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Program Structures & Algorithms  
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Assignment No. 5

### Task

Task is to implement a parallel sorting algorithm such that each partition of the array is sorted in parallel. You will consider two different schemes for deciding whether to sort in parallel.

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.

You must prepare a report that shows the results of your experiments and draws a conclusion (or more) about the efficacy of this method of parallelizing sort. Your experiments should involve sorting arrays of sufficient size for the parallel sort to make a difference. You should run with many different array sizes (they must be sufficiently large to make parallel sorting worthwhile, obviously) and different cutoff schemes.

### Output

First I wrote code in main.java for thread count (power of 2) and fixed array size.

# 1. Available thread count : 2 ; Array size: 2000000 ; Sorted 10 times(average)

```
Run: Main x
Degree of parallelism: 2
Array Size : 2000000
cutoff: 510000      10times Time:1191ms
cutoff: 520000      10times Time:956ms
cutoff: 530000      10times Time:926ms
cutoff: 540000      10times Time:939ms
cutoff: 550000      10times Time:946ms
cutoff: 560000      10times Time:945ms
cutoff: 570000      10times Time:947ms
cutoff: 580000      10times Time:951ms
cutoff: 590000      10times Time:957ms
cutoff: 600000      10times Time:958ms
cutoff: 610000      10times Time:952ms
cutoff: 620000      10times Time:955ms
cutoff: 630000      10times Time:963ms
cutoff: 640000      10times Time:951ms
cutoff: 650000      10times Time:953ms
cutoff: 660000      10times Time:952ms
cutoff: 670000      10times Time:951ms
cutoff: 680000      10times Time:952ms
cutoff: 690000      10times Time:956ms
cutoff: 700000      10times Time:961ms
cutoff: 710000      10times Time:958ms
cutoff: 720000      10times Time:955ms
cutoff: 730000      10times Time:954ms
cutoff: 740000      10times Time:959ms
cutoff: 750000      10times Time:974ms
cutoff: 760000      10times Time:952ms
cutoff: 770000      10times Time:957ms
cutoff: 780000      10times Time:960ms
cutoff: 790000      10times Time:957ms
cutoff: 800000      10times Time:957ms
cutoff: 810000      10times Time:959ms
cutoff: 820000      10times Time:961ms
cutoff: 830000      10times Time:962ms
cutoff: 840000      10times Time:959ms
cutoff: 850000      10times Time:960ms
cutoff: 860000      10times Time:959ms
cutoff: 870000      10times Time:1025ms
cutoff: 880000      10times Time:957ms
cutoff: 890000      10times Time:961ms
cutoff: 900000      10times Time:960ms
cutoff: 910000      10times Time:956ms
cutoff: 920000      10times Time:957ms
```

## 2. Available thread count : 4 ; Array size: 2000000 ; Sorted 10 times(average)

```
Run: Main x
Degree of parallelism: 4
Array Size : 2000000
cutoff: 510000      10times Time:1556ms
cutoff: 520000      10times Time:732ms
cutoff: 530000      10times Time:817ms
cutoff: 540000      10times Time:826ms
cutoff: 550000      10times Time:863ms
cutoff: 560000      10times Time:846ms
cutoff: 570000      10times Time:870ms
cutoff: 580000      10times Time:812ms
cutoff: 590000      10times Time:813ms
cutoff: 600000      10times Time:858ms
cutoff: 610000      10times Time:932ms
cutoff: 620000      10times Time:947ms
cutoff: 630000      10times Time:964ms
cutoff: 640000      10times Time:934ms
cutoff: 650000      10times Time:912ms
cutoff: 660000      10times Time:899ms
cutoff: 670000      10times Time:890ms
cutoff: 680000      10times Time:907ms
cutoff: 690000      10times Time:885ms
cutoff: 700000      10times Time:882ms
cutoff: 710000      10times Time:833ms
cutoff: 720000      10times Time:928ms
cutoff: 730000      10times Time:924ms
cutoff: 740000      10times Time:893ms
cutoff: 750000      10times Time:927ms
cutoff: 760000      10times Time:914ms
cutoff: 770000      10times Time:923ms
cutoff: 780000      10times Time:927ms
cutoff: 790000      10times Time:908ms
cutoff: 800000      10times Time:912ms
cutoff: 810000      10times Time:930ms
cutoff: 820000      10times Time:931ms
cutoff: 830000      10times Time:904ms
cutoff: 840000      10times Time:933ms
cutoff: 850000      10times Time:930ms
cutoff: 860000      10times Time:939ms
cutoff: 870000      10times Time:906ms
cutoff: 880000      10times Time:933ms
cutoff: 890000      10times Time:955ms
cutoff: 900000      10times Time:931ms
cutoff: 910000      10times Time:906ms
cutoff: 920000      10times Time:931ms
```

### 3. Available thread count : 8 ; Array size: 2000000 ; Sorted 10 times(average)

```
Run: Main x
Degree of parallelism: 8
Array Size : 2000000
cutoff: 510000      10times Time:1322ms
cutoff: 520000      10times Time:769ms
cutoff: 530000      10times Time:722ms
cutoff: 540000      10times Time:717ms
cutoff: 550000      10times Time:735ms
cutoff: 560000      10times Time:737ms
cutoff: 570000      10times Time:735ms
cutoff: 580000      10times Time:734ms
cutoff: 590000      10times Time:742ms
cutoff: 600000      10times Time:772ms
cutoff: 610000      10times Time:757ms
cutoff: 620000      10times Time:770ms
cutoff: 630000      10times Time:748ms
cutoff: 640000      10times Time:748ms
cutoff: 650000      10times Time:774ms
cutoff: 660000      10times Time:753ms
cutoff: 670000      10times Time:757ms
cutoff: 680000      10times Time:742ms
cutoff: 690000      10times Time:739ms
cutoff: 700000      10times Time:745ms
cutoff: 710000      10times Time:738ms
cutoff: 720000      10times Time:737ms
cutoff: 730000      10times Time:736ms
cutoff: 740000      10times Time:748ms
cutoff: 750000      10times Time:743ms
cutoff: 760000      10times Time:748ms
cutoff: 770000      10times Time:736ms
cutoff: 780000      10times Time:741ms
cutoff: 790000      10times Time:744ms
cutoff: 800000      10times Time:751ms
cutoff: 810000      10times Time:738ms
cutoff: 820000      10times Time:740ms
cutoff: 830000      10times Time:740ms
cutoff: 840000      10times Time:754ms
cutoff: 850000      10times Time:737ms
cutoff: 860000      10times Time:739ms
cutoff: 870000      10times Time:753ms
cutoff: 880000      10times Time:771ms
cutoff: 890000      10times Time:741ms
cutoff: 900000      10times Time:736ms
cutoff: 910000      10times Time:739ms
cutoff: 920000      10times Time:745ms
```

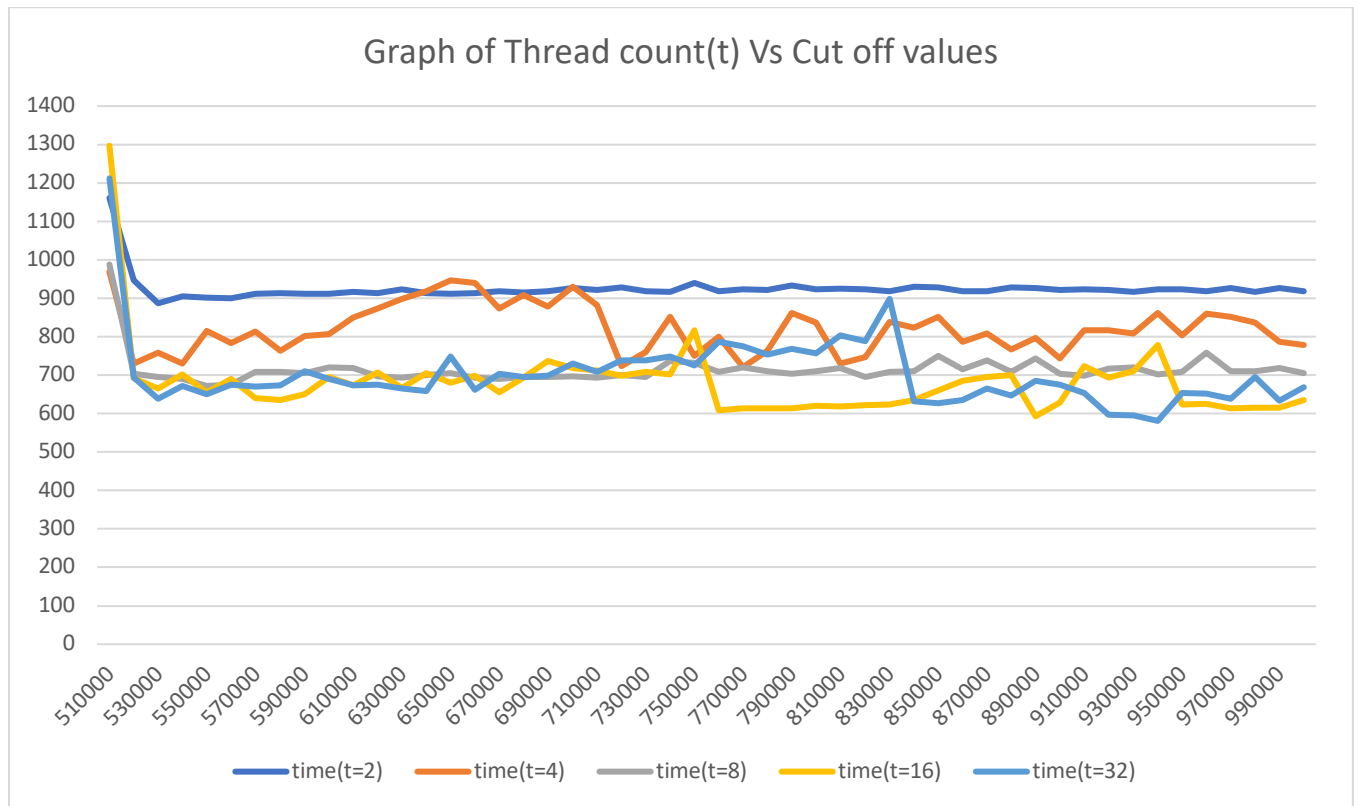
#### 4. Available thread count : 16 ; Array size: 2000000 ; Sorted 10 times(average)

```
Run: Main x
Degree of parallelism: 16
Array Size : 2000000
cutoff: 510000      10times Time:1110ms
cutoff: 520000      10times Time:755ms
cutoff: 530000      10times Time:750ms
cutoff: 540000      10times Time:723ms
cutoff: 550000      10times Time:759ms
cutoff: 560000      10times Time:860ms
cutoff: 570000      10times Time:769ms
cutoff: 580000      10times Time:998ms
cutoff: 590000      10times Time:1658ms
cutoff: 600000      10times Time:1485ms
cutoff: 610000      10times Time:760ms
cutoff: 620000      10times Time:1041ms
cutoff: 630000      10times Time:1098ms
cutoff: 640000      10times Time:764ms
cutoff: 650000      10times Time:861ms
cutoff: 660000      10times Time:900ms
cutoff: 670000      10times Time:884ms
cutoff: 680000      10times Time:789ms
cutoff: 690000      10times Time:826ms
cutoff: 700000      10times Time:814ms
cutoff: 710000      10times Time:768ms
cutoff: 720000      10times Time:758ms
cutoff: 730000      10times Time:797ms
cutoff: 740000      10times Time:1421ms
cutoff: 750000      10times Time:899ms
cutoff: 760000      10times Time:784ms
cutoff: 770000      10times Time:946ms
cutoff: 780000      10times Time:916ms
cutoff: 790000      10times Time:884ms
cutoff: 800000      10times Time:865ms
cutoff: 810000      10times Time:971ms
cutoff: 820000      10times Time:772ms
cutoff: 830000      10times Time:1066ms
cutoff: 840000      10times Time:680ms
cutoff: 850000      10times Time:719ms
cutoff: 860000      10times Time:747ms
cutoff: 870000      10times Time:882ms
cutoff: 880000      10times Time:687ms
cutoff: 890000      10times Time:697ms
cutoff: 900000      10times Time:712ms
cutoff: 910000      10times Time:710ms
cutoff: 920000      10times Time:707ms
```

## 5. Available thread count : 32 ; Array size: 2000000 ; Sorted 10 times(average)

```
Run: Main x
Degree of parallelism: 32
Array Size : 2000000
cutoff: 510000      10times Time:1109ms
cutoff: 520000      10times Time:726ms
cutoff: 530000      10times Time:707ms
cutoff: 540000      10times Time:704ms
cutoff: 550000      10times Time:726ms
cutoff: 560000      10times Time:697ms
cutoff: 570000      10times Time:710ms
cutoff: 580000      10times Time:729ms
cutoff: 590000      10times Time:711ms
cutoff: 600000      10times Time:713ms
cutoff: 610000      10times Time:725ms
cutoff: 620000      10times Time:723ms
cutoff: 630000      10times Time:740ms
cutoff: 640000      10times Time:723ms
cutoff: 650000      10times Time:717ms
cutoff: 660000      10times Time:722ms
cutoff: 670000      10times Time:717ms
cutoff: 680000      10times Time:728ms
cutoff: 690000      10times Time:724ms
cutoff: 700000      10times Time:730ms
cutoff: 710000      10times Time:728ms
cutoff: 720000      10times Time:718ms
cutoff: 730000      10times Time:711ms
cutoff: 740000      10times Time:717ms
cutoff: 750000      10times Time:737ms
cutoff: 760000      10times Time:730ms
cutoff: 770000      10times Time:746ms
cutoff: 780000      10times Time:714ms
cutoff: 790000      10times Time:734ms
cutoff: 800000      10times Time:716ms
cutoff: 810000      10times Time:715ms
cutoff: 820000      10times Time:716ms
cutoff: 830000      10times Time:717ms
cutoff: 840000      10times Time:711ms
cutoff: 850000      10times Time:714ms
cutoff: 860000      10times Time:720ms
cutoff: 870000      10times Time:719ms
cutoff: 880000      10times Time:719ms
cutoff: 890000      10times Time:723ms
cutoff: 900000      10times Time:728ms
cutoff: 910000      10times Time:718ms
cutoff: 920000      10times Time:715ms
```

## Graphical representation of evidence :



Above experiment carried out with cut off range from 510000 – 920000 and array size of 2000000 and thread count from 2- 32.

From above experiments, it is observed that, ideal cut off value between 580000-650000. Hence, 620000 and it is most efficient when thread count 8.

Let's re-confirm this by carrying out experiment with thread count as 8 and range 510000-920000 for different sizes of array by modifying main.java with respect to array size.

**Available thread count : 8 ; Array size: 3000000 ; Sorted 10 times(average)**

```
Run: Main x
Degree of parallelism: 8
Array Size : 3000000
cutoff: 510000      10times Time:1524ms
cutoff: 520000      10times Time:1185ms
cutoff: 530000      10times Time:1168ms
cutoff: 540000      10times Time:1084ms
cutoff: 550000      10times Time:1041ms
cutoff: 560000      10times Time:1016ms
cutoff: 570000      10times Time:1123ms
cutoff: 580000      10times Time:1051ms
cutoff: 590000      10times Time:1084ms
cutoff: 600000      10times Time:981ms
cutoff: 610000      10times Time:1195ms
cutoff: 620000      10times Time:904ms
cutoff: 630000      10times Time:945ms
cutoff: 640000      10times Time:940ms
cutoff: 650000      10times Time:1029ms
cutoff: 660000      10times Time:1079ms
cutoff: 670000      10times Time:1027ms
cutoff: 680000      10times Time:1190ms
cutoff: 690000      10times Time:920ms
cutoff: 700000      10times Time:831ms
cutoff: 710000      10times Time:950ms
cutoff: 720000      10times Time:946ms
cutoff: 730000      10times Time:1035ms
cutoff: 740000      10times Time:1195ms
cutoff: 750000      10times Time:889ms
cutoff: 760000      10times Time:1026ms
cutoff: 770000      10times Time:1035ms
cutoff: 780000      10times Time:1023ms
cutoff: 790000      10times Time:1034ms
cutoff: 800000      10times Time:1131ms
cutoff: 810000      10times Time:1107ms
cutoff: 820000      10times Time:1203ms
cutoff: 830000      10times Time:1026ms
cutoff: 840000      10times Time:1026ms
cutoff: 850000      10times Time:1043ms
cutoff: 860000      10times Time:1032ms
cutoff: 870000      10times Time:1045ms
cutoff: 880000      10times Time:1136ms
cutoff: 890000      10times Time:1129ms
cutoff: 900000      10times Time:1144ms
cutoff: 910000      10times Time:1153ms
cutoff: 920000      10times Time:1072ms
```



**Available thread count : 8 ; Array size: 4000000 ; Sorted 10 times(average)**

```
Run: Main x
Degree of parallelism: 8
Array Size : 4000000
cutoff: 510000      10times Time:2285ms
cutoff: 520000      10times Time:1615ms
cutoff: 530000      10times Time:1505ms
cutoff: 540000      10times Time:1562ms
cutoff: 550000      10times Time:1432ms
cutoff: 560000      10times Time:1457ms
cutoff: 570000      10times Time:1505ms
cutoff: 580000      10times Time:1447ms
cutoff: 590000      10times Time:1579ms
cutoff: 600000      10times Time:1489ms
cutoff: 610000      10times Time:1583ms
cutoff: 620000      10times Time:1241ms
cutoff: 630000      10times Time:1280ms
cutoff: 640000      10times Time:1279ms
cutoff: 650000      10times Time:1359ms
cutoff: 660000      10times Time:1505ms
cutoff: 670000      10times Time:1525ms
cutoff: 680000      10times Time:1290ms
cutoff: 690000      10times Time:1389ms
cutoff: 700000      10times Time:1476ms
cutoff: 710000      10times Time:1827ms
cutoff: 720000      10times Time:1283ms
cutoff: 730000      10times Time:1254ms
cutoff: 740000      10times Time:1427ms
cutoff: 750000      10times Time:1529ms
cutoff: 760000      10times Time:1540ms
cutoff: 770000      10times Time:1608ms
cutoff: 780000      10times Time:1554ms
cutoff: 790000      10times Time:1685ms
cutoff: 800000      10times Time:1250ms
cutoff: 810000      10times Time:1229ms
cutoff: 820000      10times Time:1298ms
cutoff: 830000      10times Time:1319ms
cutoff: 840000      10times Time:1441ms
cutoff: 850000      10times Time:1601ms
cutoff: 860000      10times Time:1219ms
cutoff: 870000      10times Time:1278ms
cutoff: 880000      10times Time:1367ms
cutoff: 890000      10times Time:1561ms
cutoff: 900000      10times Time:1460ms
cutoff: 910000      10times Time:1278ms
cutoff: 920000      10times Time:1318ms
```

Available thread count : 8 ; Array size: 5000000 ; Sorted 10 times(average)

Run: Main

## **Conclusion**

From experiments carried out above, it confirms that, even when we increased the Array size from 2000000 till 5000000 by difference of 1000000, It might have taken more time but when cut off value is 620000 and thread count is 8, algorithm work with the most efficiency.

Cut off Time : 620000

Thread count : 8