Homework 8

VE370 - Intro to Computer Organization Summer 2022

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Exercise 1

Assume that main memory accesses take 70 ns and that memory accesses are 36% of all instructions. The following table shows parameters for a two-level cache memory.

	Size	Miss Rate	Hit Time
L1	16 KB	7.3%	1.18 ns
L2	1MB	1.5%	5.34 ns

(1) What is the AMAT for the computer?

(2) Assuming the L1 hit time determines the cycle times and a base CPI is 1.0 without any memory stalls, what is the total CPI?

Answer:

(1)

$$\text{AMAT } = 1.18 + 7.3\% * 5.34 + 7.3\% * 1.5\% * 70 = 1.18 + 0.384 + 0.077 = 1.646 \text{ ns}$$

(2)

$$\text{Total CPI } = 1 + 36\% * 7.3\% * 98.5\% * 5.34/1.18 + 36\% * 7.3\% * 1.5\% * (70 + 5.34)/1.18 = 1.142$$

Exercise 2

In this exercise, we will examine how replacement policies impact miss rate. Assume a 2-way set associative cache with 4 blocks. Following table gives addresses for memory access.

(1) Assuming an LRU replacement policy, how many hits does this address sequence exhibit?

(2) Assuming an MRU (most recently used) replacement policy, how many hits does this address sequence exhibit?

(3) Simulate a random replacement policy by flipping a coin. For example, "heads" means to evict the first block in a set and "tails" means to evict the second block in a set. How many hits does this address sequence exhibit? Note: you should flip the coin yourself, not by computer.

You may find following table is useful:

Block Address of memory	Hit/Miss	Evicted Block	Contents of Cache			
			Set 0		Set 1	
1						
3						
5						
1						
3						
1						
3						
5						
3						

Answer:

(1)

Block Address of memory	Hit/Miss	Evicted Block	Contents of Cache			
			Set 0		Set 1	
1	M				1	
3	M				1	3
5	M	1			5	3
1	M	3			5	1
3	M	5			3	1
1	H				3	1
3	H				3	1
5	M	1			3	5
3	H				3	5

There are 3 hits.

(2)

Block Address of memory	Hit/Miss	Evicted Block	Contents of Cache			
			Set 0		Set 1	
1	M				1	
3	M				1	3
5	M	3			1	5
1	H				1	5
3	M	1			3	5
1	M	3			1	5
3	M	1			3	5
5	H				3	5
3	H				3	5

There are 3 hits.

(3) I flipped a coin and get the sequence "HHHTHTTTH". If we need to change the block, I will use this sequence.

Block Address of memory	Hit/Miss	Evicted Block	Contents of Cache			
			Set 0		Set 1	
1	M				1	
3	M				1	3
5	M	1			5	3
1	M	5			1	3
3	H				1	3
1	H				1	3
3	H				1	3
5	M	1			5	3
3	H				5	3

There are 4 hits.

Exercise 3

Virtual memory uses a page table to track the mapping of virtual addresses to physical addresses. The following is a stream of virtual byte addresses used to access memory. Virtual addresses (in decimal): $12648, 45419, 46824, 16975, 40004, 12707, 52236$

Assume 4 KB pages, a 4-entry fully associative TLB, and LRU replacement. If pages must be brought in from disk, increment to the next largest page number.

TLB:

Valid	Tag	Physical Page Number
1	11	12
1	7	4
1	3	6
0	4	9

Page Table:

Valid	Physical Page Number
1	5
0	Disk
0	Disk
1	6
1	9
1	11
0	Disk
1	4
0	Disk
0	Disk
1	3
1	12

(1) Given the virtual address stream, and the initial TLB and page table states shown above, show the final state of the system. Also list for each reference if it is a hit in the TLB, a hit in the page table, or a page fault.

(2) Repeat question (1), but this time use 16 KB pages instead of 4 KB pages.

(3) What would be some of the advantages and disadvantages of having a larger page size?

(4) Show the final contents of the TLB if it is 2-way set associative.

Answer:

(1) a. 12648 = 0x3168, VPN = 3 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	11	12
1	7	4
1	3	6
0	4	9

b. 45419 = 0xB16B, VPN = 11 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	11	12
1	7	4
1	3	6
0	4	9

c. 46824 = 0xB6E8, VPN = 11 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	11	12
1	7	4
1	3	6
0	4	9

d. 16975 = 0x424F, VPN = 4 , miss in TLB but can find it in Page Table

Valid	Tag	Physical Page Number
1	11	12
1	7	4
1	3	6
1	4	9

e. 40004 = 0x9C44, VPN = 9 , miss in TLB and Page Table, which means it is a Page Fault and we use LRU to change Tag 7 to 9. The PPN will be incremented to 13.

Valid	Tag	Physical Page Number
1	11	12
1	9	13
1	3	6
1	4	9

f. 12707 = 0x31A3, VPN = 3 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	11	12
1	9	13
1	3	6
1	4	9

g. 52236 = 0xCC0C, VPN = 12 , miss in TLB and Page Table, which means it is a Page Fault and we use LRU to change Tag 11 to 12. The PPN will be incremented to 14.

Valid	Tag	Physical Page Number
1	12	14
1	9	13
1	3	6
1	4	9

Page Table:

Valid	Physical Page Number
1	5
0	Disk
0	Disk
1	6
1	9
1	11
0	Disk
1	4
0	Disk
1	13
1	3
1	12
1	14

(2) a. 12648 = 0x3168, VPN = 0, miss in TLB but can find it in Page Table

Valid	Tag	Physical Page Number
1	11	12
1	7	4
1	3	6
1	0	5

b. 45419 = 0xB16B, VPN = 2 , miss in TLB and Page Table, which means it is a Page Fault and we use LRU to change Tag 11 to 2. The PPN will be incremented to 13.

Valid	Tag	Physical Page Number
1	2	13
1	7	4
1	3	6
1	0	5

c. 46824 = 0xB6E8, VPN = 2 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	2	13
1	7	4
1	3	6
1	0	5

d. 16975 = 0x424F, VPN = 1 , miss in TLB and Page Table, which means it is a Page Fault and we use LRU to change Tag 7 to 1. The PPN will be incremented to 14.

Valid	Tag	Physical Page Number
1	2	13
1	1	14
1	3	6
1	0	5

e. 40004 = 0x9C44, VPN = 2 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	2	13
1	1	14
1	3	6
1	0	5

f. 12707 = 0x31A3, VPN = 1 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	2	13
1	1	14
1	3	6
1	0	5

g. 52236 = 0xCC0C, VPN = 3 , hit in TLB and Page Table

Valid	Tag	Physical Page Number
1	2	13
1	1	14
1	3	6
1	0	5

Page Table:

Valid	Physical Page Number
1	5
1	14
1	13
1	6
1	9
1	11
0	Disk
1	4
0	Disk
0	Disk
1	3
1	12

(3) Advantage: page fault rate will be reduced because it can store more page numbers.

Disadvantage: Miss penalty for page fault will be increased gradually because we need to spend more time to find the page.

(4) a. 12648 = 0x3168, VPN = 3, Set Index = 1, Tag = 1, miss in TLB and Page Table, which means it is a Page Fault and we use LRU to change Tag 0 to 1. The PPN will be incremented to 13.

Set Index	Valid	Tag	Physical Page Number
0	1	11	12
0	1	7	4
1	1	3	6
1	1	1	13

b. 45419 = 0xB16B, VPN = 11, Set Index = 1, Tag = 5, miss in TLB but can find it in Page Table

Set Index	Valid	Tag	Physical Page Number
0	1	11	12
0	1	7	4
1	1	5	11
1	1	1	13

c. 46824 = 0xB6E8, VPN = 11, Set Index = 1, Tag = 5, hit in TLB and Page Table

Set Index	Valid	Tag	Physical Page Number
0	1	11	12
0	1	7	4
1	1	5	11
1	1	1	13

d. 16975 = 0x424F, VPN = 4, Set Index = 0, Tag = 2, miss in TLB and Page Table, which means it is a Page Fault and we use LRU to change Tag 11 to 2. The PPN will be incremented to 14.

Set Index	Valid	Tag	Physical Page Number
0	1	2	14
0	1	7	4
1	1	5	11
1	1	1	13

e. 40004 = 0x9C44, VPN = 9, Set Index = 1, Tag = 4, miss in TLB but can find it in Page Table

Set Index	Valid	Tag	Physical Page Number
0	1	2	14
0	1	7	4
1	1	5	11
1	1	4	9

f. 12707 = 0x31A3, VPN = 3, Set Index = 1, Tag = 1, miss in TLB but can find it in Page Table

Set Index	Valid	Tag	Physical Page Number
0	1	2	14
0	1	7	4
1	1	1	13
1	1	4	9

g. 52236 = 0xCC0C, VPN = 12, Set Index = 0, Tag = 6, miss in TLB and Page Table, which means it is a Page Fault and we use LRU to change Tag 7 to 6. The PPN will be incremented to 15.

Set Index	Valid	Tag	Physical Page Number
0	1	2	14
0	1	6	15
1	1	1	13
1	1	4	9

Page Table:

Valid	Physical Page Number
1	5
1	13
1	14
1	6
1	9
1	11
1	15
1	4
0	Disk
0	Disk
1	3
1	12