Introduction to Computer Systems

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Today

- Memory Hierarchy

- Caches

- Exam Review

- Cachelab

Caching

- Temporal Locality (Time)

  - A memory location accessed is likely to be accessed again multiple times in the future

  - After accessing address X in memory, save the bytes in cache for future access

- Spatial Locality (Space)

  - If a location is accessed, then nearby locations are likely to be accessed in the future.

  - After accessing address X, save the block of memory around X in cache for future access

Memory Addresses

- A *cache* is a set of 2^s cache sets

- A *cache set* is a set of E cache lines

  - E = 1 → Direct-mapped

  - E-way associative

- Each cache line stores a block

  - Each block has 2^b bytes

Tag	Set Index	Block Offset
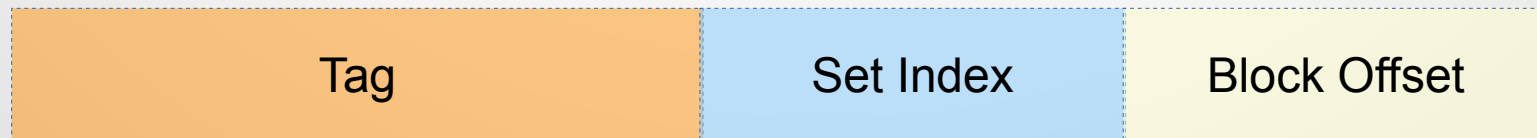
Miss Rate

- Fraction of memory references not found in the cache

$$Missrate = 1 - Hitrate$$

Real Example!

- 8 bit-address space

- Direct-mapped 32-byte cache
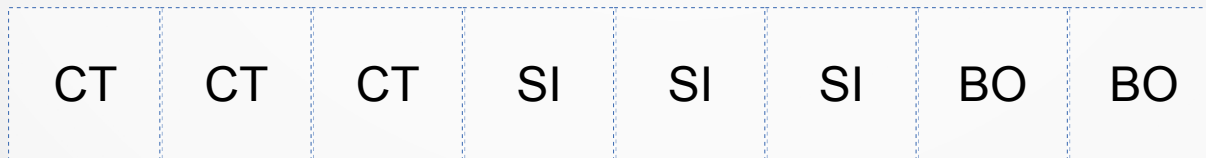
  - 4 byte cache blocks

Real Example!

- Indicate which fields do the bits represent
  - "SI" → Set index
  - "BO" → Block offset
  - "CT" → Cache tag

Real Example!

- Indicate which fields do the bits represent
    - **"SI"** → Set index
    - **"BO"** → Block offset
    - **"CT"** → Cache tag

CT	CT	CT	SI	SI	SI	BO	BO

Real Example!

Load No.	Hex Address	Binary Address	Set Number?	Hit or Miss?
1	c7	110 001 11		
2	55	010 101 01		
3	1a	000 110 10		
4	c5	110 001 01		
5	e6	111 001 10		
6	56	010 101 10		
7	77	011 101 11		
8	28	001 010 00		
9	75	011 101 01		
10	94	100 101 00		

Real Example!

Load No.	Hex Address	Binary Address	Set Number?	Hit or Miss?
1	c7	110 001 11	1	M
2	55	010 101 01	5	M
3	1a	000 110 10	6	M
4	c5	110 001 01	1	H
5	e6	111 001 10	1	M
6	56	010 101 10	5	H
7	77	011 101 11	5	M
8	28	001 010 00	2	M
9	75	011 101 01	5	H
10	94	100 101 00	5	M

Real Example!

- Which of the following is a possible final state for the cache:

0	1	2	3	4	5	6	7
X	7	1	X	X	4	1	X

0	1	2	3	4	5	6	7
1	7	X	X	1	4	0	X

0	1	2	3	4	5	6	7
X	1	1	X	0	2	0	X

0	1	2	3	4	5	6	7
X	1	7	X	X	4	4	0

0	1	2	3	4	5	6	7
X	1	7	X	4	4	0	X

0	1	2	3	4	5	6	7
X	7	1	X	X	4	0	X

0	1	2	3	4	5	6	7
7	X	1	0	4	4	0	X

Real Example!

- Which of the following is a possible final state for the cache:

0	1	2	3	4	5	6	7
X	7	1	X	X	4	1	X

0	1	2	3	4	5	6	7
1	7	X	X	1	4	0	X

0	1	2	3	4	5	6	7
X	1	1	X	0	2	0	X

0	1	2	3	4	5	6	7
X	1	7	X	X	4	4	0

0	1	2	3	4	5	6	7
X	1	7	X	4	4	0	X

0	1	2	3	4	5	6	7
X	7	1	X	X	4	0	X

0	1	2	3	4	5	6	7
7	X	1	0	4	4	0	X

Cachelab

- Due: Sometime after Eid \o/

- Office Hours/Piazza