CSC209 Summer 2015 — Software Tools and Systems Programming

www.cdf.toronto.edu/~csc209h/summer/

Week 8 — July 2, 2015

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Some materials courtesy of Karen Reid

Announcements

- Next Tuesday (July 7) office hour is postponed:
    - Friday, July 10?

Announcements

- *No* lab period tonight
    - There is a lab this week (see Piazza) and it is due Sunday 10pm

Agenda

- The course half way point
- Unix processes
- **`fork`**, **`wait`** and **`exec`** system calls

First Half of CSC209

- Shell as user interface
- C language syntax and semantics

Second Half of CSC209

- Mechanisms and abstractions provided by *Unix* operating systems
  - Processes
  - Files
  - Inter-process communication: signals and pipes
  - Network programming with sockets
  - Parallelism and concurrency
- Advanced shell usage

Week 8 lab exercise

Agree *or* Disagree

Agree *or* Disagree

You can only *really* do three things with the C language programming language:

1) Perform arithmetic
2) Evaluate logical expressions
3) Access memory

Unix Processes

Kerrisk ch. 6

"A process *is an instance of an executing program."*

Kerrisk p113

Unix Processes

- Every system has *many* processes currently active:
  - Special operating system processes
  - User process
  - Your personal shell, compiler and test programs…

```
ps aux
```

Unix Processes

- Each process is given the illusion of isolation:
  - Exclusive control of the CPU
  - Virtual memory address space
  - Currently open files (including notions of **`stdout`**, **`stdin`** and **`stderr`**)
  - Current working directory
  - Other system resources integral to its execution

Unix Processes

- The OS kernel is an arbitrator that divides physically limited resources out among processes:
    - Memory
    - CPU time
    - Disk
    - Network
    - Access to peripherals, etc.

Unix Processes

- The OS kernel grants each process a slice of the CPU (a short period of time during which the process may run), and then *preemptively* stops that process and switches to let another one run for a time
    - Your processes generally do not even notice that this is happening (the illusion of exclusivity)

System Calls

- The kernel lets processes use *system calls* in order to make requests:
    - File I/O
    - Certain kinds of memory management (**`mmap`**, but not necessarily **`malloc`**)
    - Process management
    - Communications (networking and IPC)

`getpid`, `getppid` - get process identification

```
pid_t getpid(void);
pid_t getppid(void);
```

From the manpage: *“**`getpid()`** returns the process ID of the calling process.*

***`getppid()`** returns the process ID of the* parent *of the calling process.”*

`getpid.c`

What's the difference between a *system library function* like

`strncpy`

and a *system call function* like

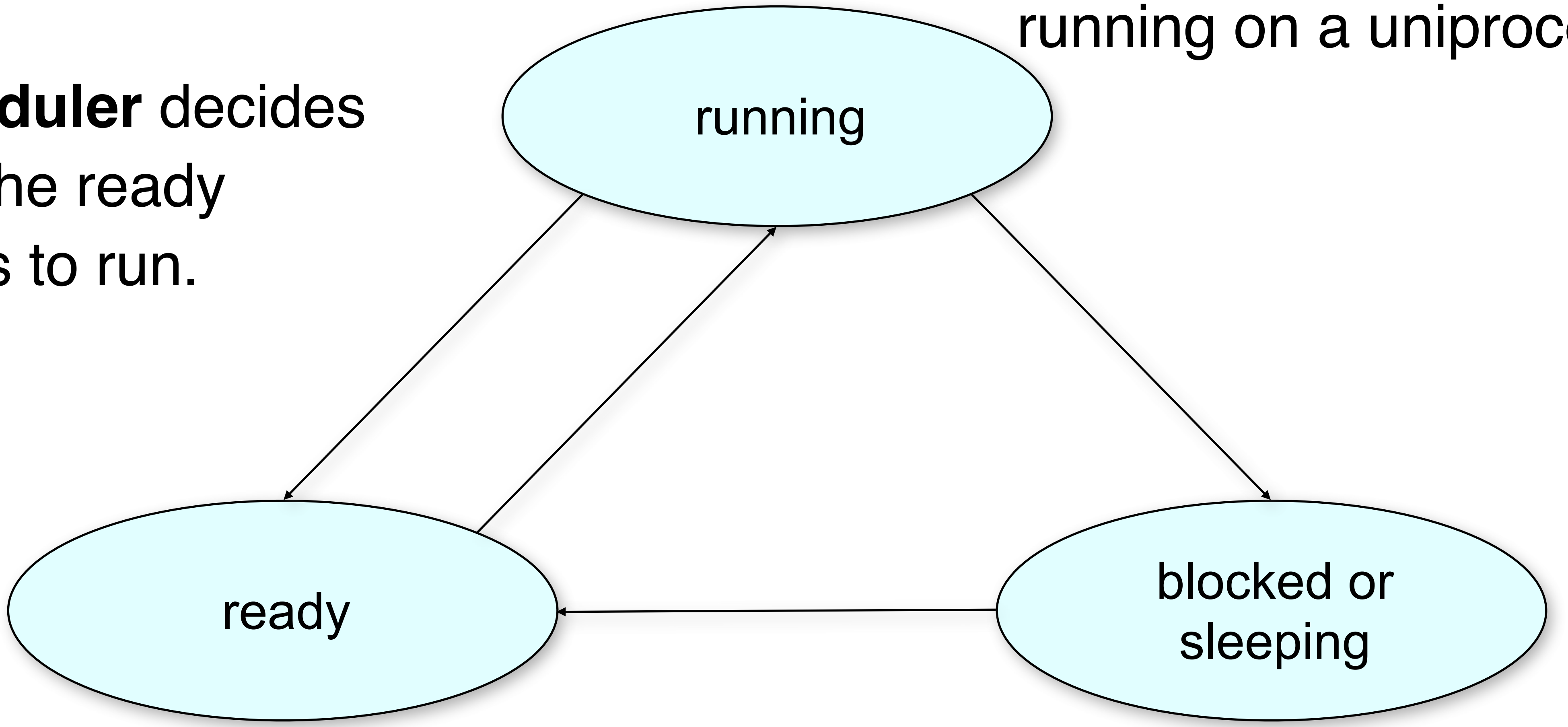
`getpid`

?

Process State

Only one process can be running on a uniprocessor

The **scheduler** decides which of the ready processes to run.



A process is *ready* if it could use the CPU immediately.

A process is *blocked* if it waiting for an event (I/O, signal)

sleep.c

`fork` system call

Kerrisk ch. 24

`fork`

- The **`fork`** system call creates a copy of the currently running process, diverging from the point of the system call itself:
  - The newly created *child* process receives a return value of **`0`** from the call
  - The original *parent* process receives a the PID of the newly created child

fork

pid=123:

```
A();
B();
C();
pid = fork();
// pid == ???
D();
E();
F();
```

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fork

parent *(pid=123)*:

```
A();
B();
C();
pid = fork();
// pid == ???
D();
E();
F();
```

child *(pid=456)*:

```
A();
B();
C();
pid = fork();
// pid == ???
D();
E();
F();
```

fork

parent *(pid=123)*:

```
A();
B();
C();
pid = fork();
// pid == 456
D();
E();
F();
```

child *(pid=456)*:

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```

`fork.c`

`fork`

- Fork can and will *fail* (i.e. return `-1`) if your user account has created too many processes, or if a system wide limit has been reached

`fork` — what's initially the same between parent and child?

- Properties of parent *inherited* by child:
  - UID, GID
  - Controlling terminal
  - Current working directory and notion of root directory
  - Signal mask, environment, resource limits
  - Shared memory (SHM) segments

`fork` — what’s changes between parent and child?

- *Differences* between parent and child
  - PID, PPID
  - *Return value* from **`fork()`**
  - Pending *alarms* cleared for child
  - Pending *signals* are cleared for child

Process Termination

Kerrisk ch. 25

Process Termination

- A process *terminates* when either it explicitly calls **`exit(`*`int`*` status)`** or implicitly when it *returns* from **`main`** with a status code
    - Status code of **`0`** indicates *success* (or, the absence of failure)
    - Anything else indicates *failure*
- The Bash shell stores the exit status code of the last process run in a special variable named **`$?`**

exitstatus.c

Process Termination

- Every normal process is the child process of some parent process
- A terminating process sends its parent a **`SIGCHLD`** signal and waits for its parent to accept its exit code

What happens if the parent *exits* before the child?

Orphaned Processes

- Any process whose parent terminates before it does will become *orphaned*, and its parent process becomes PID 1 (the `init` process, which is the first process in the entire system) forkorphan.c

How does a parent process *wait* for its child to exit before itself terminating?

`wait` - wait for child process to change state

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

- A process that calls `wait()` can:
  - *block* (if all of its children are still running)
  - return immediately with the termination status of a child (if a child has terminated and is waiting for its termination status to be fetched)
  - return immediately with an error (if it doesn't have any child processes.)

Kerrisk ch. 26

wait.c

Zombies

- A *zombie* process:
  - a process that is “waiting” for its parent to accept its exit status code
  - a parent accepts a child’s status code by executing **`wait()`**
  - shows up as Z in **`ps –a`**
  - A terminating process may be a (multiple) parent; the kernel ensures all of its children are orphaned and adopted by **`init`**

zombie.c

`wait` and `waitpid`

- **`wait()`** can
  - block
  - return with termination status
  - return with error
- If there is more than one child, **`wait()`** returns on termination of *any* of its children
- **`waitpid()`** can be used to wait for a *specific* child PID
  - Also has an option to block or not to block

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

- if `pid == -1:`
  - Wait for *any* child (otherwise wait only for that specific child `pid`)
- if `option == WNOHANG:`
  - Return immediately *if* there is no child to wait for (i.e. do *not* block)
- if `option == 0`:
  - *Do* wait (block) until there is a child to deal with

`wait(&status)` is equivalent to `waitpid(-1, &status, 0)`

waitpid.c

`waitmany.c` and `kill(1)`

`fork` is the only way to create new processes

… how do we ever run *existing* programs then?

`exec`

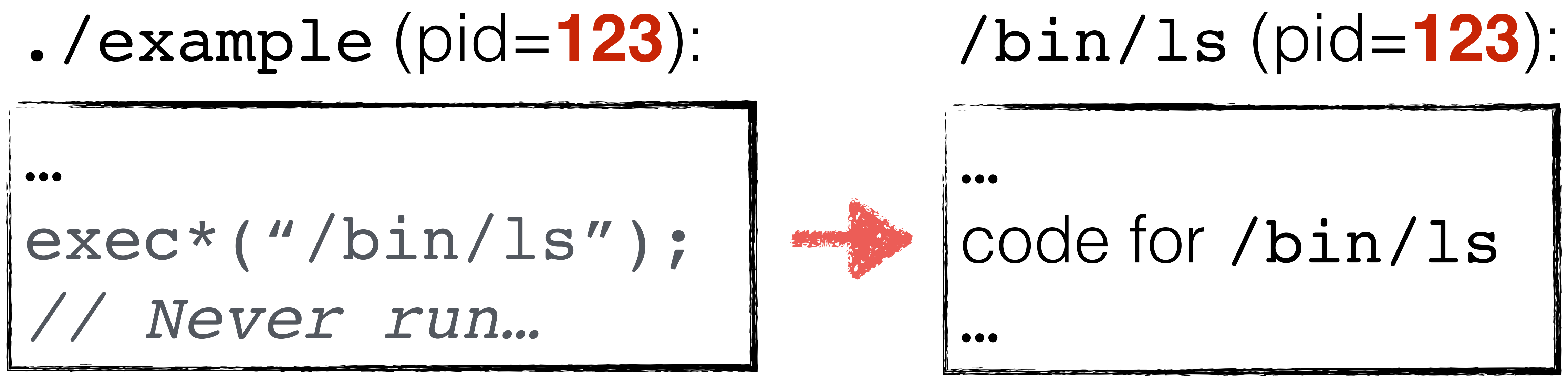
Kerrisk ch. 27

`exec` - replace the currently running process

- A family of system calls with several different variations
- Replaces the program that the process is currently running with another
- On success, `exec` will *never* return (because success means another program is now running in your place), and on failure will return `-1`

`./example` (pid=**123**):

```
…
exec*("/bin/ls");
// Never run…
```



```
…
exec*("/bin/ls");
// Never run…
```

```
…
code for /bin/ls
…
```

Properties of `exec`

- New process *inherits* from calling process:
  - *PID and PPID*
  - Real UID, GID
  - Controlling terminal
  - CWD, root directory, resource limits
  - Pending signals
  - Pending alarms

Variations of **`exec`**

```
int execve(const char *filename, char *const argv[], char *const envp[]);
int execv(const char *path, char *const argv[]);

int execl(const char *path, const char *arg, …);
int execle(const char *path, const char *arg, ..., char * const envp[]);
int execlp(const char *file, const char *arg, …);

int execvp(const char *file, char *const argv[]);
int execvpe(const char *file, char *const argv[],
            char *const envp[]);
```

Variations: **`execv`**

```
int execv(const char *path,
          char *const argv[]);
```

Exec the binary executable located at **`path`**, passing in the given **`argv`** array (which must be **`NULL`** terminated) `execv.c`

Variations: `exec*p*`

```
int execvp(const char *file, char *const argv[]);
int execlp(const char *file, const char *arg, ...);
int execvpe(const char *file, char *const argv[],
            char *const envp[]);
```

Use the **`PATH`** environment variable to search for executables with the name specified in **`file`**

execvp.c

Variations: `exec*l*`

```
int execl(const char *path, const char *arg, ...);
int execlp(const char *file, const char *arg, ...);
int execle(const char *path, const char *arg, ...,
           char * const envp[]);
```

Uses C *variadic* functions (which allow a variable number of parameters) to let you specify the contents of **`argv`** (must have signal the end with an explicit **`NULL`**.)

Variations: `exec*e`

```
int execve(const char *filename, char *const argv[],
           char *const envp[]);

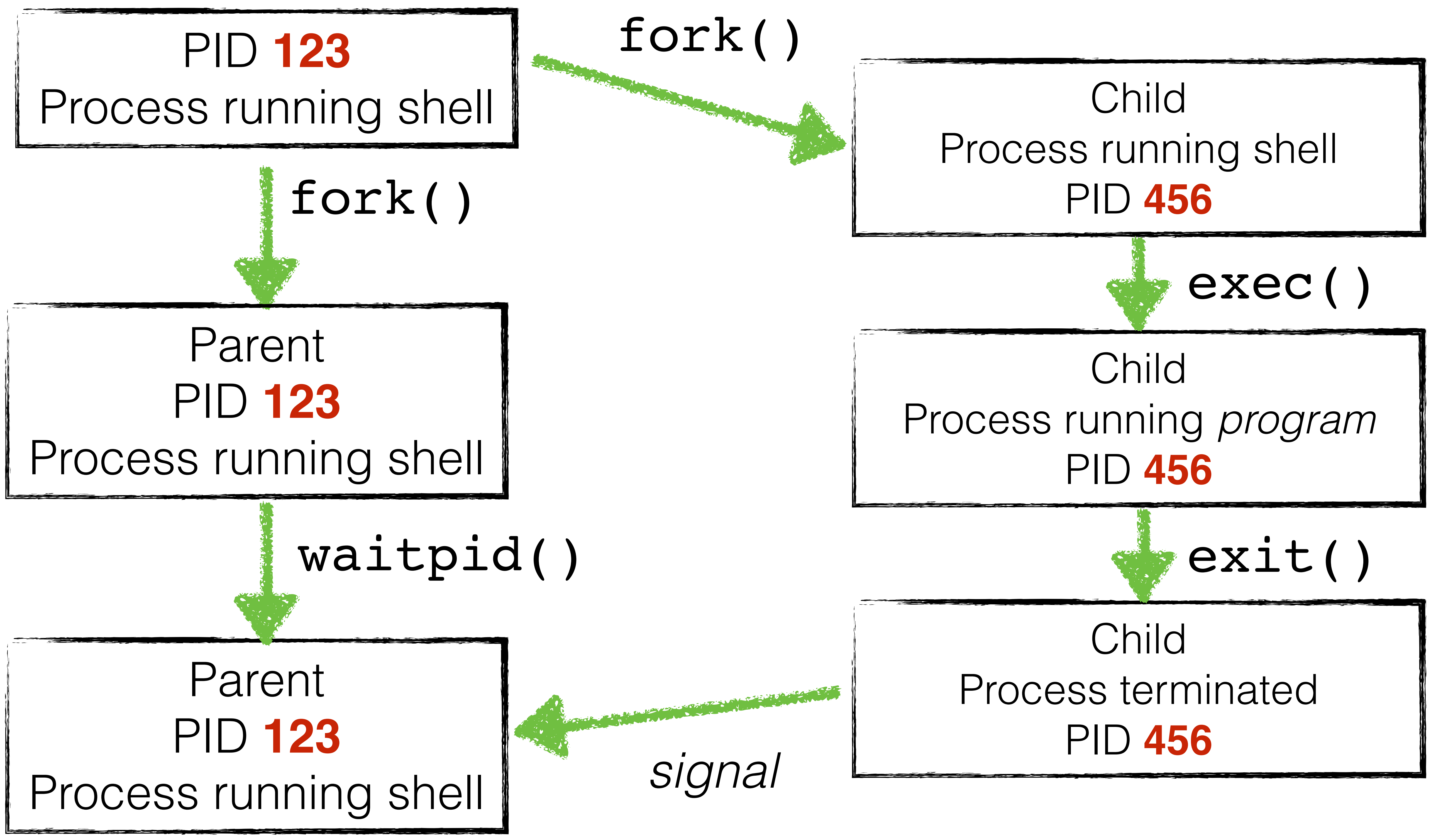
int execvpe(const char *file, char *const argv[],
            char *const envp[]);

int execle(const char *path, const char *arg, ...,
           char * const envp[]);
```

Specify the *environment* (**`envp`** array) to exec the program in.

forkexec.c

How a shell works



`fork` is the only way to create new processes

`exec` is the only way to run existing programs

Midterms