

Program Structures and Algorithms - Assignment 4

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Problem Statement:

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 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.

Output Screenshots:

Array Size - 25000

```
cutoff: 25500 10times Time:49ms
cutoff: 26000 10times Time:24ms
cutoff: 26500 10times Time:19ms
cutoff: 27000 10times Time:28ms
cutoff: 27500 10times Time:29ms
cutoff: 28000 10times Time:12ms
cutoff: 28500 10times Time:11ms
cutoff: 29000 10times Time:12ms
cutoff: 29500 10times Time:24ms
cutoff: 30000 10times Time:19ms
cutoff: 30500 10times Time:12ms
cutoff: 31000 10times Time:12ms
cutoff: 31500 10times Time:26ms
cutoff: 32000 10times Time:25ms
cutoff: 32500 10times Time:13ms
cutoff: 33000 10times Time:12ms
cutoff: 33500 10times Time:12ms
cutoff: 34000 10times Time:12ms
cutoff: 34500 10times Time:12ms
cutoff: 35000 10times Time:12ms
cutoff: 35500 10times Time:12ms
cutoff: 36000 10times Time:11ms
cutoff: 36500 10times Time:26ms
cutoff: 37000 10times Time:21ms
cutoff: 37500 10times Time:12ms
cutoff: 38000 10times Time:13ms
cutoff: 38500 10times Time:13ms
cutoff: 39000 10times Time:13ms
cutoff: 39500 10times Time:12ms
cutoff: 40000 10times Time:12ms
cutoff: 40500 10times Time:11ms
```

The screenshot shows two separate runs of a Java application within an IDE. Both runs are titled 'Main' and are located in the 'INFO6205' project under the 'src/main/java/edu/neu/coe/info6205/sort/par' package. The top run is set to 4 threads, and the bottom run is set to 8 threads. Both runs output performance metrics for different cutoff values, showing the number of times the algorithm was run and the execution time.

Run 1 (4 threads):

```
Threads - 4
Degree of Parallelism - 4
cutoff: 25500    10times Time:12ms
cutoff: 26000    10times Time:12ms
cutoff: 26500    10times Time:11ms
cutoff: 27000    10times Time:11ms
cutoff: 27500    10times Time:12ms
cutoff: 28000    10times Time:12ms
cutoff: 28500    10times Time:12ms
cutoff: 29000    10times Time:12ms
cutoff: 29500    10times Time:12ms
cutoff: 30000    10times Time:11ms
cutoff: 30500    10times Time:11ms
cutoff: 31000    10times Time:12ms
cutoff: 31500    10times Time:12ms
cutoff: 32000    10times Time:11ms
cutoff: 32500    10times Time:12ms
cutoff: 33000    10times Time:14ms
cutoff: 33500    10times Time:12ms
cutoff: 34000    10times Time:11ms
cutoff: 34500    10times Time:12ms
cutoff: 35000    10times Time:13ms
cutoff: 35500    10times Time:12ms
cutoff: 36000    10times Time:12ms
cutoff: 36500    10times Time:11ms
cutoff: 37000    10times Time:12ms
cutoff: 37500    10times Time:12ms
cutoff: 38000    10times Time:12ms
cutoff: 38500    10times Time:12ms
cutoff: 39000    10times Time:12ms
cutoff: 39500    10times Time:12ms
cutoff: 40000    10times Time:12ms
cutoff: 40500    10times Time:12ms
cutoff: 41000    10times Time:12ms
cutoff: 41500    10times Time:12ms
```

Run 2 (8 threads):

```
Threads - 8
Degree of Parallelism - 8
cutoff: 25500    10times Time:12ms
cutoff: 26000    10times Time:11ms
cutoff: 26500    10times Time:12ms
cutoff: 27000    10times Time:12ms
cutoff: 27500    10times Time:11ms
cutoff: 28000    10times Time:12ms
cutoff: 28500    10times Time:12ms
cutoff: 29000    10times Time:12ms
cutoff: 29500    10times Time:12ms
cutoff: 30000    10times Time:11ms
cutoff: 30500    10times Time:11ms
cutoff: 31000    10times Time:12ms
cutoff: 31500    10times Time:11ms
cutoff: 32000    10times Time:11ms
cutoff: 32500    10times Time:11ms
cutoff: 33000    10times Time:12ms
cutoff: 34000    10times Time:11ms
cutoff: 34500    10times Time:11ms
cutoff: 35000    10times Time:11ms
cutoff: 35500    10times Time:11ms
cutoff: 36000    10times Time:11ms
cutoff: 36500    10times Time:11ms
cutoff: 37000    10times Time:11ms
cutoff: 37500    10times Time:11ms
cutoff: 38000    10times Time:11ms
cutoff: 38500    10times Time:11ms
cutoff: 39000    10times Time:11ms
cutoff: 39500    10times Time:11ms
cutoff: 40000    10times Time:11ms
cutoff: 40500    10times Time:11ms
cutoff: 41000    10times Time:11ms
cutoff: 41500    10times Time:12ms
```

Program Structure and Algorithm > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > par > Main > size

Project Run: Main

```
Threads - 16
Degree of Parallelism - 16
cutoff: 25500    10times Time:11ms
cutoff: 26000    10times Time:11ms
cutoff: 26500    10times Time:11ms
cutoff: 27000    10times Time:11ms
cutoff: 27500    10times Time:11ms
cutoff: 28000    10times Time:11ms
cutoff: 28500    10times Time:11ms
cutoff: 29000    10times Time:11ms
cutoff: 29500    10times Time:11ms
cutoff: 30000    10times Time:11ms
cutoff: 30500    10times Time:11ms
cutoff: 31000    10times Time:11ms
cutoff: 31500    10times Time:11ms
cutoff: 32000    10times Time:11ms
cutoff: 32500    10times Time:11ms
cutoff: 33000    10times Time:11ms
cutoff: 33500    10times Time:11ms
cutoff: 34000    10times Time:11ms
cutoff: 34500    10times Time:12ms
cutoff: 35000    10times Time:11ms
cutoff: 35500    10times Time:11ms
cutoff: 36000    10times Time:11ms
cutoff: 36500    10times Time:11ms
cutoff: 37000    10times Time:11ms
cutoff: 37500    10times Time:10ms
cutoff: 38000    10times Time:11ms
cutoff: 38500    10times Time:10ms
cutoff: 39000    10times Time:11ms
cutoff: 39500    10times Time:11ms
cutoff: 40000    10times Time:11ms
cutoff: 40500    10times Time:11ms
cutoff: 41000    10times Time:11ms
cutoff: 41500    10times Time:11ms
```

Git Run TODO Problems Terminal Build Dependencies Event Log

Build completed successfully in 2 sec, 905 ms (a minute ago)

Program Structure and Algorithm > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > par > Main > size

Project Run: Main

```
Threads - 32
Degree of Parallelism - 32
cutoff: 25500    10times Time:11ms
cutoff: 26000    10times Time:12ms
cutoff: 26500    10times Time:11ms
cutoff: 27000    10times Time:12ms
cutoff: 27500    10times Time:11ms
cutoff: 28000    10times Time:12ms
cutoff: 28500    10times Time:11ms
cutoff: 29000    10times Time:12ms
cutoff: 29500    10times Time:12ms
cutoff: 30000    10times Time:11ms
cutoff: 30500    10times Time:12ms
cutoff: 31000    10times Time:11ms
cutoff: 31500    10times Time:12ms
cutoff: 32000    10times Time:11ms
cutoff: 32500    10times Time:11ms
cutoff: 33000    10times Time:11ms
cutoff: 33500    10times Time:11ms
cutoff: 34000    10times Time:11ms
cutoff: 34500    10times Time:11ms
cutoff: 35000    10times Time:12ms
cutoff: 35500    10times Time:11ms
cutoff: 36000    10times Time:12ms
cutoff: 36500    10times Time:11ms
cutoff: 37000    10times Time:11ms
cutoff: 37500    10times Time:11ms
cutoff: 38000    10times Time:11ms
cutoff: 38500    10times Time:12ms
cutoff: 39000    10times Time:11ms
cutoff: 39500    10times Time:11ms
cutoff: 40000    10times Time:12ms
cutoff: 40500    10times Time:11ms
cutoff: 41000    10times Time:11ms
cutoff: 41500    10times Time:11ms
```

Git Run TODO Problems Terminal Build Dependencies Event Log

Build completed successfully in 2 sec, 905 ms (a minute ago)

Program Structure and Algorithm > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > par > Main > size

Project Main ParSort.java

Run: Main

Threads - 64
Degree of Parallelism - 64
cutoff: 25500 10times Time:11ms
cutoff: 26000 10times Time:11ms
cutoff: 26500 10times Time:11ms
cutoff: 27000 10times Time:11ms
cutoff: 27500 10times Time:11ms
cutoff: 28000 10times Time:11ms
cutoff: 28500 10times Time:11ms
cutoff: 29000 10times Time:11ms
cutoff: 29500 10times Time:11ms
cutoff: 30000 10times Time:11ms
cutoff: 30500 10times Time:11ms
cutoff: 31000 10times Time:11ms
cutoff: 31500 10times Time:11ms
cutoff: 32000 10times Time:12ms
cutoff: 32500 10times Time:11ms
cutoff: 33000 10times Time:11ms
cutoff: 33500 10times Time:11ms
cutoff: 34000 10times Time:11ms
cutoff: 34500 10times Time:11ms
cutoff: 35000 10times Time:11ms
cutoff: 35500 10times Time:11ms
cutoff: 36000 10times Time:11ms
cutoff: 36500 10times Time:11ms
cutoff: 37000 10times Time:11ms
cutoff: 37500 10times Time:11ms
cutoff: 38000 10times Time:11ms
cutoff: 38500 10times Time:11ms
cutoff: 39000 10times Time:11ms
cutoff: 39500 10times Time:11ms
cutoff: 40000 10times Time:12ms
cutoff: 40500 10times Time:11ms
cutoff: 41000 10times Time:11ms
cutoff: 41500 10times Time:11ms

Git Run TODO Problems Terminal Build Dependencies Event Log

Build completed successfully in 2 sec, 905 ms (a minute ago) 95:40 LF UTF-8 4 spaces Spring2022

Array Size- 50000

The following table summarizes the execution times for both runs:

Cutoff Value	Time (ms) - 2 threads	Time (ms) - 4 threads
25500	176ms	18ms
26000	90ms	17ms
26500	43ms	17ms
27000	49ms	23ms
27500	29ms	16ms
28000	19ms	16ms
28500	19ms	16ms
29000	18ms	16ms
29500	23ms	17ms
30000	19ms	16ms
30500	17ms	16ms
31000	17ms	16ms
31500	18ms	16ms
32000	17ms	16ms
32500	18ms	16ms
33000	19ms	16ms
33500	24ms	16ms
34000	17ms	16ms
34500	16ms	16ms
35000	20ms	16ms
35500	19ms	16ms
36000	19ms	16ms
36500	17ms	16ms
37000	19ms	16ms
37500	18ms	16ms
38000	23ms	16ms
38500	17ms	16ms
39000	18ms	16ms
39500	17ms	16ms
40000	18ms	16ms
40500	18ms	16ms

The image displays two side-by-side screenshots of a Java IDE interface, likely IntelliJ IDEA, showing the output of a parallel sorting algorithm's execution.

Top Window (Threads - 8):

```
Threads - 8
Degree of Parallelism - 8
cutoff: 25500    10times Time:17ms
cutoff: 26000    10times Time:17ms
cutoff: 26500    10times Time:16ms
cutoff: 27000    10times Time:16ms
cutoff: 27500    10times Time:17ms
cutoff: 28000    10times Time:17ms
cutoff: 28500    10times Time:16ms
cutoff: 29000    10times Time:17ms
cutoff: 29500    10times Time:22ms
cutoff: 30000    10times Time:16ms
cutoff: 30500    10times Time:17ms
cutoff: 31000    10times Time:17ms
cutoff: 31500    10times Time:17ms
cutoff: 32000    10times Time:17ms
cutoff: 32500    10times Time:17ms
cutoff: 33000    10times Time:17ms
cutoff: 33500    10times Time:18ms
cutoff: 34000    10times Time:17ms
cutoff: 34500    10times Time:16ms
cutoff: 35000    10times Time:16ms
cutoff: 35500    10times Time:16ms
cutoff: 36000    10times Time:17ms
cutoff: 36500    10times Time:17ms
cutoff: 37000    10times Time:16ms
cutoff: 37500    10times Time:16ms
cutoff: 38000    10times Time:16ms
cutoff: 38500    10times Time:22ms
cutoff: 39000    10times Time:16ms
cutoff: 39500    10times Time:16ms
cutoff: 40000    10times Time:17ms
cutoff: 40500    10times Time:16ms
cutoff: 41000    10times Time:17ms
cutoff: 41500    10times Time:16ms
```

Bottom Window (Threads - 16):

```
Threads - 16
Degree of Parallelism - 16
cutoff: 25500    10times Time:18ms
cutoff: 26000    10times Time:16ms
cutoff: 26500    10times Time:16ms
cutoff: 27000    10times Time:17ms
cutoff: 27500    10times Time:16ms
cutoff: 28000    10times Time:17ms
cutoff: 28500    10times Time:16ms
cutoff: 29000    10times Time:17ms
cutoff: 29500    10times Time:16ms
cutoff: 30000    10times Time:17ms
cutoff: 30500    10times Time:16ms
cutoff: 31000    10times Time:17ms
cutoff: 31500    10times Time:16ms
cutoff: 32000    10times Time:21ms
cutoff: 32500    10times Time:16ms
cutoff: 33000    10times Time:16ms
cutoff: 33500    10times Time:17ms
cutoff: 34000    10times Time:16ms
cutoff: 34500    10times Time:16ms
cutoff: 35000    10times Time:17ms
cutoff: 35500    10times Time:16ms
cutoff: 36000    10times Time:17ms
cutoff: 36500    10times Time:16ms
cutoff: 37000    10times Time:16ms
cutoff: 37500    10times Time:17ms
cutoff: 38000    10times Time:16ms
cutoff: 38500    10times Time:16ms
cutoff: 39000    10times Time:16ms
cutoff: 39500    10times Time:17ms
cutoff: 40000    10times Time:17ms
cutoff: 40500    10times Time:16ms
cutoff: 41000    10times Time:23ms
cutoff: 41500    10times Time:17ms
```

Both windows show the same log output, indicating the execution of a parallel sorting algorithm across different thread counts (8 and 16). The log entries show the cutoff value and the number of parallel operations (10times) along with the execution time in milliseconds.

Program Structure and Algorithm > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > par > Main > size

Project Run: Main

```
Threads - 32
Degree of Parallelism - 32
cutoff: 25500    10times Time:17ms
cutoff: 26000    10times Time:16ms
cutoff: 26500    10times Time:16ms
cutoff: 27000    10times Time:17ms
cutoff: 27500    10times Time:17ms
cutoff: 28000    10times Time:16ms
cutoff: 28500    10times Time:16ms
cutoff: 29000    10times Time:16ms
cutoff: 29500    10times Time:16ms
cutoff: 30000    10times Time:17ms
cutoff: 30500    10times Time:16ms
cutoff: 31000    10times Time:17ms
cutoff: 31500    10times Time:16ms
cutoff: 32000    10times Time:17ms
cutoff: 32500    10times Time:16ms
cutoff: 33000    10times Time:16ms
cutoff: 33500    10times Time:17ms
cutoff: 34000    10times Time:22ms
cutoff: 34500    10times Time:16ms
cutoff: 35000    10times Time:17ms
cutoff: 35500    10times Time:16ms
cutoff: 36000    10times Time:17ms
cutoff: 36500    10times Time:17ms
cutoff: 37000    10times Time:16ms
cutoff: 37500    10times Time:16ms
cutoff: 38000    10times Time:16ms
cutoff: 38500    10times Time:17ms
cutoff: 39000    10times Time:16ms
cutoff: 39500    10times Time:17ms
cutoff: 40000    10times Time:16ms
cutoff: 40500    10times Time:17ms
cutoff: 41000    10times Time:16ms
cutoff: 41500    10times Time:17ms
```

Build completed successfully in 2 sec, 665 ms (33 minutes ago)

Event Log

11:36 LF UTF-8 4 spaces Spring2022

Project Run: Main

```
Threads - 64
Degree of Parallelism - 64
cutoff: 25500    10times Time:17ms
cutoff: 26000    10times Time:17ms
cutoff: 26500    10times Time:16ms
cutoff: 27000    10times Time:16ms
cutoff: 27500    10times Time:21ms
cutoff: 28000    10times Time:16ms
cutoff: 28500    10times Time:17ms
cutoff: 29000    10times Time:16ms
cutoff: 29500    10times Time:16ms
cutoff: 30000    10times Time:18ms
cutoff: 30500    10times Time:18ms
cutoff: 31000    10times Time:17ms
cutoff: 31500    10times Time:17ms
cutoff: 32000    10times Time:18ms
cutoff: 32500    10times Time:17ms
cutoff: 33000    10times Time:17ms
cutoff: 33500    10times Time:16ms
cutoff: 34000    10times Time:18ms
cutoff: 34500    10times Time:16ms
cutoff: 35000    10times Time:17ms
cutoff: 35500    10times Time:16ms
cutoff: 36000    10times Time:16ms
cutoff: 36500    10times Time:23ms
cutoff: 37000    10times Time:16ms
cutoff: 37500    10times Time:17ms
cutoff: 38000    10times Time:18ms
cutoff: 38500    10times Time:16ms
cutoff: 39000    10times Time:16ms
cutoff: 39500    10times Time:16ms
cutoff: 40000    10times Time:16ms
cutoff: 40500    10times Time:16ms
cutoff: 41000    10times Time:18ms
cutoff: 41500    10times Time:16ms
```

Build completed successfully in 2 sec, 665 ms (33 minutes ago)

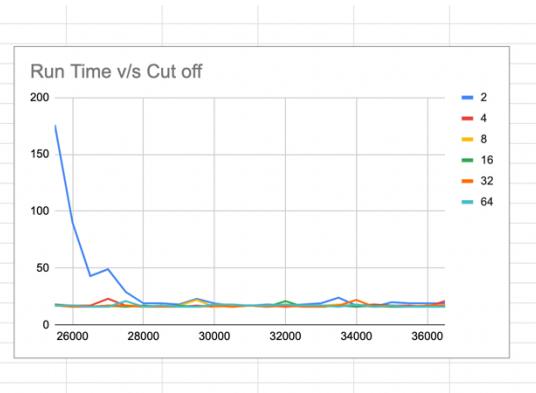
Event Log

11:36 LF UTF-8 4 spaces Spring2022

Graphs:

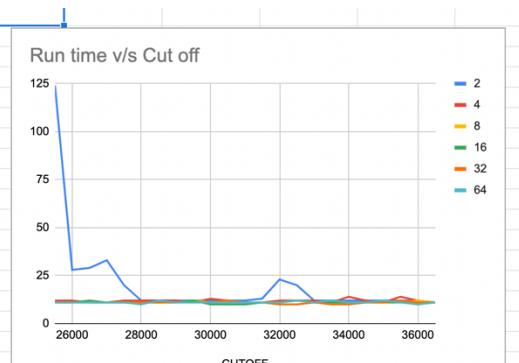
Array Size – 50000

CUTOFF	2	4	8	16	32	64
25500	176	18	17	18	17	17
26000	90	17	17	16	16	17
26500	43	17	16	16	16	16
27000	49	23	16	17	17	16
27500	29	17	17	16	17	21
28000	19	16	17	17	16	16
28500	19	17	16	16	16	17
29000	18	16	17	17	16	16
29500	23	17	22	16	16	16
30000	19	16	16	17	17	18
30500	17	17	17	16	16	18
31000	17	17	17	17	17	17
31500	18	17	17	16	16	17
32000	17	16	17	21	17	18
32500	18	17	17	16	16	17
33000	19	16	17	16	16	17
33500	24	17	18	17	17	16
34000	17	17	17	16	22	18
34500	16	18	16	17	16	16
35000	20	17	16	16	17	17
35500	19	17	16	16	16	16
36000	19	16	17	17	17	16
36500	19	21	17	16	17	16



Array Size - 25000

CUTOFF	2	4	8	16	32	64
25500	124	12	11	11	11	11
26000	28	12	11	11	11	11
26500	29	11	11	12	11	11
27000	33	11	11	11	11	11
27500	20	12	11	11	11	11
28000	12	12	11	11	11	10
28500	12	12	11	11	11	12
29000	12	12	11	11	11	11
29500	12	11	12	12	11	11
30000	12	13	11	10	11	11
30500	12	12	11	10	12	11
31000	12	11	11	10	11	11
31500	13	11	11	11	11	11
32000	23	12	11	11	10	11
32500	20	12	12	12	10	12
33000	12	12	11	11	11	11
33500	12	11	11	11	10	12
34000	12	14	11	11	10	11
34500	12	12	11	11	11	11
35000	12	11	11	11	11	12
35500	12	14	11	11	12	11
36000	12	12	12	11	11	10
36500	11	11	11	11	11	11



Conclusion –

Running parallel sorting algorithms with different values of threads i.e., 2, 4, 8, 16, 32, 64 and the array sizes for 25000 and 50000, the performance is quite stable after thread 4 onwards. Thread is updated at every step by factor of 2. Total no of threads used at every step is 2^d , where d is recursion depth.