Project 4:
Writing your own shell

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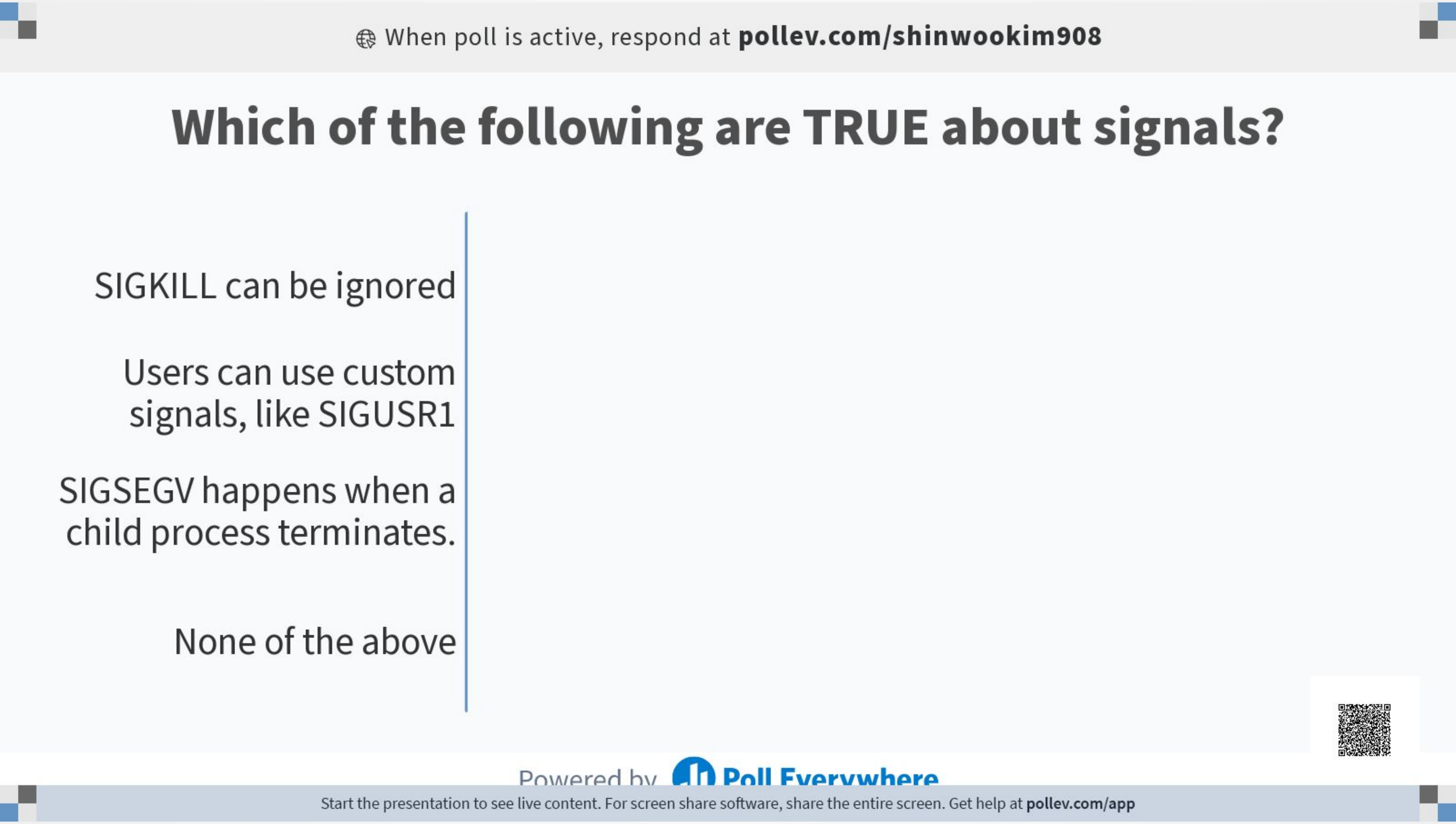
Spring 2023, Term 2234
Friday 12 PM Recitation
5502 Sennott Square
Mar 2nd, 2023

Course News!

- Exams
  - Exam I grades were returned on March 24th, 2023
    - Check your email for class statistics
    - Request regrades if needed (this may adjust your grade up or down)
  - Exam II was on March 30th, 2023 during lecture
    - Still a few people who haven't taken it yet…so won't discuss
- Labs
  - Lab 5 (Process Lab) was due on March 30th, 2023 @ 11:59 PM EST
- Projects
  - Project III: Late submission closed on March 27th, 2023 @11:59 PM EST
    - Remember to schedule check-off meetings if you haven't already
  - Project IV was released on March 30th, 2023
    - **Due: April 10th, 2023 @ 11:59 PM EST**
- Poll Everywhere
  - www.pollev.com/shinwookim908
  - Solutions to recitation questions will be posted on website

PEV: Signals



When poll is active, respond at **pollev.com/shinwookim908**

Which of the following are TRUE about signals?

SIGKILL can be ignored

Users can use custom signals, like SIGUSR1

SIGSEGV happens when a child process terminates.

None of the above

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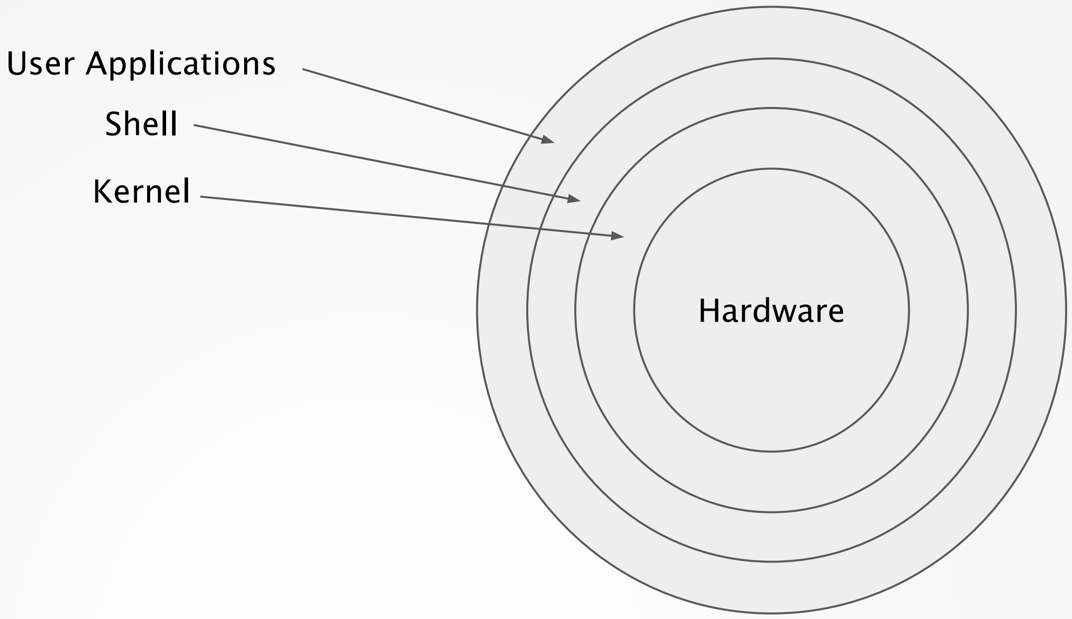
Project IV

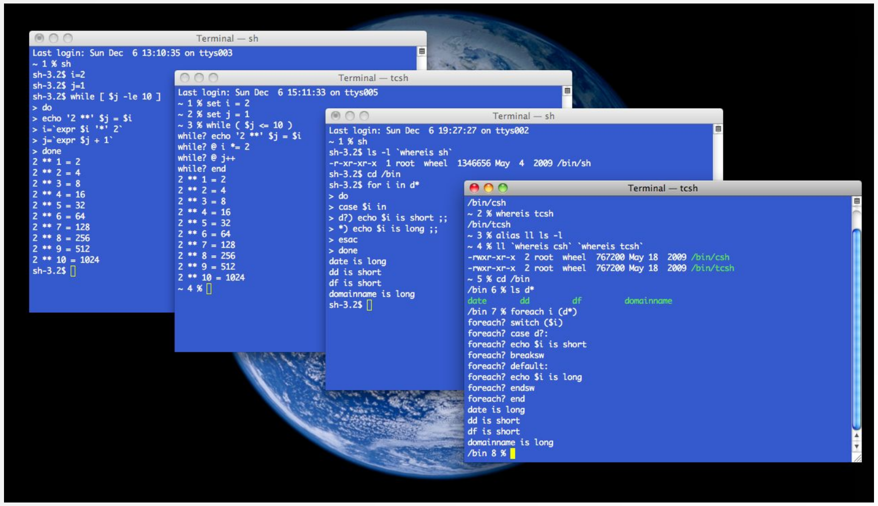
Writing your own shell



The shell

is the outermost layer of the operating system

What’s a *shell*?



```
Last login: Sun Dec  6 13:10:35 on ttys003
~ 1 % sh
sh-3.2$ i=2
sh-3.2$ j=1
sh-3.2$ while [ $j -le 10 ]
> do
> echo '2 **' $j = $i
> i=`expr $i '*' 2`
> j=`expr $j + 1`
> done
2 ** 1 = 2
2 ** 2 = 4
2 ** 3 = 8
2 ** 4 = 16
2 ** 5 = 32
2 ** 6 = 64
2 ** 7 = 128
2 ** 8 = 256
2 ** 9 = 512
2 ** 10 = 1024
sh-3.2$ 
```

```
Last login: Sun Dec  6 15:11:33 on ttys005
~ 1 % set i = 2
~ 2 % set j = 1
~ 3 % while ( $j <= 10 )
while? echo '2 **' $j = $i
while? @ i *= 2
while? @ j++
while? end
2 ** 1 = 2
2 ** 2 = 4
2 ** 3 = 8
2 ** 4 = 16
2 ** 5 = 32
2 ** 6 = 64
2 ** 7 = 128
2 ** 8 = 256
2 ** 9 = 512
2 ** 10 = 1024
~ 4 % 
```

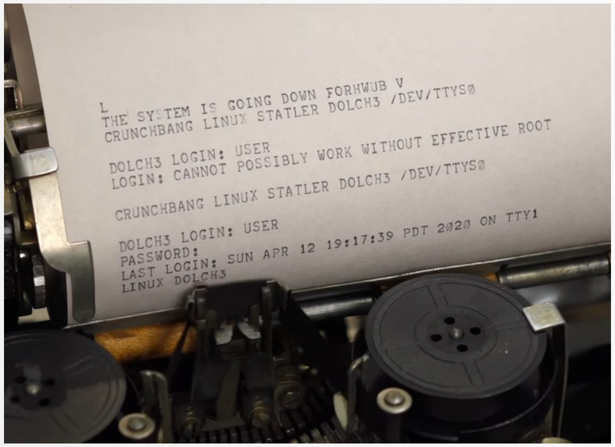
```
Last login: Sun Dec  6 19:27:27 on ttys002
~ 1 % sh
sh-3.2$ ls -l `whereis sh`
-r-xr-xr-x  1 root  wheel  1346656 May  4  2009 /bin/sh
sh-3.2$ cd /bin
sh-3.2$ for i in d*
> do
> case $i in
> d?) echo $i is short ;;
> *) echo $i is long ;;
> esac
> done
date is long
dd is short
df is short
domainname is long
sh-3.2$ 
```

```
/bin/csh
~ 2 % whereis tcsh
/bin/tcsh
~ 3 % alias ll ls -l
~ 4 % ll `whereis csh` `whereis tcsh`
-rwxr-xr-x  2 root  wheel  767200 May 18  2009 /bin/csh
-rwxr-xr-x  2 root  wheel  767200 May 18  2009 /bin/tcsh
~ 5 % cd /bin
/bin 6 % ls d*
date        dd          df          domainname
/bin 7 % foreach i (d*)
foreach? switch ($i)
foreach? case d?:
foreach? echo $i is short
foreach? breaksw
foreach? default:
foreach? echo $i is long
foreach? endsw
foreach? end
date is long
dd is short
df is short
domainname is long
/bin 8 % 
```

- It’s the *“command line”*
- A ***shell*** is an application program that runs programs on behalf of the user.
- Typically a shell is a program that
  1. Repeatedly prints a prompt
  2. Waits for a *command line* on `stdin`
  3. Carries out some action (as directed by the contents of the command line)
- A ***Read*** → ***Evaluate*** → ***Print*** loop *(REPL)*

Some terminology

- A **shell** is a user interface for accessing an computer system
- Most often the user interacts with the shell using a **command-line interface** (**CLI**).
- The **terminal** is a program that opens a graphical window and lets you interact with the shell.
  - Actually this is a **terminal emulator** or **virtual console**
  - Technically, terminals are physical machines that provides an interface with a larger machine
    - Teletypewriters
    - Video display terminals
- In reality, all these terms are *more or less* used interchangeably.

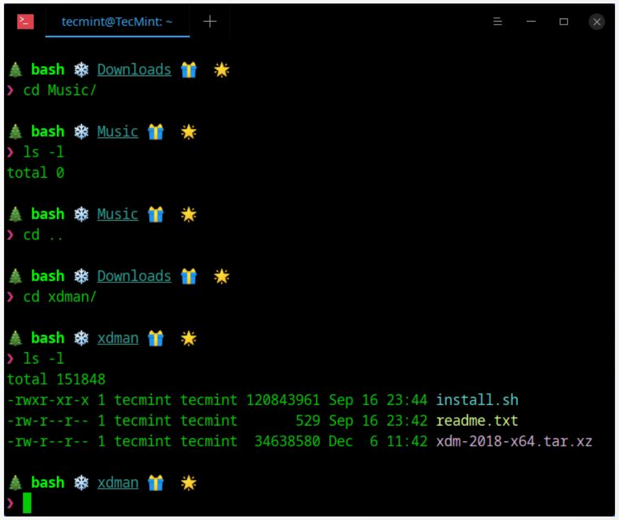


```
L
THE SYSTEM IS GOING DOWN FORHWUB V
CRUNCHBANG LINUX STATLER DOLCH3 /DEV/TTYSØ

DOLCH3 LOGIN: USER
LOGIN: CANNOT POSSIBLY WORK WITHOUT EFFECTIVE ROOT

CRUNCHBANG LINUX STATLER DOLCH3 /DEV/TTYSØ

DOLCH3 LOGIN: USER
PASSWORD:
LAST LOGIN: SUN APR 12 19:17:39 PDT 2Ø2Ø ON TTY1
LINUX DOLCH3
```



```
🎄 bash ❄ Downloads 🎁  🌟
❯ cd Music/

🎄 bash ❄ Music 🎁  🌟
❯ ls -l
total 0

🎄 bash ❄ Music 🎁  🌟
❯ cd ..

🎄 bash ❄ Downloads 🎁  🌟
❯ cd xdman/

🎄 bash ❄ xdman 🎁  🌟
❯ ls -l
total 151848
-rwxr-xr-x 1 tecmint tecmint 120843961 Sep 16 23:44 install.sh
-rw-r--r-- 1 tecmint tecmint       529 Sep 16 23:42 readme.txt
-rw-r--r-- 1 tecmint tecmint  34638580 Dec  6 11:42 xdm-2018-x64.tar.xz

🎄 bash ❄ xdman 🎁  🌟
❯
```

Many different shells, including your very own!

- There are various different shells that you can use.
  - `sh` – Original Unix shell (Stephen Bourne, AT&T Bell Labs, 1977)
- Most common is the Bourne-Again shell (bash)
  - Preinstalled with most Linux distributions
    - It's the one that's installed on Thoth
  - Just another program → `/bin/bash`
- Some others include:
  - Z-shell (zsh) → `/bin/zsh`
    - Comes preinstalled for modern MacOS, modern Linux distributions
  - PowerShell, COMMAND.COM
    - For Windows
    - Not a Unix-Shell
  - fish/csh, and much more
- For project IV, you will implement your very own shell
  - Primitive, yet still functional
  - *It accomplishes all that needs to be done*

msh specification *Hopefully you can come up with a good name for your shell that ends with "-sh"*

Your shell should:

- Print a prompt: ">"
- Read user input
  - The command line input by the user consists of a *name* and zero or more arguments (delimited by spaces)

```
> ls             # command: ls; arguments: ls
> ls -a          # command: ls; arguments: ls, -a
> exit           # command: exit; arguments: exit
> load better_ls # command: load; arguments load, better_ls
```

msh specification

Your shell should:

- Support built-in commands
  - `exit`: The shell should exit upon receiving this command
  - `load`: The shell should dynamically load a plugin and initialize it
- Support extensioning built-in commands via plugins
  - Plugin Interface:
    - `int initialize()`
      - Returns `0` on success
    - `int run(char **argv)`
      - `argv`: array of Strings terminated by `NULL`
        - `argv = {"ls", "-a", NULL}`
      - Returns `0` on success
  - Throw error message if plugin could not be loaded
    `Error: Plugin <plugin> initialization failed!`
  - Once loaded, user should be able to run the extended functionality by invoking the plugin's name

msh specification

Your shell should:

- Support extensioning built-in commands via plugins

```
> broken_better_ls   # Not loaded
> load broken_better_ls
Error: Plugin broken_better_ls initialization failed!
> broken_better_ls   # Still not loaded
> better_ls          # Not loaded
> load better_ls     # Success
> better_ls          # Loaded
msh    msh.c     better_ls.c   better_ls.so
>
```

msh specification

Your shell should:

- Allow for instantiating other executables *and pass in arguments*

```
shk148@thoth $ ./msh
> vim better_ls.c
> gcc better_ls.c -o better_ls.so -shared
> load better_ls
> better_ls
msh    msh.c     better_ls.c   better_ls.so
> exit
shk148@thoth $
```

msh specification limitations

To simplify your implementation, testing will be limited to:

1. Commands will have a maximum size of 200 characters
2. Program names and arguments will have a maximum size of 20 characters
3. There will be at most 20 arguments
4. Your shell need only support loading upto 10 plugins

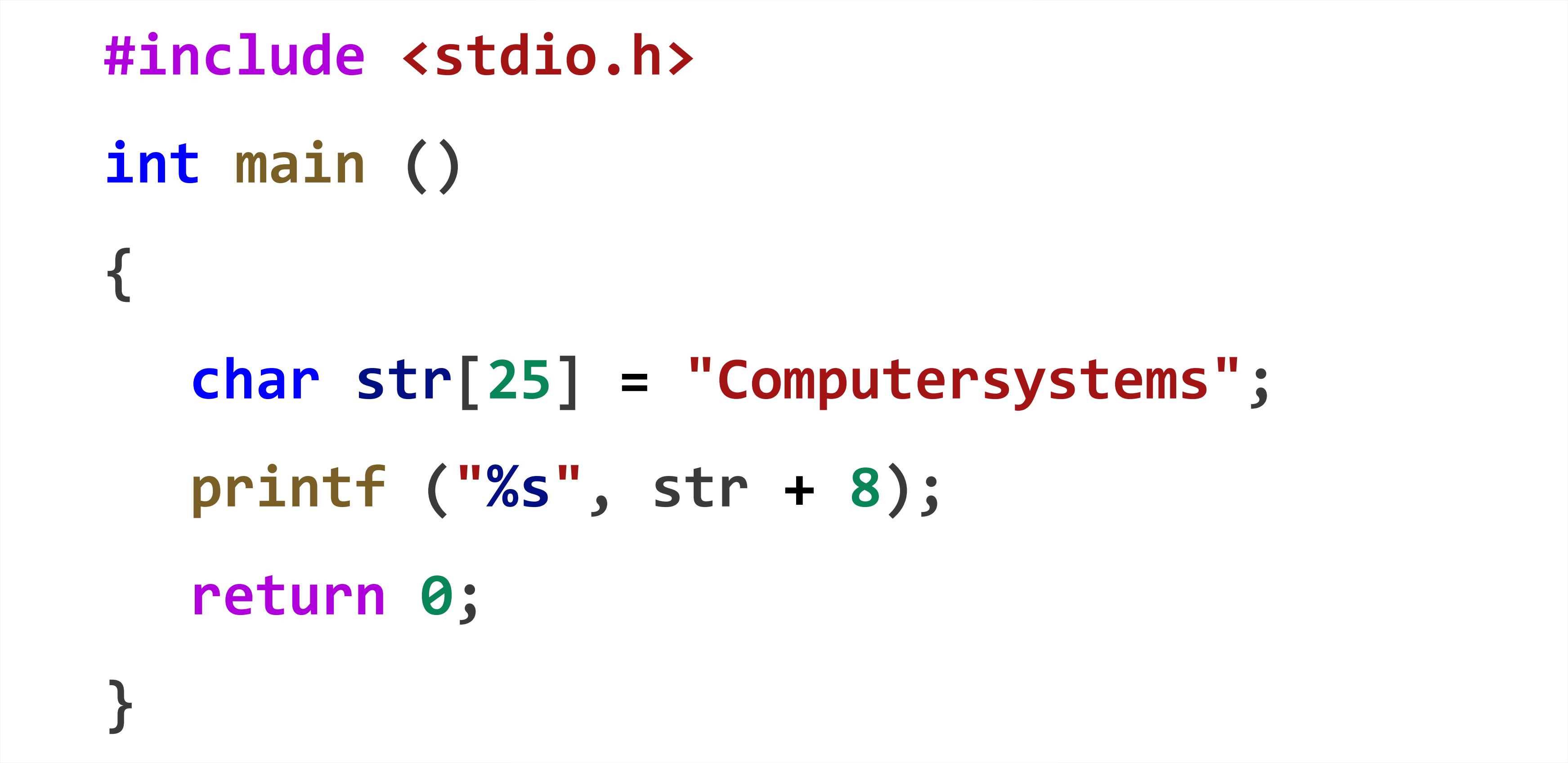
Building the shell: ~~Skeleton~~ Shelleton

```
int main(){
    while (TRUE)  When do we break out of this loop?
    {   /* Infinite Loop for REPL */
        PrintCommandPrompt()
        cmdLine = readFromStdIn();
        cmd = parseCommand(cmdLine);
        If (cmd is BuiltInCommand) {executeBuiltInCommand(cmd)};
        Else
        { If the command not a built-in command, we should check if it's a name of an executable file
            fork()
            // Child process should run the executable
         What should the parent process do while the child process is running?
        }
    }
}
```

...This is just one approach to building your shell

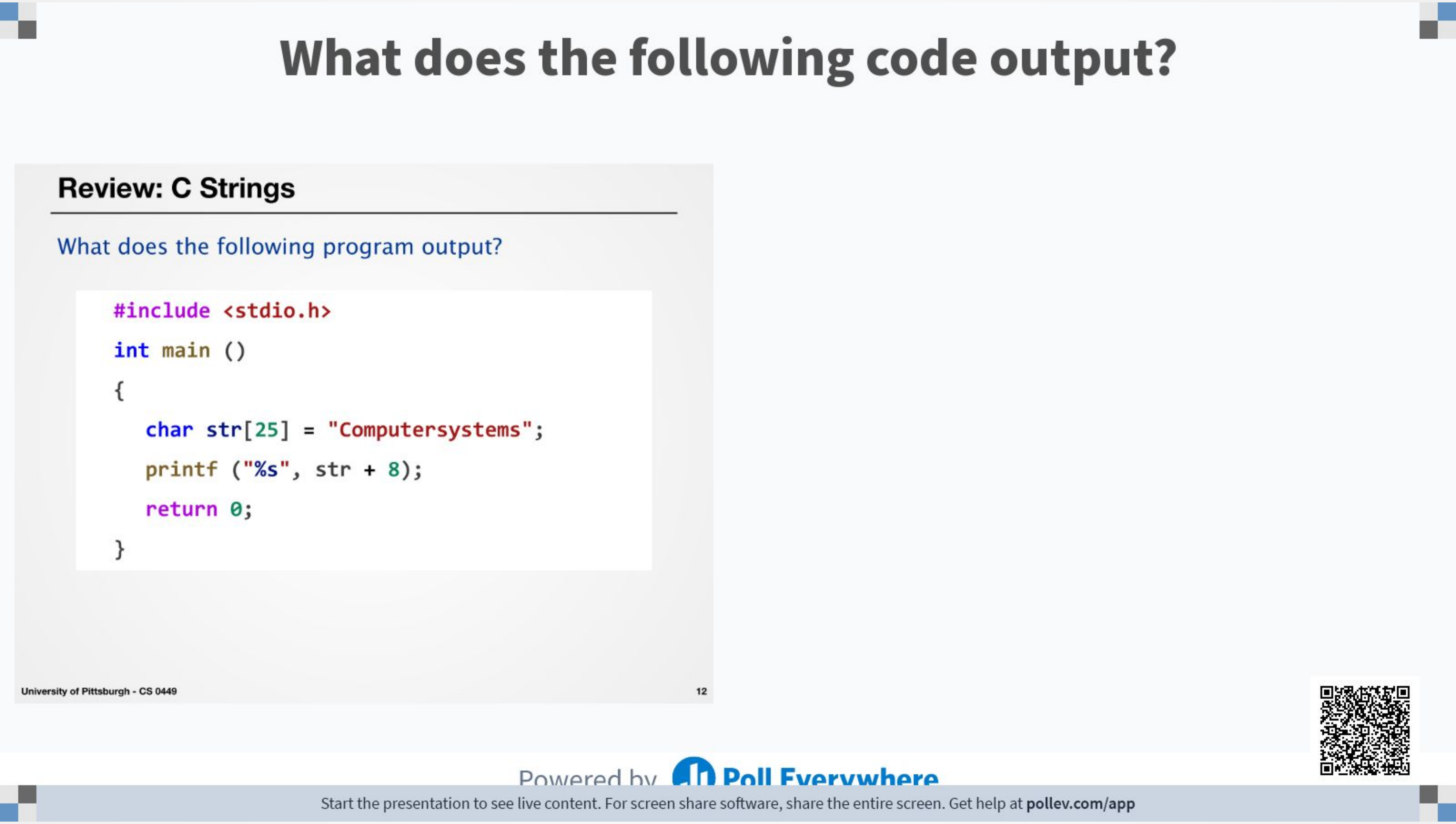
Review: C Strings

What does the following program output?



```
#include <stdio.h>
int main ()
{
    char str[25] = "Computersystems";
    printf ("%s", str + 8);
    return 0;
}
```

PEV: C Strings



What does the following code output?

Review: C Strings

What does the following program output?

```
#include <stdio.h>
int main ()
{
   char str[25] = "Computersystems";
   printf ("%s", str + 8);
   return 0;
}
```

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Building the shell: Reading and Parsing Input

Built-in command or path to another executable

Command line arguments

```
$ ls -l -a /usr
```

- A command goes in → 📦 → a process comes out
  - A shell, at its simplest, is a program that reads input from the user and tries to execute commands.
- We can read in a line of input using `fgets()`
- Given a user input, we need to categorize it as
  - Built in command or
  - Name of an executable
- But before we can interpret the input, we need to tokenize it

```
"ls -l -a /usr" /* delimited by ‘ ’*/

     ⇒ {"ls", "-l", "-a", "/usr"}
```

`man strtok` abridged

- The `strtok()` function can help tokenize strings
- `#include <string.h>`
- `char *strtok(char *str, const char *delim);`
  - Breaks string `str` into a series of tokens using the delimiter `delim`.
  - Returns a pointer to the next token, or NULL if there are no more tokens.
- Called in one of two ways:
  1. `strtok(str, d) // starts processing a new string`
  2. `strtok(NULL, d) // continue processing a string`

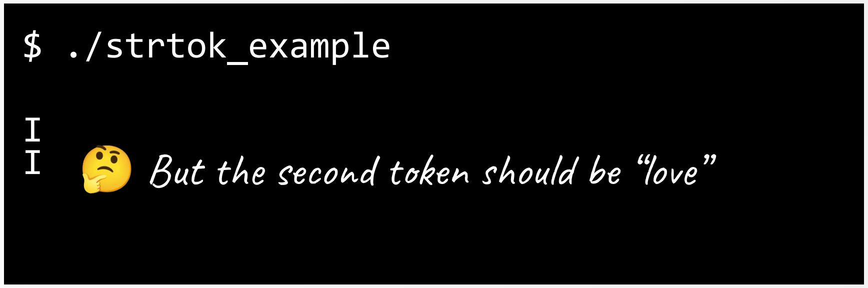
A strtok() example

```
$ ./strtok_example

I
```

```c
#include <stdio.h>
#include <string.h>
int main(){
    char str[] = "I:love-programming";
    char delim[] = "-:";
    char *token;
    token = strtok(str, delim);
    printf("%s\n", token);
    return 0;
}
```

What will be printed?

A strtok() example



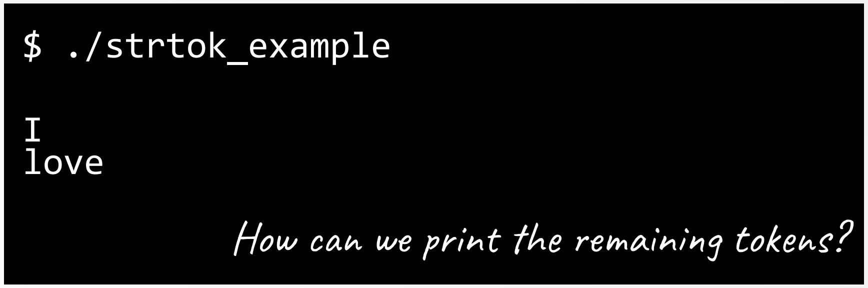
```
$ ./strtok_example

I
I
```

🤔 *But the second token should be "love"*

```c
#include <stdio.h>
#include <string.h>
int main(){
    char str[] = "I:love-programming";
    char delim[] = "-:";
    char *token;
    token = strtok(str, delim);
    printf("%s\n", token);
    token = strtok(str, delim);
    printf("%s\n", token);
    return 0;
}
```

What will be printed?

A strtok() example



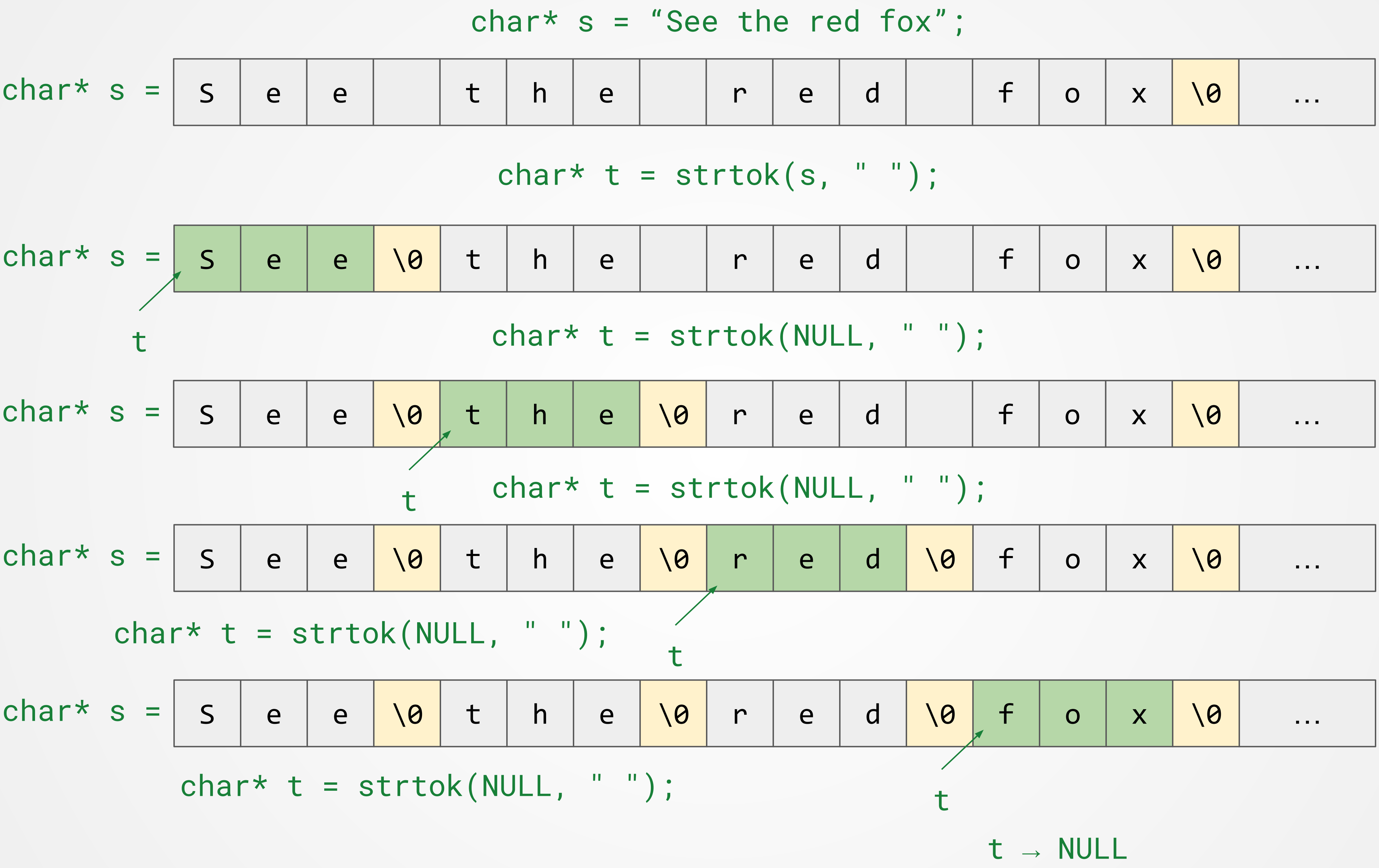
```
$ ./strtok_example

I
love
```

How can we print the remaining tokens?

```c
#include <stdio.h>
#include <string.h>
int main(){
    char str[] = "I:love-programming";
    char delim[] = "-:";
    char *token;
    token = strtok(str, delim);
    printf("%s\n", token);
    token = strtok(NULL, delim);
    printf("%s\n", token);
    return 0;
}
```

What will be printed?

A strtok() example



```
char* s = “See the red fox”;
```

char* s =	S	e	e		t	h	e		r	e	d		f	o	x	\0	...

```
char* t = strtok(s, " ");
```

char* s =	S	e	e	\0	t	h	e		r	e	d		f	o	x	\0	...

```
char* t = strtok(NULL, " ");
```

char* s =	S	e	e	\0	t	h	e	\0	r	e	d		f	o	x	\0	...

```
char* t = strtok(NULL, " ");
```

char* s =	S	e	e	\0	t	h	e	\0	r	e	d	\0	f	o	x	\0	...

```
char* t = strtok(NULL, " ");
```

char* s =	S	e	e	\0	t	h	e	\0	r	e	d	\0	f	o	x	\0	...

```
char* t = strtok(NULL, " ");
```

t → NULL

- strtok() changes the string that has been parsed!

idem·po·tent

- The `strtok()` function exhibits some weird behavior
  - `strtok()` changes the string that has been parsed
  - Replacing the character in place with a null terminator (`'\0'`)
- `strtok()` produces different results when called multiple times
  - It’s a **non-idempotent** function
    - Which has ***side effects***.
- In comparison, functions that have no side effects are called **idempotent**.

```
x = 2; // Assignment operations are
x = 2; // idempotent
x = 2;
x = 2; // Calling it multiple times
x = 2; // always produces the same result
```

`man strtok` #NOTES-AND-BUGS

- Be cautious when using these functions. If you do use them, note that:
  - These functions modify their first argument.
  - These functions cannot be used on constant strings.
  - The identity of the delimiting byte is lost.
- For instance, if you try
  - `strtok(“String Constant”, delim)`
  - Segmentation fault! (attempting to write to a literal)

Still unsure? Read the man pages!

```
$ man strtok
```

- What arguments does the function take?
  - read **SYNOPSIS**
- What does the function do?
  - read **DESCRIPTION**
- What does the function return?
  - read **RETURN VALUES**
- What errors can the function fail with?
  - read **ERRORS**
- Is there anything I should watch out for?
  - read **NOTES**
- I want an example
  - read **EXAMPLES**
  - https://pitt.edu/~shk148/teaching/CS0449-2234/code/strtok.c.html

strtok() vs strsep()

- Alternatively, you can use strsep()
- A *replacement* for strtok()
- But not all C versions support it
  - For instance, ANSI-C does not support strtok()
  - Hence, it is *less portable*
- You may use either strsep() or strtok() in this project
  - Read the documentation (man pages) to see how each work!

Building the shell: Executing command

- Once we’ve tokenized the input, we can use standard C-string functions to *compare*
  - `strcmp()` and friends
- If the keyword matches a built-in command
  - Run it!
  - Some functionalities may require dynamically loading *plugins*
    - Just as you did for lab 5
- If the keyword is unknown,
  - It’s probably the name of an executable
  - So run it!
    - `fork()` and friends
      - `exec*()`
        - `wait()`

Building the shell: Executing command

- Once we've tokenized the input, we can use standard C-string functions to *compare*
  - `strcmp()` and friends
- If the keyword matches a built-in command
  - Run it!
  - Refer to lab 5 on how to dynamically load plugins
- If the keyword is unknown,
  - It's probably the name of an executable
  - So run it!
    - `fork()` and friends

Building the shell: Executing command

```
{"ls", "-l", "-a", "/usr"}
```

- Once we've tokenized the input, we can use standard C-string functions to *compare*
  - `strcmp()` and friends
- If the keyword matches a built-in command
  1. `exit` ⇒ Exit the program
  2. `load` ⇒ Dynamically load plugins (just like lab 5)
     - Since our shell needs to support dynamically loading multiple plugins
       - Devise some data structure to store them
       - Create helper functions to add and access plugins

Building the shell: Executing command

- If the keyword does not match a built-in command
- Check if it’s a plugin
  - and run it
- If it’s not a plugin
  - It must be an executable name
  - `fork()`, `exec*()`, and their friends!
    - Make sure to use the correct `exec*()` function
    - And correctly pass in arguments

Implementation Hints

1. When multiprogramming with fork()s
   - ○ Think about the order in which processes need to run
   - ○ Does a process need to wait for another?
2. String parsing is weird and hard
   - ○ Especially since the standard functions exhibits odd behavior
   - ○ Carefully read the documentation
   - ○ Verify output before moving onto next step
3. There is a lot to program
   - ○ Break your program down into smaller functions
   - ○ `readInput()`, `parseInput()`, `runBuiltIn()`, …
   - ○ To pass values between functions, you have to store them in the heap!

➢ Since this project requires access to many standard library functions, we highly recommend developing on Thoth or another Linux machine
   - ○ And plan for outages!
     - ➢ Back-up frequently (to your local machine)

Implementation Challenges

1. This project ties in everything you've learned so far
   - C programming & debugging
     - ➢ *See Lab0 (Hello lab)*
   - C-Strings and standard library functions
     - ➢ *See Project I (BMP Steganography) for a guide*
   - Maintaining data structures in C
     - ➢ *Lab3 (Queue lab)*
   - Pointers and management of memory
     - ➢ *See Lab2 (Pointer lab), Project II (Malloc)*
   - Process management and dynamic loading
     - ➢ *See Lab5 (Loading and Forking)*
2. One common issue: *Memory leaks*
   - Not maintaining pointers
   - `malloc()` without `free()`
   - Test your code for memory leaks using **valgrind**!

Implementation Challenges

2. One common issue: *Memory leaks*

- Not maintaining pointers
- `malloc()` without `free()`
- Test your code for memory leaks using **valgrind**!

```
$ valgrind --leak-check=full --show-leak-kinds=all ./msh
```

```
HEAP SUMMARY:
==630754==     in use at exit: 3,683 bytes in 6 blocks
==630754==   total heap usage: 8 allocs, 2 frees, 5,731 bytes allocated
==630754==
==630754== 820 (808 direct, 12 indirect) bytes in 1 blocks are definitely lost in loss record 4 of 5
==630754==    at 0x484DA83: calloc (in /usr/libexec/valgrind/vgpreload_memcheck-amd64-linux.so)
==630754==    by 0x10981F: get_user_input (luis.c:134)
==630754==    by 0x1097D7: main (luis.c:124)
==630754==
==630754== 2,050 bytes in 2 blocks are definitely lost in loss record 5 of 5
==630754==    at 0x484DA83: calloc (in /usr/libexec/valgrind/vgpreload_memcheck-amd64-linux.so)
==630754==    by 0x10983A: get_user_input (luis.c:137)
==630754==    by 0x1097D7: main (luis.c:124)
==630754==
==630754== LEAK SUMMARY:
==630754==    definitely lost: 2,858 bytes in 3 blocks
==630754==    indirectly lost: 12 bytes in 1 blocks
==630754==      possibly lost: 0 bytes in 0 blocks
==630754==    still reachable: 813 bytes in 2 blocks
==630754==         suppressed: 0 bytes in 0 blocks
```

Debugging

- Debugging this project is hard
  - So many functionalities to look out for
    - So many places to go wrong
    - So many places to shoot yourself in the foot
  - Measure twice, cut once!
- This project is fairly open-ended in its implementation
  - *You should be able to explain your own code!*
  - ~~“I wrote it and it sort of works, but I don’t know why~~”

GDB: GNU Debugger

"the archer fish is known to shoot down bugs from low hanging plants by spitting water at them" -- Jamie Guinan

www.gnu.org/software/gdb/

Valgrind Memcheck

"hunting down heap memory errors with...origami?"

valgrind.org

Works Referred

- Creative Commons photography courtesy of Arnold Reinhold and technikum29 via the Wikimedia Foundations
- `strtok()` examples adapted from Weber State University