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Overview

The main goal is calculating the average angular distance between 30,000 stars in the Tycho Star Catalogue. The average is calculated by comparing each star to the other 29,999 stars. This process is time inefficient due to the program calculating the average one star at a time. Utilizing multithreading allows the program to run efficiently by using a “divide and conquer” technique.

Solution Summary

In order to achieve the goal of multithreading the given code must be altered. Altering the code to include multithreading would require the implantation of the pthread.h library, splitting the array of stars into equal pieces for each thread to run, and ensuring that the program knows when the start and end index occurs per piece of the array. To compare the run time of the program, a timing method is required in order to determine what number of threads yields the most time efficiency.

Program Timer

The method of capturing time is by inserting “time” in the command line before running the program. This method gives an accurate and consistent measurement of time when looking at the “real” time printed at the end of the program. Another method of calculating time was by importing the time.h library and using the clock function. This attempt would ultimately fail due to the inconsistency between the time produced and the actual time. An example of inconsistency can be seen in Figure 3.0 where the actual time is accurate and the time recorded with the time.h library is significantly different. The use of deadlocking via Mutex can be used to ensure the program runs without error. However, when using a deadlock, the run time of the program increases significantly which makes deadlocking obsolete. An example of deadlocking increasing time can be seen in Figure 4.0 and the calculated average, min, and max are relatively similar to the program running without the deadlock. A chart and table of the relationship between runtime and the number of threads are provided in Figure 1.0 and Figure 2.0 respectively.

Data Collection Process

Each entry of data is collected by running the program with the line “time ./findAngular -t #” where # is the number of threads.

Conclusion

In conclusion, running the program with 2 threads yields the best run time. One reason this is the case is that the program is run through Codespace which may run the program with 1 core and 2 threads. There is an anomaly in the average angular distance each time the program runs. However, the average does not deviate too extreme.

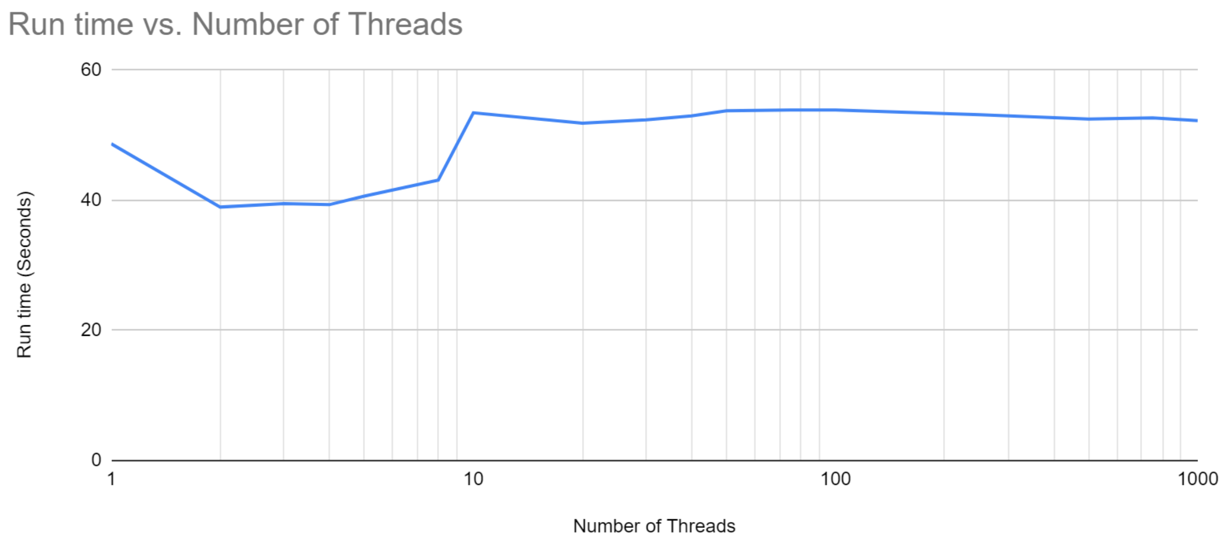
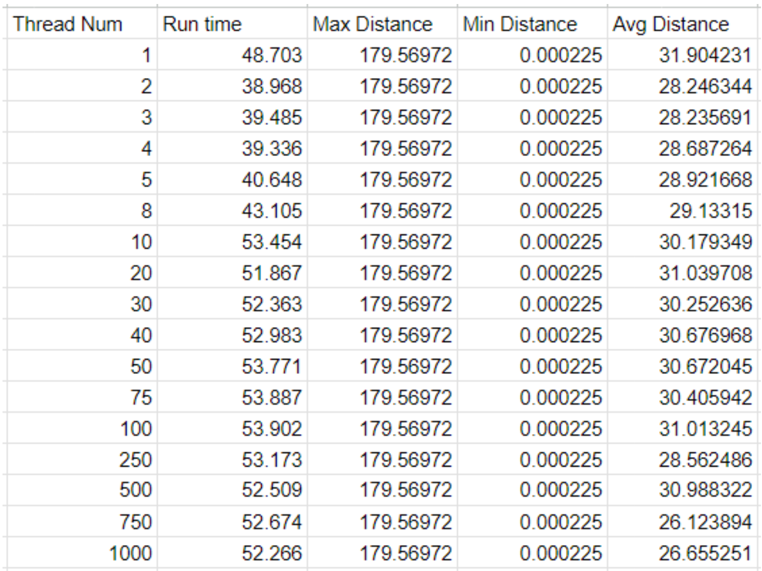
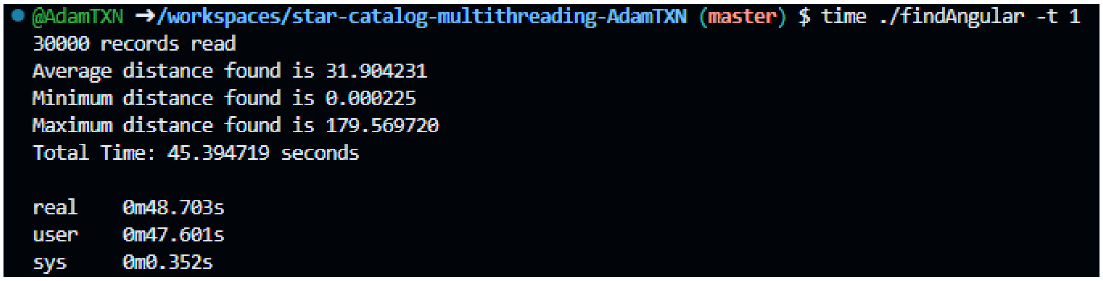


Figure 1.0
Graph of Run time vs Number of Threads. The x-axis is shown in a logarithmic scale.



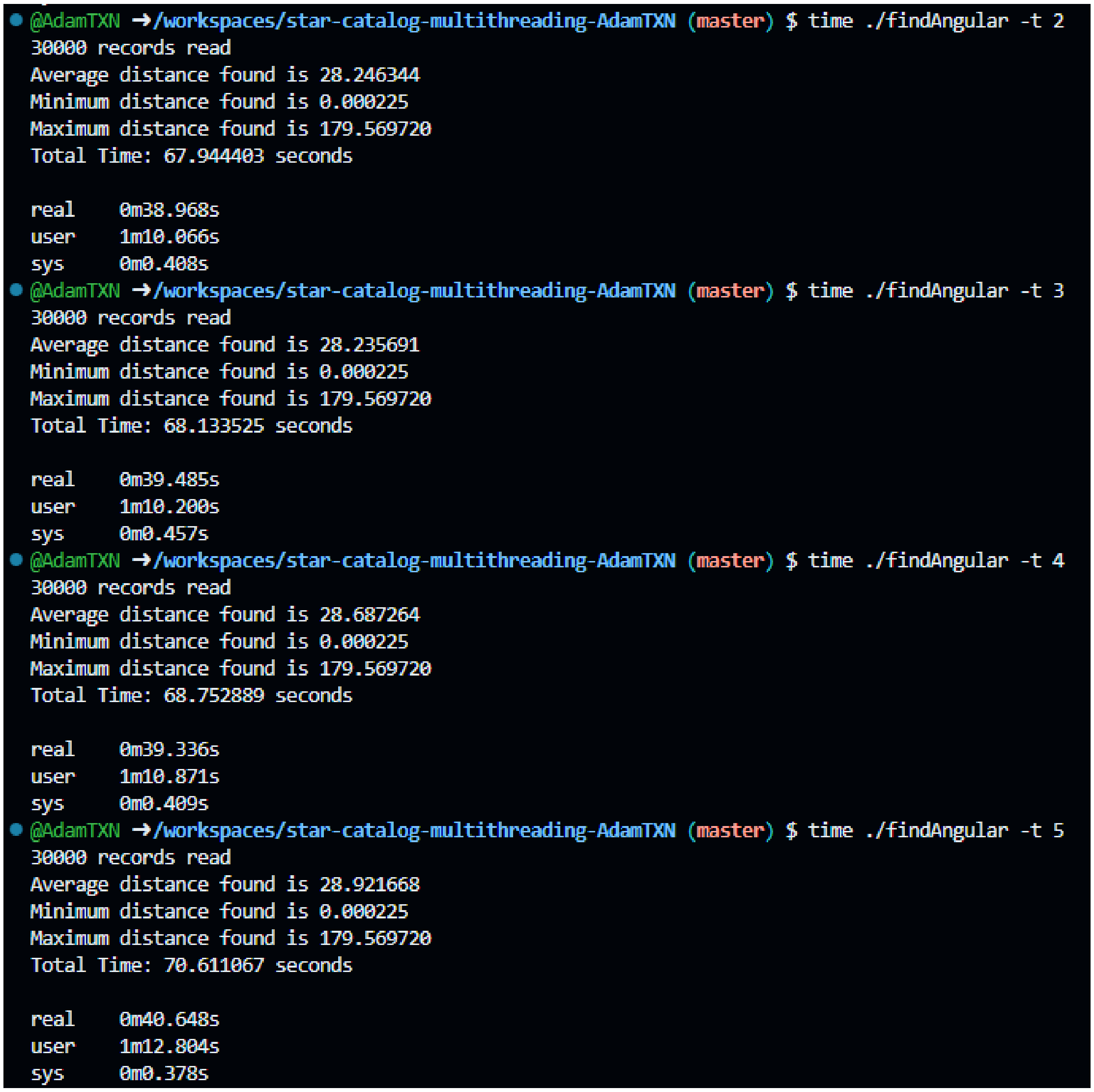
Thread Num	Run time	Max Distance	Min Distance	Avg Distance
1	48.703	179.56972	0.000225	31.904231
2	38.968	179.56972	0.000225	28.246344
3	39.485	179.56972	0.000225	28.235691
4	39.336	179.56972	0.000225	28.687264
5	40.648	179.56972	0.000225	28.921668
8	43.105	179.56972	0.000225	29.13315
10	53.454	179.56972	0.000225	30.179349
20	51.867	179.56972	0.000225	31.039708
30	52.363	179.56972	0.000225	30.252636
40	52.983	179.56972	0.000225	30.676968
50	53.771	179.56972	0.000225	30.672045
75	53.887	179.56972	0.000225	30.405942
100	53.902	179.56972	0.000225	31.013245
250	53.173	179.56972	0.000225	28.562486
500	52.509	179.56972	0.000225	30.988322
750	52.674	179.56972	0.000225	26.123894
1000	52.266	179.56972	0.000225	26.655251

Figure 2.0
Table of data recorded from running the program with no deadlocks and by initializing the number of threads in the command line.



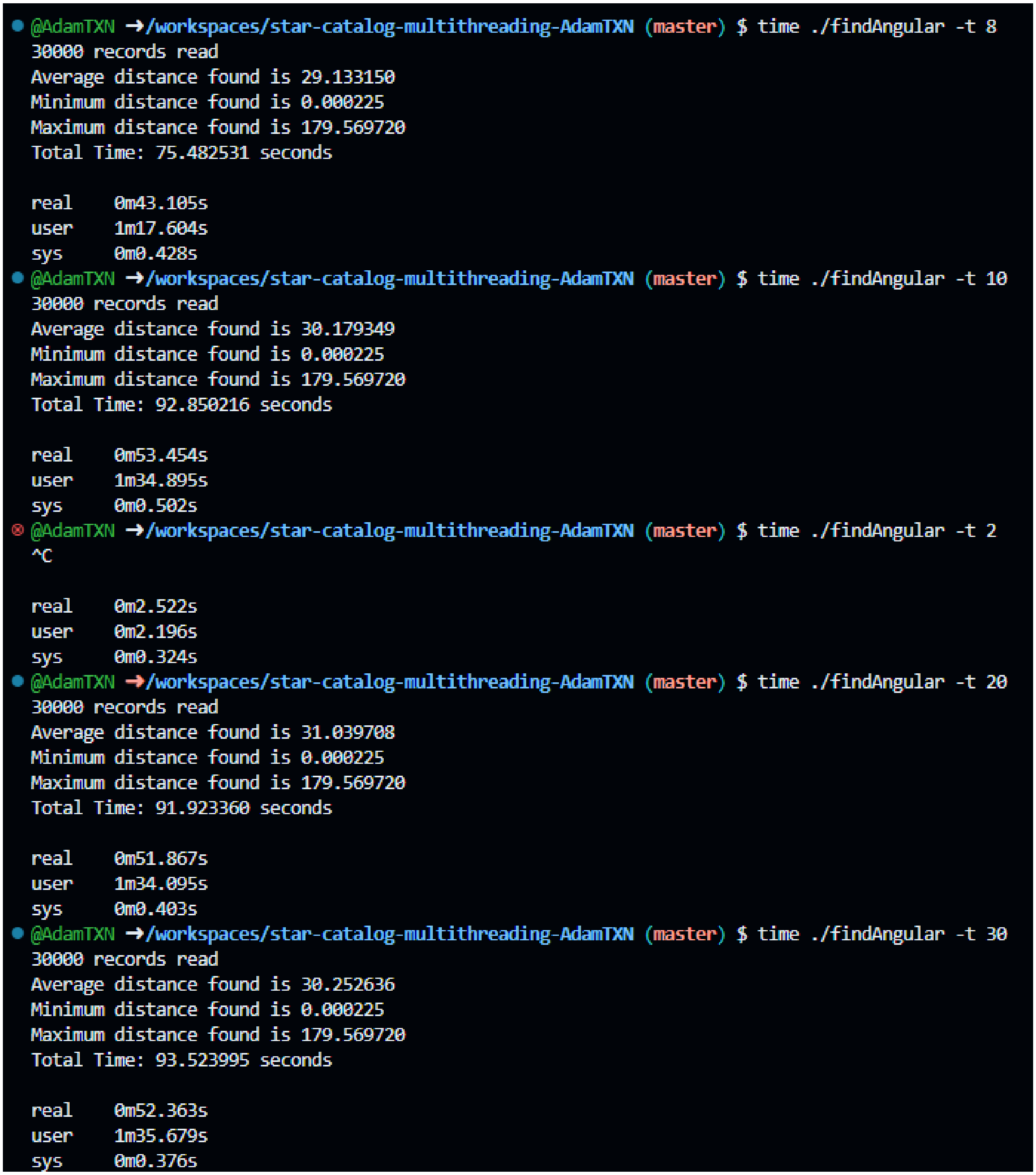
```
@AdamTXN →/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 1
30000 records read
Average distance found is 31.904231
Minimum distance found is 0.000225
Maximum distance found is 179.569720
Total Time: 45.394719 seconds

real    0m48.703s
user    0m47.601s
sys     0m0.352s
```

Figure 2.1
The program print statement after running with 1 thread, with no deadlocks.



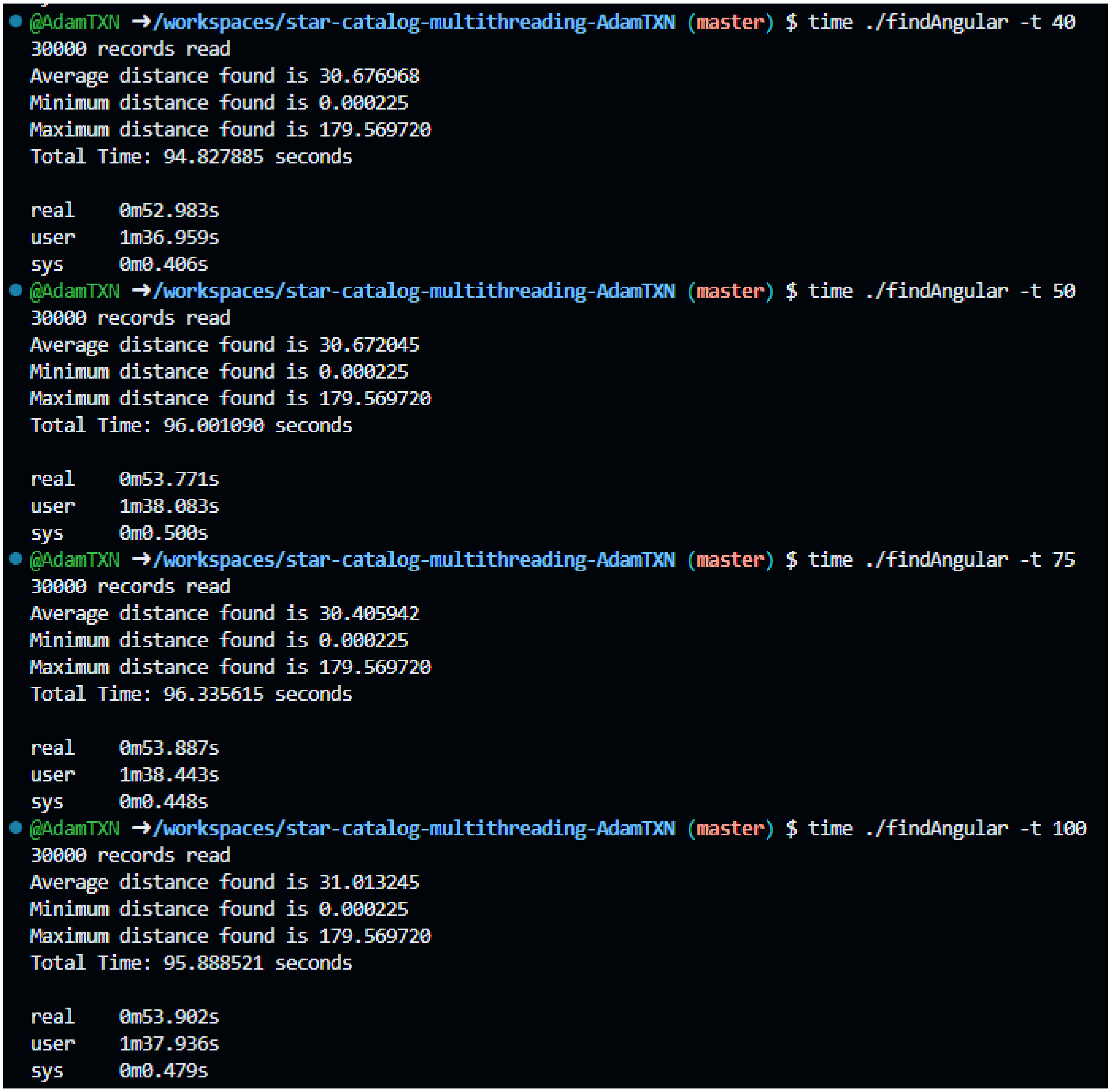
```
@AdamTXN →/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 2
30000 records read
Average distance found is 28.246344
Minimum distance found is 0.000225
Maximum distance found is 179.569720
Total Time: 67.944403 seconds

real    0m38.968s
user    1m10.066s
sys     0m0.408s
@AdamTXN →/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 3
30000 records read
Average distance found is 28.235691
Minimum distance found is 0.000225
Maximum distance found is 179.569720
Total Time: 68.133525 seconds

real    0m39.485s
user    1m10.200s
sys     0m0.457s
@AdamTXN →/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 4
30000 records read
Average distance found is 28.687264
Minimum distance found is 0.000225
Maximum distance found is 179.569720
Total Time: 68.752889 seconds

real    0m39.336s
user    1m10.871s
sys     0m0.409s
@AdamTXN →/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 5
30000 records read
Average distance found is 28.921668
Minimum distance found is 0.000225
Maximum distance found is 179.569720
Total Time: 70.611067 seconds

real    0m40.648s
user    1m12.804s
sys     0m0.378s
```

Figure 2.2
The program print statement after running with 2 to 5 threads, with no deadlocks.



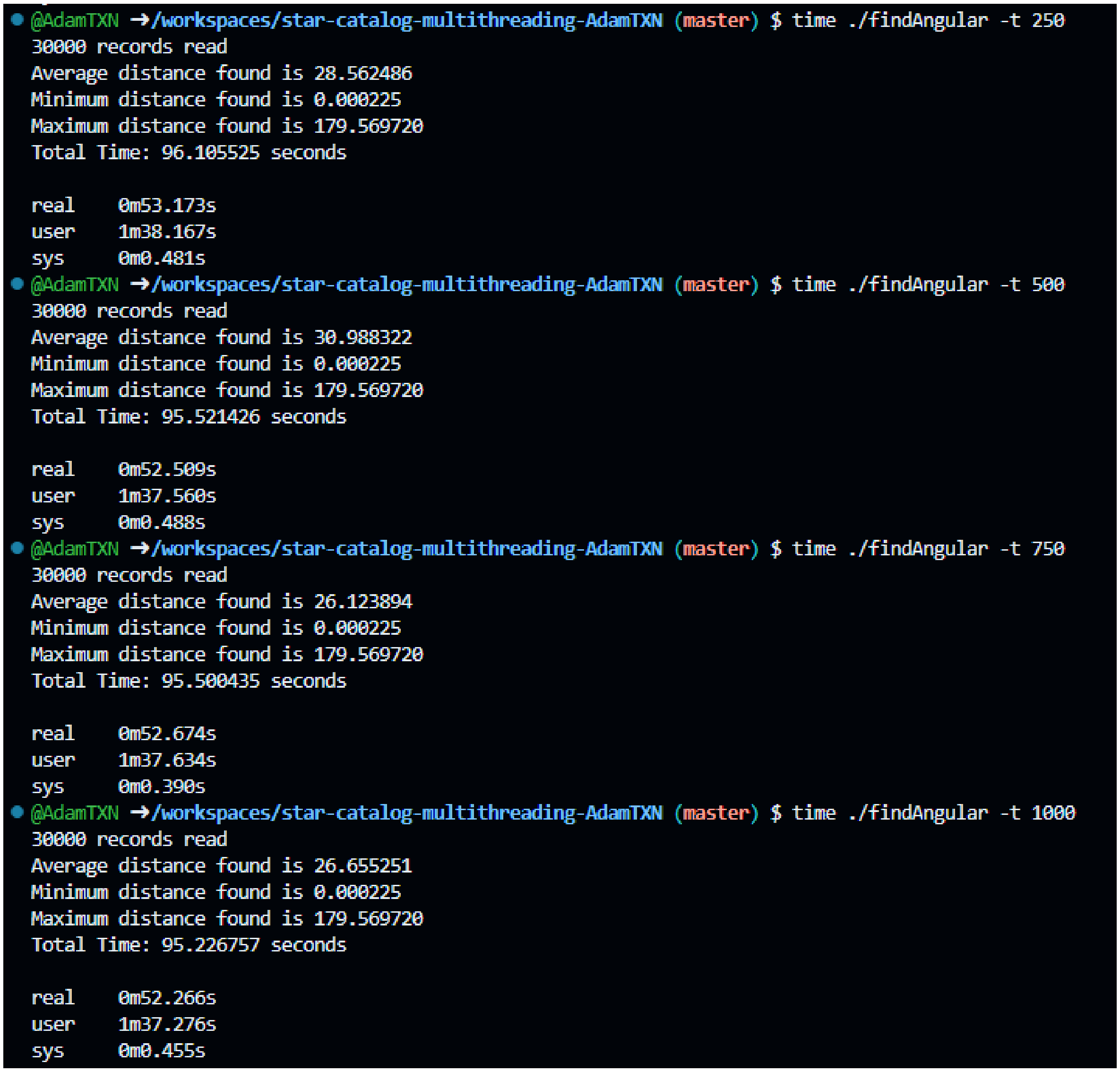
```
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 8
  30000 records read
  Average distance found is 29.133150
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 75.482531 seconds

  real    0m43.105s
  user    1m17.604s
  sys     0m0.428s
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 10
  30000 records read
  Average distance found is 30.179349
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 92.850216 seconds

  real    0m53.454s
  user    1m34.895s
  sys     0m0.502s
⊗ @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 2
  ^C

  real    0m2.522s
  user    0m2.196s
  sys     0m0.324s
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 20
  30000 records read
  Average distance found is 31.039708
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 91.923360 seconds

  real    0m51.867s
  user    1m34.095s
  sys     0m0.403s
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 30
  30000 records read
  Average distance found is 30.252636
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 93.523995 seconds

  real    0m52.363s
  user    1m35.679s
  sys     0m0.376s
```

Figure 2.3
The program print statement after running with 8, 10, 20, and 30 threads, with no deadlocks.



```
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 40
  30000 records read
  Average distance found is 30.676968
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 94.827885 seconds

  real    0m52.983s
  user    1m36.959s
  sys     0m0.406s
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 50
  30000 records read
  Average distance found is 30.672045
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 96.001090 seconds

  real    0m53.771s
  user    1m38.083s
  sys     0m0.500s
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 75
  30000 records read
  Average distance found is 30.405942
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 96.335615 seconds

  real    0m53.887s
  user    1m38.443s
  sys     0m0.448s
● @AdamTXN ➜/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 100
  30000 records read
  Average distance found is 31.013245
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 95.888521 seconds

  real    0m53.902s
  user    1m37.936s
  sys     0m0.479s
```

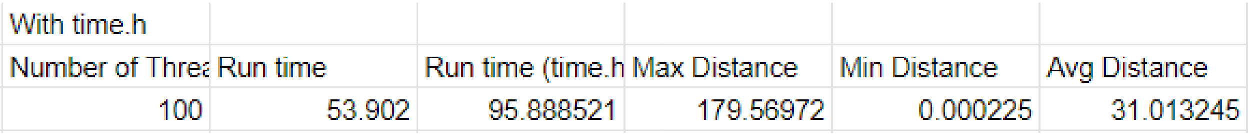
Figure 2.4
The program print statement after running with 40, 50, 75, and 100 threads, with no deadlocks.



```
● @AdamTXN ➜ /workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 250
  30000 records read
  Average distance found is 28.562486
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 96.105525 seconds

  real    0m53.173s
  user    1m38.167s
  sys     0m0.481s
● @AdamTXN ➜ /workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 500
  30000 records read
  Average distance found is 30.988322
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 95.521426 seconds

  real    0m52.509s
  user    1m37.560s
  sys     0m0.488s
● @AdamTXN ➜ /workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 750
  30000 records read
  Average distance found is 26.123894
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 95.500435 seconds

  real    0m52.674s
  user    1m37.634s
  sys     0m0.390s
● @AdamTXN ➜ /workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 1000
  30000 records read
  Average distance found is 26.655251
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 95.226757 seconds

  real    0m52.266s
  user    1m37.276s
  sys     0m0.455s
```

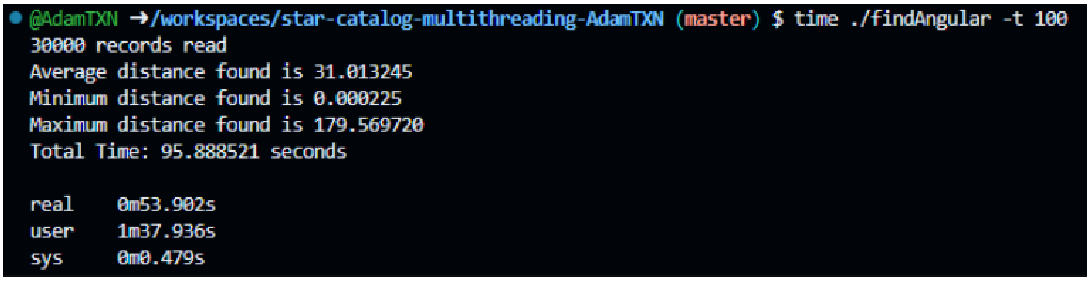
Figure 2.5

The program print statement after running with 250, 500, 750, and 1000 threads, with no deadlocks.



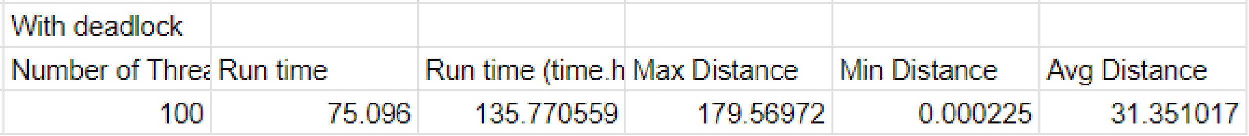
With time.h					
Number of Threa	Run time	Run time (time.h	Max Distance	Min Distance	Avg Distance
100	53.902	95.888521	179.56972	0.000225	31.013245

Figure 3.0
Inconsistency is shown between the run time shown when inserting "time" into the command line and the time.h library.



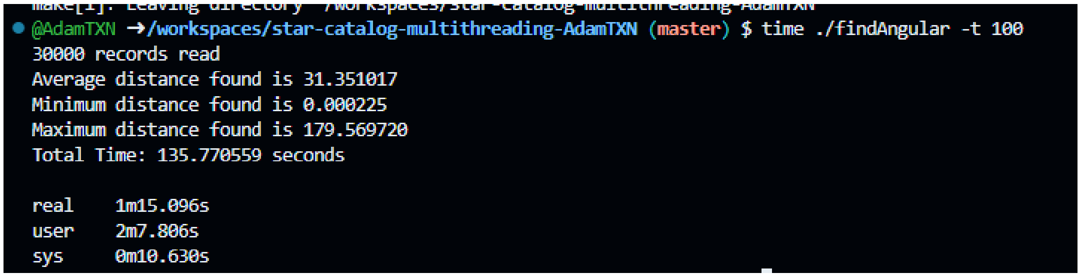
```
● @AdamTXN →/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 100
  30000 records read
  Average distance found is 31.013245
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 95.888521 seconds

  real    0m53.902s
  user    1m37.936s
  sys     0m0.479s
```

Figure 3.1
The print statement from the program proving the inconsistency shown between the run time shown when inserting "time" into the command line and the time.h library.



With deadlock					
Number of Threa	Run time	Run time (time.h	Max Distance	Min Distance	Avg Distance
100	75.096	135.770559	179.56972	0.000225	31.351017

Figure 4.0
The run time increases when a deadlock is used in the program. Deadlocking does not seem to affect the calculations.



```
  make[1]: Leaving directory '/workspaces/star-catalog-multithreading-AdamTXN'
● @AdamTXN →/workspaces/star-catalog-multithreading-AdamTXN (master) $ time ./findAngular -t 100
  30000 records read
  Average distance found is 31.351017
  Minimum distance found is 0.000225
  Maximum distance found is 179.569720
  Total Time: 135.770559 seconds

  real    1m15.096s
  user    2m7.806s
  sys     0m10.630s
```

Figure 4.1
The print statement from the program proving that the run time increases when a deadlock is used in the program.