Program Structures and Algorithms
Spring 2023(SEC 1)

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Assignment: 5

Task: Your task is

Please see the presentation on Assignment on Parallel Sorting under the Exams. etc. module.
Your task is to implement a parallel sorting algorithm such that each partition of the array is sorted in parallel. You will consider two different 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).
An appropriate combination of these.
There is a Main class and the ParSort class in the sort.par package of the INFO6205 repository. The Main class can be used as is but the ParSort class needs to be implemented where you see "TODO..." [it turns out that these TODOs are already implemented].
Unless you have a good reason not to, you should just go along with the Java8-style future implementations provided for you in the class repository.
You must prepare a report that shows the results of your experiments and draws a conclusion (or more) about the efficacy of this method of parallelizing sort. Your experiments should involve sorting arrays of sufficient size for the parallel sort to make a difference. You should run with many different array sizes (they must be sufficiently large to make parallel sorting worthwhile, obviously) and different cutoff schemes.

Relationship Conclusion:

- **Number of threads:** After conducting different experiments with changing the array size and number of threads, **8 threads** is the best option since there's no drastic change in results for my system after increasing the threads beyond 8.
- **Cutoff Value:** For different experiments, the best sorting time was yielded for the cutoff range of 10% - 20% of the array size with ~15% being the best in each case. Hence, **~15%** of the array size is the optimal cutoff value.

Evidence to support that conclusion:

Experiment 1: For Array Size: 1000000 and Cutoff range: 50000 to 500000

Cutoff	2 threads	4 threads	8 threads	16 threads	32 threads	64 threads
50000	542	325	362	333	264	267
100000	333	284	271	256	255	258
150000	355	293	279	254	252	257
200000	366	294	256	256	252	257
250000	361	345	255	255	255	257
300000	398	319	273	275	285	275
350000	396	290	278	274	274	275
400000	397	340	281	276	275	280
450000	397	286	282	278	276	276
500000	400	283	304	281	276	280

Experiment 2: For Array Size: 2000000 and Cutoff range: 100000 to 1000000

Cutoff	2 threads	4 threads	8 threads	16 threads	32 threads	64 threads
100000	910	721	675	764	530	540
200000	671	588	534	539	539	529
300000	728	612	541	517	548	516
400000	765	619	544	506	541	503
500000	756	613	541	505	530	519
600000	818	581	578	569	566	563
700000	836	581	576	565	573	570
800000	820	572	566	568	568	563
900000	829	573	575	565	565	565
1000000	834	584	566	567	581	564

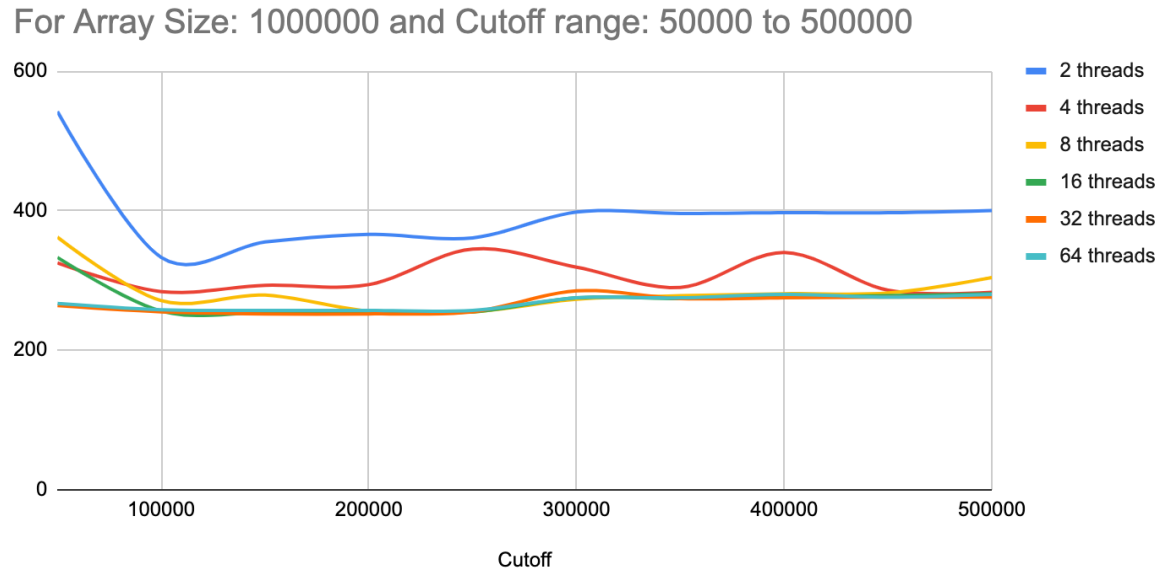
Experiment 3: For Array Size: 5000000 and Cutoff range: 75000 to 750000

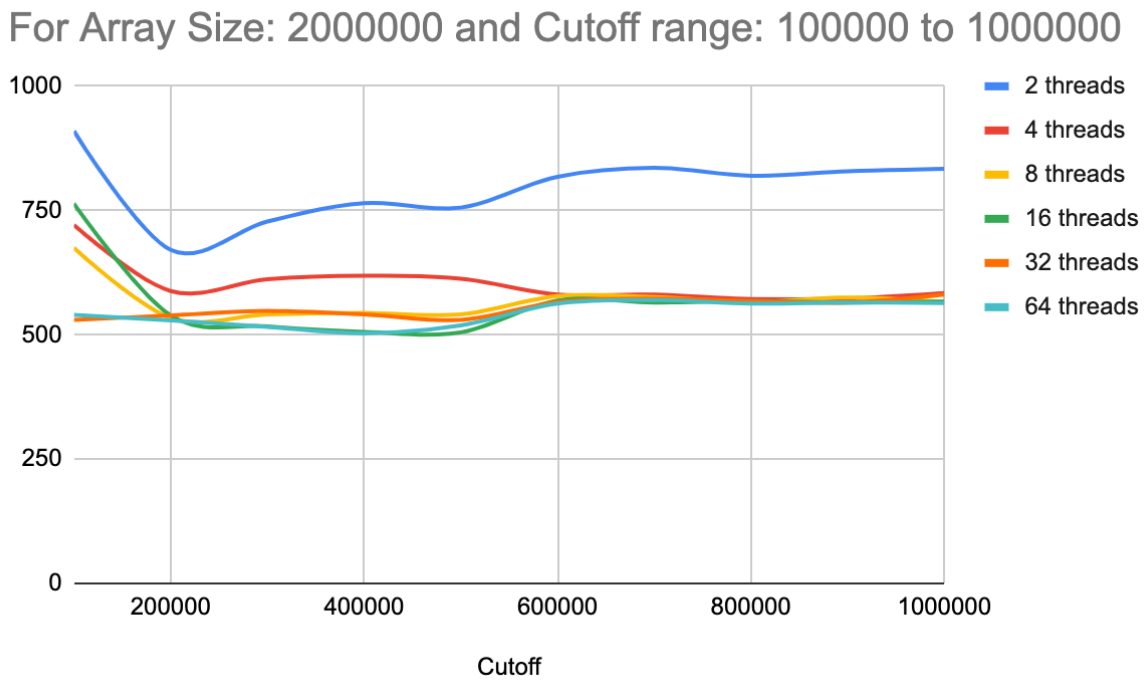
Cutoff	2 threads	4 threads	8 threads	16 threads	32 threads	64 threads
75000	1809	1646	1663	1532	2161	1550
150000	1416	1388	1378	1394	1442	1630
225000	1496	1421	1492	1387	1358	1458
300000	1494	1412	1461	1355	1420	1355
375000	1673	1526	1365	1344	1347	1375
450000	1682	1575	1348	1421	1350	1372
525000	1802	1569	1379	1421	1344	1684

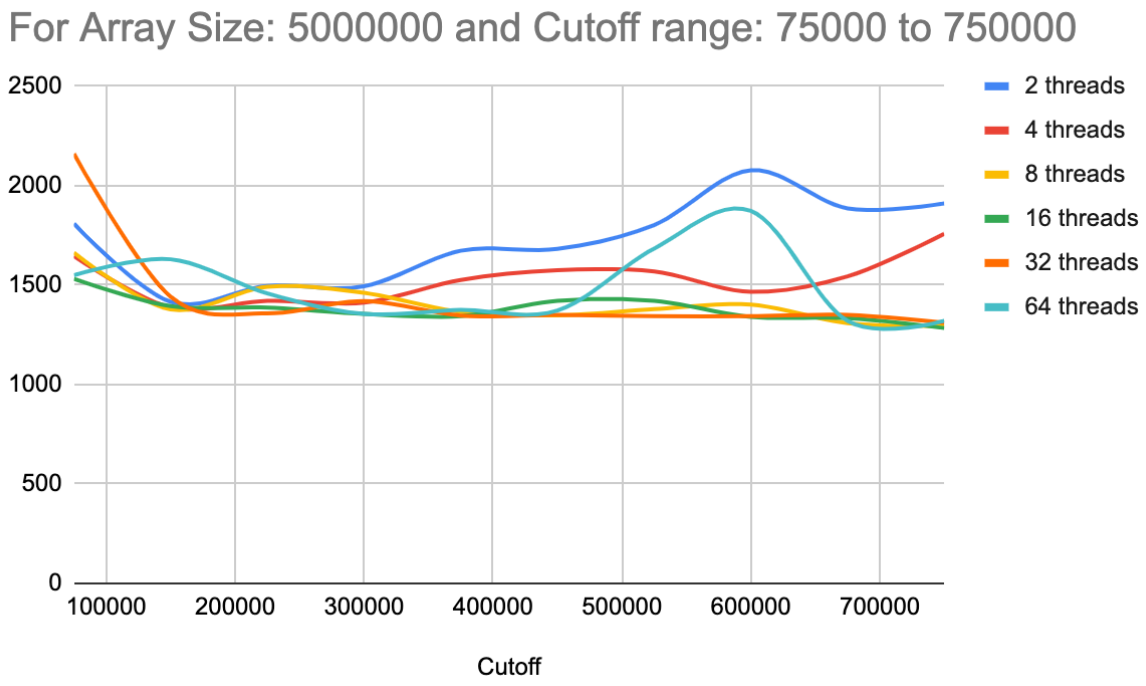
600000	2078	1466	1402	1340	1344	1873
675000	1886	1544	1309	1334	1350	1320
750000	1911	1758	1295	1284	1311	1321

Observation: For all the experiments, there's a notable difference in execution time with 2 & 4 threads vs 8, 16, 32 & 64 threads. After increasing the threads from 8 onwards, there's no notable improvement in performance. For all the experiments, the execution time dropped in the cutoff range of 10% - 20%.of the array size

Graphical Representation:



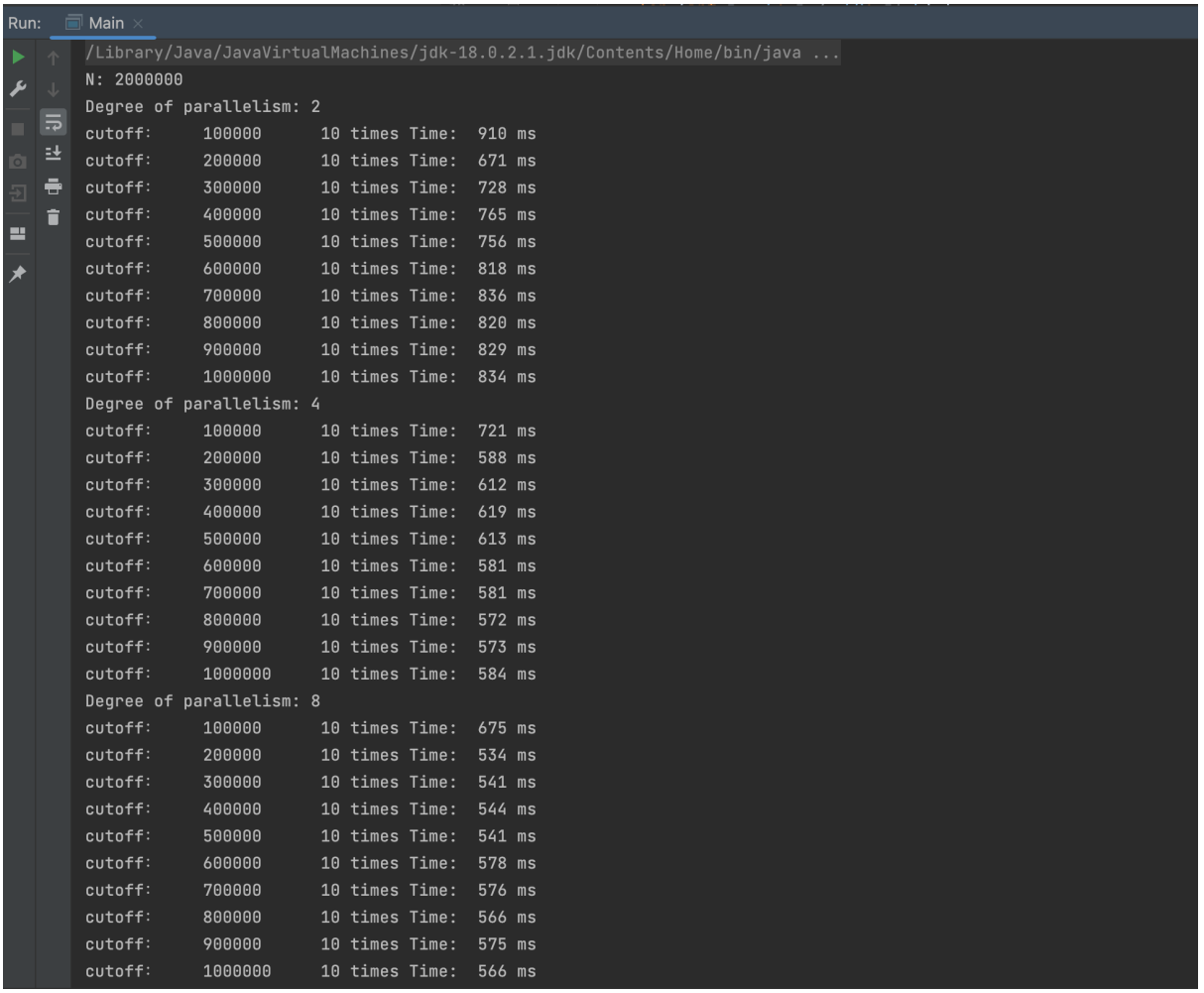


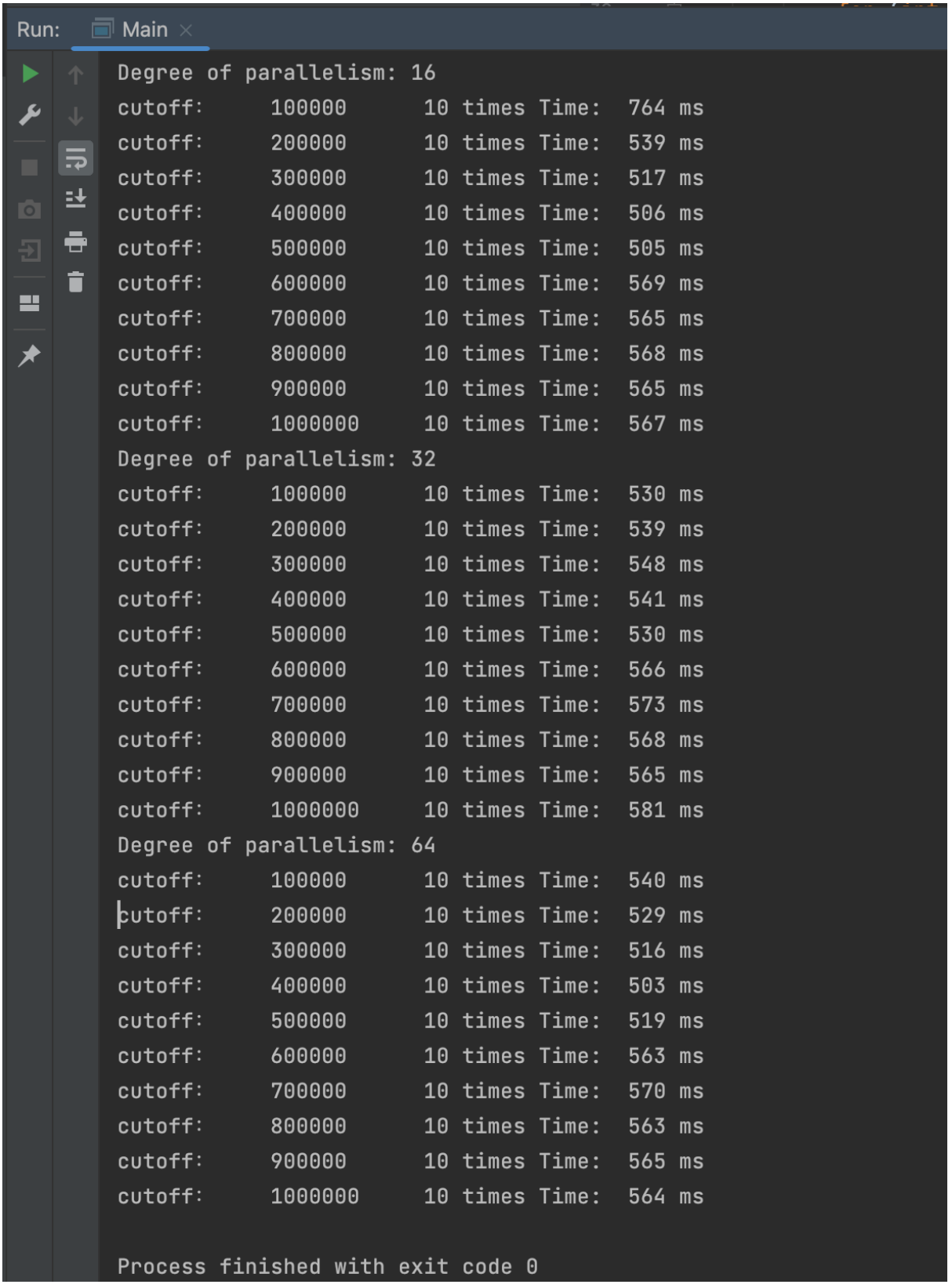


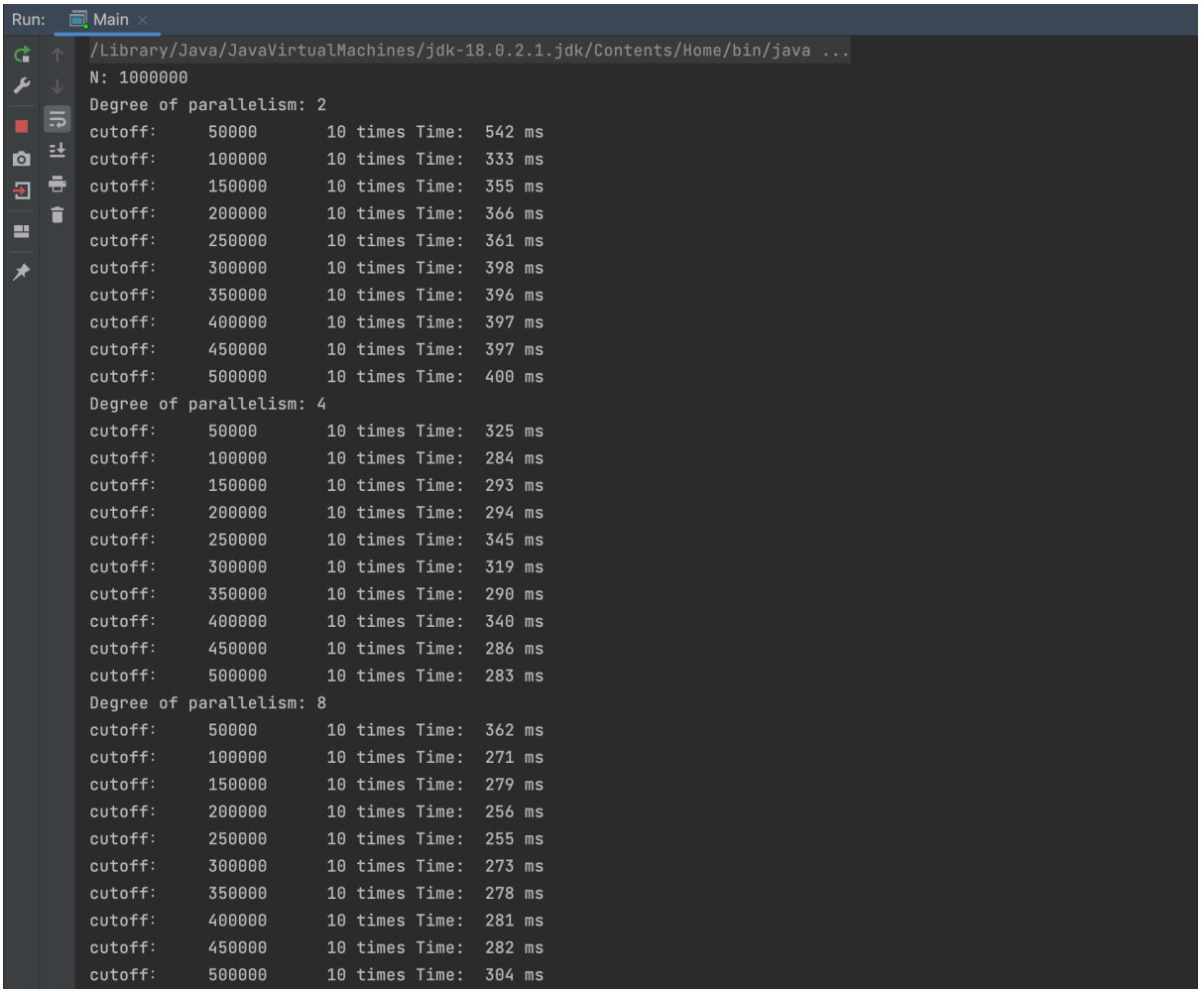
Screenshots:

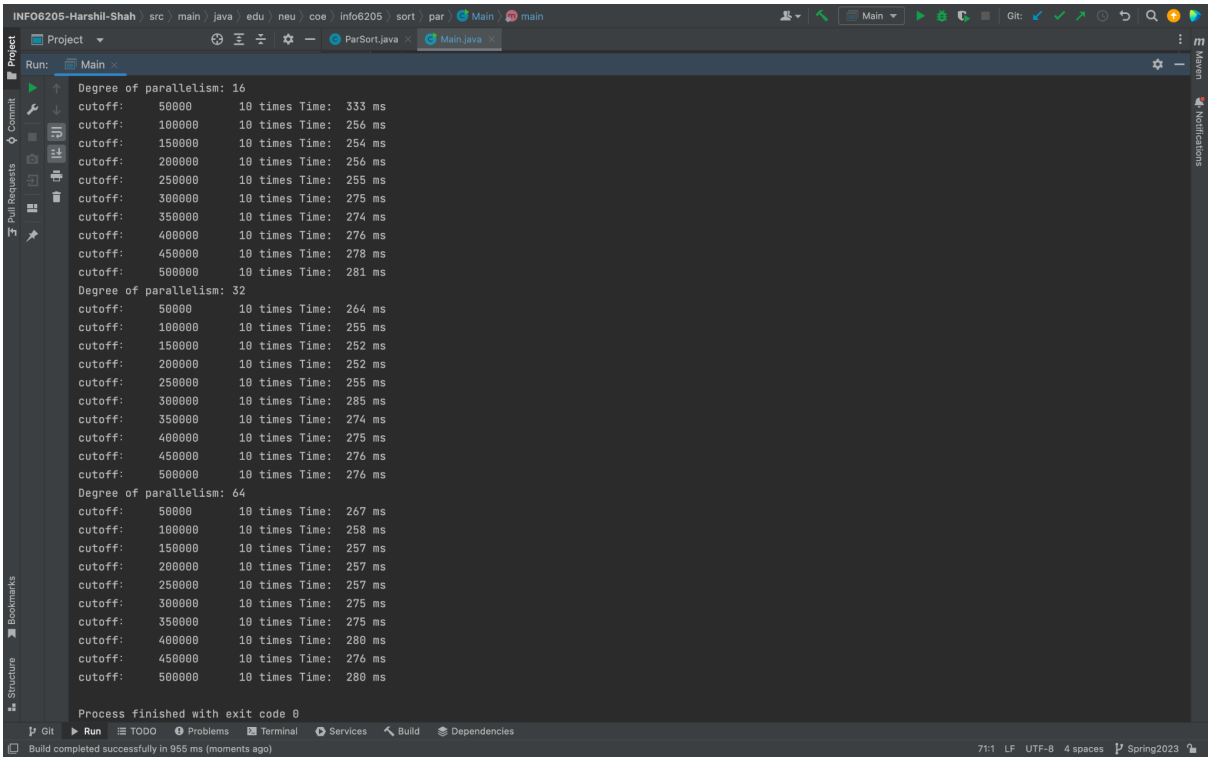
```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...
N: 5000000
Degree of parallelism: 2
cutoff:     75000       10 times Time:  1809    ms
cutoff:     150000      10 times Time:  1416    ms
cutoff:     225000      10 times Time:  1496    ms
cutoff:     300000      10 times Time:  1494    ms
cutoff:     375000      10 times Time:  1673    ms
cutoff:     450000      10 times Time:  1682    ms
cutoff:     525000      10 times Time:  1802    ms
cutoff:     600000      10 times Time:  2078    ms
cutoff:     675000      10 times Time:  1886    ms
cutoff:     750000      10 times Time:  1911    ms
Degree of parallelism: 4
cutoff:     75000       10 times Time:  1646    ms
cutoff:     150000      10 times Time:  1388    ms
cutoff:     225000      10 times Time:  1421    ms
cutoff:     300000      10 times Time:  1412    ms
cutoff:     375000      10 times Time:  1526    ms
cutoff:     450000      10 times Time:  1575    ms
cutoff:     525000      10 times Time:  1569    ms
cutoff:     600000      10 times Time:  1466    ms
cutoff:     675000      10 times Time:  1544    ms
cutoff:     750000      10 times Time:  1758    ms
Degree of parallelism: 8
cutoff:     75000       10 times Time:  1663    ms
cutoff:     150000      10 times Time:  1378    ms
cutoff:     225000      10 times Time:  1492    ms
cutoff:     300000      10 times Time:  1461    ms
cutoff:     375000      10 times Time:  1365    ms
cutoff:     450000      10 times Time:  1348    ms
cutoff:     525000      10 times Time:  1379    ms
cutoff:     600000      10 times Time:  1402    ms
cutoff:     675000      10 times Time:  1309    ms
cutoff:     750000      10 times Time:  1295    ms
```

```
Degree of parallelism: 16
cutoff:     75000       10 times Time:  1532    ms
cutoff:     150000      10 times Time:  1394    ms
cutoff:     225000      10 times Time:  1387    ms
cutoff:     300000      10 times Time:  1355    ms
cutoff:     375000      10 times Time:  1344    ms
cutoff:     450000      10 times Time:  1421    ms
cutoff:     525000      10 times Time:  1421    ms
cutoff:     600000      10 times Time:  1340    ms
cutoff:     675000      10 times Time:  1334    ms
cutoff:     750000      10 times Time:  1284    ms
Degree of parallelism: 32
cutoff:     75000       10 times Time:  2161    ms
cutoff:     150000      10 times Time:  1442    ms
cutoff:     225000      10 times Time:  1358    ms
cutoff:     300000      10 times Time:  1420    ms
cutoff:     375000      10 times Time:  1347    ms
cutoff:     450000      10 times Time:  1350    ms
cutoff:     525000      10 times Time:  1344    ms
cutoff:     600000      10 times Time:  1344    ms
cutoff:     675000      10 times Time:  1350    ms
cutoff:     750000      10 times Time:  1311    ms
Degree of parallelism: 64
cutoff:     75000       10 times Time:  1550    ms
cutoff:     150000      10 times Time:  1630    ms
cutoff:     225000      10 times Time:  1458    ms
cutoff:     300000      10 times Time:  1355    ms
cutoff:     375000      10 times Time:  1375    ms
cutoff:     450000      10 times Time:  1372    ms
cutoff:     525000      10 times Time:  1684    ms
cutoff:     600000      10 times Time:  1873    ms
cutoff:     675000      10 times Time:  1320    ms
cutoff:     750000      10 times Time:  1321    ms
```


Run:
Main
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...
N: 2000000
Degree of parallelism: 2
cutoff: 100000 10 times Time: 910 ms
cutoff: 200000 10 times Time: 671 ms
cutoff: 300000 10 times Time: 728 ms
cutoff: 400000 10 times Time: 765 ms
cutoff: 500000 10 times Time: 756 ms
cutoff: 600000 10 times Time: 818 ms
cutoff: 700000 10 times Time: 836 ms
cutoff: 800000 10 times Time: 820 ms
cutoff: 900000 10 times Time: 829 ms
cutoff: 1000000 10 times Time: 834 ms
Degree of parallelism: 4
cutoff: 100000 10 times Time: 721 ms
cutoff: 200000 10 times Time: 588 ms
cutoff: 300000 10 times Time: 612 ms
cutoff: 400000 10 times Time: 619 ms
cutoff: 500000 10 times Time: 613 ms
cutoff: 600000 10 times Time: 581 ms
cutoff: 700000 10 times Time: 581 ms
cutoff: 800000 10 times Time: 572 ms
cutoff: 900000 10 times Time: 573 ms
cutoff: 1000000 10 times Time: 584 ms
Degree of parallelism: 8
cutoff: 100000 10 times Time: 675 ms
cutoff: 200000 10 times Time: 534 ms
cutoff: 300000 10 times Time: 541 ms
cutoff: 400000 10 times Time: 544 ms
cutoff: 500000 10 times Time: 541 ms
cutoff: 600000 10 times Time: 578 ms
cutoff: 700000 10 times Time: 576 ms
cutoff: 800000 10 times Time: 566 ms
cutoff: 900000 10 times Time: 575 ms
cutoff: 1000000 10 times Time: 566 ms


Run:
Main
Degree of parallelism: 16
cutoff: 100000 10 times Time: 764 ms
cutoff: 200000 10 times Time: 539 ms
cutoff: 300000 10 times Time: 517 ms
cutoff: 400000 10 times Time: 506 ms
cutoff: 500000 10 times Time: 505 ms
cutoff: 600000 10 times Time: 569 ms
cutoff: 700000 10 times Time: 565 ms
cutoff: 800000 10 times Time: 568 ms
cutoff: 900000 10 times Time: 565 ms
cutoff: 1000000 10 times Time: 567 ms
Degree of parallelism: 32
cutoff: 100000 10 times Time: 530 ms
cutoff: 200000 10 times Time: 539 ms
cutoff: 300000 10 times Time: 548 ms
cutoff: 400000 10 times Time: 541 ms
cutoff: 500000 10 times Time: 530 ms
cutoff: 600000 10 times Time: 566 ms
cutoff: 700000 10 times Time: 573 ms
cutoff: 800000 10 times Time: 568 ms
cutoff: 900000 10 times Time: 565 ms
cutoff: 1000000 10 times Time: 581 ms
Degree of parallelism: 64
cutoff: 100000 10 times Time: 540 ms
cutoff: 200000 10 times Time: 529 ms
cutoff: 300000 10 times Time: 516 ms
cutoff: 400000 10 times Time: 503 ms
cutoff: 500000 10 times Time: 519 ms
cutoff: 600000 10 times Time: 563 ms
cutoff: 700000 10 times Time: 570 ms
cutoff: 800000 10 times Time: 563 ms
cutoff: 900000 10 times Time: 565 ms
cutoff: 1000000 10 times Time: 564 ms
Process finished with exit code 0


Run: Main
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...
N: 1000000
Degree of parallelism: 2
cutoff: 50000 10 times Time: 542 ms
cutoff: 100000 10 times Time: 333 ms
cutoff: 150000 10 times Time: 355 ms
cutoff: 200000 10 times Time: 366 ms
cutoff: 250000 10 times Time: 361 ms
cutoff: 300000 10 times Time: 398 ms
cutoff: 350000 10 times Time: 396 ms
cutoff: 400000 10 times Time: 397 ms
cutoff: 450000 10 times Time: 397 ms
cutoff: 500000 10 times Time: 400 ms
Degree of parallelism: 4
cutoff: 50000 10 times Time: 325 ms
cutoff: 100000 10 times Time: 284 ms
cutoff: 150000 10 times Time: 293 ms
cutoff: 200000 10 times Time: 294 ms
cutoff: 250000 10 times Time: 345 ms
cutoff: 300000 10 times Time: 319 ms
cutoff: 350000 10 times Time: 290 ms
cutoff: 400000 10 times Time: 340 ms
cutoff: 450000 10 times Time: 286 ms
cutoff: 500000 10 times Time: 283 ms
Degree of parallelism: 8
cutoff: 50000 10 times Time: 362 ms
cutoff: 100000 10 times Time: 271 ms
cutoff: 150000 10 times Time: 279 ms
cutoff: 200000 10 times Time: 256 ms
cutoff: 250000 10 times Time: 255 ms
cutoff: 300000 10 times Time: 273 ms
cutoff: 350000 10 times Time: 278 ms
cutoff: 400000 10 times Time: 281 ms
cutoff: 450000 10 times Time: 282 ms
cutoff: 500000 10 times Time: 304 ms


INFO6205-Harshil-Shah
Run: Main
Degree of parallelism: 16
cutoff: 50000 10 times Time: 333 ms
cutoff: 100000 10 times Time: 256 ms
cutoff: 150000 10 times Time: 254 ms
cutoff: 200000 10 times Time: 256 ms
cutoff: 250000 10 times Time: 255 ms
cutoff: 300000 10 times Time: 275 ms
cutoff: 350000 10 times Time: 274 ms
cutoff: 400000 10 times Time: 276 ms
cutoff: 450000 10 times Time: 278 ms
cutoff: 500000 10 times Time: 281 ms
Degree of parallelism: 32
cutoff: 50000 10 times Time: 264 ms
cutoff: 100000 10 times Time: 255 ms
cutoff: 150000 10 times Time: 252 ms
cutoff: 200000 10 times Time: 252 ms
cutoff: 250000 10 times Time: 255 ms
cutoff: 300000 10 times Time: 285 ms
cutoff: 350000 10 times Time: 274 ms
cutoff: 400000 10 times Time: 275 ms
cutoff: 450000 10 times Time: 276 ms
cutoff: 500000 10 times Time: 276 ms
Degree of parallelism: 64
cutoff: 50000 10 times Time: 267 ms
cutoff: 100000 10 times Time: 258 ms
cutoff: 150000 10 times Time: 257 ms
cutoff: 200000 10 times Time: 257 ms
cutoff: 250000 10 times Time: 257 ms
cutoff: 300000 10 times Time: 275 ms
cutoff: 350000 10 times Time: 275 ms
cutoff: 400000 10 times Time: 280 ms
cutoff: 450000 10 times Time: 276 ms
cutoff: 500000 10 times Time: 280 ms
Process finished with exit code 0
Build completed successfully in 955 ms (moments ago)