15-213 Recitation 11

Processes, Signals, Tshlab

March 30, 2020

Your TAs

Outline

- Logistics
- Process Lifecycle
- Error Handling
- Signal Handling

Learning Objectives

- **Expectations:**
  - Basic understanding of signals & processes
- **Goals:**
  - Better understanding of signals & processes
  - Understand what a shell does and how to interact with it
  - Understand how to properly handle errors

Logistics

- Malloc Final due April 2nd (Delayed by 2 days!!) 🤓
  - **THIS THURSDAY**
  - Can use up to 2 late days!
  - Style grading mm.c (not checkheap)

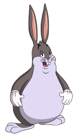
Shell Lab

- **Due date:** next Saturday (April 11th)
- Simulate a Linux-like shell

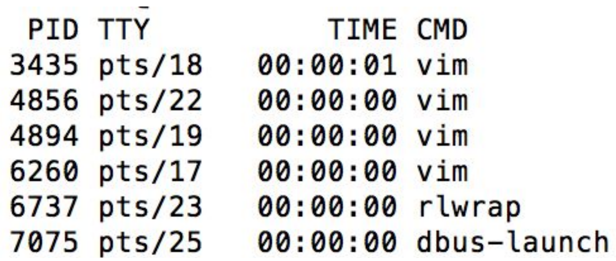
- **Review the writeup carefully.**
  - Review once before starting, and again when halfway through
  - This will save you a lot of style points and a lot of grief!

- **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.**

Shell demo



- **Process Lifecycle**
  - `$ ps -a`
    - This reports a snapshot of all the current processes. You can identify them by PID



```
 PID TTY          TIME CMD
3435 pts/18   00:00:01 vim
4856 pts/22   00:00:00 vim
4894 pts/19   00:00:00 vim
6260 pts/17   00:00:00 vim
6737 pts/23   00:00:00 rlwrap
7075 pts/25   00:00:00 dbus-launch
```

  - `$ ctrl+z` sends SIGTSTP and stops the current foreground process
    - fg/bg to run the most recently stopped process in the foreground/background
  - `$ ./long_binary_with_lots_of_io &`
    - Appending **&** to the end of a command runs it in the background
- **I/O redirection**
  - `$ ./hex2raw < exploit.txt > exploit-raw.txt`
    - **<** to redirect input and **>** to redirect output to the specified file

Shell Demo

- Login to shark machine
- wget http://www.cs.cmu.edu/~213/activities/rec11.tar
- tar -xvf rec11.tar
- cd rec11

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

Processes are separate

- How many lines are printed?
- Will the pid address be different?
- Will the pid be different?

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

Processes are separate

- How many lines are printed?
- Will the pid address be different?
- Will the pid be different?

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

```
pid addr: 0x7fff2bcc264c - pid: 24750
pid addr: 0x7fff2bcc264c - pid: 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?
- Assume that /bin/blahblah does **not** exist.

```
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?
- Assume that /bin/blahblah does **not** exist.

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

```
Hi 14513!
```

Exit values can convey information

- Two values are printed. What are they?

```
int main(void) {
    pid_t pid = fork();
    if (pid == 0) { exit(0x213); }
    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. What are they?

```
int main(void) {
    pid_t pid = fork();
    if (pid == 0) { exit(0x213); }
    else {
        int status = 0;
        waitpid(pid, &status, 0);
        printf("0x%x exited with 0x%x\n", pid,
               WEXITSTATUS(status));
    }
    exit(0);
}
```

```
0x7b54 exited with 0x13
```

WEXITSTATUS(status) will only return 1 byte of information

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());
    }

    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);
}
```

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

Process Graphs

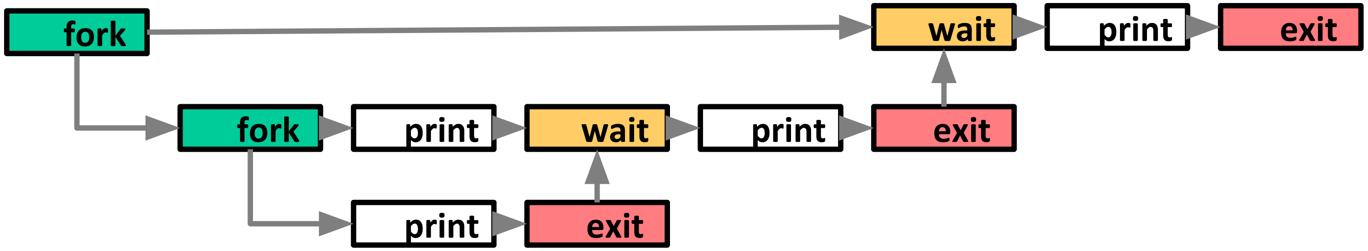
- How many different sequences can be printed?

```
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";
    sigset_t mask, old_mask;
    sigemptyset(&mask);
    sigaddset(&mask, SIGINT);
    sigprocmask(SIG_SETMASK, &mask, &old_mask); // Block
    pid_t pid = fork();
    if (pid == 0) {
        pid = getppid(); // Get parent pid
        tgt = "parent";
    }
    kill(pid, SIGINT);
    sigprocmask(SIG_SETMASK, &old_mask, NULL); // Unblock
    printf("Sent SIGINT to %s:%d\n", tgt, pid);
    exit(0);
}
```

Process Graphs

- **How many different lines are printed?**

```
int main(void) {
    char *tgt = "child";
    sigset_t mask, old_mask;
    sigemptyset(&mask);
    sigaddset(&mask, SIGINT);
    sigprocmask(SIG_SETMASK, &mask, &old_mask); // Block
    pid_t pid = fork();
    if (pid == 0) {
        pid = getppid(); // Get parent pid
        tgt = "parent";
    }
    kill(pid, SIGINT);
    sigprocmask(SIG_SETMASK, &old_mask, NULL); // Unblock
    printf("Sent SIGINT to %s:%d\n", tgt, pid);
    exit(0);
}
```

0 or 1 line. The parent and child try to terminate each other.

Error in UNIX - return value

- **Can syscalls 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 syscalls fail?**
- **How to tell the difference?**
  - Returned -1
- **So, my fantastic syscalls failed.**
- **How can I tell what went wrong?**

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

Error in UNIX - What error?

- **Can syscalls fail?**
- **How to tell the difference?**
  - Returned -1
- **So, my fantastic syscalls failed.**
- **How can I tell what went wrong?**
  - **errno** is a global variable that syscalls store information in when they fail

```
int main() {
    int fd = open("213Grades.txt",
                  O_RDWR);
    if (fd < 0) {
        fprintf(stderr, "Failed with
         error %s\n",
          strerror(errno));
        exit(-1);
    }
    // Change grades to As or Fs
}
```

Tip: you can use perror (`$ man  perror`) rather than interpreting errno yourself

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.

sigsuspend

```
int sigsuspend(const sigset_t *mask);
```

- Suspend current process until a signal is received, you can specify which one using a mask

This is an atomic version of:

```
sigprocmask(SIG_SETMASK, &mask, &prev)
pause();
sigprocmask(SIG_SETMASK, &prev, NULL);
```

- This still doesn’t fix the issue of signals coalescing!

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 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)
  - Think about what would work for the case you are using, not one rule

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: Notes on Examples

- **Full source code of all programs is available**
  - TAs may demo specific programs

- **In the 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!

Appendix: Example Question: Possible outputs?

```
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);
}
```

- **There is no deterministic interleaving of the parent and child after the call to fork()**

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`.