

# Assignment 5 (Parallel Sorting)

## 1. Intro

In this question, I was asked to consider whether I should use Parallel Sorting or not in different schemes. Then, find out a good value for the cutoff and the threads count.

## 2. Evidence

Due to the length of the article, only 50,000 to 1,150,000 cutoffs are displayed here. The complete experimental result data is placed in the same level folder. (cutoffs between 50,000 and 2,000,000)

### 2.1 Array's Length: 2000,000

Degree of parallelism: 2		Degree of parallelism: 4	
cutoff: 50000	10times Time:1397ms, Array's Length:2000000	cutoff: 50000	10times Time:1235ms, Array's Length:2000000
cutoff: 100000	10times Time:824ms, Array's Length:2000000	cutoff: 100000	10times Time:688ms, Array's Length:2000000
cutoff: 150000	10times Time:840ms, Array's Length:2000000	cutoff: 150000	10times Time:639ms, Array's Length:2000000
cutoff: 200000	10times Time:843ms, Array's Length:2000000	cutoff: 200000	10times Time:605ms, Array's Length:2000000
cutoff: 250000	10times Time:847ms, Array's Length:2000000	cutoff: 250000	10times Time:604ms, Array's Length:2000000
cutoff: 300000	10times Time:863ms, Array's Length:2000000	cutoff: 300000	10times Time:616ms, Array's Length:2000000
cutoff: 350000	10times Time:891ms, Array's Length:2000000	cutoff: 350000	10times Time:623ms, Array's Length:2000000
cutoff: 400000	10times Time:887ms, Array's Length:2000000	cutoff: 400000	10times Time:614ms, Array's Length:2000000
cutoff: 450000	10times Time:901ms, Array's Length:2000000	cutoff: 450000	10times Time:618ms, Array's Length:2000000
cutoff: 500000	10times Time:958ms, Array's Length:2000000	cutoff: 500000	10times Time:615ms, Array's Length:2000000
cutoff: 550000	10times Time:958ms, Array's Length:2000000	cutoff: 550000	10times Time:582ms, Array's Length:2000000
cutoff: 600000	10times Time:945ms, Array's Length:2000000	cutoff: 600000	10times Time:588ms, Array's Length:2000000
cutoff: 650000	10times Time:944ms, Array's Length:2000000	cutoff: 650000	10times Time:585ms, Array's Length:2000000
cutoff: 700000	10times Time:939ms, Array's Length:2000000	cutoff: 700000	10times Time:578ms, Array's Length:2000000
cutoff: 750000	10times Time:947ms, Array's Length:2000000	cutoff: 750000	10times Time:586ms, Array's Length:2000000
cutoff: 800000	10times Time:932ms, Array's Length:2000000	cutoff: 800000	10times Time:590ms, Array's Length:2000000
cutoff: 850000	10times Time:943ms, Array's Length:2000000	cutoff: 850000	10times Time:583ms, Array's Length:2000000
cutoff: 900000	10times Time:934ms, Array's Length:2000000	cutoff: 900000	10times Time:585ms, Array's Length:2000000
cutoff: 950000	10times Time:924ms, Array's Length:2000000	cutoff: 950000	10times Time:618ms, Array's Length:2000000
cutoff: 1000000	10times Time:924ms, Array's Length:2000000	cutoff: 1000000	10times Time:580ms, Array's Length:2000000
cutoff: 1050000	10times Time:855ms, Array's Length:2000000	cutoff: 1050000	10times Time:820ms, Array's Length:2000000
cutoff: 1100000	10times Time:859ms, Array's Length:2000000	cutoff: 1100000	10times Time:817ms, Array's Length:2000000
cutoff: 1150000	10times Time:853ms, Array's Length:2000000	cutoff: 1150000	10times Time:816ms, Array's Length:2000000

Degree of parallelism: 8

cutoff: 50000	10times Time:1313ms, Array's Length:2000000
cutoff: 100000	10times Time:570ms, Array's Length:2000000
cutoff: 150000	10times Time:551ms, Array's Length:2000000
cutoff: 200000	10times Time:550ms, Array's Length:2000000
cutoff: 250000	10times Time:547ms, Array's Length:2000000
cutoff: 300000	10times Time:553ms, Array's Length:2000000
cutoff: 350000	10times Time:554ms, Array's Length:2000000
cutoff: 400000	10times Time:554ms, Array's Length:2000000
cutoff: 450000	10times Time:548ms, Array's Length:2000000
cutoff: 500000	10times Time:560ms, Array's Length:2000000
cutoff: 550000	10times Time:587ms, Array's Length:2000000
cutoff: 600000	10times Time:580ms, Array's Length:2000000
cutoff: 650000	10times Time:584ms, Array's Length:2000000
cutoff: 700000	10times Time:585ms, Array's Length:2000000
cutoff: 750000	10times Time:580ms, Array's Length:2000000
cutoff: 800000	10times Time:579ms, Array's Length:2000000
cutoff: 850000	10times Time:580ms, Array's Length:2000000
cutoff: 900000	10times Time:578ms, Array's Length:2000000
cutoff: 950000	10times Time:584ms, Array's Length:2000000
cutoff: 1000000	10times Time:581ms, Array's Length:2000000
cutoff: 1050000	10times Time:813ms, Array's Length:2000000
cutoff: 1100000	10times Time:814ms, Array's Length:2000000
cutoff: 1150000	10times Time:812ms, Array's Length:2000000

Degree of parallelism: 16

cutoff: 500000	10times Time:1356ms, Array's Length:2000000
cutoff: 1000000	10times Time:554ms, Array's Length:2000000
cutoff: 1500000	10times Time:538ms, Array's Length:2000000
cutoff: 2000000	10times Time:559ms, Array's Length:2000000
cutoff: 2500000	10times Time:556ms, Array's Length:2000000
cutoff: 3000000	10times Time:537ms, Array's Length:2000000
cutoff: 3500000	10times Time:533ms, Array's Length:2000000
cutoff: 4000000	10times Time:536ms, Array's Length:2000000
cutoff: 4500000	10times Time:534ms, Array's Length:2000000
cutoff: 5000000	10times Time:537ms, Array's Length:2000000
cutoff: 5500000	10times Time:583ms, Array's Length:2000000
cutoff: 6000000	10times Time:577ms, Array's Length:2000000
cutoff: 6500000	10times Time:582ms, Array's Length:2000000
cutoff: 7000000	10times Time:579ms, Array's Length:2000000
cutoff: 7500000	10times Time:579ms, Array's Length:2000000
cutoff: 8000000	10times Time:579ms, Array's Length:2000000
cutoff: 8500000	10times Time:580ms, Array's Length:2000000
cutoff: 9000000	10times Time:576ms, Array's Length:2000000
cutoff: 9500000	10times Time:581ms, Array's Length:2000000
cutoff: 10000000	10times Time:578ms, Array's Length:2000000
cutoff: 10500000	10times Time:812ms, Array's Length:2000000
cutoff: 11000000	10times Time:812ms, Array's Length:2000000
cutoff: 11500000	10times Time:809ms, Array's Length:2000000

Degree of parallelism: 32

cutoff: 50000	10times Time:1340ms, Array's Length:2000000
cutoff: 100000	10Times Time:754ms, Array's Length:2000000
cutoff: 150000	10Times Time:521ms, Array's Length:2000000
cutoff: 200000	10Times Time:527ms, Array's Length:2000000
cutoff: 250000	10Times Time:524ms, Array's Length:2000000
cutoff: 300000	10Times Time:540ms, Array's Length:2000000
cutoff: 350000	10Times Time:529ms, Array's Length:2000000
cutoff: 400000	10Times Time:525ms, Array's Length:2000000
cutoff: 450000	10Times Time:532ms, Array's Length:2000000
cutoff: 500000	10Times Time:535ms, Array's Length:2000000
cutoff: 550000	10Times Time:588ms, Array's Length:2000000
cutoff: 600000	10Times Time:581ms, Array's Length:2000000
cutoff: 650000	10Times Time:584ms, Array's Length:2000000
cutoff: 700000	10Times Time:581ms, Array's Length:2000000
cutoff: 750000	10Times Time:584ms, Array's Length:2000000
cutoff: 800000	10Times Time:579ms, Array's Length:2000000
cutoff: 850000	10Times Time:585ms, Array's Length:2000000
cutoff: 900000	10Times Time:580ms, Array's Length:2000000
cutoff: 950000	10Times Time:578ms, Array's Length:2000000
cutoff: 1000000	10Times Time:584ms, Array's Length:2000000
cutoff: 1050000	10Times Time:819ms, Array's Length:2000000
cutoff: 1100000	10Times Time:817ms, Array's Length:2000000
cutoff: 1150000	10Times Time:816ms, Array's Length:2000000

## 2.2 Array's Length: 4000,000



```

=====
cutoff: 50000      10times Time:1348ms, Array's Length:4000000
cutoff: 100000     10times Time:1039ms, Array's Length:4000000
cutoff: 150000     10times Time:1010ms, Array's Length:4000000
cutoff: 200000     10times Time:1006ms, Array's Length:4000000
cutoff: 250000     10times Time:1004ms, Array's Length:4000000
cutoff: 300000     10times Time:1003ms, Array's Length:4000000
cutoff: 350000     10times Time:1035ms, Array's Length:4000000
cutoff: 400000     10times Time:1007ms, Array's Length:4000000
cutoff: 450000     10times Time:1004ms, Array's Length:4000000
cutoff: 500000     10times Time:1000ms, Array's Length:4000000
cutoff: 550000     10times Time:995ms, Array's Length:4000000
cutoff: 600000     10times Time:976ms, Array's Length:4000000
cutoff: 650000     10times Time:986ms, Array's Length:4000000
cutoff: 700000     10times Time:972ms, Array's Length:4000000
cutoff: 750000     10times Time:976ms, Array's Length:4000000
cutoff: 800000     10times Time:994ms, Array's Length:4000000
cutoff: 850000     10times Time:1025ms, Array's Length:4000000
cutoff: 900000     10times Time:978ms, Array's Length:4000000
cutoff: 950000     10times Time:986ms, Array's Length:4000000
cutoff: 1000000    10times Time:983ms, Array's Length:4000000
cutoff: 1050000    10times Time:1158ms, Array's Length:4000000
cutoff: 1100000    10times Time:1151ms, Array's Length:4000000
cutoff: 1150000    10times Time:1150ms, Array's Length:4000000
=====
```

The number of parallelisms from the top left corner to the bottom right corner in order is: 2, 4, 8, 16, 32.

## 2.3 Array's Length: 6000,000

```

=====
cutoff: 50000      10times Time:1965ms, Array's Length:6000000
cutoff: 100000     10times Time:2147ms, Array's Length:6000000
cutoff: 150000     10times Time:2141ms, Array's Length:6000000
cutoff: 200000     10times Time:2221ms, Array's Length:6000000
cutoff: 250000     10times Time:2260ms, Array's Length:6000000
cutoff: 300000     10times Time:2218ms, Array's Length:6000000
cutoff: 350000     10times Time:2294ms, Array's Length:6000000
cutoff: 400000     10times Time:2349ms, Array's Length:6000000
cutoff: 450000     10times Time:2386ms, Array's Length:6000000
cutoff: 500000     10times Time:2436ms, Array's Length:6000000
cutoff: 550000     10times Time:2475ms, Array's Length:6000000
cutoff: 600000     10times Time:2426ms, Array's Length:6000000
cutoff: 650000     10times Time:2369ms, Array's Length:6000000
cutoff: 700000     10times Time:2394ms, Array's Length:6000000
cutoff: 750000     10times Time:2376ms, Array's Length:6000000
cutoff: 800000     10times Time:2530ms, Array's Length:6000000
cutoff: 850000     10times Time:2562ms, Array's Length:6000000
cutoff: 900000     10times Time:2512ms, Array's Length:6000000
cutoff: 950000     10times Time:2491ms, Array's Length:6000000
cutoff: 1000000    10times Time:2509ms, Array's Length:6000000
cutoff: 1050000    10times Time:2391ms, Array's Length:6000000
cutoff: 1100000    10times Time:2534ms, Array's Length:6000000
cutoff: 1150000    10times Time:2585ms, Array's Length:6000000
=====
```

```

=====
cutoff: 50000      10times Time:1697ms, Array's Length:6000000
cutoff: 100000     10times Time:1665ms, Array's Length:6000000
cutoff: 150000     10times Time:1666ms, Array's Length:6000000
cutoff: 200000     10times Time:1688ms, Array's Length:6000000
cutoff: 250000     10times Time:1700ms, Array's Length:6000000
cutoff: 300000     10times Time:1722ms, Array's Length:6000000
cutoff: 350000     10times Time:1706ms, Array's Length:6000000
cutoff: 400000     10times Time:1754ms, Array's Length:6000000
cutoff: 450000     10times Time:1786ms, Array's Length:6000000
cutoff: 500000     10times Time:1796ms, Array's Length:6000000
cutoff: 550000     10times Time:1777ms, Array's Length:6000000
cutoff: 600000     10times Time:1767ms, Array's Length:6000000
cutoff: 650000     10times Time:1787ms, Array's Length:6000000
cutoff: 700000     10times Time:1734ms, Array's Length:6000000
cutoff: 750000     10times Time:1756ms, Array's Length:6000000
cutoff: 800000     10times Time:1845ms, Array's Length:6000000
cutoff: 850000     10times Time:1844ms, Array's Length:6000000
cutoff: 900000     10times Time:1854ms, Array's Length:6000000
cutoff: 950000     10times Time:1849ms, Array's Length:6000000
cutoff: 1000000    10times Time:1852ms, Array's Length:6000000
cutoff: 1050000    10times Time:1839ms, Array's Length:6000000
cutoff: 1100000    10times Time:1838ms, Array's Length:6000000
cutoff: 1150000    10times Time:1859ms, Array's Length:6000000
=====
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cutoff: 50000	10times Time:1934ms, Array's Length:6000000	cutoff: 50000	10times Time:1581ms, Array's Length:6000000
cutoff: 100000	10times Time:1698ms, Array's Length:6000000	cutoff: 100000	10times Time:1585ms, Array's Length:6000000
cutoff: 150000	10times Time:1672ms, Array's Length:6000000	cutoff: 150000	10times Time:1581ms, Array's Length:6000000
cutoff: 200000	10times Time:1778ms, Array's Length:6000000	cutoff: 200000	10times Time:1692ms, Array's Length:6000000
cutoff: 250000	10times Time:1610ms, Array's Length:6000000	cutoff: 250000	10times Time:1585ms, Array's Length:6000000
cutoff: 300000	10times Time:1598ms, Array's Length:6000000	cutoff: 300000	10times Time:1624ms, Array's Length:6000000
cutoff: 350000	10times Time:1565ms, Array's Length:6000000	cutoff: 350000	10times Time:1521ms, Array's Length:6000000
cutoff: 400000	10times Time:1548ms, Array's Length:6000000	cutoff: 400000	10times Time:1542ms, Array's Length:6000000
cutoff: 450000	10times Time:1553ms, Array's Length:6000000	cutoff: 450000	10times Time:1515ms, Array's Length:6000000
cutoff: 500000	10times Time:1543ms, Array's Length:6000000	cutoff: 500000	10times Time:1625ms, Array's Length:6000000
cutoff: 550000	10times Time:1538ms, Array's Length:6000000	cutoff: 550000	10times Time:1593ms, Array's Length:6000000
cutoff: 600000	10times Time:1564ms, Array's Length:6000000	cutoff: 600000	10times Time:1700ms, Array's Length:6000000
cutoff: 650000	10times Time:1541ms, Array's Length:6000000	cutoff: 650000	10times Time:1587ms, Array's Length:6000000
cutoff: 700000	10times Time:1543ms, Array's Length:6000000	cutoff: 700000	10times Time:1641ms, Array's Length:6000000
cutoff: 750000	10times Time:1542ms, Array's Length:6000000	cutoff: 750000	10times Time:1578ms, Array's Length:6000000
cutoff: 800000	10times Time:1526ms, Array's Length:6000000	cutoff: 800000	10times Time:1544ms, Array's Length:6000000
cutoff: 850000	10times Time:1503ms, Array's Length:6000000	cutoff: 850000	10times Time:1646ms, Array's Length:6000000
cutoff: 900000	10times Time:1525ms, Array's Length:6000000	cutoff: 900000	10times Time:1615ms, Array's Length:6000000
cutoff: 950000	10times Time:1523ms, Array's Length:6000000	cutoff: 950000	10times Time:1607ms, Array's Length:6000000
cutoff: 1000000	10times Time:1518ms, Array's Length:6000000	cutoff: 1000000	10times Time:1662ms, Array's Length:6000000
cutoff: 1050000	10times Time:1516ms, Array's Length:6000000	cutoff: 1050000	10times Time:1742ms, Array's Length:6000000
cutoff: 1100000	10times Time:1507ms, Array's Length:6000000	cutoff: 1100000	10times Time:1535ms, Array's Length:6000000
cutoff: 1150000	10times Time:1543ms, Array's Length:6000000	cutoff: 1150000	10times Time:1621ms, Array's Length:6000000

cutoff: 50000	10times Time:1752ms, Array's Length:6000000
cutoff: 100000	10times Time:1540ms, Array's Length:6000000
cutoff: 150000	10times Time:1701ms, Array's Length:6000000
cutoff: 200000	10times Time:1536ms, Array's Length:6000000
cutoff: 250000	10times Time:1519ms, Array's Length:6000000
cutoff: 300000	10times Time:1518ms, Array's Length:6000000
cutoff: 350000	10times Time:1525ms, Array's Length:6000000
cutoff: 400000	10times Time:1526ms, Array's Length:6000000
cutoff: 450000	10times Time:1548ms, Array's Length:6000000
cutoff: 500000	10times Time:1508ms, Array's Length:6000000
cutoff: 550000	10times Time:1500ms, Array's Length:6000000
cutoff: 600000	10times Time:1518ms, Array's Length:6000000
cutoff: 650000	10times Time:1551ms, Array's Length:6000000
cutoff: 700000	10times Time:1523ms, Array's Length:6000000
cutoff: 750000	10times Time:1495ms, Array's Length:6000000
cutoff: 800000	10times Time:1482ms, Array's Length:6000000
cutoff: 850000	10times Time:1475ms, Array's Length:6000000
cutoff: 900000	10times Time:1477ms, Array's Length:6000000
cutoff: 950000	10times Time:1481ms, Array's Length:6000000
cutoff: 1000000	10times Time:1465ms, Array's Length:6000000
cutoff: 1050000	10times Time:1473ms, Array's Length:6000000
cutoff: 1100000	10times Time:1469ms, Array's Length:6000000
cutoff: 1150000	10times Time:1487ms, Array's Length:6000000

The number of parallelisms from the top left corner to the bottom right corner in order is: 2, 4, 8, 16, 32.

## 2.4 Array's Length: 8000,000

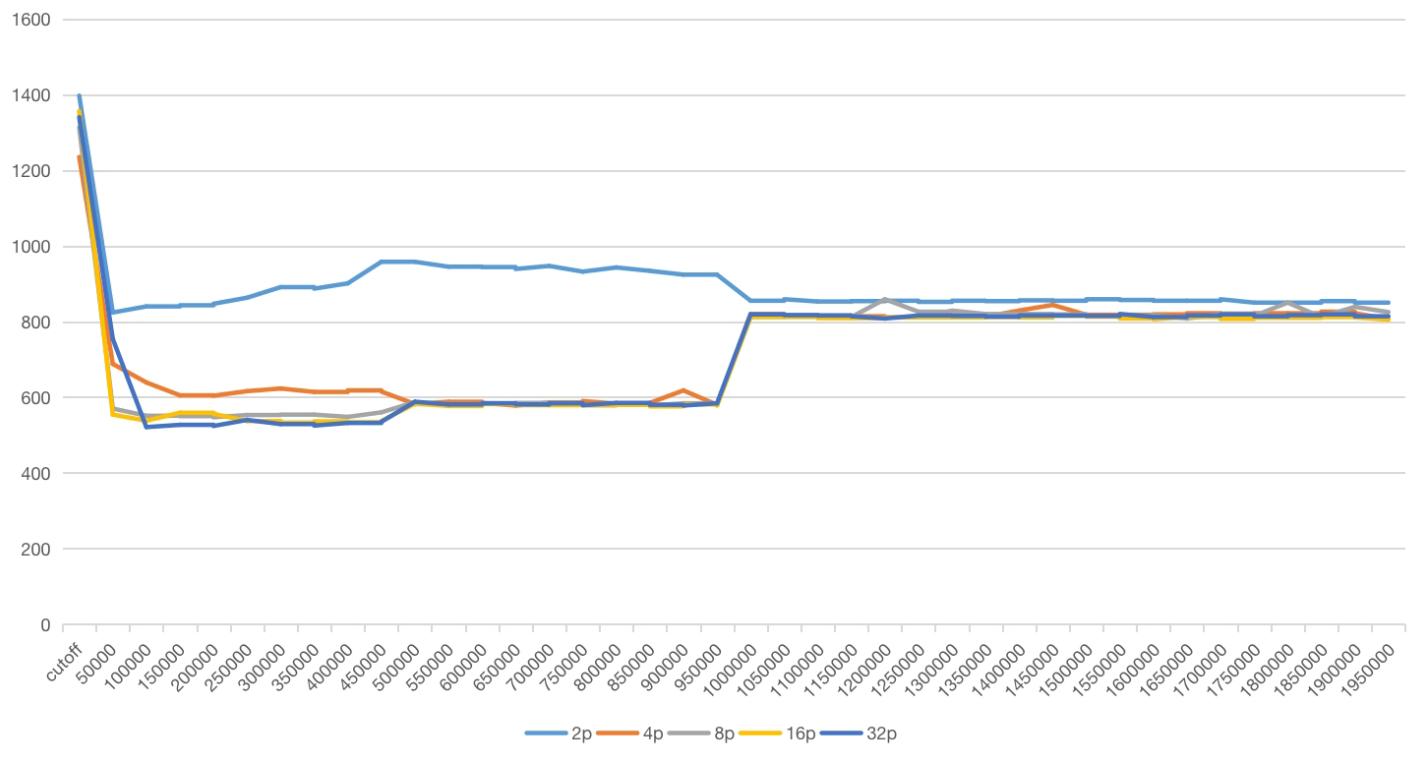
```
=====
cutoff: 50000      10times Time:2542ms, Array's Length:8000000
cutoff: 100000     10times Time:2166ms, Array's Length:8000000
cutoff: 150000     10times Time:2055ms, Array's Length:8000000
cutoff: 200000     10times Time:2023ms, Array's Length:8000000
cutoff: 250000     10times Time:2036ms, Array's Length:8000000
cutoff: 300000     10times Time:1999ms, Array's Length:8000000
cutoff: 350000     10times Time:2030ms, Array's Length:8000000
cutoff: 400000     10times Time:2016ms, Array's Length:8000000
cutoff: 450000     10times Time:2019ms, Array's Length:8000000
cutoff: 500000     10times Time:2012ms, Array's Length:8000000
cutoff: 550000     10times Time:2019ms, Array's Length:8000000
cutoff: 600000     10times Time:2027ms, Array's Length:8000000
cutoff: 650000     10times Time:2026ms, Array's Length:8000000
cutoff: 700000     10times Time:2018ms, Array's Length:8000000
cutoff: 750000     10times Time:2026ms, Array's Length:8000000
cutoff: 800000     10times Time:2011ms, Array's Length:8000000
cutoff: 850000     10times Time:1985ms, Array's Length:8000000
cutoff: 900000     10times Time:2034ms, Array's Length:8000000
cutoff: 950000     10times Time:2020ms, Array's Length:8000000
cutoff: 1000000    10times Time:1998ms, Array's Length:8000000
cutoff: 1050000    10times Time:1962ms, Array's Length:8000000
cutoff: 1100000    10times Time:1985ms, Array's Length:8000000
cutoff: 1150000    10times Time:1959ms, Array's Length:8000000
```

The number of parallelisms from the top left corner to the bottom right corner in order is: 2, 4, 8, 16, 32.

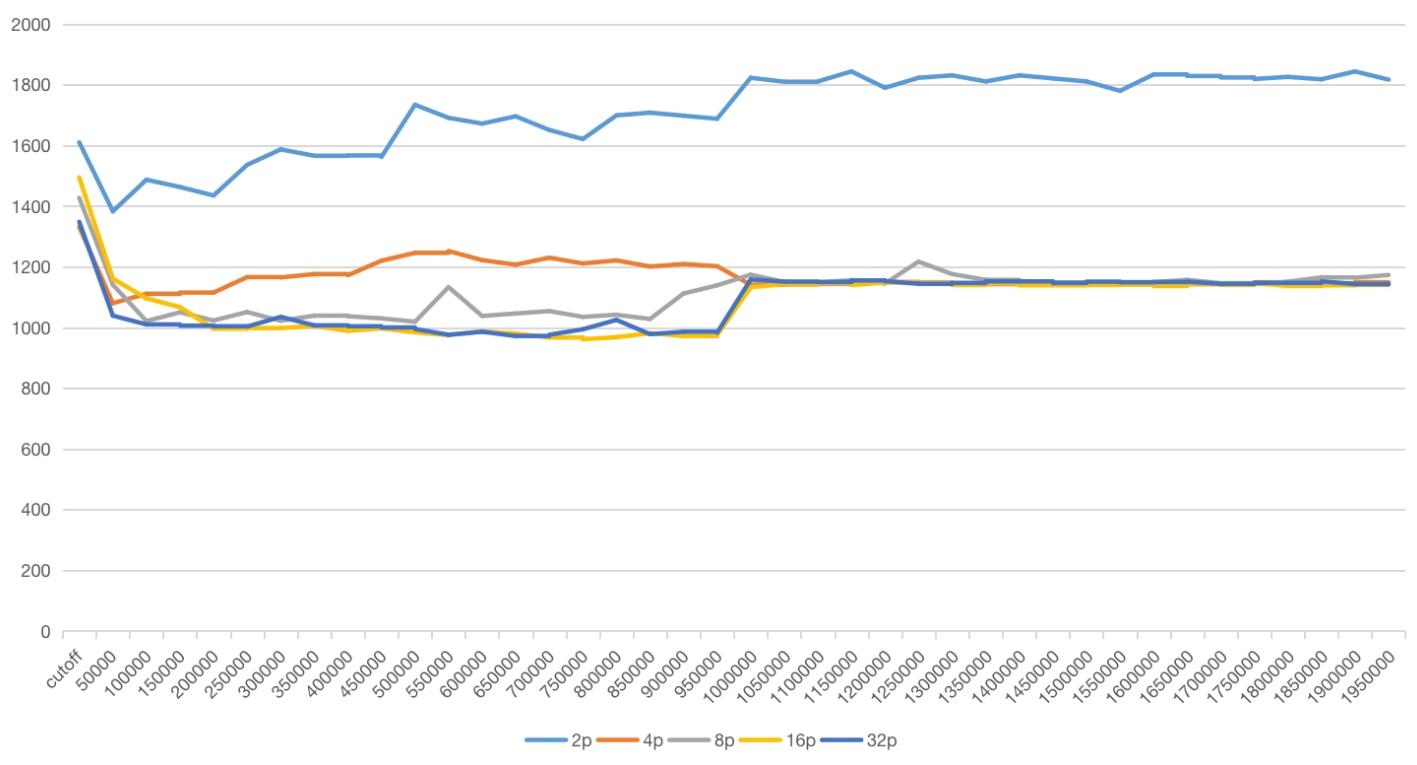
### 3. Statistical Graph

- $p$ (parallelism) represents the number of threads
- The vertical coordinate represents the time it takes (in ms)
- The horizontal coordinate represents the value of cutoff

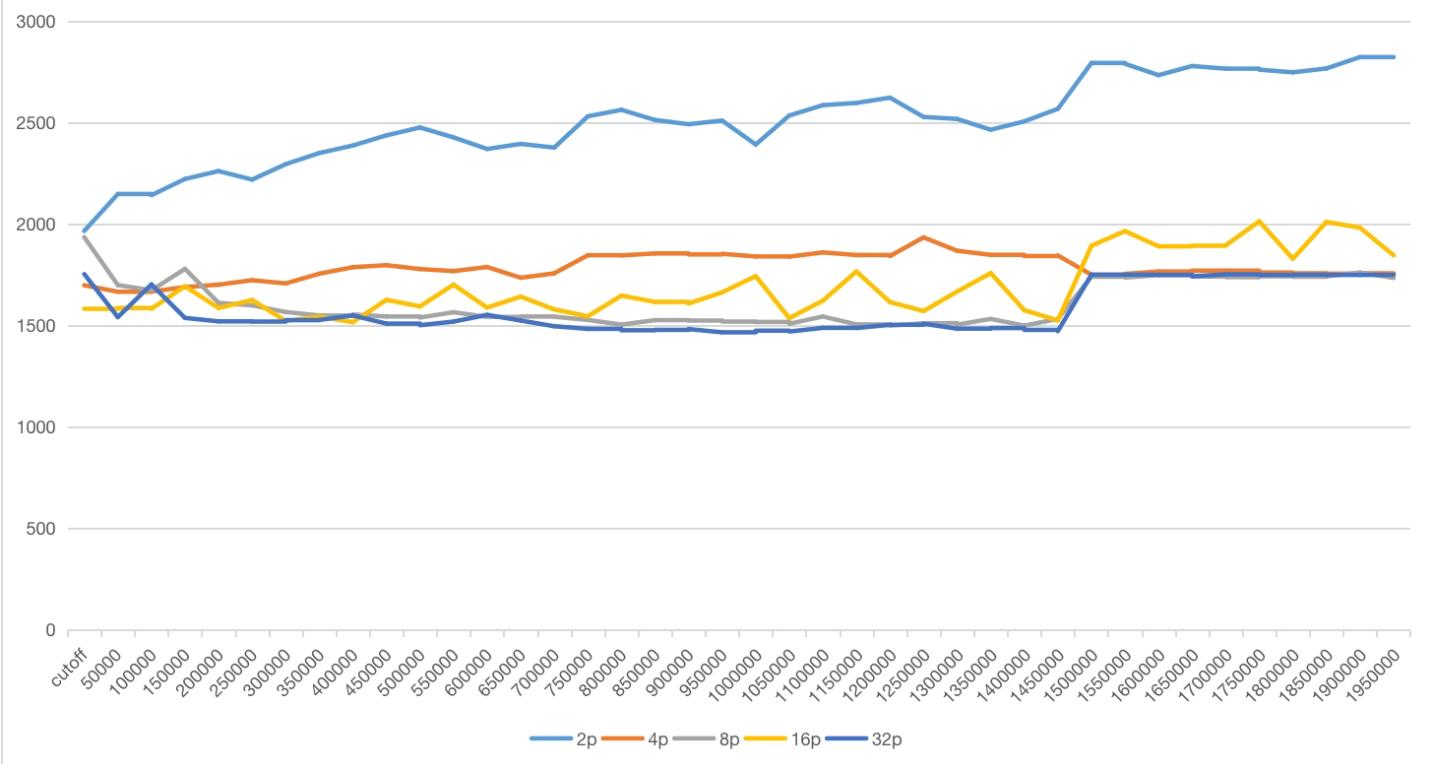
The length of array: 2,000,000



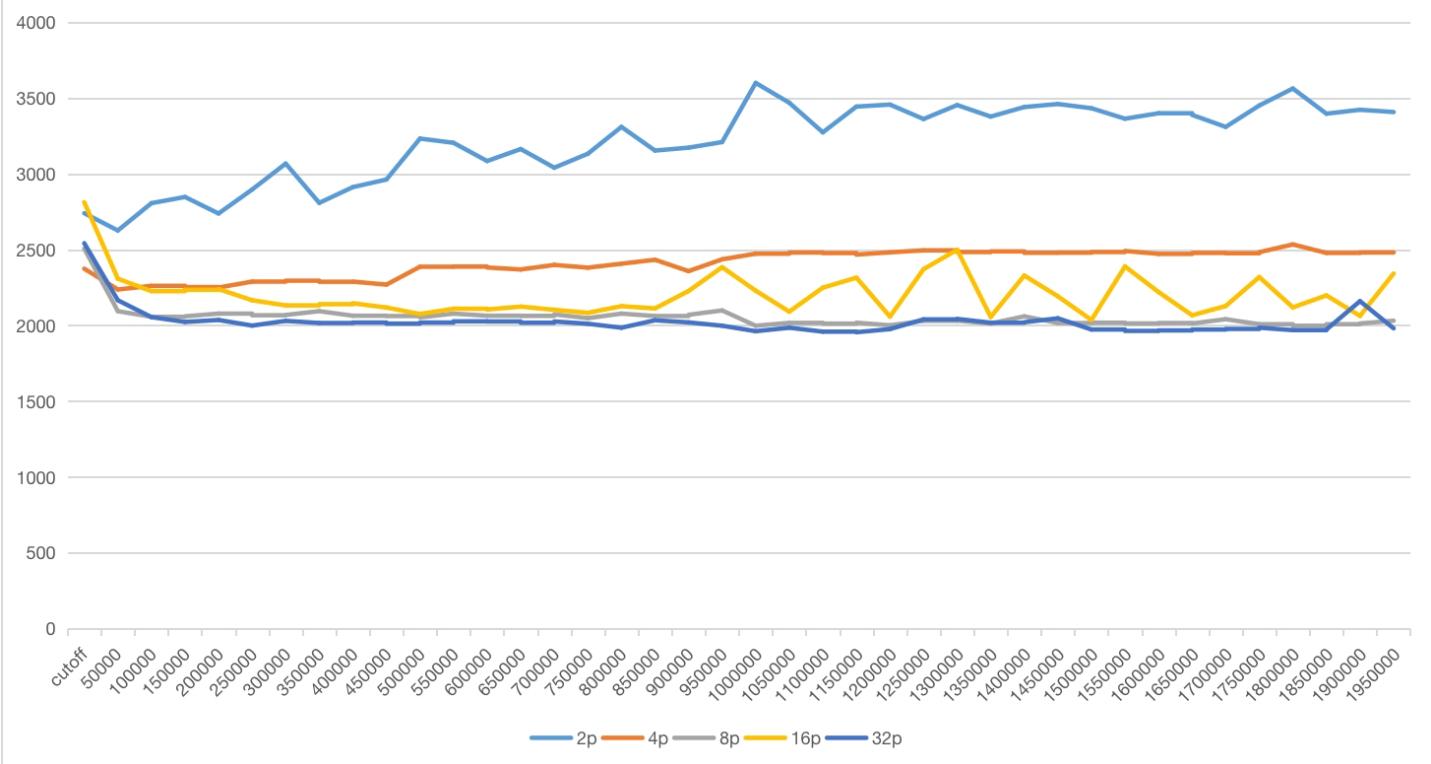
The length of array: 4,000,000



The length of array: 6,000,000



The length of array: 8,000,000



## 4. Conclusion

## **Relationship:**

- The good value for the cutoff: [100000, 0.25 \* len] (len: The length of array)
- Ideal number ( $t$ ) of separate threads: 8 (My Mac has 8 cores)

## **4.1 The good value for the cutoff**

From the graphs of the chapter 3, we can observe that when the value of cutoff is larger than 100,000, the time taken to sort the entire array is reduced to almost the minimum. However, when the value of cutoff reaches to the one-fourth of the array length, the time spent grows rapidly again.

## **4.2 Ideal number ( $t$ ) of separate threads**

We can notice that when the counts of threads reaches more than 8, the time spent on the program did not decrease significantly, but increased a little.

In my opinion, the ideal number of separate threads depends on the number of cpu's in your computer (May be approximately equal to the number of cpu of your computer). If the number of threads exceeds the number of your computer's cpu, your computer will spend more time to split the task and combine them. This is the reason why when the number of threads exceeds 8, the program's running time does not decrease, but rather increases.

Too few threads will reduce the overall performance of the program, while too many threads will consume other resources such as memory. Therefore, when we execute tasks in parallel, we have to take into account all the conditions to optimize the programs.