[CS665] [Group 10]
PA-2

PART A:implement an inclusive LLC and count Back-hits.

Configuration:
Number of CPUs: 1
LLC sets: 1024
LLC ways: 16

**Back invalidation hits in private cache :**

	gcc_39B		h26ref_178B		hmmer_397B		milc_409B	
Instructions	L1 Back hit	L2 Back hit	L1 Back hit	L2 Back hit	L1 Back hit	L2 Back hit	L1 Back hit	L2 Back hit
10M	0	0	1	20	140	708	54	54
20M	0	0	9	57	411	1409	140	140
30M	1	1	32	133	678	2116	229	229
40M	36	43	133	348	910	2602	308	308
50M	67	85	1105	369	1105	3264	398	398

Inclusive Back Hits
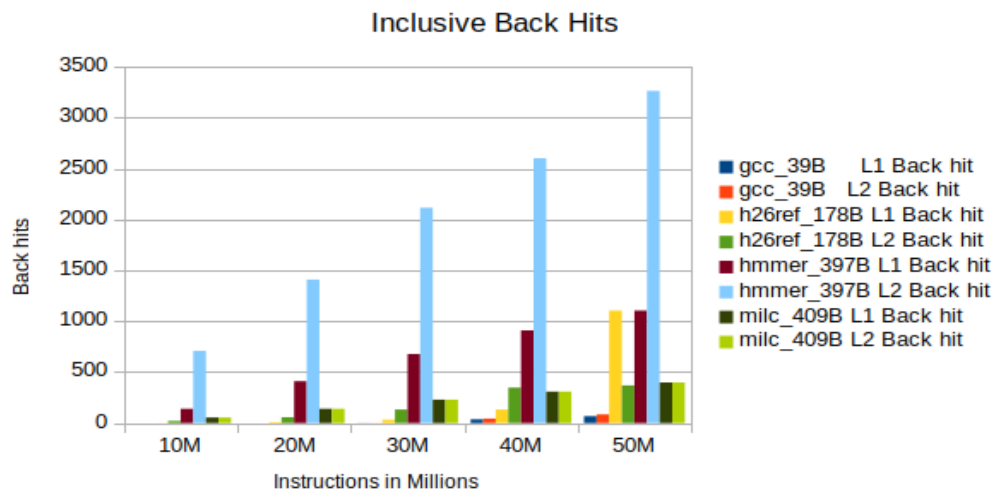
Total LLC evictions:

	Total LLC Evictions			
	gcc_39B	h26ref_178B	hmmer_397B	milc_409B
10M	0	4173	19487	378776
20M	0	16852	43866	532884
30M	2	32480	75507	686673
40M	218	60845	107298	839735
50M	643	69088	140273	992797
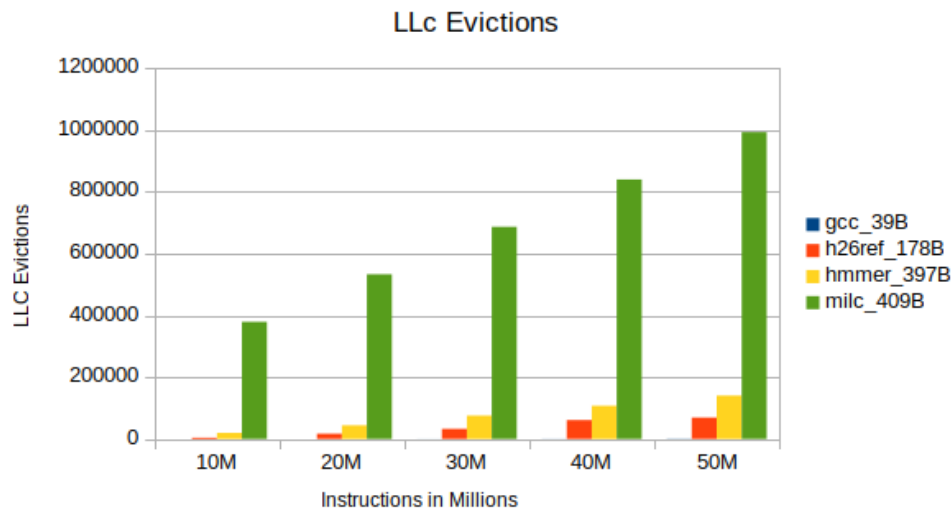
LLc Evictions

Result in above tables are calculated for different number of instructions to make result visible.

Explanation:
As it is seen from above table ,when we simulate inclusive LLC on 4 different traces,
Back hits and total LLC Evictions increasess as number of instructions increases.

If we consider only last three traces max L2 back hits are around **3.64%** of total LLC evictions.
And for the first trace also L2 backhits drop from **19.72%** to **13.21 %** as number of instructions
changs from **40M to 50M.**

Since L2 size is smller than LLC, probablity of a block gettting replaced from L2 is high while it is
still in LLC. So, whenever LLC miss occur which results in LLC eviction the given block is already
evicted from L2(due to L2 Miss).
Hence as number of insructions grow,probablity of back invalidations hit in Private cache are much
lower than **(size of private cache/size of LLC) .**

PART B: LLC replacement policy that prevents cross-core evictions

Configuration:
Warmup Instructions: 1000000
Simulation Instructions: 20000000
Number of CPUs: 2
L2: Set-512 Way-8
LLC:Set-256/2048 Way-16

We changed existing LRU policy to prevent Cross core eviction :
Instead of directly returning LRU block,we use following steps in-order
1. Return any invalid block.
2. Return block that is only in LLC but not in any processor's L2.
3. Return block that is only caller's private cache.
4. Return according to normal LRU policy.

Below is the result of running **LRU and New_LRU on 4 different traces**
1.In first case apply single trace to two cores.
2.In second case apply different trace to different cores.

When LLC sets are 2048,there no or slightly small difference in performance of LRU and new
LRU. So we decrease size of LLC to show significant results.

		GCC_39B					
		LLC sets =256(128 * 2(num cpu))			LLC sets =2048(1024 * 2(num cpu))		
		LRU	NEW LRU	Performance Gain	LRU	NEW LRU	Performance Gain
CPU 0 (gcc_39B)	Cross-Core Eviction	2563	0	-2563	0	0	0
	IPC	0.708792	0.710229	0.001437	0.71523	0.71523	0
	L1 Back hits	1210	1106	-104	0	0	0
	L2 Back hits	5223	4283	-940	0	0	0
	LLC Evictions	5657	5245	-412	0	0	0
CPU 1 (gcc_39B)	Cross-Core Eviction	2578	0	-2578	0	0	0
	IPC	0.708793	0.710218	0.001425	0.715228	0.715228	0
	L1 Back hits	1273	1161	-112	0	0	0
	L2 Back hits	5238	4305	-933	0	0	0
	LLC Evictions	5626	5284	-342	0	0	0
Overall Performance Gain	**Cross-Core Eviction**	**5141**	**0**	**-5141**	**0**	**0**	**0**
	IPC	**0.7087925**	**0.7102235**	**0.001431**	**0.715229**	**0.715229**	**0**

		h26ref_178B					
		LLC sets =256(128 * 2(num cpu))			LLC sets =2048(1024 * 2(num cpu))		
		LRU	NEW LRU	Performance Gain	LRU	NEW LRU	Performance Gain
CPU 0 (h2ref_178B)	Cross-Core Eviction	18476	0	-18476	65	0	-65
	IPC	0.807413	0.813453	0.00604	0.844447	0.844536	8.9E-05
	L1 Back hits	7062	5360	-1702	29	0	-29
	L2 Back hits	36942	27681	-9261	113	0	-113
	LLC Evictions	46222	43842	-2380	16906	16862	-44
CPU 1 (h2ref_178B)	Cross-Core Eviction	18301	1	-18300	52	0	-52
	IPC	0.81083	0.813631	0.002801	0.844446	0.844541	9.5E-05
	L1 Back hits	7561	6006	-1555	23	0	-23
	L2 Back hits	36601	28063	-8538	118	0	-118
	LLC Evictions	45365	44202	-1163	16823	16804	-19
Overall Performance Gain	Cross-Core Eviction	36777	1	-36776	117	0	-117
	IPC	0.8091215	0.813542	0.0044205	0.8444465	0.8445385	9.2E-05

		hmmer_397B					
		LLC sets =256(128 * 2(num cpu))			LLC sets =2048(1024 * 2(num cpu))		
		LRU	NEW LRU	Performance Gain	LRU	NEW LRU	Performance Gain
CPU 0 (hmmer_397B)	Cross-Core Eviction	23996	87	-23909	646	0	-646
	IPC	0.958102	0.960921	0.002819	1.00292	1.01247	0.00955
	L1 Back hits	2350	1162	-1188	336	0	-336
	L2 Back hits	48008	9373	-38635	1484	0	-1484
	LLC Evictions	71090	71676	586	43961	42884	-1077
				0			
CPU 1 (hmmer_397B)	Cross-Core Eviction	24163	28	-24135	784	0	-784
	IPC	0.958382	0.961159	0.002777	1.00292	1.01247	0.00955
	L1 Back hits	2142	972	-1170	292	0	-292
	L2 Back hits	47805	8983	-38822	1333	0	-1333
	LLC Evictions	70858	71626	768	43836	42705	-1131
Overall Performance Gain	Cross-Core Eviction	48159	115	-48044	1430	0	-1430
	IPC	0.958242	0.96104	0.002798	1.00292	1.01247	0.00955

		milc_409B						
		LLC sets =256(128 * 2(num cpu))				LLC sets =2048(1024 * 2(num cpu))		
		LRU	NEW LRU	Performance Gain		LRU	NEW LRU	Performance Gain
CPU 0 (milc_409B)	Cross-Core Eviction	201898	3584	-198314		3279	0	-3279
	IPC	0.406546	0.412755	0.006209		0.404692	0.402449	-0.002243
	L1 Back hits	2559	27351	24792		146	0	-146
	L2 Back hits	426610	278624	-147986		4107	0	-4107
	LLC Evictions	549450	548547	-903		532947	533403	456
				0				
CPU 1 (milc_409B)	Cross-Core Eviction	202564	3571	-198993		3301	0	-3301
	IPC	0.406767	0.412994	0.006227		0.404692	0.402064	-0.002628
	L1 Back hits	2356	27216	24860		145	0	-145
	L2 Back hits	425157	282791	-142366		4156	0	-4156
	LLC Evictions	549391	278624	-270767		532968	532720	-248
Overall Performance Gain	Cross-Core Eviction	404462	7155	-397307		6580	0	-6580
	IPC	0.4066565	0.4128745	0.006218		0.404692	0.4022565	-0.0024355

		gcc_39B- milc_409B						
		LLC sets =256(128 * 2(num cpu))				LLC sets =2048(1024 * 2(num cpu))		
		LRU	NEW LRU	Performance Gain		LRU	NEW LRU	Performance Gain
CPU 0 (gcc_39B)	Cross-Core Eviction	6586	44	-6542		0	0	0
	IPC	0.708265	0.701316	-0.006949		0.679836	0.709416	0.02958
	L1 Back hits	3046	2502	-544		8773	0	-8773
	L2 Back hits	9015	8114	-901		15116	0	-15116
	LLC Evictions	10418	10695	277		17046	7924	-9122
				0				
CPU 1 (milc_409B)	Cross-Core Eviction	8436	53	-8383		14244	0	-14244
	IPC	0.456697	0.458034	0.001337		0.450206	0.450123	-8.3E-05
	L1 Back hits	1388	6160	4772		73	0	-73
	L2 Back hits	371787	288351	-83436		73	0	-73
	LLC Evictions	550865	551038	173		521106	521045	
Overall Performance Gain	Cross-Core Eviction	15022	97	-14925		14244	0	-14244
	IPC	0.582481	0.579675	-0.002806		0.565021	0.5797695	0.0147485

		hmmer_397B- href_178B						
		LLC sets =256(128 * 2(num cpu))				LLC sets =2048(1024 * 2(num cpu))		
		LRU	NEW LRU	Performance Gain		LRU	NEW LRU	Performance Gain
CPU 0 (hmmer_397B)	Cross-Core Eviction	18160	3139	-15021		615	0	-615
	IPC	0.966938	0.967467	0.000529		1.02618	1.03402	0.00784
	L1 Back hits	3315	6912	3597		240	0	-240
	L2 Back hits	53892	15259	-38633		868	0	-868
	LLC Evictions	45561	85386	39825		42637	41954	-683
				0				
CPU 1 (href_178B)	Cross-Core Eviction	18246	0	-18246		344	0	-344
	IPC	0.813011	0.827571	0.01456		0.845295	0.846287	0.000992
	L1 Back hits	8351	2134	-6217		170	0	-170
	L2 Back hits	29963	14290	-15673		939	0	-939
	LLC Evictions	85898	41721	-44177		23480	23367	-113
Overall Performance Gain	Cross-Core Eviction	36406	3139	-33267		959	0	-959
	IPC	0.8899745	0.897519	0.0075445		0.9357375	0.9401535	0.004416

Performance gain column in above table show net effect by applying new policy.
For example,in below table there is reduction of **33267** cross core evictions and IPC is increased by **0.0075445.**

In most of the cases case there is sharp increase in performance and also decrease in Back hits because normal LRU doesn't check for a block in lower levels while making replacement decision.

It can also be seen that,Performance in terms of IPC for every cpu may decrease but that loss is compensated by another CPU and net Performance is not reduced.

PART C:Generic LLC replacement policy that prevents cross-core evictions

Configurations:
Warmup Instructions: 1000000
Simulation Instructions: 10000000
Number of CPUs: 4
LLC sets: 8192 / 512
LLC ways: 16

Generic algorithm to prevent cross core eviction:
We added following steps while calling find victim:
1.while (count)
      A.find victim way using normal find victim and check if the returned block is present in other cpu's L2
            I.   if present then update that block replacement state as it is hit
            II. else return that way
      B.Decrement count and goto step 1
2.Return last way at end of the loop.

***count:**we can set value of count as Total LLC ways or less and depends on that we get performance and cross core evictions.
In our code it is number of Ways in LLC.

Performance of LRU and Drrip with different count values:
Traces:
CPU0**:** h264ref_178B
CPU1:hmmer_397B

			LRU					
Ways(count)	4		8		12		16	
	CPU 0	CPU 1	CPU 0	CPU 1	CPU 0	CPU 1	CPU 0	CPU 1
Cross-core evictions(tota	51	308	0	4	0	0	0	0
IPC(Avg)	0.726057	0.973454	0.7257	0.970423	0.726066	0.973065	0.726066	0.973065
			Drrip					
Cross-core evictions(tota	373	1543	137	482	0	101	0	7
IPC(Avg)	0.724224	0.979281	0.724158	0.976743	0.726035	0.978531	0.726071	0.97832

  As it is seen from above table as we increase count value cross core evictions decreases and performance remains almost constant.
So,setting count to number of way in LLC is preferable.

LRU,DRRIP and SRRIP Performance details For 4 cores:

CPU 0 runs ../Traces/h264ref_178B.trace.gz
CPU 1 runs ../Traces/gcc_39B.trace.gz
CPU 2 runs ../Traces/hmmer_397B.trace.gz
CPU 3 runs ../Traces/milc_409B.trace.gz

While using the default LLC size the Cross-Core Evictions are coming 0. So we changed the values
LLC size to 512(128*num_cpu).

		LLC sets =8192(2048 * 4(num cpu))			LLC sets =512(128 * 4(num cpu))		
		LRU	NEW LRU	Performance Gain	LRU	NEW LRU	Performance Gain
CPU 0	Cross-Core Eviction	569	0	-569	17671	0	-17671
	IPC	0.727462	0.732999	0.005537	0.669152	0.710008	0.040856
CPU 1	Cross-Core Eviction	97	0	-97	3338	13	-3325
	IPC	0.694853	0.707786	0.012933	0.696786	0.70702	0.010234
CPU 2	Cross-Core Eviction	1179	0	-1179	22919	0	-22919
	IPC	0.939939	0.953669	0.01373	0.876757	0.913653	0.036896
CPU 3	Cross-Core Eviction	9209	0	-9209	71140	0	-71140
	IPC	0.376731	0.376155	-0.000576	0.371714	0.3717	-1.4E-05
Overall Performance Gain	Cross-Core Eviction	11054	0	**-11054**	115068	13	-115055
	IPC	0.6847463	0.69265225	**0.007906**	0.65360225	0.67559525	**0.021993**

LRU Performance comparison

		LLC sets =8192(2048 * 4(num cpu))			LLC sets =512(128 * 4(num cpu))		
		SRRIP	NEW SRRIP	Performance Gain	SRRIP	NEW SRRIP	Performance Gain
CPU 0	Cross-Core Eviction	1109	0	-1109	24924	0	-24924
	IPC	0.729796	0.746253	0.016457	0.683481	0.70853	0.025049
CPU 1	Cross-Core Eviction	321	0	-321	4278	21	-4257
	IPC	0.686711	0.708239	0.021528	0.703079	0.70693	0.003851
CPU 2	Cross-Core Eviction	2080	0	-2080	36005	15825	-20180
	IPC	0.943996	0.968404	0.024408	0.895089	0.911297	0.016208
CPU 3	Cross-Core Eviction	18458	0	-18458	61058	1	-61057
	IPC	0.397124	0.39441	-0.002714	0.368987	0.368708	-0.000279
Overall Performance Gain	Cross-Core Eviction	21968	0	**-21968**	126265	15847	-110418
	IPC	0.68940675	0.7043265	**0.01491975**	0.662659	0.67386625	**0.01120725**

SRRIP Performance comparison

		LLC sets =8192(2048 * 4(num cpu))			LLC sets =512(128 * 4(num cpu))		
		DRRIP	NEW DRRIP	Performance Gain	DRRIP	NEW DRRIP	Performance Gain
CPU 0	Cross-Core Eviction	454	0	-454	23030	2	-23028
	IPC	0.729477	0.73481	0.005333	0.654976	0.708296	0.05332
CPU 1	Cross-Core Eviction	102	0	-102	5141	30	-5111
	IPC	0.693622	0.707787	0.014165	0.67686	0.706352	0.029492
CPU 2	Cross-Core Eviction	1300	0	-1300	30682	48	-30634
	IPC	0.944889	0.961664	0.016775	0.886767	0.906827	0.02006
CPU 3	Cross-Core Eviction	8901	0	-8901	67556	6	-67550
	IPC	0.376696	0.374635	-0.002061	0.369469	0.369648	0.000179
Overall Performance Gain	Cross-Core Eviction	10757	0	**-10757**	126409	86	**-126323**
	IPC	0.686171	0.694724	**0.008553**	0.647018	0.67278075	**0.02576275**

DRRIP Performance comparison

The above tables shows that the number of **Cross-Core eviction has been decreased** by large number. Also the overall **IPC has increased slightly.**
DRRIP gives highest increase in performance **(**when LLC sets=512**)** in terms of both cross core evictions and IPC.

DRRIP, SRRIP and LRU Performance details For 2 cores:

Warmup Instructions: 1000000
Simulation Instructions: 10000000
Number of CPUs: 2
LLC sets: 4096/256
LLC ways: 16

CPU 0 runs ../Traces/h264ref_178B.trace.gz
CPU 1 runs ../Traces/hmmer_397B.trace.gz

		LLC sets =4096(2048 * 2(num cpu))				LLC sets =256(128 * 2(num cpu))		
		LRU	NEW LRU	Performance Gain		LRU	NEW LRU	Performance Gain
CPU 0	Cross-Core Eviction	18	0	-18		11627	0	-11627
	IPC	0.757214	0.75721	-3.9999999999E-06		0.715182	0.726066	0.010884
CPU 1	Cross-Core Eviction	9	0	-9		11174	0	-11174
	IPC	1.07834	1.07826	-8E-05		0.9762	0.973065	-0.003135
Overall Performance Gain	Cross-Core Eviction	27	0	**-27**	0	22801	0	**-22801**
	IPC	0.917777	0.917735	**-4.2E-05**	0	0.845691	0.8495655	**0.0038745**

LRU Performance comparison

		LLC sets =4096(2048 * 2(num cpu))				LLC sets =256(128 * 2(num cpu))		
		SRRIP	NEW SRRIP	Performance Gain		SRRIP	NEW SRRIP	Performance Gain
CPU 0	Cross-Core Eviction	79	0	-79		11096	0	-11096
	IPC	0.757664	0.757776	0.000112		0.716267	0.727848	0.011581
CPU 1	Cross-Core Eviction	181	0	-181		11523	0	-11523
	IPC	1.07843	1.07843	0		0.966528	0.976953	0.010425
Overall Performance Gain	Cross-Core Eviction	260	0	**-260**	0	22619	0	**-22619**
	IPC	0.918047	0.918103	**5.6E-05**	0	0.8413975	0.8524005	**0.011003**

SRRIP Performance comparison

		LLC sets =4096(2048 * 2(num cpu))				LLC sets =256(128 * 2(num cpu))		
		DRRIP	NEW DRRIP	Performance Gain		DRRIP	NEW DRRIP	Performance Gain
CPU 0	Cross-Core Eviction	53	0	-53		11360	0	-11360
	IPC	0.757149	0.758435	0.001286		0.695489	0.725028	0.029539
CPU 1	Cross-Core Eviction	137	0	-137		14349	7	-14342
	IPC	1.07866	1.08077	0.00211		0.966113	0.983254	0.017141
Overall Performance Gain	Cross-Core Eviction	190	0	**-190**		25709	7	**-25702**
	IPC	0.9179045	0.9196025	**0.001698**		0.830801	0.854141	**0.02334**

DRRIP Performance comparison

Again,DRRIP gives highest increase in performance **(**when LLC sets=512**)** in terms of both cross core evictions and IPC.

Part D:

In part c,when all the blocks in a set are shared with some other cores,we simply pick last seen way as victim.
Instead of it ,now for all blocks we keep track of count that indicate with how many CPU' that block is shared.
And when we found that all the blocks are shared by some cpu(other than caller) ,we select victim which is shared by minimum number of CPU's.

Configuration:
Traces
 CPU0:h264ref_178B
CPU1:hmmer_397B
Warmup Instructions: 1000000
Simulation Instructions: 10000000
Number of CPUs: 2
LLC sets: 256
LLC ways: 16

DRRIP, SRRIP and LRU Performance details For 2 cores:

		LLC sets =256(128 * 2(num cpu))		
		SRRIP	NEW1 SRRIP	Performance Gain
CPU 0	Cross-Core Evictic	11096	0	-11096
	IPC	0.716267	0.727848	0.011581
CPU 1	Cross-Core Evictic	11523	0	-11523
	IPC	0.966528	0.976953	0.010425
				0
Overall Performance Gain	Cross-Core Eviction	22619	0	**-22619**
	IPC	0.8413975	0.8524005	**0.011003**

SRRIP Performance comparison

		LLC sets =256(128 * 2(num cpu))		
		LRU	NEW1 LRU	Performance Gain
CPU 0	Cross-Core Eviction	11627	0	-11627
	IPC	0.715182	0.726066	0.010884
CPU 1	Cross-Core Eviction	11174	0	-11174
	IPC	0.9762	0.973065	-0.003135
Overall Performance Gain	Cross-Core Eviction	22801	0	**-22801**
	IPC	0.845691	0.8495655	**0.0038745**

LRU Performance comparison

		LLC sets =256(128 * 2(num cpu))		
		Drrip	NEW1 Drrip	Performance Gain
CPU 0	Cross-Core Eviction	11360	0	-11360
	IPC	0.695489	0.726772	0.031283
CPU 1	Cross-Core Eviction	14349	6	-14343
	IPC	0.966113	0.9773	0.011187
Overall Performance Gain	Cross-Core Eviction	25709	6	**-25703**
	IPC	0.830801	0.852036	**0.021235**

DRRIP Performance comparison

Division of labour:

	Swapnil	Jatin
Part A	50%	50%
Part B	50%	50%
Part C	50%	50%
Part D	50%	50%