CS 241: Systems Programming
Lecture 3. More Shell

Fall 2019

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Unix philosophy

As summarized by Peter H. Salus

- Write programs that do one thing and do it well.
- Write programs to work together.
- Write programs to handle text streams, because that is a universal interface.

Leads to many small utilities that we string together with the shell

Typical Unix tool behavior

```
$ program
```

- reads from stdin, writes to stdout

```
$ program file1 file2 file3
```

- runs ‘program’ on the 3 files, write to stdout

```
$ program –
```

- For programs that require filenames, might read from stdin

Standard input/output/error

Every running program has (by default) 3 open "files" referred to by their file descriptor number

Input comes from stdin (file descriptor 0)

- `input()` # Python: Read a line
- `System.in.read(var)` // Java: Read bytes and store in `var` array
- `$ IFS= read -r var` # Read a line and store in `var` variable

Standard input/output/error

Normal output goes to stdout (file descriptor 1)

- `print(var)` # Python
- `System.out.println(var)` // Java
- `$ echo "${var}"` # Bash

Error messages traditionally go to stderr (file descriptor 2)

- `print(var, file=sys.stderr)` # Python
- `System.err.println(var)` // Java
- `$ echo "${var}" >&2` # Bash

Redirection

`>file` — redirect standard output (stdout) to `file` with truncation

`>>file` — redirect stdout to `file`, but append

`<file` — redirect input (stdin) to come from `file`

`|` — connect stdout from left to stdin on right

- `$ ls | wc`

`2>file` — redirect standard error (stderr) to `file` with truncation

`2>&1` — redirect stderr to stdout

Redirection examples

```
$ echo 'Hi!' >output.txt
$ cat <input.txt
$ sort <input.txt >output.txt
$ ps -ax | grep bash
$ grep hello file | sort | uniq -c
$ echo Hello | cut -c 1-4 >>result.txt
$ ./process <input | tail -n 4 >output
```

(Almost) everything is a file

Files on the file system

Network sockets (for communicating with remote computers, e.g., web browsers, ssh, mail clients etc.)

Terminal I/O

A bunch of special files

- `/dev/null` — Writes are ignored, reads return end-of-file (EOF)
- `/dev/zero` — Writes are ignored, reads return arbitrarily many 0 bytes
- `/dev/urandom` — Reads return arbitrarily many (pseudo) random bytes

Given that `/dev/null` ignores all data written to it, how can we run the program `./foo` and redirect stderr so no error messages appear in our terminal?

```
A. $ ./foo >/dev/null

B. $ ./foo 1>/dev/null

C. $ ./foo 2>/dev/null

D. $ ./foo | /dev/null

E. $ ./foo &2>/dev/null
```

Some programs read all of their input before terminating. How can we run a program ./foo such that it has no input at all?

```
A. $ ./foo </dev/null

B. $ ./foo </dev/zero

C. $ ./foo </dev/urandom

D. $ ./foo </dev/eof

E. $ echo | ./foo
```

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

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

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 foocbar`
- `'{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

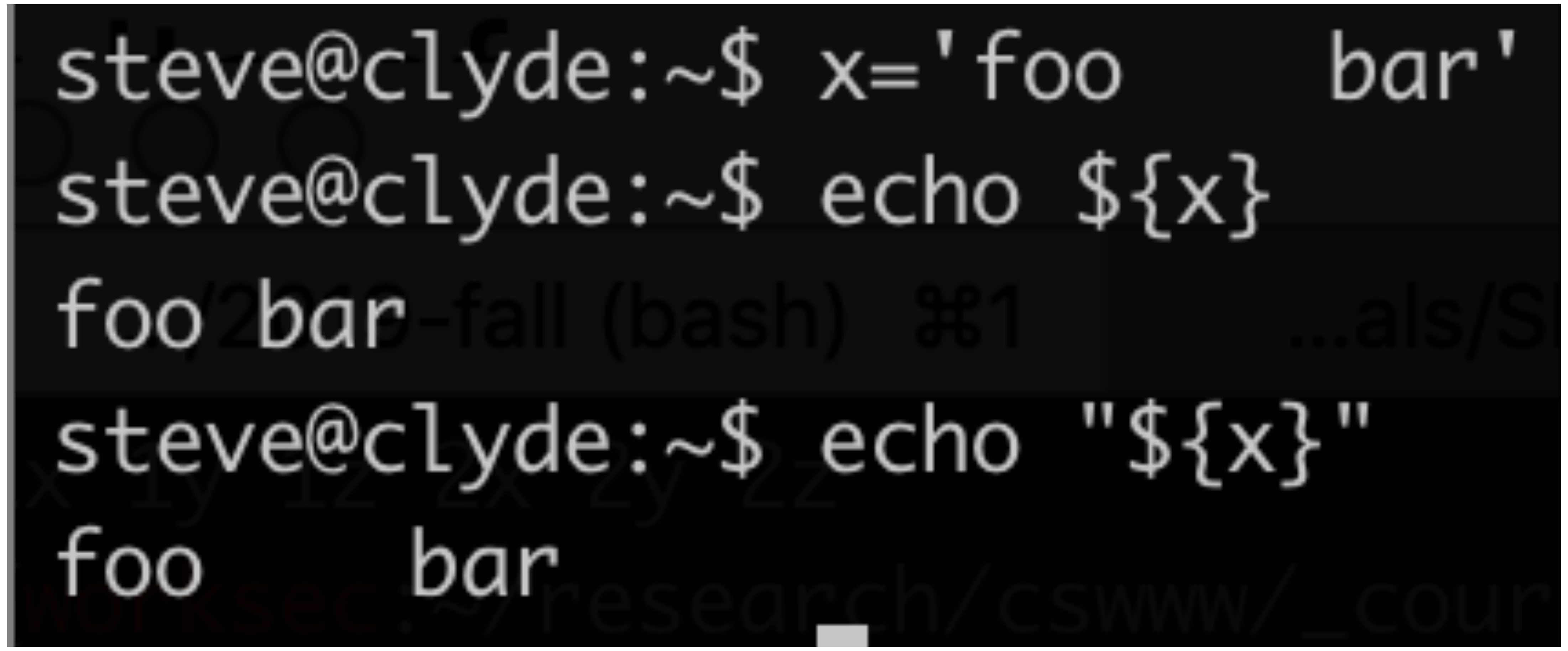
$((arithmetic expression)) expands to the result, assume `x=10`

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



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

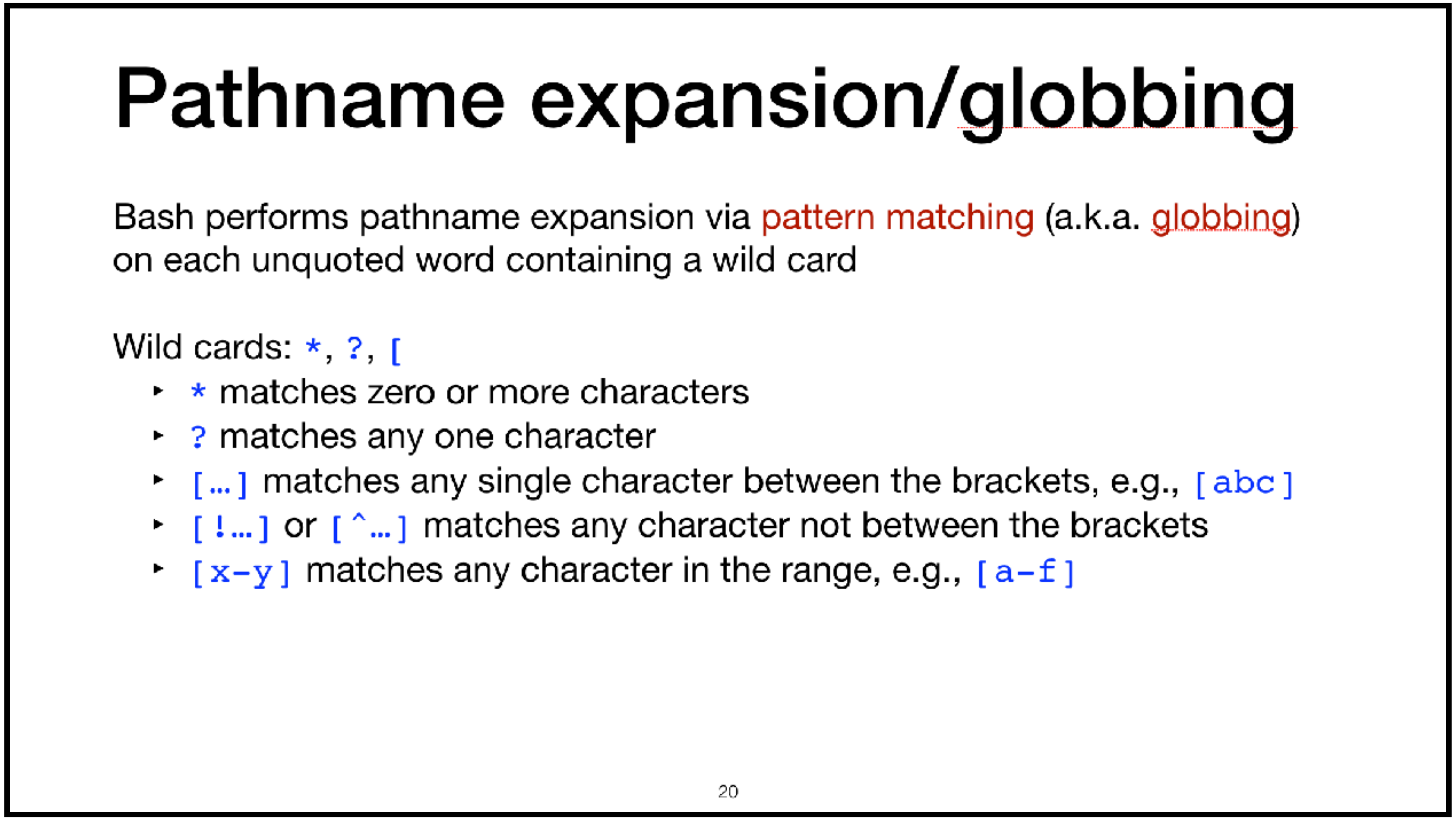
A misfeature in bash!

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

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

Pathname expansion

We saw this last time!



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]`

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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}`

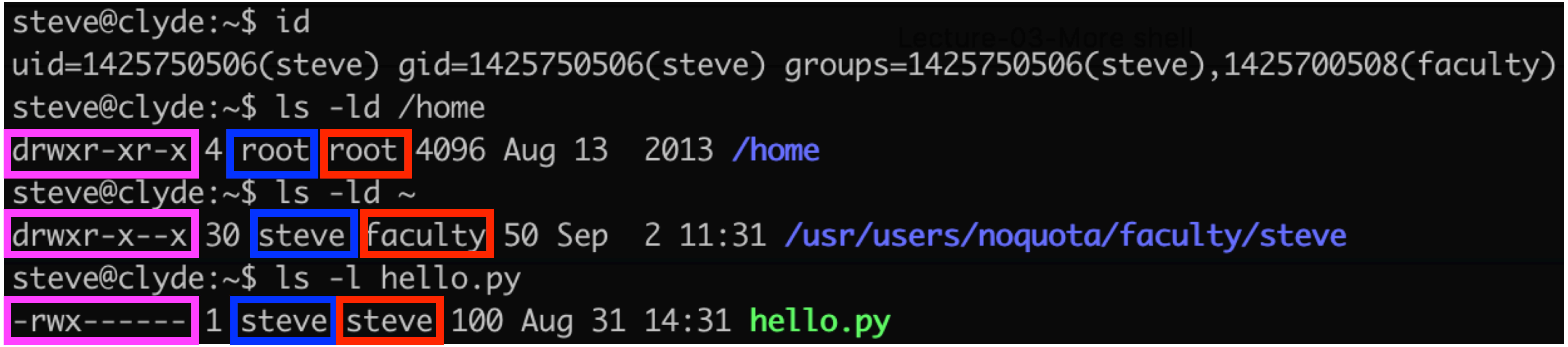
D. `$ mkdir $(books)`

E. `$ mkdir $books`

Permissions

Every user has an id (uid), a group id (gid) and belongs to a set of groups

Every file has an owner, a group, and a set of permissions



```
steve@clyde:~$ id
uid=1425750506(steve) gid=1425750506(steve) groups=1425750506(steve),1425700508(faculty)
steve@clyde:~$ ls -ld /home
drwxr-xr-x 4 root root 4096 Aug 13  2013 /home
steve@clyde:~$ ls -ld ~
drwxr-x--x 30 steve faculty 50 Sep  2 11:31 /usr/users/noquota/faculty/steve
steve@clyde:~$ ls -l hello.py
-rwx------ 1 steve steve 100 Aug 31 14:31 hello.py
```

First letter of permissions says what type of file it is: - is file, d is directory

Permissions

The next 9 letters `rwxrwxrwx` control who has what type of access

- owner
- group
- other (everyone else)

Each group of 3 determines what access the corresponding people have

- Files
  - r — the owner/group/other can read the file
  - w — the owner/group/other can write the file
  - x — the owner/group/other can execute the file (run it as a program)
- Directories
  - r — the owner/group/other can see which files are in the directory
  - w — the owner/group/other can add/delete files in the directory
  - x — the owner/group/other can access files in the directory

Permissions example

```
-rw-r--r-- 1 steve steve 0 Sep  3 14:25 foo
```

The owner (steve) can read and write foo, everyone else can read it

```
-rwx------ 1 steve steve 100 Aug 31 14:31 hello.py
```

The owner can read, write, or execute, everyone else can do nothing

```
drwxr-x--x 33 steve faculty 54 Sep  3 14:25 .
drwxrwxr-x 2 steve faculty 4 Sep  2 11:45 books/
```

steve and all faculty have full access to ./books, everyone else can see the directory contents

Changing owner/group/perms

Handy shell commands

- `chown` — Change owner (and group) of files/directories
- `chgrp` — Change group of files/directories
- `chmod` — Change permissions for files/directories

Permissions are often specified in octal (base 8)

- `0 = ---     4 = r--`
- `1 = --x     5 = r-x`
- `2 = -w-     6 = rw-`
- `3 = -wx     7 = rwx`

Common values 777 (`rwxrwxrwx`), 755 (`rwxr-xr-x`) and 644 (`rw-r--r--`)

We can set a file's permissions by giving the numeric value of the permission (recall r = 4, w = 2, x = 1) as an argument to chmod. Which command should we use to make a file, `foo`, readable and writable by the owner, readable by anyone in the file's group, and no permissions otherwise?

```
A. $ chmod 644 foo

B. $ chmod 641 foo

C. $ chmod 640 foo

D. $ chmod 421 foo

E. $ chmod 046 foo
```

In-class exercise

https://checkoway.net/teaching/cs241/2019-fall/exercises/Lecture-03.html

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