[544] Caching

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Learning Objectives

- describe the cache hierarchy
- trace through access patterns with LRU and FIFO policies
- calculate cache performance metrics

Outline

Challenge: Latency

Cache Hierarchy

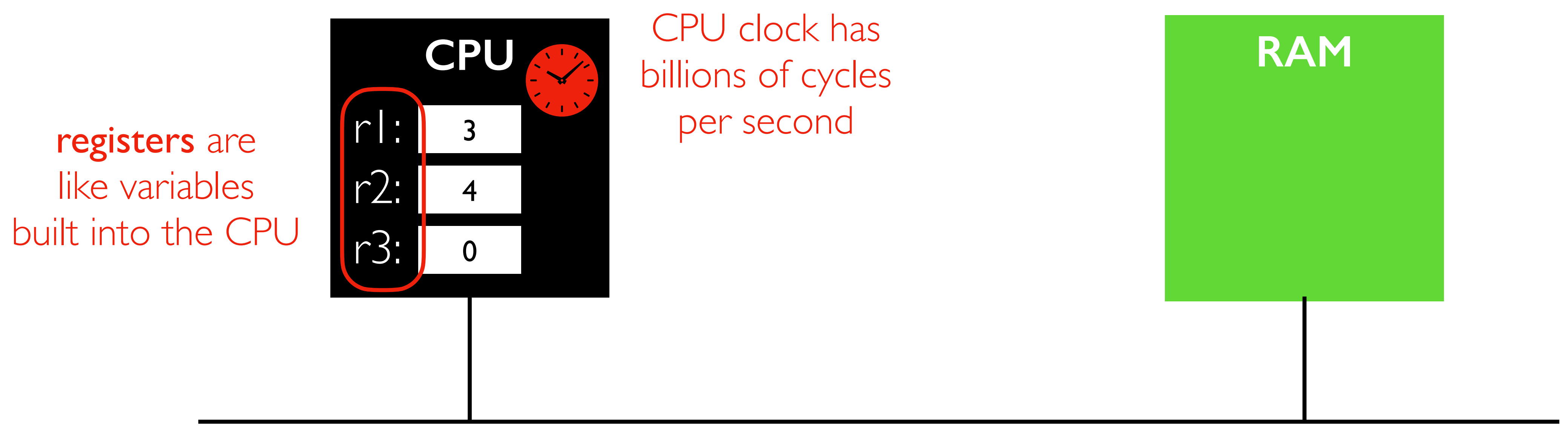
- CPU, RAM, SSD, Disk, Network
- Tradeoffs

Policy: what data should be cached?

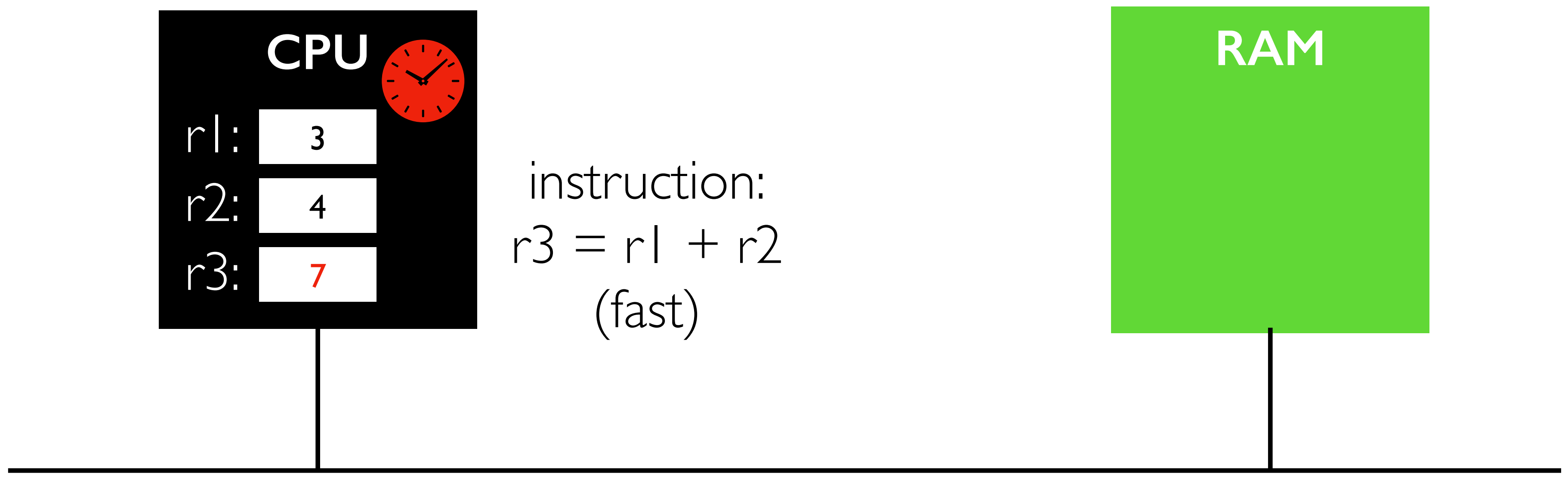
- manual
- expiration
- eviction policies: random, FIFO, LRU

Practice

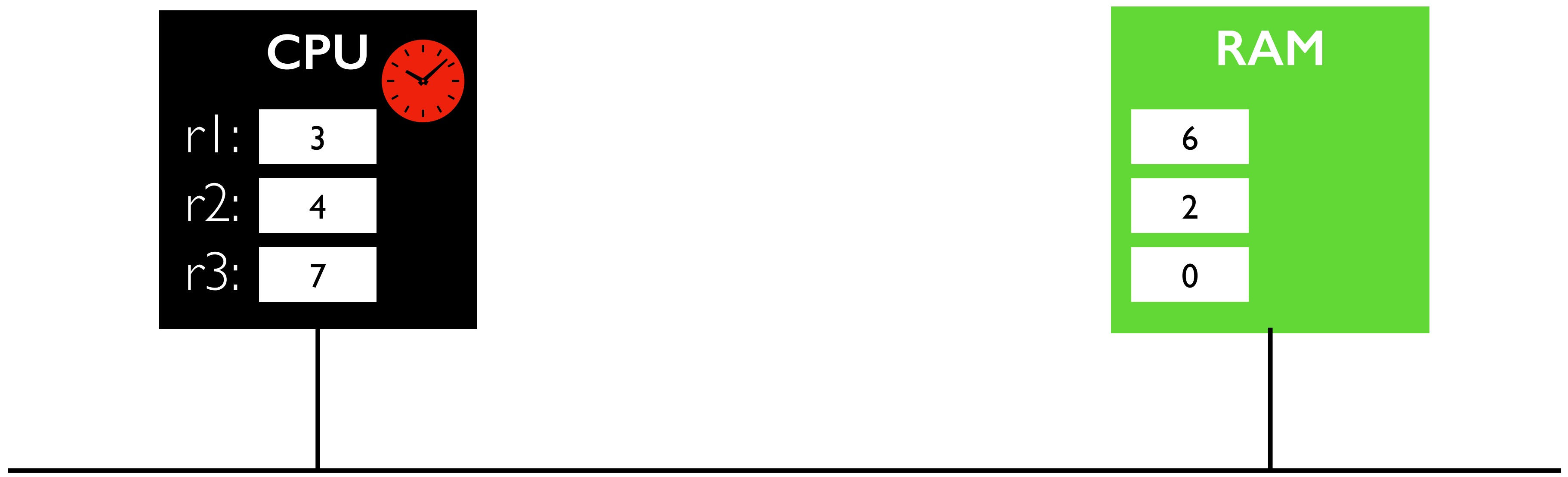
CPU and RAM


CPU
r1:
3
r2:
4
r3:
0
RAM
registers are like variables built into the CPU
CPU clock has billions of cycles per second

CPU and RAM

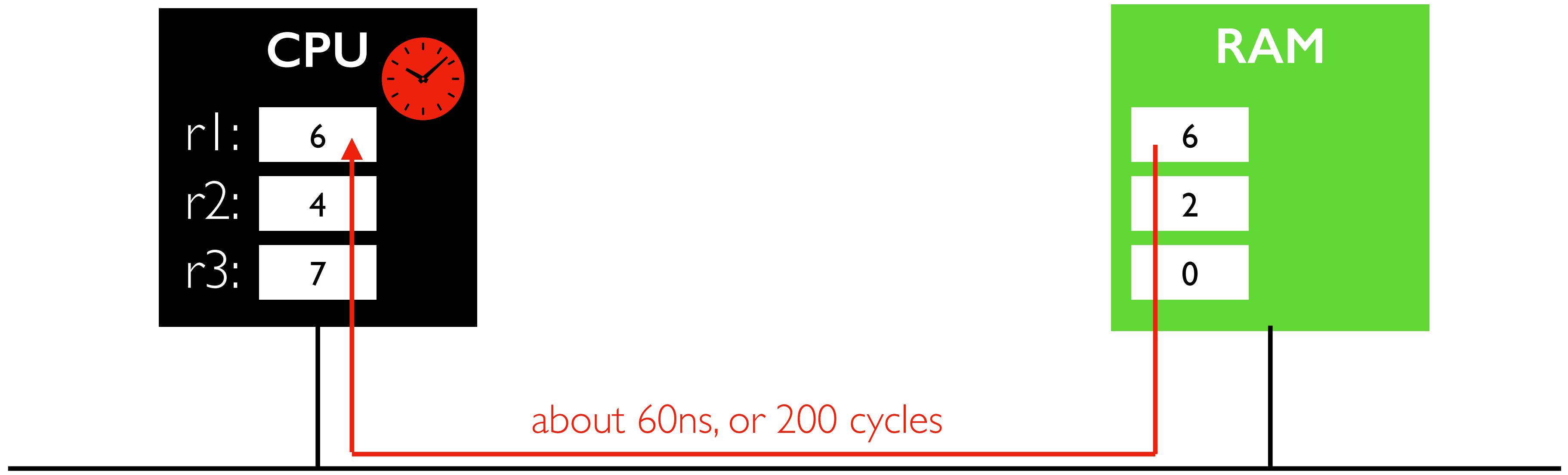


Load and Store

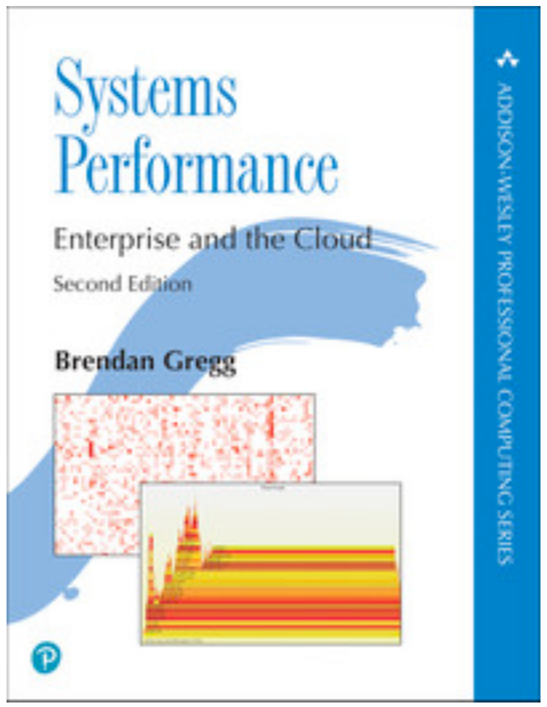


challenge: if we want to add some numbers stored in RAM, we need to **load** before adding and **store** after

Latency

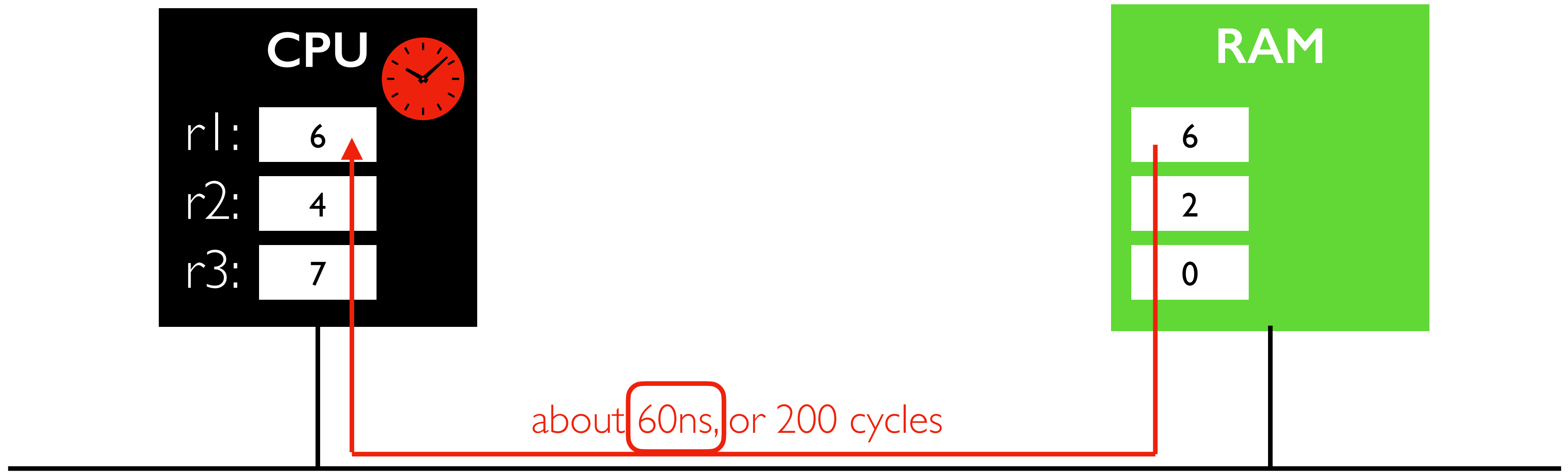


very slow, but not long enough to
switch to a different process...

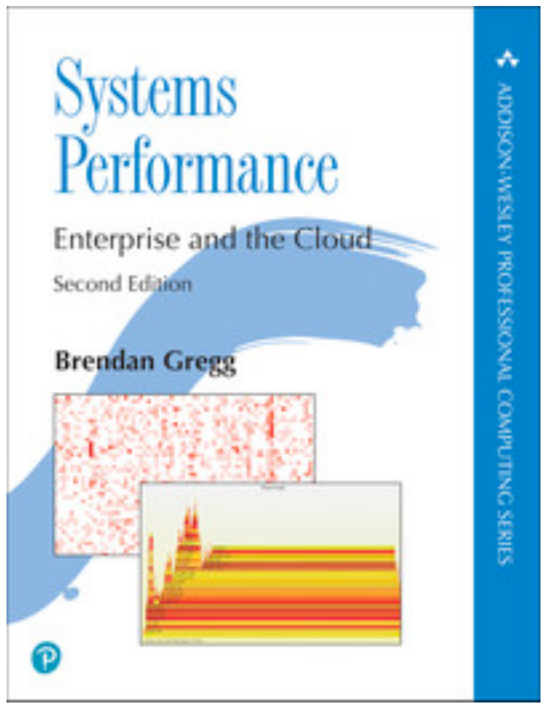


source: visuals, estimates

Latency



"how much time" is a latency measure.
Throughput (bytes/second) would depend on how many loads like these we can do simultaneously.



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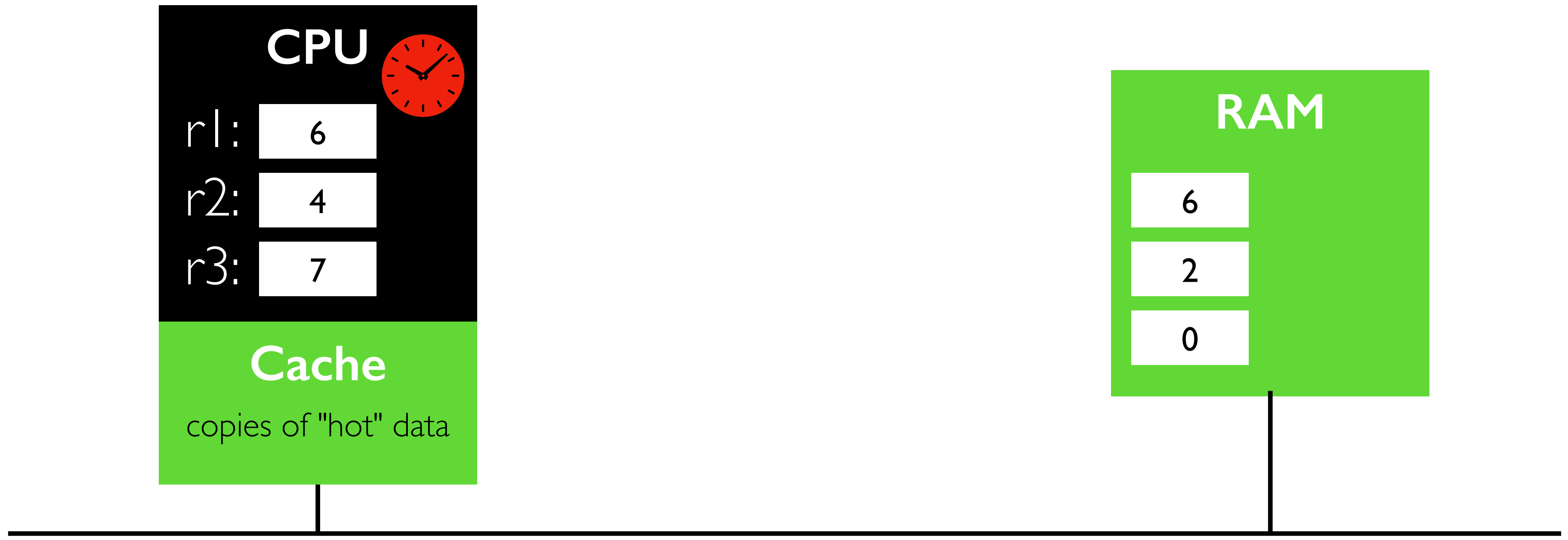
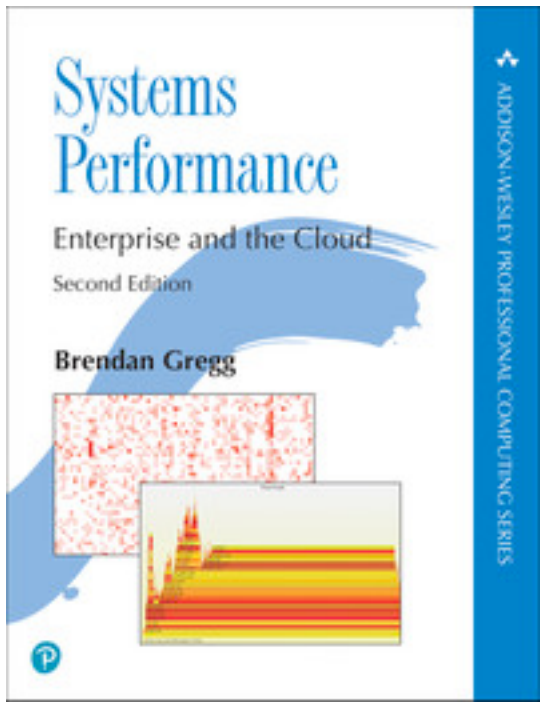
Cache



Idea: CPUs can have a small/fast memory built in for data that is accessed frequently



source: visuals, estimates

Performance Measurements

Metrics

- throughput
- average or median latency
- "tail" latency
  - for example, 99th percentile, 99.9th percentile, etc. (abbreviated p99 or p99.9)

Which metrics do we expect caching to help with the most?

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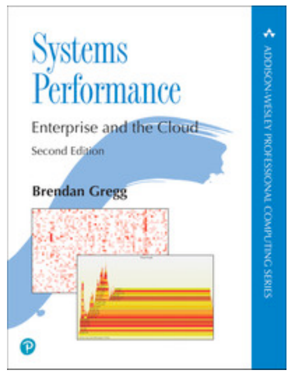
Cache Hierarchy



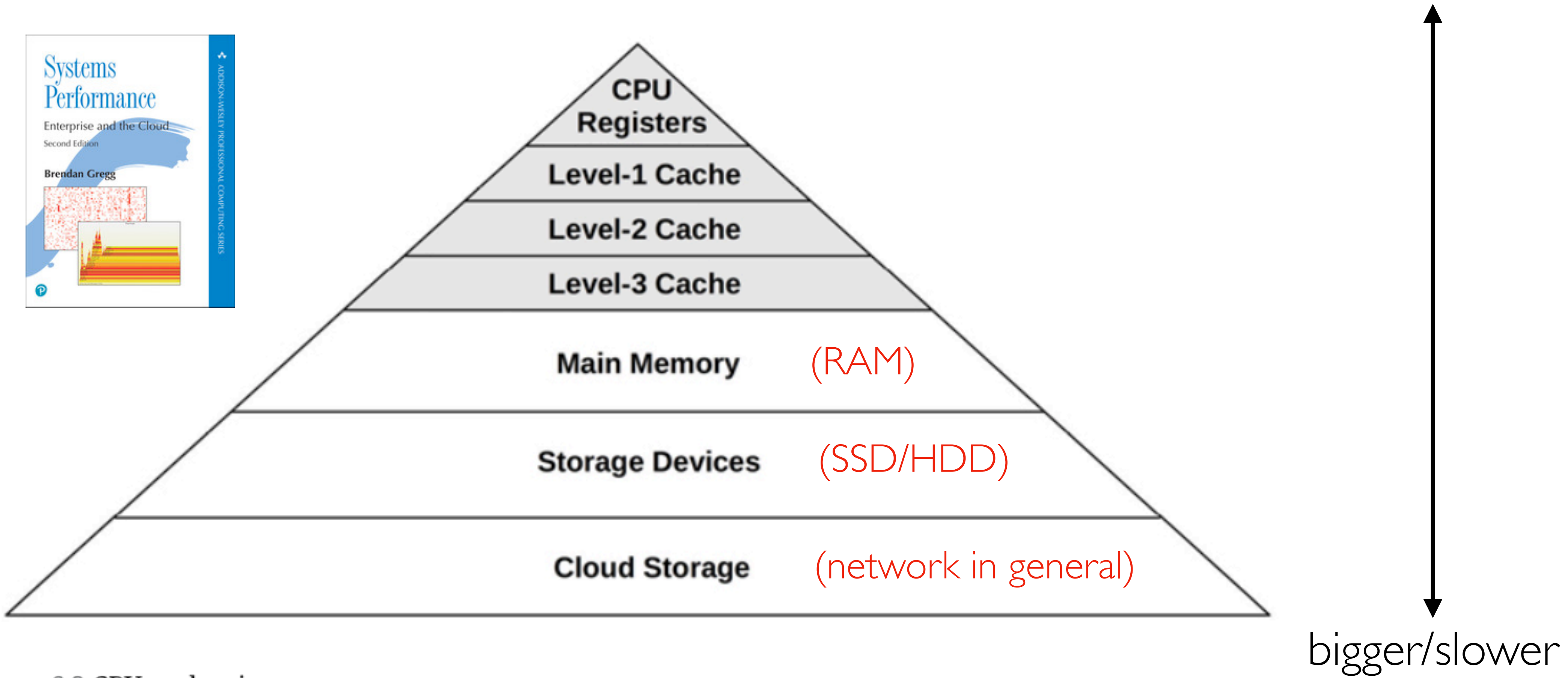
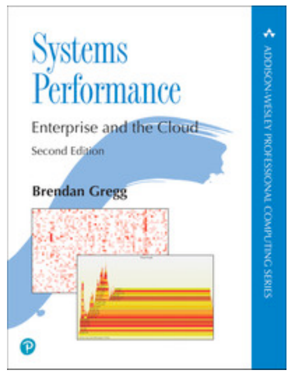


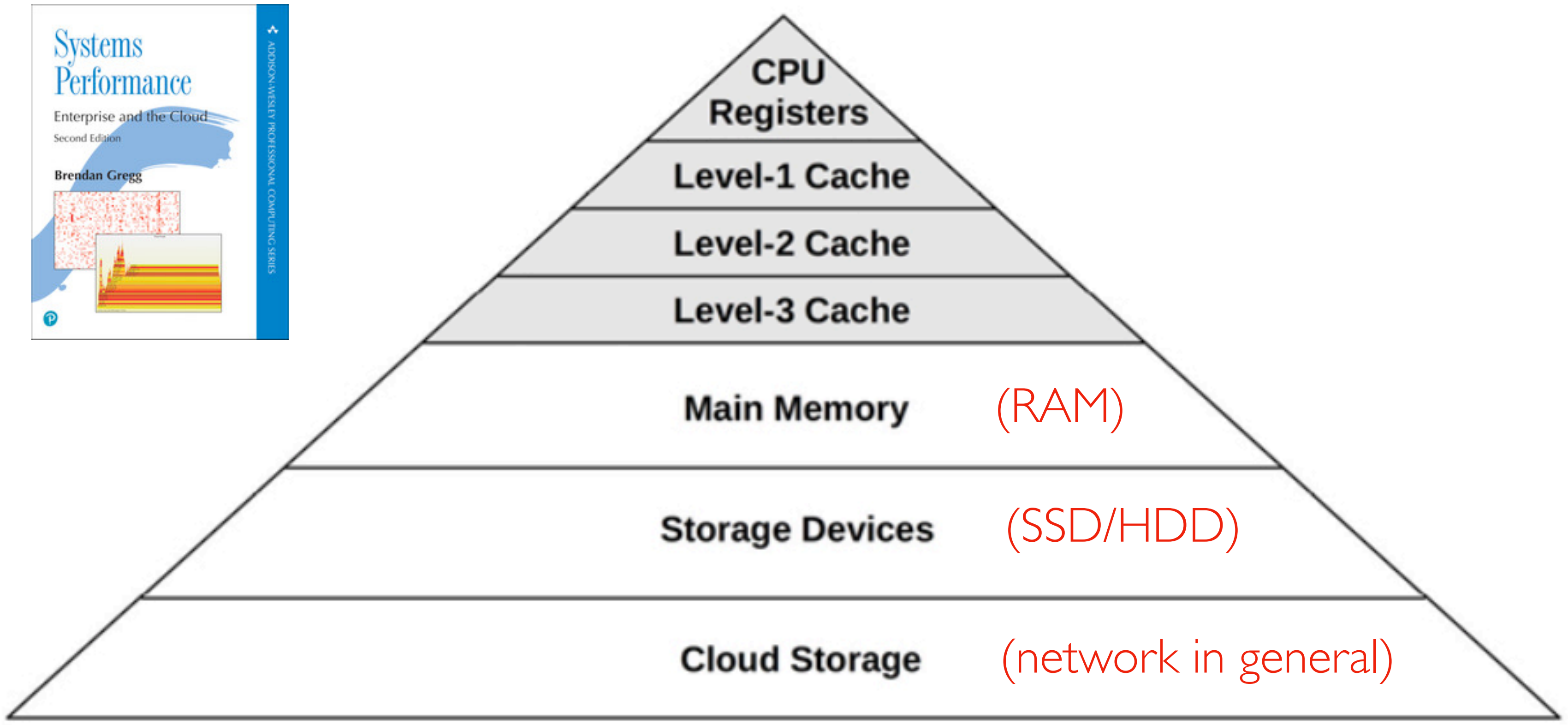
Figure 6.2 CPU cache sizes

Example: Intel Xeon Platinum 9282 (2019)

- L1: 64 KB
- L2: 1 MB
- L3: 77 MB

Cache Hierarchy

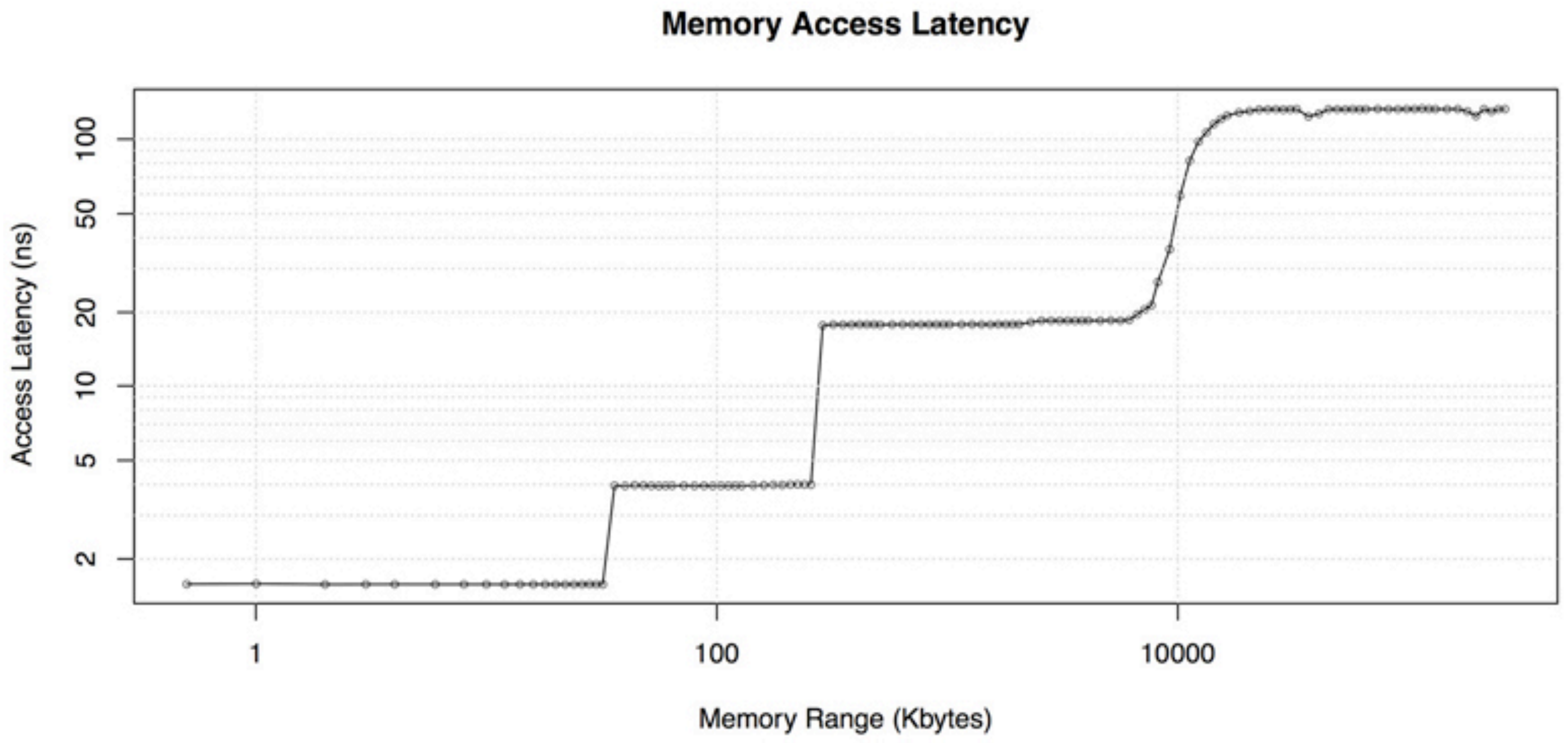




faster/smaller

bigger/slower

Figure 6.2 CPU cache sizes



about how big is the L3 cache?
what is the latency for an L3 cache access?

Resource Tradeoffs

Operating system caches file data in RAM

- use memory
- avoid storage reads

Browser caches recently visited page as file

- uses storage space/reads
- avoid network transfers

Python dictionary caches return values in a dict (key=args, val=return)

- uses memory space
- avoid repeated compute

```
cache = {}
def f(x):
    if not x in cache:
        cache[x] = g(x)
    return cache[x]
```

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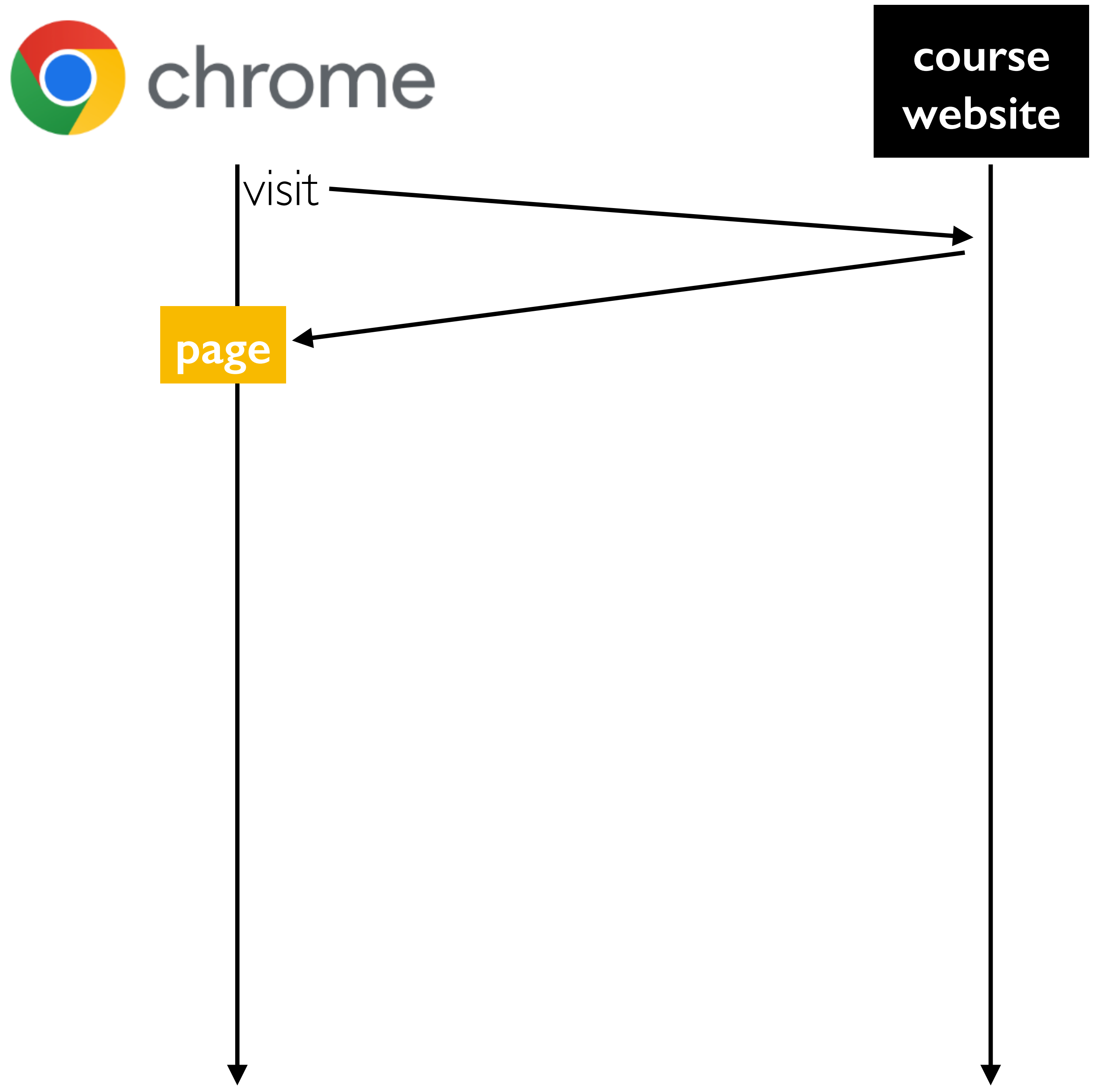
Practice

Manual Caching: Spark Example

```
spark_df = ???? # not usually in memory

spark_df.cache() # put it in memory

# use spark_df for a lot of calculations

spark_df.unpersist() # free up memory
```

we'll be spending lots of time on Spark later in the semester

Expiration: Browser Example



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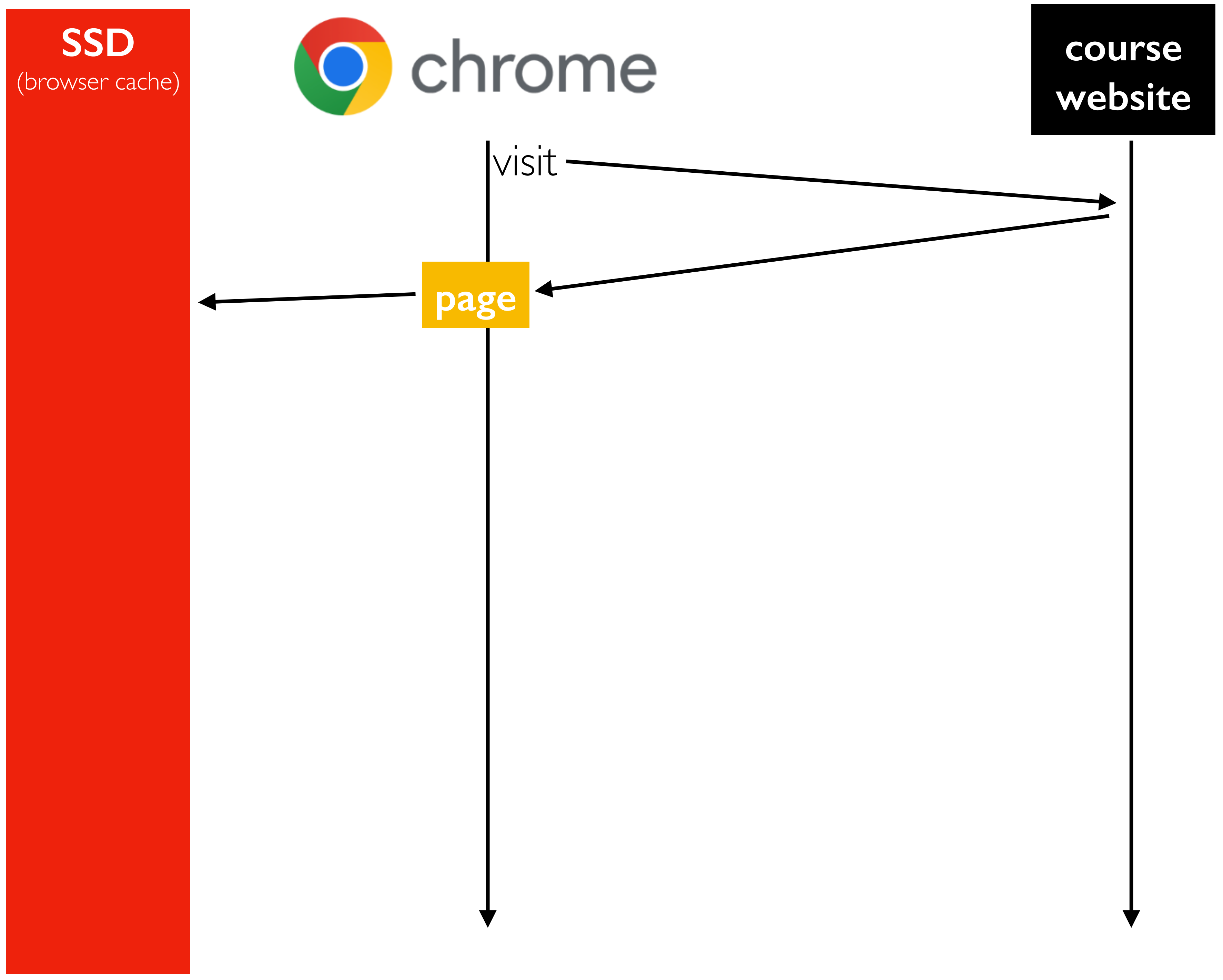

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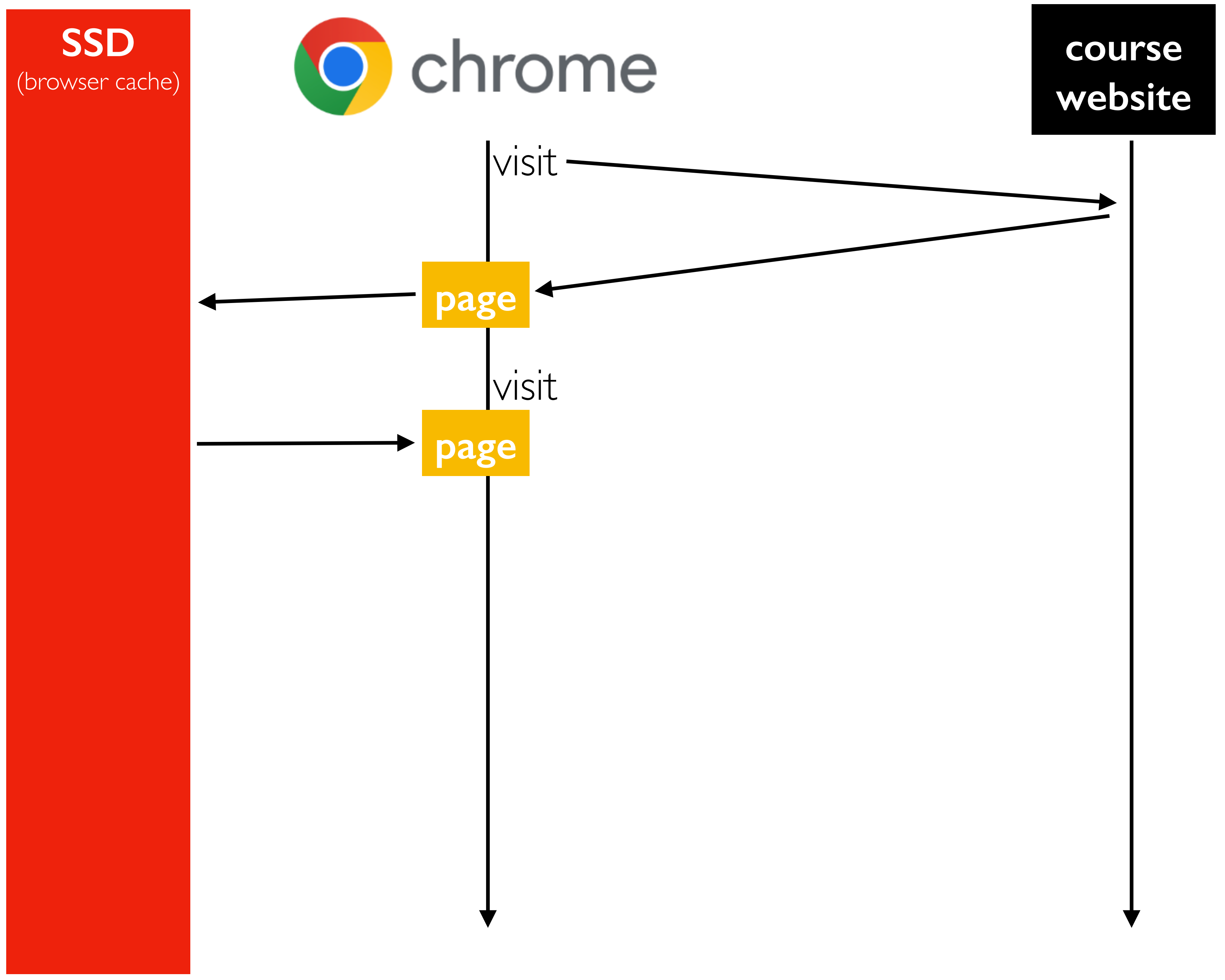

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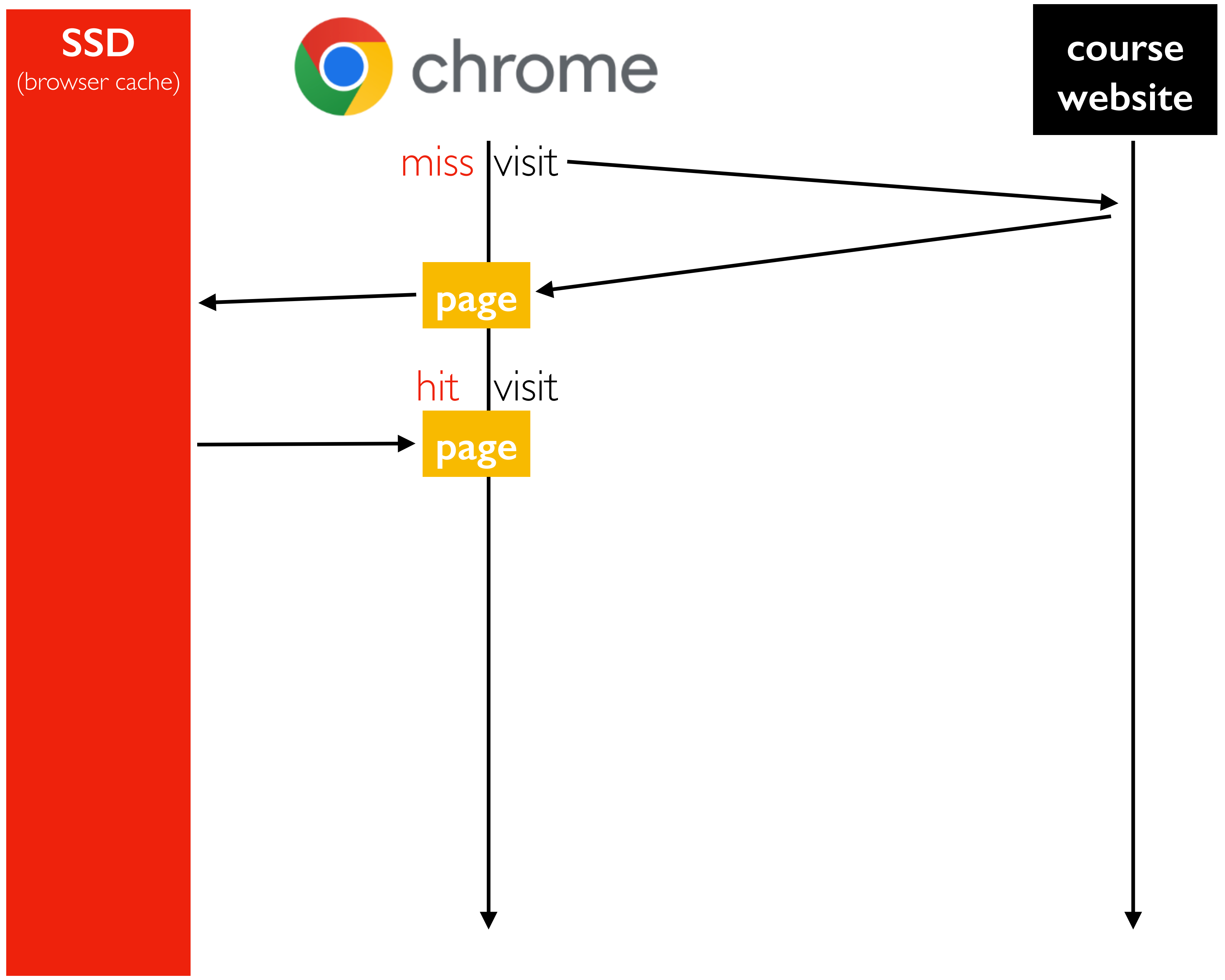

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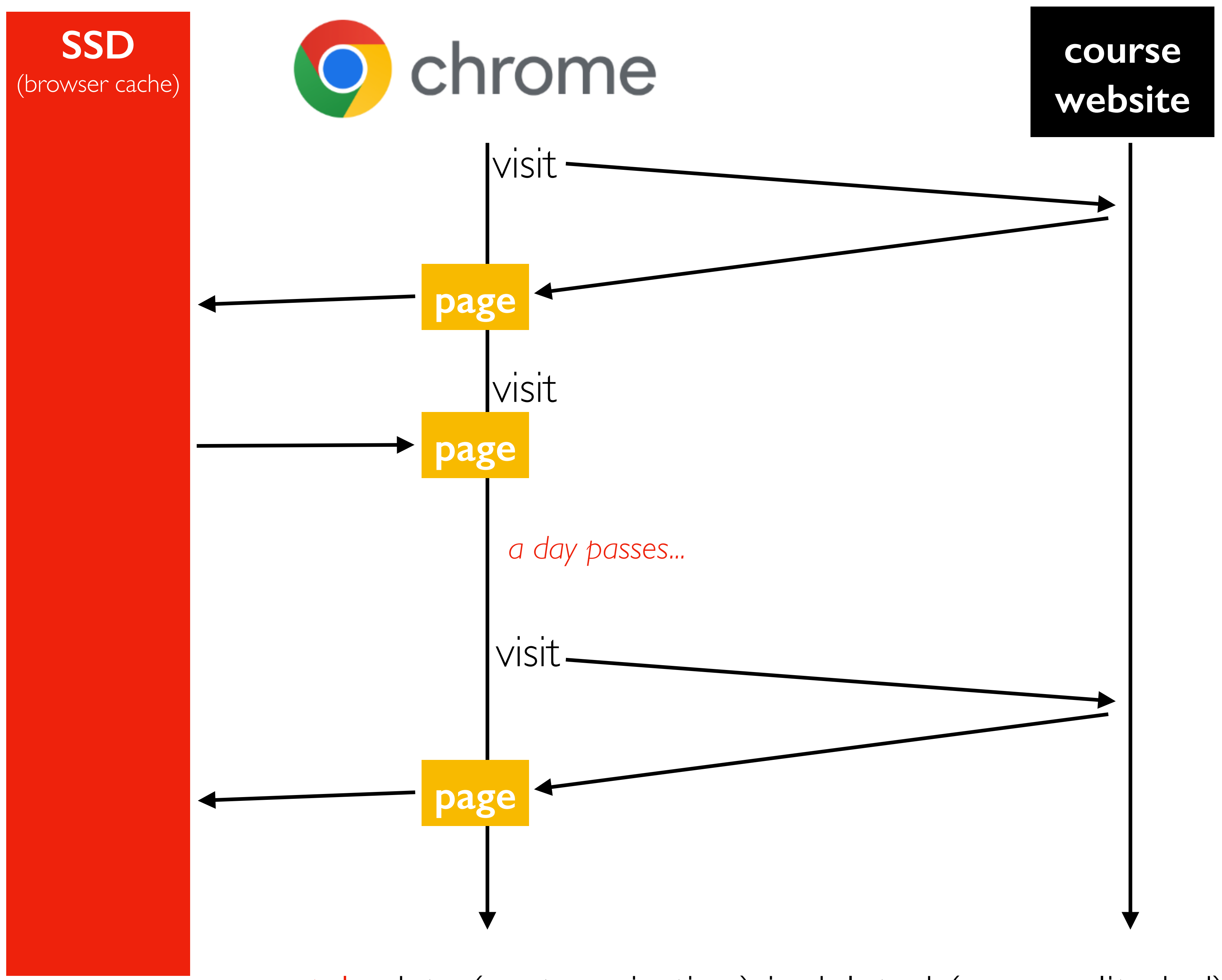

stale data (past expiration) is deleted (or re-valitaded).
SSD is large so freshness is a more important factor than space.

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Cache Policies

When to load data to a cache?

- usually whenever we read something, add it
- an exception: programmer knows it will never be read again
  - for example, F_NOCACHE option in Linux. Example program:
    - read file.txt (caching off)
    - compress it
    - write file.txt.gz
    - delete file.txt

When to evict data to a cache? Several policies

- random
  - select any entry at random as victim for eviction
- FIFO (first in, first out)
  - evict whichever entry has been in the cache the longest
- LRU (least recently used)
  - evict whichever entry has been used the least recently

Worksheet

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