DPST1092 24T3 — Processes

https://www.cse.unsw.edu.au/~dp1092/24T3/

Housekeeping

Catch UP / ADMIN

Rest of the term

- Week 9 Processes
- Week 10 THREADS
- Week 11 VIRTUAL MEMORY (Not in final exam)
- Week 12 Revision Important information
- Final exam on 20th November(will review in W12)
- Assignemnt 2 is out. Due Week 12 Friday
- No more Friday lectures (Tue and Thur only).

Processes

A *process* is an instance of an executing program

Each process has an *execution state*, defined by

- current execution point (PC register)
- current values of CPU registers
- current contents of its virtual address space
- information about open files, sockets, etc.

Unix Processes

Every process in Unix/Linux is allocated a unique process ID (PID)

- a +ve integer, unique among currently executing processes
- with type **`pid_t`** (defined in <unistd.h>)
- PID 0 is often used for the *Operating System* Kernel process. Can't be killed by users
- PID 1 is `init` ("used to boot the system")
- low PIDs are typically system-related as they start when the system is booted (but PIDs are recyled so this is not always the case)

Parent Processes

Each process has a *parent process*

- typically, the process that created the current process
- if the parent of the process dies, it becomes an orphan and is inherited by process 1

A process may have *child processes*

- these are processes that it created

Unix Tools

Unix provides a range of tools for manipulating processes

Commands:

- **`ps`** ... show process information
  - ps
  - ps -ef
  - ps -u z1234567 -o pid,ppid,time,stat,args
- **`top`** ... show high-cpu-usage process information
- **`kill`** ... send a signal to a process

System Calls to Get information about a process

`pid_t getpid()`

- requires `#include <sys/types.h>`
- returns the process ID of the current process

`pid_t getppid()`

- requires `#include <sys/types.h>`
- returns the parent process ID of the current process

For more details: `man 2 getpid`

System Calls to Get information about a process

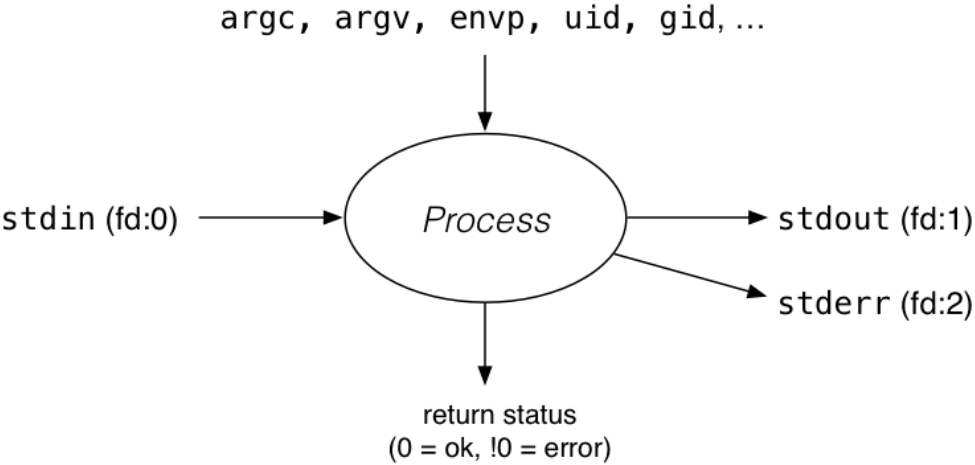
Minimal example for `getpid()` and `getppid()`:

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>

int main(void){
   printf("My PID is (%d)\n", getpid());
   printf("My parent's PID is (%d)\n", getppid());
   return 0;
}
```

Unix/Linux Processes

Environment for processes running on Unix/Linux systems



Environment Variables

Every process is passed a set of *environment variables* as an array of strings of the form name=value, terminated with NULL.

These can be accessed via

- access via global variable environ
- many C implementation also provide as 3rd parameter to main: `int main(int argc, char *argv[], char *env[])`

```
// print all environment variables
extern char **environ;
for (int i = 0; environ[i] != NULL; i++) {
    printf("%s\n", environ[i]);
}
```

source code for environ.c

- Most programs instead use getenv() and setenv() to access environment variables

getenv() — get an environment variable

```
#include <stdlib.h>

char *getenv(const char *name);
```

- search environment variable array for **name=value**
- returns **value**
- returns **NULL** if **name** not in environment variable array

```
char *value = getenv("PATH");
printf("Environment variable 'PATH' has value '%s'\n", value);
```

source code for get_env.c

setenv() — set an environment variable

```
#include <stdlib.h>

int setenv(const char *name, const char *value, int overwrite);
```

- adds **name=value** to environment variable array
- if **name** in array, value changed if **overwrite** is non-zero

Environment Variables - Why are they useful

- Unix-like shells have simple syntax to set environment variables
  - common to set environment in startup files (e.g `.profile`)
  - then passed to any programs they run
- Almost all program pass the environment variables they are given to any programs they run
  - perhaps adding/changing the value of specific environment variables
- Provides simple mechanism to pass settings to all processes, e.g
  - timezone (TZ)
  - user's prefered language (LANG)
  - directories to search for promrams (PATH)
  - user's home directory (HOME)

Multi-tasking

Process management is a critical OS functionality

On a typical modern operating system

- multiple processes are active "simultaneously" (*multi-tasking*)

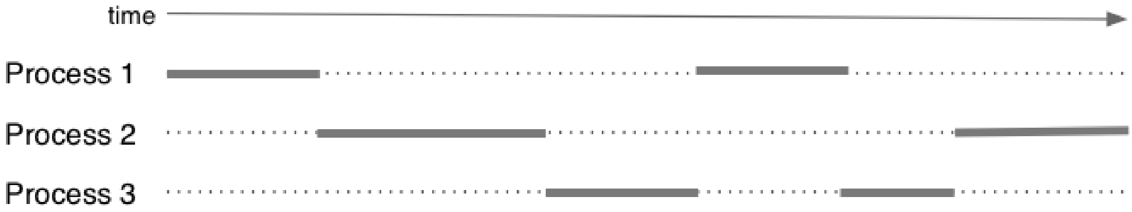
The operating system provides a virtual machine to each process:

- each process executes as if it is the only process running on the machine
- each process has its own address space (N bytes, addressed 0..N-1)

Multi-tasking

When there are multiple processes running on the machine

- each process uses the CPU until *pre-empted* or exits
- then another process uses the CPU until it too is pre-empted
- eventually, the first process will get another run on the CPU



Overall impression: three programs running simultaneously

Multi-tasking

What can cause a process to be pre-empted?

- it runs ”long enough” and the OS replaces it by a waiting process
- it needs to wait for input/output or some other operation

On pre-emption ...

- the process’s entire state must be stored
- the new process’s state must be restored
- this change is called a **context switch** (these are very expensive)

Multi-tasking

The context (or *state*) for each process is store in a Process Control Block (PBC).

Typical contents of a PCB:

- PID
- static information: program code and constant data
- dynamic state: heap, stack, registers, program counter
- OS-supplied state: environment variables, stdin, stdout
- status running, ready, suspended, exited
- privileges: effective user ids
- memory management info: (reference to) page table
- accounting: CPU time used, amount of I/O done
- I/O: open file descriptors

The operating system maintains a table of PCBs. One for each active process.

More Process-related System Calls

Unix/Linux system calls:

- **`fork()`** ... create a new process
- **`_exit()`** ... terminate an executing process
- **`wait()`** ... wait for state change in child process
- **`execve()`** ... convert one process into another

fork

`pid_t fork(void)`

- requires `#include <unistd.h>`
- creates new process by duplicating the calling process
- new process is the *child*, calling process is the *parent*
- child has a different process ID (pid) to the parent
- in the child, `fork()` returns 0
- in the parent, `fork()` returns the pid of the child
- if the system call fails, `fork()` returns -1
- child inherits copies of parent's address space and open fd's

Typically, the child pid is a small increment over the parent pid

fork

Minimal example for `fork()`:

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

int main(void){
   pid_t pid;
   pid = fork();
   if (pid < 0)
      perror("fork() failed");
   else if (pid == 0)
      printf("I am the child.\n");
   else
      printf("I am the parent.\n");
   return 0;
}
```

_exit

`void _exit(int status)`

- terminates current process
- closes any open file descriptors
- a `SIGCHLD` signal is sent to parent
- returns `status` to parent (via `wait()`)
- any child processes are inherited by `init` (pid=1)
- termination may be delayed waiting for i/o to complete

On final exit, process's process table and page table entries are removed

exit

`void exit(int status)`

- triggers any functions registered as `atexit()`
- flushes stdio buffers; closes open `FILE *`'s
- then behaves like `_exit()`

Exercise: The _exit() Function

What do you think the difference in output will be between the following 2 programs?

```
int main(void){
   printf("Hello");
   exit(0);
}

int main(void){
   printf("Hello");
   _exit(0);
}
```

Zombie Processes

Photo credit: kenny Louie, Flickr.com

Zombie Processes

A process cannot terminate until its parent is notified.

- if exit() called, operating system sends SIGCHLD signal to parent
- exit() will not return until parent handles SIGCHLD

Zombie process = exiting process waiting for parent to handle SIGCHLD

- all processes become zombie until `SIGCHLD` handled
- bug in parent that ignores `SIGCHLD` creates long-term zombies
- note that zombies occupy a slot in the process table and wastes resources

Orphan process = a process whose parent has exited

- when parent exits, orphan is assigned pid=1 as its parent
- pid=1 always handles `SIGCHLD` when process exits

waitpid

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

- pause current process until process `pid` changes state
  - where state changes include finishing, stopping, re-starting, ...
- ensures that child resources are released on exit (ie does not become a zombie)
- special values for `pid` ...
  - if `pid` = -1, wait on any child process
  - if `pid` = 0, wait on any child in process group
  - if `pid` > 0, wait on the specified process

```
pid_t wait(int *status)
```

- equivalent to `waitpid(-1, &status, 0)`
- pauses until one of the child processes terminates

waitpid

More on **`waitpid(pid, &status, 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`

waitpid

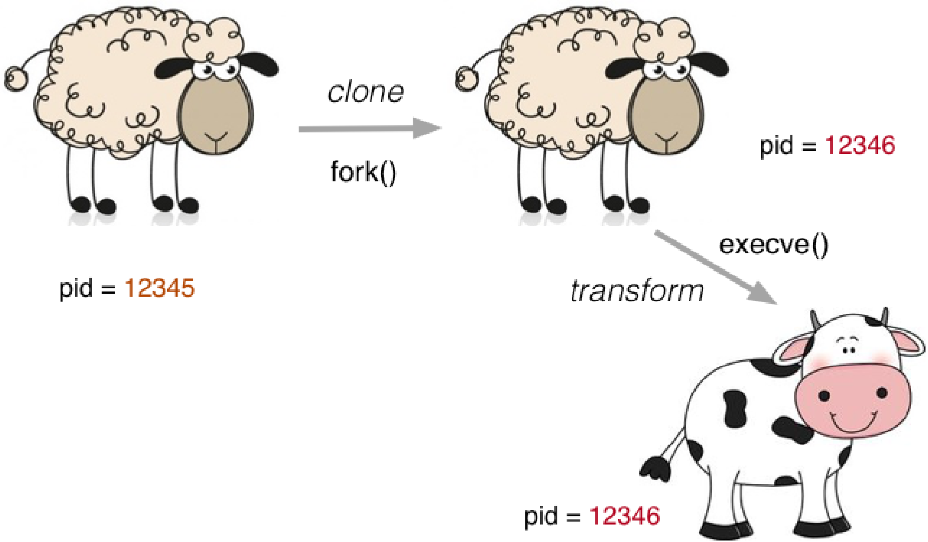
Minimal example for `wait()`:

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

int main(void)
{
   pid_t pid;
   pid = fork();
   if (pid == 0)
      printf("I am the child.\n");
   else {
      wait(NULL);
      printf("I am the parent.\n");
   }
   return 0;
}
```

execve

How Unix creates processes:



execve

```
int execve(char *Path, char *Argv[], char *Envp[])
```

- transforms current process by executing `Path` object
  - `Path` must be an executable, binary or script (starting with `#!`)
- passes arrays of strings to new process
  - both arrays terminated by a `NULL` pointer element
  - `envp[]` contains strings of the form `key=value`
- much of the state of the original process is lost, e.g.
  - new virtual address space is created, signal handlers reset, ...
- new process inherits open file descriptors from original process
- on error, returns -1 and sets `errno`
- if successful, does not return

execve

On Unix, processes create new different processes via:

```
pid_t pid = fork();
if (pid > 0)
   // parent ...
   wait(NULL); // wait for child to complete
else {
   // child ...
   char *cmd = "/x/y/z"; // name of executable
   char **args;
   ... // set up command-line arguments
   char **env;
   ... // set up environment varables

   execve(cmd, args, env); // child is transformed
}
```

Exercise: Executor

Write a small program that will run other programs

- reads, one per line, values for command-line arguments
- trims each line and stores pointer to it in array `args[]`
- uses `args[0]` as the path of the program to run
- uses `args[]` as `argv[]` in the exec'd process
- passes no `envp[]` values (i.e. `envp=NULL`)
- invokes the specified program then waits for it to complete
- displays the exit status of the invoked process

posix_spawn

```
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[]);
```

- creates new process, running program at path
- argv specifies argv of new program
- envp specifies environment of new program
- *pid set to process id of new program
- file_actions specifies file actions to be performed before running program
  - can be used to re-direct stdin or stdout to file or pipe
  - advanced topic
- attrp specifies attributes for new process

Review: Processes and Multi-tasking

Multi-tasking = multiple processes are ”active” at the same time

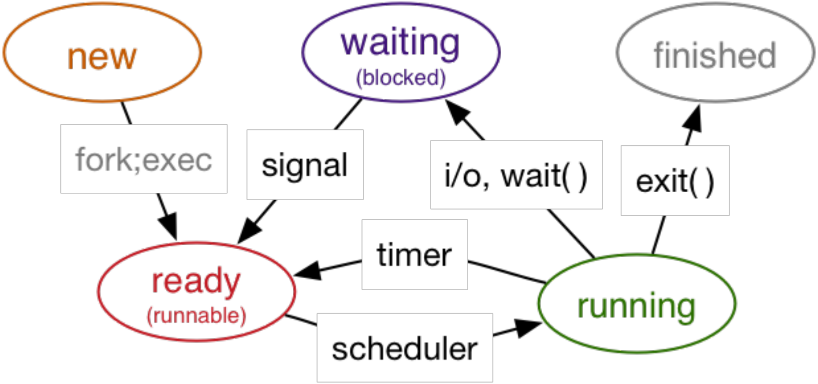
- processes are not necessarily *executing* simultaneously
    - although this could happen if there are multiple CPUs
- more likely, have a mixture of processes
    - some are *blocked* waiting on a signal (e.g. i/o completion)
    - some are *runnable* (ready to execute)
    - one is running (on each CPU)

Aims to give the appearance of multiple simultaneous processes

- by switching process after one runs for a defined *time slice*
- after timer counts down, current process is *pre-empted*
- a new process is selected to run by the system *scheduler*

Process States

How process state changes during execution ...



`pipe()` — stream bytes between processes

A common style of inter process interaction (communication)

- producer process writes to byte stream (cf. stdout)
- consumer process reads from same byte stream

A *pipe* provides buffered i/o between producer and consumer

- producer blocks when buffer full; consumer blocks when buffer empty

Pipes are bidirectional unless processes close one file descriptor.

It is a good idea to do this and only use pipes for unidirectional communication. If you need two way communication, use two pipes.

`pipe()` — stream bytes between processes

`int pipe(int fd[2])`

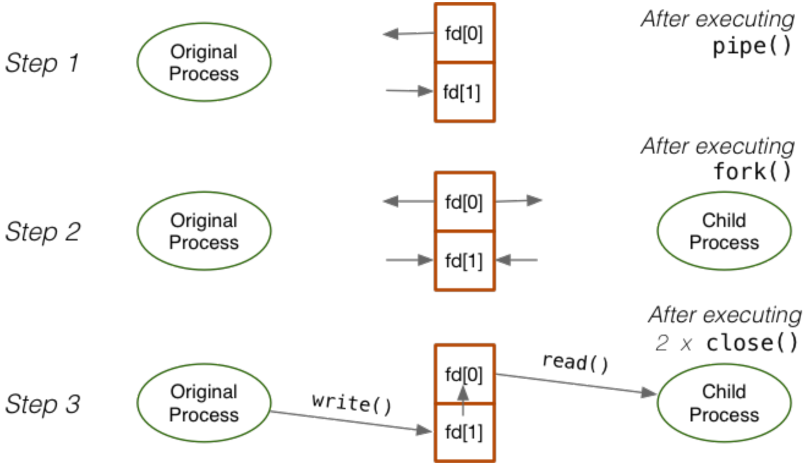
- open two file descriptors (to be shared by processes)
- `fd[0]` is opened for reading; `fd[1]` is opened for writing
- return 0 if OK, otherwise return -1 and sets `errno`

Creating the pipe would then be followed by

- `fork()` to create a child process
- both processes have copies of `fd[]`
- one can write to `fd[1]`, the other can read from `fd[0]`

pipe() — stream bytes between processes

Creating a pipe ...



pipe() — stream bytes between processes

Example: setting up a pipe

```
int main(void) {
   int fd[2], pid;  char buffer[10];
   assert(pipe(fd) == 0);
   pid = fork();
   assert(pid >= 0);
   if (pid != 0) {  // parent
      close(fd[0]); // writer; don't need fd[0]
      write(fd[1], "123456789", 10);
      close(fd[1]);
   }
   else {           // child
      close(fd[1]); // reader; don't need fd[1]
      read(fd[0], buffer, 10);
      printf("got \"%s\"\n", buffer);
      close(fd[0]);
   }
   return 0;
```

`pipe()` — stream bytes between processes

It is important to close unused duplicate pipe file descriptors

- If there are open write end file descriptors, read(2) won't return 0 and will wait for more input
- If all read end file descriptors have been closed, then a write(2) will cause a SIGPIPE signal to be generated.

popen() — a convenient but unsafe way to set up pipe

A common pattern in pipe usage

- set up a pipe between parent and child
- `exec()` child to become a new process talking to parent

Because so common, a library function is available for it ...

`FILE *popen(char *Cmd, char *Mode)`

- analogous to `fopen`, except first arg is a command
- Cmd is passed to shell for interpretation
- returns `FILE*` which be read/written depending on `Mode`
- returns `NULL` if can't establish pipe or invalid Cmd

popen() — a convenient but unsafe way to set up pipe

Example of popen()

```
//popen is a convenient but unsafe way to set up a pipe
//It passes a string to a shell for evaluation
//It is brittle and highly vulnerable to security exploits
//Suitable for quick debugging or throw away programs only
int main(void)
{
   FILE *p = popen("ls -l", "r");
   assert(p != NULL);
   char line[200], a[20],b[20],c[20],d[20];
   long int tot = 0, size = 0;
   while (fgets(line,199,p) != NULL) {
      sscanf(line, "%s %s %s %s %ld",
                  a, b, c, d, &size);
      fputs(line, stdout);
      tot += size;
   }
   printf("Total: %ld\n", tot);
```

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 operations with posix_spawn process creation
- awkward to understand & use - but robust
- example: capturing output from a process - source code for spawn_read_pipe.c
- example: sending input to a process - source code for spawn_write_pipe.c