CSCI 4061: Making Processes

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Logistics

Reading: Stevens and Rago, Ch 8

- Covers basic process creation and management functions

Assignments

- Lab01 / HW01: Due Mon 2/01
- Lab02 / HW02: Release over the weekend, focus on Process creation and coordination
- Project 1: Discuss next week

Goals

- Complete Unix basics
- Creating Child Processes
- Waiting for them
- Running other programs

Processes

- Hardware just executes a stream of instructions
- The OS creates the notion of a **process**: instructions comprising a **running program**
- Processes can be executed for a while, then paused while another process executes
- To accomplish this, OS usually provides...
  1. Bookkeeping info for processes (resources)
  2. Ability to interrupt / pre-empt a running process to allow OS actions to take place
  3. Scheduler that decides which process runs and for how long
- Will discuss all of these things from a systems programming perspective

Overview of Process Creation/Coordination

`getpid()` / `getppid()`

- Get process ID of the currently running process
- Get parent process ID

`fork()`

- Create a child process
- Identical to parent EXCEPT for return value of fork() call
- Determines child/parent

`wait()` / `waitpid()`

- Wait for any child to finish (wait)
- Wait for a specific child to finish (waitpid)
- Get return status of child

`exec()` family

- Replace currently running process with a different program image
- Process becomes something else losing previous code
- Focus on `execvp()`

Overview of Process Creation/Coordination

getpid() / getppid()

```
pid_t my_pid = getpid();
printf("I'm proces %d\n",my_pid);
pid_t par_pid = getppid();
printf("My parent is %d\n",par_pid);
```

fork()

```
pid_t child_pid = fork();
if(child_pid == 0){
  printf("Child!\n");
}
else{
  printf("Parent!\n");
}
```

wait() / waitpid()

```
int status;
waitpid(child_pid, &status, 0);
printf("Child %d done, status %d\n",
       child_pid, status);
```

exec() family

```
char *new_argv[] = {"ls","-l",NULL};
char *command = "ls";
printf("Goodbye old code, hello LS!\n");
execvp(command, new_argv);
```

Exercise: Standard Use: Get Child to Do Something

Child Labor

- Examine the file `child_labor.c` and discuss
- Makes use of `getpid()`, `getppid()`, `fork()`, `execvp()`
- Explain how these system calls are used

Child Waiting

- `child_labor.c` has concurrency issues: parent/child output mixed
- Modify with a call to `wait()` to ensure parent output comes AFTER child output

Write down your answers as a team for screen sharing

Suggestion: Copy `child_labor.c` to `child_wait.c` and modify it to fix the concurrency problem

Answers: `child_labor.c` commentary

```
 1  // child_labor.c: demonstrate the basics of fork/exec to launch a
 2  // child process to do "labor"; e.g. run a another program via
 3  // exec. Make sure that the the 'complain' program is compiled first.
 4  #include <stdio.h>
 5  #include <stdlib.h>
 6  #include <sys/wait.h>
 7  #include <unistd.h>
 8
 9  int main(int argc, char* argv){
10
11    // char *child_argv[] = {"complain",NULL};              // argument array to child, must end with NULL
12    // char *child_cmd = "complain";                        // actual command to run, must be on path
13
14    char *child_argv[] = {"ls","-l","-ah",NULL};       // alternative argv/command swap commenting
15    char *child_cmd = "ls";                            // with above to alter what child does
16
17    printf("I'm %d, and I really don't feel like '%s'ing\n",
18           getpid(),child_cmd);                             // use of getpid() to get current PID
19    printf("I have a solution\n");
20
21    pid_t child_pid = fork();                               // clone a child
22
23    if(child_pid == 0){                                     // child will have a 0 here
24      printf("   I'm %d My pa '%d' wants me to '%s'. This sucks.\n",
25             getpid(), getppid(), child_cmd);               // use of getpid() and getppid()
26
27      execvp(child_cmd, child_argv);                        // replace running image with child_cmd
28
29      printf("   I don't feel like myself anymore...\n"); // unreachable statement
30    }
31    else{                                                   // parent will see nonzero in child_pid
32      printf("Great, junior %d is taking care of that\n",
33             child_pid);
34    }
35    return 0;
36  }
```

Answers: `child_wait.c` modification

```
 1  // child_wait.c: fork/exec plus parent waits for child to
 2  // complete printing befor printing itself.
 3
 4  #include <stdio.h>
 5  #include <stdlib.h>
 6  #include <sys/wait.h>
 7  #include <unistd.h>
 8
 9  int main(int argc, char* argv){
10
11    // char *child_argv[] = {"ls","-l","-ah",NULL};          // argument array to child, must end with NULL
12    // char *child_cmd = "ls";                               // actual command to run, must be on path
13
14    char *child_argv[] = {"./complain",NULL};          // alternative commands
15    char *child_cmd = "complain";
16
17    printf("I'm %d, and I really don't feel like '%s'ing\n",
18           getpid(),child_cmd);
19    printf("I have a solution\n");
20
21    pid_t child_pid = fork();
22
23    if(child_pid == 0){
24      printf("   I'm %d My pa '%d' wants me to '%s'. This sucks.\n",
25             getpid(), getppid(), child_cmd);
26      execvp(child_cmd, child_argv);
27      printf("   I don't feel like myself anymore...\n"); // unreachable
28    }
29    else{
30      int status;
31      wait(&status);                                      // wait for child to finish, collect status
32      printf("Great, junior %d is done with that '%s'ing\n",
33             child_pid, child_cmd);
34    }
35    return 0;
36  }
```

Effects of `fork()`

- Single process becomes 2 processes
- Sole difference is return value from `fork()`
- All other aspects of process are copied

Before fork(): 1 process

Process 1234

STACK	heap_str	0x500
	myint	5
	child_pid	?
	...	...
HEAP	0x500	h
	0x501	i
	0x502	\0
	...	...
GLOBALS	glob_doub	1.23
	...	...

TEXT/CODE

```
int main(){
   char *heap_str = malloc(..);
   int myint = 5;
   glob_doub = 1.23;
>> int child_pid = fork()
   if(child_pid == 0){
     myint = 19;
   }
   printf("myint: %d\n", myint);
   ...
```

After fork(): 2 processes

Process 1234 (parent)

STACK	heap_str	0x500
	myint	5
	child_pid	5678
	...	...
HEAP	0x500	h
	0x501	i
	0x502	\0
	...	...
GLOBALS	glob_doub	1.23
	...	...

TEXT/CODE

```
int main(){
   char *heap_str = malloc(..);
   int myint = 5;
   glob_doub = 1.23;
   int child_pid = fork()
>> if(child_pid == 0){
     myint = 19;
   }
   printf("myint: %d\n", myint);
   ...
```

Process 5678 (child)

STACK	heap_str	0x500
	myint	5
	child_pid	0
	...	...
HEAP	0x500	h
	0x501	i
	0x502	\0
	...	...
GLOBALS	glob_doub	1.23
	...	...

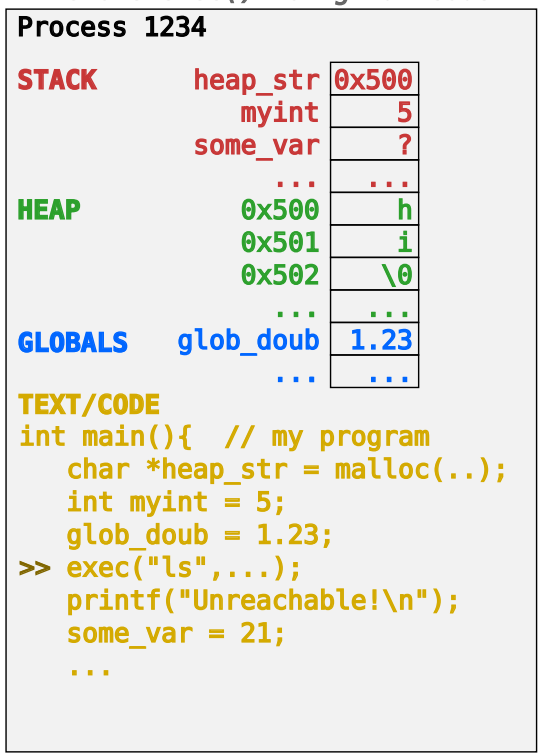
TEXT/CODE

```
int main(){
   char *heap_str = malloc(..);
   int myint = 5;
   glob_doub = 1.23;
   int child_pid = fork()
>> if(child_pid == 0){
     myint = 19;
   }
   printf("myint: %d\n", myint);
   ...
```

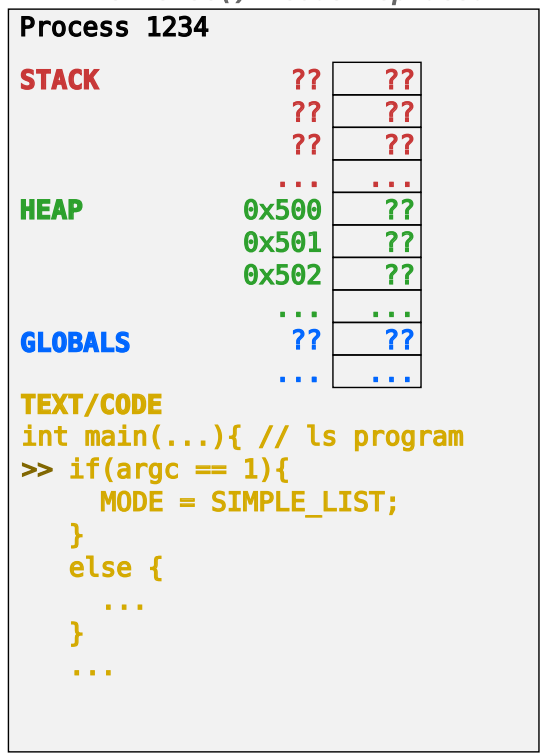
Effects of `exec()`

- Entire Memory image of process is replaced/reset
- Original process Text/Code is replaced, begin new `main()`
- Successful `exec()` does not return to original code

Before exec(): original code



After exec(): code replaced



Exercise: Child Exit Status

- A successful call to `wait()` sets a status variable giving info about child

  ```
  int status;
  wait(&status);
  ```

- Several macros are used to parse out this variable

  ```
  // determine if child actually exited
  // other things like signals can cause
  // wait to return
  if(WIFEXITED(status)){

    // get the return value of program
    int retval = WEXITSTATUS(status);
  }
  ```

- **Modify** `child_labor.c` so that parent checks child exit status
- Convention: 0 normal, nonzero error, print something if non-zero

```
# program that returns non-zero
> gcc -o complain complain.c

# EDIT FILE TO HAVE CHILD RUN 'complain'
> gcc child_labor_wait_returnval.c
> ./a.out
I'm 2239, and I really don't feel
like 'complain'ing
I have a solution
   I'm 2240 My pa '2239' wants me to 'complain'.
   This sucks.
COMPLAIN: God this sucks. On a scale of 0 to 10
          I hate pa ...

Great, junior 2240 did that and told me '10'
That little punk gave me a non-zero return.
I'm glad he's dead
>
```

Answers: Child Exit Status

```
 1  // child_wait_returnval.c: fork/exec plus parent waits for child and
 2  // checks their status using macors. If nonzero, parent reports.
 3
 4  #include <stdio.h>
 5  #include <stdlib.h>
 6  #include <sys/wait.h>
 7  #include <unistd.h>
 8
 9  int main(int argc, char* argv){
10    char *child_argv[] = {"./complain",NULL};             // program returns non-zero
11    char *child_cmd = "complain";
12
13    printf("I'm %d, and I really don't feel like '%s'ing\n",
14           getpid(),child_cmd);
15    printf("I have a solution\n");
16
17    pid_t child_pid = fork();
18
19    if(child_pid == 0){
20      printf("   I'm %d My pa '%d' wants me to '%s'. This sucks.\n",
21             getpid(), getppid(), child_cmd);
22      execvp(child_cmd, child_argv);
23      printf("   I don't feel like myself anymore...\n"); // unreachable
24    }
25    else{
26      int status;
27      wait(&status);                                      // wait for child to finish, collect status
28      if(WIFEXITED(status)){
29        int retval = WEXITSTATUS(status);                 // decode status to 0-255
30        printf("Great, junior %d did that and told me '%d'\n",
31               child_pid, retval);
32        if(retval != 0){                                  // nonzero exit codes usually indicate failure
33          printf("That little punk gave me a non-zero return. I'm glad he's dead\n");
34        }
35      }
36    }
37    return 0;
38  }
```

Return Value for `wait()` family

- Return value for `wait()` and `waitpid()` is the PID of the child that finished
- Makes a lot of sense for `wait()` as multiple children can be started and `wait()` reports which finished
- One `wait()` per child process is typical
- See `faster_child.c`

```
// parent waits for each child
for(int i=0; i<3; i++){
  int status;
  int child_pid = wait(&status);
  if(WIFEXITED(status)){
    int retval = WEXITSTATUS(status);
    printf("PARENT: Finished child proc %d, retval: %d\n",
           child_pid, retval);
  }
}
```

Blocking vs. Nonblocking Activities

Blocking

- A call to `wait()` and `waitpid()` may cause calling process to **block** (hang, stall, pause, suspend, so many names...)
- Blocking is associated with other activities as well
  - I/O, obtain a lock, get a signal, etc.
- Generally creates **synchronous** situations: waiting for something to finish means the next action *always* happens.. next (e.g. print after `wait()` returns)

```
// BLOCKING VERSION
int pid = waitpid(child_pid, &status, 0);
```

Non-blocking

- Contrast with **non-blocking** (asynchronous) activities: calling process goes ahead even if something isn't finished yet
- `wait()` is always blocking
- `waitpid()` can be blocking or non-blocking

Non-Blocking waitpid()

- Use the `WNOHANG` option
- Returns immediately regardless of the child's status

```
int child_pid = fork();
int status;

// NON-BLOCKING
int pid = waitpid(child_pid, &status, WNOHANG); // specific child
OR                                      |||||||
int pid = waitpid(       -1, &status, WNOHANG); // any child
```

Returned `pid` is

Returned	Means
`child_pid`	status of child that changed / exited
0	there is no status change for child / none exited
-1	an error

Examine `impatient_parent.c`

impatient_parent.c

```
 1  // impatient_parent.c: demonstrate non-blocking waitpid(),
 2
 3  #include <stdio.h>
 4  #include <stdlib.h>
 5  #include <sys/wait.h>
 6  #include <unistd.h>
 7
 8  int main(int argc, char* argv){
 9    char *child_argv[] = {"./complain",NULL};
10    char *child_cmd = "complain";
11    printf("PARENT: Junior is about to '%s', I'll keep an eye on him\n",
12           child_cmd);
13    pid_t child_pid = fork();
14
15    // CHILD CODE
16    if(child_pid == 0){
17      printf("CHILD: I'm %d and I'm about to '%s'\n",
18             getpid(), child_cmd);
19      execvp(child_cmd, child_argv);
20    }
21
22    // PARENT CODE
23    int status;
24    int retcode = waitpid(child_pid, &status, WNOHANG);   // non-blocking wait
25    if(retcode == 0){                                     // 0 means child has not exited/changed status
26      printf("PARENT: 0? The kid's not done yet. I'm bored\n");
27    }
28    else{                                                 // child has changed status / exited
29      printf("PARENT: Something happend to junior!\n");
30      if(WIFEXITED(status)){
31        printf("Ah, he Exited with code %d", WEXITSTATUS(status));
32      }
33      else{
34        printf("Junior didn't exit, what happened to him?\n");
35      }
36    }
37    return 0;
38  }
```

Runs of impatient_parent.c

```
> gcc impatient_parent.c
> a.out
PARENT: Junior is about to 'complain', I'll keep an eye on him
PARENT: 0? The kid's not done yet. I'm bored
CHILD: I'm 1863 and I'm about to 'complain'
> COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...

> a.out
PARENT: Junior is about to 'complain', I'll keep an eye on him
PARENT: 0? The kid's not done yet. I'm bored
CHILD: I'm 1865 and I'm about to 'complain'
> COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...
```

Exercise: Helicopter Parent

©Zits Partnership

- Modify `impatient_parent.c` to `helicopter_parent.c`
- Checks continuously on child process
- Will need a loop for this...

```
> gcc helicopter_parent.c
> a.out
PARENT: Junior is about to 'complain', I'll keep an eye on him
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
...
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
CHILD: I'm 21789 and I'm about to 'complain'
Oh, junior's taking so long. Is he among the 50% of people that are below average?
...
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
COMPLAIN: God this sucks. On a scale of 0 to 10 I hate pa ...
Oh, junior's taking so long. Is he among the 50% of people that are below average?
Oh, junior's taking so long. Is he among the 50% of people that are below average?
...
PARENT: Good job junior. I only checked on you 226 times.
```

Answers: Helicopter Parent

```c
// helicopter_parent.c: demonstrate non-blocking waitpid() in excess
#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <unistd.h>

int main(int argc, char* argv){

  char *child_argv[] = {"./complain",NULL};
  char *child_cmd = "complain";

  printf("PARENT: Junior is about to '%s', I'll keep an eye on him\n",
         child_cmd);

  pid_t child_pid = fork();

  // CHILD CODE
  if(child_pid == 0){
    printf("CHILD: I'm %d and I'm about to '%s'\n",
           getpid(), child_cmd);
    execvp(child_cmd, child_argv);
  }

  // PARENT CODE
  int status;
  int checked = 0;
  while(1){
    int cpid = waitpid(child_pid,&status,WNOHANG); // Check if child done, but don't actually wait
    if(cpid == child_pid){                         // Child did finish
      break;
    }
    printf("Oh, junior's taking so long. Is he among the 50%% of people that are below average?\n");
    checked++;
  }
  printf("PARENT: Good job junior. I only checked on you %d times.\n",checked);
  return 0;
}
```

Polling vs Interrupts

- `helicopter_parent.c` is an example of **polling**: checking on something repeatedly until it achieves a ready state
- Easy to program, generally inefficient
- Alternative: **interrupt** style is closer to `wait()` and `waitpid()` *without* `WNOHANG`: rest until notified of a change
- Usually requires cooperation with OS/hardware which must wake up process when stuff is ready
- Both polling-style and interrupt-style programming have uses

Zombies...

- Parent creates a child
- Child completes
- Child becomes a **zombie** (!!!)
- Parent waits for child
- Child eliminated

All we want is the attention of a loving parent...

Zombie Process

A process that has finished, but has not been `wait()`'ed for by its parent yet so cannot be (entirely) eliminated from the system. OS can reclaim child resources like memory once parent `wait()`'s.

Demonstrate

Requires a process monitoring with `top/ps` but can see zombies created using `spawn_undead.c`

Tree of Processes

```
> pstree
systemd-+-NetworkManager---2*[{NetworkManager}]
        |-accounts-daemon---2*[{accounts-daemon}]
        |-colord---2*[{colord}]
        |-csd-printer---2*[{csd-printer}]
        |-cupsd
        |-dbus-daemon
        |-drjava---java-+-java---27*[{java}]
        |               `-37*[{java}]
        |-dropbox---106*[{dropbox}]
        |-emacs-+-aspell
        |       |-bash---pstree
        |       |-evince---4*[{evince}]
        |       |-idn
        |       `-3*[{emacs}]
        |-gdm-+-gdm-session-wor-+-gdm-wayland-ses-+-gnome-session-b-+-gnome-shell-+-Xwayland---14*[{Xwayland}]
        ...       ...
        |         |-gnome-terminal--+-bash-+-chromium-+-chrome-sandbox---chromium---chromium-+-8*[chromium---12*[{chromium}]]
        |         |                 |      |          |                                      |-chromium---11*[{chromium}]
        |         |                 |      |          |                                      |-chromium---14*[{chromium}]
        |         |                 |      |          |                                      |-chromium---15*[{chromium}]
        |         |                 |      |          |                                      `-chromium---18*[{chromium}]
        |         |                 |      |          |-chromium---9*[{chromium}]
        |         |                 |      |          `-42*[{chromium}]
        |         |                 |      `-cinnamon---21*[{cinnamon}]
        |         |                 |-bash---ssh
        |         |                 `-3*[{gnome-terminal-}]
```

- Processes exist in a tree: see with shell command `pstree`
- Children can be **orphaned** by parents: parent exits without `wait()`'ing for child
- Orphans are adopted by the root process (PID==1)
  - `init` traditionally
  - `systemd` in many modern systems
- Root process occasionally `wait()`'s to "reap" zombies

Orphans are always Adopted

- Survey code in `baudelair_orphans.c` which demonstrates what happens to orphans
- Parent exits without `wait()`'ing, leaving them orphaned.
- Adopted by root process with PID=1

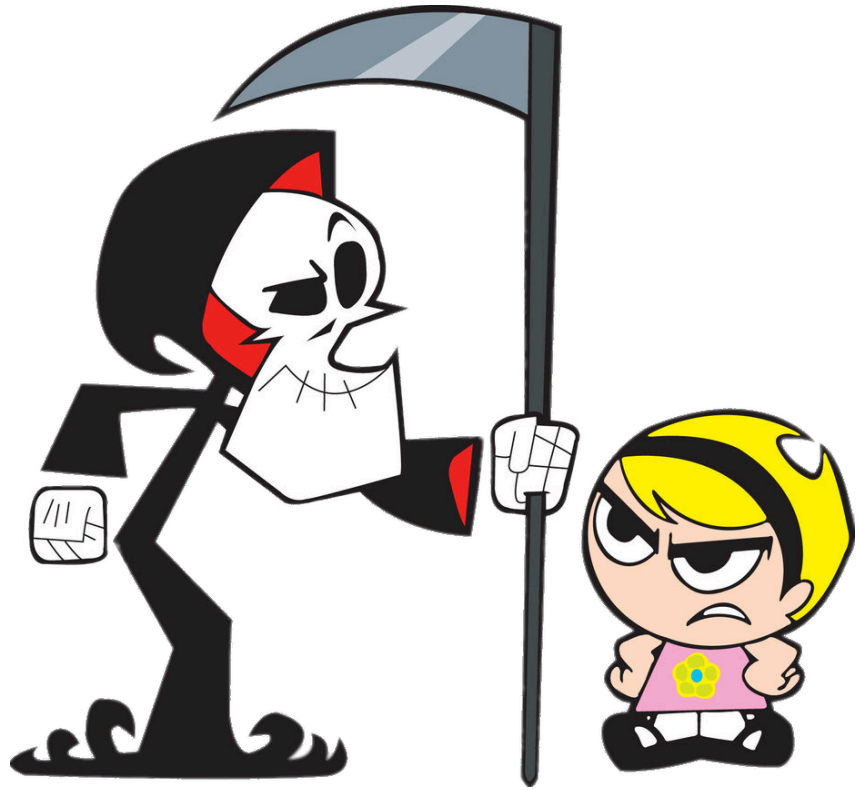
```
> gcc baudelaire_orphans.c

> ./a.out
1754593: I'm Klaus and my parent is 1754592
1754594: I'm Violet and my parent is 1754592
1754596: (Sunny blows raspberry) 1754592
1754593: My original parent was 1754592, my current parent is 1754592
> 1754594: My original parent was 1754592, my current parent is 1
1754594: I've been orphaned. How Unforunate.
1754596: My original parent was 1754592, my current parent is 1
1754596: I've been orphaned. How Unforunate.
```

Reapers and the Subreapers

- Process X creates many children, Orphans them
- Children of X complete, become Zombies until...
- Newly assigned Parent `wait()`'s for them
- Adoptive parent like Process 1 sometimes referred to as a **Reaper** process: "reaps the dead processes"
- System may designate a Subreaper to do this per user so orphans NOT re-parented to process ID 1

- Graphical Login on Ubuntu Linux systems usually designates a Subreaper for each user



Source: Cartoongoodies.com

Reaper and Orphan? More like Subreaper...