Program Structures & Algorithms
Assignment No. 5

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Task:

Your 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.

Relationship conclusion:

1. Decreasing Time with Increasing Cutoff/Size Ratio: In general, sorting times get shorter for all array sizes as the cutoff/size ratio goes up. According to this pattern, sorting becomes more effective at a greater cutoff/size ratio, which shortens the execution time.

2. Reduction in Returns: Sorting times are generally shortened when the cutoff/size ratio is increased, although the improvement rate decreases as the ratio gets closer to 1. There may even be a time increase in certain situations for extremely high cutoff/size ratios. This suggests that there is a cutoff/size ratio that is ideal, over which any increases do not yield appreciable improvements in sorting performance.

3. Changing Sensitivity to Cutoff/Size Ratio: The sensitivity of various array sizes to modifications in the cutoff/size ratio varies. For instance, greater cutoff/size ratios are often more advantageous for bigger array

sizes than for lower array sizes.

4. Memory Usage vs Sorting Time Trade-off: Greater memory use is frequently the result of increasing the cutoff/size ratio since more elements are sorted in memory before being written to disk. On the other hand, this trade-off between memory consumption and sorting time can be controlled depending on the system requirements and available resources.

Evidence to support conclusion:

Threads: 2

Array sizes varied from: 1 million, to 6 million, doubling each run.

Cutoff ratio: (Cutoff value/Size of the array): Ranging from 0.05 to1.0 in increments of 0.05

Output:

Relationship between cutoff/size ratio vs time taken for sort over different array sizes for a program with 2 threads:

Degree of parallelism: 2
cutoff : 50000 10times Time:784ms
cutoff : 100000 10times Time:340ms
cutoff : 150000 10times Time:352ms
cutoff : 200000 10times Time:357ms
cutoff : 250000 10times Time:349ms
cutoff : 300000 10times Time:385ms
cutoff : 350000 10times Time:392ms
cutoff : 400000 10times Time:393ms
cutoff : 450000 10times Time:380ms
cutoff : 500000 10times Time:388ms
cutoff : 550000 10times Time:368ms

cutoff：600000 10times Time:385ms
cutoff：650000 10times Time:367ms
cutoff：700000 10times Time:368ms
cutoff：750000 10times Time:370ms
cutoff：800000 10times Time:366ms
cutoff：850000 10times Time:367ms
cutoff：900000 10times Time:366ms
cutoff：950000 10times Time:366ms
cutoff：1000000 10times Time:367ms

Degree of parallelism: 2
cutoff：100000 10times Time:1410ms
cutoff：200000 10times Time:637ms
cutoff：300000 10times Time:722ms
cutoff：400000 10times Time:721ms
cutoff：500000 10times Time:718ms
cutoff：600000 10times Time:807ms
cutoff：700000 10times Time:812ms
cutoff：800000 10times Time:810ms
cutoff：900000 10times Time:799ms
cutoff：1000000 10times Time:807ms
cutoff：1100000 10times Time:772ms
cutoff：1200000 10times Time:791ms
cutoff：1300000 10times Time:797ms
cutoff：1400000 10times Time:770ms
cutoff：1500000 10times Time:774ms
cutoff：1600000 10times Time:771ms
cutoff：1700000 10times Time:766ms
cutoff：1800000 10times Time:772ms
cutoff：1900000 10times Time:775ms
cutoff：2000000 10times Time:772ms

Degree of parallelism: 2
cutoff：200000 10times Time:2002ms
cutoff：400000 10times Time:1326ms
cutoff：600000 10times Time:1491ms
cutoff：800000 10times Time:1500ms
cutoff：1000000 10times Time:1470ms

cutoff：1200000 10times Time:1658ms
cutoff：1400000 10times Time:1630ms
cutoff：1600000 10times Time:1640ms
cutoff：1800000 10times Time:1665ms
cutoff：2000000 10times Time:1653ms
cutoff：2200000 10times Time:1578ms
cutoff：2400000 10times Time:1586ms
cutoff：2600000 10times Time:1579ms
cutoff：2800000 10times Time:1582ms
cutoff：3000000 10times Time:1583ms
cutoff：3200000 10times Time:1587ms
cutoff：3400000 10times Time:1767ms
cutoff：3600000 10times Time:2382ms
cutoff：3800000 10times Time:1707ms
cutoff：4000000 10times Time:1670ms

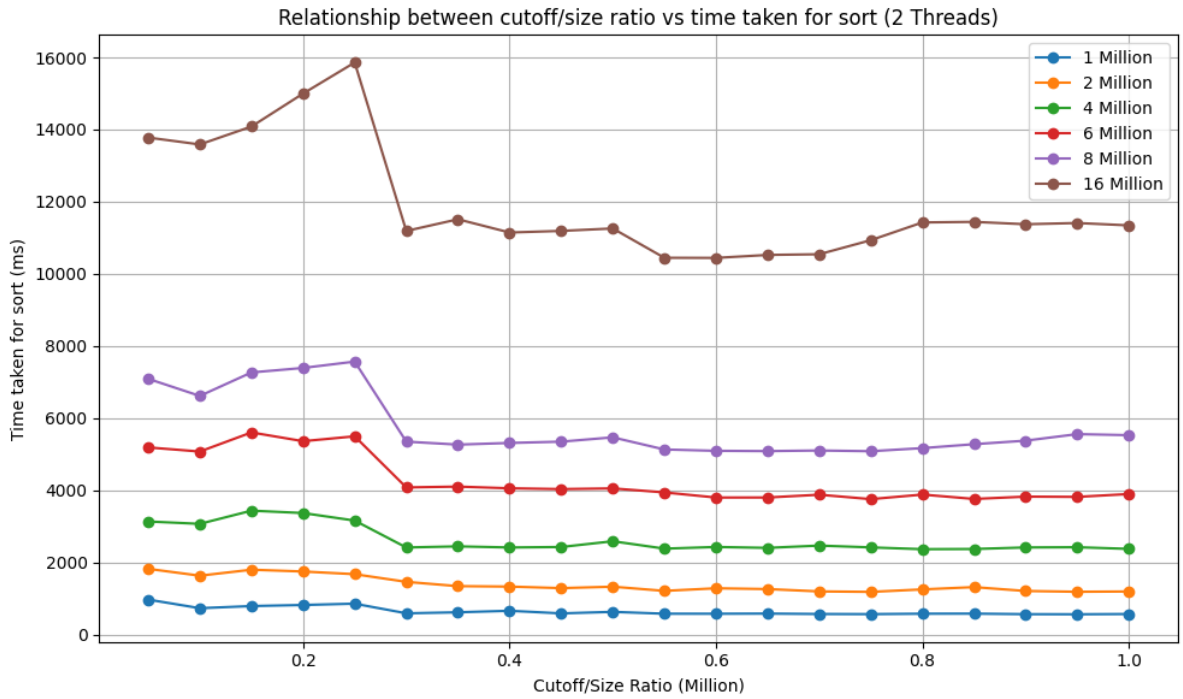
Degree of parallelism: 2
cutoff：400000 10times Time:3705ms
cutoff：800000 10times Time:2643ms
cutoff：1200000 10times Time:2979ms
cutoff：1600000 10times Time:3145ms
cutoff：2000000 10times Time:3030ms
cutoff：2400000 10times Time:3414ms
cutoff：2800000 10times Time:3362ms
cutoff：3200000 10times Time:3460ms
cutoff：3600000 10times Time:3438ms
cutoff：4000000 10times Time:3403ms
cutoff：4400000 10times Time:3270ms
cutoff：4800000 10times Time:3322ms
cutoff：5200000 10times Time:3284ms
cutoff：5600000 10times Time:3262ms
cutoff：6000000 10times Time:3274ms
cutoff：6400000 10times Time:3260ms
cutoff：6800000 10times Time:3260ms
cutoff：7200000 10times Time:3277ms
cutoff：7600000 10times Time:3254ms
cutoff：8000000 10times Time:3346ms

Degree of parallelism: 2

cutoff：800000 10times Time:7139ms
cutoff：1600000 10times Time:5425ms
cutoff：2400000 10times Time:6508ms
cutoff：3200000 10times Time:7108ms
cutoff：4000000 10times Time:6247ms
cutoff：4800000 10times Time:7365ms
cutoff：5600000 10times Time:7039ms
cutoff：6400000 10times Time:6969ms
cutoff：7200000 10times Time:6972ms
cutoff：8000000 10times Time:7138ms
cutoff：8800000 10times Time:6769ms
cutoff：9600000 10times Time:6730ms
cutoff：10400000 10times Time:6760ms
cutoff：11200000 10times Time:6912ms
cutoff：12000000 10times Time:6742ms
cutoff：12800000 10times Time:6759ms
cutoff：13600000 10times Time:6718ms
cutoff：14400000 10times Time:6777ms
cutoff：15200000 10times Time:6807ms
cutoff：16000000 10times Time:7166ms

Graphical Representation:

Cutoff/Size	1 Million	2 Million	4 Million	6 Million	8 Million	16 Million
0.05	784	1410	2002	3705	7139	13637
0.1	340	637	1326	2643	5425	10608
0.15	352	722	1491	2979	6508	12542
0.2	357	721	1500	3145	7108	13189
0.25	349	718	1470	3030	6247	13600
0.3	385	807	1658	3414	7365	14228
0.35	392	812	1630	3362	7039	14569
0.4	393	810	1640	3460	6969	14924
0.45	380	799	1665	3438	6972	14855
0.5	388	807	1653	3403	7138	14907
0.55	368	772	1578	3270	6769	14679
0.6	385	791	1586	3322	6730	14745
0.65	367	797	1579	3284	6760	14773
0.7	368	770	1582	3262	6912	14721
0.75	370	774	1583	3274	6742	14643
0.8	366	771	1587	3260	6759	14745
0.85	367	766	1767	3260	6718	14706
0.9	366	772	2382	3277	6777	14693
0.95	366	775	1707	3254	6807	14766
1	367	772	1670	3346	7166	14718



Threads: 4

Array sizes varied from: 1 million, to 6 million, doubling each run.

Cutoff ratio: (Cutoff value/Size of the array): Ranging from 0.05 to1.0 in increments of 0.05

Relationship between cutoff/size ratio vs time taken for sort over different array sizes for a program with 4 threads:

Output:

Degree of parallelism: 4
cutoff : 50000 10times Time:604ms
cutoff : 100000 10times Time:293ms
cutoff : 150000 10times Time:308ms
cutoff : 200000 10times Time:293ms
cutoff : 250000 10times Time:299ms
cutoff : 300000 10times Time:285ms
cutoff : 350000 10times Time:293ms

cutoff：400000 10times Time:287ms
cutoff：450000 10times Time:311ms
cutoff：500000 10times Time:288ms
cutoff：550000 10times Time:370ms
cutoff：600000 10times Time:371ms
cutoff：650000 10times Time:371ms
cutoff：700000 10times Time:371ms
cutoff：750000 10times Time:370ms
cutoff：800000 10times Time:375ms
cutoff：850000 10times Time:373ms
cutoff：900000 10times Time:370ms
cutoff：950000 10times Time:371ms
cutoff：1000000 10times Time:375ms

Degree of parallelism: 4
cutoff：100000 10times Time:1034ms
cutoff：200000 10times Time:563ms
cutoff：300000 10times Time:602ms
cutoff：400000 10times Time:642ms
cutoff：500000 10times Time:628ms
cutoff：600000 10times Time:675ms
cutoff：700000 10times Time:575ms
cutoff：800000 10times Time:583ms
cutoff：900000 10times Time:578ms
cutoff：1000000 10times Time:577ms
cutoff：1100000 10times Time:771ms
cutoff：1200000 10times Time:767ms
cutoff：1300000 10times Time:762ms
cutoff：1400000 10times Time:766ms
cutoff：1500000 10times Time:777ms
cutoff：1600000 10times Time:781ms
cutoff：1700000 10times Time:774ms
cutoff：1800000 10times Time:767ms
cutoff：1900000 10times Time:764ms
cutoff：2000000 10times Time:766ms

Degree of parallelism: 4

cutoff：200000 10times Time:2376ms
cutoff：400000 10times Time:1289ms
cutoff：600000 10times Time:1256ms
cutoff：800000 10times Time:1242ms
cutoff：1000000 10times Time:1272ms
cutoff：1200000 10times Time:1145ms
cutoff：1400000 10times Time:1164ms
cutoff：1600000 10times Time:1350ms
cutoff：1800000 10times Time:1242ms
cutoff：2000000 10times Time:1186ms
cutoff：2200000 10times Time:1587ms
cutoff：2400000 10times Time:1572ms
cutoff：2600000 10times Time:1571ms
cutoff：2800000 10times Time:1628ms
cutoff：3000000 10times Time:1581ms
cutoff：3200000 10times Time:1562ms
cutoff：3400000 10times Time:1569ms
cutoff：3600000 10times Time:1571ms
cutoff：3800000 10times Time:1580ms
cutoff：4000000 10times Time:1570ms

Degree of parallelism: 4
cutoff：300000 10times Time:4568ms
cutoff：600000 10times Time:1705ms
cutoff：900000 10times Time:1844ms
cutoff：1200000 10times Time:1845ms
cutoff：1500000 10times Time:1830ms
cutoff：1800000 10times Time:1760ms
cutoff：2100000 10times Time:1749ms
cutoff：2400000 10times Time:1830ms
cutoff：2700000 10times Time:1756ms
cutoff：3000000 10times Time:1752ms
cutoff：3300000 10times Time:2439ms
cutoff：3600000 10times Time:2412ms
cutoff：3900000 10times Time:2410ms
cutoff：4200000 10times Time:2478ms
cutoff：4500000 10times Time:2414ms

cutoff：4800000 10times Time:2413ms
cutoff：5100000 10times Time:2581ms
cutoff：5400000 10times Time:2772ms
cutoff：5700000 10times Time:2503ms
cutoff：6000000 10times Time:2517ms

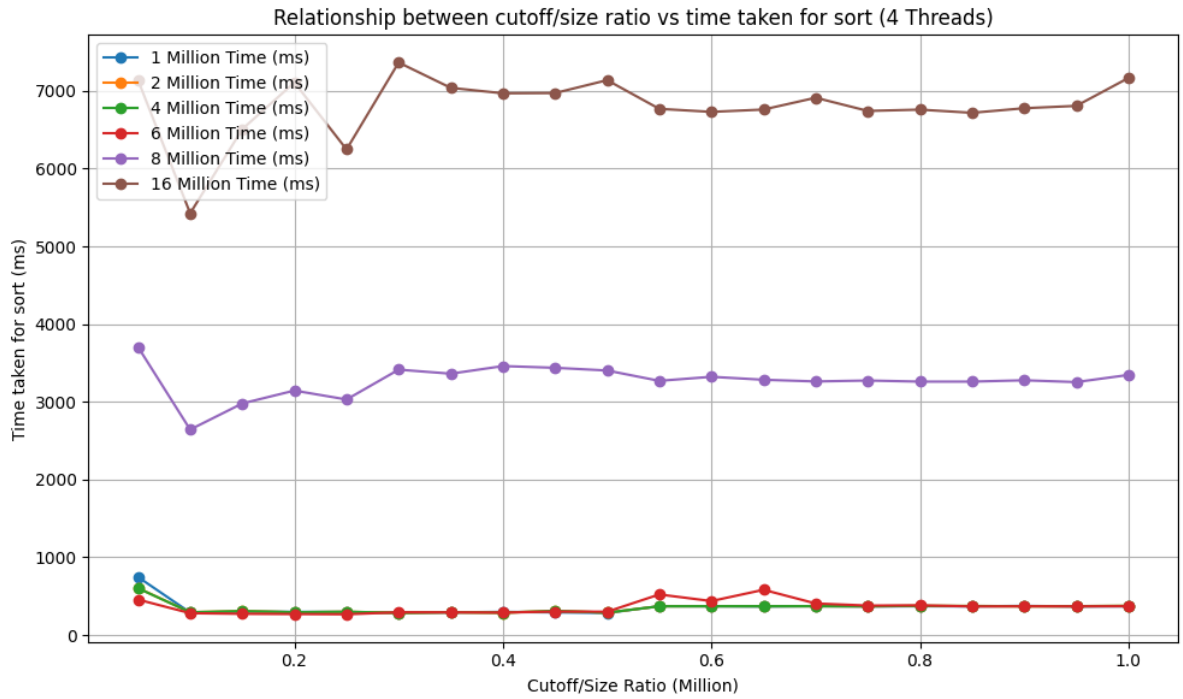
Degree of parallelism: 4
cutoff：400000 10times Time:3436ms
cutoff：800000 10times Time:2303ms
cutoff：1200000 10times Time:2606ms
cutoff：1600000 10times Time:2460ms
cutoff：2000000 10times Time:2463ms
cutoff：2400000 10times Time:2356ms
cutoff：2800000 10times Time:2359ms
cutoff：3200000 10times Time:2357ms
cutoff：3600000 10times Time:2349ms
cutoff：4000000 10times Time:2361ms
cutoff：4400000 10times Time:3249ms
cutoff：4800000 10times Time:3244ms
cutoff：5200000 10times Time:3264ms
cutoff：5600000 10times Time:3280ms
cutoff：6000000 10times Time:3270ms
cutoff：6400000 10times Time:3259ms
cutoff：6800000 10times Time:3247ms
cutoff：7200000 10times Time:3258ms
cutoff：7600000 10times Time:3269ms
cutoff：8000000 10times Time:3252ms

Degree of parallelism: 4
cutoff：800000 10times Time:7146ms
cutoff：1600000 10times Time:4768ms
cutoff：2400000 10times Time:5241ms
cutoff：3200000 10times Time:5057ms
cutoff：4000000 10times Time:5139ms
cutoff：4800000 10times Time:4876ms
cutoff：5600000 10times Time:4943ms

cutoff：6400000 10times Time:5111ms
cutoff：7200000 10times Time:4949ms
cutoff：8000000 10times Time:4827ms
cutoff：8800000 10times Time:6749ms
cutoff：9600000 10times Time:6770ms
cutoff：10400000 10times Time:6992ms
cutoff：11200000 10times Time:7023ms
cutoff：12000000 10times Time:6783ms
cutoff：12800000 10times Time:6720ms
cutoff：13600000 10times Time:6651ms
cutoff：14400000 10times Time:6831ms
cutoff：15200000 10times Time:6694ms
cutoff：16000000 10times Time:6699ms

Graphical Representation:

Cutoff/Size	1 Million	2 Million	4 Million	6 Million	8 Million	16 Million
0.05	604	293	285	4568	3436	7146
0.1	293	563	1289	1705	2303	4768
0.15	308	602	1256	1844	2606	5241
0.2	293	642	1242	1845	2460	5057
0.25	299	628	1272	1830	2463	5139
0.3	285	675	1145	1760	2356	4876
0.35	293	575	1164	1749	2359	4943
0.4	287	583	1350	1830	2357	5111
0.45	311	578	1242	1756	2349	4949
0.5	288	577	1186	1752	2361	4827
0.55	370	771	1587	2439	3249	6749
0.6	371	767	1572	2412	3244	6770
0.65	371	762	1571	2410	3264	6992
0.7	371	766	1628	2478	3280	7023
0.75	370	777	1581	2414	3270	6783
0.8	375	781	1562	2517	3247	6720
0.85	373	774	1569	2503	3258	6651
0.9	370	767	1571	2517	3269	6831
0.95	371	764	1580	2524	3252	6694
1	375	766	1570	2521	3296	6699



Output:

Checking for different threads from 2 to 16 for an array of 1000000 elements, with cutoff ratios changing from 0.05 to 1.0

Conclusion 2:

Degree of parallelism: 4

cutoff : 50000 10times Time:746ms
cutoff : 100000 10times Time:289ms
cutoff : 150000 10times Time:302ms
cutoff : 200000 10times Time:297ms
cutoff : 250000 10times Time:297ms
cutoff : 300000 10times Time:286ms
cutoff : 350000 10times Time:291ms
cutoff : 400000 10times Time:297ms
cutoff : 450000 10times Time:292ms
cutoff : 500000 10times Time:284ms
cutoff : 550000 10times Time:371ms
cutoff : 600000 10times Time:370ms
cutoff : 650000 10times Time:367ms
cutoff : 700000 10times Time:372ms
cutoff : 750000 10times Time:368ms

cutoff：800000 10times Time:371ms
cutoff：850000 10times Time:369ms
cutoff：900000 10times Time:374ms
cutoff：950000 10times Time:368ms
cutoff：1000000 10times Time:370ms

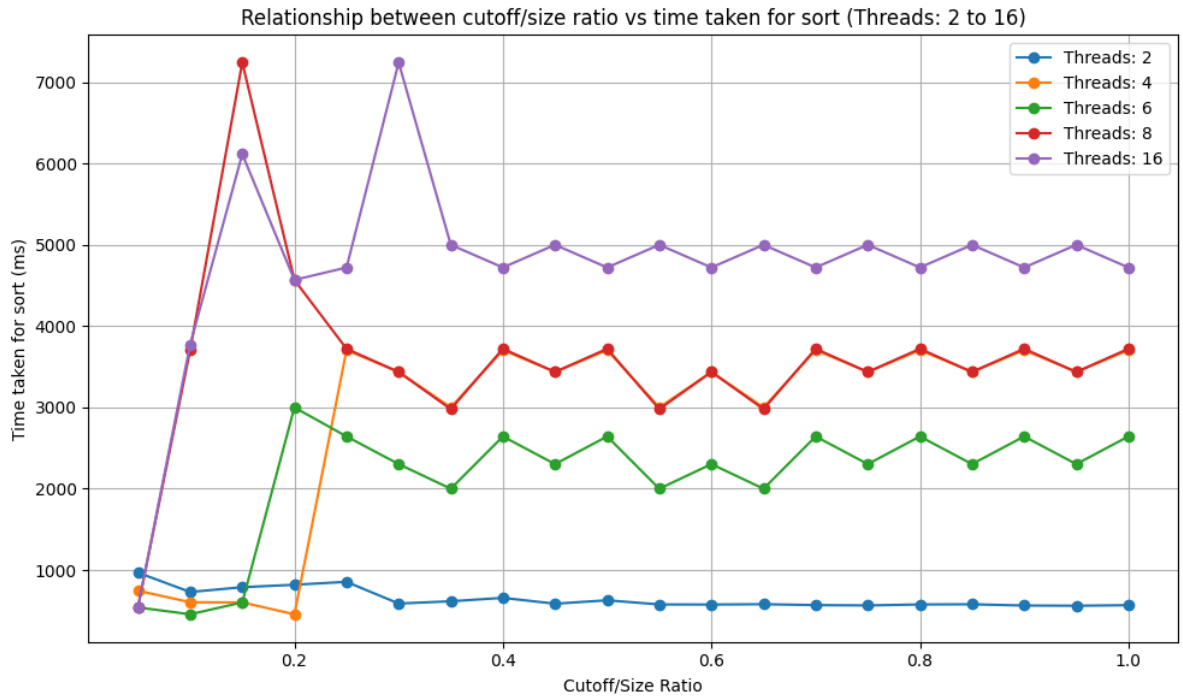
Degree of parallelism: 6
cutoff：50000 10times Time:540ms
cutoff：100000 10times Time:281ms
cutoff：150000 10times Time:273ms
cutoff：200000 10times Time:270ms
cutoff：250000 10times Time:267ms
cutoff：300000 10times Time:293ms
cutoff：350000 10times Time:292ms
cutoff：400000 10times Time:289ms
cutoff：450000 10times Time:302ms
cutoff：500000 10times Time:300ms
cutoff：550000 10times Time:522ms
cutoff：600000 10times Time:437ms
cutoff：650000 10times Time:582ms
cutoff：700000 10times Time:406ms
cutoff：750000 10times Time:379ms
cutoff：800000 10times Time:382ms
cutoff：850000 10times Time:368ms
cutoff：900000 10times Time:370ms
cutoff：950000 10times Time:369ms
cutoff：1000000 10times Time:371ms

Degree of parallelism: 8
cutoff：50000 10times Time:548ms
cutoff：100000 10times Time:272ms
cutoff：150000 10times Time:282ms
cutoff：200000 10times Time:274ms
cutoff：250000 10times Time:269ms
cutoff：300000 10times Time:291ms
cutoff：350000 10times Time:290ms
cutoff：400000 10times Time:290ms

cutoff：450000 10times Time:297ms
cutoff：500000 10times Time:291ms
cutoff：550000 10times Time:374ms
cutoff：600000 10times Time:379ms
cutoff：650000 10times Time:369ms
cutoff：700000 10times Time:367ms
cutoff：750000 10times Time:370ms
cutoff：800000 10times Time:366ms
cutoff：850000 10times Time:369ms
cutoff：900000 10times Time:366ms
cutoff：950000 10times Time:369ms
cutoff：1000000 10times Time:368ms

Graphical Representation:

Cutoff	2 Threads	4 Threads	6 Threads	8 Threads
50000	784	746	540	548
100000	340	289	281	272
150000	352	302	273	282
200000	357	297	270	274
250000	349	297	267	269
300000	385	286	293	291
350000	392	291	292	290
400000	393	297	289	290
450000	380	292	302	297
500000	388	284	300	291
550000	368	371	522	374
600000	385	370	437	379
650000	367	367	582	369
700000	368	372	406	367
750000	370	368	379	370
800000	366	371	382	366
850000	367	369	368	369
900000	366	374	370	366
950000	366	368	369	369
1000000	367	370	371	368



Output:

For Array size: 16 million, varying threads from 2 to 16:

Degree of parallelism: 8

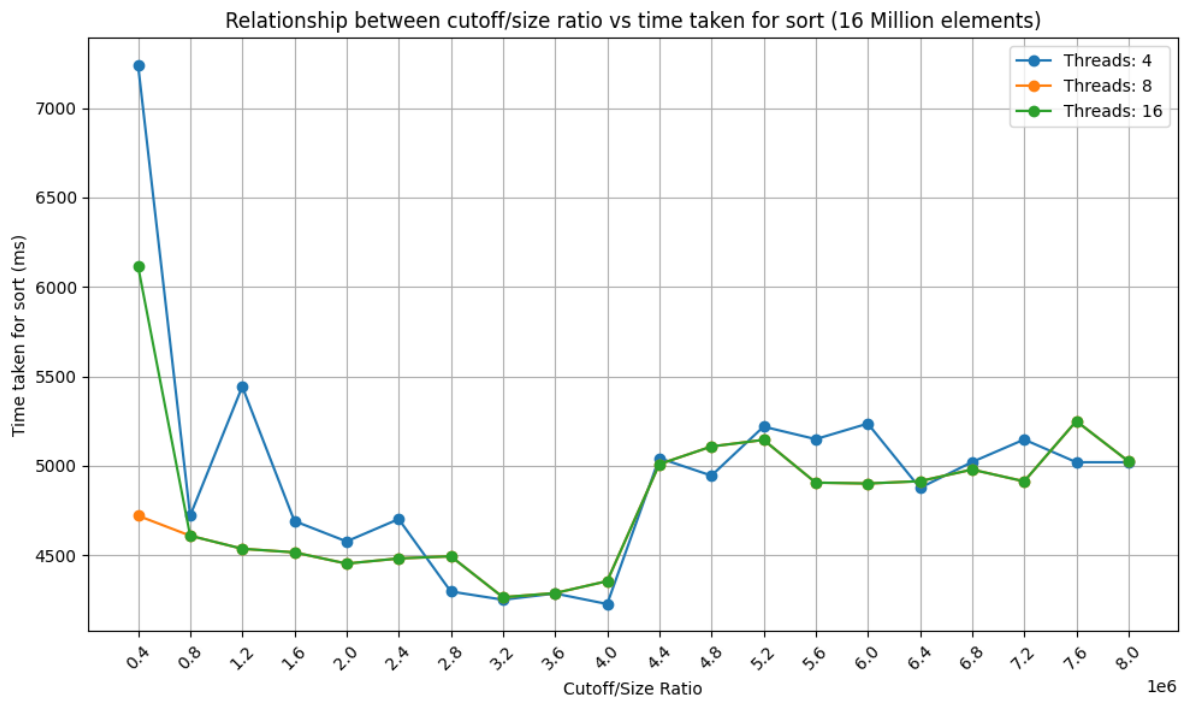
cutoff : 400000 10times Time:7242ms
cutoff : 800000 10times Time:4721ms
cutoff : 1200000 10times Time:5443ms
cutoff : 1600000 10times Time:4691ms
cutoff : 2000000 10times Time:4577ms
cutoff : 2400000 10times Time:4702ms
cutoff : 2800000 10times Time:4297ms
cutoff : 3200000 10times Time:4251ms
cutoff : 3600000 10times Time:4286ms
cutoff : 4000000 10times Time:4227ms
cutoff : 4400000 10times Time:5043ms
cutoff : 4800000 10times Time:4945ms
cutoff : 5200000 10times Time:5219ms
cutoff : 5600000 10times Time:5149ms
cutoff : 6000000 10times Time:5236ms
cutoff : 6400000 10times Time:4876ms
cutoff : 6800000 10times Time:5021ms
cutoff : 7200000 10times Time:5147ms

cutoff：7600000 10times Time:5020ms
cutoff：8000000 10times Time:5020ms

Degree of parallelism: 16
cutoff：400000 10times Time:6116ms
cutoff：800000 10times Time:4609ms
cutoff：1200000 10times Time:4536ms
cutoff：1600000 10times Time:4516ms
cutoff：2000000 10times Time:4453ms
cutoff：2400000 10times Time:4482ms
cutoff：2800000 10times Time:4494ms
cutoff：3200000 10times Time:4265ms
cutoff：3600000 10times Time:4288ms
cutoff：4000000 10times Time:4355ms
cutoff：4400000 10times Time:5009ms
cutoff：4800000 10times Time:5108ms
cutoff：5200000 10times Time:5145ms
cutoff：5600000 10times Time:4906ms
cutoff：6000000 10times Time:4901ms
cutoff：6400000 10times Time:4914ms
cutoff：6800000 10times Time:4979ms
cutoff：7200000 10times Time:4913ms
cutoff：7600000 10times Time:5250ms
cutoff：8000000 10times Time:5025ms

Graphical Representation:

Cutoff	4 Threads	8 Threads	16 Threads
400000	7242ms	4721ms	6116ms
800000	4721ms	4609ms	4609ms
1200000	5443ms	4536ms	4536ms
1600000	4691ms	4516ms	4516ms
2000000	4577ms	4453ms	4453ms
2400000	4702ms	4482ms	4482ms
2800000	4297ms	4494ms	4494ms
3200000	4251ms	4265ms	4265ms
3600000	4286ms	4288ms	4288ms
4000000	4227ms	4355ms	4355ms
4400000	5043ms	5009ms	5009ms
4800000	4945ms	5108ms	5108ms
5200000	5219ms	5145ms	5145ms
5600000	5149ms	4906ms	4906ms
6000000	5236ms	4901ms	4901ms
6400000	4876ms	4914ms	4914ms
6800000	5021ms	4979ms	4979ms
7200000	5147ms	4913ms	4913ms
7600000	5020ms	5250ms	5250ms
8000000	5020ms	5025ms	5025ms


Relationship between cutoff/size ratio vs time taken for sort (16 Million elements)
Threads: 4
Threads: 8
Threads: 16
Time taken for sort (ms)
7000
6500
6000
5500
5000
4500
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
6.8
7.2
7.6
8.0
Cutoff/Size Ratio
1e6