VIRGINIA TECH

CS 3214: Project 1

The Customizable Shell

Help Session:
Thursday Feb 9, 2023 7:00 PM

Timothy Wu <wutp20@vt.edu>
Tanvi Allada <tanviallada@vt.edu>

Topics

- Shell Concepts
- Project Overview / Logistics
- Version Control (Git)
- Debugging (GDB)
- Advice
- Q & A

VIRGINIA TECH™

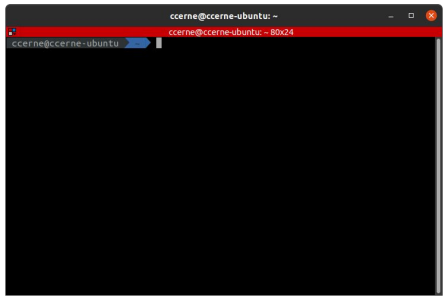
Shell Concepts

What is a shell?

- Command Interpreter
  - Reads user input and executes user requests
  - Not to be confused with a “Terminal” (next slide explains distinction)

Terminal vs Shell

Terminal (the front-end GUI of our shell)



Examples: gnome-terminal, terminator, Terminal.app (macOS) etc.

The 80s called, they want their Terminal back!

Shell (an executable with no GUI)

```
ccerne@ccerne-ubuntu:~/Documents$ ls -l
ls -l
total 16
drwxrwxr-x 7 ccerne ccerne 4096 Aug 23 10:37 CTF
drwxrwxr-x 6 ccerne ccerne 4096 Sep 11 21:42 Programming
drwxrwxr-x 5 ccerne ccerne 4096 Sep  1 16:56 Programs
drwxrwxr-x 5 ccerne ccerne 4096 Sep 13 21:19 VirginiaTech
ccerne@ccerne-ubuntu:~/Documents$ echo $SHELL
/usr/bin/zsh
```

This terminal is running zsh, a shell

Behind the Scenes

```
$ echo 'Welcome to Systems!'
```

f
o
r
k

```
Welcome to Systems!
```

FOUR STEPS for *non-built-in*

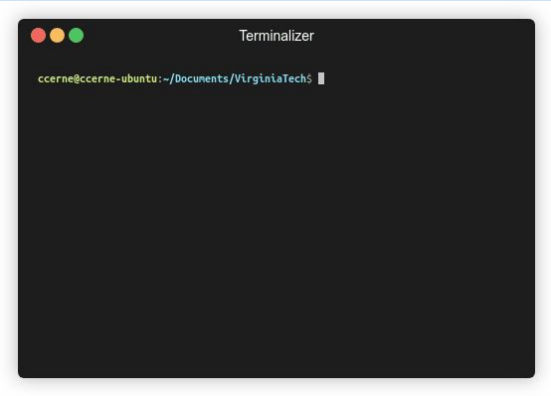
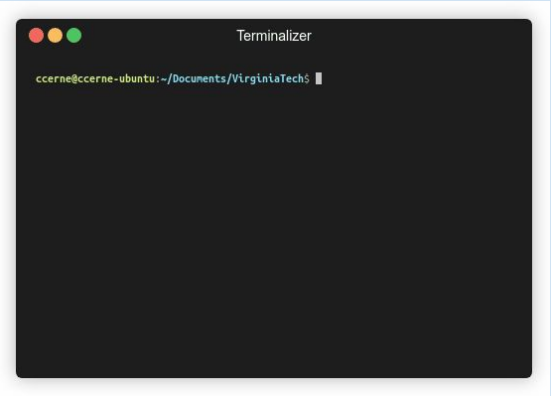
1. Shell waits for user input
2. Shell interprets command
3. Forks a process
4. If it's a foreground parent waits for child to finish. Else, parent repeats the process again.
   - Child executes the command

Additional Features for the Shell (where you come in)

- Foreground / Background Processes
- Process Groups
- Built-in Commands
- I/O Piping
- I/O Redirection
- Signal Handling

Foreground / Background Processes

- The shell can fork processes into the foreground or background

Foreground	Background
- Only one foreground process group at a time - Have access to the terminal 	- Does not have terminal access - Using ‘&’ sends command to background to run 

Process Groups

- A Job is essentially a pipelined-command
- Each Job has its own process group
  - Each command within a Job should have the same PGID
  - Two methodologies of creating new processes:
    - fork() and execvp()
    - posix_spawn
- Jobs are deleted when they are completed
  - Be careful not to delete a job prematurely
  - See the comment above wait_for_job()

```
<justv@cottonwood justv>$ sleep 20 | sleep 20 | sleep 20 &
```

```
<justv@cottonwood justv>$ ps xj | head -n 1; ps xj | tail -n 6
   PPID     PID    PGID     SID TTY        TPGID STAT   UID   TIME COMMAND
1357688 1363886 1363886 1357688 pts/0    1365438 S    24908   0:00 /home/courses/cs3214/bin/cush-gback
1363886 1365308 1365308 1357688 pts/0    1365438 S    24908   0:00 sleep 20
1363886 1365309 1365308 1357688 pts/0    1365438 S    24908   0:00 sleep 20
1363886 1365310 1365308 1357688 pts/0    1365438 S    24908   0:00 sleep 20
```

Notice the PID and PGID!

POSIX Spawn

- Replaces fork() + exec() entirely
- Code is “linear” rather than handling multiple processes in if-else statements
- posix_spawnattr_t and posix_spawn_file_actions_t are used to store information process groups and I/O redirection/piping respectively. These structs don’t do anything until posix_spawnp is used.

- Example: posix_spawn(3) - Linux manual page (man7.org)

Note: You need to include “spawn.h” in your cush.c to use these functions. The file is located in the posix_spawn directory. Also be sure to use the Makefile and compile posix_spawn.

fork() + exec()

```
if (fork() == 0) {
    //child stuff

    execvp(/* program arguments */);
}
else {
    //parentstuff
}
```

posix_spawn()

```
posix_spawn_file_actions_t child_file_attr;
posix_spawnattr_t child_spawn_attr;

posix_spawnattr_int(&child_file_attr);
posix_spawn_file_actions_init(&child_file_attr);

// setup for attributes

posix_spawnp(/*pid*/, /*program*/, &child_file_attr,
&child_spawn_attr, /*program arguments*/, environ)
```

We recommend using posix_spawn() for this project, but it is not required.

POSIX Spawn Attributes

- Process Groups - posix_spawnattr_setpgroup()
- Terminal Control - posix_spawnattr_tcsetpgrp_np()
- Piping - posix_spawn_file_actions_adddup2()
- I/O Redirection - posix_spawn_file_actions_addopen()

More listed on both the spec and <spawn.h>.

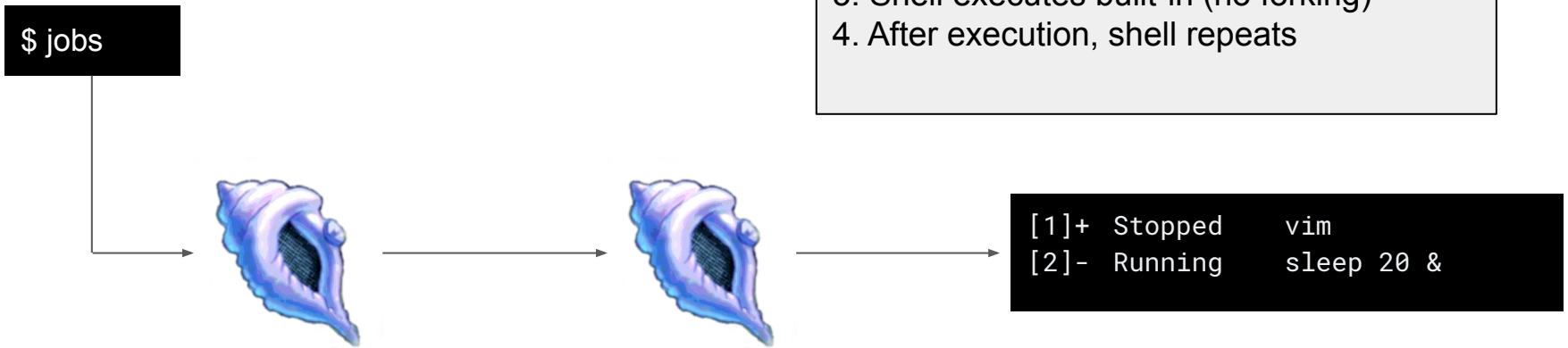
Built-in Commands

- Commands that are defined within the program by you
  - No need to fork off and execute an external program
- Required Built-In Commands for your shell:
  - kill - kills a process
  - jobs - displays a list of jobs
  - stop - stops a process
  - fg - sends a process to foreground
  - bg - sends a process to background
  - exit - exits the shell
- Built-in Commands are not considered Jobs
- Two additional built-ins / functionality extenders also required
  - One low-effort
  - One high-effort

Built-ins Behind the Scenes

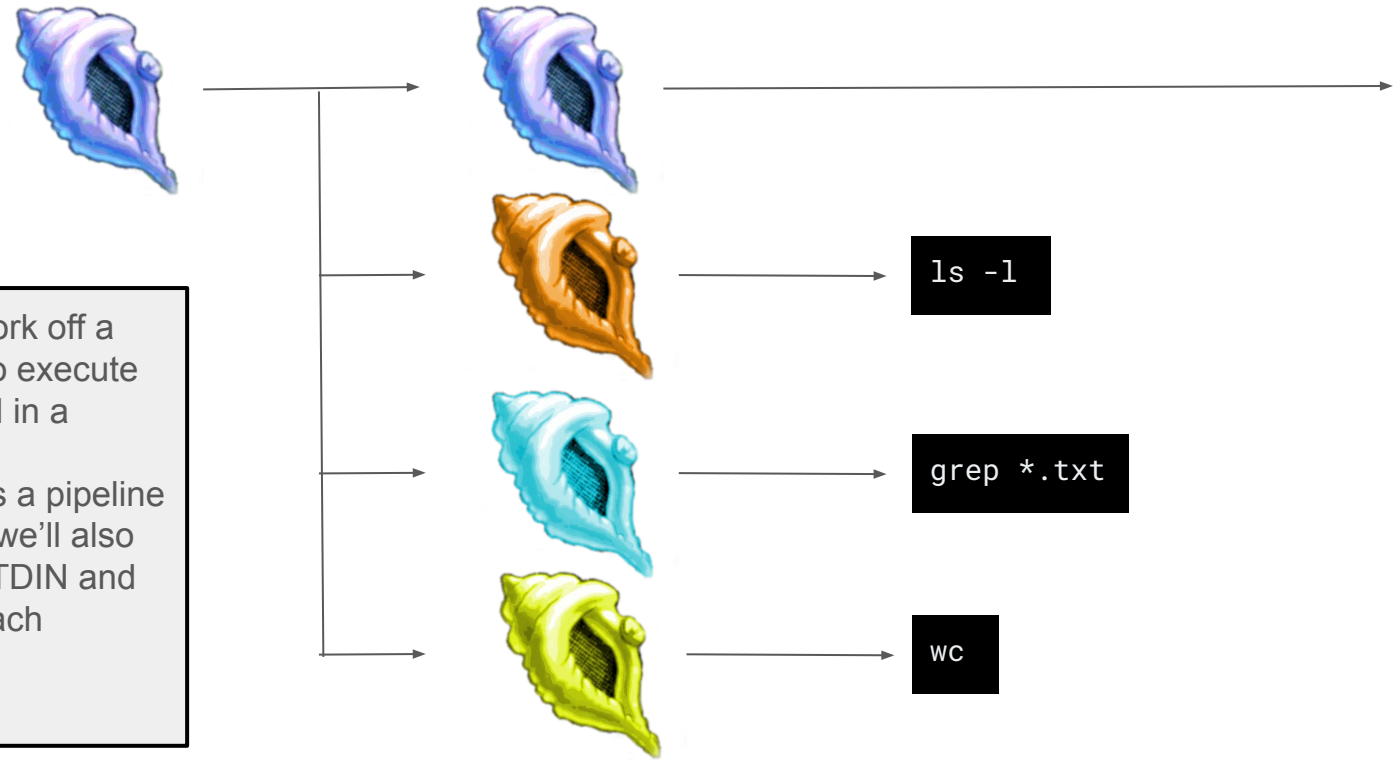
FOUR STEPS for *built-in*

1. Shell waits for user input
2. Shell realizes this is a built in command
3. Shell executes built-in (no forking)
4. After execution, shell repeats



I/O Piping

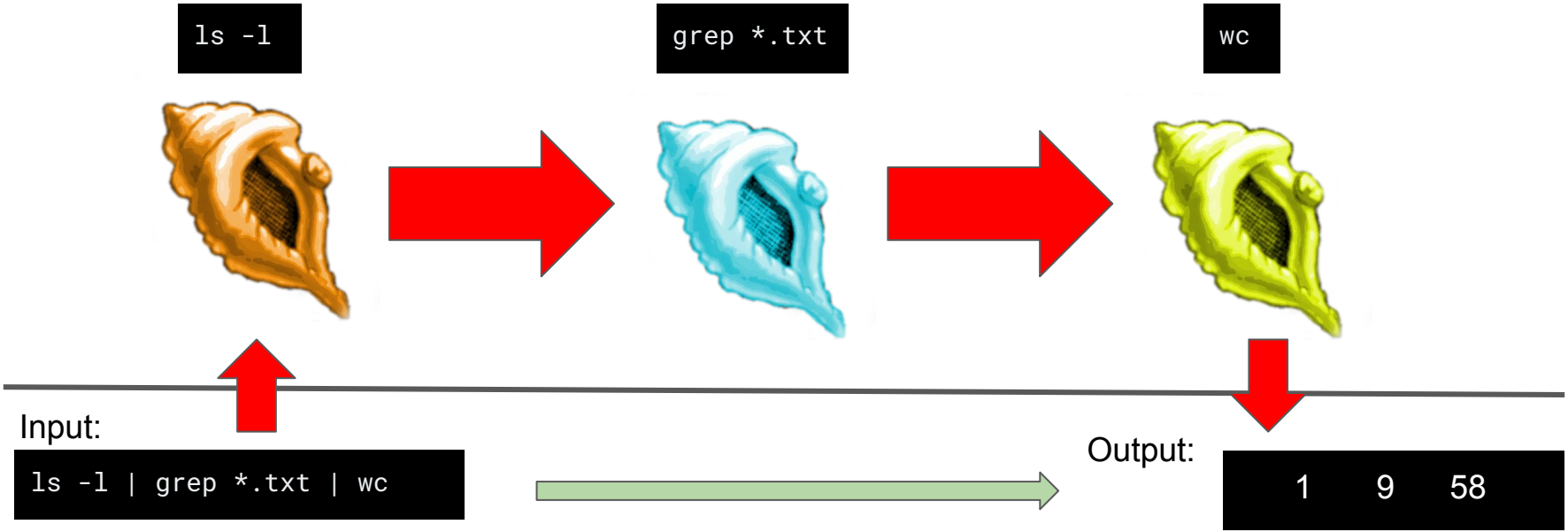
```
ls -l | grep *.txt | wc
```



- The Shell will fork off a child process to execute each command in a pipeline
- But since this is a pipeline of commands, we'll also need to wire STDIN and STDOUT for each process….

I/O Piping

- Processes will wait on previous process, final process outputs to terminal
- STDIN and STDOUT for processes are joined to create the pipeline

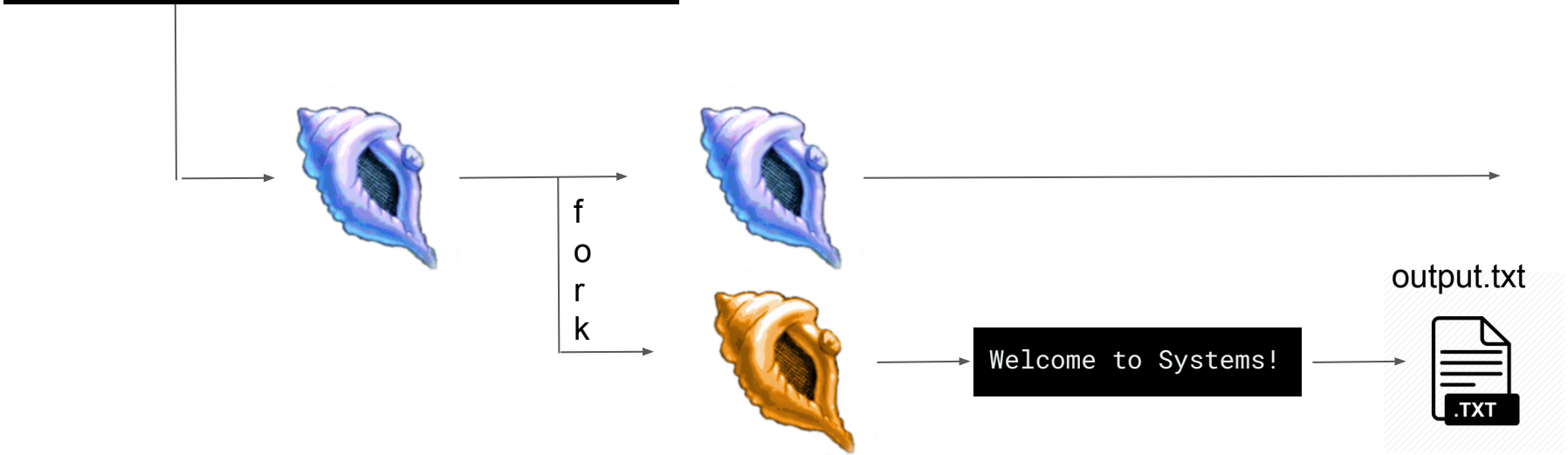


I/O Redirection

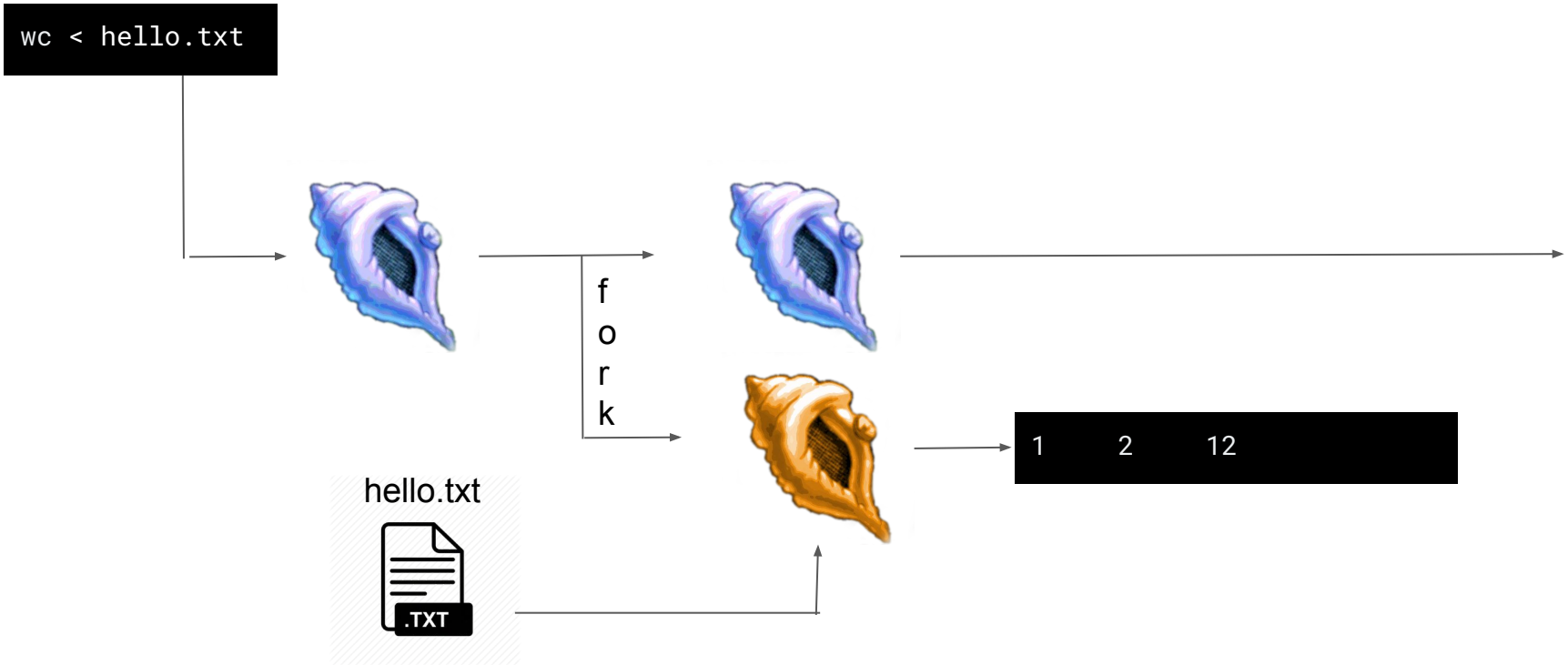
- `>` overwrites original file contents before writing out
- `>>` appends to the end of contents in file
- `<` read input from existing file rather than STDIN

I/O Redirection (Output)

```
echo 'Welcome to Systems!' > output.txt
```



I/O Redirection (Input)



I/O Redirection (Stderr)

- Contents written to STDERR can also be piped into other processes using |& and outputted to files using >&.

```c
int main() {
    fprintf(stderr, "Write to stderr.\n");
    fprintf(stdout, "Write to stdout\n");
}
```

```
[wutp20@ash p1_help_session]$ ./stderr_to_pipe | wc
Write to stderr.
      1       3      16
[wutp20@ash p1_help_session]$ ./stderr_to_pipe |& wc
      2       6      33
[wutp20@ash p1_help_session]$ ./stderr_to_pipe > file.txt
Write to stderr.
[wutp20@ash p1_help_session]$ ./stderr_to_pipe >& file.txt
[wutp20@ash p1_help_session]$
```

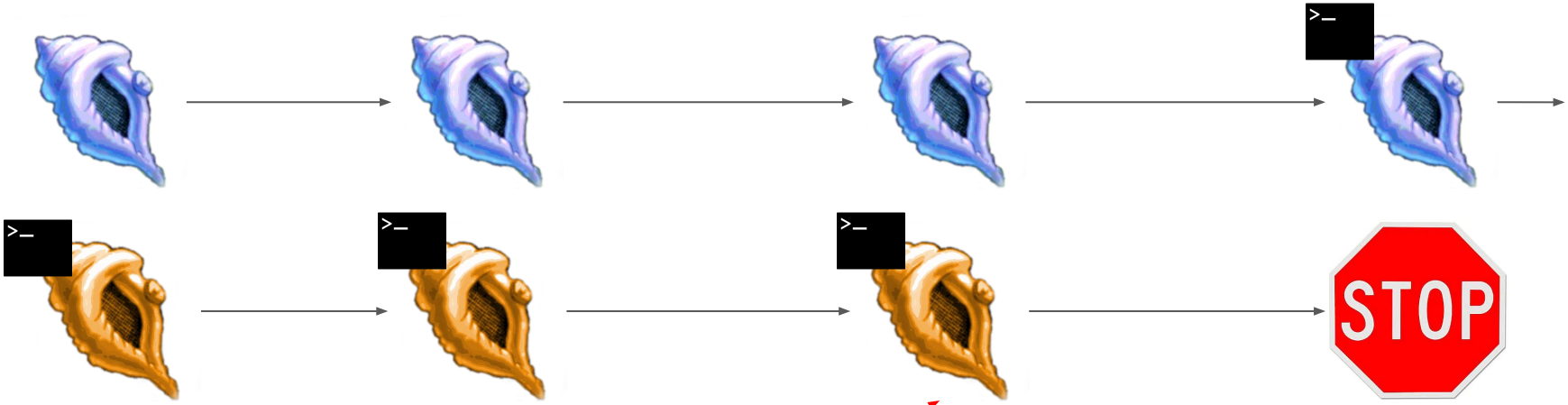
Notice how the message “Write to stderr.” was not outputted.

Signal Handling

- Shells can handle signals sent to them
  - SIGINT (Ctrl + C)
  - SIGTSTP (Ctrl + Z)
  - SIGCHLD (when a child process terminates)

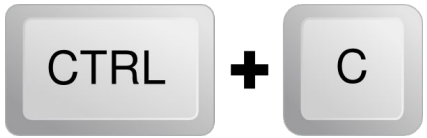
- Most of the functionality of this will be done in handle_child_status(pid_t pid, int status)

Handling SIGINT (Ctrl + C)



1. Shell and single child process (in the foreground) are running

2. User sends SIGINT (Ctrl +C)

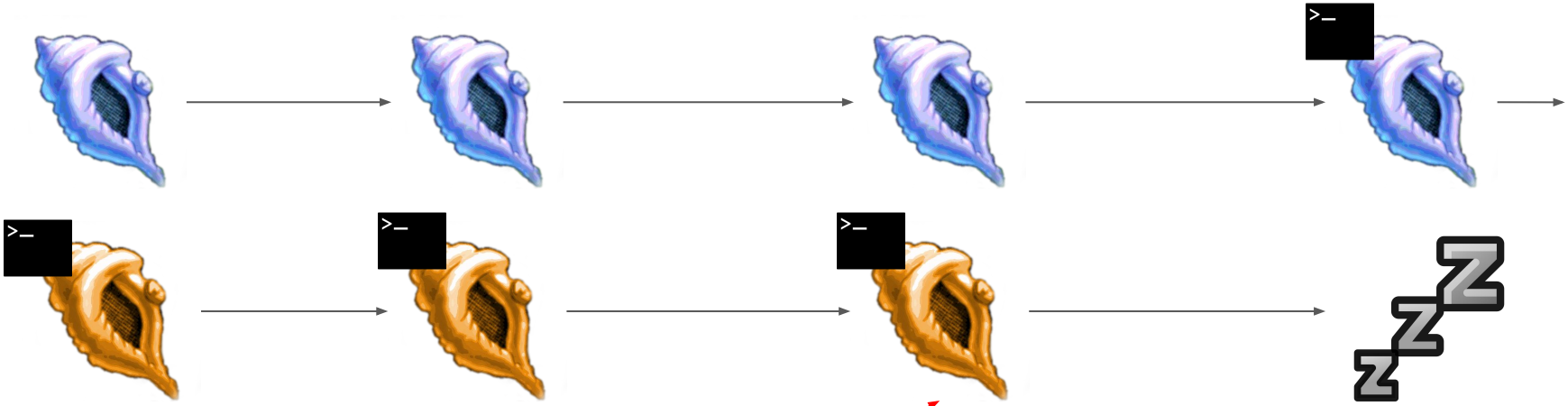


3. Signal sent to foreground process group

4. Group is forced to terminate, shell reacquires terminal control

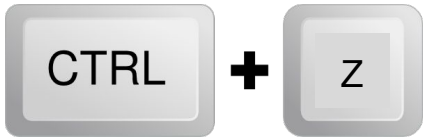
Explanation : https://en.wikipedia.org/wiki/Process_group#Applications

Handling SIGTSTP (Ctrl + Z)



1. Shell and single child process (in the foreground) are running

2. User sends SIGTSTP (Ctrl + Z)

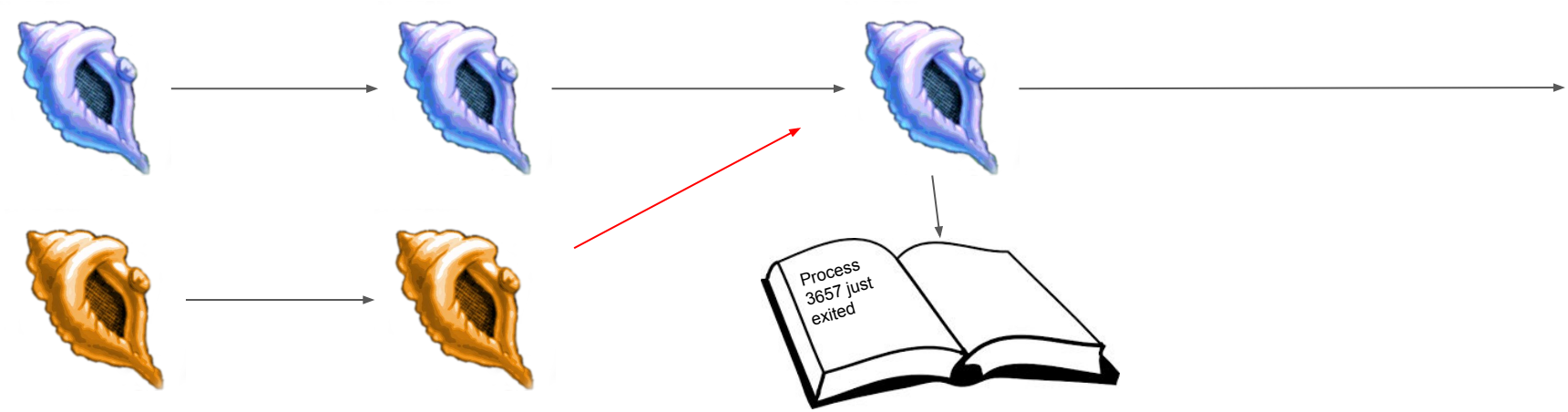


3. Signal sent to foreground process group

4. Group is forced to stop, shell reacquires terminal control

Explanation : https://en.wikipedia.org/wiki/Process_group#Applications

Handling SIGCHLD



1. Shell and single child process (**foreground or background**) are running

2. Child process is finished and terminates - notifies parent by sending SIGCHLD

3. The shell's SIGCHLD handler code uses info to perform any necessary bookkeeping

4. Shell continues running

Explanation : https://en.wikipedia.org/wiki/Process_group#Applications

Handling SIGCHLD: WIF* Macros

- When wait* is called it will return a pid and a status for a child process that changes state. Using macros, we can decode this status to discover what state a process changed to and how it happened:
  - WIFEXITED(status) - did child process exit normally?
  - WIFSIGNALED(status) - was child process signaled to terminate?
  - WIFSTOPPED(status) - was child process signaled to stop?

Event	How to check for it	Additional info	Process stopped?	Process dead?
User stops fg process with Ctrl-Z	WIFSTOPPED	WSTOPSIG equals SIGTSTP	yes	no
User stops process with kill -STOP	WIFSTOPPED	WSTOPSIG equals SIGSTOP	yes	no
non-foreground process wants terminal access	WIFSTOPPED	WSTOPSIG equals SIGTTOU or SIGTTIN	yes	no
process exits via `exit()`	WIFEXITED	WEXITSTATUS has return code	no	yes
user terminates process with Ctrl-C	WIFSIGNALED	WTERMSIG equals SIGINT	no	yes
user terminates process with kill	WIFSIGNALED	WTERMSIG equals SIGTERM	no	yes
user terminates process with kill -9	WIFSIGNALED	WTERMSIG equals SIGKILL	no	yes
process has been terminated (general case)	WIFSIGNALED	WTERMSIG equals signal number	no	yes

Additional information can be found in the GNU C library manual, available at `http://www.gnu.org/s/libc/manual/html_node/index.html`. Read, in particular, the sections on Signal Handling and Job Control.

VIRGINIA TECH™

Project Overview

Requirements and Grading

1. Basic Functionality - 50 pts
    a. Start foreground and background jobs
    b. Built-in commands : ‘jobs’, ‘fg’, ‘bg’, ‘kill’, ‘stop’
    c. Signal Handling (SIGINT, SIGTSTP, SIGCHLD)
2. Advanced Functionality - 50 pts
    a. I/O Pipes
    b. I/O Redirection
    c. Running programs requiring exclusive terminal access (ex: vim)
3. Two Extra Built-ins - 20 pts
    a. One low effort
    b. One high effort
4. Version Control (git) - 10 pts
    a. At least 3 commits per partner
5. Documentation - 10 pts

Total : 140 points

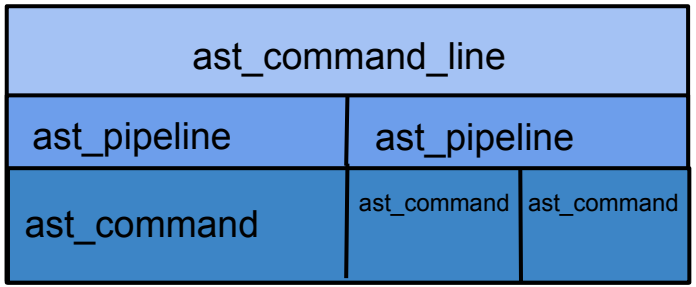
Before You Start Coding ….

- Take time to read over, understand, and comment the starter code
- Read the provided lecture material and Chapter 8 in the textbook
- Watch the P1 help session recording
- Understand Exercise 1
  - fork() / exec() model
  - Piping : pipe(), dup2(), close()
- Check out Dr. Back’s example shell
  - Located at **~cs3214/bin/cush-gback** in rlogin
  - Can be useful for comparing outputs with your shell

Base Code

- Already includes a parser!
- Parser spits out hierarchical data structures

Data Structures



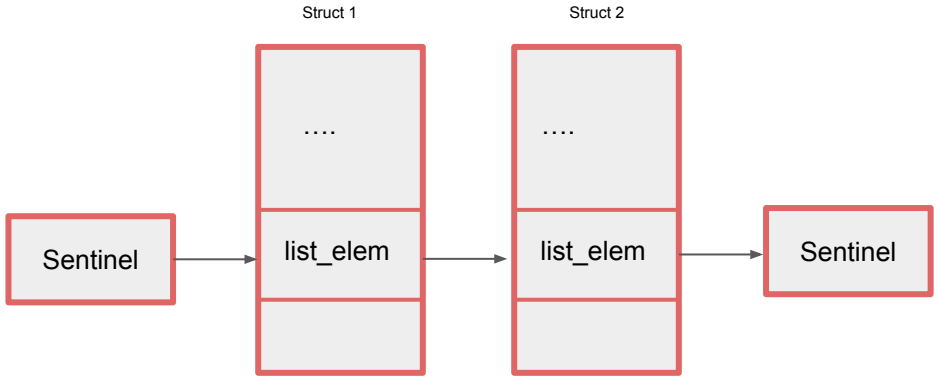
List Data Structure

- You’re also provided with a linked list data structure
  - Check out list.h and list.c
- You’ll be using this list throughout the semester
- Read through list.h before using it

“Data contains node” vs “Node points to data”

Your Linked List

```
struct list_elem {
        struct list_elem * prev;
        struct list_elem * next;
}
```

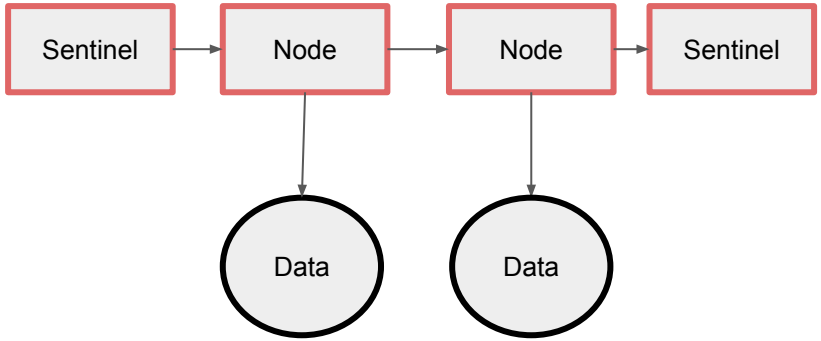


Retrieve data from a struct list_elem by using the **list_entry macro**:

```
struct ast_command * cmd = list_entry(e, struct ast_command, elem);
```

A Regular Linked List

```
class listnode<T> {
        T data;
        listnode<T> next;
}
```



An example of an element in a list

```
struct ast_pipeline {
    struct list/* <ast_command> */ commands;    /* List of commands */
    char *iored_input;       /* If non-NULL, first command should read from
                                file 'iored_input' */
    char *iored_output;      /* If non-NULL, last command should write to
                                file 'iored_output' */
    bool append_to_output;   /* True if user typed >> to append */
    bool bg_job;             /* True if user entered & */
    struct list_elem elem;   /* Link element. */
};
```


Adding `list_elem` to a structure allows this structure to be added to a list

List Pitfalls

- **Don't:**
  - Use the same list_elem for multiple lists
  - Edit an element while iterating
    - Naive loop to remove elements in a list will fail!
  - Forget to list_init()

BAD IDEA :(

```
// invalid example
for (list_elem in list)
{

      // do stuff

      if  (someCondition)
      {
            list_remove(currElem);
      }
}
```

```
// valid example: deallocates a pipeline struct and any commands stored in it while iterating
void ast_pipeline_free(struct ast_pipeline *pipe)
{
    for (struct list_elem * e = list_begin(&pipe->commands); e != list_end(&pipe->commands); ) {
        struct ast_command *cmd = list_entry(e, struct ast_command, elem);
        e = list_remove(e); //Acts as the iterator; stores next element into e
        ast_command_free(cmd);
    }
    free(pipe);
} // make sure to remove an ast_pipeline from a list before adding it to another!
// bottom line with lists? ALWAYS TEST
```

Utility Functions (Strongly Recommended)

- Signal Support (signal_support.c / .h)
  - signal_block()
  - signal_unblock()
  - singal_set_handler()
- Terminal State Management (termstate_management.c / .h)
  - termstate_init()
  - termstate_give_terminal_to()
  - termstate_give_terminal_back_to_shell()
  - termstate_get_current_terminal_owner()
  - termstate_save()
  - termstate_restore()

Additional Built-ins and extensions

- Your shell must contain two extra built-ins / functionality extensions
  - One high effort and one low effort (bolded is low-effort)
- Ideas include:
  - ***Customizable Prompt***
  - ***Setting/unsetting env vars***
  - ***Implementing the 'cd' built-in***
  - Glob expansion (e.g., *.c)
  - Timing commands (ex. time)
  - Alias support
  - Shell Variables
  - Directory Stack
  - Command-line history
  - Backquote substitution
  - Smart command-line completion
  - Embedded Apps
- Unix Philosophy - implement only functionality that is not already supported using Unix commands. If you have an idea not shown on the list or have any doubts please ask us

Testing / Submission

- Please submit code that compiles!
- Test the driver before submitting, don’t just run tests individually
- Use GDB to fix any errors (compile with -g flag!)
- When grading, tests will be ran 3-5 times. If you crash a single time, it’s considered failing

Test Driver

- The driver reads from .tst file that describes a test suite (ex. basic.tst)
  - Ex: basic.tst contains a series of test scripts that it will run from the folder /tests/basic

```
cd src/
../tests/stdriver.py [options]
```

*- stdriver.py also available at ~cs3214/bin/stdriver.py

Options:

- -b : basic tests (processes, built-ins, signals)
- -a : advanced tests (I/O Piping, I/O Redirection, exclusive terminal access)
- -h : list all the options

Additional Tests

- You are required to write tests for your two extra built-ins
  - Create a .tst file in ‘tests’ and create a directory that will store your test scripts
- Inside <custom>.tst file:

```
= <custom> Tests
pts <custom>/<test_name>.py
pts <custom>/<test_name>.py
…
```

```
= Milestone Tests
1 basic/foreground.py
1 basic/cmdfail_and_exit_test.py
```

- The driver checks number of total points (pts) to use for a test. Since this is just your own custom tests you can put an arbitrary number here

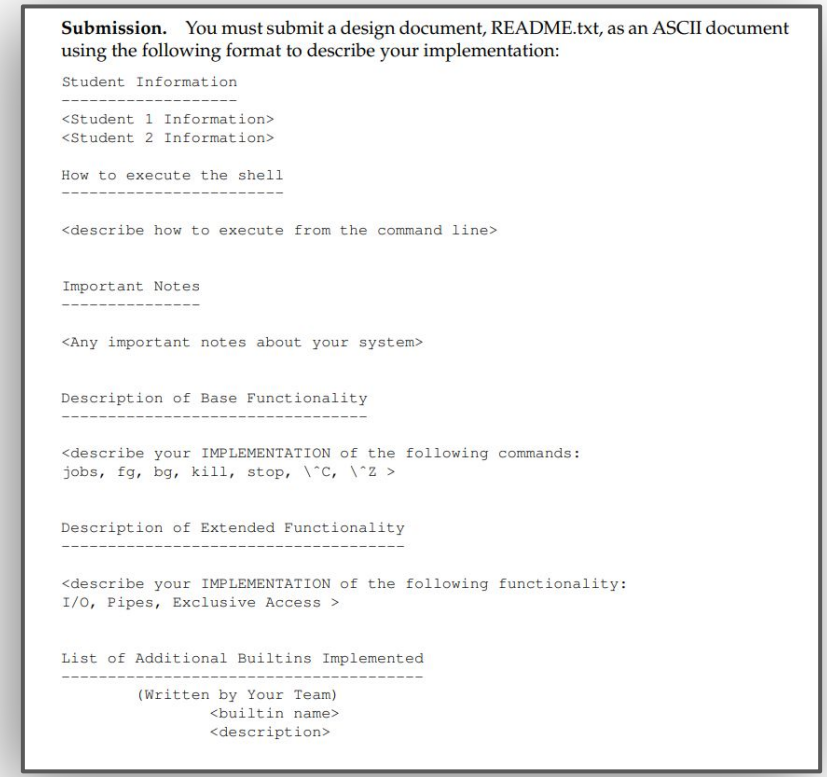
Additional Tests (Part 2)

- Make sure your custom.tst file is of type “ASCII text”

- If it includes Windows terminators (CR, CRLF, etc.), see **man tr**
- We want \n, not \r\n

Design Document

- When you submit you must include a README.txt describing your implementation of P1
- Explain the custom built-ins created and approach taken to develop them.
- TAs will assign credit only for the functionality for which test cases and documentation exist



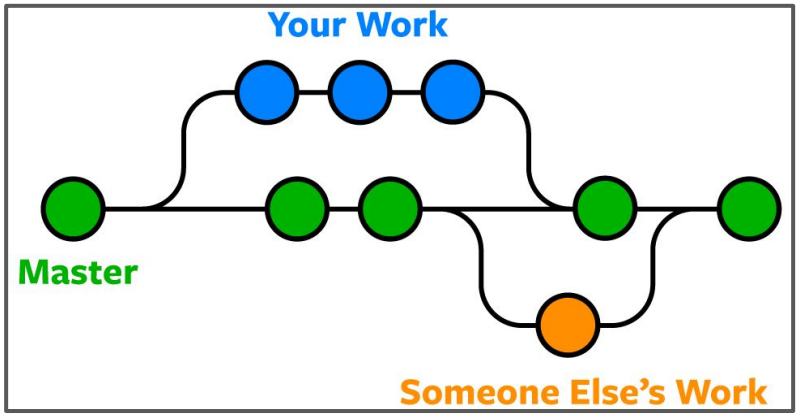
Submission. You must submit a design document, README.txt, as an ASCII document using the following format to describe your implementation:

```
Student Information
-------------------
<Student 1 Information>
<Student 2 Information>

How to execute the shell
------------------------

<describe how to execute from the command line>


Important Notes
---------------

<Any important notes about your system>


Description of Base Functionality
---------------------------------

<describe your IMPLEMENTATION of the following commands:
jobs, fg, bg, kill, stop, \^C, \^Z >


Description of Extended Functionality
-------------------------------------

<describe your IMPLEMENTATION of the following functionality:
I/O, Pipes, Exclusive Access >


List of Additional Builtins Implemented
---------------------------------------
        (Written by Your Team)
                <builtin name>
                <description>
```

Version Control

Version Control

- You will be using Git for managing your source code
- Why?
  - Organizes your code
  - Keeps track of features
  - Allows collaborators to work freely without messing up other existing code
  - Back-ups whenever something goes wrong



Basic Git Commands

- Stage file for commit:

```
$ git add <file_name>
```

- Commit files:

```
$ git commit -m ‘Add a description here’
```

- Push changes to remote (note: always pull before push!)

```
$ git push [origin <branch_name>]
```

Basic Git Commands

- Fetch changes from remote:

```
$ git pull
```

- Check status:

```
$ git status
```

- Revert to the previous commit:

```
$ git reset [--hard]
```

Basic Git Commands

- Create a new branch from the current branch:

```
$ git checkout –b <new_branch_name>
```

- Switch to another branch:

```
$ git checkout <branch_name>
```

- Merge a branch into the current branch

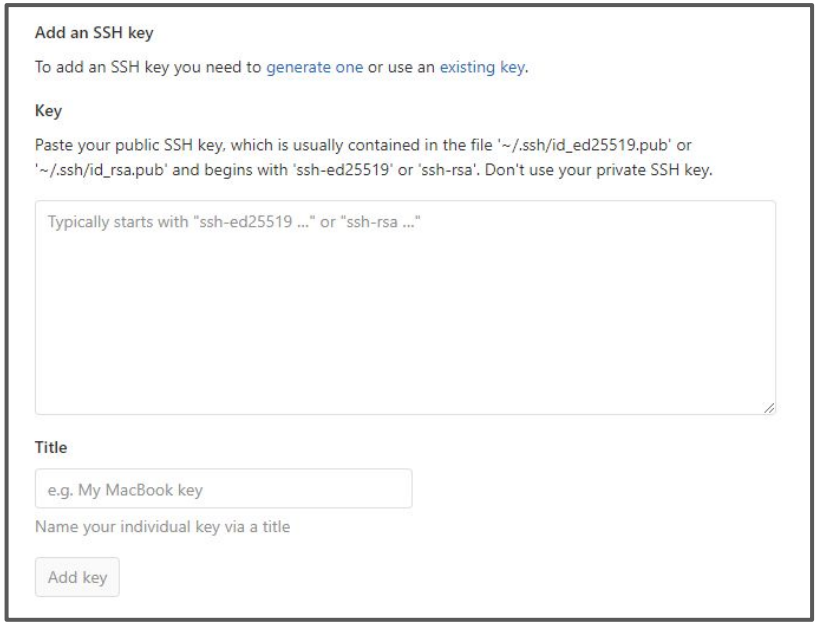
```
$ git merge <branch_name>
```

Setup Git Access

- You'll need an SSH Key to get access to projects at git.cs.vt.edu
- If you don't already have a key…
  - Create a new key:

```
$ ssh-keygen -t rsa -b 4096 -C "email@vt.edu" \

-f ~/.ssh/id_rsa
```

  - Add Key to https://git.cs.vt.edu/profile/keys
    - You will paste public key here ---------->



Verify Git Access

- Verify you have access
- The first time you connect you will be asked to verify the host, just answer ‘Yes’ to continue

```
11 spencetk@linden  ~ >ssh git@git.cs.vt.edu
```

```
PTY allocation request failed on channel 0
Welcome to GitLab, @spencetk!      ← Your pid should be displayed here
Connection to git.cs.vt.edu closed.
```

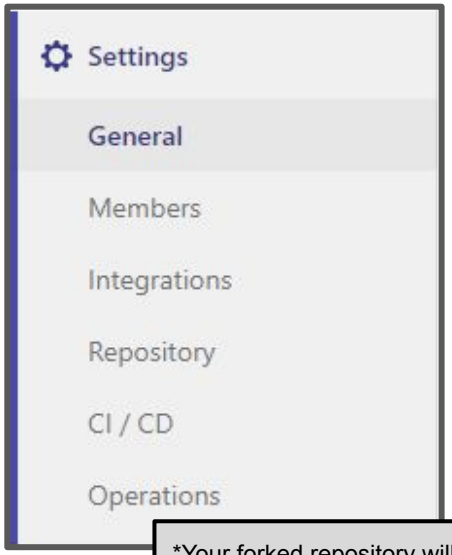
- You can get in-depth explanations here:
  - Generate a key
  - Use an existing key

GitLab Project Setup

1. One member will fork the base repository:
   - https://git.cs.vt.edu/cs3214-staff/cs3214-cush
2. Invite partner to collaborate
   - Go to Settings > Members to add them
   - Check partner role permissions too
3. Both members will clone the forked repository on their machines:

```
$ git clone <your git repo url>.git
```

→ `cs3214-cush`



*Your forked repository will have a navigation menu on the left side. Click under Settings to add members and set repo to private

IMPORTANT: Set forked repository to **private**

Go to Settings > General > Visibility, project features, permissions

The GNU Project Debugger

Starting GDB

- Invoke GDB with a program and arguments:

```
$ gdb --args program arg1 arg2
```

- Better alternative:

```
(gdb) run arg1 arg2
```

- Must be compiled with debug symbols, -g

Breakpoints

- Set a breakpoint

```
(gdb) b <func_name>     OR
(gdb) b <line_number>
```

- Set a conditional breakpoint:

```
(gdb) b <func_name> if <condition>
```

- Ignore breakpoint #1 100 times

```
(gdb) ignore 1 100
```

- Show # of times breakpoint was hit

```
(gdb) info b
```

Backtrace and Frames

- Show backtrace:

```
(gdb) backtrace
```

- Show frame:
  - After selecting frame, you can print all variables declared in that function call

```
(gdb) frame <num>
```

Follow-Fork-Mode

- Which process to follow after a fork (parent / child):

```
(gdb) set follow-fork-mode <mode>
```

  - ‘parent’ = ignore child process and continue debugging the parent
  - ‘child’ = begin debugging the child process when fork() is called

- Retaining debugger control after fork:
  - After a fork, specify whether to freeze the child or allow it to run (this may make it difficult to find race conditions)

```
(gdb) set detach-on-fork <mode>
```

Light reading: https://visualgdb.com/gdbreference/commands/set_follow-fork-mode

Layout Source

- Show source code lines while debugging
- Far superior alternative to ‘list’
- Toggle with Ctrl-X+A

```
(gdb) layout src
```

VIRGINIA TECH

Advice

How Can I Not Fail Systems?

- Utilize your class resources
- Manage your time wisely
- Understand your tools
- Get along with your partner
- Break down the problem
- Understand the concepts

Advice

- **START EARLY**
- Create a roadmap before starting projects
- Utilize TAs
  - Come with questions prepared, try to figure out what the problem is first
  - **Be organized and have clean code** - the cleaner it is, the faster we can help!
  - **Run valgrind and try debugging with GDB before consulting us**
  - Discord, Zoom, Class Forum
- Understand the Exercises
- Use valgrind! This can isolate many bugs
- Become an expert at the debugger
- Find what works best for communicating with your partner
  - In-Person Meetings, Discord, Zoom, etc.

Sources

- Referred to previous help session slides created by previous UTA's Kent McDonough, Connor Shugg, Joe D'Anna, Chris Cerne, Justin Vita, Sam Lightfoot, and Alex Kyer since the Spring 2021 Semester
- Spencer Keefer created the revised slides

VIRGINIA TECH™

Thanks for attending!

Questions?