James Shah(NUID - 002107975)

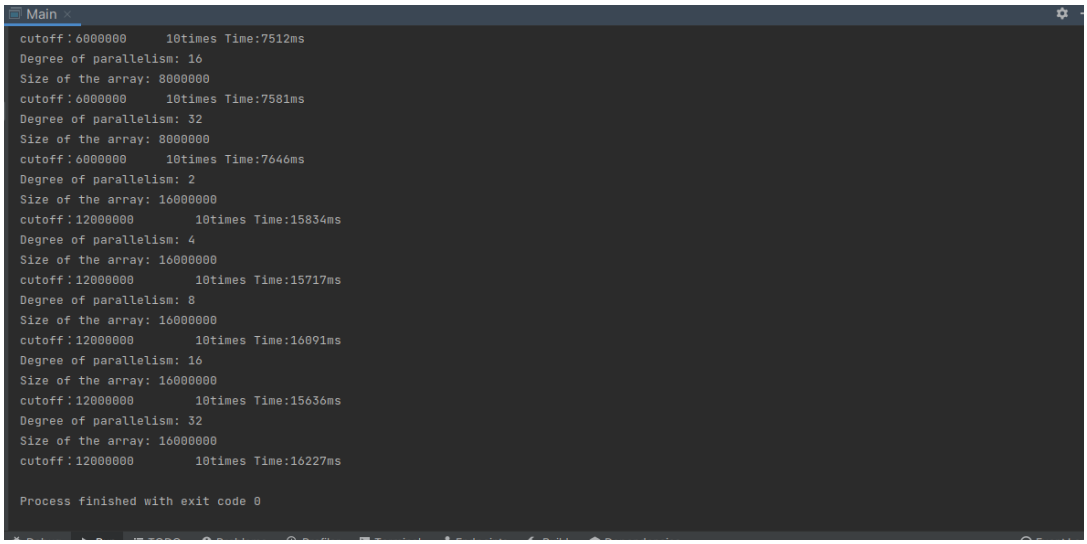
Program Structures & Algorithms
Fall 2021
Assignment No. 5

- **Tasks:**
  - Implement a parallel sorting algorithm such that each partition in merge sort is sorted parallelly.
  - Experiment with various values of cutoff, number of threads, and a combination of both to examine the effect of parallel sorting in merge sort.

- **Relationship Conclusion:**
  - One noticeable thing in the experiment was that after some point increasing the number of threads doesn't make any difference with the same cutoff scheme. i.e., increasing the number of threads from 16 to 32 doesn't improve performance in a significant manner when the cutoff values are identical.
  - A reasonably **good value of cutoff is half the value of array size**. A relatively big (¾ * array size) or a small (¼ * array size) value of cutoff also works but not for the much bigger value of array size.

- **Evidence to support the conclusion:**

  1. The output of the program:



James Shah(NUID - 002107975)

```
cutoff:3000000     10times Time:3839ms
Degree of parallelism: 32
Size of the array: 4000000
cutoff:3000000     10times Time:3291ms
Degree of parallelism: 2
Size of the array: 8000000
cutoff:6000000     10times Time:7513ms
Degree of parallelism: 4
Size of the array: 8000000
cutoff:6000000     10times Time:7596ms
Degree of parallelism: 8
Size of the array: 8000000
cutoff:6000000     10times Time:7512ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff:6000000     10times Time:7581ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff:6000000     10times Time:7646ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff:12000000        10times Time:15834ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff:12000000        10times Time:15717ms
```

```
cutoff:750000      10times Time:905ms
Degree of parallelism: 2
Size of the array: 2000000
cutoff:1500000     10times Time:2019ms
Degree of parallelism: 4
Size of the array: 2000000
cutoff:1500000     10times Time:1616ms
Degree of parallelism: 8
Size of the array: 2000000
cutoff:1500000     10times Time:1534ms
Degree of parallelism: 16
Size of the array: 2000000
cutoff:1500000     10times Time:1772ms
Degree of parallelism: 32
Size of the array: 2000000
cutoff:1500000     10times Time:1911ms
Degree of parallelism: 2
Size of the array: 4000000
cutoff:3000000     10times Time:3381ms
Degree of parallelism: 4
Size of the array: 4000000
cutoff:3000000     10times Time:3832ms
Degree of parallelism: 8
Size of the array: 4000000
cutoff:3000000     10times Time:3326ms
```

```
/usr/lib/jvm/java-1.11.0-openjdk-amd64/bin/java ...
Degree of parallelism: 2
Size of the array: 1000000
cutoff:750000      10times Time:1519ms
Degree of parallelism: 4
Size of the array: 1000000
cutoff:750000      10times Time:800ms
Degree of parallelism: 8
Size of the array: 1000000
cutoff:750000      10times Time:729ms
Degree of parallelism: 16
Size of the array: 1000000
cutoff:750000      10times Time:931ms
Degree of parallelism: 32
Size of the array: 1000000
cutoff:750000      10times Time:905ms
Degree of parallelism: 2
Size of the array: 2000000
cutoff:1500000     10times Time:2019ms
Degree of parallelism: 4
Size of the array: 2000000
cutoff:1500000     10times Time:1616ms
Degree of parallelism: 8
Size of the array: 2000000
cutoff:1500000     10times Time:1534ms
```

James Shah(NUID - 002107975)

```
cutoff：2000000     10times Time:8136ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff：2000000     10times Time:6906ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff：2000000     10times Time:6589ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff：4000000     10times Time:18977ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff：4000000     10times Time:17503ms
Degree of parallelism: 8
Size of the array: 16000000
cutoff：4000000     10times Time:15932ms
Degree of parallelism: 16
Size of the array: 16000000
cutoff：4000000     10times Time:13129ms
Degree of parallelism: 32
Size of the array: 16000000
cutoff：4000000     10times Time:13029ms

Process finished with exit code 0
```

```
cutoff：2000000     10times Time:8985ms
Degree of parallelism: 4
Size of the array: 8000000
cutoff：2000000     10times Time:9969ms
Degree of parallelism: 8
Size of the array: 8000000
cutoff：2000000     10times Time:8136ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff：2000000     10times Time:6906ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff：2000000     10times Time:6589ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff：4000000     10times Time:18977ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff：4000000     10times Time:17503ms
Degree of parallelism: 8
Size of the array: 16000000
cutoff：4000000     10times Time:15932ms
Degree of parallelism: 16
Size of the array: 16000000
cutoff：4000000     10times Time:13129ms
```

```
cutoff：500000      10times Time:1517ms
Degree of parallelism: 16
Size of the array: 2000000
cutoff：500000      10times Time:1522ms
Degree of parallelism: 32
Size of the array: 2000000
cutoff：500000      10times Time:1637ms
Degree of parallelism: 2
Size of the array: 4000000
cutoff：1000000     10times Time:4207ms
Degree of parallelism: 4
Size of the array: 4000000
cutoff：1000000     10times Time:4662ms
Degree of parallelism: 8
Size of the array: 4000000
cutoff：1000000     10times Time:3847ms
Degree of parallelism: 16
Size of the array: 4000000
cutoff：1000000     10times Time:3433ms
Degree of parallelism: 32
Size of the array: 4000000
cutoff：1000000     10times Time:3315ms
Degree of parallelism: 2
Size of the array: 8000000
cutoff：2000000     10times Time:8985ms
```

James Shah(NUID - 002107975)

```
Degree of parallelism: 2
Size of the array: 1000000
cutoff:250000      10times Time:1467ms
Degree of parallelism: 4
Size of the array: 1000000
cutoff:250000      10times Time:1260ms
Degree of parallelism: 8
Size of the array: 1000000
cutoff:250000      10times Time:931ms
Degree of parallelism: 16
Size of the array: 1000000
cutoff:250000      10times Time:774ms
Degree of parallelism: 32
Size of the array: 1000000
cutoff:250000      10times Time:765ms
Degree of parallelism: 2
Size of the array: 2000000
cutoff:500000      10times Time:2200ms
Degree of parallelism: 4
Size of the array: 2000000
cutoff:500000      10times Time:2193ms
Degree of parallelism: 8
Size of the array: 2000000
cutoff:500000      10times Time:1517ms
```

```
cutoff:4000000     10times Time:6674ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff:4000000     10times Time:6758ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff:4000000     10times Time:6869ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff:8000000     10times Time:22130ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff:8000000     10times Time:17609ms
Degree of parallelism: 8
Size of the array: 16000000
cutoff:8000000     10times Time:13213ms
Degree of parallelism: 16
Size of the array: 16000000
cutoff:8000000     10times Time:12621ms
Degree of parallelism: 32
Size of the array: 16000000
cutoff:8000000     10times Time:13307ms

Process finished with exit code 0
```

```
cutoff:4000000     10times Time:11792ms
Degree of parallelism: 4
Size of the array: 8000000
cutoff:4000000     10times Time:8989ms
Degree of parallelism: 8
Size of the array: 8000000
cutoff:4000000     10times Time:6674ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff:4000000     10times Time:6758ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff:4000000     10times Time:6869ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff:8000000     10times Time:22130ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff:8000000     10times Time:17609ms
Degree of parallelism: 8
Size of the array: 16000000
cutoff:8000000     10times Time:13213ms
Degree of parallelism: 16
Size of the array: 16000000
cutoff:8000000     10times Time:12621ms
```

James Shah(NUID - 002107975)

```
cutoff : 1000000     10times Time:1639ms
Degree of parallelism: 16
Size of the array: 2000000
cutoff : 1000000     10times Time:1572ms
Degree of parallelism: 32
Size of the array: 2000000
cutoff : 1000000     10times Time:1692ms
Degree of parallelism: 2
Size of the array: 4000000
cutoff : 2000000     10times Time:5586ms
Degree of parallelism: 4
Size of the array: 4000000
cutoff : 2000000     10times Time:4332ms
Degree of parallelism: 8
Size of the array: 4000000
cutoff : 2000000     10times Time:3305ms
Degree of parallelism: 16
Size of the array: 4000000
cutoff : 2000000     10times Time:3306ms
Degree of parallelism: 32
Size of the array: 4000000
cutoff : 2000000     10times Time:3395ms
Degree of parallelism: 2
Size of the array: 8000000
cutoff : 4000000     10times Time:11792ms
```

```
/usr/lib/jvm/java-1.11.0-openjdk-amd64/bin/java ...
Degree of parallelism: 2
Size of the array: 1000000
cutoff : 500000      10times Time:1908ms
Degree of parallelism: 4
Size of the array: 1000000
cutoff : 500000      10times Time:1283ms
Degree of parallelism: 8
Size of the array: 1000000
cutoff : 500000      10times Time:764ms
Degree of parallelism: 16
Size of the array: 1000000
cutoff : 500000      10times Time:753ms
Degree of parallelism: 32
Size of the array: 1000000
cutoff : 500000      10times Time:769ms
Degree of parallelism: 2
Size of the array: 2000000
cutoff : 1000000     10times Time:2720ms
Degree of parallelism: 4
Size of the array: 2000000
cutoff : 1000000     10times Time:2077ms
Degree of parallelism: 8
Size of the array: 2000000
cutoff : 1000000     10times Time:1639ms
```

```
cutoff : 5000        10times Time:8335ms
Degree of parallelism: 8
Size of the array: 8000000
cutoff : 5000        10times Time:8614ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff : 5000        10times Time:8687ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff : 5000        10times Time:8659ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff : 5000        10times Time:18868ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff : 5000        10times Time:18311ms
Degree of parallelism: 8
Size of the array: 16000000
cutoff : 5000        10times Time:19586ms
Degree of parallelism: 16
Size of the array: 16000000
cutoff : 5000        10times Time:19311ms
Degree of parallelism: 32
Size of the array: 16000000
cutoff : 5000        10times Time:22669ms
```

```
cutoff:5000        10times Time:1877ms
Degree of parallelism: 16
Size of the array: 2000000
cutoff:5000        10times Time:1841ms
Degree of parallelism: 32
Size of the array: 2000000
cutoff:5000        10times Time:1716ms
Degree of parallelism: 2
Size of the array: 4000000
cutoff:5000        10times Time:4020ms
Degree of parallelism: 4
Size of the array: 4000000
cutoff:5000        10times Time:3968ms
Degree of parallelism: 8
Size of the array: 4000000
cutoff:5000        10times Time:3576ms
Degree of parallelism: 16
Size of the array: 4000000
cutoff:5000        10times Time:3650ms
Degree of parallelism: 32
Size of the array: 4000000
cutoff:5000        10times Time:3680ms
Degree of parallelism: 2
Size of the array: 8000000
cutoff:5000        10times Time:8014ms
```

```
Degree of parallelism: 2
Size of the array: 1000000
cutoff:5000        10times Time:2079ms
Degree of parallelism: 4
Size of the array: 1000000
cutoff:5000        10times Time:1209ms
Degree of parallelism: 8
Size of the array: 1000000
cutoff:5000        10times Time:1093ms
Degree of parallelism: 16
Size of the array: 1000000
cutoff:5000        10times Time:845ms
Degree of parallelism: 32
Size of the array: 1000000
cutoff:5000        10times Time:886ms
Degree of parallelism: 2
Size of the array: 2000000
cutoff:5000        10times Time:1865ms
Degree of parallelism: 4
Size of the array: 2000000
cutoff:5000        10times Time:1892ms
Degree of parallelism: 8
Size of the array: 2000000
cutoff:5000        10times Time:1877ms
```

```
Size of the array: 8000000
cutoff:400000      10times Time:9047ms
Degree of parallelism: 8
Size of the array: 8000000
cutoff:400000      10times Time:8927ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff:400000      10times Time:8730ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff:400000      10times Time:7997ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff:400000      10times Time:16473ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff:400000      10times Time:16598ms
Degree of parallelism: 8
Size of the array: 16000000
cutoff:400000      10times Time:17516ms
Degree of parallelism: 16
Size of the array: 16000000
cutoff:400000      10times Time:17579ms
Degree of parallelism: 32
Size of the array: 16000000
```

James Shah(NUID - 002107975)

```
Degree of parallelism: 16
Size of the array: 2000000
cutoff：400000      10times Time:1679ms
Degree of parallelism: 32
Size of the array: 2000000
cutoff：400000      10times Time:1764ms
Degree of parallelism: 2
Size of the array: 4000000
cutoff：400000      10times Time:3675ms
Degree of parallelism: 4
Size of the array: 4000000
cutoff：400000      10times Time:4634ms
Degree of parallelism: 8
Size of the array: 4000000
cutoff：400000      10times Time:4454ms
Degree of parallelism: 16
Size of the array: 4000000
cutoff：400000      10times Time:3876ms
Degree of parallelism: 32
Size of the array: 4000000
cutoff：400000      10times Time:3721ms
Degree of parallelism: 2
Size of the array: 8000000
cutoff：400000      10times Time:9013ms
Degree of parallelism: 4
```

```
Degree of parallelism: 2
Size of the array: 1000000
cutoff：400000      10times Time:2069ms
Degree of parallelism: 4
Size of the array: 1000000
cutoff：400000      10times Time:1101ms
Degree of parallelism: 8
Size of the array: 1000000
cutoff：400000      10times Time:760ms
Degree of parallelism: 16
Size of the array: 1000000
cutoff：400000      10times Time:751ms
Degree of parallelism: 32
Size of the array: 1000000
cutoff：400000      10times Time:903ms
Degree of parallelism: 2
Size of the array: 2000000
cutoff：400000      10times Time:2358ms
Degree of parallelism: 4
Size of the array: 2000000
cutoff：400000      10times Time:2370ms
Degree of parallelism: 8
Size of the array: 2000000
cutoff：400000      10times Time:1908ms
```

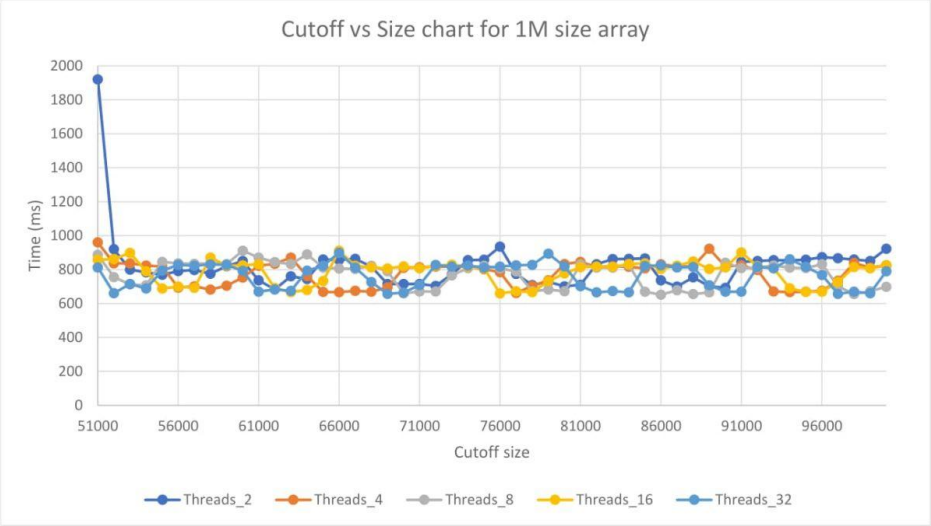
```
Size of the array: 8000000
cutoff：200000      10times Time:8451ms
Degree of parallelism: 8
Size of the array: 8000000
cutoff：200000      10times Time:8048ms
Degree of parallelism: 16
Size of the array: 8000000
cutoff：200000      10times Time:7886ms
Degree of parallelism: 32
Size of the array: 8000000
cutoff：200000      10times Time:7812ms
Degree of parallelism: 2
Size of the array: 16000000
cutoff：200000      10times Time:16530ms
Degree of parallelism: 4
Size of the array: 16000000
cutoff：200000      10times Time:18135ms
Degree of parallelism: 8
Size of the array: 16000000
cutoff：200000      10times Time:16592ms
Degree of parallelism: 16
Size of the array: 16000000
cutoff：200000      10times Time:17973ms
Degree of parallelism: 32
Size of the array: 16000000
```

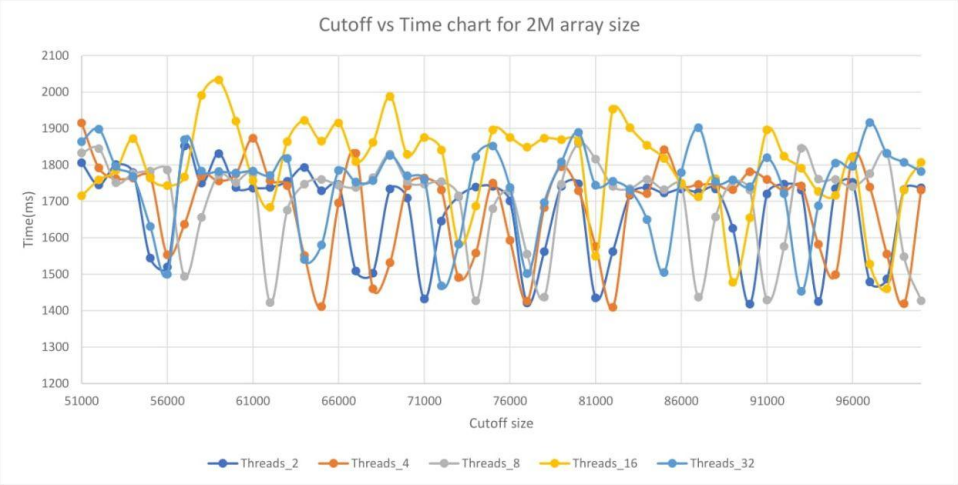
James Shah(NUID - 002107975)

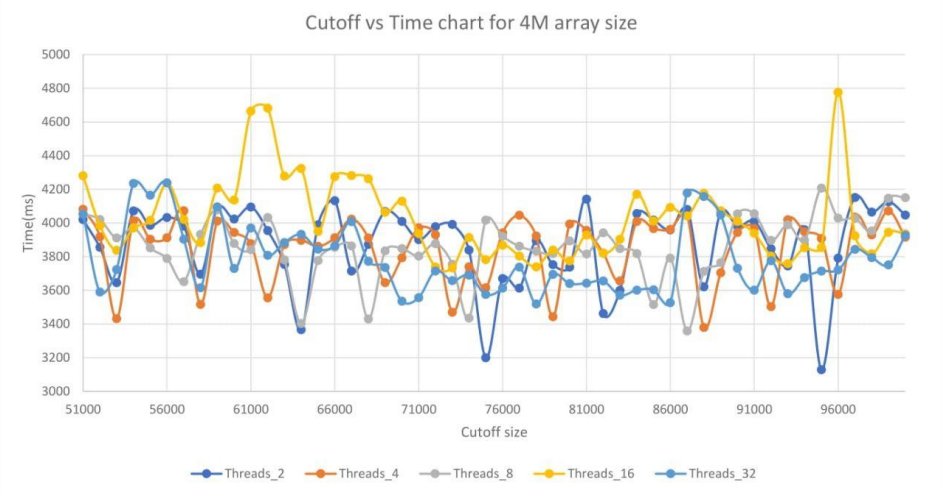
```
Size of the array: 2000000
cutoff:200000      10times Time:1743ms
Degree of parallelism: 32
Size of the array: 2000000
cutoff:200000      10times Time:1760ms
Degree of parallelism: 2
Size of the array: 4000000
cutoff:200000      10times Time:4481ms
Degree of parallelism: 4
Size of the array: 4000000
cutoff:200000      10times Time:4400ms
Degree of parallelism: 8
Size of the array: 4000000
cutoff:200000      10times Time:4499ms
Degree of parallelism: 16
Size of the array: 4000000
cutoff:200000      10times Time:4132ms
Degree of parallelism: 32
Size of the array: 4000000
cutoff:200000      10times Time:3834ms
Degree of parallelism: 2
Size of the array: 8000000
cutoff:200000      10times Time:8230ms
Degree of parallelism: 4
Size of the array: 8000000
```

```
Degree of parallelism: 2
Size of the array: 1000000
cutoff:200000      10times Time:1667ms
Degree of parallelism: 4
Size of the array: 1000000
cutoff:200000      10times Time:1450ms
Degree of parallelism: 8
Size of the array: 1000000
cutoff:200000      10times Time:932ms
Degree of parallelism: 16
Size of the array: 1000000
cutoff:200000      10times Time:778ms
Degree of parallelism: 32
Size of the array: 1000000
cutoff:200000      10times Time:797ms
Degree of parallelism: 2
Size of the array: 2000000
cutoff:200000      10times Time:2276ms
Degree of parallelism: 4
Size of the array: 2000000
cutoff:200000      10times Time:1530ms
Degree of parallelism: 8
Size of the array: 2000000
cutoff:200000      10times Time:1873ms
```

2. Graphical Representation:







Conclusion:

A good balance of cutoff and number of threads seems to be **half of the array size as cutoff** and **8 threads** for relatively large arrays (millions of elements). A really small or a really large number of cutoff won't make much of a difference because other costs will compensate for the parallel sorting and the number of threads doesn't make difference after a point(generally around 8-16) as we can see from the plots and outputs.