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Cache Project Report

1. Code description:

For our cache code structure, we have three python classes for L1, L2, and DRAM. The cache_sim.py contains code for our cache simulator that loops through each trace file and prints out the total time, energy consumption, and L1/L2 access and miss counts for associativities of 2, 4, and 8, and energy consumption of L1 instruction cache, L1 data cache, L2, and DRAM

Our L1 cache is direct mapped per the assignment instructions with two cache data structures: one for the instruction cache and one for the data cache. Initially we tried to implement a write-back policy from L1 to L2 cache but after discussion with the TAs during office hours we decided to do write-through from L1 to L2. We have a cache line object that we stored in each cache data structure that contains the tag of the memory address put into the cache. Upon changing our write policy to write-through, a dirty field was not needed. We also have a method to return the energy used by active L1 reads and writes. For the L1 active energy we multiplied the total L1 access time of 0.5 ns by the sum of 1W active power used by L1, the 0.8W of idle power used by L2, and the 0.8W of idle power used by DRAM. We converted the nanoseconds to seconds and multiplied this by the power sum to return the energy consumed in joules.

Our L2 cache includes a set associative cache. For our write policy from L2 to DRAM we implemented write-back after attending TA office hours and recognizing that write-back would be a more energy efficient design by not having to access DRAM as often. With this design our L2 cache is similar to L1 with changes made for a singular cache data structure given the combined cache and including set associativity which was set in the constructor. We implemented a random replacement policy for the sets in each block of the cache and returned a boolean to identify if the cache line being replaced was dirty and needed to be written to DRAM before being replaced. We also included a method to return the energy consumption for active L2 reads and writes with the same method as mentioned in L1. The calculation: (5ns (converted to seconds) * (2W active L2 + 0.5 idle L1 and 0.8 idle DRAM)) plus the 5 pJ of data transfer energy (converted to joules).

For our DRAM class, since the data was not necessary to keep track of to implement our cache simulator, this class calculates and returns the energy consumption for active DRAM. Which was calculated as: (50 ns (converted to seconds) * (4W active dram + 0.5W idle L1 + 0.8W idle L2)) + 640 pJ (converted to joules)

For energy calculations, each time a cache or dram is accessed, the active energy for that part is added to that object's total energy consumption as well as the idle powers of the other components. For L1, this energy consumption is also split by instruction or data caches. Each class has a method called read_write_energy() that computes this active energy. For cache misses this same active energy is added to the overall component energy consumption by again calling read_write_energy() and adding that to an energy summation instance variable that each class contains. The access methods in each class simulate a memory access and returns whether or not it was a hit or miss. DRAM only adds to its energy consumption and returns nothing.

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For our write policy, when writing to L1, we include the immediate write to L2 and that energy cost, so for writes to L1, L1 active energy and L2 active energy are calculated. When implementing write back from L2 to DRAM, the L2 access method returns a boolean that indicates whether or not writing to DRAM is needed if a dirty cache line is being replaced. If true, the cost of accessing DRAM is also included in the energy cost.

Code source: Our code was mainly written from scratch with the use of ChatGPT to help with some aspects such as the extract addresses method and basic foundation code.

2. Output tables for each file:

048.ora.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**827748.9999829654**	**0.0024362131350079484**				**Accesses: 59529** **Misses: 542** **Energy Consumed: 0.000991471854999346 J**
4	**827748.9999829654**	**0.0024362131350079484**	**Accesses: 799771** **Misses: 354** **Energy Consumed: 0.0010401625000066724 J**	**Accesses: 200231** **Misses: 232** **Energy Consumed: 0.00026060190000089977 J**	**Accesses: 542** **Energy Consumed: 00014397687999999988 J**	**Accesses: 59529** **Misses: 542** **Energy Consumed: 0.000991471854999346 J**
8	**827748.9999829654**	**0.0024362131350079484**				**Accesses: 59529** **Misses: 542** **Energy Consumed: 0.000991471854999346 J**

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015.doduc.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	1135617.4999705723	0.0036585492700067306				Accesses: 97690 Misses: 2600 Energy Consumed: 0.0016552864499980897 J
4	1134507.499970601	0.0036527727700067314	Accesses: 755193 Misses: 4219 Energy Consumed: 0.0009872356000062805 J	Accesses: 244807 Misses: 2816 Energy Consumed: 0.00032190990000135377 J	Accesses: 2592 Energy Consumed: 0.0006848199199999773 J	Accesses: 97690 Misses: 2588 Energy Consumed: 0.0016550883899980901 J
8	1133757.4999706023	0.003648888760006732				Accesses: 97690 Misses: 2578 Energy Consumed: 0.0016549233399980904 J

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Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**1118795.9999713209**	**0.003482050280006476**				**Accesses: 107568** **Misses: 1360** **Energy Consumed: 0.00179785663999782 J**
4	**1114045.9999713833**	**0.003457216840006478 4**	**Accesses: 742254** **Misses: 2382** **Energy Consumed: 0.0009680268000061384 J**	**Accesses: 257749** **Misses: 4827** **Energy Consumed: 0.0003413488000014977**	**Accesses: 1320** **Energy Consumed: 0.0003506447999999912 J**	**Accesses: 107568** **Misses: 1320** **Energy Consumed: 0.0017971964399978212 J**
8	**1114045.999971383**	**0.0034572168400064784**				**Accesses: 107568** **Misses: 1320** **Energy Consumed: 0.0017971964399978212 J**

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026.compress.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	1699055.9999561522	0.006012984660004817				Accesses: 59529 Misses: 542 Energy Consumed: 0.000991471854999346 J
4	1697935.9999562602	0.006006772790004811	Accesses: 721216 Misses: 123 Energy Consumed: 0.0009377407000059141 J	Accesses: 278784 Misses: 12869 Energy Consumed: 0.00037914890000177764 J	Accesses: 7598 Energy Consumed: 0.002018332719999975 J	Accesses: 156922 Misses: 6176 Energy Consumed: 0.002691932489996128 J
8	1701885.999956254	0.006027154810004824				Accesses: Misses: Energy Consumed:

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085.gcc.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	1158042.4999722277	0.00376446915000684				Accesses: 97319 Misses: 2779 Energy Consumed: 0.0016521174899980957 J
4	1137992.4999725162	0.0036606634400068528	Accesses: 779515 Misses: 12708 Energy Consumed: 0.0010298899000065964 J	Accesses: 220485 Misses: 5497 Energy Consumed: 0.00029377660000114543 J	Accesses: 2595 Energy Consumed: 0.0006893357999999771 J	Accesses: 97319 Misses: 2509 Energy Consumed: 0.0016476611399981042 J
8	1136342.499972611	0.003652098500006854				Accesses: 97319 Misses: 2489 Energy Consumed: 0.0016473310399981048 J

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094.fpppp.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	1180356.499973737	0.0037919204650064932				Accesses: 107515 Misses: 2322 Energy Consumed: 0.0018128596849977916 J
4	1165776.4999738736	0.0037156266850065	Accesses: 700500 Misses: 7768 Energy Consumed: 0.0009207484000057882 J	Accesses: 299500 Misses: 5375 Energy Consumed: 0.0003963375000019049 J	Accesses: 2212 Energy Consumed: 0.0005875956799999813 J	Accesses: 107515 Misses: 2206 Energy Consumed: 0.0018109451049977952 J
8	1165421.4999738734	0.0037137507000064994				Accesses: 107515 Misses: 2205 Energy Consumed: 0.0018109285999977952 J

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008.espresso.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	857511.4999814987	0.002560173010007868				Accesses: 62380 Misses: 802 Energy Consumed: 0.0010428189099992487 J
4	857141.4999815222	0.0025582475100078684	Accesses: 809368 Misses: 1701 Energy Consumed: 0.0010543897000067778 J	Accesses: 190632 Misses: 1002 Energy Consumed: 0.0002491242000008148 J	Accesses: 798 Energy Consumed: 0.00021198071999999703 J	Accesses: 62380 Misses: 798 Energy Consumed: 0.0010427528899992489 J
8	857141.4999815222	0.0025582475100078684				Accesses: 62380 Misses: 798 Energy consumption 0.0010427528899992489 J

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013.spice2g6.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	937445.9999783384	0.0028409926850074298				Accesses: 76413 Misses: 976 Energy Consumed: 0.001277305444998805 J
4	937445.9999783384	0.0028409926850074298	Accesses: 784179 Misses: 2607 Energy Consumed: 0.001022821800006544 J	Accesses: 215823 Misses: 793 Energy Consumed: 0.00028160080000105527 J	Accesses: 976 Energy Consumed: 0.00025926463999999505 J	Accesses: 76413 Misses: 976 Energy Consumed: 0.001277305444998805 J
8	937445.9999783384	0.0028409926850074298				Accesses: 76413 Misses: 976 Energy Consumed: 0.001277305444998805 J

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047.tomcatv.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**1869179.4999641108**	**0.007143700585006648**				**Accesses: 132102** **Misses: 8703** **Energy Consumed: 0.0023239865249968243 J**
4	**1864169.4999646787**	**0.007117707115006631**	**Accesses: 615544** **Misses: 88** **Energy Consumed: 0.0008003216000048965 J**	**Accesses: 384456** **Misses: 10321** **Energy Consumed: 0.0005132101000027703 J**	**Accesses: 13105** **Energy Consumed: 0.0034812122000011077 J**	**Accesses: 132102** **Misses: 8641** **Energy Consumed: 0.0023229632149968263 J**
8	**1862569.4999647953**	**0.0071094078150066254**				**Accesses: 132102** **Misses: 8621** **Energy Consumed: 0.002322633114996827 J**

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089.su2cor.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**1258207.999970272**	**0.004109684370006057**				**Accesses: 117717** **Misses: 2933** **Energy Consumed: 0.001991328249997454 J**
4	**1252672.999970363**	**0.004080449025006059**	**Accesses: 737181** **Misses: 481** **Energy Consumed: 0.0009589606000060712 J**	**Accesses: 262819** **Misses: 3135** **Energy Consumed: 0.00034574020000153024 J**	**Accesses: 2954** **Energy Consumed: 0.0007847005599999731 J**	**Accesses: 117717** **Misses: 2916** **Energy Consumed: 0.0019910476649974544 J**
8	**1251022.999970386**	**0.00407168290500606**				**Accesses: 117717** **Misses: 2916** **Energy Consumed: 0.0019910476649974544 J**

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Associativity of L2	Total Time (ns)	Total Energy (J)	L1 i	L1 d	DRAM	L2
2	1401610.999961306	0.005078757370006918				Accesses: 92311 Misses: 6499 Energy Consumed: 0.001630859049998136 J
4	1374695.9999614046	0.00493810710500682	Accesses: 748688 Misses: 887 Energy Consumed: 0.0009744475000061859 J	Accesses: 251312 Misses: 11935 Energy Consumed: 0.0003422211000015042 J	Accesses: 7508 Energy Consumed: 0.0019944251199999563 J	Accesses: 92311 Misses: 6266 Energy Consumed: 0.0016270133849981432 J
8	1375150.9999614013	0.004940514370006821				Accesses: 92311 Misses: 6267 Energy Consumed: 0.0016270298899981432 J

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093.nasa7.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**1079423.999975282**	**0.003540437955007233**				**Accesses: 79880** **Misses: 2971** **Energy Consumed: 0.0013674557549986344 J**
4	**1069323.9999755477**	**0.0034867786750072353**	**Accesses: 802971** **Misses: 463** **Energy Consumed: 0.0010444642000067043 J**	**Accesses: 197029** **Misses: 2875** **Energy Consumed: 0.0002598752000008944 J**	**Accesses: 3068** **Energy Consumed: 0.0008149835199999718 J**	**Accesses: 79880** **Misses: 2971** **Energy Consumed: 0.0013674557549986344 J**
8	**1064573.9999755525**	**0.003461542875007236**				**Accesses: 79880** **Misses: 2971** **Energy Consumed: 0.0013674557549986344 J**

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039.wave5.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**786016.999984462**	**0.002318588170008272**				**Accesses: 48947** **Misses: 743** **Energy Consumed: 0.00082013344999967 J**
4	**786016.999984462**	**0.002318588170008272**	**Accesses: 827600** **Misses: 465** **Energy Consumed: 0.0010764845000069414 J**	**Accesses: 172400** **Misses: 369** **Energy Consumed: 0.0002245997000006332 J**	**Accesses: 743** **Energy Consumed: 0.00019737051999999764 J**	**Accesses: 48947** **Misses: 743** **Energy Consumed: 0.00082013344999967 J**
8	**786016.999984462**	**0.002318588170008272**				**Accesses: 48947** **Misses: 743** **Energy Consumed: 0.00082013344999967 J**

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Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**989571.4999762397**	**0.003075719885007276**				**Accesses: 80142** **Misses: 1595** **Energy Consumed: 0.0013490691849986692 J**
4	**989571.4999762397**	**0.003075719885007276**	**Accesses: 769759** **Misses: 217** **Energy Consumed: 0.0010009688000063822 J**	**Accesses: 230241** **Misses: 2056** **Energy Consumed: 0.00030198610000120623 J**	**Accesses: 1595** **Energy Consumed: 0.00042369579999998816 J**	**Accesses: 80142** **Misses: 1595** **Energy Consumed: 0.0013490691849986692 J**
8	**989571.4999762397**	**0.003075719885007276**				**Accesses: 80142** **Misses: 1595** **Energy Consumed: 0.0013490691849986692 J**

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034.mdljdp2.din

Associativity of L2	Total Time (ns)	Total Energy (J)	L1 I	L1 D	DRAM	L2
2	**906183.4999800741**	**0.002783759205007751**				**Accesses: 65259** **Misses: 1422** **Energy Consumed: 0.0011005699049991395 J**
4	**905728.4999800739**	**0.0027813519400077505**	**Accesses: 768543** **Misses: 1120** **Energy Consumed: 0.0010005619000063792 J**	**Accesses: 231457** **Misses: 1437** **Energy Consumed: 0.000302762200001212 J**	**Accesses: 1421** **Energy Consumed: 0.0003774744399999901 J**	**Accesses: 65259** **Misses: 1421** **Energy Consumed: 0.0011005533999991395 J**
8	**905728.4999800739**	**0.0027813519400077505**				**Accesses: 65259** **Misses: 1421** **Energy Consumed: 0.0011005533999991395 J**

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3. Associativity Analysis:

For most trace files, as we increased the associativity, the L2 miss rate went down slightly or stayed about the same. The decrease in L2 misses we believe can be attributed to there being more cache lines that can be stored in each set with higher associativities, and more data being stored in the cache means lower miss rates. Some traces had different behavior, the 026.compress traces had L2 miss counts increase as we increased associativity. Due to the compress trace file being quite large, it was difficult to fully analyze why this was the case, but an inference we made was that there could have been more writes than reads and more data needing to be cached that outweighed the benefits of a larger associativity and the random replacement policy choosing cache lines to be replaced that would be access later, causing more misses.