Program Structures & Algorithms

Spring 2022

Assignment No. 4

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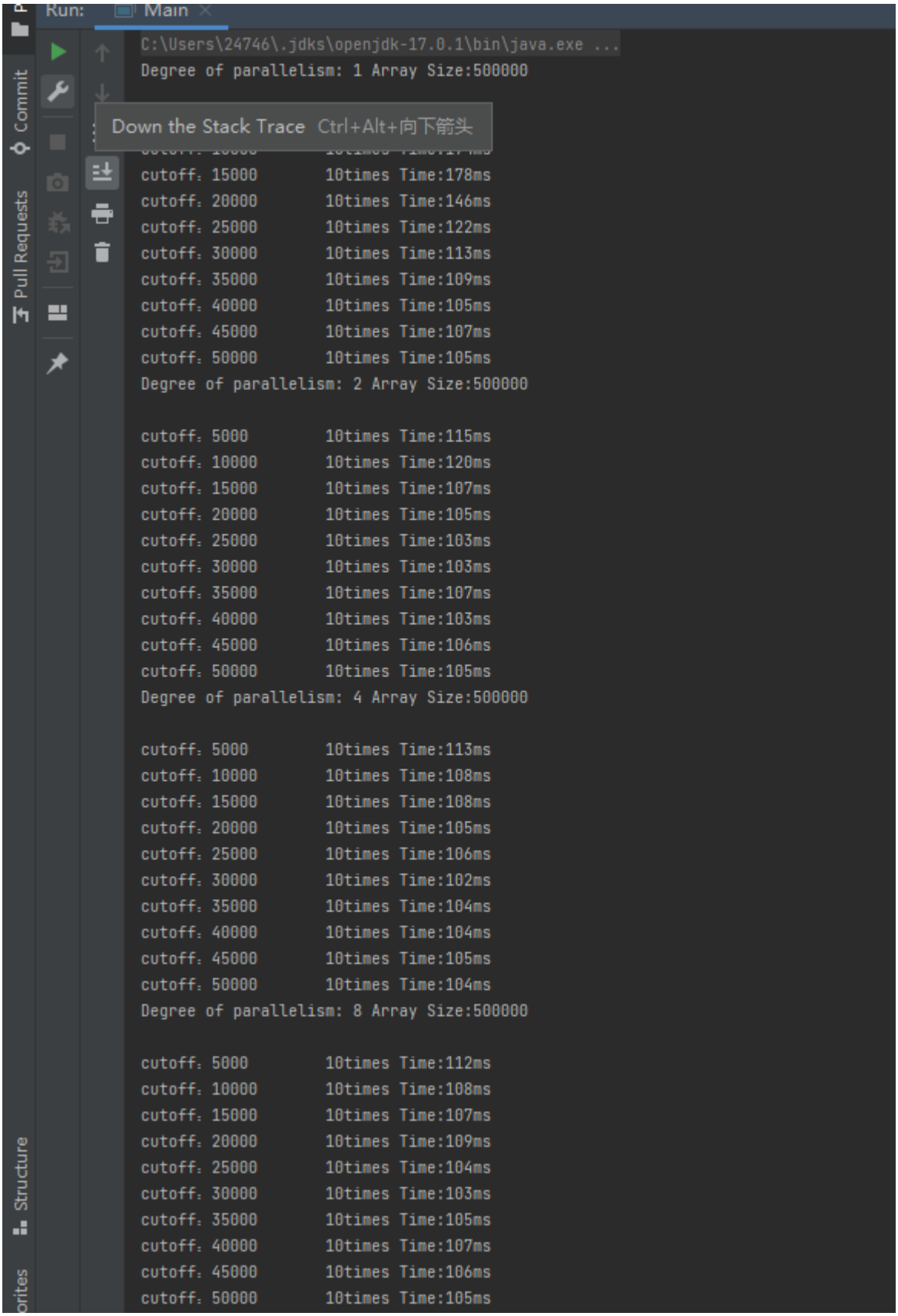
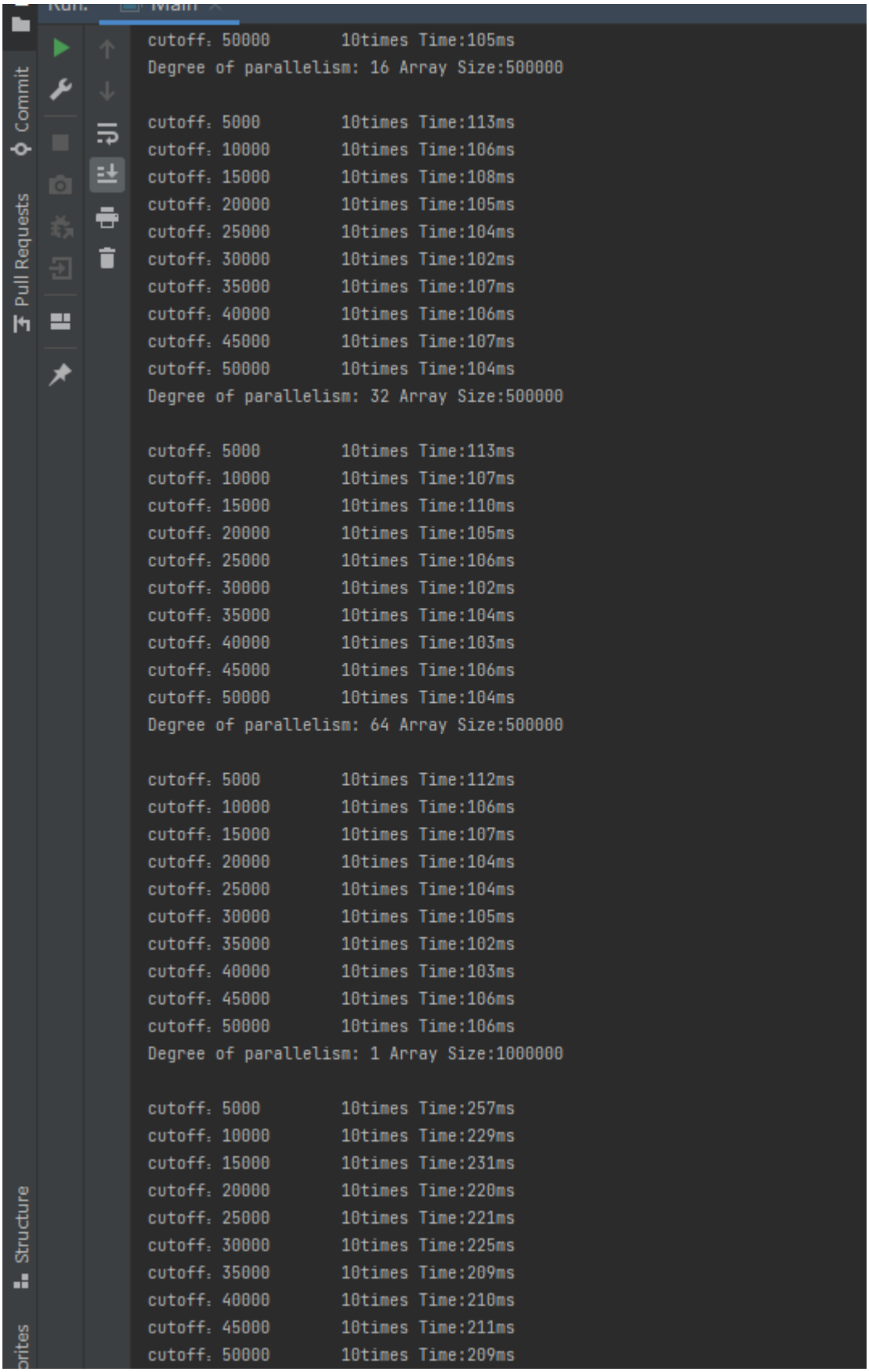
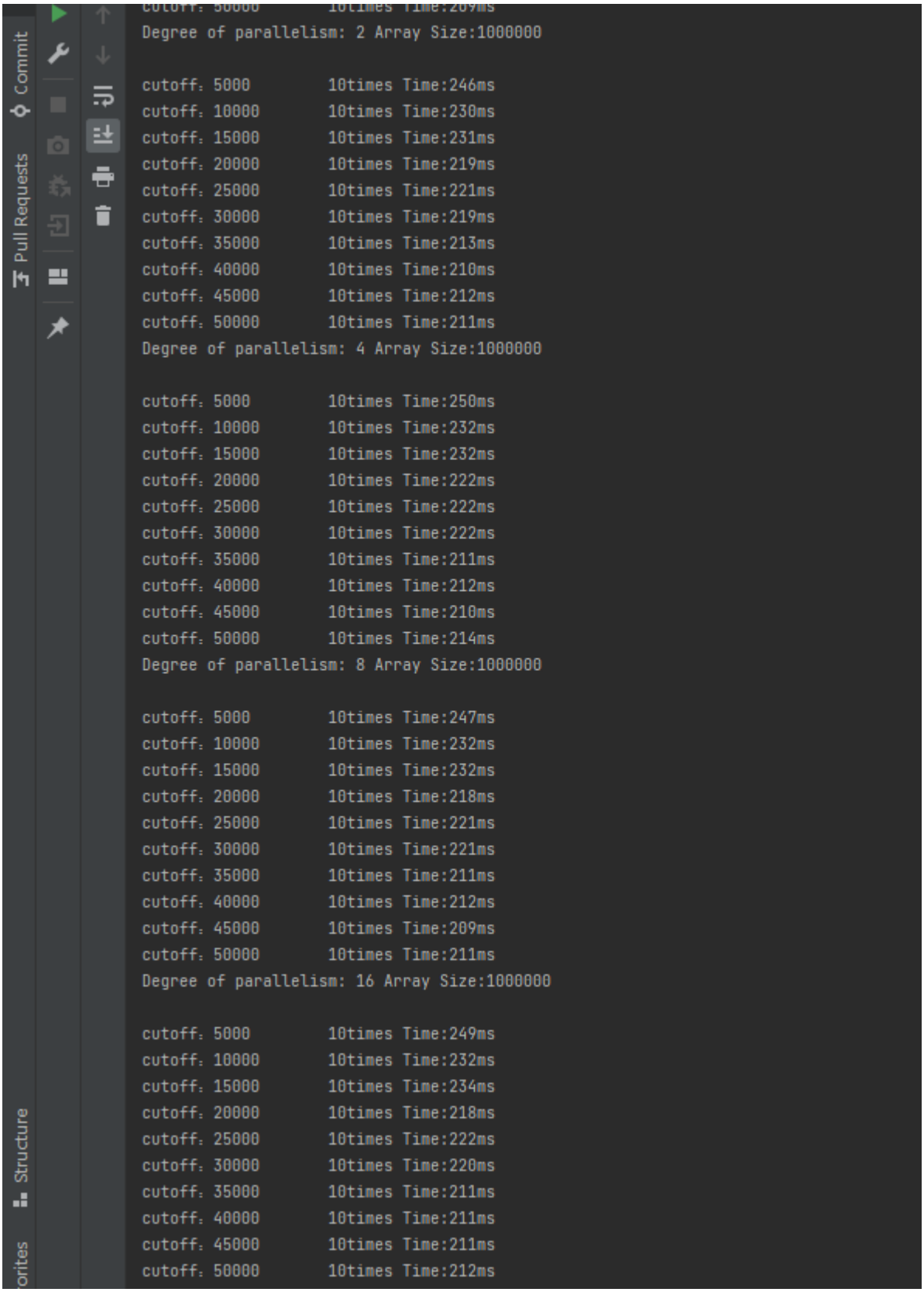
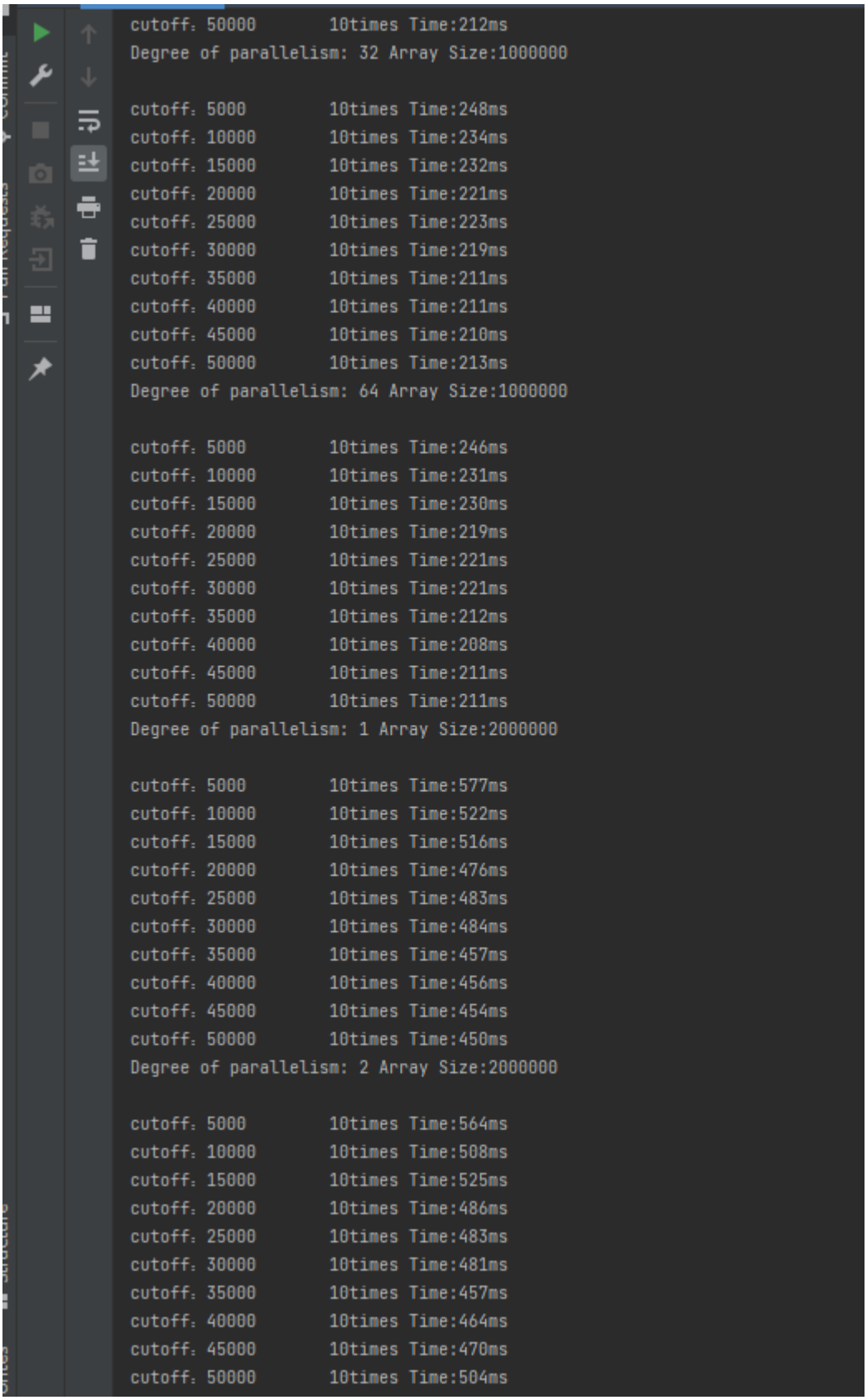
(NUID): 002192983

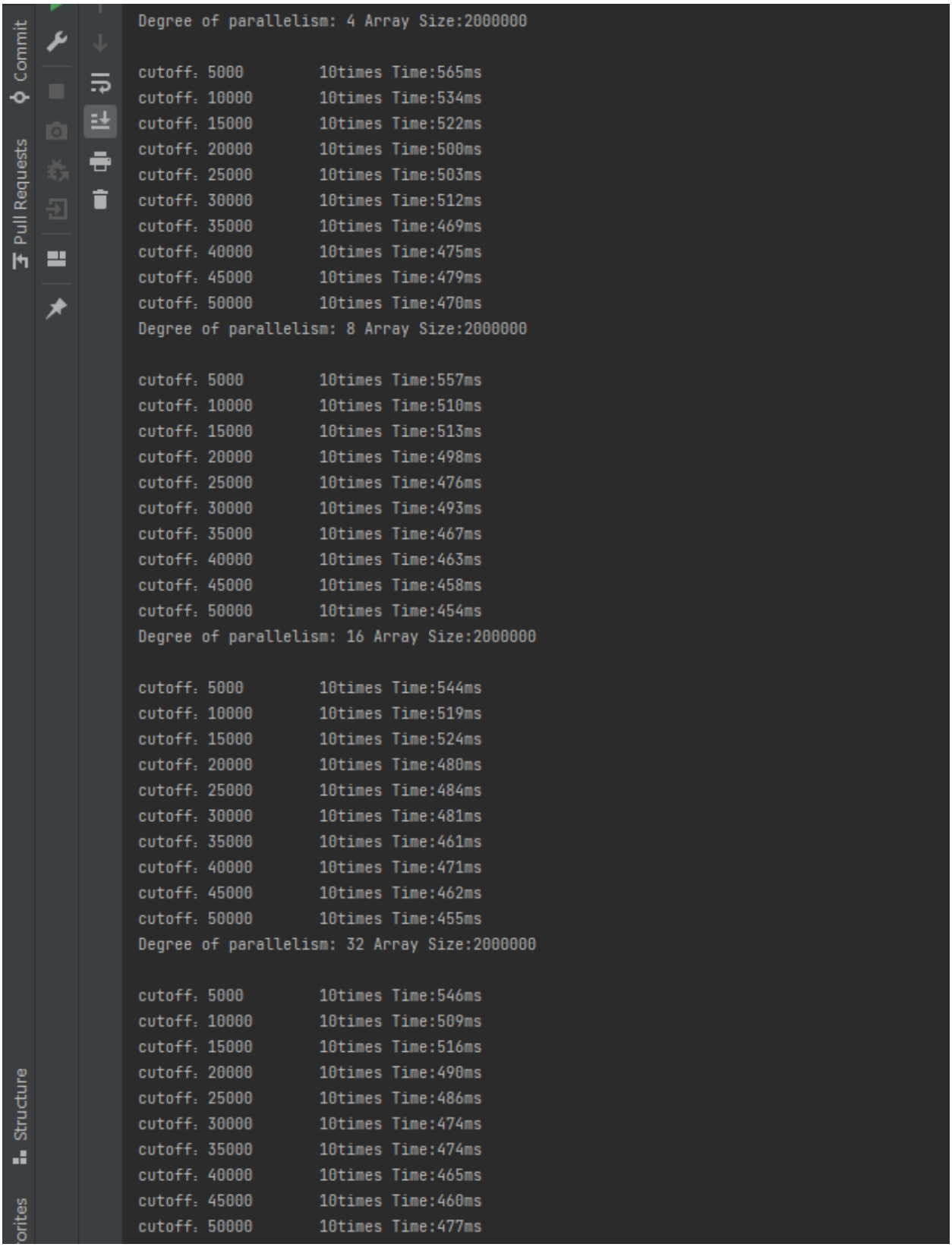
- **Task**
  - Consider two schemes for deciding whether to sort in parallel.
    - A cutoff (defaults to, say, 1000) which you will update according to the first argument in the command line when running. It's your job to experiment and come up with a good value for this cutoff. If there are fewer elements to sort than the cutoff, then you should use the system sort instead.
    - Recursion depth or the number of available threads. Using this determination, you might decide on an ideal number (t) of separate threads (stick to powers of 2) and arrange for that number of partitions to be parallelized (by preventing recursion after the depth of lg t is reached).
  - A combination of these.
  - The test is based on different cutoff (from 5000 to 50000), 7 different degrees of parallelism (1, 2, 4, 8, 16, 32, 64), and 5 different sizes of the array (500000, 1000000, 2000000, 4000000, 8000000)
- **Output screenshot**

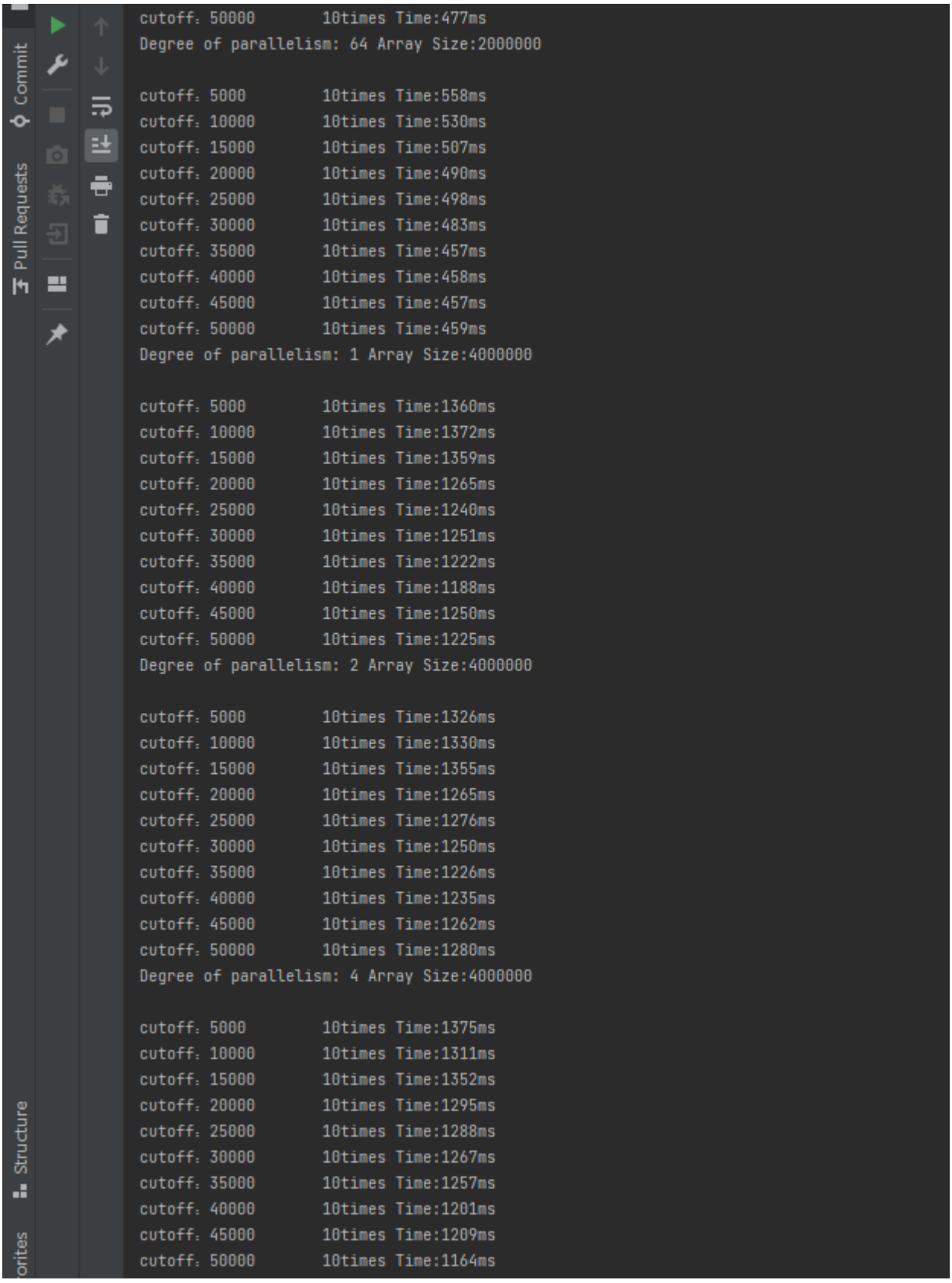

Run:
Main
C:\Users\24746\.jdks\openjdk-17.0.1\bin\java.exe ...
Degree of parallelism: 1 Array Size:500000
Down the Stack Trace Ctrl+Alt+向下箭头
cutoff: 15000 10times Time:178ms
cutoff: 20000 10times Time:146ms
cutoff: 25000 10times Time:122ms
cutoff: 30000 10times Time:113ms
cutoff: 35000 10times Time:109ms
cutoff: 40000 10times Time:105ms
cutoff: 45000 10times Time:107ms
cutoff: 50000 10times Time:105ms
Degree of parallelism: 2 Array Size:500000
cutoff: 5000 10times Time:115ms
cutoff: 10000 10times Time:120ms
cutoff: 15000 10times Time:107ms
cutoff: 20000 10times Time:105ms
cutoff: 25000 10times Time:103ms
cutoff: 30000 10times Time:103ms
cutoff: 35000 10times Time:107ms
cutoff: 40000 10times Time:103ms
cutoff: 45000 10times Time:106ms
cutoff: 50000 10times Time:105ms
Degree of parallelism: 4 Array Size:500000
cutoff: 5000 10times Time:113ms
cutoff: 10000 10times Time:108ms
cutoff: 15000 10times Time:108ms
cutoff: 20000 10times Time:105ms
cutoff: 25000 10times Time:106ms
cutoff: 30000 10times Time:102ms
cutoff: 35000 10times Time:104ms
cutoff: 40000 10times Time:104ms
cutoff: 45000 10times Time:105ms
cutoff: 50000 10times Time:104ms
Degree of parallelism: 8 Array Size:500000
cutoff: 5000 10times Time:112ms
cutoff: 10000 10times Time:108ms
cutoff: 15000 10times Time:107ms
cutoff: 20000 10times Time:109ms
cutoff: 25000 10times Time:104ms
cutoff: 30000 10times Time:103ms
cutoff: 35000 10times Time:105ms
cutoff: 40000 10times Time:107ms
cutoff: 45000 10times Time:106ms
cutoff: 50000 10times Time:105ms
Commit
Pull Requests
Structure

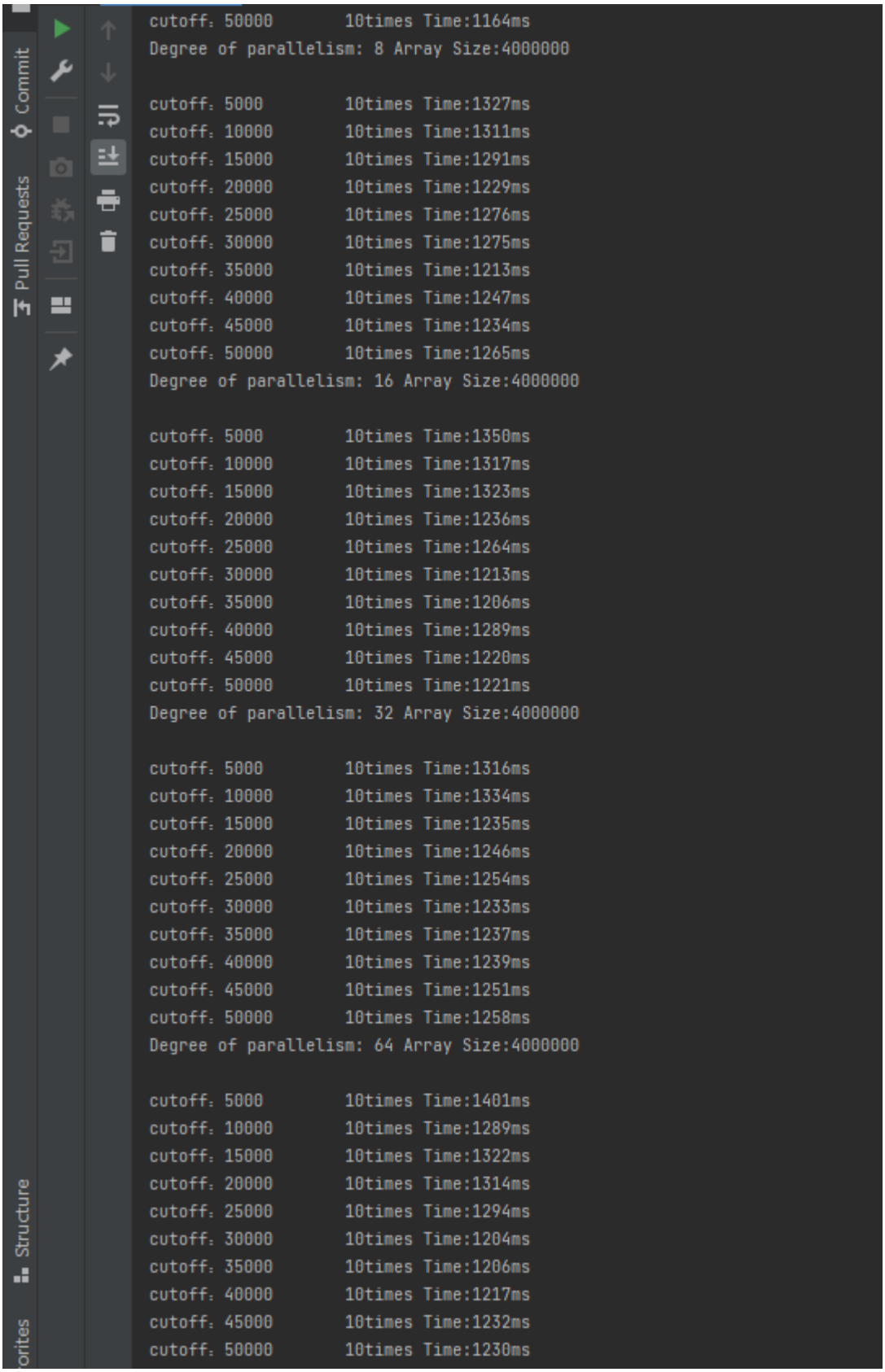

Run:
Main
Commit
Pull Requests
Structure
cutoff: 50000 10times Time:105ms
Degree of parallelism: 16 Array Size:500000
cutoff: 5000 10times Time:113ms
cutoff: 10000 10times Time:106ms
cutoff: 15000 10times Time:108ms
cutoff: 20000 10times Time:105ms
cutoff: 25000 10times Time:104ms
cutoff: 30000 10times Time:102ms
cutoff: 35000 10times Time:107ms
cutoff: 40000 10times Time:106ms
cutoff: 45000 10times Time:107ms
cutoff: 50000 10times Time:104ms
Degree of parallelism: 32 Array Size:500000
cutoff: 5000 10times Time:113ms
cutoff: 10000 10times Time:107ms
cutoff: 15000 10times Time:110ms
cutoff: 20000 10times Time:105ms
cutoff: 25000 10times Time:106ms
cutoff: 30000 10times Time:102ms
cutoff: 35000 10times Time:104ms
cutoff: 40000 10times Time:103ms
cutoff: 45000 10times Time:106ms
cutoff: 50000 10times Time:104ms
Degree of parallelism: 64 Array Size:500000
cutoff: 5000 10times Time:112ms
cutoff: 10000 10times Time:106ms
cutoff: 15000 10times Time:107ms
cutoff: 20000 10times Time:104ms
cutoff: 25000 10times Time:104ms
cutoff: 30000 10times Time:105ms
cutoff: 35000 10times Time:102ms
cutoff: 40000 10times Time:103ms
cutoff: 45000 10times Time:106ms
cutoff: 50000 10times Time:106ms
Degree of parallelism: 1 Array Size:1000000
cutoff: 5000 10times Time:257ms
cutoff: 10000 10times Time:229ms
cutoff: 15000 10times Time:231ms
cutoff: 20000 10times Time:220ms
cutoff: 25000 10times Time:221ms
cutoff: 30000 10times Time:225ms
cutoff: 35000 10times Time:209ms
cutoff: 40000 10times Time:210ms
cutoff: 45000 10times Time:211ms
cutoff: 50000 10times Time:209ms

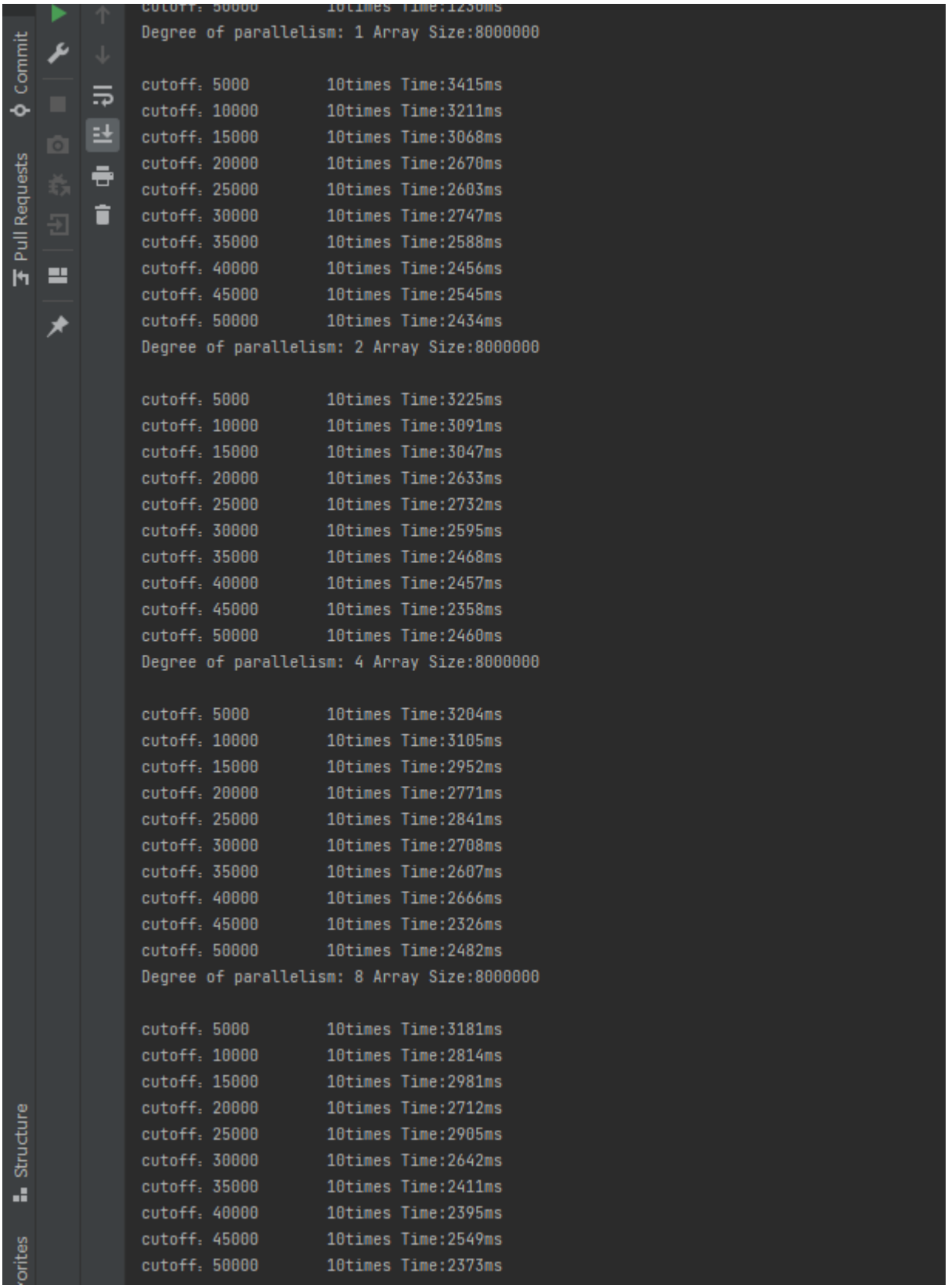

Commit
Pull Requests
Structure
cutoff: 50000 10times Time:209ms
Degree of parallelism: 2 Array Size:1000000
cutoff: 5000 10times Time:246ms
cutoff: 10000 10times Time:230ms
cutoff: 15000 10times Time:231ms
cutoff: 20000 10times Time:219ms
cutoff: 25000 10times Time:221ms
cutoff: 30000 10times Time:219ms
cutoff: 35000 10times Time:213ms
cutoff: 40000 10times Time:210ms
cutoff: 45000 10times Time:212ms
cutoff: 50000 10times Time:211ms
Degree of parallelism: 4 Array Size:1000000
cutoff: 5000 10times Time:250ms
cutoff: 10000 10times Time:232ms
cutoff: 15000 10times Time:232ms
cutoff: 20000 10times Time:222ms
cutoff: 25000 10times Time:222ms
cutoff: 30000 10times Time:222ms
cutoff: 35000 10times Time:211ms
cutoff: 40000 10times Time:212ms
cutoff: 45000 10times Time:210ms
cutoff: 50000 10times Time:214ms
Degree of parallelism: 8 Array Size:1000000
cutoff: 5000 10times Time:247ms
cutoff: 10000 10times Time:232ms
cutoff: 15000 10times Time:232ms
cutoff: 20000 10times Time:218ms
cutoff: 25000 10times Time:221ms
cutoff: 30000 10times Time:221ms
cutoff: 35000 10times Time:211ms
cutoff: 40000 10times Time:212ms
cutoff: 45000 10times Time:209ms
cutoff: 50000 10times Time:211ms
Degree of parallelism: 16 Array Size:1000000
cutoff: 5000 10times Time:249ms
cutoff: 10000 10times Time:232ms
cutoff: 15000 10times Time:234ms
cutoff: 20000 10times Time:218ms
cutoff: 25000 10times Time:222ms
cutoff: 30000 10times Time:220ms
cutoff: 35000 10times Time:211ms
cutoff: 40000 10times Time:211ms
cutoff: 45000 10times Time:211ms
cutoff: 50000 10times Time:212ms

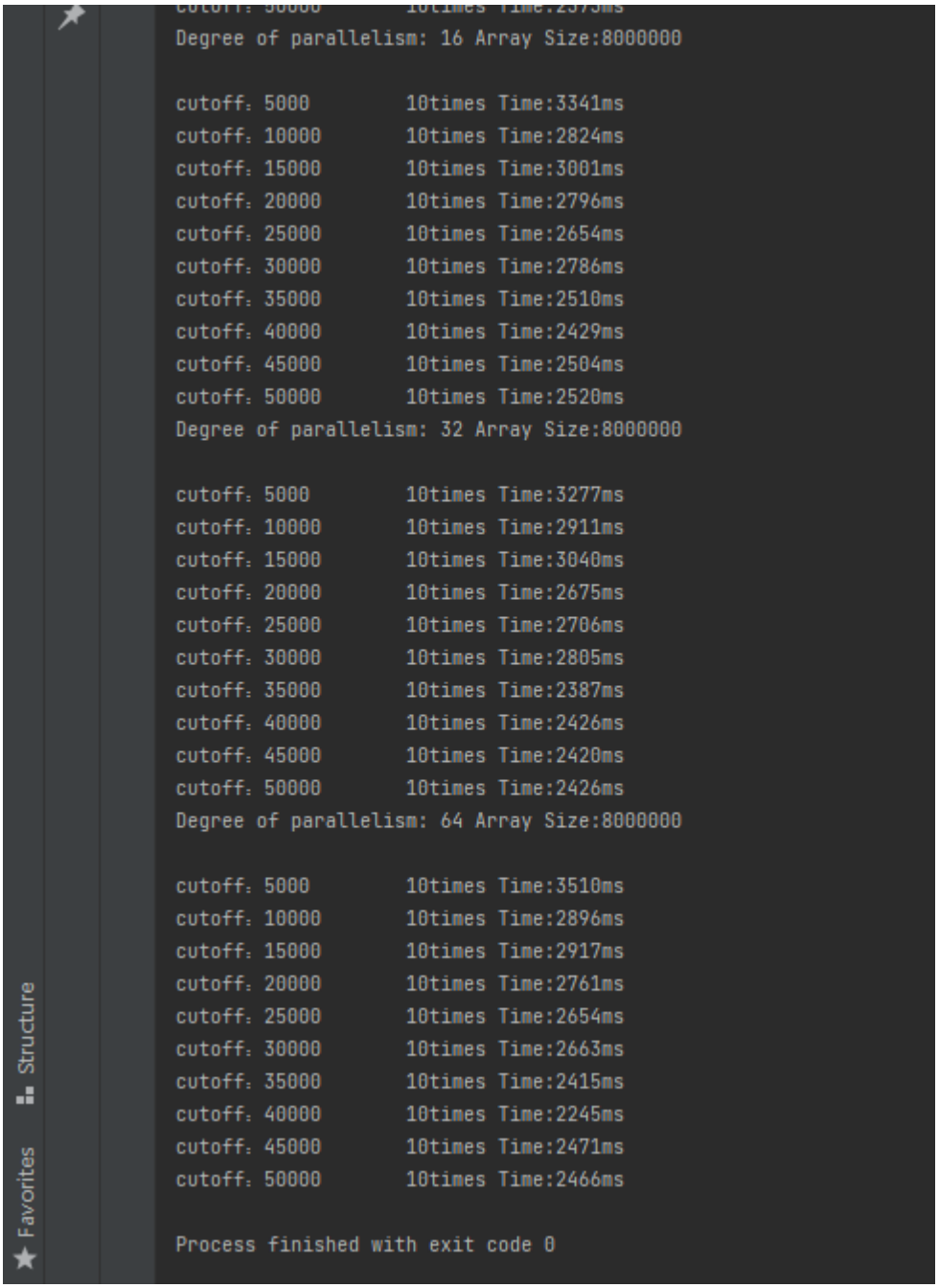

cutoff: 50000 10times Time:212ms
Degree of parallelism: 32 Array Size:1000000
cutoff: 5000 10times Time:248ms
cutoff: 10000 10times Time:234ms
cutoff: 15000 10times Time:232ms
cutoff: 20000 10times Time:221ms
cutoff: 25000 10times Time:223ms
cutoff: 30000 10times Time:219ms
cutoff: 35000 10times Time:211ms
cutoff: 40000 10times Time:211ms
cutoff: 45000 10times Time:210ms
cutoff: 50000 10times Time:213ms
Degree of parallelism: 64 Array Size:1000000
cutoff: 5000 10times Time:246ms
cutoff: 10000 10times Time:231ms
cutoff: 15000 10times Time:230ms
cutoff: 20000 10times Time:219ms
cutoff: 25000 10times Time:221ms
cutoff: 30000 10times Time:221ms
cutoff: 35000 10times Time:212ms
cutoff: 40000 10times Time:208ms
cutoff: 45000 10times Time:211ms
cutoff: 50000 10times Time:211ms
Degree of parallelism: 1 Array Size:2000000
cutoff: 5000 10times Time:577ms
cutoff: 10000 10times Time:522ms
cutoff: 15000 10times Time:516ms
cutoff: 20000 10times Time:476ms
cutoff: 25000 10times Time:483ms
cutoff: 30000 10times Time:484ms
cutoff: 35000 10times Time:457ms
cutoff: 40000 10times Time:456ms
cutoff: 45000 10times Time:454ms
cutoff: 50000 10times Time:450ms
Degree of parallelism: 2 Array Size:2000000
cutoff: 5000 10times Time:564ms
cutoff: 10000 10times Time:508ms
cutoff: 15000 10times Time:525ms
cutoff: 20000 10times Time:486ms
cutoff: 25000 10times Time:483ms
cutoff: 30000 10times Time:481ms
cutoff: 35000 10times Time:457ms
cutoff: 40000 10times Time:464ms
cutoff: 45000 10times Time:470ms
cutoff: 50000 10times Time:504ms


Commit
Pull Requests
Structure
Degree of parallelism: 4 Array Size:2000000
cutoff: 5000 10times Time:565ms
cutoff: 10000 10times Time:534ms
cutoff: 15000 10times Time:522ms
cutoff: 20000 10times Time:500ms
cutoff: 25000 10times Time:503ms
cutoff: 30000 10times Time:512ms
cutoff: 35000 10times Time:469ms
cutoff: 40000 10times Time:475ms
cutoff: 45000 10times Time:479ms
cutoff: 50000 10times Time:470ms
Degree of parallelism: 8 Array Size:2000000
cutoff: 5000 10times Time:557ms
cutoff: 10000 10times Time:510ms
cutoff: 15000 10times Time:513ms
cutoff: 20000 10times Time:498ms
cutoff: 25000 10times Time:476ms
cutoff: 30000 10times Time:493ms
cutoff: 35000 10times Time:467ms
cutoff: 40000 10times Time:463ms
cutoff: 45000 10times Time:458ms
cutoff: 50000 10times Time:454ms
Degree of parallelism: 16 Array Size:2000000
cutoff: 5000 10times Time:544ms
cutoff: 10000 10times Time:519ms
cutoff: 15000 10times Time:524ms
cutoff: 20000 10times Time:480ms
cutoff: 25000 10times Time:484ms
cutoff: 30000 10times Time:481ms
cutoff: 35000 10times Time:461ms
cutoff: 40000 10times Time:471ms
cutoff: 45000 10times Time:462ms
cutoff: 50000 10times Time:455ms
Degree of parallelism: 32 Array Size:2000000
cutoff: 5000 10times Time:546ms
cutoff: 10000 10times Time:509ms
cutoff: 15000 10times Time:516ms
cutoff: 20000 10times Time:490ms
cutoff: 25000 10times Time:486ms
cutoff: 30000 10times Time:474ms
cutoff: 35000 10times Time:474ms
cutoff: 40000 10times Time:465ms
cutoff: 45000 10times Time:460ms
cutoff: 50000 10times Time:477ms


Commit
Pull Requests
Structure
cutoff: 50000 10times Time:477ms
Degree of parallelism: 64 Array Size:2000000
cutoff: 5000 10times Time:558ms
cutoff: 10000 10times Time:530ms
cutoff: 15000 10times Time:507ms
cutoff: 20000 10times Time:490ms
cutoff: 25000 10times Time:498ms
cutoff: 30000 10times Time:483ms
cutoff: 35000 10times Time:457ms
cutoff: 40000 10times Time:458ms
cutoff: 45000 10times Time:457ms
cutoff: 50000 10times Time:459ms
Degree of parallelism: 1 Array Size:4000000
cutoff: 5000 10times Time:1360ms
cutoff: 10000 10times Time:1372ms
cutoff: 15000 10times Time:1359ms
cutoff: 20000 10times Time:1265ms
cutoff: 25000 10times Time:1240ms
cutoff: 30000 10times Time:1251ms
cutoff: 35000 10times Time:1222ms
cutoff: 40000 10times Time:1188ms
cutoff: 45000 10times Time:1250ms
cutoff: 50000 10times Time:1225ms
Degree of parallelism: 2 Array Size:4000000
cutoff: 5000 10times Time:1326ms
cutoff: 10000 10times Time:1330ms
cutoff: 15000 10times Time:1355ms
cutoff: 20000 10times Time:1265ms
cutoff: 25000 10times Time:1276ms
cutoff: 30000 10times Time:1250ms
cutoff: 35000 10times Time:1226ms
cutoff: 40000 10times Time:1235ms
cutoff: 45000 10times Time:1262ms
cutoff: 50000 10times Time:1280ms
Degree of parallelism: 4 Array Size:4000000
cutoff: 5000 10times Time:1375ms
cutoff: 10000 10times Time:1311ms
cutoff: 15000 10times Time:1352ms
cutoff: 20000 10times Time:1295ms
cutoff: 25000 10times Time:1288ms
cutoff: 30000 10times Time:1267ms
cutoff: 35000 10times Time:1257ms
cutoff: 40000 10times Time:1201ms
cutoff: 45000 10times Time:1209ms
cutoff: 50000 10times Time:1164ms

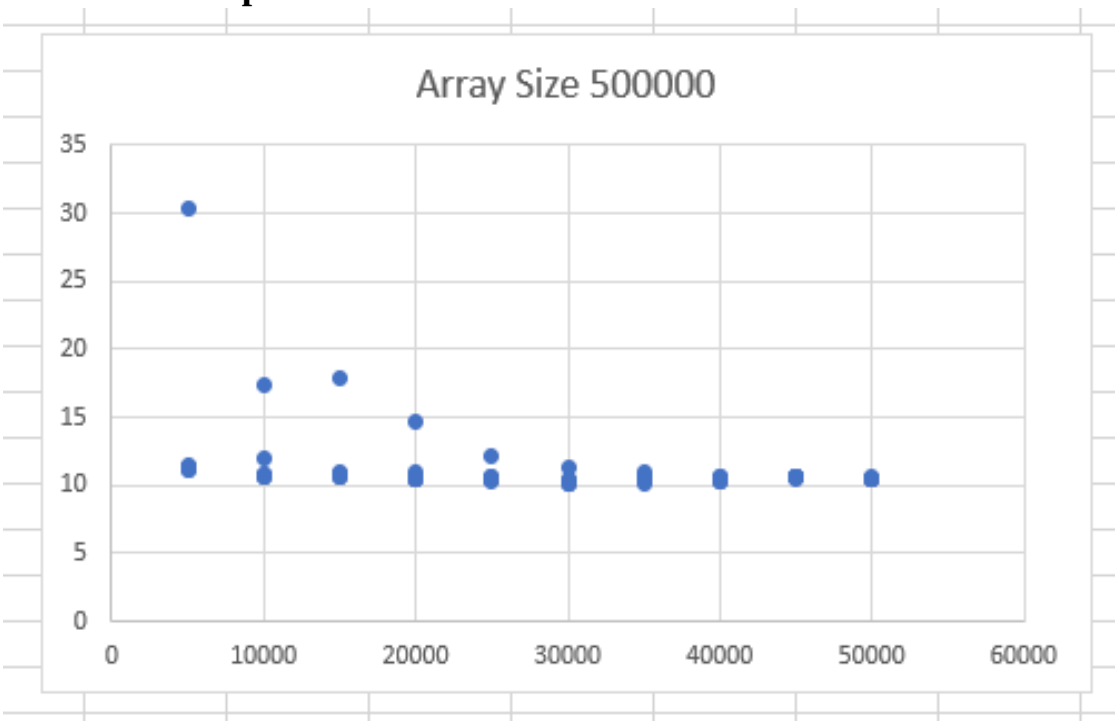

cutoff: 50000 10times Time:1164ms
Degree of parallelism: 8 Array Size:4000000
cutoff: 5000 10times Time:1327ms
cutoff: 10000 10times Time:1311ms
cutoff: 15000 10times Time:1291ms
cutoff: 20000 10times Time:1229ms
cutoff: 25000 10times Time:1276ms
cutoff: 30000 10times Time:1275ms
cutoff: 35000 10times Time:1213ms
cutoff: 40000 10times Time:1247ms
cutoff: 45000 10times Time:1234ms
cutoff: 50000 10times Time:1265ms
Degree of parallelism: 16 Array Size:4000000
cutoff: 5000 10times Time:1350ms
cutoff: 10000 10times Time:1317ms
cutoff: 15000 10times Time:1323ms
cutoff: 20000 10times Time:1236ms
cutoff: 25000 10times Time:1264ms
cutoff: 30000 10times Time:1213ms
cutoff: 35000 10times Time:1206ms
cutoff: 40000 10times Time:1289ms
cutoff: 45000 10times Time:1220ms
cutoff: 50000 10times Time:1221ms
Degree of parallelism: 32 Array Size:4000000
cutoff: 5000 10times Time:1316ms
cutoff: 10000 10times Time:1334ms
cutoff: 15000 10times Time:1235ms
cutoff: 20000 10times Time:1246ms
cutoff: 25000 10times Time:1254ms
cutoff: 30000 10times Time:1233ms
cutoff: 35000 10times Time:1237ms
cutoff: 40000 10times Time:1239ms
cutoff: 45000 10times Time:1251ms
cutoff: 50000 10times Time:1258ms
Degree of parallelism: 64 Array Size:4000000
cutoff: 5000 10times Time:1401ms
cutoff: 10000 10times Time:1289ms
cutoff: 15000 10times Time:1322ms
cutoff: 20000 10times Time:1314ms
cutoff: 25000 10times Time:1294ms
cutoff: 30000 10times Time:1204ms
cutoff: 35000 10times Time:1206ms
cutoff: 40000 10times Time:1217ms
cutoff: 45000 10times Time:1232ms
cutoff: 50000 10times Time:1230ms
Commit
Pull Requests
Structure

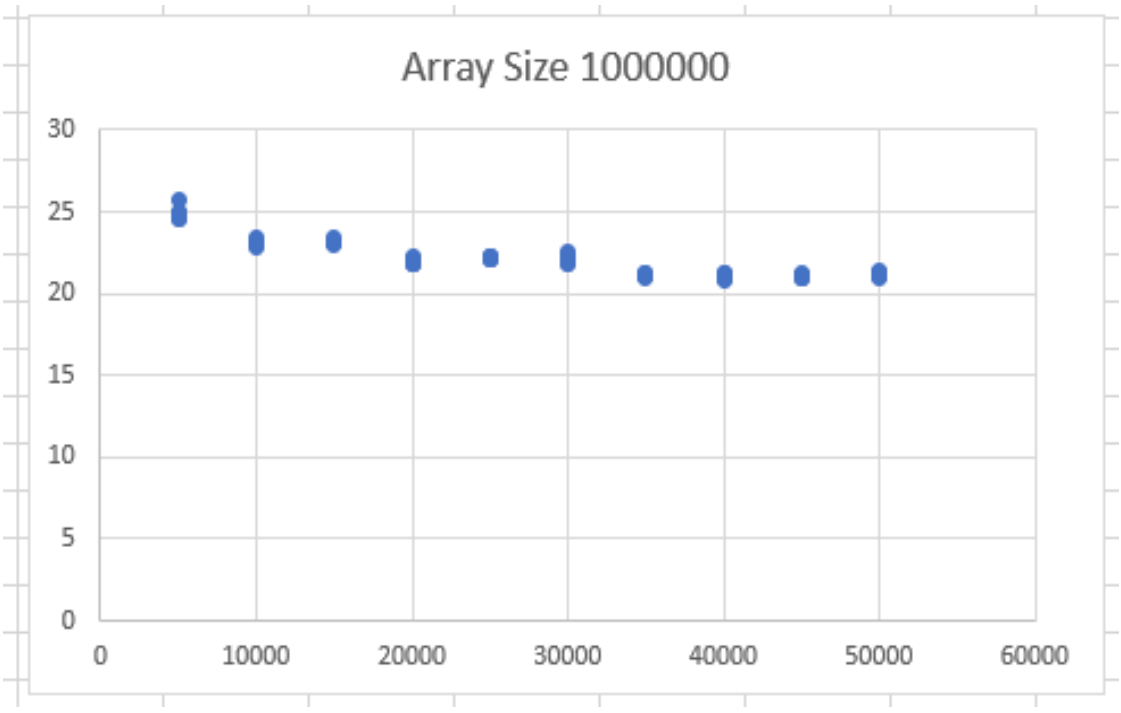

Commit
Pull Requests
Structure
cutoff: 50000 10times Time:1250ms
Degree of parallelism: 1 Array Size:8000000
cutoff: 5000 10times Time:3415ms
cutoff: 10000 10times Time:3211ms
cutoff: 15000 10times Time:3068ms
cutoff: 20000 10times Time:2670ms
cutoff: 25000 10times Time:2603ms
cutoff: 30000 10times Time:2747ms
cutoff: 35000 10times Time:2588ms
cutoff: 40000 10times Time:2456ms
cutoff: 45000 10times Time:2545ms
cutoff: 50000 10times Time:2434ms
Degree of parallelism: 2 Array Size:8000000
cutoff: 5000 10times Time:3225ms
cutoff: 10000 10times Time:3091ms
cutoff: 15000 10times Time:3047ms
cutoff: 20000 10times Time:2633ms
cutoff: 25000 10times Time:2732ms
cutoff: 30000 10times Time:2595ms
cutoff: 35000 10times Time:2468ms
cutoff: 40000 10times Time:2457ms
cutoff: 45000 10times Time:2358ms
cutoff: 50000 10times Time:2460ms
Degree of parallelism: 4 Array Size:8000000
cutoff: 5000 10times Time:3204ms
cutoff: 10000 10times Time:3105ms
cutoff: 15000 10times Time:2952ms
cutoff: 20000 10times Time:2771ms
cutoff: 25000 10times Time:2841ms
cutoff: 30000 10times Time:2708ms
cutoff: 35000 10times Time:2607ms
cutoff: 40000 10times Time:2666ms
cutoff: 45000 10times Time:2326ms
cutoff: 50000 10times Time:2482ms
Degree of parallelism: 8 Array Size:8000000
cutoff: 5000 10times Time:3181ms
cutoff: 10000 10times Time:2814ms
cutoff: 15000 10times Time:2981ms
cutoff: 20000 10times Time:2712ms
cutoff: 25000 10times Time:2905ms
cutoff: 30000 10times Time:2642ms
cutoff: 35000 10times Time:2411ms
cutoff: 40000 10times Time:2395ms
cutoff: 45000 10times Time:2549ms
cutoff: 50000 10times Time:2373ms

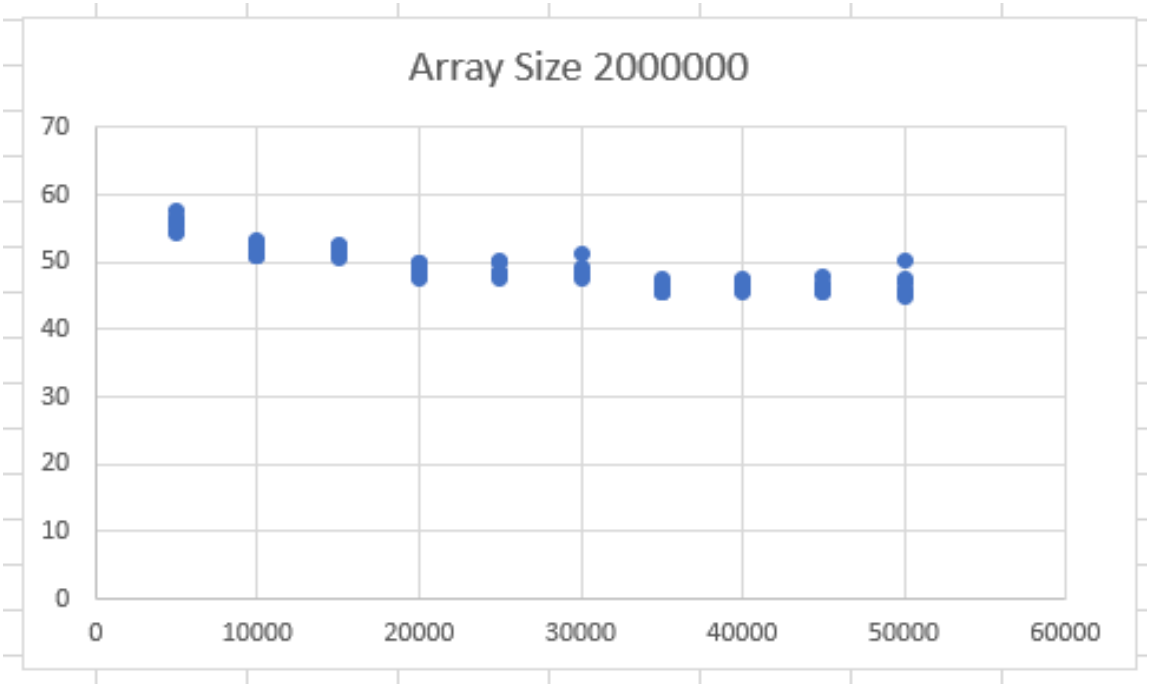

Degree of parallelism: 16 Array Size:8000000
cutoff: 5000 10times Time:3341ms
cutoff: 10000 10times Time:2824ms
cutoff: 15000 10times Time:3001ms
cutoff: 20000 10times Time:2796ms
cutoff: 25000 10times Time:2654ms
cutoff: 30000 10times Time:2786ms
cutoff: 35000 10times Time:2510ms
cutoff: 40000 10times Time:2429ms
cutoff: 45000 10times Time:2504ms
cutoff: 50000 10times Time:2520ms
Degree of parallelism: 32 Array Size:8000000
cutoff: 5000 10times Time:3277ms
cutoff: 10000 10times Time:2911ms
cutoff: 15000 10times Time:3040ms
cutoff: 20000 10times Time:2675ms
cutoff: 25000 10times Time:2706ms
cutoff: 30000 10times Time:2805ms
cutoff: 35000 10times Time:2387ms
cutoff: 40000 10times Time:2426ms
cutoff: 45000 10times Time:2420ms
cutoff: 50000 10times Time:2426ms
Degree of parallelism: 64 Array Size:8000000
cutoff: 5000 10times Time:3510ms
cutoff: 10000 10times Time:2896ms
cutoff: 15000 10times Time:2917ms
cutoff: 20000 10times Time:2761ms
cutoff: 25000 10times Time:2654ms
cutoff: 30000 10times Time:2663ms
cutoff: 35000 10times Time:2415ms
cutoff: 40000 10times Time:2245ms
cutoff: 45000 10times Time:2471ms
cutoff: 50000 10times Time:2466ms
Process finished with exit code 0
Structure
Favorites

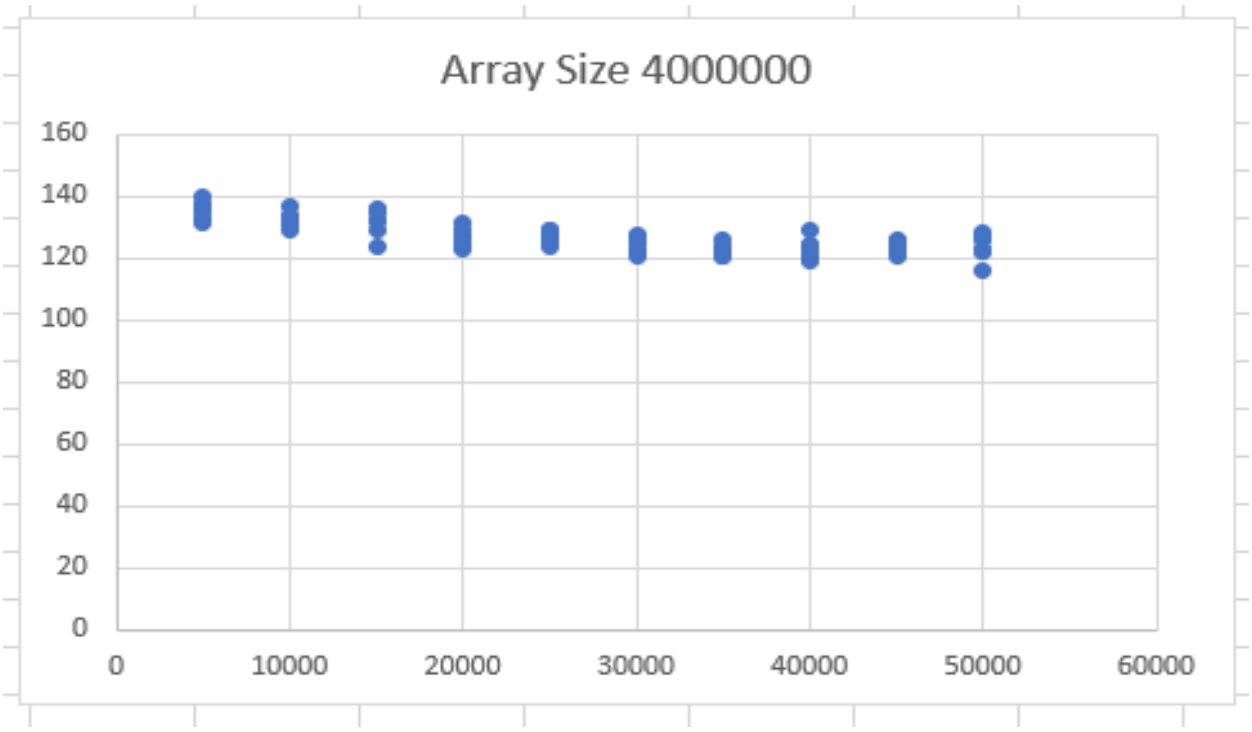
- **Relationship Conclusion**
  - The result-WithDiagram.xlsx is in the INFO6205-Spring2022/src and different array size's diagram is in the different sheet of the result-WithDiagram.xlsx file.
  - Based on the diagram, we can find when the *cutoff = 35000 and 40000*, running time is relatively short at different array sizes and different numbers of threads, and the performance is very good.
  - For the degree of the parallelism, we test the 7 different values which is: 1, 2, 4, 8, 16, 32, 64.
  - After we take the average base on the different degree of parallelism and the different number of the cutoff, we can find when the degree of parallelism is 64 and the cutoff = 40000, we got the minimum running time.
  - This conclusion is also in line with we analyzed above when the cutoff is 40000, running time is relatively short at different array sizes and different numbers of threads.

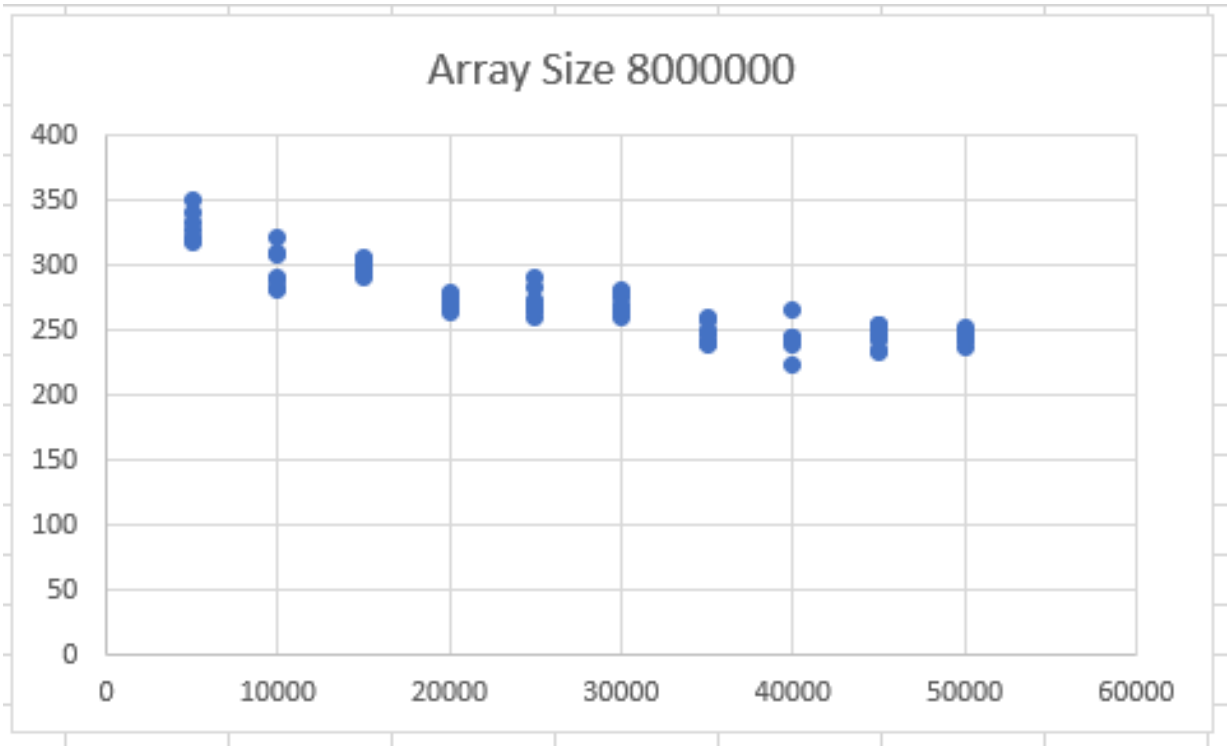
- **Evidence / Graph**




Array Size 1000000
30
25
20
15
10
5
0
0
10000
20000
30000
40000
50000
60000


Array Size 2000000
70
60
50
40
30
20
10
0
0
10000
20000
30000
40000
50000
60000


Array Size 4000000
160
140
120
100
80
60
40
20
0
0
10000
20000
30000
40000
50000
60000


Array Size 8000000
400
350
300
250
200
150
100
50
0
0
10000
20000
30000
40000
50000
60000

	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
1	118.26	110.16	107.04	95.54	93.38	96.4	91.7	88.3	91.34	88.46
2	109.52	105.58	105.3	94.16	96.3	92.96	89.42	89.38	88.16	91.2
4	110.14	105.8	103.32	97.86	99.2	96.22	92.96	93.16	86.58	88.68
8	108.48	99.5	102.48	95.32	99.64	94.68	88.14	88.48	91.12	88.16
16	111.94	99.96	103.8	96.7	94.56	96.04	89.9	90.12	90.08	90.24
32	110	101.9	102.66	94.74	95.5	96.66	88.26	88.88	88.88	89.56
64	116.54	101.04	101.66	97.76	95.42	93.52	87.84	84.62	89.54	89.44

- **Unit tests result**
  - There is no unit tests of the Assignment 4.