EE382V - Systems Programming
Project 1: yet another shell (yash)

Due Date: Sunday 2/27 at Midnight
(Document updated to with an FAQ (in blue))

Objective

In this project you will be introduced to both the command line interface and the Unix programming environment. You will write a command line interpreter (a **shell**) that takes commands from standard input and executes the commands by creating processes.

Features

A standard shell like `bash/tcsh/csh` etc. has a rich set of features that it supports. You will implement a subset of these features.

Preparing to Code: First, you should exercise all of these features in a shell like `bash`. Once you understand how to use them you will get a sense of how you can implement them.

Here is the complete list of features you must implement:

- File redirection
  - with creation of files if they don't exist for output redirection
  - fail command if input redirection (a file) does not exist
  - < will replace `stdin` with the file that is the next token
  - > will replace `stdout` with the file that is the next token
  - A command can have both the redirection symbols (No `2>&1`)
- Piping
  - | separates two commands
    - The left command will have `stdout` replaced with the input to a pipe
    - The right command will have `stdin` replaced with the output from the same pipe
  - Children within the same pipeline will be started and stopped simultaneously
  - **Only one | must be present in each pipeline**
- Signals (`SIGINT, SIGTSTP, SIGCHLD`)
  - `Ctrl-c` must quit current foreground process (if one exists) and not the shell and should not print the process (unlike bash)
  - `Ctrl-z` must send `SIGTSTP` to the current foreground process and should not print the process (unlike bash)

    - The shell will not be stopped on `SIGTSTP`
- Job control
    - Background a job using `&`
    - **You can only background a single command (no pipeline). In other words `|` and `&` are mutually exclusive. Also, you cannot use `Ctrl-z` to put a pipelined command chain into the background.**
    - `fg` must send `SIGCONT` to the most recent background or stopped process, print the process name to `stdout`, and wait for completion
    - `bg` must send `SIGCONT` to the most recent stopped process, print the process name to stdout in the jobs format, and not wait for completion (as if `&`)
    - `jobs` will print the job control table similar to bash:
        - with a `[<jobnum>]`
        - a `+` or `-` indicating the current job. Which job would be run with an `fg`, is indicated with a `+` and, all others with a `-`
        - a "`Stopped`" or "`Running`" indicating the status of the process
        - and finally the original command
        - e.g.

```
[1] - Running   sleep 5 &
[2] - Stopped   sleep 5 &
[3] + Running   long_running_command | grep > output.txt &
```

    - Terminated background jobs will be printed after the newline character sent on `stdin` with a `Done` in place of the Stopped or Running.
    - A command chain with a pipeline is considered a single job as seen in the example above
- Misc
    - Children must inherit the environment from the parent
    - Your shell must search the `PATH` environment variable for every executable
    - All child processes will be dead on exit
    - The prompt must be printed as a '`#` ' (hashtag-sign with a space after it) before accepting user input.

Restrictions on the input

These restrictions will help you simplify the parsing the command line:

- Everything that can be a token (`<`, `>`, `|`, etc.) will have a space before and after it. Also, any redirections will follow the command after all its args
- `&` will always be the last token in a line (only one `&` makes sense)
- Each line contains one command or two commands in one pipeline
- Lines will not exceed 200 characters
- All characters will be ASCII
- `Ctrl-d` will exit the shell

Restrictions on programming environment

- All code will be in C (ANSI, C99, GNU99, etc.)
- Code may only include headers from the operating system and the GNU C `stdlib`. Use of the `system` library call is not allowed.
- Must create a `Makefile`, so grader only executes "`make`" in your unarchived project directory and expects the executable to be named "`yash`"
- All code will run on GNU/Linux (it will be tested on x86-64)

Workload Estimation

- Students often make the mistake of finishing input parsing and file redirection and then thinking the rest of the lab will be similar in difficulty … then they spend the last day of office hours panicking at the TA
- Here's an estimate of how long you'll spend on each part of the lab
    - Input parsing (5%)
    - File redirections (5%)
    - Programming in C (incorrectly using malloc, incorrectly using pointers, segfaults, etc.) (10%)
    - Pipes (30%)
    - Signals (30%)
    - Jobs (20%)

Submission

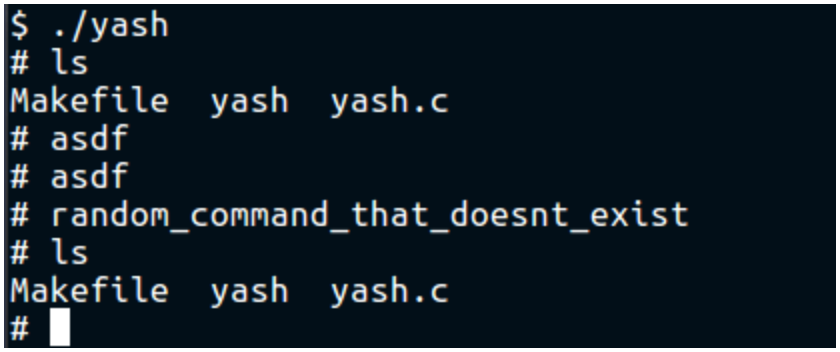
You will submit a single file named **yash.tgz** that contains all the files in a folder by the same name (**yash**). Make sure there is a **Makefile** that will build your shell with a single command (`make`). The executable that your makefile should create must also be called **yash**. If you have any doubts about submission please post a question on Piazza. It is important that everybody follows these instructions so we can automate the grading process.

```
~/yash >>> ls
Makefile  yash.c
~/yash >>> cd ..
~ >>> tar czvf yash.tgz yash
a yash
a yash/Makefile
a yash/yash.c
~ >>>
```

```
~ >>> tar xf yash.tgz
~ >>> cd yash
~/yash >>> ls
Makefile  yash.c
~/yash >>> make
gcc -o yash yash.c
~/yash >>> ls
Makefile  yash*     yash.c
```

Lab 1 FAQ

1. If given an invalid command, simply ignore it and print a new line.



    a. An "invalid command" in that case does not mean a command that outputs error to your terminal.
    b. An "invalid command" is more like a program that doesn't exist on your computer so execvp() cannot execute it. An example of expected behavior for an invalid command is shown above. Notice how the invalid commands output nothing to stdout except a newline character to move the prompt "#" to a new line. The 'ls' command is a known command and is therefore valid.

2. Inputs will start with commands and not <, >, &, |. Here are some examples
    a. Invalid commands
        i. < ls
        ii. > ls
        iii. | ls
        iv. & ls
    b. Valid commands
        i. ls > out.txt

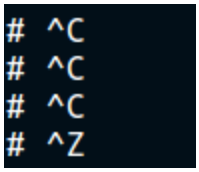
3. If there is a conflict between *bash*, *zsh*, *fish*, or any other shell's behavior for a command, please go with *bash's* output. Meaning, your *yash* shell should try to follow what bash does except when specified otherwise.
    a. For example, the jobs command gives different output for each of the two shells when a situation occurs such that the jobs are numbered 1, 2, 4 and then a new job is created. *zsh* gives the new process the job number 3, whereas *bash* gives

the new process the job number 5. Since we defer to *bash*, your yash shell should give the new process the job number 5

4. Which libraries are allowed? The lab document says the following: "code may only include headers from the operating system and the GNU C stdlib. Use of the system library call is not allowed."
    a. This means that you cannot use the `system()` function provided in the `<stdlib.h>` library. This is because the function can execute any command that can run on the terminal and is allowed by your operating system. Meaning, that one function call can do your entire lab. Since we are trying to make you learn, we don't want you to use this function. Other than this rule, most libraries allowed (e.g. `<stdio.h>`, `<string.h>`, `<stdlib.h>`, etc.).
    b. Note: `<malloc.h>` may exist on some BSD and Darwin systems, but it is deprecated and won't work on Linux. Use `<stdlib.h>`.

5. We don't expect you to implement more than we ask for. This includes implementing tab-completion or multiple pipes. If you want to add cool things to your shell to make it more realistic then please go ahead and let us know in the submission comment for Canvas. We'd love to check it out. However, just know that you could be spending your time getting ahead on the next labs instead.

6. It is okay if your yash shell prints `^Z` when you press `Ctrl-Z` and `^C` for `Ctrl-c`.



7. We won't test your shells with `top`, `apt install`, `cd`, `history`, `vim`, or `man`.

8. Make sure to remove the line feed character (`'\n'`) from the input before parsing it (if you're using readline, then this might not be a problem). Since you have to press the enter key to send the input, the input command will have a line feed character at the end. If you don't remove this character before sending your tokens to `execvp()`, then your yash shell won't be able to recognize the command.
    a. For example, let's say the input is `"ls"` and then you hit enter to send the command to your shell
    b. Your C program will say the input is `"ls\n"`. If you then send this to execvp(), it will try to look for a program called `"ls\n"` and then try to execute it. This won't work because there is no executable called `"ls\n"`.
    c. Therefore, you have to remove the `'\n'` by replacing it with a NULL character (i.e. find the `'\n'` and then replace it with `'\0'`).

9. When creating files with output or error redirection, make sure to set the permission bits correctly or else you won't be able to access the file (if you don't then you'll get a "permission denied" error when you try to read from the created file)
    a. Take a look at the `open` function
    b. The first argument is the name of the file to create
    c. The second argument is a bitwise OR of flags specifying how you want to open the file (read-only, write-only, create, etc.) (read the documentation)
    d. The third argument is a list of bitwise OR of flags specifying the permissions to use when creating the file (see documentation)
        i. Since we don't expect you to know these, just use the following: `S_IRUSR|S_IWUSR|S_IRGRP|S_IWGRP|S_IROTH`
        ii. This creates the file with read/write permissions for the owner of the file, read/write permissions for the group, read permissions for other users

10. Are we expected to be able to run user programs within our yash shell?
    a. Yes, but it's no extra effort on your part. After all, it only involves running another program that exists on your computer (`gcc`) and then executing it like any other program (e.g. `"ls"`)

```
# gcc -o hello hello_world.c
# ./hello
hello world
```

11. Reasonable pipe test cases that involve redirection (these are just examples not actual test cases)

```
# Contents of in1.txt goes to out1.txt
# Contents of in2.txt goes to stdout
# The end of the pipe receives no input from the beginning
# of the pipe so the only input to the second cat is in2.txt
cat in1.txt > out1.txt | cat < in2.txt
```

```
# cat in1.txt > out1.txt | cat < in2.txt
in2.txt stuff
# cat out1.txt
in1.txt stuff
```

```
# contents of in1.txt goes through the pipe to
# the 2nd cat and gets output to stdout
cat in1.txt | cat
```

```
# cat in1.txt | cat
in1.txt stuff
```

12. We won't have any complex testing when it comes to the fg, bg, jobs commands. Meaning, we will only test their basic functionality and will not combine those commands with redirections, pipes, etc.
    a. **Not allowed:** `fg &`
    b. **Not allowed:** `fg | echo`
    c. **Allowed:** `fg`
    d. **Allowed:** `bg`
    e. **Allowed:** `jobs`

13. What do I print out to stdout for `fg`/`bg`?
    a. Example 1

```
# sleep 4
^Z# fg
sleep 4
```

        i. Note how the command was printed back out to stdout after executing the `fg` command (same as bash)

    b. Example 2

```
# sleep 4
^Z# bg
[1]+ sleep 4 &
```

        i. Note how the command was printed back out to stdout in the jobs format with an `&` at the end after executing `bg` (same as bash)

14. What do I print out to stdout for a command that was run in the background using `&`?

    Example:

```
# sleep 4 &
# jobs
[1]+  Running                 sleep 4 &
```

    Note how nothing was printed back out to stdout after running the sleep command in the background (this is **different** from bash)

15. What should the output of the `jobs` command look like?
    a. For the most part, it should look the way *bash* does it, not *zsh*
    b. Major differences between our jobs output and Bash's jobs output. The intent of the differences was to make it easier to write your yash shell
        i. Our yash shell has a minus sign (-) next to **EVERY** job entry, whereas Bash only has a single minus sign next to the previous stopped command.

ii. Our yash shell will put a plus sign (+) next to the most recent command **regardless of whether it was a stopped or backgrounded** command. In contrast, Bash only puts a plus/minus sign next to stopped commands

c. Don't worry about spacing for the jobs command output

d. Don't worry about printing the output of a command before/after the "Done" output (either of the two outputs below is fine)

i.
```
# sleep 2 &
# ls
[1]+  Done                    sleep 2 &
Makefile  yash  yash.c
```

ii.
```
# sleep 2 &
# ls
Makefile  yash  yash.c
#
[1]+  Done                    sleep 2 &
```

e. Examples of correct yash input and output for the jobs command

i. Example 1 - basic jobs output

```
# sleep 5
^Z# sleep 10
^Z# sleep 15
^Z# sleep 20
^Z# jobs
[1]-  Stopped                 sleep 5
[2]-  Stopped                 sleep 10
[3]-  Stopped                 sleep 15
[4]+  Stopped                 sleep 20
```

1. Note where the `^Z` (`Ctrl-z`) is being entered

ii. Example 2 - jobs output w/ background processes that haven't finished yet

```
# sleep 10
^Z# sleep 15
^Z# sleep 5 &
# sleep 20
^Z# jobs
[1]-  Stopped                 sleep 10
[2]-  Stopped                 sleep 15
[3]-  Running                 sleep 5 &
[4]+  Stopped                 sleep 20
```

1. Note that 'sleep 5 &' had **not** completed in the background yet, and then I ran 'jobs'

iii. Example 3 - jobs output w/ background processes that have finished
   1. The input is the same as Example 2
   2. This time, let's say 'sleep 5 &' **has completed** in the background and then you run 'jobs'

```
# sleep 10
^Z# sleep 15
^Z# sleep 5 &
# sleep 20
^Z# jobs
[3]-  Done                    sleep 5 &
[1]-  Stopped                 sleep 10
[2]-  Stopped                 sleep 15
[4]+  Stopped                 sleep 20
# jobs
[1]-  Stopped                 sleep 10
[2]-  Stopped                 sleep 15
[4]+  Stopped                 sleep 20
```

iv. Example 4 - jobs output numbering (follow bash not zsh)
   1. Note in the example above, after the sleep 5 command finished and you entered jobs the 2nd time, the job entry is gone from the table
   2. Note also that the job number goes 1 → 2 → 4 instead of 1 → 2 → 3

v. Example 5 - jobs output numbering
   1. Let's say you then created and stopped a new job
      - Input

        sleep 25 → Ctrl-z
      - Output

```
[1]-   Stopped   sleep 10
[2]-   Stopped   sleep 15
```

```
[4]-   Stopped   sleep 20
[5]+   Stopped   sleep 25
```

2. Again notice that the number 3 was skipped
    - This is because bash and your yash shell assign (1 + highest job number) to the new process.
    - See Example 5 for an example showing this

vi. Example 5 - jobs output numbering continuation of Example 4 and use of fg

1. Let's say you're now continuing from Example 4 and run these commands
2. Input
    - fg → wait (if you have to) for job 5 to complete
        i. Remember that fg always brings the most recent job (AKA the job at the bottom of your table) (AKA the job with the current highest job number) to the foreground
        ii. Now that it is in the foreground, your stopped command can finish or be killed with `Ctrl-c`
3. Output
    - `[1]-   Stopped   sleep 10`
    - `[2]-   Stopped   sleep 15`
    - `[4]+   Stopped   sleep 20`
4. Input
    - fg → wait (if you have to) for job 4 to complete
5. Output
    - `[1]-   Stopped   sleep 10`
    - `[2]+   Stopped   sleep 15`
6. Input
    - sleep 60 → Ctrl-z
7. Output
    - `[1]-   Stopped   sleep 10`
    - `[2]-   Stopped   sleep 15`
    - `[3]+   Stopped   sleep 60`
8. Notice that our job number is back at 3 again
    - This is because bash and your yash shell assign (1 + highest job number) to the new process
    - i.e., our job numbers are now (1, 2, 3) and **NOT** (1, 2, 6)

16. You need to handle multiple file redirections of ***different types*** per line. However, you don't need to handle multiple file redirections of the ***same type*** per line. Each end of the pipeline will only have at most one of each file redirection type. See examples below.
    a. **Allowed:** `echo "hello world" > temp.txt`
    b. **Allowed:** `cat < temp.txt`

c. **Allowed:** `cat < temp.txt > output.txt`
d. **Allowed:** `cat < in1.txt > out1.txt | cat < in2.txt > out2.txt`
e. **Not Allowed:** `cat temp.txt > output1.txt > output2.txt`
f. **Not Allowed**: `cat < output1.txt < output2.txt`

17. Do we need to parse for quotation marks? TLDR: no just parse for whitespace
    a. **Input**: `echo "hello world"`
    b. **Expected output:** `"hello world"`
        i. This output is easier to implement because it doesn't worry about quotation marks. This output can be achieved by simply parsing the input command for whitespace and then sending each token to the echo command.
        ii. Token 0: "hello
        iii. Token 1: world"
    c. **Bash Output**: `hello world`
        i. This is the output given by your bash shell and we don't expect you to do your parsing this way. Please output "hello world" with the quotation marks

18. Why do commands like "cd" and "history" not work in my yash shell? TL;DR: we don't expect you to implement "cd" or "history."
    a. The only commands you have to write/implement yourself are the `jobs`, `fg`, and `bg` commands. Every other command will be executed through existing programs on your computer (i.e. they come with your Linux operating system). For example, if you type `ls` on your yash shell or bash shell, what really happens is your shell checks your $PATH environment variable to see if it can find an existing file/executable called "ls". If your shell can find an "ls" executable, it then calls that program with the arguments provided to the shell. Note: in Linux, executables are denoted with no file ending.
    b. However, "cd" and "history" are programs built into the bash shell itself. Therefore, when you try to run those commands in your yash shell, it won't be able to find programs to execute those commands.
    c. To see which programs exist on your computer, run the "which" command.
        i. `which ls`
            1. This outputs `/bin/ls`
            2. Pretty cool that "ls" is really just an executable that exists on your computer
        ii. `which cd`
            1. This outputs nothing. Try `man builtin` in bash to see a list of builtin commands.