CMSC 125: Operating Systems

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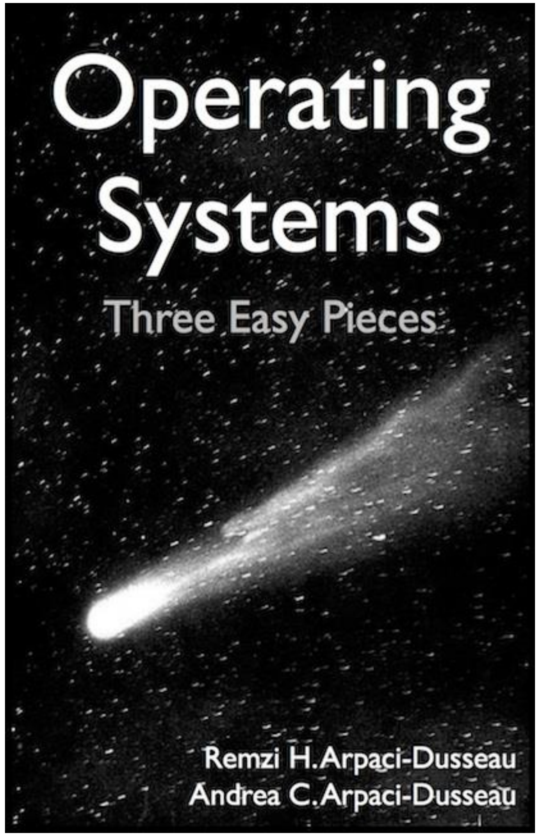
Resources

Book: https://pages.cs.wisc.edu/~remzi/OSTEP/

Slides Template:
https://pages.cs.wisc.edu/~remzi/OSTEP/Educators-Slides/Youjip/



Acknowledgement

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5. Interlude: Process API

Operating System: Three Easy Pieces

Process creation and control in Unix

- Use of `fork()` and `exec()` system calls
- A process can wait for a process it has created using `wait()` system call

The fork() system call

- Create a new process
  - The newly-created process has its own private copy of the **address space**, **registers**, and **PC**.

p1.c

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main(int argc, char *argv[]){
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {          // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) { // child (new process)
        printf("hello, I am child (pid:%d)\n", (int) getpid());
    } else {               // parent goes down this path (main)
        printf("hello, I am parent of %d (pid:%d)\n",
        rc, (int) getpid());
    }
    return 0;
}
```

Calling fork() example (Cont.)

Result (Not deterministic)

```
prompt> ./p1
hello world (pid:29146)
hello, I am parent of 29147 (pid:29146)
hello, I am child (pid:29147)
prompt>
```

or

```
prompt> ./p1
hello world (pid:29146)
hello, I am child (pid:29147)
hello, I am parent of 29147 (pid:29146)
prompt>
```

- The “original” p1 process prints its PID which is 29146 – the parent process
- Then a call to `fork()` is made which creates a new process with PID 29417 that is (almost) similar to the parent process – the child process
- Notice that the child process began execution after the call to `fork()` instead of at the start of `main()`
- The child process has its own private **address space**, **registers**, and **PC** which is different from parent process
- `fork()` returns **zero(0)** to the child process and the **child PID** to the parent process
- The order of execution of the parent and child processes is **non-deterministic**, dependent on the **scheduler**

The wait() system call

- Allows the parent process to <u>wait</u> for the child process to finish first before continuing/terminating
- This system call won't return until the child has run and exited

p2.c

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>

int main(int argc, char *argv[]){
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {          // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) { // child (new process)
        printf("hello, I am child (pid:%d)\n", (int) getpid());
    } else {              // parent goes down this path (main)
        int wc = wait(NULL);
        printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
        rc, wc, (int) getpid());
    }
    return 0;
}
```

The wait() system call (Cont.)

Result (Deterministic)

```
prompt> ./p2
hello world (pid:29266)
hello, I am child (pid:29267)
hello, I am parent of 29267 (wc:29267) (pid:29266)
prompt>
```

- Adding the call to `wait()` on the code block for the parent process guarantees that the child process will finish first before the parent process – thus **deterministic** order of execution
- Even if right after the call to `fork()` the parent process is selected by the scheduler, it will not proceed with its execution because of the `wait()` call which will not return until the child process has finished

The exec() system call

- Run a program that is different from the calling program
- The child process will have different **code**, **static data**, **address space**, **registers**, **PC**
  - In the previous examples, **code** and **static data** of the child process are the same as the parent process after a call to `fork()`

p3.c

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>
#include <sys/wait.h>

int main(int argc, char *argv[]){
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {                    // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) {            // child (new process)
        printf("hello, I am child (pid:%d)\n", (int) getpid());
        char *myargs[3];
        myargs[0] = strdup("wc");         // program: "wc" (word count)
        myargs[1] = strdup("p3.c");       // argument: file to count
        myargs[2] = NULL;                 // marks end of array
        …
```

The exec() system call (Cont.)

p3.c (Cont.)

```
…
        execvp(myargs[0], myargs); // runs word count
        printf("this shouldn't print out");
    } else {                          // parent goes down this path (main)
        int wc = wait(NULL);
        printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
            rc, wc, (int) getpid());
    }
    return 0;
}
```

Result

```
prompt> ./p3
hello world (pid:29383)
hello, I am child (pid:29384)
29 107 1030 p3.c
hello, I am parent of 29384 (wc:29384) (pid:29383)
prompt>
```

- `exec()` **loads** the code and static data, given the name of the executable (ex. `wc`), into the child process' **address space** which originally contains the code and static data of the parent process copied during the call to `fork()`
- A successful call to `exec()` never returns – why?

Why separate fork() and exec()?

- Essential for building a **shell** – an "interface" program that accepts commands from users to access the services of the OS
  - Ex. BASH and ZSH in Linux, Command Prompt and Powershell in Windows
- With this separation, the shell can run some code *after* the call to `fork()` but *before* the call to `exec()`
  - It allows the shell to alter the **environment** of the about to be run program by `exec()`, enabling more features (ex. **Pipes** and **I/O redirection**) to be implemented

Why separate fork() and exec()? (Cont.)

- Example: The output of `wc`, instead of being shown in the screen is saved (**redirected**) to a text file

```
prompt> wc p3.c > newfile.txt
```

- To implement this, the shell closes the STDOUT of the process after `fork()` then `open()`'s `newfile.txt` before calling `exec()`
- This works because the `open()` system call starts from zero when looking for available file descriptors to use. Since STDOUT (fd=1) was closed, the call to `open()` will assign fd=1 to `newfile.txt` and will be treated as the STDOUT after the call to `exec()`
- **Pipes** works in a similar manner but uses in-kernel data structures for Interprocess Communication (IPC) through the `pipe()` system call
  - Example: The STDOUT of `ps` is connected to the STDIN of `grep` through a pipe (the vertical bar syntax in BASH)

```
prompt> ps -A | grep cpu.elf
```

Implementing STDOUT redirection to a file

p4.c

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>
#include <fcntl.h>
#include <sys/wait.h>

int
main(int argc, char *argv[]){
    int rc = fork();
    if (rc < 0) {         // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) { // child: redirect standard output to a file
        close(STDOUT_FILENO);
        open("./p4.output", O_CREAT|O_WRONLY|O_TRUNC, S_IRWXU);
        …
```

Implementing STDOUT redirection to a file(Cont.)

p4.c

```
        …
        // now exec "wc"...
        char *myargs[3];
        myargs[0] = strdup("wc");          // program: "wc" (word count)
        myargs[1] = strdup("p4.c");        // argument: file to count
        myargs[2] = NULL;                  // marks end of array
        execvp(myargs[0], myargs);         // runs word count
    } else {                           // parent goes down this path (main)
        int wc = wait(NULL);
    }
    return 0;
}
```

Result

```
prompt> ./p4
prompt> cat p4.output
32 109 846 p4.c
prompt>
```

Process Control and Users

- There are other process-related system calls
- `kill()` – used to send **signals** to a process
  - `SIGINT` – pressing CTRL+c
  - `SIGSTOP` – pressing CTRL+z
  - `SIGCONT` – `fg` command
- Signals subsystem enable the delivery of events to processes
  - Processes and **process groups** can have signal handlers (via `signal()` system call) to perform a specific action whenever a specific signal is received
- Processes are associated to **users** in order to provide ownership and control, as well as limited security and protection
  - `getuid()` – system call to return the user id of the user of the process calling it

Useful programs and commands

- `man`
- `top/htop`
- `ps/pstree`
- `kill/killall`
- `fg/jobs`
- `/proc`