Program Structures and Algorithms
Spring 2023(Section - 1)

Name: Mani Charan Reddy Loka
NUID: 002727403

Task:
1)A cutoff (defaults to, say, 1000) which you will update
2)Recursion depth or the number of available threads.

Relationship Conclusion:

By running the experiments for different combinations of cutoff values, threads, and array sizes, sufficient data is generated to conclude the optimal number of threads required for the algorithm. Upon analyzing the same, it can be seen that using 4 threads gives the best performance while increasing it any further does not have a significant improvement in the performance as the cost of thread creation and synchronization might offset the work done by parallelism.

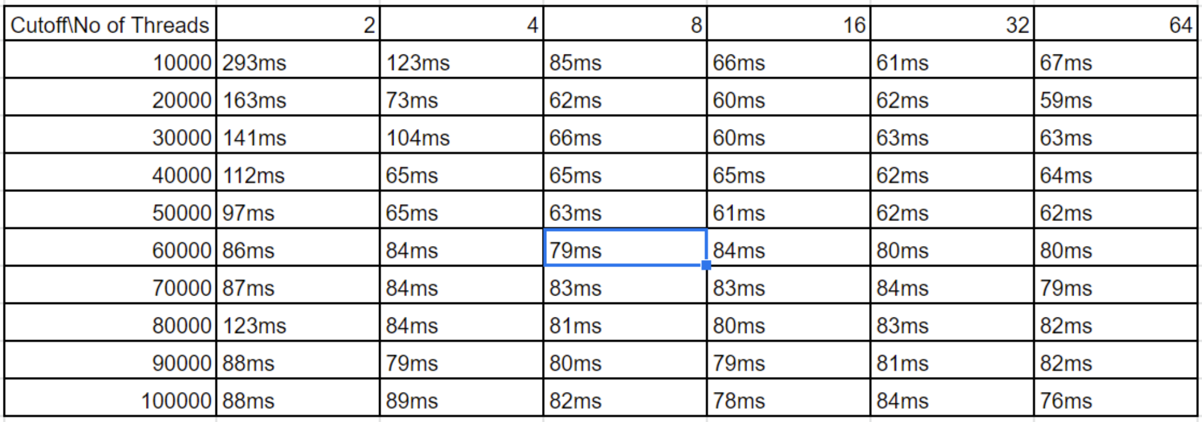
On average, the lowest runtime is achieved when the cutoff value is 30% of the array size.

The relationship between thread count(t) and recursion depth d is t=2^d

Evidence to Conclusion:

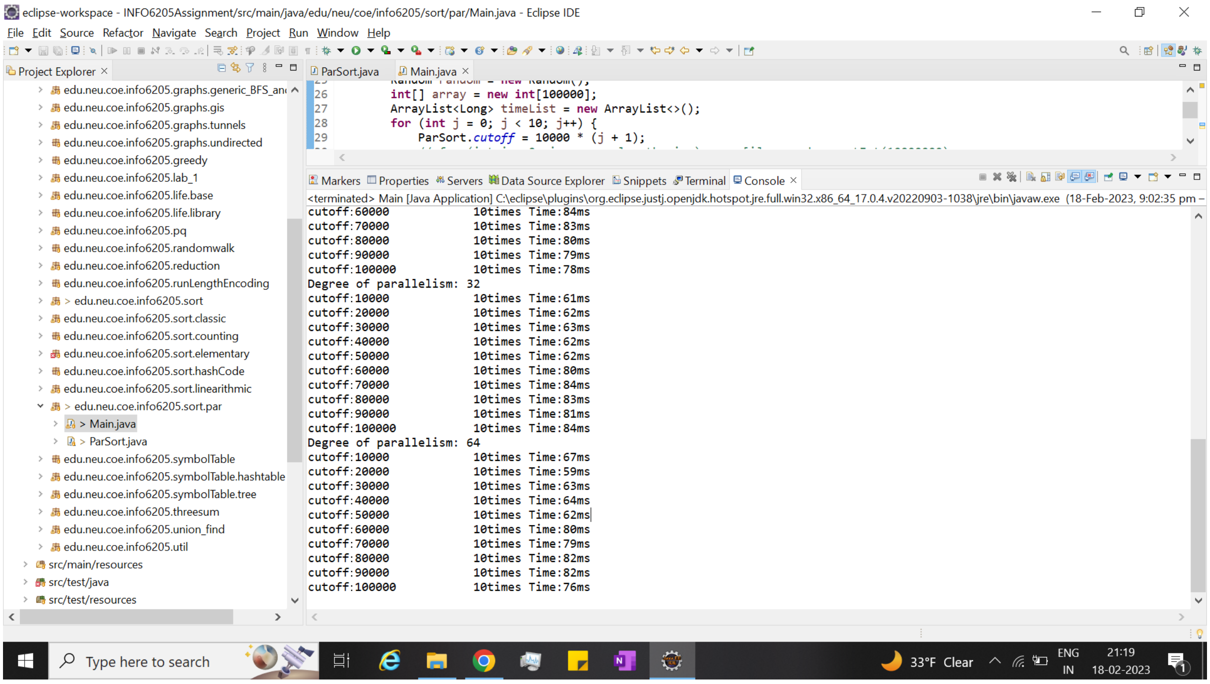
Below are the runtimes in ms for different combinations of array size, threads, and cutoffs

ArraySize: 100000



Cutoff\No of Threads	2	4	8	16	32	64
10000	293ms	123ms	85ms	66ms	61ms	67ms
20000	163ms	73ms	62ms	60ms	62ms	59ms
30000	141ms	104ms	66ms	60ms	63ms	63ms
40000	112ms	65ms	65ms	65ms	62ms	64ms
50000	97ms	65ms	63ms	61ms	62ms	62ms
60000	86ms	84ms	79ms	84ms	80ms	80ms
70000	87ms	84ms	83ms	83ms	84ms	79ms
80000	123ms	84ms	81ms	80ms	83ms	82ms
90000	88ms	79ms	80ms	79ms	81ms	82ms
100000	88ms	89ms	82ms	78ms	84ms	76ms

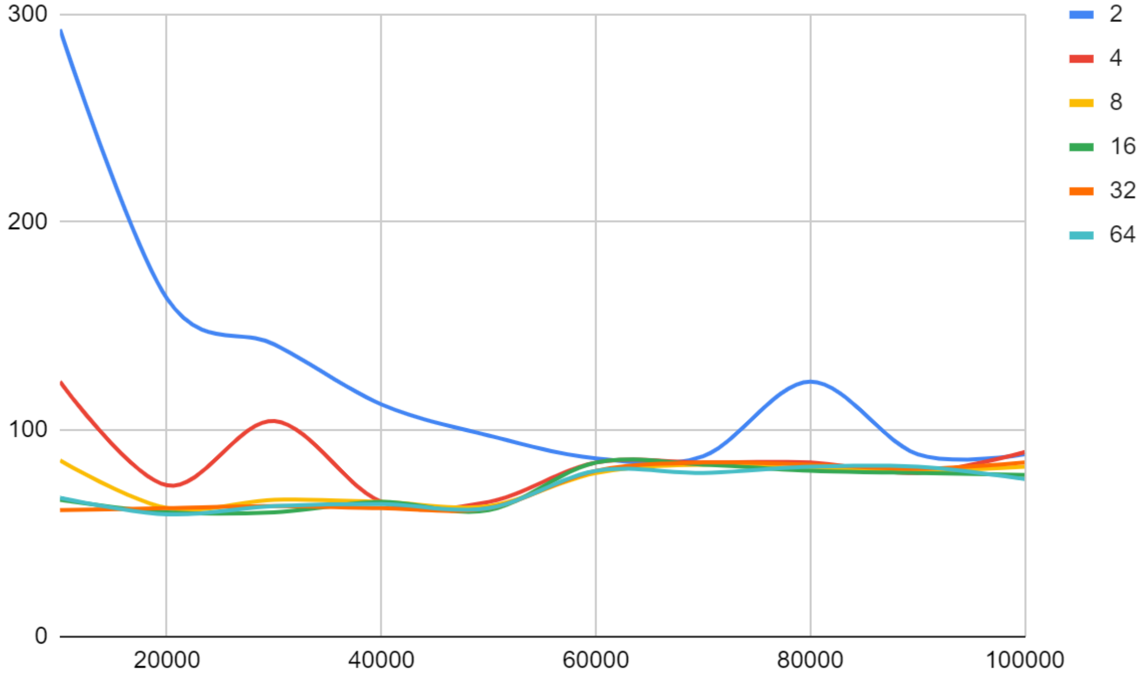
Program Structures and Algorithms
Spring 2023(Section - 1)


eclipse-workspace - INFO6205Assignment/src/main/java/edu/neu/coe/info6205/sort/par/Main.java - Eclipse IDE
File Edit Source Refactor Navigate Search Project Run Window Help
Project Explorer
edu.neu.coe.info6205.graphs.generic_BFS_an
edu.neu.coe.info6205.graphs.gis
edu.neu.coe.info6205.graphs.tunnels
edu.neu.coe.info6205.graphs.undirected
edu.neu.coe.info6205.greedy
edu.neu.coe.info6205.lab_1
edu.neu.coe.info6205.life.base
edu.neu.coe.info6205.life.library
edu.neu.coe.info6205.pq
edu.neu.coe.info6205.randomwalk
edu.neu.coe.info6205.reduction
edu.neu.coe.info6205.runLengthEncoding
> edu.neu.coe.info6205.sort
edu.neu.coe.info6205.sort.classic
edu.neu.coe.info6205.sort.counting
edu.neu.coe.info6205.sort.elementary
edu.neu.coe.info6205.sort.hashCode
edu.neu.coe.info6205.sort.linearithmic
> edu.neu.coe.info6205.sort.par
> Main.java
> ParSort.java
edu.neu.coe.info6205.symbolTable
edu.neu.coe.info6205.symbolTable.hashtable
edu.neu.coe.info6205.symbolTable.tree
edu.neu.coe.info6205.threesum
edu.neu.coe.info6205.union_find
edu.neu.coe.info6205.util
src/main/resources
src/test/java
src/test/resources
ParSort.java
Main.java
Markers
Properties
Servers
Data Source Explorer
Snippets
Terminal
Console
Type here to search
33°F Clear
ENG
IN
21:19
18-02-2023

```
        int[] array = new int[100000];
        ArrayList<Long> timeList = new ArrayList<>();
        for (int j = 0; j < 10; j++) {
            ParSort.cutoff = 10000 * (j + 1);
```

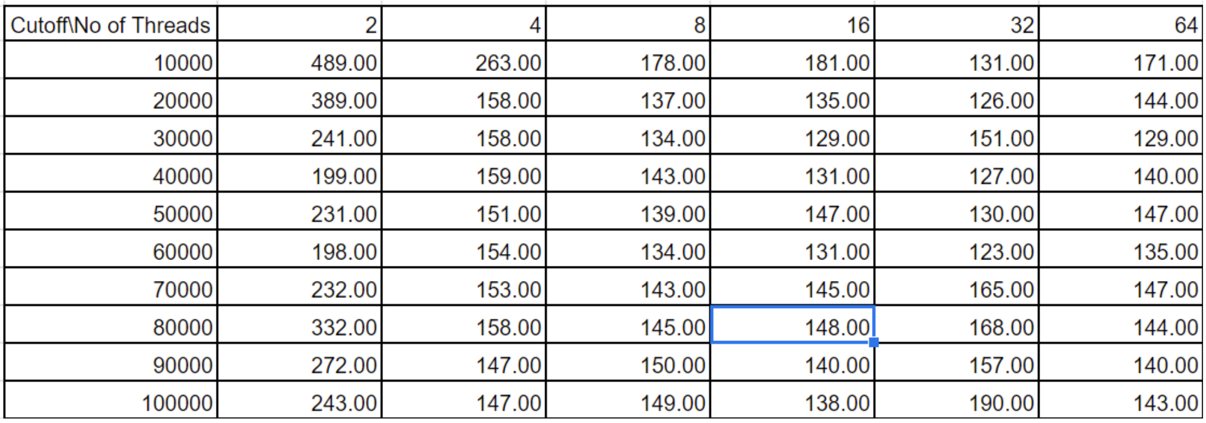
```
<terminated> Main [Java Application] C:\eclipse\plugins\org.eclipse.justj.openjdk.hotspot.jre.full.win32.x86_64_17.0.4.v20220903-1038\jre\bin\javaw.exe  (18-Feb-2023, 9:02:35 pm –
cutoff:60000            10times Time:84ms
cutoff:70000            10times Time:83ms
cutoff:80000            10times Time:80ms
cutoff:90000            10times Time:79ms
cutoff:100000           10times Time:78ms
Degree of parallelism: 32
cutoff:10000            10times Time:61ms
cutoff:20000            10times Time:62ms
cutoff:30000            10times Time:63ms
cutoff:40000            10times Time:62ms
cutoff:50000            10times Time:62ms
cutoff:60000            10times Time:80ms
cutoff:70000            10times Time:84ms
cutoff:80000            10times Time:83ms
cutoff:90000            10times Time:81ms
cutoff:100000           10times Time:84ms
Degree of parallelism: 64
cutoff:10000            10times Time:67ms
cutoff:20000            10times Time:59ms
cutoff:30000            10times Time:63ms
cutoff:40000            10times Time:64ms
cutoff:50000            10times Time:62ms
cutoff:60000            10times Time:80ms
cutoff:70000            10times Time:79ms
cutoff:80000            10times Time:82ms
cutoff:90000            10times Time:82ms
cutoff:100000           10times Time:76ms
```

Time in ms vs cut-off graph for array size of 100000.

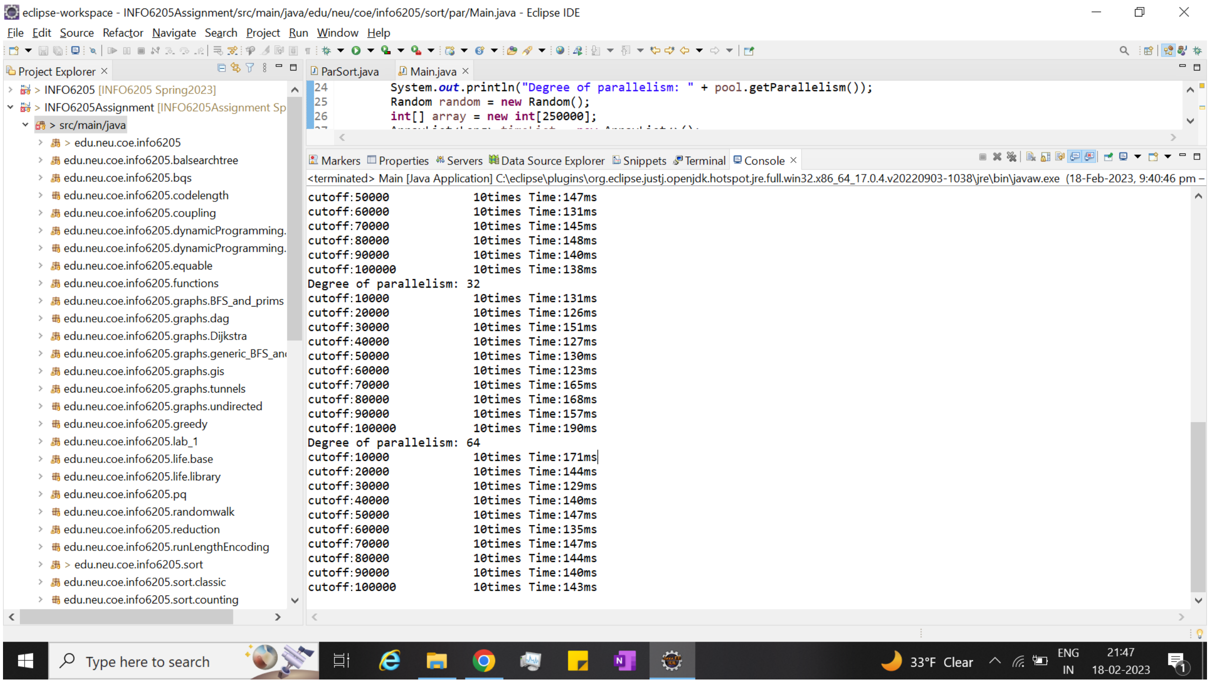


Program Structures and Algorithms
Spring 2023(Section - 1)

Below are the values for array size 250000



Cutoff\No of Threads	2	4	8	16	32	64
10000	489.00	263.00	178.00	181.00	131.00	171.00
20000	389.00	158.00	137.00	135.00	126.00	144.00
30000	241.00	158.00	134.00	129.00	151.00	129.00
40000	199.00	159.00	143.00	131.00	127.00	140.00
50000	231.00	151.00	139.00	147.00	130.00	147.00
60000	198.00	154.00	134.00	131.00	123.00	135.00
70000	232.00	153.00	143.00	145.00	165.00	147.00
80000	332.00	158.00	145.00	148.00	168.00	144.00
90000	272.00	147.00	150.00	140.00	157.00	140.00
100000	243.00	147.00	149.00	138.00	190.00	143.00


eclipse-workspace - INFO6205Assignment/src/main/java/edu/neu/coe/info6205/sort/par/Main.java - Eclipse IDE
File Edit Source Refactor Navigate Search Project Run Window Help
Project Explorer
INFO6205 [INFO6205 Spring2023]
INFO6205Assignment [INFO6205Assignment Sp
src/main/java
edu.neu.coe.info6205
edu.neu.coe.info6205.balsearchtree
edu.neu.coe.info6205.bqs
edu.neu.coe.info6205.codelength
edu.neu.coe.info6205.coupling
edu.neu.coe.info6205.dynamicProgramming.
edu.neu.coe.info6205.dynamicProgramming.
edu.neu.coe.info6205.equable
edu.neu.coe.info6205.functions
edu.neu.coe.info6205.graphs.BFS_and_prims
edu.neu.coe.info6205.graphs.dag
edu.neu.coe.info6205.graphs.Dijkstra
edu.neu.coe.info6205.graphs.generic_BFS_and
edu.neu.coe.info6205.graphs.gis
edu.neu.coe.info6205.graphs.tunnels
edu.neu.coe.info6205.graphs.undirected
edu.neu.coe.info6205.greedy
edu.neu.coe.info6205.lab_1
edu.neu.coe.info6205.life.base
edu.neu.coe.info6205.life.library
edu.neu.coe.info6205.pq
edu.neu.coe.info6205.randomwalk
edu.neu.coe.info6205.reduction
edu.neu.coe.info6205.runLengthEncoding
edu.neu.coe.info6205.sort
edu.neu.coe.info6205.sort.classic
edu.neu.coe.info6205.sort.counting
ParSort.java
Main.java
Markers
Properties
Servers
Data Source Explorer
Snippets
Terminal
Console
Type here to search
33°F Clear
ENG
IN
21:47
18-02-2023

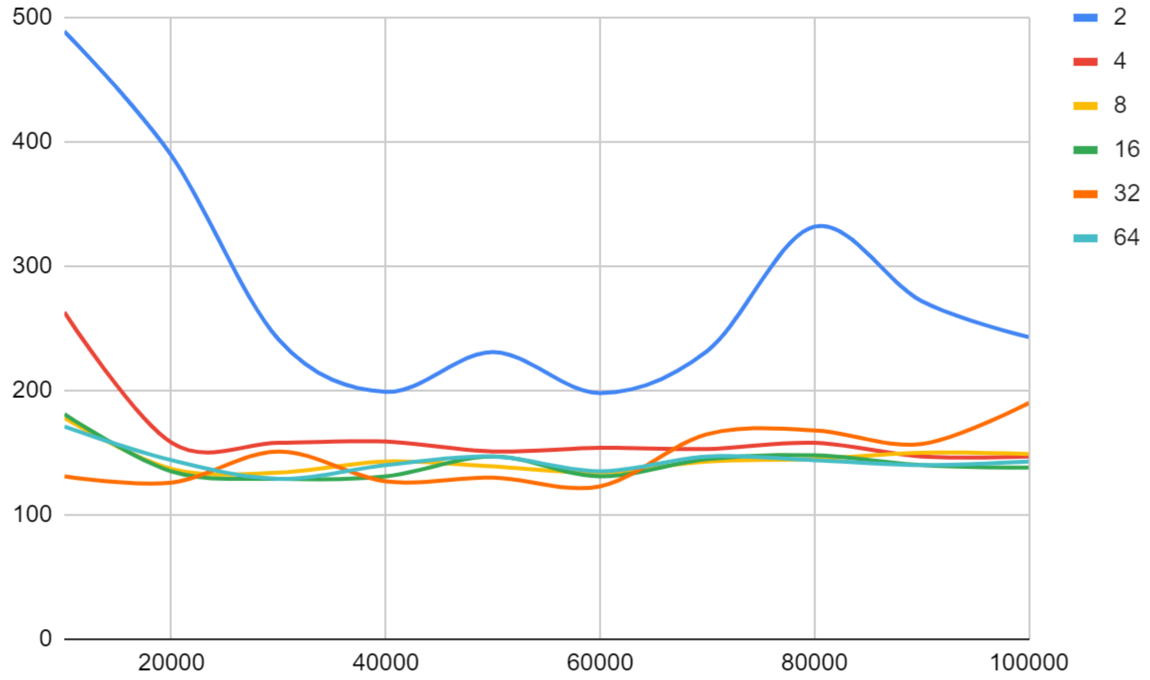
```
        System.out.println("Degree of parallelism: " + pool.getParallelism());
        Random random = new Random();
        int[] array = new int[250000];
```

<terminated> Main [Java Application] C:\eclipse\plugins\org.eclipse.justj.openjdk.hotspot.jre.full.win32.x86_64_17.0.4.v20220903-1038\jre\bin\javaw.exe (18-Feb-2023, 9:40:46 pm –

```
cutoff:50000            10times Time:147ms
cutoff:60000            10times Time:131ms
cutoff:70000            10times Time:145ms
cutoff:80000            10times Time:148ms
cutoff:90000            10times Time:140ms
cutoff:100000           10times Time:138ms
Degree of parallelism: 32
cutoff:10000            10times Time:131ms
cutoff:20000            10times Time:126ms
cutoff:30000            10times Time:151ms
cutoff:40000            10times Time:127ms
cutoff:50000            10times Time:130ms
cutoff:60000            10times Time:123ms
cutoff:70000            10times Time:165ms
cutoff:80000            10times Time:168ms
cutoff:90000            10times Time:157ms
cutoff:100000           10times Time:190ms
Degree of parallelism: 64
cutoff:10000            10times Time:171ms
cutoff:20000            10times Time:144ms
cutoff:30000            10times Time:129ms
cutoff:40000            10times Time:140ms
cutoff:50000            10times Time:147ms
cutoff:60000            10times Time:135ms
cutoff:70000            10times Time:147ms
cutoff:80000            10times Time:144ms
cutoff:90000            10times Time:140ms
cutoff:100000           10times Time:143ms
```

Program Structures and Algorithms
Spring 2023(Section - 1)

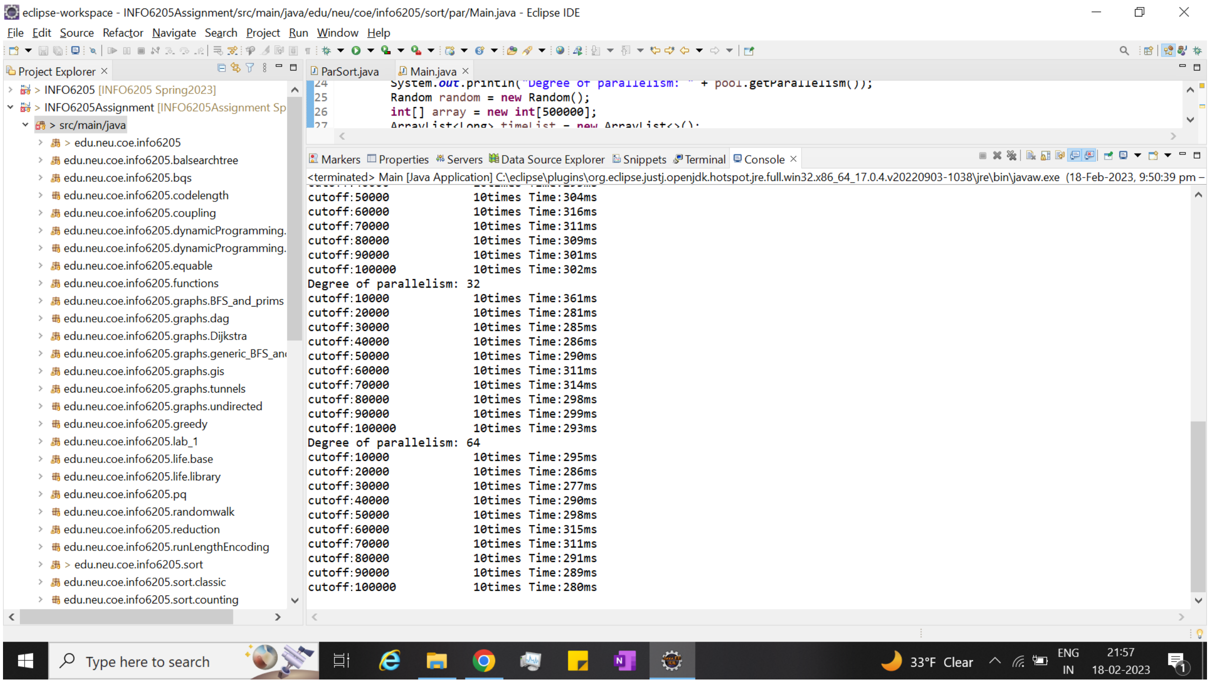
Time in ms vs cutoff graph for array size = 250000



Below are the values for array size = 500000

Cutoff\No of Threads	2	4	8	16	32	64
10000	961.00	396.00	306.00	315.00	361.00	295.00
20000	346.00	322.00	247.00	289.00	281.00	286.00
30000	368.00	280.00	253.00	289.00	285.00	277.00
40000	394.00	290.00	260.00	293.00	286.00	290.00
50000	353.00	291.00	282.00	304.00	290.00	298.00
60000	360.00	299.00	281.00	316.00	311.00	315.00
70000	417.00	305.00	275.00	311.00	314.00	311.00
80000	411.00	297.00	257.00	309.00	298.00	291.00
90000	410.00	296.00	259.00	301.00	299.00	289.00
100000	406.00	299.00	255.00	301.00	293.00	280.00

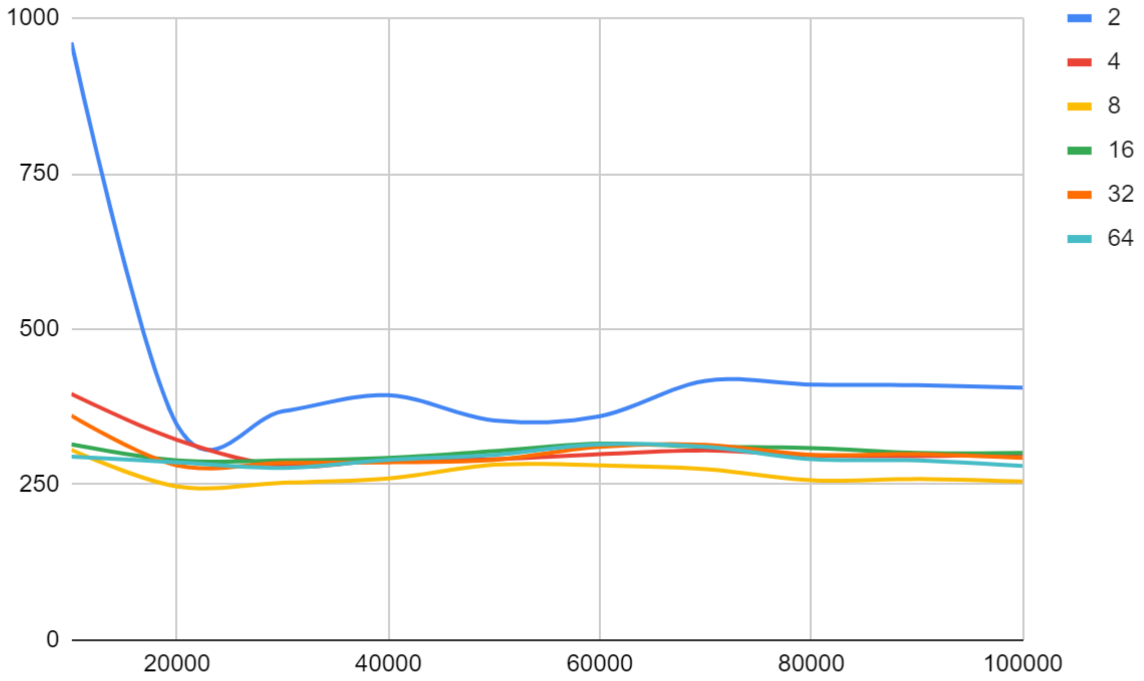
Program Structures and Algorithms
Spring 2023(Section - 1)


eclipse-workspace - INFO6205Assignment/src/main/java/edu/neu/coe/info6205/sort/par/Main.java - Eclipse IDE
File Edit Source Refactor Navigate Search Project Run Window Help
Project Explorer
> INFO6205 [INFO6205 Spring2023]
> INFO6205Assignment [INFO6205Assignment Sp
> src/main/java
> edu.neu.coe.info6205
edu.neu.coe.info6205.balsearchtree
edu.neu.coe.info6205.bqs
edu.neu.coe.info6205.codelength
edu.neu.coe.info6205.coupling
edu.neu.coe.info6205.dynamicProgramming.
edu.neu.coe.info6205.dynamicProgramming.
edu.neu.coe.info6205.equable
edu.neu.coe.info6205.functions
edu.neu.coe.info6205.graphs.BFS_and_prims
edu.neu.coe.info6205.graphs.dag
edu.neu.coe.info6205.graphs.Dijkstra
edu.neu.coe.info6205.graphs.generic_BFS_anc
edu.neu.coe.info6205.graphs.gis
edu.neu.coe.info6205.graphs.tunnels
edu.neu.coe.info6205.graphs.undirected
edu.neu.coe.info6205.greedy
edu.neu.coe.info6205.lab_1
edu.neu.coe.info6205.life.base
edu.neu.coe.info6205.life.library
edu.neu.coe.info6205.pq
edu.neu.coe.info6205.randomwalk
edu.neu.coe.info6205.reduction
edu.neu.coe.info6205.runLengthEncoding
> edu.neu.coe.info6205.sort
edu.neu.coe.info6205.sort.classic
edu.neu.coe.info6205.sort.counting
ParSort.java
Main.java
Markers Properties Servers Data Source Explorer Snippets Terminal Console
Type here to search
33°F Clear
ENG
IN
21:57
18-02-2023

```
        System.out.println("Degree of parallelism: " + pool.getParallelism());
        Random random = new Random();
        int[] array = new int[500000];
        ArrayList<Long> timeList = new ArrayList<>();
```

```
<terminated> Main [Java Application] C:\eclipse\plugins\org.eclipse.justj.openjdk.hotspot.jre.full.win32.x86_64_17.0.4.v20220903-1038\jre\bin\javaw.exe (18-Feb-2023, 9:50:39 pm –
cutoff:50000          10times Time:304ms
cutoff:60000          10times Time:316ms
cutoff:70000          10times Time:311ms
cutoff:80000          10times Time:309ms
cutoff:90000          10times Time:301ms
cutoff:100000         10times Time:302ms
Degree of parallelism: 32
cutoff:10000          10times Time:361ms
cutoff:20000          10times Time:281ms
cutoff:30000          10times Time:285ms
cutoff:40000          10times Time:286ms
cutoff:50000          10times Time:290ms
cutoff:60000          10times Time:311ms
cutoff:70000          10times Time:314ms
cutoff:80000          10times Time:298ms
cutoff:90000          10times Time:299ms
cutoff:100000         10times Time:293ms
Degree of parallelism: 64
cutoff:10000          10times Time:295ms
cutoff:20000          10times Time:286ms
cutoff:30000          10times Time:277ms
cutoff:40000          10times Time:290ms
cutoff:50000          10times Time:298ms
cutoff:60000          10times Time:315ms
cutoff:70000          10times Time:311ms
cutoff:80000          10times Time:291ms
cutoff:90000          10times Time:289ms
cutoff:100000         10times Time:280ms
```

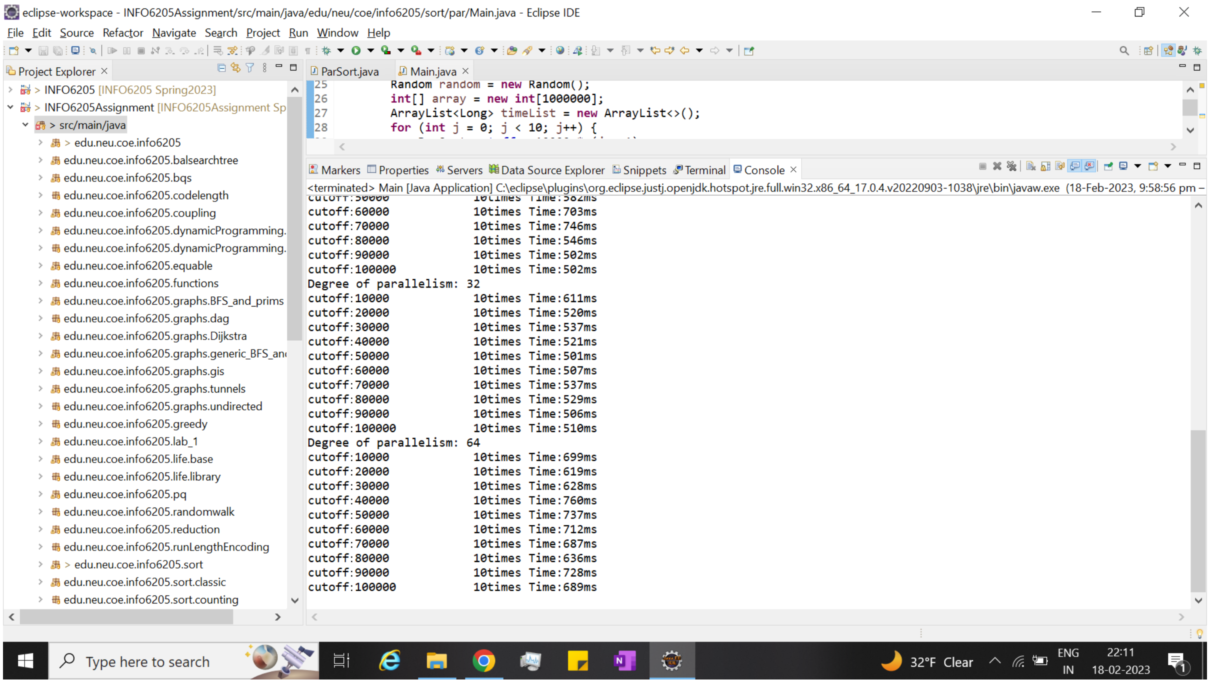
Time in ms vs cutoff graph for array size = 500000



Program Structures and Algorithms
Spring 2023(Section - 1)

Below are the values for array size = 1000000

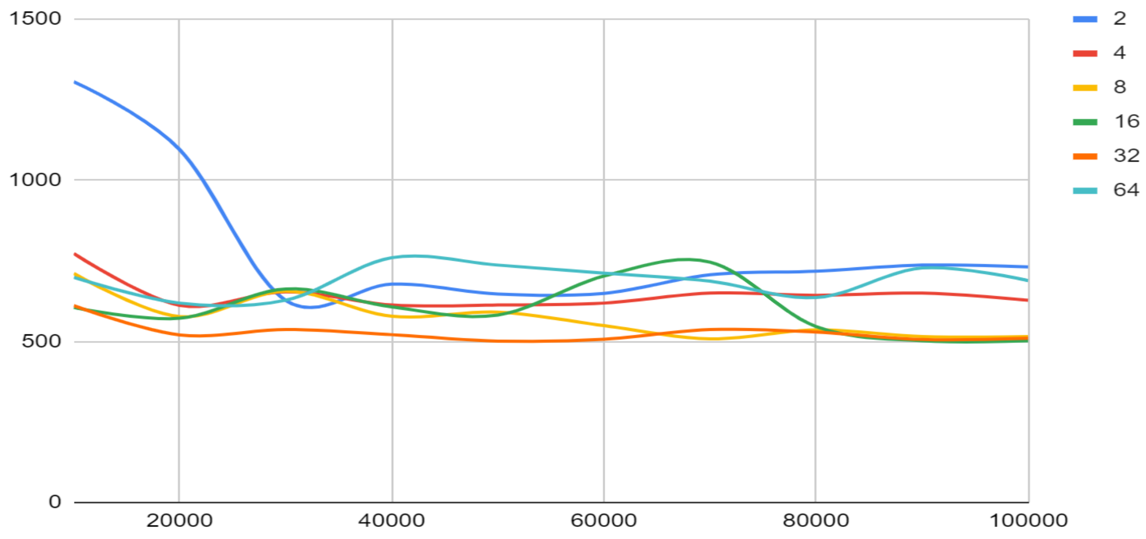
Cutoff\No of Threads	2	4	8	16	32	64
10000	1,306.00	773.00	711.00	605.00	611.00	699.00
20000	1,095.00	612.00	577.00	572.00	520.00	619.00
30000	627.00	654.00	656.00	663.00	537.00	628.00
40000	678.00	613.00	578.00	607.00	521.00	760.00
50000	647.00	613.00	591.00	582.00	501.00	737.00
60000	649.00	619.00	549.00	703.00	507.00	712.00
70000	707.00	650.00	508.00	746.00	537.00	687.00
80000	718.00	643.00	536.00	546.00	529.00	636.00
90000	737.00	650.00	515.00	502.00	506.00	728.00
100000	731.00	628.00	515.00	502.00	510.00	689.00


eclipse-workspace - INFO6205Assignment/src/main/java/edu/neu/coe/info6205/sort/par/Main.java - Eclipse IDE
File Edit Source Refactor Navigate Search Project Run Window Help
Project Explorer
INFO6205 [INFO6205 Spring2023]
INFO6205Assignment [INFO6205Assignment Sp
src/main/java
edu.neu.coe.info6205
edu.neu.coe.info6205.balsearchtree
edu.neu.coe.info6205.bqs
edu.neu.coe.info6205.codelength
edu.neu.coe.info6205.coupling
edu.neu.coe.info6205.dynamicProgramming.
edu.neu.coe.info6205.dynamicProgramming.
edu.neu.coe.info6205.equable
edu.neu.coe.info6205.functions
edu.neu.coe.info6205.graphs.BFS_and_prims
edu.neu.coe.info6205.graphs.dag
edu.neu.coe.info6205.graphs.Dijkstra
edu.neu.coe.info6205.graphs.generic_BFS_an
edu.neu.coe.info6205.graphs.gis
edu.neu.coe.info6205.graphs.tunnels
edu.neu.coe.info6205.graphs.undirected
edu.neu.coe.info6205.greedy
edu.neu.coe.info6205.lab_1
edu.neu.coe.info6205.life.base
edu.neu.coe.info6205.life.library
edu.neu.coe.info6205.pq
edu.neu.coe.info6205.randomwalk
edu.neu.coe.info6205.reduction
edu.neu.coe.info6205.runLengthEncoding
edu.neu.coe.info6205.sort
edu.neu.coe.info6205.sort.classic
edu.neu.coe.info6205.sort.counting
ParSort.java
Main.java
Markers
Properties
Servers
Data Source Explorer
Snippets
Terminal
Console
Type here to search
32°F Clear
ENG
IN
22:11
18-02-2023

```java
        Random random = new Random();
        int[] array = new int[1000000];
        ArrayList<Long> timeList = new ArrayList<>();
        for (int j = 0; j < 10; j++) {
```

```
<terminated> Main [Java Application] C:\eclipse\plugins\org.eclipse.justj.openjdk.hotspot.jre.full.win32.x86_64_17.0.4.v20220903-1038\jre\bin\javaw.exe  (18-Feb-2023, 9:58:56 pm –
cutoff:50000            10times Time:582ms
cutoff:60000            10times Time:703ms
cutoff:70000            10times Time:746ms
cutoff:80000            10times Time:546ms
cutoff:90000            10times Time:502ms
cutoff:100000           10times Time:502ms
Degree of parallelism: 32
cutoff:10000            10times Time:611ms
cutoff:20000            10times Time:520ms
cutoff:30000            10times Time:537ms
cutoff:40000            10times Time:521ms
cutoff:50000            10times Time:501ms
cutoff:60000            10times Time:507ms
cutoff:70000            10times Time:537ms
cutoff:80000            10times Time:529ms
cutoff:90000            10times Time:506ms
cutoff:100000           10times Time:510ms
Degree of parallelism: 64
cutoff:10000            10times Time:699ms
cutoff:20000            10times Time:619ms
cutoff:30000            10times Time:628ms
cutoff:40000            10times Time:760ms
cutoff:50000            10times Time:737ms
cutoff:60000            10times Time:712ms
cutoff:70000            10times Time:687ms
cutoff:80000            10times Time:636ms
cutoff:90000            10times Time:728ms
cutoff:100000           10times Time:689ms
```

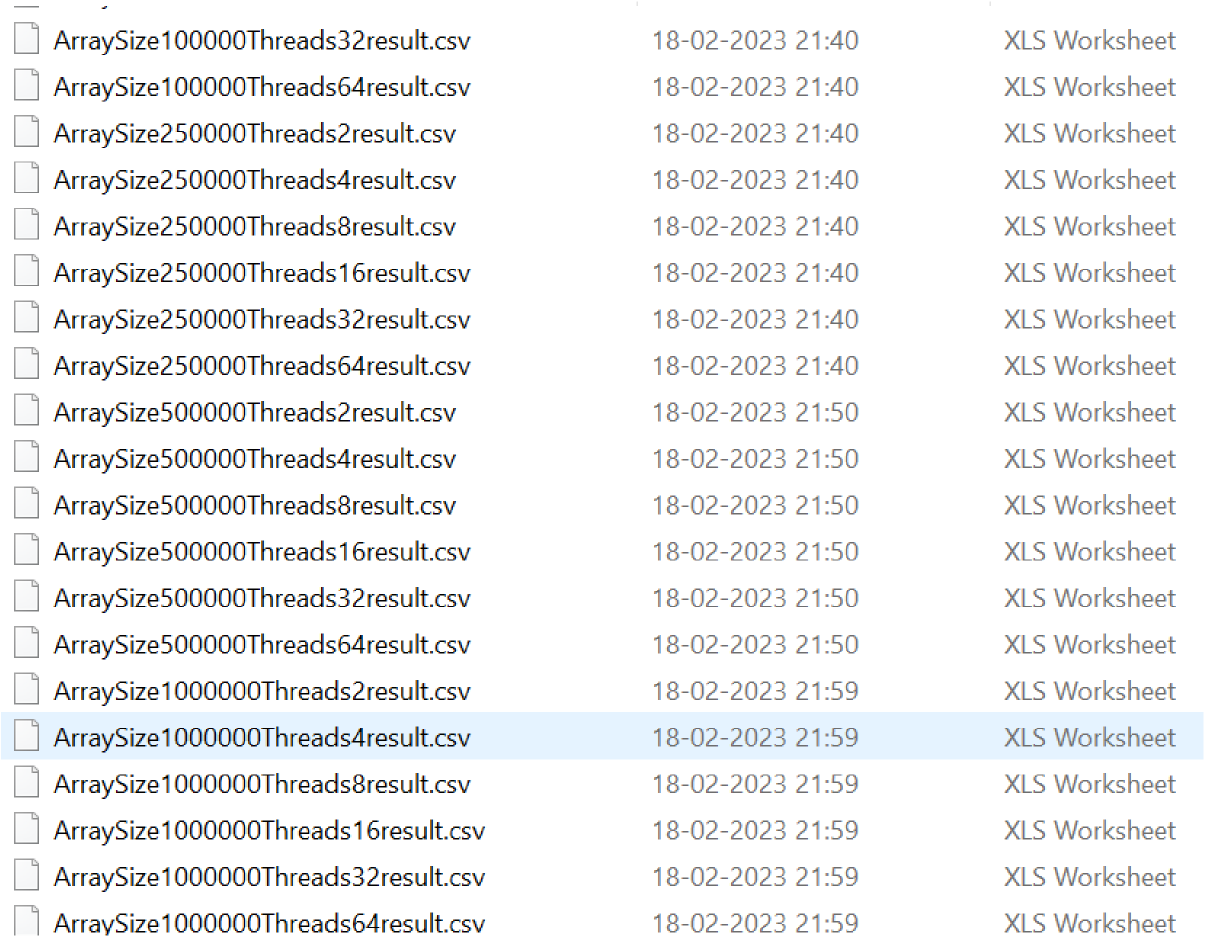
Time in ms vs cutoff graph for array size = 1000000



The graphs show that increasing the thread count doesn't significantly improve the sort time of the parallel sort. The sort time is optimal when the value of thread is 4. Hence, using 4 threads is the optimal way of using parallel sorting.

Also, upon comparing the cutoff at which the which the 4 thread time is optimal we can find out that it is always optimal when the cutoff length is about 20~40% of the input length. Hence, we can average the value to around 30%.

Below is the screenshot of csv files generated for every different combination of array size and thread count



ArraySize100000Threads32result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize100000Threads64result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize250000Threads2result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize250000Threads4result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize250000Threads8result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize250000Threads16result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize250000Threads32result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize250000Threads64result.csv	18-02-2023 21:40	XLS Worksheet
ArraySize500000Threads2result.csv	18-02-2023 21:50	XLS Worksheet
ArraySize500000Threads4result.csv	18-02-2023 21:50	XLS Worksheet
ArraySize500000Threads8result.csv	18-02-2023 21:50	XLS Worksheet
ArraySize500000Threads16result.csv	18-02-2023 21:50	XLS Worksheet
ArraySize500000Threads32result.csv	18-02-2023 21:50	XLS Worksheet
ArraySize500000Threads64result.csv	18-02-2023 21:50	XLS Worksheet
ArraySize1000000Threads2result.csv	18-02-2023 21:59	XLS Worksheet
ArraySize1000000Threads4result.csv	18-02-2023 21:59	XLS Worksheet
ArraySize1000000Threads8result.csv	18-02-2023 21:59	XLS Worksheet
ArraySize1000000Threads16result.csv	18-02-2023 21:59	XLS Worksheet
ArraySize1000000Threads32result.csv	18-02-2023 21:59	XLS Worksheet
ArraySize1000000Threads64result.csv	18-02-2023 21:59	XLS Worksheet