File	Associativity	l1_data_hits	l1_data_hits	l1_data_miss	l1_data_miss	l1_instructio	l1_instructio	l1_instructio	l1_instructio	l2_hits mean
008.espresso	2	189609.9	0.53851648	1022.1	0.53851648	807013	0	2355	0	2578.2
008.espresso	4	189610.45	0.66895441	1021.55	0.66895441	807013	0	2355	0	2578.6
008.espresso	8	189610.633	0.60461191	1021.36667	0.60461191	807013	0	2355	0	2578.73333
013.spice2g6	2	214959	0	864	0	781217	0	2962	0	2852
013.spice2g6	4	214959	0	864	0	781217	0	2962	0	2852
013.spice2g6	8	214959	0	864	0	781217	0	2962	0	2852
015.doduc.di	2	241911.4	1.11355287	2895.6	1.11355287	750732	0	4461	0	4763.5
015.doduc.di	4	241911.8	0.9797959	2895.2	0.9797959	750732	0	4461	0	4767.45
015.doduc.di	8	241912.2	0.9797959	2894.8	0.9797959	750732	0	4461	0	4771.63333
022.li.din	2	252739	2	5010	2	739440.6	0.91651514	2813.4	0.91651514	6464
022.li.din	4	252741.5	2.87228132	5007.5	2.87228132	739440.3	0.71414284	2813.7	0.71414284	6482
022.li.din	8	252742.333	2.62466929	5006.66667	2.62466929	739440.2	0.6	2813.8	0.6	6488
023.eqntott.c	2	228208	0	2033	0	769542	0	217	0	656
023.eqntott.c	4	228208	0	2033	0	769542	0	217	0	656
023.eqntott.c	8	228208	0	2033	0	769542	0	217	0	656
026.compres	2	265481.8	9.9979998	13302.2	9.9979998	721093	0	123	0	7355.8
026.compres	4	265486.3	10.775435	13297.7	10.775435	721093	0	123	0	7353.15
026.compres	8	265489.967	12.2813771	13294.0333	12.2813771	721093	0	123	0	7331.16667
034.mdljdp2.	2	229997	0	1460	0	767392	0	1151	0	1193.8
034.mdljdp2.	4	229997	0	1460	0	767392	0	1151	0	1194.4
034.mdljdp2.	8	229997	0	1460	0	767392	0	1151	0	1194.6
039.wave5.di	2	172033	0	367	0	827138	0	462	0	87
039.wave5.di	4	172033	0	367	0	827138	0	462	0	87
039.wave5.di	8	172033	0	367	0	827138	0	462	0	87
047.tomcatv.	2	374197.5	1.80277564	10258.5	1.80277564	615454	0	90	0	1723.7
047.tomcatv.	4	374202.95	5.95378031	10253.05	5.95378031	615454	0	90	0	1752.15
047.tomcatv.	8	374207.1	7.80747505	10248.9	7.80747505	615454	0	90	0	1767.3
048.ora.din	2	200000	0	231	0	799414	0	357	0	46
048.ora.din	4	200000	0	231	0	799414	0	357	0	46
048.ora.din	8	200000	0	231	0	799414	0	357	0	46
085.gcc.din	2	214476	3.13049517	6009	3.13049517	764712.7	5.9674115	14802.3	5.9674115	18090.5
085.gcc.din	4	214476.1	2.38537209	6008.9	2.38537209	764706.8	7.29794492	14808.2	7.29794492	18208.1

085.gcc.din	8	214476.2	2.03960781	6008.8	2.03960781	764704.467	6.83487787	14810.5333	6.83487787	18255.7333
089.su2cor.d	2	259687.7	0.64031242	3131.3	0.64031242	736702	0	479	0	687.1
089.su2cor.d	4	259687.85	0.4769696	3131.15	0.4769696	736702	0	479	0	691.55
089.su2cor.d	8	259687.9	0.3958114	3131.1	0.3958114	736702	0	479	0	693.033333
090.hydro2d.	2	239225.9	1.64012195	12086.1	1.64012195	747777	0	911	0	6537.1
090.hydro2d.	4	239225.3	2.79463772	12086.7	2.79463772	747777	0	911	0	6630.4
090.hydro2d.	8	239226.567	3.28312182	12085.4333	3.28312182	747777	0	911	0	6659.56667
093.nasa7.di	2	194152	0	2877	0	802502	0	469	0	375
093.nasa7.di	4	194152	0	2877	0	802502	0	469	0	375
093.nasa7.di	8	194152	0	2877	0	802502	0	469	0	375
094.fpppp.dir	2	293868.8	1.46969385	5631.2	1.46969385	691885.2	2.27156334	8614.8	2.27156334	11916.2
094.fpppp.dir	4	293869.35	1.19478032	5630.65	1.19478032	691882.6	3.05614136	8617.4	3.05614136	11980.2
094.fpppp.dir	8	293869.567	1.02252411	5630.43333	1.02252411	691881.733	2.78008793	8618.26667	2.78008793	12002.1333

l2_hits std	l2_misses me	l2_misses std	l1_energy_co	l1_energy_co	l2_energy_co	l2_energy_co	total_energy_	total_energy	total_time m	total_time st
0.6	798.9	0.7	0.00105823	1.23E-07	0.00048243	9.11E-08	0.00214901	8.20E-07	0.00055823	1.23E-07
0.58309519	797.95	1.07121426	0.001058	2.47E-07	0.00048224	1.94E-07	0.00214748	1.64E-06	0.000558	2.47E-07
0.51207638	797.633333	0.98262687	0.00105792	2.29E-07	0.00048218	1.80E-07	0.00214697	1.52E-06	0.00055792	2.29E-07
0	974	0	0.00106881	0	0.00049528	0	0.00221456	0	0.00056881	0
0	974	0	0.00106881	0	0.00049528	0	0.00221456	4.34E-19	0.00056881	1.08E-19
0	974	0	0.00106881	0	0.00049528	0	0.00221456	4.34E-19	0.00056881	1.08E-19
2.20227156	2593.1	2.91376046	0.00117407	1.32E-07	0.00062648	1.20E-07	0.00286337	8.59E-07	0.00067407	1.32E-07
4.35287262	2588.75	4.95857843	0.00117373	3.62E-07	0.00062619	3.21E-07	0.00286116	2.37E-06	0.00067373	3.62E-07
6.90161012	2584.16667	7.64235275	0.00117326	7.21E-07	0.00062582	5.86E-07	0.00285808	4.76E-06	0.00067326	7.21E-07
4	1359.4	3.7469988	0.0011197	4.23E-07	0.00059446	3.23E-07	0.00249228	2.81E-06	0.0006197	4.23E-07
18.2208672	1339.2	20.3730214	0.00111748	2.24E-06	0.00059267	1.81E-06	0.00247763	1.48E-05	0.00061748	2.24E-06
17.1269768	1332.46667	19.1672174	0.00111674	2.11E-06	0.00059207	1.71E-06	0.00247274	1.39E-05	0.00061674	2.11E-06
0	1594	0	0.00109584	0	0.00050896	0	0.00240129	4.34E-19	0.00059584	0
0	1594	0	0.00109584	2.17E-19	0.00050896	0	0.00240129	4.34E-19	0.00059584	0
0	1594	0	0.00109584	2.17E-19	0.00050896	0	0.00240129	4.34E-19	0.00059584	1.08E-19
21.146158	6069.4	18.6558302	0.00148836	1.53E-06	0.00099402	1.23E-06	0.00482503	1.01E-05	0.00098836	1.53E-06
20.9911291	6067.55	19.3066698	0.00149033	2.48E-06	0.00099573	2.11E-06	0.00483791	1.63E-05	0.00099033	2.48E-06
40.9569557	6085.86667	34.0301174	0.00149275	4.23E-06	0.00099772	3.49E-06	0.00485385	2.79E-05	0.00099275	4.23E-06
0.74833148	1417.2	0.74833148	0.00108626	1.67E-07	0.00049932	1.36E-07	0.00233996	1.10E-06	0.00058626	1.67E-07
0.8	1416.6	0.8	0.0010861	1.98E-07	0.00049919	1.62E-07	0.00233891	1.31E-06	0.0005861	1.98E-07
0.71180522	1416.4	0.71180522	0.00108605	1.78E-07	0.00049914	1.46E-07	0.00233856	1.18E-06	0.00058605	1.78E-07
0	742	0	0.00104149	0	0.00044197	5.42E-20	0.00206552	0	0.00054149	1.08E-19
0	742	0	0.00104149	0	0.00044197	5.42E-20	0.00206552	0	0.00054149	1.08E-19
0	742	0	0.00104149	0	0.00044197	1.08E-19	0.00206552	0	0.00054149	1.08E-19
7.07177488	8624.8	7.03988636	0.00173403	4.72E-07	0.00116518	4.31E-07	0.00647507	3.07E-06	0.00123403	4.72E-07
29.2767399	8590.9	34.7331254	0.00173095	3.14E-06	0.00116251	2.73E-06	0.00645495	2.05E-05	0.00123095	3.14E-06
32.2574539	8571.6	39.5749079	0.00172926	3.52E-06	0.00116103	3.08E-06	0.00644391	2.30E-05	0.00122926	3.52E-06
0	542	0	0.00103015	2.17E-19	0.00043021	0	0.00199321	0	0.00053015	1.08E-19
0	542	0	0.00103015	2.17E-19	0.00043021	0	0.00199321	4.34E-19	0.00053014	1.08E-19
0	542	0	0.00103015	2.17E-19	0.00043021	5.42E-20	0.00199321	4.34E-19	0.00053014	1.08E-19
15.1013245	2720.8	11.8894912	0.00125496	6.94E-07	0.00083076	5.43E-07	0.003258	4.60E-06	0.00075496	6.94E-07
118.191328	2609	112.215863	0.00124769	7.29E-06	0.00082508	5.70E-06	0.00320979	4.84E-05	0.00074769	7.29E-06

117.732729	2563.6	111.917112	0.00124485	7.19E-06	0.00082285	5.62E-06	0.00319092	4.77E-05	0.00074485	7.19E-06
1.75783958	2923.2	2.03960781	0.00117738	3.00E-07	0.00059796	2.58E-07	0.00291659	1.97E-06	0.00067738	3.00E-07
4.62033549	2918.6	4.82078832	0.00117607	1.32E-06	0.0005969	1.08E-06	0.00290799	8.72E-06	0.00067607	1.32E-06
4.31650579	2917.06667	4.49394655	0.00117533	1.51E-06	0.0005963	1.22E-06	0.00290307	9.95E-06	0.00067533	1.51E-06
20.0621534	6460	19.6621464	0.0014955	1.73E-06	0.00096937	1.38E-06	0.00490272	1.15E-05	0.0009955	1.73E-06
95.9314339	6367.3	95.4437531	0.00148595	9.82E-06	0.00096169	7.89E-06	0.00483961	6.49E-05	0.00098595	9.82E-06
89.7476772	6336.86667	90.214091	0.00148362	8.77E-06	0.00095982	7.05E-06	0.00482423	5.80E-05	0.00098362	8.77E-06
0	2971	0	0.00118489	2.96E-07	0.00060133	2.37E-07	0.00296891	1.96E-06	0.00068489	2.96E-07
0	2971	0	0.00118174	3.16E-06	0.00059881	2.53E-06	0.00294808	2.09E-05	0.00068174	3.16E-06
0	2971	0	0.00117959	3.98E-06	0.0005971	3.19E-06	0.00293391	2.63E-05	0.00067959	3.98E-06
12.5682139	2329.8	11.8050837	0.00120711	6.00E-07	0.00073119	4.85E-07	0.00300315	3.96E-06	0.00070711	6.00E-07
64.6263104	2267.85	62.5214163	0.0012003	6.82E-06	0.00072588	5.33E-06	0.00295802	4.52E-05	0.0007003	6.82E-06
61.2087866	2246.56667	59.261389	0.00119788	6.54E-06	0.00072398	5.11E-06	0.00294197	4.33E-05	0.00069788	6.54E-06

average_mer	average_memory_access_time std
0.55590635	0.00012194
0.55567673	0.00024527
0.5556002	0.00022764
0.56608914	1.11E-16
0.56608914	1.11E-16
0.56608914	0
0.66742618	0.00012847
0.66709438	0.00035484
0.66663721	0.00070849
0.61405453	0.00041718
0.6118692	0.00220514
0.61114076	0.00207437
0.59355537	0
0.59355537	0
0.59355537	2.22E-16
0.96946408	0.00148465
0.97140159	0.00242631
0.97375845	0.00412857
0.58390902	0.00016605
0.58375095	0.00019691
0.58369826	0.00017721
0.54063866	0
0.54063866	0
0.54063866	0
1.21105009	0.00045571
1.20807894	0.00302961
1.20644873	0.00340025
0.52954506	1.11E-16
0.52954506	1.11E-16
0.52954506	1.11E-16
0.73760524	0.00067055
0.7305757	0.00704942

0.72782657	0.00694826
0.67297818	0.00029685
0.67168695	0.00130979
0.67094859	0.00149478
0.97649628	0.00168183
0.96721557	0.00954432
0.96496305	0.00852233
0.68058727	0.00029459
0.67745735	0.00314324
0.67532769	0.003957
0.69557666	0.00058348
0.68892158	0.00666882
0.686554	0.00639215

In our simulation we implemented an L1 data cache as well as an L1 instruction cache. Both L1 Caches have the same parameters, the only difference being whether we add data or instructions to the cache. This is done in our run_cache function where we check the tag of the incoming address and based on the tag which is defined in the 'code' variable in our program we add it to the cache specified. If the code is 2 we place it in the instruction cache else the address goes into the L1 data cache. Our L2 cache isn't split into two separate caches like L1 is. Instead we maintain a 256Kb cache that stores both data and instructions. We maintain inclusivity between the L2 and L1 caches by implementing write through. This means that both of the L1s are a subset of the L2 cache. To maintain this inclusivity we have programmed in write through behavior in the instance of certain cache misses, reads and writes. For example, when there is a cache miss in both the L1 and L2 cache, we write the value from DRAM into not only the L1 cache, but the L2 as well to maintain inclusivity. As for the DRAM the only variable we keep track of are the accesses which we then use to calculate the time and energy cost. As for the layout of our program, we have two main files that contain most of the logic behind our program. Cache.py contains the Cache class. In our CacheSimulator.py we create the L1 data, L1 instruction and L2 caches, which are instances of the Cache class. CacheSimulator contains our main function, which reads in the file and adds it to a 'data' variable. Then in main, we call our run_cache function with the data as the parameter. In run_cache for each line in the 'data' variable we run the simulation. We first split each line in the data into its code and address. Based on the code we determine what L1 cache we need to add the line to. After determining the correct cache we call our 'try_access' method which is located in the Cache class. In 'try_access' we check to see if the line is present in the cache. This is where we determine if we have a cache hit or miss. If it is a miss, we add the line to a random place in the cache. Since our simulation implements a write back cache policy, if we evict a random line, then we write back the data to the L2 cache. This logic is done back in the CacheSimulator class. We determine if the line needs to be written back through the use of a dirty bit. If the L1 cache wasn't a hit we then run try_access on the L2 cache. If it is a hit in L2, we write the value into L1, using our 'place_in_cache' method. If L2 was a miss as well, we get the address from the DRAM and place the data in both the L1 and L2 cache to maintain inclusivity. If a line in L2 gets evicted we then write back to the DRAM if it was dirty. After run_cache is run for every line in the input file, the main method returns and the program is done.

Looking at the results of the table we can see that using a set associativity of 2 is very consistently leading to more cache misses in both the L1 data cache and the L2 cache. This in turn increases the number of hits in the DRAM and increases the energy consumption of the workload. The reason behind this can be explained by thrashing, which is when the contents of a cache are being constantly flushed and refilled with new data which results in more cache misses. Having a set associativity of 2 increases the amount of thrashing comparatively because the set size is too small relative to the working set given by the test files. This in turn explains the increase in the number of cache misses in L2. In the table included, looking at the results from the 047.tomcatv.din file, the L2 miss rate for set associativity 2 is 8629.7, compared to 8592.15 for associativity 4 and 8571.833333 for associativity 8. In the table for the same 047.tomcatv.din test file, the L1 Cache miss rate went from 10260.2 for associativity 2, to 10253.8 for associativity 4 and 10249.43333 for associativity 8. Now the L1 cache is directly mapped in all the tests that were run and the only cache that had its associativity changed was the L2. So increasing the set associativity of the L2 cache shouldn't explain the slightly increased miss rate of the L1 cache. However since the miss rate of the L2 cache increases due to the higher rate of thrashing, and the L1 caches are a subset of L2, this means that evicting from L2 will also mean that there is a possibility that data or instructions in the L1 caches are also evicted. Since this the eviction is done at random, this could evict data/instructions in the L1 that is requested for again thus increasing the miss rate in the L1 caches albeit slightly. This explains why the L1 miss rate only increased by ~11 going from associativity 8 to 2 whereas for the L2 cache miss rate the difference is 57.866667. As for increasing the set associativity of the L2 cache from 4 to 8, there is an increase in the hit rates for the L2 cache and an extremely marginal increase in the hit rate for the L1 cache. This can be seen in almost all test files, one of which being 022.li.din. The L2 hit rate in 022.li.din for associativity 2 is 6461.9, which then improves to 6480.95 for associativity 4 and then a smaller increase to 6487.3 for a set associativity of 8 for the L2 cache. This same pattern can be seen in the 090.hydro2d.din test file and the 094.fpppp.din file, where there is a larger increase in the hit rate when changing the associativity from 2 to 4 compared to the increase in hit rate going from 4 to 8. This data clearly shows a pattern in diminishing returns when increasing the set associativity. For a few files, the increase in the number of hits is just as significant going from 4 to 8 as it is from 2 to 4. This just means that the file and working set benefits from a larger set associativity in the L2 cache due to its size. However, while not tested in this experiment, there will also be a point when increasing the set associativity even higher will result in increasingly diminishing returns. As for the total energy cost, it is directly related to the number of accesses in the L1 caches, the L2 cache and the DRAM. Since there is a higher cost associated with accessing the DRAM, having a set associativity of 2 will increase the total energy consumed due to the higher number of DRAM access because the L1 and L2 cache will miss more often. Since the hit rate still improves in the L1 caches and L2 caches when going from a set associativity of 4 to 8, there is still a reduction in the total energy consumed. That being said the reduction of energy will plateau as the set associativity of the L2 cache is set higher.