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20 PT.

**Question 1**

**5.2** Caches are important to providing a high-performance memory hierarchy to processors. Below is a list of 32-bit memory address references, given as word addresses.

3, 180, 43, 2, 191, 88, 190, 14, 181, 44, 186, 253

**5.2.1** For each of these references, identify the binary address, the tag, and the index given a direct-mapped cache with 16 one-word blocks. Also list if each reference is a hit or a miss, assuming the cache is initially empty.

**5.2.2** For each of these references, identify the binary address, the tag, and the index given a direct-mapped cache with two-word blocks and a total size of 8 blocks. Also list if each reference is a hit or a miss, assuming the cache is initially empty.

**5.2.3** You are asked to optimize a cache design for the given references. There are three direct-mapped cache designs possible, all with a total of 8 words of data: C1 has 1-word blocks, C2 has 2-word blocks, and C3 has 4-word blocks. In terms of miss rate, which cache design is the best? If the miss stall time is 25 cycles, and C1 has an access time of 2 cycles, C2 takes 3 cycles, and C3 takes 5 cycles, which is the best cache design?

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**Question 2**

**5.3** For a direct-mapped cache design with a 32-bit address, the following bits of the address are used to access the cache.

Tag	Index	Offset
31-10	9-5	4-0

**5.3.1** What is the cache block size (in words)?

**5.3.2** How many entries does the cache have?

**5.3.3** What is the ratio between total bits required for such a cache implementation over the data storage bits?

Starting from power on, the following byte-addressed cache references are recorded.

Address											
0	4	16	132	232	160	1024	30	140	3100	180	2180

**5.3.4** How many blocks are replaced?

**5.3.5** What is the hit ratio?

**5.3.6** List the final state of the cache, with each valid entry represented as a record of <index, tag, data>.

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Question 3

Assume an instruction cache miss rate for an application is 2% and the data cache miss rate of 4%. Assume further that our CPU has a CPI of 2 without any memory stalls and the miss penalty is 40 cycles for all misses.

- a. Determine the overall CPI with the indicated misses, provided the frequency of all loads and stores in the application is 20%.
- b. Suppose we increase the performance of the machine in the above example by reducing its CPI from 2 to 1 via pipelining. Determine the new overall CPI.

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Question 4

The following is a series of address references given as word addresses: 9, 4, 20, 4, 8, 15, 5, 19, 4, 20, 4, 22, 7, 17, 10.

- a. Assume direct map with a word size of 1 byte, a block size of 1 word, and a total size of 8 words. Show the hits and misses and final cache contents. Show the final cache content.

Location	Hit/Miss?
9	
4	
20	
4	
8	
15	
5	
19	
4	
20	
4	
22	
7	
17	
10	

- b. Assume direct map with word size of 1 byte, a block size of 2, and a total size of 8 words. Show the hits and misses and final cache contents.
- c. Assume two way associative for the same total cache locations as of part b. Show the hits and misses and the final cache contents.

- d. Assume a fully associated cache for the same total cache locations as of part b.  
Show the hits and misses and the final cache contents.

Due: Thursday 5/2/2022

## Key

20 PT.

Question 1, Do problem 5.2.1, 5.2.2, 5.2.3

**5.2.1**

Word Address	Binary Address	Tag	Index	Hit/Miss
3	0000 0011	0	3	M
180	1011 0100	11	4	M
43	0010 1011	2	11	M
2	0000 0010	0	2	M
191	1011 1111	11	15	M
88	0101 1000	5	8	M
190	1011 1110	11	14	M
14	0000 1110	0	14	M
181	1011 0101	11	5	M
44	0010 1100	2	12	M
186	1011 1010	11	10	M
253	1111 1101	15	13	M

**5.2.2**

Word Address	Binary Address	Tag	Index	Hit/Miss
3	0000 0011	0	1	M
180	1011 0100	11	2	M
43	0010 1011	2	5	M
2	0000 0010	0	1	H
191	1011 1111	11	7	M
88	0101 1000	5	4	M
190	1011 1110	11	7	H
14	0000 1110	0	7	M
181	1011 0101	11	2	H
44	0010 1100	2	6	M
186	1011 1010	11	5	M
253	1111 1101	15	6	M

### 5.2.3

Word Address	Binary Address	Tag	Cache 1		Cache 2		Cache 3	
			index	hit/miss	index	hit/miss	index	hit/miss
3	0000 0011	0	3	M	1	M	0	M
180	1011 0100	22	4	M	2	M	1	M
43	0010 1011	5	3	M	1	M	0	M
2	0000 0010	0	2	M	1	M	0	M
191	1011 1111	23	7	M	3	M	1	M
88	0101 1000	11	0	M	0	M	0	M
190	1011 1110	23	6	M	3	H	1	H
14	0000 1110	1	6	M	3	M	1	M
181	1011 0101	22	5	M	2	H	1	M
44	0010 1100	5	4	M	2	M	1	M
186	1011 1010	23	2	M	1	M	0	M
253	1111 1101	31	5	M	2	M	1	M

Cache 1 miss rate = 100%

Cache 1 total cycles =  $12 \times 25 + 12 \times 2 = 324$

Cache 2 miss rate =  $10/12 = 83\%$

Cache 2 total cycles =  $10 \times 25 + 12 \times 3 = 286$

Cache 3 miss rate =  $11/12 = 92\%$

Cache 3 total cycles =  $11 \times 25 + 12 \times 5 = 335$

Cache 2 provides the best performance.

20 PT. Question 2, Do problem 5.3

5.3.1 8

5.3.2 32

5.3.3 1\_ (22/8/32) \_ 1.086

5.3.4 3

5.3.5 0.25

5.3.6 \_Index, tag, data\_

<0000012, 00012, mem[1024]>

<0000012, 00112, mem[16]>

<0010112, 00002, mem[176]>

<0010002, 00102, mem[2176]>

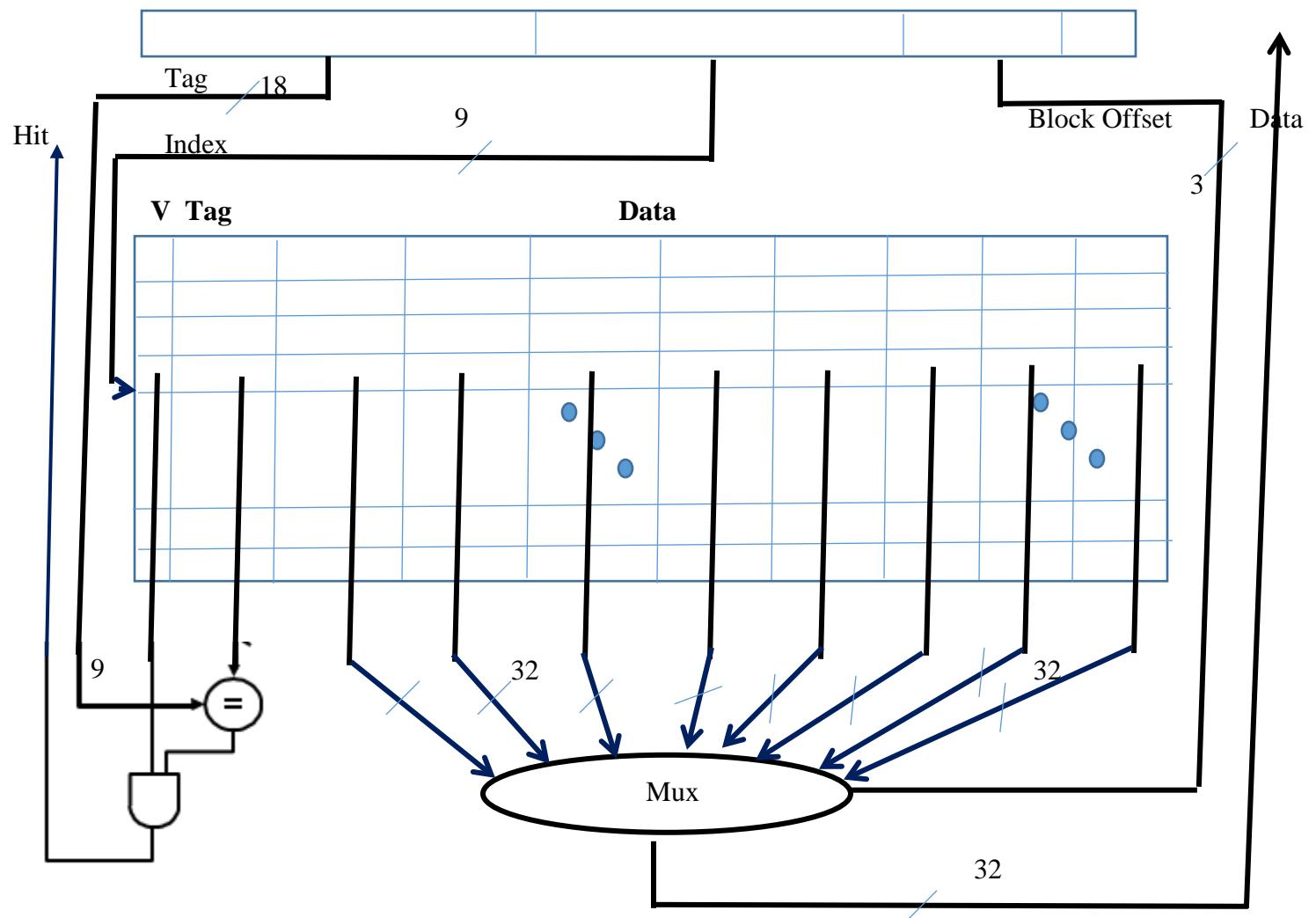
<0011102, 00002, mem[224]>

<0010102, 00002, mem[160]>

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Question 3

Show internal architecture of a direct cache with 512 blocks and 8 words per block.



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Question 4

The following is a series of address references given as word addresses: 9, 4, 20, 4, 8, 15, 5, 19, 4, 20, 4, 22, 7, 17, 10.

- a. Assume direct map with a word size of 1 and a total size of 8 words. Show the hits and misses and final cache contents. Show the final cache content.

Location	Hit/Miss?
9	miss
4	miss
20	miss
4	miss
8	miss
15	miss
5	miss
19	miss
4	hit
20	miss
4	miss
22	miss
7	miss
17	miss
10	miss

Index	Data for Memory Location
000	8
001	9-17
010	10
011	19
100	4-20 4-20 4
101	5
110	22
111	15 7

- b. Assume direct map with a word size of 2 and a total size of 8 words. Show the hits and misses and final cache contents.

<b>Location</b>	<b>Hit/Miss?</b>
<b>9</b>	<b>miss</b>
<b>4</b>	<b>miss</b>
<b>20</b>	<b>miss</b>
<b>4</b>	<b>miss</b>
<b>8</b>	<b>Hit</b>
<b>15</b>	<b>miss</b>
<b>5</b>	<b>Hit</b>
<b>19</b>	<b>Miss</b>
<b>4</b>	<b>Hit</b>
<b>20</b>	<b>miss</b>
<b>4</b>	<b>miss</b>
<b>22</b>	<b>miss</b>
<b>7</b>	<b>miss</b>
<b>17</b>	<b>miss</b>
<b>10</b>	<b>miss</b>

<b>Index</b>	<b>Data for Memory Location</b>	<b>Data for Memory Location</b>
00	8 16	9-17
01	48 10	19 11
10	4 20 4 20 4	5 21 5 21 5
11	14 22 6	15 23 7

- c. Assume two way associative for the same total cache locations as of part b. Show the hits and misses and the final cache contents.

<b>Location</b>	<b>Hit/Miss?</b>
<b>9</b>	<b>miss</b>
<b>4</b>	<b>miss</b>
<b>20</b>	<b>miss</b>
<b>4</b>	<b>hit</b>
<b>8</b>	<b>miss</b>
<b>15</b>	<b>miss</b>
<b>5</b>	<b>miss</b>
<b>19</b>	<b>Miss</b>
<b>4</b>	<b>hit</b>
<b>20</b>	<b>miss</b>
<b>4</b>	<b>hit</b>
<b>22</b>	<b>miss</b>
<b>7</b>	<b>miss</b>
<b>17</b>	<b>miss</b>
<b>10</b>	<b>miss</b>

I used LRU replacement algorithm. In case both had the same usage, I used FIFO.

Index	Data for Memory Location	Data for Memory Location
00	4	20, 8, 20
01	9, 17	5
10	22	10
11	15, 7	19

- d. Assume a fully associated cache for the same total cache locations as of part b.  
Show the hits and misses and the final cache contents.

Location	Hit/Miss?
9	miss
4	miss
20	miss
4	hit
8	miss
15	miss
5	miss
19	miss
4	hit
20	hit
4	hit
22	miss
7	miss
17	miss
10	miss

I used LRU replacement algorithm. In case both had the same usage, I used FIFO.

Location	Data for Memory Location
0	9, 7
1	4
2	20
3	8, 17
4	15, 10
5	5
6	19
7	22

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Question 5

Assume an instruction cache miss rate for an application is 2% and the data cache miss rate of 4%. Assume further that our CPU has a CPI of 2 without any memory stalls and the miss penalty is 40 cycles for all misses.

- a. Determine the overall CPI with the indicated misses, provided the frequency of all loads and stores in the application is 20%.
- b. Suppose we increase the performance of the machine in the above example by reducing its CPI from 2 to 1 via pipelining. Determine the new overall CPI.

a.

I-cache miss rate = 2%

D-cache miss rate = 4%

Miss penalty = 40 cycles

Base CPI (ideal cache) = 2

Load & stores are 20% of instructions

Miss cycles per instruction

I-cache:  $0.02 \times 40 = .8$

D-cache:  $0.2 \times 0.04 \times 40 = .32$

Actual CPI =  $2 + .8 + .32 = 3.12$

e. Actual CPI =  $1 + .8 + .32 = 2.12$