Preview:

Problem 6 asks you to read an article on system calls. This reading should help you better understand how system calls are implemented for one architecture, the IA32 (Intel).

In Problem 8, you are given the source code to part of a test harness for `xssha` and are asked to complete the source code so that it can handle a small number of `xssha` commands. A real shell interpreter accepts commands from stdin. But the test harness initializes an array with a fixed command sequence. Having a fixed set of commands for interpretation will allow you to focus on implementing some core shell interpreter functions.

Some students do not complete this problem, but the important part is the effort that you put into this problem. The coding required may be more intense than you have experienced in the past (about 100 lines of code), but the journey will prepare you for Project A. Try to look under the hood by inserting debug output that verifies your understanding of the behavior of the code.

Problem 7 will introduce you to a few simple `xssha` commands by asking you to write shell scripts using these commands. But since the commands are also found in the `bash` shell, you should be able to test the same scripts by creating shell scripts and running them in any Unix system. Note that the shell scripts each consist of no more than three or four commands (excluding comments and blank lines). So, there is more thinking involved than writing.

---

**Problem 1** (0 Points) [ Gnu C Library ]

The Process item in the course Syllabus contains a link to the section of The Gnu C Library Reference Manual which discusses Processes. Read this section. Follow the Top link to the Main Menu and familiarize yourself with what is documented in the other sections.

**Problem 2** (0 Points) [ fork ]

Consider the following code fragment:

```c
printf("mypid = %d\n", getpid());
for (int i=0; i<2; i++) {
    pid_t p = Fork(); // never returns an error
    printf("i = %d (pid = %d), fork returned = %d\n", 
           i, getpid(), p);
    ... code goes here ...
}
```

a) Complete the code fragment so that it will produce a chain of three (3) processes where the original process is the parent of a child which is the parent of the another child.

b) If we assume that process IDs start at 1000 and assigned consecutively for each new fork call, what will be the output of the code in Part a? Explain.

c) Will the output be different if I replace the call to printf with a call to "fprintf (stderr, 
...)” and redirect stdout and stderr to the file xxx? Explain.
**Problem 3** (0 Points) (From Tanenbaum, modified) [ PIDs ]

When a new Unix process is created by forking, it must be assigned a unique integer as its PID. Typically, a Unix kernel assigns a new PID using a 16-bit unsigned integer counter that indicates the PID of the newest process.

a) The kernel can’t just increment this counter and assign the value as the PID of the next new process. Why not?

b) Give an algorithm that uses the counter for properly assigning a unique PID.

c) Where is the PID of a Unix process stored?

**Problem 4** (0 Points) [ boot ]
The Linux man page `boot(7)` describes five steps involved in booting a Unix system.

a) Summarize what is done in the first three steps.

b) When booting most operating systems, the bootstrap loader in sector 0 of the boot disk first loads a boot program which then loads the operating system. Why is a multi-step boot procedure used instead of a single-step one?

**Problem 5** (0 Points) [ environ ]
The Linux man page `environ(5)` describes environment variables.

a) What is a login shell?

b) What is an environment variable and how are they different than other shell variables?

c) How does Linux determine the value of the environment variables `HOME` and `SHELL` in a login shell?

d) How would you set the value of the variable `TRACE_OPTS` to `-g -r` and put it in the environment when using the Bourne shell `sh`? The Bash shell `bash`? The C shell `csh`?

**Problem 6** (4 Points) [ System Call Implementation ]
The course Web page contains a link to the on-line article ”Linux System Calls” that describes Linux system calls in the IA32 architecture. Read the article and answer the following questions.

a) When a user-space application makes a simple system call, what instruction causes a trap to kernel mode and how does this instruction operate?

b) How is the system call number passed into the kernel?

c) How are arguments to the system call passed? Consider both simple and complex argument lists.

d) When the trap to kernel mode occurs, the processor jumps to the `system_call` entry point defined in the source file `entry.S`. List and summarize atleast four things that this code at the entry point does.
Problem 7 (4 Points) [Shell Language]

The last problem in this homework describes the shell language xshA. xshA interprets $ as the PID of the current process just like all other shells (e.g., sh, csh, tcsh, bash). The kill command (see kill(1)) sends a signal to a process. For example, ‘kill -STOP $$’ puts the current process to sleep by sending a STOP signal to itself. The -CONT (continue) signal will resume the process. Other signals are described in signal(7).

See sh(1), kill(1), chmod(1) and signal(7). Specifically in sh(1), the sh symbol & (background); sh parameter $$ (current process PID); the interpreter specification #!

a) Write the simplest xshA shell scripts X, Y, and Z that will create the following process hierarchy:

- The xshA process that interprets the script "X" is the parent of the xshA process that interprets the script "Y".
- The xshA process that interprets the script "Y" is the parent of two instances of xshA processes that each interprets the script "Z".
- All processes display on stdout their process ID ($ is the PID of the process) as their first action.
- All processes put themselves to sleep as their last action.

Note that you can assume that xshA is executed within a standard shell and therefore, if the first line begins with "#!", the remainder of the line contains the pathname of the interpreter (e.g., #!/usr/home/kevin/bin/xshA).

Submit a listing of the three scripts X, Y and Z. Note that although this is a paper and pencil exercise, you should still submit a printed solution.

b) The Bourne and bash shells have a syntax that is almost identical to xshA. Run your scripts in Part a using the Bourne or bash shell and determine how killing of the xshA process that interprets the Y script affects the process hierarchy in a real shell. (Note: If process Y has PID 7777, ‘kill 7777’ terminates process Y. The ps command indicates the process hierarchy.)

Submit an explanation of what happens to the process hierarchy.

Problem 8 (10 Points) [The Simple Shell xshA]

The course Web page has a link to the source code for the test harness for xshA. xshA is a very simple shell language which is a subset of the language xsh which will be implemented in Project A. It is a test harness in the sense that the command sequence is hardcoded into the simple two-dimensional array cmd[][] where cmd[i] points to the ith command and cmd[i][j] points to the jth word of command i.

We use metasymbols below to describe the syntax of the shell language. For example, "W" stands for a single word. A non-whitespace character (SPACE or TAB) or a newline character terminates a word. "..." indicates a continuation of 0 or more repetitions of the preceding symbol. For example, "W ..." means one or more W's. "I" stands for integer.
xsshA supports the following *builtin* (internal) commands:

- **echo \W ...**: Display the arguments followed by a newline. Multiple spaces/tabs should be reduced to a single space.
- **quit \I**: Quit the shell with an exit status of \I where \I is an integer.
- **wait \I**: The shell should wait for process \I to terminate where \I is the PID of the process.

All other commands are assumed to be executables in a directory listed in the PATH environment variable.

Here are the other features of xsshA:

a) The command line prompt should be the three character sequence '>> ' (i.e., >, >, space).

b) A non-built-in command is assumed to be a Unix executable that can be found in a directory listed in the PATH environment variable.

c) $! should be treated as the process number of the last backgrounded process and has an initial value of the null string.

d) An ampersand character (&) at the beginning of a line indicates that the command should be run in the background.

Note that there is almost no variable substitution except for $!, and there is no filename substitution nor command substitution. See fork(2), waitpid(2), execvp(2), sh(1), gettimeofday(2), exit(3).

You should fill in the test harness xsshA.c so that it can interpret the xsshA language. Note that the code recognizes two flags: -x and -d. The -x flag indicates that the command line should be displayed after replacing $!. The -d flag indicates that debugging output should be displayed on stderr. **When debugging is turned on with -d, the values returned from each major system call (e.g., fork, wait, exec) should be displayed even if the value is returned in the parameter list (e.g., waitpid) and the input parameters to every call to an exec function should be displayed.** The debug output should be labeled with the variable names when appropriate so that it is clear what variables are associated with what values. Choose a format that is simple but easy to read.

Submit the following:

a) Your source code.

b) The output of the test harness when run with the -x and -d flags.

c) For each command, indicate whether your code is working properly or not. If so, explain how the output shows that the code is working properly. If not, indicate what is wrong and what needs to be done to fix the bug(s).