

CS 241: Systems Programming

Lecture 4. Environment and expansion

Spring 2020

Prof. Stephen Checkoway

Announcement

Homework 1 is on the course web page

- ▶ It's due on the 23th
- ▶ Work in groups of 2 (or by yourself if you really want)
- ▶ It involves shell scripting which we'll start talking about on Friday and using Git which we'll talk about on Wednesday

Program behavior

Most programs can have different behaviors when run multiple times. E.g., the `ls` program can list the contents of different directories and can display the output in multiple formats

```
[worksec:~/teaching/241/S20] steve$ ls
check_clicker.py  examples  notes.md  old-notes.md  rubrics  slides
[worksec:~/teaching/241/S20] steve$ ls rubrics
hw1-rubric.md  hw2-rubric.md  hw3-rubric.md  hw4-rubric.md
hw5-rubric.md  hw6-rubric.md
[worksec:~/teaching/241/S20] steve$ ls -l rubrics
total 32
-rw-r--r--  1 steve  staff  3929 Feb  3 09:38 hw1-rubric.md
-rw-r--r--  1 steve  staff  6147 Feb  3 09:38 hw2-rubric.md
-rw-r--r--  1 steve  staff  5159 Feb  3 09:38 hw3-rubric.md
-rw-r--r--  1 steve  staff  4034 Feb  3 09:38 hw4-rubric.md
-rw-r--r--  1 steve  staff   424 Feb  3 09:38 hw5-rubric.md
-rw-r--r--  1 steve  staff   782 Feb  3 09:38 hw6-rubric.md
```

What controls program behavior?

What controls program behavior?

Input arguments (e.g., file/directory paths, a URLs or command names)

Contents of the input files

Command line options

Configuration/preference files (or OS-specific configuration/preference databases)

User input (for interactive programs)

Environment variables!

Bash simple command revisited

Recall we said a simple command has the form:

⟨command⟩ ⟨options⟩ ⟨arguments⟩

The truth is more complicated

- ▶ ⟨variable assignments⟩ ⟨words and redirections⟩ ⟨control operator⟩
- ▶ Variables and their assigned values are available to the command
- ▶ The first **word** is the command, the rest are **arguments***
- ▶ `FOO=blah BAR=okay cmd aaa >out bbb 2>err ccc <in ;`
- ▶ `FOO=blah BAR=okay cmd aaa bbb ccc <in >out 2>err`
- ▶ Real example: `$ IFS= read -r var`

* Bash doesn't distinguish between options and arguments, that's up to each command

Environment variables

Another method for passing data to a program

Essentially a key/value store (i.e., a hash map)

- ▶ `$ FOO=blah BAR=okay cmd aaa bbb ccc`
- ▶ `cmd` has access to the `FOO` and `BAR` environment variables plus args

Environment variables are inherited from the parent

- ▶ Every program started from the shell has access to a copy of the shell's environment

Example: color output from ls

```
steve@worksec: ~/teaching/241/S20
[worksec:~/teaching/241/S20] steve$ ls rubrics
hw1-rubric.md hw2-rubric.md hw3-rubric.md hw4-rubric.md hw5-rubric.md hw6-rubric.md
[worksec:~/teaching/241/S20] steve$ LS_COLORS='*.md=01;35' ls rubrics
hw1-rubric.md hw2-rubric.md hw3-rubric.md hw4-rubric.md hw5-rubric.md hw6-rubric.md
[worksec:~/teaching/241/S20] steve$ LS_COLORS='*.md=01;35;44' ls rubrics
hw1-rubric.md hw2-rubric.md hw3-rubric.md hw4-rubric.md hw5-rubric.md hw6-rubric.md
[worksec:~/teaching/241/S20] steve$ LS_COLORS='*.md=36;42' ls rubrics
hw1-rubric.md hw2-rubric.md hw3-rubric.md hw4-rubric.md hw5-rubric.md hw6-rubric.md
[worksec:~/teaching/241/S20] steve$ LS_COLORS='*.md=31;41' ls rubrics
hw1-rubric.md hw2-rubric.md hw3-rubric.md hw4-rubric.md hw5-rubric.md hw6-rubric.md
[worksec:~/teaching/241/S20] steve$
```


Bash variables

Setting and using variables in bash

- ▶ `$ place=Earth`
`$ echo "Hello ${place}."`
Hello Earth.

By default, variables set in bash aren't inherited by children

- ▶ `$ bash # Start a new shell`
`$ echo "Hello ${place}."`
Hello . # `${place}` expanded to the empty string

Exporting variables

We can **export** a variable which causes it to appear in the environment of children

```
$ place=World
$ export place
$ bash          # Starting a new shell
$ echo "Hello ${place}."
Hello World.
```

Equivalently, `$ export place=World`

Summarizing

Summarizing

```
$ FOO=bar cmd1
```

```
$ cmd2
```

- ▶ FOO available to `cmd1` but not `cmd2`

Summarizing

```
$ FOO=bar cmd1
```

```
$ cmd2
```

- ▶ FOO available to `cmd1` but not `cmd2`

```
$ FOO=bar
```

```
$ cmd1
```

```
$ cmd2
```

- ▶ FOO not available to either `cmd1` or `cmd2`

Summarizing

```
$ FOO=bar cmd1
```

```
$ cmd2
```

- ▶ FOO available to `cmd1` but not `cmd2`

```
$ FOO=bar
```

```
$ cmd1
```

```
$ cmd2
```

- ▶ FOO not available to either `cmd1` or `cmd2`

```
$ export FOO=bar
```

```
$ cmd1
```

```
$ cmd2
```

- ▶ FOO available to both `cmd1` and `cmd2`

If bash is started via

```
$ W=foo bash
```

(so `W` is in bash's environment) and then following lines are executed,

```
$ X=bar
```

```
$ export Y=qux
```

```
$ Z=X command
```

which environment variables are available to `command`?

A. `W`, `X`, `Y`, and `Z`

D. `Y` and `Z`

B. `W`, `Y`, and `Z`

E. `Z`

C. `X`, `Y`, and `Z`

What is printed when I run this?

```
$ FOO=before
```

```
$ FOO=after echo "${FOO}"
```

A. before

B. after

C. beforeafter

D. Just a newline

E. Nothing, it's a syntax error

Useful environment variables

- EDITOR — Used when some commands need to launch an editor (e.g., git)
- HOME — Your home directory
- LANG — The language programs should use (this is complicated!)
- PAGER — A program like less that's used to display pages of text
- PATH** — Colon-separated list of directories to search for commands
- PS1 — The shell's prompt
- PWD — The current working directory
- SHELL — The shell you're using
- TERM — The terminal type, used to control things like color support
- UID — The real user ID number
- USER — User name

Adding directories to PATH

If you install software in `${HOME}/local/bin`, you can modify your `PATH` to access it

```
$ export PATH="${HOME}/local/bin:${PATH}"
```

This adds `${HOME}/local/bin` to the front of the `PATH` so it is searched first

```
$ export PATH="${PATH}:${HOME}/local/bin"
```

This adds `${HOME}/local/bin` to the end of the `PATH` so it is searched last

Bash expansion

Bash first splits lines into words by (unquoted) space or tab characters

```
$ echo 'quoted string' unquoted string
```

- ▶ Word 1: echo
- ▶ Word 2: 'quoted string'
- ▶ Word 3: unquoted
- ▶ Word 4: string

Most words then undergo **expansion**

- ▶ The values in variable assignment `var=value` (but not the names)
- ▶ The command and arguments
- ▶ The right side of redirections, e.g., `2>path`

Bash expansion

Order of expansion

- ▶ Brace expansion
- ▶ In left-to-right order, but at the same time
 - Tilde expansion
 - Variable expansion
 - Arithmetic expansion
 - Command expansion
 - Process substitution
- ▶ Word splitting (yes, this happens after the shell split the input into words!)
- ▶ Pathname expansion

And then each of the results undergoes quote removal

In-class exercise

<https://checkoway.net/teaching/cs241/2020-spring/exercises/Lecture-04.html>

Grab a laptop and a partner and try to get as much of that done as you can!

If you get stuck, look at the following slides (remember, all slides are on the course web page linked from the readings page).

Brace expansion

Unquoted braces `{ }` expand to multiple words

- ▶ `{foo,bar,baz}.txt` → `foo.txt bar.txt baz.txt`
- ▶ `foo{a,b,,c}bar` → `fooabar foobbar foobar fooobar`
- ▶ `'{a,b}'` → `'{a,b}'`
- ▶ `"{a,b}"` → `"{a,b}"`
- ▶ `{1..5}` → `1 2 3 4 5`
- ▶ `{x..z}` → `x y z`
- ▶ `{1,2}{x..z}` → `1x 1y 1z 2x 2y 2z`
- ▶ `{a,b{c,d}}` → `a bc bd`

Tilde expansion

Words starting with unquoted tildes expand to home directories

- ▶ `~` → `/usr/users/noquota/faculty/steve`
- ▶ `~steve` → `/usr/users/noquota/faculty/steve`
- ▶ `~aeck` → `/usr/users/noquota/faculty/aeck`
- ▶ `\~steve` → `\~steve`
- ▶ `'~steve'` → `'~steve'`

Parameter/variable expansion

We can assign variables via `var=value` (e.g., `class='CS 241'`) the shell defines others like `HOME` and `PWD`

Words containing `${var}` or `$var` are expanded to their value, even in double quoted strings

- ▶ `${HOME}` → `/usr/users/noquota/faculty/steve`
- ▶ `x${PWD}y` → `x/tmpy` # the current working directory
- ▶ `x$PWDy` → `x` # no `PWDy` variable so it expands to the empty string
- ▶ `'${class}'` → `'${class}'`
- ▶ `\${class}` → `\${class}`
- ▶ `"${class}"` → `"CS 241"`

Command substitution

Replaces `$(command)` with its output (with the trailing newline stripped)

▸ `"Hello $(echo "${class}" | cut -c 4-)"` → `"Hello 241"`

These can be nested

You can also use ``command`` instead, but don't do that, use `$(...)`

Arithmetic expansion

`$(arithmetic expression)` expands to the result, assume `x=10`

- ▶ `$((3+x*2 % 6))` → 5
- ▶ `\$((3+x*2 % 6))` → # syntax error
- ▶ `'$((3+x*2 % 6))'` → `'$((3+x*2 % 6))'`
- ▶ `"$((3+x*2 % 6))"` → `"5"`

Process substitution

Read the man page for bash if you want, we may come back to it

Word splitting

A misfeature in bash!

The results of
parameter/variable expansion `${...}`,
command substitution `$(...)`, and
arithmetic expansion `$((...))`

not in double quotes is split into words by splitting on (by default) space, tab, and newline

```
steve@clyde:~$ x='foo bar'  
steve@clyde:~$ echo ${x}  
foo bar  
steve@clyde:~$ echo "${x}"  
foo bar
```

You never want word splitting! If you're using a \$, put it in double quotes!

Pathname expansion

We saw this previously!

Pathname expansion/globbing

Bash performs pathname expansion via **pattern matching** (a.k.a. **globbing**) on each unquoted word containing a wild card

Wild cards: *****, **?**, **[**

- ▶ ***** matches zero or more characters
- ▶ **?** matches any one character
- ▶ **[...]** matches any single character between the brackets, e.g., **[abc]**
- ▶ **[!...]** or **[^...]** matches any character not between the brackets
- ▶ **[x-y]** matches any character in the range, e.g., **[a-f]**

Quote removal

Unquoted ', ", and \ characters are removed in the final step

- ▶ 'foo bar' → foo bar (one word)
- ▶ "foo bar" → foo bar (one word)
- ▶ "\${class}" → CS 241 (one word)
- ▶ "\${class} is" 'fun' → CS 241 is fun (one word)

Expansion summary

Braces form separate words `[{a,b,c}]` → `[a] [b] [c]`

Tildes give you home directories `~` → `/home/steve`

Variables expand to their values `"${class}"` → `"CS 241"`

Commands expand to their output `"$(ls *.txt | wc -l)"` → `"3"`

Wildcards expand to matching file names `*.txt` → `a.txt b.txt c.txt`

Put literal strings in `'single quotes'`

Put strings with variables/commands in `"${double} $(quotes)"`

If we have set a variable
`books='Good books'`
and we want to create a directory with that name, which command should we use?

A. `$ mkdir "${books}"`

B. `$ mkdir "$(books)"`

C. `$ mkdir ${books}`

D. `$ mkdir $(books)`

E. `$ mkdir $books`