Program Structures and Algorithms
Spring 2023(SEC –8)

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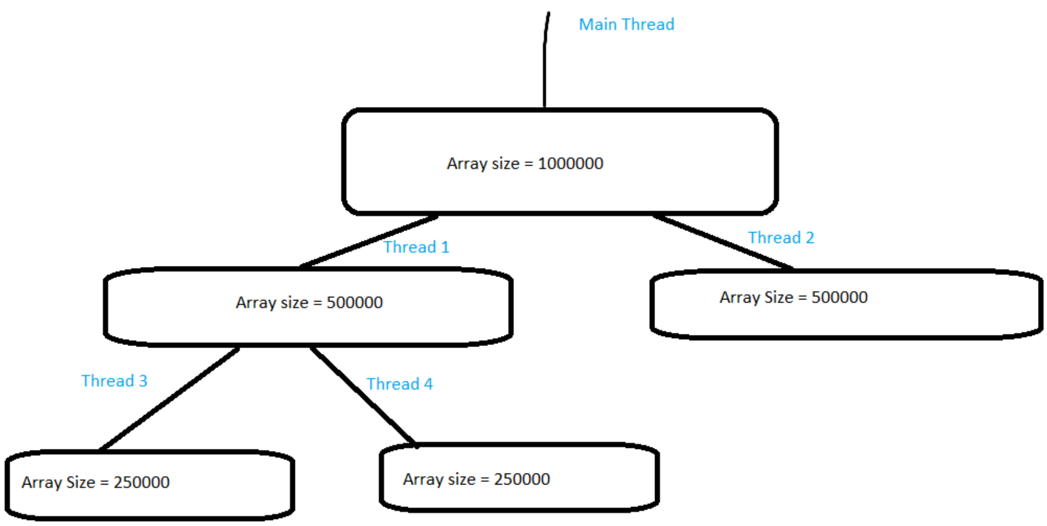
Task: To shows the results of your experiments and draws a conclusion (or more) about the efficacy of this method of parallelization sort.

Relationship Conclusion: With the experiments I would conclude that yes parallel sort indeed works wonder (wonder in terms of milliseconds okay) but for it to work an appropriate cutoff value is needed for each parallelism. Parallelism here means number of threads which could be run concurrently. Cutoff value is the size of the array after which we won't be doing any parallel sort. What I hypothesize is that cutoff value should be a reached when all the threads are running in parallel and we reach a certain depth That is the Array size at the depth we reach by parallelizing all the threads should be equal to cutoff. For example – suppose we have an array of size 1000000 and we could run total of 4 threads in parallel so the depth we would reach when all the threads are working in parallel would be 2. Now from the diagram we can see instead of waiting for other threads to get free so that we delegate our work to them I feel like Thread 3 and 4 should do their own work. This will remove unnecessary waiting time for threads. So Suppose the cutoff value is X, depth is D and N is size of array so lets find D in terms of X. It would be $N/2^D = X$.
$N/X = 2^D$
$\log_2(N/X) = D$.



Paralleling more would have better result provided with a good cutoff values for that particular Parallelization. Also it could been the case that Parallelizing with 32 and 64 threads could have been better since the test which I ran was on a machine having 16 total logical processors or threads.

Table of CutOff / array size ratio to speed or efficiency of different Parallelizing.
P_4 – represent Parallelizing with four threads similarly with other P_8 – 8 threads, P_16 – 16 threads

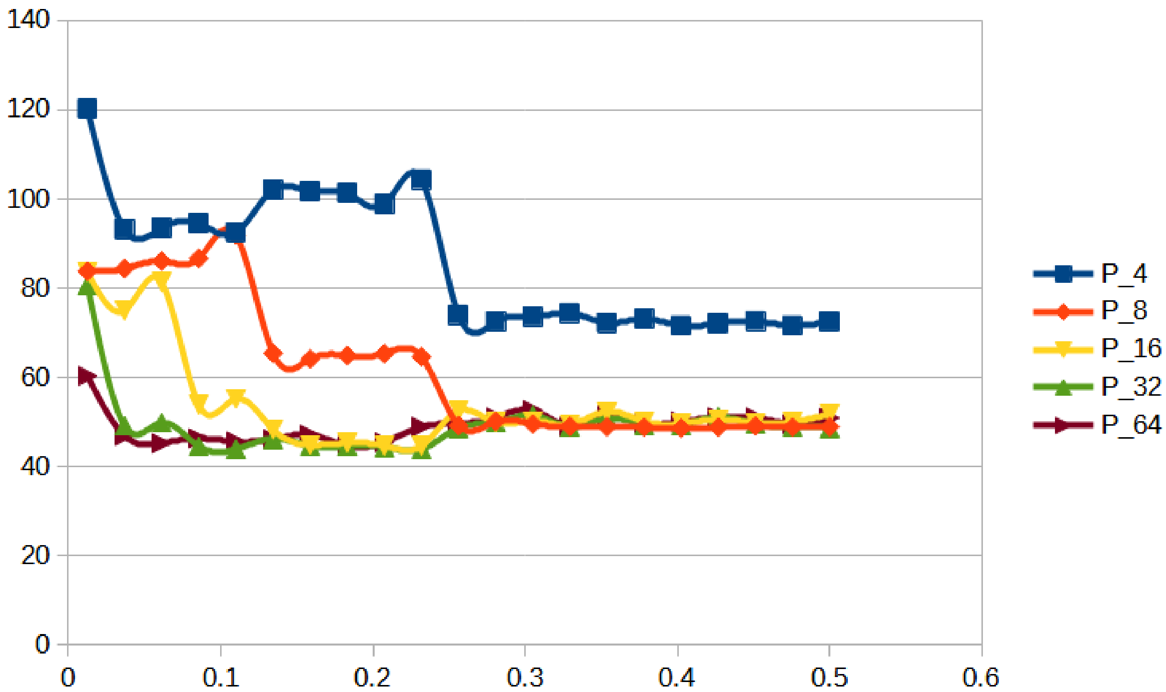
Cutoff Ratio	P_4	P_8	P_16	P_32	P_64
0 – 0.02	4th	3rd	2nd	1st	1st
0.02 – 0.15	4th	3rd	2nd	1st (fastest in whole series)	1st (fastest in whole series)
0.15 – 0.25	3rd	2nd	1st	1st	1st
0.25 – 0.5	2nd	1st	1st	1st	1st

- Before we go any further Max depth achieved by each Parallelization **-**
- P_4 – depth of 2
- P_8 – depth of 3
- P_16 – depth of 4
- P_32 – depth of 5
- P_64 – depth of 6
- **Behavior for Cutoff ratio from (0 – 0.02)** – Here mostly depth needed to reach the cutoff is from 7-10 which cannot be achieved by any of the Parallelizing which we are using. So the times are worst.
- **Behavior for Cutoff ratio from (0.02 – 0.15) -** Here depth is between 4-6 where cutoff is reached. Which is kind of best case scenario for P_32 and _64 which could reach such depths. Now the question comes to mind why did not the P_16 is performing as well as the P_32 where depth is 4, this could be because when P_16 reaches the depth of 4 it has only 2 threads which will work on that level, where as P_32 would have more threads to work on the same depth. Now it's time for the runner ups presenting P_16, P_8 and P_4 in sequence. Each doing there best parallel work and the one who could run as many parallel threads would win which is P_16 then P_8 and then P_4.
- **Behavior for Cutoff ratio from (0.15 – 0.25) -** Here depth is 3 – 4 where cutoff is reached. Here comes The P_16 merging with P_32 and P_64. This because after level 3 the cutoff would kick in and no one would be able to do parallelizing and there for P_32 and P_64 won't be able to use its extra threads and P_64, P_32 and P_16 would become one. While P_8 and P_4 are improving. One of the reason for P_8 and P_4 to improve could be as the depth gets lower the waiting time needed for threads to free up would get shorter as Less depth equals to less parallelizing.
- **Behavior for Cutoff ratio from (0.25 – 0.5)** – Here depth is around 2 where cutoff is reached. and since P_8 can reach depth of 3 it could utilize all the threads at depth level 2 and P_16, P_32 and P_64 they would reach cutoff due to the low depth. So P_8, P_16, P_32, P_64 would perform at the same level. And still P_4 is not able to reach their level or efficiency because it could go to depth of 2 but at depth 2 it could not have all the process parallel as shown in above figure. Where as P-8 to P_64 could have all the threads in parallel at depth 2.

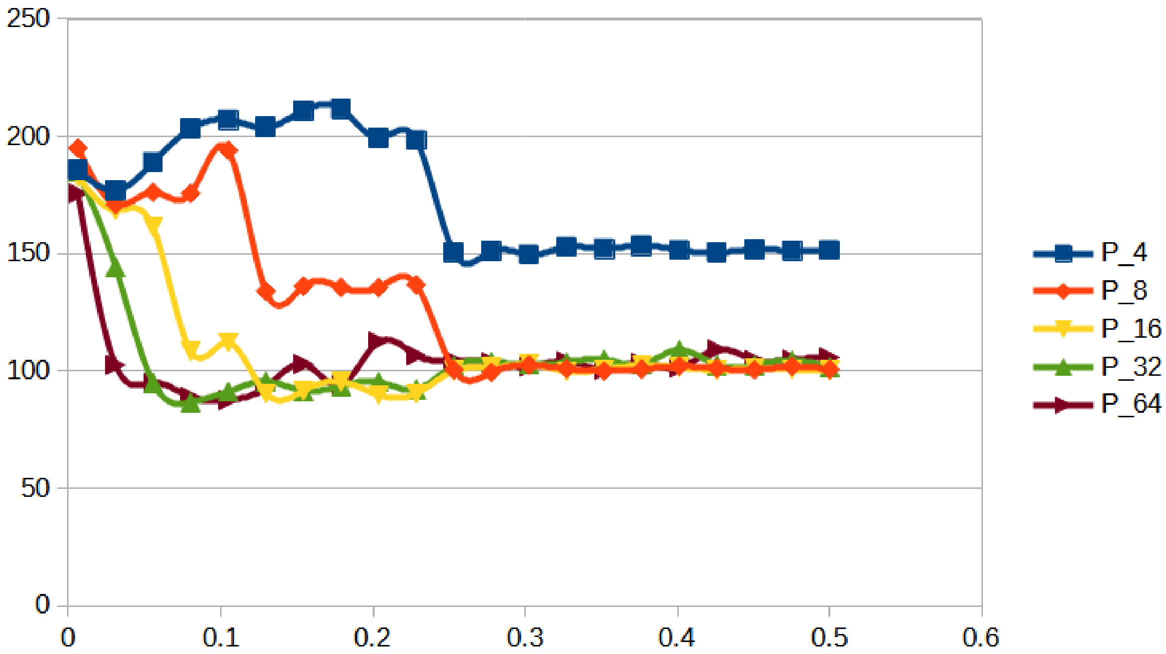
Data for graph and all these calculation could be found with file named – 2000000_WOC_parallelism_4_8_16_32_64.ods, 4000000_WOC_parallelism_4_8_16_32_64.ods, 8000000_WOC_parallelism_4_8_16_32_64.ods, 16000000_WOC_parallelism_4_8_16_32_64.ods

Graphical Representation:
All the graph have X axis as ratio of CutOff to Array Size. And Y axis is time in milliseconds.

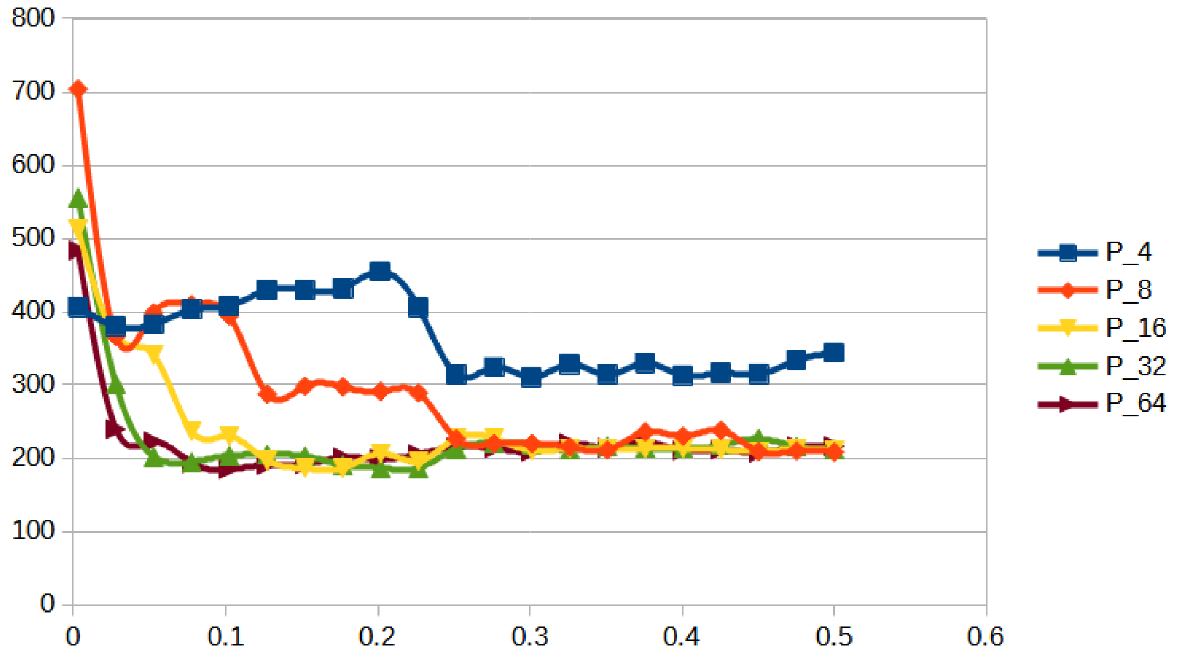
Array of Size = 2000000



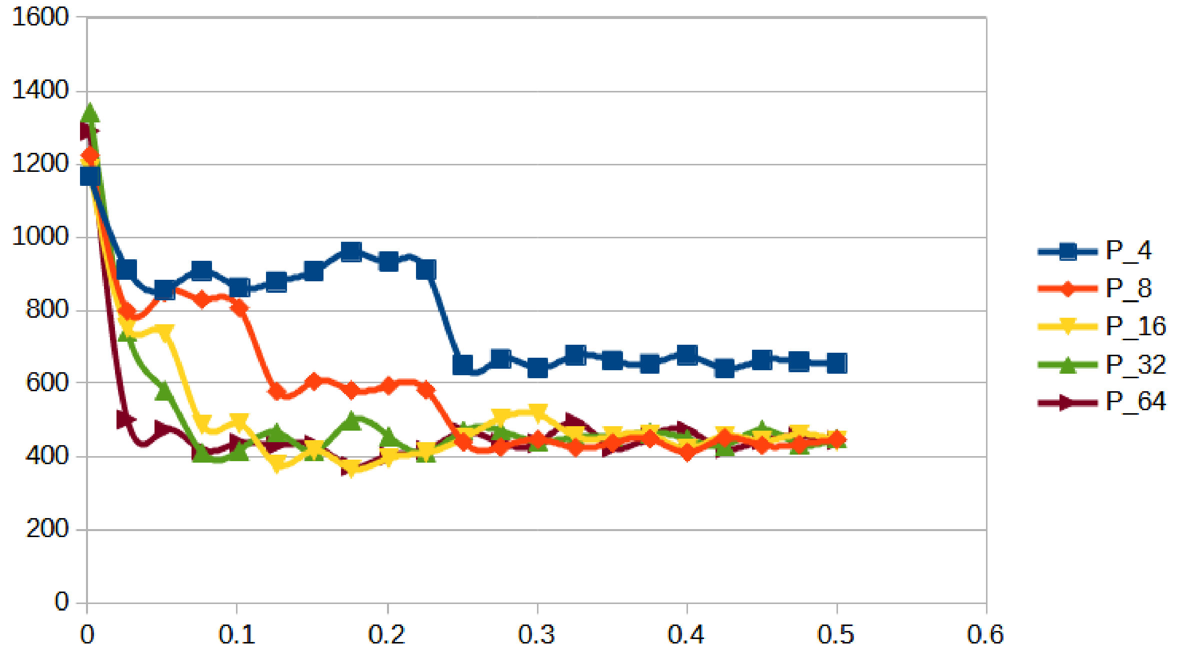
Array of Size = 4000000



Array of Size = 8000000



Array of Size = 16000000



Evidence to support that conclusion:

- Depth and Cutoff values from which the graphs are created -

Array of Size = 2000000

1	CutOff Ratio	P_4	P_8	P_16	P_32	P_64		Depth To reach Cut-Off
2	0.0125	120.2	83.8	83.6	80.7	60.3		6.32192809488736
3	0.036875	93.2	84.4	75	49.1	46.9		4.76121314041288
4	0.06125	93.5	86.1	81.3	49.8	45.2		4.02914634565952
5	0.085625	94.5	86.7	53.8	44.5	46.3		3.5458241068142
6	0.11	92.5	91.9	55.2	43.9	45.6		3.18442457113743
7	0.134375	102.1	65.4	48.3	46.2	46.1		2.89566334018526
8	0.15875	101.7	64.1	44.8	44.7	47.1		2.65517150300256
9	0.183125	101.3	64.9	45.3	44.5	44.6		2.44909933535248
10	0.2075	98.8	65.3	44.6	44.4	45.4		2.2688167584278
11	0.231875	104.4	64.6	44.6	43.8	48.9		2.10858081315392
12	0.25625	74	49.2	52.5	48.7	49.6		1.96437609026928
13	0.280625	72.5	50.1	49.9	49.8	51		1.83328455503358
14	0.305	73.6	49.5	50.2	51.5	52.6		1.71311885221184
15	0.329375	74.4	49	49.4	48.9	48.9		1.60219703813751
16	0.35375	72.2	48.9	52.3	50.8	51.5		1.49919794694284
17	0.378125	73.1	48.8	50.1	49.4	49.6		1.40306485761277
18	0.4025	71.6	48.6	49.6	49.3	50.1		1.31293931166011
19	0.426875	72.1	48.8	50.5	51.1	51		1.22811442148463
20	0.45125	72.6	49.1	49.8	49.5	51		1.14800116288755
21	0.475625	71.6	48.8	50	49	49.5		1.07210354627118
22	0.5	72.5	48.9	51.7	48.7	50.9		1
23								
24	Average	85.8285714285714	61.7571428571429	53.9285714285714	49.4428571428571	49.147619047619		
25								
26		2	3	4	5	6		

Array of Size = 4000000

8000000_WOC_parallelism_4_8_16_32_64.ods - LibreOffice Calc

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	A	B	C	D	E	F	G	H	I
1	CutOff	P_4	P_8	P_16	P_32	P_64		Depth To reach Cut-Off	
2	0.003125	406	703.6	511.4	555.2	483.6		8.32192809488736	
3	0.02796875	380.1	365.9	365.5	300.7	239.4		5.16004041251047	
4	0.0528125	382.4	398.4	340.3	201.8	222.3		4.24297675349254	
5	0.07765625	402.6	409.5	236.4	194.3	192.9		3.68675414821244	
6	0.1025	407.6	394	229.5	203.3	184.6		3.28630418515664	
7	0.12734375	429.2	287.2	196.2	204.4	190.6		2.97319994065629	
8	0.1521875	428.9	297.9	185.9	202.6	191.5		2.71607822769238	
9	0.17703125	431.4	297	185.5	190.5	200.5		2.49792404395421	
10	0.201875	454.6	290.8	206.1	186.3	198.6		2.3084658350808	
11	0.22671875	405.9	288.7	195.4	186.2	205.1		2.14102438570798	
12	0.2515625	313.7	226	227	212.5	214.5		1.99101121677275	
13	0.27640625	323.7	219.5	226.6	220.5	213.4		1.85513785708427	
14	0.30125	310.2	219.4	210.1	218.5	208.7		1.73096685354476	
15	0.32609375	327.9	215	212.7	211.3	219.9		1.61664130461489	
16	0.3509375	314.2	210.7	211.8	216.2	213.8		1.51071397737412	
17	0.37578125	329.5	235.6	213.1	213.3	221.6		1.41203501111732	
18	0.400625	312.7	229.8	213	213	210.2		1.31967564315598	
19	0.42546875	315.6	237.5	211.4	217.5	211.4		1.23287492273093	
20	0.4503125	314.5	208.7	208.8	226.4	207.2		1.15100156959998	
21	0.47515625	333.1	209.6	212.4	215.3	215.8		1.07352608874393	
22	0.5	343.3	207.9	209.7	211.7	216.1		1	
23									
24	Average =	365.1	292.985714285714	238.514285714286	228.642857142857	221.985714285714			

Array of Size = 8000000

8000000_WOC_parallelism_4_8_16_32_64.ods - LibreOffice Calc

CutOff	P_4	P_8	P_16	P_32	P_64	Depth To reach Cut-Off
0.003125	406	703.6	511.4	555.2	483.6	8.32192809488736
0.02796875	380.1	365.9	365.5	300.7	239.4	5.16004041251047
0.0528125	382.4	398.4	340.3	201.8	222.3	4.24297675349254
0.07765625	402.6	409.5	236.4	194.3	192.9	3.68675414821244
0.1025	407.6	394	229.5	203.3	184.6	3.28630418515664
0.12734375	429.2	287.2	196.2	204.4	190.6	2.97319994065629
0.1521875	428.9	297.9	185.9	202.6	191.5	2.71607822769238
0.17703125	431.4	297	185.5	190.5	200.5	2.49792404395421
0.201875	454.6	290.8	206.1	186.3	198.6	2.3084658350808
0.22671875	405.9	288.7	195.4	186.2	205.1	2.14102438570798
0.2515625	313.7	226	227	212.5	214.5	1.99101121677275
0.27640625	323.7	219.5	226.6	220.5	213.4	1.85513785708427
0.30125	310.2	219.4	210.1	218.5	208.7	1.73096685354476
0.32609375	327.9	215	212.7	211.3	219.9	1.61664130461489
0.3509375	314.2	210.7	211.8	216.2	213.8	1.51071397737412
0.37578125	329.5	235.6	213.1	213.3	221.6	1.41203501111732
0.400625	312.7	229.8	213	213	210.2	1.31967564315598
0.42546875	315.6	237.5	211.4	217.5	211.4	1.23287492273093
0.4503125	314.5	208.7	208.8	226.4	207.2	1.15100156959998
0.47515625	333.1	209.6	212.4	215.3	215.8	1.07352608874393
0.5	343.3	207.9	209.7	211.7	216.1	1
Average =	365.1	292.985714285714	238.514285714286	228.642857142857	221.985714285714	

Array of Size = 16000000

Cutt off ratio	P_4	P_8	P_16	P_32	P_64	Depth To reach Cut-Off
0.0015625	1165	1223.2	1185.2	1341.8	1289.8	9.321928095
0.026484375	910	797.7	750.7	740.4	500.6	5.238714727
0.05140625	854.6	847.9	735.2	580.1	472.5	4.281912416
0.076328125	907.1	828.7	486	409.7	416.4	3.711641438
0.10125	861.1	806	488.8	415.1	436.4	3.304006187
0.126171875	877.4	577.7	377	465.5	429.8	2.98653774
0.15109375	905.8	605.1	415.3	414.1	431.4	2.72648411
0.176015625	959.5	580.6	365.6	498.6	372.6	2.506224592
0.2009375	931.6	592.8	394.3	454.4	401.2	2.315181262
0.225859375	910.6	581.5	409.2	410	416.8	2.146503296
0.25078125	648.3	438.6	449.6	469.6	465.3	1.995498608
0.275703125	665.5	424.8	503.5	469.5	436.9	1.858812475
0.300625	640.5	445.9	514.5	439.5	435.7	1.733963106
0.325546875	675.9	423.4	454.3	452.3	493	1.619062805
0.35046875	660.7	436.2	454.5	454.1	423.8	1.512642285
0.375390625	652.1	447.8	459.7	464.5	455.6	1.413535474
0.4003125	676.3	410.6	421.2	447.7	470	1.320801429
0.425234375	639.3	450.1	456.4	429.5	420.9	1.233669869
0.45015625	662.6	429.6	440.7	473	443.8	1.151502245
0.475078125	658.9	432.1	461.1	433.3	453.8	1.073763316
0.5	653.1	445.8	441.1	448.5	443.8	1
Average =	786.471428571429	582.195238095238	507.804761904762	510.057142857143	481.433333333333	