

Program Structures & Algorithms

Spring 2022

Assignment No. 4

Name: Jayanth Vakkalagadda
(NUID): 002950342

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 draw 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:

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

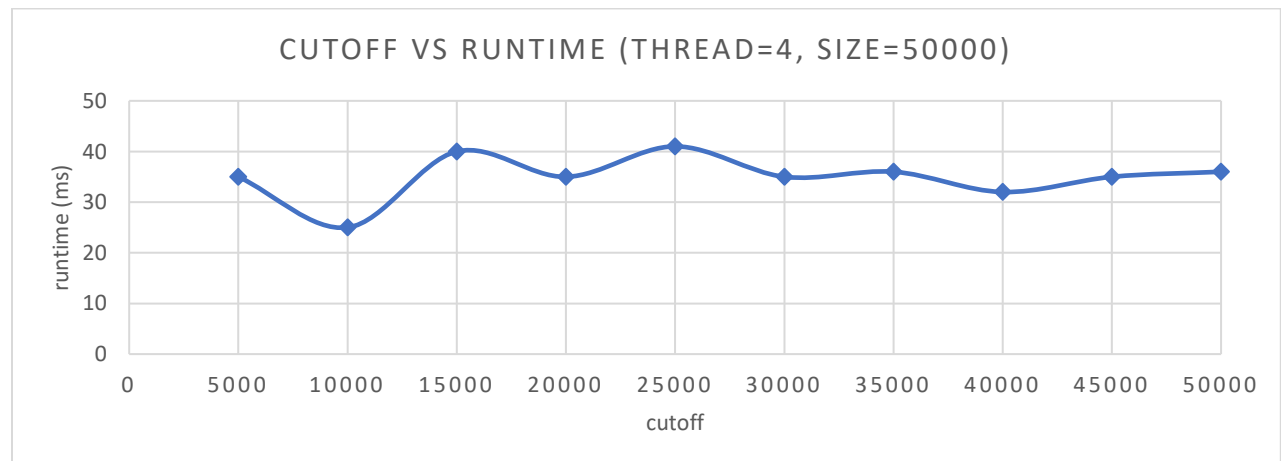
Any depth more significant than the max depth is not feasible as the partitioned arrays hit the cutoff and turned into a system sort.

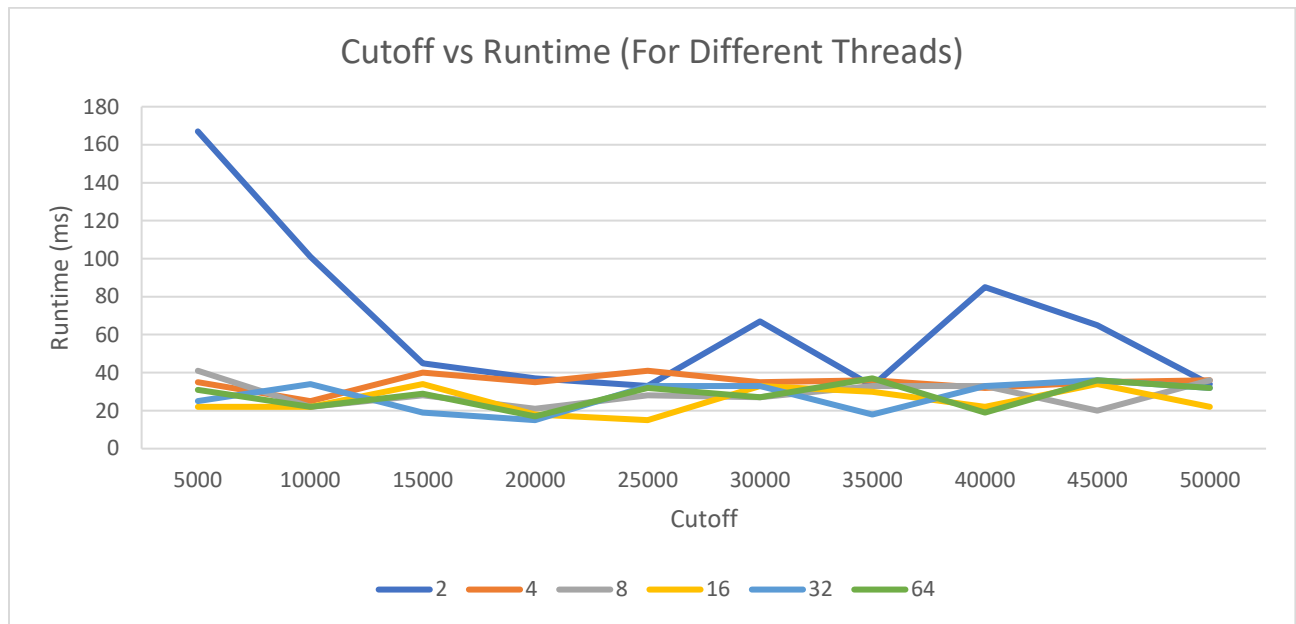
Evidence to the Conclusion

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

Array size = 50000

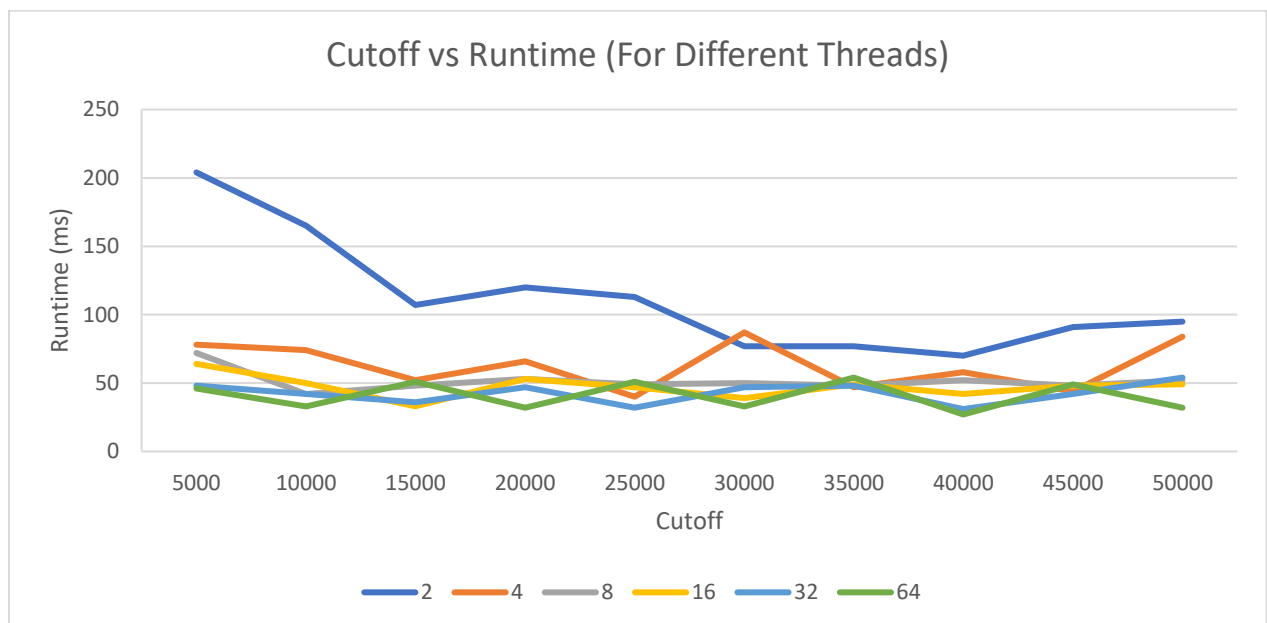
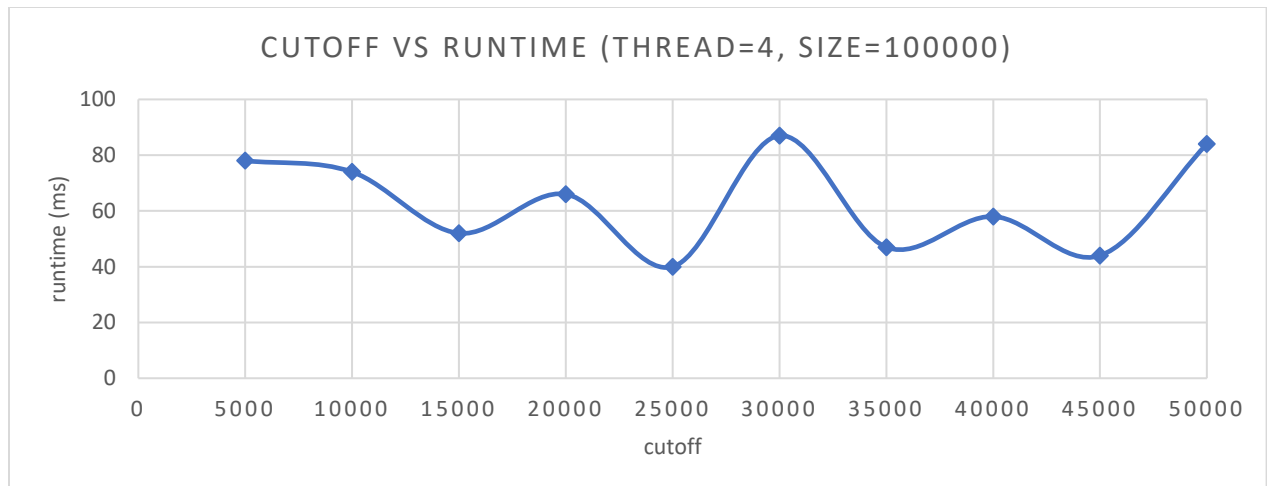
Cutoff	Thread					
	2	4	8	16	32	64
5000	167	35	41	22	25	31
10000	101	25	22	22	34	22
15000	45	40	28	34	19	29
20000	37	35	21	18	15	17
25000	33	41	28	15	33	32
30000	67	35	27	33	33	27
35000	33	36	33	30	18	37
40000	85	32	33	22	33	19
45000	65	35	20	34	36	36
50000	34	36	36	22	32	32





Array size = 100000

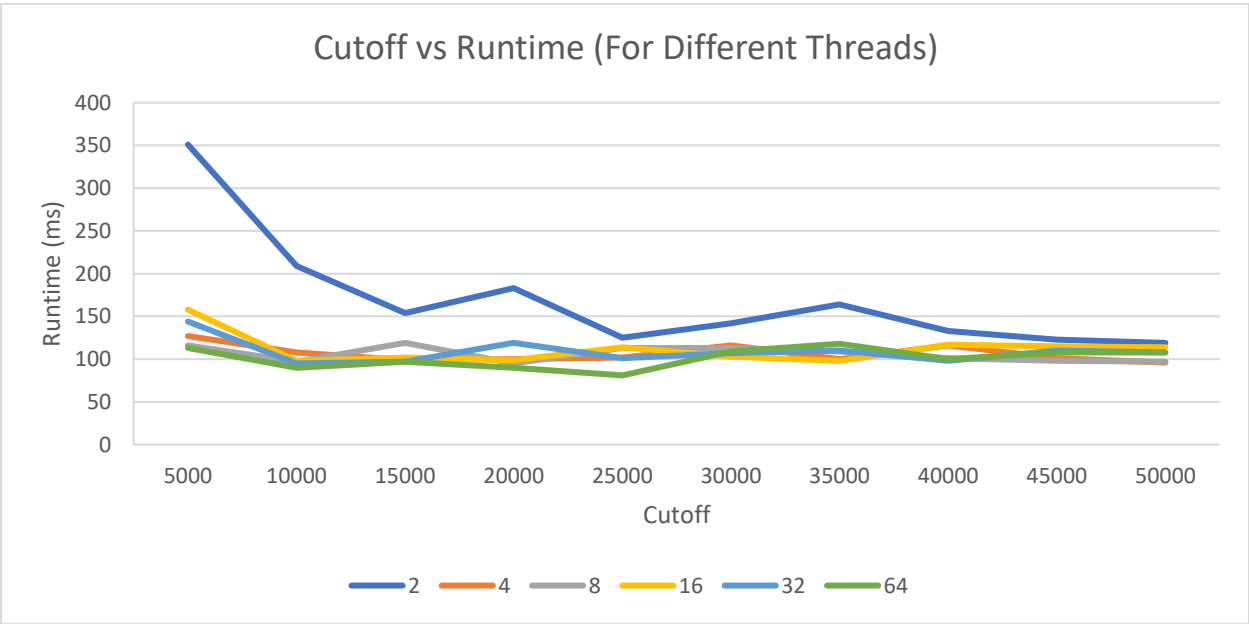
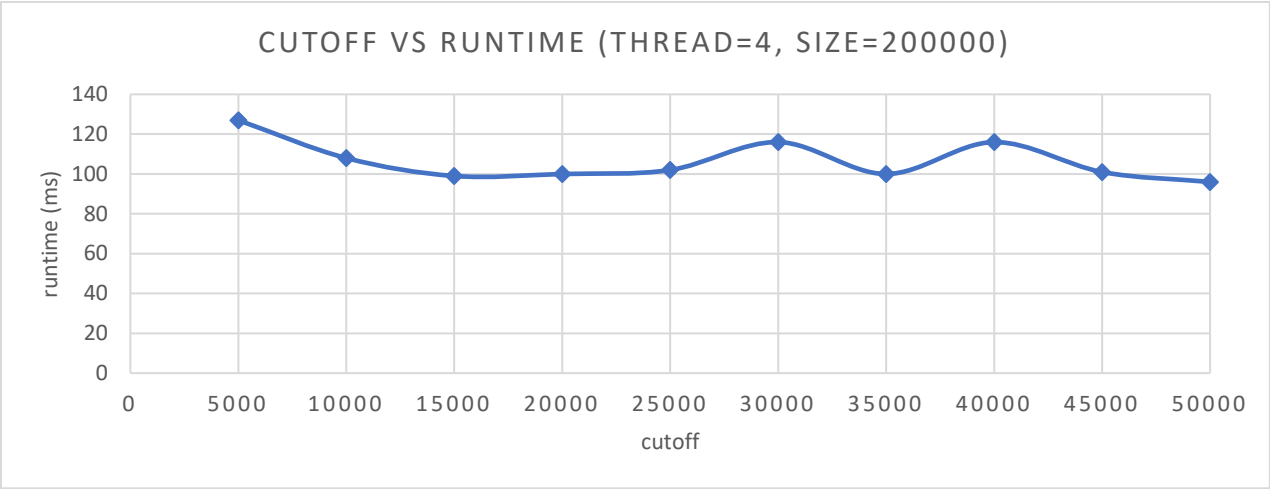
Cutoff	Thread					
	2	4	8	16	32	64
5000	204	78	72	64	48	46
10000	165	74	42	50	42	33
15000	107	52	48	33	36	51
20000	120	66	53	53	47	32
25000	113	40	49	47	32	51
30000	77	87	50	39	47	33
35000	77	47	48	49	48	54
40000	70	58	52	42	31	27
45000	91	44	48	48	42	49
50000	95	84	52	49	54	32



Array size = 200000

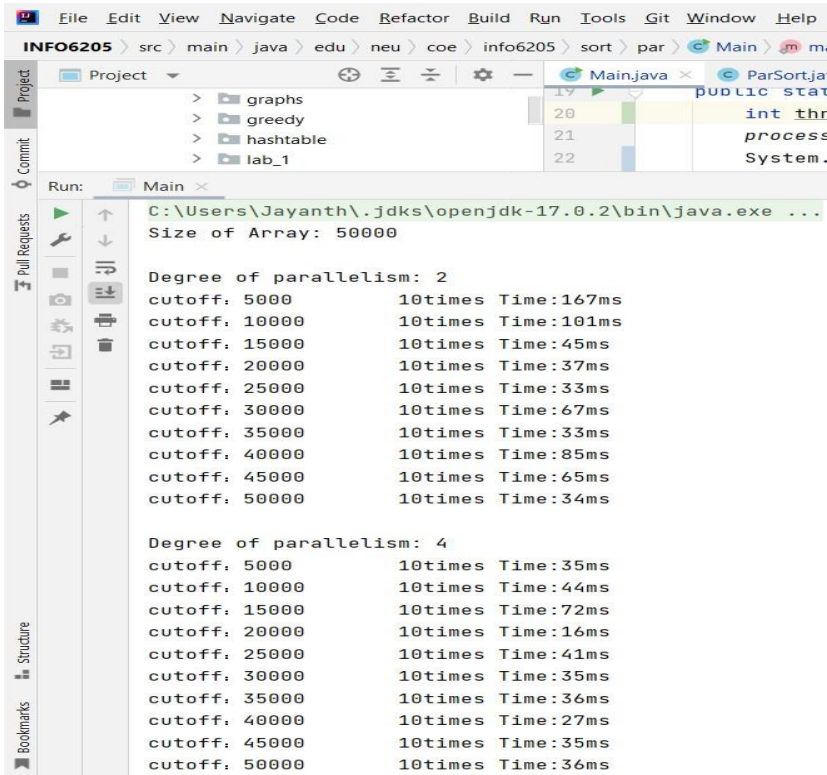
Cutoff	Thread					
	2	4	8	16	32	64
5000	351	127	116	158	144	113
10000	209	108	97	98	95	90
15000	154	99	119	102	97	97
20000	183	100	95	99	119	90
25000	125	102	113	114	101	81
30000	142	116	113	103	107	109

35000	164	100	109	98	110	118
40000	133	116	101	117	98	100
45000	123	101	98	115	110	108
50000	119	96	97	114	108	108



Output Screenshot

Array size = 50000



The screenshot shows an IDE window with the following components:

- Project Explorer:** Shows a project structure with folders: `graphs`, `greedy`, `hashtable`, and `lab_1`.
- Run Configuration:** The `Run` tab is active, showing the command: `C:\Users\Jayanth\.jdk\openjdk-17.0.2\bin\java.exe ...` and the parameter: `Size of Array: 50000`.
- Console Output:** Displays the results of the program execution.

Console Output:

```
19 public stat
20 int thr
21 process
22 System.
```

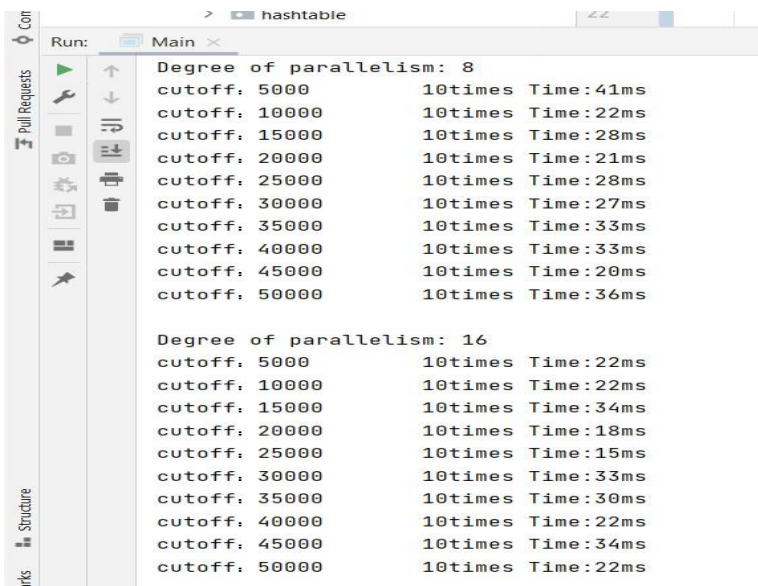
Size of Array: 50000

Degree of parallelism: 2

cutoff	10times	Time
5000	10times	167ms
10000	10times	101ms
15000	10times	45ms
20000	10times	37ms
25000	10times	33ms
30000	10times	67ms
35000	10times	33ms
40000	10times	85ms
45000	10times	65ms
50000	10times	34ms

Degree of parallelism: 4

cutoff	10times	Time
5000	10times	35ms
10000	10times	44ms
15000	10times	72ms
20000	10times	16ms
25000	10times	41ms
30000	10times	35ms
35000	10times	36ms
40000	10times	27ms
45000	10times	35ms
50000	10times	36ms



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- Project Explorer:** Shows a project structure with folders: `graphs`, `greedy`, `hashtable`, and `lab_1`.
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- Console Output:** Displays the results of the program execution.

Console Output:

```
19 public stat
20 int thr
21 process
22 System.
```

Size of Array: 50000

Degree of parallelism: 8

cutoff	10times	Time
5000	10times	41ms
10000	10times	22ms
15000	10times	28ms
20000	10times	21ms
25000	10times	28ms
30000	10times	27ms
35000	10times	33ms
40000	10times	33ms
45000	10times	20ms
50000	10times	36ms

Degree of parallelism: 16

cutoff	10times	Time
5000	10times	22ms
10000	10times	22ms
15000	10times	34ms
20000	10times	18ms
25000	10times	15ms
30000	10times	33ms
35000	10times	30ms
40000	10times	22ms
45000	10times	34ms
50000	10times	22ms

```
hashtable 22
Run: Main x
Degree of parallelism: 32
cutoff: 5000      10times Time:25ms
cutoff: 10000     10times Time:34ms
cutoff: 15000     10times Time:19ms
cutoff: 20000     10times Time:15ms
cutoff: 25000     10times Time:33ms
cutoff: 30000     10times Time:33ms
cutoff: 35000     10times Time:18ms
cutoff: 40000     10times Time:33ms
cutoff: 45000     10times Time:36ms
cutoff: 50000     10times Time:32ms

Degree of parallelism: 64
cutoff: 5000      10times Time:31ms
cutoff: 10000     10times Time:22ms
cutoff: 15000     10times Time:29ms
cutoff: 20000     10times Time:17ms
cutoff: 25000     10times Time:32ms
cutoff: 30000     10times Time:27ms
cutoff: 35000     10times Time:37ms
cutoff: 40000     10times Time:19ms
cutoff: 45000     10times Time:36ms
cutoff: 50000     10times Time:32ms

Process finished with exit code 0
```

Array size = 100000

```
File Edit View Navigate Code Refactor Build Run Tools Git Window Help
INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > par > Main > m.
Project > Project > functions 20 int thr
> graphs 21 process
> greedy 22 System.
> hashtable
Run: Main x
C:\Users\Jayanth\jdk\openjdk-17.0.2\bin\java.exe ...
Size of Array: 100000

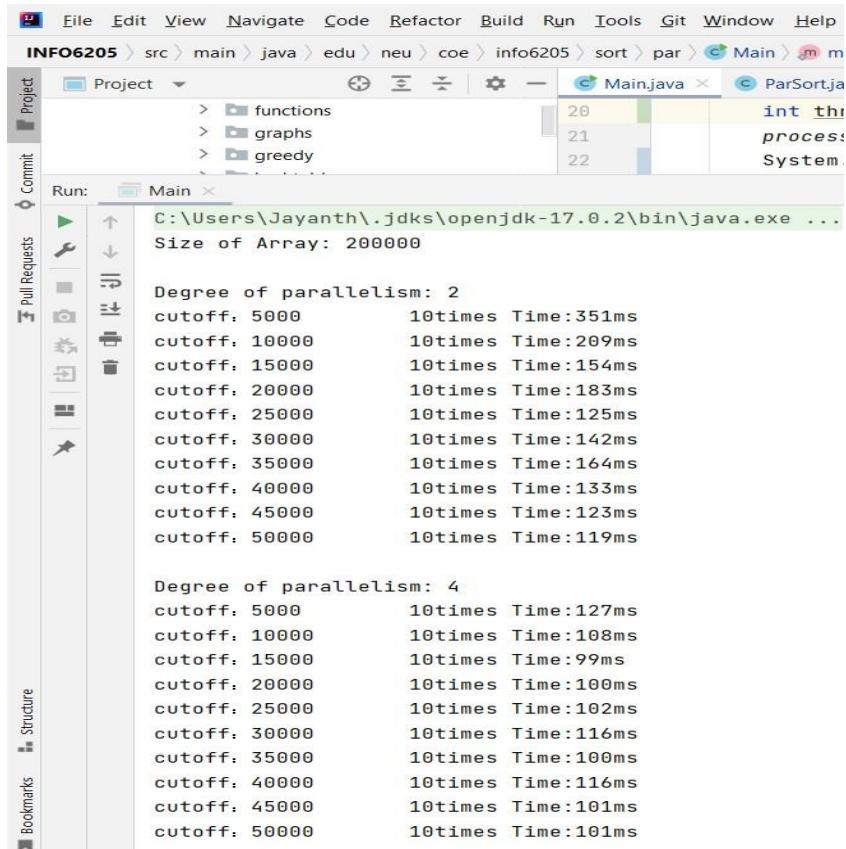
Degree of parallelism: 2
cutoff: 5000      10times Time:204ms
cutoff: 10000     10times Time:165ms
cutoff: 15000     10times Time:107ms
cutoff: 20000     10times Time:120ms
cutoff: 25000     10times Time:113ms
cutoff: 30000     10times Time:77ms
cutoff: 35000     10times Time:77ms
cutoff: 40000     10times Time:70ms
cutoff: 45000     10times Time:91ms
cutoff: 50000     10times Time:95ms

Degree of parallelism: 4
cutoff: 5000      10times Time:78ms
cutoff: 10000     10times Time:74ms
cutoff: 15000     10times Time:52ms
cutoff: 20000     10times Time:66ms
cutoff: 25000     10times Time:49ms
cutoff: 30000     10times Time:87ms
cutoff: 35000     10times Time:47ms
cutoff: 40000     10times Time:58ms
cutoff: 45000     10times Time:44ms
cutoff: 50000     10times Time:84ms
```

The screenshot shows an IDE window with a terminal output. The left sidebar contains icons for Commit, Pull Requests, and Structure. The top toolbar has icons for Run, Debug, and Test. The terminal output displays benchmark results for two different degrees of parallelism: 8 and 16. Each degree of parallelism is tested with cutoff values from 5000 to 50000 in increments of 5000. The results show the number of iterations (10times) and the time taken for each test.

Degree of parallelism	cutoff	iterations	Time
8	5000	10times	72ms
	10000	10times	42ms
	15000	10times	48ms
	20000	10times	53ms
	25000	10times	49ms
	30000	10times	50ms
	35000	10times	48ms
	40000	10times	52ms
	45000	10times	48ms
	50000	10times	52ms
16	5000	10times	64ms
	10000	10times	50ms
	15000	10times	33ms
	20000	10times	53ms
	25000	10times	47ms
	30000	10times	39ms
	35000	10times	49ms
	40000	10times	42ms
	45000	10times	48ms
	50000	10times	49ms

Array size = 200000

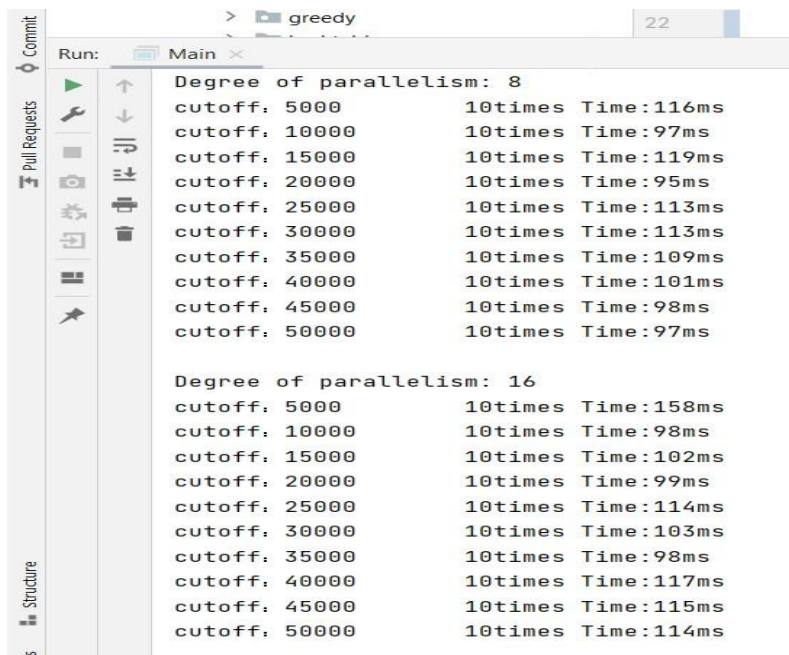


```
INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > par > Main > m m
Project: > functions 20 int th
> graphs 21 proces
> greedy 22 System.

Run: Main x
C:\Users\Jayanth\.jdk\openjdk-17.0.2\bin\java.exe ...
Size of Array: 200000

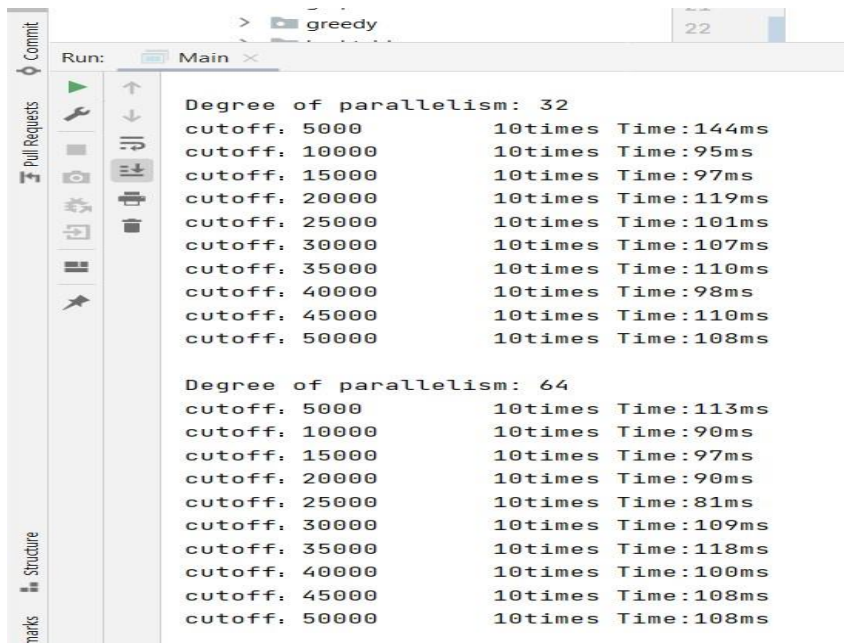
Degree of parallelism: 2
cutoff, 5000 10times Time:351ms
cutoff, 10000 10times Time:209ms
cutoff, 15000 10times Time:154ms
cutoff, 20000 10times Time:183ms
cutoff, 25000 10times Time:125ms
cutoff, 30000 10times Time:142ms
cutoff, 35000 10times Time:164ms
cutoff, 40000 10times Time:133ms
cutoff, 45000 10times Time:123ms
cutoff, 50000 10times Time:119ms

Degree of parallelism: 4
cutoff, 5000 10times Time:127ms
cutoff, 10000 10times Time:108ms
cutoff, 15000 10times Time:99ms
cutoff, 20000 10times Time:100ms
cutoff, 25000 10times Time:102ms
cutoff, 30000 10times Time:116ms
cutoff, 35000 10times Time:100ms
cutoff, 40000 10times Time:116ms
cutoff, 45000 10times Time:101ms
cutoff, 50000 10times Time:101ms
```



```
> greedy 22
Run: Main x
Degree of parallelism: 8
cutoff, 5000 10times Time:116ms
cutoff, 10000 10times Time:97ms
cutoff, 15000 10times Time:119ms
cutoff, 20000 10times Time:95ms
cutoff, 25000 10times Time:113ms
cutoff, 30000 10times Time:113ms
cutoff, 35000 10times Time:109ms
cutoff, 40000 10times Time:101ms
cutoff, 45000 10times Time:98ms
cutoff, 50000 10times Time:97ms

Degree of parallelism: 16
cutoff, 5000 10times Time:158ms
cutoff, 10000 10times Time:98ms
cutoff, 15000 10times Time:102ms
cutoff, 20000 10times Time:99ms
cutoff, 25000 10times Time:114ms
cutoff, 30000 10times Time:103ms
cutoff, 35000 10times Time:98ms
cutoff, 40000 10times Time:117ms
cutoff, 45000 10times Time:115ms
cutoff, 50000 10times Time:114ms
```



Output

Size of Array: 50000

Degree of parallelism: 2

cutoff : 5000	10times Time:167ms
cutoff : 10000	10times Time:101ms
cutoff : 15000	10times Time:45ms
cutoff : 20000	10times Time:37ms
cutoff : 25000	10times Time:33ms
cutoff : 30000	10times Time:67ms
cutoff : 35000	10times Time:33ms
cutoff : 40000	10times Time:85ms
cutoff : 45000	10times Time:65ms
cutoff : 50000	10times Time:34ms

Degree of parallelism: 4

cutoff : 5000	10times Time:35ms
cutoff : 10000	10times Time:44ms
cutoff : 15000	10times Time:72ms
cutoff : 20000	10times Time:16ms
cutoff : 25000	10times Time:41ms
cutoff : 30000	10times Time:35ms
cutoff : 35000	10times Time:36ms
cutoff : 40000	10times Time:27ms
cutoff : 45000	10times Time:35ms
cutoff : 50000	10times Time:36ms

Degree of parallelism: 8

cutoff : 5000	10times Time:41ms
cutoff : 10000	10times Time:22ms
cutoff : 15000	10times Time:28ms
cutoff : 20000	10times Time:21ms
cutoff : 25000	10times Time:28ms
cutoff : 30000	10times Time:27ms
cutoff : 35000	10times Time:33ms
cutoff : 40000	10times Time:33ms
cutoff : 45000	10times Time:20ms
cutoff : 50000	10times Time:36ms

Degree of parallelism: 16

cutoff : 5000	10times Time:22ms
cutoff : 10000	10times Time:22ms
cutoff : 15000	10times Time:34ms
cutoff : 20000	10times Time:18ms
cutoff : 25000	10times Time:15ms
cutoff : 30000	10times Time:33ms
cutoff : 35000	10times Time:30ms
cutoff : 40000	10times Time:22ms
cutoff : 45000	10times Time:34ms
cutoff : 50000	10times Time:22ms

Degree of parallelism: 32

cutoff : 5000	10times Time:25ms
cutoff : 10000	10times Time:34ms
cutoff : 15000	10times Time:19ms
cutoff : 20000	10times Time:15ms
cutoff : 25000	10times Time:33ms
cutoff : 30000	10times Time:33ms
cutoff : 35000	10times Time:18ms
cutoff : 40000	10times Time:33ms
cutoff : 45000	10times Time:36ms
cutoff : 50000	10times Time:32ms

Degree of parallelism: 64

cutoff : 5000	10times Time:31ms
cutoff : 10000	10times Time:22ms
cutoff : 15000	10times Time:29ms
cutoff : 20000	10times Time:17ms
cutoff : 25000	10times Time:32ms
cutoff : 30000	10times Time:27ms
cutoff : 35000	10times Time:37ms
cutoff : 40000	10times Time:19ms
cutoff : 45000	10times Time:36ms
cutoff : 50000	10times Time:32ms

Process finished with exit code 0

cutoff : 5000	10times Time:64ms
cutoff : 10000	10times Time:50ms
cutoff : 15000	10times Time:33ms
cutoff : 20000	10times Time:53ms
cutoff : 25000	10times Time:47ms
cutoff : 30000	10times Time:39ms
cutoff : 35000	10times Time:49ms
cutoff : 40000	10times Time:42ms
cutoff : 45000	10times Time:48ms

cutoff : 20000	10times Time:100ms
cutoff : 25000	10times Time:102ms
cutoff : 30000	10times Time:116ms
cutoff : 35000	10times Time:100ms
cutoff : 40000	10times Time:116ms
cutoff : 45000	10times Time:101ms
cutoff : 50000	10times Time:101ms

Degree of parallelism: 8

cutoff : 5000	10times Time:116ms
cutoff : 10000	10times Time:97ms
cutoff : 15000	10times Time:119ms
cutoff : 20000	10times Time:95ms
cutoff : 25000	10times Time:113ms
cutoff : 30000	10times Time:113ms
cutoff : 35000	10times Time:109ms
cutoff : 40000	10times Time:101ms
cutoff : 45000	10times Time:98ms
cutoff : 50000	10times Time:97ms

Degree of parallelism: 16

cutoff : 5000	10times Time:158ms
cutoff : 10000	10times Time:98ms
cutoff : 15000	10times Time:102ms
cutoff : 20000	10times Time:99ms
cutoff : 25000	10times Time:114ms
cutoff : 30000	10times Time:103ms
cutoff : 35000	10times Time:98ms
cutoff : 40000	10times Time:117ms
cutoff : 45000	10times Time:115ms
cutoff : 50000	10times Time:114ms

Degree of parallelism: 32

cutoff : 5000	10times Time:144ms
cutoff : 10000	10times Time:95ms
cutoff : 15000	10times Time:97ms
cutoff : 20000	10times Time:119ms
cutoff : 25000	10times Time:101ms
cutoff : 30000	10times Time:107ms
cutoff : 35000	10times Time:110ms
cutoff : 40000	10times Time:98ms
cutoff : 45000	10times Time:110ms
cutoff : 50000	10times Time:108ms

Degree of parallelism: 64

cutoff : 5000	10times Time:113ms
cutoff : 10000	10times Time:90ms
cutoff : 15000	10times Time:97ms
cutoff : 20000	10times Time:90ms
cutoff : 25000	10times Time:81ms

cutoff : 30000	10times Time:109ms
cutoff : 35000	10times Time:118ms
cutoff : 40000	10times Time:100ms
cutoff : 45000	10times Time:108ms
cutoff : 50000	10times Time:108ms

Process finished with exit code 0