Program Structures and Algorithms
Spring 2023(SEC –8)
Assignment 5 (Parallel Sorting)

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Task:

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.

Relationship Conclusion:

1. According to the experiment, the ideal thread number is 16(degree is 4, t = 2^d) . The running time of threads less than 16 is much bigger, and after 16 threads, there are not obvious change.
2. And the running time is less than others when the ratio of cutoff be-tween 10% and 25%.

I’ve set fixed number of thread pool and try to find the relationship of the ratio of cutoff to array size. I set the base as 0.02 and increase 0.02 each step. I’ve change the array size as 1000000, 2000000, 4000000.

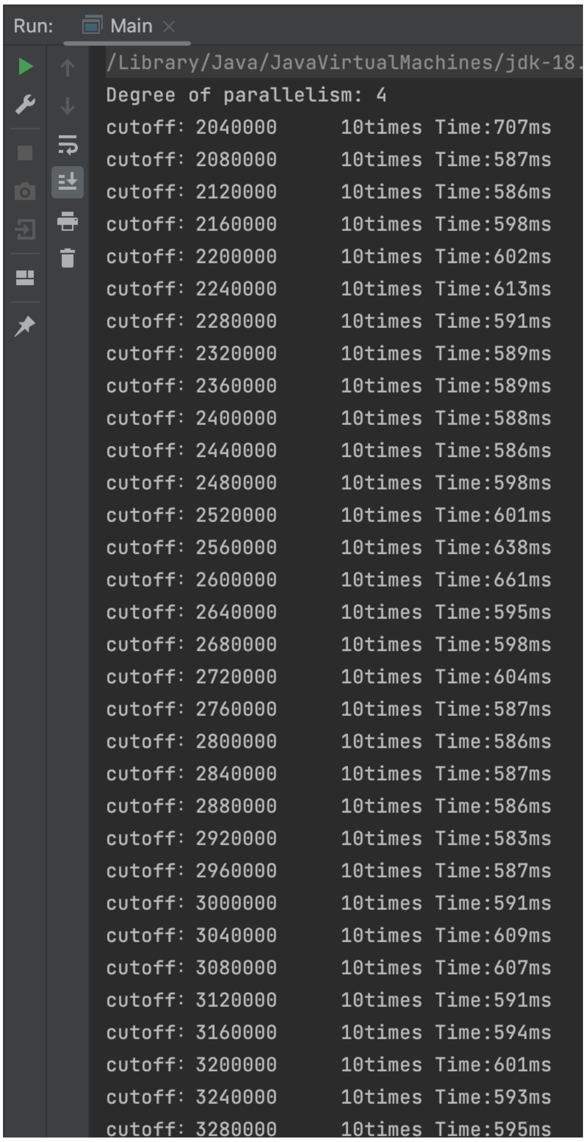
Evidence to support that conclusion:

Run: Main

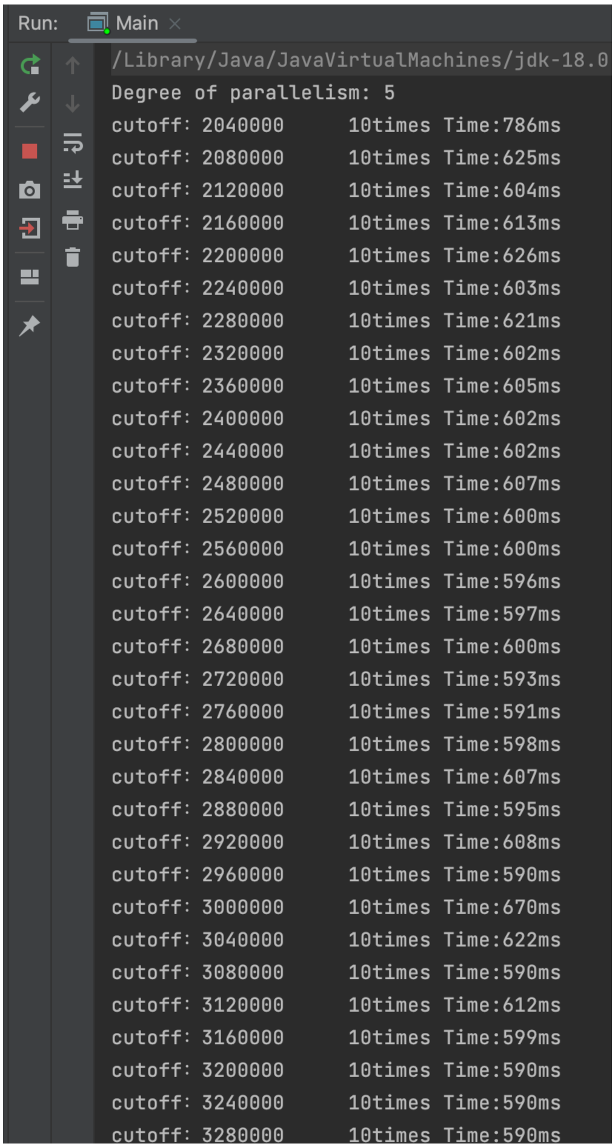
```
/Library/Java/JavaVirtualMachines/jdk-18
Degree of parallelism: 1
cutoff: 2040000     10times Time:722ms
cutoff: 2080000     10times Time:596ms
cutoff: 2120000     10times Time:588ms
cutoff: 2160000     10times Time:590ms
cutoff: 2200000     10times Time:587ms
cutoff: 2240000     10times Time:585ms
cutoff: 2280000     10times Time:586ms
cutoff: 2320000     10times Time:589ms
cutoff: 2360000     10times Time:593ms
cutoff: 2400000     10times Time:590ms
cutoff: 2440000     10times Time:593ms
cutoff: 2480000     10times Time:586ms
cutoff: 2520000     10times Time:585ms
cutoff: 2560000     10times Time:583ms
cutoff: 2600000     10times Time:584ms
cutoff: 2640000     10times Time:581ms
cutoff: 2680000     10times Time:582ms
cutoff: 2720000     10times Time:583ms
cutoff: 2760000     10times Time:584ms
cutoff: 2800000     10times Time:585ms
cutoff: 2840000     10times Time:582ms
cutoff: 2880000     10times Time:612ms
cutoff: 2920000     10times Time:615ms
cutoff: 2960000     10times Time:598ms
cutoff: 3000000     10times Time:612ms
cutoff: 3040000     10times Time:603ms
cutoff: 3080000     10times Time:595ms
cutoff: 3120000     10times Time:587ms
cutoff: 3160000     10times Time:586ms
cutoff: 3200000     10times Time:584ms
cutoff: 3240000     10times Time:585ms
cutoff: 3280000     10times Time:581ms
```

Run: Main

```
/Library/Java/JavaVirtualMachines/jdk-18
Degree of parallelism: 2
cutoff: 2040000     10times Time:751ms
cutoff: 2080000     10times Time:588ms
cutoff: 2120000     10times Time:587ms
cutoff: 2160000     10times Time:588ms
cutoff: 2200000     10times Time:595ms
cutoff: 2240000     10times Time:587ms
cutoff: 2280000     10times Time:584ms
cutoff: 2320000     10times Time:580ms
cutoff: 2360000     10times Time:581ms
cutoff: 2400000     10times Time:582ms
cutoff: 2440000     10times Time:599ms
cutoff: 2480000     10times Time:608ms
cutoff: 2520000     10times Time:605ms
cutoff: 2560000     10times Time:606ms
cutoff: 2600000     10times Time:604ms
cutoff: 2640000     10times Time:641ms
cutoff: 2680000     10times Time:592ms
cutoff: 2720000     10times Time:657ms
cutoff: 2760000     10times Time:667ms
cutoff: 2800000     10times Time:604ms
cutoff: 2840000     10times Time:604ms
cutoff: 2880000     10times Time:638ms
cutoff: 2920000     10times Time:585ms
cutoff: 2960000     10times Time:594ms
cutoff: 3000000     10times Time:614ms
cutoff: 3040000     10times Time:608ms
cutoff: 3080000     10times Time:605ms
cutoff: 3120000     10times Time:616ms
cutoff: 3160000     10times Time:617ms
cutoff: 3200000     10times Time:602ms
cutoff: 3240000     10times Time:582ms
cutoff: 3280000     10times Time:590ms
```



```
Run:  Main
/Library/Java/JavaVirtualMachines/jdk-18.
Degree of parallelism: 4
cutoff: 2040000      10times Time:707ms
cutoff: 2080000      10times Time:587ms
cutoff: 2120000      10times Time:586ms
cutoff: 2160000      10times Time:598ms
cutoff: 2200000      10times Time:602ms
cutoff: 2240000      10times Time:613ms
cutoff: 2280000      10times Time:591ms
cutoff: 2320000      10times Time:589ms
cutoff: 2360000      10times Time:589ms
cutoff: 2400000      10times Time:588ms
cutoff: 2440000      10times Time:586ms
cutoff: 2480000      10times Time:598ms
cutoff: 2520000      10times Time:601ms
cutoff: 2560000      10times Time:638ms
cutoff: 2600000      10times Time:661ms
cutoff: 2640000      10times Time:595ms
cutoff: 2680000      10times Time:598ms
cutoff: 2720000      10times Time:604ms
cutoff: 2760000      10times Time:587ms
cutoff: 2800000      10times Time:586ms
cutoff: 2840000      10times Time:587ms
cutoff: 2880000      10times Time:586ms
cutoff: 2920000      10times Time:583ms
cutoff: 2960000      10times Time:587ms
cutoff: 3000000      10times Time:591ms
cutoff: 3040000      10times Time:609ms
cutoff: 3080000      10times Time:607ms
cutoff: 3120000      10times Time:591ms
cutoff: 3160000      10times Time:594ms
cutoff: 3200000      10times Time:601ms
cutoff: 3240000      10times Time:593ms
cutoff: 3280000      10times Time:595ms
```



```
Run:  Main
/Library/Java/JavaVirtualMachines/jdk-18.0
Degree of parallelism: 5
cutoff: 2040000      10times Time:786ms
cutoff: 2080000      10times Time:625ms
cutoff: 2120000      10times Time:604ms
cutoff: 2160000      10times Time:613ms
cutoff: 2200000      10times Time:626ms
cutoff: 2240000      10times Time:603ms
cutoff: 2280000      10times Time:621ms
cutoff: 2320000      10times Time:602ms
cutoff: 2360000      10times Time:605ms
cutoff: 2400000      10times Time:602ms
cutoff: 2440000      10times Time:602ms
cutoff: 2480000      10times Time:607ms
cutoff: 2520000      10times Time:600ms
cutoff: 2560000      10times Time:600ms
cutoff: 2600000      10times Time:596ms
cutoff: 2640000      10times Time:597ms
cutoff: 2680000      10times Time:600ms
cutoff: 2720000      10times Time:593ms
cutoff: 2760000      10times Time:591ms
cutoff: 2800000      10times Time:598ms
cutoff: 2840000      10times Time:607ms
cutoff: 2880000      10times Time:595ms
cutoff: 2920000      10times Time:608ms
cutoff: 2960000      10times Time:590ms
cutoff: 3000000      10times Time:670ms
cutoff: 3040000      10times Time:622ms
cutoff: 3080000      10times Time:590ms
cutoff: 3120000      10times Time:612ms
cutoff: 3160000      10times Time:599ms
cutoff: 3200000      10times Time:590ms
cutoff: 3240000      10times Time:590ms
cutoff: 3280000      10times Time:590ms
```

Run: Main

```
/Library/Java/JavaVirtualMachines/jdk-1
Degree of parallelism: 6
cutoff: 2040000      10times Time:727ms
cutoff: 2080000      10times Time:595ms
cutoff: 2120000      10times Time:593ms
cutoff: 2160000      10times Time:583ms
cutoff: 2200000      10times Time:592ms
cutoff: 2240000      10times Time:583ms
cutoff: 2280000      10times Time:604ms
cutoff: 2320000      10times Time:615ms
cutoff: 2360000      10times Time:600ms
cutoff: 2400000      10times Time:589ms
cutoff: 2440000      10times Time:580ms
cutoff: 2480000      10times Time:582ms
cutoff: 2520000      10times Time:582ms
cutoff: 2560000      10times Time:582ms
cutoff: 2600000      10times Time:581ms
cutoff: 2640000      10times Time:585ms
cutoff: 2680000      10times Time:601ms
cutoff: 2720000      10times Time:586ms
cutoff: 2760000      10times Time:581ms
cutoff: 2800000      10times Time:583ms
cutoff: 2840000      10times Time:582ms
cutoff: 2880000      10times Time:580ms
cutoff: 2920000      10times Time:584ms
cutoff: 2960000      10times Time:580ms
cutoff: 3000000      10times Time:585ms
cutoff: 3040000      10times Time:591ms
cutoff: 3080000      10times Time:584ms
cutoff: 3120000      10times Time:587ms
cutoff: 3160000      10times Time:594ms
cutoff: 3200000      10times Time:593ms
cutoff: 3240000      10times Time:581ms
cutoff: 3280000      10times Time:578ms
```

cutoff/arraysize	time(thread=2)	time(thread=4)	time(thread=8)	time(thread=16)	time(thread=32)	time(thread=64)
0.02	**72.2**	**75.1**	**67.5**	**70.7**	**78.6**	**72.7**
0.04	59.6	58.8	60.5	58.7	62.5	59.5
0.06	58.8	58.7	58.7	58.6	60.4	59.3
0.08	59	58.8	58.5	59.8	61.3	58.3
0.1	58.7	59.5	61	60.2	62.6	59.2
0.12	58.5	58.7	59	61.3	60.3	58.3
0.14	58.6	58.4	59.1	59.1	62.1	60.4
0.16	58.9	58	59.1	58.9	60.2	61.5
0.18	59.3	58.1	58.5	58.9	60.5	60
0.2	59	58.2	58.5	58.8	60.2	58.9
0.22	59.3	59.9	58.5	58.6	60.2	58
0.24	58.6	60.8	58.1	59.8	60.7	58.2
0.26	58.5	60.5	58.5	60.1	60	58.2
0.28	58.3	60.6	58.5	63.8	60	58.2
0.3	58.4	60.4	58.5	66.1	59.6	58.1
0.32	58.1	64.1	59.1	59.5	59.7	58.5
0.34	58.2	59.2	58.6	59.8	60	60.1
0.36	58.3	65.7	58.2	60.4	59.3	58.6
0.38	58.4	66.7	58.5	58.7	59.1	58.1
0.4	58.5	60.4	58.3	58.6	59.8	58.3
0.42	58.2	60.4	58.6	58.7	60.7	58.2
0.44	61.2	63.8	58.3	58.6	59.5	58
0.46	61.5	58.5	58.6	58.3	60.8	58.4
0.48	59.8	59.4	58.5	58.7	59	58
0.5	61.2	61.4	59.1	59.1	67	58.5
0.52	60.3	60.8	61.1	60.9	62.2	59.1
0.54	59.5	60.5	58.6	60.7	59	58.4
0.56	58.7	61.6	59.2	59.1	61.2	58.7
0.58	58.6	61.7	58.6	59.4	59.9	59.4
0.6	58.4	60.2	58.5	60.1	59	59.3
0.62	58.5	58.2	57.9	59.3	59	58.1
0.64	58.1	59	58.5	59.5	59	57.8
0.66	58.5	60	58.8	59.1	60.5	58
0.68	59.9	61.9	61.4	58.4	60.9	58.3
0.7	61	59.3	62.2	58.6	58.9	58.1
0.72	60	59.6	60.2	59.9	61	59.4
0.74	58.9	59.4	64.1	59.7	59.2	58.4
0.76	58	58.2	59.5	58.2	59.1	58.4
0.78	58.4	58.3	58.7	59.3	59.3	60
0.8	58.6	60.4	58.8	60.1	59.3	58.6
0.82	58.5	58.2	58.2	58.4	59.6	62.9
0.84	58.3	58.2	58.9	60	59	61.1
0.86	58.3	59.3	58.8	60.4	60.5	68.4
0.88	58	59.5	59.2	58.3	61.6	70.9
0.9	59	60.3	59	58.5	63.2	60.6
0.92	60	60	58.1	58.5	63.8	62.7
0.94	61.4	61.3	58.3	58.4	80.8	63.4
0.96	60.7	60.5	58.7	58.4	62.5	61.6
0.98	60.6	58.8	58.3	58.5	62.5	60
1	58.5	59.6	59	58.3	63.3	59.1

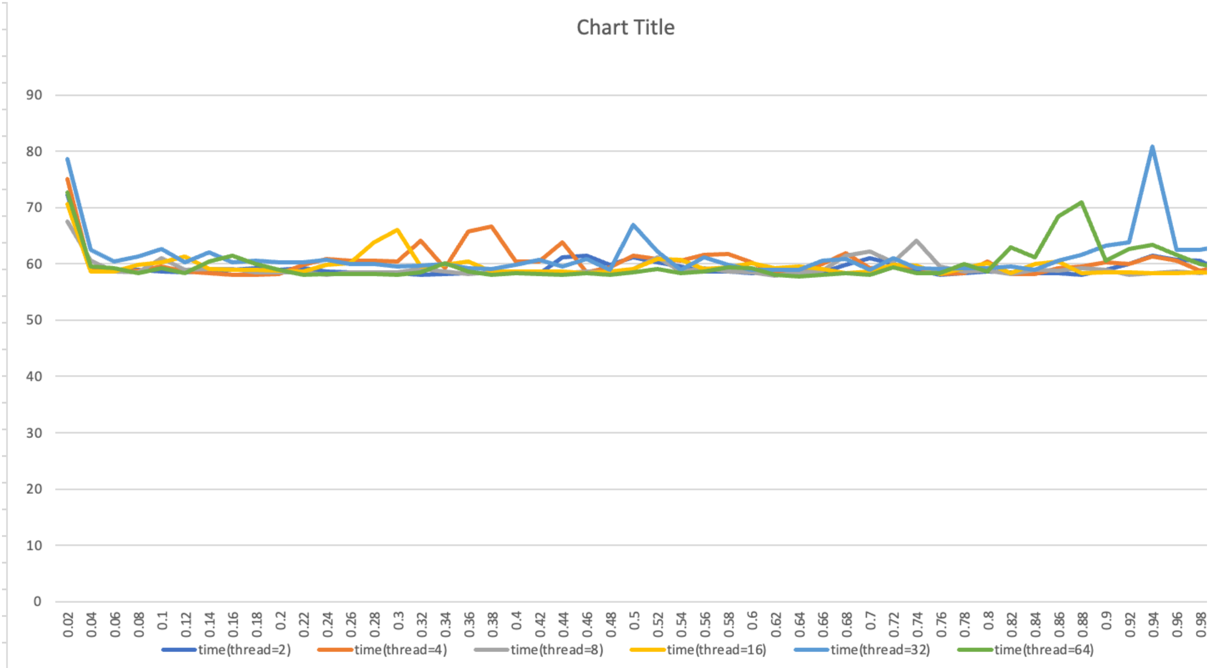


Chart Title
90
80
70
60
50
40
30
20
10
0
0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2 0.22 0.24 0.26 0.28 0.3 0.32 0.34 0.36 0.38 0.4 0.42 0.44 0.46 0.48 0.5 0.52 0.54 0.56 0.58 0.6 0.62 0.64 0.66 0.68 0.7 0.72 0.74 0.76 0.78 0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
time(thread=2)
time(thread=4)
time(thread=8)
time(thread=16)
time(thread=32)
time(thread=64)