

Program Structure and Algorithms (INFO 6205)
Assignment 5: Parallel Sorting

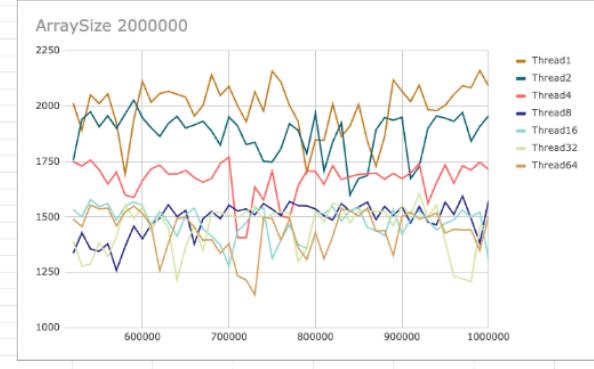
Task:

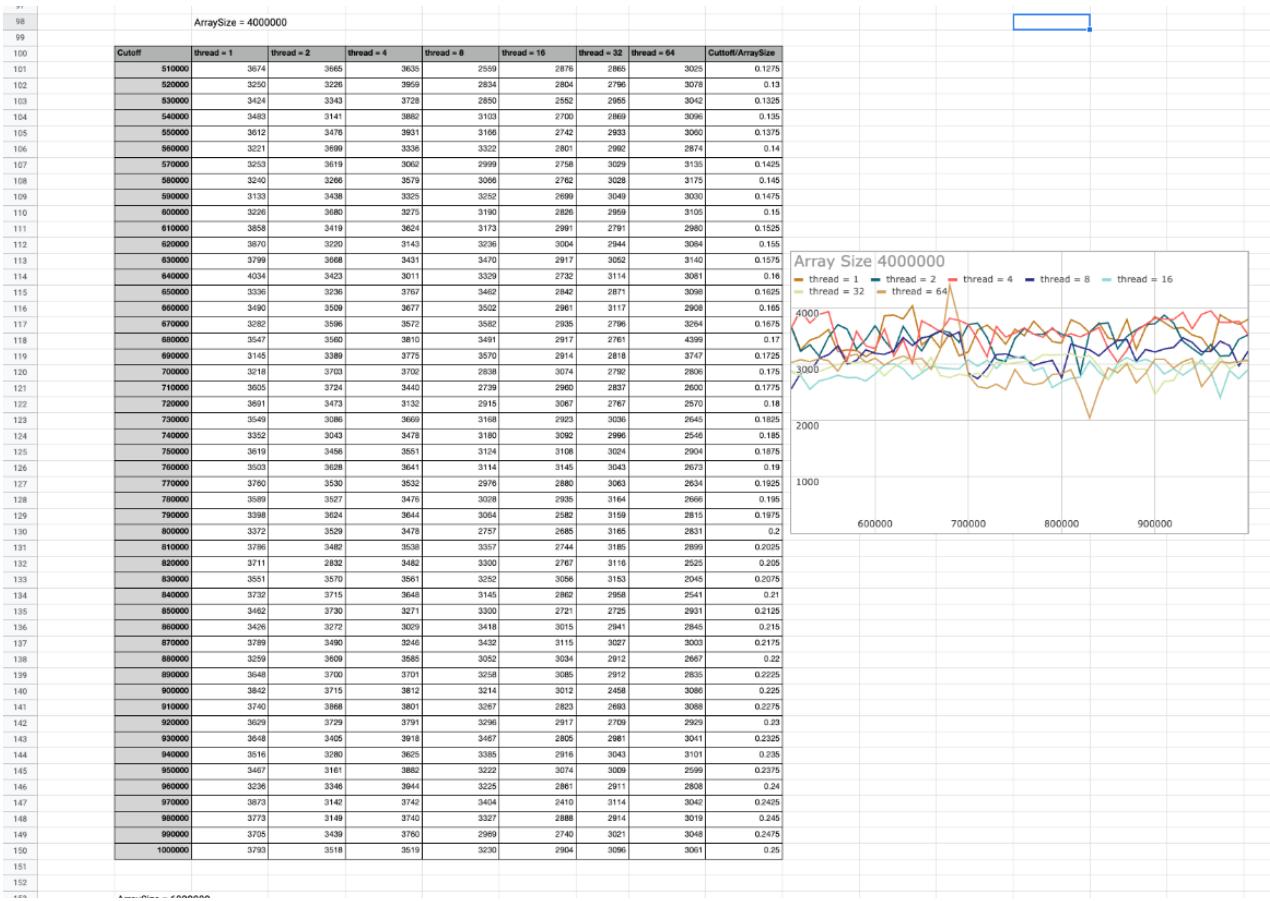
The task of this assignment is to modify the mergesort algorithm to implement a parallel sorting method. This involves sorting each partition of the input array in parallel using asynchronous function calls in Java 8.

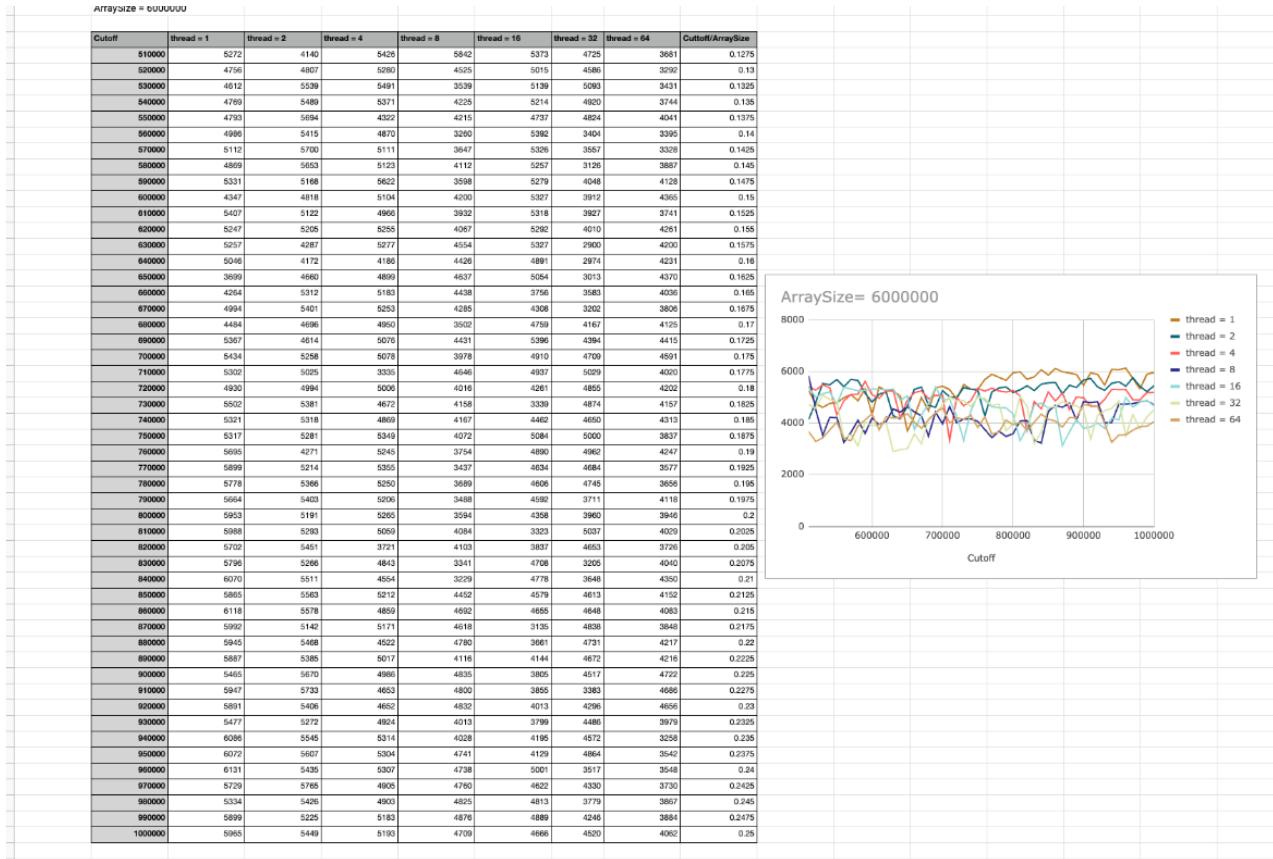
Evidence:

I tried three different values for the size of the array (2 million to 6 million). The cutoff value increases based on the percentage of array size.

	Cutoff	thread = 1	thread = 2	thread = 4	thread = 8	thread = 16	thread = 32	thread = 64	Cutoff/ArraySize
42									
43	510000	2013	1755	1750	1336	1533	1391	1490	0.255
44	520000	1893	1941	1730	1428	1501	1278	1456	0.26
45	530000	2052	1975	1757	1355	1579	1288	1554	0.265
46	540000	2012	1907	1713	1345	1547	1383	1536	0.27
47	550000	2086	1957	1649	1379	1560	1321	1540	0.275
48	560000	1954	1900	1762	1299	1486	1411	1459	0.28
49	570000	1692	1965	1599	1366	1549	1554	1522	0.285
50	580000	1938	2028	1588	1458	1568	1482	1549	0.29
51	590000	2112	1948	1664	1401	1551	1547	1515	0.295
52	600000	2018	1903	1717	1466	1463	1438	1463	0.3
53	610000	2057	1963	1754	1494	1525	1509	1257	0.305
54	620000	2087	1922	1694	1555	1477	1449	1382	0.31
55	630000	2054	1954	1694	1501	1412	1215	1491	0.315
56	640000	2041	1901	1710	1530	1509	1366	1499	0.32
57	650000	1956	1916	1678	1378	1540	1461	1452	0.325
58	660000	2003	1932	1657	1491	1445	1349	1395	0.33
59	670000	2142	1888	1674	1525	1414	1520	1397	0.335
60	680000	2048	1824	1741	1492	1373	1520	1336	0.34
61	690000	2090	1952	1770	1553	1277	1506	1380	0.345
62	700000	2002	1911	1407	1527	1434	1497	1234	0.35
63	710000	1930	1827	1406	1536	1474	1522	1215	0.355
64	720000	2064	1837	1636	1510	1537	1550	1148	0.36
65	730000	1978	1751	1577	1560	1539	1485	1497	0.365
66	740000	2159	1748	1707	1535	1311	1514	1493	0.37
67	750000	2110	1807	1505	1508	1396	1524	1395	0.375
68	760000	2004	1921	1498	1569	1464	1518	1490	0.38
69	770000	1932	1891	1640	1551	1376	1299	1361	0.385
70	780000	1702	1785	1708	1550	1358	1355	1308	0.39
71	790000	1848	1967	1705	1536	1524	1525	1429	0.395
72	800000	1846	1707	1647	1505	1514	1477	1311	0.4
73	810000	2011	1839	1731	1488	1547	1562	1413	0.405
74	820000	1863	1925	1669	1560	1481	1543	1535	0.41
75	830000	1911	1600	1682	1526	1529	1473	1529	0.415
76	840000	2009	1674	1692	1545	1541	1529	1504	0.42
77	850000	1843	1686	1695	1567	1452	1527	1541	0.425
78	860000	1730	1893	1698	1488	1439	1525	1435	0.43
79	870000	1863	1949	1670	1548	1416	1524	1439	0.435
80	880000	2119	1937	1697	1506	1535	1459	1324	0.44
81	890000	2068	1950	1673	1546	1423	1553	1503	0.445
82	900000	2021	1673	1699	1473	1487	1510	1521	0.45
83	910000	2095	1728	1741	1547	1528	1605	1491	0.455
84	920000	1985	1900	1582	1477	1485	1499	1499	0.46
85	930000	1980	1956	1655	1464	1441	1555	1518	0.465
86	940000	2004	1946	1735	1567	1471	1389	1427	0.47
87	950000	2053	1932	1652	1511	1486	1232	1444	0.475
88	960000	2092	1791	1731	1594	1531	1221	1441	0.48
89	970000	2084	1842	1712	1492	1499	1206	1441	0.485
90	980000	2182	1909	1747	1382	1522	1459	1347	0.49
91	990000	2092	1956	1715	1572	1308	1459	1502	0.495
92	1000000	2129	1856	1483	1489	1149	1524	1307	0.5
93									
94									
95									







Observation

The performance of the parallel sorting algorithm is influenced by the cutoff value and the number of threads. The cutoff value is the threshold that determines when to switch from parallel to sequential sorting. The results suggest that the performance of the algorithm is better when the cutoff value is set above 25% of the array size.

The number of threads also plays a significant role in determining the sorting speed. The data shows that increasing the number of threads improves the sorting efficiency until a certain point.

Specifically, the results suggest that when the number of threads is greater than 16, there is no significant improvement in sorting speed. For the number of threads, it seems that the more threads we

have, the faster the algorithm sorts the array. For threads numbering more than 16, there is no obvious difference.

In addition, the results suggest that the sorting time tends to be stable at some intervals of cutoff values. These intervals correspond to values between $1/(n+1)2$ and $1/n$, where $n = 2, 3, 4$, and so on. As n increases, the efficiency of sorting decreases. Therefore, it is recommended to set the cutoff value higher than 50% of the array size to achieve the highest and most stable sorting efficiency.

Conclusion

Since we are using a merge sort strategy, this strategy requires dividing the array into halves. The number of dividing operations depends on the cutoff value. This results in increasing the dividing operation to n times when the cutoff is less than $1/n2$, where $n \geq 2$. This is why the sorting time is different between the previously mentioned intervals

when the cutoff value is smaller, or, in another word, when there are more partitions. Using more threads results in significant performance gains. However, whenever two adjacent partitions are sorted and merged, some threads will be idle and not participate in the rest of the sorting. So when the cutoff value is too small, the sorting efficiency is low.

In conclusion, the best strategy for parallel sorting is to set the cutoff value greater than 50% of the array size and use two threads. This approach provides the highest and most stable sorting efficiency, taking into account the number of threads and the cutoff value.

Screenshots

The screenshot shows the Eclipse IDE interface. On the left, the Project Explorer displays a file tree with various Java files, resources, and Maven-related items. Two consoles are open on the right: the top one is titled 'Console' and shows the output of a Java application named 'Main'. The bottom console is also titled 'Console' and shows the source code for the same application. Both consoles display the same log output, which includes the degree of parallelism (7), array size (6000000), and numerous entries for cutoff values and execution times.

```
> edu.neu.cse.info6205.util
> src/main/resources
> src/test/java
> src/test/resources
> JRE System Library [JavaSE-11]
> Maven Dependencies
  target/generated-sources/annotations
  target/generated-test-sources/test-annotations
> logs
> project
> src
> target
  LICENSE
  pom.xml
> INF06205
> lab3_student
> lab5_student

<terminated> Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.justj.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/re/bin/java [Feb 18, 2023, Degree of parallelism: 7

ArraySize: 6000000  No of Threads: 1
cutoff: 510000    10times Time:5272ms
cutoff: 520000    10times Time:4756ms
cutoff: 530000    10times Time:4612ms
cutoff: 540000    10times Time:4769ms
cutoff: 550000    10times Time:4793ms
cutoff: 560000    10times Time:4986ms
cutoff: 570000    10times Time:5112ms
cutoff: 580000    10times Time:4869ms
cutoff: 590000    10times Time:5313ms
cutoff: 600000    10times Time:4347ms
cutoff: 610000    10times Time:5407ms
cutoff: 620000    10times Time:5247ms

24      ArrayList<Long> timeList = new ArrayList<>();
<terminated> Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.justj.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/re/bin/java [Feb 18, 23
Degree of parallelism: 7

ArraySize: 6000000  No of Threads: 1
cutoff: 510000    10times Time:5272ms
cutoff: 520000    10times Time:4756ms
cutoff: 530000    10times Time:4612ms
cutoff: 540000    10times Time:4769ms
cutoff: 550000    10times Time:4793ms
cutoff: 560000    10times Time:4960ms
cutoff: 570000    10times Time:5112ms
cutoff: 580000    10times Time:4869ms
cutoff: 590000    10times Time:5313ms
cutoff: 600000    10times Time:4347ms
cutoff: 610000    10times Time:5407ms
cutoff: 620000    10times Time:5247ms
cutoff: 630000    10times Time:5257ms
cutoff: 640000    10times Time:5046ms
cutoff: 650000    10times Time:3699ms
cutoff: 660000    10times Time:4264ms
cutoff: 670000    10times Time:4994ms
cutoff: 680000    10times Time:4484ms
cutoff: 690000    10times Time:5367ms
cutoff: 700000    10times Time:5434ms
cutoff: 710000    10times Time:5302ms
cutoff: 720000    10times Time:4930ms
cutoff: 730000    10times Time:5502ms
cutoff: 740000    10times Time:5321ms
cutoff: 750000    10times Time:5317ms
cutoff: 760000    10times Time:5695ms
cutoff: 770000    10times Time:5899ms
cutoff: 780000    10times Time:5778ms
cutoff: 790000    10times Time:5664ms
cutoff: 800000    10times Time:5953ms
```

```
> edu.neu.coe.info6205.pq
> edu.neu.coe.info6205.randomwalk
> edu.neu.coe.info6205.rnlengthEncoding
> edu.neu.coe.info6205.sort
> edu.neu.coe.info6205.sort.classic
> edu.neu.coe.info6205.sort.counting
> edu.neu.coe.info6205.sort.elementary
> edu.neu.coe.info6205.sort.hashCode
> edu.neu.coe.info6205.sort.linearithmic
> edu.neu.coe.info6205.sort.par
> Main.java
> ParSort.java
> edu.neu.coe.info6205.symbolTable
> edu.neu.coe.info6205.symbolTable.hashtable
> edu.neu.coe.info6205.symbolTable.tree
> edu.neu.coe.info6205.threesum
> edu.neu.coe.info6205.union_find
> edu.neu.coe.info6205.util
> src/main/resources
> src/test/java
> src/test/resources
> JRE System Library [JavaSE-11]
> Maven Dependencies
  target/generated-sources/annotations
  target/generated-test-sources/test-annotations
> logs
> project
> src
> target
  LICENSE
  pom.xml
> INF-06205
> lab3_student
> lab5_student
```

Console X

```
terminated: Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.jst:j.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/jre/bin/java (Feb 18, 2023,
```

```
cutoff: 980000    10times Time:534ms
cutoff: 990000    10times Time:589ms
cutoff: 1000000    10times Time:596ms
ArraySize: 6000000  No of Threads: 2
cutoff: 510000    10times Time:414ms
cutoff: 520000    10times Time:480ms
cutoff: 530000    10times Time:539ms
cutoff: 540000    10times Time:548ms
cutoff: 550000    10times Time:569ms
cutoff: 560000    10times Time:541ms
cutoff: 570000    10times Time:570ms
cutoff: 580000    10times Time:563ms
cutoff: 590000    10times Time:516ms
cutoff: 600000    10times Time:481ms
cutoff: 610000    10times Time:512ms
cutoff: 620000    10times Time:505ms
cutoff: 630000    10times Time:427ms
cutoff: 640000    10times Time:417ms
cutoff: 650000    10times Time:466ms
cutoff: 660000    10times Time:531ms
cutoff: 670000    10times Time:540ms
cutoff: 680000    10times Time:496ms
cutoff: 690000    10times Time:461ms
cutoff: 700000    10times Time:528ms
cutoff: 710000    10times Time:502ms
cutoff: 720000    10times Time:494ms
cutoff: 730000    10times Time:538ms
cutoff: 740000    10times Time:531ms
cutoff: 750000    10times Time:528ms
cutoff: 760000    10times Time:427ms
cutoff: 770000    10times Time:521ms
cutoff: 780000    10times Time:536ms
cutoff: 790000    10times Time:540ms
cutoff: 800000    10times Time:519ms
cutoff: 810000    10times Time:593ms
cutoff: 820000    10times Time:545ms
cutoff: 830000    10times Time:526ms
cutoff: 840000    10times Time:551ms
cutoff: 850000    10times Time:556ms
cutoff: 860000    10times Time:557ms
cutoff: 870000    10times Time:5142ms
cutoff: 880000    10times Time:5468ms
cutoff: 890000    10times Time:5385ms
cutoff: 900000    10times Time:5670ms
cutoff: 910000    10times Time:5733ms
cutoff: 920000    10times Time:5406ms
cutoff: 930000    10times Time:5272ms
cutoff: 940000    10times Time:5545ms
cutoff: 950000    10times Time:5607ms
cutoff: 960000    10times Time:5435ms
cutoff: 970000    10times Time:5765ms
cutoff: 980000    10times Time:5426ms
cutoff: 990000    10times Time:5225ms
cutoff: 1000000   10times Time:5499ms
ArraySize: 6000000  No of Threads: 4
cutoff: 510000    10times Time:5426ms
cutoff: 520000    10times Time:5280ms
cutoff: 530000    10times Time:5491ms
```

```
> terminated: Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.jst:j.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/jre/bin/java (Feb 18, 2023,
```

```
cutoff: 730000    10times Time:5381ms
cutoff: 740000    10times Time:5318ms
cutoff: 750000    10times Time:5281ms
cutoff: 760000    10times Time:4271ms
cutoff: 770000    10times Time:5214ms
cutoff: 780000    10times Time:5366ms
cutoff: 790000    10times Time:5403ms
cutoff: 800000    10times Time:5191ms
cutoff: 810000    10times Time:593ms
cutoff: 820000    10times Time:5451ms
cutoff: 830000    10times Time:5266ms
cutoff: 840000    10times Time:5511ms
cutoff: 850000    10times Time:5563ms
cutoff: 860000    10times Time:5578ms
cutoff: 870000    10times Time:5142ms
cutoff: 880000    10times Time:5468ms
cutoff: 890000    10times Time:5385ms
cutoff: 900000    10times Time:5670ms
cutoff: 910000    10times Time:5733ms
cutoff: 920000    10times Time:5406ms
cutoff: 930000    10times Time:5272ms
cutoff: 940000    10times Time:5545ms
cutoff: 950000    10times Time:5607ms
cutoff: 960000    10times Time:5435ms
cutoff: 970000    10times Time:5765ms
cutoff: 980000    10times Time:5426ms
cutoff: 990000    10times Time:5225ms
cutoff: 1000000   10times Time:5499ms
ArraySize: 6000000  No of Threads: 4
cutoff: 510000    10times Time:5426ms
cutoff: 520000    10times Time:5280ms
cutoff: 530000    10times Time:5491ms
```

```
> terminated: Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.jst:j.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/jre/bin/java (Feb 18, 2023,
```

```
cutoff: 850000    10times Time:5212ms
cutoff: 860000    10times Time:489ms
cutoff: 870000    10times Time:5171ms
cutoff: 880000    10times Time:4522ms
cutoff: 890000    10times Time:5017ms
cutoff: 900000    10times Time:4986ms
cutoff: 910000    10times Time:4653ms
cutoff: 920000    10times Time:4652ms
cutoff: 930000    10times Time:4924ms
cutoff: 940000    10times Time:5314ms
cutoff: 950000    10times Time:5304ms
cutoff: 960000    10times Time:5307ms
cutoff: 970000    10times Time:4905ms
cutoff: 980000    10times Time:4903ms
cutoff: 990000    10times Time:5183ms
cutoff: 1000000   10times Time:5193ms
ArraySize: 6000000  No of Threads: 8
cutoff: 510000    10times Time:5842ms
cutoff: 520000    10times Time:4525ms
cutoff: 530000    10times Time:3539ms
cutoff: 540000    10times Time:4225ms
cutoff: 550000    10times Time:4215ms
cutoff: 560000    10times Time:3260ms
cutoff: 570000    10times Time:3647ms
cutoff: 580000    10times Time:4112ms
cutoff: 590000    10times Time:3598ms
cutoff: 600000    10times Time:4200ms
cutoff: 610000    10times Time:3932ms
cutoff: 620000    10times Time:4067ms
cutoff: 630000    10times Time:4554ms
cutoff: 640000    10times Time:4426ms
cutoff: 650000    10times Time:4637ms
```

```
<terminated> Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.just.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/jre/bin/java [Feb 18, 2023, ArraySize: 5000000 No of Threads: 16
cutoff: 1000000 10times Time:1709ms
cutoff: 5000000 10times Time:5373ms
cutoff: 5100000 10times Time:5015ms
cutoff: 5200000 10times Time:5139ms
cutoff: 5300000 10times Time:5214ms
cutoff: 5400000 10times Time:4737ms
cutoff: 5500000 10times Time:5392ms
cutoff: 5600000 10times Time:526ms
cutoff: 5700000 10times Time:5256ms
cutoff: 5800000 10times Time:527ms
cutoff: 5900000 10times Time:5279ms
cutoff: 6000000 10times Time:5327ms
cutoff: 6100000 10times Time:5318ms
cutoff: 6200000 10times Time:5292ms
cutoff: 6300000 10times Time:5327ms
cutoff: 6400000 10times Time:4891ms
cutoff: 6500000 10times Time:5054ms
cutoff: 6600000 10times Time:5756ms
cutoff: 6700000 10times Time:4308ms
cutoff: 6800000 10times Time:4759ms
cutoff: 6900000 10times Time:5396ms
cutoff: 7000000 10times Time:4910ms
cutoff: 7100000 10times Time:4937ms
cutoff: 7200000 10times Time:4261ms
cutoff: 7300000 10times Time:3339ms
cutoff: 7400000 10times Time:4462ms
cutoff: 7500000 10times Time:5084ms
cutoff: 7600000 10times Time:4890ms
cutoff: 7700000 10times Time:4634ms
cutoff: 7800000 10times Time:4606ms
cutoff: 7900000 10times Time:4592ms
cutoff: 8000000 10times Time:4358ms
```



```
<terminated> Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.just.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/jre/bin/java [Feb 18, 2023, cutoff: 5000000 10times Time:5799ms
cutoff: 9400000 10times Time:4195ms
cutoff: 9500000 10times Time:4129ms
cutoff: 9600000 10times Time:5001ms
cutoff: 9700000 10times Time:4622ms
cutoff: 9800000 10times Time:4813ms
cutoff: 9900000 10times Time:4889ms
cutoff: 10000000 10times Time:4666ms
ArraySize: 6000000 No of Threads: 32
cutoff: 510000 10times Time:4725ms
cutoff: 520000 10times Time:4586ms
cutoff: 530000 10times Time:5093ms
cutoff: 540000 10times Time:4920ms
cutoff: 550000 10times Time:4824ms
cutoff: 560000 10times Time:3404ms
cutoff: 570000 10times Time:3557ms
cutoff: 580000 10times Time:3126ms
cutoff: 590000 10times Time:4048ms
cutoff: 600000 10times Time:3912ms
cutoff: 610000 10times Time:3927ms
cutoff: 620000 10times Time:4010ms
cutoff: 630000 10times Time:2900ms
cutoff: 640000 10times Time:2974ms
cutoff: 650000 10times Time:3013ms
cutoff: 660000 10times Time:3583ms
cutoff: 670000 10times Time:3202ms
cutoff: 680000 10times Time:4167ms
cutoff: 690000 10times Time:4394ms
cutoff: 700000 10times Time:4709ms
cutoff: 710000 10times Time:5029ms
cutoff: 720000 10times Time:4855ms
cutoff: 730000 10times Time:4874ms
```



```
<terminated> Main [Java Application] /Applications/Eclipse Java.app/Contents/Eclipse/plugins/org.eclipse.just.openjdk.hotspot.jre.full.macosx.aarch64_17.0.5.v20221102-0933/jre/bin/java [Feb 18, 2023, cutoff: 5000000 10times Time:4520ms
cutoff: 1000000 10times Time:4520ms
ArraySize: 6000000 No of Threads: 64
cutoff: 510000 10times Time:3681ms
cutoff: 520000 10times Time:3292ms
cutoff: 530000 10times Time:3431ms
cutoff: 540000 10times Time:3744ms
cutoff: 550000 10times Time:4041ms
cutoff: 560000 10times Time:3395ms
cutoff: 570000 10times Time:3328ms
cutoff: 580000 10times Time:3887ms
cutoff: 590000 10times Time:4128ms
cutoff: 600000 10times Time:4365ms
cutoff: 610000 10times Time:3741ms
cutoff: 620000 10times Time:4261ms
cutoff: 630000 10times Time:4200ms
cutoff: 640000 10times Time:4231ms
cutoff: 650000 10times Time:4370ms
cutoff: 660000 10times Time:4036ms
cutoff: 670000 10times Time:3806ms
cutoff: 680000 10times Time:4125ms
cutoff: 690000 10times Time:4155ms
cutoff: 700000 10times Time:4591ms
cutoff: 710000 10times Time:4620ms
cutoff: 720000 10times Time:4262ms
cutoff: 730000 10times Time:4157ms
cutoff: 740000 10times Time:4313ms
cutoff: 750000 10times Time:3837ms
cutoff: 760000 10times Time:4247ms
cutoff: 770000 10times Time:3577ms
cutoff: 780000 10times Time:3656ms
cutoff: 790000 10times Time:4119ms
```



