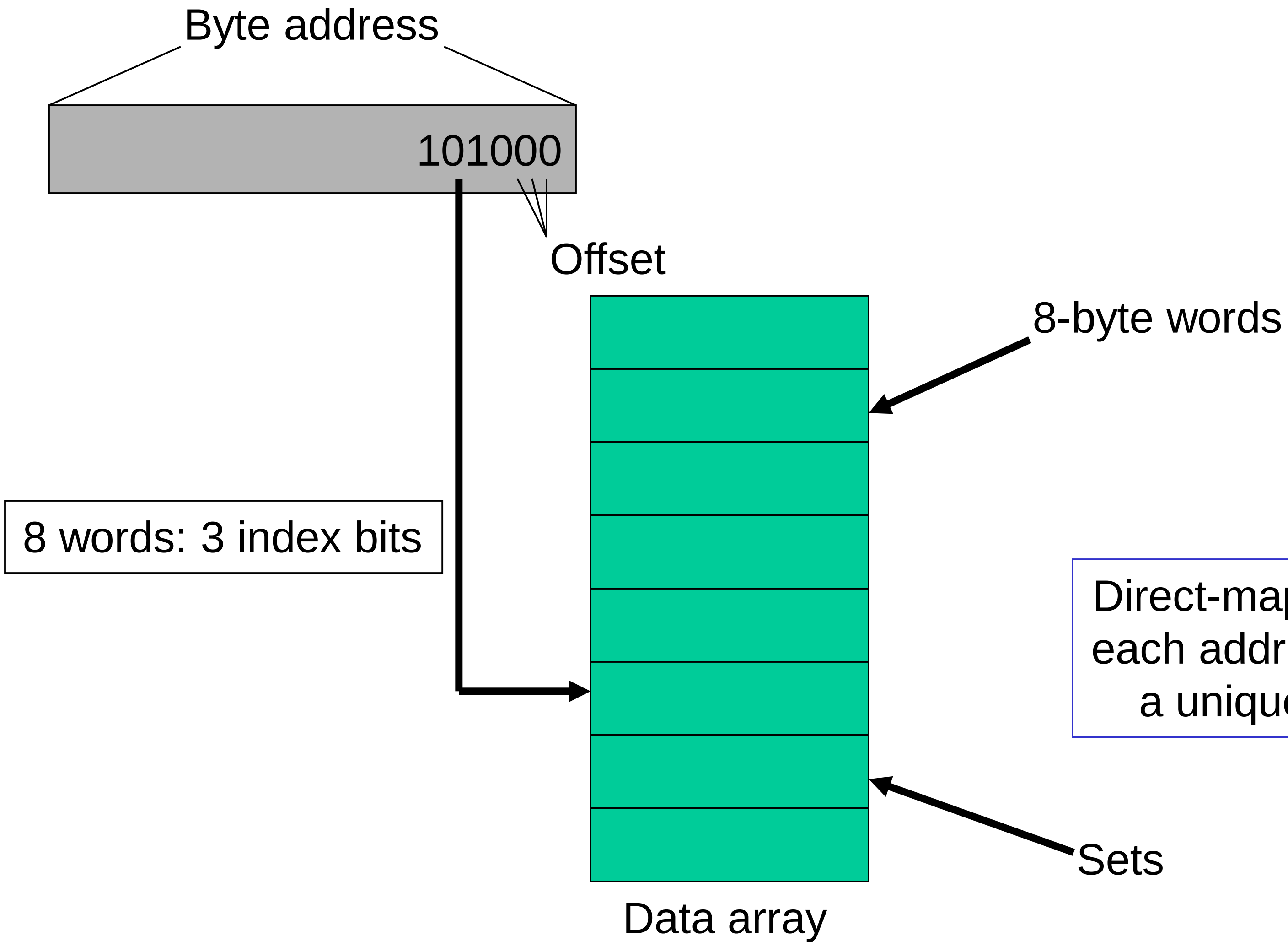
Lecture: Cache Hierarchies

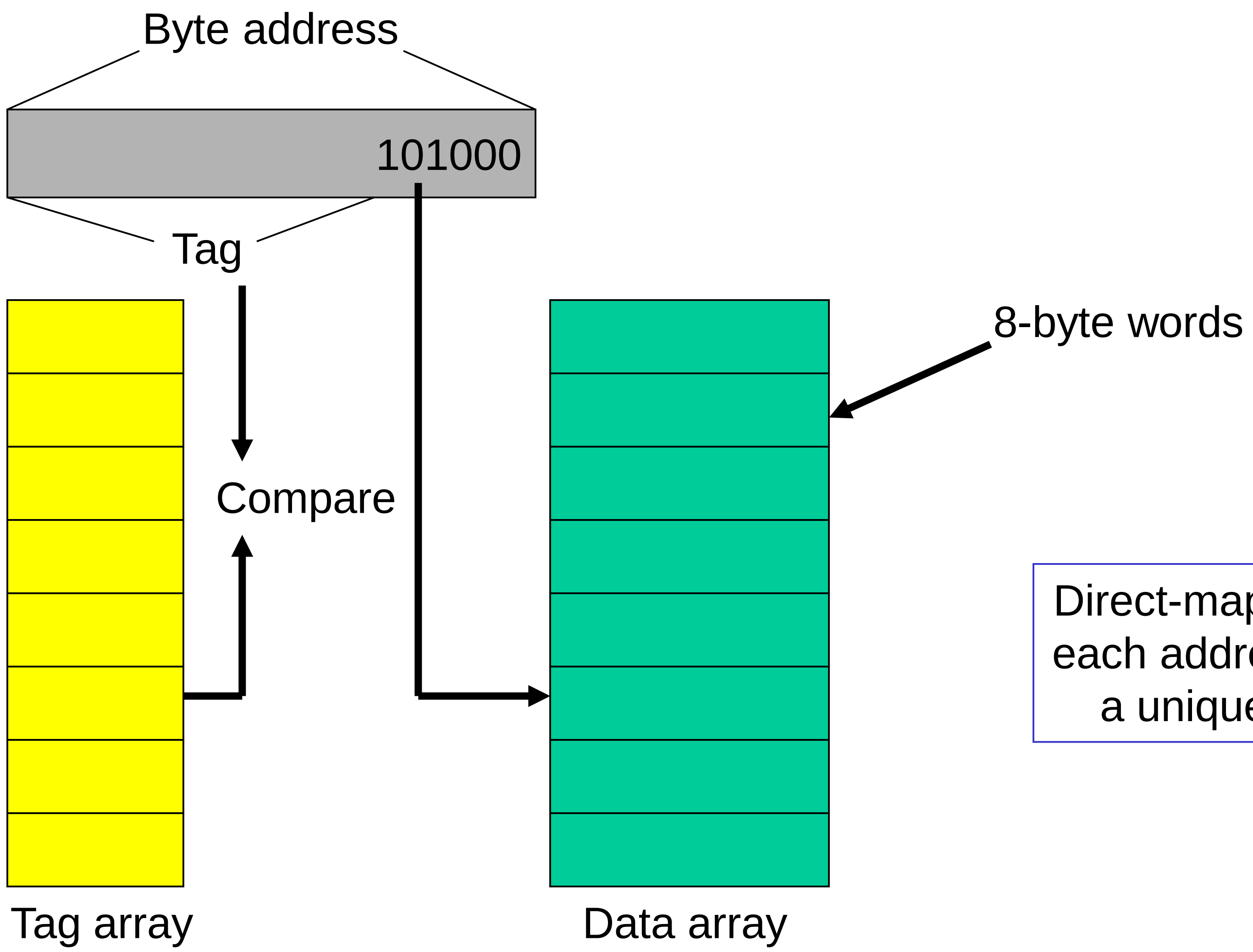
- Topics: cache innovations (Sections B.1-B.3, 2.1)

Accessing the Cache



Direct-mapped cache: each address maps to a unique address

The Tag Array



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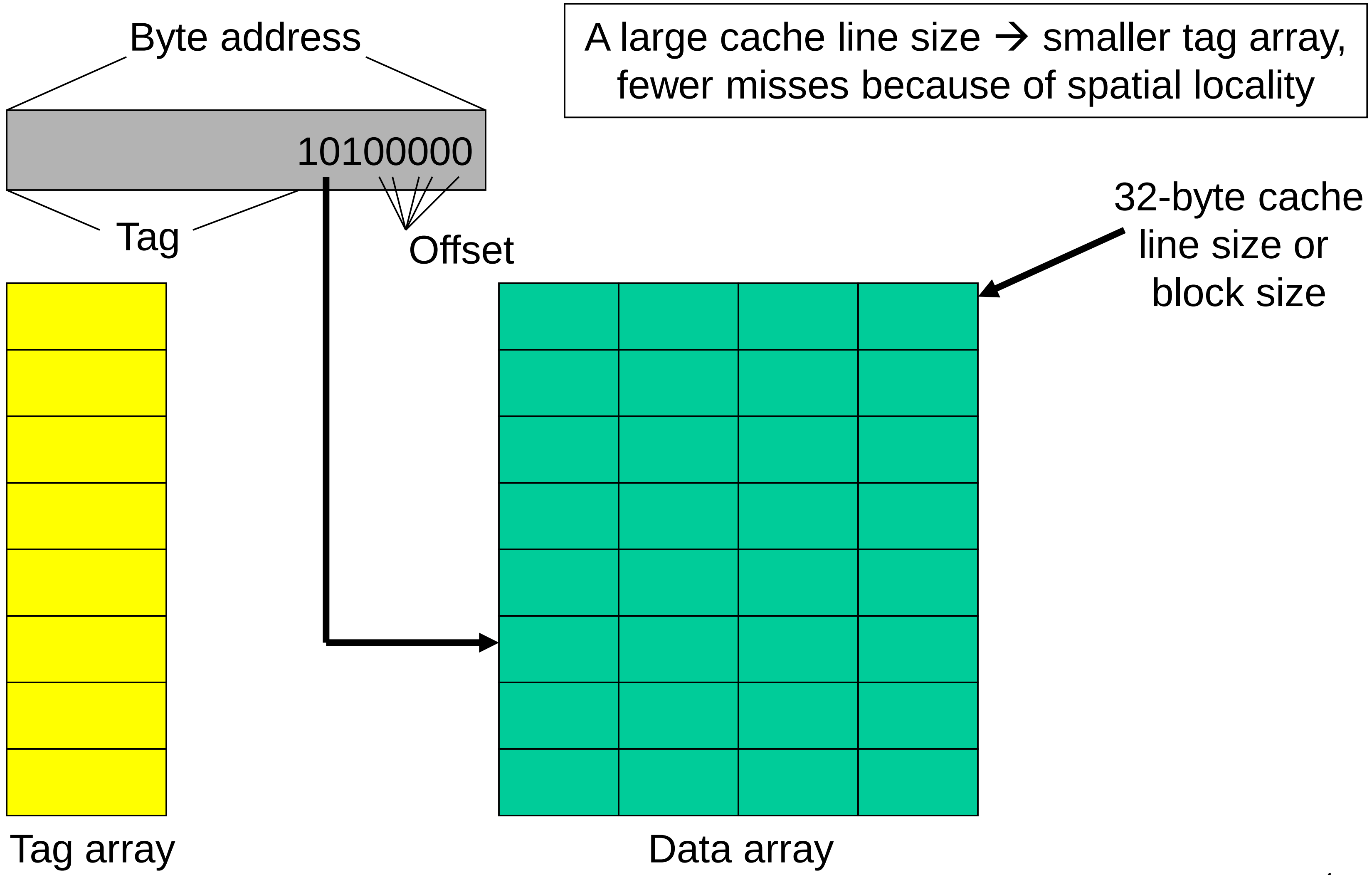
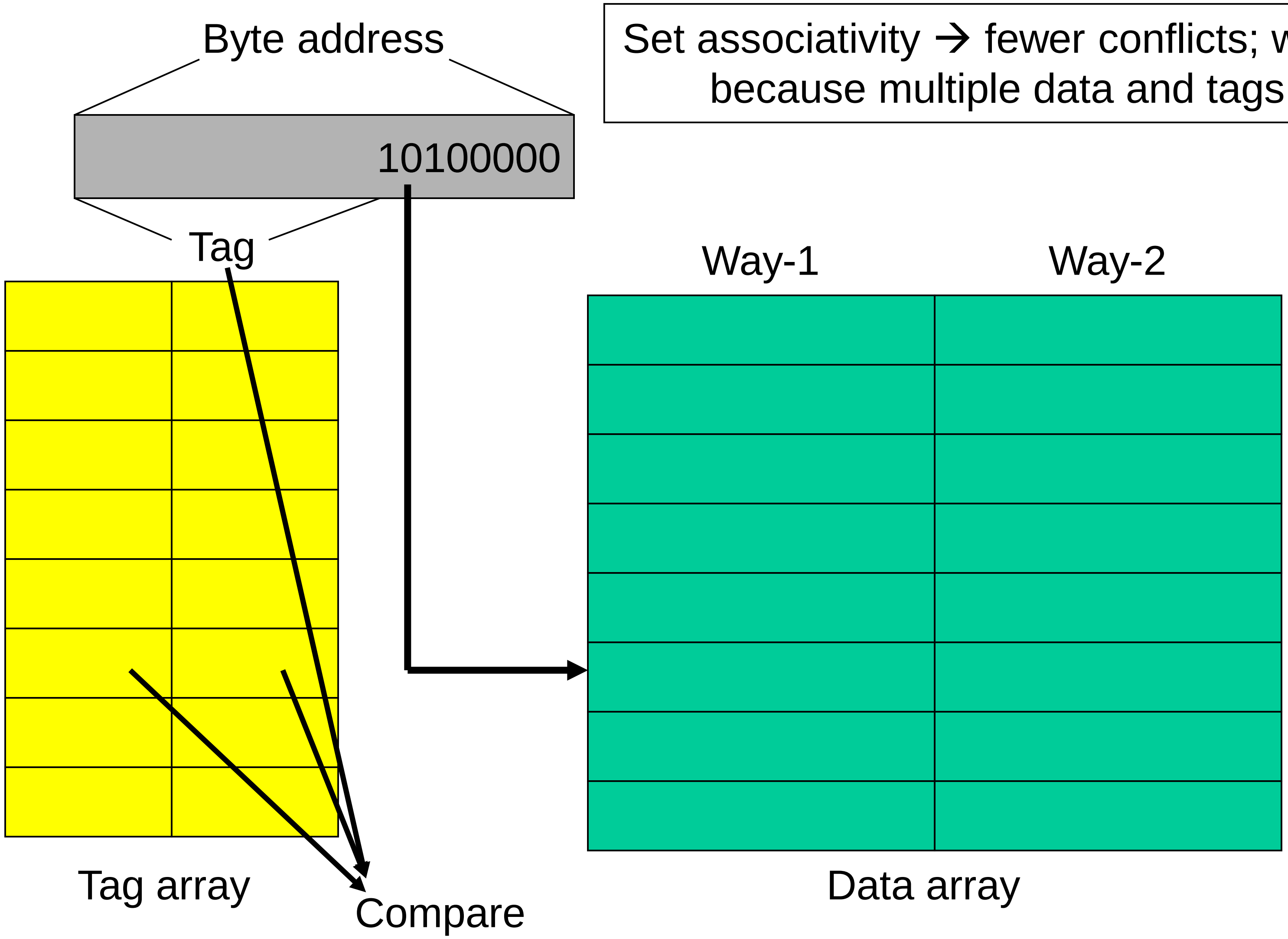
Increasing Line Size

A large cache line size → smaller tag array, fewer misses because of spatial locality



Associativity

Set associativity → fewer conflicts; wasted power because multiple data and tags are read



Problem 2

- Assume a direct-mapped cache with just 4 sets. Assume that block A maps to set 0, B to 1, C to 2, D to 3, E to 0, and so on. For the following access pattern, estimate the hits and misses:

  A B B E C C A D B F A E G C G A

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Problem 3

- Assume a 2-way set-associative cache with just 2 sets. Assume that block A maps to set 0, B to 1, C to 0, D to 1, E to 0, and so on. For the following access pattern, estimate the hits and misses:

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Problem 4

- 64 KB 16-way set-associative data cache array with 64 byte line sizes, assume a 40-bit address
- How many sets?
- How many index bits, offset bits, tag bits?
- How large is the tag array?

Problem 4

- 64 KB 16-way set-associative data cache array with 64 byte line sizes, assume a 40-bit address
- How many sets? 64
- How many index bits (6), offset bits (6), tag bits (28)?
- How large is the tag array (28 Kb)?

Problem 5

- 8 KB fully-associative data cache array with 64 byte line sizes, assume a 40-bit address
- How many sets? How many ways?
- How many index bits, offset bits, tag bits?
- How large is the tag array?

Problem 5

- 8 KB fully-associative data cache array with 64 byte line sizes, assume a 40-bit address
- How many sets (1) ? How many ways (128) ?
- How many index bits (0), offset bits (6), tag bits (34) ?
- How large is the tag array (544 bytes) ?

Types of Cache Misses

- Compulsory misses: happens the first time a memory word is accessed – the misses for an infinite cache
- Capacity misses: happens because the program touched many other words before re-touching the same word – the misses for a fully-associative cache
- Conflict misses: happens because two words map to the same location in the cache – the misses generated while moving from a fully-associative to a direct-mapped cache
- Sidenote: can a fully-associative cache have more misses than a direct-mapped cache of the same size?

What Influences Cache Misses?

	Compulsory	Capacity	Conflict
Increasing cache capacity			
Increasing number of sets			
Increasing block size			
Increasing associativity			

Reducing Miss Rate

- Large block size – reduces compulsory misses, reduces miss penalty in case of spatial locality – increases traffic between different levels, space waste, and conflict misses
- Large cache – reduces capacity/conflict misses – access time penalty
- High associativity – reduces conflict misses – rule of thumb: 2-way cache of capacity N/2 has the same miss rate as 1-way cache of capacity N – more energy

More Cache Basics

- L1 caches are split as instruction and data; L2 and L3 are unified

- The L1/L2 hierarchy can be inclusive, exclusive, or non-inclusive

- On a write, you can do write-allocate or write-no-allocate

- On a write, you can do writeback or write-through; write-back reduces traffic, write-through simplifies coherence

- Reads get higher priority; writes are usually buffered

- L1 does parallel tag/data access; L2/L3 does serial tag/data

Tolerating Miss Penalty

- Out of order execution: can do other useful work while waiting for the miss – can have multiple cache misses -- cache controller has to keep track of multiple outstanding misses (non-blocking cache)

- Hardware and software prefetching into prefetch buffers – aggressive prefetching can increase contention for buses

Techniques to Reduce Cache Misses

- Victim caches
- Better replacement policies – pseudo-LRU, NRU, DRRIP
- Prefetching, cache compression

Victim Caches

- A direct-mapped cache suffers from misses because multiple pieces of data map to the same location
- The processor often tries to access data that it recently discarded – all discards are placed in a small victim cache (4 or 8 entries) – the victim cache is checked before going to L2
- Can be viewed as additional associativity for a few sets that tend to have the most conflicts

Replacement Policies

- Pseudo-LRU: maintain a tree and keep track of which side of the tree was touched more recently; simple bit ops

- NRU: every block in a set has a bit; the bit is made zero when the block is touched; if all are zero, make all one; a block with bit set to 1 is evicted

Prefetching

- Hardware prefetching can be employed for any of the cache levels

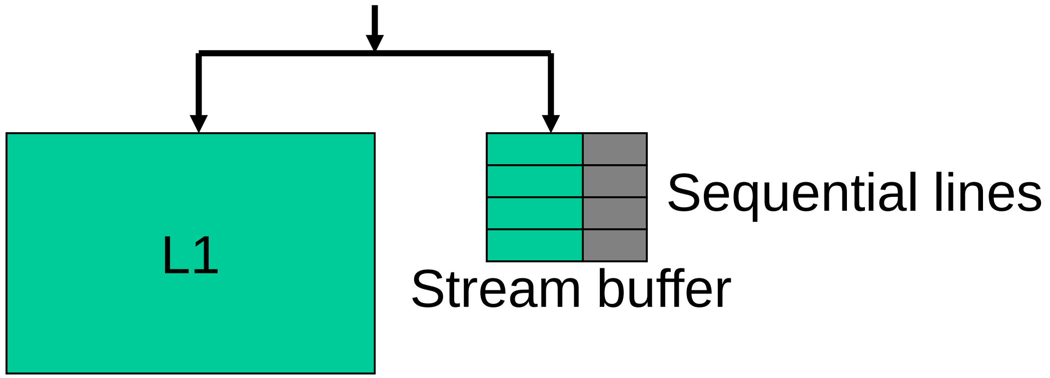
- It can introduce cache pollution – prefetched data is often placed in a separate prefetch buffer to avoid pollution – this buffer must be looked up in parallel with the cache access

- Aggressive prefetching increases “coverage”, but leads to a reduction in “accuracy” → wasted memory bandwidth

- Prefetches must be timely: they must be issued sufficiently in advance to hide the latency, but not too early (to avoid pollution and eviction before use)

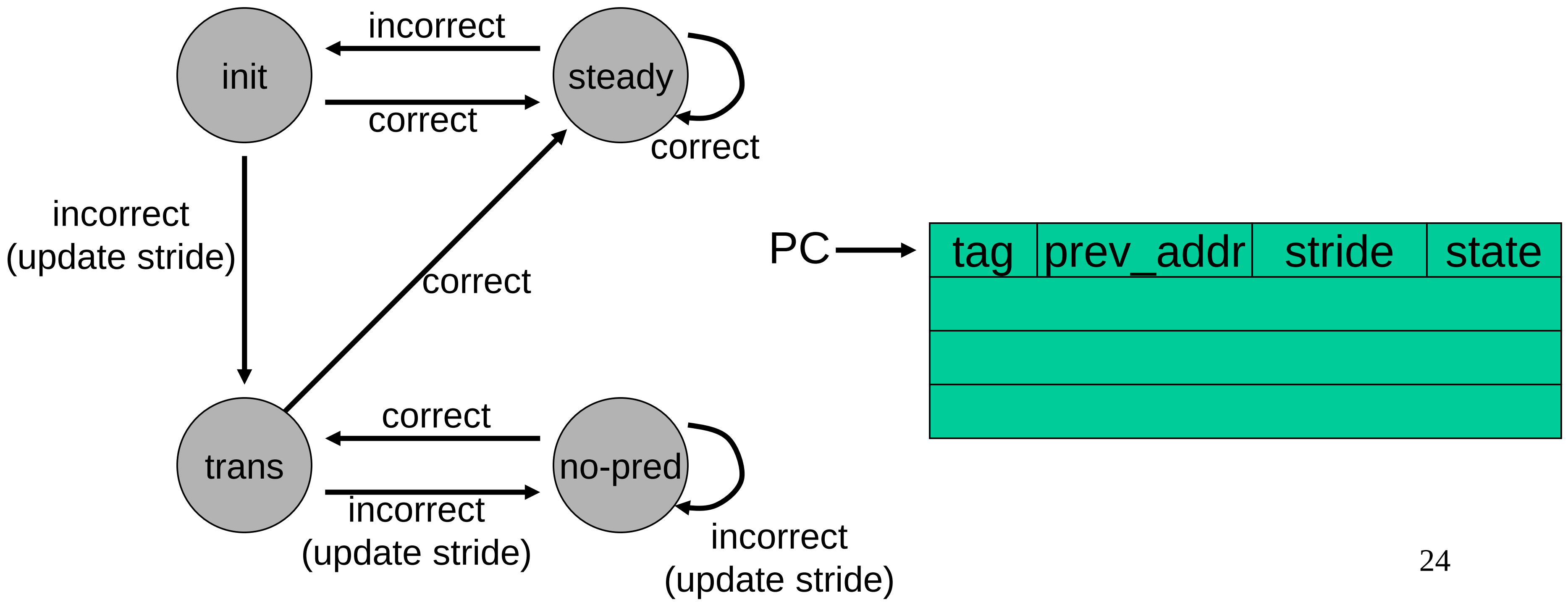
Stream Buffers

- Simplest form of prefetch: on every miss, bring in multiple cache lines
- When you read the top of the queue, bring in the next line



Stride-Based Prefetching

- For each load, keep track of the last address accessed by the load and a possibly consistent stride
- FSM detects consistent stride and issues prefetches



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