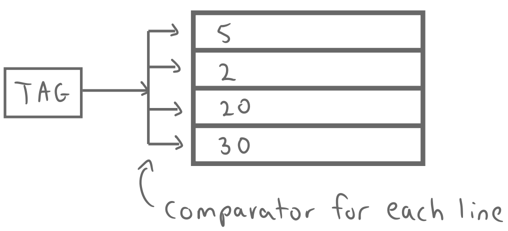
Cache Mapping Strategies

Associative Mapping

- A main memory block can go into any line in the cache
- The block number serves as the tag, and so this is known also as Fully Associative
- Cache contains
  - Valid/Invalid bit
  - Tag (block number)
  - Data (could be multiple words)
- Searches are done in parallel, requiring one comparator per line
  - fast but expensive due to hardware complexity
- Associativity here means we can "associate" a block with any line

Cache lines



× indicates a miss

× × × × ×
MM blocks: 5, 2, 20, 30, 15

Since 15 is a miss and we have no room in the cache for it, it needs to replace one of the lines (the least recently used)

Problem statement

Find the number of misses with a fully associative mapping, consisting of 4 one-word blocks given the following sequence of block addresses:

1, 2, 4, 6, 1, 2, 4, 2, 4, 3, 5

0	~~1~~ 5
1	2
2	4
3	~~6~~ 3

× × × × ✓ ✓ ✓ ✓ ✓ × × → 6 misses
1, 2, 4, 6, 1, 2, 4, 2, 4, 3, 5

Direct Mapping

- Each memory block maps to exactly one cache line
  - Cache line = (Block Number) mod (cache size)
- Cache structure includes:
  - Tag (to differentiate blocks with same index)
  - Line Index
  - Word offset (if multiple words per block)
- Simple and inexpensive, but prone to higher rate of cache misses

Problem statement

Find the number of misses with Direct mapping, consisting of 4 one-word blocks given the following sequence of block addresses:

1, 2, 4, 6, 1, 2, 4, 2, 4, 3, 5

0	4
1	~~1~~ 5
2	2 6 2
3	3

* Block # goes into line:
(block #) mod (# of cache lines)

✗ ✗ ✗ ✗ ✓ ✗ ✓ ✓ ✓ ✗ ✗ → 7 misses

1, 2, 4, 6, 1, 2, 4, 2, 4, 3, 5

Set Associative Mapping

- Combines aspects of both fully associative and direct mapping
- Cache is divided into sets, each with multiple lines
  - eg. 8 lines and 2 sets = 4 lines per set → 4-way associative
- Block mapping:
  - Set index = (Block #) mod (# of sets)
  - Block can go into any line within its assigned set
  - Lines within a set are searched in parallel
- Requires fewer comparators than fully associative
- Examples:
  - 8 lines, 2 sets → 4-way associative (4 lines per set)
  - 8 lines, 4 sets → 2-way associative (2 lines per set)

Problem statement

Find the number of misses with a 2- way set Associative Mapping, consisting of 4 one-word blocks given the following sequence of block addresses:

1, 2, 4, 6, 1, 2, 4, 2, 4, 3, 5

0	~~2~~ ~~6~~ 4	S_0
1	~~4~~ 2	
2	~~1~~ 5	S_1
3	3	

× × × × ✓ × × ✓ ✓ × ×

1, 2, 4, 6, 1, 2, 4, 2, 4, 3, 5

$$\text{\# of sets} = \frac{\text{\# of lines}}{\text{\# of lines per set}} = 4/2 = 2 \text{ sets}$$

Blocks are inserted into set #:

(block #) mod (# of sets)

In this example, when we encounter the first 6, which needs to go into set 0, it is already full, so we need to determine which block # from S_0 to evict.

With the LRU strategy, we'll have to backtrack along the sequence of numbers given to us, and find the 2nd least recently used number from S_0.

- Unique numbers from S_0 encountered while backtracking from the first 6:

  4, 2 → we need to evict 2 from S_0. (We stop counting after we reach the 2nd unique number)

* Our sets contain 2 lines each