

## Program Structures and Algorithms

Spring 2023 (SEC – 8)

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### Assignment 5

#### Task:

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.

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. The experiments should involve sorting arrays of sufficient size for the parallel sort to make a difference.

#### Link to report:

<https://github.com/RishiDesai17/INFO6205/blob/Spring2023/assignments/assignment-5/Assignment%205.pdf>

#### Link to code:

<https://github.com/RishiDesai17/INFO6205/tree/Spring2023/src/main/java/edu/neu/coe/info6205/sort/par>

#### Relationship Conclusion:

Based on the results, I found that for most cases the best performance was obtained when the cutoff was 25% of the array size. In my experiments, for the array size 200000 (smallest size in my experiments), the best performance for most cases was obtained when cutoff was 50% of the array size. But for all the remaining array sizes (which are all greater than 200000), it was

always 25% of the array size. Hence, we can conclude that a cutoff value that is 25% of the array size is optimal based on my experiments.

About the number of threads, I noticed that for most cases, the performance kept improving until we reached 8 threads, After that, in most cases performance did not vary too much and in a few cases it deteriorated slightly. Hence, we can conclude that 8 is the ideal number of threads based on my experiments.

The maximum recursive depth would be  $\log_2(\text{array size} / \text{cutoff})$ . This value will be maximum because after cutoff is reached, we use system sorting instead of parallel sort. The number threads are increased in powers of 2, so number of threads =  $2^{(\text{recursive depth})}$ .

### **Evidence to support that conclusion:**

Following are the results of parallel sorting for various combinations of array sizes, threads, and cutoffs:

Array size: 200000

Threads: 2

Cutoff / Array size	Time taken
0.25	62.7
0.5	36.2
0.75	27.7
1	23.4
1.25	34.3
1.5	31.5
1.75	29.1
2	29
2.25	29.3
2.5	28.8

Threads: 4

Cutoff / Array size	Time taken
0.25	37.8
0.5	19.4
0.75	22.2
1	22.1
1.25	32.6
1.5	31.9

1.75	31.1
2	35.7
2.25	35.2
2.5	29.8

Threads: 8

Cutoff / Array size	Time taken
0.25	25.5
0.5	20.1
0.75	22.5
1	22.1
1.25	33.8
1.5	34.8
1.75	34.5
2	29.1
2.25	28.2
2.5	13.3

Threads: 16

Cutoff / Array size	Time taken
0.25	13.4
0.5	15.6
0.75	24
1	22.6
1.25	34
1.5	34.1
1.75	29.4
2	29.8
2.25	20.9
2.5	35

Threads: 32

Cutoff / Array size	Time taken
0.25	22.4
0.5	17.7
0.75	22.2
1	23.1
1.25	34.5
1.5	30.5

1.75	35.5
2	34.9
2.25	29.6
2.5	35

Threads: 64

Cutoff / Array size	Time taken
0.25	27.7
0.5	19.4
0.75	21.7
1	22.1
1.25	33.7
1.5	35.1
1.75	29.3
2	29.5
2.25	33.3
2.5	38.3

Array size: 400000

Threads: 2

Cutoff / Array size	Time taken
0.125	62.5
0.25	45
0.375	50.4
0.5	43.2
0.625	46.7
0.75	46.7
0.875	42.9
1	47.1
1.125	70.4
1.25	70.2

Threads: 4

Cutoff / Array size	Time taken
0.125	57.1

0.25	38.2
0.375	35.9
0.5	35.3
0.625	46.3
0.75	45.7
0.875	47.8
1	47.3
1.125	72.5
1.25	66.1

Threads: 8

Cutoff / Array size	Time taken
0.125	53.9
0.25	32.4
0.375	35.8
0.5	35.4
0.625	45.3
0.75	47.4
0.875	46.9
1	38.5
1.125	72.4
1.25	68.9

Threads: 16

Cutoff / Array size	Time taken
0.125	46.2
0.25	33.8
0.375	34.5
0.5	35.8
0.625	45.3
0.75	46.5
0.875	45.3
1	45.4
1.125	69.4
1.25	55.6

Threads: 32

Cutoff / Array size	Time taken
0.125	26

0.25	31.5
0.375	34
0.5	35.6
0.625	45.1
0.75	46.6
0.875	45.7
1	46.7
1.125	68.5
1.25	73.3

Threads: 64

Cutoff / Array size	Time taken
0.125	49.9
0.25	31.3
0.375	36.6
0.5	38
0.625	46.3
0.75	50.5
0.875	43.5
1	49.9
1.125	69.2
1.25	61.8

Array size: 800000

Threads: 2

Cutoff / Array size	Time taken
0.0625	100.3
0.125	80.3
0.1875	93.1
0.25	96.9
0.3125	102.8
0.375	103.1
0.4375	95.4
0.5	102.4
0.5625	101.3
0.625	109.4

Threads: 4

Cutoff / Array size	Time taken
0.0625	91.1
0.125	69.7
0.1875	78.5
0.25	77.9
0.3125	75.7
0.375	81
0.4375	75.5
0.5	72.8
0.5625	95
0.625	98.9

Threads: 8

Cutoff / Array size	Time taken
0.0625	97.8
0.125	69.9
0.1875	61.4
0.25	62.7
0.3125	72.8
0.375	78.3
0.4375	80.4
0.5	82.8
0.5625	110.7
0.625	110.8

Threads: 16

Cutoff / Array size	Time taken
0.0625	93.3
0.125	64.1
0.1875	41.3
0.25	29.6
0.3125	32.1
0.375	45.1
0.4375	63.7
0.5	79.8
0.5625	89.4
0.625	96.5

Threads: 32

Cutoff / Array size	Time taken
0.0625	68
0.125	61.6
0.1875	63.1
0.25	62.9
0.3125	72.5
0.375	74.5
0.4375	75
0.5	72.3
0.5625	98
0.625	100

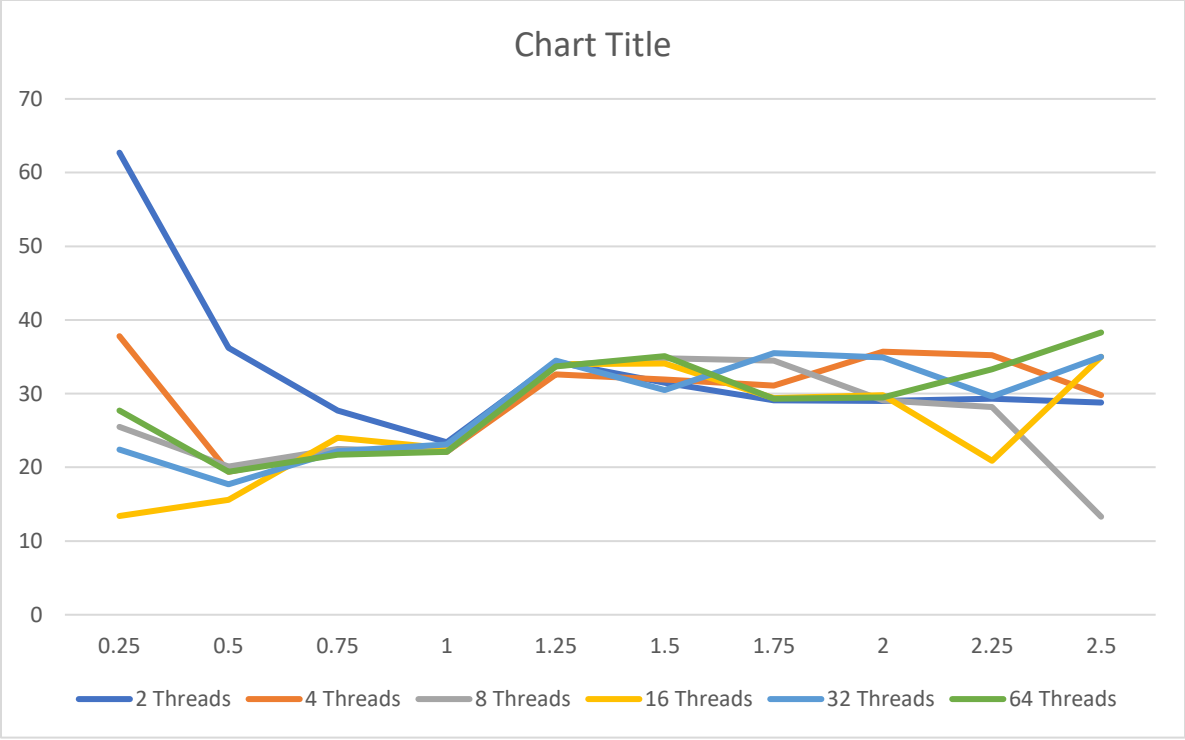
Threads: 64

Cutoff / Array size	Time taken
0.0625	69.1
0.125	62.1
0.1875	61.8
0.25	68.1
0.3125	73.8
0.375	75
0.4375	82.1
0.5	74.1
0.5625	105.8
0.625	105.9

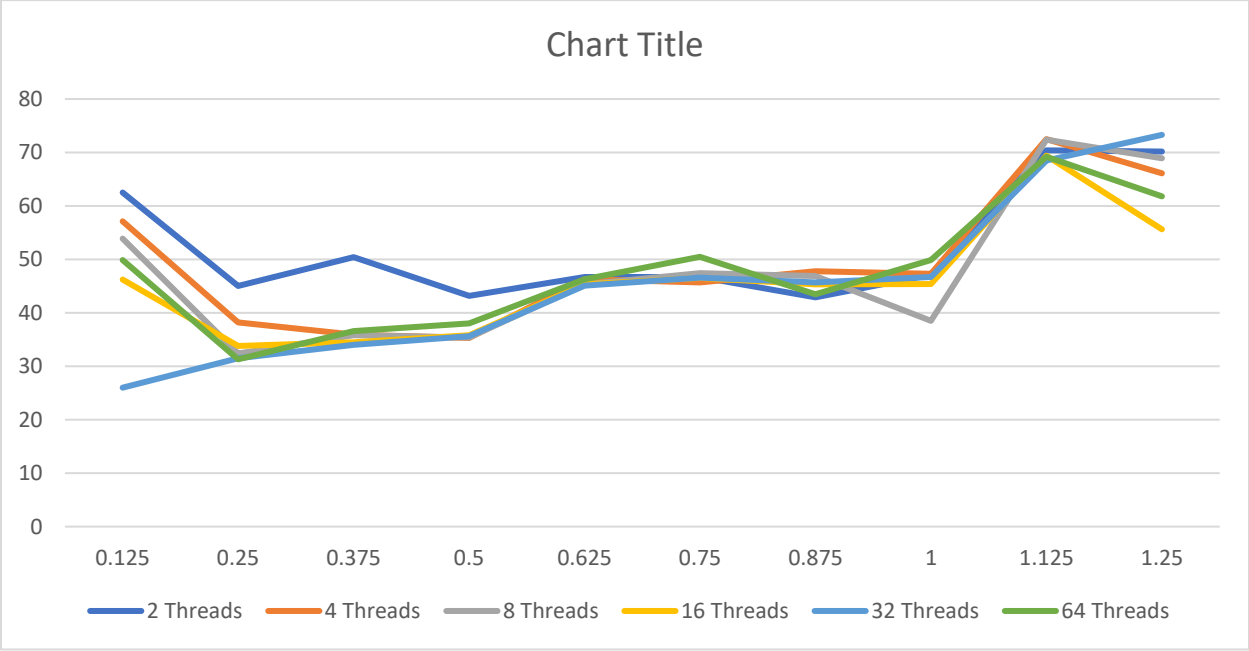
**Graphical Representation:**

Array size: 200000

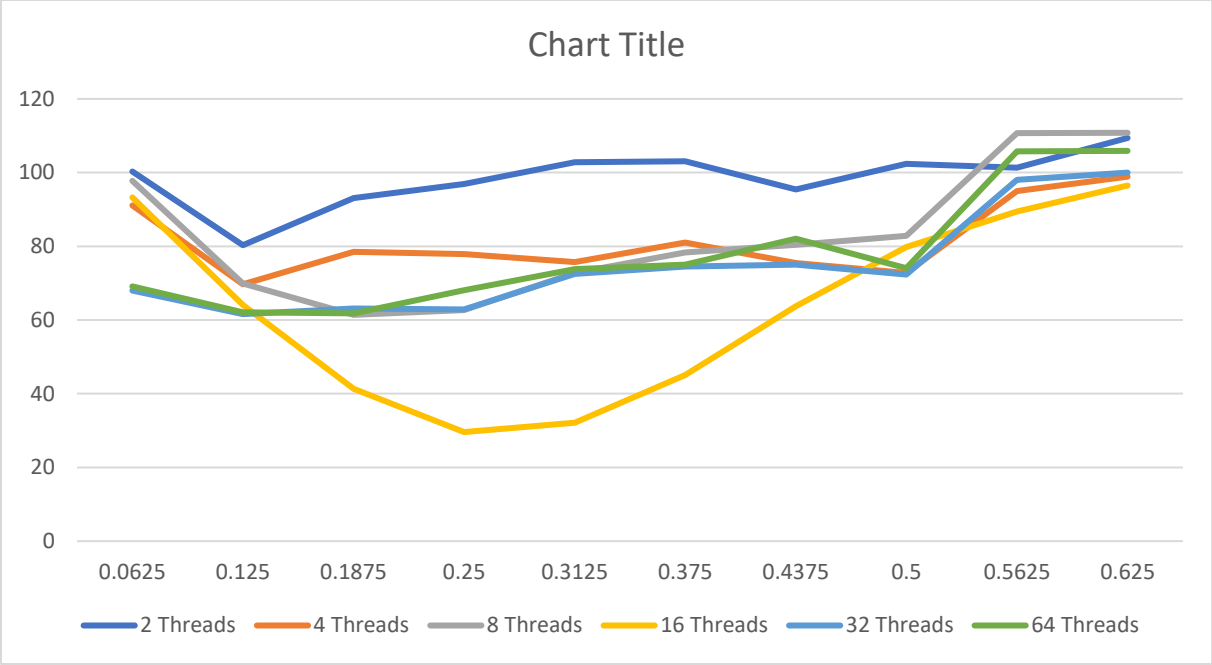




Array size: 400000



Array size: 800000



Output:

```
Array size: 200000
Degree of parallelism: 2
cutoff: 50000      10times Time:627ms
cutoff: 100000     10times Time:362ms
cutoff: 150000     10times Time:277ms
cutoff: 200000     10times Time:234ms
cutoff: 250000     10times Time:343ms
cutoff: 300000     10times Time:315ms
cutoff: 350000     10times Time:291ms
cutoff: 400000     10times Time:290ms
cutoff: 450000     10times Time:293ms
cutoff: 500000     10times Time:288ms
Degree of parallelism: 4
cutoff: 50000      10times Time:378ms
cutoff: 100000     10times Time:194ms
cutoff: 150000     10times Time:222ms
cutoff: 200000     10times Time:221ms
cutoff: 250000     10times Time:326ms
cutoff: 300000     10times Time:319ms
cutoff: 350000     10times Time:311ms
cutoff: 400000     10times Time:357ms
cutoff: 450000     10times Time:352ms
cutoff: 500000     10times Time:298ms
Degree of parallelism: 8
cutoff: 50000      10times Time:255ms
cutoff: 100000     10times Time:201ms
cutoff: 150000     10times Time:225ms
cutoff: 200000     10times Time:221ms
cutoff: 250000     10times Time:338ms
cutoff: 300000     10times Time:348ms
cutoff: 350000     10times Time:345ms
cutoff: 400000     10times Time:291ms
cutoff: 450000     10times Time:282ms
cutoff: 500000     10times Time:133ms
```

```
Degree of parallelism: 16
cutoff: 50000      10times Time:134ms
cutoff: 100000    10times Time:156ms
cutoff: 150000    10times Time:240ms
cutoff: 200000    10times Time:226ms
cutoff: 250000    10times Time:340ms
cutoff: 300000    10times Time:341ms
cutoff: 350000    10times Time:294ms
cutoff: 400000    10times Time:298ms
cutoff: 450000    10times Time:209ms
cutoff: 500000    10times Time:350ms
Degree of parallelism: 32
cutoff: 50000      10times Time:224ms
cutoff: 100000    10times Time:177ms
cutoff: 150000    10times Time:222ms
cutoff: 200000    10times Time:231ms
cutoff: 250000    10times Time:345ms
cutoff: 300000    10times Time:305ms
cutoff: 350000    10times Time:355ms
cutoff: 400000    10times Time:349ms
cutoff: 450000    10times Time:296ms
cutoff: 500000    10times Time:350ms
Degree of parallelism: 64
cutoff: 50000      10times Time:277ms
cutoff: 100000    10times Time:194ms
cutoff: 150000    10times Time:217ms
cutoff: 200000    10times Time:221ms
cutoff: 250000    10times Time:337ms
cutoff: 300000    10times Time:351ms
cutoff: 350000    10times Time:293ms
cutoff: 400000    10times Time:295ms
cutoff: 450000    10times Time:333ms
cutoff: 500000    10times Time:383ms
```

```
Array size: 400000
Degree of parallelism: 2
cutoff: 50000      10times Time:625ms
cutoff: 100000     10times Time:450ms
cutoff: 150000     10times Time:504ms
cutoff: 200000     10times Time:432ms
cutoff: 250000     10times Time:467ms
cutoff: 300000     10times Time:467ms
cutoff: 350000     10times Time:429ms
cutoff: 400000     10times Time:471ms
cutoff: 450000     10times Time:704ms
cutoff: 500000     10times Time:702ms
Degree of parallelism: 4
cutoff: 50000      10times Time:571ms
cutoff: 100000     10times Time:382ms
cutoff: 150000     10times Time:359ms
cutoff: 200000     10times Time:353ms
cutoff: 250000     10times Time:463ms
cutoff: 300000     10times Time:457ms
cutoff: 350000     10times Time:478ms
cutoff: 400000     10times Time:473ms
cutoff: 450000     10times Time:725ms
cutoff: 500000     10times Time:661ms
Degree of parallelism: 8
cutoff: 50000      10times Time:539ms
cutoff: 100000     10times Time:324ms
cutoff: 150000     10times Time:358ms
cutoff: 200000     10times Time:354ms
cutoff: 250000     10times Time:453ms
cutoff: 300000     10times Time:474ms
cutoff: 350000     10times Time:469ms
cutoff: 400000     10times Time:385ms
cutoff: 450000     10times Time:724ms
cutoff: 500000     10times Time:689ms
```

```
Degree of parallelism: 16
cutoff: 50000      10times Time:462ms
cutoff: 100000    10times Time:338ms
cutoff: 150000    10times Time:345ms
cutoff: 200000    10times Time:358ms
cutoff: 250000    10times Time:453ms
cutoff: 300000    10times Time:465ms
cutoff: 350000    10times Time:453ms
cutoff: 400000    10times Time:454ms
cutoff: 450000    10times Time:694ms
cutoff: 500000    10times Time:556ms
Degree of parallelism: 32
cutoff: 50000      10times Time:260ms
cutoff: 100000    10times Time:315ms
cutoff: 150000    10times Time:340ms
cutoff: 200000    10times Time:356ms
cutoff: 250000    10times Time:451ms
cutoff: 300000    10times Time:466ms
cutoff: 350000    10times Time:457ms
cutoff: 400000    10times Time:467ms
cutoff: 450000    10times Time:685ms
cutoff: 500000    10times Time:733ms
Degree of parallelism: 64
cutoff: 50000      10times Time:499ms
cutoff: 100000    10times Time:313ms
cutoff: 150000    10times Time:366ms
cutoff: 200000    10times Time:380ms
cutoff: 250000    10times Time:463ms
cutoff: 300000    10times Time:505ms
cutoff: 350000    10times Time:435ms
cutoff: 400000    10times Time:499ms
cutoff: 450000    10times Time:692ms
cutoff: 500000    10times Time:618ms
```

Array size: 800000

Degree of parallelism: 2

cutoff: 50000	10times	Time:1003ms
cutoff: 100000	10times	Time:803ms
cutoff: 150000	10times	Time:931ms
cutoff: 200000	10times	Time:969ms
cutoff: 250000	10times	Time:1028ms
cutoff: 300000	10times	Time:1031ms
cutoff: 350000	10times	Time:954ms
cutoff: 400000	10times	Time:1024ms
cutoff: 450000	10times	Time:1013ms
cutoff: 500000	10times	Time:1094ms

Degree of parallelism: 4

cutoff: 50000	10times	Time:911ms
cutoff: 100000	10times	Time:697ms
cutoff: 150000	10times	Time:785ms
cutoff: 200000	10times	Time:779ms
cutoff: 250000	10times	Time:757ms
cutoff: 300000	10times	Time:810ms
cutoff: 350000	10times	Time:755ms
cutoff: 400000	10times	Time:728ms
cutoff: 450000	10times	Time:950ms
cutoff: 500000	10times	Time:989ms

Degree of parallelism: 8

cutoff: 50000	10times	Time:978ms
cutoff: 100000	10times	Time:699ms
cutoff: 150000	10times	Time:614ms
cutoff: 200000	10times	Time:627ms
cutoff: 250000	10times	Time:728ms
cutoff: 300000	10times	Time:783ms
cutoff: 350000	10times	Time:804ms
cutoff: 400000	10times	Time:828ms
cutoff: 450000	10times	Time:1107ms
cutoff: 500000	10times	Time:1108ms

Degree of parallelism: 16

cutoff: 50000	10times	Time:933ms
cutoff: 100000	10times	Time:641ms
cutoff: 150000	10times	Time:413ms
cutoff: 200000	10times	Time:296ms
cutoff: 250000	10times	Time:321ms
cutoff: 300000	10times	Time:451ms
cutoff: 350000	10times	Time:637ms
cutoff: 400000	10times	Time:798ms
cutoff: 450000	10times	Time:894ms
cutoff: 500000	10times	Time:965ms

Degree of parallelism: 32

cutoff: 50000	10times	Time:680ms
cutoff: 100000	10times	Time:616ms
cutoff: 150000	10times	Time:631ms
cutoff: 200000	10times	Time:629ms
cutoff: 250000	10times	Time:725ms
cutoff: 300000	10times	Time:745ms
cutoff: 350000	10times	Time:750ms
cutoff: 400000	10times	Time:723ms
cutoff: 450000	10times	Time:980ms
cutoff: 500000	10times	Time:1000ms

Degree of parallelism: 64

cutoff: 50000	10times	Time:691ms
cutoff: 100000	10times	Time:621ms
cutoff: 150000	10times	Time:618ms
cutoff: 200000	10times	Time:681ms
cutoff: 250000	10times	Time:738ms
cutoff: 300000	10times	Time:750ms
cutoff: 350000	10times	Time:821ms
cutoff: 400000	10times	Time:741ms
cutoff: 450000	10times	Time:1058ms
cutoff: 500000	10times	Time:1059ms