# CSCI 210: Computer Architecture
# Lecture 34: Caches II

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Jan. 5, 2022

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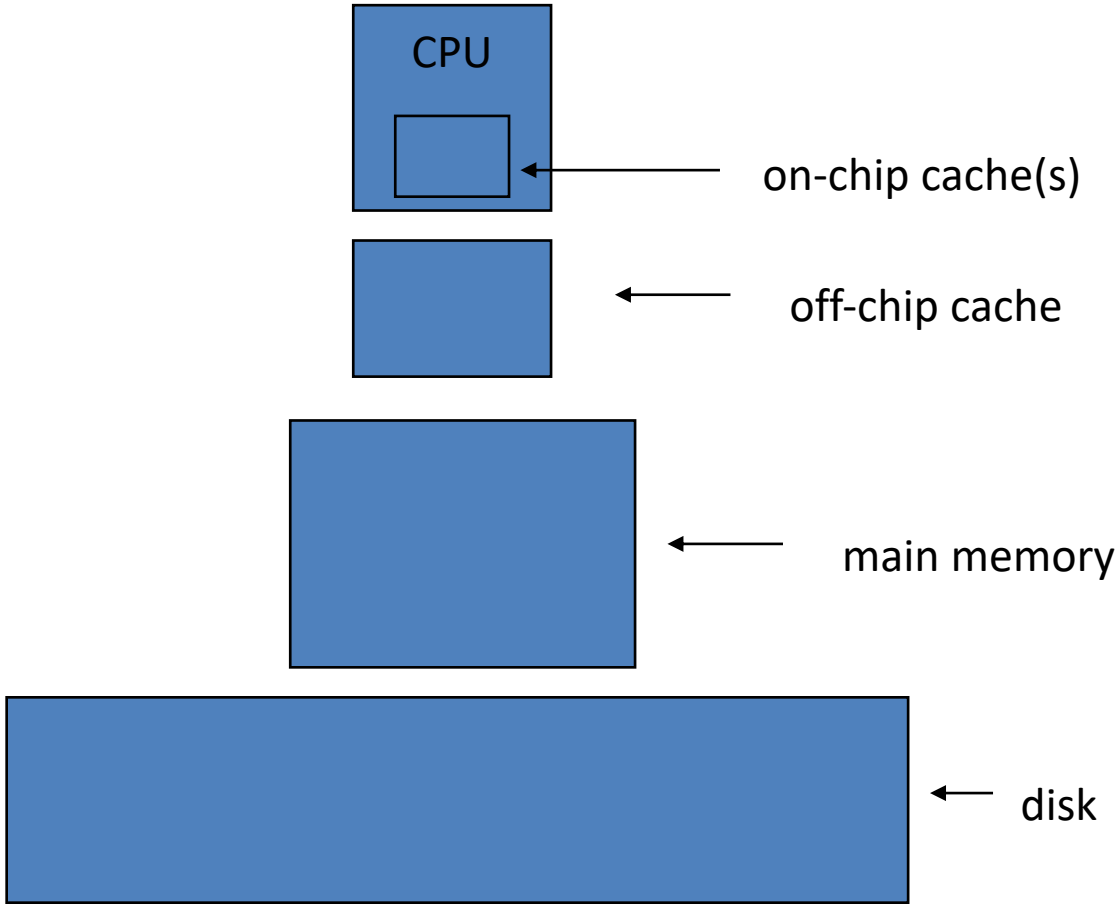
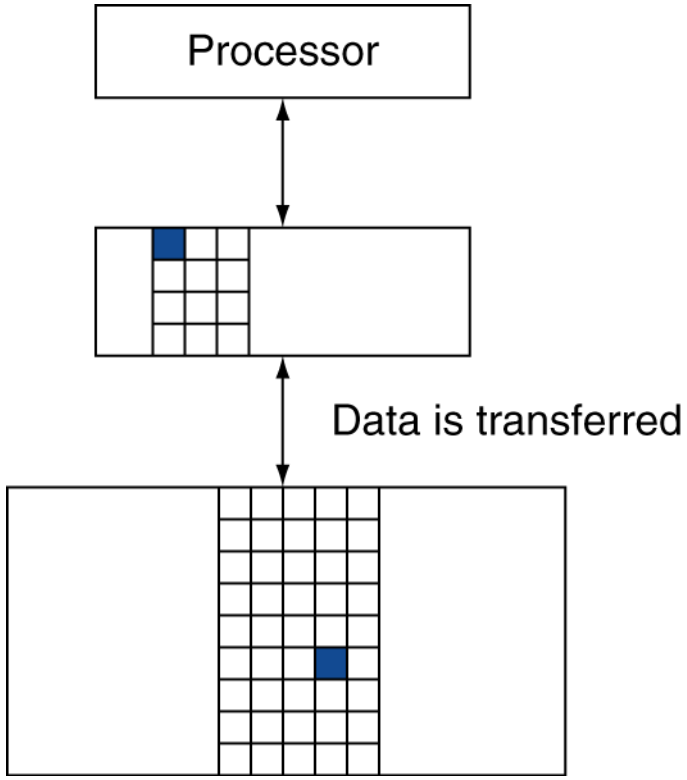
# Memory Access

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



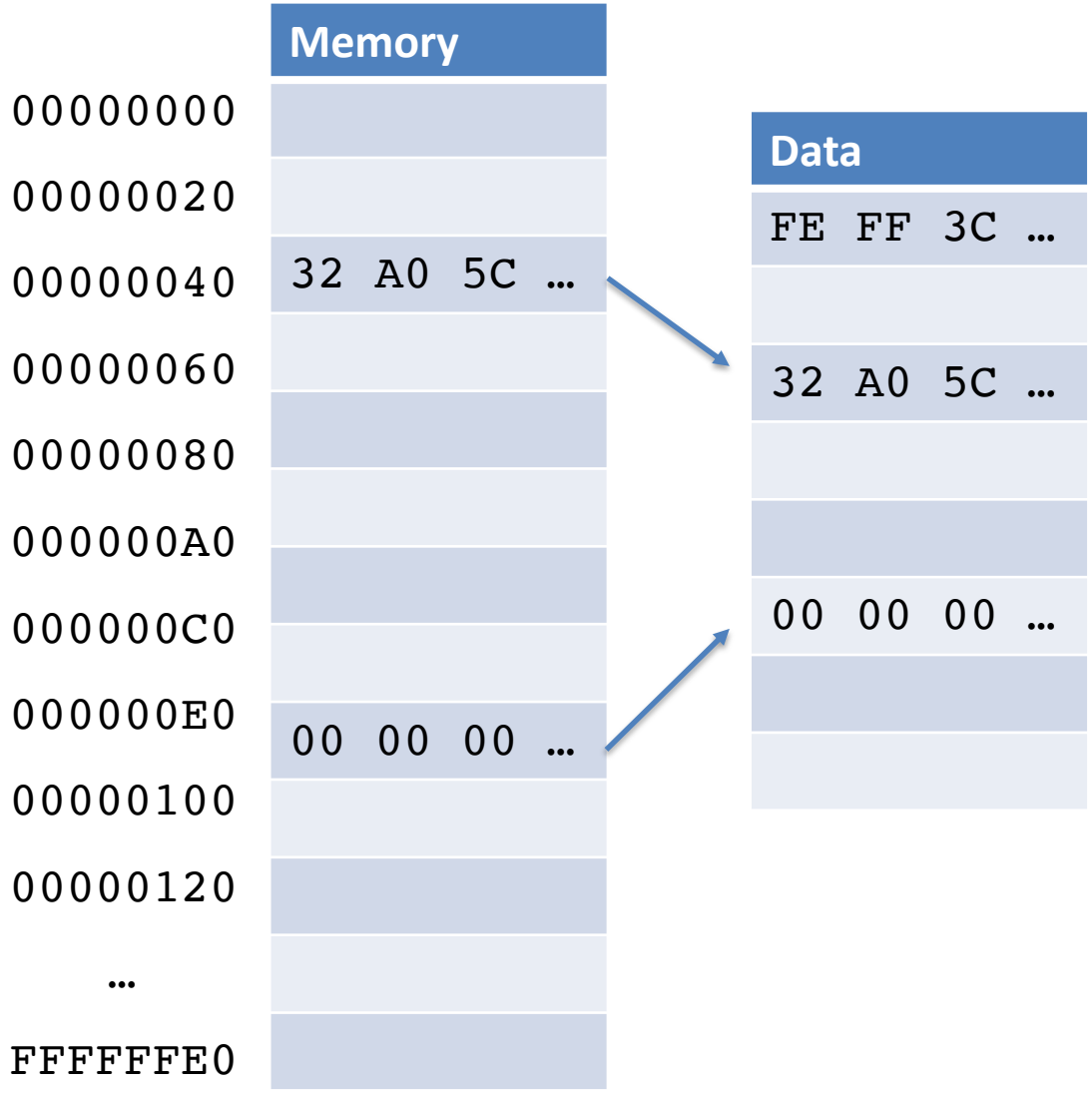
# Memory Hierarchy Terms




- Block: unit of copying
  - May be multiple words
  - On x86-64, a block is 64 bytes
- Hit: data in the cache
  - Hit ratio: hits/accesses
- 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 at a time
- To access data, check if it exists in the cache before checking memory



# Memory addresses, block addresses, offsets

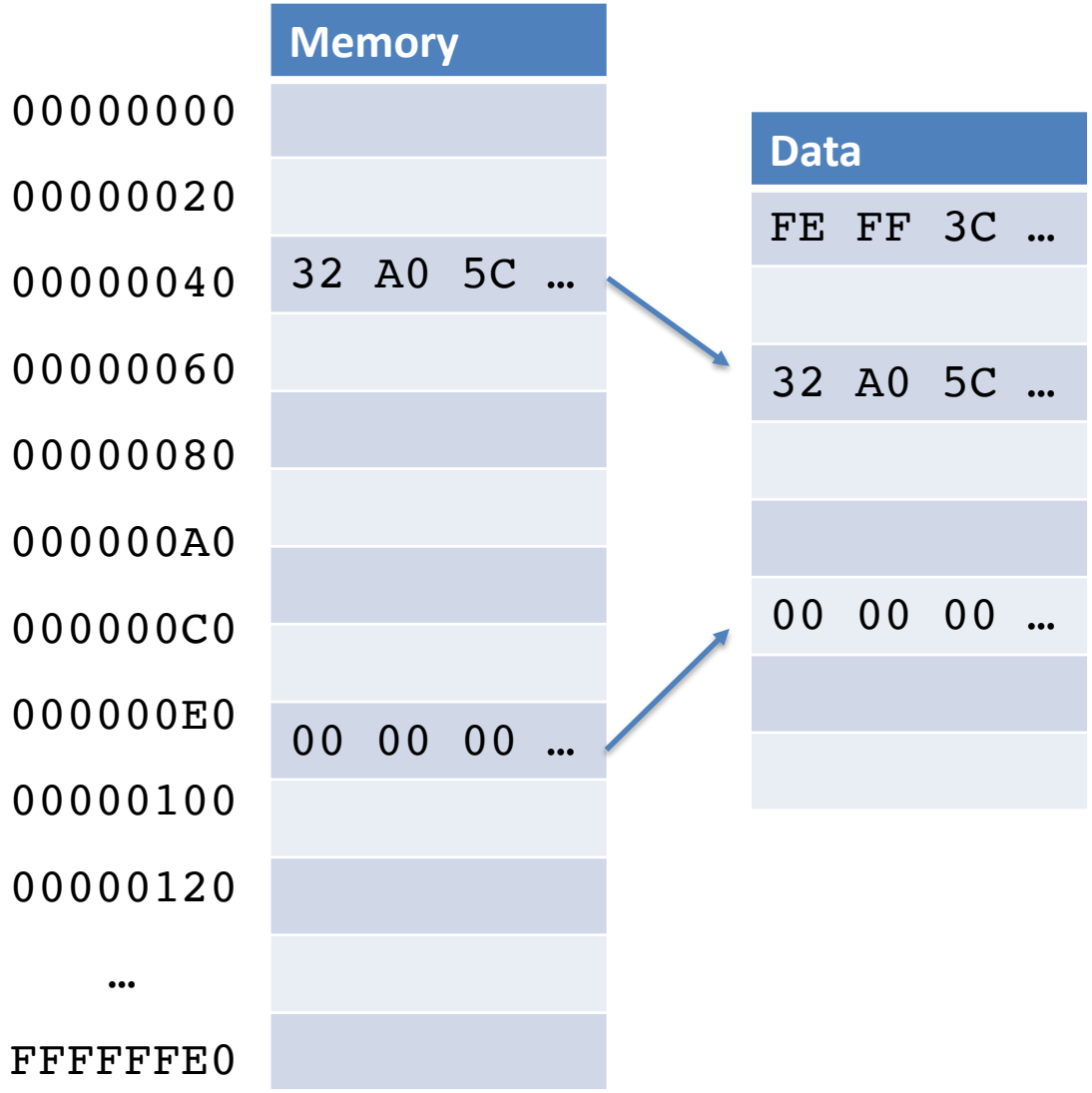

- Imagine we have blocks of size 32 bytes (not bits!)
- Every byte of memory can be specified by giving
  - A (32 – 5)-bit block address (in purple)
  - A 5-bit offset into the block (in green)
- To read a byte of memory
  - find the appropriate 32-byte block in either cache or memory using the block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

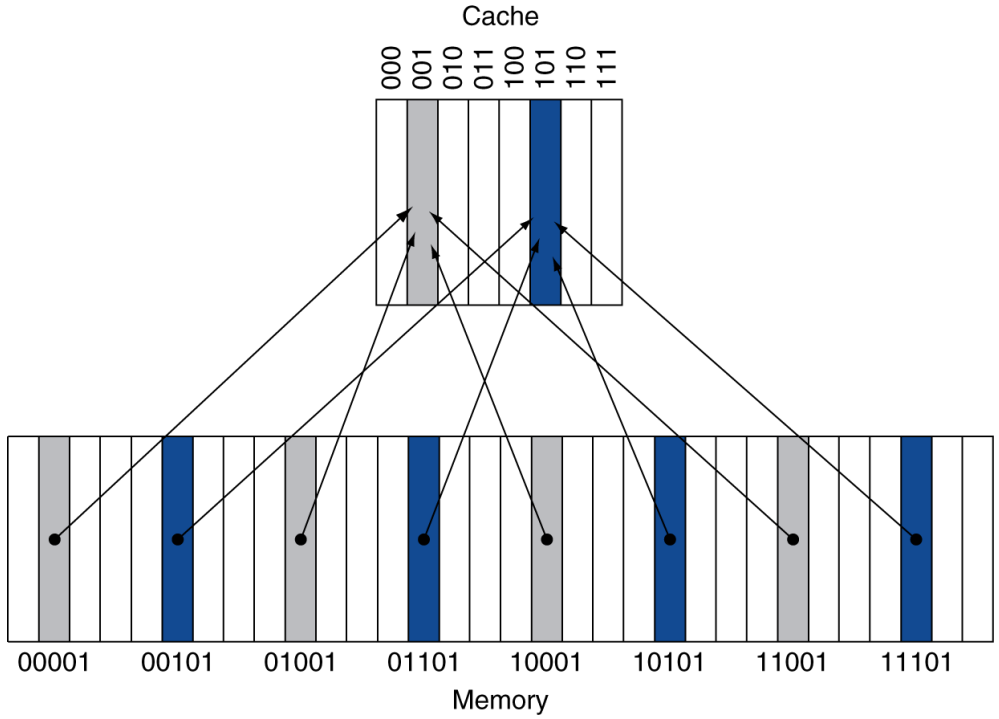
# Where is a block of memory stored in cache?

- 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

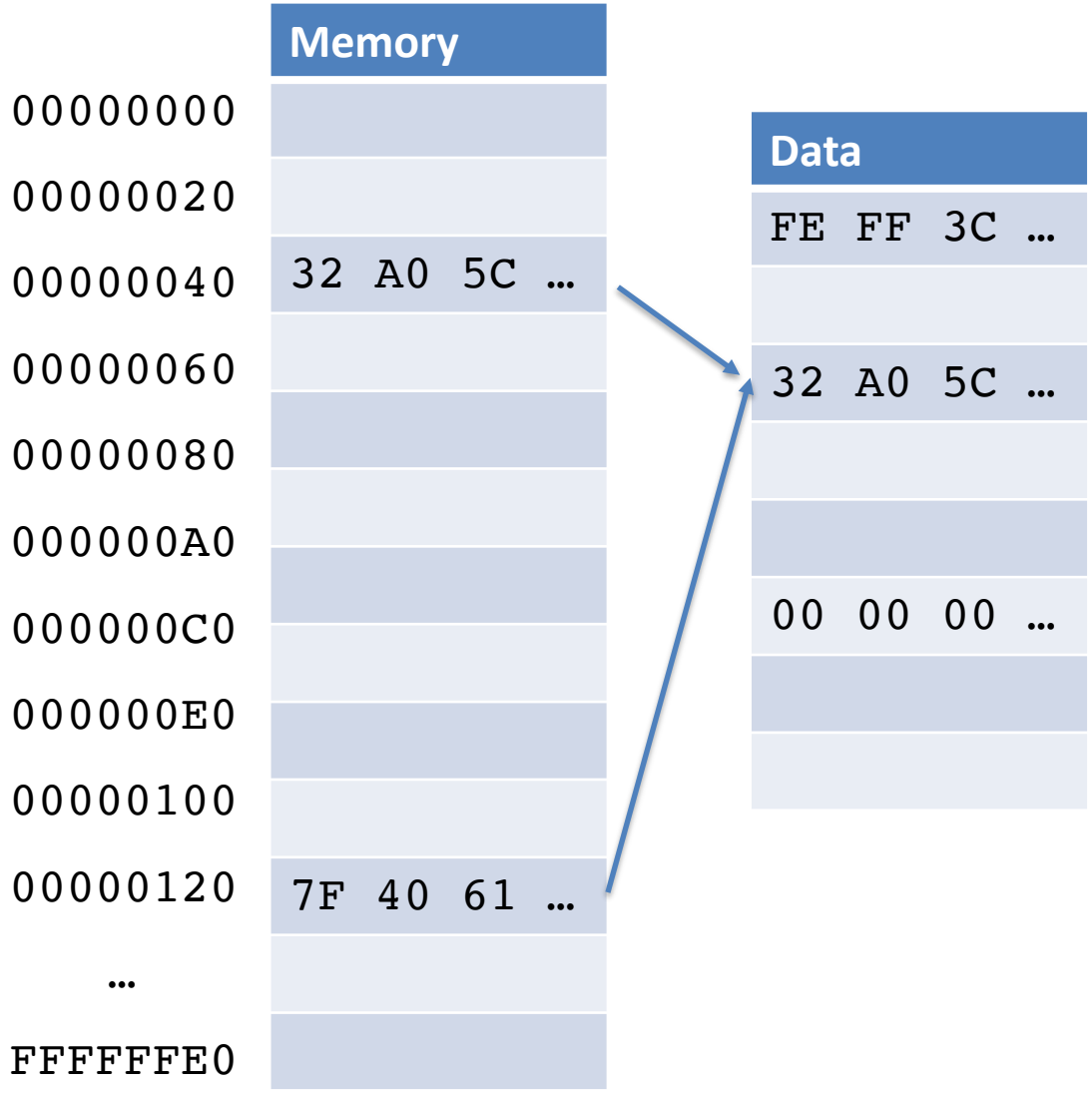
- Block location in cache determined by block address
- Direct mapped: only one possible location
  - (Block address) modulo (#Blocks in cache)




- #Blocks is a power of 2
- Use low-order address bits

# 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 |

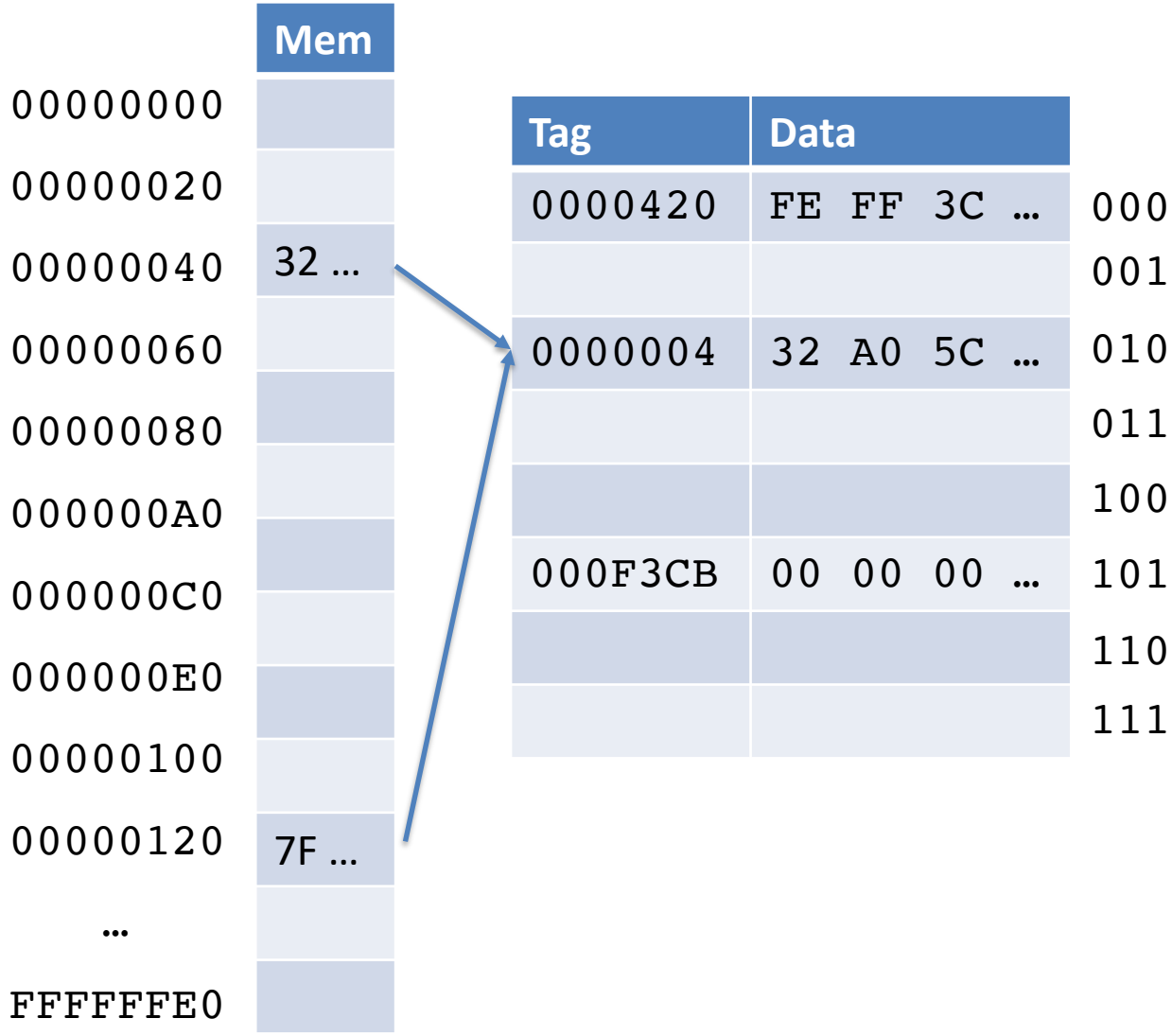
# Cache layout (so far)

- 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

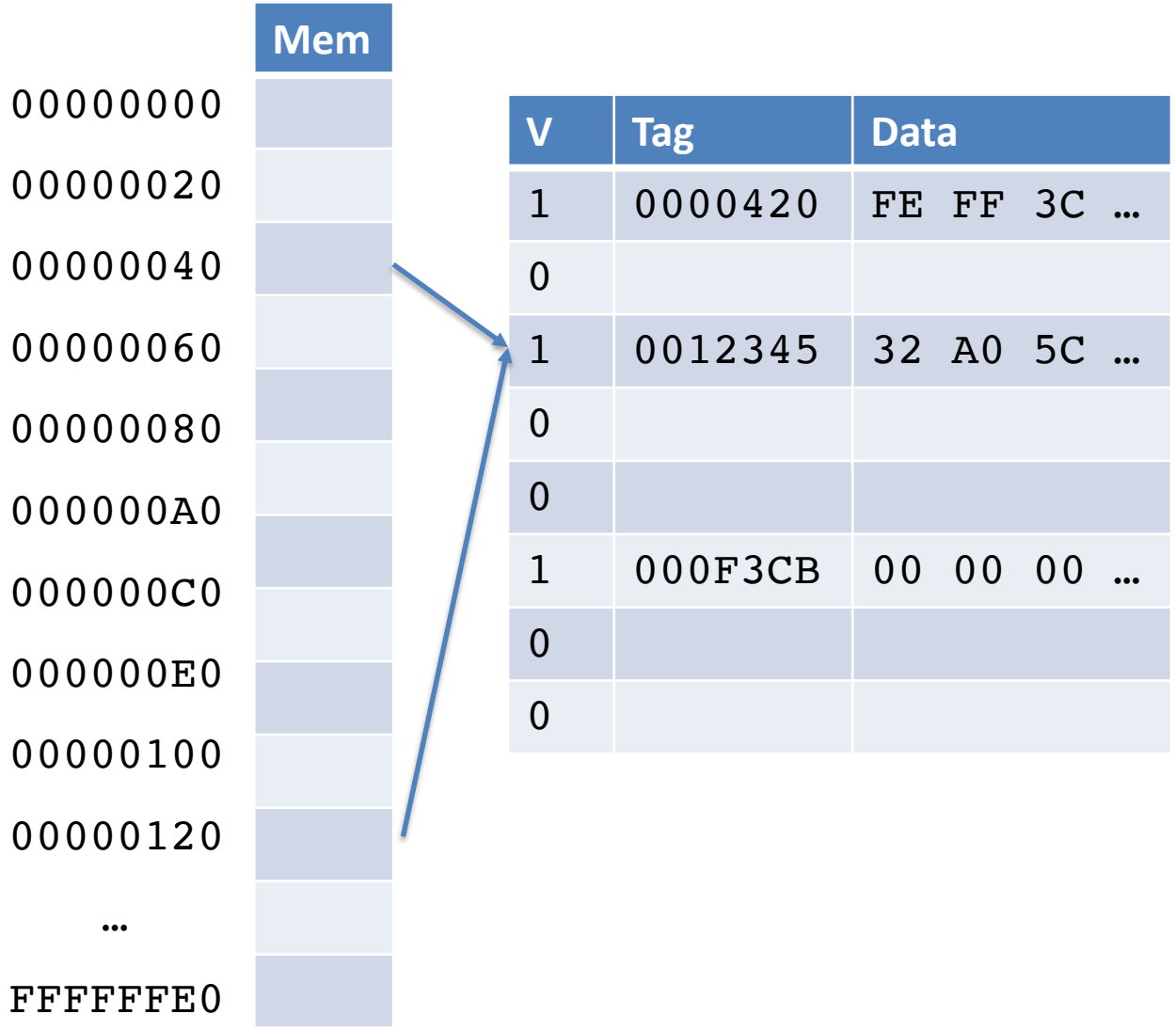
# Direct-mapped cache layout

- 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 | | |

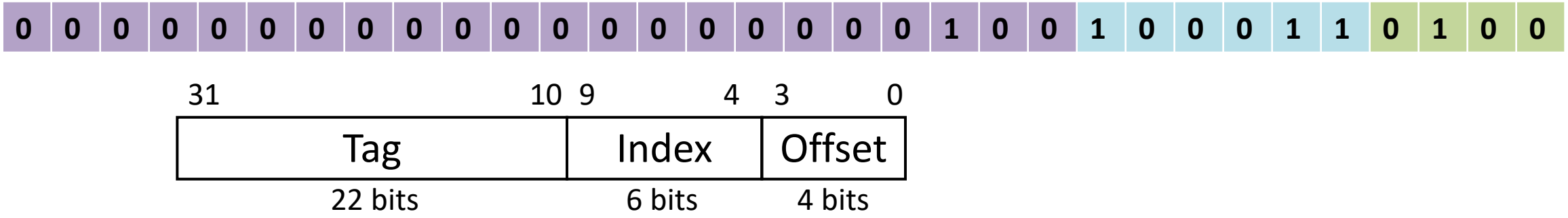
# High-level cache strategy

- 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

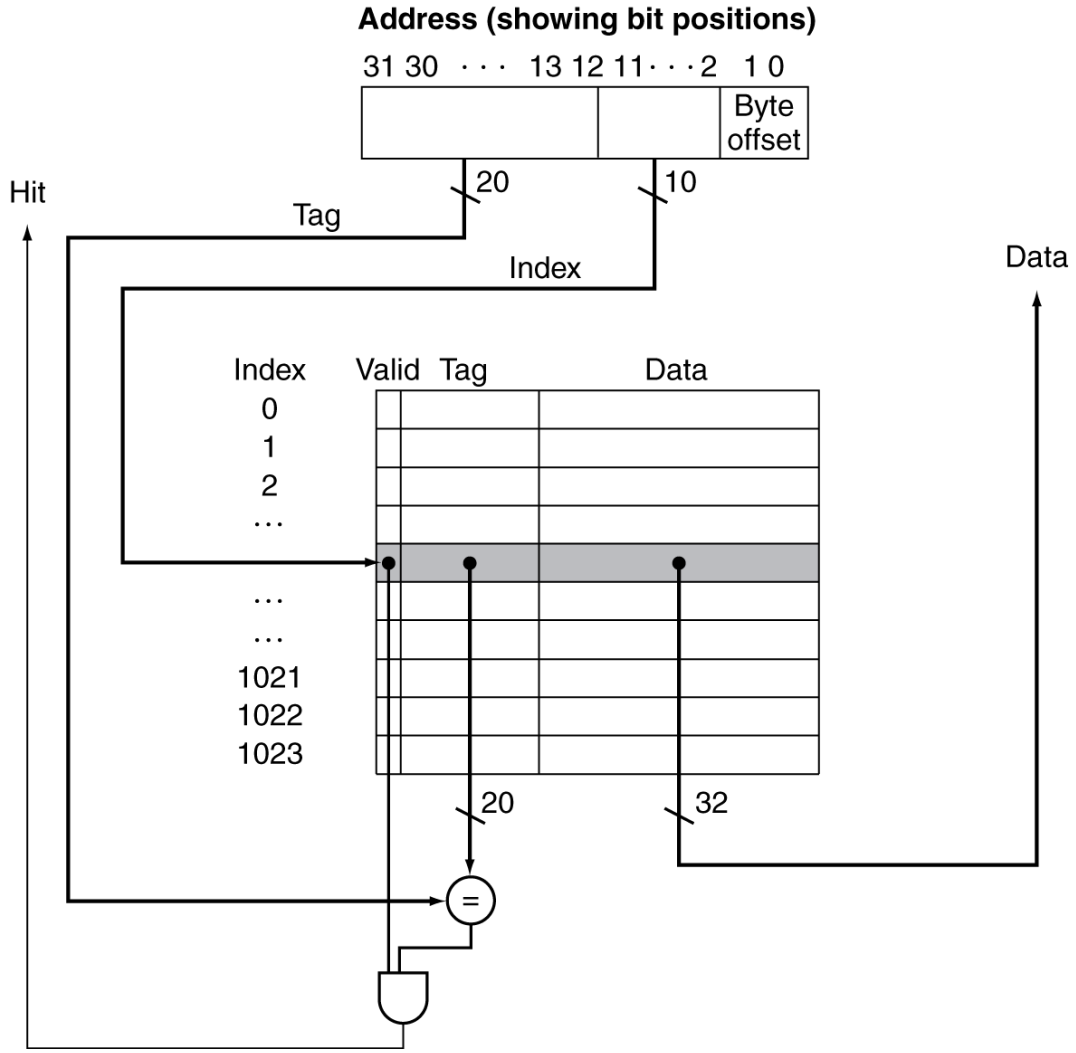


# Example

- 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



# Reading

- Next lecture:  More Caches!
  - Section 6.4

- Problem Set 11 due Friday