

## **Program Structures and Algorithms - Assignment 4**

**Name - Janhavi Patil | Section - 1 | NU ID - 001523317**

### **Tasks:**

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.

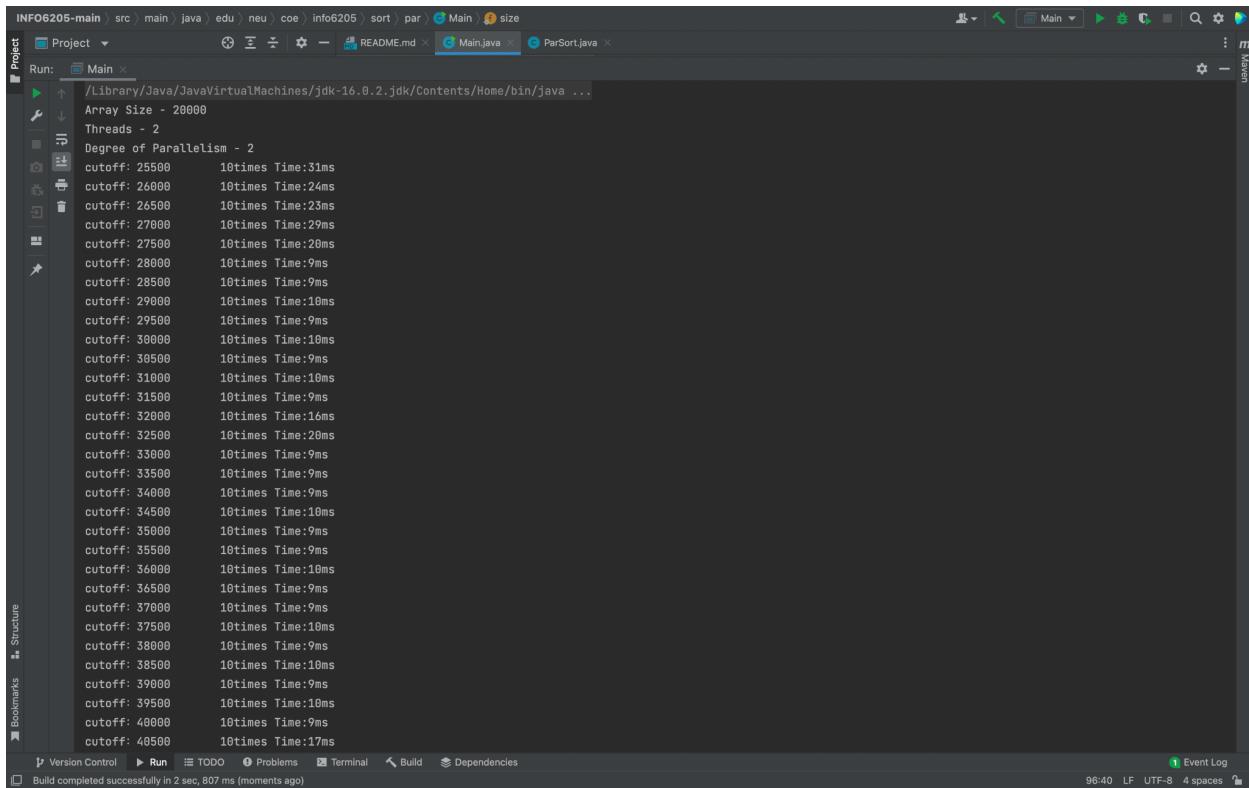
There is a *Main* class and the *ParSort* class in the *sort.par* package of the INFO6205 repository. The *Main* class can be used as is but the *ParSort* class needs to be implemented where you see "TODO..." [it turns out that these TODOs are already implemented].

Unless you have a good reason not to, you should just go along with the Java8-style future implementations provided for you in the class repository.

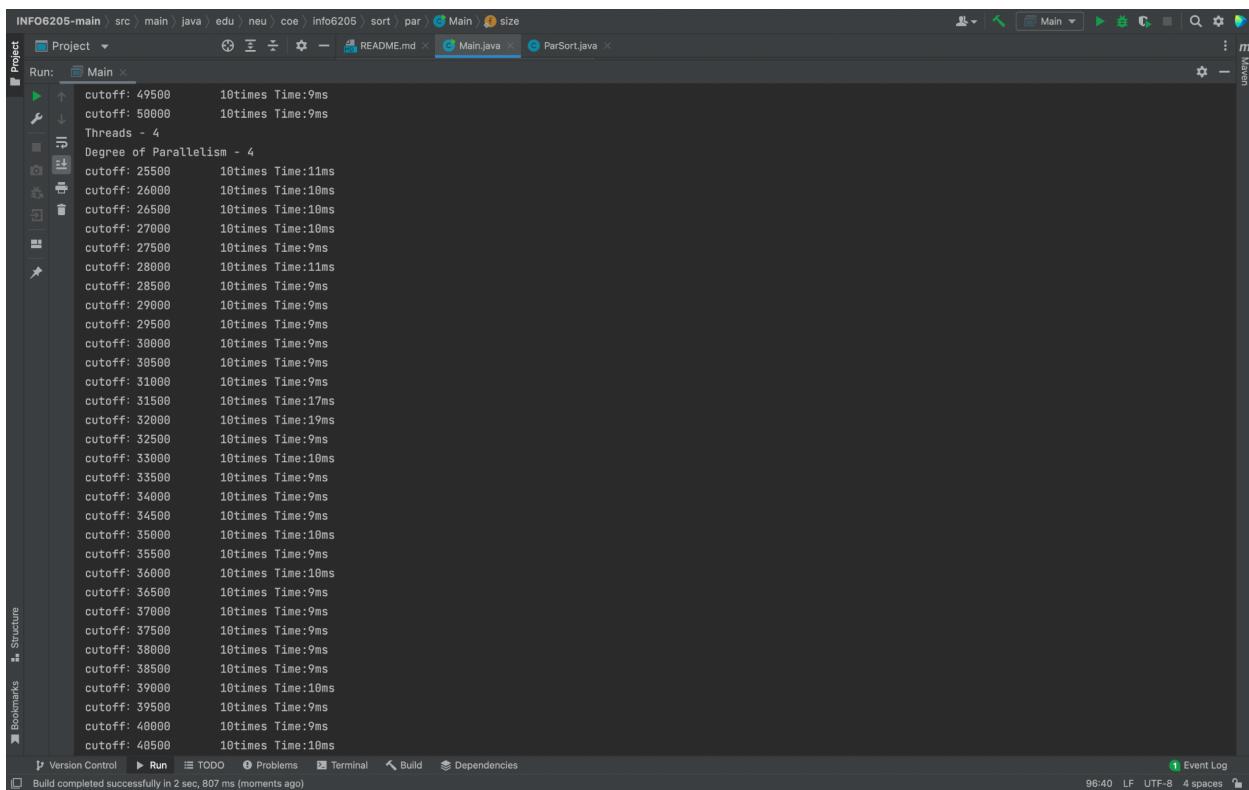
You must prepare a report that shows the results of your experiments and draws a conclusion (or more) about the efficacy of this method of parallelizing sort. Your experiments should involve sorting arrays of sufficient size for the parallel sort to make a difference. You should run with many different array sizes (they must be sufficiently large to make parallel sorting worthwhile, obviously) and different cutoff schemes.

## Run Time Screenshots -

### Array Size - 20000



```
INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | size
Run: Main
/Library/Java/JavaVirtualMachines/jdk-16.0.2.jdk/Contents/Home/bin/java ...
Array Size - 20000
Threads - 2
Degree of Parallelism - 2
cutoff: 25500    10times Time:31ms
cutoff: 26000    10times Time:24ms
cutoff: 26500    10times Time:25ms
cutoff: 27000    10times Time:29ms
cutoff: 27500    10times Time:20ms
cutoff: 28000    10times Time:9ms
cutoff: 28500    10times Time:9ms
cutoff: 29000    10times Time:10ms
cutoff: 29500    10times Time:9ms
cutoff: 30000    10times Time:10ms
cutoff: 30500    10times Time:9ms
cutoff: 31000    10times Time:10ms
cutoff: 31500    10times Time:9ms
cutoff: 32000    10times Time:16ms
cutoff: 32500    10times Time:20ms
cutoff: 33000    10times Time:9ms
cutoff: 33500    10times Time:9ms
cutoff: 34000    10times Time:9ms
cutoff: 34500    10times Time:10ms
cutoff: 35000    10times Time:9ms
cutoff: 35500    10times Time:9ms
cutoff: 36000    10times Time:10ms
cutoff: 36500    10times Time:9ms
cutoff: 37000    10times Time:9ms
cutoff: 37500    10times Time:10ms
cutoff: 38000    10times Time:9ms
cutoff: 38500    10times Time:10ms
cutoff: 39000    10times Time:9ms
cutoff: 39500    10times Time:10ms
cutoff: 40000    10times Time:9ms
cutoff: 40500    10times Time:17ms
```



```
INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | size
Run: Main
cutoff: 49500    10times Time:9ms
cutoff: 50000    10times Time:9ms
Threads - 4
Degree of Parallelism - 4
cutoff: 25500    10times Time:11ms
cutoff: 26000    10times Time:10ms
cutoff: 26500    10times Time:10ms
cutoff: 27000    10times Time:10ms
cutoff: 27500    10times Time:9ms
cutoff: 28000    10times Time:11ms
cutoff: 28500    10times Time:9ms
cutoff: 29000    10times Time:9ms
cutoff: 29500    10times Time:9ms
cutoff: 30000    10times Time:9ms
cutoff: 30500    10times Time:9ms
cutoff: 31000    10times Time:9ms
cutoff: 31500    10times Time:17ms
cutoff: 32000    10times Time:19ms
cutoff: 32500    10times Time:9ms
cutoff: 33000    10times Time:10ms
cutoff: 33500    10times Time:9ms
cutoff: 34000    10times Time:9ms
cutoff: 34500    10times Time:9ms
cutoff: 35000    10times Time:10ms
cutoff: 35500    10times Time:9ms
cutoff: 36000    10times Time:10ms
cutoff: 36500    10times Time:9ms
cutoff: 37000    10times Time:9ms
cutoff: 37500    10times Time:9ms
cutoff: 38000    10times Time:9ms
cutoff: 38500    10times Time:9ms
cutoff: 39000    10times Time:10ms
cutoff: 39500    10times Time:9ms
cutoff: 40000    10times Time:9ms
cutoff: 40500    10times Time:10ms
```

```
INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | ParSort.java | size
Project Run: Main
Run: Main
cutoff: 49500    10times Time:9ms
cutoff: 50000    10times Time:9ms
Threads - 8
Degree of Parallelism - 8
cutoff: 25500    10times Time:9ms
cutoff: 26000    10times Time:9ms
cutoff: 26500    10times Time:9ms
cutoff: 27000    10times Time:9ms
cutoff: 27500    10times Time:9ms
cutoff: 28000    10times Time:9ms
cutoff: 28500    10times Time:9ms
cutoff: 29000    10times Time:9ms
cutoff: 29500    10times Time:9ms
cutoff: 30000    10times Time:10ms
cutoff: 30500    10times Time:9ms
cutoff: 31000    10times Time:9ms
cutoff: 31500    10times Time:9ms
cutoff: 32000    10times Time:9ms
cutoff: 32500    10times Time:10ms
cutoff: 33000    10times Time:9ms
cutoff: 33500    10times Time:9ms
cutoff: 34000    10times Time:9ms
cutoff: 34500    10times Time:10ms
cutoff: 35000    10times Time:10ms
cutoff: 35500    10times Time:9ms
cutoff: 36000    10times Time:10ms
cutoff: 36500    10times Time:9ms
cutoff: 37000    10times Time:9ms
cutoff: 37500    10times Time:9ms
cutoff: 38000    10times Time:10ms
cutoff: 38500    10times Time:9ms
cutoff: 39000    10times Time:10ms
cutoff: 39500    10times Time:10ms
cutoff: 40000    10times Time:9ms
cutoff: 40500    10times Time:10ms
Build completed successfully in 2 sec, 807 ms (moments ago)
```

```
INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | ParSort.java | size
Project Run: Main
Run: Main
cutoff: 49500    10times Time:9ms
cutoff: 50000    10times Time:9ms
Threads - 16
Degree of Parallelism - 16
cutoff: 25500    10times Time:9ms
cutoff: 26000    10times Time:9ms
cutoff: 26500    10times Time:9ms
cutoff: 27000    10times Time:9ms
cutoff: 27500    10times Time:9ms
cutoff: 28000    10times Time:9ms
cutoff: 28500    10times Time:9ms
cutoff: 29000    10times Time:10ms
cutoff: 29500    10times Time:9ms
cutoff: 30000    10times Time:9ms
cutoff: 30500    10times Time:9ms
cutoff: 31000    10times Time:9ms
cutoff: 31500    10times Time:10ms
cutoff: 32000    10times Time:9ms
cutoff: 32500    10times Time:9ms
cutoff: 33000    10times Time:9ms
cutoff: 33500    10times Time:10ms
cutoff: 34000    10times Time:15ms
cutoff: 34500    10times Time:9ms
cutoff: 35000    10times Time:9ms
cutoff: 35500    10times Time:9ms
cutoff: 36000    10times Time:9ms
cutoff: 36500    10times Time:12ms
cutoff: 37000    10times Time:14ms
cutoff: 37500    10times Time:11ms
cutoff: 38000    10times Time:9ms
cutoff: 38500    10times Time:9ms
cutoff: 39000    10times Time:9ms
cutoff: 39500    10times Time:9ms
cutoff: 40000    10times Time:9ms
cutoff: 40500    10times Time:9ms
Build completed successfully in 2 sec, 807 ms (moments ago)
```

INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main | size

Project Run: Main

```
cutoff: 50000    10times Time:8ms
Threads - 32
Degree of Parallelism - 32
cutoff: 25500    10times Time:9ms
cutoff: 26000    10times Time:8ms
cutoff: 26500    10times Time:9ms
cutoff: 27000    10times Time:9ms
cutoff: 27500    10times Time:8ms
cutoff: 28000    10times Time:9ms
cutoff: 28500    10times Time:9ms
cutoff: 29000    10times Time:8ms
cutoff: 29500    10times Time:9ms
cutoff: 30000    10times Time:9ms
cutoff: 30500    10times Time:8ms
cutoff: 31000    10times Time:9ms
cutoff: 31500    10times Time:9ms
cutoff: 32000    10times Time:8ms
cutoff: 32500    10times Time:9ms
cutoff: 33000    10times Time:9ms
cutoff: 33500    10times Time:8ms
cutoff: 34000    10times Time:9ms
cutoff: 34500    10times Time:9ms
cutoff: 35000    10times Time:9ms
cutoff: 35500    10times Time:8ms
cutoff: 36000    10times Time:8ms
cutoff: 36500    10times Time:9ms
cutoff: 37000    10times Time:8ms
cutoff: 37500    10times Time:9ms
cutoff: 38000    10times Time:9ms
cutoff: 38500    10times Time:8ms
cutoff: 39000    10times Time:9ms
cutoff: 39500    10times Time:9ms
cutoff: 40000    10times Time:8ms
cutoff: 40500    10times Time:9ms
cutoff: 41000    10times Time:9ms
```

Version Control Run TODO Problems Terminal Build Dependencies Event Log

Build completed successfully in 2 sec, 807 ms (a minute ago)

INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main | size

Project Run: Main

```
cutoff: 50000    10times Time:9ms
Threads - 64
Degree of Parallelism - 64
cutoff: 25500    10times Time:9ms
cutoff: 26000    10times Time:8ms
cutoff: 26500    10times Time:9ms
cutoff: 27000    10times Time:9ms
cutoff: 27500    10times Time:8ms
cutoff: 28000    10times Time:9ms
cutoff: 28500    10times Time:9ms
cutoff: 29000    10times Time:9ms
cutoff: 29500    10times Time:8ms
cutoff: 30000    10times Time:9ms
cutoff: 30500    10times Time:9ms
cutoff: 31000    10times Time:8ms
cutoff: 31500    10times Time:9ms
cutoff: 32000    10times Time:8ms
cutoff: 32500    10times Time:9ms
cutoff: 33000    10times Time:8ms
cutoff: 33500    10times Time:9ms
cutoff: 34000    10times Time:8ms
cutoff: 34500    10times Time:9ms
cutoff: 35000    10times Time:8ms
cutoff: 35500    10times Time:9ms
cutoff: 36000    10times Time:9ms
cutoff: 36500    10times Time:8ms
cutoff: 37000    10times Time:9ms
cutoff: 37500    10times Time:8ms
cutoff: 38000    10times Time:9ms
cutoff: 38500    10times Time:9ms
cutoff: 39000    10times Time:8ms
cutoff: 39500    10times Time:9ms
cutoff: 40000    10times Time:9ms
cutoff: 40500    10times Time:9ms
cutoff: 41000    10times Time:9ms
```

Version Control Run TODO Problems Terminal Build Dependencies Event Log

Build completed successfully in 2 sec, 807 ms (a minute ago)

## Array Size - 40000

```
INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | ParSort.java | README.md | Run: Main | /Library/Java/JavaVirtualMachines/jdk-16.0.2.jdk/Contents/Home/bin/java ...  
Array Size - 40000  
Threads - 2  
Degree of Parallelism - 2  
cutoff: 25500 10times Time:158ms  
cutoff: 26000 10times Time:47ms  
cutoff: 26500 10times Time:41ms  
cutoff: 27000 10times Time:29ms  
cutoff: 27500 10times Time:34ms  
cutoff: 28000 10times Time:16ms  
cutoff: 28500 10times Time:54ms  
cutoff: 29000 10times Time:14ms  
cutoff: 29500 10times Time:20ms  
cutoff: 30000 10times Time:14ms  
cutoff: 30500 10times Time:14ms  
cutoff: 31000 10times Time:14ms  
cutoff: 31500 10times Time:17ms  
cutoff: 32000 10times Time:14ms  
cutoff: 32500 10times Time:14ms  
cutoff: 33000 10times Time:15ms  
cutoff: 33500 10times Time:14ms  
cutoff: 34000 10times Time:14ms  
cutoff: 34500 10times Time:14ms  
cutoff: 35000 10times Time:15ms  
cutoff: 35500 10times Time:14ms  
cutoff: 36000 10times Time:14ms  
cutoff: 36500 10times Time:18ms  
cutoff: 37000 10times Time:13ms  
cutoff: 37500 10times Time:13ms  
cutoff: 38000 10times Time:18ms  
cutoff: 38500 10times Time:13ms  
cutoff: 39000 10times Time:13ms  
cutoff: 39500 10times Time:15ms  
cutoff: 40000 10times Time:15ms  
cutoff: 40500 10times Time:20ms  
Build completed successfully in 2 sec, 716 ms (moments ago) | Event Log | 19:45 | LF | UTF-8 | 4 spaces |
```

```
INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | ParSort.java | README.md | Run: Main | /Library/Java/JavaVirtualMachines/jdk-16.0.2.jdk/Contents/Home/bin/java ...  
Array Size - 40000  
Threads - 4  
Degree of Parallelism - 4  
cutoff: 49500 10times Time:28ms  
cutoff: 50000 10times Time:19ms  
cutoff: 25500 10times Time:17ms  
cutoff: 26000 10times Time:16ms  
cutoff: 26500 10times Time:15ms  
cutoff: 27000 10times Time:16ms  
cutoff: 27500 10times Time:15ms  
cutoff: 28000 10times Time:14ms  
cutoff: 28500 10times Time:14ms  
cutoff: 29000 10times Time:14ms  
cutoff: 29500 10times Time:16ms  
cutoff: 30000 10times Time:15ms  
cutoff: 30500 10times Time:15ms  
cutoff: 31000 10times Time:14ms  
cutoff: 31500 10times Time:14ms  
cutoff: 32000 10times Time:17ms  
cutoff: 32500 10times Time:15ms  
cutoff: 33000 10times Time:25ms  
cutoff: 33500 10times Time:13ms  
cutoff: 34000 10times Time:15ms  
cutoff: 34500 10times Time:13ms  
cutoff: 35000 10times Time:14ms  
cutoff: 35500 10times Time:15ms  
cutoff: 36000 10times Time:13ms  
cutoff: 36500 10times Time:13ms  
cutoff: 37000 10times Time:15ms  
cutoff: 37500 10times Time:15ms  
cutoff: 38000 10times Time:13ms  
cutoff: 38500 10times Time:13ms  
cutoff: 39000 10times Time:13ms  
cutoff: 39500 10times Time:15ms  
cutoff: 40000 10times Time:13ms  
cutoff: 40500 10times Time:19ms  
Build completed successfully in 2 sec, 716 ms (moments ago) | Event Log | 19:45 | LF | UTF-8 | 4 spaces |
```

INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | ParSort.java

Project Run: Main

```
cutoff: 50000    10times Time:19ms
Threads - 8
Degree of Parallelism - 8
cutoff: 25500    10times Time:14ms
cutoff: 26000    10times Time:13ms
cutoff: 26500    10times Time:14ms
cutoff: 27000    10times Time:13ms
cutoff: 27500    10times Time:13ms
cutoff: 28000    10times Time:13ms
cutoff: 28500    10times Time:13ms
cutoff: 29000    10times Time:13ms
cutoff: 29500    10times Time:14ms
cutoff: 30000    10times Time:18ms
cutoff: 30500    10times Time:15ms
cutoff: 31000    10times Time:13ms
cutoff: 31500    10times Time:12ms
cutoff: 32000    10times Time:14ms
cutoff: 32500    10times Time:14ms
cutoff: 33000    10times Time:13ms
cutoff: 33500    10times Time:13ms
cutoff: 34000    10times Time:12ms
cutoff: 34500    10times Time:13ms
cutoff: 35000    10times Time:15ms
cutoff: 35500    10times Time:15ms
cutoff: 36000    10times Time:13ms
cutoff: 36500    10times Time:13ms
cutoff: 37000    10times Time:13ms
cutoff: 37500    10times Time:15ms
cutoff: 38000    10times Time:13ms
cutoff: 38500    10times Time:13ms
cutoff: 39000    10times Time:15ms
cutoff: 39500    10times Time:12ms
cutoff: 40000    10times Time:13ms
cutoff: 40500    10times Time:19ms
cutoff: 41000    10times Time:18ms
```

Version Control Run TODO Problems Terminal Build Dependencies Event Log

Build completed successfully in 2 sec, 716 ms (moments ago)

INFO6205-main | src | main | java | edu | neu | coe | info6205 | sort | par | Main.java | ParSort.java

Project Run: Main

```
cutoff: 49500    10times Time:18ms
cutoff: 50000    10times Time:19ms
Threads - 16
Degree of Parallelism - 16
cutoff: 25500    10times Time:15ms
cutoff: 26000    10times Time:13ms
cutoff: 26500    10times Time:13ms
cutoff: 27000    10times Time:19ms
cutoff: 27500    10times Time:13ms
cutoff: 28000    10times Time:13ms
cutoff: 28500    10times Time:15ms
cutoff: 29000    10times Time:12ms
cutoff: 29500    10times Time:13ms
cutoff: 30000    10times Time:13ms
cutoff: 30500    10times Time:15ms
cutoff: 31000    10times Time:13ms
cutoff: 31500    10times Time:13ms
cutoff: 32000    10times Time:13ms
cutoff: 32500    10times Time:15ms
cutoff: 33000    10times Time:13ms
cutoff: 33500    10times Time:13ms
cutoff: 34000    10times Time:15ms
cutoff: 34500    10times Time:13ms
cutoff: 35000    10times Time:13ms
cutoff: 35500    10times Time:13ms
cutoff: 36000    10times Time:13ms
cutoff: 36500    10times Time:13ms
cutoff: 37000    10times Time:12ms
cutoff: 37500    10times Time:15ms
cutoff: 38000    10times Time:13ms
cutoff: 38500    10times Time:19ms
cutoff: 39000    10times Time:13ms
cutoff: 39500    10times Time:13ms
cutoff: 40000    10times Time:13ms
cutoff: 40500    10times Time:19ms
```

Version Control Run TODO Problems Terminal Build Dependencies Event Log

Build completed successfully in 2 sec, 716 ms (moments ago)

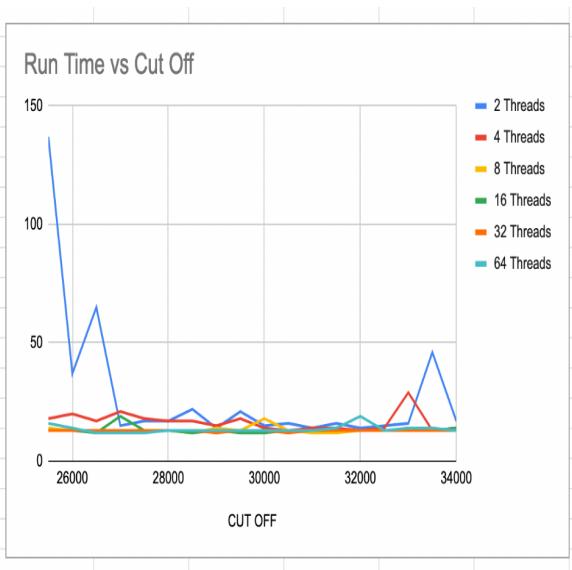
```
cutoff: 49500    10times Time:19ms
cutoff: 50000    10times Time:19ms
Threads - 32
Degree of Parallelism - 32
cutoff: 25500    10times Time:14ms
cutoff: 26000    10times Time:15ms
cutoff: 26500    10times Time:13ms
cutoff: 27000    10times Time:15ms
cutoff: 27500    10times Time:15ms
cutoff: 28000    10times Time:13ms
cutoff: 28500    10times Time:15ms
cutoff: 29000    10times Time:14ms
cutoff: 29500    10times Time:14ms
cutoff: 30000    10times Time:13ms
cutoff: 30500    10times Time:13ms
cutoff: 31000    10times Time:12ms
cutoff: 31500    10times Time:13ms
cutoff: 32000    10times Time:13ms
cutoff: 32500    10times Time:15ms
cutoff: 33000    10times Time:13ms
cutoff: 33500    10times Time:13ms
cutoff: 34000    10times Time:15ms
cutoff: 34500    10times Time:15ms
cutoff: 35000    10times Time:15ms
cutoff: 35500    10times Time:19ms
cutoff: 36000    10times Time:13ms
cutoff: 36500    10times Time:15ms
cutoff: 37000    10times Time:13ms
cutoff: 37500    10times Time:13ms
cutoff: 38000    10times Time:14ms
cutoff: 38500    10times Time:13ms
cutoff: 39000    10times Time:15ms
cutoff: 39500    10times Time:15ms
cutoff: 40000    10times Time:15ms
cutoff: 40500    10times Time:19ms
```

```
cutoff: 30000    10times Time:19ms
Threads - 64
Degree of Parallelism - 64
cutoff: 25500    10times Time:14ms
cutoff: 26000    10times Time:15ms
cutoff: 26500    10times Time:13ms
cutoff: 27000    10times Time:13ms
cutoff: 27500    10times Time:15ms
cutoff: 28000    10times Time:13ms
cutoff: 28500    10times Time:13ms
cutoff: 29000    10times Time:15ms
cutoff: 29500    10times Time:15ms
cutoff: 30000    10times Time:13ms
cutoff: 30500    10times Time:15ms
cutoff: 31000    10times Time:13ms
cutoff: 31500    10times Time:12ms
cutoff: 32000    10times Time:18ms
cutoff: 32500    10times Time:13ms
cutoff: 33000    10times Time:15ms
cutoff: 33500    10times Time:13ms
cutoff: 34000    10times Time:13ms
cutoff: 34500    10times Time:12ms
cutoff: 35000    10times Time:13ms
cutoff: 35500    10times Time:13ms
cutoff: 36000    10times Time:15ms
cutoff: 36500    10times Time:15ms
cutoff: 37000    10times Time:13ms
cutoff: 37500    10times Time:13ms
cutoff: 38000    10times Time:13ms
cutoff: 38500    10times Time:15ms
cutoff: 39000    10times Time:12ms
cutoff: 39500    10times Time:13ms
cutoff: 40000    10times Time:15ms
cutoff: 40500    10times Time:19ms
cutoff: 41000    10times Time:19ms
cutoff: 41500    10times Time:19ms
```

## Tables and Graphs -

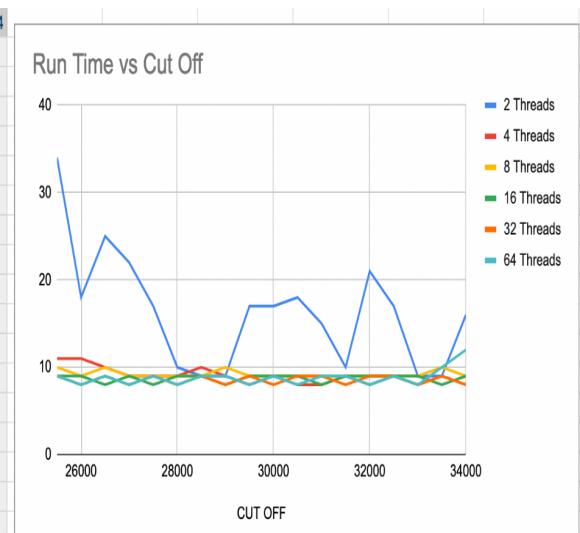
Array Size - 20000

CUT OFF	2	4	8	16	32	64
25500	137	18	14	13	13	16
26000	37	20	13	13	13	14
26500	65	17	13	12	13	12
27000	15	21	13	19	13	12
27500	17	18	13	13	13	12
28000	17	17	13	13	13	13
28500	22	17	12	12	13	13
29000	14	15	14	13	12	13
29500	21	18	13	12	13	13
30000	15	14	18	12	13	13
30500	16	13	13	13	12	13
31000	14	14	12	13	13	13
31500	16	14	12	13	13	14
32000	14	13	13	13	13	19
32500	15	14	13	13	13	13
33000	16	29	13	13	13	14
33500	46	13	13	13	13	14
34000	17	14	13	14	13	13



Array Size - 40000

CUT OFF	2	4	8	16	32	64
25500	34	11	10	9	9	9
26000	18	11	9	9	8	8
26500	25	10	10	8	9	9
27000	22	9	9	9	8	8
27500	17	9	9	8	9	9
28000	10	9	9	9	8	8
28500	9	10	9	9	9	9
29000	9	9	10	8	8	9
29500	17	8	9	9	9	8
30000	17	9	9	9	8	9
30500	18	8	9	9	9	8
31000	15	8	9	8	9	9
31500	10	9	9	9	8	9
32000	21	8	9	9	9	8
32500	17	9	9	9	9	9
33000	9	8	9	9	8	8
33500	9	9	10	8	9	10
34000	16	8	9	9	8	12



### **Relationship Conclusion -**

My conclusion is that running this algorithm with different values of array size and threads, the performance is stable or say optimal. Since, the thread is changed by  $2^n$ , where n is recursion depth. If the size of the array is not very big, the value of the cutoff does not play an important role in our efficiency, but when the size of the array becomes larger, the efficiency will be lower with the increase of the cutoff value. This is my understanding and conclusion from the assignment.