**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:**

A screenshot of a table

Description automatically generated

A graph of different colored lines

Description automatically generated

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

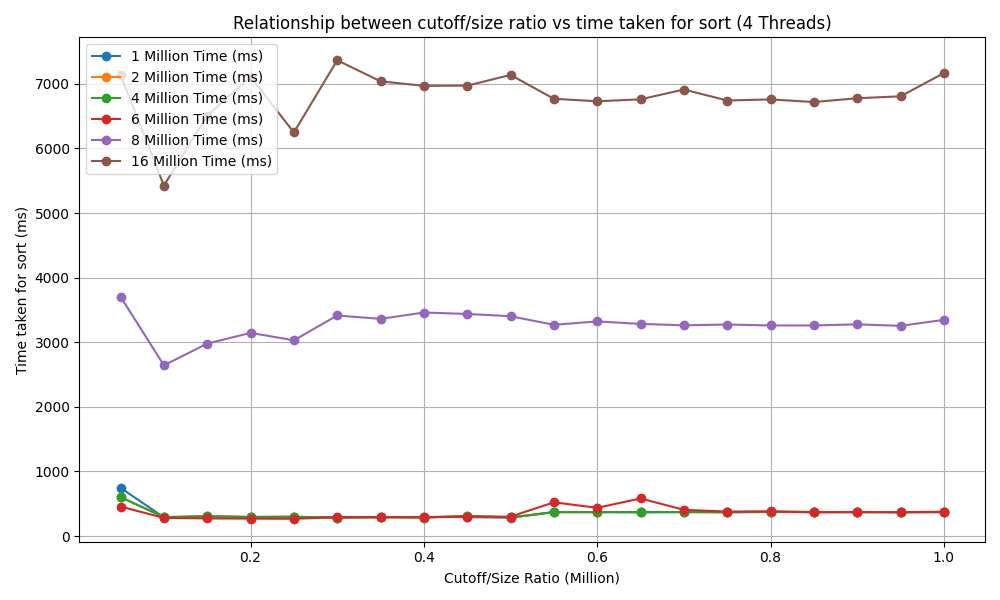
cutoff：15200000 10times Time:6694ms

cutoff：16000000 10times Time:6699ms

**Graphical Representation:**

A screenshot of a table

Description automatically generated



**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:**

A screenshot of a table

Description automatically generated

A graph of different colored lines

Description automatically generated

**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:**

A screenshot of a number table

Description automatically generated

A graph with lines and numbers

Description automatically generated