

# CS111, Lecture 9

## Multiprocessing System Calls

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# CS111 Topic 2: Multiprocessing

**Key Question:** *How can our program create and interact with other programs? How does the operating system manage user programs?*

Multiprocessing  
Introduction

**Lecture 8**



Managing  
processes and  
running other  
programs

**Today**



Inter-process  
communication  
with pipes

**Lecture 10 - 11**

**assign3:** implement your own shell!

# Learning Goals

- Learn how to use **waitpid()** to wait for a child process to finish.
- Understand how to use **execvp()** to run a new program within a process.
- See how a shell is implemented using **fork** + **execvp** + **waitpid**

# Plan For Today

- **Recap**: `fork()`
- `waitpid()` and waiting for child processes
- **Demo**: waiting for children
- `execvp()`
- **Demo**: our first shell

```
cp -r /afs/ir/class/cs111/lecture-code/lect9 .
```

# Plan For Today

- **Recap: fork()**
- `waitpid()` and waiting for child processes
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```

# fork()

A system call that creates a new *child process*

- The "parent" is the process that creates the other "child" process
- From then on, both processes are running the code after the fork
- The child process is *identical* to the parent, except:
  - it has a new Process ID (PID)
  - for the parent, fork() returns the PID of the child; for the child, fork() returns 0
  - fork() is **called once**, but **returns twice**

```
pid_t pidOrZero = fork();  
// both parent and child run code here onwards  
printf("This is printed by two processes.\n");
```

# fork()

```
pid_t pidOrZero = fork();  
if (pidOrZero == 0) {  
    // Only executed by the child  
} else {  
    // Only executed by the parent  
}  
  
// Executed by both parent and child (if they get here)
```

# fork() In Helper Functions

```
void helperFn() {
    pid_t pidOrZero = fork();
    if (pidOrZero == 0) {
        printf("I am the child\n");
    } else {
        printf("I am the parent\n");
    }
}

int main(int argc, char *argv[]) {
    helperFn();
    printf("This is printed twice!\n");
}
```



# fork() In Helper Functions

```
void helperFn() {
    pid_t pidOrZero = fork();
    if (pidOrZero == 0) {
        printf("I am the child\n");
        exit(0);
    } else {
        printf("I am the parent\n");
    }
}

int main(int argc, char *argv[]) {
    helperFn();
    printf("This is printed once\n");
}
```

# Process Clones

```
$ ./fork-copy  
str's address is 0x7ffc8cfa9990  
I am the parent. str's address is 0x7ffc8cfa9990  
I am the parent, and I'm going to sleep for 2sec.  
I am the child. str's address is 0x7ffc8cfa9990  
I am the child and I changed str to Howdy. str's address is still  
0x7ffc8cfa9990  
I am the parent. I just woke up. str's address is 0x7ffc8cfa9990, and its  
value is Hello
```

How can the parent and child use the same address to store different data?

- Each program thinks it is given all memory addresses to use
- The operating system maps these *virtual* addresses to *physical* addresses
- When a process forks, its virtual address space stays the same
- **Copy on write:** only as needed, the operating system will map the child's virtual addresses to different physical addresses than for the parent

# Our Goal: Shell

A *shell* is a program that prompts the user for a command to run, runs that command, waits for the command to finish, and then prompts the user again.

```
while (true) {  
    char *user_command = ... // user input  
    pid_t pidOrZero = fork();  
    if (pidOrZero == 0) {  
        // run user's command in the child, then terminate  
        ???  
    }  
  
    // parent waits for child before continuing  
    ???  
}
```

# Our Goal: Shell

A *shell* is a program that prompts the user for a command to run, runs that command, waits for the command to finish, and then prompts the user again.

```
while (true) {  
    char *user_command = ... // user input  
    pid_t pidOrZero = fork();  
    if (pidOrZero == 0) {  
        // run user's command in the child,  
        ???  
    }  
  
    // parent waits for child before continuing  
    ???  
}
```

**Key idea:** we can only run one program per process, so we need to run the user's command in another process – otherwise, the shell will go away!

# Our Goal: Shell

A *shell* is a program that prompts the user for a command to run, runs that command, waits for the command to finish, and then prompts the user again.

```
while (true) {  
    char *user_command = ... // user input  
    pid_t pidOrZero = fork();  
    if (pidOrZero == 0) {  
        // run user's command in the child, then terminate  
        execvp  
    }  
  
    // parent waits for child before continuing  
    waitpid  
}
```

# Plan For Today

- Recap: `fork()`
- **`waitpid()`** and waiting for child processes
- **Demo**: waiting for children
- `execvp()`
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```
cp -r /afs/ir/class/cs111/lecture-code/lect9 .
```

**It would be nice if there was a function we could call that would "stall" our program until the child is finished.**

# waitpid()

A system call that a parent can call to wait for its child to exit:

```
pid_t waitpid(pid_t pid, int *status, int options);
```

- **pid**: the PID of the child to wait on (we'll see other options later)
- **status**: where to put info about the child's termination (or NULL)
- **options**: optional flags to customize behavior (always 0 for now)
- the function returns when the specified **child process** exits
- the return value is the PID of the child that exited, or -1 on error (e.g. no child to wait on)
- If the child process has already exited, this returns immediately - otherwise, it blocks



# waitpid()

```
// waitpid.c
int main(int argc, char *argv[]) {
    printf("Before.\n");
    pid_t pidOrZero = fork();
    if (pidOrZero == 0) {
        sleep(2);
        printf("I (the child) slept and the parent waited for me.\n");
    } else {
        pid_t result = waitpid(pidOrZero, NULL, 0);
        printf("I (the parent) finished waiting for the child. This
            always prints last.\n");
    }
    return 0;
}
```

Before.  
I (the child) slept and the parent waited for me.  
I (the parent) finished waiting for the child. This always prints last.

# waitpid()

```
// waitpid-status.c
int main(int argc, char *argv[]) {
    pid_t pid = fork();
    if (pid == 0) {
        printf("I'm the child, and the parent will wait up for me.\n");
        return 111; // contrived exit status (not a bad number, though)
    } else {
        int status;
        int result = waitpid(pid, &status, 0);
        if (WIFEXITED(status)) {
            printf("Child exited with status %d.\n", WEXITSTATUS(status));
        } else {
            printf("Child terminated abnormally.\n");
        }
        return 0;
    }
}
```

I'm the child, and the parent will wait up for me.  
Child exited with status 111.

# waitpid()

```
...
int status;
int result = waitpid(pid, &status, 0);
if (WIFEXITED(status)) {
    printf("Child exited with status %d.\n", WEXITSTATUS(status));
} else {
    printf("Child terminated abnormally.\n");
}
...
```


Provided macros (see man page for full list) let us extract info from the status.

- **WIFEXITED** – check if child terminated normally
- **WEXITSTATUS** – get exit status of child

This output will be the same every time! The parent will always wait for the child to finish before continuing.

# waitpid()

Another benefit of **waitpid**: it cleans up the state of the terminated child process

- A process that finished but hasn't yet been waited on by its parent is called a *zombie* .
- Zombies take up system resources (until they are ultimately cleaned up later by the OS). Therefore, a parent process should always wait on its children processes.
- If a child is still running, waitpid in the parent will block until the child finishes, and then clean it up. If a child process is a zombie, waitpid will return immediately and clean it up.
- Child processes whose parent process terminates without waiting on them get the **init** process (PID 1) as their parent.

Make sure to clean up after your zombie  
children.  
(wait, what?)

# Which output is *\*not\** possible?

```
int main() {
    pid_t pidOrZero1 = fork();
    if (pidOrZero1 == 0) {
        printf("Hello 1!\n");
        return 0;
    }

    pid_t pidOrZero2 = fork();
    if (pidOrZero2 == 0) {
        printf("Hi 2!\n");
        return 0;
    }

    waitpid(pidOrZero1, NULL, 0);
    printf("Goodbye 1\n");
    waitpid(pidOrZero2, NULL, 0);
    printf("Goodbye 2\n");
    return 0;
}
```

A)  
Hello 1!  
Hi 2!  
Goodbye 1  
Goodbye 2

B)  
Hi 2!  
Hello 1!  
Goodbye 1  
Goodbye 2

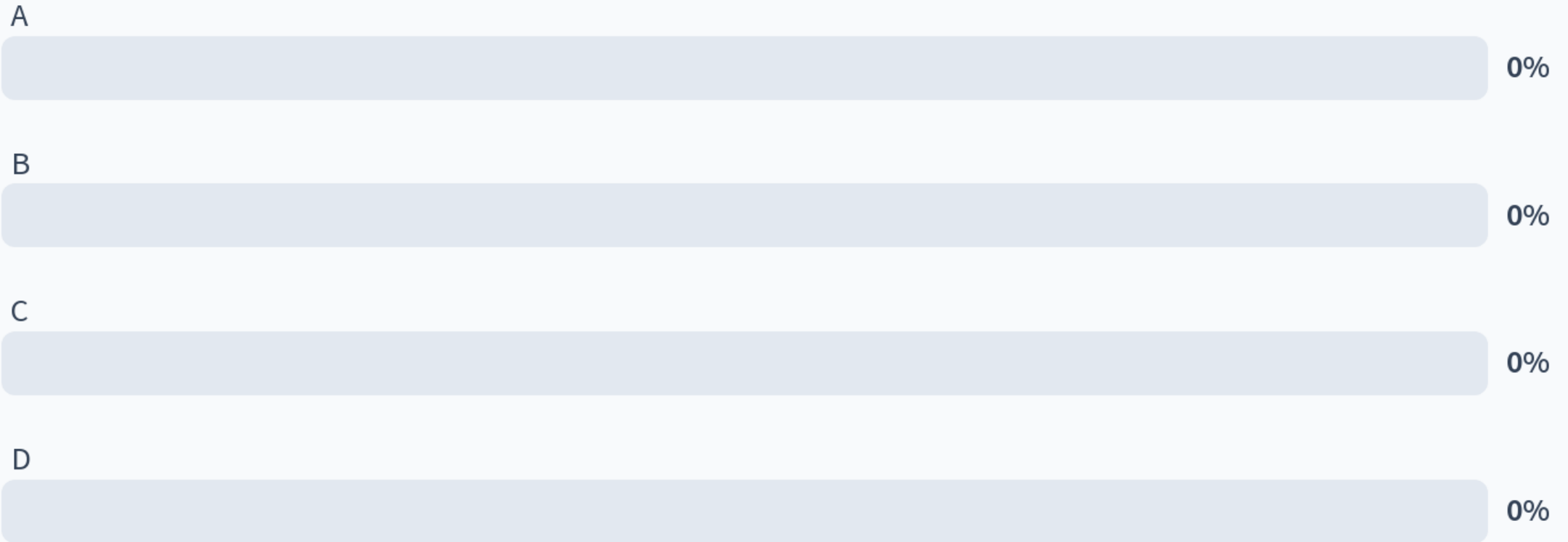
C)  
Hello 1!  
Goodbye 1  
Hi 2!  
Goodbye 2

D)  
Hi 2!  
Goodbye 1  
Hello 1!  
Goodbye 2

**Respond on PollEv:** [pollev.com/cs111](https://pollev.com/cs111)  
or text CS111 to 22333 once to join.



## Which of these outputs is *\*not\** possible?



# Plan For Today

- Recap: `fork()`
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- **Demo: waiting for children**
- `execvp()`
- **Demo**: our first shell

```
cp -r /afs/ir/class/cs111/lecture-code/lect9 .
```



# Waiting for Children

**Problem:** if we have multiple children and want to wait on all of them, in what order do we wait on them to finish?

*Ideally we could say "wait until one of my children finishes".*

- A parent can pass **-1** as the PID to **waitpid** to wait on *any one* of its children.
- **Key Idea:** the children may terminate in *any* order!
- If **waitpid** returns **-1** and sets **errno** to **ECHILD**, this means there are no more children.
- We can do this in a loop to wait on all children in the order they exit

Let's see a demo!



[reap-as-they-exit.c](#)

# Plan For Today

- Recap: `fork()`
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```
cp -r /afs/ir/class/cs111/lecture-code/lect9 .
```

# execvp()

The most common use for **fork** is not to spawn multiple processes to split up work, but instead to run a *completely separate program* under your control and communicate with it. This is the behavior of a **shell**!

# execvp()

**execvp** is a function that lets us run *another program* in the current process.

```
int execvp(const char *path, char *argv[])
```

It runs the executable at the given path, *completely cannibalizing the current process*.

- If successful, **execvp** **never returns** in the calling process
- If unsuccessful, **execvp** returns -1

To run another executable, we must specify the (NULL-terminated) arguments to be passed into its **main** function, via the argv parameter.

- For our programs, **path** and **argv[0]** will be the same

**execvp** has many variants (see **man execvp**) but we'll just be using **execvp**.

# execvp()

```
// execvp-demo.c
int main(int argc, char *argv[]) {
    printf("Hello, world!\n");
    char *args[] = {"/bin/ls", "-l", "/usr/class/cs111/lecture-code",
                    NULL};
    execvp(args[0], args);
    printf("This only prints if an error occurred.\n");
    return 0;
}
```

```
$ ./execvp-demo
Hello, world!
total 4
drwx----- 2 troccoli operator 2048 Oct  9 16:21 lect5
drwx----- 2 troccoli operator 2048 Oct 13 22:19 lect9
```

# How is `execvp` useful?

- This is the way that we can run other programs
- However, we often don't want to cannibalize the current process
- Instead: we will usually fork off a child process and call `execvp` there. The child process will be consumed, but that's ok
- Key idea: the process is still the child process, and **the parent can still wait on it**. It's just running another program.

# Plan For Today

- Recap: `fork()`
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```
cp -r /afs/ir/class/cs111/lecture-code/lect9 .
```

# Implementing a Shell

A shell is essentially a program that repeats asking the user for a command and running that command

## How do we run a command entered by the user?

1. Call **fork** to create a child process
2. In the child, call **execvp** with the command to execute
3. In the parent, wait for the child with **waitpid**

For assign3, you'll use this pattern to build your own shell, stsh ("Stanford shell") with various functionality of real Unix shells.



# Implementing a Shell

```
while (true) {
    char *user_command = ... // user input
    if (strcmp(user_command, "sort") == 0) {
        // code for sort here
    } else if (strcmp(user_command, "ls") == 0) {
        // code for ls functionality here
    }
    ...
}
```

**Why do we need `execvp`? Why can't we implement a shell like this?**

- Would need to implement every possible command's logic (yikes!)
- Couldn't run a command the shell doesn't know about (e.g. own programs)

**Demo: first-shell-soln.cc**

# Recap

- **Recap**: `fork()`
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- `execvp`
- **Demo**: our first shell

**Next time**: how processes can communicate with pipes

**Lecture 9 takeaway: `waitpid`** lets a parent process wait for a child process to finish. **`execvp`** takes over the calling process to run the specified program. Shells work by spawning child processes with **`fork`** that call **`execvp`**, and then waiting for them to finish with **`waitpid`**.