Program Structures & Algorithms
Spring 2022
Assignment No 4

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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 the 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 cut-off 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 are 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:

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

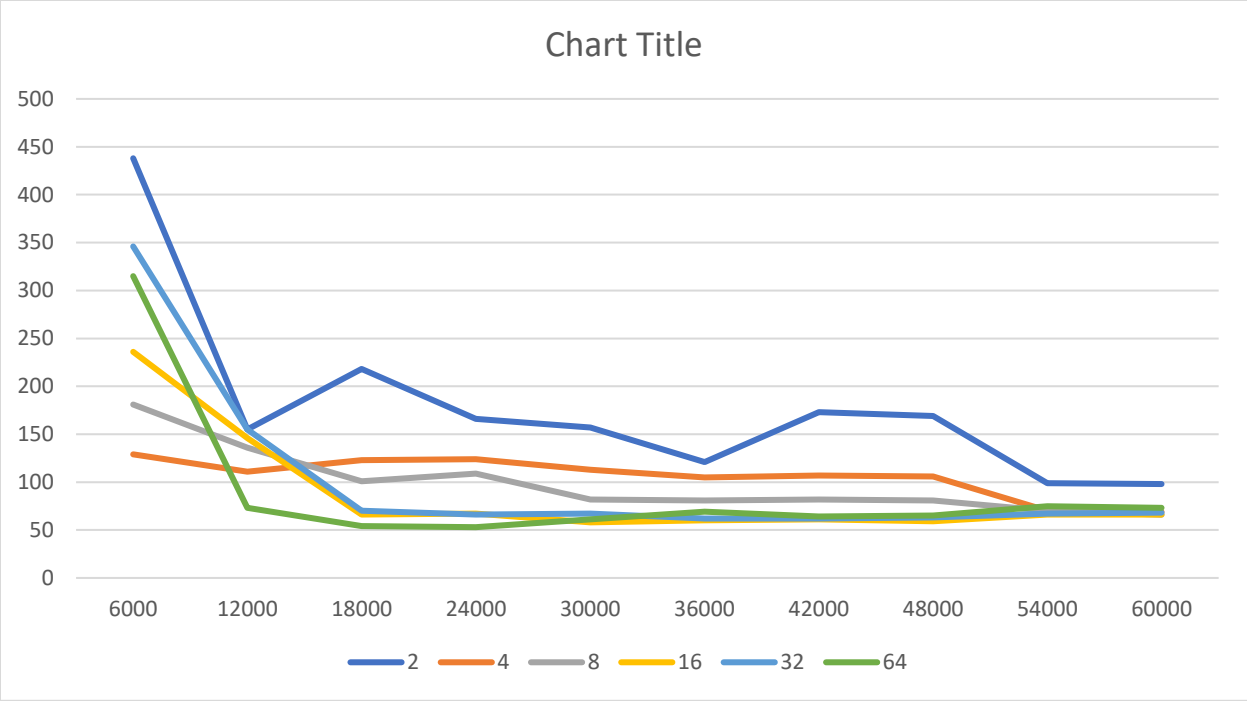
Any depth more significant than the max depth is not feasible as the partitioned arrays hit the cutoff and turned into a system sort.

Evidence to the Conclusion :

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

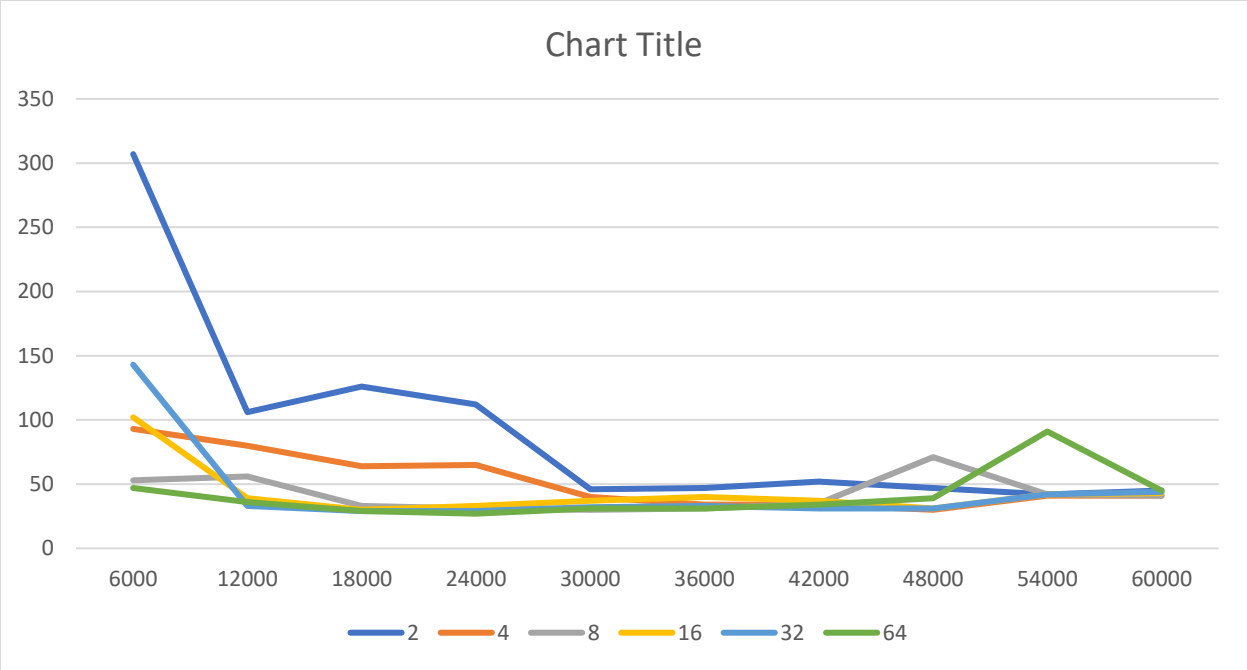
Array size = 200000

Cutoff	2	4	8	16	32	64
6000	438	129	181	236	346	315
12000	155	111	136	146	155	73
18000	218	123	101	66	70	54
24000	166	124	109	67	66	53
30000	157	113	82	58	67	61
36000	121	105	81	60	62	69
42000	173	107	82	61	62	64
48000	169	106	81	59	63	65
54000	99	70	70	66	67	75
60000	98	69	66	66	68	73



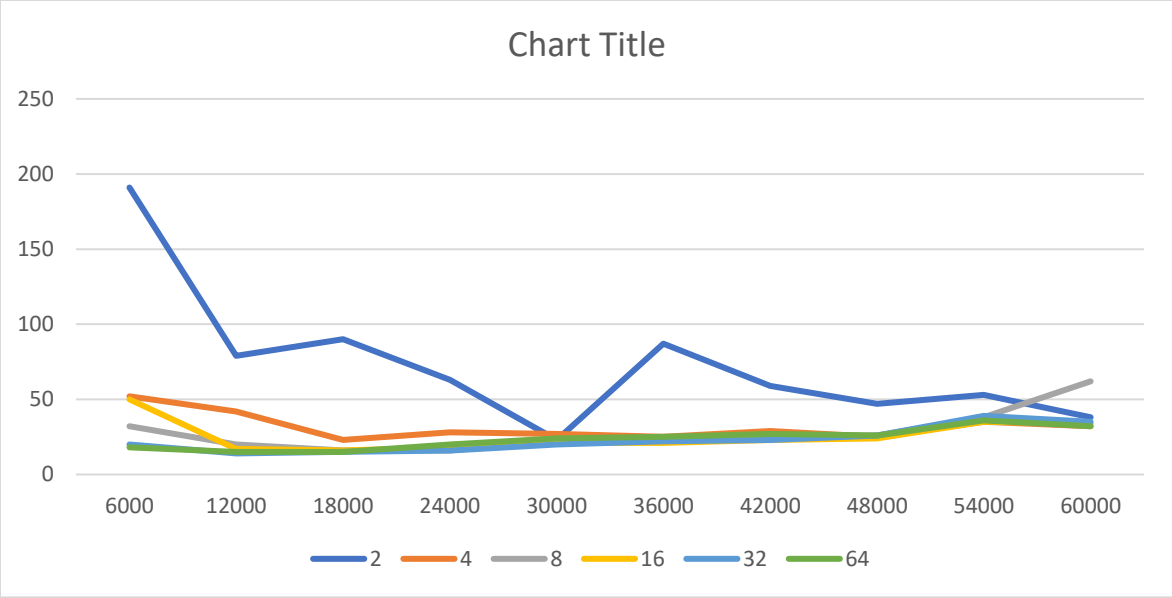
Array size = 100000

Cutoff	2	4	8	16	32	64
6000	307	93	53	102	143	47
12000	106	80	56	39	33	36
18000	126	64	33	30	29	29
24000	112	65	31	33	29	27
30000	46	40	30	37	32	31
36000	47	34	31	40	33	31
42000	52	34	35	37	31	34
48000	47	30	Merge & Center		31	39
54000	42	41	42	42	42	91
60000	45	41	41	43	44	45



Array size = 50000

Cutoff	2	4	8	16	32	64
6000	191	52	32	50	20	18
12000	79	42	20	17	14	15
18000	90	23	16	16	15	15
24000	63	28	16	18	16	20
30000	23	27	22	21	20	24
36000	87	25	23	21	22	25
42000	59	29	26	23	23	27
48000	47	25	26	24	26	26
54000	53	35	38	35	39	36
60000	38	32	62	34	35	32



OUTPUT :

```
/Library/Java/JavaVirtualMachines/adoptopenjdk-8.jdk/Contents/Home/bin/java ...
Size of Array:200000

Degree of parallelism: 2
cutoff: 6000          10times Time:339ms
cutoff: 12000         10times Time:201ms
cutoff: 18000         10times Time:183ms
cutoff: 24000         10times Time:223ms
cutoff: 30000         10times Time:139ms
cutoff: 36000         10times Time:171ms
cutoff: 42000         10times Time:155ms
cutoff: 48000         10times Time:143ms
cutoff: 54000         10times Time:104ms
cutoff: 60000         10times Time:109ms

Degree of parallelism: 4
cutoff: 6000          10times Time:135ms
cutoff: 12000         10times Time:117ms
cutoff: 18000         10times Time:123ms
cutoff: 24000         10times Time:121ms
cutoff: 30000         10times Time:107ms
cutoff: 36000         10times Time:116ms
cutoff: 42000         10times Time:126ms
cutoff: 48000         10times Time:114ms
cutoff: 54000         10times Time:70ms
cutoff: 60000         10times Time:105ms

Degree of parallelism: 8
cutoff: 6000          10times Time:124ms
cutoff: 12000         10times Time:111ms
cutoff: 18000         10times Time:113ms
cutoff: 24000         10times Time:108ms
cutoff: 30000         10times Time:76ms
cutoff: 36000         10times Time:76ms
cutoff: 42000         10times Time:75ms
cutoff: 48000         10times Time:73ms
cutoff: 54000         10times Time:70ms
cutoff: 60000         10times Time:69ms
```

```
Degree of parallelism: 16
cutoff: 6000          10times Time:163ms
cutoff: 12000         10times Time:131ms
cutoff: 18000         10times Time:69ms
cutoff: 24000         10times Time:73ms
cutoff: 30000         10times Time:60ms
cutoff: 36000         10times Time:60ms
cutoff: 42000         10times Time:60ms
cutoff: 48000         10times Time:63ms
cutoff: 54000         10times Time:74ms
cutoff: 60000         10times Time:69ms

Degree of parallelism: 32
cutoff: 6000          10times Time:502ms
cutoff: 12000         10times Time:158ms
cutoff: 18000         10times Time:60ms
cutoff: 24000         10times Time:64ms
cutoff: 30000         10times Time:62ms
cutoff: 36000         10times Time:107ms
cutoff: 42000         10times Time:58ms
cutoff: 48000         10times Time:60ms
cutoff: 54000         10times Time:65ms
cutoff: 60000         10times Time:69ms

Degree of parallelism: 64
cutoff: 6000          10times Time:309ms
cutoff: 12000         10times Time:87ms
cutoff: 18000         10times Time:57ms
cutoff: 24000         10times Time:61ms
cutoff: 30000         10times Time:61ms
cutoff: 36000         10times Time:63ms
cutoff: 42000         10times Time:58ms
cutoff: 48000         10times Time:61ms
cutoff: 54000         10times Time:68ms
cutoff: 60000         10times Time:71ms

Process finished with exit code 0
```

```
/Library/Java/JavaVirtualMachines/adoptopenjdk-8.jdk/Contents/Home/bin/java ...
Size of Array:100000

Degree of parallelism: 2
cutoff: 6000          10times Time:307ms
cutoff: 12000         10times Time:106ms
cutoff: 18000         10times Time:126ms
cutoff: 24000         10times Time:112ms
cutoff: 30000         10times Time:46ms
cutoff: 36000         10times Time:47ms
cutoff: 42000         10times Time:52ms
cutoff: 48000         10times Time:47ms
cutoff: 54000         10times Time:42ms
cutoff: 60000         10times Time:45ms

Degree of parallelism: 4
cutoff: 6000          10times Time:93ms
cutoff: 12000         10times Time:80ms
cutoff: 18000         10times Time:64ms
cutoff: 24000         10times Time:65ms
cutoff: 30000         10times Time:40ms
cutoff: 36000         10times Time:34ms
cutoff: 42000         10times Time:34ms
cutoff: 48000         10times Time:30ms
cutoff: 54000         10times Time:41ms
cutoff: 60000         10times Time:41ms

Degree of parallelism: 8
cutoff: 6000          10times Time:53ms
cutoff: 12000         10times Time:56ms
cutoff: 18000         10times Time:33ms
cutoff: 24000         10times Time:31ms
cutoff: 30000         10times Time:30ms
cutoff: 36000         10times Time:31ms
cutoff: 42000         10times Time:35ms
cutoff: 48000         10times Time:71ms
cutoff: 54000         10times Time:42ms
cutoff: 60000         10times Time:41ms
```

```
Degree of parallelism: 16
cutoff: 6000        10times Time:102ms
cutoff: 12000       10times Time:39ms
cutoff: 18000       10times Time:30ms
cutoff: 24000       10times Time:33ms
cutoff: 30000       10times Time:37ms
cutoff: 36000       10times Time:40ms
cutoff: 42000       10times Time:37ms
cutoff: 48000       10times Time:31ms
cutoff: 54000       10times Time:42ms
cutoff: 60000       10times Time:43ms

Degree of parallelism: 32
cutoff: 6000        10times Time:143ms
cutoff: 12000       10times Time:33ms
cutoff: 18000       10times Time:29ms
cutoff: 24000       10times Time:29ms
cutoff: 30000       10times Time:32ms
cutoff: 36000       10times Time:33ms
cutoff: 42000       10times Time:31ms
cutoff: 48000       10times Time:31ms
cutoff: 54000       10times Time:42ms
cutoff: 60000       10times Time:44ms

Degree of parallelism: 64
cutoff: 6000        10times Time:47ms
cutoff: 12000       10times Time:36ms
cutoff: 18000       10times Time:29ms
cutoff: 24000       10times Time:27ms
cutoff: 30000       10times Time:31ms
cutoff: 36000       10times Time:31ms
cutoff: 42000       10times Time:34ms
cutoff: 48000       10times Time:39ms
cutoff: 54000       10times Time:91ms
cutoff: 60000       10times Time:45ms

Process finished with exit code 0
```

```
Size of Array:50000

Degree of parallelism: 2
cutoff: 6000        10times Time:191ms
cutoff: 12000       10times Time:79ms
cutoff: 18000       10times Time:90ms
cutoff: 24000       10times Time:63ms
cutoff: 30000       10times Time:23ms
cutoff: 36000       10times Time:87ms
cutoff: 42000       10times Time:59ms
cutoff: 48000       10times Time:47ms
cutoff: 54000       10times Time:53ms
cutoff: 60000       10times Time:38ms

Degree of parallelism: 4
cutoff: 6000        10times Time:52ms
cutoff: 12000       10times Time:42ms
cutoff: 18000       10times Time:23ms
cutoff: 24000       10times Time:28ms
cutoff: 30000       10times Time:27ms
cutoff: 36000       10times Time:25ms
cutoff: 42000       10times Time:29ms
cutoff: 48000       10times Time:25ms
cutoff: 54000       10times Time:35ms
cutoff: 60000       10times Time:32ms

Degree of parallelism: 8
cutoff: 6000        10times Time:32ms
cutoff: 12000       10times Time:20ms
cutoff: 18000       10times Time:16ms
cutoff: 24000       10times Time:16ms
cutoff: 30000       10times Time:22ms
cutoff: 36000       10times Time:23ms
cutoff: 42000       10times Time:26ms
cutoff: 48000       10times Time:26ms
cutoff: 54000       10times Time:38ms
cutoff: 60000       10times Time:62ms
```

```
Degree of parallelism: 16
cutoff: 6000        10times Time:50ms
cutoff: 12000       10times Time:17ms
cutoff: 18000       10times Time:16ms
cutoff: 24000       10times Time:18ms
cutoff: 30000       10times Time:21ms
cutoff: 36000       10times Time:21ms
cutoff: 42000       10times Time:23ms
cutoff: 48000       10times Time:24ms
cutoff: 54000       10times Time:35ms
cutoff: 60000       10times Time:34ms

Degree of parallelism: 32
cutoff: 6000        10times Time:20ms
cutoff: 12000       10times Time:14ms
cutoff: 18000       10times Time:15ms
cutoff: 24000       10times Time:16ms
cutoff: 30000       10times Time:20ms
cutoff: 36000       10times Time:22ms
cutoff: 42000       10times Time:23ms
cutoff: 48000       10times Time:26ms
cutoff: 54000       10times Time:39ms
cutoff: 60000       10times Time:35ms

Degree of parallelism: 64
cutoff: 6000        10times Time:18ms
cutoff: 12000       10times Time:15ms
cutoff: 18000       10times Time:15ms
cutoff: 24000       10times Time:20ms
cutoff: 30000       10times Time:24ms
cutoff: 36000       10times Time:25ms
cutoff: 42000       10times Time:27ms
cutoff: 48000       10times Time:26ms
cutoff: 54000       10times Time:36ms
cutoff: 60000       10times Time:32ms

Process finished with exit code 0
```