

CS 232- Lab5 VTUNES CHAMPSIM

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1 VTunes

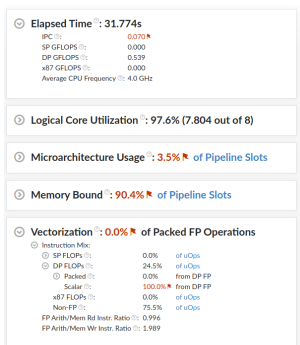
2 Champsim

3 Best Offset L2 Prefetcher

Matrix Multiplication

Performance Snapshot

- IPC : 0.07
- Bad Speculation : 0.1% of pipelined slots
- Logic Core Utilisation : 7.804 out of 8



Matrix Multiplication

Hotspot Detection



- Hotspot Function : Multiply1
- CPU Time : 100%

Elapsed Time : 24.638s

 CPU Time : 190.010s
Total Thread Count: 9
Paused Time : 0s

Top Hotspots

This section lists the most active functions in your application. Optimizing these hotspot functions typically improves application performance.

Function	Module	CPU Time 	% of CPU Time 
multiply1	matrix	190.000s	100.0%
init_arr	matrix	0.010s	0.0%

*N/A is applied to non-summable metrics.

Effective CPU Utilization Histogram

This histogram displays a percentage of the wall time the specific number of CPUs were running simultaneously.

7.4

Matrix Multiplication

Memory Access Analysis

- L1 Bound : 0.0%
- L2 Bound : 0.7%
- LLC Bound : 92.3%

⌵ Elapsed Time ⓘ:	33.162s	
CPU Time ⓘ:	256.047s	
⌵ Memory Bound ⓘ:	89.8% ⚡	of Pipeline Slots
L1 Bound ⓘ:	0.8%	of Clockticks
L2 Bound ⓘ:	0.0%	of Clockticks
L3 Bound ⓘ:	0.7%	of Clockticks
⌵ DRAM Bound ⓘ:	92.3% ⚡	of Clockticks
Store Bound ⓘ:	0.0%	of Clockticks
Loads:	17,468,197,254	
Stores:	8,793,354,169	
LLC Miss Count ⓘ:	7,085,541,972	
Total Thread Count:	10	
Paused Time ⓘ:	0s	

Microarchitecture exploration

- ### Elapsed Time ●: 23.607s

Category	Value	Percentage
Clockticks	732,919,200,000	
Instructions Retired	69,729,600,000	
CPI Rate ●	10.511 ■	
Retiring ●	4.9%	of Pipeline Slots
Front-End Bound ●	3.3%	of Pipeline Slots
Bad Speculation ●	0.1%	of Pipeline Slots
Branch Mispredict ●	0.0%	of Pipeline Slots
Machine Clears ●	0.1%	of Pipeline Slots
Back-End Bound ●	91.7%	of Pipeline Slots
Memory Bound ●	66.7%	of Pipeline Slots
L1 Bound ●	0.0%	of Clockticks
L2 Bound ●	0.0%	of Clockticks
L3 Bound ●	10.7%	of Clockticks
Contested Accesses ●	0.5%	of Clockticks
Data Sharing ●	15.0%	of Clockticks
L3 Latency ●	5.7%	of Clockticks
SQ Full ●	0.0%	of Clockticks
DRAM Bound ●	80.3%	of Clockticks
Memory Bandwidth ●	76.1%	of Clockticks
Memory Latency ●	22.0%	of Clockticks
Store Bound ●	0.0%	of Clockticks
Core Bound ●	5.0%	of Pipeline Slots
Divisor ●	0.0%	of Clockticks
Port Utilization ●	4.4%	of Clockticks
Cycles of 0 Ports Utilized ●	66.3%	of Clockticks
Cycles of 1 Port Utilized ●	7.1%	of Clockticks
Cycles of 2 Ports Utilized ●	3.7%	of Clockticks
Cycles of 3+ Ports Utilized ●	2.8%	of Clockticks
Vector Capacity Usage (FPU) ●	25.0%	
Average CPU Frequency ●	4.0 GHz	
Total Thread Count	16	
Paused Time ●	0s	

The metric value is high. This can indicate that the significant fraction of execution pipeline slots could be stalled due to demand memory load and stores. Use Memory Access analysis to have the metric breakdown by memory hierarchy, memory bandwidth information, correlation by memory objects.

μPipe

This diagram represents inefficiencies in CPU usage. Treat it as a pipe with an output flow equal to the "pipe efficiency" ratio: (Actual Instructions Retired)/(Maximum Possible Instruction Retired). If there are pipeline stalls decreasing the pipe efficiency, the pipe shape gets more narrow.

Cracker Phase 0

The original performance is as follows

=== VTune profiling demo ===

=====

memory malloc +OK

initializing from built-in data

memory malloc +OK

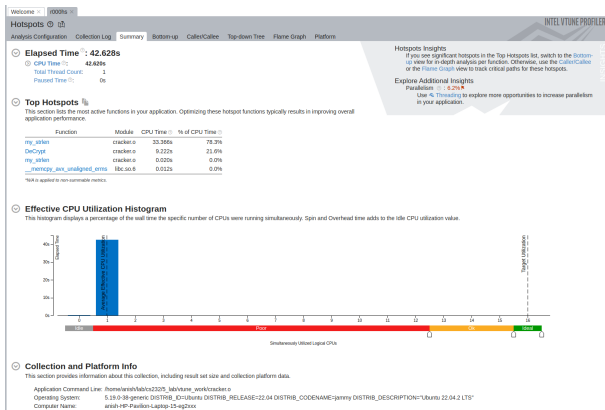
max iter 10000

===

try search... wait!

Password per sec: 210

Cracker Phase 0



Cracker Phase 1

- In the hotspots we saw that `my_strlen` takes most amount of time
- Hence we first tried to optimize `my_strlen`
- We are accessing memory byte by byte to find null character
- We can speed up the process by fetching 8 bytes at a time from memory using unsigned long long int

Cracker Phase 1

```
terminal help
C:cracker> x
19
20 struct key_ptr
21 {
22     int x1;
23     long k1;
24     char a[2];
25     int l1;
26 };
27 struct key_ptr key[KEY_SIZE];
28
29 char correct_plaintext[PLAIN_LEN]; // zeroed out plaintext to do a final check against.
30
31 int my_strlen(char *str)
32 {
33     unsigned long long int *x = (unsigned long long int*) str;
34     int t=0;
35     while(1){
36
37         if(!*x255==0){
38             return t;
39         }
40         else if(*x65280==0){
41             return t+1;
42         }
43         else if(*x16711680==0){
44             return t+2;
45         }
46         else if(*x4278190880==0){
47             return t+3;
48         }
49         x = x+1;
50         t = t+1;
51     }
52 }
53
54 // Decrypting ciphertext using the found password
55 char *Decrpt(char *ciphertext, char *pwd)
56 {
57     int sub_func(int num)
58     {
59         switch (num)
60         {
61             case 0:
62                 return 1;
63         }
64     }
65 }
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Cracker Phase 1

= = = VTune profiling demo = = =

=====

memory malloc +OK

initializing from built-in data

memory malloc +OK

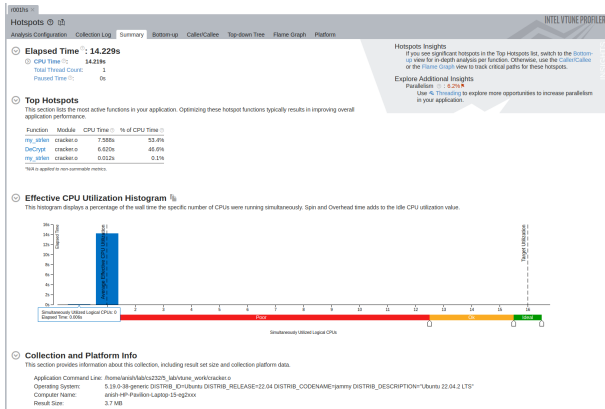
max iter 10000

===

try search... wait!

Password per sec: 661

Cracker Phase 1



Cracker Phase 2

- We saw a three times increase after optimising `my_strlen`
- But still it is the major hotspot, so we check all places where it is called
- We discovered that in `Decrypt` it was calling `my_strlen` inside a loop with same argument
- We optimised this by calling it just once outside the loop and storing it as variable

Cracker Phase 2

```
terminal help
C:\cracker> x

step 3: C:\cracker> x
88     return 17;
89     case 14:
90     return 12;
91     case 31:
92     return 182;
93     default:
94     return -1;
95     }
96 }
97
98 char *buff = (char *)malloc(my_strlen(ciphertext) + 1);
99 memcpy(buff, ciphertext, my_strlen(ciphertext) + 1);
100
101 int px = 0, py = 0;
102 int cypher_len = my_strlen(ciphertext);
103
104 do
105 {
106     int px = 0;
107     do
108     {
109         int p = px * PASS_V_LIM + py;
110         struct key_ptr key_i = key[p];
111
112         int prf_int = (key_i.l1 * key_i.l2 + key_i.k1) & 15;
113         int mask = key_i.a[(prf_int + 1) >> 4];
114
115         if (prf_int == 15)
116         {
117             prf_int = 31;
118         }
119
120         int sub_result = sub_func(prf_int & mask) ^ powd[p];
121
122         buff[p % cypher_len] ^= sub_result;
123     } while ((++py < PASS_V_LIM));
124 } while ((++px < PASS_V_LIM));
125
126 return buff;
127 }
128
129 int my_memcpy(char *dst, char *src, unsigned count)
130 {
131     while (count && (dst[0] != '\0'))
132     {
133         *dst++ = *src++;
134         count--;
135     }
136 }
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```

Cracker Phase 2

= = = VTune profiling demo = = =

=====

memory malloc +OK

initializing from built-in data

memory malloc +OK

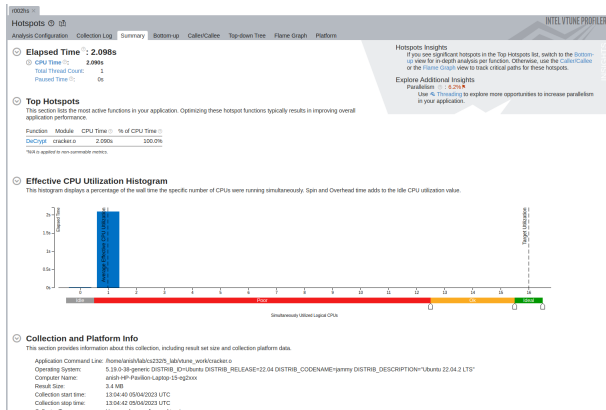
max iter 10000

===

try search... wait!

Password per sec: 51,91

Cracker Phase 2



Cracker Phase 3

- Now the hotspot is in the Decrypt function.
- The main contributing factors seems to be towards the end of the loop
- So we make two modifications, turn the two loops into a single loop and instead of taking % we simply keep track of the proper index at all times.
- Also at the start of the loop `key[p]` is copied into a fresh structure `key_attr`, this takes unnecessary time by calling copy constructor
- So instead we just access `key[p]` directly

Cracker Phase 3

```
terminal help
C:\cracker> gcc cracker.c -o cracker

94         return -1;
95     }
96 }
97
98 char *buff = (char *)malloc(my_strlen(ciphertext) + 1);
99 memcpy(buff, ciphertext, my_strlen(ciphertext) + 1);
100
101 int p = 0, q = 0;
102 char* tempbuff = buff;
103 int temp_res;
104 int cypher_len = my_strlen(ciphertext);
105
106 do {
107     //struct key_attr key_k = key[p];
108
109     int prf_int = (key[p].l1 ^ key[p].l2 ^ key[p].k1) & 15;
110     int mask = key[p].a1(prf_int-1) >= 4;
111
112     if(prf_int == 15)
113     {
114         prf_int = 3;
115     }
116
117     int sub_result = sub_func(prf_int & mask) ^ pow(p);
118
119     *tempbuff ^= sub_result;
120
121     p++;
122     q++;
123     tempbuff++;
124
125     if(q==cypher_len) {
126         tempbuff = buff;
127         q=0;
128     }
129 }
130 while(p>PASS_X_LEN*PASS_Y_LEN);
131
132 return buff;
133 }
134
135 int my_memcpy(char *dst, char *src, unsigned count)
136 {
137     ...
138 }
139
140 int main() {
141     ...
142 }
143
144 int my_strlen(char *str) {
145     ...
146 }
147
148 int my_strcmp(char *s1, char *s2) {
149     ...
150 }
151
152 int my_strncmp(char *s1, char *s2, int n) {
153     ...
154 }
155
156 int my_strcpy(char *dst, char *src) {
157     ...
158 }
159
160 int my_strncpy(char *dst, char *src, int n) {
161     ...
162 }
163
164 int my_strcat(char *dst, char *src) {
165     ...
166 }
167
168 int my_strncat(char *dst, char *src, int n) {
169     ...
170 }
171
172 int my_strchr(char *str, char c) {
173     ...
174 }
175
176 int my_strrchr(char *str, char c) {
177     ...
178 }
179
180 int my_strstr(char *hay, char *needle) {
181     ...
182 }
183
184 int my_strnstr(char *hay, char *needle, int n) {
185     ...
186 }
187
188 int my_strnchr(char *str, char c, int n) {
189     ...
190 }
191
192 int my_strnrchr(char *str, char c, int n) {
193     ...
194 }
195
196 int my_strnstrn(char *hay, char *needle, int n) {
197     ...
198 }
199
200 int my_strnchrn(char *str, char c, int n) {
201     ...
202 }
203
204 int my_strnrchrn(char *str, char c, int n) {
205     ...
206 }
207
208 int my_strnstrn(char *hay, char *needle, int n) {
209     ...
210 }
211
212 int my_strnchrn(char *str, char c, int n) {
213     ...
214 }
215
216 int my_strnrchrn(char *str, char c, int n) {
217     ...
218 }
219
220 int my_strnstrn(char *hay, char *needle, int n) {
221     ...
222 }
223
224 int my_strnchrn(char *str, char c, int n) {
225     ...
226 }
227
228 int my_strnrchrn(char *str, char c, int n) {
229     ...
230 }
231
232 int my_strnstrn(char *hay, char *needle, int n) {
233     ...
234 }
235
236 int my_strnchrn(char *str, char c, int n) {
237     ...
238 }
239
240 int my_strnrchrn(char *str, char c, int n) {
241     ...
242 }
243
244 int my_strnstrn(char *hay, char *needle, int n) {
245     ...
246 }
247
248 int my_strnchrn(char *str, char c, int n) {
249     ...
250 }
251
252 int my_strnrchrn(char *str, char c, int n) {
253     ...
254 }
255
256 int my_strnstrn(char *hay, char *needle, int n) {
257     ...
258 }
259
260 int my_strnchrn(char *str, char c, int n) {
261     ...
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263
264 int my_strnrchrn(char *str, char c, int n) {
265     ...
266 }
267
268 int my_strnstrn(char *hay, char *needle, int n) {
269     ...
270 }
271
272 int my_strnchrn(char *str, char c, int n) {
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275
276 int my_strnrchrn(char *str, char c, int n) {
277     ...
278 }
279
280 int my_strnstrn(char *hay, char *needle, int n) {
281     ...
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283
284 int my_strnchrn(char *str, char c, int n) {
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286 }
287
288 int my_strnrchrn(char *str, char c, int n) {
289     ...
290 }
291
292 int my_strnstrn(char *hay, char *needle, int n) {
293     ...
294 }
295
296 int my_strnchrn(char *str, char c, int n) {
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299
300 int my_strnrchrn(char *str, char c, int n) {
301     ...
302 }
303
304 int my_strnstrn(char *hay, char *needle, int n) {
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307
308 int my_strnchrn(char *str, char c, int n) {
309     ...
310 }
311
312 int my_strnrchrn(char *str, char c, int n) {
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314 }
315
316 int my_strnstrn(char *hay, char *needle, int n) {
317     ...
318 }
319
320 int my_strnchrn(char *str, char c, int n) {
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323
324 int my_strnrchrn(char *str, char c, int n) {
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328 int my_strnstrn(char *hay, char *needle, int n) {
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331
332 int my_strnchrn(char *str, char c, int n) {
333     ...
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336 int my_strnrchrn(char *str, char c, int n) {
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340 int my_strnstrn(char *hay, char *needle, int n) {
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344 int my_strnchrn(char *str, char c, int n) {
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348 int my_strnrchrn(char *str, char c, int n) {
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352 int my_strnstrn(char *hay, char *needle, int n) {
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356 int my_strnchrn(char *str, char c, int n) {
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360 int my_strnrchrn(char *str, char c, int n) {
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362 }
363
364 int my_strnstrn(char *hay, char *needle, int n) {
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366 }
367
368 int my_strnchrn(char *str, char c, int n) {
369     ...
370 }
371
372 int my_strnrchrn(char *str, char c, int n) {
373     ...
374 }
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376 int my_strnstrn(char *hay, char *needle, int n) {
377     ...
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380 int my_strnchrn(char *str, char c, int n) {
381     ...
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384 int my_strnrchrn(char *str, char c, int n) {
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388 int my_strnstrn(char *hay, char *needle, int n) {
389     ...
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391
392 int my_strnchrn(char *str, char c, int n) {
393     ...
394 }
395
396 int my_strnrchrn(char *str, char c, int n) {
397     ...
398 }
399
400 int my_strnstrn(char *hay, char *needle, int n) {
401     ...
402 }
403
404 int my_strnchrn(char *str, char c, int n) {
405     ...
406 }
407
408 int my_strnrchrn(char *str, char c, int n) {
409     ...
410 }
411
412 int my_strnstrn(char *hay, char *needle, int n) {
413     ...
414 }
415
416 int my_strnchrn(char *str, char c, int n) {
417     ...
418 }
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420 int my_strnrchrn(char *str, char c, int n) {
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1314 }
1315
1316 int my_strnchrn(char *str, char c, int n) {
1317     ...
1318 }
1319
1320 int my_strnrchrn(char *str, char c, int n) {
1321     ...
1322 }
1323
1324 int my_strnstrn(char *hay, char *needle, int n) {
1325     ...
1326 }
1327
1328 int my_strnchrn(char *str, char c, int n) {
1329     ...
1330 }
1331
1332 int my_strnrchrn(char *str, char c, int n) {
1333     ...
1334 }
1335
1336 int my_strnstrn(char *hay, char *needle, int n) {
1337     ...
1338 }
1339
1340 int my_strnchrn(char *str, char c, int n) {
1341     ...
1342 }
1343
1344 int my_strnrchrn(char *str, char c, int n) {
1345     ...
1346 }
1347
1348 int my_strnstrn(char *hay, char *needle, int n) {
1349     ...
1350 }
1351
1352 int my_strnchrn(char *str, char c, int n) {
1353     ...
1354 }
1355
1356 int my_strnrchrn(char *str, char c, int n) {
1357     ...
1358 }
1359
1360 int my_strnstrn(char *hay, char *needle, int n) {
1361     ...
1362 }
1363
1364 int my_strnchrn(char *str, char c, int n) {
1365     ...
1366 }
1367
1368 int my_strnrchrn(char *str, char c, int n) {
1369     ...
1370 }
1371
1372 int my_strnstrn(char *hay, char *needle, int n) {
1373     ...
1374 }
1375
1376 int my_strnchrn(char *str, char c, int n) {
1377     ...
1378 }
1379
1380 int my_strnrchrn(char *str, char c, int n) {
1381     ...
1382 }
1383
1384 int my_strnstrn(char *hay, char *needle, int n) {
1385     ...
1386 }
1387
1388 int my_strnchrn(char *str, char c, int n) {
1389     ...
1390 }
1391
1392 int my_strnrchrn(char *str, char c, int n) {
1393     ...
1394 }
1395
1396 int my_strnstrn(char *hay, char *needle, int n) {
1397     ...
1398 }
1399
1400 int my_strnchrn(char *str, char c, int n) {
1401     ...
1402 }
1403
1404 int my_strnrchrn(char *str, char c, int n) {
1405     ...
1406
```

Cracker Phase 3

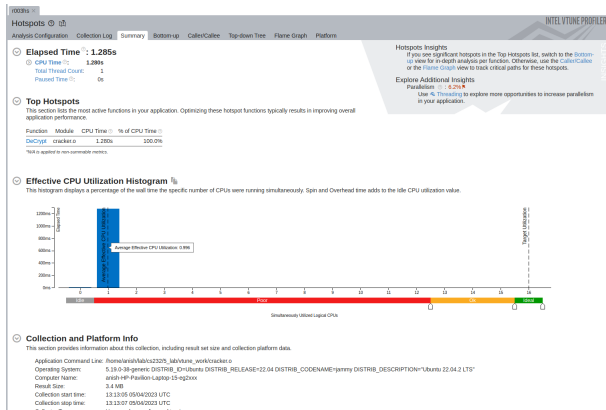
= = = VTune profiling demo = = =

=====

memory malloc +OK
initializing from built-in data
memory malloc +OK
max iter 10000
===

try search... wait!
Password per sec: 94,17

Cracker Phase 3



Question 1

The `handle_fill()` function

- This function is called when a new fill comes from a lower level cache in response to a request sent by the current cache.
- First, a victim is found in the corresponding set to be removed.
- If this victim line is dirty, i.e., it has been written to directly in the cache, a write-back request is sent.
- Writeback request is necessary because the line currently stores updated data which is not present in the lower caches.
- Note that if there is not enough space for the write-back request in the lower level cache queue we need to stall.
- If the victim is not dirty it is replaced by the new fill

Question 1

Fill Level

- Fill_level of a cache is a level associated with each cache, and this field in the packets stores which cache to fetch the data to.

Cache Level	L1	L2	LLC	DRAM
Fill_level	1	2	4	16

- If the fill level of the packet is less than the fill level of the current cache then the data is forwarded to the next higher level cache.

Question 1

Set and Way

- Finding a set from address is really easy, in cache.cc there is a function `get_set` for the same.
- In `get_set`, we take last $\log_2(\text{NUM_SET})$ bits of address and get the corresponding set.
- For way, if it is a hit then way is the corresponding location of the hit.
- If it is a miss, request is sent to lower cache for the data.
- After this data arrives we call replacement policy function for the respective cache to decide which victim to eject and insert the received data.

Question 1

`return_data`

- The `return_data` returns data from a lower cache to a higher cache in response to a data request
- First `check_mshr` function is called to check if MSHR still contains the request.
- Then the data is stored in `MSHR.data`(for the corresponding index) and `MSHR.returned` is set to `COMPLETED`. This data is later copied into the cache in `cache_fill`.
- Next, `update_fill_cycle` is called to find the next index from MSHR to be called.

Least Frequently Used

Implemented by keeping track of the number of times an address got a hit.

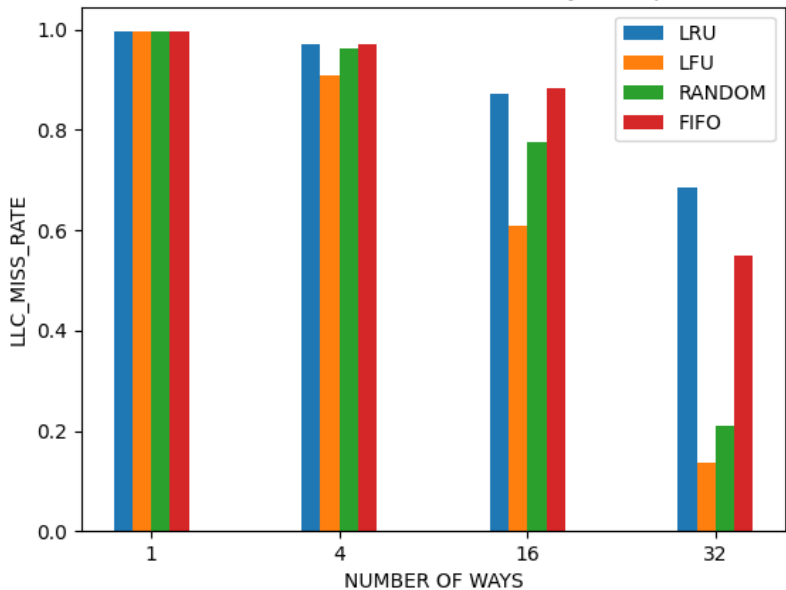
First in First Out

Implemented by keeping a queue and removing the end of the queue which was inserted first.

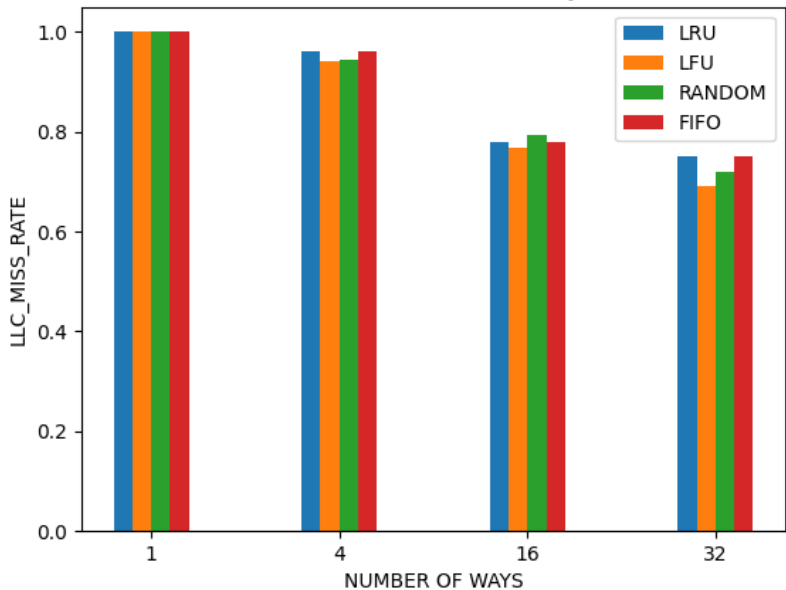
Random Replacement

Implemented by choosing a random way in the given set from a uniform distribution in case of a miss.

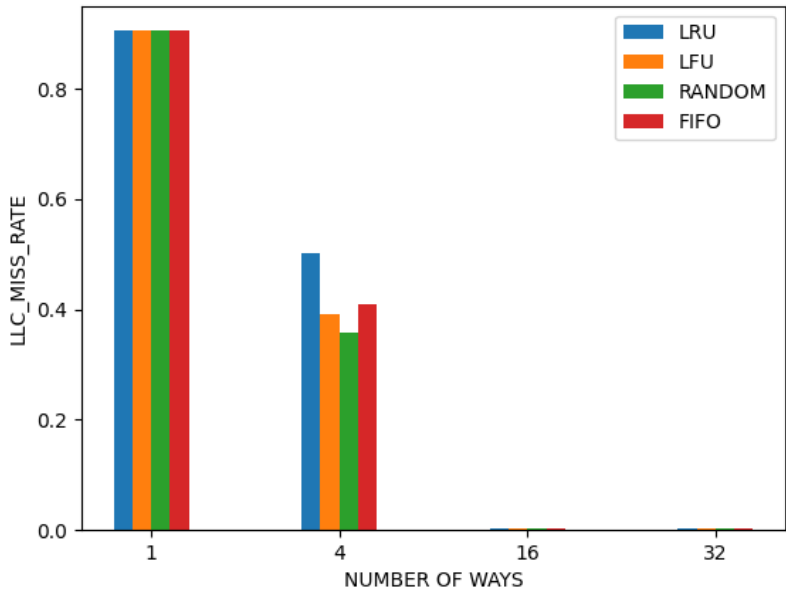
LLC Miss rate versus Number of Ways for sphinx



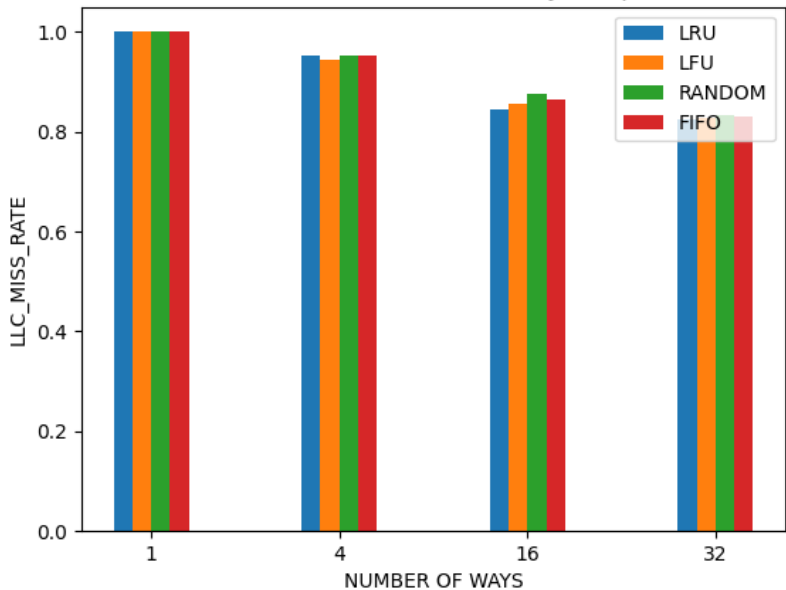
LLC Miss rate versus Number of Ways for cactus



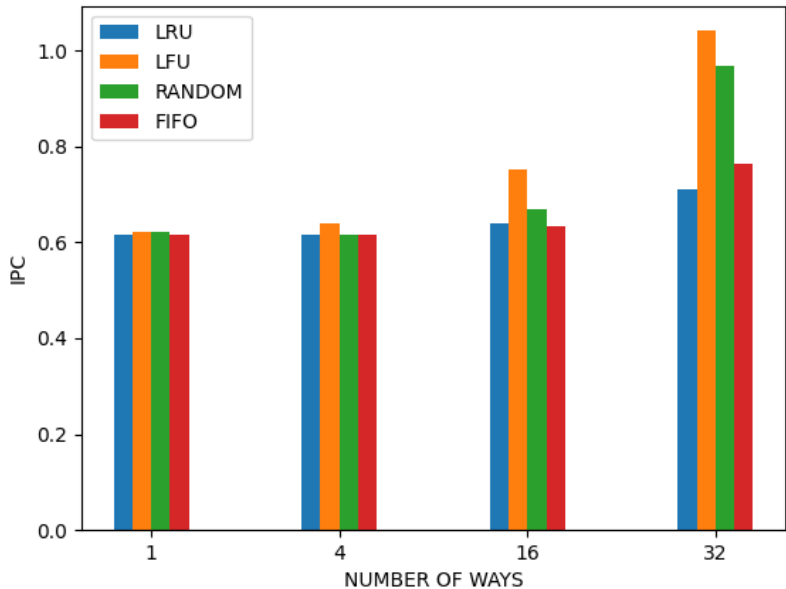
LLC Miss rate versus Number of Ways for gcc



LLC Miss rate versus Number of Ways for perlbench



IPC versus Number of Ways for gcc



- We see that LFU is clearly the best policy. Random is at second place followed by a LRU and FIFO.
- LFU's win can be explained by the fact that it has good memory. For example if a certain address was used a lot of times in past and hasn't been used in a while LFU will remember it but other policies will not.
- FIFO and LRU are bad because they may kick out memory addresses used with high frequency for more recent low frequency addresses.
- Random is in middle because it doesn't have a preference and the high frequency addresses have a chance of staying

Fixed Offset Prefetchers

- Generalization of next line prefetchers
- Prefetch $X+1$ in case of an L2 miss for X or has been prefetched into L2 but not fetched by L1
- Offset prefetchers fetch a line at a fixed offset from X

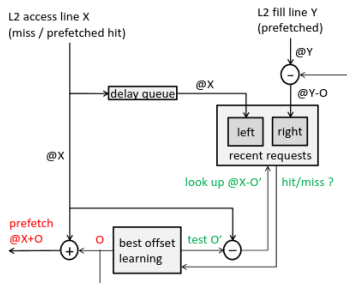
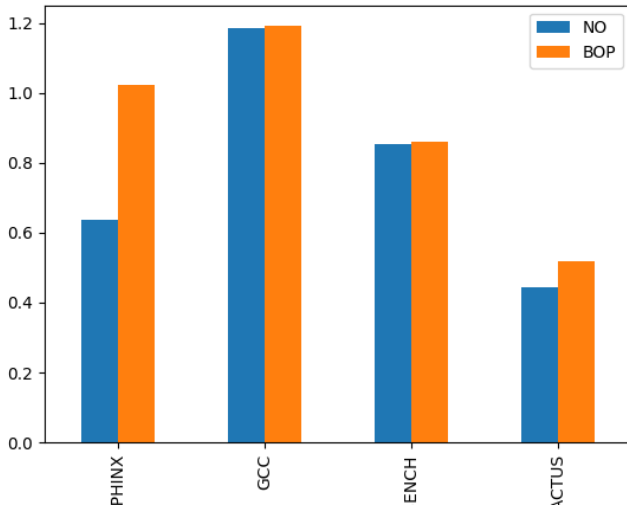


Figure 1: The BO prefetcher

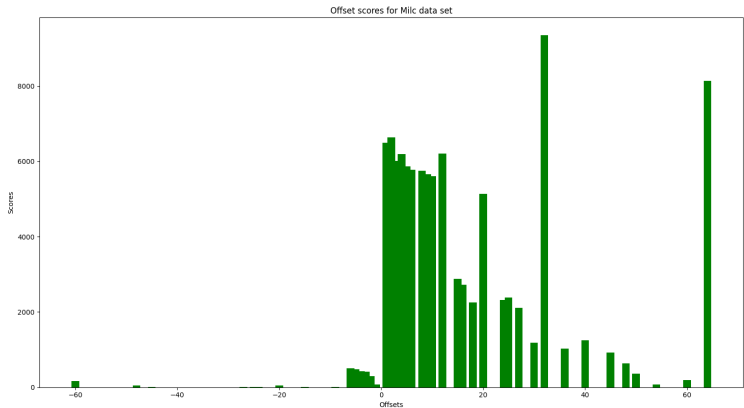
Best Offset Prefetchers

- The aim is to find the best possible offset to prefetch from
- Keep a current offset O
- Keep a recent requests table
- Store a list of offsets (O_i) to choose from, each with a score
- The following happens in what is called a *learning phase*
- A round begins, set i to 0
- For every L2 miss or prefetched hit X , we check if $X - O_i$ is in the RR table
- If so, increase the score of O_i , else don't and store X after a delay
- If Y is prefetched, store $Y - O$ in RR table
- If score reaches Score MAX or rounds reach Round MAX at the end of a round, a phase ends

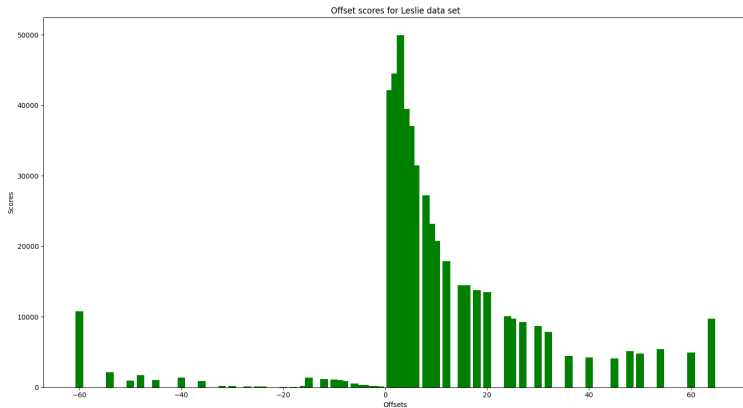
Best Offset Prefetchers



Best Offset Prefetchers



Best Offset Prefetchers



We concluded the following:

- The optimal value for SCORE_MAX is 40 and that of ROUND_MAX is 50.
- We tried searching for all $X-O_i$ s (for all 'i's in one round instead of just 1). However, this resulted in a decrease in IPC.