Project 1
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PROBLEM STATEMENT

Cache design choices affect the performance of a microprocessor. In this Assignment, you are asked to finetune the cache hierarchy on X86 architecture based on the gem5 simulator. The cache design parameters you can modify are as follows:
- CPU Types: Different CPU models.
- Cache levels: No cache at all, one level or two levels.
- Size: Cache size, one of the most important choices.
- Associativity: Selection of cache associativity (e.g. direct mapped, 2-way set associative, etc.).
- Block size: Block size of the cache, usually 64 or 32 bytes.

While larger caches generally mean better performance, they also come at a greater cost. Thus, sensible design choices and trade-offs are required. To this end, in this Assignment you will also be asked to define a cost function and to use it in order to identify the optimal configuration.

Used Resources:
Modeling and Optimization of Parallel and Distributed Embedded Systems
A look into CPU Cache
Zen 2 Architecture
Why is the L1 cache always smaller than the L2 cache
What is the Cost of an L1 Cache Miss?
Opteron Architecture
Sram vs Dram

IMPLEMENTATION

The benchmarks were run on the eecs server where we have the Gem5 installed. Following benchmarks have been tested:

1. 401.bzip2
2. 429.mcf
3. 456.hmmer
4. 458.sjeng
5. 470.lbm

This assignment was a bit unclear and my lack of experience in architecture made it quite complicated, but I did as much analysis as I could, plots and solutions listed bellow

Part 2

Bzip
- sim_seconds= 0.083982
- system.cpu.cpi= 1.679650
- system.cpu.dcache.overall_miss_rate::total= 0.014798 [//]: # (Miss rate for overall accesses for L1 data cache)
- system.cpu.icache.overall_miss_rate::total= 0.000077 [//]: # (Miss rate for overall accesses for L1 instruction cache)
- system.l2.overall_miss_rate::total= 0.282163 [//]: # (Miss rate for overall accesses for L2)

Mcf
- sim_seconds= 0.064955
- system.cpu.cpi= 1.299095
- system.cpu.dcache.overall_miss_rate::total= 0.002108
- system.cpu.icache.overall_miss_rate::total= 0.023612
- system.l2.overall_miss_rate::total= 0.055046

Hmmer
- sim_seconds= 0.059396
- system.cpu.cpi= 1.187917
- system.cpu.dcache.overall_miss_rate::total= 0.001637
- system.cpu.icache.overall_miss_rate::total= 0.000221
- system.l2.overall_miss_rate::total= 0.077760

Sjeng
- sim_seconds= 0.513528
- system.cpu.cpi= 10.270554
- system.cpu.dcache.overall_miss_rate::total= 0.121831
- system.cpu.icache.overall_miss_rate::total= 0.000020
- system.l2.overall_miss_rate::total= 0.999972

Libm
- sim_seconds= 0.174671

- system.cpu.cpi= 3.493415
- system.cpu.dcache.overall_miss_rate::total= 0.060972
- system.cpu.icache.overall_miss_rate::total= 0.000094
- system.l2.overall_miss_rate::total= 0.999944

Part 3

Bzip

./build/ARM/gem5.opt -d spec_results/specbzipTEST5 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=128kB --l1i_size=32kB --l2_size=4MB --l1i_assoc=1 --l1d_assoc=4 --l2_assoc=4 --cacheline_size=256 --cpu-clock=2GHz -c spec_cpu2006/401.bzip2/src/specbzip -o "spec_cpu2006/401.bzip2/data/input.program 10" -I 100000000

 CPI is 1.600465, while default CPI is 1.679650. improvement of 4.714375%.

Mcf

./build/ARM/gem5.opt -d spec_results/specmcfTEST4 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=32kB --l1i_size=128kB --l2_size=2MB --l1i_assoc=1 --l1d_assoc=4 --l2_assoc=2 --cacheline_size=128 --cpu-clock=2GHz -c spec_cpu2006/429.mcf/src/specmcf -o "spec_cpu2006/429.mcf/data/inp.in" -I 100000000

  CPI is 1.125518, while default CPI is 1.299095. 13.36% improvement.

Hmmer

./build/ARM/gem5.opt -d spec_results/spechmmerTEST7 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=128kB --l1i_size=64kB --l2_size=4MB --l1i_assoc=2 --l1d_assoc=4 --l2_assoc=4 --cacheline_size=128 --cpu-clock=2GHz -c spec_cpu2006/456.hmmer/src/spechmmer -o "--fixed 0 --mean 325 --num 45000 --sd 200 --seed 0 spec_cpu2006/456.hmmer/data/bombesin.hmm" -I 100000000

  CPI is 1.179809, default CPI is 1.187917. 0.68% improvement.

Sjeng

./build/ARM/gem5.opt -d spec_results/specsjengTEST3 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=128kB --l1i_size=32kB --l2_size=4MB --l1i_assoc=2 --l1d_assoc=4 --l2_assoc=8 --cacheline_size=256 --cpu-clock=2GHz -c spec_cpu2006/458.sjeng/src/specsjeng -o "spec_cpu2006/458.sjeng/data/test.txt" -I 100000000

  CPI is 5.171443, default being 10.270554. 49.64%

Libm

./build/ARM/gem5.opt -d spec_results/speclibmTEST6 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=128kB --l1i_size=64kB --l2_size=4MB --l1i_assoc=1 --l1d_assoc=2 --l2_assoc=4 --cacheline_size=256 --cpu-clock=2GHz -c spec_cpu2006/470.lbm/src/speclibm -o "20 spec_cpu2006/470.lbm/data/lbm.in 0 1 spec_cpu2006/470.lbm/data/100_100_130_cf_a.of" -I 100000000

CPI is 1.989308, default being 3.493415. 43.01% improvement.

Tests for Part 3

LIBM

./build/ARM/gem5.opt -d spec_results/speclibmTEST1 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=32kB --l1i_size=64kB --l2_size=4MB --l1i_assoc=1 --l1d_assoc=1 --l2_assoc=2 --cacheline_size=64 --cpu-clock=2GHz -c spec_cpu2006/470.lbm/src/speclibm -o "20 spec_cpu2006/470.lbm/data/lbm.in 0 1 spec_cpu2006/470.lbm/data/100_100_130_cf_a.of" -I 100000000

./build/ARM/gem5.opt -d spec_results/speclibmTEST2 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=128kB --l1i_size=64kB --l2_size=2MB --l1i_assoc=1 --l1d_assoc=1 --l2_assoc=2 --cacheline_size=64 --cpu-clock=2GHz -c spec_cpu2006/470.lbm/src/speclibm -o "20 spec_cpu2006/470.lbm/data/lbm.in 0 1 spec_cpu2006/470.lbm/data/100_100_130_cf_a.of" -I 100000000

ETC.

./build/ARM/gem5.opt -d spec_results/specsjengTEST6 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=128kB --l1i_size=32kB --l2_size=4MB --l1i_assoc=1 --l1d_assoc=4 --l2_assoc=4 --cacheline_size=128 --cpu-clock=2GHz -c spec_cpu2006/458.sjeng/src/specsjeng -o "spec_cpu2006/458.sjeng/data/test.txt" -I 100000000

./build/ARM/gem5.opt -d spec_results/specsjengTEST7 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=64kB --l1i_size=32kB --l2_size=4MB --l1i_assoc=1 --l1d_assoc=2 --l2_assoc=4 --cacheline_size=128 --cpu-clock=2GHz -c spec_cpu2006/458.sjeng/src/specsjeng -o "spec_cpu2006/458.sjeng/data/test.txt" -I 100000000

./build/ARM/gem5.opt -d spec_results/specsjengTEST8 configs/test.py --cpu-type=TimingSimpleCPU --caches --l2cache --l1d_size=128kB --l1i_size=32kB --l2_size=4MB --l1i_assoc=2 --l1d_assoc=2 --l2_assoc=4 --cacheline_size=128 --cpu-clock=2GHz -c spec_cpu2006/458.sjeng/src/specsjeng -o "spec_cpu2006/458.sjeng/data/test.txt" -I 100000000

Part 4

Associativity of L1 be	A1	Associativity of L2 be	A2	Replacement policy be	R
Block Size be	BS	Cost of Splitting L1 be	S1	Cost of splitting L2 be	S2
Cost Factor for L1	CF1	Cost Factor for L2	CF2		

Cost Function Assignments:

R for Random	= 10
R for FIFO	= 30
R for LRU	= 80
Cost for 1-way	= 10
Cost for 2-way	= 20
Cost for 4-way	= 40
Cost for 8-way	= 80
S1	= 2

```
S2              = 1
CF1             = 5
CF2             = 1
```
When the associativity of the cache increases the area of the cache also increases, which results in increase in cost of the cache. So, higher associativity leads to higher cache cost as hardware required is more. So, the design cost associated with increase in associativity is proportional to n-way associativity.

And since the L1 cache is of smaller size with greater associativity and is placed near the processor than L2 cache, L1 cache is faster than L2 cache. So, the cost associated with L1 is higher than L2. This factor is included in the design as Cost Factor (CF) term. The CF associated with L1 is 5 and L2 is 1.

Considering the replacement policy, changing form Random to FIFO increases the cost only by a smaller amount. LRU replacement is much costlier than random and FIFO. Splitting the cache also results in increase in cache cost. Since they require additional hardware and it also results in increased bandwidth. Hence the cost for splitting the cache is also added to the total cost.

$$\text{Total cost} = (\text{Cache size}_{L1}*CF1+S1) + (\text{Cache size}_{L2}*CF2+S2) +A1+A2+R1+R2$$

Part 5

Bzip

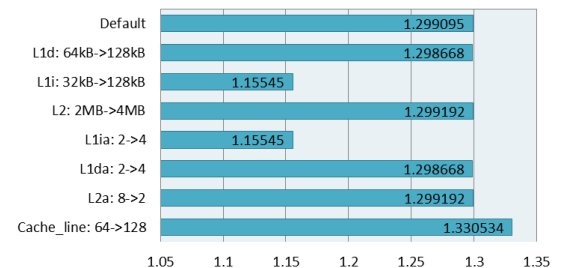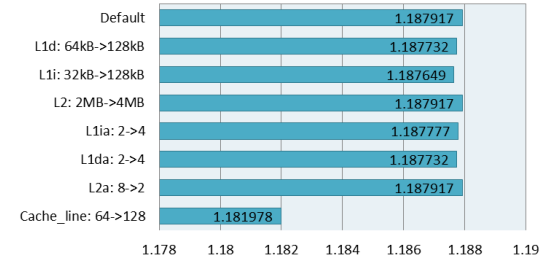Bzip cost: 64*((384*(2*128*2*6) + (32*2*6))+(4096*4))) = 1.196.416 . An increase of.
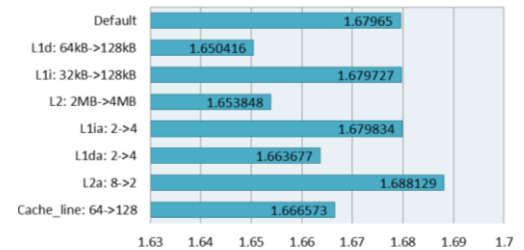
Mcf

Mcf cost: 64*((384*(2*32*2*6) + (64*2*6))+(1024*2))) = 297.728.

Hmmer

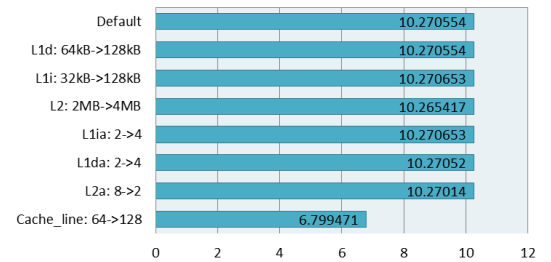Hmmer cost: $128*((384*(2*32*2*6) + (32*2*6))+(1024*4)))$ = 299.392.

Config	Value
Default	1.187917
L1d: 64kB->128kB	1.187732
L1i: 32kB->128kB	1.187649
L2: 2MB->4MB	1.187917
L1ia: 2->4	1.187777
L1da: 2->4	1.187732
L2a: 8->2	1.187917
Cache_line: 64->128	1.181978

Sjeng

Sjeng cost: $128*((384*(2*32*2*6) + (32*2*6)) + (1024*2)))$ = 297.344.

Config	Value
Default	10.270554
L1d: 64kB->128kB	10.270554
L1i: 32kB->128kB	10.270653
L2: 2MB->4MB	10.265417
L1ia: 2->4	10.270653
L1da: 2->4	10.27052
L2a: 8->2	10.27014
Cache_line: 64->128	6.799471

Libm

 Libm cost will be same as Sjeng, at 297.344.

Config	Value
Default	3.493415
L1d: 64kB->128kB	3.493415
L1i: 32kB->128kB	3.493293
L2: 2MB->4MB	3.489639
L1ia: 2->4	3.493293
L1da: 2->4	3.493415
L2a: 8->2	3.493415
Cache_line: 64->128	2.581299
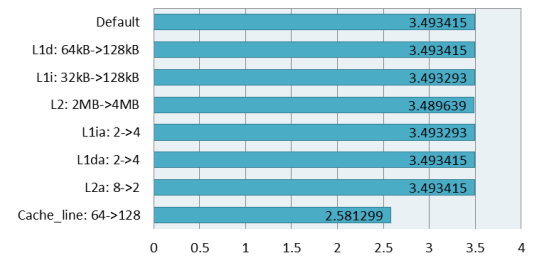
Benchmark: 401.bzip2

For convenience I have organized parts by their benchmark

1. L1-D cache size
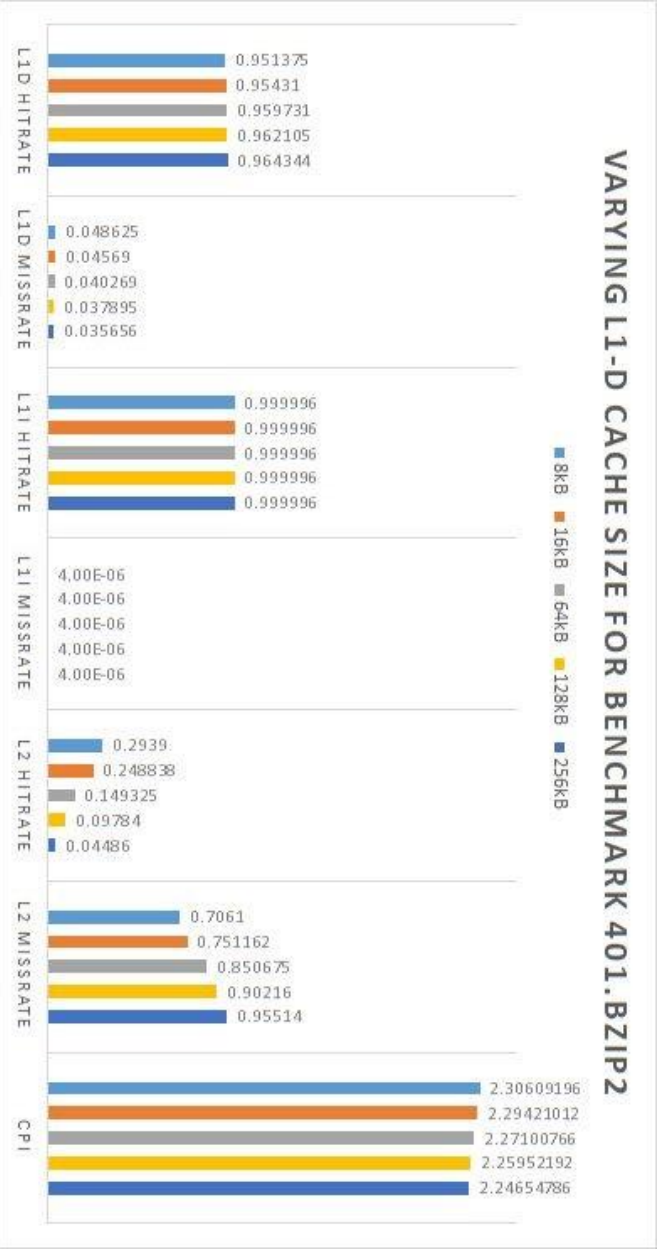
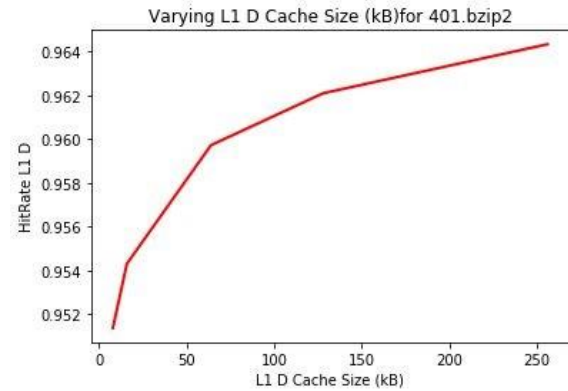Varying L1-D Cache Size for 401.bzip2

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8kB	0.951375	0.048625	0.999996	4e-06	0.2939	0.7061	2.30609
16kB	0.95431	0.04569	0.999996	4e-06	0.248838	0.751162	2.29421
64kB	0.959731	0.040269	0.999996	4e-06	0.149325	0.850675	2.27101
128kB	0.962105	0.037895	0.999996	4e-06	0.09784	0.90216	2.25952
256kB	0.964344	0.035656	0.999996	4e-06	0.04486	0.95514	2.24655

VARYING L1-D CACHE SIZE FOR BENCHMARK 401.BZIP2

Varying L1 D Cache Size (kB)for 401.bzip2
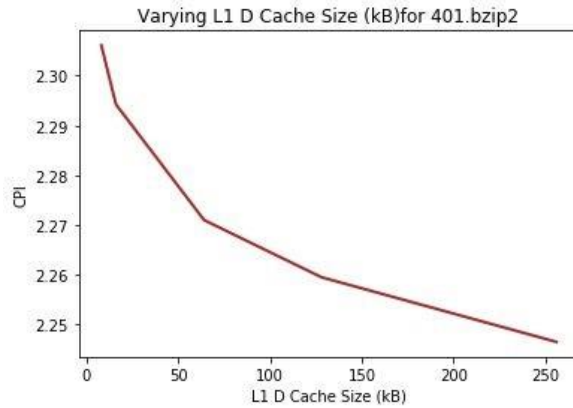
2. L1-I cache size

Varying L1-I Cache Size for 401.bzip2

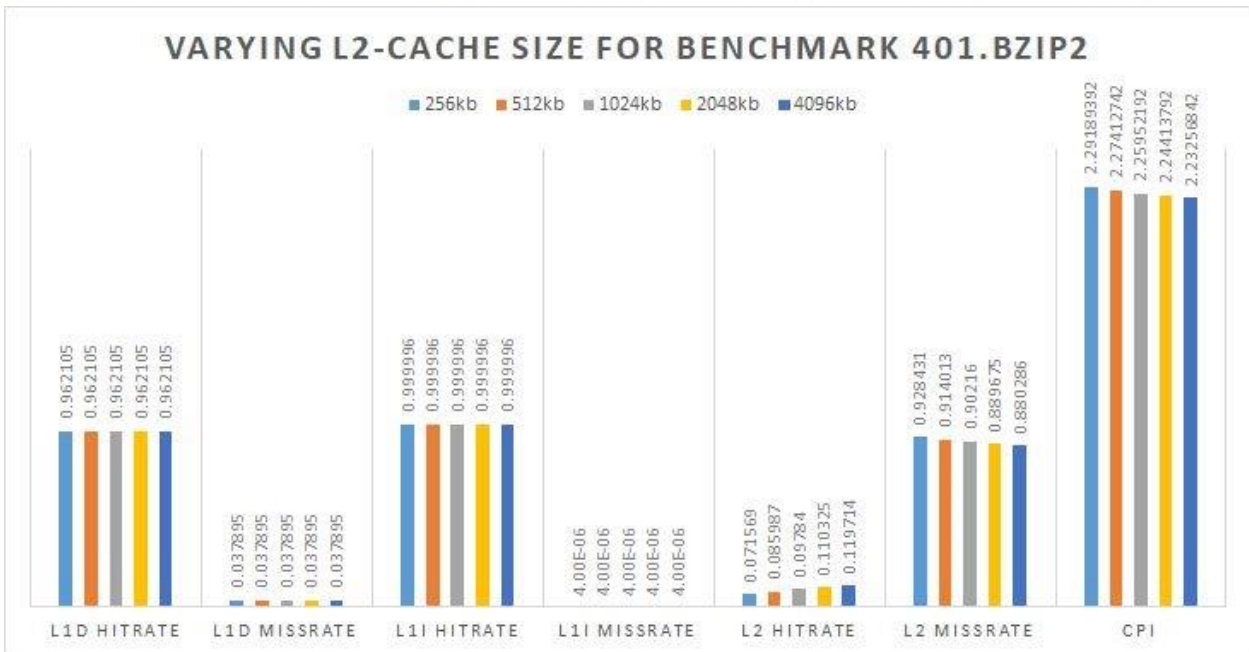| Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
4kb	0.962105	0.037895	0.999959	4.1e-05	0.099561	0.900439	2.25996
8kb	0.962105	0.037895	0.999994	6e-06	0.0979	0.9021	2.2596
16kb	0.962105	0.037895	0.999995	5e-06	0.097862	0.902138	2.25955
64kb	0.962105	0.037895	0.999996	4e-06	0.09784	0.90216	2.25952
128kb	0.962105	0.037895	0.999996	4e-06	0.097837	0.902163	2.25952
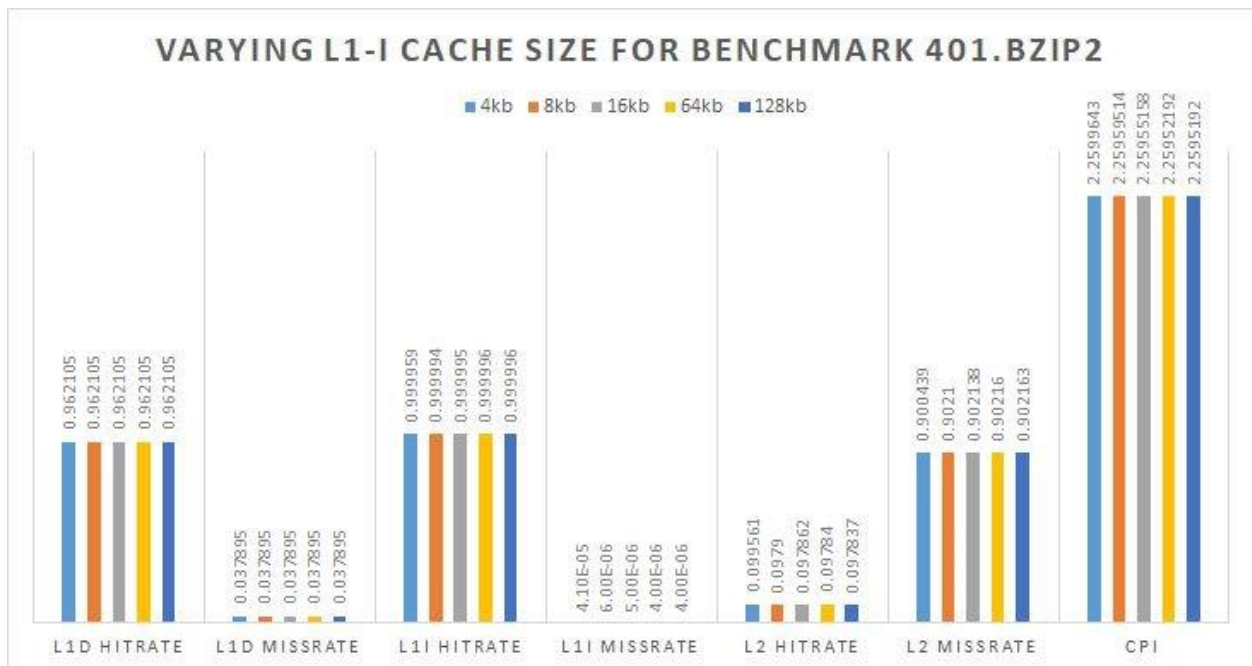
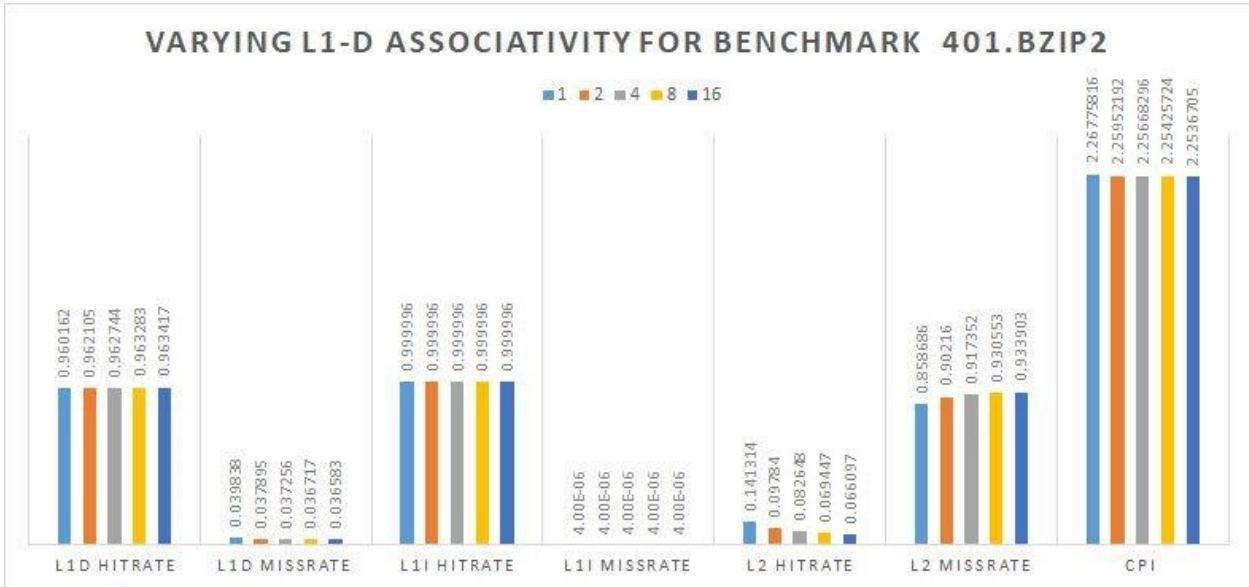# 3. Varying L2 cache size

Varying L2 Cache Size for 401.bzip2

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
256kb	0.962105	0.037895	0.999996	4e-06	0.071569	0.928431	2.29189
512kb	0.962105	0.037895	0.999996	4e-06	0.085987	0.914013	2.27413
1024kb	0.962105	0.037895	0.999996	4e-06	0.09784	0.90216	2.25952
2048kb	0.962105	0.037895	0.999996	4e-06	0.110325	0.889675	2.24414
4096kb	0.962105	0.037895	0.999996	4e-06	0.119714	0.880286	2.23257

VARYING L2-CACHE SIZE FOR BENCHMARK 401.BZIP2

4.L1-D Associativity

Varying L1 D Associative Cache Size for 401.bzip2

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.960162	0.039838	0.999996	4e-06	0.141314	0.858686	2.26776
2	0.962105	0.037895	0.999996	4e-06	0.09784	0.90216	2.25952
4	0.962744	0.037256	0.999996	4e-06	0.082648	0.917352	2.25668
8	0.963283	0.036717	0.999996	4e-06	0.069447	0.930553	2.25426
16	0.963417	0.036583	0.999996	4e-06	0.066097	0.933903	2.25367

VARYING L1-D ASSOCIATIVITY FOR BENCHMARK 401.BZIP2

5. L1-I Associativity

Varying L1 I Associative Cache Size for 401.bzip2

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.962105	0.037895	0.999996	4e-06	0.097847	0.902153	2.25953
2	0.962105	0.037895	0.999996	4e-06	0.09784	0.90216	2.25952
4	0.962105	0.037895	0.999996	4e-06	0.097838	0.902162	2.25952
8	0.962105	0.037895	0.999996	4e-06	0.097837	0.902163	2.25952
16	0.962105	0.037895	0.999996	4e-06	0.097837	0.902163	2.25952

6. L2 Associativity

Varying L2 Associative Cache Size for 401.bzip2

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.962105	0.037895	0.999996	4e-06	0.09784	0.90216	2.25952
2	0.962105	0.037895	0.999996	4e-06	0.105111	0.894889	2.25056
4	0.962105	0.037895	0.999996	4e-06	0.106925	0.893075	2.24833
8	0.962105	0.037895	0.999996	4e-06	0.107692	0.892308	2.24738
16	0.962105	0.037895	0.999996	4e-06	0.108238	0.891762	2.24671

VARYING L2 ASSOCIATIVITY FOR BENCHMARK 401.BZIP2

7. Cache Block size

Varying Cache Block Size for 401.bzip2

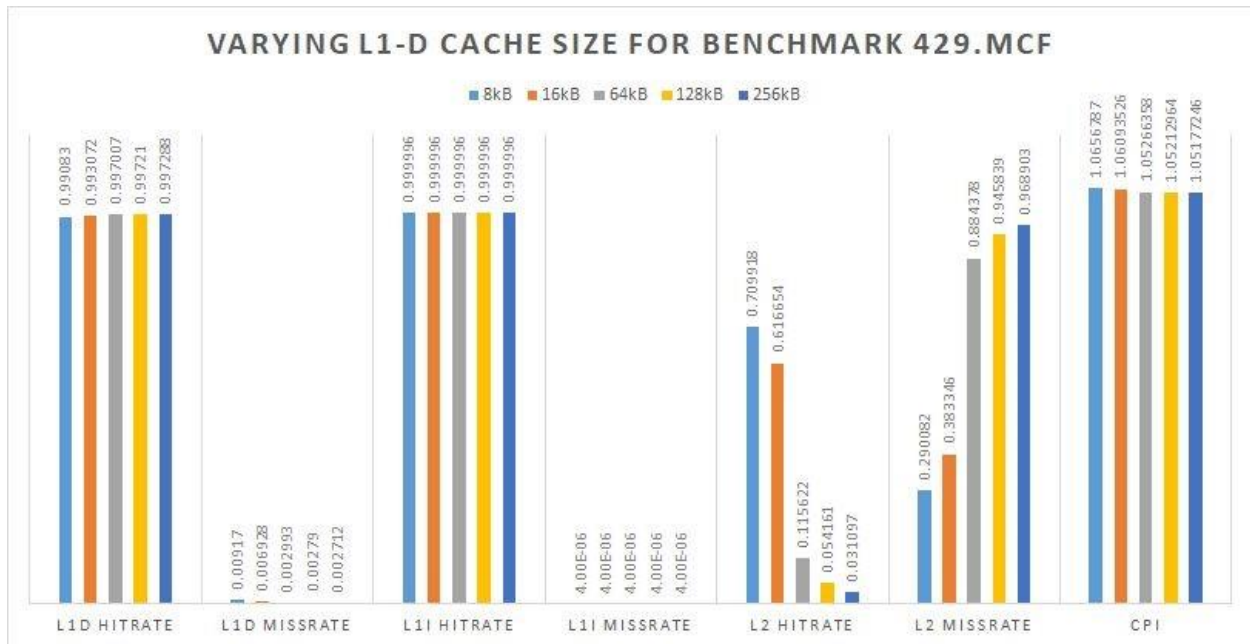| Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8	0.7553	0.2447	0.999979	2.1e-05	0.021759	0.978241	6.1438
16	0.873866	0.126134	0.999989	1.1e-05	0.02345	0.97655	5.4973
32	0.93283	0.06717	0.999993	7e-06	0.049632	0.950368	3.33779
64	0.962105	0.037895	0.999996	4e-06	0.09784	0.90216	2.25952
128	0.976148	0.023852	0.999998	2e-06	0.184776	0.815224	1.72533
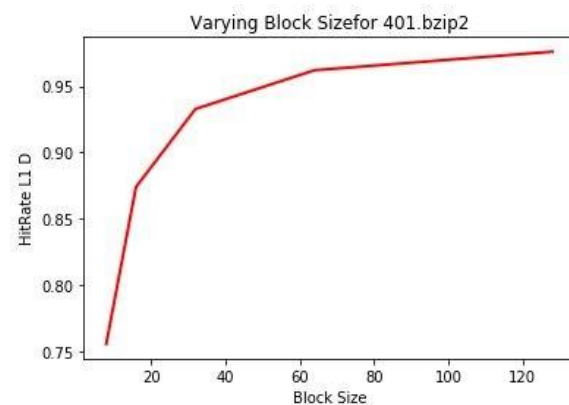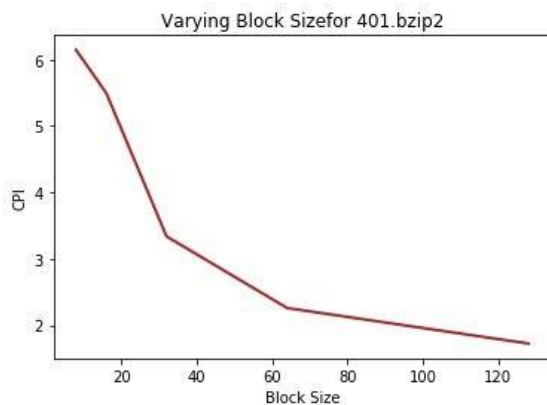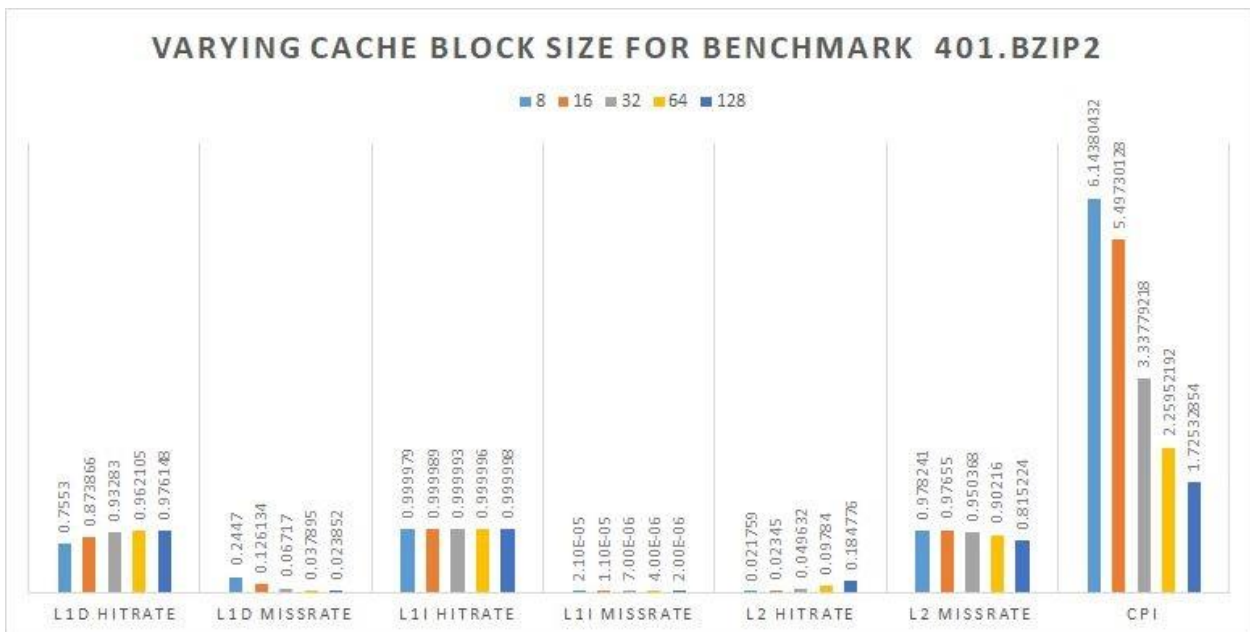
Benchmark: 429.mcf

1. L1-D cache size

Varying L1-D Cache Size for 429.mcf

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8kB	0.99083	0.00917	0.999996	4e-06	0.709918	0.290082	1.06568
16kB	0.993072	0.006928	0.999996	4e-06	0.616654	0.383346	1.06094
64kB	0.997007	0.002993	0.999996	4e-06	0.115622	0.884378	1.05266
128kB	0.99721	0.00279	0.999996	4e-06	0.054161	0.945839	1.05213
256kB	0.997288	0.002712	0.999996	4e-06	0.031097	0.968903	1.05177

2. Varying L1-I cache size

Varying L1-I Cache Size for 429.mcf

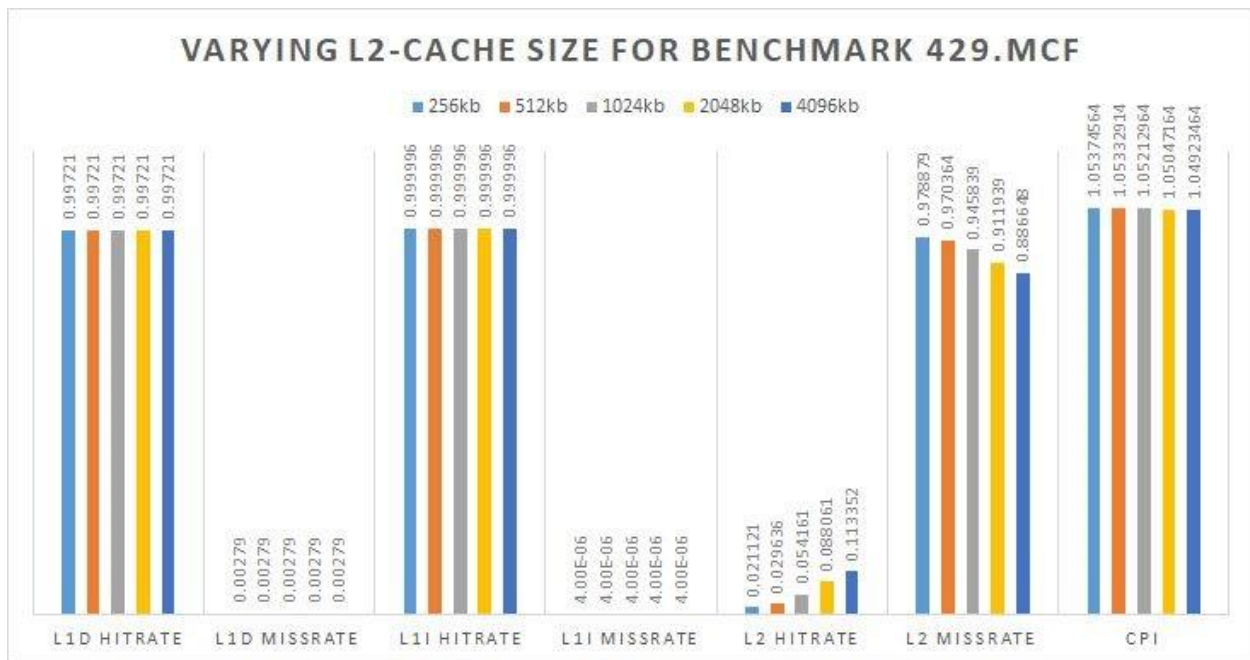| Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
4kb	0.99721	0.00279	0.947528	0.052472	0.987174	0.012826	1.48411
8kb	0.99721	0.00279	0.986146	0.013854	0.953447	0.046553	1.16624
16kb	0.99721	0.00279	0.996141	0.003859	0.852084	0.147916	1.08389
64kb	0.99721	0.00279	0.999996	4e-06	0.054161	0.945839	1.05213
128kb	0.99721	0.00279	0.999996	4e-06	0.054123	0.945877	1.05213
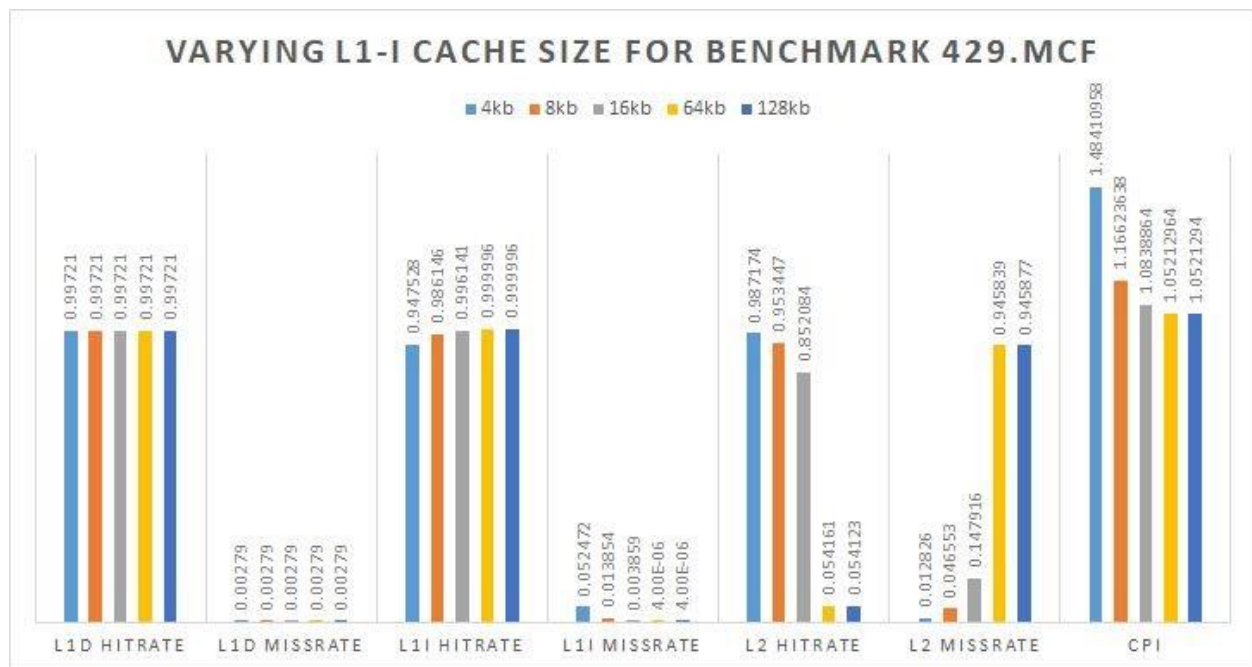
The L1-I miss-rate reduces here significantly as the cache size is doubled. The CPI is also seen to reduce slightly. This benchmark works quite well, in that, the CPI is very close to 1. The L2 miss-rate increases significantly as the L1 hit-rate increases.

3. L2 cache size

Varying L2 Cache Size for 429.mcf

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
256kb	0.99721	0.00279	0.999996	4e-06	0.021121	0.978879	1.05375
512kb	0.99721	0.00279	0.999996	4e-06	0.029636	0.970364	1.05333
1024kb	0.99721	0.00279	0.999996	4e-06	0.054161	0.945839	1.05213
2048kb	0.99721	0.00279	0.999996	4e-06	0.088061	0.911939	1.05047
4096kb	0.99721	0.00279	0.999996	4e-06	0.113352	0.886648	1.04923

4. Varying L1-D Associativity

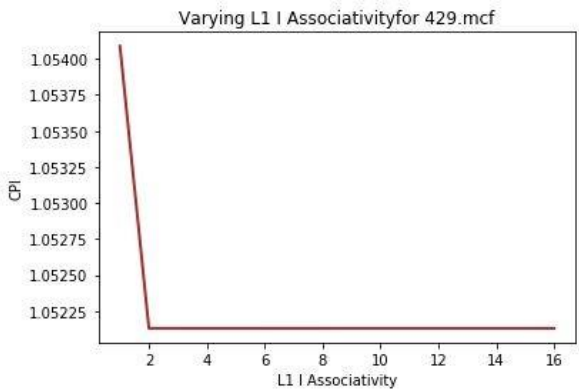Varying L1 D Associative Cache Size for 429.mcf

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.996863	0.003137	0.999996	4e-06	0.153332	0.846668	1.05312
2	0.99721	0.00279	0.999996	4e-06	0.054161	0.945839	1.05213
4	0.997254	0.002746	0.999996	4e-06	0.041674	0.958326	1.05191
8	0.99727	0.00273	0.999996	4e-06	0.038243	0.961757	1.05176
16	0.997271	0.002729	0.999996	4e-06	0.038052	0.961948	1.05175

5. L1-I Associativity
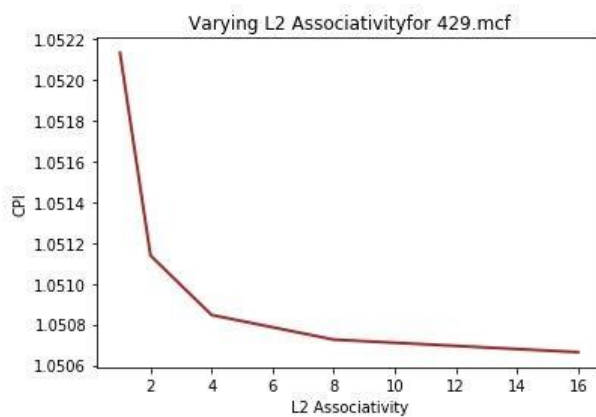
Varying L1 I Associative Cache Size for 429.mcf

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.99721	0.00279	0.999759	0.000241	0.289934	0.710066	1.05409
2	0.99721	0.00279	0.999996	4e-06	0.054161	0.945839	1.05213
4	0.99721	0.00279	0.999996	4e-06	0.054132	0.945868	1.05213
8	0.99721	0.00279	0.999996	4e-06	0.054123	0.945877	1.05213
16	0.99721	0.00279	0.999996	4e-06	0.054123	0.945877	1.05213
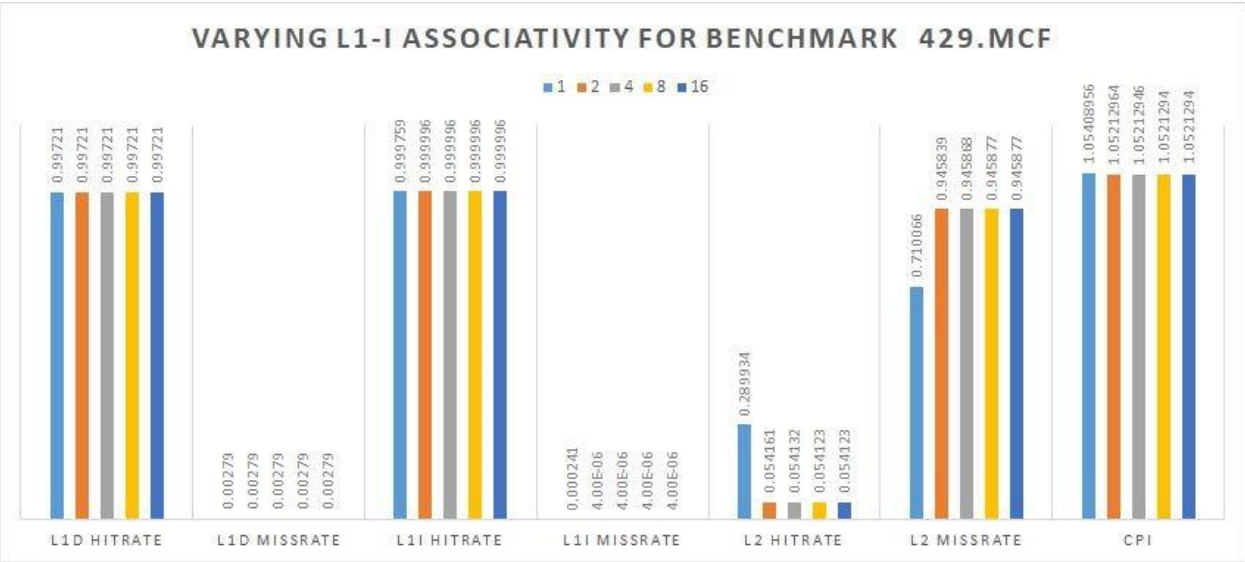
VARYING L1-I ASSOCIATIVITY FOR BENCHMARK 429.MCF

Varying L1 I Associativity for 429.mcf

6. L2 Associativity

Varying L2 Associative Cache Size for 429.mcf

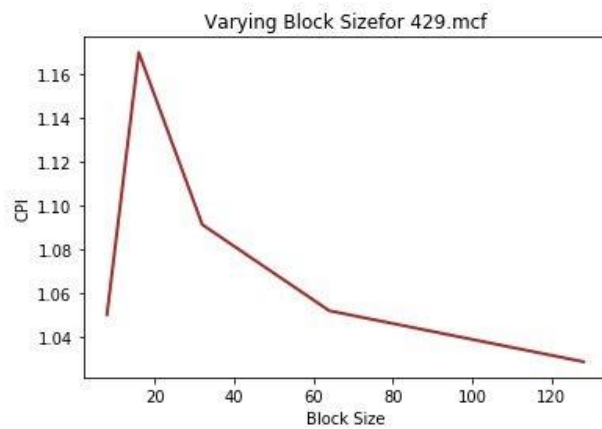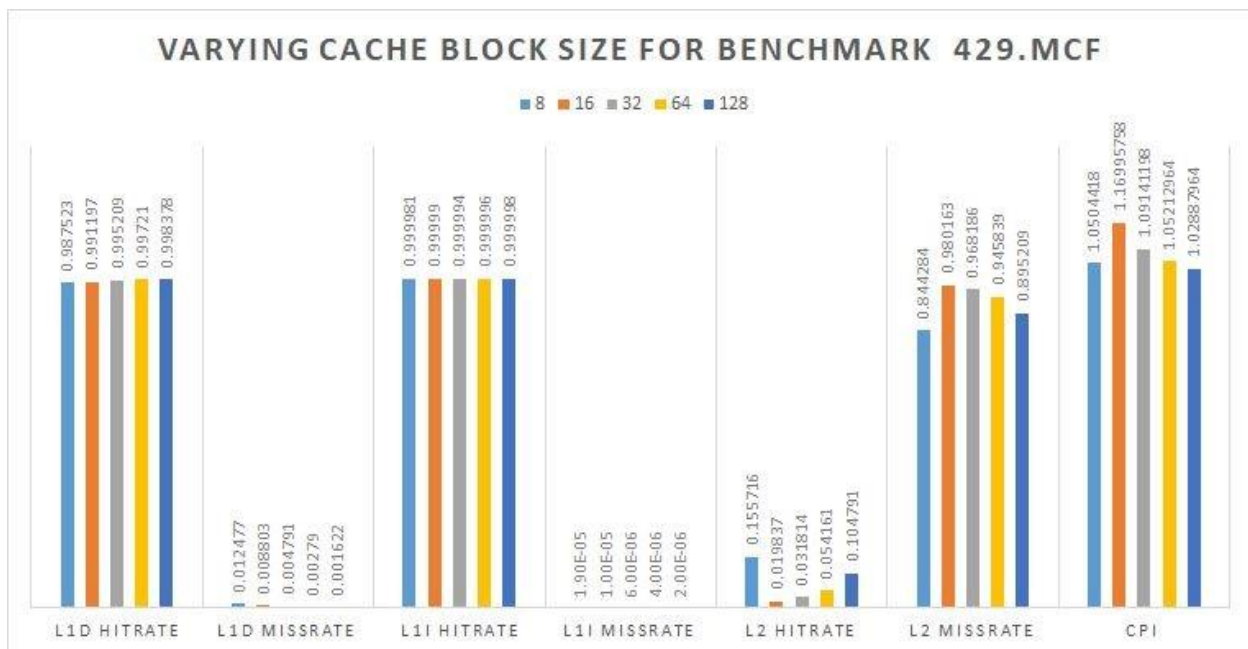| Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.99721	0.00279	0.999996	4e-06	0.054161	0.945839	1.05213
2	0.99721	0.00279	0.999996	4e-06	0.074444	0.925556	1.05114
4	0.99721	0.00279	0.999996	4e-06	0.080393	0.919607	1.05085
8	0.99721	0.00279	0.999996	4e-06	0.082857	0.917143	1.05073
16	0.99721	0.00279	0.999996	4e-06	0.084115	0.915885	1.05066
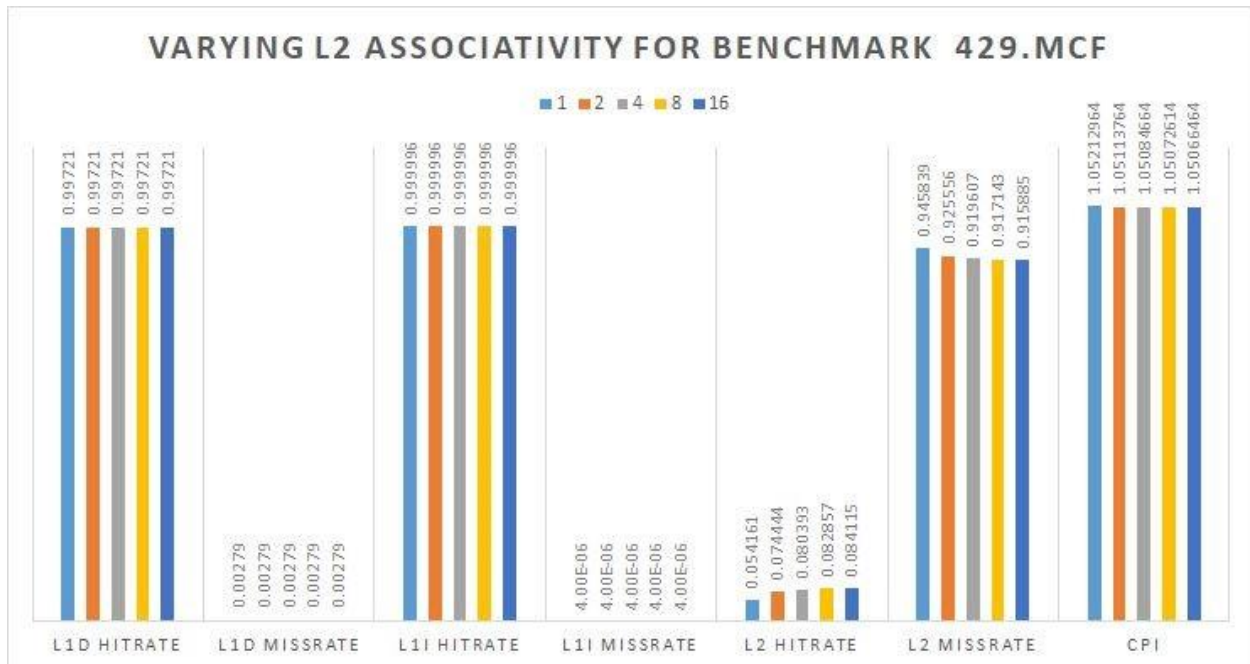
7. Cache Block size

Varying Cache Block Size for 429.mcf

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8	0.987523	0.012477	0.999981	1.9e-05	0.155716	0.844284	1.05044
16	0.991197	0.008803	0.99999	1e-05	0.019837	0.980163	1.16996
32	0.995209	0.004791	0.999994	6e-06	0.031814	0.968186	1.09141
64	0.99721	0.00279	0.999996	4e-06	0.054161	0.945839	1.05213
128	0.998378	0.001622	0.999998	2e-06	0.104791	0.895209	1.02888

VARYING CACHE BLOCK SIZE FOR BENCHMARK 429.MCF

Varying Block Sizefor 429.mcf

Benchmark : 456.hmmer

1. Varying L1-D cache size

Varying L1-D Cache Size for 456.hmmer

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8kB	0.993867	0.006133	0.999985	1.5e-05	0.979316	0.020684	1.02216
16kB	0.995691	0.004309	0.999985	1.5e-05	0.970701	0.029299	1.01657
64kB	0.998137	0.001863	0.999985	1.5e-05	0.932679	0.067321	1.0091
128kB	0.999175	0.000825	0.999985	1.5e-05	0.852157	0.147843	1.00591
256kB	0.999888	0.000112	0.999985	1.5e-05	0.174804	0.825196	1.00367

Varying L1 D Cache Size (kB)for 456.hmmer

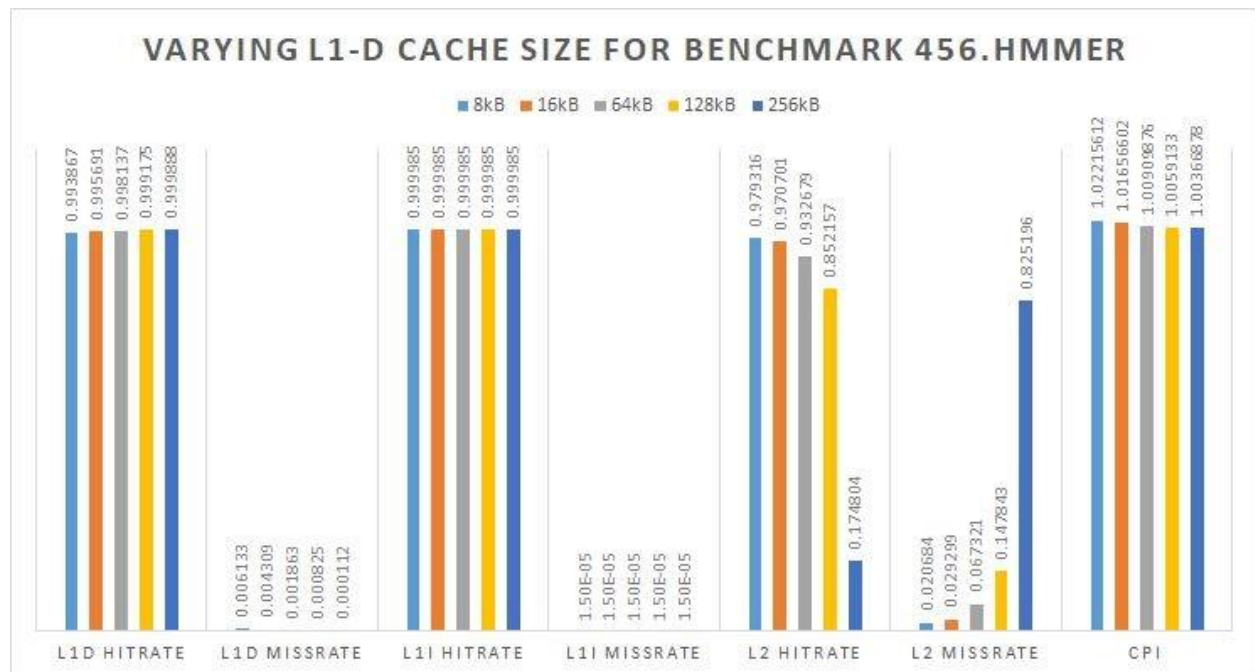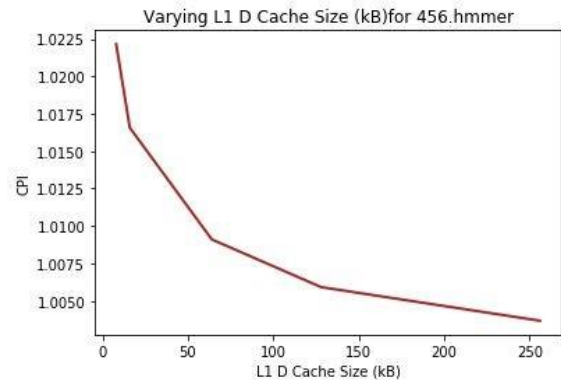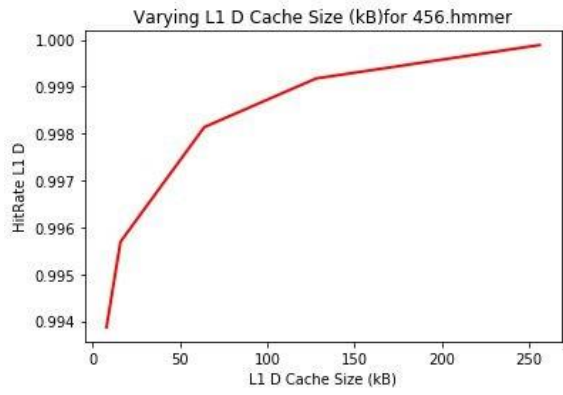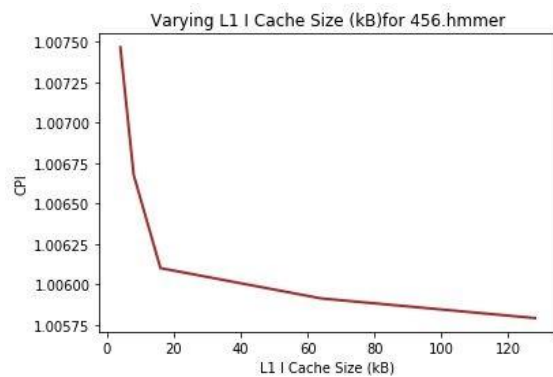## Varying L1 D Cache Size (kB)for 456.hmmer

2. Varying L1-I cache size

Varying L1-I Cache Size for 456.hmmer

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
4kb	0.999175	0.000825	0.999803	0.000197	0.905095	0.094905	1.00747
8kb	0.999175	0.000825	0.999896	0.000104	0.883761	0.116239	1.00668
16kb	0.999175	0.000825	0.999964	3.6e-05	0.86077	0.13923	1.0061
64kb	0.999175	0.000825	0.999985	1.5e-05	0.852157	0.147843	1.00591
128kb	0.999175	0.000825	0.99999	1e-05	0.853318	0.146682	1.00579

VARYING L1-I CACHE SIZE FOR BENCHMARK 456.HMMER

Varying L1 I Cache Size (kB)for 456.hmmer

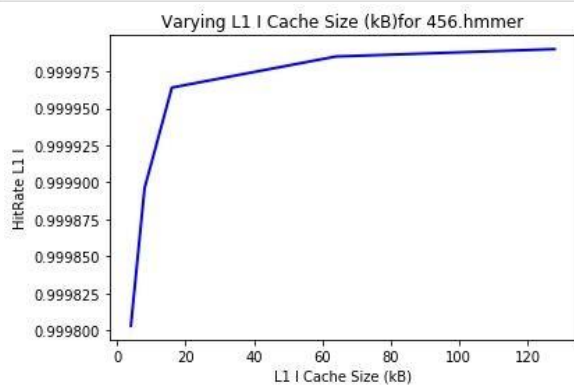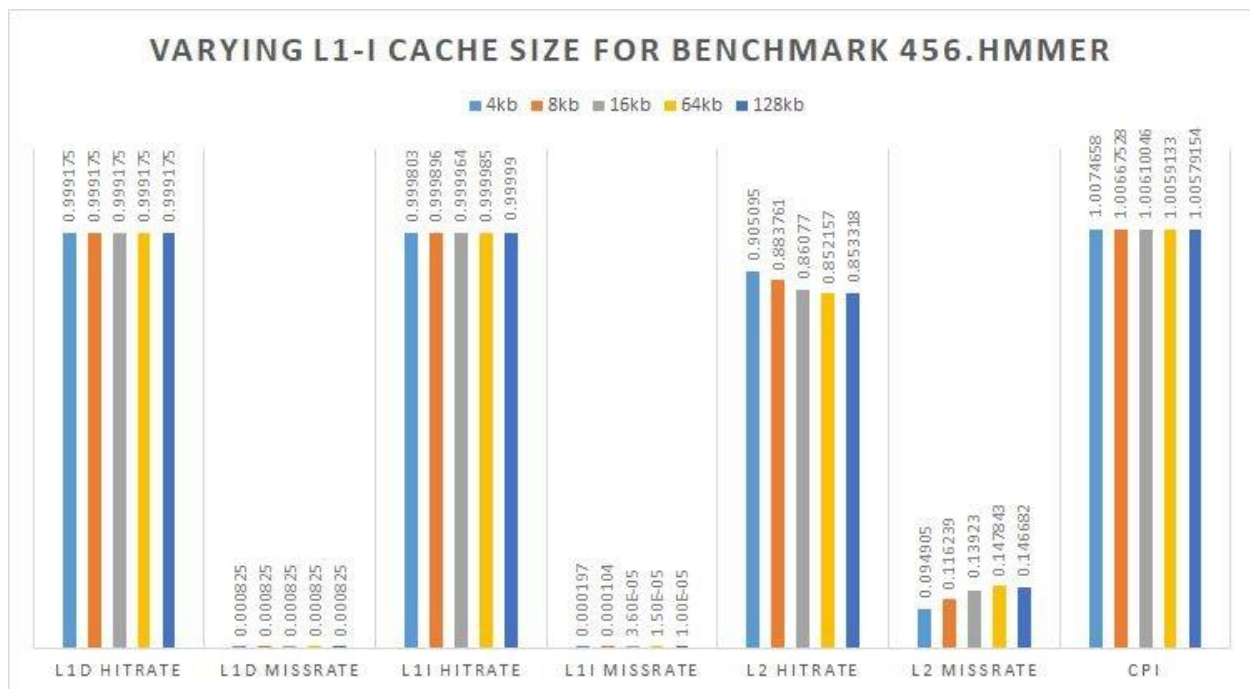Varying L1 I Cache Size (kB)for 456.hmmer

3. L2 cache size

Varying L2 Cache Size for 456.hmmer

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
256kb	0.999175	0.000825	0.999985	1.5e-05	0.837753	0.162247	1.00623
512kb	0.999175	0.000825	0.999985	1.5e-05	0.848828	0.151172	1.00599
1024kb	0.999175	0.000825	0.999985	1.5e-05	0.852157	0.147843	1.00591
2048kb	0.999175	0.000825	0.999985	1.5e-05	0.855758	0.144242	1.00583
4096kb	0.999175	0.000825	0.999985	1.5e-05	0.855758	0.144242	1.00583
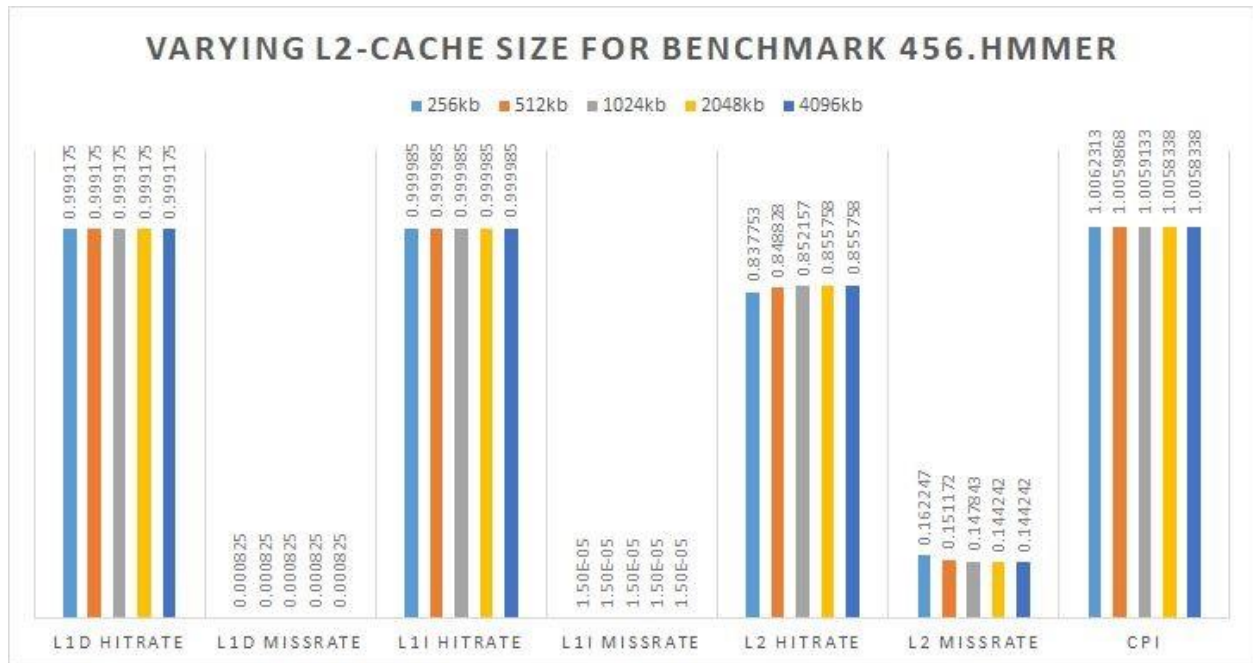
VARYING L2-CACHE SIZE FOR BENCHMARK 456.HMMER

4. L1-D Associativity

Varying L1 D Associative Cache Size for 456.hmmer

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.998729	0.001271	0.999985	1.5e-05	0.903198	0.096802	1.00725
2	0.999175	0.000825	0.999985	1.5e-05	0.852157	0.147843	1.00591
4	0.999351	0.000649	0.999985	1.5e-05	0.817169	0.182831	1.00533
8	0.999385	0.000615	0.999985	1.5e-05	0.808177	0.191823	1.00521
16	0.999413	0.000587	0.999985	1.5e-05	0.799706	0.200294	1.00512
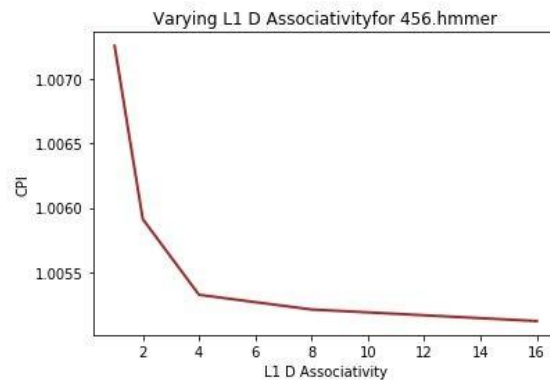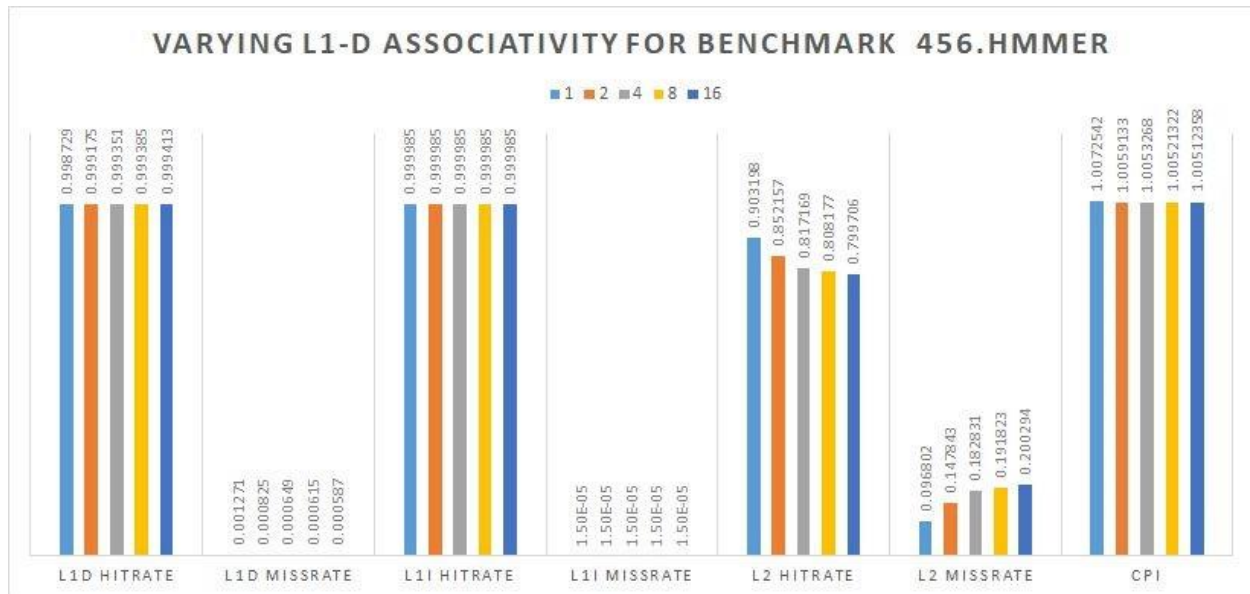
VARYING L1-D ASSOCIATIVITY FOR BENCHMARK 456.HMMER

Varying L1 D Associativity for 456.hmmer

5. L1-I Associativity

Varying L1 I Associative Cache Size for 456.hmmer

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.999175	0.000825	0.999958	4.2e-05	0.866753	0.133247	1.00606
2	0.999175	0.000825	0.999985	1.5e-05	0.852157	0.147843	1.00591
4	0.999175	0.000825	0.99999	1e-05	0.85328	0.14672	1.0058
8	0.999175	0.000825	0.99999	1e-05	0.853194	0.146806	1.0058
16	0.999175	0.000825	0.99999	1e-05	0.853342	0.146658	1.00579
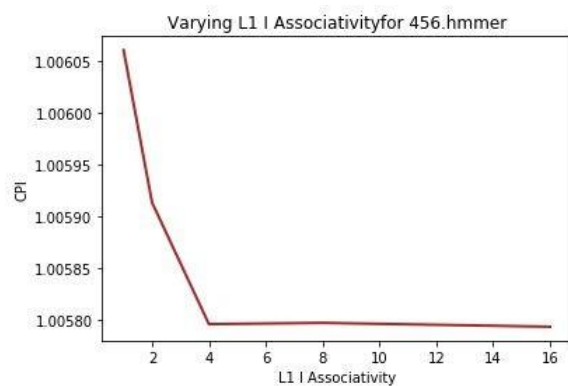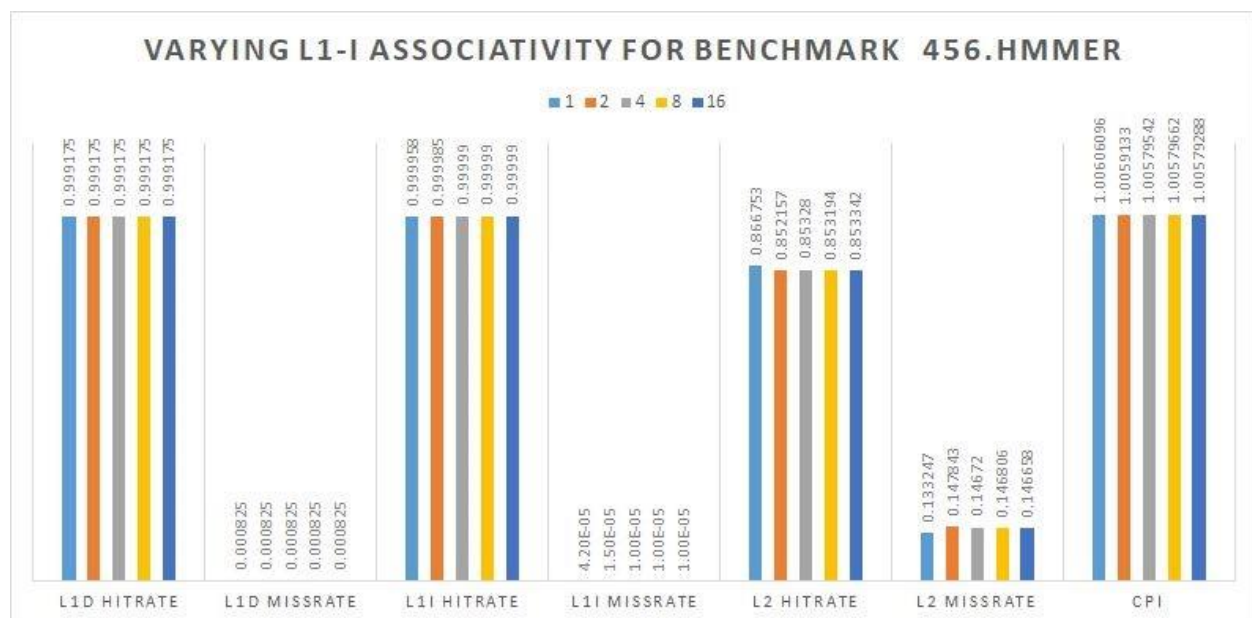
VARYING L1-I ASSOCIATIVITY FOR BENCHMARK 456.HMMER

Varying L1 I Associativity for 456.hmmer

6. L2 Associativity

Varying L2 Associative Cache Size for 456.hmmer

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.999175	0.000825	0.999985	1.5e-05	0.852157	0.147843	1.00591
2	0.999175	0.000825	0.999985	1.5e-05	0.853788	0.146212	1.00588
4	0.999175	0.000825	0.999985	1.5e-05	0.855758	0.144242	1.00583
8	0.999175	0.000825	0.999985	1.5e-05	0.855758	0.144242	1.00583
16	0.999175	0.000825	0.999985	1.5e-05	0.855758	0.144242	1.00583

VARYING L2 ASSOCIATIVITY FOR BENCHMARK 456.HMMER
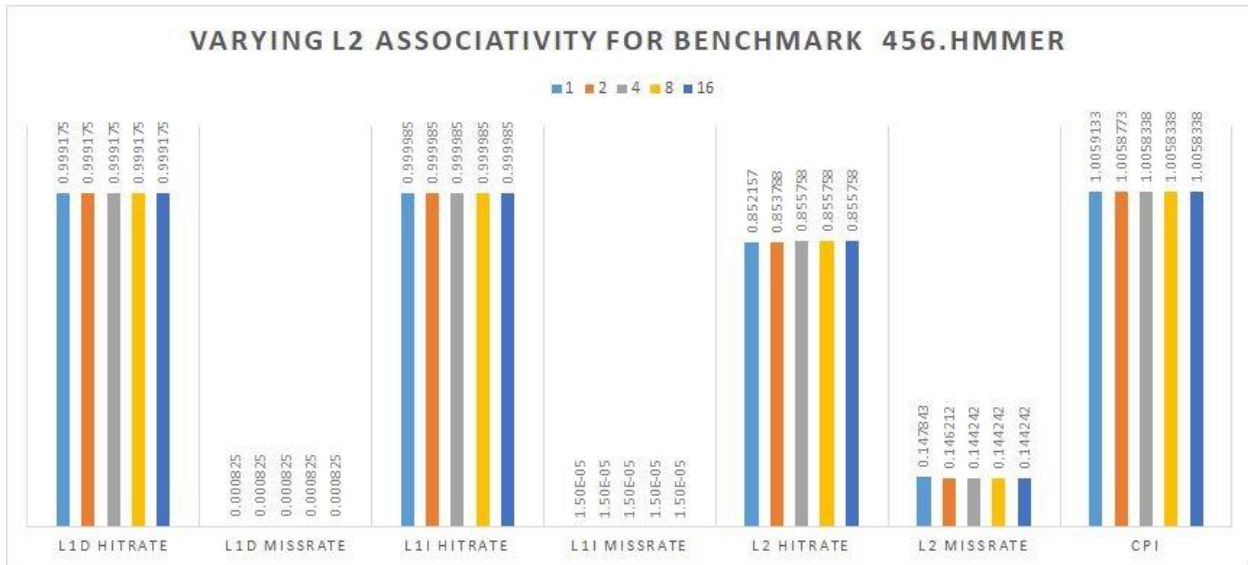
7. Cache Block size

Varying Cache Block Size for 456.hmmer

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8	0.994265	0.005735	0.999925	7.5e-05	0.900582	0.099418	1.03125
16	0.996888	0.003112	0.99996	4e-05	0.858179	0.141821	1.02165
32	0.998403	0.001597	0.999975	2.5e-05	0.85542	0.14458	1.01123
64	0.999175	0.000825	0.999985	1.5e-05	0.852157	0.147843	1.00591
128	0.99957	0.00043	0.999987	1.3e-05	0.854075	0.145925	1.00315

VARYING CACHE BLOCK SIZE FOR BENCHMARK 456.HMMER

■ 8 ■ 16 ■ 32 ■ 64 ■ 128

Metric	8	16	32	64	128
L1D HITRATE	0.994265	0.996888	0.98403	0.99175	0.99957
L1D MISSRATE	0.005735	0.003112	0.001597	0.000825	0.00043
L1I HITRATE	0.99925	0.99996	0.999975	0.999985	0.999987
L1I MISSRATE	7.50E-05	4.00E-05	2.50E-05	1.50E-05	1.30E-05
L2 HITRATE	0.900582	0.858179	0.8542	0.852157	0.85407
L2 MISSRATE	0.099418	0.141821	0.14458	0.147843	0.145925
CPI	1.03124622	1.02164502	1.01122972	1.0059133	1.00315174

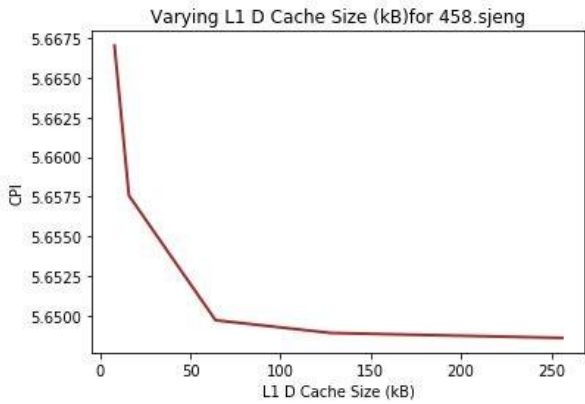Varying Block Sizefor 456.hmmer

Benchmark: 458.sjeng

1. L1-D cache size

Varying L1-D Cache Size for 458.sjeng

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8kB	0.899154	0.100846	0.999723	0.000277	0.037816	0.962184	5.66701
16kB	0.900978	0.099022	0.999723	0.000277	0.020203	0.979797	5.65758
64kB	0.902425	0.097575	0.999723	0.000277	0.005846	0.994154	5.64973
128kB	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.64893
256kB	0.902564	0.097436	0.999723	0.000277	0.004536	0.995464	5.64862

VARYING L1-D CACHE SIZE FOR BENCHMARK 458.SJENG

Varying L1 D Cache Size (kB)for 458.sjeng
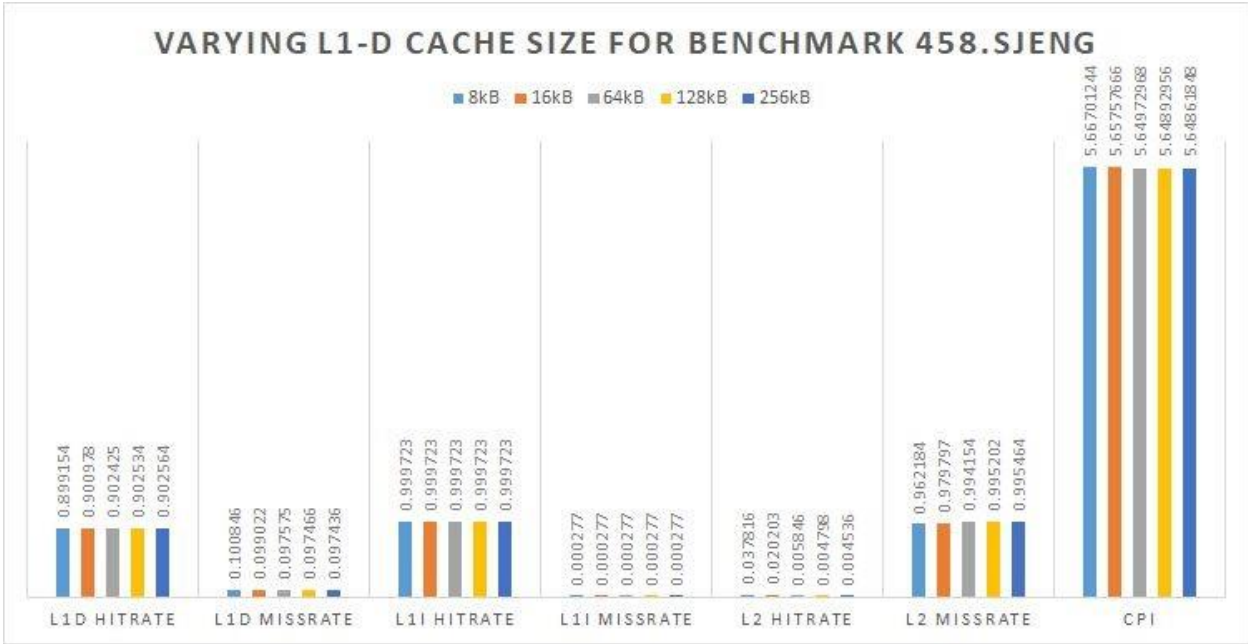
2. L1-I cache size

Varying L1-I Cache Size for 458.sjeng

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
4kb	0.902534	0.097466	0.991596	0.008404	0.123562	0.876438	5.71723
8kb	0.902534	0.097466	0.994152	0.005848	0.089371	0.910629	5.69584
16kb	0.902534	0.097466	0.996863	0.003137	0.050066	0.949934	5.67311
64kb	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.64893
128kb	0.902534	0.097466	0.999984	1.6e-05	0.000455	0.999545	5.64666

VARYING L1-I CACHE SIZE FOR BENCHMARK 458.SJENG

Varying L1 I Cache Size (kB)for 458.sjeng
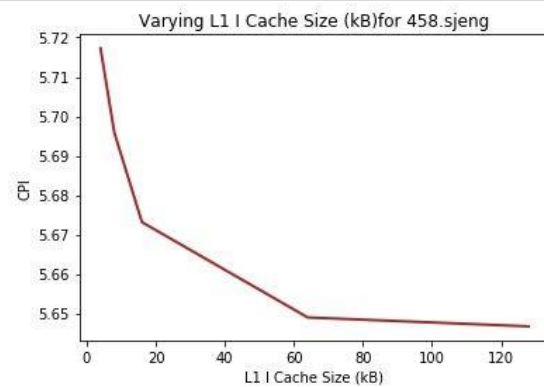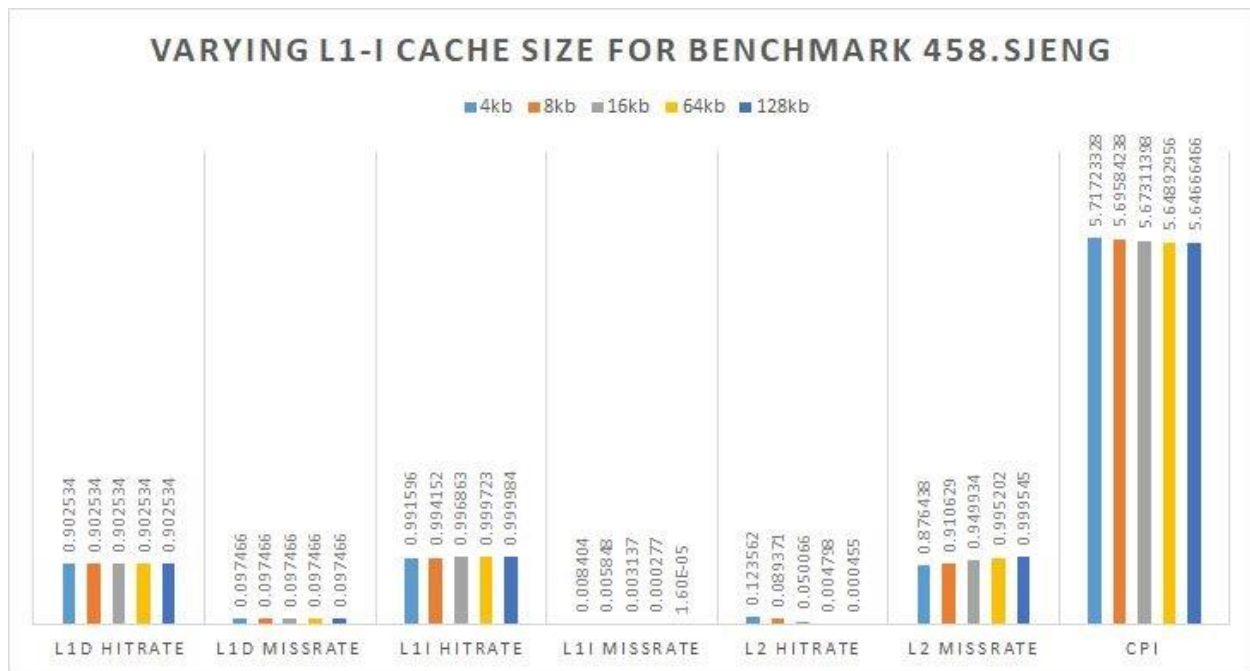
3. L2 cache size

Varying L2 Cache Size for 458.sjeng

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
256kb	0.902534	0.097466	0.999723	0.000277	0.004677	0.995323	5.64943
512kb	0.902534	0.097466	0.999723	0.000277	0.004767	0.995233	5.64906
1024kb	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.64893
2048kb	0.902534	0.097466	0.999723	0.000277	0.004827	0.995173	5.64881
4096kb	0.902534	0.097466	0.999723	0.000277	0.004876	0.995124	5.6486
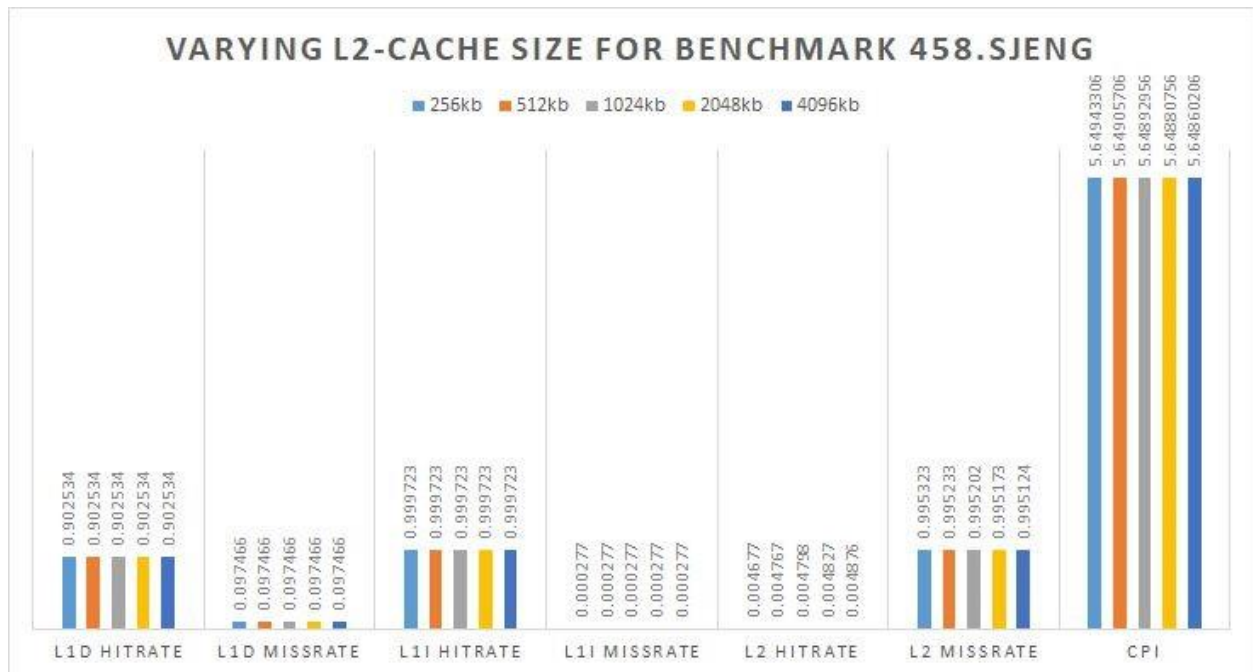
VARYING L2-CACHE SIZE FOR BENCHMARK 458.SJENG

4. L1-D Associativity

Varying L1 D Associative Cache Size for 458.sjeng

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.902358	0.097642	0.999723	0.000277	0.006531	0.993469	5.65006
2	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.64893
4	0.902553	0.097447	0.999723	0.000277	0.004619	0.995381	5.64876
8	0.902557	0.097443	0.999723	0.000277	0.004586	0.995414	5.64872
16	0.902561	0.097439	0.999723	0.000277	0.004559	0.995441	5.64867
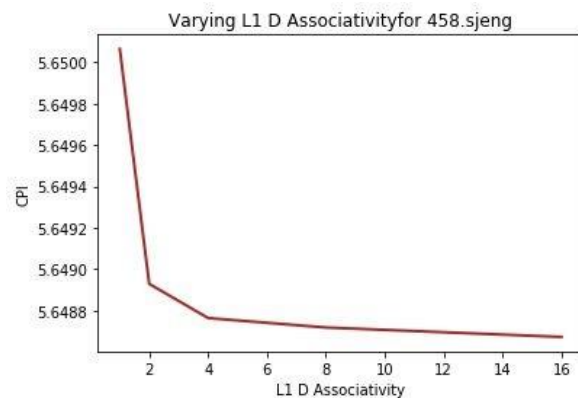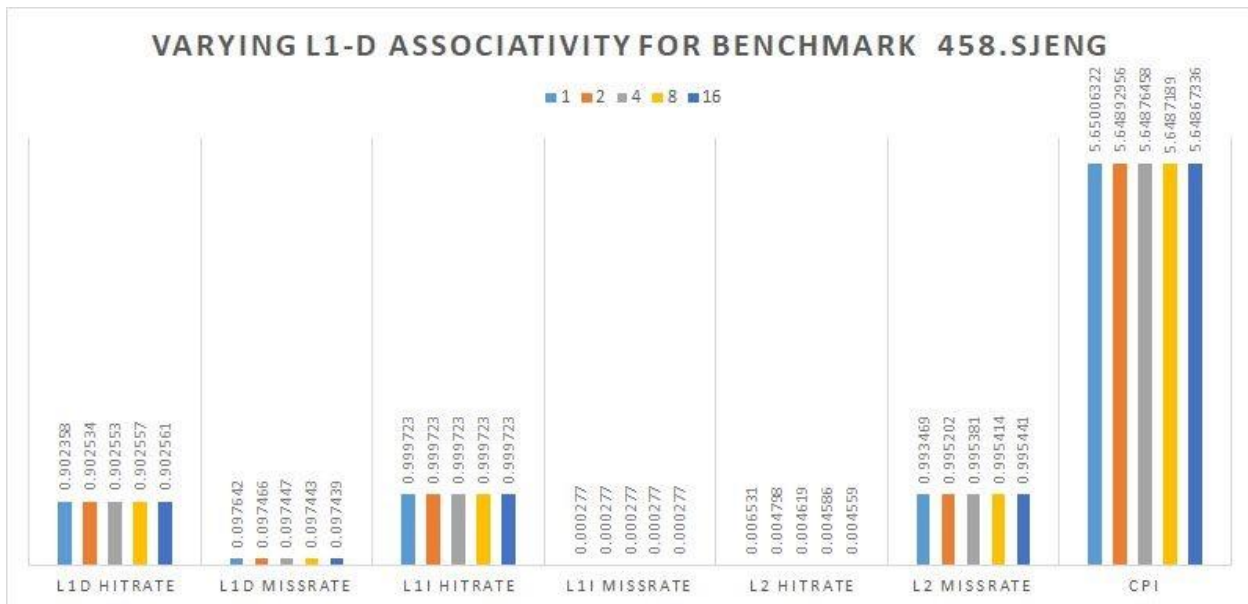
Varying L1-D Associativity for Benchmark 458.sjeng

Varying L1 D Associativity for 458.sjeng

5. L1-I Associativity

Varying L1 I Associative Cache Size for 458.sjeng

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.902534	0.097466	0.9991	0.0009	0.015024	0.984976	5.6542
2	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.64893
4	0.902534	0.097466	0.99992	8e-05	0.001524	0.998476	5.64724
8	0.902534	0.097466	0.999982	1.8e-05	0.000486	0.999514	5.64671
16	0.902534	0.097466	0.999985	1.5e-05	0.000434	0.999566	5.64667
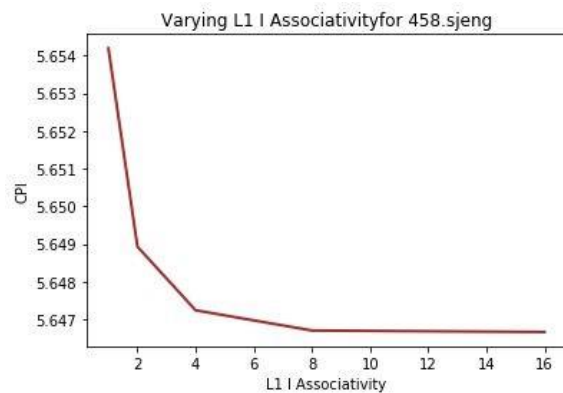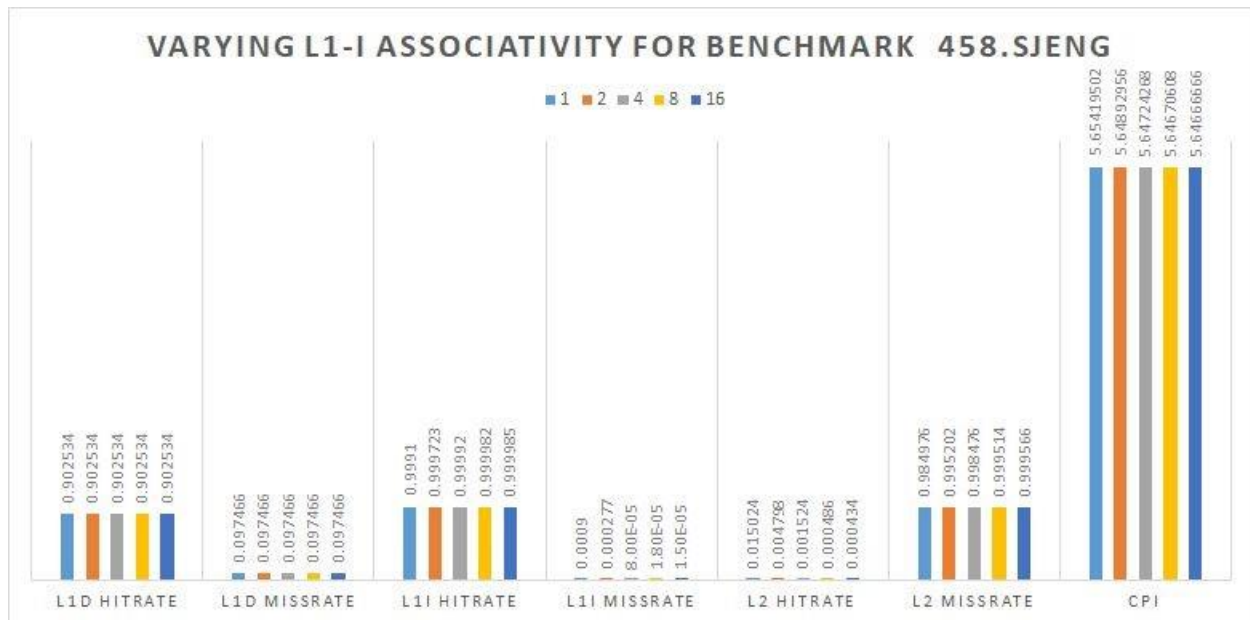
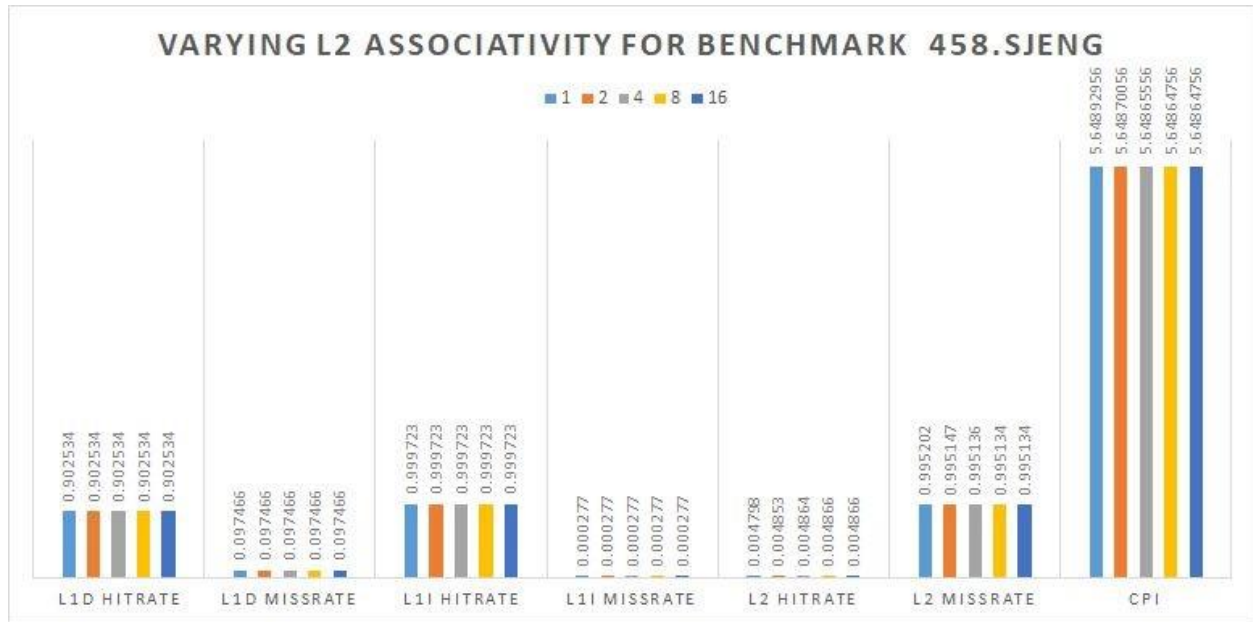Varying L1 I Associativity for 458.sjeng

6. L2 Associativity

Varying L2 Associative Cache Size for 458.sjeng

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.64893
2	0.902534	0.097466	0.999723	0.000277	0.004853	0.995147	5.6487
4	0.902534	0.097466	0.999723	0.000277	0.004864	0.995136	5.64866
8	0.902534	0.097466	0.999723	0.000277	0.004866	0.995134	5.64865
16	0.902534	0.097466	0.999723	0.000277	0.004866	0.995134	5.64865

VARYING L2 ASSOCIATIVITY FOR BENCHMARK 458.SJENG

7. Cache Block size

Varying Cache Block Size for 458.sjeng

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8	0.221054	0.778946	0.999325	0.000675	0.66219	0.33781	5.007
16	0.610476	0.389524	0.999543	0.000457	0.001816	0.998184	19.5787
32	0.805186	0.194814	0.999681	0.000319	0.002638	0.997362	10.292
64	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.64893
128	0.95119	0.04881	0.999771	0.000229	0.008545	0.991455	3.32729

VARYING CACHE BLOCK SIZE FOR BENCHMARK 458.SJENG

■ 8 ■ 16 ■ 32 ■ 64 ■ 128

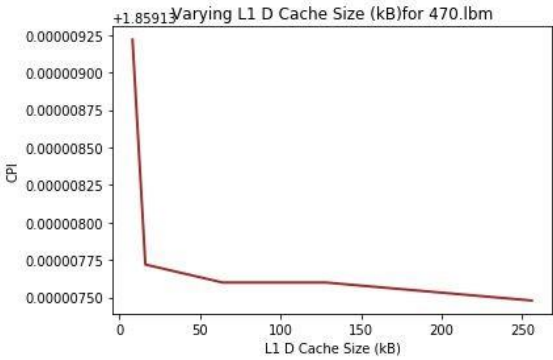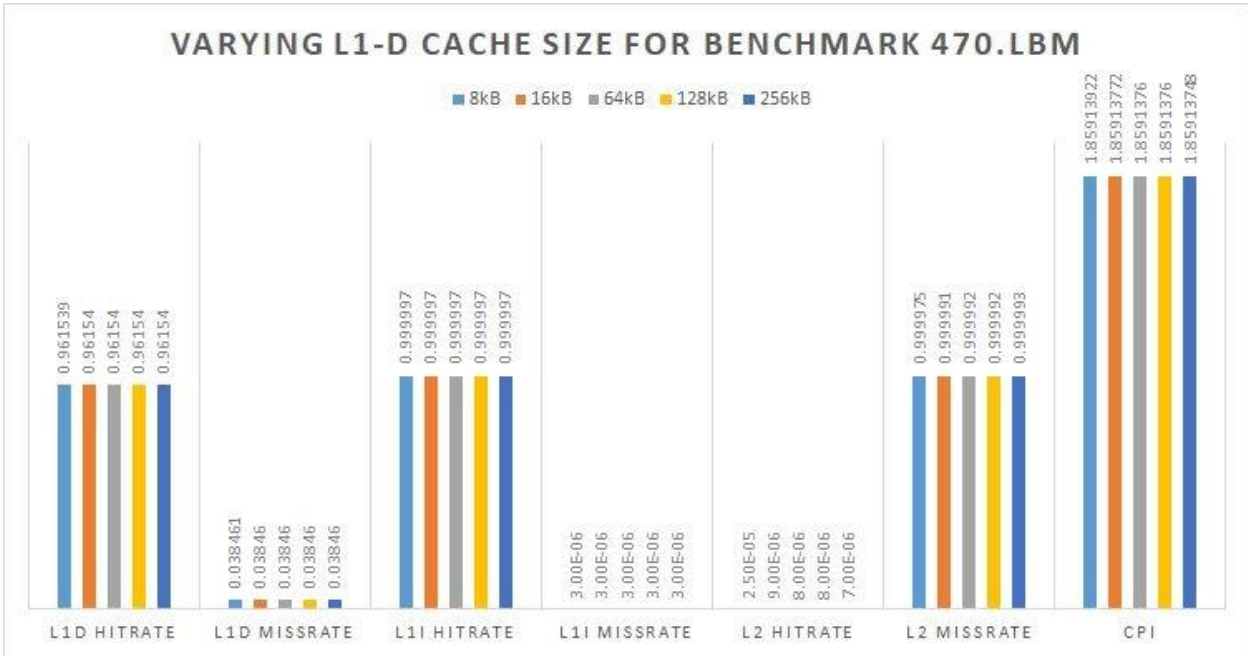|	L1D HITRATE	L1D MISSRATE	L1I HITRATE	L1I MISSRATE	L2 HITRATE	L2 MISSRATE	CPI
8	0.221054	0.778946	0.999325	0.000675	0.66219	0.33781	5.00699658
16	0.610476	0.389524	0.999543	0.000457	0.001816	0.998184	19.57865988
32	0.805186	0.194814	0.999681	0.000319	0.002638	0.997362	10.2919627
64	0.902534	0.097466	0.999723	0.000277	0.004798	0.995202	5.6492956
128	0.95119	0.04881	0.999771	0.000229	0.008545	0.991455	3.32728776

Varying Block Sizefor 458.sjeng

Benchmark: 470.lbm

1. L1-D cache size

Varying L1-D Cache Size for 470.lbm

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8kB	0.961539	0.038461	0.999997	3e-06	2.5e-05	0.999975	1.85914
16kB	0.96154	0.03846	0.999997	3e-06	9e-06	0.999991	1.85914
64kB	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
128kB	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
256kB	0.96154	0.03846	0.999997	3e-06	7e-06	0.999993	1.85914

2. L1-I cache size

Varying L1-I Cache Size for 470.lbm

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
4kb	0.96154	0.03846	0.999995	5e-06	0.000151	0.999849	1.85915
8kb	0.96154	0.03846	0.999996	4e-06	8e-05	0.99992	1.85914
16kb	0.96154	0.03846	0.999996	4e-06	3.8e-05	0.999962	1.85914
64kb	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
128kb	0.96154	0.03846	0.999997	3e-06	2e-06	0.999998	1.85914
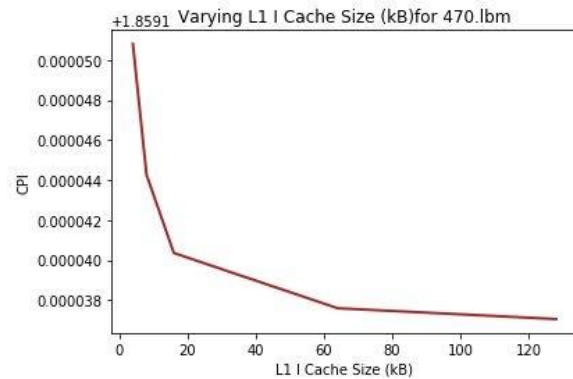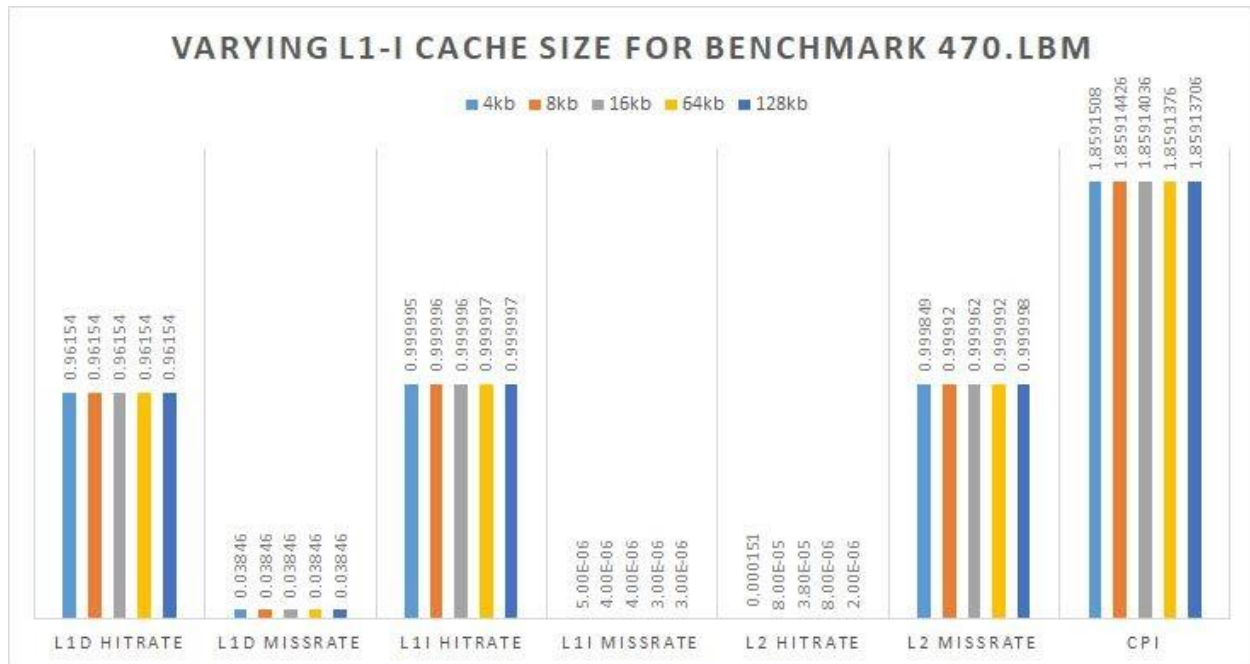
3. L2 cache size

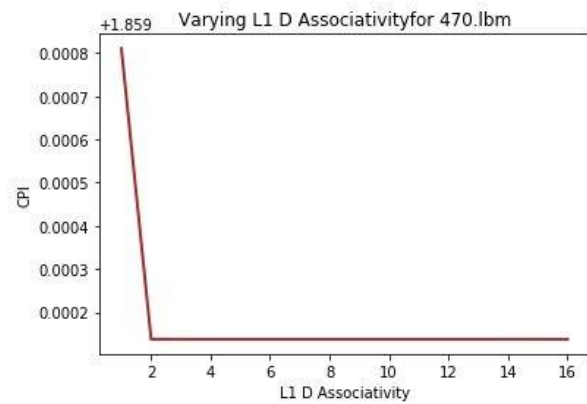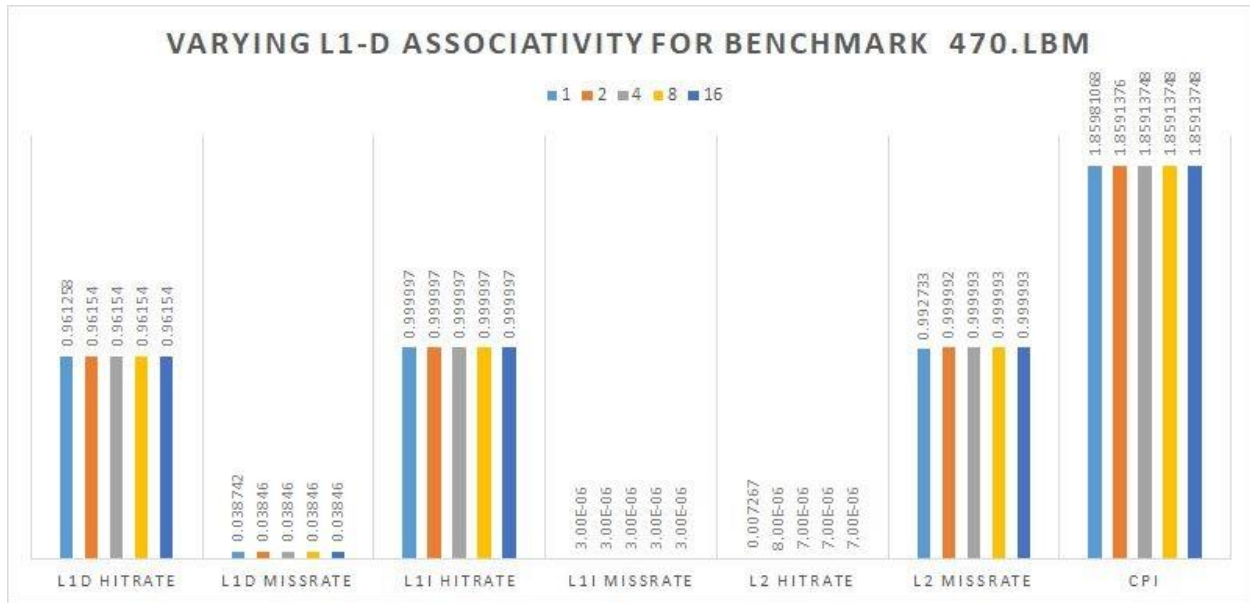Varying L2 Cache Size for 470.lbm

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
256kb	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
512kb	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
1024kb	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
2048kb	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
4096kb	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
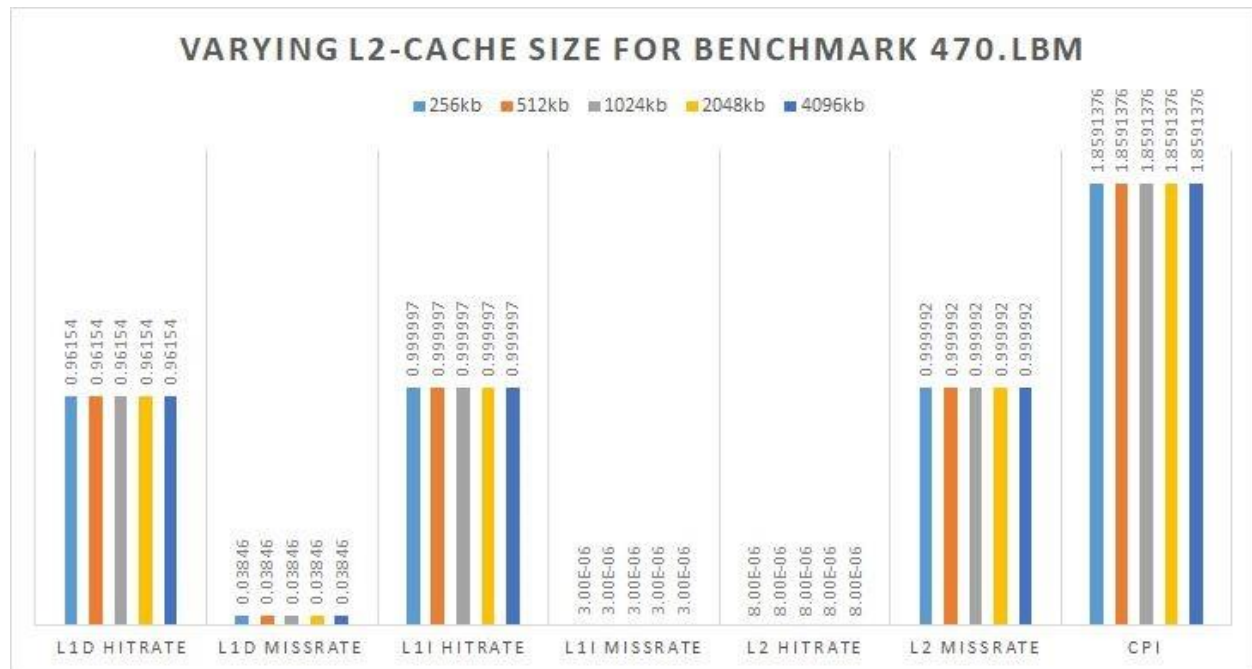
4. L1-D Associativity

Varying L1 D Associative Cache Size for 470.lbm

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.961258	0.038742	0.999997	3e-06	0.007267	0.992733	1.85981
2	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
4	0.96154	0.03846	0.999997	3e-06	7e-06	0.999993	1.85914
8	0.96154	0.03846	0.999997	3e-06	7e-06	0.999993	1.85914
16	0.96154	0.03846	0.999997	3e-06	7e-06	0.999993	1.85914

VARYING L1-D ASSOCIATIVITY FOR BENCHMARK 470.LBM

Varying L1 D Associativity for 470.lbm

5. L1-I Associativity

Varying L1 I Associative Cache Size for 470.lbm

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.96154	0.03846	0.999997	3e-06	1.6e-05	0.999984	1.85914
2	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
4	0.96154	0.03846	0.999997	3e-06	3e-06	0.999997	1.85914
8	0.96154	0.03846	0.999997	3e-06	2e-06	0.999998	1.85914
16	0.96154	0.03846	0.999997	3e-06	2e-06	0.999998	1.85914
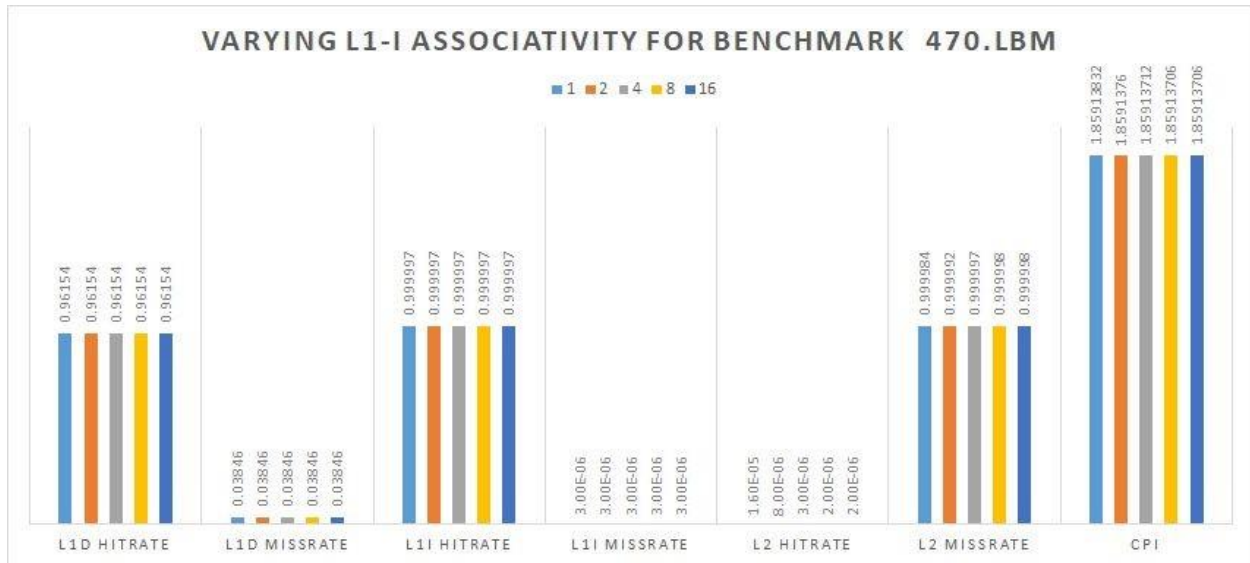
VARYING L1-I ASSOCIATIVITY FOR BENCHMARK 470.LBM

6. L2 Associativity

Varying L2 Associative Cache Size for 470.lbm

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
1	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
2	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
4	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
8	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
16	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914

VARYING L2 ASSOCIATIVITY FOR BENCHMARK 470.LBM
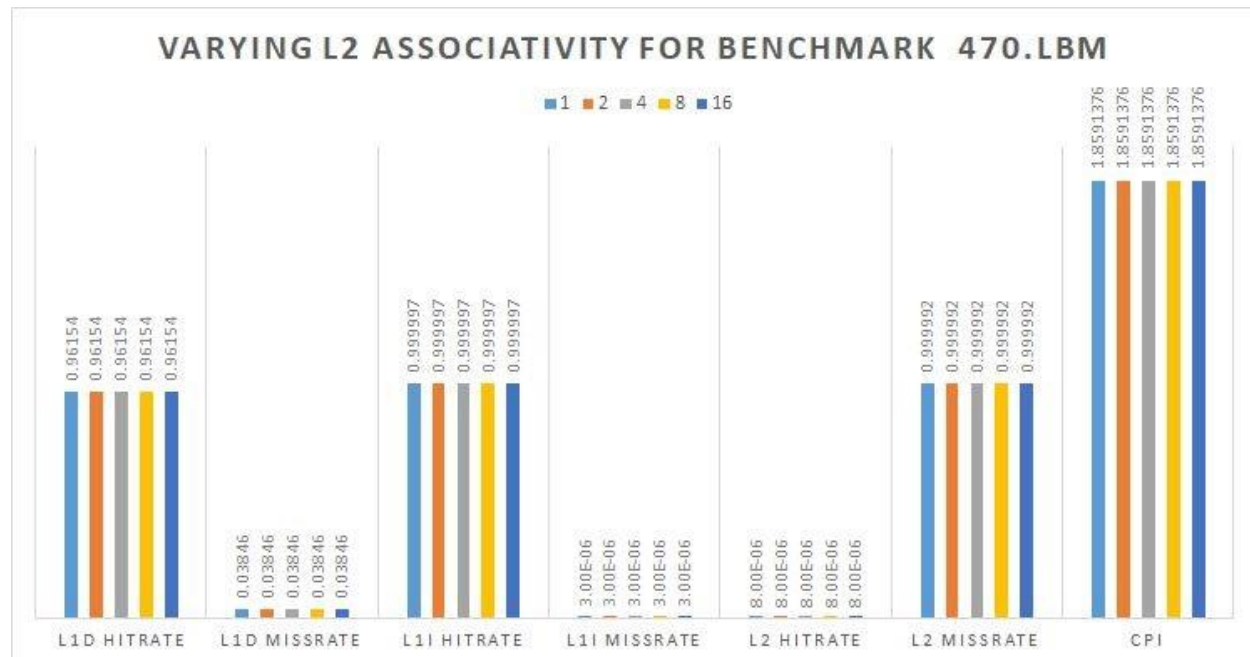
7. Cache Block size

Varying Cache Block Size for 470.lbm

Size	L1D HitRate	L1D MissRate	L1I HitRate	L1I MissRate	L2 HitRate	L2 MissRate	CPI
8	0.692336	0.307664	0.999984	1.6e-05	3.2e-05	0.999968	2.04438
16	0.846166	0.153834	0.999991	9e-06	2e-06	0.999998	4.43606
32	0.923082	0.076918	0.999995	5e-06	4e-06	0.999996	2.71812
64	0.96154	0.03846	0.999997	3e-06	8e-06	0.999992	1.85914
128	0.980769	0.019231	0.999998	2e-06	1.6e-05	0.999984	1.42962

VARYING CACHE BLOCK SIZE FOR BENCHMARK 470.LBM

Varying Block Size for 470.lbm