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CSCI 4061 Project 1: Going Commando

- **Due: 11:59pm Sat 6/27/2020**
- *Approximately 10.0% of total grade*
- Submit to **Gradescope** (*Submission will open soon*)
- Projects may be done in groups of 1 or 2. Indicate groups in the `GROUP-MEMBERS.txt` file **and on Gradescope when submitting**
- No additional collaboration with other students is allowed. Seek help from course staff if you get stuck for too long.

CODE DISTRIBUTION: p1-code.zip

CHANGELOG:

Thu 18 Jun 2020 10:48:27 AM CDT
The weight for the project in the overall grading scheme for the course was was stated incorrectly; it has been corrected be 10.0% as there will be 3 projects each worth 10% for a total of 30% of the overall course grade.

Table of Contents

1 Introduction: A Simple Shell

Command line shells allow one to access the capabilities of a computer using simple, interactive means. Type the name of a program and the shell will bring it into being, run it, and show output. Familiarizing yourself with the basics of shell job management will make work on terminal-only machines much more palatable.

The goal of this project is to write a simple, quasi-command line shell called `commando`. The shell will be less functional in many ways from standard shells like `bash` (default on most Linux machines), but will have some properties that distinguish it such as the ability to recall output for any child

process. Like most interesting projects, `commando` uses a variety of system calls together to accomplish its overall purpose. Most of these will be individually discussed in lecture but the interactions between them is what inspires real danger and romance.

Completing `commando` will educate an implementer on the following systems programming topics.

- **Basic C Memory Discipline**: A variety of strings and structs are allocated and de-allocated during execution which will require attention to detail and judicious use of memory tools like Valgrind.
- **fork() and exec()**: Text entered that is not recognized as a built-in is treated as an command (external program) to be executed. This spawns a child process which executes the new program.
- **Pipes, dup2(), read():** Rather than immediately print child output to the screen, child output is redirected into pipes and then retrieved on request by commando.
- **wait() and waitpid(), blocking and nonblocking:** Child processes usually take a while to finish so the shell will check on their status every so often

2 Download Code and Setup

As in labs, download the code pack linked at the top of the page. Unzip this which will create a folder and create your files in that folder.

File	State	Notes
`GROUP_MEMBERS.txt`	Edit	Fill in names of group members to indicate partnerships
`Makefile`	CREATE	Build project, run tests
`commando.c`	CREATE	main() function for commando interactive shell
`cmd.c`	CREATE	Functions to deal with the cmd_t struct
`cmdcol.c`	CREATE	Functions to deal with the $cmdcol_t$ struct
`commando.h`	Provided	Header file which contains required structs, defines, and prototypes
`util.c`	Provided	Utility methods for creating argv[] arrays and pausing execution
`test_functions.c`	Testing	Tests specific C function calls
`test_utils.c`	Testing	Testing utility functions
`test_utils.h`	Testing	Testing utility header
`standardize_pids`	Testing	Converts commando output to standard format to allow testing
`test_commando.sh`	Testing	Tests commando executable
`test_commando_data.sh`	Testing	Data for commando tests
`test-results/`	Testing	Directory containing temporary files for testing, removed via make `clean-tests`
`test-data/`	Test Data	Directory containing below files used in testing
`3K.txt`	Test Data	Large-ish file with numbers
`gettysburg.txt`	Test Data	Gettysburg address
`print_args.c`	Test Data	Program that prints command line arguments
`quote.txt`	Test Data	Quote from Edsger Dijkstra
`README`	Test Data	Description of directory
`sleep_print.c`	Test Data	Program which sleeps then prints
`stuff/`	Test Data	Subdirectory with oddities for doing listings
`table.sh`	Test Data	Shell scrip which prints table of squares/cubes

3 Opening Demo

The best way to get a sense of any program is to see how it behaves. In the below demonstration, `commando` is first built then started. Input is entered in `commando` after its prompt on lines that look like

```
@> commands here
```

Other lines contain output from the program. To the right of the demo after the # symbol are comments on what is happening.

```
lila  [a1-code]% make                                          # Build commando
gcc -Wall -g -c commando.c
gcc -Wall -g -c cmd.c
gcc -Wall -g -c cmdcol.c
gcc -Wall -g -c util.c
gcc -Wall -g -o commando commando.o cmd.o cmdcol.o util.o

lila  [a1-code]% commando                                      # Start commando, prompt is @>

@> help                                                        # Show available built-ins
COMMANDO COMMANDS
help               : show this message
exit               : exit the program
list               : list all jobs that have been started giving information on each
pause nanos secs   : pause for the given number of nanseconds and seconds
output-for int     : print the output for given job number
output-all         : print output for all jobs
wait-for int       : wait until the given job number finishes
wait-all           : wait for all jobs to finish
command arg1 ...   : non-built-in is run as a job              # Runs a command as a child process
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> ls test-data/                                               # Run ls on test-data/ directory
@> list                                                        # ls now present as a running job
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #26532      -1        RUN   -1 ls test-data/
@!!! ls[#26532]: EXIT(0)                                       # @!!! is an alert: job finished
@> list                                                        # list again: see exit and output size
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #26532       0    EXIT(0)  145 ls test-data/
@> output-for 0                                                # show output for job 0 (ls)
@<<< Output for ls[#26532] (145 bytes):
----------------------------------------
3K.txt                                                         # actual output of ls
actual.tmp
diff.tmp
expect.tmp
gettysburg.txt
print_args
print_args.c
quote.txt
README
sleep_print.c
stuff
table.sh
temp.tmp
valgrind.tmp
----------------------------------------
@> ls -l test-data/                                            # run another child job
@> list                                                        # now have two jobs
JOB  #PID      STAT   STR_STAT OUTB COMMAND                   # one finished one running
0    #26532       0    EXIT(0)  145 ls test-data/
1    #26908      -1        RUN   -1 ls -l test-data/
@!!! ls[#26908]: EXIT(0)                                       # alert: job finished
@> list                                                        # listing shows completed jobs
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #26532       0    EXIT(0)  145 ls test-data/
1    #26908       0    EXIT(0)  855 ls -l test-data/         # output should be larger due to -l option
@> output-for 1                                                # show output for job 1
@<<< Output for ls[#26908] (855 bytes):
----------------------------------------
total 204
-rw-r----- 1 kauffman kauffman 13893 Sep 27  2017 3K.txt
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 actual.tmp
-rw-rw---- 1 kauffman kauffman 30921 Feb  5 12:13 diff.tmp
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 expect.tmp
-rw-rw---- 1 kauffman kauffman  1511 Sep 18  2017 gettysburg.txt
-rwxrwx--- 1 kauffman kauffman 16576 Feb  5 12:14 print_args
-rw-rw---- 1 kauffman kauffman   218 Sep 11  2017 print_args.c
```

```
-rw-rw---- 1 kauffman kauffman   125 Sep 18  2017 quote.txt
-rw-rw---- 1 kauffman kauffman   298 Feb  1 11:13 README
-rw-rw---- 1 kauffman kauffman   346 Sep 26  2017 sleep_print.c
drwxrwx--- 2 kauffman kauffman  4096 Feb  4 21:17 stuff
-rwxrwx--- 1 kauffman kauffman   427 Sep 26  2017 table.sh
-rw-rw---- 1 kauffman kauffman 14926 Feb  5 12:13 temp.tmp
-rw-rw---- 1 kauffman kauffman  1656 Feb  5 12:14 valgrind.tmp
----------------------------------------
@> output-for 0                                              # output for job 0, permanently available
@<<< Output for ls[#26532] (145 bytes):                      # despite having run othe jobs
----------------------------------------
3K.txt
actual.tmp
diff.tmp
expect.tmp
gettysburg.txt
print_args
print_args.c
quote.txt
README
sleep_print.c
stuff
table.sh
temp.tmp
valgrind.tmp
----------------------------------------
@> grep Lincoln test-data/gettysburg.txt                     # start another job with grep
@>                                                           # press enter again, no input at prompt
@!!! grep[#27113]: EXIT(0)                                   # alert: job finished
@> list                                                      # listing shows all three jobs
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #26532       0    EXIT(0)  145 ls test-data/
1    #26908       0    EXIT(0)  855 ls -l test-data/
2    #27113       0    EXIT(0)   16 grep Lincoln test-data/gettysburg.txt
@> output-all                                                # output all jobs in the listing
@<<< Output for ls[#26532] (145 bytes):
----------------------------------------
3K.txt                                                       # output for job 1
actual.tmp
diff.tmp
expect.tmp
gettysburg.txt
print_args
print_args.c
quote.txt
README
sleep_print.c
stuff
table.sh
temp.tmp
valgrind.tmp
----------------------------------------
@<<< Output for ls[#26908] (855 bytes):
----------------------------------------
total 204                                                    # output for job 2
-rw-r----- 1 kauffman kauffman 13893 Sep 27  2017 3K.txt
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 actual.tmp
-rw-rw---- 1 kauffman kauffman 30921 Feb  5 12:13 diff.tmp
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 expect.tmp
-rw-rw---- 1 kauffman kauffman  1511 Sep 18  2017 gettysburg.txt
-rwxrwx--- 1 kauffman kauffman 16576 Feb  5 12:14 print_args
-rw-rw---- 1 kauffman kauffman   218 Sep 11  2017 print_args.c
-rw-rw---- 1 kauffman kauffman   125 Sep 18  2017 quote.txt
-rw-rw---- 1 kauffman kauffman   298 Feb  1 11:13 README
-rw-rw---- 1 kauffman kauffman   346 Sep 26  2017 sleep_print.c
drwxrwx--- 2 kauffman kauffman  4096 Feb  4 21:17 stuff
-rwxrwx--- 1 kauffman kauffman   427 Sep 26  2017 table.sh
-rw-rw---- 1 kauffman kauffman 14926 Feb  5 12:13 temp.tmp
-rw-rw---- 1 kauffman kauffman  1656 Feb  5 12:14 valgrind.tmp
----------------------------------------
@<<< Output for grep[#27113] (16 bytes):
----------------------------------------
Abraham Lincoln                                              # output for job 3
----------------------------------------
```

```
@> grep Abradolf test-data/gettysburg.txt                    # run one more command
@>
@!!! grep[#27514]: EXIT(1)                                   # grep exit code 1 when string not found
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #26532       0    EXIT(0)  145 ls test-data/
1    #26908       0    EXIT(0)  855 ls -l test-data/
2    #27113       0    EXIT(0)   16 grep Lincoln test-data/gettysburg.txt
3    #27514       1    EXIT(1)    0 grep Abradolf test-data/gettysburg.txt
@> output-for 3                                              # show output
@<<< Output for grep[#27514] (0 bytes):                      # not much to see
----------------------------------------
----------------------------------------
@> exit                                                      # exit commando
lila [a1-code]%                                              # returns to normal shell prompt
```

Things to Note

- The child processes (jobs) that `commando` starts do not show any output by default and run concurrently with the main process which gives back the `@>` prompt immediately. This is different from a normal shell such as `bash` which starts jobs in the foreground, shows their output immediately, and will wait until a job finishes before showing the command prompt for additional input.
- The output for all jobs is saved by `commando` and can be recalled at any time using the `output-for int` built-in command.
- Not all of the built-in commands are shown in the demo but each will be discussed in later sections.
- It should be clear that `commando` is not a full shell (no signals, built-in scripting, or pipes), but it is a mid-sized project which will take some organization. Luckily, this document prescribes a simple architecture to make the coding manageable.

4 Overall Architecture

4.1 What Needs to be Implemented

`commando` is divided into the following parts which must be implemented to complete the project. Each part corresponds to a single C file.

`cmd_t` command data structure

The `cmd_t` type is defined in the `commando` header file. It is intended to encapsulate the state of a running or completed child process. Fields within it describe aspects such as the name of the command being run, arguments to it, its exit status, a pipe for communication with `commando` process, and an output buffer.

The functions in `cmd.c` manipulate the data structure. Basic functions for allocating and de-allocating it are present as well as functions to start a process running with the program and arguments contained with a `cmd_t` and update the data structure based on the state of the job.

Within `commando`, instances of `cmd_t` will be created each time a job is run and commands such as `output-for` and `wait-for` will need to access and alter the fields of `cmd_t` instances.

`cmdcol_t` collection of `cmd_t`

It should be clear from the demos that `commando` tracks multiple child processes / jobs. This multiplicity is simplified somewhat with a data structure to add and iterate through all child jobs. This is the role of `cmdcol_t`: it's primary fields are an array of `cmd_t` instances and a size indicating how many are present. The array is fixed size so there is a maximum number of child processes which can be handled defined in the `commando.h` header with `MAX_CMDS`.

The functions in `cmdcol.c` do basic manipulation such as adding, producing output for all commands and updating the state of all commands. There are no required allocation or de-allocation routines but they may be added if they seem useful.

`commando main()` function

The file `commando.c` will contain a `main()` function which loops over input provided by the user either interactively or via standard input as is done in the automated tests. After setup, the program executes an infinite loop until no more input is available.

- Print the `@>` prompt and parse input
- Determine what action to take: built-in or start a job
- Check for updates to the state of jobs and print alerts for changes

Some input may cause new `cmd_t` instances to be allocated for child processes. These are added into a `cmdcol_t` instance for tracking.

4.2 What's Already Done

Examine the provided files closely as they give some insight into what work is already done.

- `commando.h` can be included in most files to make programs aware of the data structures and required functions. It contains documentation of the central data structures.

- `util.c` contains a few functions that are tricky but not central to our study of systems programming. To save time, these are provided.
  - `parse_into_tokens()` is useful create `argv[]` arrays in `cmd_t` structures. It is similar to functions in some textbooks and makes use of the ever-dangerous `strtok()` function.
  - `pause_for()` causes a program to *sleep* for a period of time. This allows `commando` to suspend execution for a while so that child processes can finish.

4.3 Create a Makefile

Create a `Makefile` which has at least the following targets.

- `make` and `make commando` : builds the `commando` application, this should be the default target or be included with the default target.
- `make clean` will remove all compiled `.o` files and programs including `commando`

- Test Targets: **at the END of your Makefile** add the directive

```
include test_Makefile
```

  which will enable testing targets described in the Automatic Testing Section.

5 `cmd_t` Data Type

Information about a child process / job / command in `commando` is stored in the `cmd_t` struct which has the following form from `commando.h`.

```
// cmd_t: struct to represent a running command/child process.
typedef struct {
  char   name[NAME_MAX+1];         // name of command like "ls" or "gcc"
  char  *argv[ARG_MAX+1];          // argv for running child, NULL terminated
  pid_t  pid;                      // PID of child
  int    out_pipe[2];              // pipe for child output
  int    finished;                 // 1 if child process finished, 0 otherwise
  int    status;                   // return value of child, -1 if not finished
  char   str_status[STATUS_LEN+1]; // describes child status such as RUN or EXIT(..)
  void  *output;                   // saved output from child, NULL initially
  int    output_size;              // number of bytes in output
} cmd_t;
```

This section lists the functions that are required to be implemented for to manipulate `cmd_t`'s and how they should behave. Additional functions and fields may be added if implements see good cause for it but the reference implementation includes only those listed.

5.1 Required Functions

```
// cmd.c: functions related the cmd_t struct abstracting a
// command. Most functions maninpulate cmd_t structs.

cmd_t *cmd_new(char *argv[]);
// Allocates a new cmd_t with the given argv[] array. Makes string
// copies of each of the strings contained within argv[] using
// strdup() as they likely come from a source that will be
// altered. Ensures that cmd->argv[] is ended with NULL. Sets the name
// field to be the argv[0]. Sets finished to 0 (not finished yet). Set
// str_status to be "INIT" using snprintf(). Initializes the remaining
// fields to obvious default values such as -1s, and NULLs.

void cmd_free(cmd_t *cmd);
// Deallocates a cmd structure. Deallocates the strings in the argv[]
// array. Also deallocats the output buffer if it is not
// NULL. Finally, deallocates cmd itself.

void cmd_start(cmd_t *cmd);
// Forks a process and starts executes command in cmd in the process.
// Changes the str_status field to "RUN" using snprintf().  Creates a
// pipe for out_pipe to capture standard output.  In the parent
// process, ensures that the pid field is set to the child PID. In the
// child process, directs standard output to the pipe using the dup2()
// command. For both parent and child, ensures that unused file
// descriptors for the pipe are closed (write in the parent, read in
// the child).
```

```
void cmd_update_state(cmd_t *cmd, int block);
// If the finished flag is 1, does nothing. Otherwise, updates the
// state of cmd.  Uses waitpid() and the pid field of command to wait
// selectively for the given process. Passes block (one of DOBLOCK or
// NOBLOCK) to waitpid() to cause either non-blocking or blocking
// waits.  Uses the macro WIFEXITED to check the returned status for
// whether the command has exited. If so, sets the finished field to 1
// and sets the cmd->status field to the exit status of the cmd using
// the WEXITSTATUS macro. Calls cmd_fetch_output() to fill up the
// output buffer for later printing.
//
// When a command finishes (the first time), prints a status update
// message of the form
//
// @!!! ls[#17331]: EXIT(0)
//
// which includes the command name, PID, and exit status.

char *read_all(int fd, int *nread);
// Reads all input from the open file descriptor fd. Stores the
// results in a dynamically allocated buffer which may need to grow as
// more data is read.  Uses an efficient growth scheme such as
// doubling the size of the buffer when additional space is
// needed. Uses realloc() for resizing.  When no data is left in fd,
// sets the integer pointed to by nread to the number of bytes read
// and return a pointer to the allocated buffer. Ensures the return
// string is null-terminated. Does not call close() on the fd as this
// is done elsewhere.

void cmd_fetch_output(cmd_t *cmd);
// If cmd->finished is zero, prints an error message with the format
//
// ls[#12341] not finished yet
//
// Otherwise retrieves output from the cmd->out_pipe and fills
// cmd->output setting cmd->output_size to number of bytes in
// output. Makes use of read_all() to efficiently capture
// output. Closes the pipe associated with the command after reading
// all input.

void cmd_print_output(cmd_t *cmd);
// Prints the output of the cmd contained in the output field if it is
// non-null. Prints the error message
//
// ls[#17251] : output not ready
//
// if output is NULL. The message includes the command name and PID.
```

5.2 Allocation and Freeing

Basic allocation of a `cmd_t` is done with `cmd_new()` which takes an array of string arguments. Below are some implementation notes on this process.

1. The first and most obvious step is to use `malloc()` to allocate a hunk of memory that is `sizeof(cmd_t)`.
2. Make sure to copy the strings in the argument array as these are likely to be overwritten. The most common place where this will happen is in the `main()` loop of `commando`. In that setting, a fixed character buffer is used to read a line of text and `parse_into_tokens()` from `util.c` is used to produce the `argv[]` array. The function find pointers within the buffer for each element of `argv[]`. The next input a user enters will overwrite the text clobbering the strings unless `cmd_new()` makes copies for the `cmd_t`. The `strdup()` function makes copying strings relatively easy.
3. Ensure that the `cmd->argv[]` array is `NULL` terminated this array will likely be passed to an `exec()` family function which requires null termination.
4. While it is possible that some programs can be run with an `argv[0]` that is not equal to the program name, this is not allowed in `commando` so the `cmd->name` field is always identical to `cmd->argv[0]`.
5. To get a string into character arrays like `cmd->str_status`, the `snprintf()` method is useful: it "prints" like `printf()` but into a character array rather than onto the screen.

5.3 Starting a `cmd_t`

The real action associated with `cmd_t` is "starting" them which will cause a child process to be forked. Several things need careful attention during this process.

1. Child commands should NOT print their output to the screen. This means they need someplace to put their output which an be retrieved by the parent. A **pipe** is an excellent choice here: output is written there by the child and read from the pipe later by the parent when it is needed.
2. Before doing anything else, `cmd_start()` should create a pipe associated with the `cmd->out_pipe` field. This way both parent and child processes will have access to work with the pipe.
3. Ensure that `cmd->str_status` changes to `RUN`.
4. Fork a new process and capture its pid in the `cmd->pid` field. Use the different return values of `fork()` to distinguish parent from child process.
5. The child process will need to use `dup2()` to alter its standard output to write instead to the write to `cmd->out_pipe[PWRITE]`. This will prevent output for the child process from going to the screen.
6. Ensure that the parent closes the write end of the pipe and child closes the read end of the pipe as they only use one end apiece.
7. The child should call `execvp()` with the name of the command and `argv[]` array stored in the passed `cmd`. This should launch a new program with output that is directed into the pipe set up above.

5.4 Checking for Updated State

After a `cmd_t` has `cmd_start()` called on it, there should be a child process executing the associated command; this child process should have its PID stored in the `cmd_t`. Eventually the child will terminate. Whenever `cmd_update_state(cmd,block)` is called by the `commando` process, the child process associated with it is checked for termination. The primary means to do this is with the `waitpid()` system call. Below are notes on how to go about this function.

1. Each `cmd_t` has a `finished` field and when 1, the command has already finished so no further state changes can occur.
2. Make use of `waitpid()` to check a child. This function needs a PID which can be gotten from a `cmd_t`, a status integer and options instructing it on whether to block or not.
3. Blocking means that the calling process, likely `commando` will pause execution until the child is done. The constant `DOBLOCK` is defined in `commando.h` and can be used to trigger this if passed as the 3rd arg to `waitpid()`.
4. Non-blocking waits mean the caller gets control back immediately regardless of whether a child process is finished or not. This is more of a "check on the child" call than a proper wait. This behavior can be triggered by passing `NOBLOCK` as the 3rd argument to `waitpid()`.
5. Don't make use of `DOBLOCK` and `NOBLOCK` within `cmd_update_state()`. Instead, know that the argument `block` will be one of these.
6. Regardless of whether blocking or non-blocking waits are done, the return value of `waitpid()` is either
    - -1 on an error in which case commando should exit with non-zero status (not tested)
    - 0 if the requested child has no status change. This means there is nothing left to do in `cmd_update_state()`
    - The pid of the child indicating that there is a state change
7. If a state change has occurred, it can be dissected using a series of macros in the manual entry for `wait()` and `waitpid()`. The most important of these is the `WIFEXITED(status)` macro which is called on the status integer passed to `waitpid()`.
8. If the `WIFEXITED(status)` evaluate to nonzero, the child process has exited. Several actions need to take place at this point.
    - Retrieve its return code via a call to `WEXITSTATUS(status)` which should be assigned to the `cmd->status` field.
    - Change `cmd->str_status` to `EXIT(num)` when the process finishes.
    - Set its `finish` field to 1 which will cause later status updates to ignore the completed command.
    - Call `cmd_fetch_output()` to read the contents of the pipe into the command's output buffer.
    - Print a message like

```
@!!! ls[#17331]: EXIT(0)
```

    Note: Previously there was mention of a DOALERTS option which is not required.

9. There are a series of other macros which can be used to detect other process status changes such as signaling, stopped, and so forth but this is not required for `commando`.

5.5 Retrieving and Printing Output

When a child process completes, it will exit. If all has gone according to spec, the output for the process will be left in a pipe that is referred to in a `cmd->out_pipe` which is tracked by `commando`. The function `cmd_fetch_output()` is meant to retrieve this output for later use. The output contents will be stored in `cmd->output` which should have at least `cmd->output_size` bytes in it.

Due to the trickiness of this problem, the helper function

```
char *read_all(int fd, int *nread)
```

is used. This function reads all data from the given file descriptor and returns a buffer with the contents and sets the integer `nread` to the number of bytes in the buffer. This allows independent testing of this portion of code to isolate errors. The general process for `read_all()` is as follows.

1. Allocate some initial memory in a buffer to `read()` into from the file descriptor. For each `read()` call, limit the number of bytes read so that this buffer is not overflowed.
2. If the buffer runs out of space, call `realloc()` to get more space. This call will increase the buffer size and automatically copy data already in the buffer to a new location if required making it more handy than `malloc()` in this situation.

3. A common strategy to make buffer allocation efficient is the following. `malloc()` an initial buffer size such as 1024 bytes. When this fills up, use `realloc()` to double the current size of the buffer. Doing this in a read/resize loop will lead to sizes like 1024, 2048, 4096, etc. This balances the number of allocations versus reads done and has good amortized performance.
4. It does not matter if the buffer is not sized exacoly to the size of the output. Particularly be careful when trying to `realloc()` to a smaller size as this may fail returning a `NULL`.
5. When `read()` calls no longer give more bytes (return value of 0 or less), reading is finished. Set the integer `nread` to be the total bytes read then return the allocated buffer of data.
6. Ensure that the returned string is null-terminated. This may mean adjusting the buffer sizes in allocation a little (add 1) and then setting the character beyond the last read to be the null character as in:

```
buf[last_position] = '\0';
```

With `read_all()` in hand, the job of `cmd_fetch_output()` is relatively straight-forward.

1. A pipe is not permanent storage: unlike a file which may be read multiple times, once data is read from the pipe, it is gone. This necessitates reading the data into a memory area if the data is to be used again as is the intention here.
2. Before doing anything, check if the `cmd_t` is finished and if not, print a message of the form

```
ls[#12783] not finished yet
```

   and take no further action.

3. If the `cmd_t` is finished, use `read_all()` with `output_pipe` to extract bytes from the pipe. Make sure to read from the `PREAD` side of the pipe.
4. Associate the `cmd->output` field with the buffer returned by `read_all()` and set the `cmd->output_size` to the number of bytes read.
5. Make sure to close the pipe that was read from.

After fetching output for the command, its output can always be recalled as it is saved in the `cmd->output` field. The `cmd_print_output()` should print it on to the standard output.

1. Check that `cmd->output` is non-null; if it is `NULL`, print a message like

```
gcc[#76324] :  output not ready
```

2. Otherwise use a call to `write()` to put data on the screen. As `write()` uses file descriptors, make sure to pass `STDOUT_FILENO` along with the buffer to write and the number of bytes to write.

6 `cmdcol_t` Data Type

The intent of `cmdcol_t` is to track a collection of `cmd_t` instances and provide a few basic convenience functions for the collection. The struct definition from `commando.h` is as follows.

```
// cmdcol_t: struct for tracking multiple commands
typedef struct {
  cmd_t *cmd[MAX_CMDS];         // array of pointers to cmd_t
  int size;                     // number of cmds in the array
} cmdcol_t;
```

There is a fixed maximum on the number of children possible for the `cmdcol_t` simplifies its implementation but limits its dynamic capabilities.

This section describes the basic functionality of `cmdcol_t`.

6.1 Required Functions

```
// cmdcol.c: functions related to cmdcol_t collections of commands.

void cmdcol_add(cmdcol_t *col, cmd_t *cmd);
// Add the given cmd to the col structure. Update the cmd[] array and
// size field. Report an error if adding would cause size to exceed
```

```
// MAX_CMDS, the maximum number commands supported.

void cmdcol_print(cmdcol_t *col);
// Print all cmd elements in the given col structure.  The format of
// the table is
//
// JOB  #PID      STAT   STR_STAT OUTB COMMAND
// 0    #17434       0    EXIT(0) 2239 ls -l -a -F
// 1    #17435       0    EXIT(0) 3936 gcc --help
// 2    #17436      -1        RUN   -1 sleep 2
// 3    #17437       0    EXIT(0)  921 cat Makefile
//
// Widths of the fields and justification are as follows
//
// JOB  #PID      STAT   STR_STAT OUTB COMMAND
// 1234 #12345678 1234 1234567890 1234 Remaining
// left  left    right      right rigt left
// int   int       int     string  int string
//
// The final field should be the contents of cmd->argv[] with a space
// between each element of the array.

void cmdcol_update_state(cmdcol_t *col, int block);
// Update each cmd in col by calling cmd_update_state() which is also
// passed the block argument (either NOBLOCK or DOBLOCK)

void cmdcol_freeall(cmdcol_t *col);
// Call cmd_free() on all of the constituent cmd_t's.
```

6.2 Basic functionality

Adding a new `cmd_t` instance should be done by checking whether `size` is within the `MAX_CHILD` limit, then updating the `col->cmd` array and `col->size` fields. If not, print an error message.

The `cmdcol_print()` function should print a table of information on the `cmd_t` instances within it. Pay careful attention to the comments on formatting the table which give column widths, justification, and where to place spaces.

The `cmdcol_update_state()` and `cmdcol_freeall()` functions are just conveniences to apply the appropriate `cmd_t` functions to all constituents of the `cmdcol_t`.

7 Commando Top Level Functionalities

The `commando.c` file should tie the basic low-level pieces from `cmd.c` and `cmdcol.c` into a usable application. The only required function in `commando.c` is a `main()` which allows it to compile to an executable. Aside from that, additional helper functions in `commando.c` will likely make life easier (the did in the reference implementation).

7.1 Important Note on Buffered Output

During testing, it is desirable to get output onto the screen as soon as possible to match the output expected by the tests. This is easily done by inserting the following near the top of `main()`.

```
setvbuf(stdout, NULL, _IONBF, 0); // Turn off output buffering
```

This call disables "buffering" of standard output so that `printf()` and its ilk immediately put output onto the screen.

7.2 Main Loop

After setup, the main input loop will likely have the following basic structure.

1. Print the prompt `@>`
2. Use a call to `fgets()` to read a whole line of text from the user. The #define `MAX_LINE` limits the length of what will be read. If no input is remains, print `End of input` and break out of the loop.
3. Echo (print) given input if echoing is enabled.
4. Use a call to `parse_into_tokens()` from `util.c` to break the line up by spaces. If there are no tokens, jump to the end of the loop (the use just hit enter).
5. Examine the 0th token for built-ins like `help`, `list`, and so forth. Use `strncmp()` to determine if any match and make appropriate calls. This will be a long if/else chain of statements.

6. If no built-ins match, create a new `cmd_t` instance where the tokens are the `argv[]` for it and start it running.
7. At the end of each loop, update the state of all child processes via a call to `cmdcol_update_state()`.

7.3 Basic Help and Exiting

The `help` command should show the built-in commands required to be supported and brief descriptions of them. Here is the help message which may be copied and used in implementations.

```
@> help
COMMANDO COMMANDS
help               : show this message
exit               : exit the program
list               : list all jobs that have been started giving information on each
pause nanos secs   : pause for the given number of nanseconds and seconds
output-for int     : print the output for given job number
output-all         : print output for all jobs
wait-for int       : wait until the given job number finishes
wait-all           : wait for all jobs to finish
command arg1 ...   : non-built-in is run as a job
```

The `exit` command should immediately break out of the input loop. This also happens if there is no input remaining. After leaving the input loop and before finishing, `commando` should free all dynamically allocated memory. Most of this should be associated with a `cmdcol_t` making a call to `cmdcol_freeall()` the easiest way to get away clean.

7.4 Command Echoing

To make testing easier to understand, `commando` should support *command echoing* which means to print back to the screen what a user has typed in. If the input source is coming from somewhere else as is the case in testing, this allows the entered commands to be seen in output.

On startup, `commando` should check two places for echoing options:

- The 1th argument of `argv[]` is the string `--echo`
- The environment variable `COMMANDO_ECHO` is set to anything

If either of these are the case, echoing should be turned on. Immediately after getting input, it should be re-printed to the screen. Here are some examples.

```
lila [commando]% ./commando                          # Normal start
@> list                                              # no echoing of commands
JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> ls -a test-data/
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #32758      -1        RUN   -1 ls -a test-data/
@!!! ls[#32758]: EXIT(0)
@> exit

lila [commando]% ./commando --echo                   # echoing enabled
@> list                                              # typed command is
list                                                 # immediately printed back
JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> ls -a test-data/                                  # typed command is
ls -a test-data/                                     # echoed
@> list
list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #32760      -1        RUN   -1 ls -a test-data/
@!!! ls[#32760]: EXIT(0)
@> exit
exit

lila [commando]% export COMMANDO_ECHO=1              # enable echoing via env var
lila [commando]% ./commando
@> list                                              # type command is
list                                                 # immediately echoed
JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> exit
exit

# Input can come from other places aside from typing for which echoing
```

```
# makes the output more readily understandable

lila [commando]% printf 'list \nls test-data \nlist \nexit \n' | commando --echo
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> ls test-data/
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #385        -1        RUN   -1 ls test-data/

# Without echoing, the output is nye unreadable

lila [commando]% printf 'list \nls test-data/ \nlist \nexit \n' | commando
@> JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> @> JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #396        -1        RUN   -1 ls test-data/
@> lila [commando]%
```

7.5 Running and Listing Jobs

The main purpose of `commando` is to run jobs / child processes. If the 0th token does not match any built-in commands, it should be interpreted as a program name to be run with the remaining tokens as arguments to the program. Allocate a new `cmd_t`, add it to a `cmdcol_t`, and start it running.

Once jobs are being run, they should show up in a `list` command. `list` is simply a call to `cmdcol_print()`.

```
lila [commando]% commando
@> list                                                 # initial listing is empty
JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> gcc test-data/print_args.c                           # starting jobs
@> list                                                 # should cause them to show in the listing
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #441        -1        RUN   -1 gcc test-data/print_args.c
@!!! gcc[#441]: EXIT(0)
@> ./a.out hello goodbye                                # start another job
@> list                                                 # listing should show updated state
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #441         0    EXIT(0)    0 gcc test-data/print_args.c
1    #453        -1        RUN   -1 ./a.out hello goodbye
@!!! ./a.out[#453]: EXIT(0)
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #441         0    EXIT(0)    0 gcc test-data/print_args.c
1    #453         0    EXIT(0)   51 ./a.out hello goodbye
@> ls -F test-data
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #441         0    EXIT(0)    0 gcc test-data/print_args.c
1    #453         0    EXIT(0)   51 ./a.out hello goodbye
2    #454        -1        RUN   -1 ls -F test-data
@!!! ls[#454]: EXIT(0)
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #441         0    EXIT(0)    0 gcc test-data/print_args.c
1    #453         0    EXIT(0)   51 ./a.out hello goodbye
2    #454         0    EXIT(0)   29 ls -F test-data
@> exit
lila [commando]%
```

7.6 Output of Jobs

The output for a job is not printed to `commando` screen by default. Instead, it is stored internally as described elsewhere. To see the output of any previous command, use the `output-for int` command. This command takes job number. An easy way to convert the string token to an integer is with the `atoi()` C function. If all output for all jobs is desired, the `output-all command` can be used.

```
@> ls -l test-data/
@>
@!!! ls[#27791]: EXIT(0)
@> output-for 0
@<<< Output for ls[#27791] (855 bytes):
```

```
----------------------------------------
total 204
-rw-r----- 1 kauffman kauffman 13893 Sep 27  2017 3K.txt
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 actual.tmp
-rw-rw---- 1 kauffman kauffman 30921 Feb  5 12:13 diff.tmp
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 expect.tmp
-rw-rw---- 1 kauffman kauffman  1511 Sep 18  2017 gettysburg.txt
-rwxrwx--- 1 kauffman kauffman 16576 Feb  5 13:00 print_args
-rw-rw---- 1 kauffman kauffman   218 Sep 11  2017 print_args.c
-rw-rw---- 1 kauffman kauffman   125 Sep 18  2017 quote.txt
-rw-rw---- 1 kauffman kauffman   298 Feb  1 11:13 README
-rw-rw---- 1 kauffman kauffman   346 Sep 26  2017 sleep_print.c
drwxrwx--- 2 kauffman kauffman  4096 Feb  4 21:17 stuff
-rwxrwx--- 1 kauffman kauffman   427 Sep 26  2017 table.sh
-rw-rw---- 1 kauffman kauffman 14926 Feb  5 12:13 temp.tmp
-rw-rw---- 1 kauffman kauffman  1656 Feb  5 12:14 valgrind.tmp
----------------------------------------
@> gcc test-data/print_args.c
@>
@!!! gcc[#27864]: EXIT(0)
@> ./a.out hi bye
@>
@!!! ./a.out[#27924]: EXIT(0)
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #27791       0    EXIT(0)  855 ls -l test-data/
1    #27864       0    EXIT(0)    0 gcc test-data/print_args.c
2    #27924       0    EXIT(0)   40 ./a.out hi bye
@> output-for 1
@<<< Output for gcc[#27864] (0 bytes):
----------------------------------------
----------------------------------------
@> output-for 2
@<<< Output for ./a.out[#27924] (40 bytes):
----------------------------------------
3 args received
0: ./a.out
1: hi
2: bye
----------------------------------------
@> output-all
@<<< Output for ls[#27791] (855 bytes):
----------------------------------------
total 204
-rw-r----- 1 kauffman kauffman 13893 Sep 27  2017 3K.txt
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 actual.tmp
-rw-rw---- 1 kauffman kauffman 30921 Feb  5 12:13 diff.tmp
-rw-rw---- 1 kauffman kauffman 14834 Feb  5 12:13 expect.tmp
-rw-rw---- 1 kauffman kauffman  1511 Sep 18  2017 gettysburg.txt
-rwxrwx--- 1 kauffman kauffman 16576 Feb  5 13:00 print_args
-rw-rw---- 1 kauffman kauffman   218 Sep 11  2017 print_args.c
-rw-rw---- 1 kauffman kauffman   125 Sep 18  2017 quote.txt
-rw-rw---- 1 kauffman kauffman   298 Feb  1 11:13 README
-rw-rw---- 1 kauffman kauffman   346 Sep 26  2017 sleep_print.c
drwxrwx--- 2 kauffman kauffman  4096 Feb  4 21:17 stuff
-rwxrwx--- 1 kauffman kauffman   427 Sep 26  2017 table.sh
-rw-rw---- 1 kauffman kauffman 14926 Feb  5 12:13 temp.tmp
-rw-rw---- 1 kauffman kauffman  1656 Feb  5 12:14 valgrind.tmp
----------------------------------------
@<<< Output for gcc[#27864] (0 bytes):
----------------------------------------
----------------------------------------
@<<< Output for ./a.out[#27924] (40 bytes):
----------------------------------------
3 args received
0: ./a.out
1: hi
2: bye
----------------------------------------
@>
```

Jobs need to complete before their output is available. The prescribed order of events in the `commando` main loop dictate that even if a child process finishes, `commando` may not immediately know about it: child processes are only checked after receiving some input from the user. This means that one

may have to hit RETURN to get the calls to `cmd_update_state()` to register the change in state. Examples, some of which use the `sleep_print.c` program which causes a controllable delay before finishes.

```
@> ls test-data                                    # run an ls
@> output-for 0                                    # output hasn't been collected yet
@<<< Output for ls[#29348] (-1 bytes):
----------------------------------------
ls[#29348] : output not ready
----------------------------------------
@!!! ls[#29348]: EXIT(0)                           # now output is availble
@> output-for 0                                    # show output for 0
@<<< Output for ls[#29348] (145 bytes):
----------------------------------------
3K.txt
actual.tmp
diff.tmp
expect.tmp
gettysburg.txt
print_args
print_args.c
quote.txt
README
sleep_print.c
stuff
table.sh
temp.tmp
valgrind.tmp
----------------------------------------
@> gcc -o sleep_print test-data/sleep_print.c       # compile a program
@> output-for 1                                    # output hasn't been collected yet
@<<< Output for gcc[#29555] (-1 bytes):
----------------------------------------
gcc[#29555] : output not ready
----------------------------------------
@!!! gcc[#29555]: EXIT(0)                          # now output should be available
@> output-for 1                                    # show it
@<<< Output for gcc[#29555] (0 bytes):
----------------------------------------
----------------------------------------
@> ./sleep_print 2 waking up now                   # run a program that has a delay
@> output-for 2                                    # not there yet
@<<< Output for ./sleep_print[#29861] (-1 bytes):
----------------------------------------
./sleep_print[#29861] : output not ready
----------------------------------------
@> output-for 2                                    # still not there yet
@<<< Output for ./sleep_print[#29861] (-1 bytes):
----------------------------------------
./sleep_print[#29861] : output not ready
----------------------------------------
@!!! ./sleep_print[#29861]: EXIT(2)                # alert: output is not available
@> output-for 2                                    # show it
@<<< Output for ./sleep_print[#29861] (15 bytes):
----------------------------------------
waking up now
----------------------------------------
@>
```

7.7 End of Loop Alerts

At the end of each iteration of the main loop of `commando`, each job should be checked for updates to its status. This is done via a calls to `cmd_update_state()` but since it is called on every child, a `cmdcol_update_state()` is probably a good idea to update everything.

This call **should not block**: if processes have not finished, `commando` should not wait for them. That means the underlying calls to `waitpid()` should use the `NOBLOCK` option provided in `commando.h`. This includes `WNOHANG`, an option which causes `waitpid()` to return immediately if nothing has happened with the process.

If the call to `cmd_update_state()` detects a change it should print an alert `@!!!` message indicating the change, usually program exits. These alerts should appear only once, when a child process exits and the state is updated in `cmd_update_state()`. If `cmd->finished` is set, there can be no additional state changes so no alerts should be generated.

```
@> ls test-data/                                          # start a listing
@>                                                        # press enter to update state
@!!! ls[#31702]: EXIT(0)                                  # got an alert
@> ./sleep_print 2 awake now                              # longer running program
@>                                                        # enter to update state
@> list                                                   # not done yet, list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #31702       0    EXIT(0)  145 ls test-data/
1    #31799      -1        RUN   -1 ./sleep_print 2 awake now
@> list                                                   # not done yet, list again
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #31702       0    EXIT(0)  145 ls test-data/
1    #31799      -1        RUN   -1 ./sleep_print 2 awake now
@>                                                        # still not done, press enter
@!!! ./sleep_print[#31799]: EXIT(2)                       # finally done
@> list                                                   # shows both processes complete
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #31702       0    EXIT(0)  145 ls test-data/
1    #31799       2    EXIT(2)   11 ./sleep_print 2 awake now
1    #2395        2    EXIT(2)   11 sleep_print 2 awake now
@>
```

7.8 Waiting and Alerts

In comparison to standard shells, `commando` starts child processes roughly "in the background" giving control immediately back to `commando` to do further work. The `wait-for int` built-in command causes execution of `commando` to stop until the specified job number actually finishes. This is useful if one wants the output for the job.

The following demonstration uses the provided `sleep_print` program which sleeps for a while, 10 seconds in this case, then prints output. The `wait-for 0` command causes execution of `commando` to pause until it is finished.

```
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
@> sleep_print 10 now awake                       # start job that takes a while to finish
@> output-for 0                                   # no output yet
@<<< Output for sleep_print[#2276] (-1 bytes):
----------------------------------------
sleep_print[#2276] has no output yet
----------------------------------------
@> output-for 0                                   # no output yet
@<<< Output for sleep_print[#2276] (-1 bytes):
----------------------------------------
sleep_print[#2276] has no output yet
----------------------------------------
@> wait-for 0                                     # wait until it finishes, may take a while
@!!! sleep_print[#2276]: EXIT(10)
@> output-for 0
@<<< Output for sleep_print[#2276] (11 bytes):
----------------------------------------
now awake
----------------------------------------
@>
```

The `wait-for int` command translates to a call to `cmd_update_state()` with the `DO_BLOCK` option. `DOBLOCK` contains options to the underlying `waitpid()` call which will cause it to pause `commando` until the child process finishes.

It is the call to `cmd_update_state()` which issues the `@!!!` alert messages to be printed. Note that this function should also make a call to `cmd_fetch_output()` to make output available for printing.

Similarly, if several commands are taking a while, a call to `wait-all` will pause `commando` until all child processes are finished.

```
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #2276       10   EXIT(10)   11 sleep_print 10 now awake
@> sleep_print 4 now awake                    # Start several processes
@> sleep_print 5 now awake
@> sleep_print 2 now awake
@> wait-all                                   # wait for all to finish, may take a tick
```

```
@!!! sleep_print[#2335]: EXIT(4)
@!!! sleep_print[#2336]: EXIT(5)
@!!! sleep_print[#2337]: EXIT(2)
@> list                                        # show all of jobs finished
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #2276       10   EXIT(10)   11 sleep_print 10 now awake
1    #2335        4    EXIT(4)   11 sleep_print 4 now awake
2    #2336        5    EXIT(5)   11 sleep_print 5 now awake
3    #2337        2    EXIT(2)   11 sleep_print 2 now awake
```

7.9 Pausing

It is useful in testing to be able to have `commando` simply do nothing for a short time, accomplished with the `pause nanos secs` built-in. This should parse two tokens, the number of nanoseconds and number seconds to sleep. The provided function `pause_for()` in `util.c` should be called for to get the main program to stop temporarily.

After the pause, the standard check of all child processes for state changes should occur which can cause some processes to print that they are done as shown in the following example.

```
lila [commando]% ./commando
@> sleep_print 2 awake now              # launch job that takes 2 seconds
@> pause 0 3                            # pause for 0 nanos + 3 seconds
@!!! sleep_print[#2421]: EXIT(2)        # when control returns, state change in child is detected
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #2421        2    EXIT(2)   11 sleep_print 2 awake now
@>
```

7.10 Cleaning up at Close

When the `exit` command is issued or the end of the input is found, `commando` should free any memory it has allocated during execution. Most/all of such memory is likely associated with a `cmdcol_t` so a call to `cmdcol_freeall()` should take care of this. Tests will use Valgrind to check for memory that remains in use so you may want to run this yourself to check. Example:

```
phaedrus [commando]% valgrind ./commando                    # Start running commando with valgrind checking
==6452== Memcheck, a memory error detector                  # messages from valgrind
==6452== Copyright (C) 2002-2017, and GNU GPLd, by Julian Seward et al.
==6452== Using Valgrind-3.13.0 and LibVEX; rerun with -h for copyright info
==6452== Command: ./commando
==6452==
@> ls stuff                                                 # prompt for commando
@> sleep_print 1 hello goodbye
@!!! ls[#6453]: EXIT(0)
@> gcc --help
@!!! sleep_print[#6454]: EXIT(1)
@> ls
@!!! gcc[#6455]: EXIT(0)
@>
@!!! ls[#6457]: EXIT(0)
@> list
JOB  #PID      STAT   STR_STAT OUTB COMMAND
0    #6453        0    EXIT(0)   28 ls stuff
1    #6454        1    EXIT(1)   15 sleep_print 1 hello goodbye
2    #6455        0    EXIT(0) 3936 gcc --help
3    #6457        0    EXIT(0)  619 ls
@> exit                                                     # finishing commando
==6452==
==6452== HEAP SUMMARY:                                      # exit summary from valgrind
==6452==     in use at exit: 0 bytes in 0 blocks            # looks good
==6452==   total heap usage: 20 allocs, 20 frees, 20,723 bytes allocated
==6452==
==6452== All heap blocks were freed -- no leaks are possible   # damn straight
==6452==
==6452== For counts of detected and suppressed errors, rerun with: -v
==6452== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
phaedrus [commando]% valgrind ./commando
```

8 Manual Inspection Criteria (60%) `grading`

The following criteria will be examined during manual inspection of code by graders. Use this as a guide to avoid omitting important steps or committing bad style fouls.

Location	Wgt	Criteria
Makefile and	5	A Makefile is provided which compiles commando via `make`
Compilation		The Makefile has a `make clean` target to remove programs and `.o` files
	5	The required test targets are present: test-functions, test-commando
	5	The code builds and tests run with no warnings from the compiler
cmd.c		
`cmd_new()`	5	initializes all the fields to obvious default values
`cmd_free()`		clearly freeing all memory associated with the `cmd_t` (argv, output)
`cmd_start()`	5	creates a pipe correcoly prior to forking
		forks a child process and behaves differently for parent/child
		parent and child close the half of the pipe they won't use
		child redirects standard output to the pipe using dup2()
		child correctly exec()'s the indicated program
		basic error checking is done for system calls to detect failures
		tidy code and descriptive comments used to explain code flow
`cmd_update_state()`	5	commands that are already finished are not checked again
		waitpid() is used to check a child, the block parameter is honored
		the return value for waitpid() is checked to see if status has changed
		on a child finishing, macros are used to check for exit status
		@!!! alerts are printed on status changes but only once per change/exit
		tidy code and descriptive comments used to explain code flow
`read_all()`	5	calls to the read() function are used to get data
		as more space is needed, realloc() is used to resize the buffer
		an efficient growth scheme such as doubling the buffer size is used
`cmd_fetch_output()`	5	make use of $read_{all}$() to retrieve output from the pipe
		closes() the pipe after reading all output
`cmd_print_output()`		uses the write() system call to put command output on standard output
cmdcol.c		
`cmdcol_add()`	5	basic bounds checking on size to ensure the buffer does not overflow
`cmdcol_print()`		makes use of printf() format specifiers to get printing aligned
commando.c		
input loop	10	clear use of if/else-if conditional structure to check for built-ins
		use of strncmp() to compare strings checking for built-ins
		use fgets() to retrieve input lines, ensure the buffer doesn't overflow
		check return value of fgets() for end of input and break from loop
		use provided $parse_{intotokens}$() function to split input lines

Location	Wgt	Criteria
		tidy code and descriptive comments used to explain code flow
outside input loop	5	clear attempt made to honor the `--echo` command line option
		clear attempt made to honor the `COMMANDO_ECHO` environment variable
		clear attempt to free memory prior to exiting
	60	Total

9 Automatic Testing (40%) `grading`

Automated tests will be provided sometime after the initial release of the project. This section will explain requirements for how they will function.

9.1 Credit For Tests

There are tests for some of the C functions specified in the project and tests of the executable `commando` called shell tests. The weighting of credit is as follows.

Wgt	Criteria
20	Number of passed tests from `make test-cmd` (20 total, 1 pt per test)
20	Number of passed tests from `make test-commando` (20 total, 1 pt per test)

9.2 `test_Makefile` to include in `Makefile`

Add the following line to your `Makefile`

```
include test_Makefile
```

This will include the provided testing `test_Makefile`.

NOTE: The `test_Makefile` file has a `make zip` target in it. Remove this from your `Makefile` if it is present otherwise you will get errors about a duplicate target.

9.3 Running Tests

Including the above `test_Makefile` includes several testing targets including

```
> make test           # run all tests, both of the above
> make test-cmd       # test functions in the cmd.c and cmdcol.c files
> make test-commando  # test the commando application
> make clean-tests    # remove temporary files generated during testing
> make zip            # create a zip of the project for submission
```

A completely correct run of the tests would build and run as follows.

```
## Remove any temporary files used for testing
> make clean-tests
rm -rf test_cmd test-results/

## Test functions
> make test-cmd
gcc -Wall -Werror -g -o test_cmd test_cmd.c cmd.c cmdcol.c commando.h
./testy test_cmd.org
============================================================
== test_cmd.org : Tests of cmd.c and cmdcol.c via test_cmd.c
== Running 20 / 20 tests
1)  cmd_new_1             : ok
2)  cmd_new_2             : ok
3)  cmd_new_3             : ok
4)  cmd_start_1           : ok
```

```
5)  cmd_start_2           : ok
6)  cmd_start_3           : ok
7)  read_all_1            : ok
8)  read_all_2            : ok
9)  read_all_3            : ok
10) cmd_update_1          : ok
11) cmd_update_2          : ok
12) cmd_update_3          : ok
13) cmd_print_output_1    : ok
14) cmd_print_output_2    : ok
15) cmdcol_add_1          : ok
16) cmdcol_add_2          : ok
17) cmdcol_update_state_1 : ok
18) cmdcol_update_state_2 : ok
19) cmdcol_print_1        : ok
20) cmdcol_print_2        : ok
============================================================
RESULTS: 20 / 20 tests passed

## Test Commando
> make test-commando
gcc -Wall -g -c commando.c
gcc -Wall -g -c cmd.c
gcc -Wall -g -c cmdcol.c
gcc -Wall -g -c util.c
gcc -Wall -g -o commando commando.o cmd.o cmdcol.o util.o
./testy test_commando.org
============================================================
== test_commando.org : Commando Application Tests
== Running 20 / 20 tests
1)  Startup, Help, Exit, and List Built-in : ok
2)  Echoing via --echo and COMMANDO_ECHO   : ok
3)  End of Input                           : ok
4)  Blank Line Handling                    : ok
5)  ls on the test-data/stuff directory    : ok
6)  cat on test-data/quote.txt file        : ok
7)  sleep for 1s                           : ok
8)  ls multiple times                      : ok
9)  ls and table.sh                        : ok
10) rm, compile, run print_args            : ok
11) output-all builtin                     : ok
12) wait-all                               : ok
13) Output Changes                         : ok
14) pause builtin                          : ok
15) pause finishes single job              : ok
16) pause finishes multiple jobs           : ok
17) pause not done                         : ok
18) wait-for individual jobs               : ok
19) Stress 1                               : ok
20) Stress 2                               : ok
============================================================
RESULTS: 20 / 20 tests passed
```

9.4 Tips for Running Tests

- Individual tests can be run by setting `testnum=N` during a make invocation. Two examples are below

```
## Run only test 15 from the test-cmd set of tests
> make test-cmd testnum=15
./testy test_cmd.org 15
============================================================
== test_cmd.org : Tests of cmd.c and cmdcol.c via test_cmd.c
== Running 1 / 20 tests
15) cmdcol_add_1          : ok
============================================================
RESULTS: 1 / 1 tests passed


## Run only test 3 for commando
> make test-commando testnum=3
./testy test_commando.org 3
```

```
============================================================
== test_commando.org : Commando Application Tests
== Running 1 / 20 tests
3)  End of Input                        : ok
============================================================
RESULTS: 1 / 1 tests passed
```

- If test failures occur, a Results file will be listed giving detailed information about why the test failed. This file has the `.tmp` extension but is just a text file and should be examined in a text editor or in the terminal. For example

```
> make test-commando
./testy test_commando.org
============================================================
== test_commando.org : Commando Application Tests
== Running 20 / 20 tests
1)  Startup, Help, and Exit             : ok
2)  List Built-in                       : ok
3)  End of Input                        : ok
4)  Blank Line Handling                 : ok
5)  ls on the test-data/stuff directory : ok
6)  cat on test-data/quote.txt file     : ok
7)  sleep for 1s                        : ok
8)  ls multiple times                   : ok
9)  ls and table.sh                     : ok
10) rm, compile, run print_args         : ok
11) output-all builtin                  : ok
12) wait-all                            : ok
13) Output Changes                      : FAIL -> results in file 'test-results/commando-13-result.tmp'
14) pause builtin                       : ok
15) pause finishes single job           : ok
16) pause finishes multiple jobs        : ok
17) pause not done                      : FAIL -> results in file 'test-results/commando-17-result.tmp'
18) wait-for individual jobs            : FAIL -> results in file 'test-results/commando-18-result.tmp'
19) Stress 1                            : FAIL -> results in file 'test-results/commando-19-result.tmp'
20) Stress 2                            : FAIL -> results in file 'test-results/commando-20-result.tmp'
============================================================
RESULTS: 15 / 20 tests passed
```

  It would be a good idea to examine the first test failure Results file called `test-results/commando-13-result.tmp`. A quick way to do this would be via `less` as in

```
> less test-results/commando-13-result.tmp
```

  with 'Space' scrolling down, 'u' scrolling up, and 'q' quitting.

- When running a single test, failure Results are saved to a file AND automatically shown to the screen

```
> make test-commando testnum=13
./testy test_commando.org 13
============================================================
== test_commando.org : Commando Application Tests
== Running 1 / 20 tests
13) Output Changes                      : FAIL -> results in file 'test-results/commando-13-result.tmp'
============================================================
RESULTS: 0 / 1 tests passed


FAILURE RESULTS
---------------------------------------
(TEST 13) Output Changes
COMMENTS:
Starts a program and shows it in a listing before it is complete.
Requests output before it is complete which should be handled
gracefully showing an 'output not ready' message.


program: ./commando --echo
```

```
Failure messages:
- FAILURE: Output Mismatch at lines marked

--- Side by Side Differences ---
...
```

- The test files themselves have the extension `.org` but are just text files and can be examined in any text editor. They are run via the `testy` script which is an executable shell script.

10 Assignment Submission

10.1 Zip Target in `test_Makefile`

The `make zip` target is included in the provide `test_Makefile`. This will enable one to type `make zip` to create a `p1-code.zip` file which contains the entire project. Submit this Zip when you complete the project.

Note that in some cases, `make zip` may produce warnings for instance if the size of the zip file is very large or contains more files than is healthy. Heed these warnings as they will ensure your submission goes through.

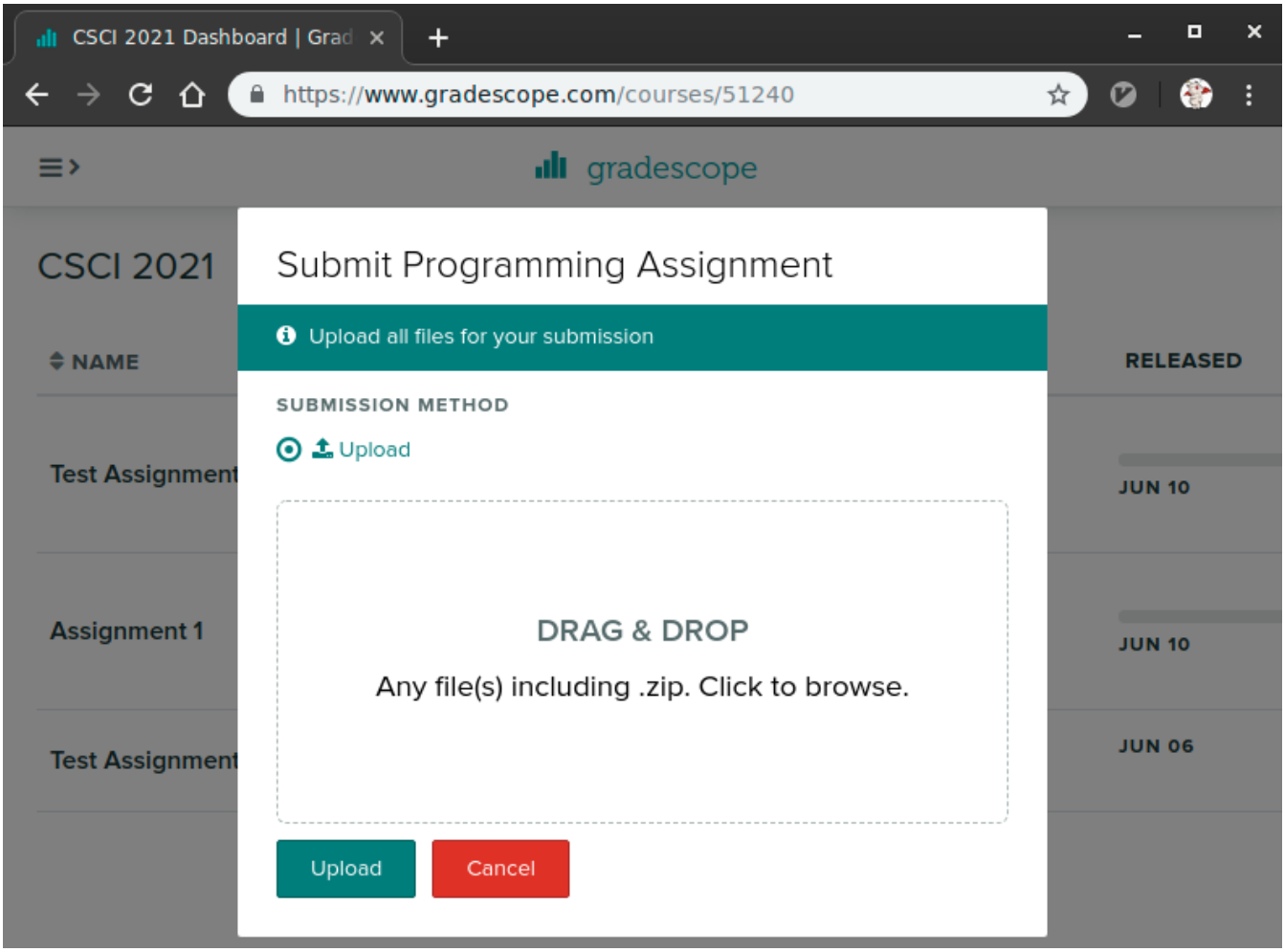
10.2 Submit to Gradescope

The below guide is for a different class and project but the basic steps are the same as for the present case except where noted.

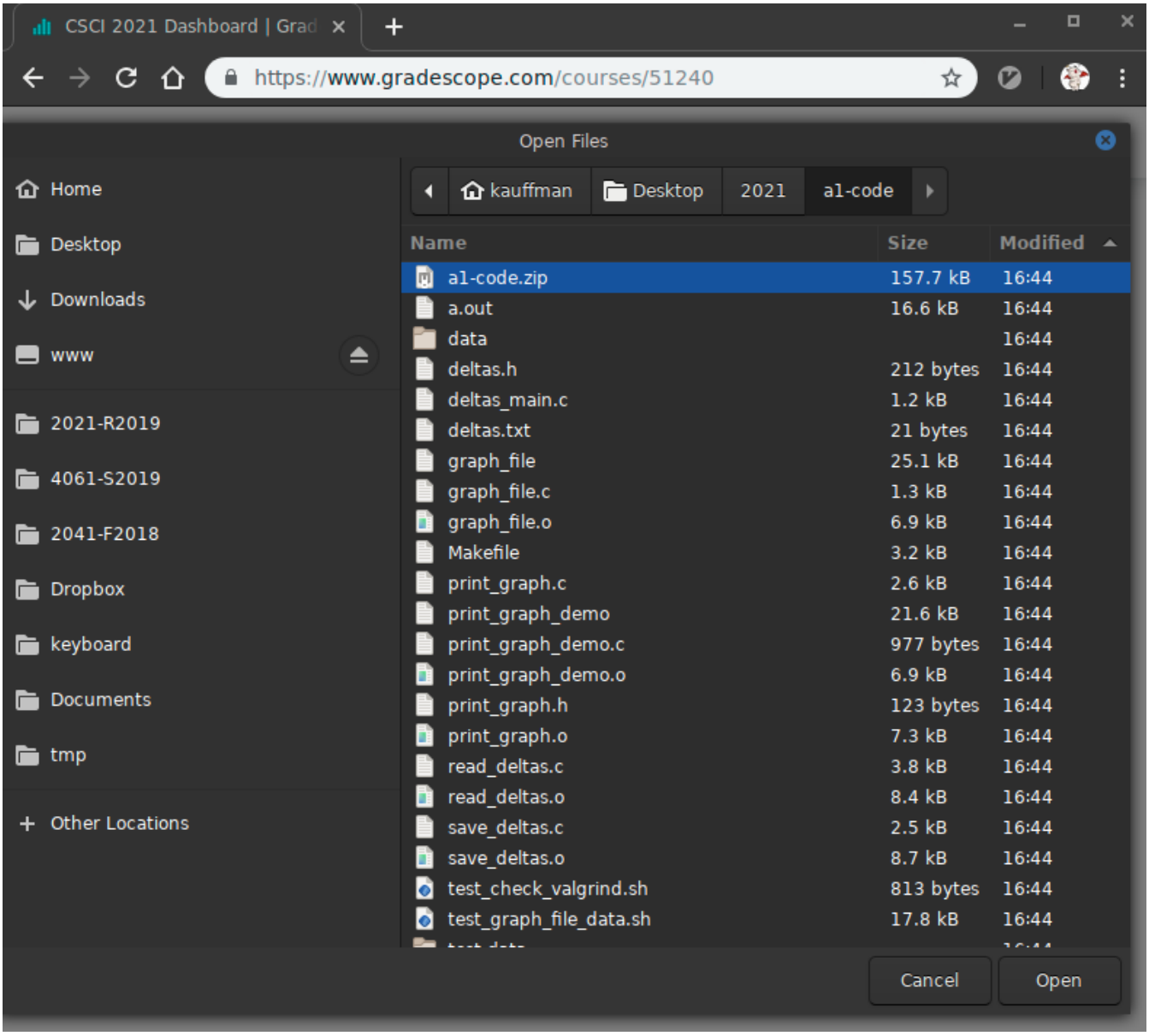
1. In a terminal, change to your project code directory and type **make zip** which will create a zip file of your code. A session should look like this:

```
> cd Desktop/2021/p1-code      # location of assignment code

> ls
Makefile    commando.c  test_commando.org  cmd.c test_Makefile
...

> make zip                     # create a zip file using Makefile target
rm -f p1-code.zip
cd .. && zip "p1-code/p1-code.zip" -r "p1-code"
  adding: p1-code/ (stored 0%)
  adding: p1-code/Makefile (deflated 68%)
  adding: p1-code/commando.c (deflated 69%)
  adding: p1-code/cmd.c (deflated 71%)
  ...
Zip created in p1-code.zip

> ls p1-code.zip
p1-code.zip
```

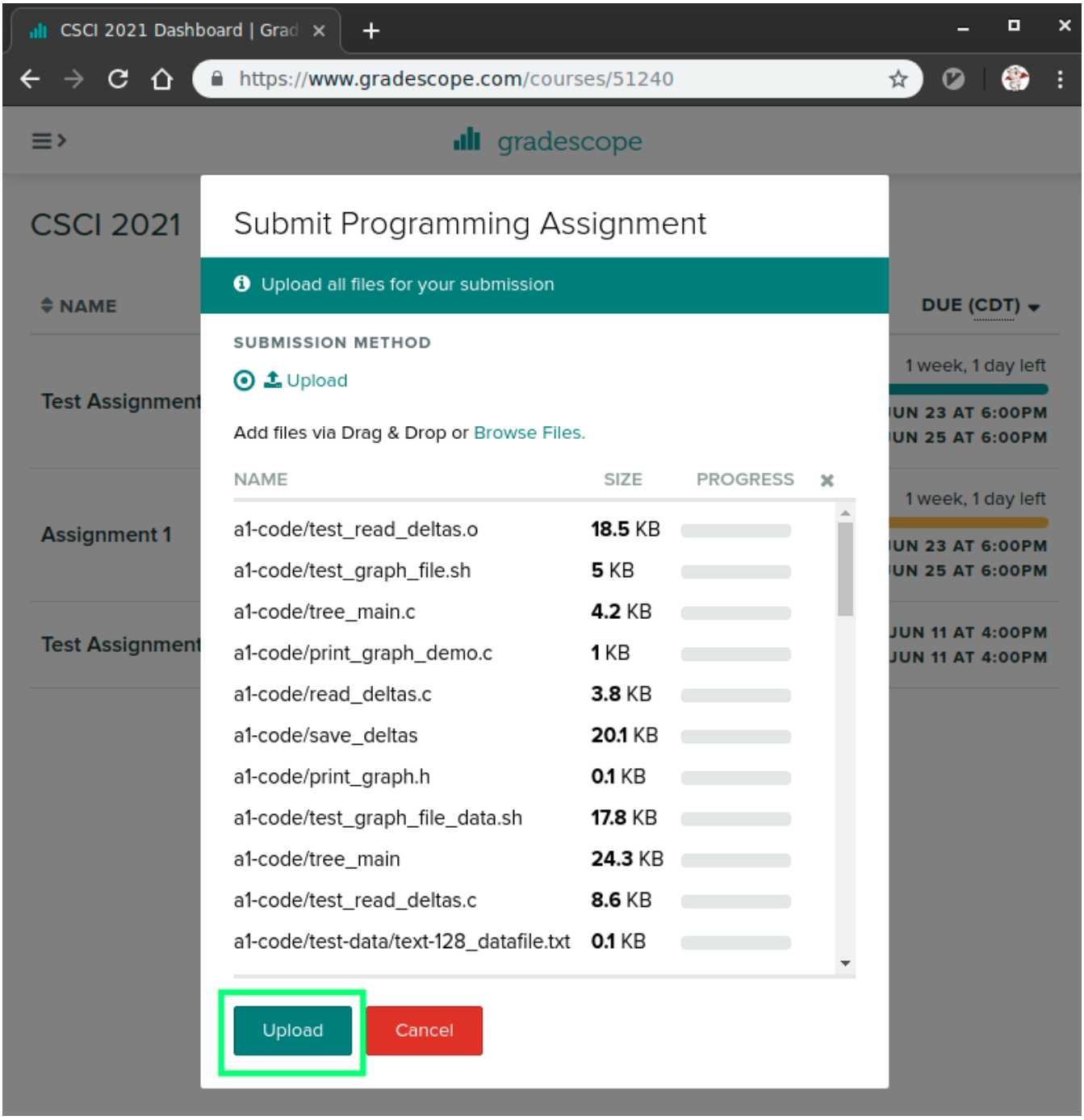
2. Log into Gradescope and locate and click 'Project 1' which will open up submission



3. Click on the 'Drag and Drop' text which will open a file selection dialog; locate and choose your `p1-code.zip` file

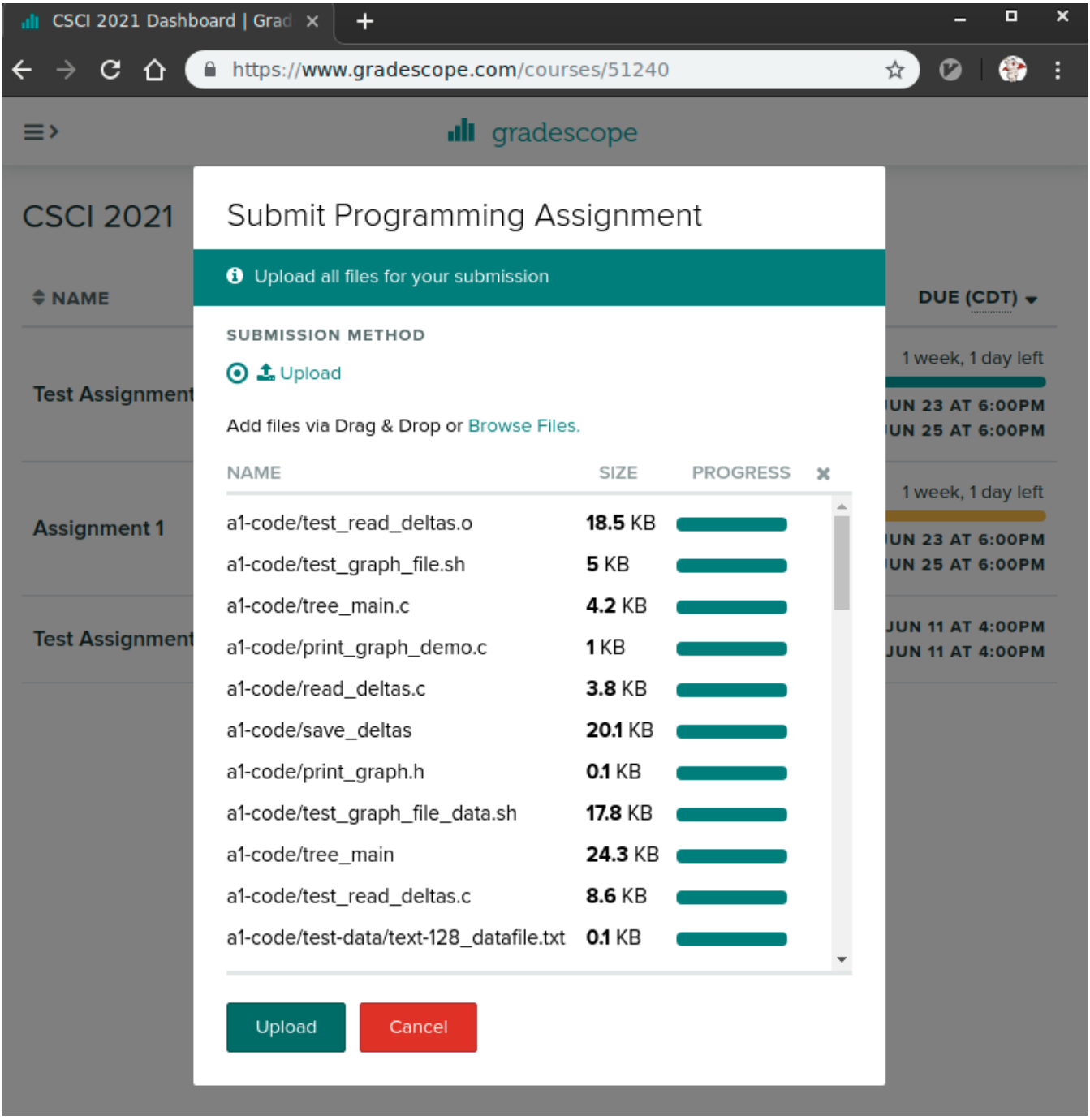


4. This will show the contents of the Zip file and should include your C source files along with testing files and directories.

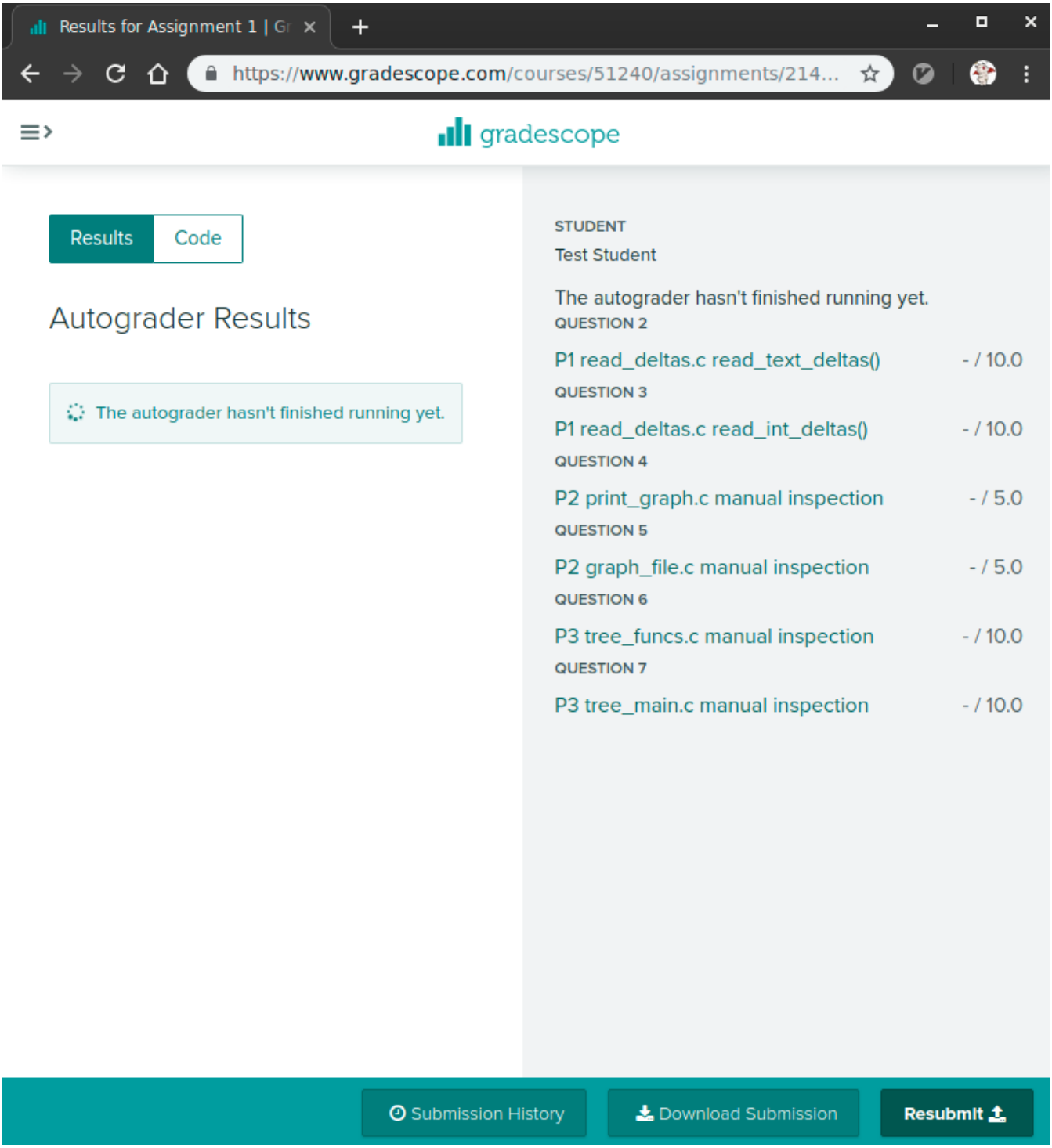


5. Click 'Upload' which will show progress uploading files. It may take a few seconds before this dialog closes to indicate that the upload is successful. Note: there is a limit of 256 files per upload; normal submissions are not likely to have problems with this but you may want to make sure that nothing has gone wrong such as infinite loops creating many files or incredibly large files.

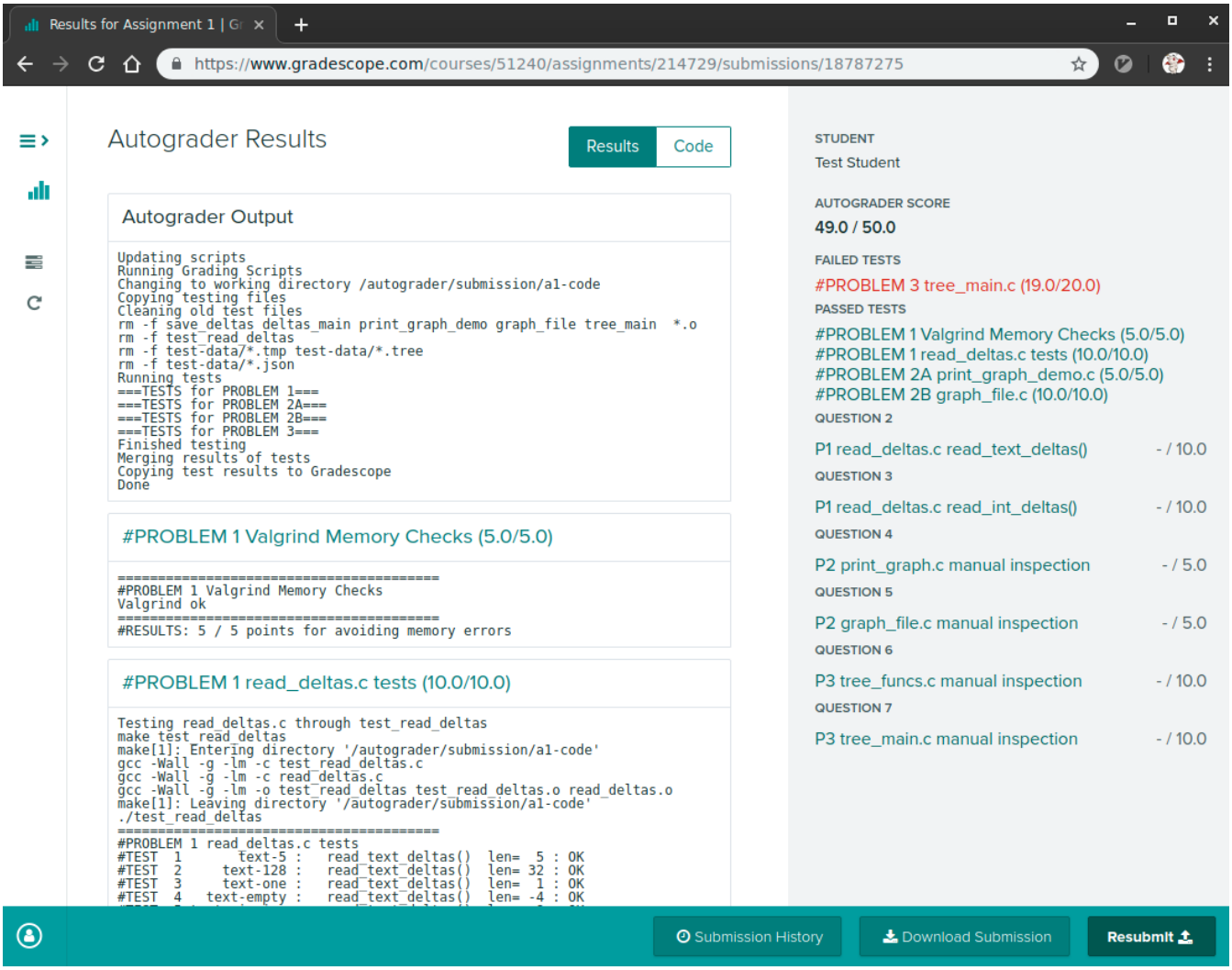
   WARNING: There is a limit of 256 files per zip. Doing `make zip` will warn if this limit is exceeded but uploading to Gradescope will fail without any helpful messages if you upload more the 256 files in a zip.



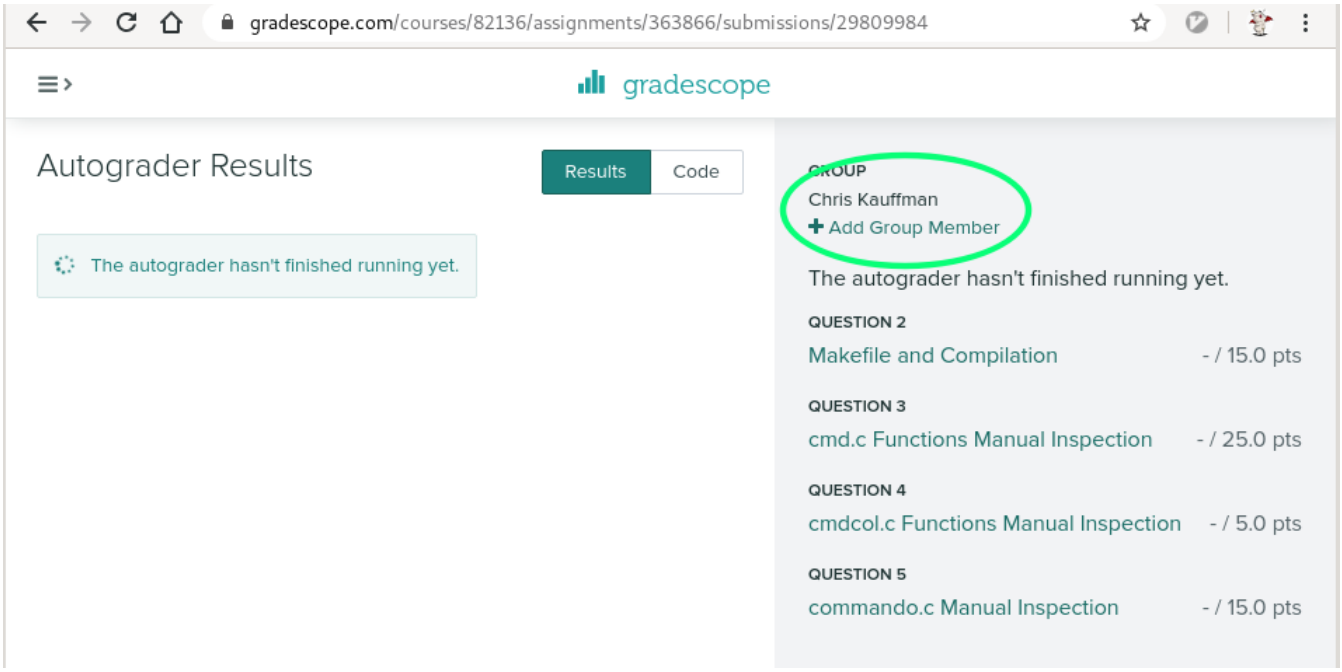
6. Once files have successfully uploaded, the Autograder will begin running the command line tests and recording results. These are the same tests that are run via `make test`.



7. When the tests have completed, results will be displayed summarizing scores along with output for each batch of tests.



8. **For those working in groups, only 1 member should upload a ZIP.** After uploading, there will be a Menu option in the upper right to **Add Group Member**. Click this and add your group members. Gradescope also provides a video on how to Add Group Members to a submission.



10.3 Late Policies

You may wish to review the policy on late project submission which will cost 1 Engagement Point per day late. **No projects will be accepted more than 48 hours after the deadline.**

https://www-users.cs.umn.edu/~kauffman/4061/syllabus.html

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