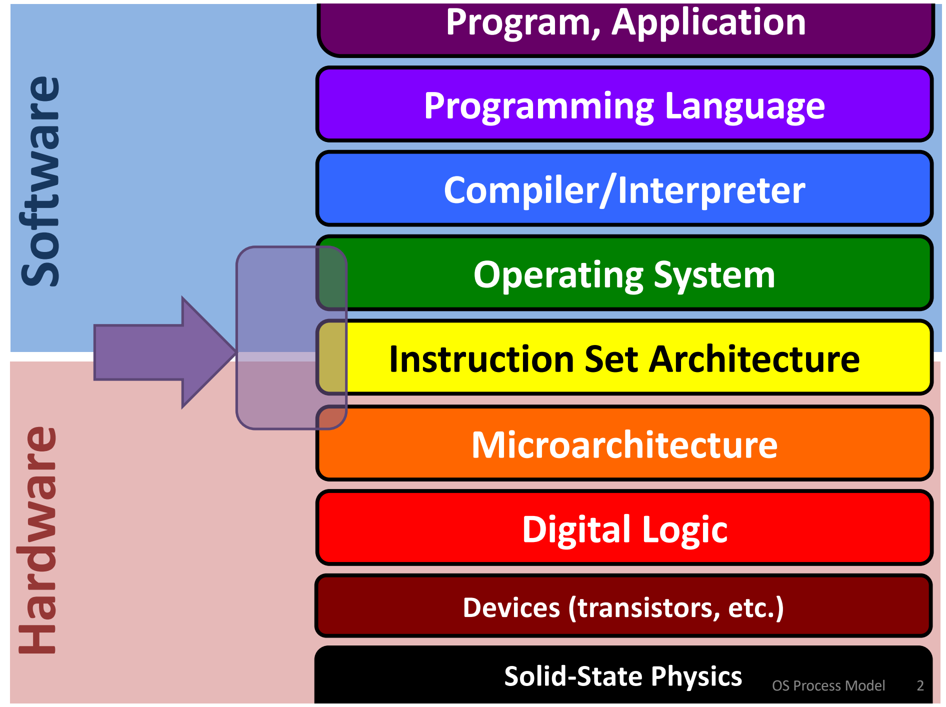
CS 240
Foundations of Computer Systems

WELLESLEY

Operating Systems and the Process Model

Process model
Process management
(Unix/Linux/macOS)



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

Each process seems to have exclusive use of the CPU

Today (parts)

Private address space

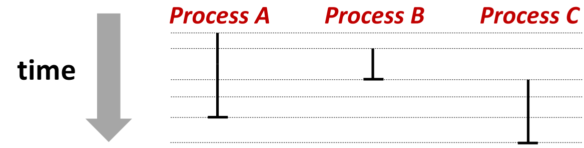
Each process seems to have exclusive use of full memory

Not This Semester
But read slides & CSAPP!

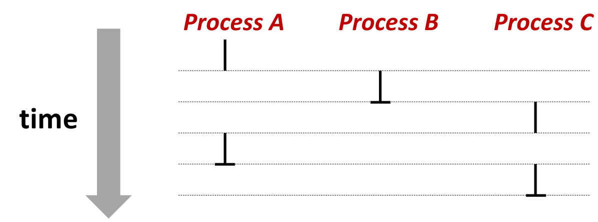
Why? How?

Implementing logical control flow

Abstraction: every process has full control over the CPU



Implementation: time-sharing

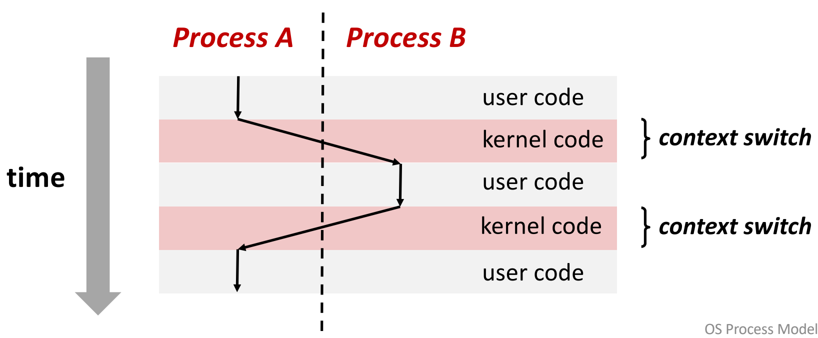


Context Switching

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 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

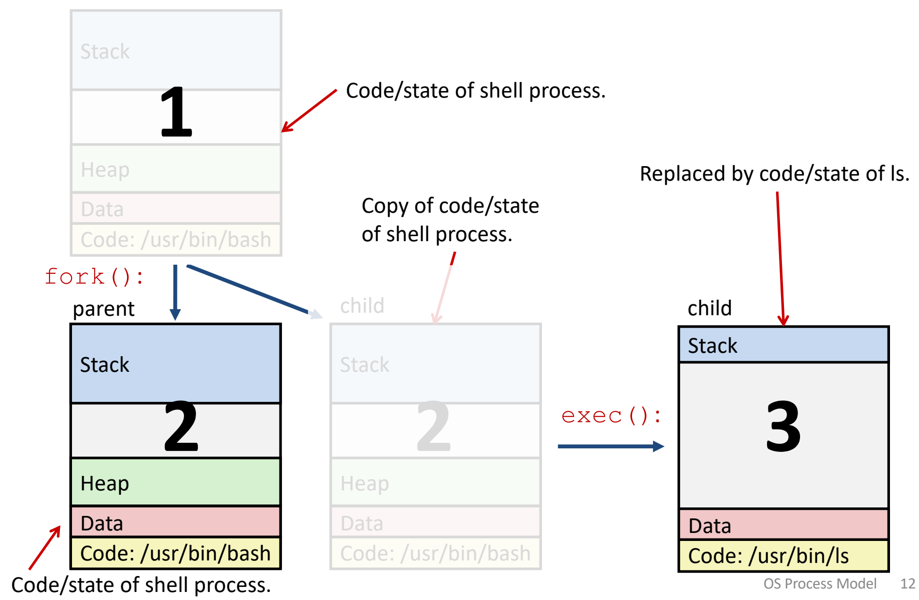
`execv()` replace process code and context (registers, memory) with a fresh program.

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");
}
```

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:

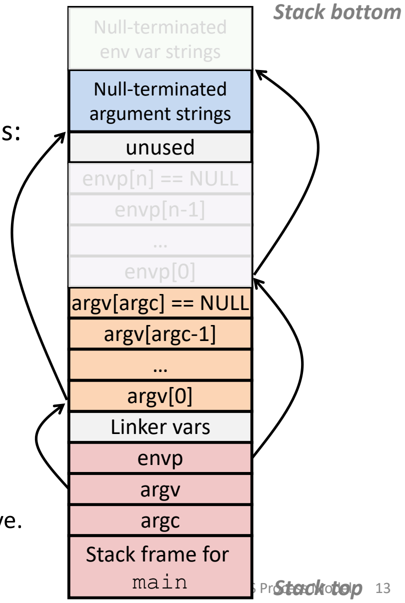
- Executable **`filename`**
- With argument list **`argv`**

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)
```

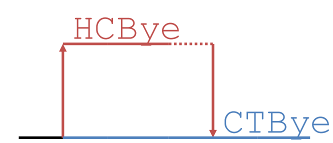
Suspend current process (i.e. parent) until child with **`pid`** ends.

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