# Submission Report

* Submission generated at 10/23/2025 at 21:06:16
* Machine info: Linux runnervmwhb2z 6.11.0-1018-azure #18~24.04.1-Ubuntu SMP Sat Jun 28 04:46:03 UTC 2025 x86\_64 x86\_64 x86\_64 GNU/Linux

## Note to Students

Please read this report carefully before submission. Ensure that all sections are complete and accurate. Look for any errors in the build or test outputs. If you find any issues, correct them before submitting. Post any questions on the class discussion board for help.

## README

# Project 3

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* Email: jonathanflores@u.boisestate.edu
* Class: 452-001

## Known Bugs or Issues

None that I am aware of

## Experience

As I progress through this course, I am slowly but surely becoming more comfortable with the C programming language again. I was very excited to tackle this project after discussing it in class with Dr. Panter, so I had an architecture already in mind when sitting down to code. As such, I started by laying out a skeleton of what I had envisioned, then started to code it up by hand. Finally, I checked all the files through AI to check for validity in terms of syntax, made a few minor adjustments, and then repeated this process for compiler errors and warnings as they began to appear. Eventually I had a working code with minimal input from AI this time, which felt good. I had a little trouble ensuring that I used a lock in this assignment to meet the assignment criteria, as my approach did not necessarily require one, but I did get one in there.

## Analysis

* Were you able to generate soething close to what the example showed?
  + Yes, but on onyx, I had to greatly increase the size of the arrays to be sorted to generate something close to the example plot. The best results I saw were for 10000000 element arrays, but after some discussion with Dr. Panter, he confirmed that this was acceptable.
* Did you see a slowdown at some point? Why or why not?
  + Oddly enough, I did see some slow down on 2 threads, most likely due to some overhead introduced in my methodology, but everything after that followed a pretty smooth pattern of decreased run time, with a very slight upwards trend as the number of threads approached the number of cores available. I have adjusted the generateplot.sh script to go up to my max thread count to further demonstrate this trend on onxy.
* Did your program run faster and faster when you added more threads? Why or Why not?
  + My program did run faster and faster for a good while when adding more threads, but eventually it stabilized, then, as the number of threads approached the number of cores, there was a slight upward trend appearing again.
* What was the optimum number of threads for your machine?
  + On Onyx, it seems like the optimal number of threads was 45.
* What was the slowest number of threads for your machine?
  + On Onyx, the slowest number of threads still seemed to be 2. This is most likely due to some overhead my method introduced.

Here is an example of how to include a plot in your README:

## Onyx Plot: 64 thread max, 10000000 element arrays

## Build Output

This section was generated by running make all in the project root directory.

make[1]: Entering directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
mkdir -p build/debug  
cc -g -O0 -DDEBUG -fno-omit-frame-pointer -fsanitize=address -c src/lab.c -o build/debug/lab.c.o  
mkdir -p build/debug  
cc -g -O0 -DDEBUG -fno-omit-frame-pointer -fsanitize=address -c src/main.c -o build/debug/main.c.o  
cc -g -O0 -DDEBUG -fno-omit-frame-pointer -fsanitize=address build/debug/lab.c.o build/debug/main.c.o -o build/debug/myapp\_d -fsanitize=address  
make[1]: Leaving directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
make[1]: Entering directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
mkdir -p build/release  
cc -Wall -Wextra -O2 -fPIE -MMD -MP -Wformat -Wformat=2 -Wconversion -Wsign-conversion -Wimplicit-fallthrough -fstack-protector-strong -Werror=format-security -Werror=implicit -Werror=incompatible-pointer-types -Werror=int-conversion -c src/lab.c -o build/release/lab.c.o  
mkdir -p build/release  
cc -Wall -Wextra -O2 -fPIE -MMD -MP -Wformat -Wformat=2 -Wconversion -Wsign-conversion -Wimplicit-fallthrough -fstack-protector-strong -Werror=format-security -Werror=implicit -Werror=incompatible-pointer-types -Werror=int-conversion -c src/main.c -o build/release/main.c.o  
cc -Wall -Wextra -O2 -fPIE -MMD -MP -Wformat -Wformat=2 -Wconversion -Wsign-conversion -Wimplicit-fallthrough -fstack-protector-strong -Werror=format-security -Werror=implicit -Werror=incompatible-pointer-types -Werror=int-conversion build/release/lab.c.o build/release/main.c.o -o build/release/myapp   
make[1]: Leaving directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
make[1]: Entering directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
mkdir -p build/tests  
cc -g -O0 -DTEST -fprofile-arcs -ftest-coverage -c src/lab.c -o build/tests/lab.c.o  
mkdir -p build/tests  
cc -g -O0 -DTEST -fprofile-arcs -ftest-coverage -c src/main.c -o build/tests/main.c.o  
mkdir -p build/tests/harness/  
cc -g -O0 -DTEST -fprofile-arcs -ftest-coverage -c tests/harness/unity.c -o build/tests/harness/unity.c.o  
mkdir -p build/tests/  
cc -g -O0 -DTEST -fprofile-arcs -ftest-coverage -c tests/lab-test.c -o build/tests/lab-test.c.o  
cc -g -O0 -DTEST -fprofile-arcs -ftest-coverage build/tests/lab.c.o build/tests/main.c.o build/tests/harness/unity.c.o build/tests/lab-test.c.o -o build/tests/myapp\_t -fprofile-arcs -ftest-coverage  
make[1]: Leaving directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
make[1]: Entering directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
mkdir -p build/debug-test  
cc -g -O0 -DDEBUG -DTEST -fno-omit-frame-pointer -fsanitize=address -c src/lab.c -o build/debug-test/lab.c.o  
mkdir -p build/debug-test  
cc -g -O0 -DDEBUG -DTEST -fno-omit-frame-pointer -fsanitize=address -c src/main.c -o build/debug-test/main.c.o  
mkdir -p build/debug-test/harness/  
cc -g -O0 -DDEBUG -DTEST -fno-omit-frame-pointer -fsanitize=address -c tests/harness/unity.c -o build/debug-test/harness/unity.c.o  
mkdir -p build/debug-test/  
cc -g -O0 -DDEBUG -DTEST -fno-omit-frame-pointer -fsanitize=address -c tests/lab-test.c -o build/debug-test/lab-test.c.o  
cc -g -O0 -DDEBUG -DTEST -fno-omit-frame-pointer -fsanitize=address build/debug-test/lab.c.o build/debug-test/main.c.o build/debug-test/harness/unity.c.o build/debug-test/lab-test.c.o -o build/debug-test/myapp\_td -fsanitize=address  
make[1]: Leaving directory '/home/runner/work/Fall2025CS452P3/Fall2025CS452P3'  
Builds completed. You can run the application with: ./build/release/myapp  
You can run the debug build with: ./build/debug/myapp\_d  
You can run the test build with: ./build/tests/myapp\_t  
You can run the debug-test build with: ./build/debug-test/myapp\_td

## Coverage Report

This section was generated by running make report in the project root directory.

tests/lab-test.c:161:test\_mergesort\_s:PASS  
tests/lab-test.c:162:test\_split\_sizes\_indices:PASS  
tests/lab-test.c:163:test\_parallel\_sort:PASS  
tests/lab-test.c:164:test\_edge\_cases:PASS  
Stress test: array\_size=10000 threads=1 time=1.229004  
Stress test: array\_size=10000 threads=2 time=1.280029  
Stress test: array\_size=10000 threads=3 time=2.035889  
Stress test: array\_size=10000 threads=4 time=2.309082  
Stress test: array\_size=10000 threads=5 time=2.135010  
Stress test: array\_size=10000 threads=6 time=2.317871  
Stress test: array\_size=10000 threads=7 time=2.364014  
Stress test: array\_size=10000 threads=8 time=2.013916  
Stress test: array\_size=50000 threads=1 time=7.763916  
Stress test: array\_size=50000 threads=2 time=7.460938  
Stress test: array\_size=50000 threads=3 time=13.207031  
Stress test: array\_size=50000 threads=4 time=12.680176  
Stress test: array\_size=50000 threads=5 time=15.700928  
Stress test: array\_size=50000 threads=6 time=13.803955  
Stress test: array\_size=50000 threads=7 time=14.034912  
Stress test: array\_size=50000 threads=8 time=14.338867  
Stress test: array\_size=100000 threads=1 time=16.258057  
Stress test: array\_size=100000 threads=2 time=23.962891  
Stress test: array\_size=100000 threads=3 time=28.091064  
Stress test: array\_size=100000 threads=4 time=27.290039  
Stress test: array\_size=100000 threads=5 time=33.291016  
Stress test: array\_size=100000 threads=6 time=28.377197  
Stress test: array\_size=100000 threads=7 time=29.720947  
Stress test: array\_size=100000 threads=8 time=31.625977  
tests/lab-test.c:165:test\_stress\_sort:PASS  
  
-----------------------  
5 Tests 0 Failures 0 Ignored   
OK  
./build/tests/myapp\_t  
tests/lab-test.c:161:test\_mergesort\_s:PASS  
tests/lab-test.c:162:test\_split\_sizes\_indices:PASS  
tests/lab-test.c:163:test\_parallel\_sort:PASS  
tests/lab-test.c:164:test\_edge\_cases:PASS  
Stress test: array\_size=10000 threads=1 time=1.243896  
Stress test: array\_size=10000 threads=2 time=1.634033  
Stress test: array\_size=10000 threads=3 time=1.961914  
Stress test: array\_size=10000 threads=4 time=2.270020  
Stress test: array\_size=10000 threads=5 time=2.471924  
Stress test: array\_size=10000 threads=6 time=2.306152  
Stress test: array\_size=10000 threads=7 time=2.427979  
Stress test: array\_size=10000 threads=8 time=2.441895  
Stress test: array\_size=50000 threads=1 time=7.423828  
Stress test: array\_size=50000 threads=2 time=9.194092  
Stress test: array\_size=50000 threads=3 time=12.822998  
Stress test: array\_size=50000 threads=4 time=12.656982  
Stress test: array\_size=50000 threads=5 time=15.534912  
Stress test: array\_size=50000 threads=6 time=13.112061  
Stress test: array\_size=50000 threads=7 time=13.887939  
Stress test: array\_size=50000 threads=8 time=14.408936  
Stress test: array\_size=100000 threads=1 time=15.562988  
Stress test: array\_size=100000 threads=2 time=23.809082  
Stress test: array\_size=100000 threads=3 time=28.218994  
Stress test: array\_size=100000 threads=4 time=27.428223  
Stress test: array\_size=100000 threads=5 time=33.172119  
Stress test: array\_size=100000 threads=6 time=28.180908  
Stress test: array\_size=100000 threads=7 time=29.822998  
Stress test: array\_size=100000 threads=8 time=31.645020  
tests/lab-test.c:165:test\_stress\_sort:PASS  
  
-----------------------  
5 Tests 0 Failures 0 Ignored   
OK  
mkdir -p ./build/report/html  
mkdir -p ./build/report/txt  
gcovr -r . --html --html-details --exclude-directories build/tests/harness --exclude '.\*main\.c$' --exclude '.\*test\.c$' -o ./build/report/html/coverage\_report.html  
(INFO) Reading coverage data...  
  
(WARNING) Unrecognized GCOV output for /home/runner/work/Fall2025CS452P3/Fall2025CS452P3/src/lab.c  
 branch 3 taken -3182732 (fallthrough)  
 This is indicative of a gcov output parse error.  
 Please report this to the gcovr developers  
 at <https://github.com/gcovr/gcovr/issues>.  
::warning::(WARNING) Unrecognized GCOV output for /home/runner/work/Fall2025CS452P3/Fall2025CS452P3/src/lab.c  
 branch 3 taken -3182732 (fallthrough)  
 This is indicative of a gcov output parse error.  
 Please report this to the gcovr developers  
 at <https://github.com/gcovr/gcovr/issues>.  
(WARNING) Exception during parsing:  
 NegativeHits: /home/runner/work/Fall2025CS452P3/Fall2025CS452P3/src/lab.c:101 Got negative hit value in: branch 3 taken -3182732 (fallthrough)  
This is caused by a bug in gcov tool, see  
https://gcc.gnu.org/bugzilla/show\_bug.cgi?id=68080. Use option  
--gcov-ignore-parse-errors with a value of negative\_hits.warn,  
or negative\_hits.warn\_once\_per\_file.  
::warning::(WARNING) Exception during parsing:  
 NegativeHits: /home/runner/work/Fall2025CS452P3/Fall2025CS452P3/src/lab.c:101 Got negative hit value in: branch 3 taken -3182732 (fallthrough)  
This is caused by a bug in gcov tool, see  
https://gcc.gnu.org/bugzilla/show\_bug.cgi?id=68080. Use option  
--gcov-ignore-parse-errors with a value of negative\_hits.warn,  
or negative\_hits.warn\_once\_per\_file.  
(ERROR) Exiting because of parse errors.  
 You can run gcovr with --gcov-ignore-parse-errors=...  
 to continue anyway.  
::error::(ERROR) Exiting because of parse errors.  
 You can run gcovr with --gcov-ignore-parse-errors=...  
 to continue anyway.  
(ERROR) Traceback (most recent call last):  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/workers.py", line 96, in worker  
 work(\*args, \*\*kwargs)  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 477, in process\_datafile  
 done = run\_gcov\_and\_process\_files(  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 846, in run\_gcov\_and\_process\_files  
 process\_gcov\_text\_data(  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 266, in process\_gcov\_text\_data  
 filecov, source\_lines = text.parse\_coverage(  
 ^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 350, in parse\_coverage  
 \_report\_lines\_with\_errors(  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 566, in \_report\_lines\_with\_errors  
 raise errors[0] # guaranteed to have at least one exception  
 ^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 294, in parse\_coverage  
 \_parse\_line(  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 701, in \_parse\_line  
 tag = \_parse\_tag\_line(  
 ^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 834, in \_parse\_tag\_line  
 hits = check\_hits(  
 ^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/common.py", line 183, in check\_hits  
 NegativeHits.raise\_if\_not\_ignored(line, ignore\_parse\_errors, persistent\_states)  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/common.py", line 86, in raise\_if\_not\_ignored  
 raise NegativeHits(line, persistent\_states)  
gcovr.formats.gcov.parser.common.NegativeHits: /home/runner/work/Fall2025CS452P3/Fall2025CS452P3/src/lab.c:101 Got negative hit value in: branch 3 taken -3182732 (fallthrough)  
This is caused by a bug in gcov tool, see  
https://gcc.gnu.org/bugzilla/show\_bug.cgi?id=68080. Use option  
--gcov-ignore-parse-errors with a value of negative\_hits.warn,  
or negative\_hits.warn\_once\_per\_file.  
  
::error::(ERROR) Traceback (most recent call last):  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/workers.py", line 96, in worker  
 work(\*args, \*\*kwargs)  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 477, in process\_datafile  
 done = run\_gcov\_and\_process\_files(  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 846, in run\_gcov\_and\_process\_files  
 process\_gcov\_text\_data(  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 266, in process\_gcov\_text\_data  
 filecov, source\_lines = text.parse\_coverage(  
 ^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 350, in parse\_coverage  
 \_report\_lines\_with\_errors(  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 566, in \_report\_lines\_with\_errors  
 raise errors[0] # guaranteed to have at least one exception  
 ^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 294, in parse\_coverage  
 \_parse\_line(  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 701, in \_parse\_line  
 tag = \_parse\_tag\_line(  
 ^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/text.py", line 834, in \_parse\_tag\_line  
 hits = check\_hits(  
 ^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/common.py", line 183, in check\_hits  
 NegativeHits.raise\_if\_not\_ignored(line, ignore\_parse\_errors, persistent\_states)  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/parser/common.py", line 86, in raise\_if\_not\_ignored  
 raise NegativeHits(line, persistent\_states)  
gcovr.formats.gcov.parser.common.NegativeHits: /home/runner/work/Fall2025CS452P3/Fall2025CS452P3/src/lab.c:101 Got negative hit value in: branch 3 taken -3182732 (fallthrough)  
This is caused by a bug in gcov tool, see  
https://gcc.gnu.org/bugzilla/show\_bug.cgi?id=68080. Use option  
--gcov-ignore-parse-errors with a value of negative\_hits.warn,  
or negative\_hits.warn\_once\_per\_file.  
  
(ERROR) Error occurred while reading reports:  
Traceback (most recent call last):  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/\_\_main\_\_.py", line 398, in main  
 covdata = gcovr\_formats.read\_reports(options)  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/\_\_init\_\_.py", line 98, in read\_reports  
 covdata = GcovHandler(options).read\_report()  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/\_\_init\_\_.py", line 238, in read\_report  
 return read\_report(self.options)  
 ^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 93, in read\_report  
 contexts = pool.wait()  
 ^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/workers.py", line 208, in wait  
 raise RuntimeError(  
RuntimeError: Worker thread raised exception, workers canceled.  
  
::error::(ERROR) Error occurred while reading reports:  
Traceback (most recent call last):  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/\_\_main\_\_.py", line 398, in main  
 covdata = gcovr\_formats.read\_reports(options)  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/\_\_init\_\_.py", line 98, in read\_reports  
 covdata = GcovHandler(options).read\_report()  
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/\_\_init\_\_.py", line 238, in read\_report  
 return read\_report(self.options)  
 ^^^^^^^^^^^^^^^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/read.py", line 93, in read\_report  
 contexts = pool.wait()  
 ^^^^^^^^^^^  
 File "/opt/hostedtoolcache/Python/3.12.7/x64/lib/python3.12/site-packages/gcovr/formats/gcov/workers.py", line 208, in wait  
 raise RuntimeError(  
RuntimeError: Worker thread raised exception, workers canceled.  
  
make: \*\*\* [Makefile:138: report] Error 64

## Address Sanitizer Report

This section was generated by running make leak-test in the project root directory.

tests/lab-test.c:161:test\_mergesort\_s:PASS  
tests/lab-test.c:162:test\_split\_sizes\_indices:PASS  
tests/lab-test.c:163:test\_parallel\_sort:PASS  
tests/lab-test.c:164:test\_edge\_cases:PASS  
Stress test: array\_size=10000 threads=1 time=6.700928  
Stress test: array\_size=10000 threads=2 time=3.573975  
Stress test: array\_size=10000 threads=3 time=1.971924  
Stress test: array\_size=10000 threads=4 time=2.862061  
Stress test: array\_size=10000 threads=5 time=2.369141  
Stress test: array\_size=10000 threads=6 time=3.423096  
Stress test: array\_size=10000 threads=7 time=3.356934  
Stress test: array\_size=10000 threads=8 time=4.148926  
Stress test: array\_size=50000 threads=1 time=21.978027  
Stress test: array\_size=50000 threads=2 time=21.020020  
Stress test: array\_size=50000 threads=3 time=10.058105  
Stress test: array\_size=50000 threads=4 time=9.471924  
Stress test: array\_size=50000 threads=5 time=9.132080  
Stress test: array\_size=50000 threads=6 time=9.600098  
Stress test: array\_size=50000 threads=7 time=9.365967  
Stress test: array\_size=50000 threads=8 time=10.535889  
Stress test: array\_size=100000 threads=1 time=42.362793  
Stress test: array\_size=100000 threads=2 time=41.662109  
Stress test: array\_size=100000 threads=3 time=20.864014  
Stress test: array\_size=100000 threads=4 time=18.583008  
Stress test: array\_size=100000 threads=5 time=17.671143  
Stress test: array\_size=100000 threads=6 time=18.119873  
Stress test: array\_size=100000 threads=7 time=17.582031  
Stress test: array\_size=100000 threads=8 time=18.704834  
tests/lab-test.c:165:test\_stress\_sort:PASS  
  
-----------------------  
5 Tests 0 Failures 0 Ignored   
OK

## Src Files

### lab.c

#include <stdlib.h>  
#include <sys/time.h>  
#include "lab.h"  
#include <pthread.h>  
  
/\*  
 \* AI use: AI Assisted  
 \*/  
typedef struct {  
 int \*A;  
 int start;  
 int mid;  
 int end;  
 pthread\_mutex\_t \*merge\_lock; // pointer to global lock  
} merge\_task\_t;  
  
/\*  
 \* @brief Thread function for sorting  
 \*  
 \* @param arg The argument passed to the thread  
 \* @return NULL  
 \* AI use: AI Assisted  
 \*/  
void \*thread\_sort(void \*arg) {  
 parallel\_args\_t \*p = (parallel\_args\_t \*)arg;  
 mergesort\_s(p->A, p->start, p->end);  
 return NULL;  
}  
  
  
/\*\*  
 \* @brief Worker function for merging two sorted subarrays with locking  
 \*  
 \* @param arg The argument passed to the thread  
 \* @return NULL  
 \* AI use: AI Assisted  
 \*/  
static void \*merge\_worker(void \*arg) {  
 merge\_task\_t \*task = (merge\_task\_t \*)arg;  
  
 // Minimal lock: protects merge operation  
 pthread\_mutex\_lock(task->merge\_lock);  
 merge\_s(task->A, task->start, task->mid, task->end);  
 pthread\_mutex\_unlock(task->merge\_lock);  
  
 return NULL;  
}  
  
/\*\*  
 \* @brief Standard insertion sort that is faster than merge sort for small array's  
 \*  
 \* @param A The array to sort  
 \* @param p The starting index  
 \* @param r The ending index  
 \*/  
static void insertion\_sort(int A[], int p, int r)  
{  
 int j;  
  
 for (j = p + 1; j <= r; j++)  
 {  
 int key = A[j];  
 int i = j - 1;  
 while ((i > p - 1) && (A[i] > key))  
 {  
 A[i + 1] = A[i];  
 i--;  
 }  
 A[i + 1] = key;  
 }  
}  
  
  
void mergesort\_s(int A[], int p, int r)  
{  
 if (r - p + 1 <= INSERTION\_SORT\_THRESHOLD)  
 {  
 insertion\_sort(A, p, r);  
 }  
 else  
 {  
 int q = (p + r) / 2;  
 mergesort\_s(A, p, q);  
 mergesort\_s(A, q + 1, r);  
 merge\_s(A, p, q, r);  
 }  
  
}  
  
void merge\_s(int A[], int p, int q, int r)  
{  
 int \*B = (int \*)malloc(sizeof(int) \* (size\_t)(r - p + 1));  
  
 int i = p;  
 int j = q + 1;  
 int k = 0;  
 int l;  
  
 /\* as long as both lists have unexamined elements \*/  
 /\* this loop keeps executing. \*/  
 while ((i <= q) && (j <= r))  
 {  
 if (A[i] < A[j])  
 {  
 B[k] = A[i];  
 i++;  
 }  
 else  
 {  
 B[k] = A[j];  
 j++;  
 }  
 k++;  
 }  
  
 /\* now only at most one list has unprocessed elements. \*/  
 if (i <= q)  
 {  
 /\* copy remaining elements from the first list \*/  
 for (l = i; l <= q; l++)  
 {  
 B[k] = A[l];  
 k++;  
 }  
 }  
 else  
 {  
 /\* copy remaining elements from the second list \*/  
 for (l = j; l <= r; l++)  
 {  
 B[k] = A[l];  
 k++;  
 }  
 }  
  
 /\* copy merged output from array B back to array A \*/  
 k = 0;  
 for (l = p; l <= r; l++)  
 {  
 A[l] = B[k];  
 k++;  
 }  
  
 free(B);  
}  
  
  
/\*\*  
 \* @brief Computes the sizes for each split given the total size and number of threads  
 \*  
 \* @param A The array to split  
 \* @param n The size of the array  
 \* @param num\_threads The number of threads  
 \* @return int\* An array of sizes for each split  
 \* AI use: AI Assisted  
 \*/  
int \*split\_sizes(int n, int num\_threads) {  
 int working\_threads = (num\_threads <= 1) ? 1 : num\_threads - 1;  
  
 int \*sizes = malloc(sizeof(int) \* (size\_t)working\_threads);  
 if (working\_threads == 1) {  
 sizes[0] = n; // single-thread mode  
 return sizes;  
 }  
  
 int chunk\_remainder = n % working\_threads;  
 int avg\_chunk\_size = n / working\_threads;  
  
 for (int i = 0; i < working\_threads; i++) {  
 sizes[i] = (i == working\_threads - 1) ? avg\_chunk\_size + chunk\_remainder : avg\_chunk\_size;  
 }  
 return sizes;  
}  
  
/\*\*  
 \* @brief Computes the starting indices for each split given the sizes  
 \*  
 \* @param sizes The sizes of each split  
 \* @param num\_threads The number of threads  
 \* @return int\* An array of starting indices for each split  
 \* AI use: AI Assisted  
 \*/  
int \*split\_indices(int \*sizes, int num\_threads) {  
 int num\_splits = (num\_threads <= 1) ? 1 : num\_threads - 1;  
 int \*indices = malloc(sizeof(int) \* (size\_t)num\_splits);  
 indices[0] = 0;  
 for (int i = 1; i < num\_splits; i++) {  
 indices[i] = indices[i - 1] + sizes[i - 1];  
 }  
 return indices;  
}  
  
/\*\*  
 \* @brief Splits the array into num\_threads parts and fills in par\_args  
 \*  
 \* @param A The array to split  
 \* @param indices The starting indices of each split  
 \* @param num\_threads The number of threads  
 \* @return int\*\* An array of pointers to the start of each subarray  
 \* AI use: AI Assisted  
 \*/  
int \*\*split\_arrays\_even(int \*A, int \*indices, int num\_threads) {  
 int worker\_threads = num\_threads - 1;  
  
 int \*\*subarrays = malloc(sizeof(int \*) \* (size\_t)worker\_threads);  
 if (!subarrays) return NULL;  
  
 for (int i = 0; i < worker\_threads; i++) {  
 subarrays[i] = &A[indices[i]];  
 }  
  
 return subarrays;  
}  
  
/\*\*  
 \* @brief Splits the array into subarray with the remainder after even splits  
 \*  
 \* @param A The array to split  
 \* @param indices The starting indices of each split  
 \* @param num\_threads The number of threads  
 \* @return int\*\* An array of pointers to the start of each subarray  
 \* AI use: AI Assisted  
 \*/  
int \*\*split\_arrays\_remainder(int \*A, int \*indices, int num\_threads) {  
 int worker\_threads = num\_threads - 1;  
  
 int \*\*remainder\_subarray = malloc(sizeof(int \*));  
 if (!remainder\_subarray) return NULL;  
  
 remainder\_subarray[0] = &A[indices[worker\_threads - 1]];  
 return remainder\_subarray;  
}  
  
/\*\*  
 \* @brief Multi-threaded mergesort  
 \*  
 \* @param A The array to sort  
 \* @param n The size of the array  
 \* @param num\_threads The number of threads to use  
 \* AI use: AI Assisted  
 \*/  
void mergesort\_mt(int \*A, int n, int num\_threads) {  
 if (num\_threads < 2) {  
 mergesort\_s(A, 0, n - 1);  
 return;  
 }  
  
 int worker\_threads = num\_threads - 1;  
 parallel\_args\_t \*par\_args = malloc(sizeof(parallel\_args\_t) \* (size\_t)worker\_threads);  
  
 int \*sizes = split\_sizes(n, num\_threads);  
 int \*indices = split\_indices(sizes, num\_threads);  
 int \*\*subarrays = split\_arrays\_even(A, indices, num\_threads);  
  
 // Launch worker threads  
 for (int i = 0; i < worker\_threads; i++) {  
 par\_args[i].A = subarrays[i];  
 par\_args[i].start = 0;  
 par\_args[i].end = sizes[i] - 1;  
 pthread\_create(&par\_args[i].tid, NULL, parallel\_mergesort, &par\_args[i]);  
 }  
  
 // Wait for all workers  
 for (int i = 0; i < worker\_threads; i++) {  
 pthread\_join(par\_args[i].tid, NULL);  
 }  
  
 // Merge all sorted segments in the main thread  
 merge\_all\_tree\_parallel\_locked(A, indices, sizes, num\_threads);  
  
 free(sizes);  
 free(indices);  
 free(subarrays);  
}  
  
/\*\*  
 \* @brief Merges all sorted segments in a tree-like fashion using multiple threads with locking  
 \*  
 \* @param A The array to merge  
 \* @param indices The starting indices of each sorted segment  
 \* @param sizes The sizes of each sorted segment  
 \* @param num\_threads The number of threads used for sorting  
 \* AI use: AI Assisted  
 \*/  
void merge\_all\_tree\_parallel\_locked(int \*A, int \*indices, int \*sizes, int num\_threads) {  
 int worker\_threads = num\_threads - 1;  
 int level\_size = worker\_threads;  
  
 pthread\_mutex\_t merge\_lock = PTHREAD\_MUTEX\_INITIALIZER;  
  
 int \*new\_indices = malloc((size\_t)level\_size \* sizeof(int));  
 int \*new\_sizes = malloc((size\_t)level\_size \* sizeof(int));  
  
 while (level\_size > 1) {  
 int merge\_pairs = level\_size / 2;  
  
 pthread\_t \*threads = malloc(sizeof(pthread\_t) \* (size\_t)merge\_pairs);  
 merge\_task\_t \*tasks = malloc(sizeof(merge\_task\_t) \* (size\_t)merge\_pairs);  
  
 int new\_count = 0;  
 int t = 0;  
  
 for (int i = 0; i < level\_size; i += 2) {  
 if (i + 1 < level\_size) {  
 int start = indices[i];  
 int mid = indices[i] + sizes[i] - 1;  
 int end = indices[i + 1] + sizes[i + 1] - 1;  
  
 tasks[t].A = A;  
 tasks[t].start = start;  
 tasks[t].mid = mid;  
 tasks[t].end = end;  
 tasks[t].merge\_lock = &merge\_lock;  
  
 pthread\_create(&threads[t], NULL, merge\_worker, &tasks[t]);  
 t++;  
  
 new\_indices[new\_count] = start;  
 new\_sizes[new\_count] = sizes[i] + sizes[i + 1];  
 new\_count++;  
 } else {  
 // Odd one out — carry forward  
 new\_indices[new\_count] = indices[i];  
 new\_sizes[new\_count] = sizes[i];  
 new\_count++;  
 }  
 }  
  
 // Wait for all merges at this level  
 for (int j = 0; j < merge\_pairs; j++) {  
 pthread\_join(threads[j], NULL);  
 }  
  
 // Prepare next level  
 for (int j = 0; j < new\_count; j++) {  
 indices[j] = new\_indices[j];  
 sizes[j] = new\_sizes[j];  
 }  
  
 free(threads);  
 free(tasks);  
 level\_size = new\_count;  
 }  
  
 free(new\_indices);  
 free(new\_sizes);  
 pthread\_mutex\_destroy(&merge\_lock);  
}  
  
/\*\*  
 \* @brief The function that is called by each thread to sort their chunk  
 \*  
 \* @param args see struct parallel\_args  
 \* @return void\* always NULL  
 \* AI use: AI Assisted  
 \*/  
void \*parallel\_mergesort(void \*args) {  
 parallel\_args\_t \*parg = (parallel\_args\_t \*)args;  
 mergesort\_s(parg->A, parg->start, parg->end);  
 return NULL;  
}  
  
double getMilliSeconds()  
{  
 struct timeval now;  
 gettimeofday(&now, (struct timezone \*)0);  
 return (double)now.tv\_sec \* 1000.0 + (double)now.tv\_usec / 1000.0;  
}

### lab.h

#ifndef LAB\_H  
#define LAB\_H  
#include <pthread.h>  
  
#ifdef \_\_cplusplus  
extern "C"  
{  
#endif  
  
 // The threshold that we will use to switch to insertion sort, make sure that  
 // you use test arrays bigger than 5 so you are testing the merge sort  
#define INSERTION\_SORT\_THRESHOLD 5  
#define MAX\_THREADS 64  
 /\*\*  
 \* @brief Sorts an array of ints into ascending order using the constant  
 \* INSERTION\_SORT\_THRESHOLD internally  
 \*  
 \* @param A A pointer to the start of the array  
 \* @param p The starting index  
 \* @param r The ending index  
 \*/  
 void mergesort\_s(int \*A, int p, int r);  
  
 /\*\*  
 \* @brief Merge two sorted sequences A[p..q] and A[q+1..r] and place merged  
 \* output back in array A. Uses extra space proportional to  
 \* A[p..r].  
 \*  
 \* @param A The array to merge into  
 \* @param p The starting index of the first half  
 \* @param q The middle  
 \* @param r The ending index of the second half  
 \*/  
 void merge\_s(int A[], int p, int q, int r);  
  
 /\*\*  
 \* @brief Sorts an array of ints into ascending order using multiple  
 \* threads  
 \*  
 \* @param A A pointer to the start of the array  
 \* @param n The size of the array  
 \* @param num\_threads The number of threads to use.  
 \*/  
 void mergesort\_mt(int \*A, int n, int num\_thread);  
  
 /\*\*  
 \* @brief retuns the current time as milliseconds  
 \* @return the number of milliseconds  
 \*/  
 double getMilliSeconds();  
  
 /\*\*  
 \* @brief Represents a chunk of the array to be sorted by a thread  
 \* AI use: AI Assisted  
 \*  
 \*/  
typedef struct parallel\_args {  
 int \*A;  
 int start;  
 int end;  
 pthread\_t tid;  
} parallel\_args\_t;  
  
 /\*\*  
 \* @brief The function that is called by each thread to sort their chunk  
 \*  
 \* @param args see struct parallel\_args  
 \* @return void\* always NULL  
 \* AI use: AI Assisted  
 \*/  
 void \*parallel\_mergesort(void \*args);  
  
   
 /\*\*  
 \* @brief Splits the array into num\_threads parts and fills in par\_args  
 \*  
 \* @param n The size of the array  
 \* @param num\_threads The number of threads  
 \* @return int\* An array of sizes for each split  
 \* AI use: AI Assited  
 \*/  
 int \*split\_sizes(int n, int num\_threads);  
  
 /\*\*  
 \* @brief Computes the starting indices for each split given the sizes  
 \*  
 \* @param sizes The sizes of each split  
 \* @param num\_threads The number of threads  
 \* @return int\* An array of starting indices for each split  
 \* AI use: AI Assisted  
 \*/  
 int \*split\_indices(int \*sizes, int num\_threads);  
  
 /\*\*  
 \* @brief Splits the array into num\_threads subarrays  
 \*  
 \* @param A The array to split  
 \* @param indices The starting indices of each split  
 \* @param num\_threads The number of threads  
 \* @return int\*\* An array of pointers to the start of each subarray  
 \* AI use: AI Assisted  
 \*/  
 int \*\*split\_arrays\_even(int \*A, int \*indices, int num\_threads);  
  
 /\*\*  
 \* @brief Splits the array into subarray with the remainder after even splits  
 \*  
 \* @param A The array to split  
 \* @param indices The starting indices of each split  
 \* @param num\_threads The number of threads  
 \* @return int\*\* An array of pointers to the start of each subarray  
 \* AI use: AI Assisted  
 \*/  
 int \*\*split\_arrays\_remainder(int \*A, int \*indices, int num\_threads);  
  
 /\*\*  
 \* @brief Merges all sorted segments in a tree-like fashion  
 \*  
 \* @param A The array to merge  
 \* @param indices The starting indices of each segment  
 \* @param sizes The sizes of each segment  
 \* @param num\_threads The number of threads used (to determine segments)  
 \* AI use: AI Assisted  
 \*/  
 void merge\_all\_tree\_parallel\_locked(int \*A, int \*indices, int \*sizes, int num\_threads);  
  
  
 /\*\*  
 \* @brief Worker thread function to sort a segment  
 \*  
 \* @param arg The parallel\_args\_t pointer  
 \* @return void\* always NULL  
 \* AI use: AI Assisted  
 \*/  
 void \*thread\_sort(void \*arg);  
  
 /\*\*  
 \* @brief Entry point for the main function  
 \*  
 \* @param argc The argument count  
 \* @param argv The argument array  
 \* @return The exit code  
 \*/  
 int myMain(int argc, char \*\*argv);  
  
#ifdef \_\_cplusplus  
} // extern "C"  
#endif  
  
#endif

### main.c

#include <stdio.h>  
#include <stdlib.h>  
#include <pthread.h>  
#include "lab.h"  
  
#ifndef TEST  
  
  
/\*\*  
 \* @brief Main function to run multi-threaded mergesort  
 \*  
 \* @param argc Argument count  
 \* @param argv Argument values  
 \* @return int Exit status  
 \* AI use: AI Assisted  
 \*/  
  
int main(int argc, char \*\*argv) {  
 if (argc < 3) {  
 printf("usage: %s <array\_size> <num\_threads>\n", argv[0]);  
 return 1;  
 }  
  
 int array\_size = atoi(argv[1]);  
 int num\_threads = atoi(argv[2]);  
 if (num\_threads < 1) num\_threads = 1; // enforce minimum  
 if (num\_threads > MAX\_THREADS) num\_threads = MAX\_THREADS; // enforce maximum  
  
 // Allocate and initialize array  
 int \*A = malloc(sizeof(int) \* (size\_t)array\_size);  
 for (int i = 0; i < array\_size; i++)  
 A[i] = rand() % 10000;  
  
 // Split array  
 int \*sizes = split\_sizes(array\_size, num\_threads);  
 int \*indices = split\_indices(sizes, num\_threads);  
  
 int worker\_threads = (num\_threads <= 1) ? 0 : num\_threads - 1;  
 parallel\_args\_t \*par\_args = (worker\_threads > 0) ?  
 malloc(sizeof(parallel\_args\_t) \* (size\_t)worker\_threads) : NULL;  
  
 double start = getMilliSeconds();  
  
 if (worker\_threads == 0) {  
 // Single-thread mode  
 mergesort\_s(A, 0, array\_size - 1);  
 } else {  
 // Multi-thread mode  
 for (int i = 0; i < worker\_threads; i++) {  
 par\_args[i].A = A;  
 par\_args[i].start = indices[i];  
 par\_args[i].end = indices[i] + sizes[i] - 1;  
 pthread\_create(&par\_args[i].tid, NULL, thread\_sort, &par\_args[i]);  
 }  
  
 for (int i = 0; i < worker\_threads; i++) {  
 pthread\_join(par\_args[i].tid, NULL);  
 }  
  
 merge\_all\_tree\_parallel\_locked(A, indices, sizes, num\_threads);  
 }  
  
 double end = getMilliSeconds();  
  
 printf("%d %f\n", num\_threads, end - start);  
  
 free(A);  
 free(sizes);  
 free(indices);  
 if (par\_args) free(par\_args);  
  
 return 0;  
}  
#endif

## Tests Files

### lab-test.c

#include <stdlib.h>  
#include <stdio.h>  
#include <string.h>  
#include "harness/unity.h"  
#include "../src/lab.h"  
#include <time.h>  
  
/\* AI use: AI Assisted \*/  
  
// ----------------------- Test Setup ------------------------//  
  
void setUp(void) { /\* Nothing to setup for now \*/ }  
void tearDown(void) { /\* Nothing to cleanup \*/ }  
  
// Helper: check if array is sorted ascending  
int is\_sorted(int \*A, int n) {  
 for (int i = 1; i < n; i++) {  
 if (A[i - 1] > A[i]) return 0;  
 }  
 return 1;  
}  
  
// --------------------------- Tests ---------------------------  
  
  
/\*AI use: AI Assisted\*/  
// Test single-threaded mergesort  
void test\_mergesort\_s(void) {  
 int A[] = {5, 2, 9, 1, 5, 6};  
 int n = sizeof(A) / sizeof(A[0]);  
 mergesort\_s(A, 0, n - 1);  
 TEST\_ASSERT\_TRUE(is\_sorted(A, n));  
}  
  
//AI use: AI Assisted  
// Test multi-threaded array split  
void test\_split\_sizes\_indices(void) {  
 int n = 10;  
 int num\_threads = 3;  
 int \*A = malloc(sizeof(int) \* n);  
 for (int i = 0; i < n; i++) A[i] = i;  
  
 int \*sizes = split\_sizes(n, num\_threads);  
 int \*indices = split\_indices(sizes, num\_threads);  
  
 int sum = 0;  
 for (int i = 0; i < num\_threads - 1; i++) sum += sizes[i];  
 TEST\_ASSERT\_EQUAL\_INT(n, sum + (n % (num\_threads - 1))); // sum of sizes matches array  
  
 TEST\_ASSERT\_EQUAL\_INT(0, indices[0]);  
 TEST\_ASSERT\_EQUAL\_INT(sizes[0], indices[1]);  
  
 free(A);  
 free(sizes);  
 free(indices);  
}  
  
//AI use: AI Assisted  
// Test multi-threaded sorting  
void test\_parallel\_sort(void) {  
 int n = 20;  
 int num\_threads = 4;  
 int \*A = malloc(sizeof(int) \* n);  
 for (int i = 0; i < n; i++) A[i] = rand() % 100;  
  
 int \*sizes = split\_sizes(n, num\_threads);  
 int \*indices = split\_indices(sizes, num\_threads);  
  
 int worker\_threads = num\_threads - 1;  
 parallel\_args\_t \*par\_args = malloc(sizeof(parallel\_args\_t) \* worker\_threads);  
  
 for (int i = 0; i < worker\_threads; i++) {  
 par\_args[i].A = A;  
 par\_args[i].start = indices[i];  
 par\_args[i].end = indices[i] + sizes[i] - 1;  
 pthread\_create(&par\_args[i].tid, NULL, thread\_sort, &par\_args[i]);  
 }  
  
 for (int i = 0; i < worker\_threads; i++)  
 pthread\_join(par\_args[i].tid, NULL);  
  
 merge\_all\_tree\_parallel\_locked(A, indices, sizes, num\_threads);  
  
 TEST\_ASSERT\_TRUE(is\_sorted(A, n));  
  
 free(A);  
 free(sizes);  
 free(indices);  
 free(par\_args);  
}  
  
//AI use: AI Assisted  
// Test edge cases: empty array, single-element array  
void test\_edge\_cases(void) {  
 int A1[] = {};  
 mergesort\_s(A1, 0, -1); // Should not crash  
 TEST\_ASSERT\_TRUE(1); // Just checking no crash  
  
 int A2[] = {42};  
 mergesort\_s(A2, 0, 0);  
 TEST\_ASSERT\_TRUE(A2[0] == 42);  
}  
  
//AI use: AI Assisted  
// Stress test with larger arrays and varying thread counts  
void test\_stress\_sort(void) {  
 const int sizes[] = {10000, 50000, 100000};  
 const int max\_threads = 8; // adjust as needed  
 for (int s = 0; s < sizeof(sizes)/sizeof(sizes[0]); s++) {  
 int n = sizes[s];  
 int \*A = malloc(sizeof(int) \* n);  
 for (int i = 0; i < n; i++) A[i] = rand() % 100000;  
  
 for (int num\_threads = 1; num\_threads <= max\_threads; num\_threads++) {  
 int \*copy = malloc(sizeof(int) \* n);  
 memcpy(copy, A, sizeof(int) \* n);  
  
 int \*sizes\_split = split\_sizes(n, num\_threads);  
 int \*indices\_split = split\_indices(sizes\_split, num\_threads);  
  
 int worker\_threads = (num\_threads <= 1) ? 0 : num\_threads - 1;  
 parallel\_args\_t \*par\_args = (worker\_threads > 0) ?  
 malloc(sizeof(parallel\_args\_t) \* worker\_threads) : NULL;  
  
 double start = getMilliSeconds();  
  
 if (worker\_threads == 0) {  
 mergesort\_s(copy, 0, n - 1);  
 } else {  
 for (int i = 0; i < worker\_threads; i++) {  
 par\_args[i].A = copy;  
 par\_args[i].start = indices\_split[i];  
 par\_args[i].end = indices\_split[i] + sizes\_split[i] - 1;  
 pthread\_create(&par\_args[i].tid, NULL, (void\*(\*)(void\*))thread\_sort, &par\_args[i]);  
 }  
  
 for (int i = 0; i < worker\_threads; i++)  
 pthread\_join(par\_args[i].tid, NULL);  
  
 merge\_all\_tree\_parallel\_locked(copy, indices\_split, sizes\_split, num\_threads);  
 }  
  
 double end = getMilliSeconds();  
 printf("Stress test: array\_size=%d threads=%d time=%f\n", n, num\_threads, end - start);  
  
 TEST\_ASSERT\_TRUE(is\_sorted(copy, n));  
  
 free(copy);  
 if (par\_args) free(par\_args);  
 free(sizes\_split);  
 free(indices\_split);  
 }  
 free(A);  
 }  
}  
  
/\* AI use: AI Assisted \*/  
// ----------------------- Test Runner ------------------------//  
int main(void) {  
 UNITY\_BEGIN();  
 RUN\_TEST(test\_mergesort\_s);  
 RUN\_TEST(test\_split\_sizes\_indices);  
 RUN\_TEST(test\_parallel\_sort);  
 RUN\_TEST(test\_edge\_cases);  
 RUN\_TEST(test\_stress\_sort);  
 return UNITY\_END();  
}

## Scripts Files

### createplot.sh

#!/usr/bin/env bash  
function usage() {  
 echo "$0 usage:" && grep " .)\ #" $0  
 exit 0  
}  
[ $# -eq 0 ] && usage  
while getopts "hs:f:" arg; do  
 case $arg in  
 s) # The size of the array to sort.  
 size=${OPTARG}  
 ;;  
 f) # The plot file name  
 name=${OPTARG}  
 ;;  
 h | \*) # Display help.  
 usage  
 exit 0  
 ;;  
 esac  
done  
MYAPP="../build/release/myapp"  
  
if [ "$name" == "" ] || [ "$size" == "" ]  
then  
 usage  
 exit 0  
fi  
if [ -e $MYAPP ]; then  
 if [ -e "data.dat" ]; then  
 rm -f data.dat  
 fi  
 echo "Running myprogram to generate data"  
 echo "#Time Threads" >> data.dat  
 for n in {1..64}; do  
 echo -ne "running $n thread \r"  
 $MYAPP "$size" "$n" >> data.dat  
 done  
 gnuplot -e "filename='$name.png'" graph.plt  
 echo "Created plot $name.png from data.dat file"  
else  
 echo "myapp is not present in the build directory. Did you compile your code?"  
fi

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## End of Report

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Do not edit the generated report. Any changes will be reported as academic dishonesty

## GitHub Info

* GitHub repo name: JonFlores3475/Fall2025CS452P3
* The repository visibility is public.
* The workflow was triggered by JonFlores3475