



The figure above shows an overview of the inputs, outputs and your program will flow. You are expected to implement the middle portion indicated by `pzip(inputs, outputs)`. Within this function, there are three major steps that you should follow to establish the parallel threads logic:

1. Call `pthread_create()` to launch parallel threads: Once threads are created they will iterate through an equal and dedicated portion of `input_chars`, store the consecutive occurrence results locally, and also update a global `char_frequency` array that holds the total/global frequency of the occurrences of each character.
2. Call `pthread_barrier()` to synchronize the pthreads, without destroying them: This barrier is required to make sure that each thread has finished locally counting their portions of characters. Threads need to synchronize because each thread needs to know how many `zipped_char` structs they have in their `localResult` arrays, so that they can calculate the exact index of `zipped_char` array that they need to copy their local results into.
3. Call `pthread_join()` to finish the parallel execution.

Please note that your code is expected **ONLY** to operate on the input and output data structures provided in the figure.

Warning

`zipped_chars` array holds consecutive occurrences, whereas `char_frequency` array holds the total number of occurrences. A character may appear more than once in `zipped_chars` array, whereas `char_frequency` is populated on-the-go as threads encounter each character.

Functionality

After running `make`, you should have an executable program named `pzip` located in the root of your repository. The usage is as follows:

```
pzip INPUT_FILE OUTPUT_FILE N_THREADS [--debug]
```

- `INPUT_FILE`: The input file name which contains only lowercase letters (a-z). The format is explained below.
- `OUTPUT_FILE`: The output file name which will be the result of your program output. The format is explained below.
- `N_THREADS`: The number of parallel threads that will be used during `pzip`.
- `[--debug]`: Optional parameter to display the content of input/output variables. When this option is set, the output becomes a human readable text file. Otherwise, it is a binary file. We will test your program without this parameter.

Assumptions

- The number of threads is assumed to be greater than or equal to zero.
- The number of characters in the input file is assumed to be a positive multiple of the number of threads.
- Each thread is expected to process an equal portion of the input characters.
- **IMPORTANT**: If the consecutive occurrence of a character spans two threads, you **SHOULD NOT** merge these two occurrences and **SHOULD** report them separately. For example, in the image

above, the character `s` appears twice for the first thread and, again, the same letter appears three times in the portion processed by the second thread. In the final output, rather than counting `s` for 5 times, we have two counts of it, which are 2 and 3, respectively.

What is implemented for you?

- `main()` function in `main/pzip.c` (**DO NOT TOUCH THIS FILE**)
- Program parameter handling
- Input file reading, parsing and conversion (i.e., mapping) to `input_chars` array
- Output file formatting, writing and conversion (i.e., mapping) from `zipped_chars` array
- Debug output

To ease your implementation and to make grading fairer, using the starter code *is a requirement of this project*. You are **NOT ALLOWED** to make any modification to the `main/pzip.c` file. You may add new structs or functions to the `main/pzip.h` file. However, you **SHOULD NOT** change/delete/modify existing functions/variables/headers/structs in `main/pzip.h` file.

What are you expected to do?

- **START FROM HERE:** Implement body of the `pzip()` function in `src/pzip.c`
- In the same file, also create a callback pthread function that will be called by `pthread_create()` within `pzip()` function.
- By the end of `pzip()` function, properly populate output pointers to `zipped_chars`, `zipped_chars_count` and `char_frequency`. Please note that the memory for these arrays and variables will be allocated and freed for you by `main()`.
- Implement other functions and global/local variables as you need.

Input File Format

The input file is already parsed into an `input_chars` array for you and the total number of chars in this file is provided to you in the `input_chars_size` variable. The input file is simply a text file that contains nothing but the 26 lower case letters (i.e., a-z). There are no white spaces, line breaks, return characters or other characters. While you don't need to parse the input file, you need to know the format so that you can prepare your own test inputs. Example input:

- Input file content: `aaeeooooooooee`
- `int input_chars_size = 12;`
- `char* input = {'a','a','e','e','o','o','o','o','o','o','e','e','e'};`

You may generate inputs of any size of NUM by using the following script in your repository root:

```
$ ./generate_chars.py NUM > test_input
```

Output Format

There are two output formats used by the program. Both of these formats are generated by the starter code using the `zipped_chars` array.

1. Binary Output (Default)

If the `--debug` option is not provided, the output of `pzip` is a binary file. This file is automatically generated using `zipped_chars` array and `zipped_chars_count` variable, which indicates the size of the array.

2. Text Output (--debug mode)

If the `--debug` option is provided in the program arguments, the contents of the `zipped_chars` array will be written as human readable text file. Each line of the output file will consist of a character and the number of consecutive occurrences of that character.

Examples

Example 1

- Input file content: aaeeooooooooee
- `int input_chars_size = 12;`
- `char* input = {'a','a','e','e','o','o','o','o','o','e','e','e'};`
- `int n_threads = 2;`
- `struct zipped_char* zipped_chars = {{'a',2}, {'e','2'},{'o',2},{'o',3}, {'e',3}};`
- Binary output file (in hexa-decimal):
61 02 65 02 6f 02 6f 03 65 03
- Text (--debug) output file (in plain text, new lines are ommitted): a 2 e 2 o 2 o 3 e 3

Example 2

- Input file content:

```
aeeeeooooooooooooooooaaaaaaaaaadddddddssssssslsssssyysyyyyywwwww
```
- ```
int input_chars_size = 64;
```
- ```
char* input = {`a`,`a`,`e`,`e`,`o`,`o`,`o`,`o`,`o`,`o`,`e`,`e`,`e`,`e`,`e`,  
`e`,`e`,`e`,`e`,`e`,`a`,`a`,`a`,`a`,`a`,`a`,`a`,`a`,`d`,`d`,`d`,  
`d`,`d`,`d`,`d`,`d`,`d`,`s`,`s`,`s`,`s`,`s`,`s`,`s`,`l`,`s`,`s`,`s`,`s`,  
`s`,`s`,`y`,`y`,`y`,`y`,`y`,`y`,`w`,`w`,`w`,`w`,`w`,`w`} ;
```
- ```
int n_threads = 4;
```
- ```
struct zipped_char\* zipped_chars = {{'a',2}, {'e','2'}},{ 'o',5}},{ 'e',7},  
{ 'e',3},{ 'a',10},{ 'd',3},{ 'd',6},{ 's',7},{ 'l',1},{ 's',2},{ 's',4},{ 'Y',6},  
{ 'w',6}};
```
- Binary output file (in hexa-decimal):

```
61 02 65 02 6f 05 65 07 65 03 61 0a 64 03 64 06 73 07 6c 01 73 02 73 04 79  
06 77 06
```
- Text (--debug) output file (in plain text, new lines are ommitted):

```
a 2 e 2 o 5 e 7 e 3 a 10 d 3 d 6 s 7 l 1 s 2 s 4 y 6 w 6
```

Warning

Note that the zipped output file is not fully compressed. In example 1, the zipped chars could have been determined as `{{ 'a', 2 }, { 'e', '2' }, { 'o', 5 }, { 'e', 3 }}`; . However, for the sake of simplicity for the project, we do not ask parallel threads to talk to each other and merge their output. You are not asked to implement this functionality, and your program may not pass our automated tests if you implement this optimization.

Evaluation and Grading

Grading

We will be grading your code based on:

- **Functionality and accuracy:**

Your program should produce the output as explained above. Please note that, due to the simplifications we have made, the output may change depending on the number of threads being used, if character sequences span thread boundaries, as in the example given in the figure. Your submitted code should have the same `mains/pzip.c` file as in the starter code.

- **Parallelism and performance:**

Most of `pzip`, including input/output and reading/writing, will operate in parallel. Your program should operate as shown in the Figure above. You should **NOT** do the counting of characters serially. Serial creation and joining of threads is OK.

- **General requirements:**

Your program should follow the non-project-specific general requirements indicated below.

Performance Measurement

- To test whether your program properly AND efficiently use threads, we will run your program with large test files (e.g. `test/input_large`). We will use the following formula to evaluate the 'parallel efficiency', i.e., `PE`, of your code:

$$PE = ((CPU_TIME_USER + CPU_TIME_SYS) / WALL_TIME) / N_THREADS$$

- In a perfectly parallel program, `PE` should be equal to 1.0, however this is never possible. Actual parallel efficiency will be less than 1.0. To measure the `PE` of your program via the `measure.py` script we provided, you may execute the following command:

```
$ ./measure.py ./pzip /tmp/CSCI-442--DO-NOT-DELETE/input_huge ./out 8
```

Performance Criteria

- On `lsengard`, our solution for the parameters in the above command runs under 1 second (`WALL_TIME < 1`) with a `PE` greater than 0.75.
- Your program is expected to run the command above on `lsengard` under 2 seconds (`WALL_TIME < 2`) with a `pe` greater than 0.5 (`PE > 0.5`). Please note that these values are valid only for the input file referenced above (`/tmp/CSCI-442--DO-NOT-DELETE/input_huge`) and with `N_THREADS=8` on `lsengard`. Your first run may be slower due to internal page caching. You will get three runs, and the fastest will be used for your grade.
- If your code fails to meet the performance criteria above, you will get a partial grade, depending on how fast and efficient your code is.
- The top three fastest and correct submissions will be given +3, +2 and +1 extra points, respectively.

Submission Information

Gradescope will NOT be used for submitting Project 3

Submission of your project will be handled using GitHub classroom.

To submit your work, type (from the base of the repo):

```
$ ./submit-my-work
```

This should be done on Isengard, even if you have developed from a computer at home. You can SSH into Isengard, clone your code, and test it there.

The script will run some minimal automated checks (e.g., check that your code compiles), and prompt you for any info required on your submission, including calculating slip days.

Warning

Only code that has been **committed** with git will be included in your submission (*not* merely saved to a `.c` file). **Make sure to commit all of your code before submitting!**

Warning

We're not joking, you need to remember to do this (hence the *second* warning box) --- **Make sure to commit all of your code before submitting!**

General Requirements

- You are **REQUIRED** to use Isengard to develop and test this project.
 - Additionally, Isengard will be used for all grading (as indicated above under "Performance Criteria") --- we will have very little sympathy for students who do not follow this requirement and receive a poor grade due to a performance difference between Isengard and their personal machine.
- You should handle errors gracefully. All system calls can fail: if this occurs print a relevant and descriptive error to `stderr` (*not* `stdout`) and exit. Your program should have a non-zero exit status if any errors are encountered.
- Your program should have a zero exit status if no errors are encountered.
- Your project must be written in the C programming language, and execute on Isengard.
- You should follow [Linux Kernel coding style](#), a common style guide for open-source C projects. A small number of points will be deducted on projects which do not follow this style guide.
- Your project must not execute external programs or use network resources.
- Your project should be memory safe. For example, if your program is susceptible to buffer-overflow based on certain inputs, it is not memory safe. As a corollary to this, you should not use any of the following functions: `strcat`, `strcpy`, or `sprintf`.
- You should `free` any memory that you heap-allocate, and `close` (or `closedir`) any files that you open.
- To compile your code, the grader should be able to `cd` into the root directory of your repository and run `make` using the provided `Makefile`.

Resources

You will be using the following pthread library calls:

- `pthread_create`
- `pthread_join`
- `pthread_mutex_init`
- `pthread_barrier_init`
- `pthread_mutex_lock`
- `pthread_mutex_unlock`
- `pthread_barrier_wait`

Please refer to <https://computing.llnl.gov/tutorials/pthreads/> for tutorials on how to use pthreads.

Collaboration Policy

This is an **individual project**. All code you submit should be written by yourself. You should not share your code with others.

Please see the syllabus for the full collaboration policy.

Warning

Plagiarism will be punished harshly!

Access to Isengard

To `ssh` into the machine with your campus MultiPass login, use this command:

```
$ ssh username@isengard.mines.edu
```

Note: you need to be on the campus network or VPN for this to work. If you are working from home, use either the VPN or hop thru `jumpbox.mines.edu` first.