COMP1521 25T1

Week 9 Lecture 1

Processes and Pipes

Adapted from Abiram Nadarajah, Hammond Pearce,
Andrew Taylor and John Shepherd's slides

Announcements

- Public Holiday Week 9 Friday and Week 10 Monday and Friday
  - Please attend a catch up class

    Week 9 and Week 10 Public Holiday Catch Up Classes - Announcements - COMP1521
- Pre-recorded video to make up for Monday Week 10 lecture
- Week 10: In person labs Practice Exams:
  - Questions are not released you need to attend
  - Not worth marks
  - Regular lab questions for marks to do too

Announcements

- Past Exams: Released before tuesday week 10, solutions released tuesday week 11

- Assignment 2 walkthrough videos are up.
  - **Questions about sf**

Today's Lecture

- Processes
  - Recap, Execve recap
  - Fork
  - Wait
  - posix_spawn
- Inter Process Communication
  - Pipes

When a Linux Process stops responding

Recap: Processes

- A process is an instance of an executing program.
- Each process has an execution state, defined by…
  - current values of CPU registers
  - current contents of its memory
  - information about open files (and other results of system calls)
- each process has a unique process ID, or PID: a positive integer, type **pid_t**, defined in <unistd.h>
- Each process has a parent process
- A process may have child processes

Recap: Example: using exec()

```
int main(void) {
    char *echo_argv[] = {"/bin/echo","good-bye","cruel","world",NULL};
    execv("/bin/echo", echo_argv);
    // if we get here there has been an error
    perror("execv");
```

```
$ dcc exec.c
$ a.out
good-bye cruel world
$
```

Demo: exec.c

fork() — clone yourself

```c
#include <sys/types.h>
#include <unistd.h>
pid_t fork(void);
```

- Creates new process by duplicating the calling process.
  - new process is the child, calling process is the parent
- Both child and parent return from fork() call… how to distinguish?
  - in the child, fork() returns 0
  - in the parent, fork() returns the pid of the child
  - if the system call failed, fork() returns -1
- Child inherits copies of parent's address space, open files …

Example: using fork()

```c
// fork creates 2 identical copies of program
// only return value is different
pid_t pid = fork();
if (pid == -1) {
    perror("fork"); // print why the fork failed
} else if (pid == 0) {
    printf("I am the child because fork() returned %d.\n", pid);
} else {
    printf("I am the parent because fork() returned %d.\n", pid);
}
```

Demo: fork.c, fork2.c

fork_gotcha.c

```c
int main(void) {
    printf("about to fork getpid() = %d...\n", getpid());
    pid_t fork_return = fork();
    printf("fork() = %d, getpid() = %d...\n",fork_return,
                                                getpid());
    return 0;
}
```

Demo: fork_gotcha.c

Exercise: How many processes?

How many processes are created when we run this program? What will it print?

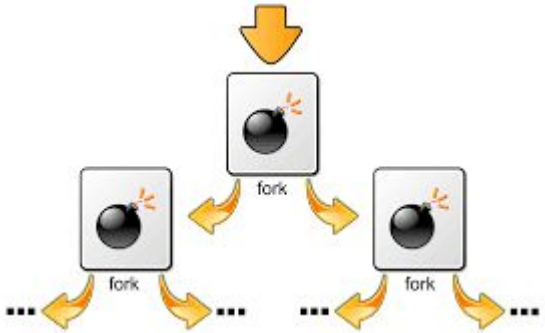
```c
int main(void) {
    printf("Hello\n");
    fork();
    fork();
    fork();
    printf("Goodbye\n");
    return 0;
}
```

Demo: fork_ex1.c

Fork dangers, e.g. a fork bomb

```c
#include <stdio.h>
#include <unistd.h>
// DO NOT RUN THIS!!!!!
int main(void) {
    for(int i = 0; i < 10; i++) {
        printf("In %d fork returned %d\n", getpid(), fork());
        sleep(1);
    }
    return 0;
}
```

WARNING!
DON'T EVEN THINK ABOUT IT!

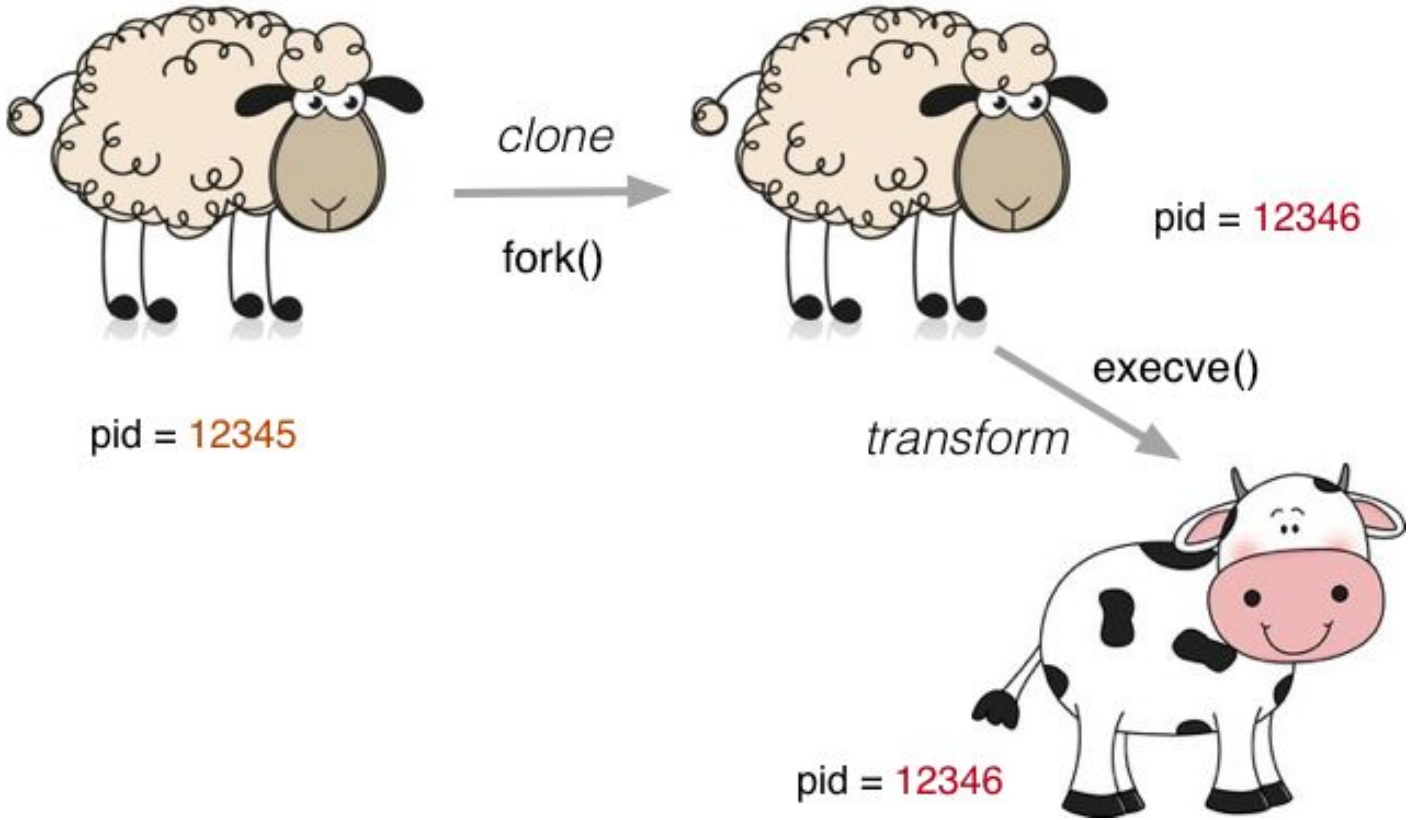


waitpid() — wait for process to change state

```
pid_t waitpid(pid_t pid, int *wstatus, int options)
```

- **`status`** is set to hold info about pid.
  - e.g., exit status if pid terminated
  - macros allow precise determination of state change
    - (e.g. WIFEXITED(status), WCOREDUMP(status))
- **`options`** provide variations in waitpid() behaviour
  - default: wait for child process to terminate
  - WNOHANG: return immediately if no child has exited
  - WCONTINUED: return if a stopped child has been restarted
- For more information, **`man 2 waitpid`**.

Fork and Exec Together!



Example: fork() and exec() to run /bin/date

```c
pid_t pid = fork();
if (pid == -1) {
    perror("fork"); // print why fork failed
} else if (pid == 0) { // child
    char *date_argv[] = {"/bin/date", "--utc", NULL};
    execv("/bin/date", date_argv);
    perror("execv"); // print why exec failed
} else { // parent
    int exit_status;
    if (waitpid(pid, &exit_status, 0) == -1) {
        perror("waitpid");
        exit(1);
    }
    printf("/bin/date exit status was %d\n", exit_status);
}
```

Demo: fork_exec.c, fork_exec2.c

system(): convenient but unsafe

```c
#include <stdlib.h>
int system(const char *command)
```

- Creates another process
  - runs command via /bin/sh.
  - waits for command to finish and returns exit status
- Don’t use in code which handles untrusted input or needs to be reliable!
  - Only use for quick debugging and throwaway code

system() — convenient but risky

- Convenient … but extremely dangerous —
  - very brittle; highly vulnerable to security exploits
  - especially dangerous in code which handles untrusted input!
  - https://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=OS+Command+Injection
  - use for quick debugging and throw-away programs only

```
// run date --utc to print current UTC
int exit_status = system("/bin/date --utc");
printf("/bin/date exit status was %d\n", exit_status);
return 0;
```

Demo: system.c

Making Processes

- Old-fashioned way **fork()** then **exec()**
  - **fork()** duplicates the current process (parent+child)
  - **exec()** “overwrites” the current process (run by child)
- Scary unsafe way **system()**
- New, standard way **posix_spawn()**

posix_spawn() — Run a new process

```
#include <spawn.h>
int posix_spawn(
    pid_t *pid, const char *path,
    const posix_spawn_file_actions_t *file_actions,
    const posix_spawnattr_t *attrp,
    char *const argv[], char *const envp[]);
```

- pid: returns process id of new program
- path: path to the program to run
- file_actions: specifies file actions to be performed before running program
    - can be used to redirect stdin, stdout to file or pipe

posix_spawn() — Run a new process

```c
#include <spawn.h>
int posix_spawn(
    pid_t *pid, const char *path,
    const posix_spawn_file_actions_t *file_actions,
    const posix_spawnattr_t *attrp,
    char *const argv[], char *const envp[]);
```

- attrp: specifies attributes for new process (not covered in COMP1521)
- argv: arguments to pass to new program
- envp: environment to pass to new program
- can also use **posix_spawnp** which searches PATH

Example: posix_spawn() to run /bin/date

```c
pid_t pid;
extern char **environ;
char *date_argv[] = {"/bin/date", "--utc", NULL};
// spawn "/bin/date" as a separate process
int ret = posix_spawn(&pid, "/bin/date", NULL, NULL, date_argv, environ);
if (ret != 0) {
    errno = ret; //posix_spawn returns error code, does not set errno
    perror("spawn"); exit(1);
}
// wait for spawned processes to finish
int exit_status;
if (waitpid(pid, &exit_status, 0) == -1) {
    perror("waitpid"); exit(1);
}
printf("/bin/date exit status was %d\n", exit_status);
```

Demo: posix_spawn.c

Example: posix_spawn() versus system()

Running ls -ld via posix_spawn()

```
char *ls_argv[2] = {"/bin/ls", "-ld", NULL};
pid_t pid; int ret;
extern char **environ;
if((ret = posix_spawn(&pid, "/bin/ls", NULL,
    NULL, ls_argv, environ)) != 0)
{
    errno = ret; perror("spawn"); exit(1);
}
int exit_status;
if (waitpid(pid, &exit_status, 0) == -1) {
    perror("waitpid"); exit(1);
}
```

Running ls -ld via system()

```
system("ls -ld");
```

Demo: lsld_spawn.c
lsld_system.c

Setting environment var for child process

```
// set environment variable STATUS
setenv("STATUS", "great", 1);
char *getenv_argv[] = {"./get_status", NULL};
pid_t pid;
extern char **environ;
int ret = posix_spawn(&pid, "./get_status", NULL, NULL,
             getenv_argv, environ);
if (ret != 0) {
    errno = ret; perror("spawn"); return 1;
}
int exit_status;
if (waitpid(pid, &exit_status, 0) == -1) {
    perror("waitpid"); exit(1);
```

Demo: set_status.c

Change behaviour with an environment var

```
pid_t pid;
char *date_argv[] = { "/bin/date", NULL };
char *date_environment[] = { "TZ=Australia/Perth", NULL };
// print time in Perth
int ret = posix_spawn(&pid, "/bin/date", NULL, NULL, date_argv,
date_environment);
if (ret != 0) {
    errno = ret; perror("spawn"); return 1;
}
int exit_status;
if (waitpid(pid, &exit_status, 0) == -1) {
    perror("waitpid"); return 1;
}
printf("/bin/date exit status was %d\n", exit_status);
```

Demo: spawn_env.c

Aside: Zombie Processes

Aside: Zombie Processes

- When a process terminates, some of its details remain in the process table, and the process is called a **zombie**.
- A **zombie** remains until its parent calls wait() or waitpid() (reaps the process)
  - this can be a problem for long running processes that don't reap their children.
  - **zombie**s that hang around waste system resources.
- Orphan process = a process whose parent has exited
  - when parent exits, orphan assigned PID 1 (init) as its new parent
  - init always accepts notifications of child terminations

exit() — terminate yourself

```c
#include <stdlib.h>
void exit(int status);
```

- triggers any functions registered as atexit()
- flushes stdio buffers; closes open FILE *'s
- terminates current process
- a SIGCHLD signal is sent to parent
- returns status to parent (via waitpid())
- any child processes are inherited by init (pid 1)

_exit() — terminate yourself without …

```c
#include <stdlib.h>

void _exit(int status);
```

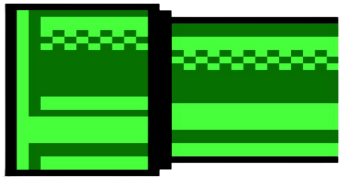
- terminates current process without triggering functions registered as atexit()
- stdio buffers not flushed
- sometimes used by children of fork() when exiting

Inter Process Communication

pipe() — stream bytes between processes

Send output of one process as input to another

Process A
WRITES
to the
pipe



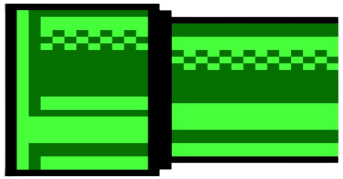
Process B
READS
from the
pipe

pipe() — stream bytes between processes

Demo: on the command line:

```
seq 1 10 | wc
```

Process A
WRITES
to the
pipe



Process B
READS
from the
pipe

pipe() — stream bytes between processes

```c
#include <unistd.h>
int pipe(int pipefd[2]);
```

- Pipes: unidirectional byte streams provided by operating system
  - **pipefd[0]**: set to file descriptor of read end of pipe
  - **pipefd[1]**: set to file descriptor of write end of pipe
  - bytes written to **pipefd[1]** will be read from **pipefd[0]**
- Child processes (by default) inherit file descriptors including pipes

Demo:pipe_fork.c, pipe_fork2.c

Closing pipes

- Parent can send/receive bytes (not both) to child via pipe
  - parent and child should both close unused pipe file descriptors
  - e.g if bytes being written (sent) parent to child
    - parent should close read end **pipefd[0]**
    - child should close write end **pipefd[1]**
- Pipe file descriptors can be used with stdio via **fdopen()**

popen() — convenient way to set up pipe

```
#include <stdio.h>
FILE *popen(const char *command, const char *type);
int pclose(FILE *stream);
```

- runs command via /bin/sh
- if type is “w” pipe to stdin of command created
- if type is “r” pipe from stdout of command created
- FILE * stream returned - get then use fgetc/fputc etc
  - NULL returned if error
- close stream with pclose (not fclose)
  - pclose waits for command and returns exit status

popen() — unsafe

```c
#include <stdio.h>
FILE *popen(const char *command, const char *type);
int pclose(FILE *stream);
```

- convenient but brittle
- vulnerable to command injection (same as system())
- try to avoid use except in debugging and throw-away programs

Example: process output with popen()

```c
// popen passes string to a shell for evaluation
// brittle and highly-vulnerable to security exploits
// popen is suitable for quick debugging and throw-away programs only
FILE *p = popen("/bin/date --utc", "r");
if (p == NULL) {
   perror(""); return 1;
}
char line[256];
if (fgets(line, sizeof line, p) == NULL) {
   fprintf(stderr, "no output from date\n"); return 1;
}
printf("output captured from /bin/date was: '%s'\n", line);
pclose(p); // returns command exit status
```

Demo: read_popen.c

Example: input to a process with popen()

```c
int main(void) {
    // popen passes command to a shell for evaluation
    // brittle and highly-vulnerable to security exploits
    //
    // tr a-z A-Z - passes stdin to stdout converting lower case to upper case
    FILE *p = popen("tr a-z A-Z", "w");
    if (p == NULL) {
        perror("");
        return 1;
    }
    fprintf(p, "hello, i am a COMP1521 aficionado\n");
    pclose(p); // returns command exit status
    return 0;
}
```

Demo: write_popen.c

posix_spawn and pipes (advanced topic)

```
int posix_spawn_file_actions_destroy(
   posix_spawn_file_actions_t *file_actions);
int posix_spawn_file_actions_init(
   posix_spawn_file_actions_t *file_actions);
int posix_spawn_file_actions_addclose(
   posix_spawn_file_actions_t *file_actions, int fildes);
int posix_spawn_file_actions_adddup2(
   posix_spawn_file_actions_t *file_actions, int fildes, int newfildes);
```

- functions to combine file ops with posix_spawn process creation
- awkward to understand and use — but robust

Example: capturing output from a process: spawn_read_pipe.c
Example: sending input to a process: spawn_write_pipe.c

What we learnt Today

- Processes
  - execv, fork, waitpid
  - posix_spawn
- Pipes
  - posix_spawn (advanced usage)

system("ls -l");

```
pid_t pid;
char *argv[] = {"/bin/ls", "-l", cmd, NULL};
posix_spawn(&pid, "/bin/ls", NULL, NULL, argv, NULL);
```

Next Lecture

- Concurrency and Parallelism
  - Threads
  - Mutexes
  - Atomics

Feedback Please!

Your feedback is valuable!

If you have any feedback from today's lecture, please follow the link below or use the QR Code.

Please remember to keep your feedback constructive, so I can action it and improve your learning experience.

https://forms.office.com/r/F5Nh1svm2e

Reach Out

Content Related Questions:
Forum

Admin related Questions email:
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My Feelings and Mental Health
Managing Low Mood, Unusual Feelings & Depression

- **Mental Health Connect** — student.unsw.edu.au/**counselling** Telehealth
- **Mind HUB** — student.unsw.edu.au/**mind-hub** Online Self-Help Resources
- **In Australia Call Afterhours UNSW Mental Health Support Line** — 1300 787 026 5pm-9am
- **Outside Australia Afterhours 24-hour Medibank Hotline** — +61 (2) 8905 0307

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Educational Adjustments
To Manage my Studies and Disability / Health Condition

- **Equitable Learning Service (ELS)** — student.unsw.edu.au/**els**

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