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INFO 6205

Program Structures & Algorithms

Fall 2020

Assignment No5

At first, I write the code in the ParSort.java, and run the Main. And I get this:

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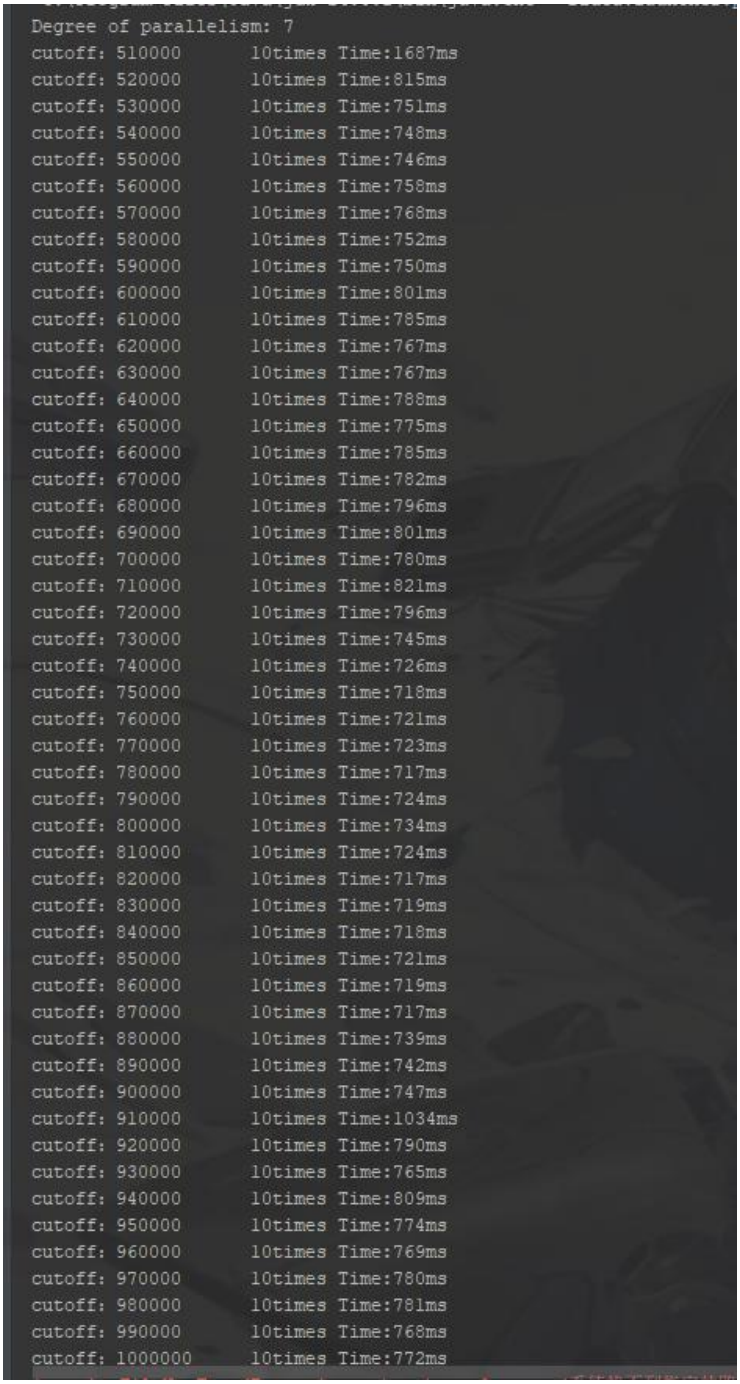

It seems that the code runs well and the it performs better when the cutoff is around 750,000.

Therefore, I change the code in the Main.java:

```
int[] array = new int[4000000];
System.out.println("Array size: " + array.length);
ArrayList<Long> timeList = new ArrayList<>();
for (int j = 4; j < 45; j++) {
    ParSort.cutoff = 50000 * j;
```

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And I change the number of available threads(the number equals to 2, 4, 8, 16 and 32), and I run the code in each condition several times, and these are some of all the outputs:

```
"C:\Program Files\Java\jdk-14.0.1\bin\java.e
Degree of parallelism: 2
Array size: 4000000
cutoff: 200000      10times Time:2965ms
cutoff: 250000      10times Time:2512ms
cutoff: 300000      10times Time:2323ms
cutoff: 350000      10times Time:2345ms
cutoff: 400000      10times Time:2387ms
cutoff: 450000      10times Time:2389ms
cutoff: 500000      10times Time:2292ms
cutoff: 550000      10times Time:2133ms
cutoff: 600000      10times Time:2358ms
cutoff: 650000      10times Time:2339ms
cutoff: 700000      10times Time:2263ms
cutoff: 750000      10times Time:2128ms
cutoff: 800000      10times Time:2689ms
cutoff: 850000      10times Time:2261ms
cutoff: 900000      10times Time:2282ms
cutoff: 950000      10times Time:2278ms
cutoff: 1000000     10times Time:2295ms
cutoff: 1050000     10times Time:2188ms
cutoff: 1100000     10times Time:2148ms
cutoff: 1150000     10times Time:2160ms
cutoff: 1200000     10times Time:2116ms
cutoff: 1250000     10times Time:2124ms
cutoff: 1300000     10times Time:2108ms
cutoff: 1350000     10times Time:2083ms
cutoff: 1400000     10times Time:2103ms
cutoff: 1450000     10times Time:2076ms
cutoff: 1500000     10times Time:2399ms
cutoff: 1550000     10times Time:2225ms
cutoff: 1600000     10times Time:2206ms
cutoff: 1650000     10times Time:2189ms
cutoff: 1700000     10times Time:2194ms
cutoff: 1750000     10times Time:2219ms
cutoff: 1800000     10times Time:2215ms
cutoff: 1850000     10times Time:2103ms
cutoff: 1900000     10times Time:2099ms
cutoff: 1950000     10times Time:2118ms
cutoff: 2000000     10times Time:2105ms
cutoff: 2050000     10times Time:2027ms
cutoff: 2100000     10times Time:2061ms
cutoff: 2150000     10times Time:2100ms
cutoff: 2200000     10times Time:2109ms
```

```
"C:\Program Files\Java\jdk-14.0.1\bin\java.exe
Degree of parallelism: 4
Array size: 4000000
cutoff: 200000      10times Time:3156ms
cutoff: 250000      10times Time:2036ms
cutoff: 300000      10times Time:1981ms
cutoff: 350000      10times Time:1929ms
cutoff: 400000      10times Time:1884ms
cutoff: 450000      10times Time:1762ms
cutoff: 500000      10times Time:1731ms
cutoff: 550000      10times Time:1670ms
cutoff: 600000      10times Time:1673ms
cutoff: 650000      10times Time:2104ms
cutoff: 700000      10times Time:1808ms
cutoff: 750000      10times Time:1748ms
cutoff: 800000      10times Time:1767ms
cutoff: 850000      10times Time:1689ms
cutoff: 900000      10times Time:1640ms
cutoff: 950000      10times Time:1637ms
cutoff: 1000000     10times Time:1667ms
cutoff: 1050000     10times Time:1865ms
cutoff: 1100000     10times Time:1678ms
cutoff: 1150000     10times Time:1692ms
cutoff: 1200000     10times Time:1698ms
cutoff: 1250000     10times Time:1705ms
cutoff: 1300000     10times Time:1701ms
cutoff: 1350000     10times Time:1696ms
cutoff: 1400000     10times Time:1623ms
cutoff: 1450000     10times Time:1602ms
cutoff: 1500000     10times Time:1621ms
cutoff: 1550000     10times Time:1618ms
cutoff: 1600000     10times Time:1628ms
cutoff: 1650000     10times Time:1610ms
cutoff: 1700000     10times Time:1874ms
cutoff: 1750000     10times Time:1702ms
cutoff: 1800000     10times Time:1693ms
cutoff: 1850000     10times Time:1682ms
cutoff: 1900000     10times Time:1687ms
cutoff: 1950000     10times Time:1676ms
cutoff: 2000000     10times Time:1691ms
cutoff: 2050000     10times Time:2158ms
cutoff: 2100000     10times Time:2152ms
cutoff: 2150000     10times Time:2149ms
cutoff: 2200000     10times Time:2134ms
```

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```
"C:\Program Files\Java\jdk-14.0.1\bin\java.ex
Degree of parallelism: 8
Array size: 4000000
cutoff: 200000      10times Time:2063ms
cutoff: 250000      10times Time:1601ms
cutoff: 300000      10times Time:1402ms
cutoff: 350000      10times Time:1405ms
cutoff: 400000      10times Time:1421ms
cutoff: 450000      10times Time:1352ms
cutoff: 500000      10times Time:1575ms
cutoff: 550000      10times Time:1368ms
cutoff: 600000      10times Time:1373ms
cutoff: 650000      10times Time:1350ms
cutoff: 700000      10times Time:1342ms
cutoff: 750000      10times Time:1249ms
cutoff: 800000      10times Time:1268ms
cutoff: 850000      10times Time:1242ms
cutoff: 900000      10times Time:1241ms
cutoff: 950000      10times Time:1617ms
cutoff: 1000000     10times Time:1372ms
cutoff: 1050000     10times Time:1544ms
cutoff: 1100000     10times Time:1535ms
cutoff: 1150000     10times Time:1537ms
cutoff: 1200000     10times Time:1573ms
cutoff: 1250000     10times Time:1483ms
cutoff: 1300000     10times Time:1447ms
cutoff: 1350000     10times Time:1500ms
cutoff: 1400000     10times Time:1479ms
cutoff: 1450000     10times Time:1467ms
cutoff: 1500000     10times Time:1466ms
cutoff: 1550000     10times Time:1765ms
cutoff: 1600000     10times Time:1546ms
cutoff: 1650000     10times Time:1526ms
cutoff: 1700000     10times Time:1534ms
cutoff: 1750000     10times Time:1547ms
cutoff: 1800000     10times Time:1529ms
cutoff: 1850000     10times Time:1499ms
cutoff: 1900000     10times Time:1449ms
cutoff: 1950000     10times Time:1434ms
cutoff: 2000000     10times Time:1447ms
cutoff: 2050000     10times Time:1927ms
cutoff: 2100000     10times Time:1925ms
cutoff: 2150000     10times Time:1928ms
cutoff: 2200000     10times Time:1935ms
```

```
"C:\Program Files\Java\jdk-14.0.1\bin\java.e
Degree of parallelism: 16
Array size: 4000000
cutoff: 200000      10times Time:2004ms
cutoff: 250000      10times Time:1670ms
cutoff: 300000      10times Time:1568ms
cutoff: 350000      10times Time:1599ms
cutoff: 400000      10times Time:1556ms
cutoff: 450000      10times Time:1738ms
cutoff: 500000      10times Time:1586ms
cutoff: 550000      10times Time:1556ms
cutoff: 600000      10times Time:1561ms
cutoff: 650000      10times Time:1547ms
cutoff: 700000      10times Time:1425ms
cutoff: 750000      10times Time:1762ms
cutoff: 800000      10times Time:1529ms
cutoff: 850000      10times Time:1534ms
cutoff: 900000      10times Time:1548ms
cutoff: 950000      10times Time:1514ms
cutoff: 1000000     10times Time:1434ms
cutoff: 1050000     10times Time:1669ms
cutoff: 1100000     10times Time:1651ms
cutoff: 1150000     10times Time:1680ms
cutoff: 1200000     10times Time:1678ms
cutoff: 1250000     10times Time:1955ms
cutoff: 1300000     10times Time:1760ms
cutoff: 1350000     10times Time:1752ms
cutoff: 1400000     10times Time:1746ms
cutoff: 1450000     10times Time:1778ms
cutoff: 1500000     10times Time:1783ms
cutoff: 1550000     10times Time:1734ms
cutoff: 1600000     10times Time:1698ms
cutoff: 1650000     10times Time:1665ms
cutoff: 1700000     10times Time:1644ms
cutoff: 1750000     10times Time:1684ms
cutoff: 1800000     10times Time:1690ms
cutoff: 1850000     10times Time:1928ms
cutoff: 1900000     10times Time:1763ms
cutoff: 1950000     10times Time:1738ms
cutoff: 2000000     10times Time:1756ms
cutoff: 2050000     10times Time:2215ms
cutoff: 2100000     10times Time:2240ms
cutoff: 2150000     10times Time:2228ms
cutoff: 2200000     10times Time:2262ms
```

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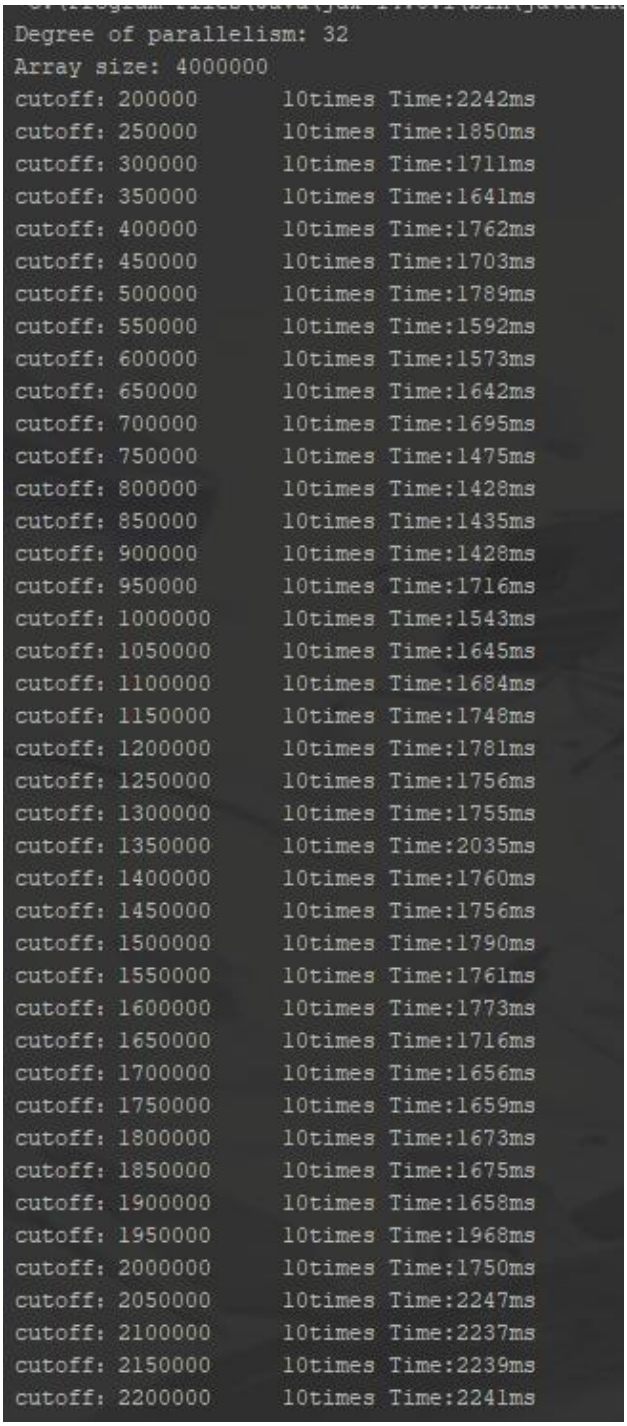

It's obvious that the algorithm works better when the number of threads equals to 8. I guess the reason is that my computer has 8 CPU, and it makes it's common pool parallelism is 7(as shown in the first picture), which is close to 8.

To confirm this, I need to change the size of array. It's reasonable to think that if the size is big enough, the treads we need might be larger. So I change the array size to 8,000,000:

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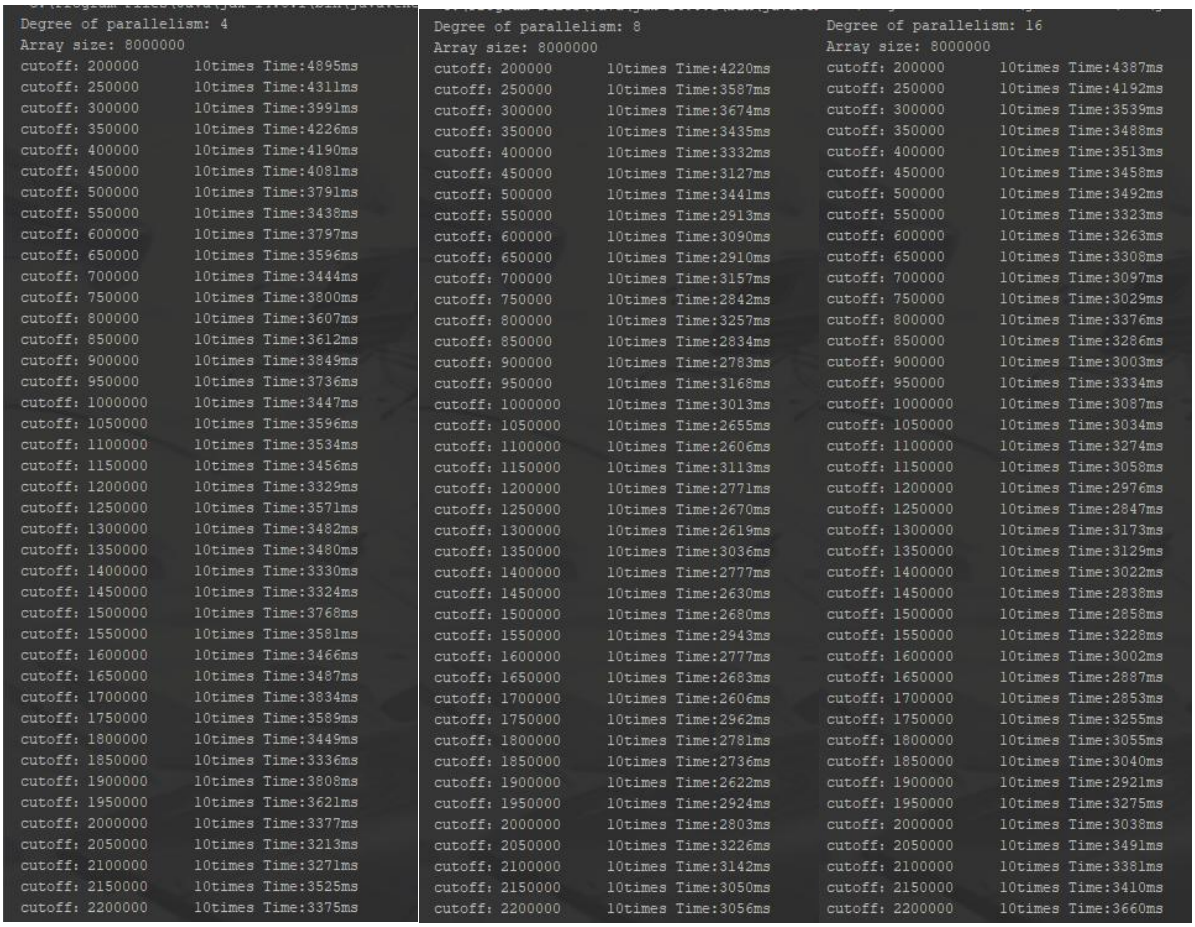

```
Degree of parallelism: 4
Array size: 8000000
cutoff: 200000      10times Time:4895ms
cutoff: 250000      10times Time:4311ms
cutoff: 300000      10times Time:3991ms
cutoff: 350000      10times Time:4226ms
cutoff: 400000      10times Time:4190ms
cutoff: 450000      10times Time:4081ms
cutoff: 500000      10times Time:3791ms
cutoff: 550000      10times Time:3438ms
cutoff: 600000      10times Time:3797ms
cutoff: 650000      10times Time:3596ms
cutoff: 700000      10times Time:3444ms
cutoff: 750000      10times Time:3800ms
cutoff: 800000      10times Time:3607ms
cutoff: 850000      10times Time:3612ms
cutoff: 900000      10times Time:3849ms
cutoff: 950000      10times Time:3736ms
cutoff: 1000000     10times Time:3447ms
cutoff: 1050000     10times Time:3596ms
cutoff: 1100000     10times Time:3534ms
cutoff: 1150000     10times Time:3456ms
cutoff: 1200000     10times Time:3329ms
cutoff: 1250000     10times Time:3571ms
cutoff: 1300000     10times Time:3482ms
cutoff: 1350000     10times Time:3480ms
cutoff: 1400000     10times Time:3330ms
cutoff: 1450000     10times Time:3324ms
cutoff: 1500000     10times Time:3768ms
cutoff: 1550000     10times Time:3581ms
cutoff: 1600000     10times Time:3466ms
cutoff: 1650000     10times Time:3487ms
cutoff: 1700000     10times Time:3834ms
cutoff: 1750000     10times Time:3589ms
cutoff: 1800000     10times Time:3449ms
cutoff: 1850000     10times Time:3336ms
cutoff: 1900000     10times Time:3808ms
cutoff: 1950000     10times Time:3621ms
cutoff: 2000000     10times Time:3377ms
cutoff: 2050000     10times Time:3213ms
cutoff: 2100000     10times Time:3271ms
cutoff: 2150000     10times Time:3525ms
cutoff: 2200000     10times Time:3375ms
```

```
Degree of parallelism: 8
Array size: 8000000
cutoff: 200000      10times Time:4220ms
cutoff: 250000      10times Time:3587ms
cutoff: 300000      10times Time:3674ms
cutoff: 350000      10times Time:3435ms
cutoff: 400000      10times Time:3332ms
cutoff: 450000      10times Time:3127ms
cutoff: 500000      10times Time:3441ms
cutoff: 550000      10times Time:2913ms
cutoff: 600000      10times Time:3090ms
cutoff: 650000      10times Time:2910ms
cutoff: 700000      10times Time:3157ms
cutoff: 750000      10times Time:2842ms
cutoff: 800000      10times Time:3257ms
cutoff: 850000      10times Time:2834ms
cutoff: 900000      10times Time:2783ms
cutoff: 950000      10times Time:3168ms
cutoff: 1000000     10times Time:3013ms
cutoff: 1050000     10times Time:2655ms
cutoff: 1100000     10times Time:2606ms
cutoff: 1150000     10times Time:3113ms
cutoff: 1200000     10times Time:2771ms
cutoff: 1250000     10times Time:2670ms
cutoff: 1300000     10times Time:2619ms
cutoff: 1350000     10times Time:3036ms
cutoff: 1400000     10times Time:2777ms
cutoff: 1450000     10times Time:2630ms
cutoff: 1500000     10times Time:2680ms
cutoff: 1550000     10times Time:2943ms
cutoff: 1600000     10times Time:2777ms
cutoff: 1650000     10times Time:2683ms
cutoff: 1700000     10times Time:2606ms
cutoff: 1750000     10times Time:2962ms
cutoff: 1800000     10times Time:2781ms
cutoff: 1850000     10times Time:2736ms
cutoff: 1900000     10times Time:2622ms
cutoff: 1950000     10times Time:2924ms
cutoff: 2000000     10times Time:2803ms
cutoff: 2050000     10times Time:3226ms
cutoff: 2100000     10times Time:3142ms
cutoff: 2150000     10times Time:3050ms
cutoff: 2200000     10times Time:3056ms
```

```
Degree of parallelism: 16
Array size: 8000000
cutoff: 200000      10times Time:4387ms
cutoff: 250000      10times Time:4192ms
cutoff: 300000      10times Time:3539ms
cutoff: 350000      10times Time:3488ms
cutoff: 400000      10times Time:3513ms
cutoff: 450000      10times Time:3458ms
cutoff: 500000      10times Time:3492ms
cutoff: 550000      10times Time:3323ms
cutoff: 600000      10times Time:3263ms
cutoff: 650000      10times Time:3308ms
cutoff: 700000      10times Time:3097ms
cutoff: 750000      10times Time:3029ms
cutoff: 800000      10times Time:3376ms
cutoff: 850000      10times Time:3286ms
cutoff: 900000      10times Time:3003ms
cutoff: 950000      10times Time:3334ms
cutoff: 1000000     10times Time:3087ms
cutoff: 1050000     10times Time:3034ms
cutoff: 1100000     10times Time:3274ms
cutoff: 1150000     10times Time:3058ms
cutoff: 1200000     10times Time:2976ms
cutoff: 1250000     10times Time:2847ms
cutoff: 1300000     10times Time:3173ms
cutoff: 1350000     10times Time:3129ms
cutoff: 1400000     10times Time:3022ms
cutoff: 1450000     10times Time:2838ms
cutoff: 1500000     10times Time:2858ms
cutoff: 1550000     10times Time:3228ms
cutoff: 1600000     10times Time:3002ms
cutoff: 1650000     10times Time:2887ms
cutoff: 1700000     10times Time:2853ms
cutoff: 1750000     10times Time:3255ms
cutoff: 1800000     10times Time:3055ms
cutoff: 1850000     10times Time:3040ms
cutoff: 1900000     10times Time:2921ms
cutoff: 1950000     10times Time:3275ms
cutoff: 2000000     10times Time:3038ms
cutoff: 2050000     10times Time:3491ms
cutoff: 2100000     10times Time:3381ms
cutoff: 2150000     10times Time:3410ms
cutoff: 2200000     10times Time:3660ms
```

And we can see: even if the size is so this big, the algorithm still works better when the number of threads is 8 than the number is 16.
So I think I can say that **the best number of threads in this algorithm on my computer is 8.**

Next, I will set the number of threads is 8 and change the size of array to find the best cutoff.
We already tested 4 million and 8 million, it looks like 750,000 is the best cutoff.
To confirm this, I will test some other array size(2 million, 3 million, 5 million and 6 million):

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```
Array size: 2000000
cutoff: 200000      10times Time:1184ms
cutoff: 250000      10times Time:957ms
cutoff: 300000      10times Time:813ms
cutoff: 350000      10times Time:803ms
cutoff: 400000      10times Time:734ms
cutoff: 450000      10times Time:717ms
cutoff: 500000      10times Time:738ms
cutoff: 550000      10times Time:836ms
cutoff: 600000      10times Time:840ms
cutoff: 650000      10times Time:837ms
cutoff: 700000      10times Time:836ms
cutoff: 750000      10times Time:840ms
cutoff: 800000      10times Time:846ms
cutoff: 850000      10times Time:842ms
cutoff: 900000      10times Time:845ms
cutoff: 950000      10times Time:843ms
cutoff: 1000000     10times Time:838ms
cutoff: 1050000     10times Time:1027ms
cutoff: 1100000     10times Time:1042ms
cutoff: 1150000     10times Time:1002ms
cutoff: 1200000     10times Time:1038ms
cutoff: 1250000     10times Time:1027ms
cutoff: 1300000     10times Time:1033ms
cutoff: 1350000     10times Time:1024ms
cutoff: 1400000     10times Time:1036ms
cutoff: 1450000     10times Time:1019ms
cutoff: 1500000     10times Time:1051ms
cutoff: 1550000     10times Time:1041ms
cutoff: 1600000     10times Time:1033ms
cutoff: 1650000     10times Time:1027ms
cutoff: 1700000     10times Time:1320ms
```

```
Degree of parallelism: 8
Array size: 3000000
cutoff: 200000      10times Time:1649ms
cutoff: 250000      10times Time:1210ms
cutoff: 300000      10times Time:1117ms
cutoff: 350000      10times Time:1096ms
cutoff: 400000      10times Time:1079ms
cutoff: 450000      10times Time:1003ms
cutoff: 500000      10times Time:1020ms
cutoff: 550000      10times Time:1009ms
cutoff: 600000      10times Time:1023ms
cutoff: 650000      10times Time:1004ms
cutoff: 700000      10times Time:965ms
cutoff: 750000      10times Time:938ms
cutoff: 800000      10times Time:1096ms
cutoff: 850000      10times Time:1094ms
cutoff: 900000      10times Time:1079ms
cutoff: 950000      10times Time:1079ms
cutoff: 1000000     10times Time:1099ms
cutoff: 1050000     10times Time:1104ms
cutoff: 1100000     10times Time:1095ms
cutoff: 1150000     10times Time:1090ms
cutoff: 1200000     10times Time:1075ms
cutoff: 1250000     10times Time:1345ms
cutoff: 1300000     10times Time:1176ms
cutoff: 1350000     10times Time:1258ms
cutoff: 1400000     10times Time:1148ms
cutoff: 1450000     10times Time:1144ms
cutoff: 1500000     10times Time:1143ms
cutoff: 1550000     10times Time:1450ms
cutoff: 1600000     10times Time:1435ms
cutoff: 1650000     10times Time:1483ms
cutoff: 1700000     10times Time:1474ms
```

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```
Degree of parallelism: 8
Array size: 5000000
cutoff: 200000      10times Time:2531ms
cutoff: 250000      10times Time:2038ms
cutoff: 300000      10times Time:1939ms
cutoff: 350000      10times Time:1863ms
cutoff: 400000      10times Time:1858ms
cutoff: 450000      10times Time:1852ms
cutoff: 500000      10times Time:1790ms
cutoff: 550000      10times Time:1798ms
cutoff: 600000      10times Time:1695ms
cutoff: 650000      10times Time:1622ms
cutoff: 700000      10times Time:1598ms
cutoff: 750000      10times Time:1873ms
cutoff: 800000      10times Time:1732ms
cutoff: 850000      10times Time:1710ms
cutoff: 900000      10times Time:1709ms
cutoff: 950000      10times Time:1740ms
cutoff: 1000000     10times Time:1744ms
cutoff: 1050000     10times Time:1794ms
cutoff: 1100000     10times Time:1709ms
cutoff: 1150000     10times Time:1690ms
cutoff: 1200000     10times Time:1693ms
cutoff: 1250000     10times Time:1714ms
cutoff: 1300000     10times Time:2245ms
cutoff: 1350000     10times Time:2087ms
cutoff: 1400000     10times Time:2076ms
cutoff: 1450000     10times Time:2053ms
cutoff: 1500000     10times Time:2074ms
cutoff: 1550000     10times Time:2050ms
cutoff: 1600000     10times Time:1941ms
cutoff: 1650000     10times Time:1958ms
cutoff: 1700000     10times Time:1942ms
cutoff: 1750000     10times Time:1948ms
cutoff: 1800000     10times Time:2225ms
cutoff: 1850000     10times Time:2041ms
cutoff: 1900000     10times Time:2016ms
cutoff: 1950000     10times Time:2034ms
cutoff: 2000000     10times Time:2022ms
cutoff: 2050000     10times Time:2005ms
cutoff: 2100000     10times Time:1953ms
cutoff: 2150000     10times Time:1930ms
```

```
Degree of parallelism: 8
Array size: 6000000
cutoff: 200000      10times Time:3089ms
cutoff: 250000      10times Time:2543ms
cutoff: 300000      10times Time:2491ms
cutoff: 350000      10times Time:2579ms
cutoff: 400000      10times Time:2635ms
cutoff: 450000      10times Time:2479ms
cutoff: 500000      10times Time:2505ms
cutoff: 550000      10times Time:2387ms
cutoff: 600000      10times Time:2368ms
cutoff: 650000      10times Time:2288ms
cutoff: 700000      10times Time:2248ms
cutoff: 750000      10times Time:2121ms
cutoff: 800000      10times Time:2554ms
cutoff: 850000      10times Time:2260ms
cutoff: 900000      10times Time:2263ms
cutoff: 950000      10times Time:2244ms
cutoff: 1000000     10times Time:2296ms
cutoff: 1050000     10times Time:2137ms
cutoff: 1100000     10times Time:2145ms
cutoff: 1150000     10times Time:2390ms
cutoff: 1200000     10times Time:2183ms
cutoff: 1250000     10times Time:2203ms
cutoff: 1300000     10times Time:2090ms
cutoff: 1350000     10times Time:2043ms
cutoff: 1400000     10times Time:2078ms
cutoff: 1450000     10times Time:2409ms
cutoff: 1500000     10times Time:2158ms
cutoff: 1550000     10times Time:2560ms
cutoff: 1600000     10times Time:2551ms
cutoff: 1650000     10times Time:2489ms
cutoff: 1700000     10times Time:2430ms
cutoff: 1750000     10times Time:2436ms
cutoff: 1800000     10times Time:2713ms
cutoff: 1850000     10times Time:2529ms
cutoff: 1900000     10times Time:2544ms
cutoff: 1950000     10times Time:2517ms
cutoff: 2000000     10times Time:2545ms
cutoff: 2050000     10times Time:2422ms
cutoff: 2100000     10times Time:2447ms
cutoff: 2150000     10times Time:2446ms
```

It’s obvious that in all these four pictures, the quickest cutoff is from 700,000 to 800,000. Considering the experimental error, I believe it’s fair to say that **the best cutoff is 750,000.**

Conclusion:

On my computer:
The cutoff should be 750,000.
The number of threads should be 8.