Lecture 5

Systems Programming:
Unix Processes Creation: fork & exec
Process Communication: Pipes

Unix Process Creation

Creation

Management

Destruction

examples are in ~mark/pub/51081/processes

Process Attributes

- Process ID:

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

  - Every unix process has an associated process id (pid)
  - each new process is assigned a new unique unused pid
  - The pid is a 32bit unsigned integer, which usually ranges from 0 to 32767
  - pids roll over after 32767 and assignment begins again at 0, issuing *unused* pids

Process Ids and init

- Every process on the system has a parent, with the exception of pid 1: init
  - the init process “hangs around”, it is responsible for the initialization and booting of the system, and for running any new programs, like the login program, and your shell
  - Init executes /etc/rc* files during initialization, and is the ultimate parent of every subsequent process in the system
  - If init is killed, the system shuts down
- Any process’s parent id (ppid) can be obtained with the pid_t getppid(void) call.

Death and Destruction

- All processes usually end at some time during runtime (with the exception of init)
- Processes may end either by the program:
  - executing a `return` from the main function
  - calling the exit(int) function
  - calling the _exit(int) function
  - calling the abort(void) function
    - generates SIGABRT signal, core dumps and then exits
- When a process exits, the OS delivers a termination status to the parent process of the recently deceased process

Environments

- All processes by default inherit the environment of their parent process
- The environment can be obtained through the char * environ[] variable.
- char * getenv(const char * name) will return the associated value for the *name* passed in:
  - char * path = getenv("PATH");
- int setenv(const char * name, const char * value, int overwrite) will set an environment variable
- *examples: environ.c*

The Spawn

- exec()
- fork()
- system()
- clone()

The exec() Functions: Out with the old, in with the new

- The exec() functions all *replace* the current program running within the process with *another* program
- bring up an xterm:
  - exec sleep 5 #what happens and *why*?
- There are two families of exec() functions, the "l" family (list), and the "v" family (vector)
- Each exec() call can choose different ways of finding the executable and whether the environment is delivered in a list or an array (vector)
- The environment, open file handles, etc. are passed into the exec'd program
- What is the return value of an exec() call?

The execl... functions

- int execl(const char * path, const char * arg0, ...);
  - executes the command at path, passing it the environment as a *list:* arg_0 ... arg_n
  - thus, the execl family breaks down argv into its individual constituents, and then passes them as a *list* to the execl? function (the *l* stands for *l*ist)
- int execlp(const char * path, const char * arg0, ...);
  - same as execl, but uses $PATH resolution for locating the program in *path*
- int execle(const char * path, const char * arg0, ... char * envp[]);
  - allows you to specifically set the new process's environment
- *examples: params.c, execl.test.c, execle.test.c, execlp.test.c, sash.c*

The execv... functions

- int execv(const char * path, char *const argv[]);
  - executes the command at path, passing it the environment contained in a single argv[] *vector*
- int execvp(const char * path, char *const argv[]); same as execv, but uses $PATH resolution for locating the program in *path*
- int execve(const char * path, char *const argv[], char * const envp[]);
  - note that this is the only system call of the lot
- *examples: execv.test & myecho.c*

fork()

- fork() spawns a child process, the OS copies the current program into it, resets the program pointer to the start of the new program, and both processes *continue execution independently*
- The child gets a copy of the parent's:
  - data segments
  - heap segment
  - stack segment
  - file descriptors

fork() Return Values

- fork() is the one Unix function that is called *once* but returns *twice, into two SEPARATE processes*:
- If fork() returns 0:
  - you're in the *new* child process
- If fork() returns > 1 (i.e., the pid of the new child process)
  - you're back in the parent process
- *examples: fork1.c, forkio.c*

Waiting on Our Children

- Unlike life, parents should always hang around for their children's lives (runtimes) to end, that is to say:
  - Parent processes should always wait for their child processes to end
- When a child process dies, a SIGCHLD signal is sent to the parent as notification
- The SIGCHLD signal's default disposition is to ignore the signal
- A parent can find out the exit status of a child process by calling one of the wait() functions…

Waiting on Our Children

- Parent processes find out the exit status of their children by executing a wait() call:
  - pid_t wait(int * status);
  - pid_t waitpid(pid_t pid, int * status, int options);
- wait() blocks until it receives the exit status
- Waitpid() can wait on a specific child, and doesn't block
- Waiting allows the parent to obtain the *return value* from the child's process
- *examples:*
  - *childdeath echo hi; childdeath false; childdeath true*
  - *forkandwait echo hello world*
  - *forkandwait sleep 10*

waitpid()

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

- pid can be any of 4 values:
  - < -1: wait for any child whose gpid is the same as pid
  - == -1: waits for any child to terminate
  - == 0: waits for a child in the same process group as the current process
  - > 0: waits for process *pid* to exit
- The following macros work on status:
  - WIFEXITED(status): true if process exited normally
  - WIFSIGNALED(status): true if process was killed by a signal
  - *examples: forkandwait2 sleep 15*

vfork() and Copy On Write

- When a process forks, the entire current process (plus segments, environment, etc.) is copied over to the new process
- When that new process called exec(), the entire address space is replaced (overlaid) with the new environment of the exec'ing program
- Efficiency question: If you know you're going to call exec immediately after fork, why have fork spend time copying the entire address space over when we know it's just going to get overwritten immediately on the exec() call?
- Answer: vfork() doesn't copy entire address space

system()

- int system(const char * cmd)
- system() forks a child process that exec's /bin/sh, which in turn runs the command cmd
- As such, it has the following qualities:
  - it's easy and familiar to use
  - it's inefficient
  - because it uses system variables and executes from a shell, it can be a security risk if the command is setuid or setgid
- example: system("ls –la /usr/bin");

Sessions and Process Groups

- A process group is a group of related processes, that share some common interest, as all the processes in a pipeline do:
  - ls –l | sort | wc –l
- A session is a further abstracted group of related process groups or individual processes, such as all the jobs in a given terminal shell session
- Sessions are generally created during login, and process groups are managed by the job processing capabilities of a given shell

Priorities and Being Nice

- The scheduler recognizes processes of three different scheduling policies:
  - SCHED_FIFO (unalterable real-time processes)
  - SCHED_RR (alterable real-time processes)
  - SCHED_OTHER (conventional, time-shared)
- Processes with SCHED_OTHER policy are assigned a default dynamic priority of 0, and can voluntarily lower their priority by incrementally raising their "niceness" value, up to 40
- *example: mynice.c*
- *gcc –O0 –g –o mynice mynice.c*
- *mynice [nice]*

Debugging Multiple Processes

- Debugging processes that fork can be a little tricky, because whereas once you had one process, now you have two.
- Which process will gdb debug? Answer: the parent
- How do you debug the child process?
  - With another gdb (ddd) session:
  - Add a sleep() call at the start of the child code
  - run gdb (ddd) on the program, and set a breakpoint right after the sleep() call in the child section
  - run the first gdb session on the parent
  - after the fork(), attach to the child process and then issue the "continue" call in the child gdb session
- *example: forkdebug.c*

Beginner's Guide to Writing a Shell

- Define a buffer to hold a command entered from the command line
- Create a forever loop that forever prompts for a new command
- Block on a read (fgets, etc.) and allow the user to enter a command
- Parse the command into parameters for exec
- fork() a child process
- have the child process exec() the parsed command
- have the parent wait on the child process to finish

Problem Children:

Orphans

Zombies

Problem Children: Orphans and Zombies

- If a child process exits before it's parent has called wait(), it would be inefficient to keep the entire child process around, since all the parent is going to want to know about is the exit status:
  - A *zombie* is a child process that that has exited before it's parent's has called wait() for the child's exit status
  - A zombie holds nothing but the child's exit status (held in the program control block)
  - Modern Unix systems have init (pid == 1) adopt zombies after their parents die, so that zombies do not hang around forever as they used to
  - Zombies often show up in process tables as <defunct>

Problem Children: Orphans and Zombies

- On the other hand, if a parent process dies *before* it's child, WHO is the child's exit status going to be returned *to*? Obviously, not the parent, the parent is dead.
- In the case where the parent dies first before the child has finished, the child process becomes an *orphan*
  - An *orphan* is immediately "adopted" by the init process (pid == 1), who will call wait() on behalf of the deceased parent when the child dies
- *examples: myzombie.c, myorphan.c*

Mnemonics

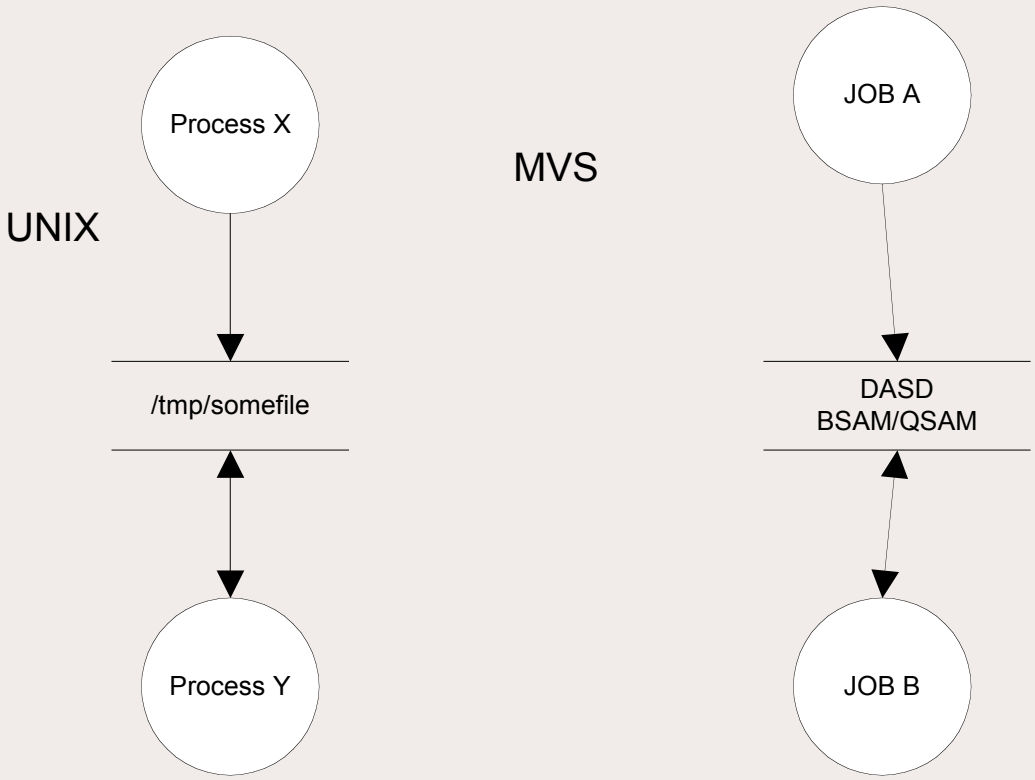
- Children turn into Zombies when the child dies *before* its parent calls **wait**()
- Children become Orphans when their parents die *without* calling **wait**()

Pipes

Interprocess Communication using pipes

Motivation: Batch Sequential Data Processing

- In the beginning, there was a void...



Px >/tmp/somefile
Py < /tmp/somefile

Batch Sequential Data Processing

- Stand-alone programs would operate on data, producing a file as output
- This file would stand as input to another stand-alone program, which would read the file in, process it, and write another file out
- Each program was dependent on its version of input before it could begin processing
- Therefore processing took place sequentially, where each process in a fixed sequence would run to completion, producing an output file in some new format, and then the next step would begin

Pipes and Filters Features

- Incremental delivery: data is output as work is conducted
- Concurrent (non-sequential) processing, data *flows* through the pipeline in a stream, so multiple filters can be working on different parts of the data stream simultaneously (in different processes or threads)
- Filters work *independently and ignorantly* of one another, and therefore are plug-and-play
- Filters are ignorant of other filters in the pipeline --there are no filter-filter interdependencies
- Maintenance is again isolated to individual filters, which are loosely coupled
- Very good at supporting producer-consumer mechanisms
- Multiple readers and writers are possible

What is a pipe?

- A pipe is an interface between two processes that allows those two processes to communicate (i.e., pass data back and forth)
- A pipe connects the STDOUT of one process (writer) and the STDIN of another (reader)
- A pipe is represented by an array of two file descriptors, each of which, instead of referencing a normal disk file, represent input and output paths for interprocess communication
- Examples:
  - ls | sort
  - ypcat passwd | awk –F: ‘{print $1}’ | sort
  - echo "2 + 2" | bc

How to create a pipe (lowlevel)

- #include <unistd.h>
- int pipe(int pipefd[2]);
- pipefd represents the pipe, and data written to pipefd[1] can be read from pipefd[0]
- pipe returns 0 if successful
- pipe returns –1 if unsuccessful, and sets the reason for failure in errno (accessible through perror())
- *examples: pipe2.c*

Pipe One-Niner, Come in

- Pipes are half duplex by default, meaning that one pipe is opened specifically for unidirectional writing, and the other is opened for unidirectional reading (i.e., there is a specific “read” end and “write” end of the pipe)
- The net effect of this is that across a given pipe, only one process does the writing (the “writer”), and the other does the reading (the “reader”)
- If two way communication is necessary, two separate pipe() calls must be made, or, use SVR5’s full duplex capability (stream pipes)
- *examples: fullduplex.c (compile and run on linux and solaris (SVR5--solaris.fullduplex))*

The Business End

- You read from fd[0] (think STDIN==0)
- You write to fd[1] (think STDOUT=1)

Redirecting STDIN

- Lessons in redirecting STDIN:
  - stdin.redirect.c
- Key 1: Every call to open() gives the next-open file descriptor from the file descriptor table.
- Key 2: The next-open file descriptor is always the lowest numbered descriptor in the array

dup()

- #include <unistd.h>
- int dup(int oldfd); //call close() manually
- Int dup2(int oldfd, int newfd); //dup2() automatically closes oldfd and open() on newfd
- Key takeaway, after the call to dup(), old and new fd's can be used interchangeably… they point to the same file

Traditional Pipes

- How would you mimic the following command in a program:
  - $ ls /usr/bin | sort
    - Create the pipe
    - Associate stdin and stdout with the proper read/ write pipes via dup2() call
    - Close unneeded ends of the pipe
    - Call exec()
- *example: ls_sort.c*

Pipes the easy way: popen()

- The simplest way (and like system() vs. fork(), the most expensive way) to create a pipe is to use popen():
  - #include <stdio.h>
  - FILE * popen(const char * cmd, const char * type);
  - ptr = popen("/usr/bin/ls", "r");
- popen() is similar to fopen(), except popen() returns a pipe via a FILE *
- you close the pipe via pclose(FILE *);

popen()

- When called, popen() does the following:
  - creates a new process
  - creates a pipe to the new process, and assigns it to either stdin or stdout (depending on char * type)
    - "r": you will be reading *from* the executing command
    - "w": you will be writing *to* the executing command
  - executes the command cmd via a bourne shell
- *example: popen_test.c, pipe_echo.c*

Meanwhile, back at the ranch...

- One thing is in common between all the examples we've seen so far:
  - All our examples have had *shared file descriptors*, shared from a parent processes forking a child process, which *inherits* the open file descriptors as part of the parent's environment for the pipe
- Question: How do two entirely *unrelated* processes communicate via a pipe?

FIFOs: Named Pipes

- FIFOs are “named” in the sense that they have a name in the filesystem
- This common name is used by two separate processes to communicate over a pipe
- The command mknod can be used to create a FIFO:
  - mkfifo MYFIFO (or “mknod MYFIFO p”)
  - ls –l
  - echo “hello world” >MYFIFO &
  - ls –l
  - cat <MYFIFO

Creating FIFOs in code

- #include <sys/types.h>
- #include <sys/stat.h>
- int mkfifo(const char * path, mode_t mode);
  - path is the pathname to the FIFO to be created on the filesystem
  - mode is a bitmask of permissions for the file, modified by the default umask
- mkfifo returns 0 on success, -1 on failure and sets errno (perror())
- mkfifo("MYFIFO", 0666);
- *examples: reader.c, writer.c*