CDN Caching

COS 316: Principles of Computer System Design

Lecture 9

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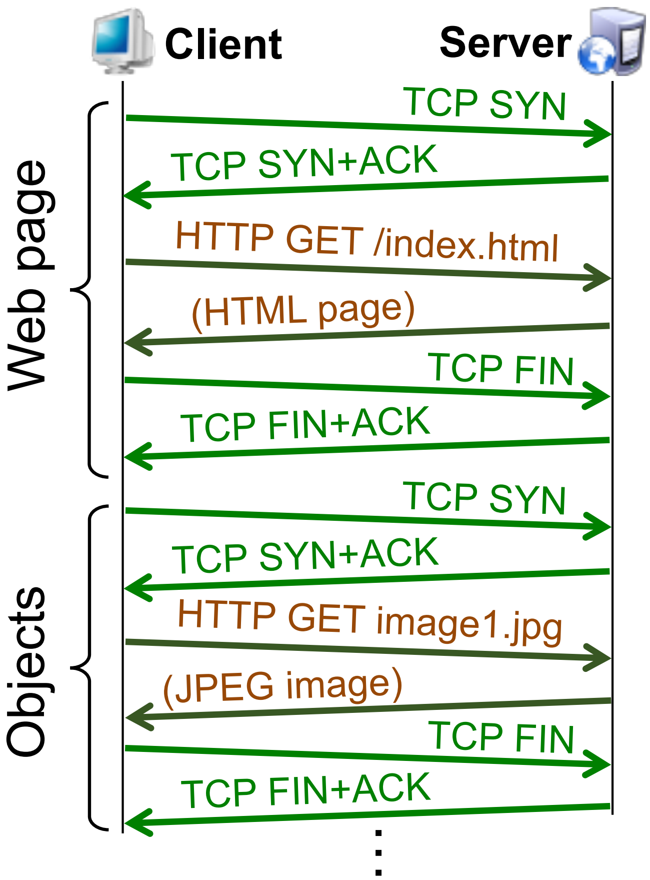
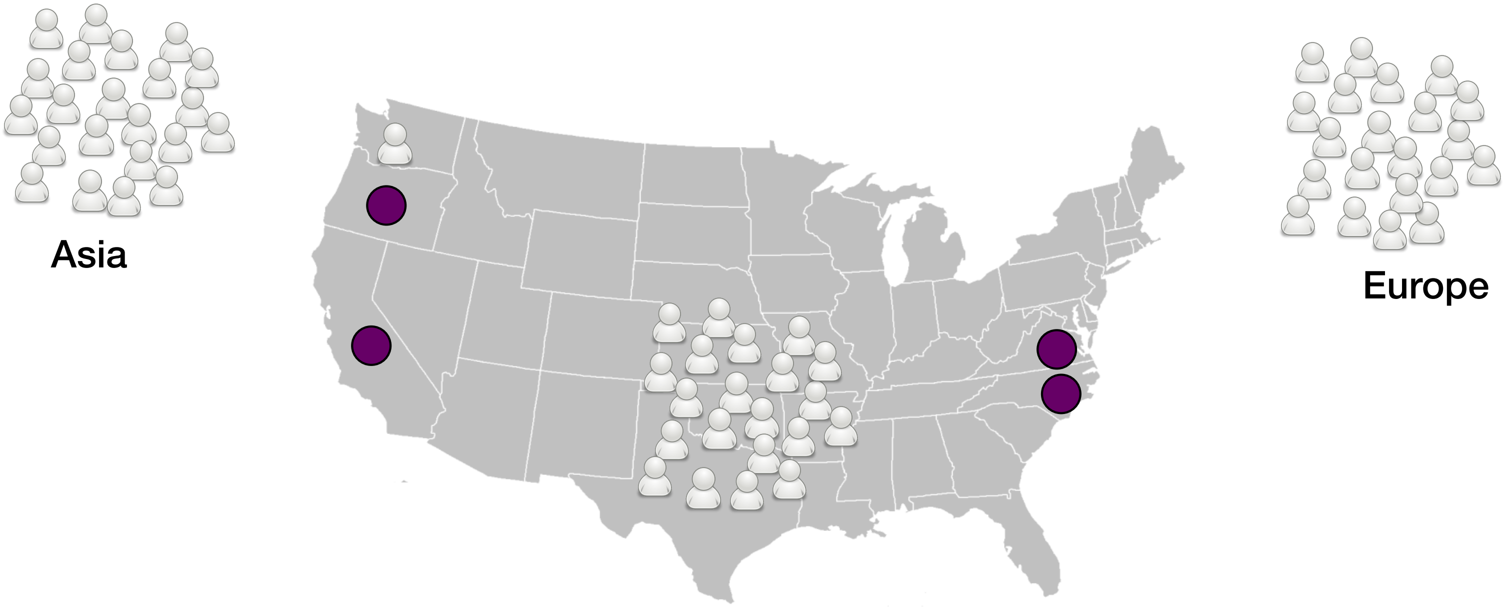
Anatomy of a Web Page Fetch

- Web page = HTML file + embedded images/objects

- HTML page does not embed objects in it
  - *Q: Why not?*

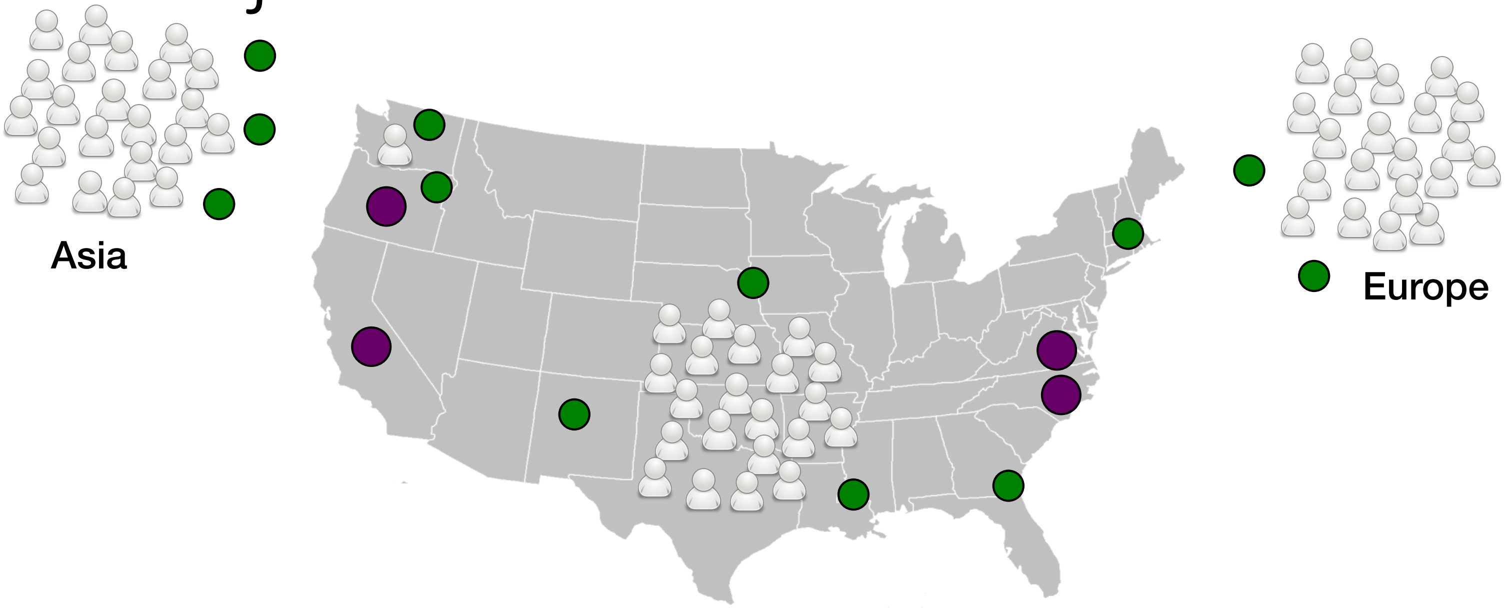


Serve It All From Datacenters?



- High latency for many clients ☹
- Use a ton of bandwidth to send the same objects over and over ☹

Serve Objects From CDN



- Lower latency because content is closer ☺

- Less global bandwidth ☺

CDN Locations

- Where can we stick machines?
- Inside our datacenters
- At colocation facilities
  (other people's DCs)
- At Internet Exchange Points
- Inside others' networks

Not *that* many machines (limited space and/or high cost)

CDN Locations vs Datacenters

- There are many more CDN locations
  - e.g., Akamai has 1000+
- CDNs are closer to people
  - Because there are more of them
  - Placed for locality
- CDN locations are much wimpier
  - Maybe 1 rack (~40 machines)
  - …
  - Maybe 8 racks (~320 machines)

Which ones do clients connect to?

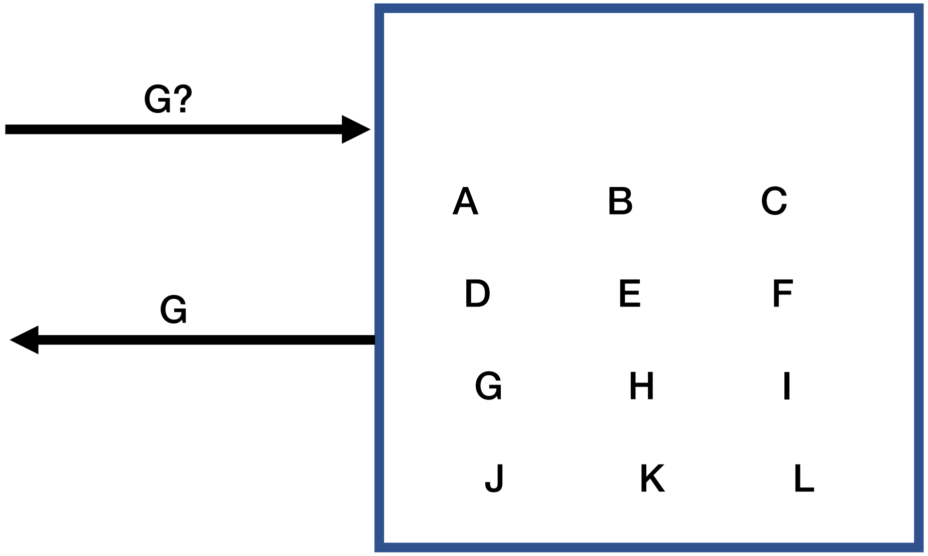
What do we store on them?

CDN Locations Store What?

- Store everything?
  - Exabytes of data for some services
  - 1 rack (40 machines):
    - 144 GB memory? * 40 -> 5.8TB memory … not even close…
    - 10x4 TB HDD? * 40 -> 1.6 PB … not even close…

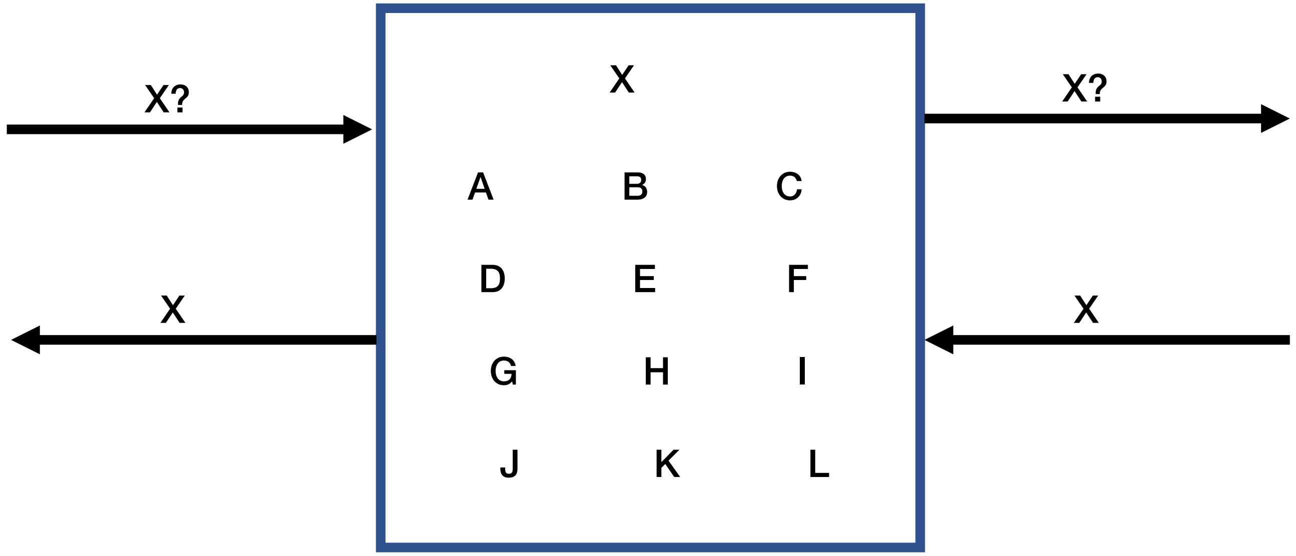
- Need to store a subset of objects!
  - *Q: But which objects to store?*

CDN Cache Hit



A B C
D E F
G H I
J K L

CDN Cache Miss



If I want to store X, what do I get rid of to make space?

Cache Algorithms 101

- First In First Out (FIFO)
- Least recently used (LRU)
- Least frequently used (LFU)
- Belady (Offline optimal)

- (Note: all fully associative today)

First-In-First-Out (FIFO)

- Evict objects added to cache longest ago
- Very simple!

- 3 item cache example:
  - Request stream: a, b, a, c, a, d, a, e, a, f, g

- Can we do better?

Least Recently Used (LRU)

- Evict object used longest ago
  - “Objects used more recently are more likely to be accessed again”
  - Exploits temporal locality

- Implementation: Update access time for every hit

- 3 item cache example:
  - Request stream: a, b, a, c, a, d, a, e, a, f, g
  - Request stream: h, h, h, i, j, k, h

Least Frequently Used (LFU)

- Evict object with fewest hits
  - "Objects used more often are more likely to be accessed again"
  - If tie, use LRU

- Implementation: Update access count for every hit

- 3 item cache example:
  - Request stream: a, b, a, c, a, d, a, e, a, f, g
  - Request stream: h, h, h, i, j, k, h
  - Request stream: l, l, m, n, o, m

Belady (Offline Optimal Caching)

- What is the best a caching algorithm could do?
- Offline: uses knowledge of the future
    - (Can't use in practice)

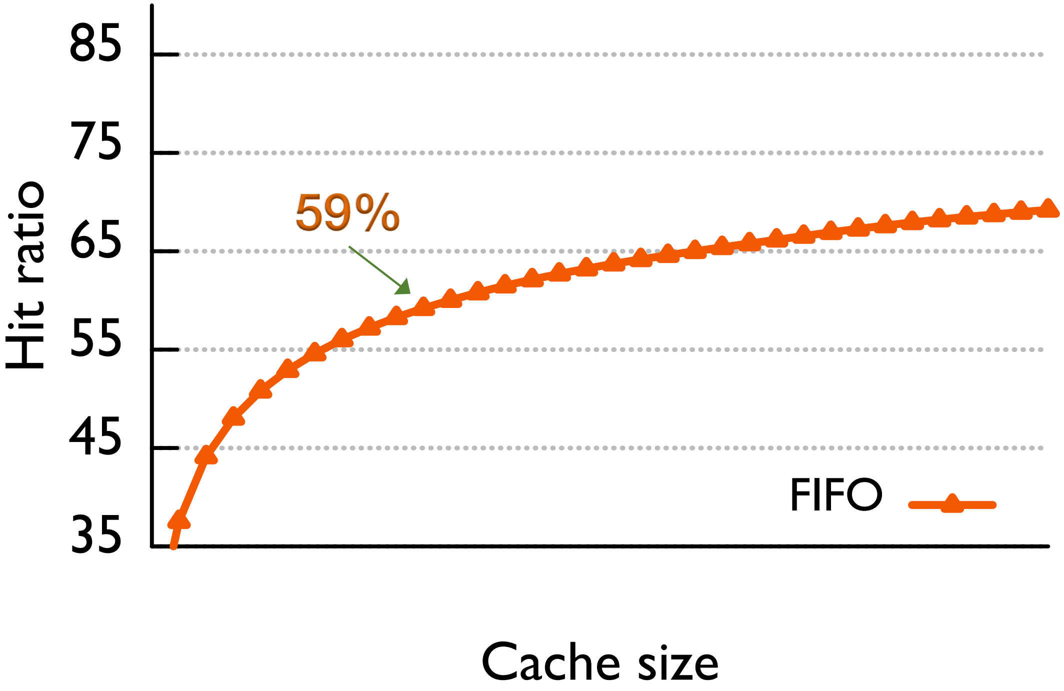
- Evict the object with the furthest **next** access time
    - Worst object to keep in the cache

- 3 item cache example:
    - Request stream: h, h, h, i, j, k, h
    - Request stream: l, l, m, n, o, m

Effectiveness of Algorithms for CDN Caching?

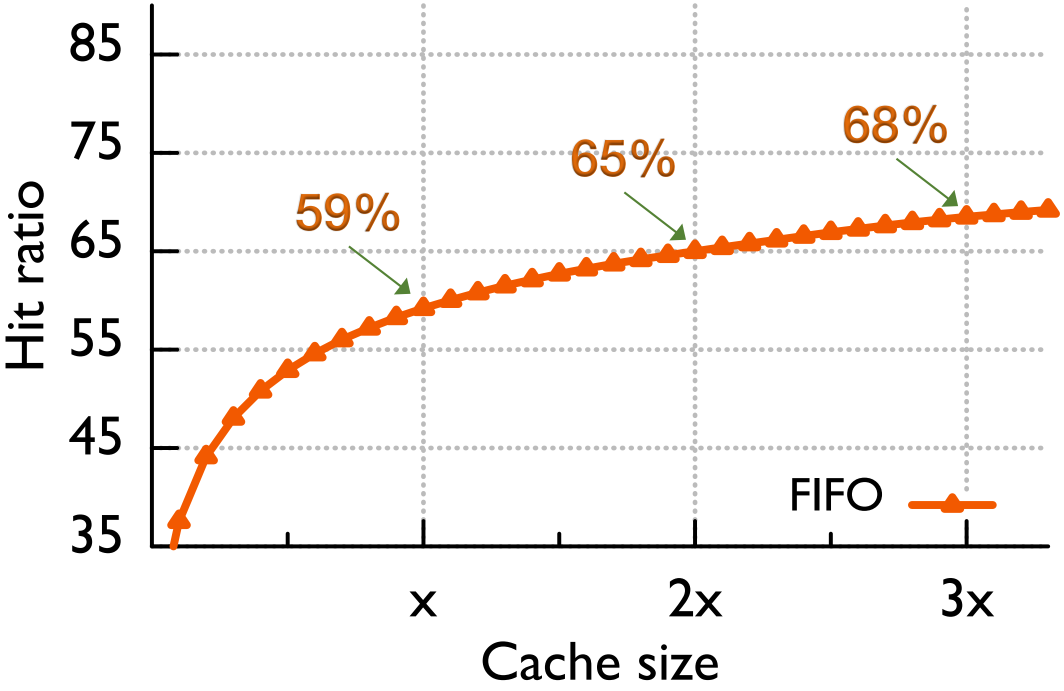
[Figures from Qi Huang’s 2013 SOSP Talk]

Edge Cache with Different Sizes



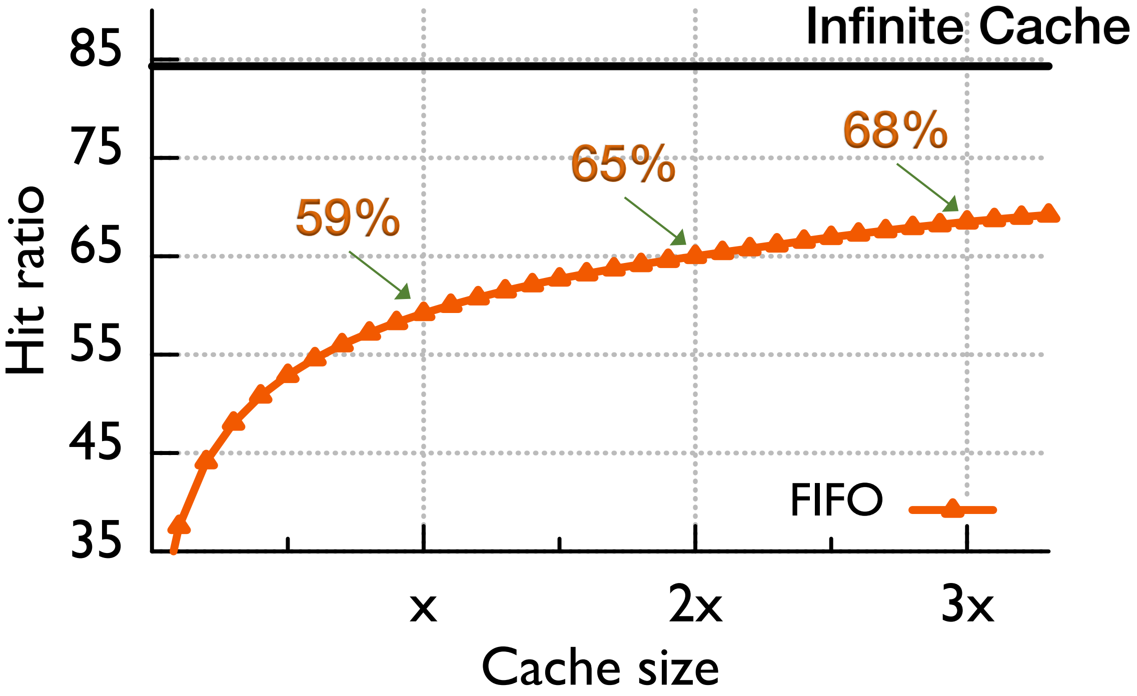
- **Facebook’s San Jose CDN edge cache circa 2013**

Edge Cache with Different Sizes



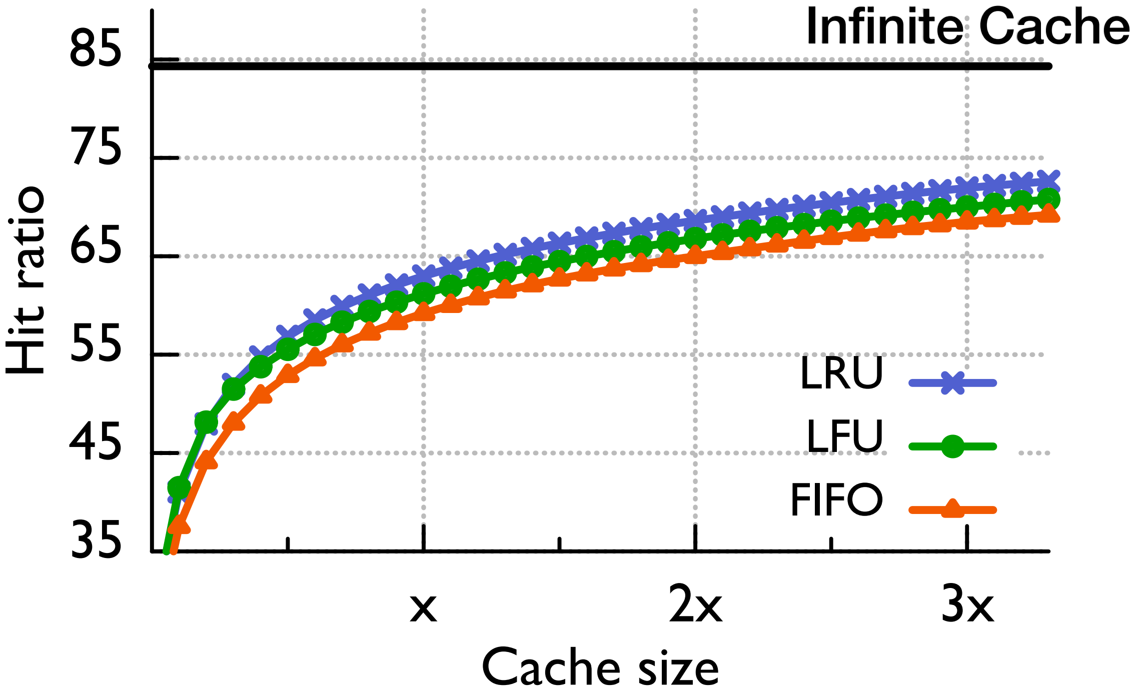
- “x” estimates deployment size (59% hit ratio)

Edge Cache with Different Sizes



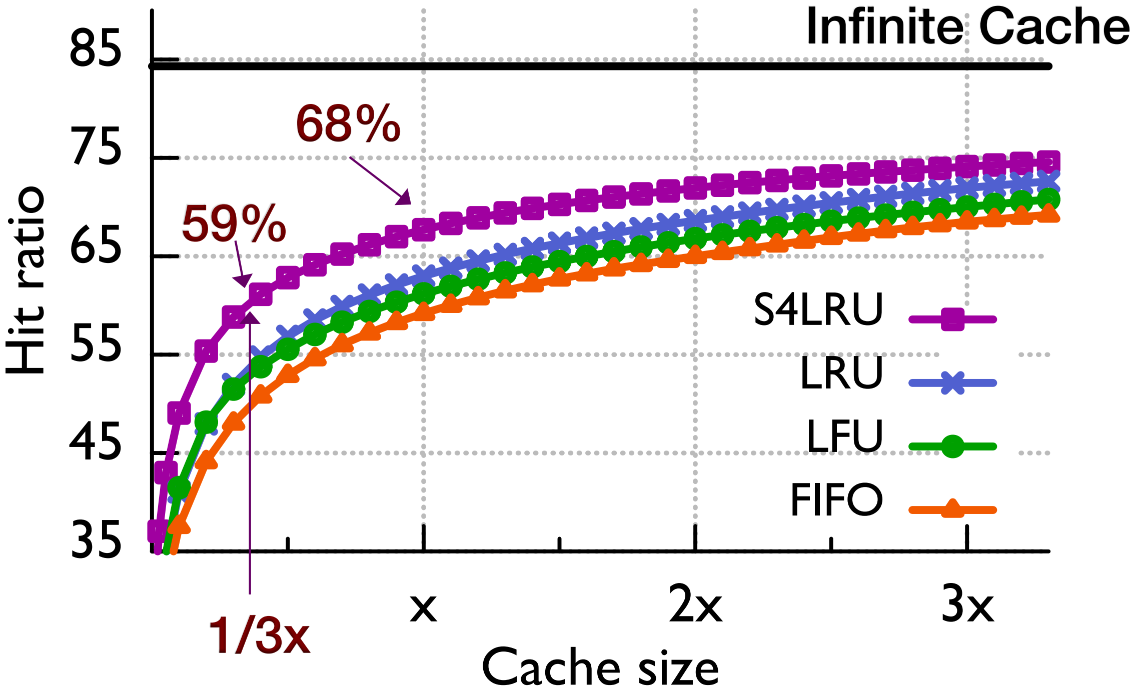
- "Infinite" size ratio needs 45x of capacity

Edge Cache with Different Algos



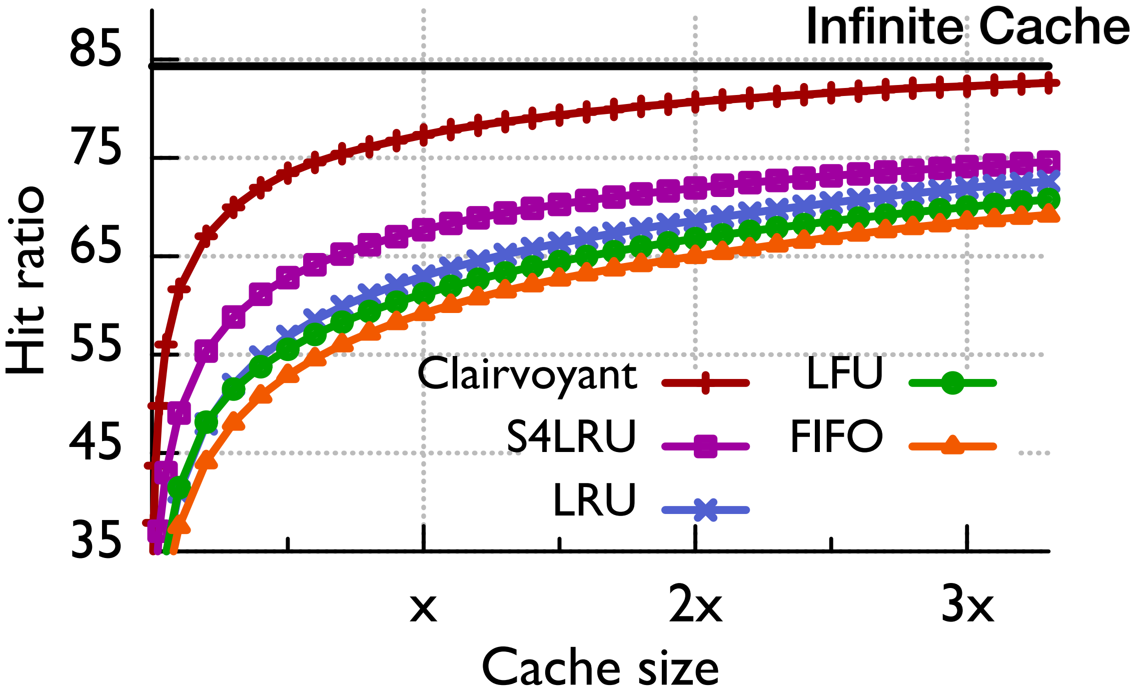
- LRU > LFU > FIFO

Edge Cache with Different Algos



- **S4LRU** is a more complex algorithm, uses recency and frequency

Edge Cache with Different Algos

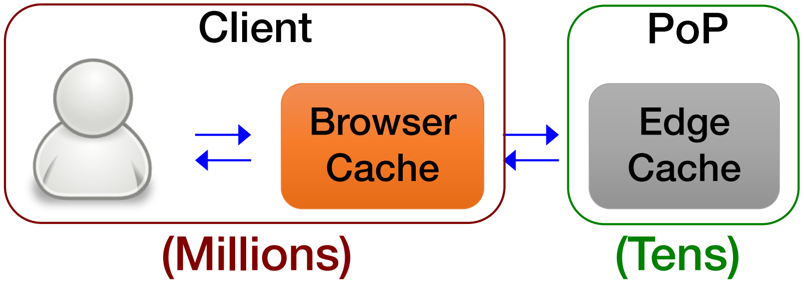


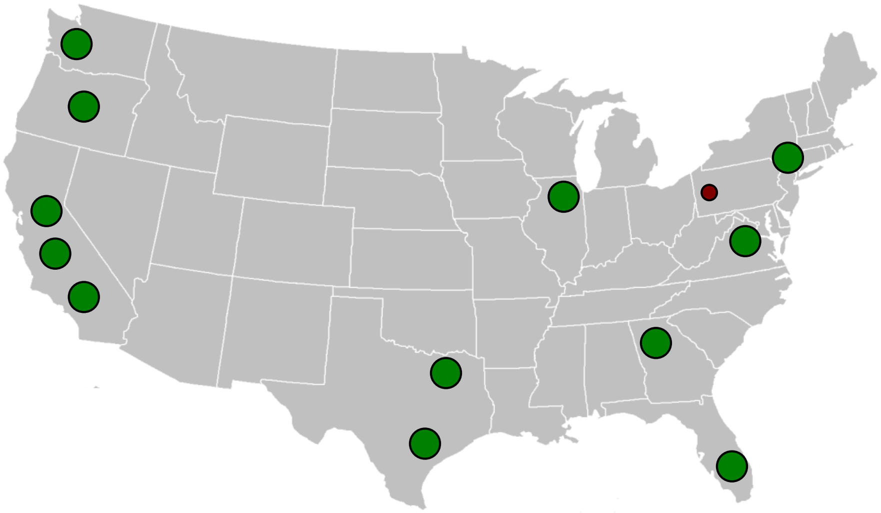
- Clairvoyant (Bélády) shows we can do much better!

A Hierarchy of CDN Caches

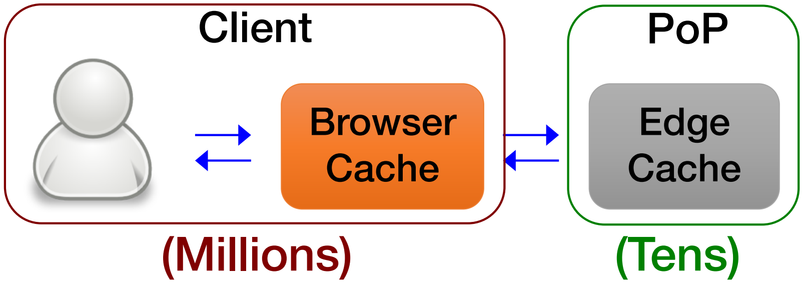
[Figures from Qi Huang's 2013 SOSP Talk]

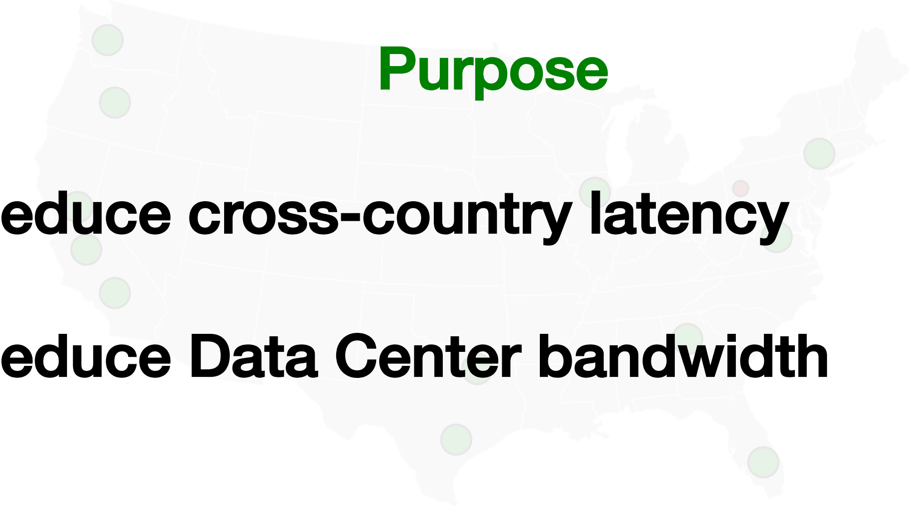
Geo-distributed Edge Cache (FIFO)





Geo-distributed Edge Cache (FIFO)

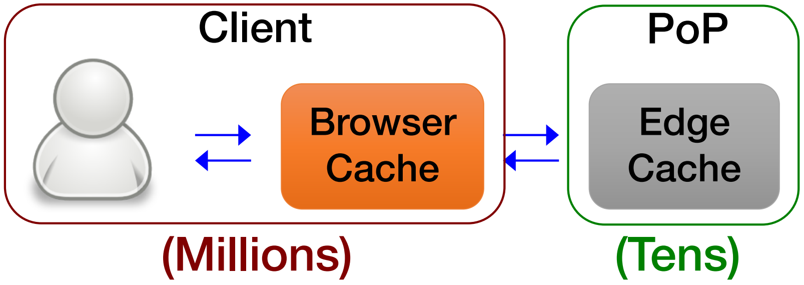




Purpose

1. **Reduce cross-country latency**
2. **Reduce Data Center bandwidth**

Geo-distributed Edge Cache (FIFO)



Client

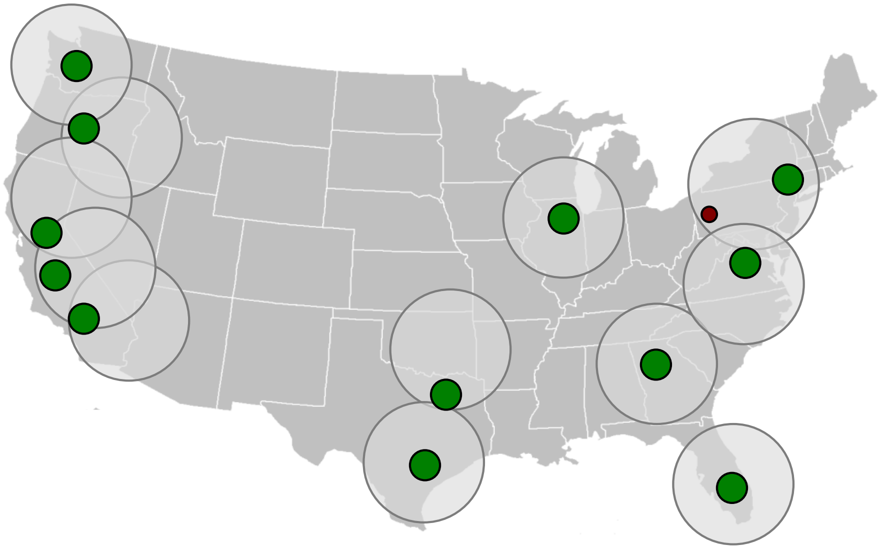
Browser Cache

PoP

Edge Cache

(Millions)

(Tens)



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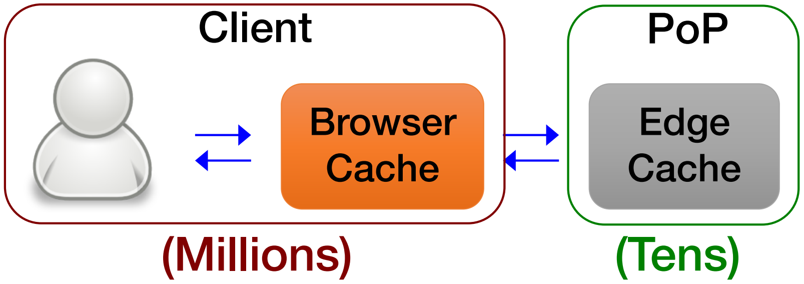
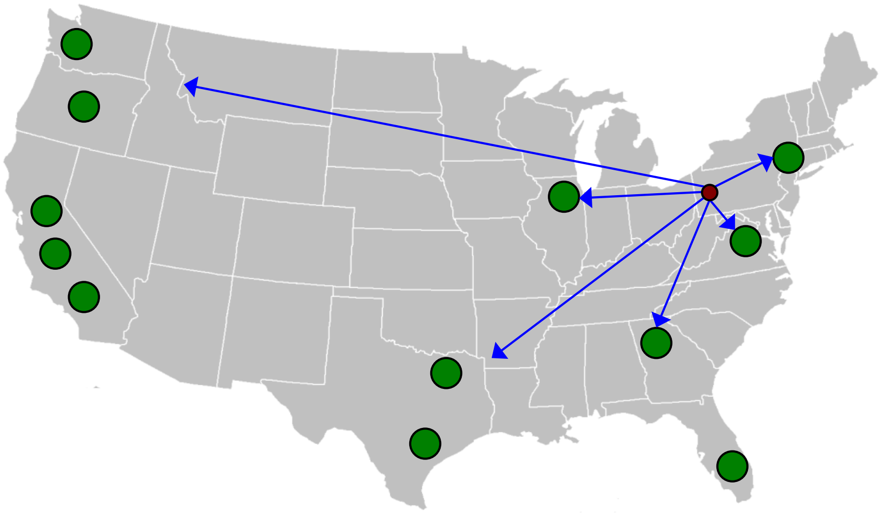
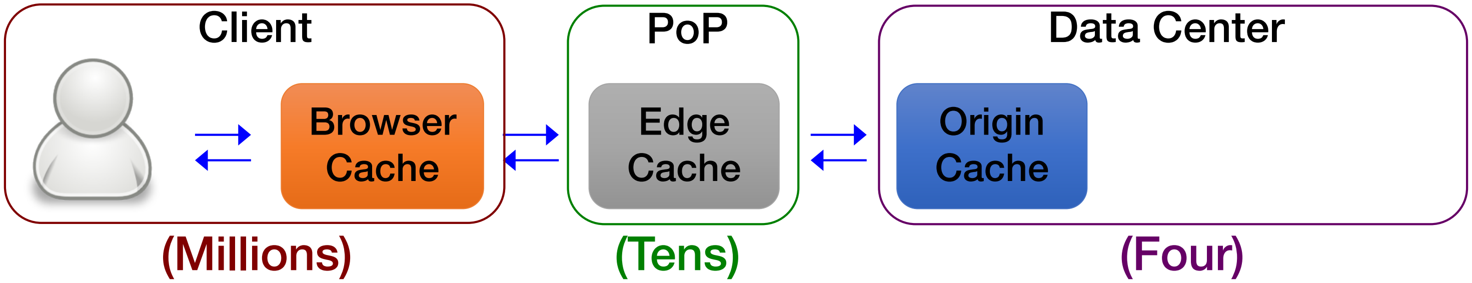
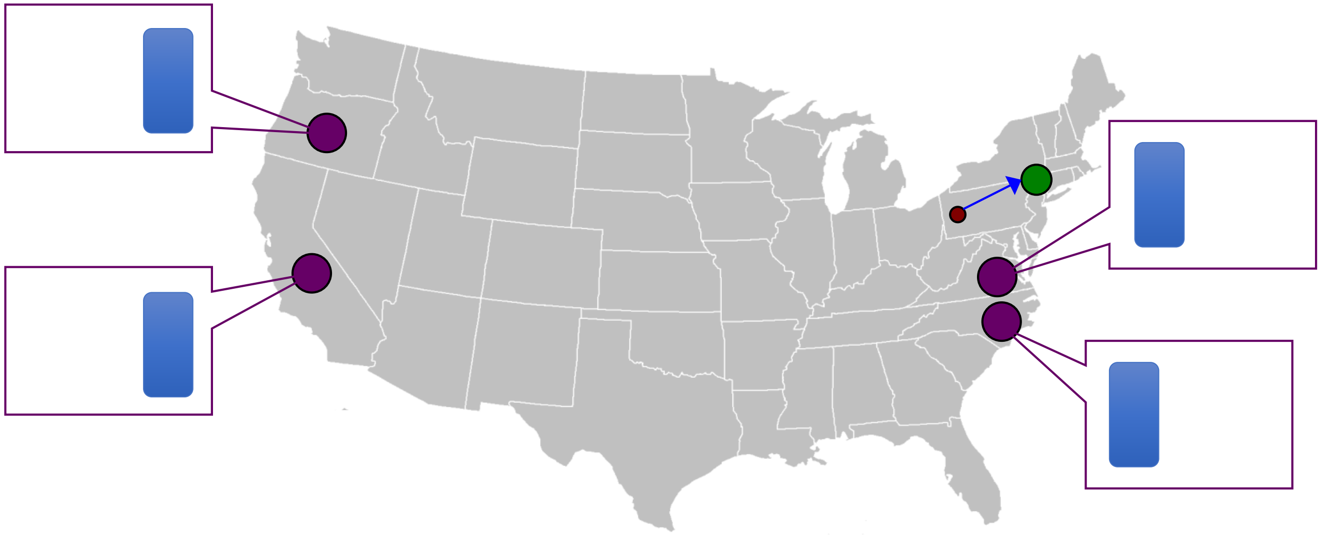




Single Global Origin Cache (FIFO)





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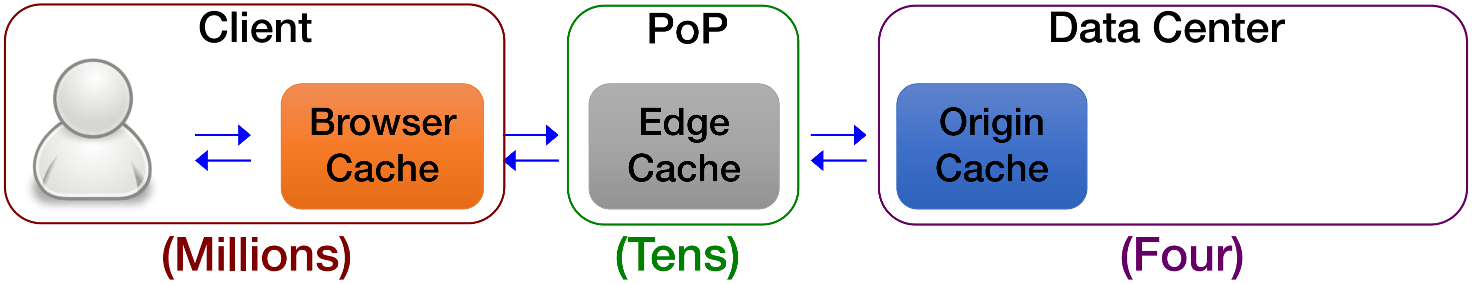

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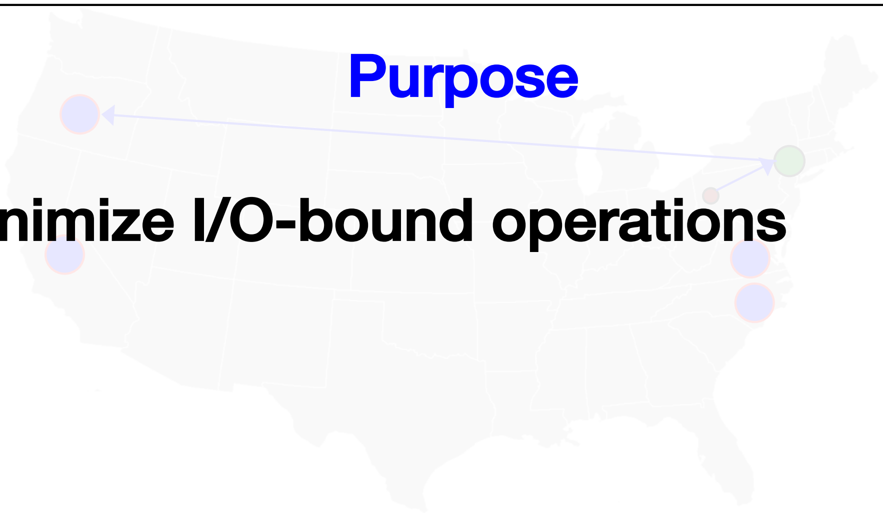
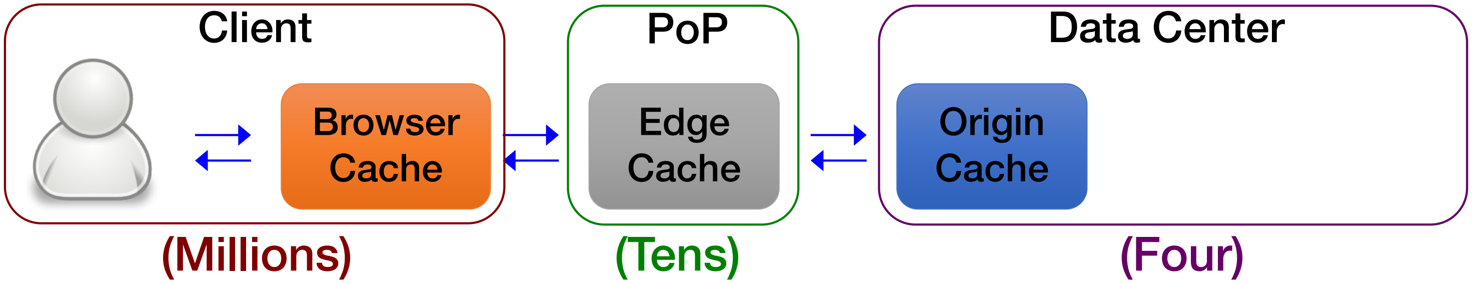


1. Minimize I/O-bound operations

Single Global Origin Cache (FIFO)



Client

Browser Cache

(Millions)

PoP

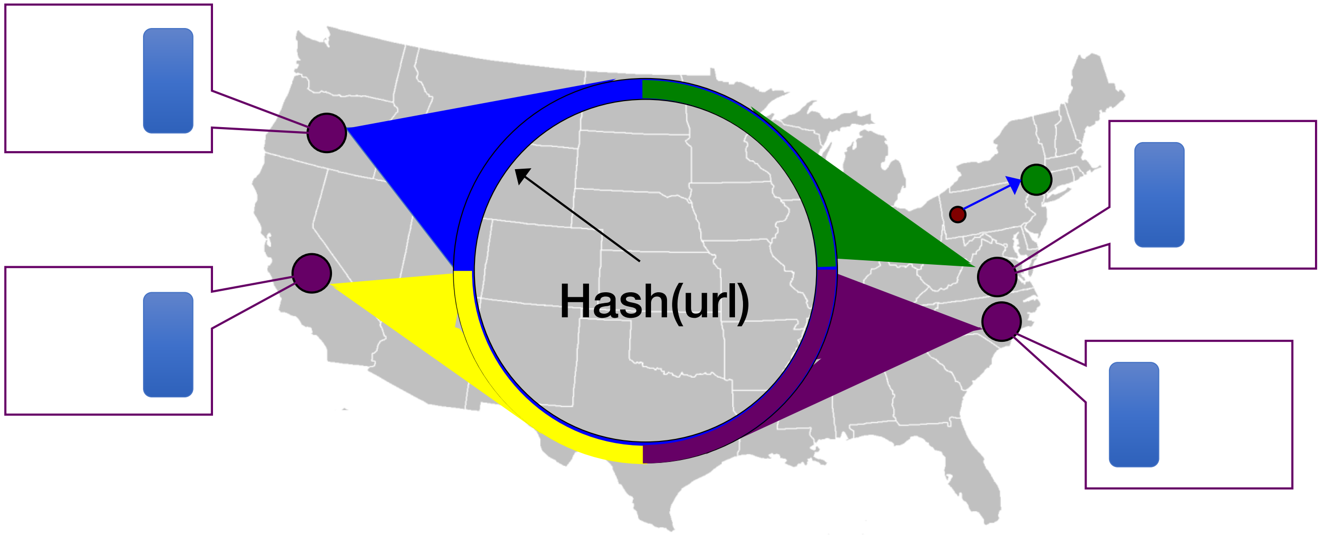
Edge Cache

(Tens)

Data Center

Origin Cache

(Four)



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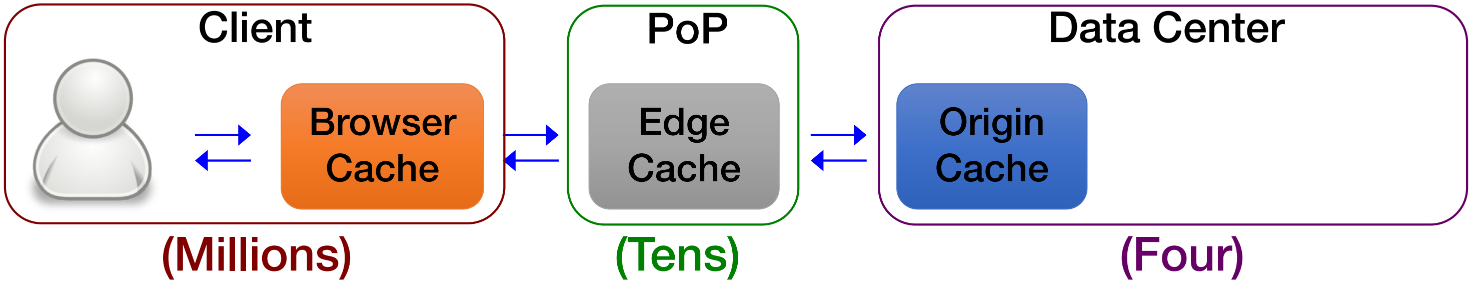

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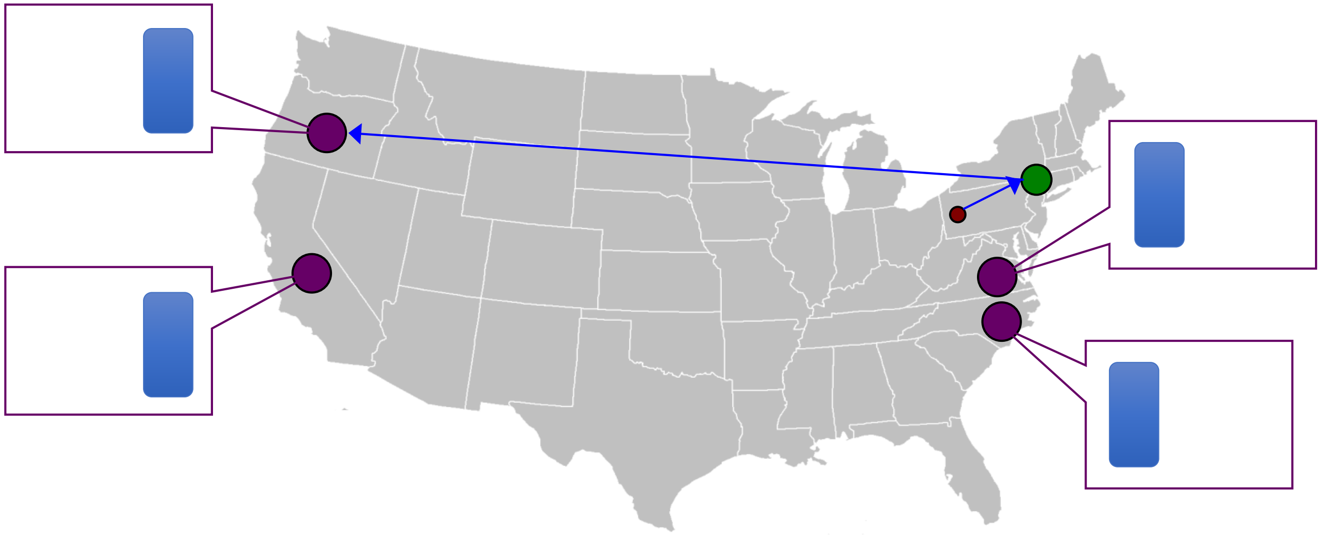
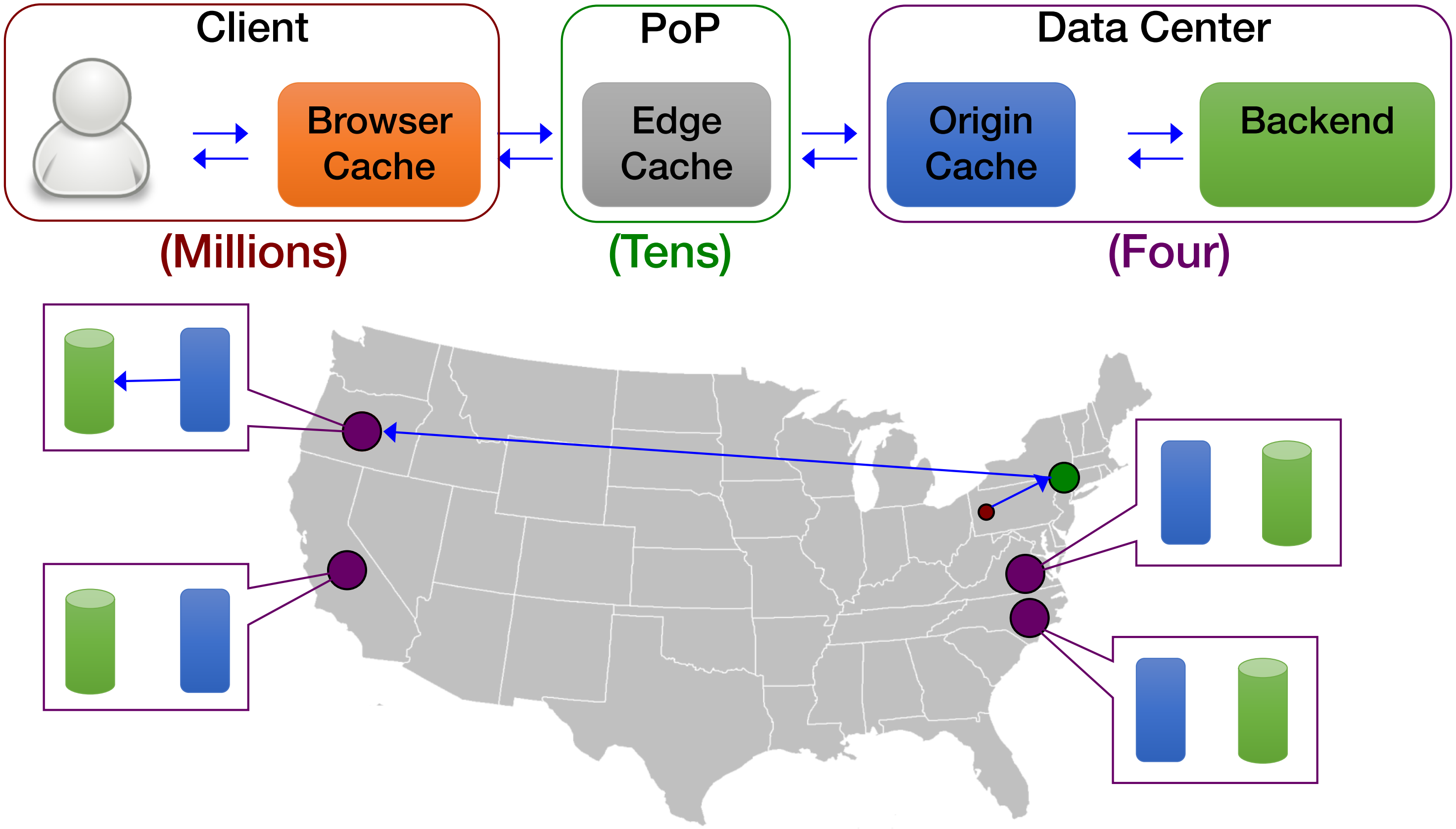


Backend


Client
Browser Cache
(Millions)
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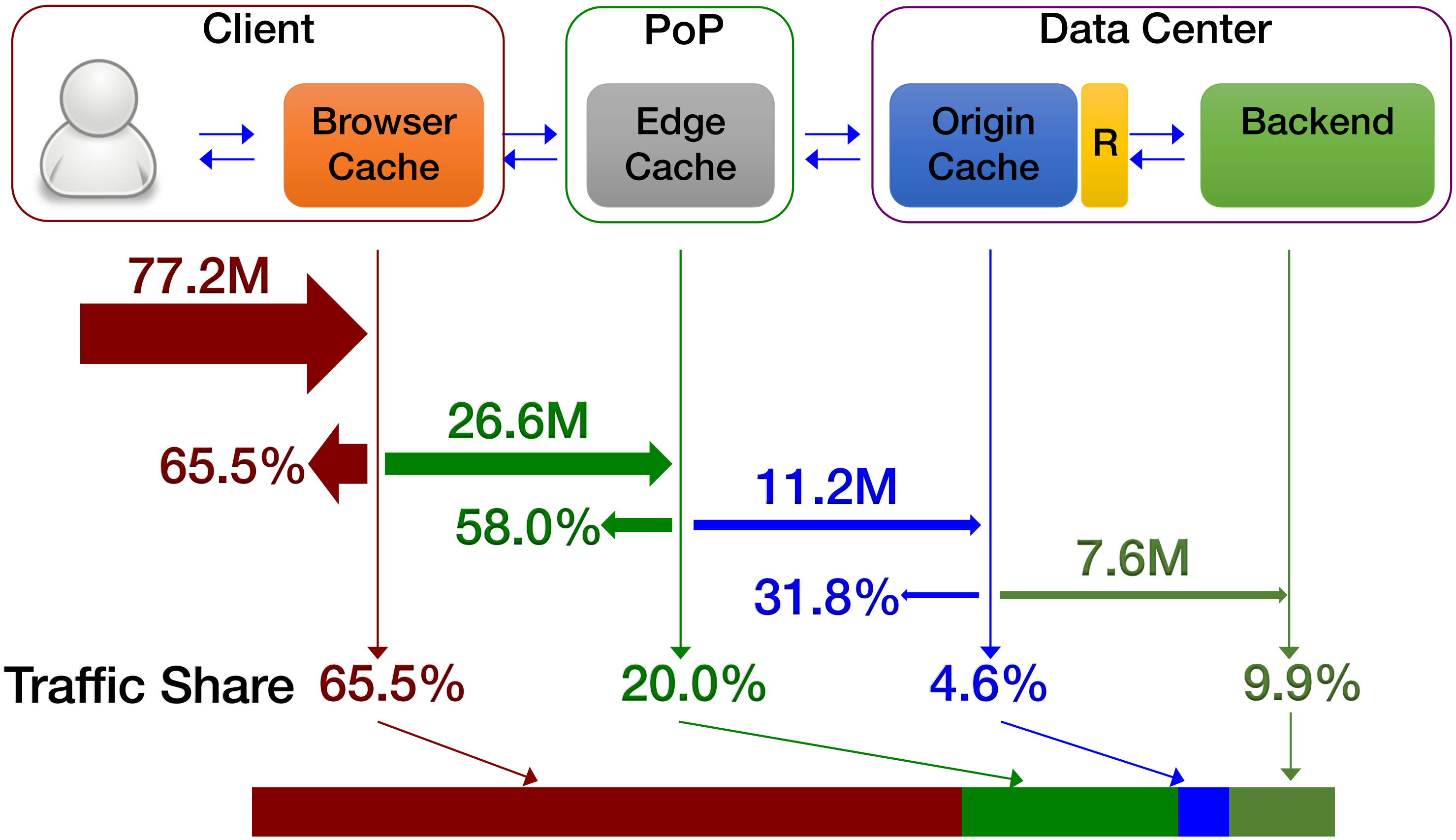
CDN Effectiveness



Content Distribution Networks

- Serve “objects” in web pages, and much more, e.g., video segments

- Caching Algorithms: What do we store on them?
    - FIFO, LRU, LFU, Belady, … active area of research

- CDN Hierarchy
    - Smaller / more localized caches → bigger / more general caches