CS 105, Fall 2003
Lab Assignment L5: Writing Your Own Unix Shell
Assigned: Nov. 13, Due: Wed., Nov. 26, 10:00PM

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Introduction

The purpose of this assignment is to become more familiar with the concepts of process control and signalling. You'll do this by writing a simple Unix shell program that supports job control.

Logistics

You may work in a group of up to two people in solving the problems for this assignment. The only "hand-in" will be electronic. Any clarifications and revisions to the assignment will be sent to the class mailing list and posted on the course Web page.

Hand Out Instructions

Start by copying the file `shlab-handout.tar` to the protected directory (the *lab directory*) in which you plan to do your work. Then do the following:

- Type the command `tar xvf shlab-handout.tar` to expand the tarfile.
- Type the command `make` to compile and link some test routines.
- Type your team member names and login IDs in the header comment at the top of `tsh.c`.

Looking at the `tsh.c` (*tiny shell*) file, you will see that it contains a functional skeleton of a simple Unix shell. To help you get started, we have already implemented the less interesting functions. Your assignment is to complete the remaining empty functions listed below. As a sanity check for you, we've listed the approximate number of lines of code for each of these functions in our reference solution (which includes lots of comments).

- `eval`: Main routine that parses and interprets the command line. [70 lines]
- `builtin_cmd`: Recognizes and interprets the built-in commands: `quit`, `fg`, `bg`, and `jobs`. [25 lines]
- `do_bgfg`: Implements the `bg` and `fg` built-in commands. [50 lines]
- `waitfg`: Waits for a foreground job to complete. [20 lines]
- `sigchld_handler`: Catches SIGCHILD signals. 80 lines]
- `sigint_handler`: Catches SIGINT (`ctrl-c`) signals. [15 lines]
- `sigtstp_handler`: Catches SIGTSTP (`ctrl-z`) signals. [15 lines]

Each time you modify your `tsh.c` file, type `make` to recompile it. To run your shell, type `tsh` to the command line:

```
unix> ./tsh
tsh> [type commands to your shell here]
```

General Overview of Unix Shells

A *shell* is an interactive command-line interpreter that runs programs on behalf of the user. A shell repeatedly prints a prompt, waits for a *command line* on `stdin`, and then carries out some action, as directed by the contents of the command line.

The command line is a sequence of ASCII text words delimited by whitespace. The first word in the command line is either the name of a built-in command or the pathname of an executable file. The remaining words are command-line arguments. If the first word is a built-in command, the shell immediately executes the command in the current process. Otherwise, the word is assumed to be the pathname of an executable program. In this case, the shell forks a child process, then loads and runs the program in the context of the child. The child processes created as a result of interpreting a single command line are known collectively as a *job*. In general, a job can consist of multiple child processes connected by Unix pipes.

If the command line ends with an ampersand "`&`", then the job runs in the *background*, which means that the shell does not wait for the job to terminate before printing the prompt and awaiting the next command line. Otherwise, the job runs in the *foreground*, which means that the shell waits for the job to terminate before awaiting the next command line. Thus, at any point in time, at most one job can be running in the foreground. However, an arbitrary number of jobs can run in the background.

For example, typing the command line

```
tsh> jobs
```

causes the shell to execute the built-in `jobs` command. Typing the command line

```
tsh> /bin/ls -l -d
```

runs the `ls` program in the foreground. By convention, the shell ensures that when the program begins executing its main routine

```
int main(int argc, char *argv[])
```

the `argc` and `argv` arguments have the following values:

- `argc == 3`,
- `argv[0] == ``/bin/ls''`,
- `argv[1]== ``-l''`,
- `argv[2]== ``-d''`.

Alternatively, typing the command line

```
tsh> /bin/ls -l -d &
```

runs the `ls` program in the background.

Unix shells support the notion of *job control*, which allows users to move jobs back and forth between background and foreground, and to change the process state (running, stopped, or terminated) of the processes in a job. Typing `ctrl-c` causes a SIGINT signal to be delivered to each process in the foreground job. The default action for SIGINT is to terminate the process. Similarly, typing `ctrl-z` causes a SIGTSTP signal to be delivered to each process in the foreground job. The default action for SIGTSTP is to place a process in the stopped state, where it remains until it is awakened by the receipt of a SIGCONT signal. Unix shells also provide various built-in commands that support job control. For example:

- `jobs`: List the running and stopped background jobs.
- `bg <job>`: Change a stopped background job to a running background job.
- `fg <job>`: Change a stopped or running background job to a running in the foreground.
- `kill <job>`: Terminate a job.

The `tsh` Specification

Your `tsh` shell should have the following features:

- The prompt should be the string "`tsh> `".
- The command line typed by the user should consist of a `name` and zero or more arguments, all separated by one or more spaces. If `name` is a built-in command, then `tsh` should handle it immediately and wait for the next command line. Otherwise, `tsh` should assume that `name` is the path of an executable file, which it loads and runs in the context of an initial child process (In this context, the term *job* refers to this initial child process).

- `tsh` need not support pipes (|) or I/O redirection (< and >).
- Typing `ctrl-c` (`ctrl-z`) should cause a SIGINT (SIGTSTP) signal to be sent to the current foreground job, as well as any descendents of that job (e.g., any child processes that it forked). If there is no foreground job, then the signal should have no effect.
- If the command line ends with an ampersand `&`, then `tsh` should run the job in the background. Otherwise, it should run the job in the foreground.
- Each job can be identified by either a process ID (PID) or a job ID (JID), which is a positive integer assigned by `tsh`. JIDs should be denoted on the command line by the prefix '`%`'. For example, "`%5`" denotes JID 5, and "`5`" denotes PID 5. (We have provided you with all of the routines you need for manipulating the job list.)
- `tsh` should support the following built-in commands:
  - The `quit` command terminates the shell.
  - The `jobs` command lists all background jobs.
  - The bg <job> command restarts <job> by sending it a SIGCONT signal, and then runs it in the background. The <job> argument can be either a PID or a JID.
  - The fg <job> command restarts <job> by sending it a SIGCONT signal, and then runs it in the foreground. The <job> argument can be either a PID or a JID.
- `tsh` should reap all of its zombie children. If any job terminates because it receives a signal that it didn't catch, then `tsh` should recognize this event and print a message with the job's PID and a description of the offending signal.

Checking Your Work

We have provided some tools to help you check your work.

Reference solution. The Linux executable `tshref` is the reference solution for the shell. Run this program to resolve any questions you have about how your shell should behave. *Your shell should emit output that is identical to the reference solution* (except for PIDs, of course, which change from run to run).

Shell driver. The `sdriver.pl` program executes a shell as a child process, sends it commands and signals as directed by a *trace file*, and captures and displays the output from the shell.

Use the -h argument to find out the usage of `sdriver.pl`:

```
unix> ./sdriver.pl -h
Usage: sdriver.pl [-hv] -t <trace> -s <shellprog> -a <args>
Options:
  -h            Print this message
  -v            Be more verbose
  -t <trace>    Trace file
  -s <shell>    Shell program to test
```

```
  -a <args>      Shell arguments
  -g             Generate output for autograder
```

We have also provided 16 trace files (`trace{01-16}.txt`) that you will use in conjunction with the shell driver to test the correctness of your shell. The lower-numbered trace files do very simple tests, and the higher-numbered tests do more complicated tests.

You can run the shell driver on your shell using trace file `trace01.txt` (for instance) by typing:

```
unix> ./sdriver.pl -t trace01.txt -s ./tsh -a "-p"
```

(the `-a "-p"` argument tells your shell not to emit a prompt), or

```
unix> make test01
```

Similarly, to compare your result with the reference shell, you can run the trace driver on the reference shell by typing:

```
unix> ./sdriver.pl -t trace01.txt -s ./tshref -a "-p"
```

or

```
unix> make rtest01
```

For your reference, `tshref.out` gives the output of the reference solution on all races. This might be more convenient for you than manually running the shell driver on all trace files.

The neat thing about the trace files is that they generate the same output you would have gotten had you run your shell interactively (except for an initial comment that identifies the trace). For example:

```
bass> make test15
./sdriver.pl -t trace15.txt -s ./tsh -a "-p"
#
# trace15.txt - Putting it all together
#
tsh> ./bogus
./bogus: Command not found.
tsh> ./myspin 10
Job (9721) terminated by signal 2
tsh> ./myspin 3 &
[1] (9723) ./myspin 3 &
tsh> ./myspin 4 &
[2] (9725) ./myspin 4 &
tsh> jobs
[1] (9723) Running    ./myspin 3 &
[2] (9725) Running    ./myspin 4 &
tsh> fg %1
Job [1] (9723) stopped by signal 20
tsh> jobs
```

```
[1] (9723) Stopped    ./myspin 3 &
[2] (9725) Running    ./myspin 4 &
tsh> bg %3
%3: No such job
tsh> bg %1
[1] (9723) ./myspin 3 &
tsh> jobs
[1] (9723) Running    ./myspin 3 &
[2] (9725) Running    ./myspin 4 &
tsh> fg %1
tsh> quit
bass>
```

Hints

- Read every word of Chapter 8 (Exceptional Control Flow) in your textbook.
- Use the trace files to guide the development of your shell. Starting with `trace01.txt`, make sure that your shell produces the *identical* output as the reference shell. Then move on to trace file `trace02.txt`, and so on.
- The `waitpid`, `kill`, `fork`, `execve`, `setpgid`, and `sigprocmask` functions will come in very handy. The WUNTRACED and WNOHANG options to `waitpid` will also be useful.
- You may prefer to use `execvp` instead of `execve`. The latter requires you to type complete pathnames such as `/bin/ls`, while `execvp` allows you to just type `ls`.
- When you implement your signal handlers, be sure to send `SIGINT` and `SIGTSTP` signals to the entire foreground process group, using ”`-pid`” instead of ”`pid`” in the argument to the `kill` function. The `sdriver.pl` program tests for this error.
- One of the tricky parts of the assignment is deciding on the allocation of work between the `waitfg` and `sigchld_handler` functions. We recommend the following approach:
  - In `waitfg`, use a busy loop around the `sleep` function.
  - In `sigchld_handler`, use exactly one call to `waitpid`.

  While other solutions are possible, such as calling `waitpid` in both `waitfg` and `sigchld_handler`, these can be very confusing. It is simpler to do all reaping in the handler.
- In `eval`, the parent must use `sigprocmask` to block `SIGCHLD` signals before it forks the child, and then unblock these signals, again using `sigprocmask` after it adds the child to the job list by calling `addjob`. Since children inherit the `blocked` vectors of their parents, the child must be sure to then unblock `SIGCHLD` signals before it execs the new program.

  The parent needs to block the `SIGCHLD` signals in this way in order to avoid the race condition where the child is reaped by `sigchld_handler` (and thus removed from the job list) *before* the parent calls `addjob`.

- Programs such as `more`, `less`, `vi`, and `emacs` do strange things with the terminal settings. Don't run these programs from your shell. Stick with simple text-based programs such as `/bin/ls`, `/bin/ps`, and `/bin/echo`.

- When you run your shell from the standard Unix shell, your shell is running in the foreground process group. If your shell then creates a child process, by default that child will also be a member of the foreground process group. Since typing `ctrl-c` sends a SIGINT to every process in the foreground group, typing `ctrl-c` will send a SIGINT to your shell, as well as to every process that your shell created, which obviously isn't correct.

  Here is the workaround: After the `fork`, but before the `execve`, the child process should call `setpgid(0, 0)`, which puts the child in a new process group whose group ID is identical to the child's PID. This ensures that there will be only one process, your shell, in the foreground process group. When you type `ctrl-c`, the shell should catch the resulting SIGINT and then forward it to the appropriate foreground job (or more precisely, the process group that contains the foreground job).

- If you get a complaint about signal 22 whenever you try to run a command, execute the command `stty -tostop` *before* you run `tsh`. (The proper solution to this problem requires manipulating process groups for both foreground and background processes as well as for the terminal; getting it right is finicky work that won't teach you a tremendous amount, so it's easier to just turn off the `tostop feature`.

Evaluation

Your score will be computed out of a maximum of 90 points based on the following distribution:

80 Correctness: 16 trace files at 5 points each.

10 Style points. We expect you to have good comments (5 pts) and to check the return value of EVERY system call (5 pts).

Your solution shell will be tested for correctness on a Linux machine, using the same shell driver and trace files that were included in your lab directory. Your shell should produce **identical** output on these traces as the reference shell, with only two exceptions:

- The PIDs can (and will) be different.

- The output of the `/bin/ps` commands in `trace11.txt`, `trace12.txt`, and `trace13.txt` will be different from run to run. However, the running states of any `mysplit` processes in the output of the `/bin/ps` command should be identical.

Hand In Instructions

- Make sure you have included your names and login IDs in the header comment of `tsh.c`.

- Create a team name of the form:
  - "ID" where ID is your login ID, if you are working alone, or
  - "ID_1+ID_2" where ID_1 is the login ID of the first team member and ID_2 is the login ID of the second team member.

  We need you to create your team names in this way so that we can autograde your assignments.

- Use `cs105submit` to submit only your `tsh.c` file.

Good luck!