

Program Structures & Algorithms

Fall 2021

Assignment No. 5

◎ Task (List down the tasks performed in the Assignment)

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.

◎ Relationship Conclusion:

1. A good cutoff is **array size / thread number**, when the cutoff is similar to this number, the performance becomes flatten and better.
2. The total number of cores of my laptop is 4, **an ideal thread number is 4**, when the thread number is larger than 4, the performance is similar.

◎ Evidence to support the conclusion:

1. Output

```
public static void main(String[] args) {
    processArgs(args);
    System.out.println("Degree of parallelism: " + ForkJoinPool.getCommonPoolParallelism());
    Random random = new Random();
    // manually set the array size from 1000000 to 3000000
    int[] array = new int[3000000]; // 1000000, 2000000, 3000000
    System.out.println("the array size is: " + array.length);
    ArrayList<Long> timeList = new ArrayList<>();
    // manually set the threads from 2 to 32
    int threads = (int) Math.pow(2, 5); // 2, 4, 8, 16, 32
    ParSort.myPool = new ForkJoinPool(threads);
    System.out.println("the number of threads is: " + threads);
    for (int j = 1; j < 110; j++) {
        ParSort.cutoff = array.length / 200 * (j + 1);
        // for (int i = 0; i < array.length; i++) array[i] = random.nextInt(10000000);
        long time =
```

The cutoff was from 1% to 55% of the array size. I manually set the array size from 1000000 to 3000000 in each main program and increased the thread number from 2 to 32. **The output was long, so I just screenshot the part of the result.**

When the thread number is 2, the outputs were:

The array size is 1000000:

Degree of parallelism: 7	cutoff: 450000	10times Time:638ms
the number of threads is: 2	cutoff: 455000	10times Time:600ms
cutoff: 10000	10times Time:1307ms	cutoff: 460000
cutoff: 15000	10times Time:882ms	cutoff: 465000
cutoff: 20000	10times Time:683ms	cutoff: 470000
cutoff: 25000	10times Time:659ms	cutoff: 475000
cutoff: 30000	10times Time:686ms	cutoff: 480000
cutoff: 35000	10times Time:675ms	cutoff: 485000
cutoff: 40000	10times Time:629ms	cutoff: 490000
cutoff: 45000	10times Time:694ms	cutoff: 495000
cutoff: 50000	10times Time:722ms	cutoff: 500000
cutoff: 55000	10times Time:632ms	cutoff: 505000
cutoff: 60000	10times Time:618ms	cutoff: 510000
cutoff: 65000	10times Time:655ms	cutoff: 515000
cutoff: 70000	10times Time:715ms	cutoff: 520000
cutoff: 75000	10times Time:736ms	cutoff: 525000
cutoff: 80000	10times Time:716ms	cutoff: 530000
cutoff: 85000	10times Time:691ms	cutoff: 535000
cutoff: 90000	10times Time:695ms	cutoff: 540000
cutoff: 95000	10times Time:699ms	cutoff: 545000
cutoff: 100000	10times Time:716ms	cutoff: 550000

The array size is 2000000:

Degree of parallelism: 7	cutoff: 900000	10times Time:1317ms
the number of threads is: 2	cutoff: 910000	10times Time:1276ms
cutoff: 20000	10times Time:1839ms	cutoff: 920000
cutoff: 30000	10times Time:1241ms	cutoff: 930000
cutoff: 40000	10times Time:1229ms	cutoff: 940000
cutoff: 50000	10times Time:1239ms	cutoff: 950000
cutoff: 60000	10times Time:1223ms	cutoff: 960000
cutoff: 70000	10times Time:1367ms	cutoff: 970000
cutoff: 80000	10times Time:1244ms	cutoff: 980000
cutoff: 90000	10times Time:1383ms	cutoff: 990000
cutoff: 100000	10times Time:1362ms	cutoff: 1000000
cutoff: 110000	10times Time:1353ms	cutoff: 1010000
cutoff: 120000	10times Time:1324ms	cutoff: 1020000
cutoff: 130000	10times Time:1559ms	cutoff: 1030000
cutoff: 140000	10times Time:1484ms	cutoff: 1040000
cutoff: 150000	10times Time:1524ms	cutoff: 1050000
cutoff: 160000	10times Time:1537ms	cutoff: 1060000
cutoff: 170000	10times Time:1546ms	cutoff: 1070000
cutoff: 180000	10times Time:1604ms	cutoff: 1080000
cutoff: 190000	10times Time:1602ms	cutoff: 1090000
cutoff: 200000	10times Time:1510ms	cutoff: 1100000

The array size is 3000000:

Degree of parallelism: 7	cutoff: 1350000	10times Time:2146ms
the number of threads is: 2	cutoff: 1365000	10times Time:2113ms
cutoff: 30000 10times Time:2924ms	cutoff: 1380000	10times Time:2182ms
cutoff: 45000 10times Time:1893ms	cutoff: 1395000	10times Time:2051ms
cutoff: 60000 10times Time:2056ms	cutoff: 1410000	10times Time:2163ms
cutoff: 75000 10times Time:2029ms	cutoff: 1425000	10times Time:2141ms
cutoff: 90000 10times Time:1987ms	cutoff: 1440000	10times Time:2066ms
cutoff: 105000 10times Time:2146ms	cutoff: 1455000	10times Time:2069ms
cutoff: 120000 10times Time:2233ms	cutoff: 1470000	10times Time:2044ms
cutoff: 135000 10times Time:2255ms	cutoff: 1485000	10times Time:2158ms
cutoff: 150000 10times Time:2237ms	cutoff: 1500000	10times Time:2160ms
cutoff: 165000 10times Time:1958ms	cutoff: 1515000	10times Time:1986ms
cutoff: 180000 10times Time:2312ms	cutoff: 1530000	10times Time:1935ms
cutoff: 195000 10times Time:2597ms	cutoff: 1545000	10times Time:1962ms
cutoff: 210000 10times Time:2376ms	cutoff: 1560000	10times Time:1963ms
cutoff: 225000 10times Time:2472ms	cutoff: 1575000	10times Time:1890ms
cutoff: 240000 10times Time:2358ms	cutoff: 1590000	10times Time:1852ms
cutoff: 255000 10times Time:2285ms	cutoff: 1605000	10times Time:1941ms
cutoff: 270000 10times Time:2301ms	cutoff: 1620000	10times Time:1832ms
cutoff: 285000 10times Time:2443ms	cutoff: 1635000	10times Time:1817ms
cutoff: 300000 10times Time:2403ms	cutoff: 1650000	10times Time:1963ms

When the thread number is 4, the outputs were:

The array size is 1000000:

Degree of parallelism: 7	cutoff: 230000	10times Time:787ms
the array size is: 1000000	cutoff: 235000	10times Time:744ms
the number of threads is: 4	cutoff: 240000	10times Time:729ms
cutoff: 10000 10times Time:1098ms	cutoff: 245000	10times Time:736ms
cutoff: 15000 10times Time:752ms	cutoff: 250000	10times Time:809ms
cutoff: 20000 10times Time:604ms	cutoff: 255000	10times Time:475ms
cutoff: 25000 10times Time:603ms	cutoff: 260000	10times Time:443ms
cutoff: 30000 10times Time:598ms	cutoff: 265000	10times Time:445ms
cutoff: 35000 10times Time:695ms	cutoff: 270000	10times Time:447ms
cutoff: 40000 10times Time:689ms	cutoff: 275000	10times Time:450ms
cutoff: 45000 10times Time:712ms	cutoff: 280000	10times Time:443ms
cutoff: 50000 10times Time:725ms	cutoff: 285000	10times Time:439ms
cutoff: 55000 10times Time:678ms	cutoff: 290000	10times Time:444ms
cutoff: 60000 10times Time:663ms	cutoff: 295000	10times Time:435ms
cutoff: 65000 10times Time:704ms	cutoff: 300000	10times Time:432ms
cutoff: 70000 10times Time:870ms	cutoff: 305000	10times Time:434ms
cutoff: 75000 10times Time:755ms	cutoff: 310000	10times Time:421ms
cutoff: 80000 10times Time:746ms	cutoff: 315000	10times Time:428ms
	cutoff: 320000	10times Time:433ms

The array size is 2000000:

Degree of parallelism: 7	cutoff: 460000	10times Time:1560ms
the array size is: 2000000	cutoff: 470000	10times Time:1583ms
the number of threads is: 4	cutoff: 480000	10times Time:1556ms
cutoff: 20000 10times Time:1944ms	cutoff: 490000	10times Time:1520ms
cutoff: 30000 10times Time:1235ms	cutoff: 500000	10times Time:1520ms
cutoff: 40000 10times Time:1207ms	cutoff: 510000	10times Time:803ms
cutoff: 50000 10times Time:1220ms	cutoff: 520000	10times Time:835ms
cutoff: 60000 10times Time:1196ms	cutoff: 530000	10times Time:858ms
cutoff: 70000 10times Time:1242ms	cutoff: 540000	10times Time:826ms
cutoff: 80000 10times Time:1315ms	cutoff: 550000	10times Time:806ms
cutoff: 90000 10times Time:1327ms	cutoff: 560000	10times Time:814ms
cutoff: 100000 10times Time:1318ms	cutoff: 570000	10times Time:853ms
cutoff: 110000 10times Time:1281ms	cutoff: 580000	10times Time:834ms
cutoff: 120000 10times Time:1300ms	cutoff: 590000	10times Time:850ms
cutoff: 130000 10times Time:1414ms	cutoff: 600000	10times Time:886ms
cutoff: 140000 10times Time:1328ms	cutoff: 610000	10times Time:837ms
cutoff: 150000 10times Time:1401ms	cutoff: 620000	10times Time:813ms
cutoff: 160000 10times Time:1360ms	cutoff: 630000	10times Time:834ms
	cutoff: 640000	10times Time:858ms

The array size is 3000000:

Degree of parallelism: 7	cutoff: 690000	10times Time:2305ms
the array size is: 3000000	cutoff: 705000	10times Time:2279ms
the number of threads is: 4	cutoff: 720000	10times Time:2420ms
cutoff: 30000 10times Time:2651ms	cutoff: 735000	10times Time:2408ms
cutoff: 45000 10times Time:2237ms	cutoff: 750000	10times Time:2334ms
cutoff: 60000 10times Time:2102ms	cutoff: 765000	10times Time:1371ms
cutoff: 75000 10times Time:2031ms	cutoff: 780000	10times Time:1265ms
cutoff: 90000 10times Time:2101ms	cutoff: 795000	10times Time:1263ms
cutoff: 105000 10times Time:2214ms	cutoff: 810000	10times Time:1253ms
cutoff: 120000 10times Time:2254ms	cutoff: 825000	10times Time:1252ms
cutoff: 135000 10times Time:2276ms	cutoff: 840000	10times Time:1251ms
cutoff: 150000 10times Time:2507ms	cutoff: 855000	10times Time:1250ms
cutoff: 165000 10times Time:2274ms	cutoff: 870000	10times Time:1253ms
cutoff: 180000 10times Time:2139ms	cutoff: 885000	10times Time:1320ms
cutoff: 195000 10times Time:2553ms	cutoff: 900000	10times Time:1346ms
cutoff: 210000 10times Time:2188ms	cutoff: 915000	10times Time:1321ms
cutoff: 225000 10times Time:2058ms	cutoff: 930000	10times Time:1331ms
cutoff: 240000 10times Time:2203ms	cutoff: 945000	10times Time:1322ms
	cutoff: 960000	10times Time:1353ms

When the thread number is 8, the outputs were:

The array size is 1000000 and 2000000:

```
Degree of parallelism: 7
the array size is: 1000000
the number of threads is: 8
cutoff: 10000      10times Time:1117ms
cutoff: 15000      10times Time:698ms
cutoff: 20000      10times Time:647ms
cutoff: 25000      10times Time:696ms
cutoff: 30000      10times Time:635ms
cutoff: 35000      10times Time:622ms
cutoff: 40000      10times Time:657ms
cutoff: 45000      10times Time:692ms
cutoff: 50000      10times Time:644ms
cutoff: 55000      10times Time:642ms
cutoff: 60000      10times Time:642ms
cutoff: 65000      10times Time:674ms
cutoff: 70000      10times Time:716ms
cutoff: 75000      10times Time:677ms
cutoff: 80000      10times Time:682ms
cutoff: 85000      10times Time:678ms
cutoff: 90000      10times Time:665ms
cutoff: 95000      10times Time:673ms
cutoff: 100000     10times Time:718ms
cutoff: 105000     10times Time:697ms
cutoff: 110000     10times Time:672ms
cutoff: 115000     10times Time:664ms
cutoff: 120000     10times Time:646ms
cutoff: 125000     10times Time:646ms
cutoff: 130000     10times Time:450ms
cutoff: 135000     10times Time:443ms
cutoff: 140000     10times Time:439ms
cutoff: 145000     10times Time:440ms
cutoff: 150000     10times Time:445ms
cutoff: 155000     10times Time:444ms
cutoff: 160000     10times Time:439ms
cutoff: 165000     10times Time:441ms
cutoff: 170000     10times Time:447ms
cutoff: 175000     10times Time:443ms
cutoff: 180000     10times Time:442ms
```

```
Degree of parallelism: 7
the array size is: 2000000
the number of threads is: 8
cutoff: 20000      10times Time:2262ms
cutoff: 30000      10times Time:1326ms
cutoff: 40000      10times Time:1380ms
cutoff: 50000      10times Time:1266ms
cutoff: 60000      10times Time:1331ms
cutoff: 70000      10times Time:1203ms
cutoff: 80000      10times Time:1250ms
cutoff: 90000      10times Time:1386ms
cutoff: 100000     10times Time:1349ms
cutoff: 110000     10times Time:1285ms
cutoff: 120000     10times Time:1228ms
cutoff: 130000     10times Time:1286ms
cutoff: 140000     10times Time:1284ms
cutoff: 150000     10times Time:1315ms
cutoff: 160000     10times Time:1216ms
cutoff: 170000     10times Time:1303ms
cutoff: 180000     10times Time:1321ms
cutoff: 190000     10times Time:1359ms
cutoff: 200000     10times Time:1316ms
cutoff: 210000     10times Time:1326ms
cutoff: 220000     10times Time:1302ms
cutoff: 230000     10times Time:1310ms
cutoff: 240000     10times Time:1323ms
cutoff: 250000     10times Time:1258ms
cutoff: 260000     10times Time:871ms
cutoff: 270000     10times Time:902ms
cutoff: 280000     10times Time:833ms
cutoff: 290000     10times Time:823ms
cutoff: 300000     10times Time:834ms
cutoff: 310000     10times Time:843ms
cutoff: 320000     10times Time:838ms
cutoff: 330000     10times Time:853ms
cutoff: 340000     10times Time:871ms
cutoff: 350000     10times Time:865ms
cutoff: 360000     10times Time:831ms
```

The array size is 3000000:

```
Degree of parallelism: 7
the array size is: 3000000
the number of threads is: 8
cutoff: 30000      10times Time:2602ms
cutoff: 45000      10times Time:1898ms
cutoff: 60000      10times Time:1858ms
cutoff: 75000      10times Time:1766ms
cutoff: 90000      10times Time:1833ms
cutoff: 105000     10times Time:1913ms
cutoff: 120000     10times Time:1872ms
cutoff: 135000     10times Time:1897ms
cutoff: 150000     10times Time:2025ms
cutoff: 165000     10times Time:2041ms
cutoff: 180000     10times Time:2023ms
cutoff: 195000     10times Time:2098ms
cutoff: 210000     10times Time:2023ms
cutoff: 225000     10times Time:2076ms
cutoff: 240000     10times Time:1994ms
cutoff: 255000     10times Time:2018ms
cutoff: 270000     10times Time:2154ms
cutoff: 285000     10times Time:1978ms
cutoff: 300000     10times Time:1994ms
cutoff: 315000     10times Time:2029ms
cutoff: 330000     10times Time:2103ms
cutoff: 345000     10times Time:2021ms
cutoff: 360000     10times Time:2056ms
cutoff: 375000     10times Time:2042ms
cutoff: 390000     10times Time:1352ms
cutoff: 405000     10times Time:1344ms
cutoff: 420000     10times Time:1328ms
cutoff: 435000     10times Time:1285ms
cutoff: 450000     10times Time:1285ms
cutoff: 465000     10times Time:1306ms
cutoff: 480000     10times Time:1300ms
cutoff: 495000     10times Time:1304ms
cutoff: 510000     10times Time:1294ms
cutoff: 525000     10times Time:1297ms
cutoff: 540000     10times Time:1281ms
```

When the thread number is 16, the outputs were:

The array size is 1000000 and 2000000:

Degree of parallelism: 7 the array size is: 1000000 the number of threads is: 16 cutoff: 10000 10times Time:1304ms cutoff: 15000 10times Time:750ms cutoff: 20000 10times Time:706ms cutoff: 25000 10times Time:828ms cutoff: 30000 10times Time:781ms cutoff: 35000 10times Time:695ms cutoff: 40000 10times Time:717ms cutoff: 45000 10times Time:682ms cutoff: 50000 10times Time:655ms cutoff: 55000 10times Time:799ms cutoff: 60000 10times Time:683ms cutoff: 65000 10times Time:498ms cutoff: 70000 10times Time:461ms cutoff: 75000 10times Time:476ms cutoff: 80000 10times Time:458ms cutoff: 85000 10times Time:491ms cutoff: 90000 10times Time:511ms cutoff: 95000 10times Time:466ms cutoff: 100000 10times Time:492ms cutoff: 105000 10times Time:482ms cutoff: 110000 10times Time:536ms cutoff: 115000 10times Time:482ms cutoff: 120000 10times Time:468ms cutoff: 125000 10times Time:514ms cutoff: 130000 10times Time:418ms cutoff: 135000 10times Time:379ms	Degree of parallelism: 7 the array size is: 2000000 the number of threads is: 16 cutoff: 20000 10times Time:1967ms cutoff: 30000 10times Time:1672ms cutoff: 40000 10times Time:1471ms cutoff: 50000 10times Time:1396ms cutoff: 60000 10times Time:1402ms cutoff: 70000 10times Time:1352ms cutoff: 80000 10times Time:1485ms cutoff: 90000 10times Time:1461ms cutoff: 100000 10times Time:1394ms cutoff: 110000 10times Time:1388ms cutoff: 120000 10times Time:1517ms cutoff: 130000 10times Time:973ms cutoff: 140000 10times Time:1024ms cutoff: 150000 10times Time:1058ms cutoff: 160000 10times Time:983ms cutoff: 170000 10times Time:942ms cutoff: 180000 10times Time:949ms cutoff: 190000 10times Time:1026ms cutoff: 200000 10times Time:984ms cutoff: 210000 10times Time:964ms cutoff: 220000 10times Time:963ms cutoff: 230000 10times Time:950ms cutoff: 240000 10times Time:1007ms cutoff: 250000 10times Time:1028ms cutoff: 260000 10times Time:852ms cutoff: 270000 10times Time:788ms
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The array size is 3000000:

Degree of parallelism: 7 the array size is: 3000000 the number of threads is: 16 cutoff: 30000 10times Time:3097ms cutoff: 45000 10times Time:2103ms cutoff: 60000 10times Time:2207ms cutoff: 75000 10times Time:2053ms cutoff: 90000 10times Time:2133ms cutoff: 105000 10times Time:2109ms cutoff: 120000 10times Time:1851ms cutoff: 135000 10times Time:1953ms cutoff: 150000 10times Time:1881ms cutoff: 165000 10times Time:1982ms cutoff: 180000 10times Time:1902ms cutoff: 195000 10times Time:1368ms cutoff: 210000 10times Time:1318ms cutoff: 225000 10times Time:1323ms cutoff: 240000 10times Time:1311ms cutoff: 255000 10times Time:1354ms cutoff: 270000 10times Time:1347ms cutoff: 285000 10times Time:1338ms cutoff: 300000 10times Time:1403ms cutoff: 315000 10times Time:1329ms cutoff: 330000 10times Time:1346ms cutoff: 345000 10times Time:1314ms cutoff: 360000 10times Time:1331ms cutoff: 375000 10times Time:1330ms cutoff: 390000 10times Time:1123ms cutoff: 405000 10times Time:1132ms

When the thread number is 16, the outputs were:

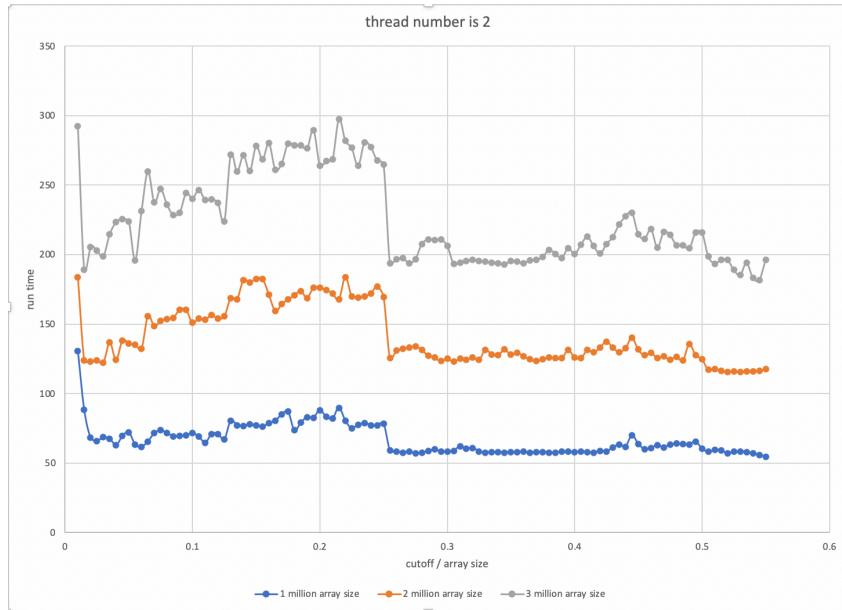
The array size is 1000000 and 2000000:

Degree of parallelism: 7 the array size is: 1000000 the number of threads is: 32 cutoff: 10000 10times Time:1692ms cutoff: 15000 10times Time:1012ms cutoff: 20000 10times Time:1005ms cutoff: 25000 10times Time:786ms cutoff: 30000 10times Time:848ms cutoff: 35000 10times Time:585ms cutoff: 40000 10times Time:590ms cutoff: 45000 10times Time:565ms cutoff: 50000 10times Time:612ms cutoff: 55000 10times Time:611ms cutoff: 60000 10times Time:593ms cutoff: 65000 10times Time:556ms cutoff: 70000 10times Time:427ms cutoff: 75000 10times Time:426ms cutoff: 80000 10times Time:440ms cutoff: 85000 10times Time:420ms cutoff: 90000 10times Time:429ms cutoff: 95000 10times Time:450ms cutoff: 100000 10times Time:450ms	Degree of parallelism: 7 the array size is: 2000000 the number of threads is: 32 cutoff: 20000 10times Time:2132ms cutoff: 30000 10times Time:1447ms cutoff: 40000 10times Time:1386ms cutoff: 50000 10times Time:1555ms cutoff: 60000 10times Time:1500ms cutoff: 70000 10times Time:1002ms cutoff: 80000 10times Time:999ms cutoff: 90000 10times Time:1041ms cutoff: 100000 10times Time:993ms cutoff: 110000 10times Time:1089ms cutoff: 120000 10times Time:1014ms cutoff: 130000 10times Time:885ms cutoff: 140000 10times Time:905ms cutoff: 150000 10times Time:927ms cutoff: 160000 10times Time:876ms cutoff: 170000 10times Time:907ms cutoff: 180000 10times Time:860ms cutoff: 190000 10times Time:907ms cutoff: 200000 10times Time:889ms
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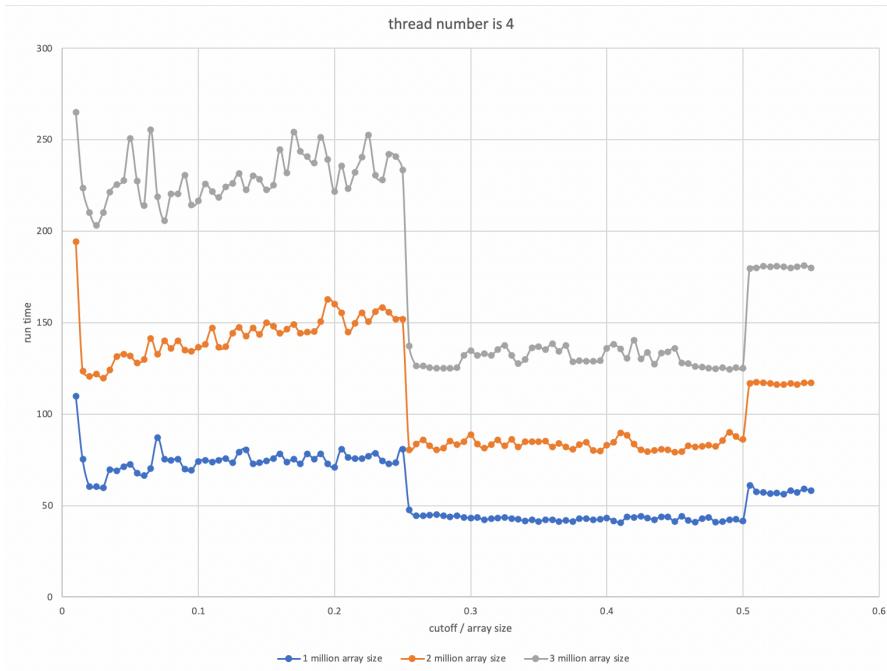
The array size is 3000000:

Degree of parallelism: 7 the array size is: 3000000 the number of threads is: 32 cutoff: 30000 10times Time:2917ms cutoff: 45000 10times Time:2091ms cutoff: 60000 10times Time:2120ms cutoff: 75000 10times Time:1962ms cutoff: 90000 10times Time:1819ms cutoff: 105000 10times Time:1457ms cutoff: 120000 10times Time:1423ms cutoff: 135000 10times Time:1402ms cutoff: 150000 10times Time:1393ms cutoff: 165000 10times Time:1467ms cutoff: 180000 10times Time:1397ms cutoff: 195000 10times Time:1231ms cutoff: 210000 10times Time:1247ms cutoff: 225000 10times Time:1261ms cutoff: 240000 10times Time:1403ms cutoff: 255000 10times Time:1283ms cutoff: 270000 10times Time:1254ms cutoff: 285000 10times Time:1231ms cutoff: 300000 10times Time:1266ms

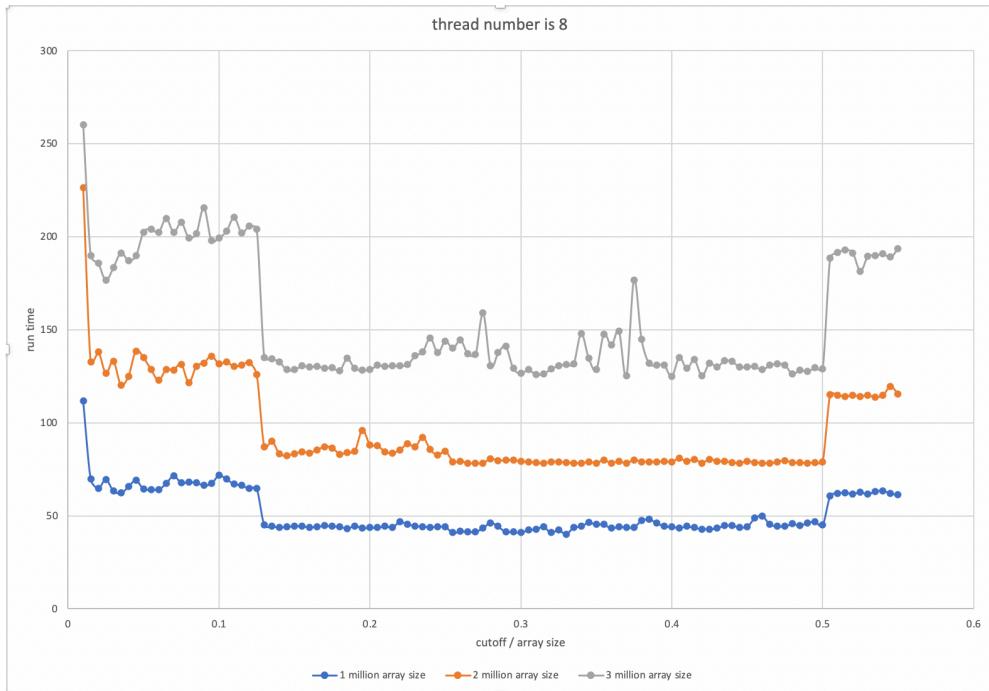
2. Graphical Representation



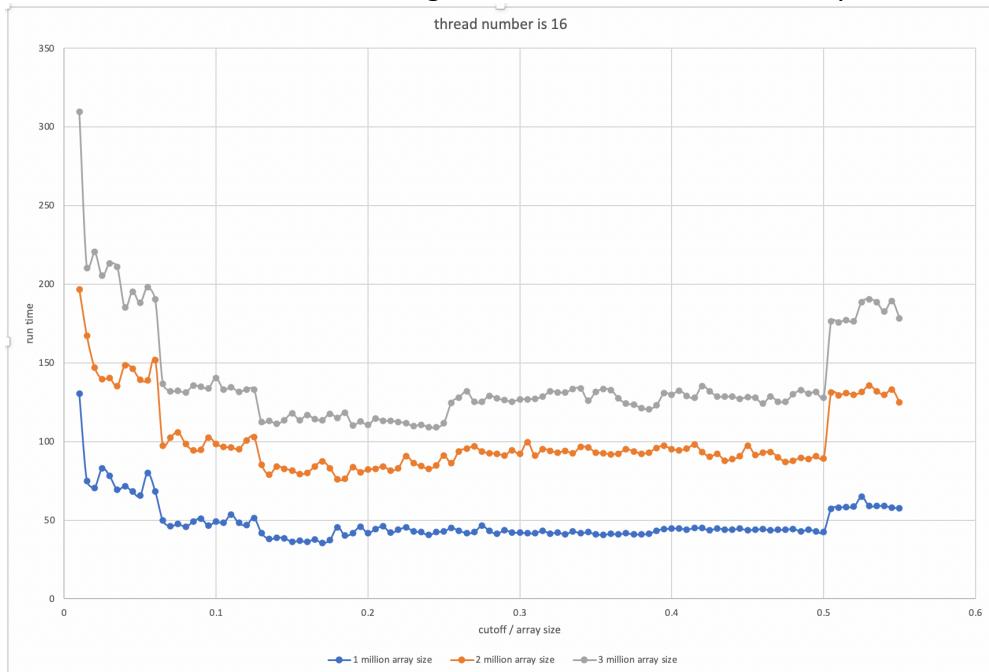
When the thread number is 2, a good cutoff is 50% of the array size



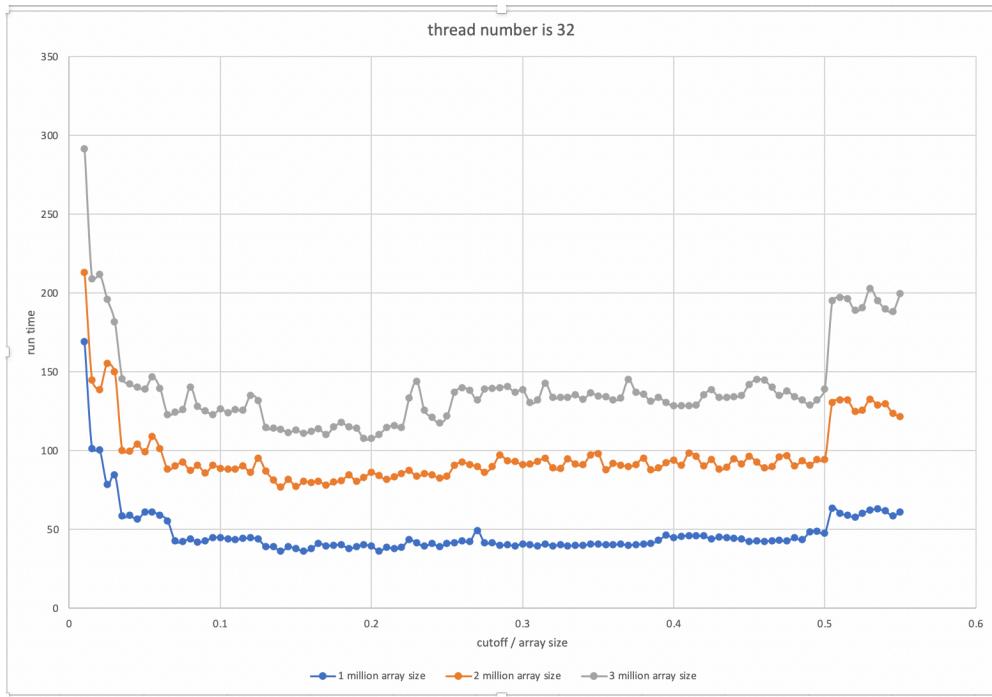
When the thread number is 4, a good cutoff is 25% of the array size



When the thread number is 8, a good cutoff is 12.5% of the array size



When the thread number is 16, a good cutoff is 6.25% of the array size



When the array size is 32, a good cutoff is 3.125% of the array size

From the above charts, we can conclude that a relatively better cutoff = array size / thread number.

Then I chose each turning point (a good cutoff) in the last five charts and tried to find a good thread number. I found out that when thread number is 4, the run time became flatten.

cutoff / array size	1 million array size	2 million array size	3 million array size
2	58.1	117.2	198.6
4	47.5	80.3	137.1
8	45	87.1	135.2
16	49.8	97.3	136.8
32	58.5	100.2	145.7

