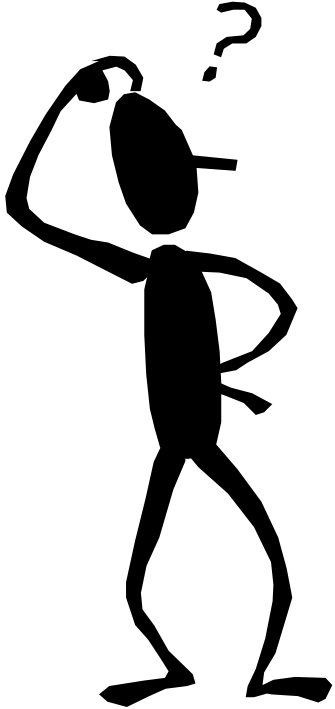


# Four important questions



1. When we copy a block of data from main memory to the cache, where exactly should we put it?
2. How can we tell if a word is already in the cache, or if it has to be fetched from main memory first?
3. Eventually, the small cache memory might fill up. To load a new block from main RAM, we'd have to replace one of the existing blocks in the cache... which one?
4. How can *write* operations be handled by the memory system?

✍ Previous lectures answered the first 3. Today, we consider the 4th.

# Writing to a cache

- ❑ Writing to a cache raises several additional issues.
- ❑ First, let's assume that the address we want to write to is already loaded in the cache. We'll assume a simple direct-mapped cache.

Index	V	Tag	Data	Address	Data
...				...	
110	1	11010	42803	1101 0110	42803
...				...	

- ❑ If we write a new value to that address, we can store the new data in the cache, and avoid an expensive main memory access.

Mem[214] = 21763

↓

Index	V	Tag	Data	Address	Data
...				...	
110	1	11010	21763	1101 0110	42803
...				...	

# Inconsistent memory

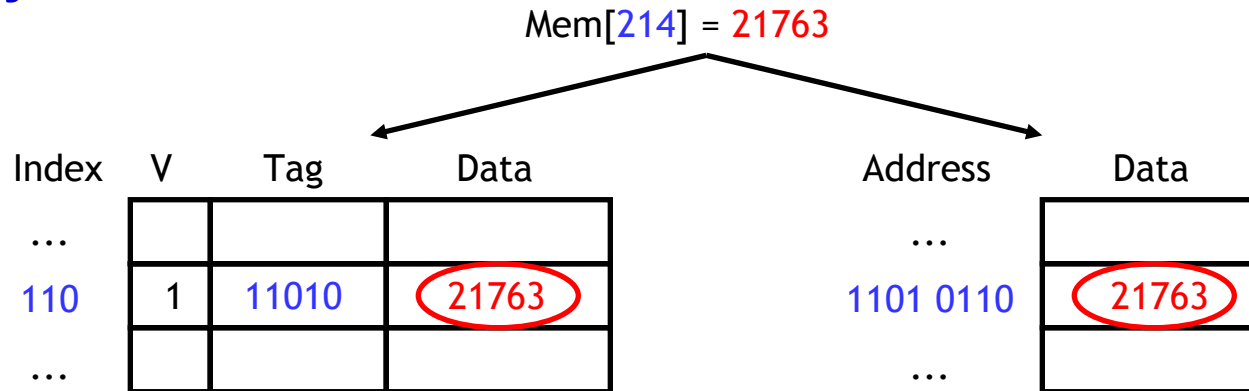
- ❑ But now the cache and memory contain different, inconsistent data!
- ❑ How can we ensure that subsequent loads will return the right value?
- ❑ This is also problematic if other devices are sharing the main memory, as in a multiprocessor system.

Index	V	Tag	Data
...			
110	1	11010	21763
...			

Address	Data
...	
1101 0110	42803
...	

# Write-through caches

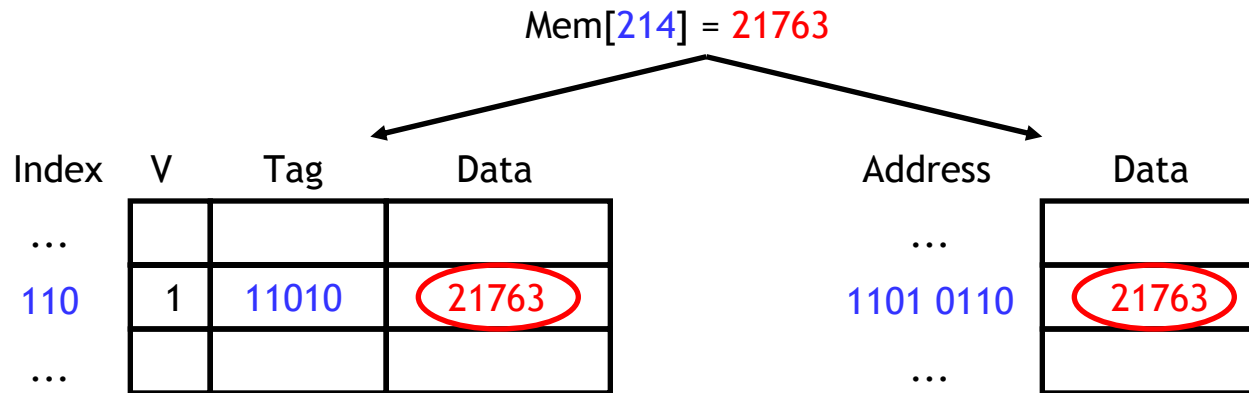
- ❑ A **write-through cache** solves the inconsistency problem by forcing all writes to update both the cache *and* the main memory.



- ❑ This is simple to implement and keeps the cache and memory consistent.
- ❑ Why is this not so good?

# Write-through caches

- ❑ A **write-through cache** solves the inconsistency problem by forcing all writes to update both the cache *and* the main memory.

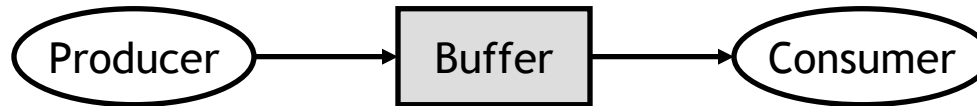


- ❑ This is simple to implement and keeps the cache and memory consistent.
- ❑ The bad thing is that forcing every write to go to main memory, we use up bandwidth between the cache and the memory.

# Write buffers

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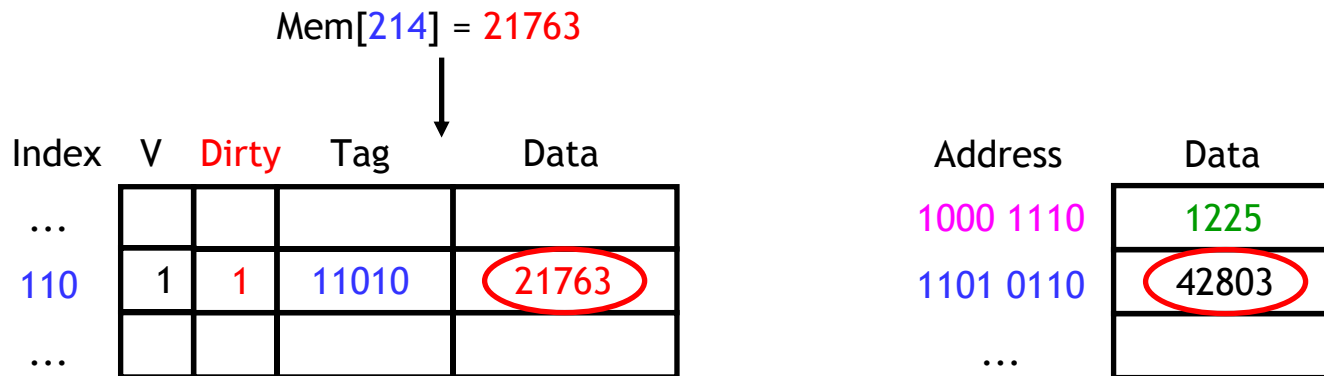
- ❑ Write-through caches can result in slow writes, so processors typically include a **write buffer**, which queues pending writes to main memory and permits the CPU to continue.



- ❑ Buffers are commonly used when two devices run at different speeds.
  - If a **producer** generates data too quickly for a **consumer** to handle, the extra data is stored in a buffer and the producer can continue on with other tasks, without waiting for the consumer.
  - Conversely, if the producer slows down, the consumer can continue running at full speed as long as there is excess data in the buffer.
- ❑ For us, the producer is the CPU and the consumer is the main memory.

# Write-back caches

- ❑ In a **write-back cache**, the memory is not updated until the cache block needs to be replaced (e.g., when loading data into a full cache set).
- ❑ For example, we might write some data to the cache at first, leaving it inconsistent with the main memory as shown before.
  - The cache block is marked “dirty” to indicate this inconsistency



- ❑ Subsequent reads to the same memory address will be serviced by the cache, which contains the correct, updated data.

# Finishing the write back

- ❑ We don't need to store the new value back to main memory unless the cache block gets replaced.
- ❑ For example, on a read from Mem[142], which maps to the same cache block, the modified cache contents will first be written to main memory.

Index	V	Dirty	Tag	Data
...				
110	1	1	11010	21763
...				

Address	Data
1000 1110	1225
1101 0110	21763
...	

- ❑ Only then can the cache block be replaced with data from address 142.

Index	V	Dirty	Tag	Data
...				
110	1	0	10001	1225
...				

Address	Data
1000 1110	1225
1101 0110	21763
...	



# Write-back cache discussion

---

- ❑ **The advantage of write-back caches is that not all write operations need to access main memory, as with write-through caches.**
  - **If a single address is frequently written to, then it doesn't pay to keep writing that data through to main memory.**
  - **If several bytes within the same cache block are modified, they will only force one memory write operation at write-back time.**

# Write-back cache discussion

---

- ❑ Each block in a write-back cache needs a **dirty bit** to indicate whether or not it must be saved to main memory before being replaced—otherwise we might perform unnecessary writebacks.
- ❑ Notice the penalty for the main memory access will not be applied until the execution of some *subsequent* instruction following the write.
  - In our example, the write to Mem[214] affected only the cache.
  - But the load from Mem[142] resulted in *two* memory accesses: one to save data to address 214, and one to load data from address 142.
    - The write can be “buffered” as was shown in write-through.
- ❑ The advantage of write-back caches is that not all write operations need to access main memory, as with write-through caches.
  - If a single address is frequently written to, then it doesn't pay to keep writing that data through to main memory.
  - If several bytes within the same cache block are modified, they will only force one memory write operation at write-back time.

# Write misses

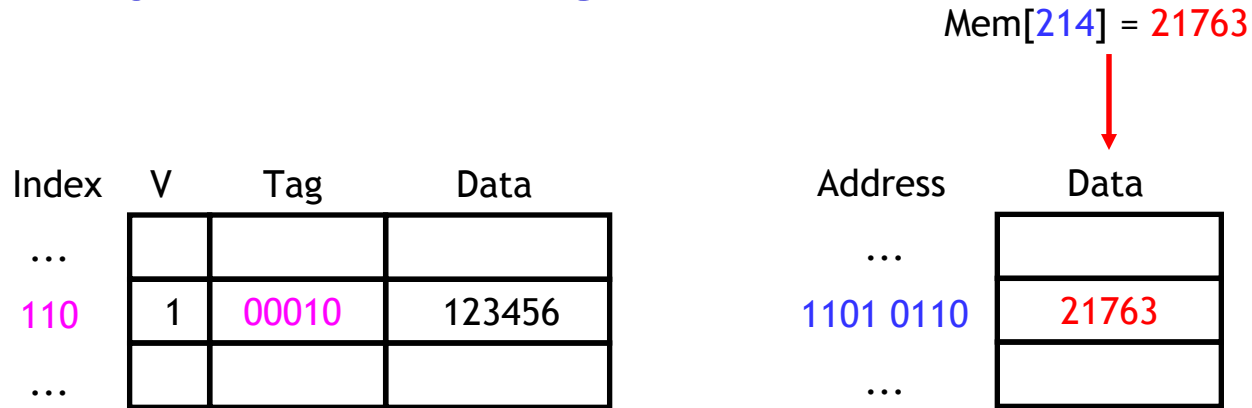
- ❑ A second scenario is if we try to write to an address that is not already contained in the cache; this is called a **write miss**.
- ❑ Let's say we want to store **21763** into Mem[**11010 110**] but we find that address is not currently in the cache.

Index	V	Tag	Data	Address	Data
...				...	
110	1	00010	123456	1101 0110	6378
...				...	

- ❑ When we update Mem[**11010 110**], should we also **load** it into the cache?

# Write around caches (a.k.a. write-no-allocate)

- With a **write around** policy, the write operation goes directly to main memory *without* affecting the cache.

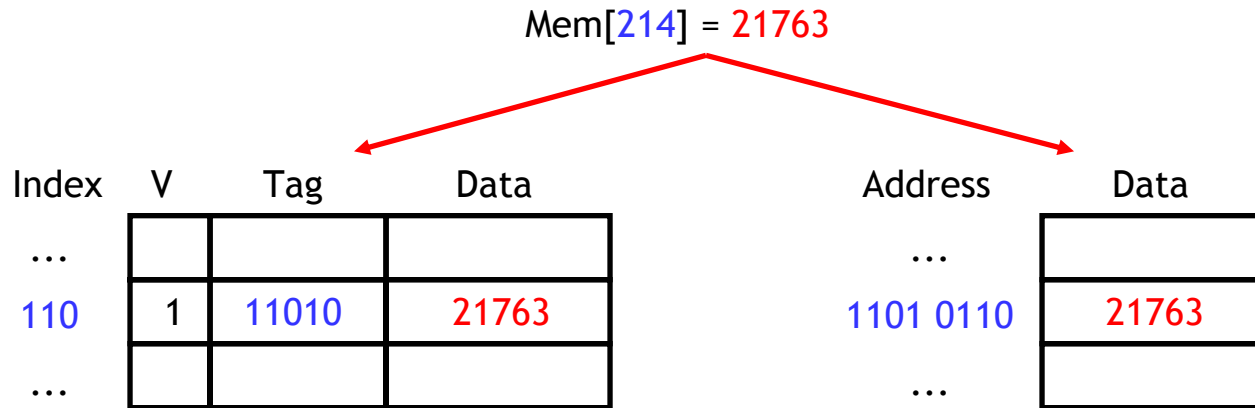


- This is good when data is written but not immediately used again, in which case there's no point to load it into the cache yet.

```
for (int i = 0; i < SIZE; i++)  
    a[i] = i;
```

# Allocate on write

- An **allocate on write** strategy would instead load the newly written data into the cache.



- If that data is needed again soon, it will be available in the cache.

# Which is it?

---

- Given the following trace of accesses, can you determine whether the cache is **write-allocate** or **write-no-allocate**?
  - Assume A and B are distinct, and can be in the cache simultaneously.

Miss Load A

Miss Store B

Hit Store A

Hit Load A

Miss Load B

Hit Load B

Hit Load A

# Which is it?

---

- Given the following trace of accesses, can you determine whether the cache is **write-allocate** or **write-no-allocate**?
  - Assume A and B are distinct, and can be in the cache simultaneously.

Miss Load A

Miss Store B

Hit Store A

Hit Load A

Miss Load B

Hit Load B

Hit Load A

Answer: Write-no-allocate

On a write-allocate cache this would be a hit

