Program Structures & Algorithms
Spring 2022
Assignment No. 4 (Parallel Sorting)

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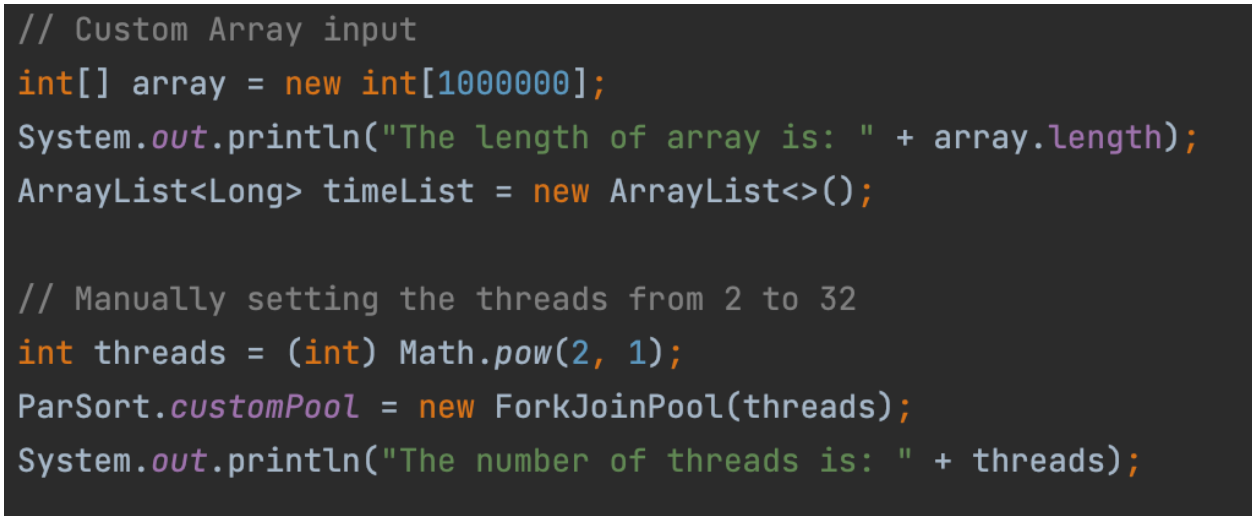
- **Task**
  1. A cutoff (defaults to, say, 1000) which you will update according to the first argument in the command line when running. It's your job to experiment and come up with a good value for this cutoff. If there are fewer elements to sort than the cutoff, then you should use the system sort 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.

4. Output screenshot

GitHub Code Repository for Parallel Sort:
https://github.com/adityamulik/INFO6205/tree/Spring2022/src/main/java/edu/neu/coe/info6205/sort/par

Below were the applicable code changes for this assignment:

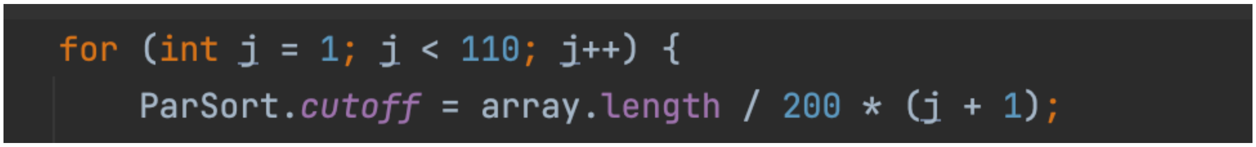
1. Array size of different size (more than the cutoff) – 1 million, 2 million and 3 million
2. Threads increased from range 2 to 32 using Math.pow function



```
// Custom Array input
int[] array = new int[1000000];
System.out.println("The length of array is: " + array.length);
ArrayList<Long> timeList = new ArrayList<>();

// Manually setting the threads from 2 to 32
int threads = (int) Math.pow(2, 1);
ParSort.customPool = new ForkJoinPool(threads);
System.out.println("The number of threads is: " + threads);
```

3. Dynamically increased cutoff

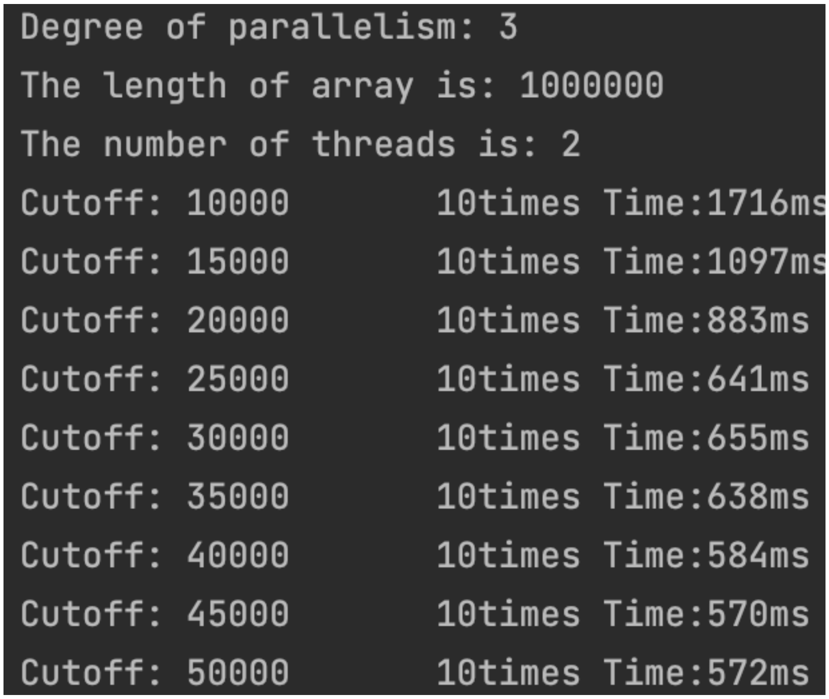


```
for (int j = 1; j < 110; j++) {
    ParSort.cutoff = array.length / 200 * (j + 1);
```

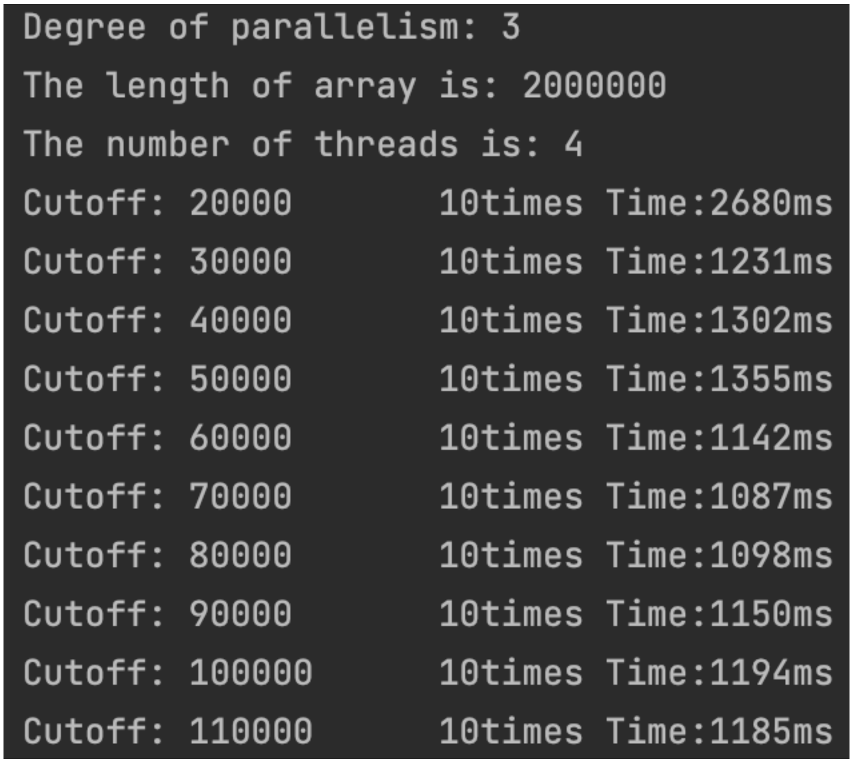
Degree of Parallelism: 3 (Based on my dual core laptop)

I ran the experiments on different cutoff values, multiple threads and 3 different array size. Below is the summarized output.

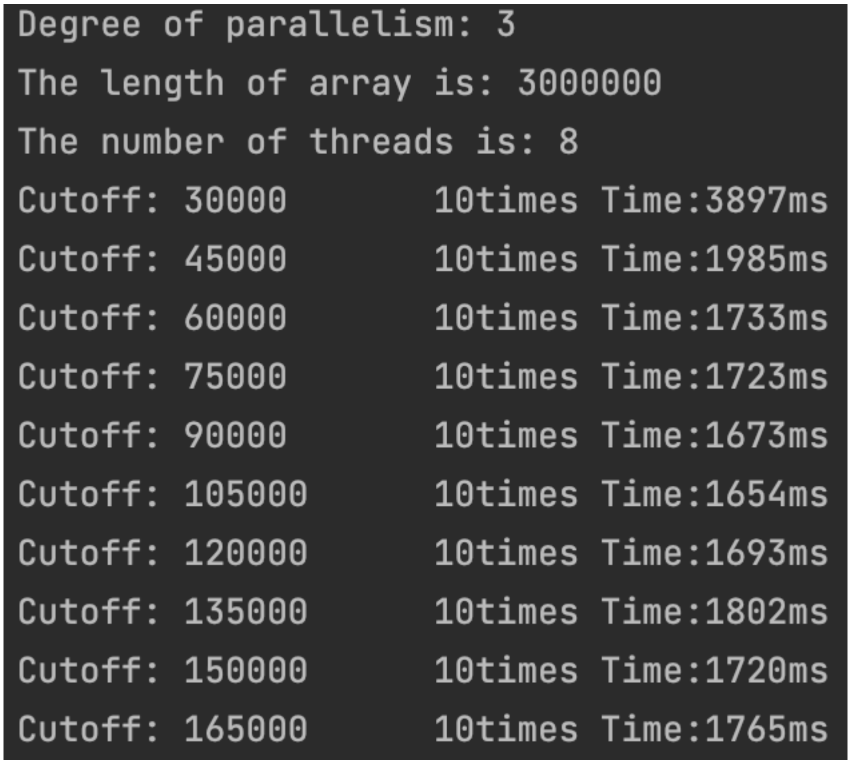
A few examples shown below.



```
Degree of parallelism: 3
The length of array is: 1000000
The number of threads is: 2
Cutoff: 10000       10times Time:1716ms
Cutoff: 15000       10times Time:1097ms
Cutoff: 20000       10times Time:883ms
Cutoff: 25000       10times Time:641ms
Cutoff: 30000       10times Time:655ms
Cutoff: 35000       10times Time:638ms
Cutoff: 40000       10times Time:584ms
Cutoff: 45000       10times Time:570ms
Cutoff: 50000       10times Time:572ms
```



```
Degree of parallelism: 3
The length of array is: 2000000
The number of threads is: 4
Cutoff: 20000       10times Time:2680ms
Cutoff: 30000       10times Time:1231ms
Cutoff: 40000       10times Time:1302ms
Cutoff: 50000       10times Time:1355ms
Cutoff: 60000       10times Time:1142ms
Cutoff: 70000       10times Time:1087ms
Cutoff: 80000       10times Time:1098ms
Cutoff: 90000       10times Time:1150ms
Cutoff: 100000      10times Time:1194ms
Cutoff: 110000      10times Time:1185ms
```

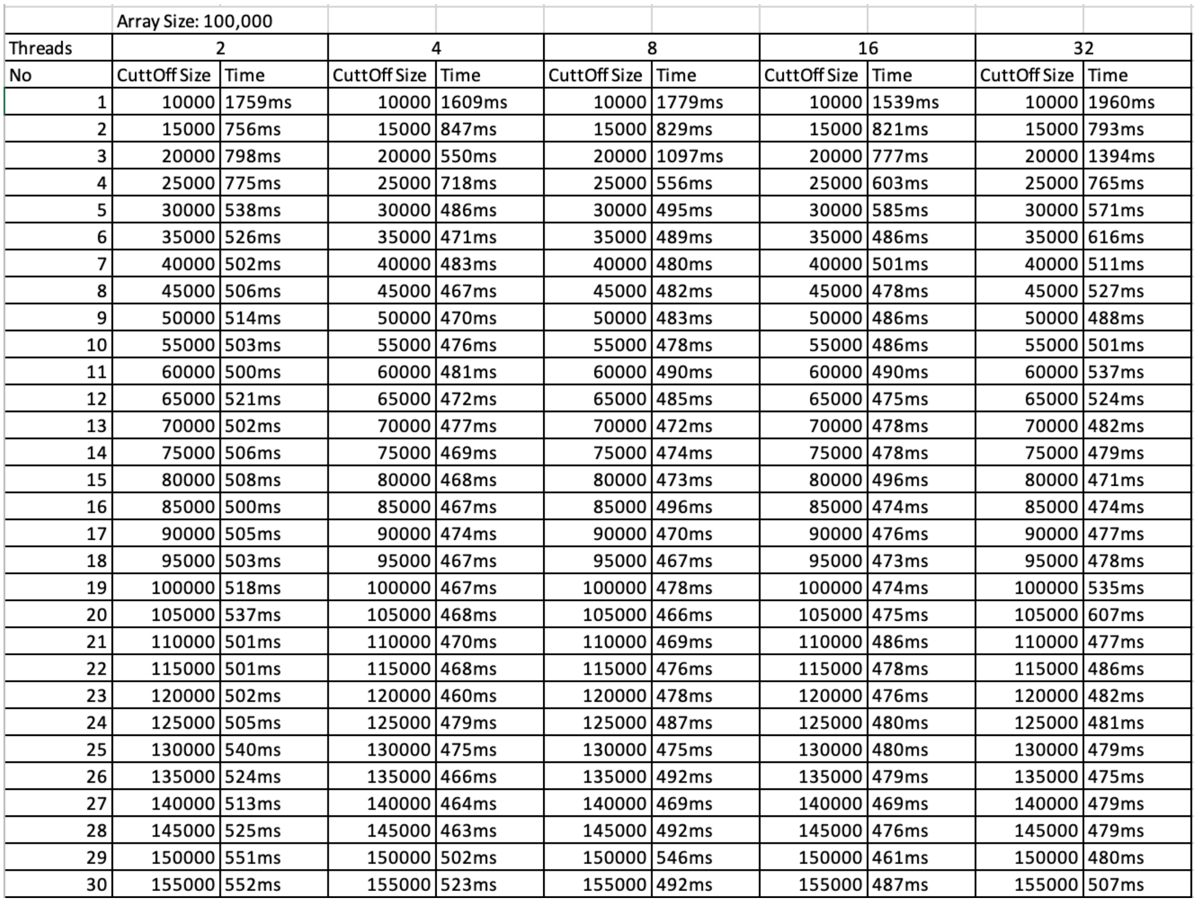


```
Degree of parallelism: 3
The length of array is: 3000000
The number of threads is: 8
Cutoff: 30000       10times Time:3897ms
Cutoff: 45000       10times Time:1985ms
Cutoff: 60000       10times Time:1733ms
Cutoff: 75000       10times Time:1723ms
Cutoff: 90000       10times Time:1673ms
Cutoff: 105000      10times Time:1654ms
Cutoff: 120000      10times Time:1693ms
Cutoff: 135000      10times Time:1802ms
Cutoff: 150000      10times Time:1720ms
Cutoff: 165000      10times Time:1765ms
```

5. Evidence / Graph

Below are some of the performance metrics in a tabular format for predefined array sizes and ran on multiple threads and different cutoff sizes.

I have taken first 30 cutoff sizes for demonstration purpose.

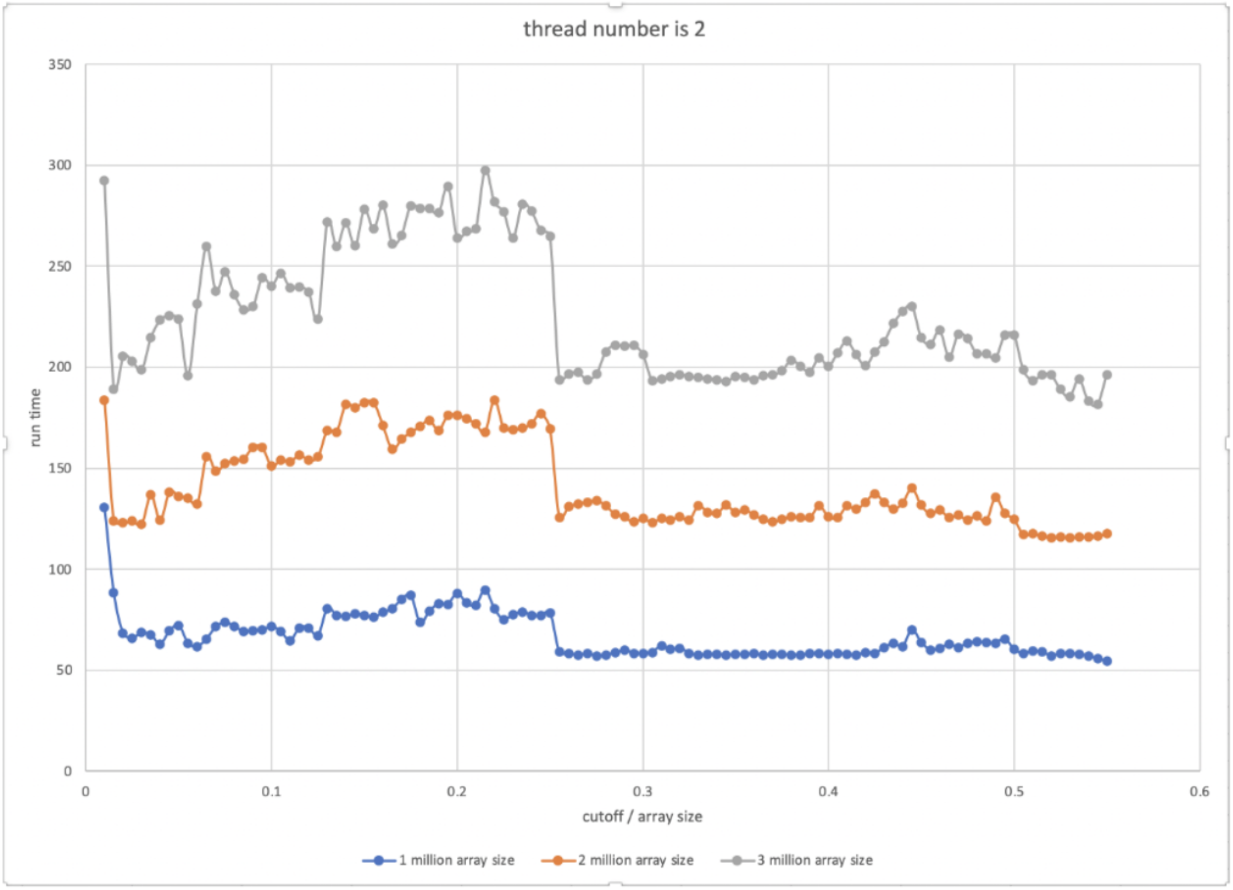


	Array Size: 100,000									
Threads	2		4		8		16		32	
No	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time
1	10000	1759ms	10000	1609ms	10000	1779ms	10000	1539ms	10000	1960ms
2	15000	756ms	15000	847ms	15000	829ms	15000	821ms	15000	793ms
3	20000	798ms	20000	550ms	20000	1097ms	20000	777ms	20000	1394ms
4	25000	775ms	25000	718ms	25000	556ms	25000	603ms	25000	765ms
5	30000	538ms	30000	486ms	30000	495ms	30000	585ms	30000	571ms
6	35000	526ms	35000	471ms	35000	489ms	35000	486ms	35000	616ms
7	40000	502ms	40000	483ms	40000	480ms	40000	501ms	40000	511ms
8	45000	506ms	45000	467ms	45000	482ms	45000	478ms	45000	527ms
9	50000	514ms	50000	470ms	50000	483ms	50000	486ms	50000	488ms
10	55000	503ms	55000	476ms	55000	478ms	55000	486ms	55000	501ms
11	60000	500ms	60000	481ms	60000	490ms	60000	490ms	60000	537ms
12	65000	521ms	65000	472ms	65000	485ms	65000	475ms	65000	524ms
13	70000	502ms	70000	477ms	70000	472ms	70000	478ms	70000	482ms
14	75000	506ms	75000	469ms	75000	474ms	75000	478ms	75000	479ms
15	80000	508ms	80000	468ms	80000	473ms	80000	496ms	80000	471ms
16	85000	500ms	85000	467ms	85000	496ms	85000	474ms	85000	474ms
17	90000	505ms	90000	474ms	90000	470ms	90000	476ms	90000	477ms
18	95000	503ms	95000	467ms	95000	467ms	95000	473ms	95000	478ms
19	100000	518ms	100000	467ms	100000	478ms	100000	474ms	100000	535ms
20	105000	537ms	105000	468ms	105000	466ms	105000	475ms	105000	607ms
21	110000	501ms	110000	470ms	110000	469ms	110000	486ms	110000	477ms
22	115000	501ms	115000	468ms	115000	476ms	115000	478ms	115000	486ms
23	120000	502ms	120000	460ms	120000	478ms	120000	476ms	120000	482ms
24	125000	505ms	125000	479ms	125000	487ms	125000	480ms	125000	481ms
25	130000	540ms	130000	475ms	130000	475ms	130000	480ms	130000	479ms
26	135000	524ms	135000	466ms	135000	492ms	135000	479ms	135000	475ms
27	140000	513ms	140000	464ms	140000	469ms	140000	469ms	140000	479ms
28	145000	525ms	145000	463ms	145000	492ms	145000	476ms	145000	479ms
29	150000	551ms	150000	502ms	150000	546ms	150000	461ms	150000	480ms
30	155000	552ms	155000	523ms	155000	492ms	155000	487ms	155000	507ms

	Array Size: 200,000									
Threads	2		4		8		16		32	
No	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time
1	20000	2014ms	20000	2215ms	20000	2426ms	20000	2410ms	20000	2296ms
2	30000	1097ms	30000	1278ms	30000	1127ms	30000	1243ms	30000	1401ms
3	40000	1054ms	40000	1055ms	40000	1133ms	40000	1201ms	40000	1151ms
4	50000	1014ms	50000	1030ms	50000	1063ms	50000	1120ms	50000	1174ms
5	60000	1006ms	60000	1007ms	60000	1006ms	60000	1121ms	60000	1106ms
6	70000	989ms	70000	990ms	70000	993ms	70000	1104ms	70000	1256ms
7	80000	994ms	80000	987ms	80000	975ms	80000	1058ms	80000	1075ms
8	90000	1011ms	90000	1024ms	90000	975ms	90000	1226ms	90000	984ms
9	100000	1022ms	100000	991ms	100000	990ms	100000	1090ms	100000	982ms
10	110000	1006ms	110000	978ms	110000	974ms	110000	1165ms	110000	975ms
11	120000	993ms	120000	990ms	120000	979ms	120000	1125ms	120000	990ms
12	130000	1008ms	130000	987ms	130000	999ms	130000	1086ms	130000	982ms
13	140000	1001ms	140000	983ms	140000	964ms	140000	1093ms	140000	979ms
14	150000	1038ms	150000	1058ms	150000	976ms	150000	1159ms	150000	982ms
15	160000	1019ms	160000	1697ms	160000	979ms	160000	1118ms	160000	983ms
16	170000	1016ms	170000	1076ms	170000	964ms	170000	1086ms	170000	969ms
17	180000	1011ms	180000	1042ms	180000	996ms	180000	1109ms	180000	990ms
18	190000	1011ms	190000	1072ms	190000	954ms	190000	1082ms	190000	973ms
19	200000	1015ms	200000	1181ms	200000	965ms	200000	1028ms	200000	972ms
20	210000	1019ms	210000	998ms	210000	959ms	210000	1062ms	210000	985ms
21	220000	1013ms	220000	988ms	220000	975ms	220000	1008ms	220000	976ms
22	230000	1002ms	230000	1002ms	230000	1059ms	230000	1153ms	230000	973ms
23	240000	1009ms	240000	984ms	240000	968ms	240000	1076ms	240000	984ms
24	250000	1000ms	250000	979ms	250000	958ms	250000	1114ms	250000	983ms
25	260000	1047ms	260000	974ms	260000	942ms	260000	1067ms	260000	942ms
26	270000	1044ms	270000	967ms	270000	1206ms	270000	1106ms	270000	963ms
27	280000	1040ms	280000	963ms	280000	1310ms	280000	1045ms	280000	959ms
28	290000	1039ms	290000	966ms	290000	1239ms	290000	1122ms	290000	1019ms
29	300000	1067ms	300000	970ms	300000	1046ms	300000	1034ms	300000	1006ms
30	310000	1064ms	310000	956ms	310000	1055ms	310000	1004ms	310000	972ms

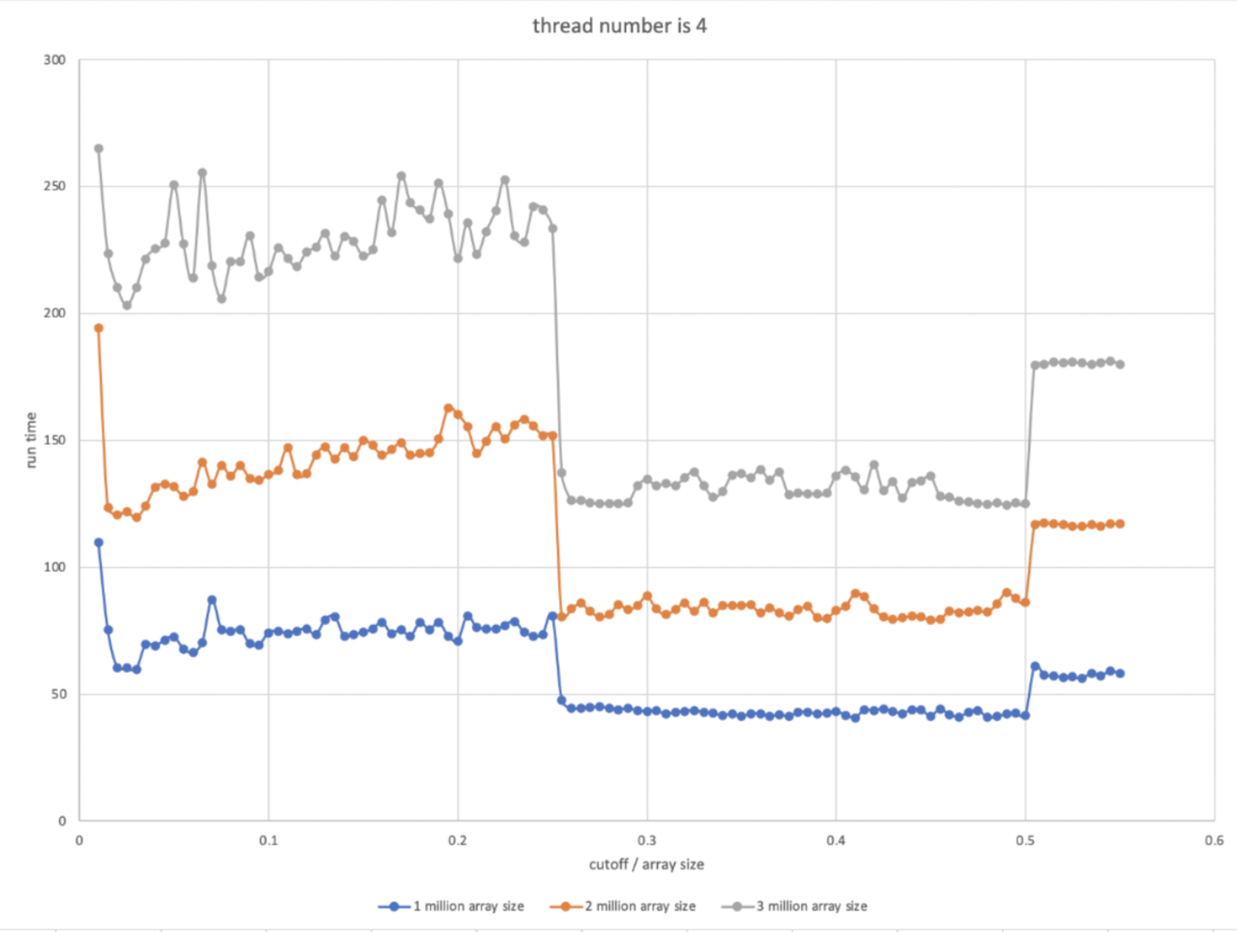
	Array Size: 300,000									
Threads	2		4		8		16		32	
No	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time	CuttOff Size	Time
1	30000	3070ms	30000	2861ms	30000	3003ms	30000	2895ms	30000	3522ms
2	45000	1922ms	45000	1824ms	45000	1773ms	45000	1770ms	45000	1792ms
3	60000	1731ms	60000	1738ms	60000	2161ms	60000	1672ms	60000	1674ms
4	75000	1697ms	75000	1767ms	75000	1916ms	75000	1628ms	75000	1662ms
5	90000	1672ms	90000	1692ms	90000	1966ms	90000	1611ms	90000	1634ms
6	105000	1771ms	105000	1639ms	105000	1901ms	105000	1542ms	105000	1552ms
7	120000	1710ms	120000	1641ms	120000	1936ms	120000	1595ms	120000	1581ms
8	135000	1766ms	135000	1663ms	135000	1864ms	135000	1573ms	135000	1568ms
9	150000	1741ms	150000	1632ms	150000	1753ms	150000	1569ms	150000	1569ms
10	165000	1637ms	165000	1636ms	165000	1761ms	165000	1567ms	165000	1576ms
11	180000	1625ms	180000	1632ms	180000	1730ms	180000	1581ms	180000	1592ms
12	195000	1761ms	195000	1635ms	195000	1685ms	195000	1548ms	195000	1515ms
13	210000	1703ms	210000	1637ms	210000	1720ms	210000	1531ms	210000	1532ms
14	225000	1549ms	225000	1634ms	225000	1686ms	225000	1531ms	225000	1527ms
15	240000	1546ms	240000	1613ms	240000	1696ms	240000	1532ms	240000	1513ms
16	255000	1554ms	255000	1674ms	255000	1734ms	255000	1564ms	255000	1533ms
17	270000	1533ms	270000	1590ms	270000	1687ms	270000	1626ms	270000	1530ms
18	285000	1555ms	285000	1525ms	285000	1713ms	285000	1536ms	285000	1746ms
19	300000	1530ms	300000	1540ms	300000	1962ms	300000	1466ms	300000	2024ms
20	315000	1550ms	315000	1501ms	315000	2073ms	315000	1449ms	315000	1686ms
21	330000	1538ms	330000	1517ms	330000	1633ms	330000	1464ms	330000	1478ms
22	345000	1537ms	345000	1501ms	345000	1634ms	345000	1468ms	345000	1462ms
23	360000	1697ms	360000	1497ms	360000	1645ms	360000	1509ms	360000	1455ms
24	375000	1538ms	375000	1492ms	375000	2086ms	375000	1534ms	375000	1506ms
25	390000	1607ms	390000	1482ms	390000	1630ms	390000	1508ms	390000	1519ms
26	405000	1609ms	405000	1499ms	405000	1592ms	405000	1510ms	405000	1523ms
27	420000	1626ms	420000	1469ms	420000	1537ms	420000	1555ms	420000	1510ms
28	435000	1638ms	435000	1530ms	435000	1576ms	435000	1582ms	435000	1530ms
29	450000	1612ms	450000	1559ms	450000	1545ms	450000	1473ms	450000	1550ms
30	465000	1641ms	465000	1523ms	465000	1534ms	465000	1445ms	465000	1589ms

Below are some of the graphical representations of how each sort performs on different threads.



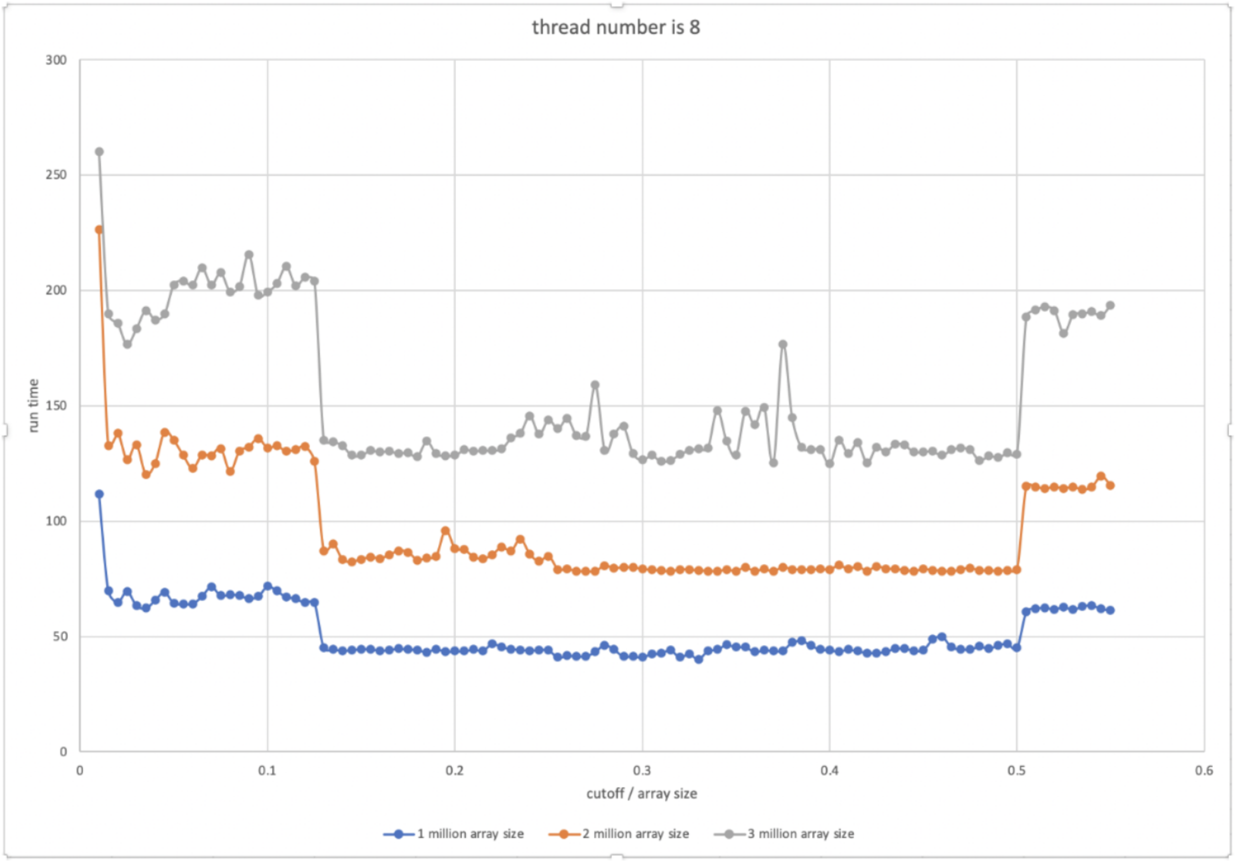
Thread: 2

Good cutoff: 50% of the array size



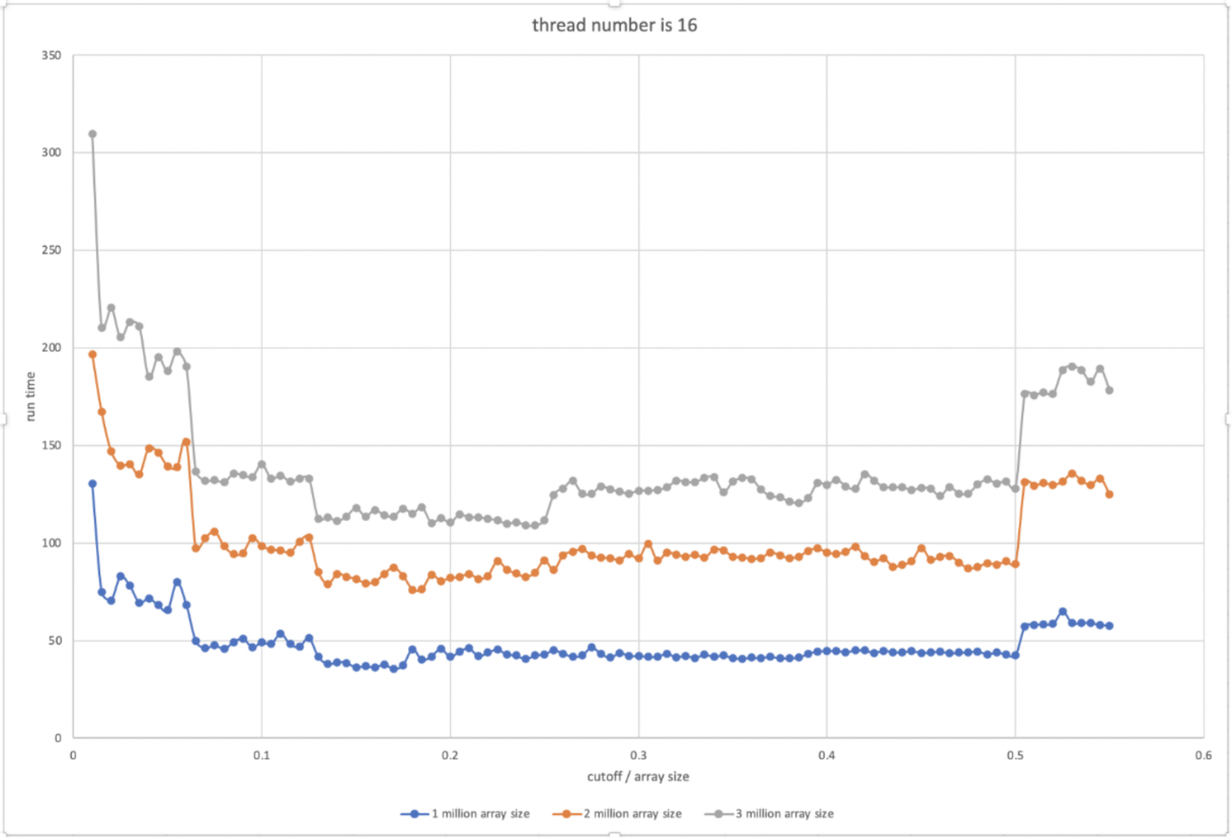
Thread: 4

Good cutoff: 25% of the array size



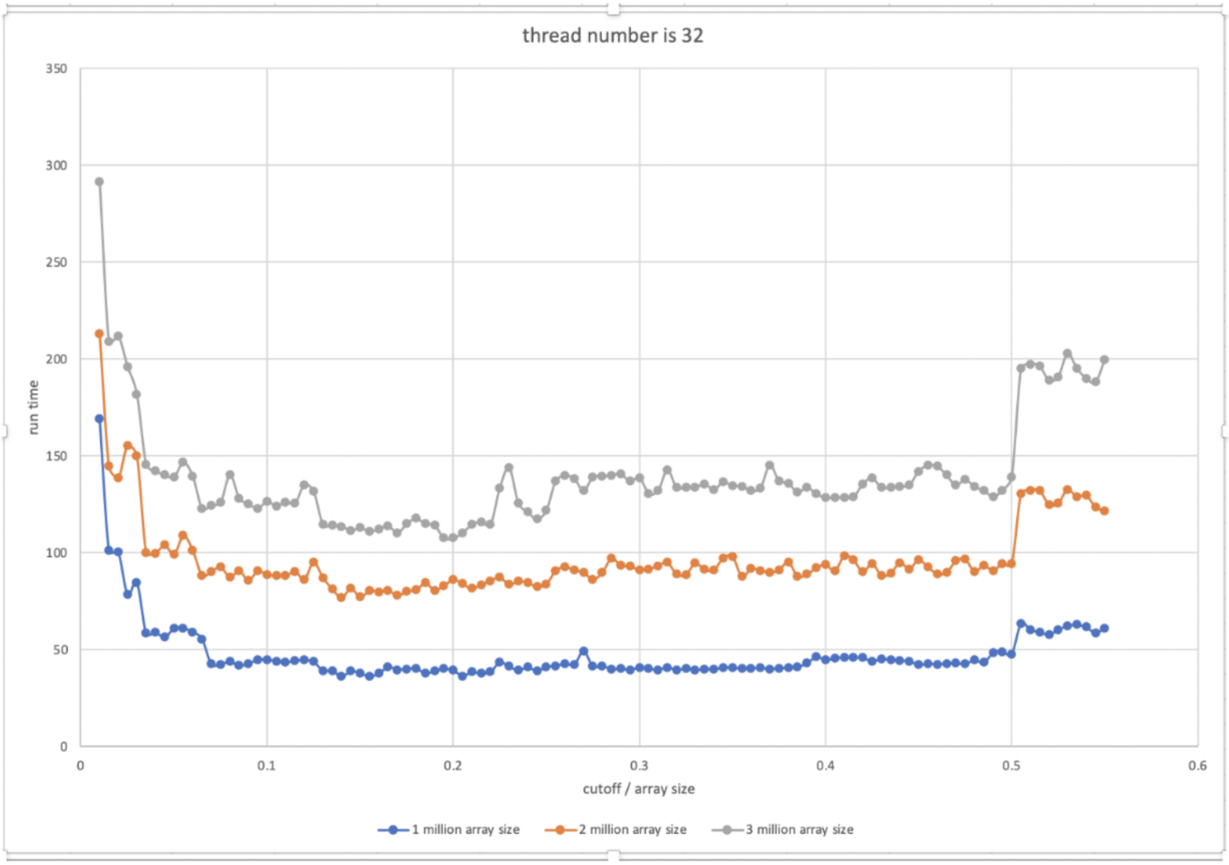
Thread: 8

Good cutoff: 12.5% of the array size



Thread: 16

Good cutoff: 6.25% of the array size



Thread: 32

Good cutoff: 3.125% of the array size

6. Relationship Conclusion

To conclude,

Best cutoff = array size / no. of threads

Also, when the number of threads is increased, despite the cores available on a system, the performance is similar.