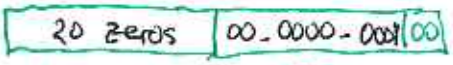
Address : 0x0000_0004



tag = 0 set = 1

0x0000_000c tag = 0 set = 3

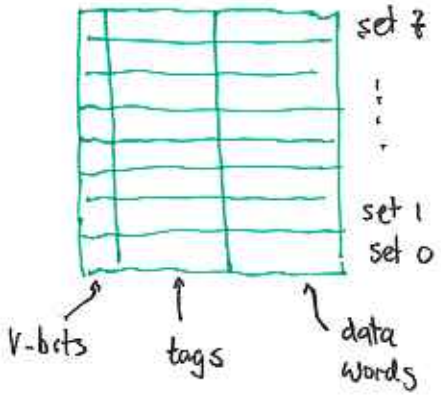
0x0000_0008 tag = 0 set = 2

On 5 times through this loop, there will be

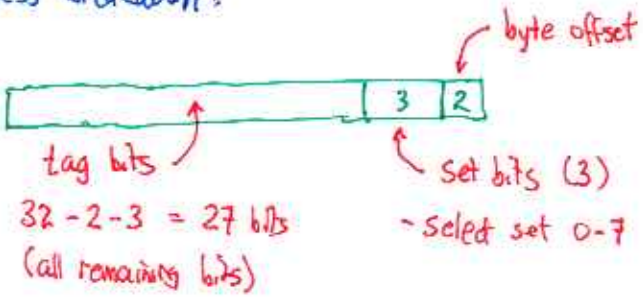
- 3 misses (first time through loop)
- 12 hits (next four loops)

Hit rate = 80%, miss = 20%

Example: Direct-mapped caches with 8 sets

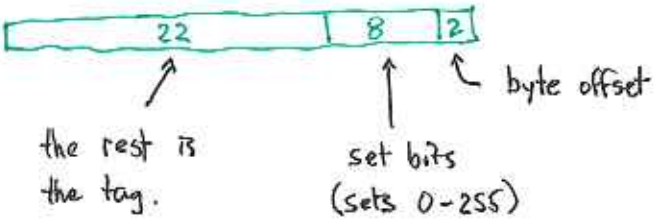


Address breakdown:



Set-bit conflicts - problems with direct-mapped caches

Say, for example, we have a direct-mapped cache with 256 sets.



And suppose we have two C functions

foo() → at address 0x0040_3540

bar() → at address 0x0041_3540

foo → 0x0040_3540 | 0000_0000_0100_0000_0011_01 | 01_0100_00 | 00

tag = 0x00100d | set = 80_{10}

bar → 0x0041_3540 tag = 0x00104d set = 80_{10}

C-code:

```
for (i=0; i<n; i++) {
    x = foo();
    bar(x);
}
```

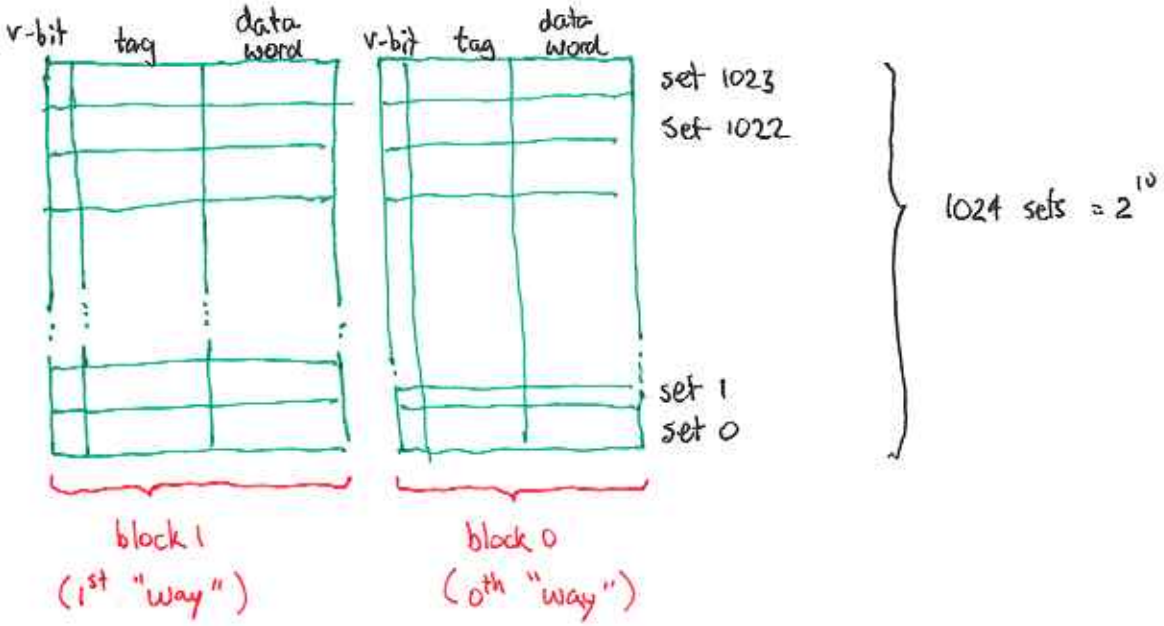
Both procedures have the same 8-bit set no. (80)

- calls to foo() and bar() cause caches misses every time
- this is a cache conflict called a set-bit conflict.
- happens in I-caches as well as D-caches.

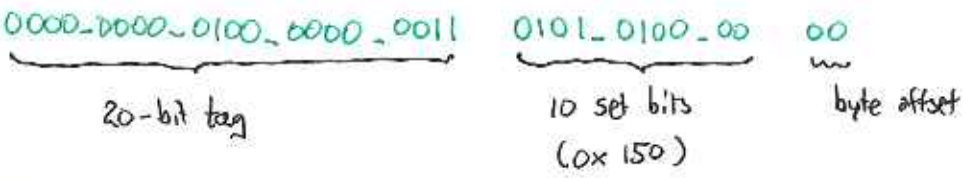
Solution — set-associative caches

Definition: An N-way set-associative cache is where a word with a given address can be in any one of N places in a single set of the cache.

Layout of a 2-way set-associative cache (10 set bits)



Address breakdown is the same as our previous example; e.g., 0x0040_3540



Set-associative caches allow addresses with the same set bits but different tags to coexist in the same set.

- E.g., for a cache lookup on set 0x150, both entries are checked simultaneously for a hit.
- A hit is when exactly one entry found with v = 1 and matching tag.

Multiple matches cannot occur.

- hardware prevents same memory word from being cached in more than one place.

Notes:
- foo() and bar() can be in the cache at the same time.
- fewer misses than a direct-mapped cache
- some set-associative caches can be multi-word. (some Intel processors have 8-way set-associative, 64 bytes per block, 8 64-bit words)

Fully associative caches

A special cache in which there is:

- just one set (a really wide one)
- contains N ways