Program Structures & Algorithms
Spring 2023
Assignment No. 5

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Task

- 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.

- (Part 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.

- (Part 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).

- (Part 3) Implement a main program to run the following benchmarks: measure the running times of this sort.

- Show the results of your experiments and draws a conclusion (or more) about the efficacy of this method of parallelizing sort.

- 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

We have run simulations of experiments with different combinations of the cutoff values, threads and array sizes. From the observations of the runtimes, we can conclude that four threads is the optimal choice and there wouldn't be much improvement in algorithm performance beyond four threads.

The lowest runtime is achieved when the cutoff value is 25% of the array size.

For recursion depth (d) and number of threads available (t):

$$t = 2^d$$

Maximum depth possible:

$$\lg\left(\frac{array\ size}{cutoff}\right)$$

Any depth more significant than the max depth is not feasible as the partitioned arrays hit the cutoff and turned into a system sort.

Evidence to the Conclusion

Below are the runtimes in 'ms' for different combinations of Array size, threads, and cutoffs.

Array size = 50000

Cutoff	Thread					
	2	4	8	16	32	64
5000	116	37	52	24	23	24
10000	61	24	19	22	23	18
15000	24	25	20	21	21	22
20000	25	25	35	22	21	21
25000	27	23	18	20	18	20
30000	49	24	21	21	20	21
35000	61	23	24	21	20	20
40000	23	42	22	20	20	20
45000	25	22	20	21	22	20
50000	60	27	21	22	22	21

Cutoff vs Runtime (For Different Threads)

Array size = 100000

Cutoff	Thread					
	2	4	8	16	32	64
5000	182	62	48	44	38	39
10000	94	39	31	39	34	36
15000	49	40	35	35	35	41
20000	52	40	38	31	53	35
25000	97	36	39	34	61	33
30000	56	34	37	36	53	36
35000	51	35	35	40	36	35
40000	55	35	35	45	39	37
45000	79	36	39	37	36	37
50000	57	35	35	35	39	39

Cutoff vs Runtime (For Different Threads)
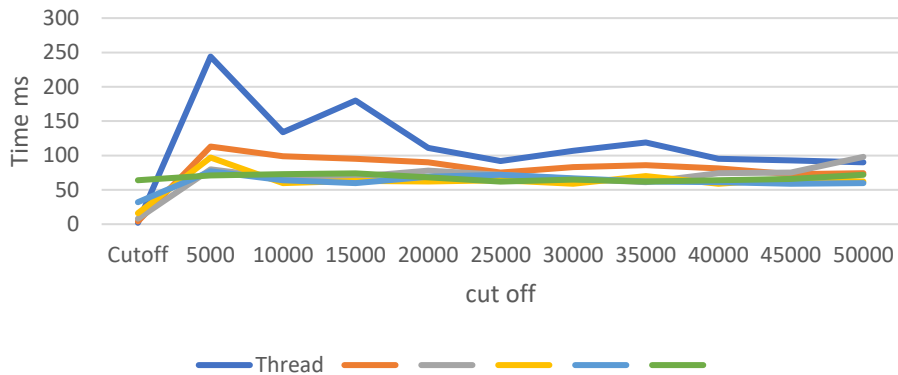
Array size = 200000

Cutoff	Thread					
	2	4	8	16	32	64
5000	244	113	80	97	77	71
10000	134	99	67	60	64	73
15000	180	95	69	63	60	74
20000	111	90	78	62	69	68
25000	92	75	72	64	72	62
30000	107	83	66	59	67	65
35000	119	86	61	70	62	62
40000	95	81	74	59	61	64
45000	93	73	75	66	59	66
50000	90	74	98	62	60	72

Cutoff vs Runtime (For Different Threads)
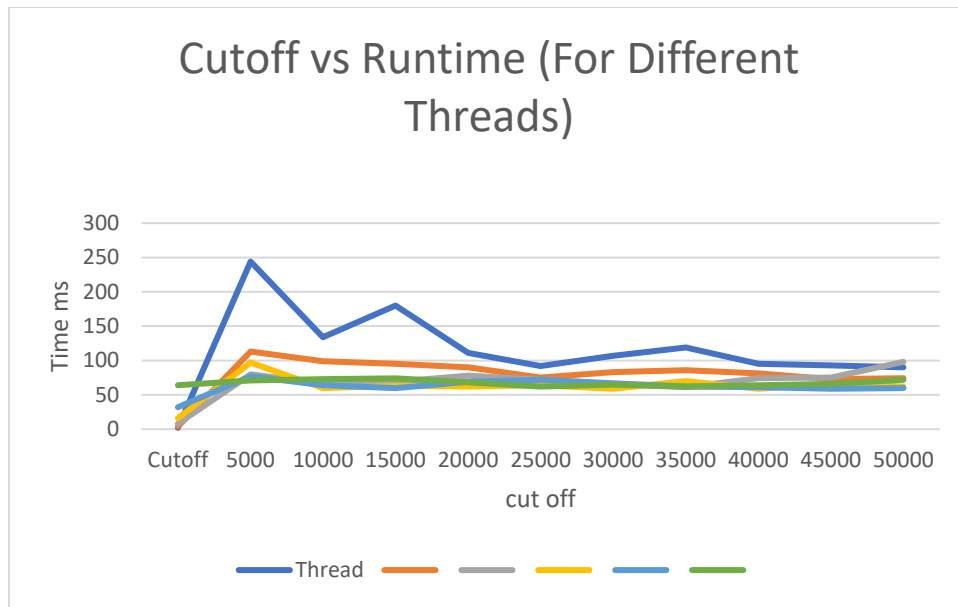
Output Screenshot

Array size = 50000

```
"C:\Program Files\Java\jdk-18.0.2.1\bin\java.exe" ...
Size of Array: 50000

Degree of parallelism: 2
cutoff: 5000         10times Time:116ms
cutoff: 10000        10times Time:61ms
cutoff: 15000        10times Time:24ms
cutoff: 20000        10times Time:25ms
cutoff: 25000        10times Time:27ms
cutoff: 30000        10times Time:49ms
cutoff: 35000        10times Time:61ms
cutoff: 40000        10times Time:23ms
cutoff: 45000        10times Time:25ms
cutoff: 50000        10times Time:60ms

Degree of parallelism: 4
cutoff: 5000         10times Time:37ms
cutoff: 10000        10times Time:24ms
cutoff: 15000        10times Time:25ms
cutoff: 20000        10times Time:25ms
cutoff: 25000        10times Time:23ms
cutoff: 30000        10times Time:24ms
cutoff: 35000        10times Time:23ms
cutoff: 40000        10times Time:42ms
cutoff: 45000        10times Time:22ms
cutoff: 50000        10times Time:27ms

Degree of parallelism: 8
cutoff: 5000         10times Time:52ms
cutoff: 10000        10times Time:19ms
```

```
cutoff: 15000        10times Time:20ms
cutoff: 20000        10times Time:35ms
cutoff: 25000        10times Time:18ms
cutoff: 30000        10times Time:21ms
cutoff: 35000        10times Time:24ms
cutoff: 40000        10times Time:22ms
cutoff: 45000        10times Time:20ms
cutoff: 50000        10times Time:21ms

Degree of parallelism: 16
cutoff: 5000         10times Time:24ms
cutoff: 10000        10times Time:22ms
cutoff: 15000        10times Time:21ms
cutoff: 20000        10times Time:22ms
cutoff: 25000        10times Time:20ms
cutoff: 30000        10times Time:21ms
cutoff: 35000        10times Time:21ms
cutoff: 40000        10times Time:20ms
cutoff: 45000        10times Time:21ms
cutoff: 50000        10times Time:22ms

Degree of parallelism: 32
cutoff: 5000         10times Time:23ms
cutoff: 10000        10times Time:23ms
cutoff: 15000        10times Time:21ms
cutoff: 20000        10times Time:21ms
cutoff: 25000        10times Time:18ms
cutoff: 30000        10times Time:20ms
cutoff: 35000        10times Time:20ms
cutoff: 40000        10times Time:20ms
```

```
cutoff: 35000        10times Time:20ms
cutoff: 40000        10times Time:20ms
cutoff: 45000        10times Time:22ms
cutoff: 50000        10times Time:22ms


Degree of parallelism: 64
cutoff: 5000         10times Time:24ms
cutoff: 10000        10times Time:18ms
cutoff: 15000        10times Time:22ms
cutoff: 20000        10times Time:21ms
cutoff: 25000        10times Time:20ms
cutoff: 30000        10times Time:21ms
cutoff: 35000        10times Time:20ms
cutoff: 40000        10times Time:20ms
cutoff: 45000        10times Time:20ms
cutoff: 50000        10times Time:21ms
```

Array size = 100000

```
"C:\Program Files\Java\jdk-18.0.2.1\bin\java.exe" ...
Size of Array: 100000

Degree of parallelism: 2
cutoff: 5000          10times Time:182ms
cutoff: 10000         10times Time:94ms
cutoff: 15000         10times Time:49ms
cutoff: 20000         10times Time:52ms
cutoff: 25000         10times Time:97ms
cutoff: 30000         10times Time:56ms
cutoff: 35000         10times Time:51ms
cutoff: 40000         10times Time:55ms
cutoff: 45000         10times Time:79ms
cutoff: 50000         10times Time:57ms

Degree of parallelism: 4
cutoff: 5000          10times Time:62ms
cutoff: 10000         10times Time:39ms
cutoff: 15000         10times Time:40ms
cutoff: 20000         10times Time:40ms
cutoff: 25000         10times Time:36ms
cutoff: 30000         10times Time:34ms
cutoff: 35000         10times Time:35ms
cutoff: 40000         10times Time:35ms
cutoff: 45000         10times Time:36ms
cutoff: 50000         10times Time:35ms

Degree of parallelism: 8
cutoff: 5000          10times Time:48ms
cutoff: 10000         10times Time:31ms
```

```
cutoff: 15000        10times Time:35ms
cutoff: 20000        10times Time:38ms
cutoff: 25000        10times Time:39ms
cutoff: 30000        10times Time:37ms
cutoff: 35000        10times Time:35ms
cutoff: 40000        10times Time:35ms
cutoff: 45000        10times Time:39ms
cutoff: 50000        10times Time:35ms

Degree of parallelism: 16
cutoff: 5000         10times Time:44ms
cutoff: 10000        10times Time:39ms
cutoff: 15000        10times Time:35ms
cutoff: 20000        10times Time:31ms
cutoff: 25000        10times Time:34ms
cutoff: 30000        10times Time:36ms
cutoff: 35000        10times Time:40ms
cutoff: 40000        10times Time:45ms
cutoff: 45000        10times Time:37ms
cutoff: 50000        10times Time:35ms

Degree of parallelism: 32
cutoff: 5000         10times Time:38ms
cutoff: 10000        10times Time:34ms
cutoff: 15000        10times Time:35ms
cutoff: 20000        10times Time:53ms
cutoff: 25000        10times Time:61ms
cutoff: 30000        10times Time:53ms
cutoff: 35000        10times Time:36ms
cutoff: 40000        10times Time:39ms
```

```
cutoff: 40000          10times Time:39ms
cutoff: 45000          10times Time:36ms
cutoff: 50000          10times Time:39ms


Degree of parallelism: 64
cutoff: 5000           10times Time:39ms
cutoff: 10000          10times Time:36ms
cutoff: 15000          10times Time:41ms
cutoff: 20000          10times Time:35ms
cutoff: 25000          10times Time:33ms
cutoff: 30000          10times Time:36ms
cutoff: 35000          10times Time:35ms
cutoff: 40000          10times Time:37ms
cutoff: 45000          10times Time:37ms
cutoff: 50000          10times Time:39ms
```

Array size = 200000

```
"C:\Program Files\Java\jdk-18.0.2.1\bin\java.exe" ...
Size of Array: 200000

Degree of parallelism: 2
cutoff: 5000         10times Time:244ms
cutoff: 10000        10times Time:134ms
cutoff: 15000        10times Time:180ms
cutoff: 20000        10times Time:111ms
cutoff: 25000        10times Time:92ms
cutoff: 30000        10times Time:107ms
cutoff: 35000        10times Time:119ms
cutoff: 40000        10times Time:95ms
cutoff: 45000        10times Time:93ms
cutoff: 50000        10times Time:90ms

Degree of parallelism: 4
cutoff: 5000         10times Time:113ms
cutoff: 10000        10times Time:99ms
cutoff: 15000        10times Time:95ms
cutoff: 20000        10times Time:90ms
cutoff: 25000        10times Time:75ms
cutoff: 30000        10times Time:83ms
cutoff: 35000        10times Time:86ms
cutoff: 40000        10times Time:81ms
cutoff: 45000        10times Time:73ms
cutoff: 50000        10times Time:74ms

Degree of parallelism: 8
cutoff: 5000         10times Time:80ms
cutoff: 10000        10times Time:67ms
```

```
cutoff: 15000          10times Time:69ms
cutoff: 20000          10times Time:78ms
cutoff: 25000          10times Time:72ms
cutoff: 30000          10times Time:66ms
cutoff: 35000          10times Time:61ms
cutoff: 40000          10times Time:74ms
cutoff: 45000          10times Time:75ms
cutoff: 50000          10times Time:98ms

Degree of parallelism: 16
cutoff: 5000           10times Time:97ms
cutoff: 10000          10times Time:60ms
cutoff: 15000          10times Time:63ms
cutoff: 20000          10times Time:62ms
cutoff: 25000          10times Time:64ms
cutoff: 30000          10times Time:59ms
cutoff: 35000          10times Time:70ms
cutoff: 40000          10times Time:59ms
cutoff: 45000          10times Time:66ms
cutoff: 50000          10times Time:62ms

Degree of parallelism: 32
cutoff: 5000           10times Time:77ms
cutoff: 10000          10times Time:64ms
cutoff: 15000          10times Time:60ms
cutoff: 20000          10times Time:69ms
cutoff: 25000          10times Time:72ms
cutoff: 30000          10times Time:67ms
cutoff: 35000          10times Time:62ms
cutoff: 40000          10times Time:61ms
```

```
cutoff: 30000        10times Time:67ms
cutoff: 35000        10times Time:62ms
cutoff: 40000        10times Time:61ms
cutoff: 45000        10times Time:59ms
cutoff: 50000        10times Time:60ms


Degree of parallelism: 64
cutoff: 5000         10times Time:71ms
cutoff: 10000        10times Time:73ms
cutoff: 15000        10times Time:74ms
cutoff: 20000        10times Time:68ms
cutoff: 25000        10times Time:62ms
cutoff: 30000        10times Time:65ms
cutoff: 35000        10times Time:62ms
cutoff: 40000        10times Time:64ms
cutoff: 45000        10times Time:66ms
cutoff: 50000        10times Time:72ms
```