Making Processes

- Topics
  - Process creation from the user level:
    - Fork, execvp, wait, waitpid, pipe
- Learning Objectives:
  - Explain how processes are created
  - Create new processes, synchronize with them, and communicate exit codes back to the forking process.
  - Start building a simple shell.

Where do Processes Come From?

- There are two models of process creation:
  - Copy an existing process (UNIX `fork/exec` model).
  - Single system call to create a new process (Windows model).
- In UNIX-like systems we use the `fork/exec` model.

Fork

- System call that copies the calling process, creating a second process that is identical (in all but one regard) to the process that called `fork`.
- We refer to the calling process as the parent and the new process as the child.
- On return from successful `fork`:
  - **Parent: return value is the pid of the child process.**
  - **Child: return value is 0.**
- If the `fork` fails:
  - No child process created.
  - Parent gets return value of -1 (and `errno` is set).

Programming with `fork`

```
#include <unistd.h>
pid_t   ret_pid;

ret_pid = fork();
switch (ret_pid){
        case 0:
                /* I am the child. */
                break;
        case -1:
                /* Something bad happened. */
                break;
        default:
                /*
                 * I am the parent and my child's
                 * pid is ret_pid.
                 */
                break;
 }
```

But what good are two identical processes?

- So `fork` let us create a new process, but it's identical to the original. That might not be very handy.
- Enter `exec` (and friends): The `exec` family of functions replaces the current process image with a new process image.
- `exec` is the original/traditional API
- `execve` is the modern day (more efficient) implementation.
- There are a pile of functions, all of which ultimately invoke `execve`; we will focus on `execvp` (which is recommended for Assignment 4).
- If `execvp` returns, then it was unsuccessful and will return -1 and set `errno`.
- If successful, `execvp` does not return, because it is off and running as a new process.
- Arguments:
  - file: Name of a file to be executed
  - args: Null-terminated argument vector; the first entry of which is (by convention) the file name associated with the file being executed.

Programming with Exec

```
#include <unistd.h>
#include <errno.h>
#include <stdio.h>
pid_t    ret_pid;

ret_pid = fork();
switch (ret_pid){
        case 0:
                /* I am the child. */
                if (execvp(path, argv) == -1)
                        printf("Something bad happened: %s\n",
                            strerror(errno));
                break;
        case -1:
                /* Something bad happened. */
                break;
        default:
                /*
                 * I am the parent and my child's
                 * pid is ret_pid.
                 */
                break;
}
```

Coordinating with your child

- Sometimes it is useful for a parent to wait until a specific child, all children, or any child exits.

```
pid_t wait (int *stat_loc)
pid_t waitpid(pid_t pid, int *stat_loc, int options)
```

- `wait`: suspends execution of the parent until some child of the parent terminates or the parent receives a signal.
  - Return value is the pid of the terminating process
  - `stat_loc` is filled in with a status indicating how/why the child terminated.
- `waitpid`: suspends until a particular child terminates.

Programming with Fork, Exec, Wait

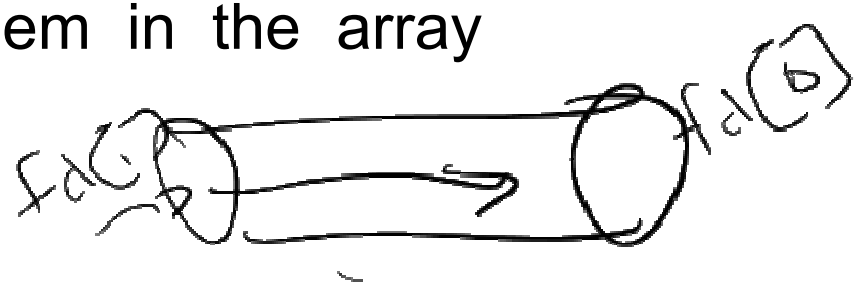
```
#include <sys/wait.h>
#include <unistd.h>
#include <errno.h>
#include <stdio.h>
pid_t      ret_pid;

ret_pid = fork();
switch (ret_pid){
          case 0:
                    /* I am the child. */
                    if (execvp(path, argv) == -1)
                              printf("Something bad happened: %s\n",
                                  strerror(errno));
                    break;
          case -1:
                    /* Something bad happened. */
                    break;
          default:
                    /*
                     * I am the parent and my child's
                     * pid is ret_pid.
                     */
                    if (waitpid(ret_pid, &exit_status, 0) != ret_pid)
                              printf ("Something bad happened!\n");
                    break;
 }
```

Communicating with child processes

- You've all used the `|` character to create pipes on the command line in the shell (I hope).
- What exactly does the pipe character do?
- The effect:
  - When you type:
    ```
    % foo | bar
    ```
  - The `stdout` stream of foo is connected to the `stdin` stream of bar.
- You've probably used the file pointers, `stderr`, `stdout`, `stdin` in `fprintf` and `fscanf`.
- STDIN_FILENO/STDOUT_FILENO(and STDERR_FILENO) are the corresponding file descriptors.
- They are opened on behalf of every process.
  - By convention, `stdin` comes from the console
  - By convention, `stdout` goes to the display
- Allowing two proceses to interact as shown above requires that we connect foo's `stdout` to bar's `stdin`

The `pipe` system call

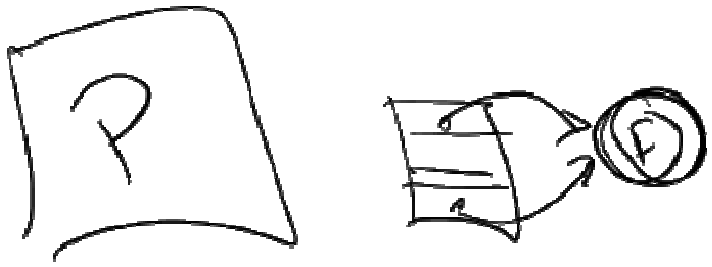
- `pipe(int filedes[2])` creates a pair of file descriptors and places them in the array referenced by filedes.
  - filedes[0] is for reading
  - filedes[1] is for writing



- **When a parent forks children, the parent and child share file descriptors.**
- By combining, `fork`, `exec`, and `pipe`, parents can communicate with children and/or set up pipelines between children.

The dup2 system call

- `dup2(int filedes, int filedes2)`
  - duplicates the first file descriptor (filedes) into the second file descriptor (`filedes2`).
  - After the call, both file descriptors refer to the same object, so reading from/writing to one descriptor changes the file position in both descriptors.
  - If filedes2 already refers to an open object, that object is closed.



Creating a Pipeline (foo | bar)

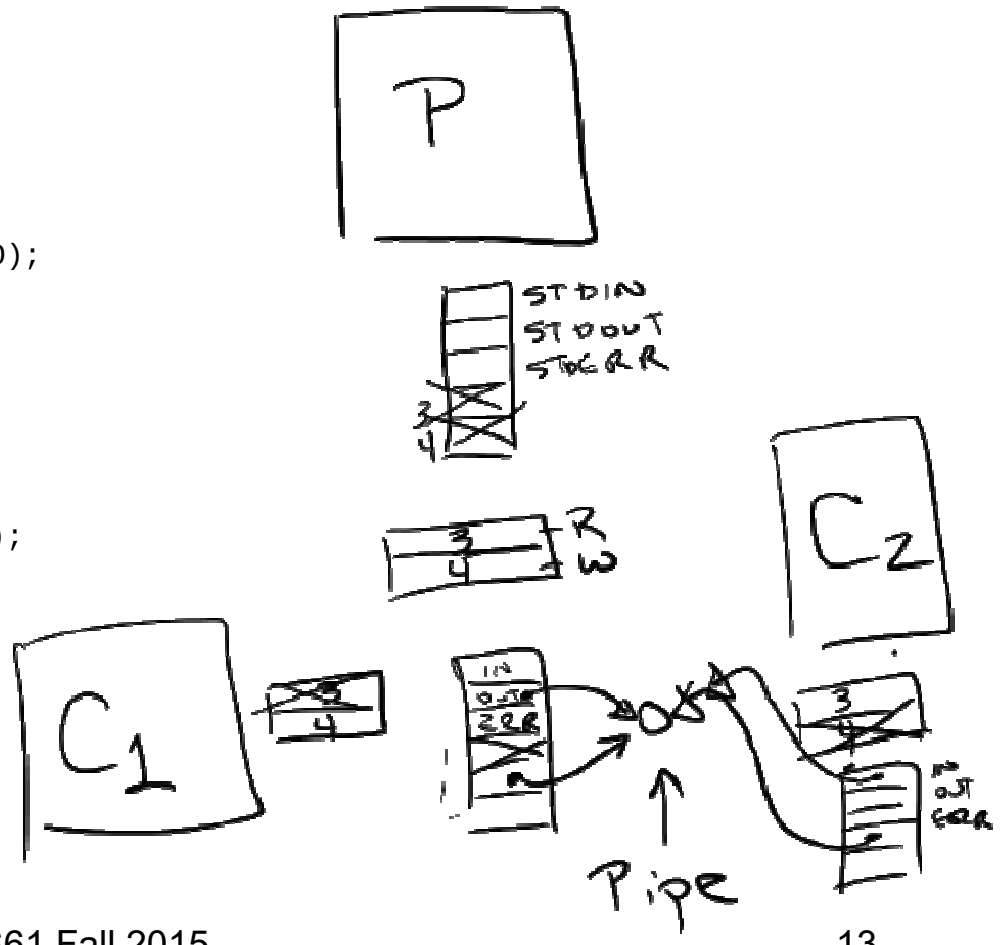
Note: Terrible error handling to save space!

```
pid_t child1, child2;
int pipedes[2], status;

assert (pipe(pipedes) == 0);              /* Create the pipe. */
child1 = fork();
if (child1 == 0) {
          /* child */
          close(pipedes[0]);              /* Close read end */
          dup2(pipedes[1], STDOUT_FILENO); /* Make stdout the same as the pipe write fd
*/
          execvp("foo", argv);            /* Assume argp is set */
}
/* only parent gets here */
child2 = fork();
if (child2 == 0) {
          /* child */
          close (pipedes[1]);             /* Close writing end */
          dup2(pipedes[0], STDIN_FILENO);  /* Make stdin the same as the pipe read fd */
          execvp("bar", argv);
}
/* Parent once again */
close (pipedes[0]);                       /* Close pipe fDs in parent. */
close (pipedes[1]);
waitpid(child2, &status, 0);              /* Wait for second process to complete. */
```

Creating a Pipeline (foo | bar)

Note: Terrible error handling to save space!

```
pid_t child1, child2;
int pipedes[2], status;

assert (pipe(pipedes) == 0);
child1 = fork();
if (child1 == 0) {
          /* child */
          close(pipedes[0]);
          dup2(pipedes[1], STDOUT_FILENO);
          execvp("foo", argv);
}
/* only parent gets here */
child2 = fork();
if (child2 == 0) {
          /* child */
          close (pipedes[1]);
          dup2(pipedes[0], STDIN_FILENO);
          execvp("bar", argv);
}
/* Parent once again */
close (pipedes[0]);
close (pipedes[1]);
waitpid(child2, &status, 0);
```



Wrapping Up

- On most UNIX-like systems today, we use `fork/exec` to create new processes.
- `wait` and `waitpid` allow parents and children to synchronize.
- The `dup2` and `pipe` calls provide for communication between parents and children.
- Next, we'll learn about signals, another mechanism used to coordinate processes.