

# **15-213 Recitation 11**

## Processes, Signals, Tshlab

4 November 2019

# Outline

- Logistics
- Process Lifecycle
- Error Handling
- Signal Handling

# Logistics

- Malloc Final due tomorrow (11/5)
  - Can use up to 2 late days!
  - Style grading mm.c (not checkheap)
  
- Midterm regrades released
  - Review exam in Professor OH

# Shell Lab

- **Due date:** next Thursday (November 14<sup>th</sup>)
- Simulate a Linux-like shell with I/O redirection
- **Review the writeup carefully.**
  - Review once before starting, and again when halfway through
  - This will save you a lot of style points and a lot of grief!
- **Read Chapter 8 in the textbook:**
  - Process lifecycle and signal handling
  - How race conditions occur, and how to avoid them
  - **Be careful not to use code from the textbook without understanding it first.**

# Process “Lifecycle”

- `fork()`  
Create a duplicate, a “child”, of the process
- `execve()`  
Replace the running program
- ... [Complete Work]
- `exit()`  
End the running program
- `waitpid()`  
Wait for a child process to terminate

# Notes on Examples

- **Full source code of all programs is available**
  - TAs may demo specific programs
- **In the following examples, `exit()` is called**
  - We do this to be explicit about the program's behavior
  - Exit should generally be reserved for terminating on error
- **Unless otherwise noted, assume all syscalls succeed**
  - Error checking code is omitted.
  - Be careful to check errors when writing your own shell!

# Processes are separate

- How many lines are printed?
- If pid is at address 0x7fff2bcc264c, what is printed?

```
int main(void) {  
    pid_t pid;  
    pid = fork();  
    printf("%p - %d\n", &pid, pid);  
    exit(0);  
}
```

# Processes are separate

- How many lines are printed?
- If pid is at address 0x7fff2bcc264c, what is printed?

```
int main(void) {  
    pid_t pid;  
    pid = fork();  
    printf("%p - %d\n", &pid, pid);  
    exit(0);  
}
```

0x7fff2bcc264c - 24750

0x7fff2bcc264c - 0

The order and the child's PID (printed by the parent) may vary, but the address will be the same in the parent and child.



# Processes Change

- What does this program print?

```
int main(void) {  
    char *args[3] = {  
        "/bin/echo", "Hi 18213!", NULL  
    };  
    execv(args[0], args);  
    printf("Hi 15213!\n");  
    exit(0);  
}
```

# Processes Change

- What does this program print?

```
int main(void) {  
    char *args[3] = {  
        "/bin/echo", "Hi 18213!", NULL  
    };  
    execv(args[0], args);  
    printf("Hi 15213!\n");  
    exit(0);  
}
```

Hi 18213!

# Processes Change

- What about this program? What does it print?

```
int main(void) {  
    char *args[3] = {  
        "/bin/blahblah", "Hi 15513!", NULL  
    };  
    execv(args[0], args);  
    printf("Hi 14513!\n");  
    exit(0);  
}
```

# Processes Change

- What about this program? What does it print?

```
int main(void) {  
    char *args[3] = {  
        "/bin/blahblah", "Hi 15513!", NULL  
    };  
    execv(args[0], args);  
    printf("Hi 14513!\n");  
    exit(0);  
}
```

Hi 14513!

# On Error

- What should we do if malloc fails?

```
const size_t HUGE = 1 * 1024 * 1024 * 1024;
int main(void) {
    char *buf = malloc(HUGE * HUGE);

    printf("Buf at %p\n", buf);
    free(buf);
    exit(0);
}
```

# On Error

- What should we do if malloc fails?

```
const size_t HUGE = 1 * 1024 * 1024 * 1024;  
int main(void) {  
    char *buf = malloc(HUGE * HUGE);
```

```
    if (buf == NULL) {  
        fprintf(stderr, "Failure at %u\n", __LINE__);  
        exit(1);  
    }
```

```
    printf("Buf at %p\n", buf);  
    free(buf);  
    exit(0);  
}
```

# Exit values can convey information

- Two values are printed. Are they related?

```
int main(void) {  
    pid_t pid = fork();  
    if (pid == 0) { exit(getpid()); }  
    else {  
        int status = 0;  
        waitpid(pid, &status, 0);  
        printf("0x%x exited with 0x%x\n", pid,  
              WEXITSTATUS(status));  
    }  
    exit(0);  
}
```

# Exit values can convey information

- Two values are printed. Are they related?

```
int main(void) {  
    pid_t pid = fork();  
    if (pid == 0) { exit(getpid()); }  
    else {  
        int status = 0;  
        waitpid(pid, &status, 0);  
        printf("0x%x exited with 0x%x\n", pid,  
              WEXITSTATUS(status));  
    }  
    exit(0);  
}
```

0x7b54 exited with 0x54

They're the same!... almost.

Exit codes are only one byte in size.



# Processes have ancestry

- What's wrong with this code? (assume that fork succeeds)

```
int main(void) {  
    int status = 0, ret = 0;  
    pid_t pid = fork();  
    if (pid == 0) {  
        pid = fork();  
        exit(getpid());  
    }  
  
    ret = waitpid(-1, &status, 0);  
    printf("Process %d exited with %d\n", ret, status);  
  
    ret = waitpid(-1, &status, 0);  
    printf("Process %d exited with %d\n", ret, status);  
    exit(0);  
}
```

# Processes have ancestry

- What's wrong with this code? (assume that fork succeeds)

```
int main(void) {  
    int status = 0, ret = 0;  
    pid_t pid = fork();  
    if (pid == 0) {  
        pid = fork();  
        exit(getpid());  
    }
```

waitpid will reap only children, not grandchildren, so the second waitpid call will return an error.

```
    ret = waitpid(-1, &status, 0);  
    printf("Process %d exited with %d\n", ret, status);
```

```
    ret = waitpid(-1, &status, 0);  
    printf("Process %d exited with %d\n", ret, status);  
    exit(0);
```

```
}
```

# Process Graphs

- How many different sequences can be printed?

```
int main(void) {  
    int status;  
    if (fork() == 0) {  
        pid_t pid = fork();  
        printf("Child: %d\n", getpid());  
        if (pid == 0) {  
            exit(0);  
        }  
        // Continues execution...  
    }  
    pid_t pid = wait(&status);  
    printf("Parent: %d\n", pid);  
    exit(0);  
}
```

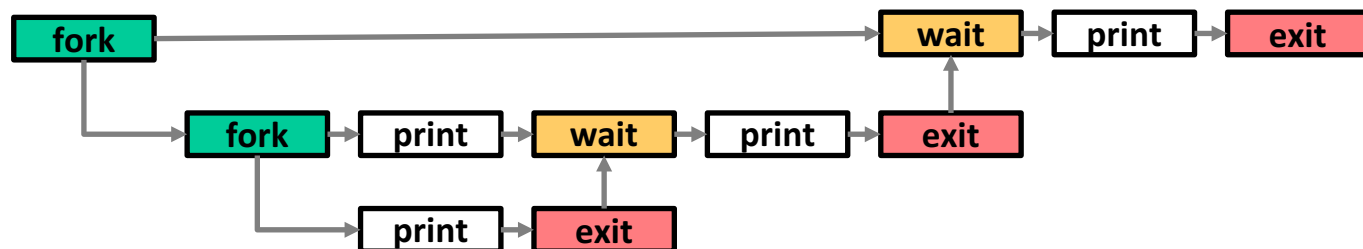
# Process Graphs

- How many different sequences can be printed?

```

int main(void) {
    int status;
    if (fork() == 0) {
        pid_t pid = fork();
        printf("Child: %d\n", getpid());
        if (pid == 0) {
            exit(0);
        }
        // Continues execution...
    }
    pid_t pid = wait(&status);
    printf("Parent: %d\n", pid);
    exit(0);
}

```



# Process Graphs

## ■ How many different lines are printed?

```
int main(void) {  
    char *tgt = "child";  
    pid_t pid = fork();  
    if (pid == 0) {  
        pid = getppid(); // Get parent pid  
        tgt = "parent";  
    }  
    kill(pid, SIGKILL);  
    printf("Sent SIGKILL to %s:%d\n", tgt, pid);  
    exit(0);  
}
```

# Process Graphs

## ■ How many different lines are printed?

```
int main(void) {  
    char *tgt = "child";  
    pid_t pid = fork();  
    if (pid == 0) {  
        pid = getppid(); // Get parent pid  
        tgt = "parent";  
    }  
    kill(pid, SIGKILL);  
    printf("Sent SIGKILL to %s:%d\n", tgt, pid);  
    exit(0);  
}
```

Anywhere from 0-2 lines. The parent and child try to terminate each other.

# Signals and Handling

- **Signals can happen at any time**
  - Control when through blocking signals
- **Signals also communicate that events have occurred**
  - What event(s) correspond to each signal?
- **Write separate routines for receiving (i.e., signals)**

# Counting with signals

## ■ Will this code terminate?

```
volatile int counter = 0;
void handler(int sig) { counter++; }

int main(void) {
    signal(SIGCHLD, handler);
    for (int i = 0; i < 10; i++) {
        if (fork() == 0) { exit(0); }
    }
    while (counter < 10) {
        mine_bitcoin();
    }
    return 0;
}
```



# Counting with signals

## ■ Will this code terminate?

```
volatile int counter = 0;
void handler(int sig) { counter++; }
```

```
int main(void) {
    signal(SIGCHLD, handler);
    for (int i = 0; i < 10; i++) {
        if (fork() == 0) { exit(0); }
    }
    while (counter < 10) {
        mine_bitcoin();
    }
    return 0;
}
```

← (Don't use signal, use  
Signal or sigaction  
instead!)

↑  
(Don't busy-wait, use  
sigsuspend instead!)

It might not, since  
signals can coalesce.

# Proper signal handling

## ■ How can we fix the previous code?


- Remember that signals will be coalesced, so the number of times a signal handler has executed is **not** necessarily the same as number of times a signal was sent.
- We need some other way to count the number of children.

# Proper signal handling

## ■ How can we fix the previous code?

- Remember that signals will be coalesced, so the number of times a signal handler has executed is **not** necessarily the same as number of times a signal was sent.
- We need some other way to count the number of children.

```
void handler(int sig) {  
    pid_t pid;  
    while ((pid = waitpid(-1, NULL, WNOHANG)) > 0) {  
        counter++;  
    }  
}
```



(This instruction isn't atomic. Why won't there be a race condition?)

# Error in UNIX - return value

- Can System call fail ?
- How to tell the difference ?

```
int main() {  
    int fd = open("213Grades.txt",  
                  O_RDWR);  
    // Change grades to As or Fs  
}
```

# Error in UNIX - What error ?

- Can System call fail ?
- How to tell the difference ?
  - Returned -1
- So, my fantastic system call failed.
- How can I tell what got wrong ?

```
int main() {  
    int fd = open("213Grades.txt",  
                  O_RDWR);  
    if (fd < 0) {  
        printf("Failed\n");  
        exit(-1);  
    }  
    // Change grades to As or Fs  
}
```

# Error handling - What now ?

## ■ Can System call fail ?

## ■ How to tell the difference ?

- Returned -1

## ■ So, my fantastic system call failed.

## ■ How can I tell what got wrong ?

- The error is in errno (global)  
(only if the syscall fail,  
what do you get on success ?)

## ■ What do I do ?

```

int main() {
    ...
    while (!quit) {
        ...
        int fd = open(userfile, O_RDWR);
        if (fd < 0) {
            printf("Failed\n");
            perror("open"); // use errno
            exit(-1);
        }
        ...
    }
    ...
}

```

# Error and signals

- Can System call fail ?
- How to tell the difference ?
  - Returned -1
- So, my fantastic system call failed.
- How can I tell what got wrong ?
  - The error is in errno (a global)
  - If success errno may contain anything
- What do I do ?
  - Look at errno and take action
- Hey, here comes a signal...

```

int main() {
    ...
    while (!quit) {
        ...
        int fd = open(userfile,O_RDWR);
        if (fd < 0) {
            if (errno == EACCESS) {
                // tell user he's wrong
                continue;
            } else if(...) {
                ...
            } else {
                perror("open"); // use errno
                exit(-1);
            }
        }
        ...
    }
    ...
}

```

# Error and signals : Recap

- You can't expect people to block signals around all error handling logic
- Hence, your signal handler shouldn't interfere with them
- Solution :
  - Do not make any system call that could set errno
  - Save and restore errno (store at beginning of handler and restore after)



# Example Question

What are all possible output values?

```
int main( ) {  
    int val = 2;  
    printf("%d", 0);  
    fflush(stdout);  
    if (fork( ) == 0) {  
        val++;  
        printf("%d", val);  
        fflush(stdout);  
    } else {  
        val--;  
        printf("%d", val);  
        fflush(stdout);  
        wait(NULL);  
    }  
    val++;  
    printf("%d", val);  
    fflush(stdout);  
    exit(0);  
}
```

# If you get stuck

- **Read the writeup!**
- **Do manual unit testing before runtrace and sdriver!**
  
- **Read the writeup!**
- **Post private questions on Piazza!**
  
- **Think carefully about error conditions.**
  - Read the man pages for each syscall when in doubt.
  - What errors can each syscall return?
  - How should the errors be handled?

# Appendix: Blocking signals

- **Surround blocks of code with calls to `sigprocmask`.**
  - Use `SIG_BLOCK` to block signals at the start.
  - Use `SIG_SETMASK` to restore the previous signal mask at the end.
- **Don't use `SIG_UNBLOCK`.**
  - We don't want to unblock a signal if it was already blocked.
  - This allows us to nest this procedure multiple times.

```
sigset_t mask, prev;  
sigemptyset(&mask, SIGINT);  
sigaddset(&mask, SIGINT);  
sigprocmask(SIG_BLOCK, &mask, &prev);  
// ...  
sigprocmask(SIG_SETMASK, &prev, NULL);
```

# Appendix: Errno

```
#include <errno.h>
```

## ■ Global integer variable used to store an error code.

- Its value is set when a system call fails.
- Only examine its value when the system call's return code indicates that an error has occurred!
- Be careful not to call make other system calls before checking the value of errno!

## ■ Lets you know why a system call failed.

- Use functions like strerror, perror to get error messages.

## ■ Example: assume there is no “foo.txt” in our path

```
int fd = open("foo.txt", O_RDONLY);  
if (fd < 0) perror("open");  
// open: No such file or directory
```

# Appendix: Writing signal handlers

## ■ G1. Call only async-signal-safe functions in your handlers.

- Do not call `printf`, `sprintf`, `malloc`, `exit`! Doing so can cause deadlocks, since these functions may require global locks.
- We've provided you with `sio_printf` which you can use instead.

## ■ G2. Save and restore `errno` on entry and exit.

- If not, the signal handler can corrupt code that tries to read `errno`.
- The driver will print a warning if `errno` is corrupted.

## ■ G3. Temporarily block signals to protect shared data.

- This will prevent race conditions when writing to shared data.

## ■ Avoid the use of global variables in `tshlab`.

- They are a source of pernicious race conditions!
- You do not need to declare any global variables to complete `tshlab`.
- Use the functions provided by `tsh_helper`.