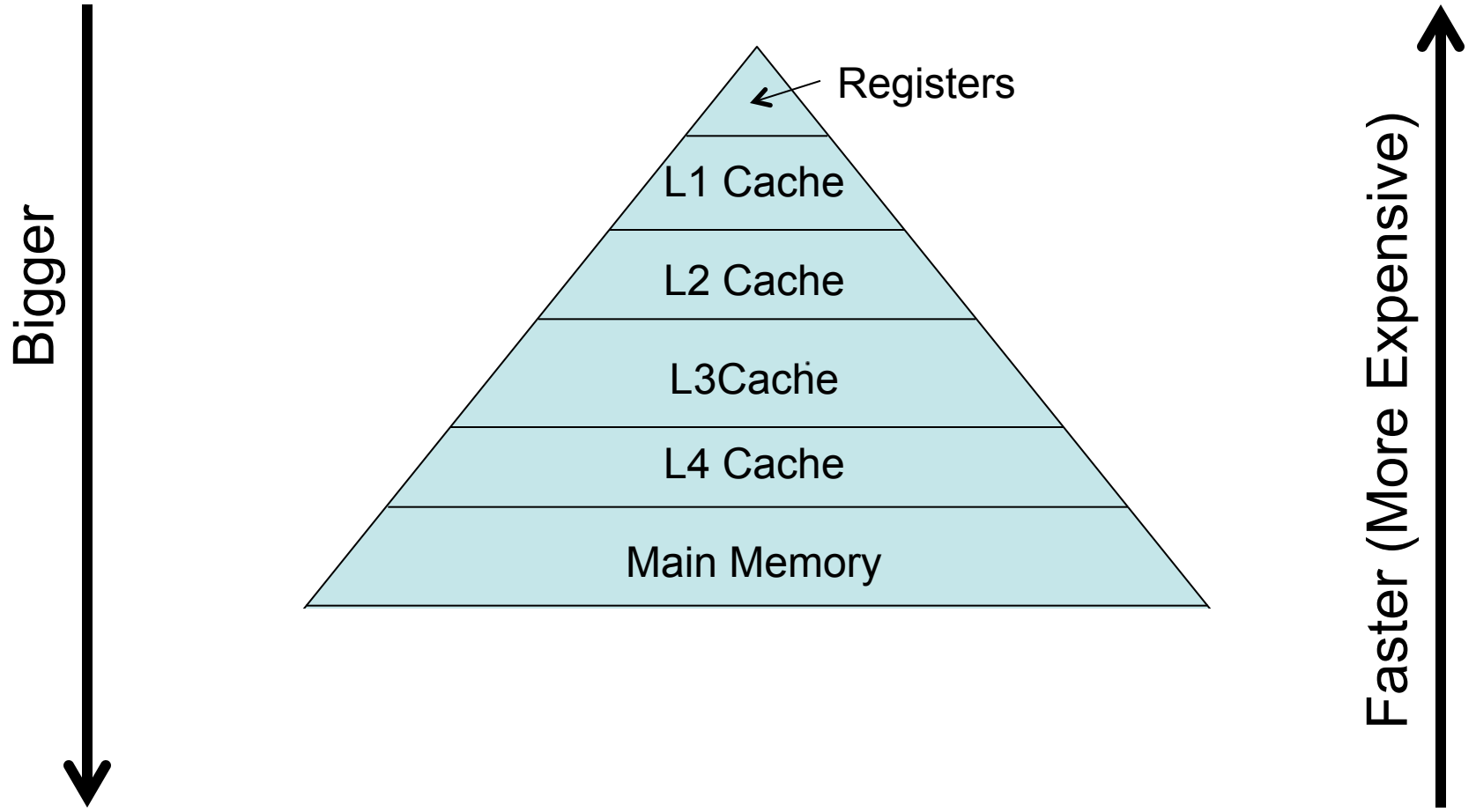
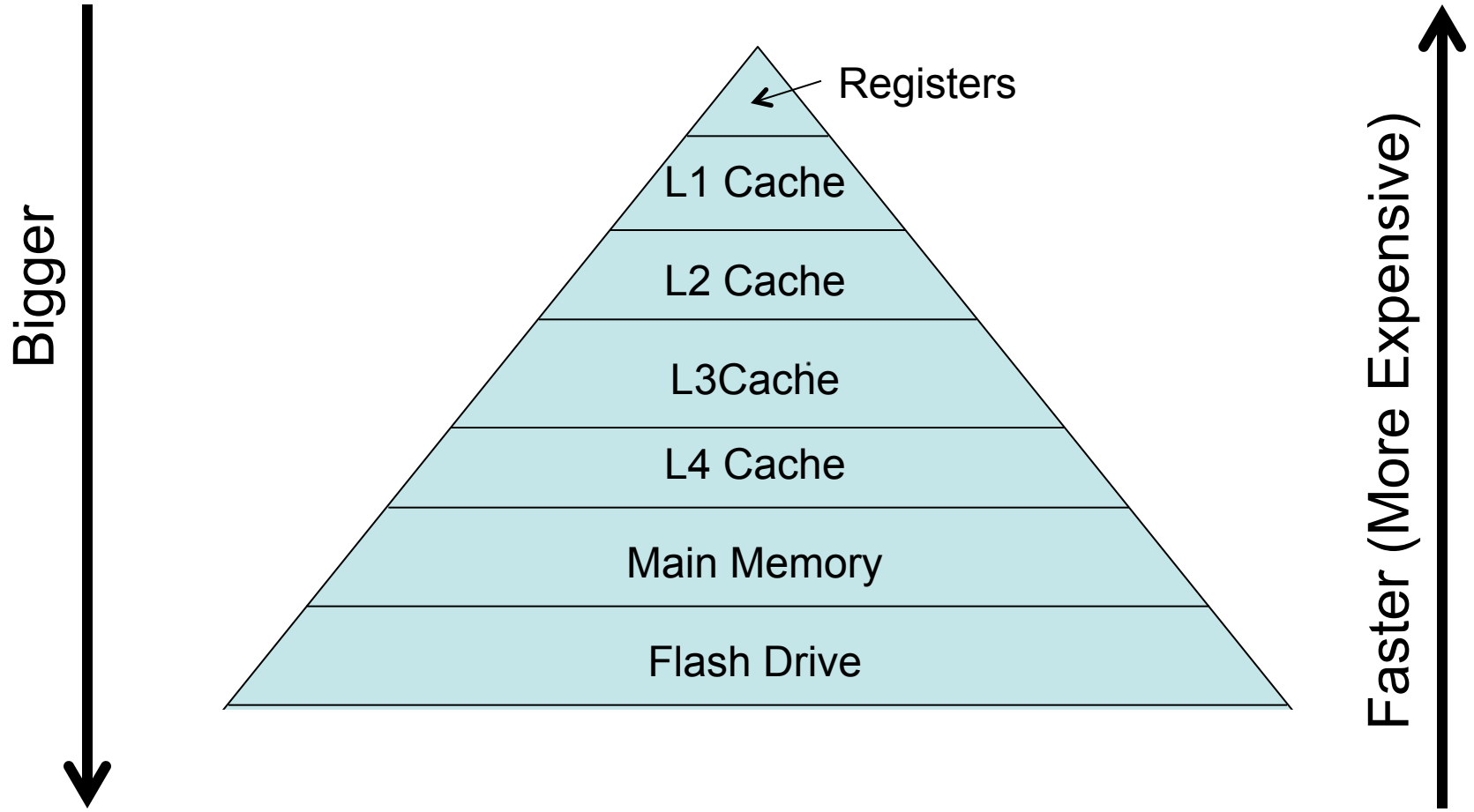
Storage 2: From HW Caching to SW caching

- Learning Objectives
  - Translate what we learned about hardware caches to software.
  - Evaluate the efficacy of a cache.
  - Define:
    - Cache block
    - Cache slot
    - Cache hit/miss rate
    - Replacement policy

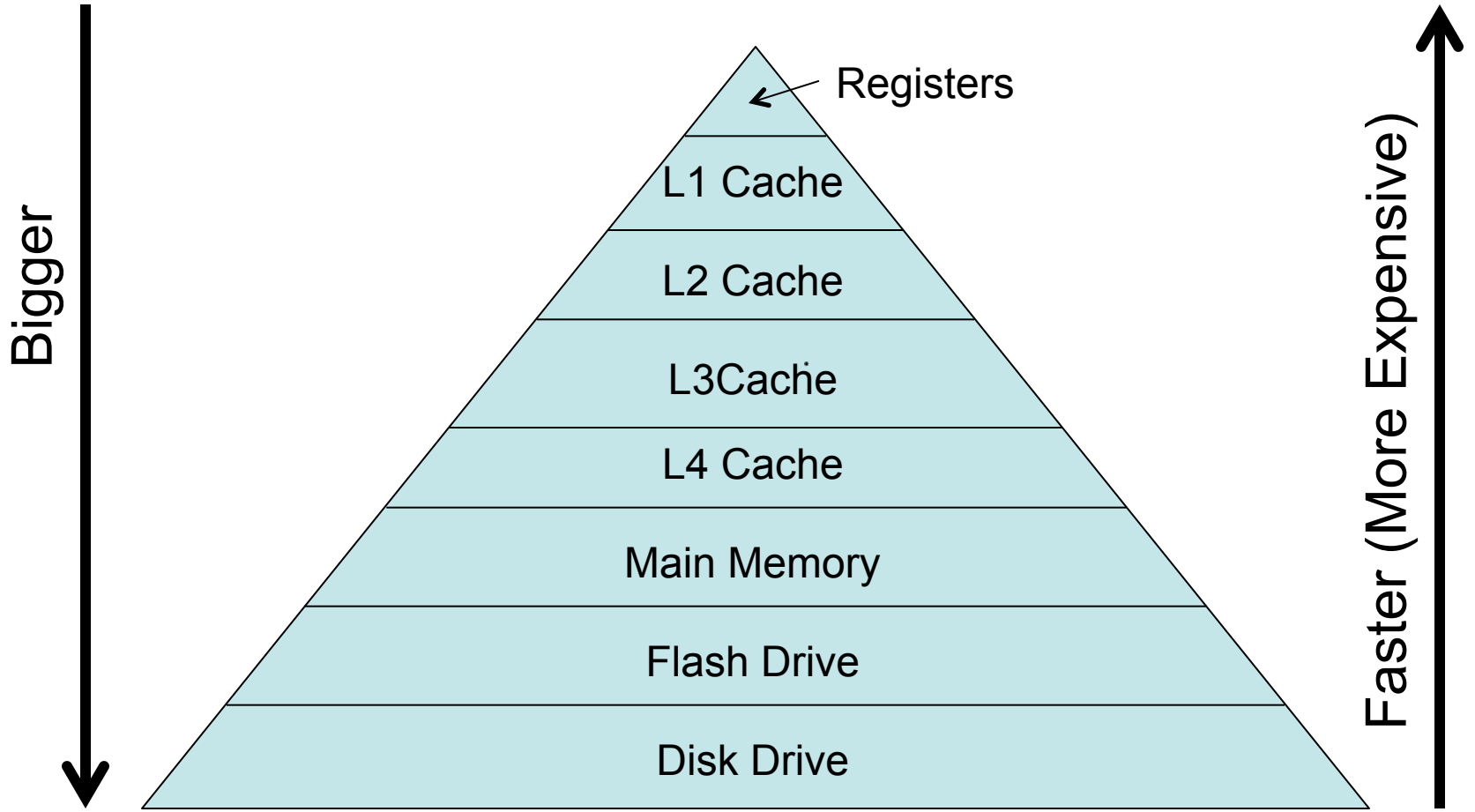
The Memory Hierarchy



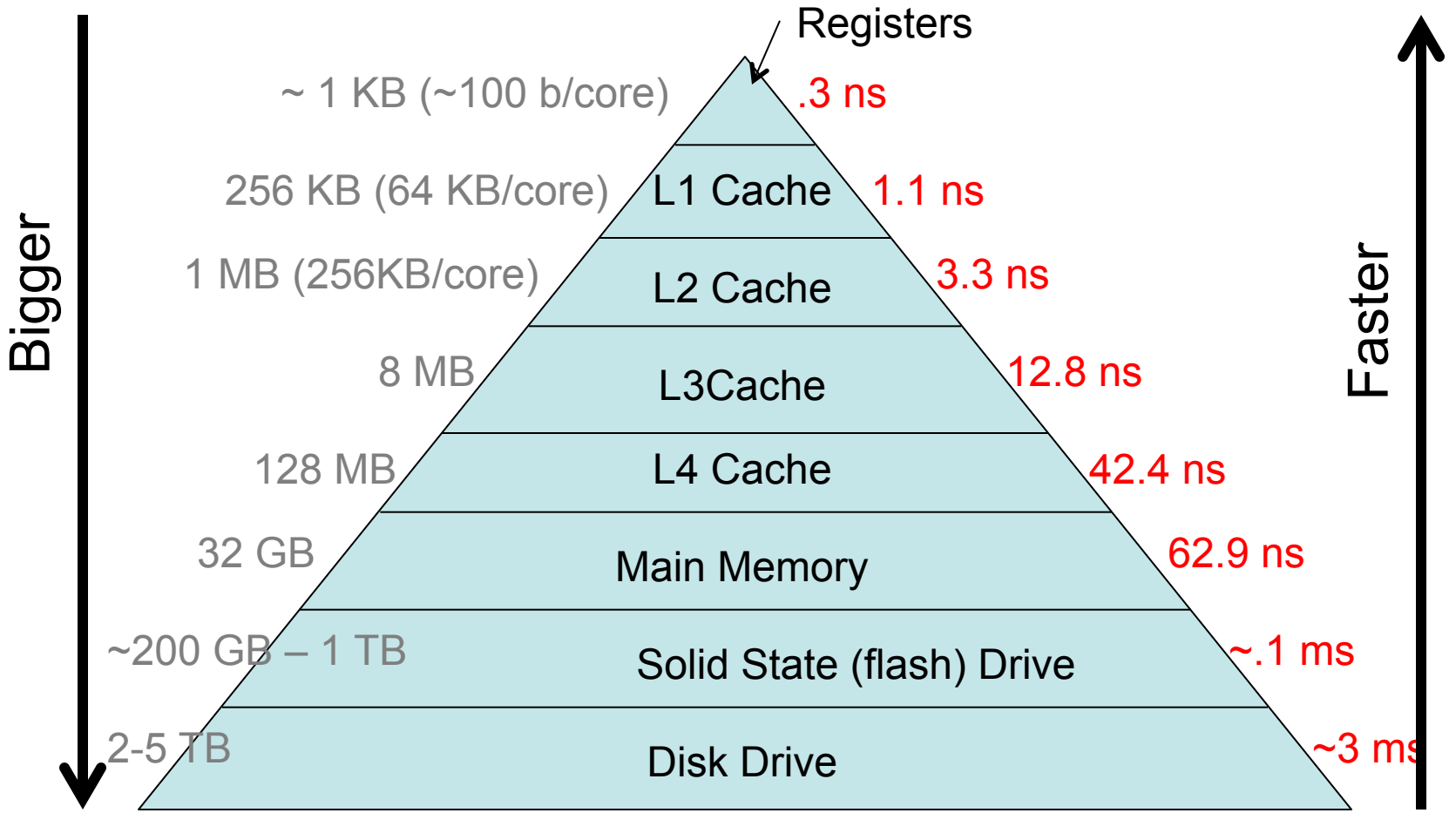
The Memory Hierarchy



The Memory Hierarchy



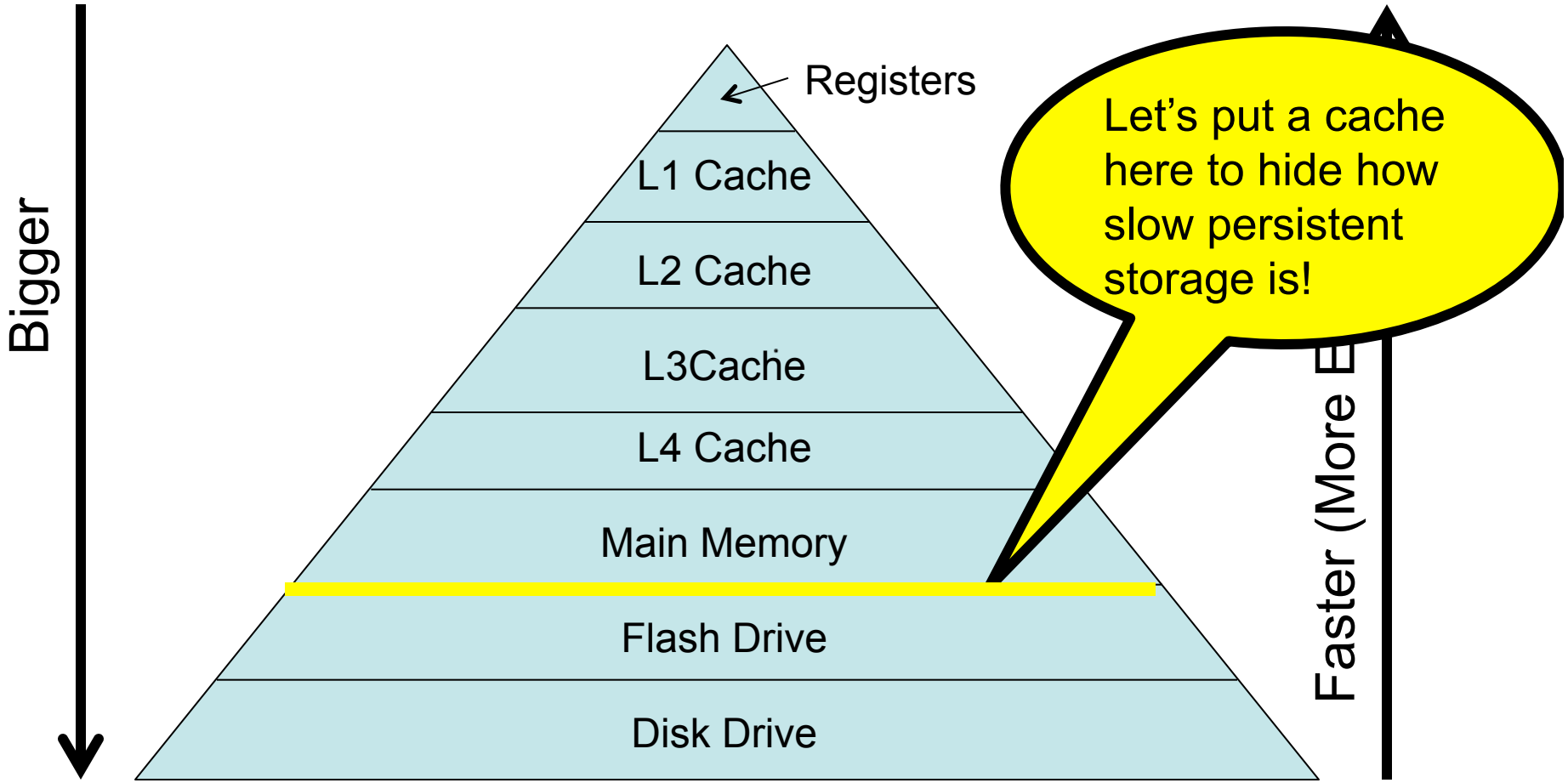
The Memory Hierarchy -- Speed



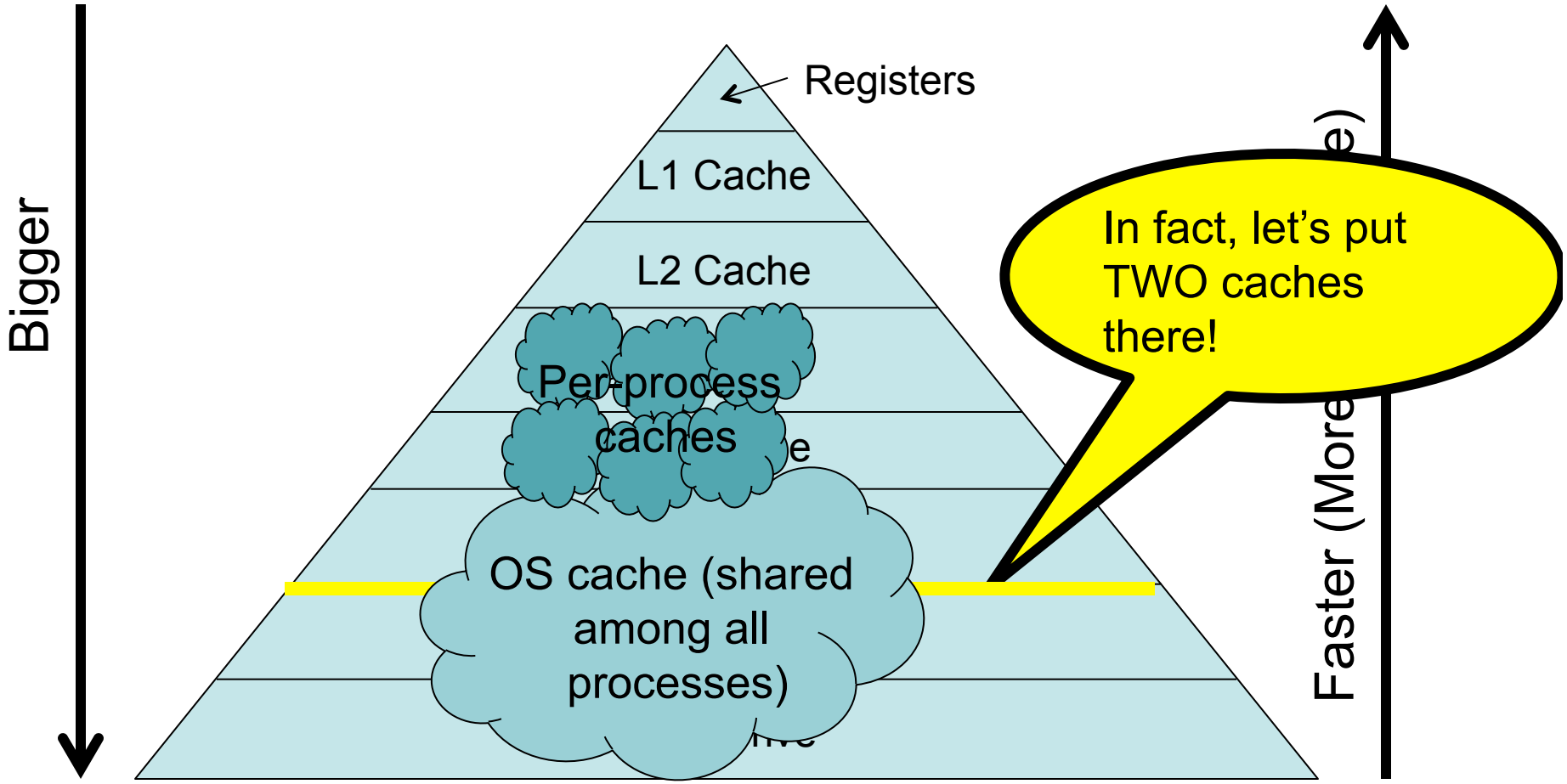
Screen Capture

- w01_sync
- w02_syscall
- w03_stdio

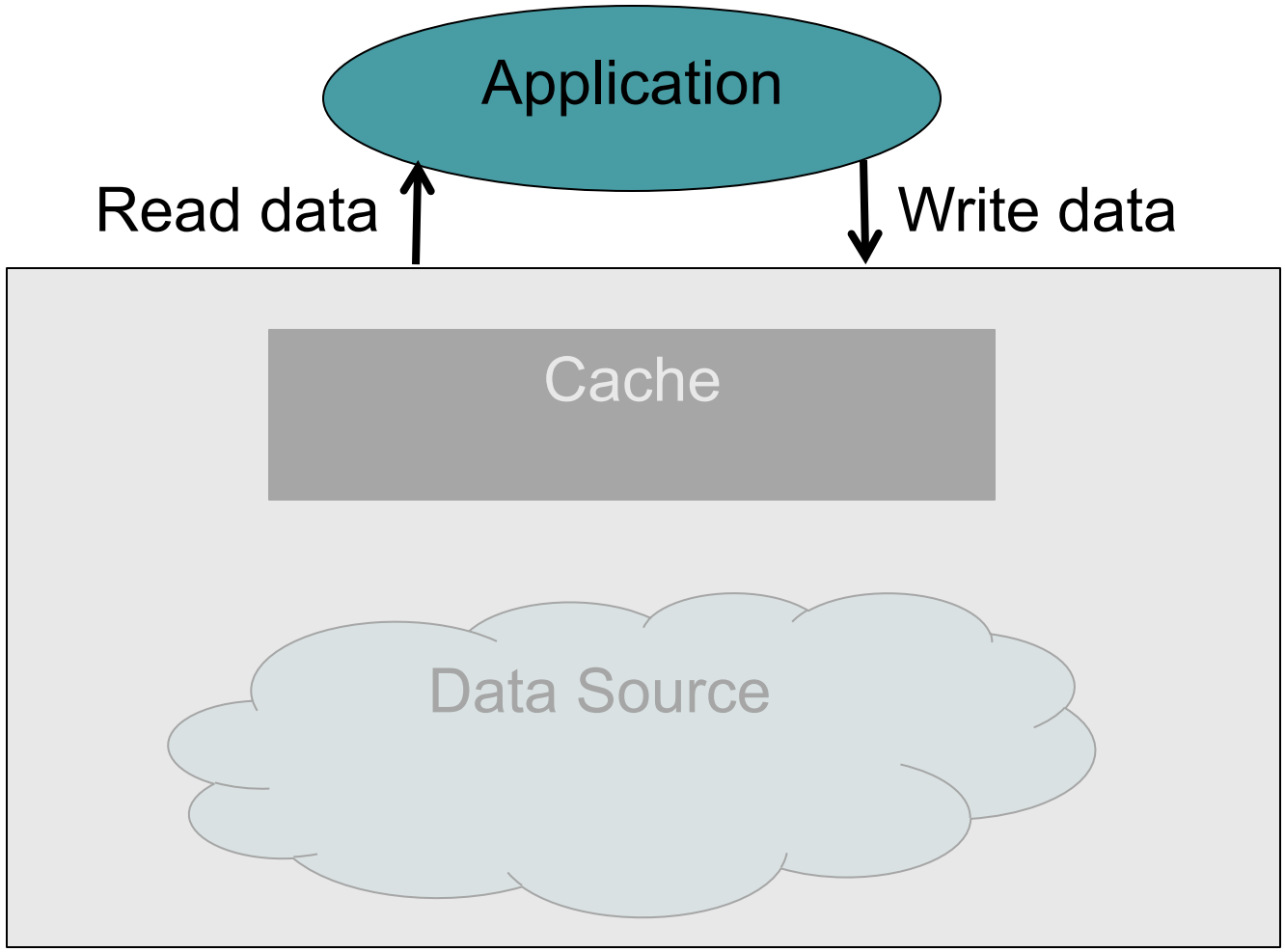
Where oh were are the SW caches?



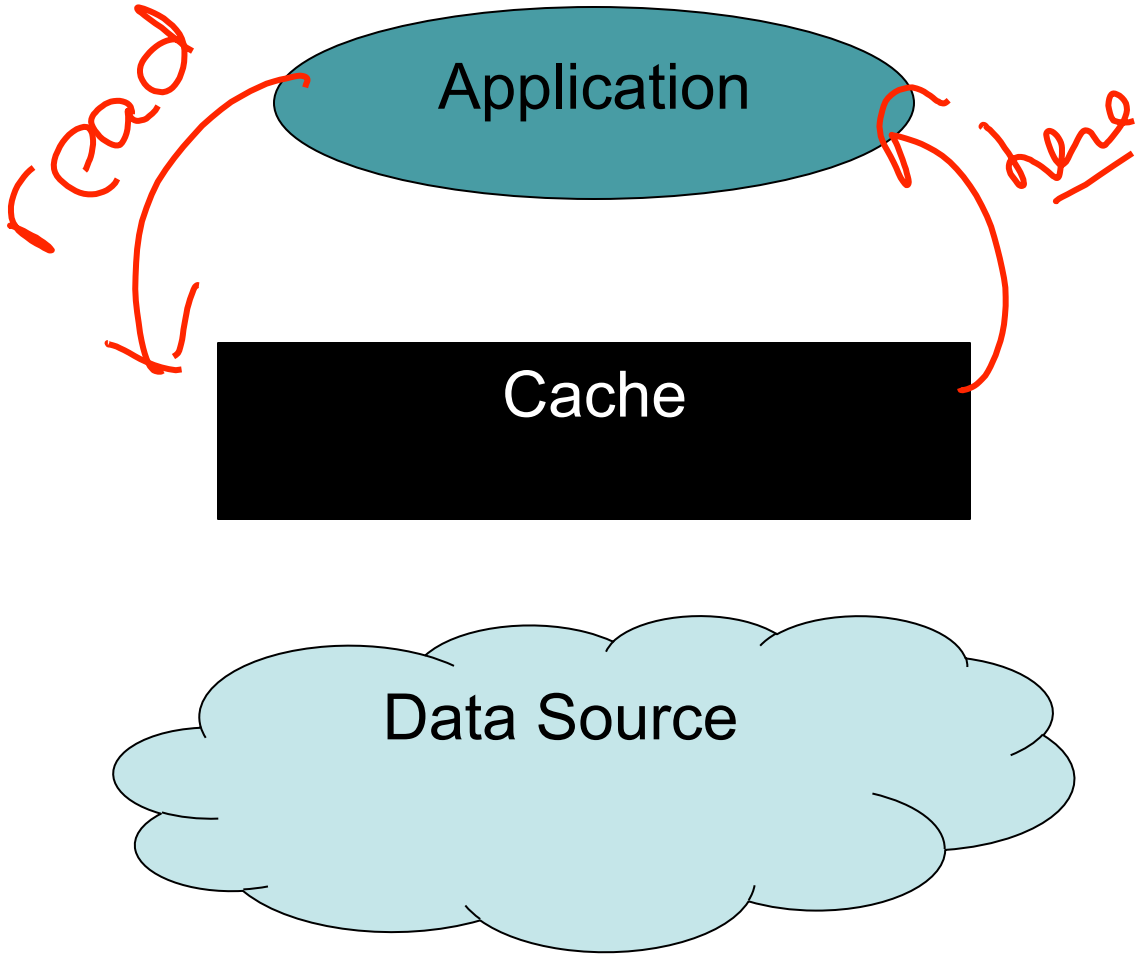
Where oh were are the SW caches?



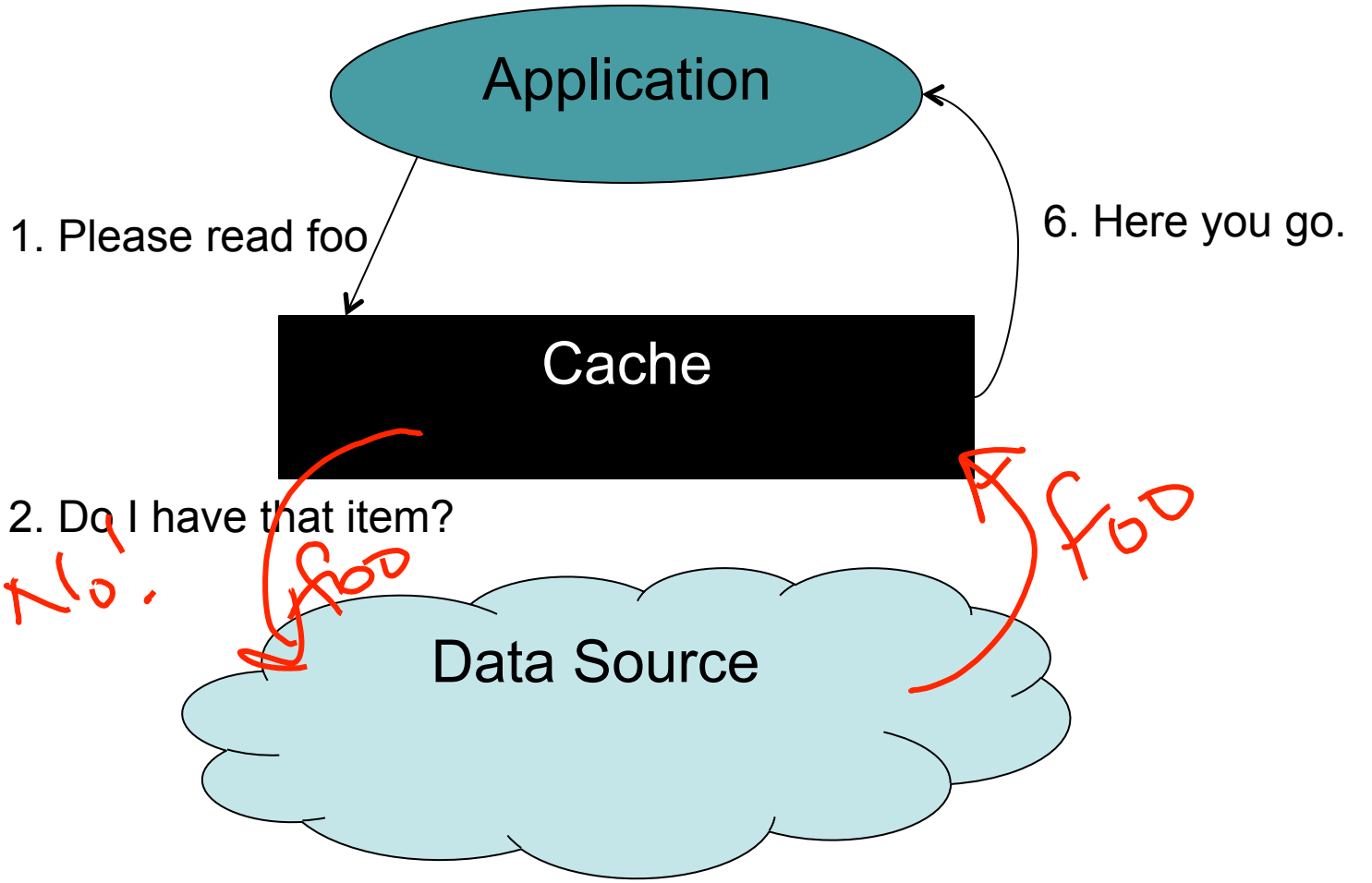
An Abstract Cache



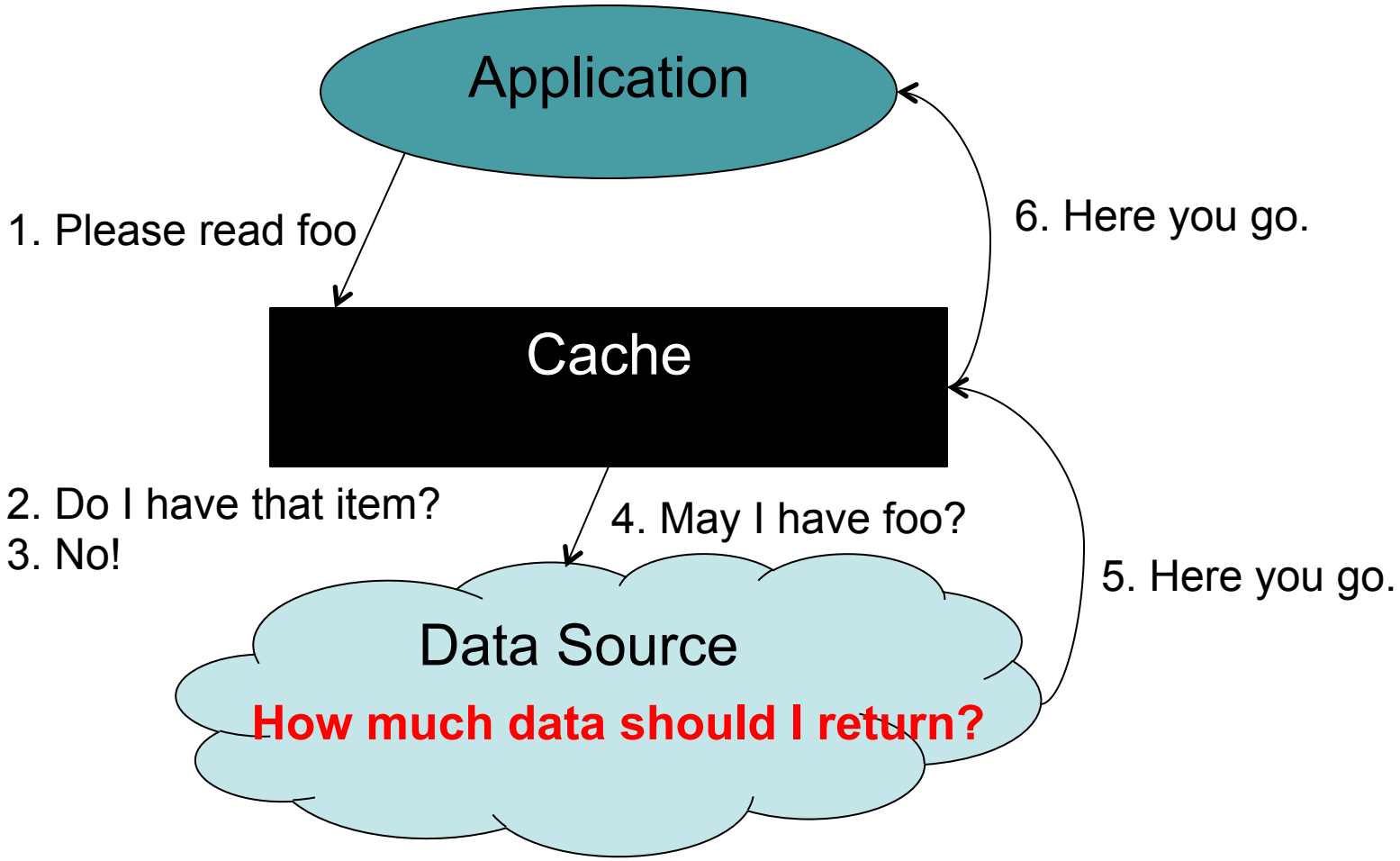
Reading from the cache: HIT



Reading from the cache: MISS



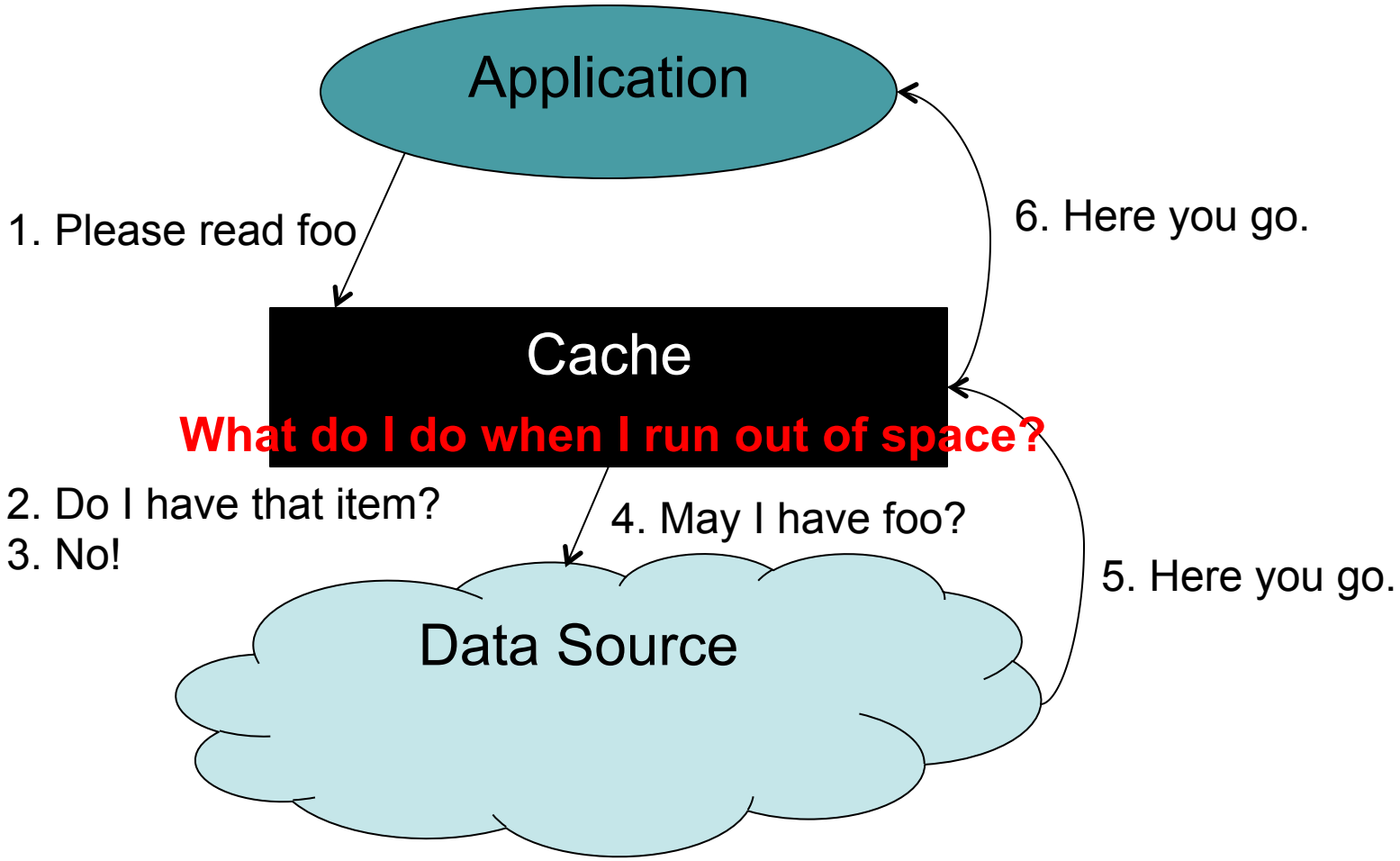
Decisions: Servicing misses (blocksize)



How much data should I return?

- Most storage devices have a native size for data access and/or transmission, e.g., disk block (4 KB).
- Recall: HW caches also have a unit they use to transfer data to/from the cache:
  - Cache lines: typically 64 or 128 bytes.
- Block size: the unit in which data is stored in a cache.
  - HW caches: 64 bytes
  - File system caches: 4+ KB
  - Object caches: size of the object

Decisions: A full cache (eviction)



What do I do when I fill up?

- A cache has a limited capacity.
- At some point, the application will fill the cache and request another item.
- Caching the new item requires evicting some other item.
- What item do I evict?
  - We need an eviction policy
  - The available decisions here vary between hardware and software.

Eviction in Hardware

- A cache is comprised of some number of slots (locations in the cache, each of which can hold a cache line or cache block).
- The hardware often limits the number of possible slots in which an item can be placed.
- Call the number of slots in which a particular item can be placed A. Let N be the total number of slots in the cache.
  - A = 1: Direct mapped: each object can live in exactly one slot in the cache, so you have no choice but to evict the item in that slot.
  - A > 1, A << N: A-way set associative: an object can live in one of A slots; A is typically 2, 4, or 8. On eviction, choose randomly from among the A slots.
  - A = N: Fully associative: an object can live in any slot.

Eviction in Software

- In software, we almost always have a fully associative cache.
- In a perfect world, we'd like to evict the item that is least valuable.
- In the real world, we don't know what that item is.
- Practically all software caches try to approximate this ideal.
  - LRU: Least-recently-used – find the item that has been unused the longest and get rid of that.
  - FIFO: First-in-first-out – find the item that has been in the cache the longest.
  - LFU: Least-frequently-used – find the item that has been used less frequently and get rid of that.
  - Clock: Used in virtual memory systems to approximate LRU, take CS161 for details.
  - Something tuned to known access patterns.

Evaluating a Cache: Hit Ratio

- Hits are much better than misses!
- We measure the efficiency of a cache in terms of its cache hit rate:
  - # cache hits / # cache accesses
  - # cache hits / (# cache hits + # cache misses)
- Example:
  - I access my cache 1000 times and have 400 hits.
    - My cache hit rate is 400/1000 = 40%
- Good performance requires high cache hit rates.

More than one way to get a hit …

- If you touch the same item more than once, you get a hit, but there is another way to get a hit.
- Think about the fact that your cache is organized in blocks…
- Consider this:
  - Let's say you are accessing an array of 4-byte integers.
  - A cache line is 64 bytes.
- Here is the question:
  - Let's say that you have 160 items in the array and you've never accessed it before, how many cache misses will you take?

Fun With Eviction

- Consider the following set of references to cache blocks:

1 2 3 1 1 2 4 5 2 1 4

- Live People Demo!