

Program Structures & Algorithms

Spring 2022

Assignment No - 4 (Parallel Sorting)

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Task

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.

1. 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.
2. 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).
3. An appropriate combination of these.

There is the *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 the 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.

For varying the number of threads available, you might want to consult the following resources:

- <https://www.callicoder.com/java-8-completablefuture-tutorial/#a-note-about-executor-and-thread-pool>
- <https://stackoverflow.com/questions/36569775/how-to-set-forkjoinpool-with-the-desired-number-of-worker-threads-in-completable>

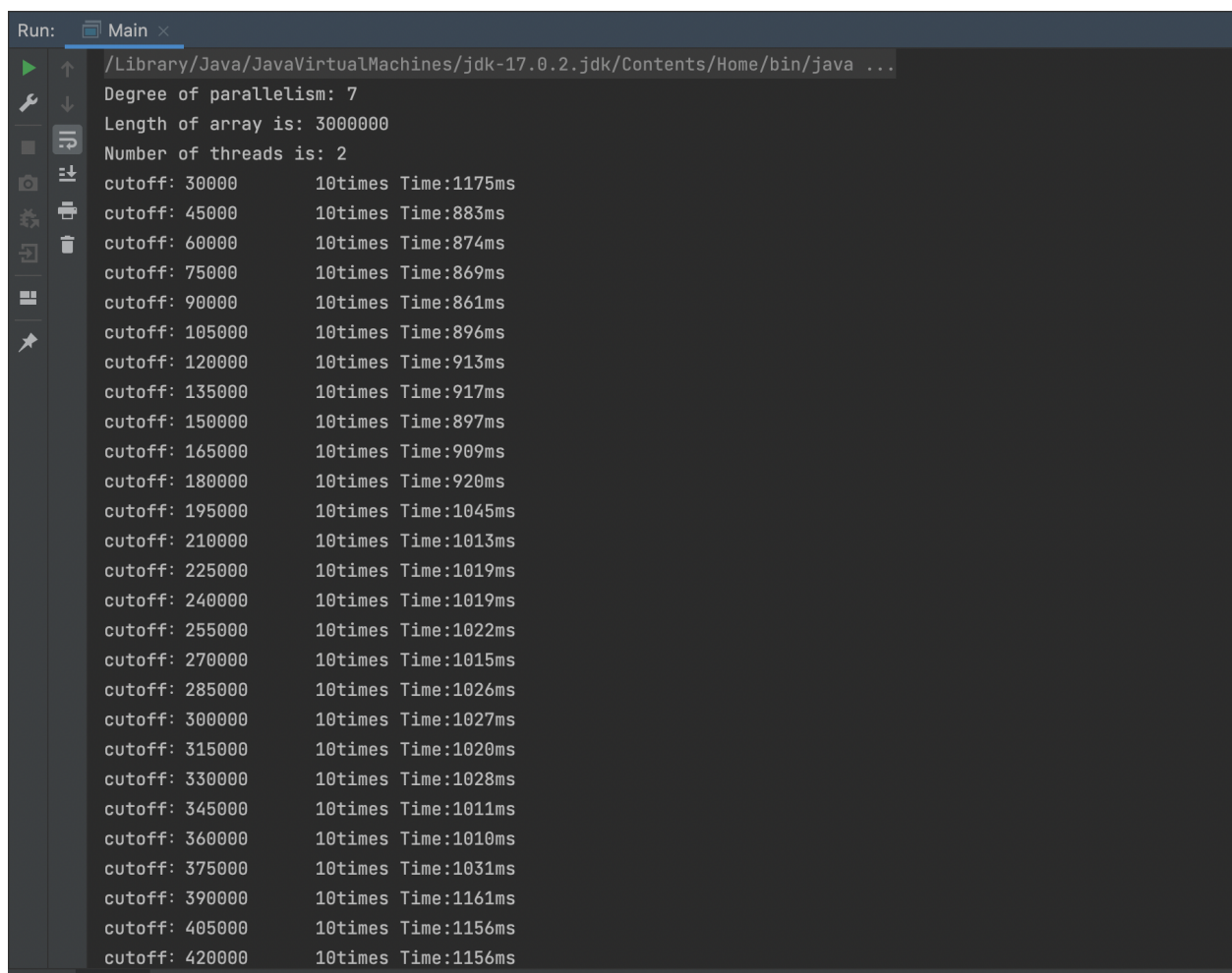
Output Screenshot

Degree of parallelism: 7

Array Length: 3000000

Thread count: 2

Number of core in test machine: 8



The screenshot shows a Java IDE console window with the following output:

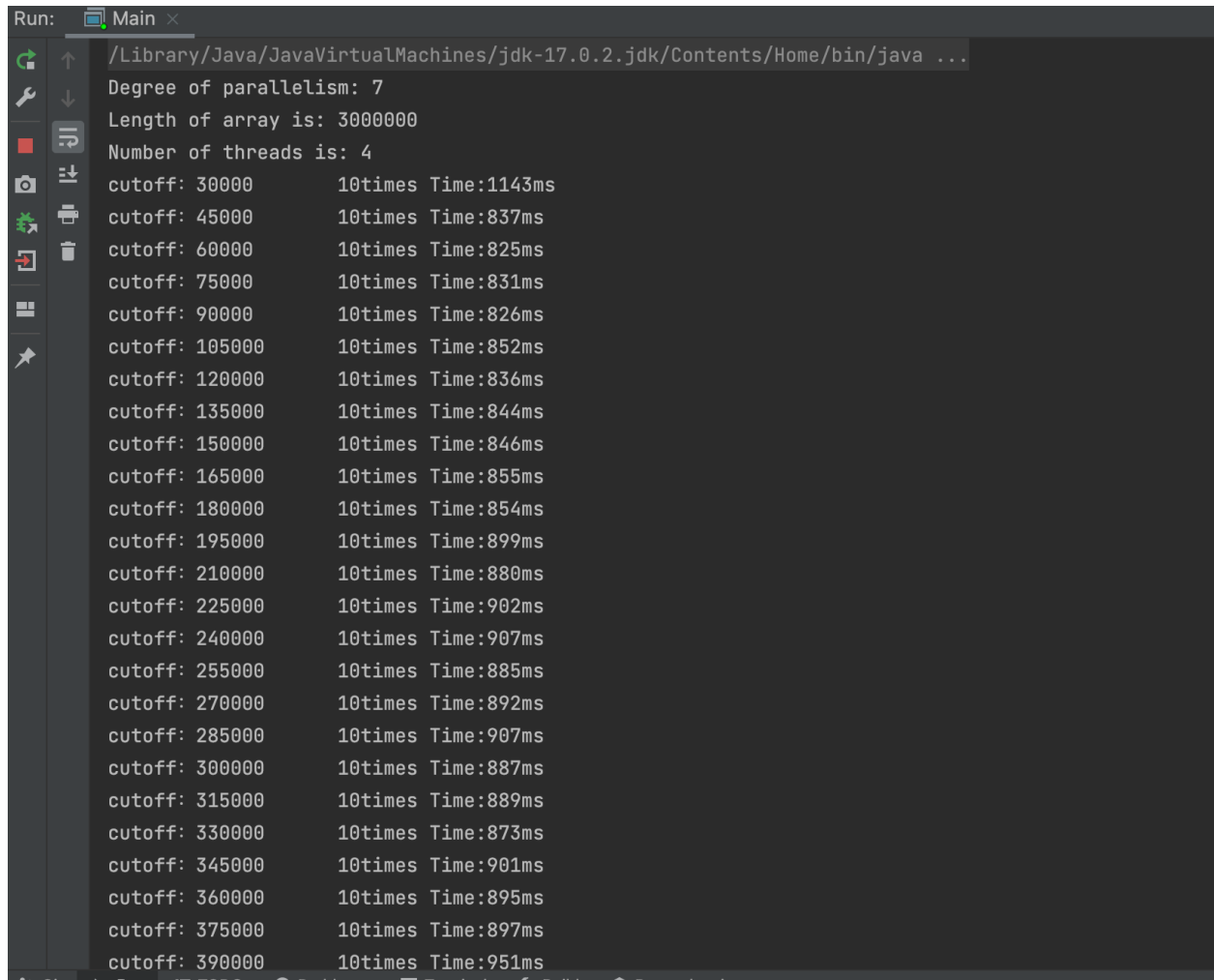
```
Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 3000000
Number of threads is: 2
cutoff: 30000      10times Time:1175ms
cutoff: 45000      10times Time:883ms
cutoff: 60000      10times Time:874ms
cutoff: 75000      10times Time:869ms
cutoff: 90000      10times Time:861ms
cutoff: 105000     10times Time:896ms
cutoff: 120000     10times Time:913ms
cutoff: 135000     10times Time:917ms
cutoff: 150000     10times Time:897ms
cutoff: 165000     10times Time:909ms
cutoff: 180000     10times Time:920ms
cutoff: 195000     10times Time:1045ms
cutoff: 210000     10times Time:1013ms
cutoff: 225000     10times Time:1019ms
cutoff: 240000     10times Time:1019ms
cutoff: 255000     10times Time:1022ms
cutoff: 270000     10times Time:1015ms
cutoff: 285000     10times Time:1026ms
cutoff: 300000     10times Time:1027ms
cutoff: 315000     10times Time:1020ms
cutoff: 330000     10times Time:1028ms
cutoff: 345000     10times Time:1011ms
cutoff: 360000     10times Time:1010ms
cutoff: 375000     10times Time:1031ms
cutoff: 390000     10times Time:1161ms
cutoff: 405000     10times Time:1156ms
cutoff: 420000     10times Time:1156ms
```

Degree of parallelism: 7

Array Length: 3000000

Thread count: 4

Number of cores in test machine: 8



The screenshot shows an IDE console window with the following output:

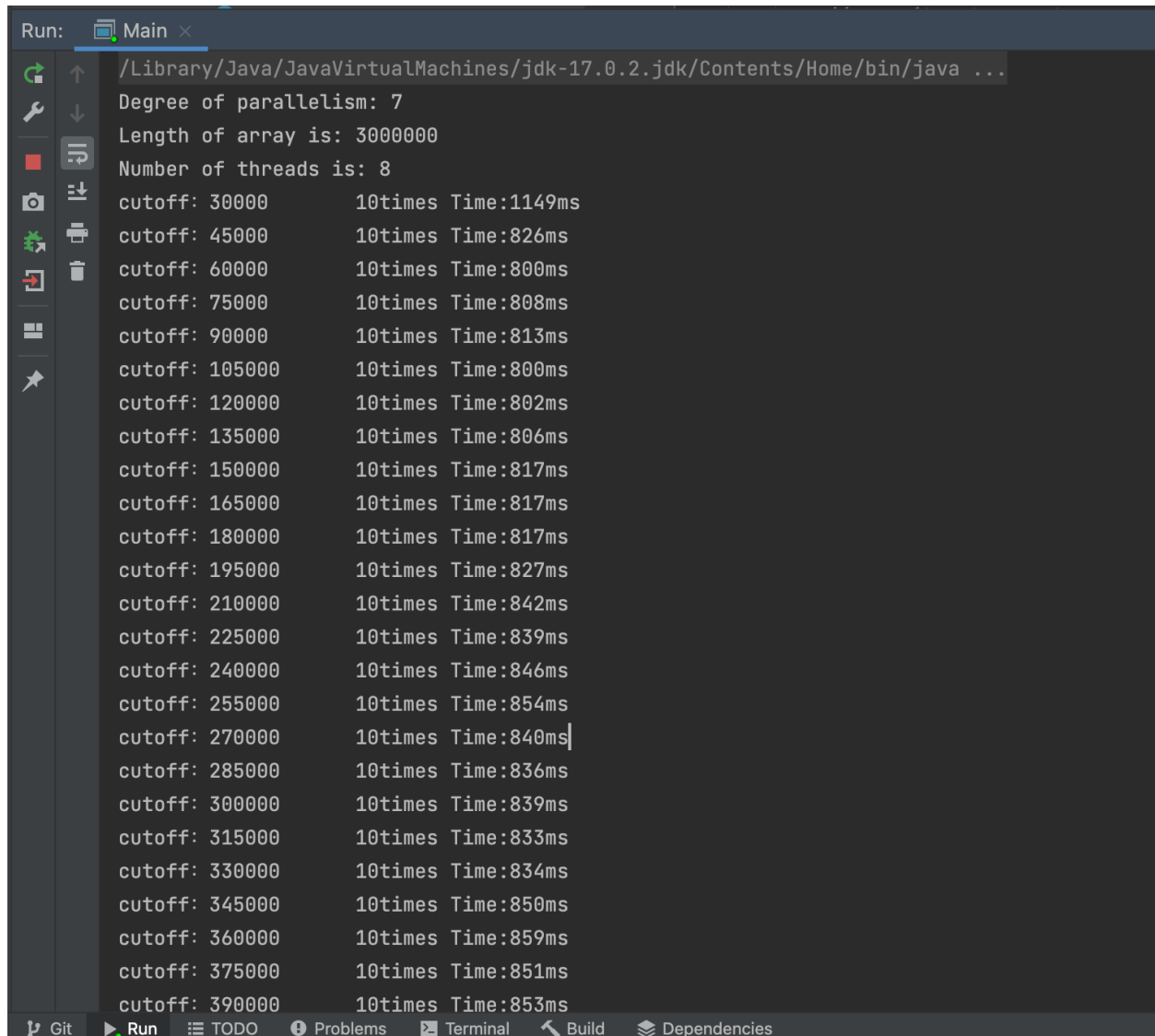
```
Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 3000000
Number of threads is: 4
cutoff: 30000      10times Time:1143ms
cutoff: 45000      10times Time:837ms
cutoff: 60000      10times Time:825ms
cutoff: 75000      10times Time:831ms
cutoff: 90000      10times Time:826ms
cutoff: 105000     10times Time:852ms
cutoff: 120000     10times Time:836ms
cutoff: 135000     10times Time:844ms
cutoff: 150000     10times Time:846ms
cutoff: 165000     10times Time:855ms
cutoff: 180000     10times Time:854ms
cutoff: 195000     10times Time:899ms
cutoff: 210000     10times Time:880ms
cutoff: 225000     10times Time:902ms
cutoff: 240000     10times Time:907ms
cutoff: 255000     10times Time:885ms
cutoff: 270000     10times Time:892ms
cutoff: 285000     10times Time:907ms
cutoff: 300000     10times Time:887ms
cutoff: 315000     10times Time:889ms
cutoff: 330000     10times Time:873ms
cutoff: 345000     10times Time:901ms
cutoff: 360000     10times Time:895ms
cutoff: 375000     10times Time:897ms
cutoff: 390000     10times Time:951ms
```

Degree of parallelism: 7

Array Length: 3000000

Thread count: 8

Number of cores in test machine: 8



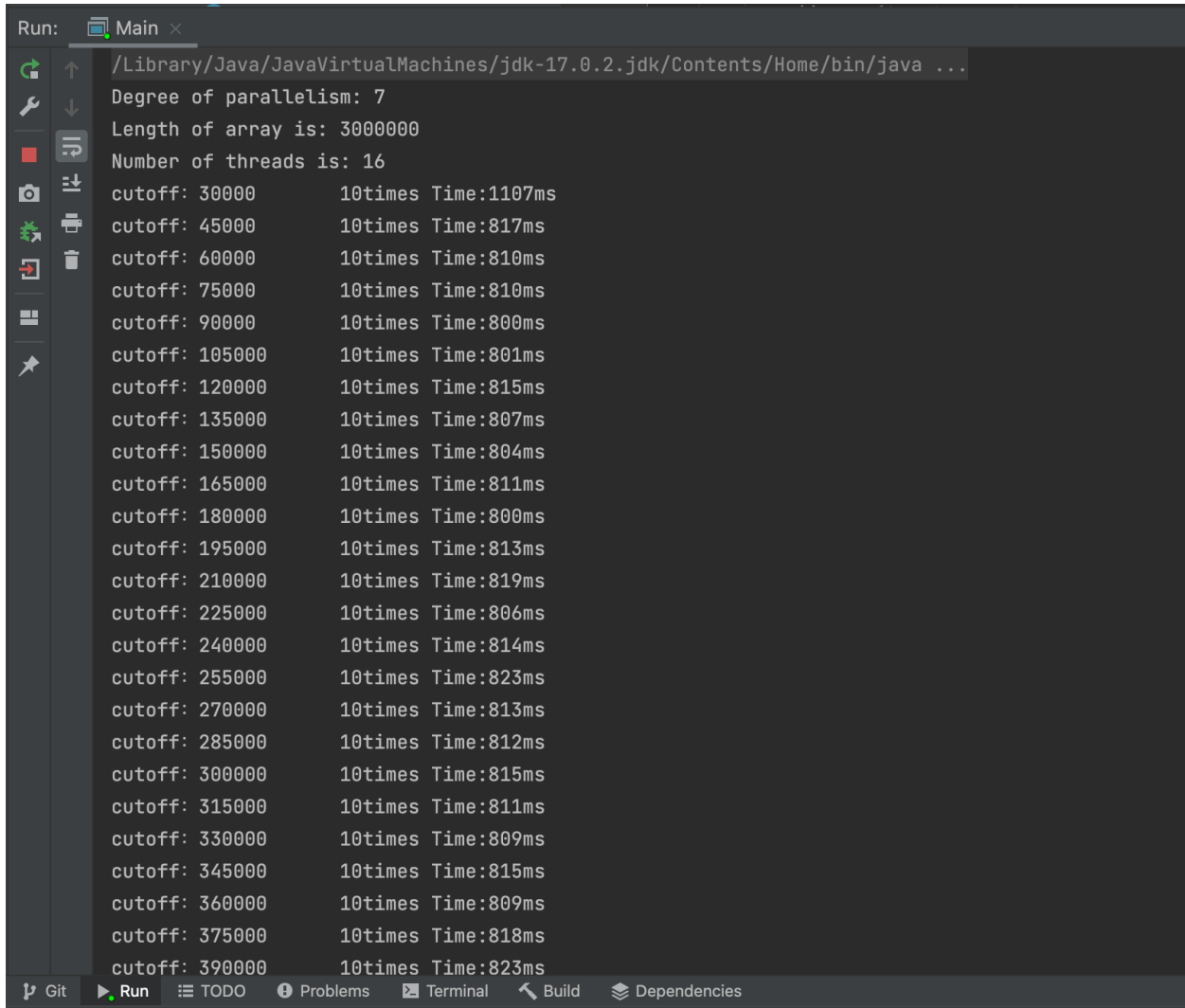
```
Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 3000000
Number of threads is: 8
cutoff: 30000      10times Time:1149ms
cutoff: 45000      10times Time:826ms
cutoff: 60000      10times Time:800ms
cutoff: 75000      10times Time:808ms
cutoff: 90000      10times Time:813ms
cutoff: 105000     10times Time:800ms
cutoff: 120000     10times Time:802ms
cutoff: 135000     10times Time:806ms
cutoff: 150000     10times Time:817ms
cutoff: 165000     10times Time:817ms
cutoff: 180000     10times Time:817ms
cutoff: 195000     10times Time:827ms
cutoff: 210000     10times Time:842ms
cutoff: 225000     10times Time:839ms
cutoff: 240000     10times Time:846ms
cutoff: 255000     10times Time:854ms
cutoff: 270000     10times Time:840ms
cutoff: 285000     10times Time:836ms
cutoff: 300000     10times Time:839ms
cutoff: 315000     10times Time:833ms
cutoff: 330000     10times Time:834ms
cutoff: 345000     10times Time:850ms
cutoff: 360000     10times Time:859ms
cutoff: 375000     10times Time:851ms
cutoff: 390000     10times Time:853ms
```

Degree of parallelism: 7

Array Length: 3000000

Thread count: 16

Number of cores in test machine: 8



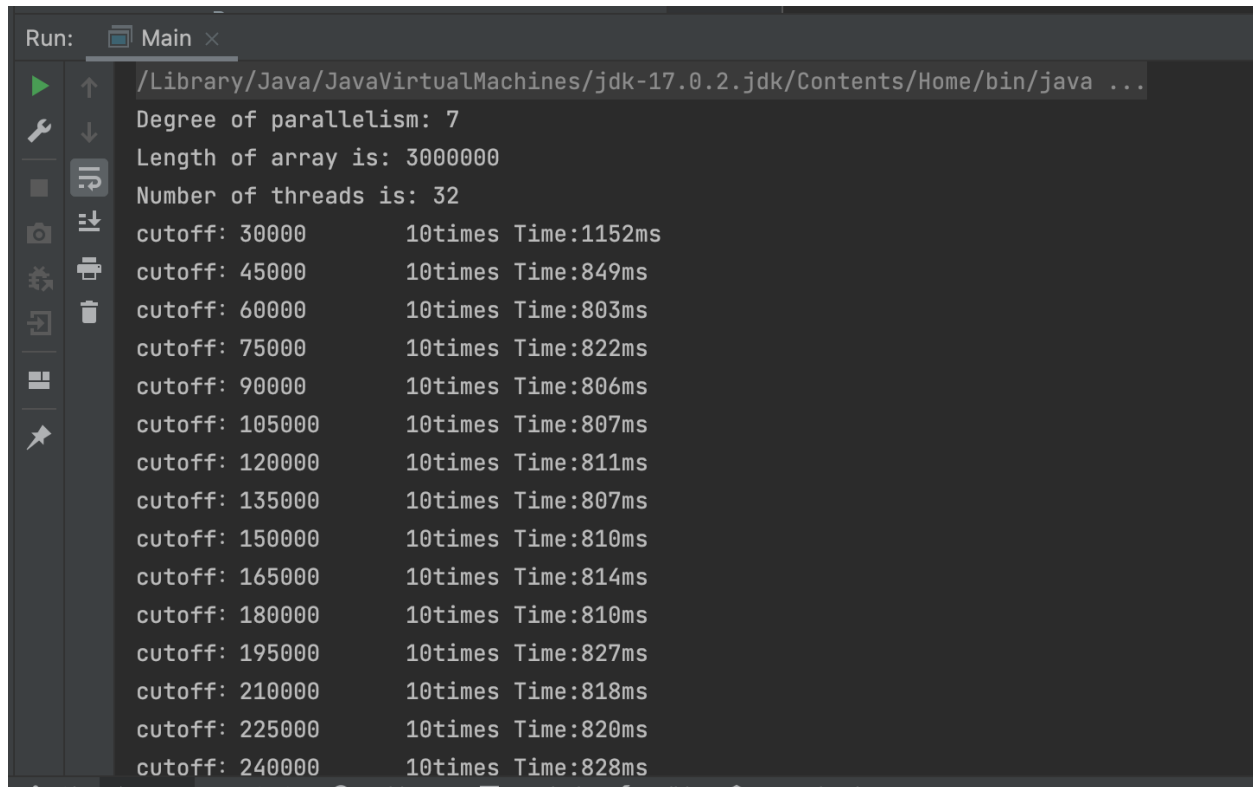
```
Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 3000000
Number of threads is: 16
cutoff: 30000      10times Time:1107ms
cutoff: 45000      10times Time:817ms
cutoff: 60000      10times Time:810ms
cutoff: 75000      10times Time:810ms
cutoff: 90000      10times Time:800ms
cutoff: 105000     10times Time:801ms
cutoff: 120000     10times Time:815ms
cutoff: 135000     10times Time:807ms
cutoff: 150000     10times Time:804ms
cutoff: 165000     10times Time:811ms
cutoff: 180000     10times Time:800ms
cutoff: 195000     10times Time:813ms
cutoff: 210000     10times Time:819ms
cutoff: 225000     10times Time:806ms
cutoff: 240000     10times Time:814ms
cutoff: 255000     10times Time:823ms
cutoff: 270000     10times Time:813ms
cutoff: 285000     10times Time:812ms
cutoff: 300000     10times Time:815ms
cutoff: 315000     10times Time:811ms
cutoff: 330000     10times Time:809ms
cutoff: 345000     10times Time:815ms
cutoff: 360000     10times Time:809ms
cutoff: 375000     10times Time:818ms
cutoff: 390000     10times Time:823ms
```

Degree of parallelism: 7

Array Length: 3000000

Thread count: 32

Number of cores in test machine: 8



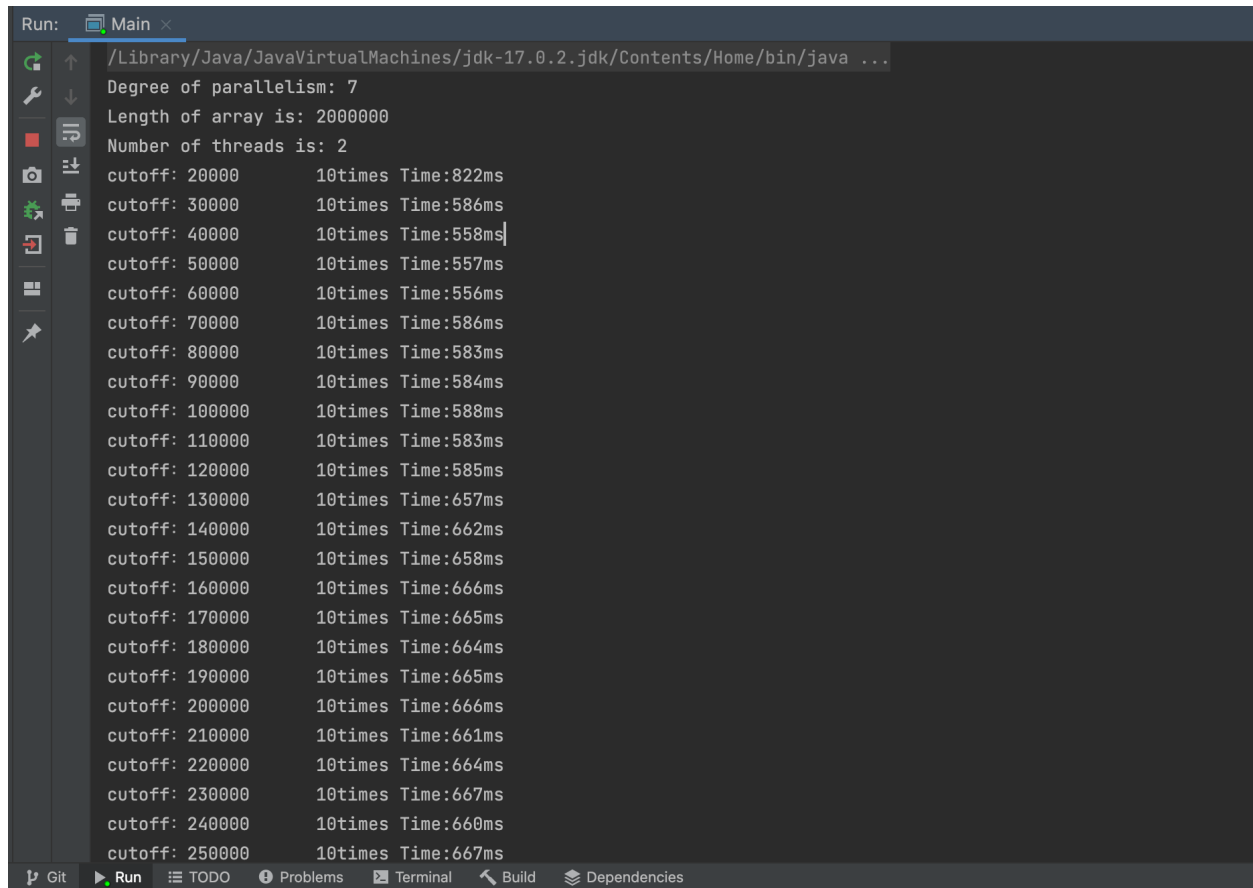
```
Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 3000000
Number of threads is: 32
cutoff: 30000      10times Time:1152ms
cutoff: 45000      10times Time:849ms
cutoff: 60000      10times Time:803ms
cutoff: 75000      10times Time:822ms
cutoff: 90000      10times Time:806ms
cutoff: 105000     10times Time:807ms
cutoff: 120000     10times Time:811ms
cutoff: 135000     10times Time:807ms
cutoff: 150000     10times Time:810ms
cutoff: 165000     10times Time:814ms
cutoff: 180000     10times Time:810ms
cutoff: 195000     10times Time:827ms
cutoff: 210000     10times Time:818ms
cutoff: 225000     10times Time:820ms
cutoff: 240000     10times Time:828ms
```

Degree of parallelism: 7

Array Length: 2000000

Thread count: 2

Number of cores in test machine: 8



The screenshot shows an IDE's console window with the following output:

```
Run: Main x  
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...  
Degree of parallelism: 7  
Length of array is: 2000000  
Number of threads is: 2  
cutoff: 20000      10times Time:822ms  
cutoff: 30000      10times Time:586ms  
cutoff: 40000      10times Time:558ms  
cutoff: 50000      10times Time:557ms  
cutoff: 60000      10times Time:556ms  
cutoff: 70000      10times Time:586ms  
cutoff: 80000      10times Time:583ms  
cutoff: 90000      10times Time:584ms  
cutoff: 100000     10times Time:588ms  
cutoff: 110000     10times Time:583ms  
cutoff: 120000     10times Time:585ms  
cutoff: 130000     10times Time:657ms  
cutoff: 140000     10times Time:662ms  
cutoff: 150000     10times Time:658ms  
cutoff: 160000     10times Time:666ms  
cutoff: 170000     10times Time:665ms  
cutoff: 180000     10times Time:664ms  
cutoff: 190000     10times Time:665ms  
cutoff: 200000     10times Time:666ms  
cutoff: 210000     10times Time:661ms  
cutoff: 220000     10times Time:664ms  
cutoff: 230000     10times Time:667ms  
cutoff: 240000     10times Time:660ms  
cutoff: 250000     10times Time:667ms
```

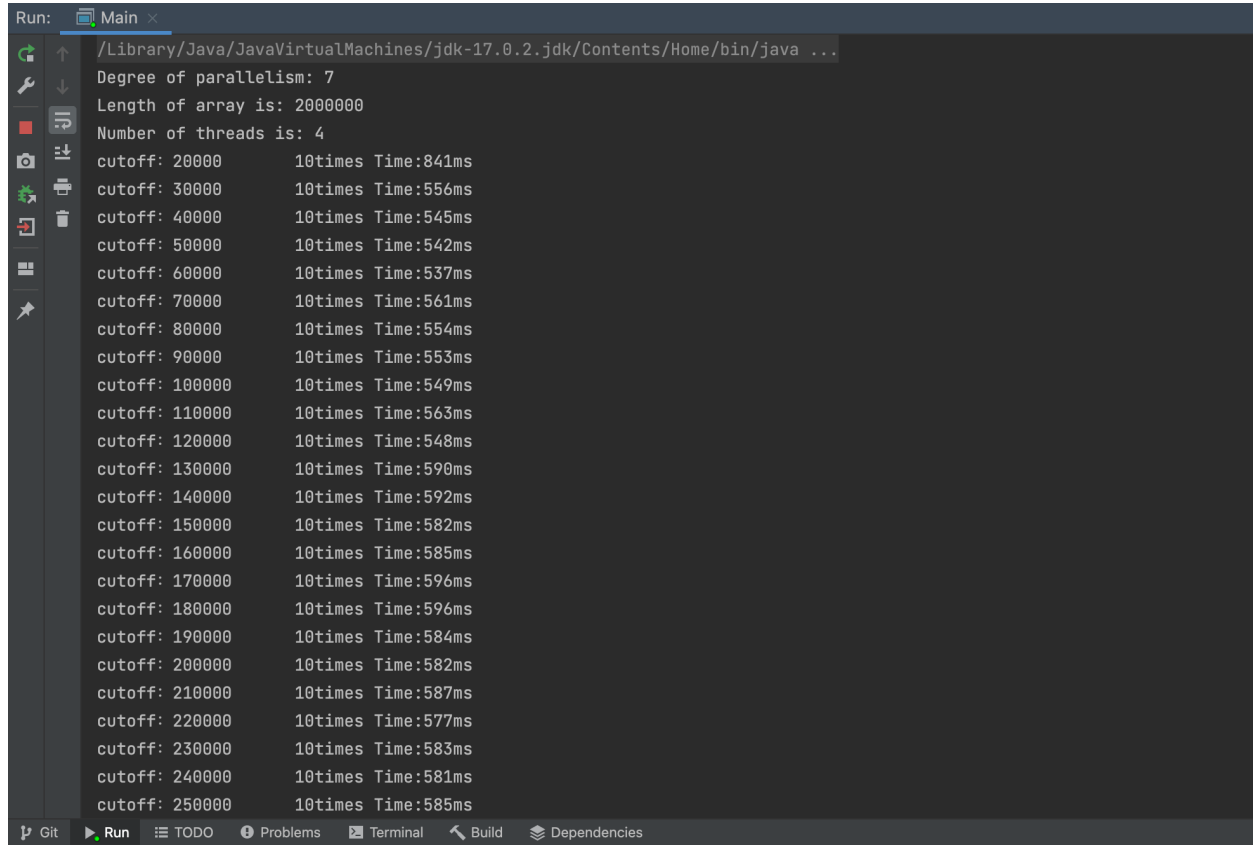
The IDE interface includes a sidebar with icons for Run, Debug, Test, and other tools, and a bottom status bar with tabs for Git, Run, TODO, Problems, Terminal, Build, and Dependencies.

Degree of parallelism: 7

Array Length: 2000000

Thread count: 4

Number of cores in test machine: 8



The screenshot shows an IDE's console window with the following output:

```
Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 2000000
Number of threads is: 4
cutoff: 20000      10times Time:841ms
cutoff: 30000      10times Time:556ms
cutoff: 40000      10times Time:545ms
cutoff: 50000      10times Time:542ms
cutoff: 60000      10times Time:537ms
cutoff: 70000      10times Time:561ms
cutoff: 80000      10times Time:554ms
cutoff: 90000      10times Time:553ms
cutoff: 100000     10times Time:549ms
cutoff: 110000     10times Time:563ms
cutoff: 120000     10times Time:548ms
cutoff: 130000     10times Time:590ms
cutoff: 140000     10times Time:592ms
cutoff: 150000     10times Time:582ms
cutoff: 160000     10times Time:585ms
cutoff: 170000     10times Time:596ms
cutoff: 180000     10times Time:596ms
cutoff: 190000     10times Time:584ms
cutoff: 200000     10times Time:582ms
cutoff: 210000     10times Time:587ms
cutoff: 220000     10times Time:577ms
cutoff: 230000     10times Time:583ms
cutoff: 240000     10times Time:581ms
cutoff: 250000     10times Time:585ms
```

The IDE interface includes a sidebar with icons for Run, Debug, Test, and other tools, and a bottom status bar with tabs for Git, Run, TODO, Problems, Terminal, Build, and Dependencies.


```
Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 2000000
Number of threads is: 8
cutoff: 20000      10times Time:820ms
cutoff: 30000      10times Time:547ms
cutoff: 40000      10times Time:519ms
cutoff: 50000      10times Time:526ms
cutoff: 60000      10times Time:531ms
cutoff: 70000      10times Time:531ms
cutoff: 80000      10times Time:542ms
cutoff: 90000      10times Time:522ms
cutoff: 100000     10times Time:534ms
cutoff: 110000     10times Time:533ms
cutoff: 120000     10times Time:529ms
cutoff: 130000     10times Time:548ms
cutoff: 140000     10times Time:536ms
cutoff: 150000     10times Time:538ms
cutoff: 160000     10times Time:537ms
cutoff: 170000     10times Time:530ms
cutoff: 180000     10times Time:548ms
cutoff: 190000     10times Time:533ms
cutoff: 200000     10times Time:536ms
cutoff: 210000     10times Time:543ms
cutoff: 220000     10times Time:538ms
cutoff: 230000     10times Time:534ms
```

The screenshot shows an IDE interface with a dark theme. The top bar indicates the current file is "Main". Below it, the terminal window displays the following output:

```
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...  
Degree of parallelism: 7  
Length of array is: 2000000  
Number of threads is: 16  
cutoff: 20000      10times Time:765ms  
cutoff: 30000      10times Time:569ms  
cutoff: 40000      10times Time:538ms  
cutoff: 50000      10times Time:535ms  
cutoff: 60000      10times Time:539ms  
cutoff: 70000      10times Time:526ms  
cutoff: 80000      10times Time:537ms  
cutoff: 90000      10times Time:530ms  
cutoff: 100000     10times Time:530ms  
cutoff: 110000     10times Time:546ms  
cutoff: 120000     10times Time:528ms  
cutoff: 130000     10times Time:530ms  
cutoff: 140000     10times Time:530ms  
cutoff: 150000     10times Time:526ms  
cutoff: 160000     10times Time:528ms  
cutoff: 170000     10times Time:537ms  
cutoff: 180000     10times Time:529ms  
cutoff: 190000     10times Time:529ms  
cutoff: 200000     10times Time:524ms  
cutoff: 210000     10times Time:529ms  
cutoff: 220000     10times Time:534ms  
cutoff: 230000     10times Time:525ms
```

The bottom status bar shows icons for Git, Run, TODO, Problems, Terminal, Build, and Dependencies.

```

Run: Main x
/Library/Java/JavaVirtualMachines/jdk-17.0.2.jdk/Contents/Home/bin/java ...
Degree of parallelism: 7
Length of array is: 2000000
Number of threads is: 32
cutoff: 20000      10times Time:858ms
cutoff: 30000      10times Time:555ms
cutoff: 40000      10times Time:539ms
cutoff: 50000      10times Time:537ms
cutoff: 60000      10times Time:529ms
cutoff: 70000      10times Time:529ms
cutoff: 80000      10times Time:531ms
cutoff: 90000      10times Time:536ms
cutoff: 100000     10times Time:531ms
cutoff: 110000     10times Time:538ms
cutoff: 120000     10times Time:546ms
cutoff: 130000     10times Time:532ms
cutoff: 140000     10times Time:528ms
cutoff: 150000     10times Time:534ms
cutoff: 160000     10times Time:540ms
cutoff: 170000     10times Time:539ms
cutoff: 180000     10times Time:535ms
cutoff: 190000     10times Time:526ms

```

Relationship Conclusion

We can conclude -

Best cutoff = array size / no. of threads

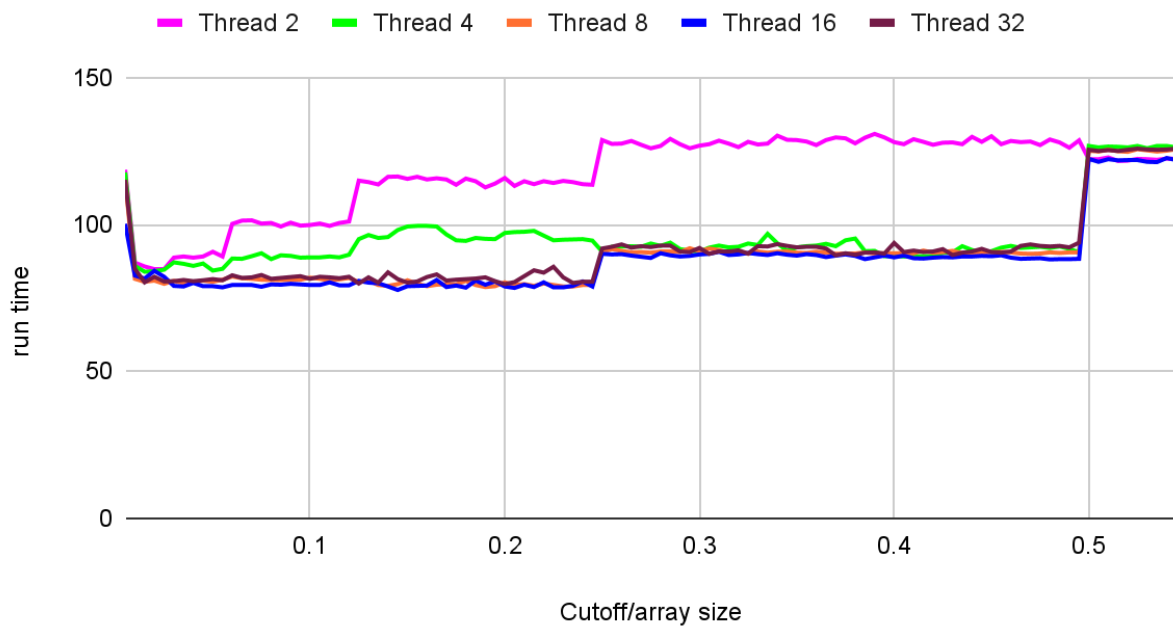
From the above data and chart where with different array sizes ranging from 1000000 and 2000000 and degree of parallelism is constant and thread count being 2, 4, 8, 16 and 32 for all the experiments, it can be observed that there is a decrease of time at first, reach the lowest point and then increase a bit where cutoff value is around 20% of the array size in all the experiments. Thus, concluding that 20% of the array size is the best cutoff value

Evidence/Graph

Degree of parallelism: 7

Array Length: 3000000

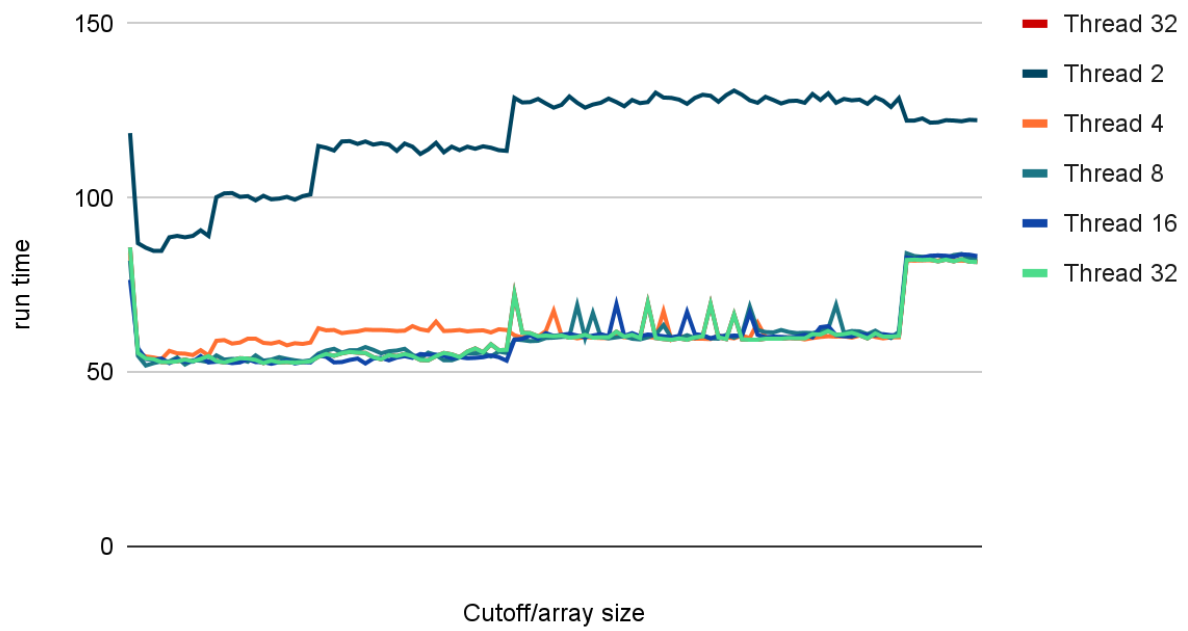
Cutoff Vs Time



Degree of parallelism: 7

Array Length: 2000000

Cutoff Vs Time



Git Repository -

<https://github.com/Naina-NEU/INFO6205/commit/97850a26d50f9efdc1571f16639dbaeae12bff0c>