CSCI 210: Computer Architecture
Lecture 34: Caches II

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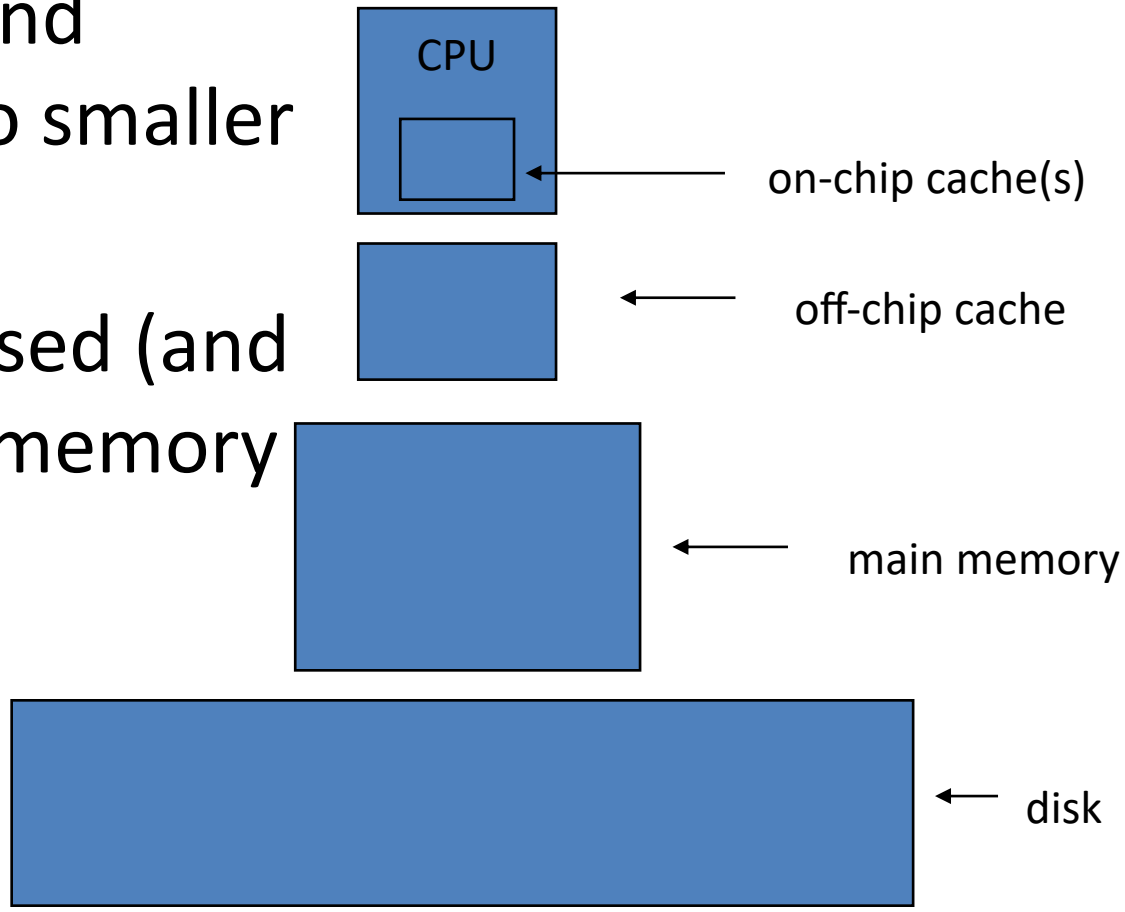
Announcements

- Problem set 11 due Friday
- Problem set 12 will be due a week from Thursday (the last day of instruction this semester)
- Office hours Tuesday 13:30–14:30

Taking Advantage of Locality

- Store everything on disk
- Copy recently accessed (and nearby) items from disk to smaller main memory
- Copy more recently accessed (and nearby) items from main memory to cache

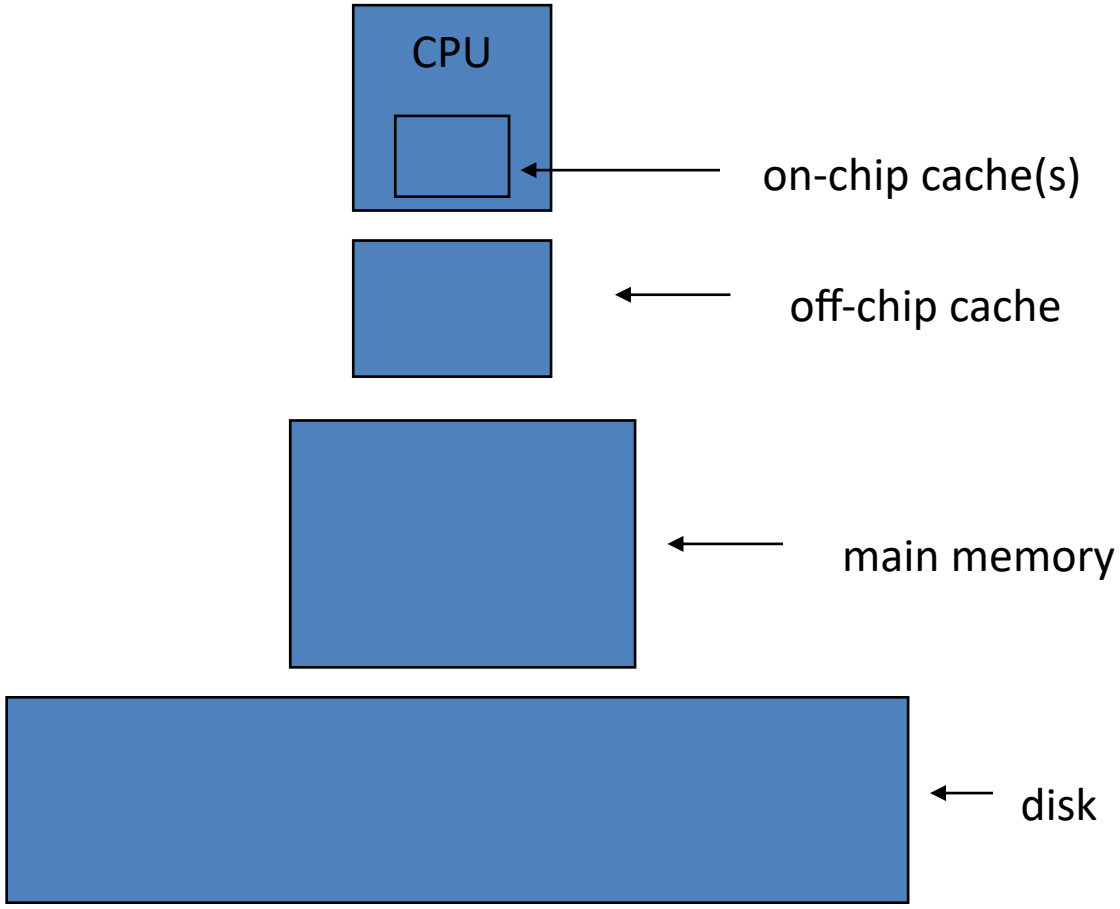


We know SRAM is very fast, expensive ($/GB), and small. We also know disks are slow, inexpensive ($/GB), and large. Which statement best describes the role of cache when it works.

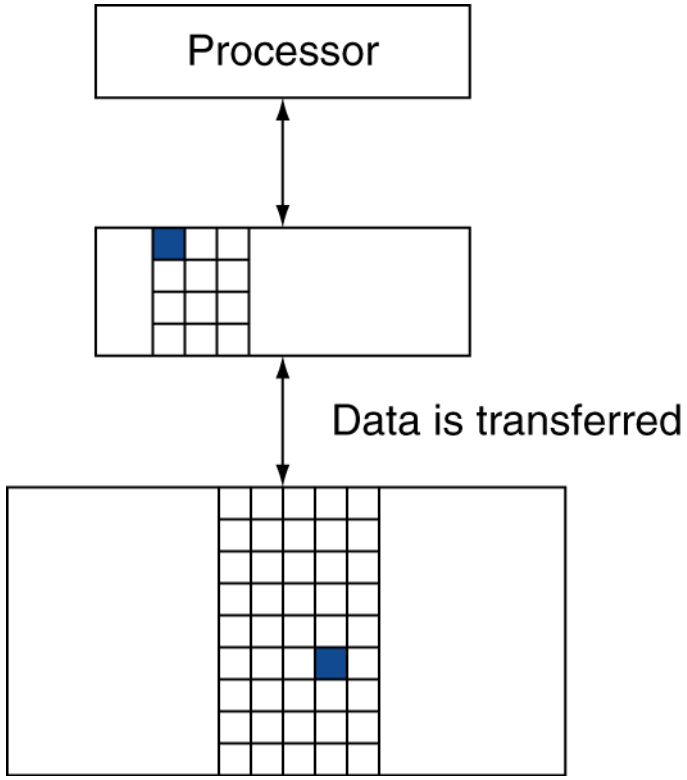
Selection	Role of caching
A	Locality allows us to keep frequently touched data in SRAM.
B	Locality allows us the illusion of memory as fast as SRAM but as large as a disk.
C	SRAM is too expensive to make large – so it must be small and caching helps use it well.
D	Disks are too slow – we have to have something faster for our processor to access.
E	None of these accurately describes the role of cache.

Memory Access

- Use main memory addresses
- When looking for data, check
  - 1. cache
  - 2. main memory
  - 3. disk



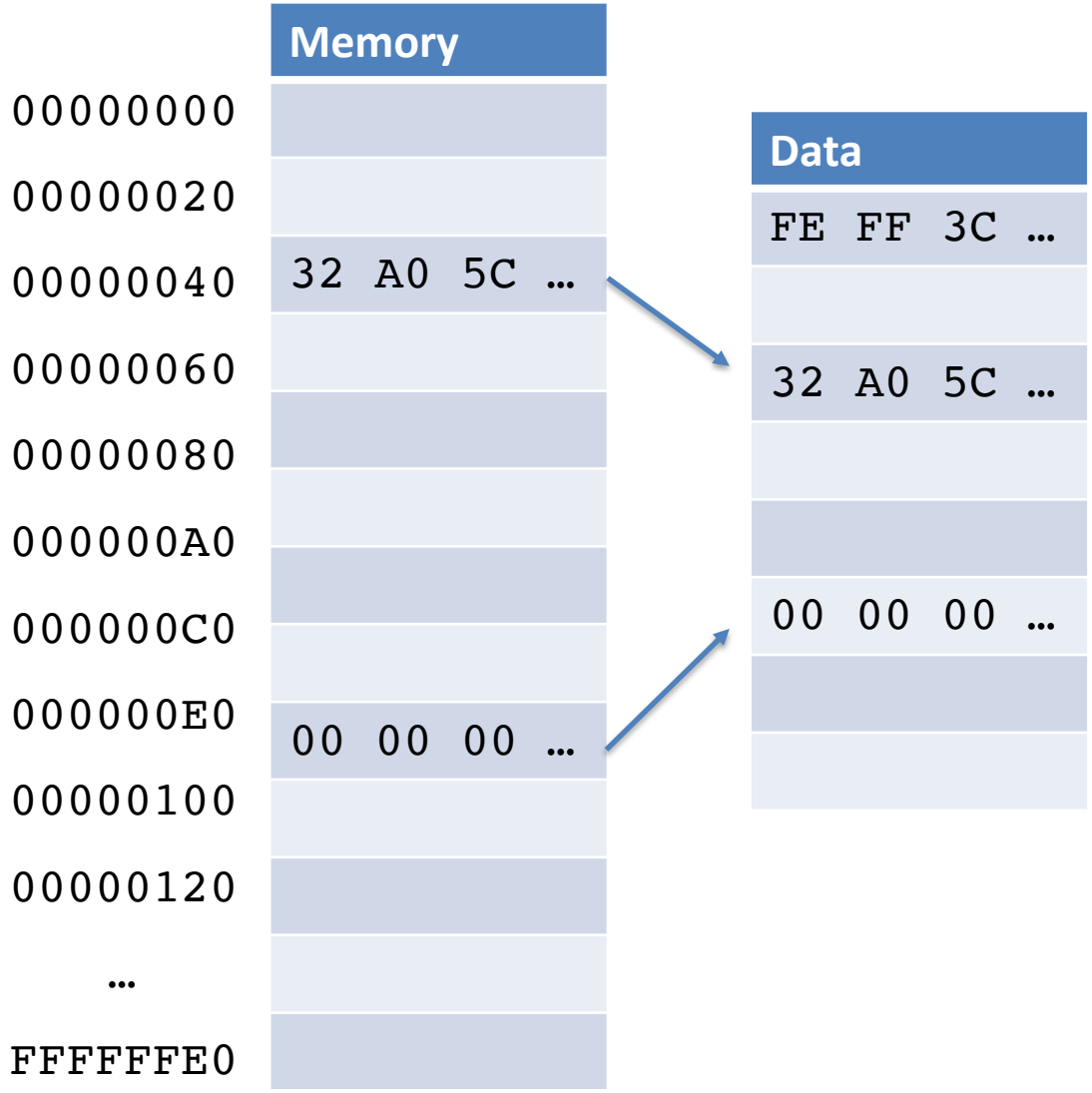
Memory Hierarchy Terms



- Block: unit of copying
  - May be multiple words
  - On x86-64, a block is 64 bytes
- Cache Hit: data in the cache
  - Hit ratio: hits/accesses
- Cache Miss: data not in the cache
  - Time taken: miss penalty
  - Miss ratio: misses/accesses
    = 1 – hit ratio

High-level cache strategy

- Divide all of memory into consecutive blocks
- Copy data (memory ↔ cache) one block (e.g., 64 bytes) at a time
- To access data, check if it exists in the cache before checking memory



Memory addresses, block addresses, offsets

- Imagine we have blocks of size 32 bytes (not bits!)
- Every byte of memory can be specified by giving
  - A (32 – 5)-bit block address (in purple)
  - A 5-bit offset into the block (in green)
- To read a byte of memory
  - find the appropriate 32-byte block in either cache or memory using the block address
  - Use the offset to select the appropriate byte from the block

With a block size of 64 bytes, how many bits is the block address? How many bits is the offset? (Assume 32-bit addresses.)

A. Block address size is 32 – 4 = 28 bits; offset size is 4 bits
B. Block address size is 32 – 5 = 27 bits; offset size is 5 bits
C. Block address size is 32 – 6 = 26 bits; offset size is 6 bits
D. Block address size is 32 – 5 = 27 bits; offset size is 4 bits
E. Block address size is 32 – 5 = 27 bits; offset size is 6 bits

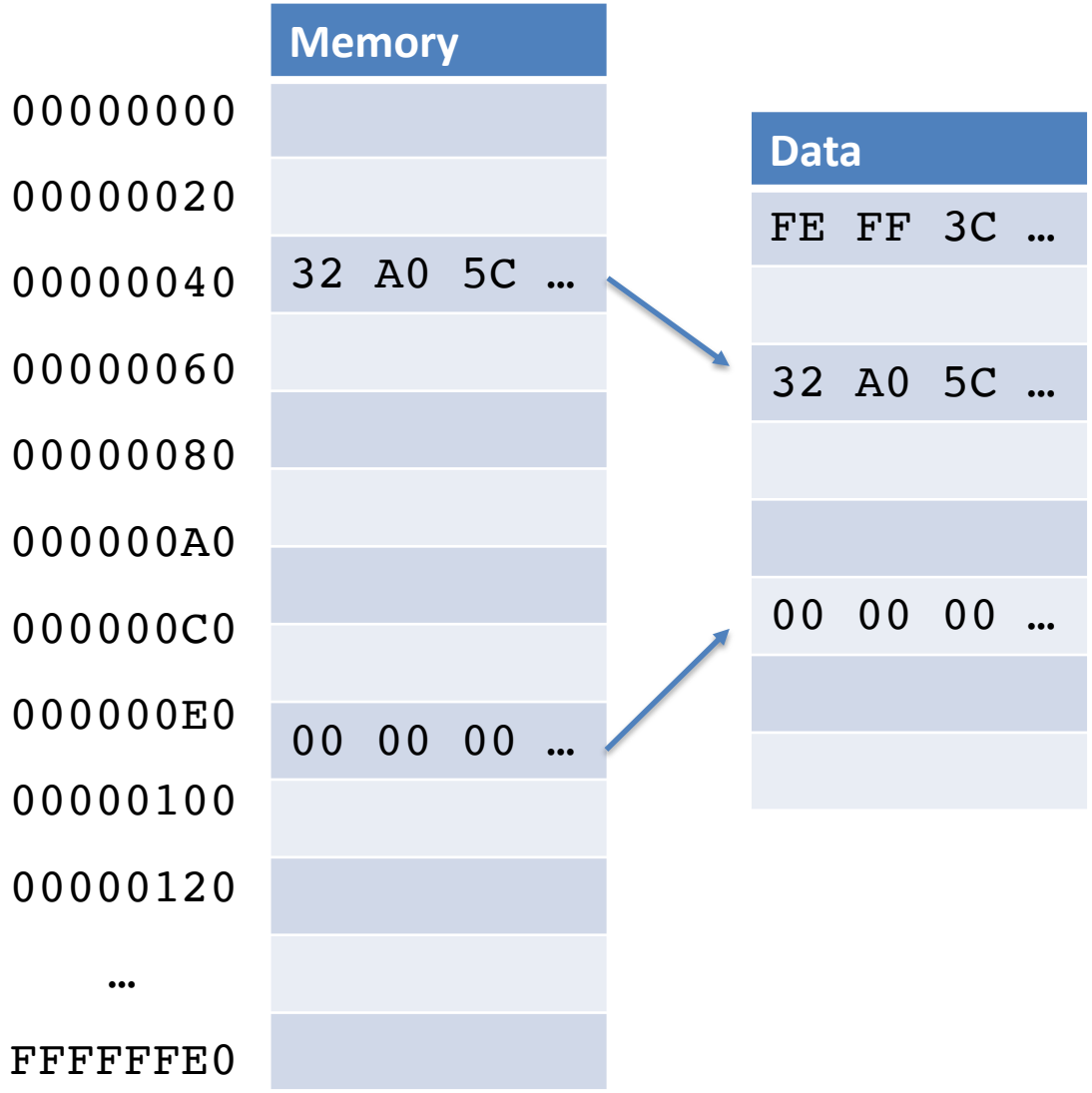
Number of offset bits

- Block sizes are powers of 2

- For a block size of 2^m bytes, the number of offset bits is *m*
  - 16-byte block size: 4 offset bits
  - 32-byte block size: 5 offset bits
  - 64-byte block size: 6 offset bits

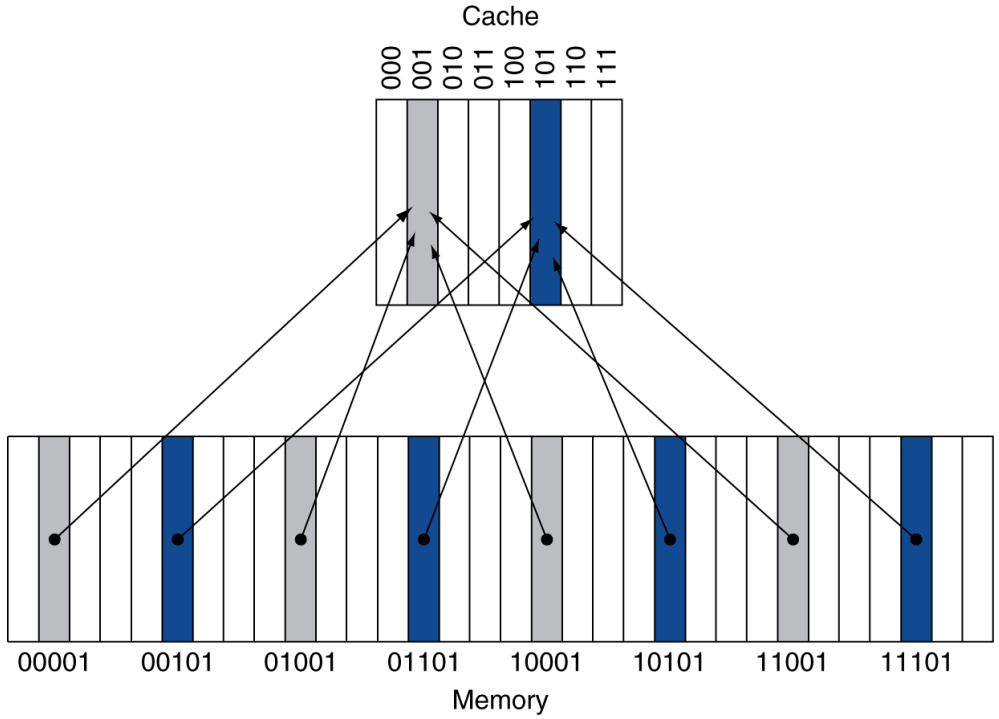
Where is a block of memory stored in cache?

- Given a memory address, we can divide it into a block address and an offset
- Where in cache is the block stored?
- Basic problem: Cache is smaller than main memory



Direct-mapped cache

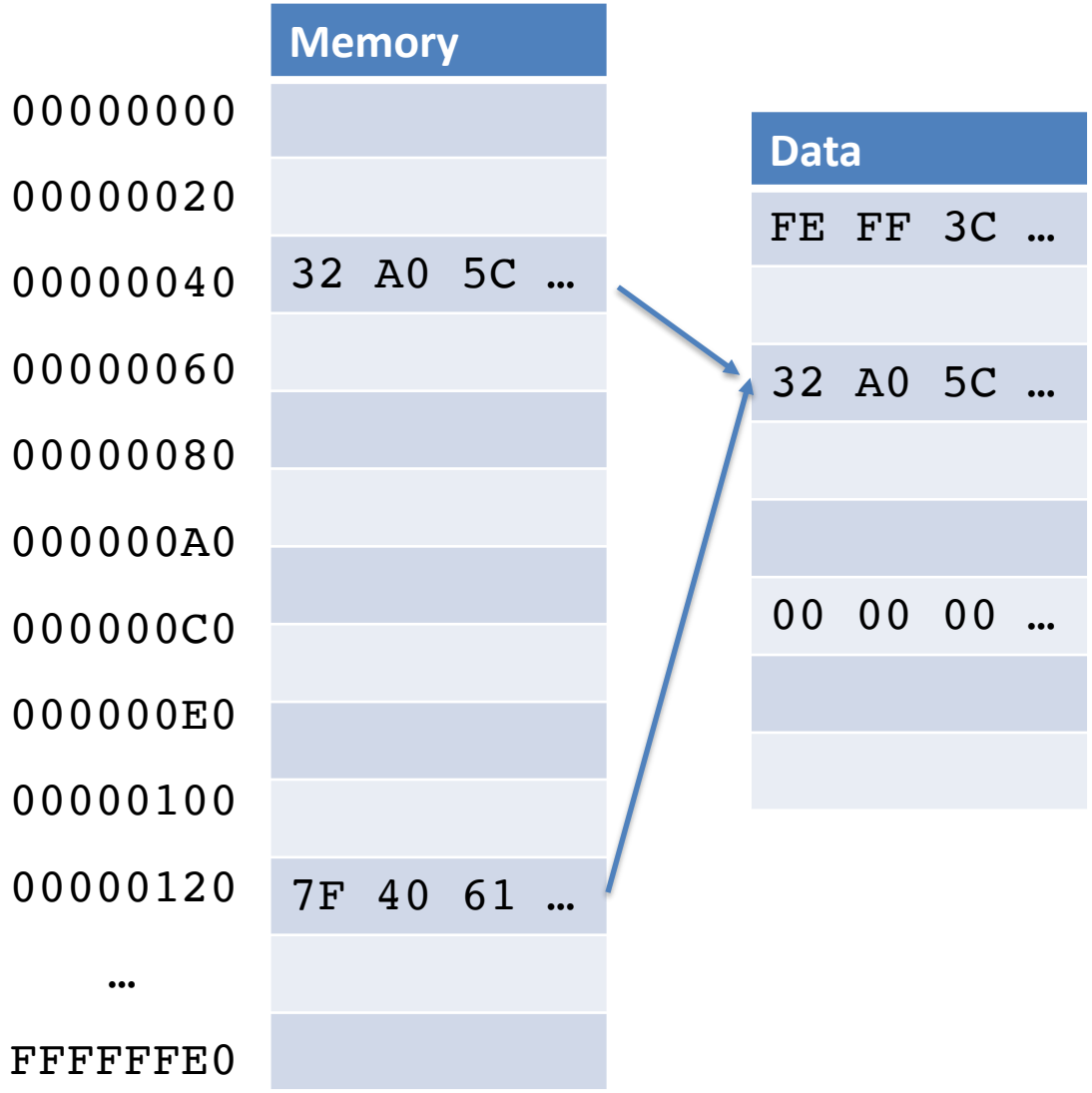
- Block location in cache determined by block address
- Direct mapped: only one possible location for a given block address
  - Index = (Block address) modulo (#Blocks in cache)



- #Blocks is a power of 2
- Direct-mapped cache is essentially an array of blocks
- Use low-order address bits of **block address** to index it

Problem: Collisions

- Many block addresses map to the same cache location
- How do we know which particular block is stored in a cache location?
  - Store block address as well as the data
  - Actually, only need the high-order bits
  - Called the **tag**



Memory addresses, block addresses, offsets

- Block size of 32 bytes (not bits!)
- 8-block cache (this is purely an example!)
- Each address
  - A (32 – 5)-bit block address (in purple and blue)
  - A 5-bit offset into the block (in green)
- Block address can be divided into
  - A (32 – 3 – 5)-bit **tag** (purple)
  - A 3-bit cache **index** (blue)

If we have a block size of 64-bytes and our cache holds 256 entries how large are the tag, index, and offset?

	Tag size (bits)	Index size (bits)	Offset size (bits)
A	32 – 3 – 8	3	8
B	32 – 3 – 6	3	6
C	32 – 6 – 8	6	8
D	32 – 8 – 6	8	6
E	32 – 8 – 8	8	8

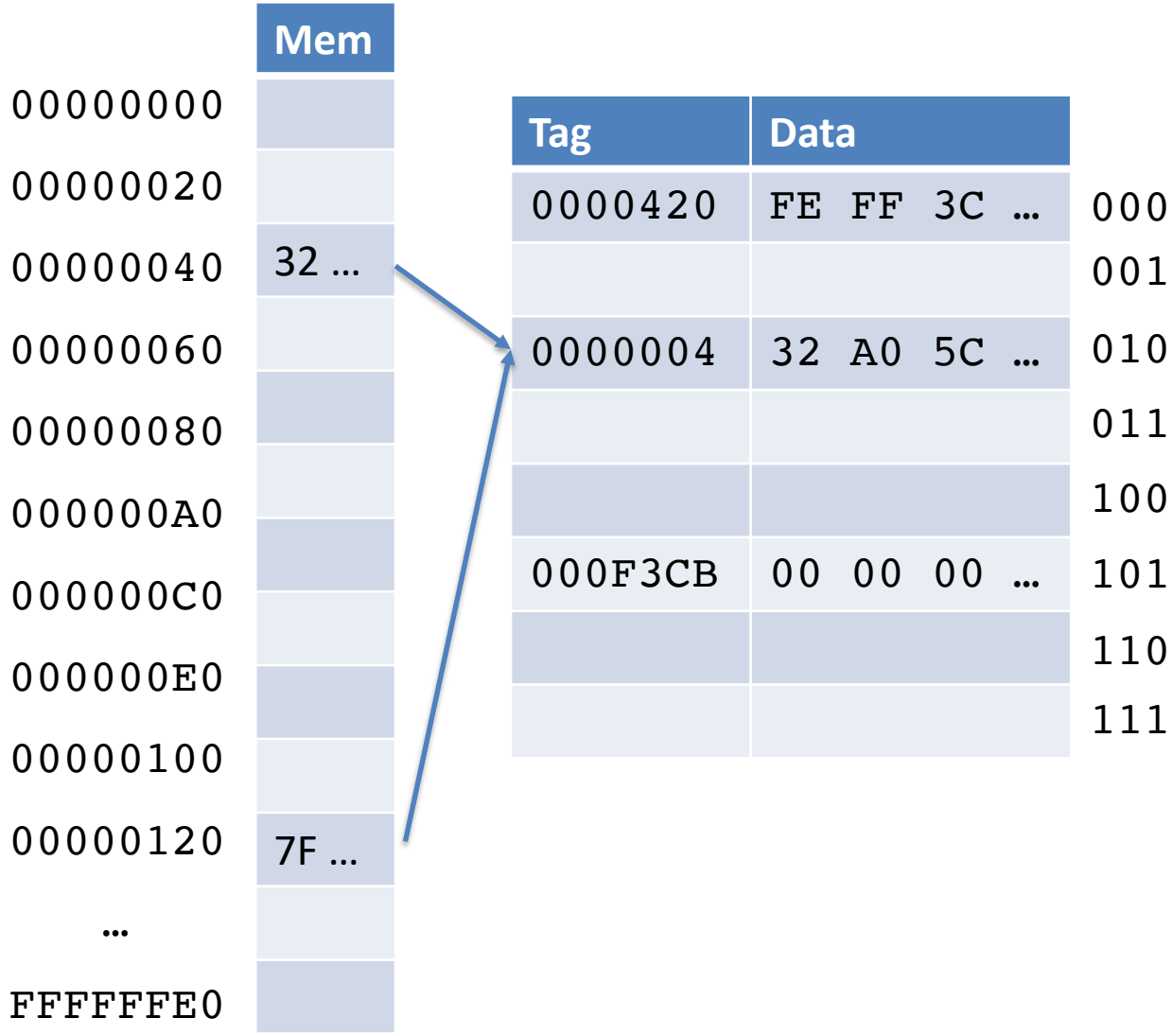
Cache layout (so far)

- Tag stores high-order bits of address
- Data stores all of the data for the block (e.g., 32 bytes)

Tag	Data
0000420	FE FF 3C 7F …
0012345	32 A0 5C 21 …
000F3CB	00 00 00 00 …

High-level cache strategy

- Divide all of memory into consecutive blocks
- Copy data (memory ↔ cache) one block at a time
- Cache lookup:
  - Get the index of the block in the cache from the address
  - Compare the tag from the address with the tag in the cache



How do we know if it’s in the cache?

- What if there is no data in a location?
  - Valid bit: 1 = present, 0 = not present
  - Initially 0

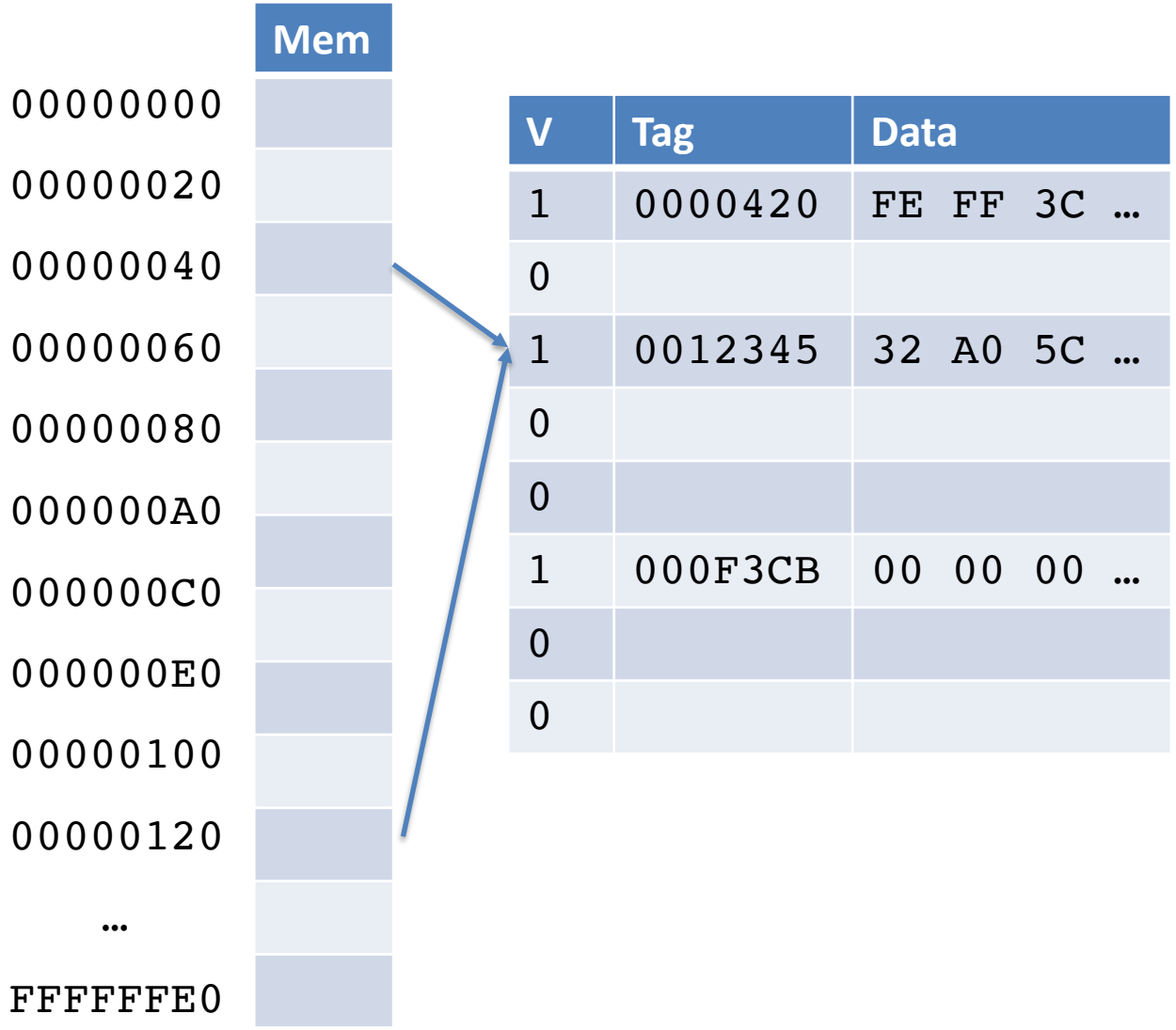
Direct-mapped cache layout

- Valid stores 1 if data is present in cache
- Tag stores high-order bits of address
- Data stores all of the data for the block (e.g., 32 bytes)

Valid	Tag	Data
1	0000420	FE FF 3C 7F …
0		
1	0012345	32 A0 5C 21 …
0		
0		
1	000F3CB	00 00 00 00 …
0		
0		

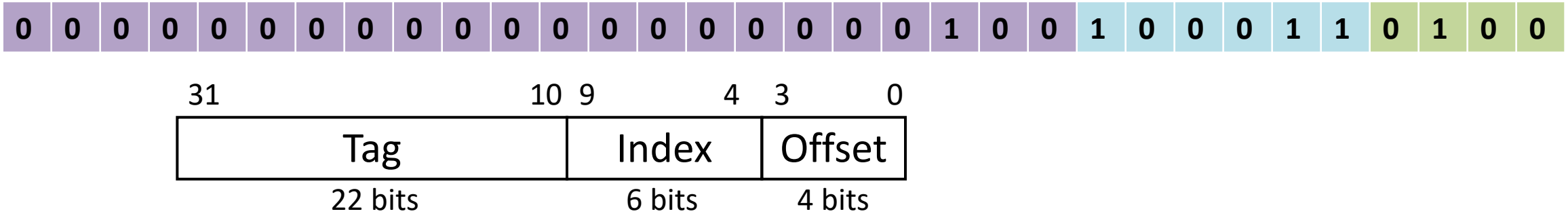
High-level cache strategy

- Divide all of memory into consecutive blocks
- Copy data (memory ↔ cache) one block at a time
- Cache lookup:
  - Get the index of the block in the cache from the address
  - Check the valid bit; compare the tag to the address

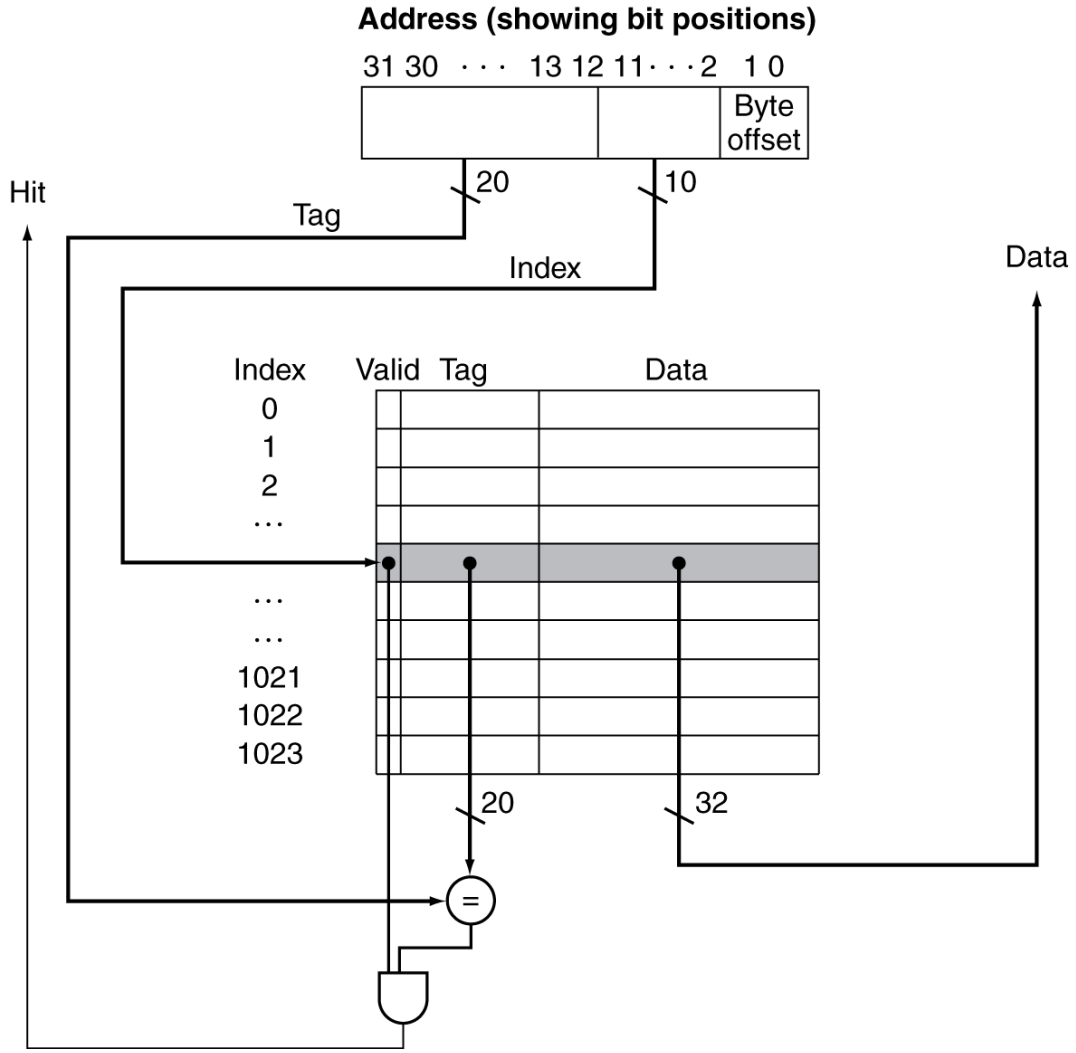


Example

- 64 blocks, 16 bytes/block
  - To what cache index does address 0x1234 map?
- Block address = $\lfloor 0x1234/16 \rfloor$ = 0x123
- Index = 0x123 modulo 64 = 0x23
- No actual math required: just select appropriate bits from address!



Memory access



Direct Mapped Cache

data	byte addresses	A	B	C	D
x	00 00 01 00	M	M	M	M
y	00 00 10 00	M	M	M	H
z	00 00 11 00	M	M	M	M
x	00 00 01 00	H	H	H	H
y	00 00 10 00	H	H	H	H
w	00 01 01 00	M	M	M	M
x	00 00 01 00	M	M	H	H
y	00 00 10 00	H	H	H	H
w	00 01 01 00	H	M	H	H
u	00 01 10 00	M	M	M	M
z	00 00 11 00	H	H	M	H
y	00 00 10 00	H	M	H	H
x	00 00 01 00	H	M	M	M

E None are correct

Four blocks, each block holds four bytes

How do we know how big a block in cache is?

A. Each block in the cache stores its size
B. The length of the tag in the cache determines the block size
C. The most significant bits of the address determine the block size
D. The least significant bits of the address determine the block size
E. For any given cache, the block size is constant

Reading

- Next lecture: More Caches!
  - Section 6.4

- Problem Set 11 due Friday