Exploiting Serverless Function to Build a Cost-effective Cloud Storage

CS 4740: Cloud Computing

Fall 2024

Lecture 14d

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Rule-breaking approach

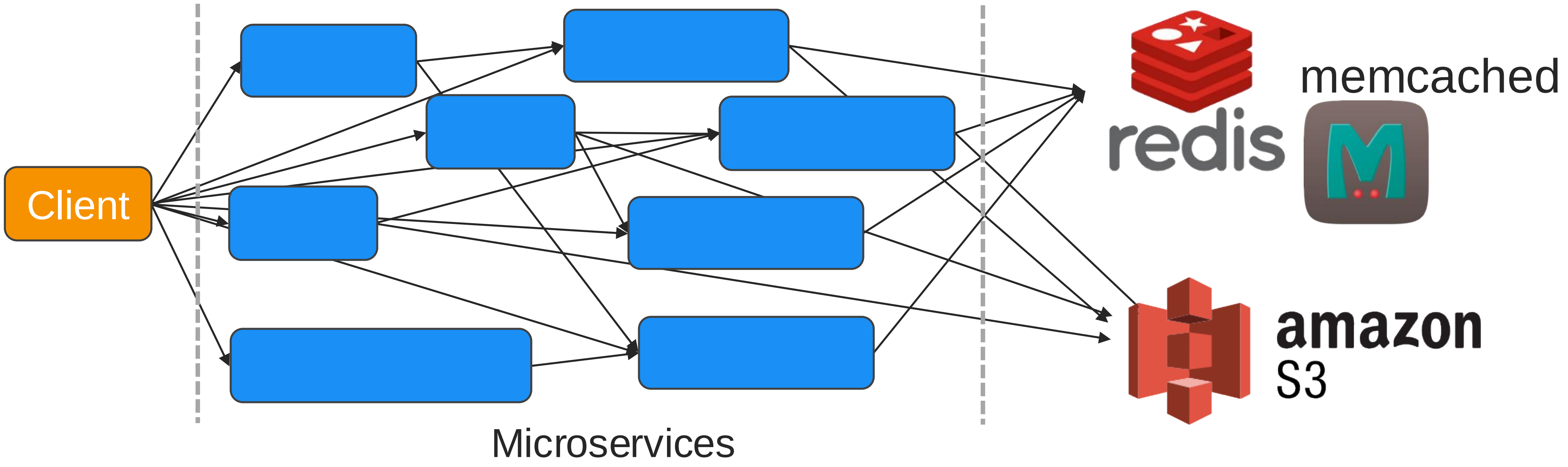
* Quoted from "*A Rule-Breaking Approach to Research*", by Todd Austin, MICRO'24.

- A rule-breaking approach is effective and exciting
  - Identify a rule no one breaks
  - Invent a way to break that rule
  - See what happens!
- You will often find yourself in fertile ground
  - The "rules" are typically learned early or based on "conventional wisdom"
  - The "rules" create dogma that hide opportunity
- 50% will be intrigued with your crazy idea
- 50% will think your crazy idea will never work
- Embrace the pushback, it will inform and sharpen

Breaking rules in serverless

- **Rule:** Serverless functions are stateless and can never work as storage
- **Rule-breaking idea:** Use functions as a brand-new storage medium to build a first-of-its-kind cloud storage system
  - Exploiting provider's function caching to retain data between func invocations
  - Erasure coding + replication to improve availability and performance
  - Reasonable performance+availability while being extremely cost-effective for not-too-busy storage workloads
  - Case study: IBM Docker registry

Internet-scale web apps are storage-intensive



Example app: IBM Cloud Container Registry

- Collected the workload traces of IBM Cloud Container Registry service for a duration of **75 days** across **seven datacenters** in 2017
- Selected datacenters: Dallas & London

Example app: IBM Cloud Container Registry

- Object size distribution
- Large objects’ reuse patterns
- Storage footprint

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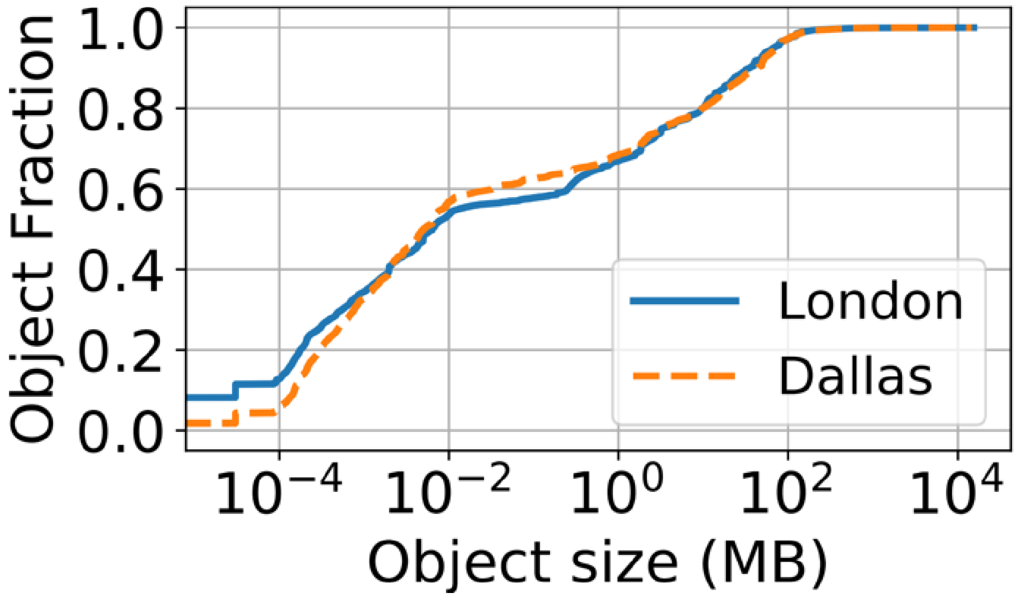
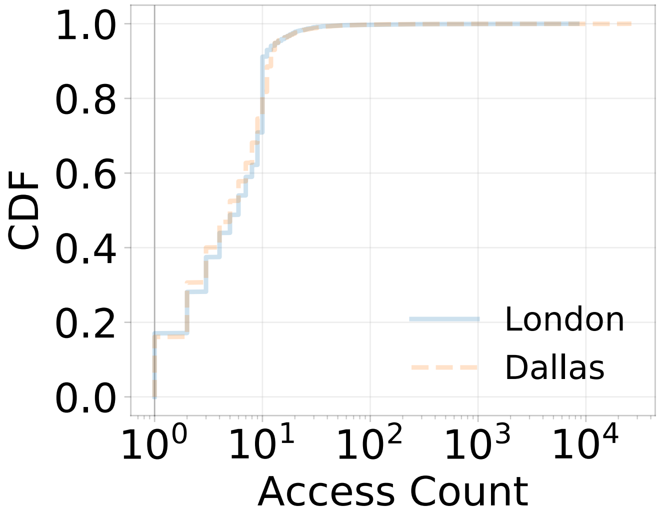


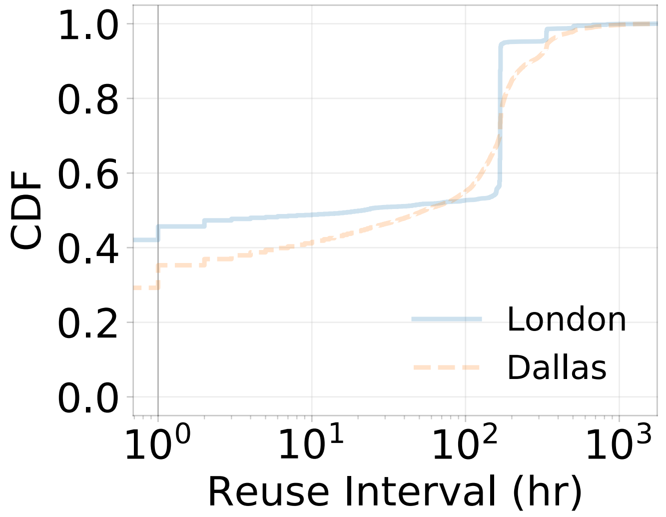
Extreme variability in object sizes:

- ➢ Object sizes span over 9 orders of magnitude
- ➢ 20% of objects > 10MB

Example app: IBM Cloud Container Registry

- Object size distribution
- Large objects' reuse patterns
- Storage footprint





Caching large objects is beneficial:

- > 30% large object being accessed 10+ times
- Around 35-45% of them get reused within 1 hour

Example app: IBM Cloud Container Registry

- Object size distribution
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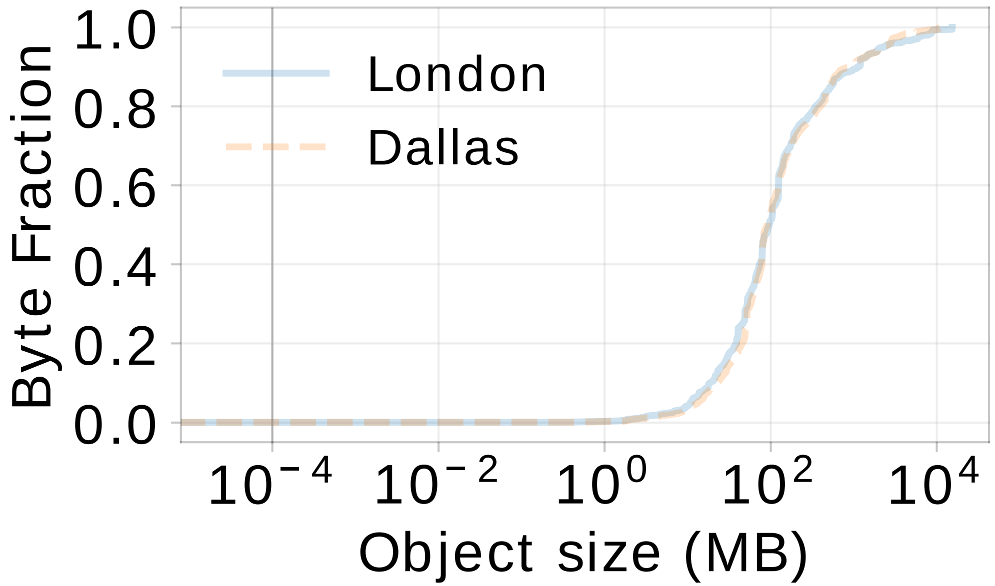
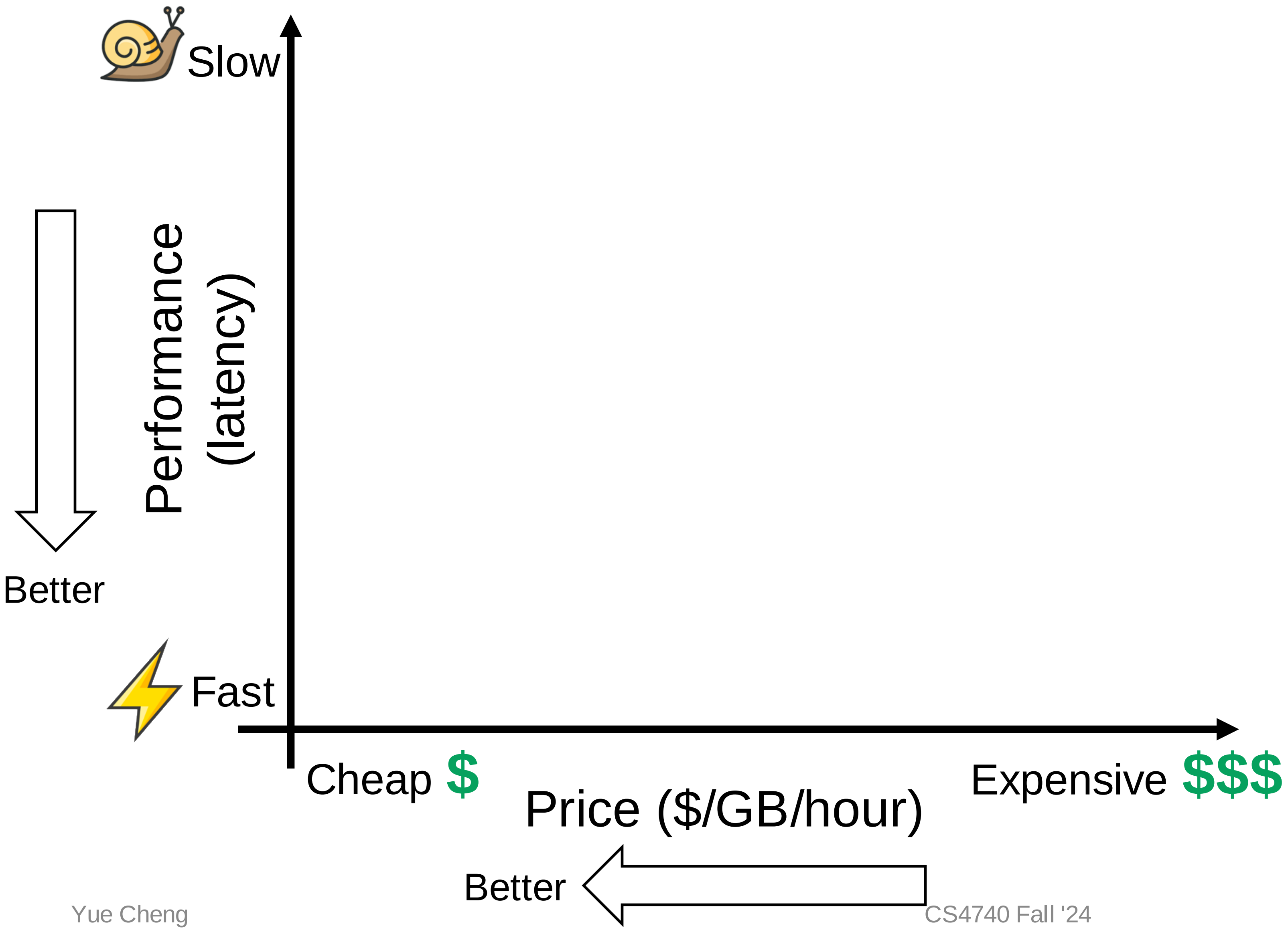


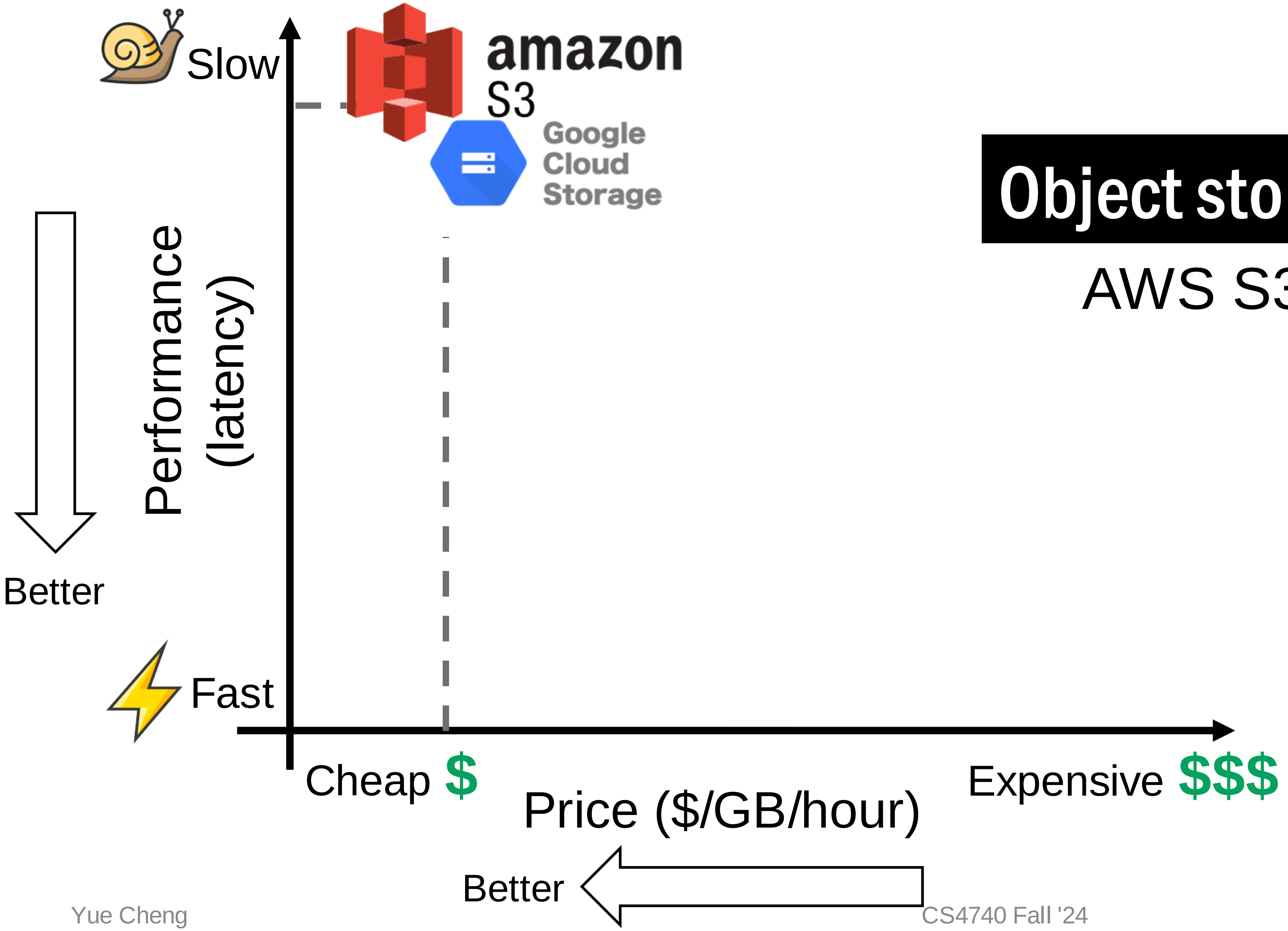
Extreme tension between small and large objects:

➢ Large objects (>10MB) occupy 95% storage footprint

Today's cloud storage landscape



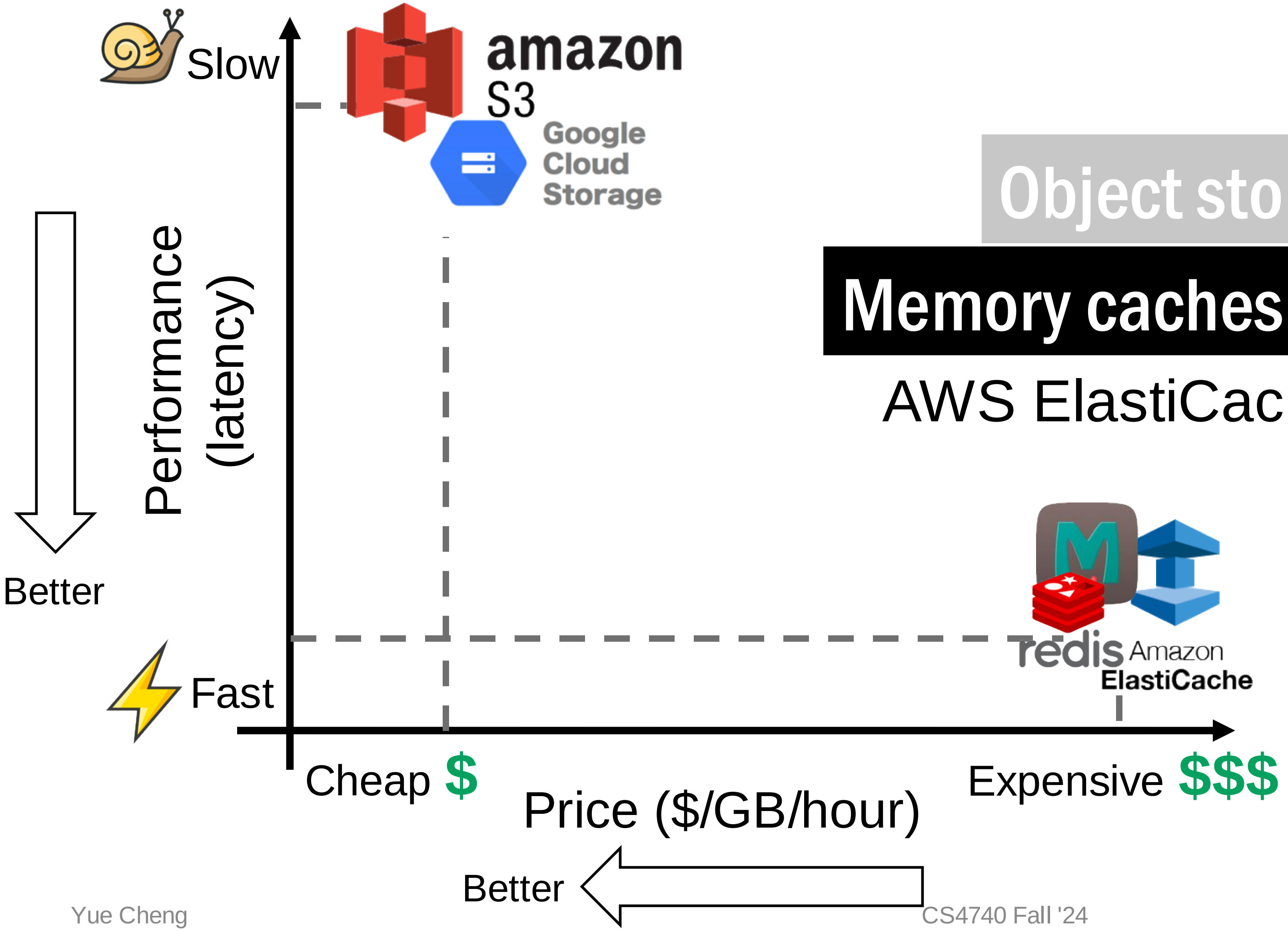
Today's cloud storage landscape



Object stores are cheap but too slow

AWS S3: $0.023 per GB per month

Today's cloud storage landscape

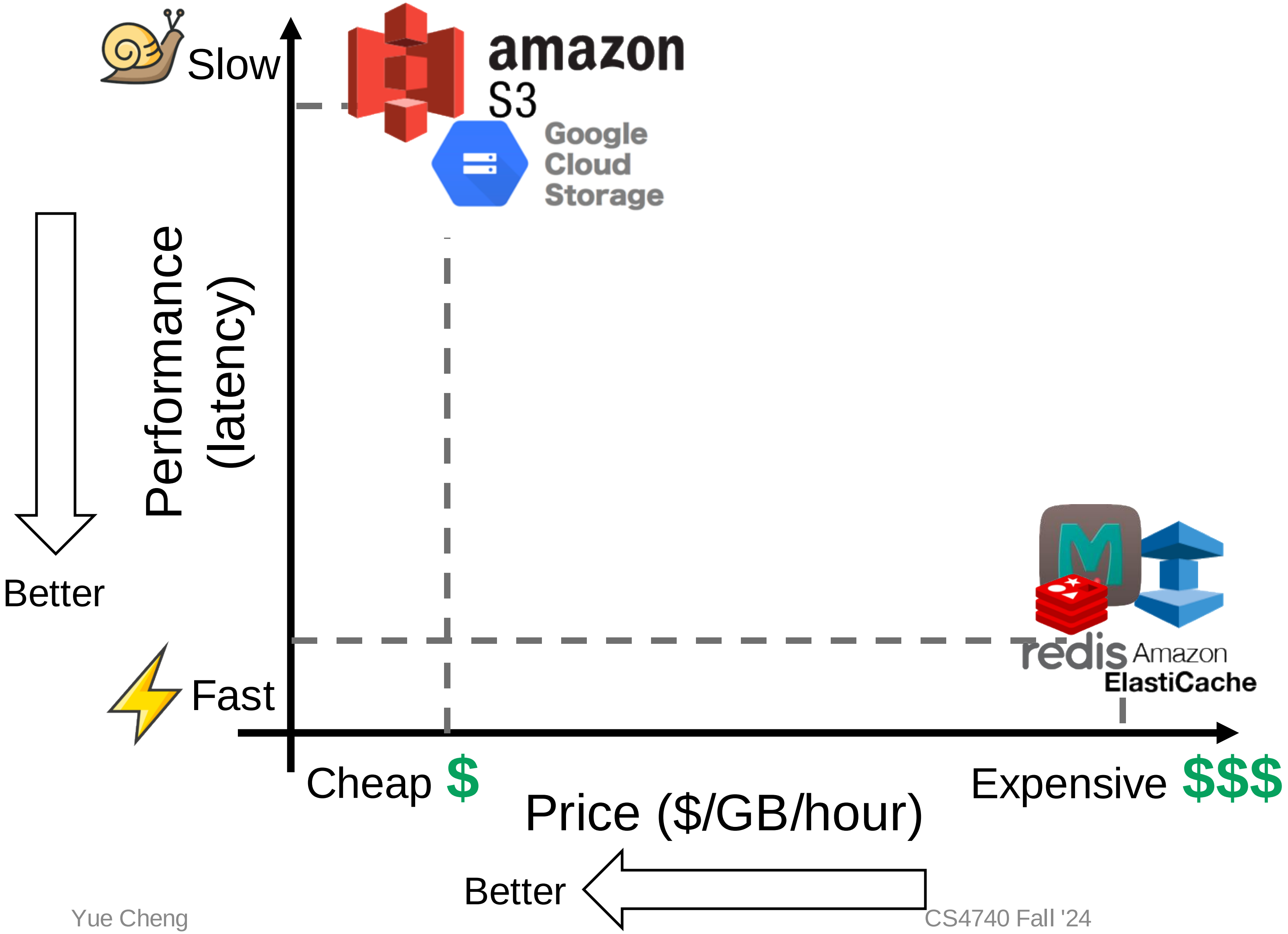


Object stores are cheap but too slow

Memory caches are fast but too expensive

AWS ElastiCache: $0.016 per GB per hour

- **Caching both small and large objects is challenging**
- **Existing solutions either too slow or too expensive**



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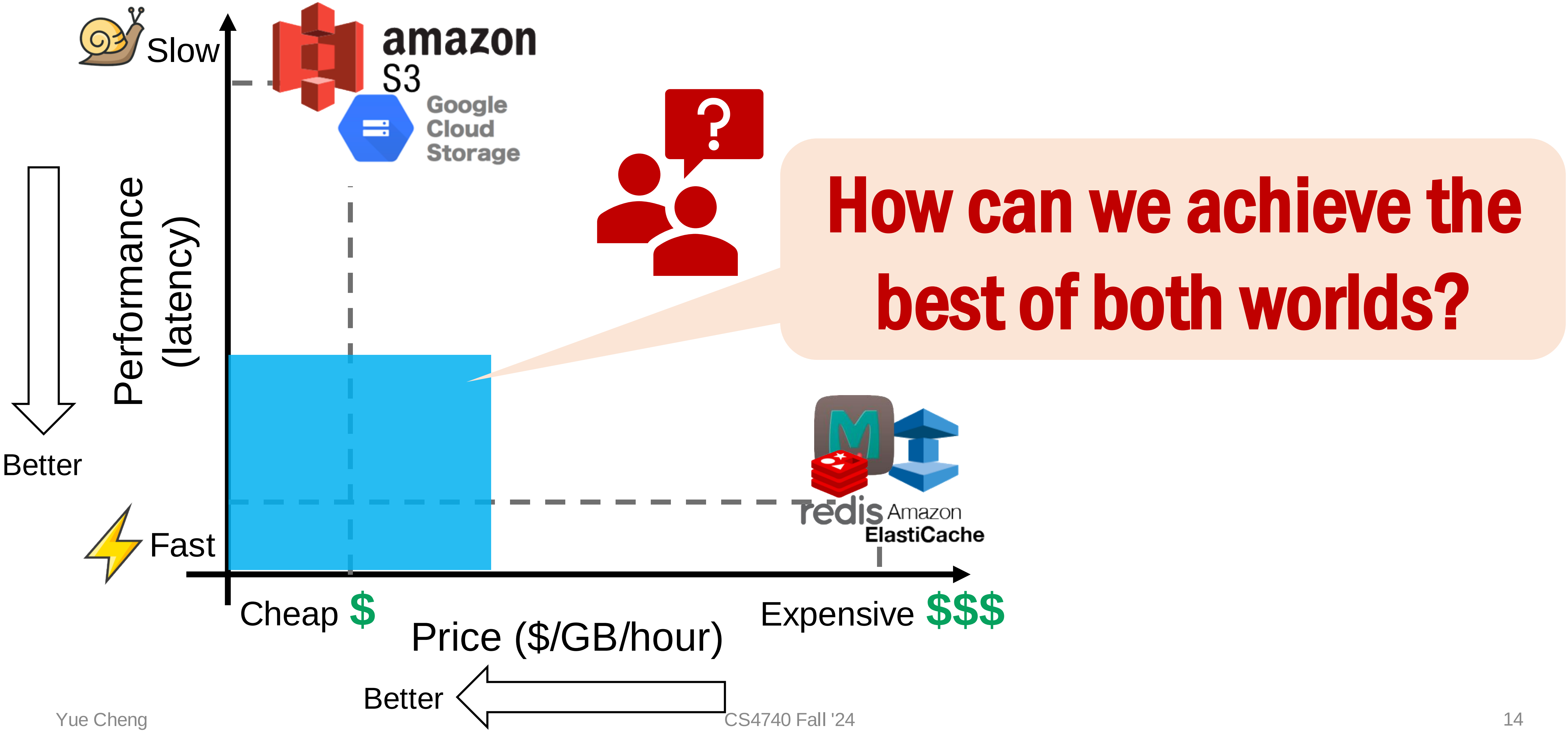

InfiniCache: A cost-effective and high-performance memory cache built atop FaaS

- **Insight #1:** Serverless functions' <CPU, RAM> resources are pay-per-use
- **Insight #2:** Serverless providers offer "free" function memory caching for tenants

InfiniCache: A cost-effective and high-performance memory cache built atop FaaS

- **Insight #1:** Serverless functions' <CPU, RAM> resources are pay-per-use → Cheap
- **Insight #2:** Serverless providers offer "free" function memory caching for tenants → Fast and cheap

Challenges to build a memory cache using serverless functions

High-level idea: Use Lambda functions to cache data objects

A strawman proposal that directly caches data objects in Lambda functions' memory may not work because of those FaaS limitations:

- No guaranteed data availability
- Banned inbound network
- Limited per-function resources

Challenges to build a memory cache using serverless functions

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- No guaranteed data availability
- Banned inbound network
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⚠ Serverless functions could be reclaimed any time
⚠ In-memory state is lost

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- **Banned inbound network**
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⚠ Serverless functions cannot run as a server

Server

Challenges to build a memory cache using serverless functions

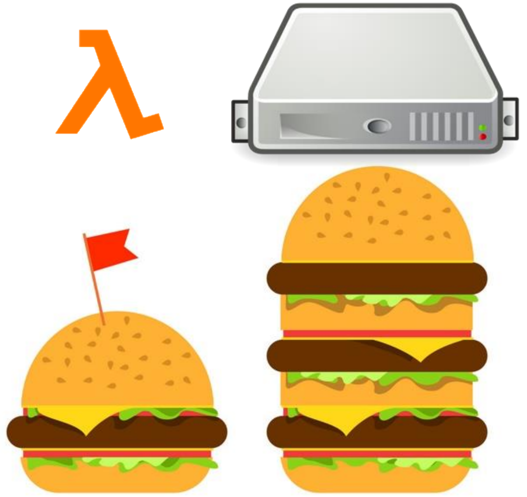
High-level idea: Use Lambda functions to cache data objects

A strawman proposal that directly caches data objects in Lambda functions' memory may not work because of those FaaS limitations:

⚠ Memory up to 10 GB

⚠ CPU up to 6 cores

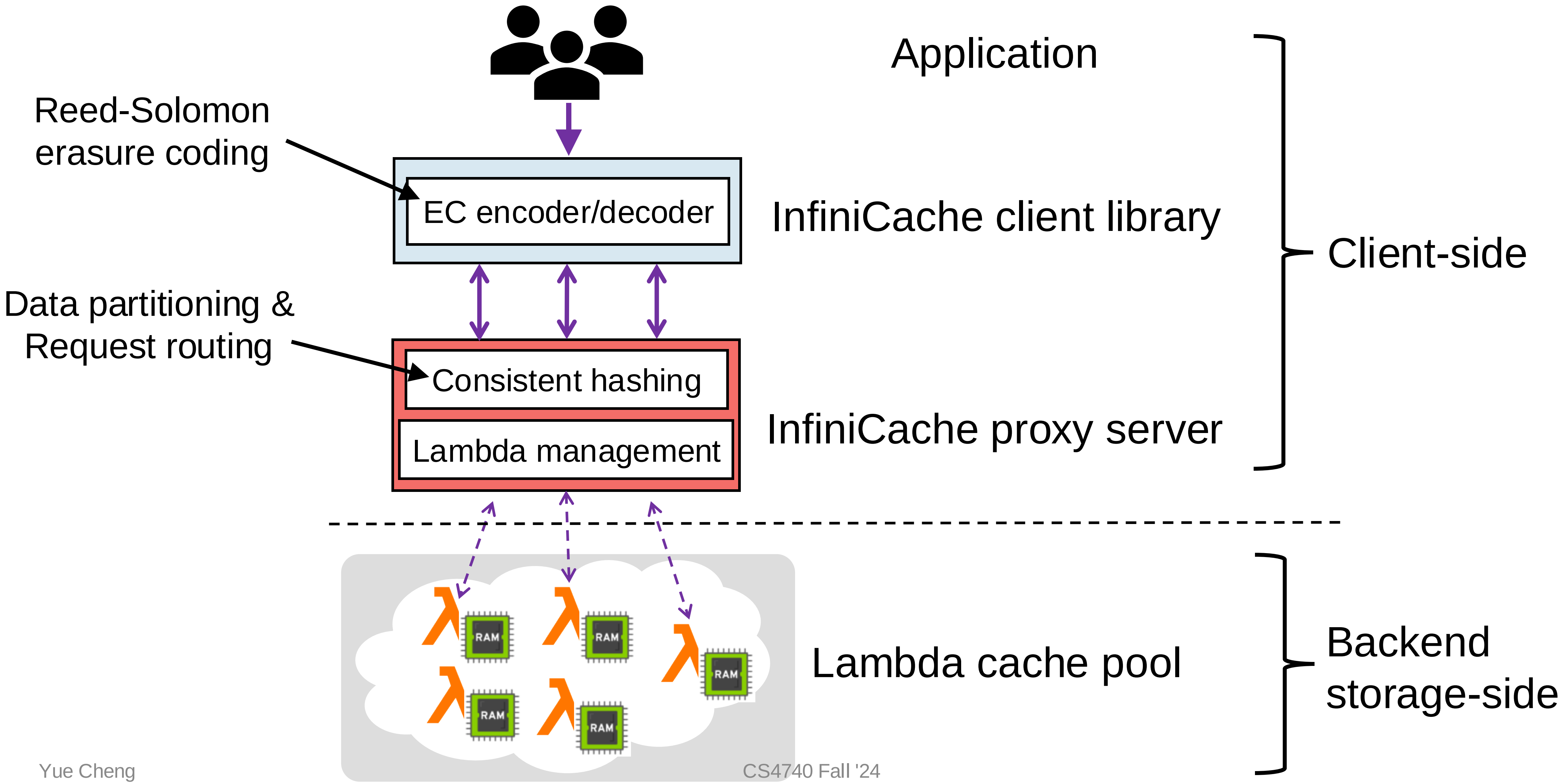
- No guaranteed data availability
- Banned inbound network
- **Limited per-function resources**



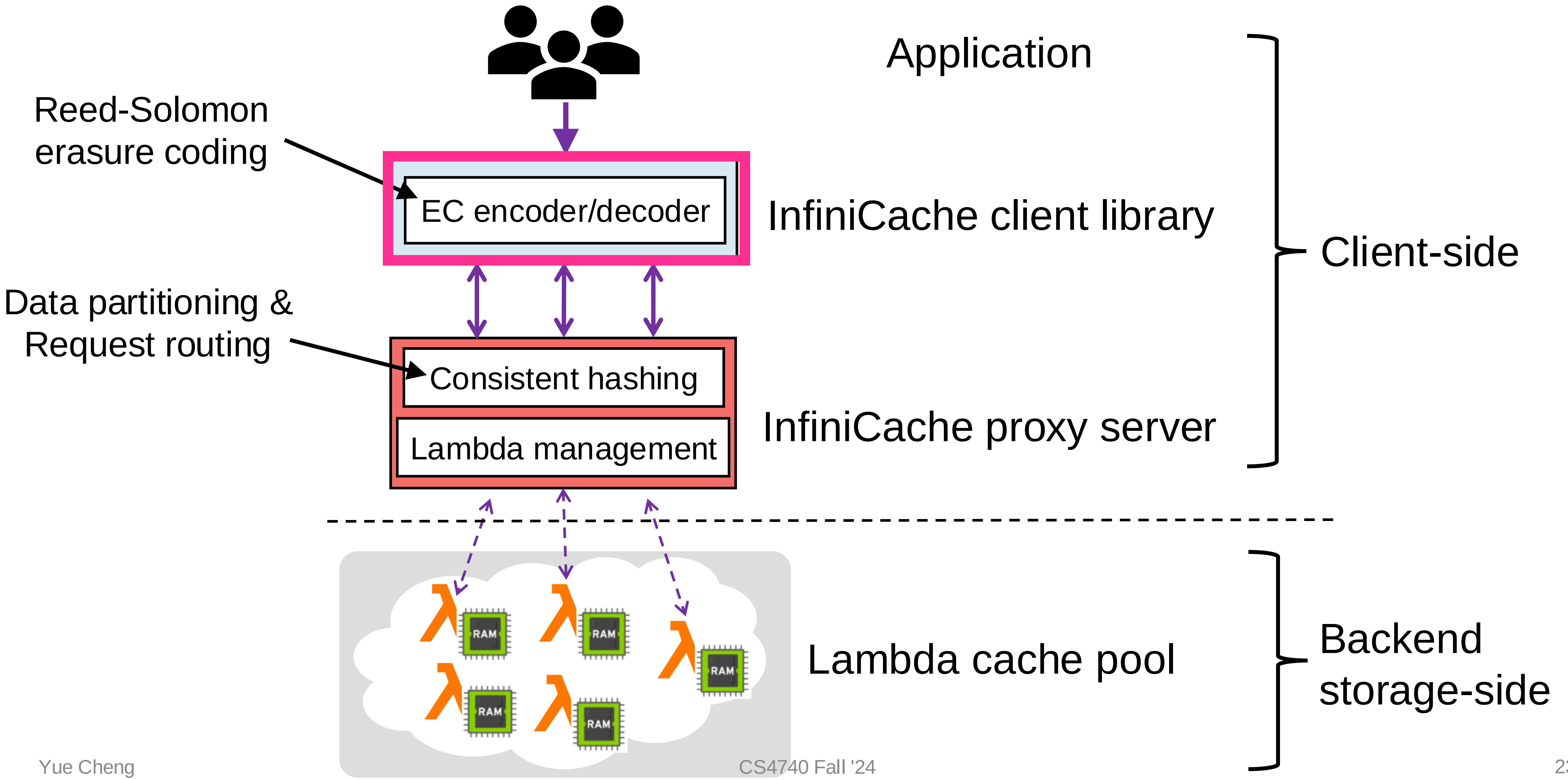
InfiniCache: The first memory cache built atop FaaS

- InfiniCache achieves high data availability by using erasure coding and delta-sync periodic data backup across functions
- InfiniCache achieves high performance by utilizing the aggregated, parallel network bandwidth of multiple functions
- InfiniCache achieves similar performance to AWS ElastiCache while reducing the $$ cost by 31-96X

InfiniCache bird's eye view



Let’s look at RAID and Reed-Solomon EC first



RAID: Redundant Array of Inexpensive Disks

Wish List for a Disk

- Wish it to be faster
  - I/O is always the performance bottleneck

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Wish List for a Disk

- Wish it to be faster
  - I/O is always the performance bottleneck
- Wish it to be larger
  - More and more data needs to be stored
- Wish it to be more reliable
  - We don’t want our valuable data to be gone

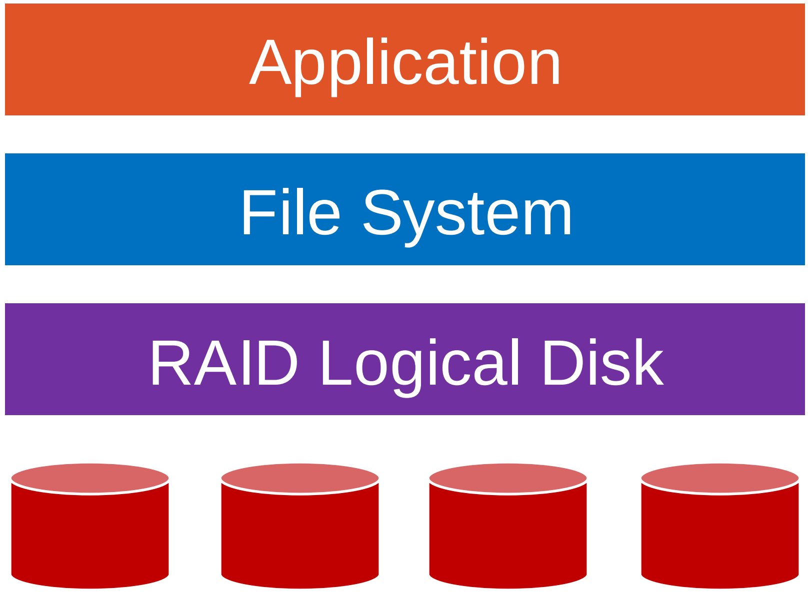
Only One Disk?

- Sometimes we want many disks
  - For higher performance
  - For larger capacity
  - For better reliability

- Challenge: Most file systems work on only one disk

Solution: RAID

RAID: Redundant Array of Inexpensive Disks

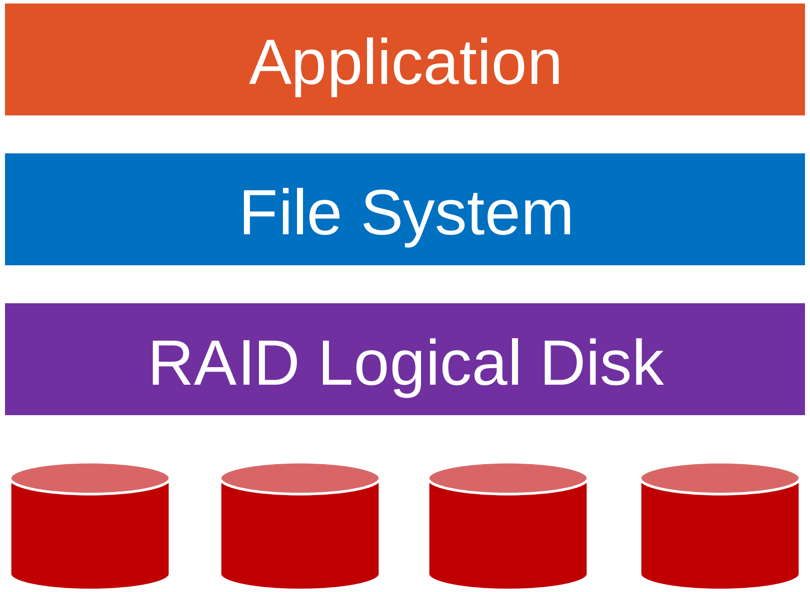


Build a logical disk from many physical disks

Solution: RAID

RAID: Redundant Array of Inexpensive Disks

RAID is
- Transparent
- Deployable



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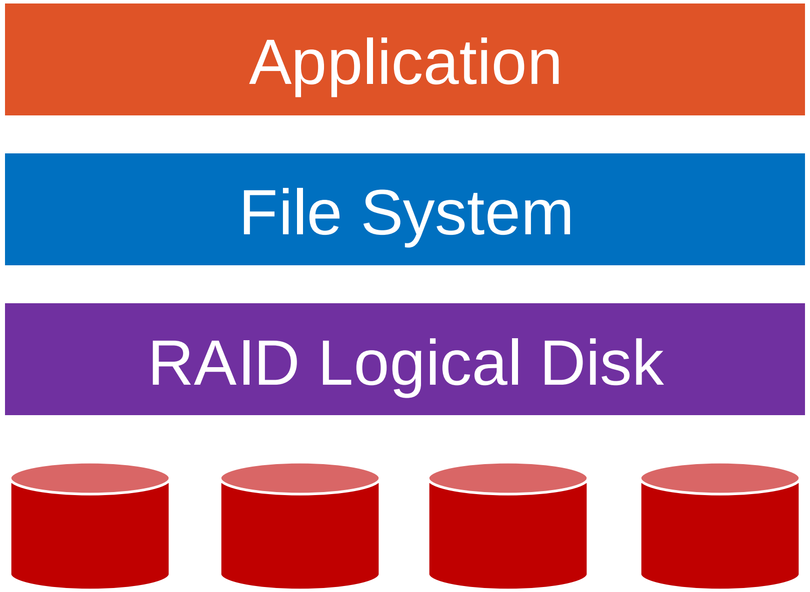

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- Performance
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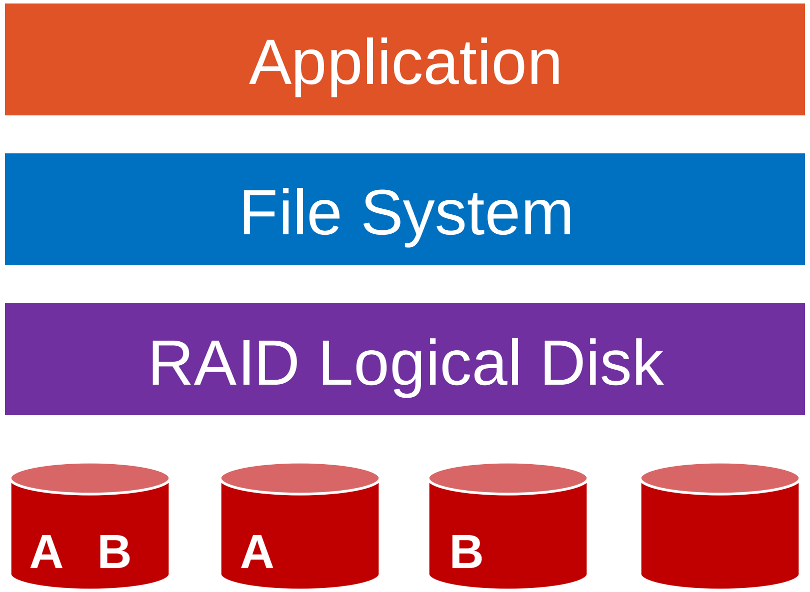

Logical disk gives
- Performance
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Build a logical disk from many physical disks

Why Inexpensive Disks?

- Economies of scale! Cheap disks are popular

- You can often get many commodity hardware components for the same price as a few expensive components

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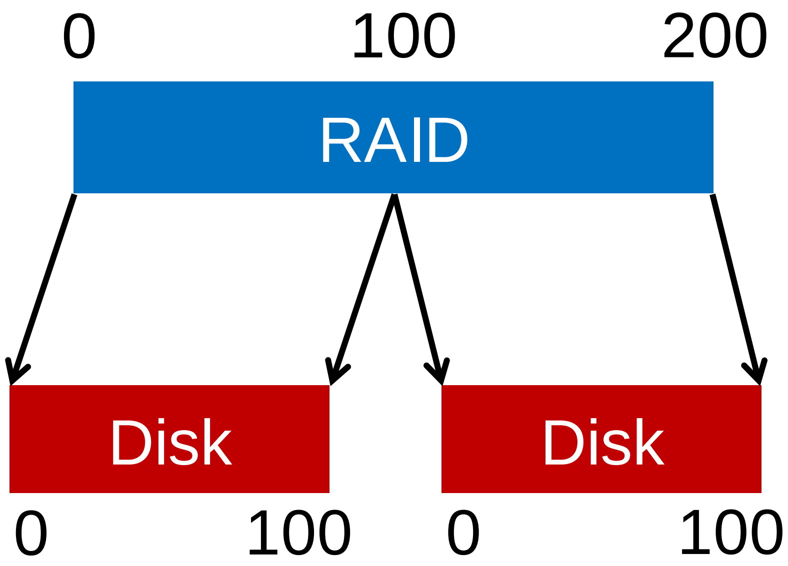
- Strategy: Write software to build high-quality logical devices from many cheap devices
    - Tradeoff: To compensate poor properties of cheap devices

General Strategy

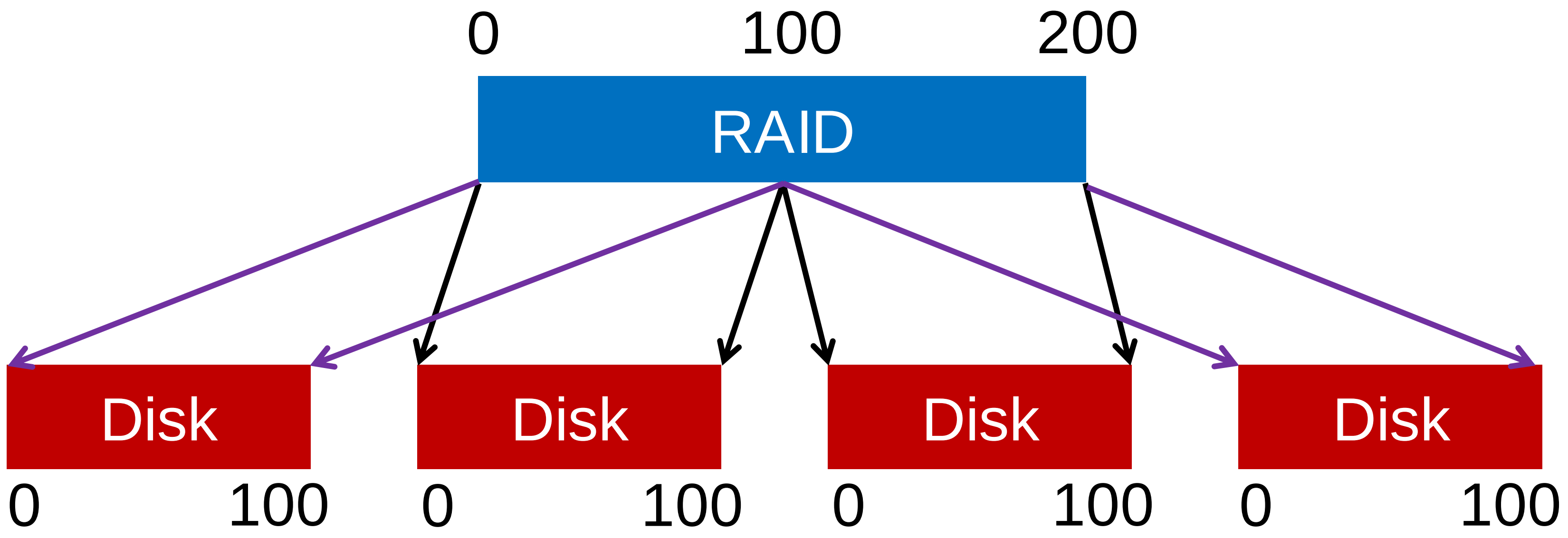
Build fast and large disks from smaller ones



General Strategy

Build fast and large disks from smaller ones

Add more disks for reliability++!

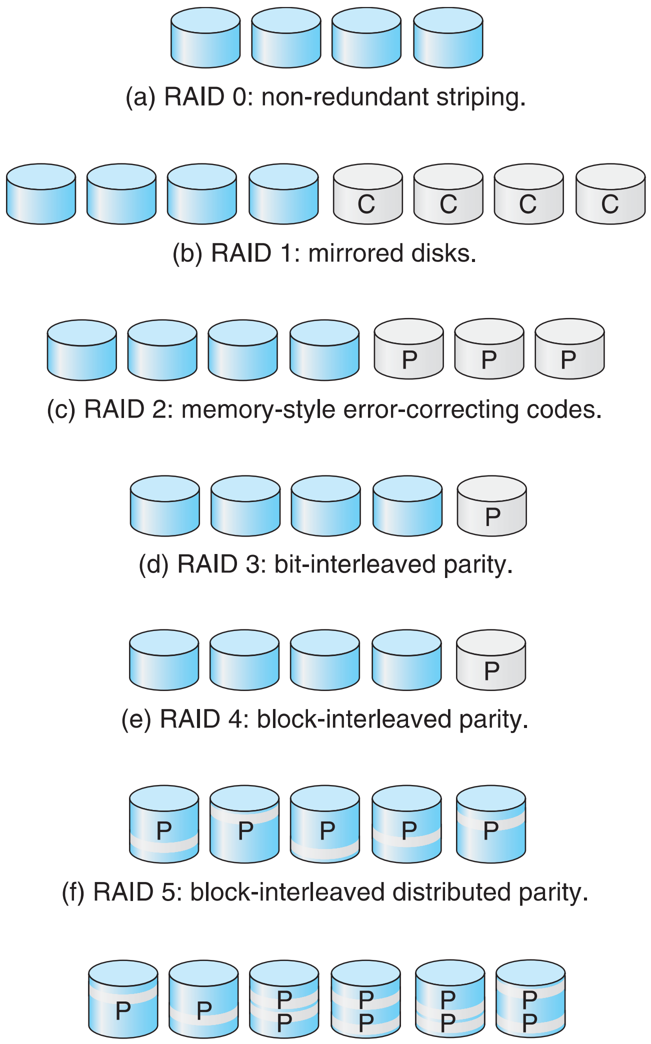


RAID Metrics

- Capacity
  - How much space can apps use?

- Reliability
  - How many disks can we safely lose?
  - Assume fail-stop model!

RAID Levels



(a) RAID 0: non-redundant striping.

(b) RAID 1: mirrored disks.

(c) RAID 2: memory-style error-correcting codes.

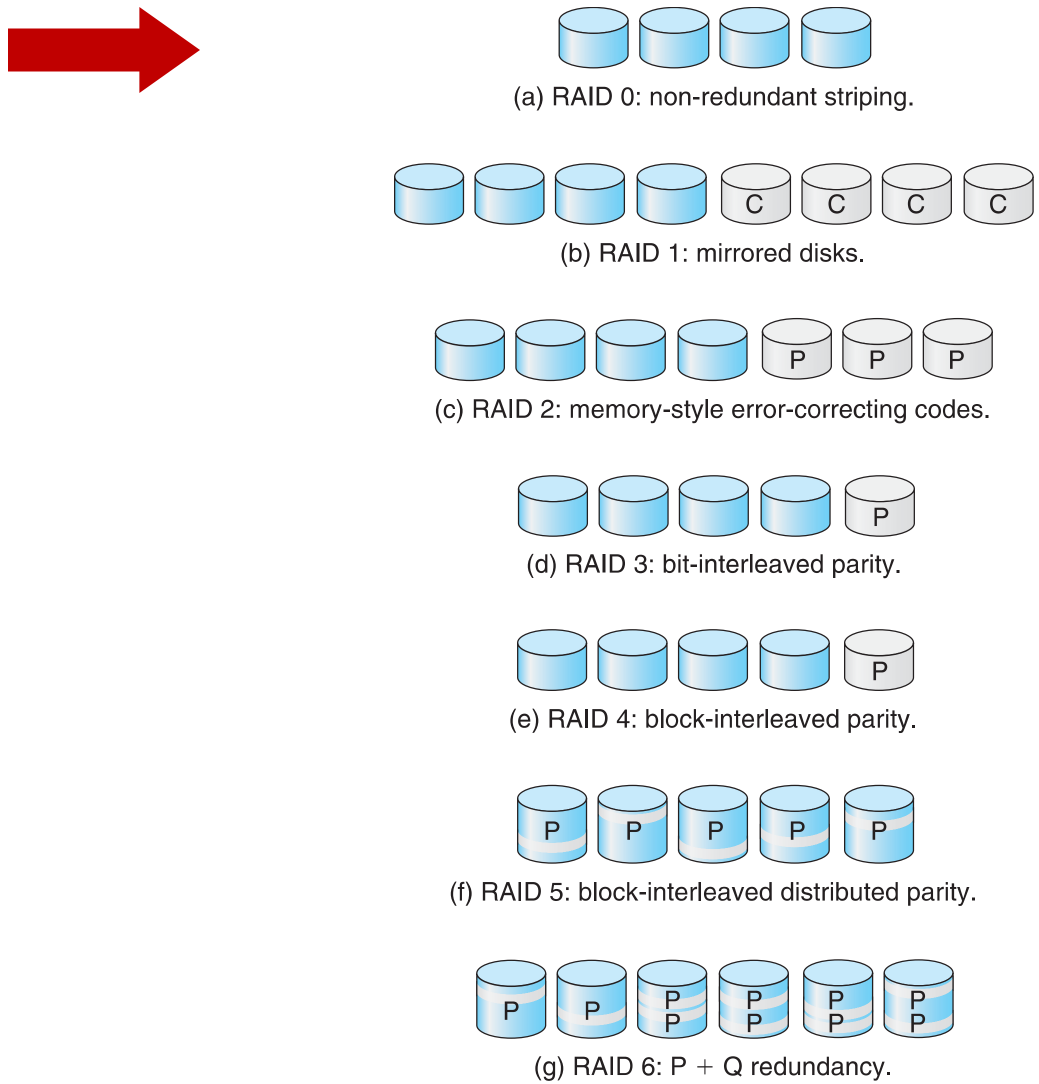
(d) RAID 3: bit-interleaved parity.

(e) RAID 4: block-interleaved parity.

(f) RAID 5: block-interleaved distributed parity.

(g) RAID 6: P + Q redundancy.

RAID Level 0


(a) RAID 0: non-redundant striping.
C
C
C
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P
P
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P
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(e) RAID 4: block-interleaved parity.
P
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P
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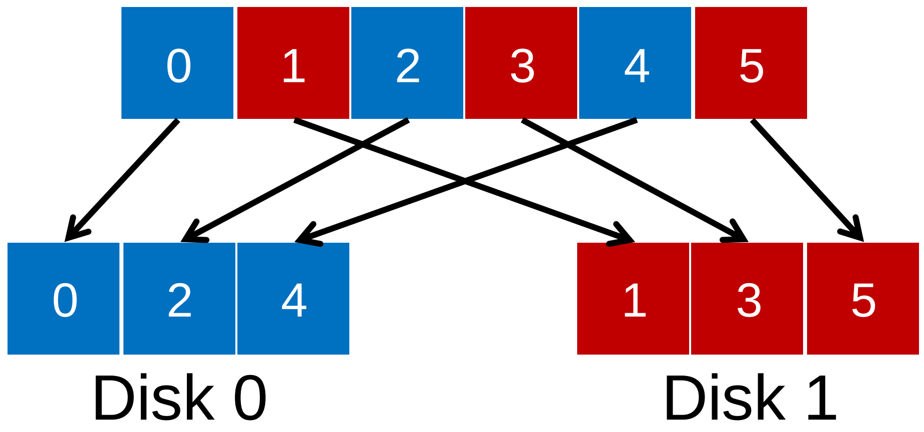
P
(f) RAID 5: block-interleaved distributed parity.
P
P
P
P
P
P
P
P
P
P
(g) RAID 6: P + Q redundancy.

RAID-0: Striping

- No redundancy

- Serves as upper bound for
  - Performance
  - Capacity

Logical blocks



4 Disks

Disk 0	Disk 1	Disk 2	Disk 3
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

4 Disks

	Disk 0	Disk 1	Disk 2	Disk 3
	0	1	2	3
stripe:	4	5	6	7
	8	9	10	11
	12	13	14	15

How to Map?

- Given logical address A:
  - Disk = …
  - Offset = …

Disk 0	Disk 1	Disk 2	Disk 3
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

How to Map?

- Given logical address A:
  - Disk = `A % disk_count`
  - Offset = `A / disk_count`

Disk 0	Disk 1	Disk 2	Disk 3
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

Mapping Example: Find Block 13

- Given logical address 13:
  - **Disk** = `13 % 4 = 1`
  - **Offset** = `13 / 4 = 3`

Offset	Disk 0	Disk 1	Disk 2	Disk 3
0	0	1	2	3
1	4	5	6	7
2	8	9	10	11
3	12	13	14	15

Chunk Size = 1

Disk 0	Disk 1	Disk 2	Disk 3
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

Chunk Size = 1

Disk 0	Disk 1	Disk 2	Disk 3
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

Chunk Size = 2

Disk 0	Disk 1	Disk 2	Disk 3	
0	2	4	6	chunk size:
1	3	5	7	2 blocks
8	10	12	14	
9	11	13	15	

Chunk Size = 1

Disk 0	Disk 1	Disk 2	Disk 3
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

In all following examples, we assume chunk size of 1

Chunk Size = 2

Disk 0	Disk 1	Disk 2	Disk 3	
0	2	4	6	chunk size:
1	3	5	7	2 blocks
8	10	12	14	
9	11	13	15	

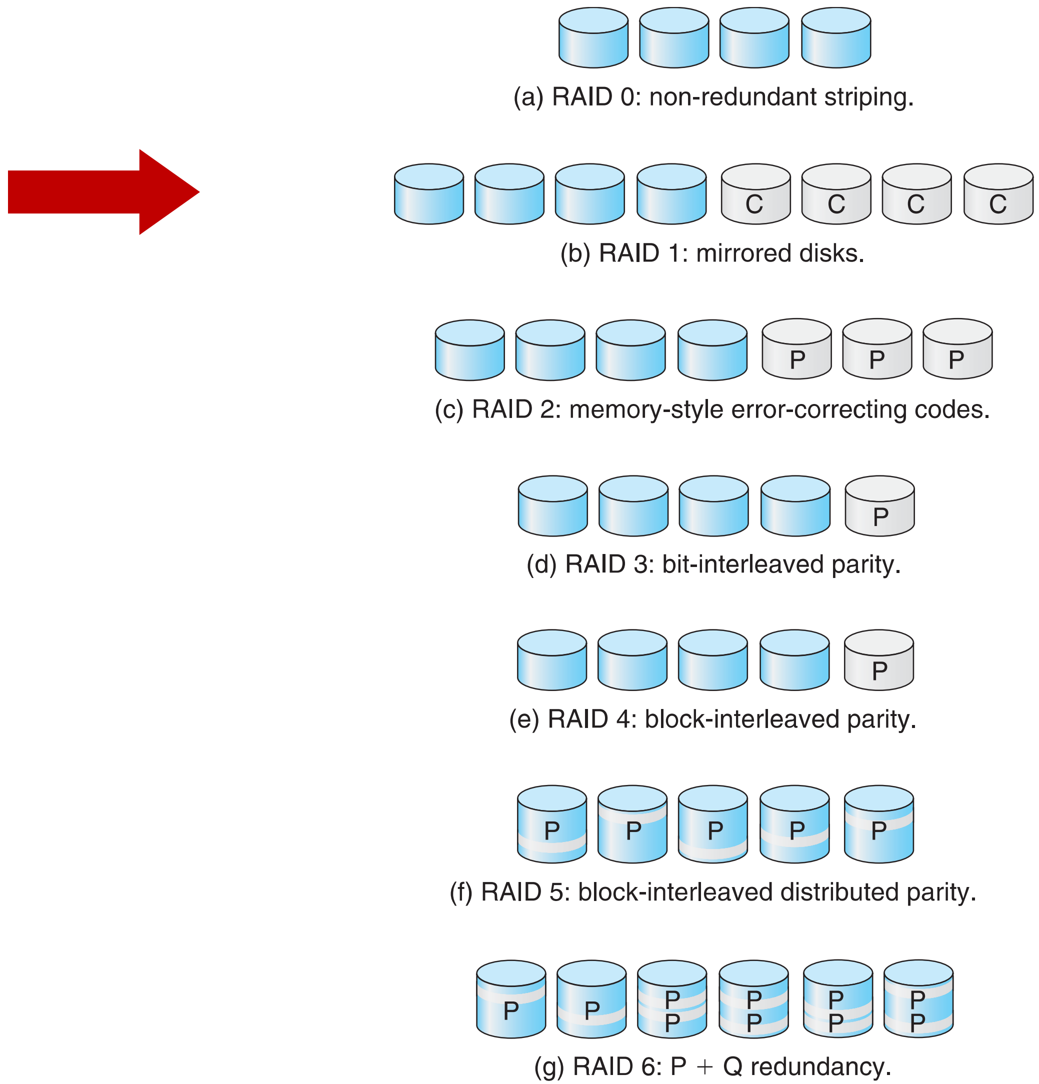
RAID-0 Analysis

N is the number of disks
C is the capacity of each disk

1. What is capacity? N * C

2. How many disks can fail? 0

RAID Level 1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P P P
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P
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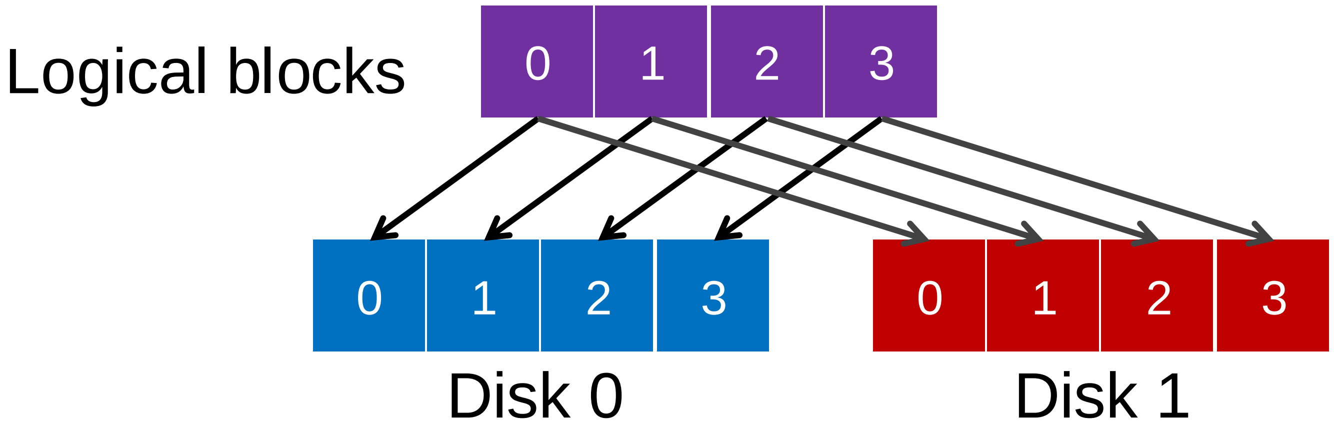
P P P P P
(f) RAID 5: block-interleaved distributed parity.
P P P P P P P P P P
(g) RAID 6: P + Q redundancy.

RAID-1: Mirroring

- RAID-1 keeps two copies of each block



Assumption

- Assume disks are fail-stop
  - Two states
    - They work or they don't
  - We know when they don't work

4 Disks

Disk 0	Disk 1	Disk 2	Disk 3
0	0	1	1
2	2	3	3
4	4	5	5
6	6	7	7

4 Disks

Disk 0	Disk 1	Disk 2	Disk 3
0	0	1	1
2	2	3	3
4	4	5	5
6	6	7	7

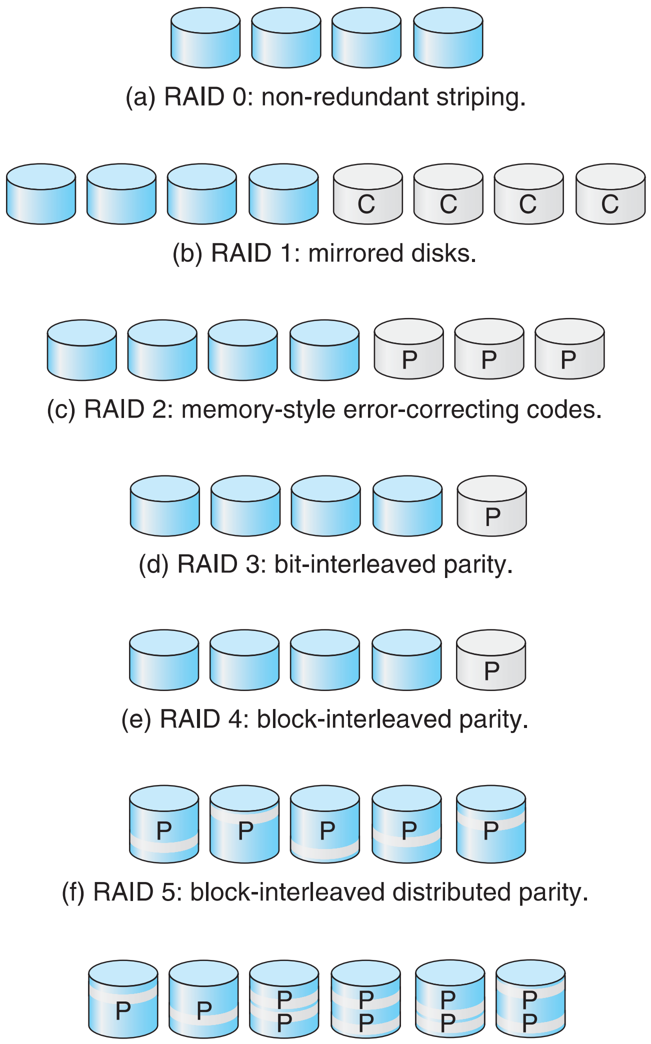
How many disks can fail?

RAID-1 Analysis

1. What is capacity? N/2 * C

2. How many disks can fail? 1 or maybe N / 2

RAID Level 4



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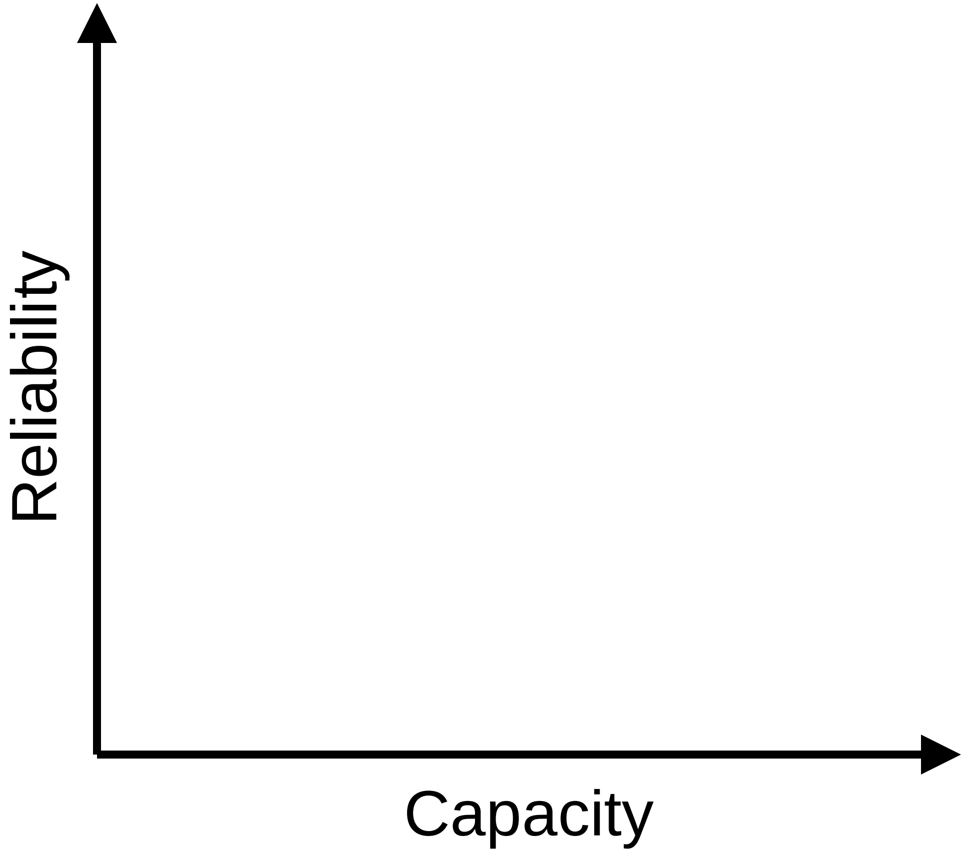
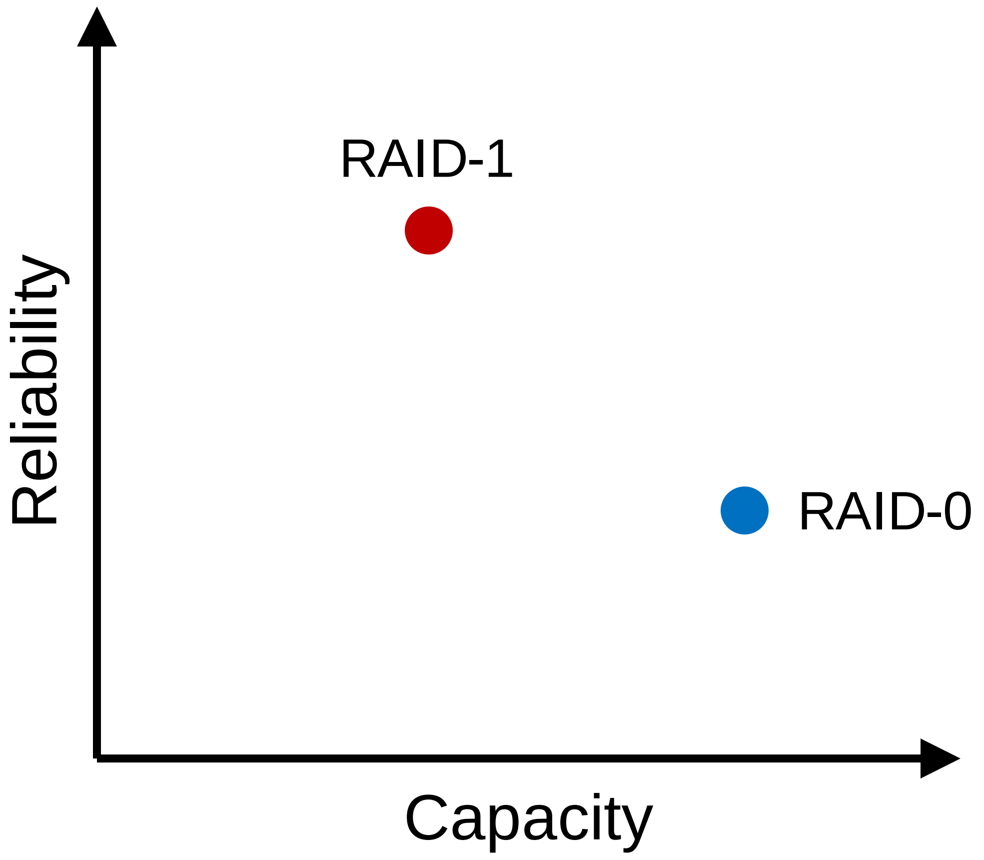
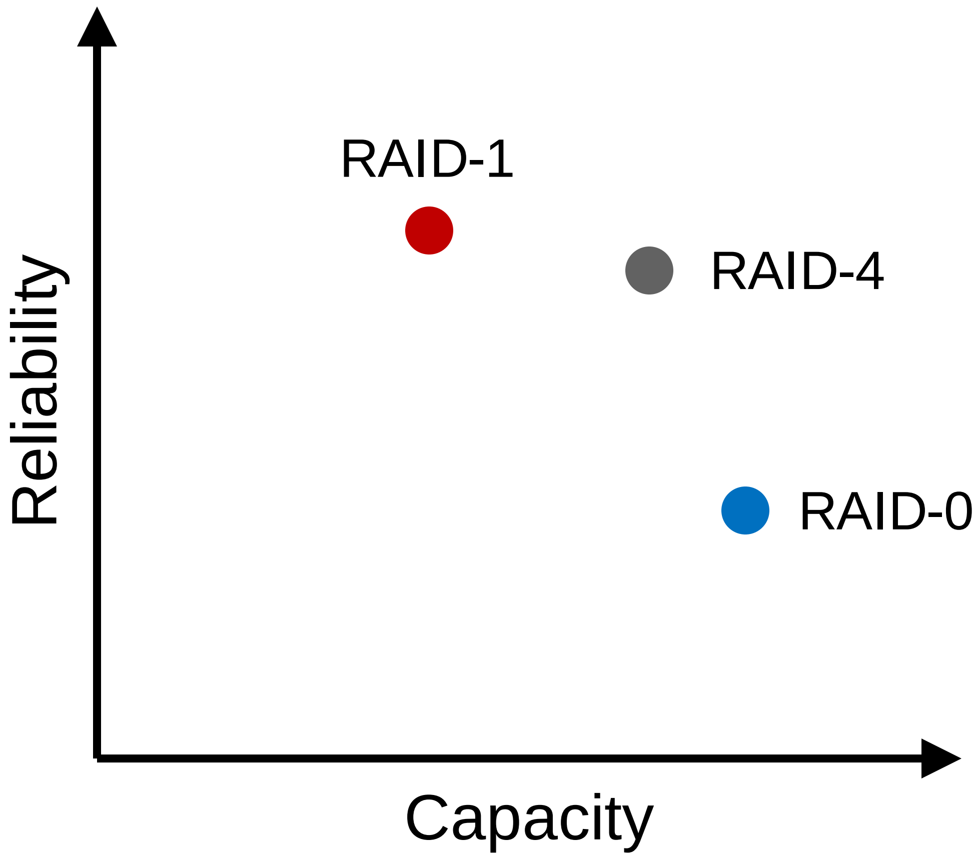
RAID-4



RAID-4



RAID-4



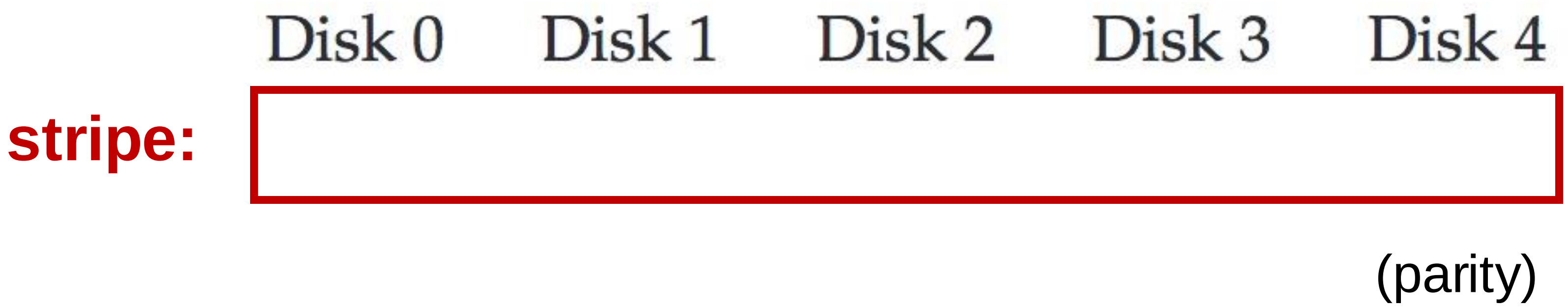
RAID-4 Strategy

- Use parity disk
- In algebra, if an equation has N variables, and N-1 are known, you can also solve for the unknown
- Treat the sectors/blocks across disks in a stripe as an equation

5 Disks

Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
0	1	2	3	P0
4	5	6	7	P1
8	9	10	11	P2
12	13	14	15	P3

Example



Example

	Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
stripe:	4	3	0	2	
					(parity)

Example

	Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
stripe:	4	3	0	2	9
					(parity)

Example

	Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
stripe:	X	3	0	2	9
					(parity)

Example

	Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
stripe:	**4**	3	0	2	9
					(parity)

Parity Function: XOR Example

C0	C1	C2	C3	P
0	0	1	1	XOR(0,0,1,1) = 0
0	1	0	0	XOR(0,1,0,0) = 1

Parity Function: XOR Example

C0	C1	C2	C3	P
0	0	1	1	XOR(0,0,1,1) = 0
0	1	0	0	XOR(0,1,0,0) = 1

XOR function:

- P = 0: The number of 1 in a stripe must be an even number
- P = 1: The number of 1 in a stripe must be an odd number

Parity Function: XOR Example

	Block0	Block1	Block2	Block3	Parity
stripe:	00	10	11	10	11
	10	01	00	01	10

XOR function:

- P = 0: The number of 1 in a stripe must be an even number
- P = 1: The number of 1 in a stripe must be an odd number

Parity Function: XOR Example

	Block0	Block1	Block2	Block3	Parity
stripe:	X	10	11	10	11
	10	01	00	01	10

XOR function:

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Parity Function: XOR Example

	Block0	Block1	Block2	Block3	Parity
stripe:	X	10	11	10	11
	10	01	00	01	10

Block0 = XOR(10,11,10,11) = 00

XOR function:

- P = 0: The number of 1 in a stripe must be an even number
- P = 1: The number of 1 in a stripe must be an odd number

Parity Function: XOR Example

	Block0	Block1	Block2	Block3	Parity
stripe:	00	10	11	10	11
	10	01	00	01	10

Block0 = XOR(10,11,10,11) = **00**

XOR function:

- P = 0: The number of 1 in a stripe must be an even number
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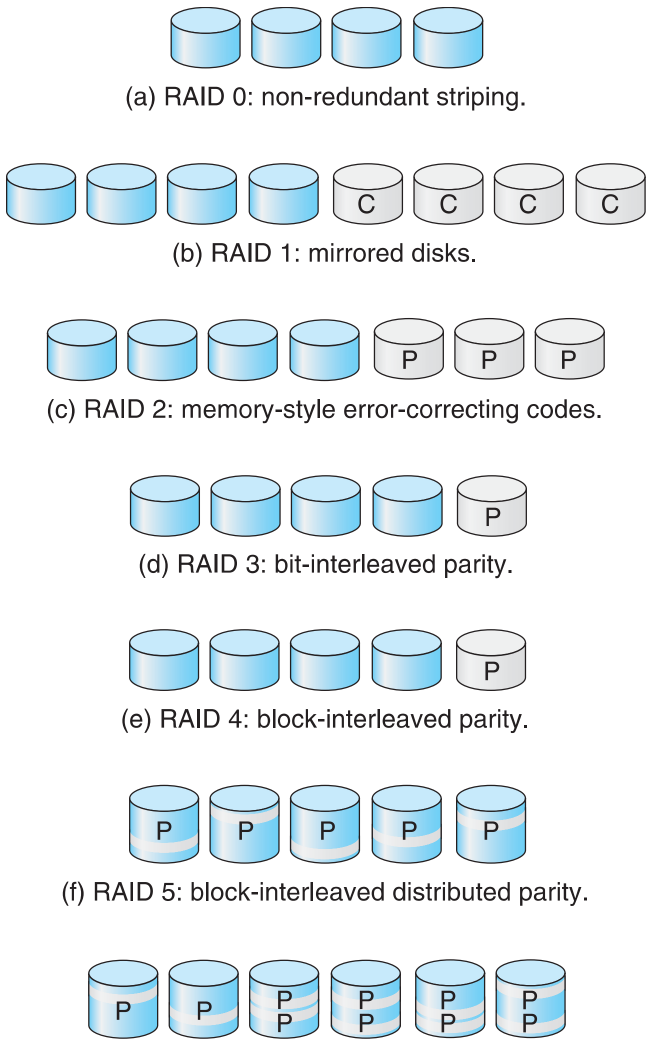
RAID-4 Analysis

1. What is capacity? (N-1) * C

2. How many disks can fail? 1

RAID Level 5



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(f) RAID 5: block-interleaved distributed parity.

(g) RAID 6: P + Q redundancy.

RAID-5: Rotating Parity

Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
0	1	2	3	P0
5	6	7	P1	4
10	11	P2	8	9
15	P3	12	13	14
P4	16	17	18	19

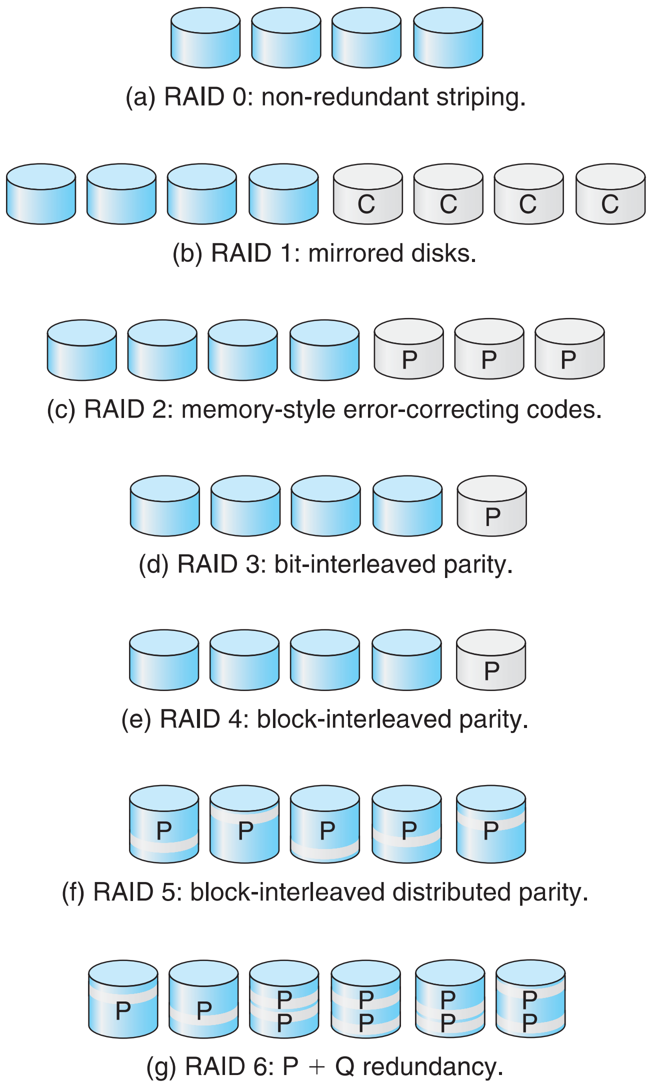
RAID-5 works almost identically to RAID-4, except that it rotates the parity block across drives

RAID-5 Analysis

1. What is capacity? (N-1) * C

2. How many disks can fail? 1

RAID Level 6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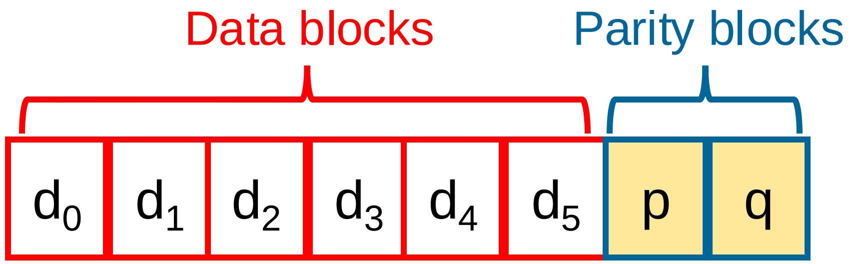
(g) RAID 6: P + Q redundancy.

RAID-6



RAID-6 can fail at most 2 disks at a time.

Encoding

$$
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 \\
1 & 1 & 1 & 1 & 1 & 1 \\
32 & 16 & 8 & 4 & 2 & 1
\end{bmatrix}
*
\begin{bmatrix}
d_0 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5
\end{bmatrix}
=
\begin{bmatrix}
d_0 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ p \\ q
\end{bmatrix}
$$

Generator matrix

The product vector is called a codeword

[8 x 6] * [6 x 1] = [8 x 1]

Encoding

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 32 & 16 & 8 & 4 & 2 & 1 \end{bmatrix} * \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \end{bmatrix} = \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ p \\ q \end{bmatrix}$$

$$d_0 \oplus d_1 \oplus d_2 \oplus d_3 \oplus d_4 \oplus d_5 \longrightarrow p$$

$$32d_0 \oplus 16d_1 \oplus 8d_2 \oplus 4d_3 \oplus 2d_4 \oplus d_5 \longrightarrow q$$

Decoding with a parity check matrix

Parity check matrix

$$\underbrace{\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ 32 & 16 & 8 & 4 & 2 & 1 & 0 & 1 \end{bmatrix}}_{\text{Parity check matrix}} * \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ p \\ q \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$d_0 \oplus d_1 \oplus d_2 \oplus d_3 \oplus d_4 \oplus d_5 \oplus p = 0$$

$$32d_0 \oplus 16d_1 \oplus 8d_2 \oplus 4d_3 \oplus 2d_4 \oplus d_5 \oplus q = 0$$

Handling failures with decoding

$$d_0 \oplus d_1 \oplus d_2 \oplus d_3 \oplus d_4 \oplus d_5 \oplus p = 0$$

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Suppose disk1 (d_1) and disk4 (d_4) fail

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Suppose disk1 (d_1) and disk4 (d_4) fail

Step 1: Put the failed data on the right of the equations.

$$d_0 \oplus d_2 \oplus d_3 \oplus d_5 \oplus p = d_1 \oplus d_4$$

$$32d_0 \oplus 8d_2 \oplus 4d_3 \oplus d_5 \oplus q = 16d_1 \oplus 2d_4$$

Handling failures with decoding

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Suppose disk1 (d_1) and disk4 (d_4) fail

Step 2: Calculate the left sides, since those all exist.

$$d_0 \oplus d_2 \oplus d_3 \oplus d_5 \oplus p = S_0 = d_1 \oplus d_4$$

$$32d_0 \oplus 8d_2 \oplus 4d_3 \oplus d_5 \oplus q = S_1 = 16d_1 \oplus 2d_4$$

Handling failures with decoding

$$d_0 \oplus d_1 \oplus d_2 \oplus d_3 \oplus d_4 \oplus d_5 \oplus p = 0$$

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Suppose disk1 (d_1) and disk4 (d_4) fail

Step 3: Solve using Gaussian Elimination or Matrix Inversion.

$$S_0 = d_1 \oplus d_4$$

$$S_1 = 16d_1 \oplus 2d_4$$

$$\longrightarrow$$

$$d_1 = \frac{(2S_0 \oplus S_1)}{(16 \oplus 2)}$$

$$d_4 = S_0 \oplus d_1$$

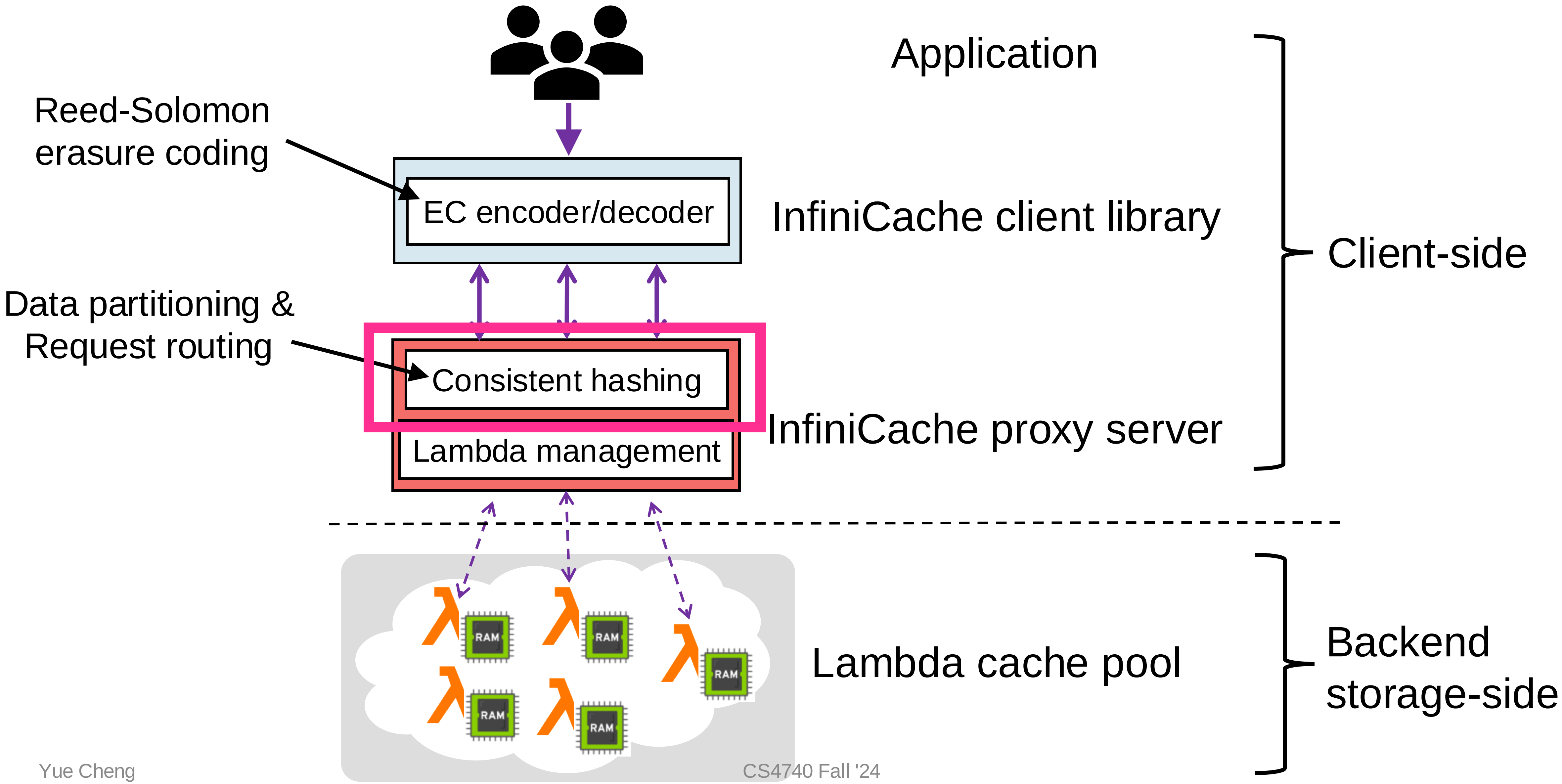
RAID-6 Analysis

Assuming a RS configuration of 6+2

1. What is capacity? (N-2) * C where N = 8

2. How many disks can fail? 2

Next basic building block: consistent hashing



Consistent hashing

Scaling out: Placement

- You have key-value pairs to be partitioned across nodes based on an id

- Problem 1: Data placement
  - On which node(s) to **place** each key-value pair?
    - Maintain mapping from data object to node(s)
    - Evenly distribute data/load

Scaling out: Partition management

- Problem 2: Partition management
  - Including how to recover from node failure
    - *e.g.*, bringing another node into partition group
  - Changes in system size, *i.e.*, nodes joining/leaving
  - Heterogeneous nodes

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  - Heterogeneous nodes

- Centralized: Cluster manager
- Decentralized: Deterministic hashing and algorithms

Modulo hashing

- First consider problem of data partition:
  - Given object id X, choose one of k servers to use

- Suppose we use modulo hashing:
  - Place X on server i = hash(X) mod k

Modulo hashing

- First consider problem of data partition:
  - Given object id X, choose one of *k* servers to use

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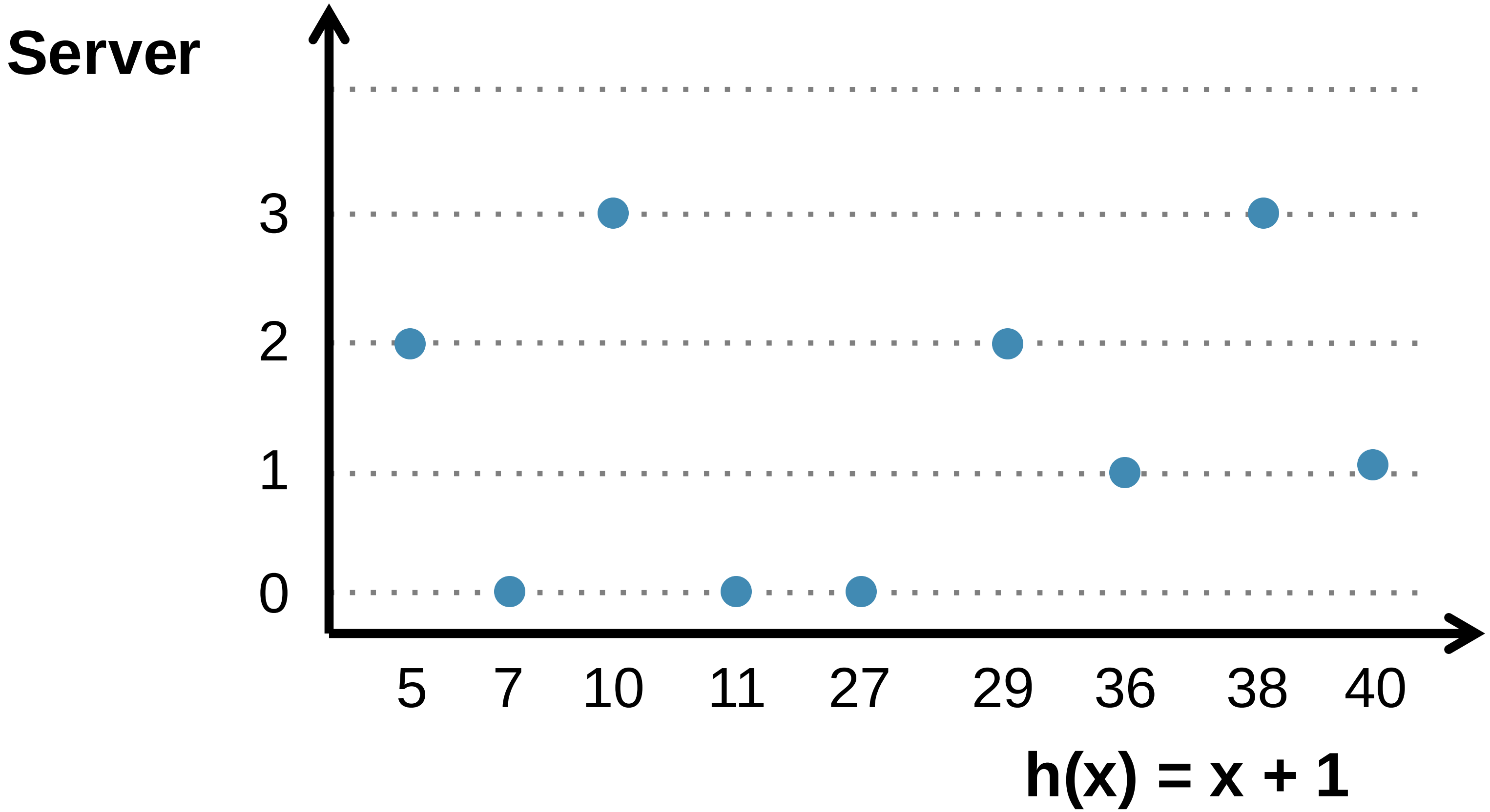
  - Place *X* on server i = hash(X) mod k

What's the problem with this method?

Problem for modulo hashing: Changing number of servers

i = h(*x*) mod 4



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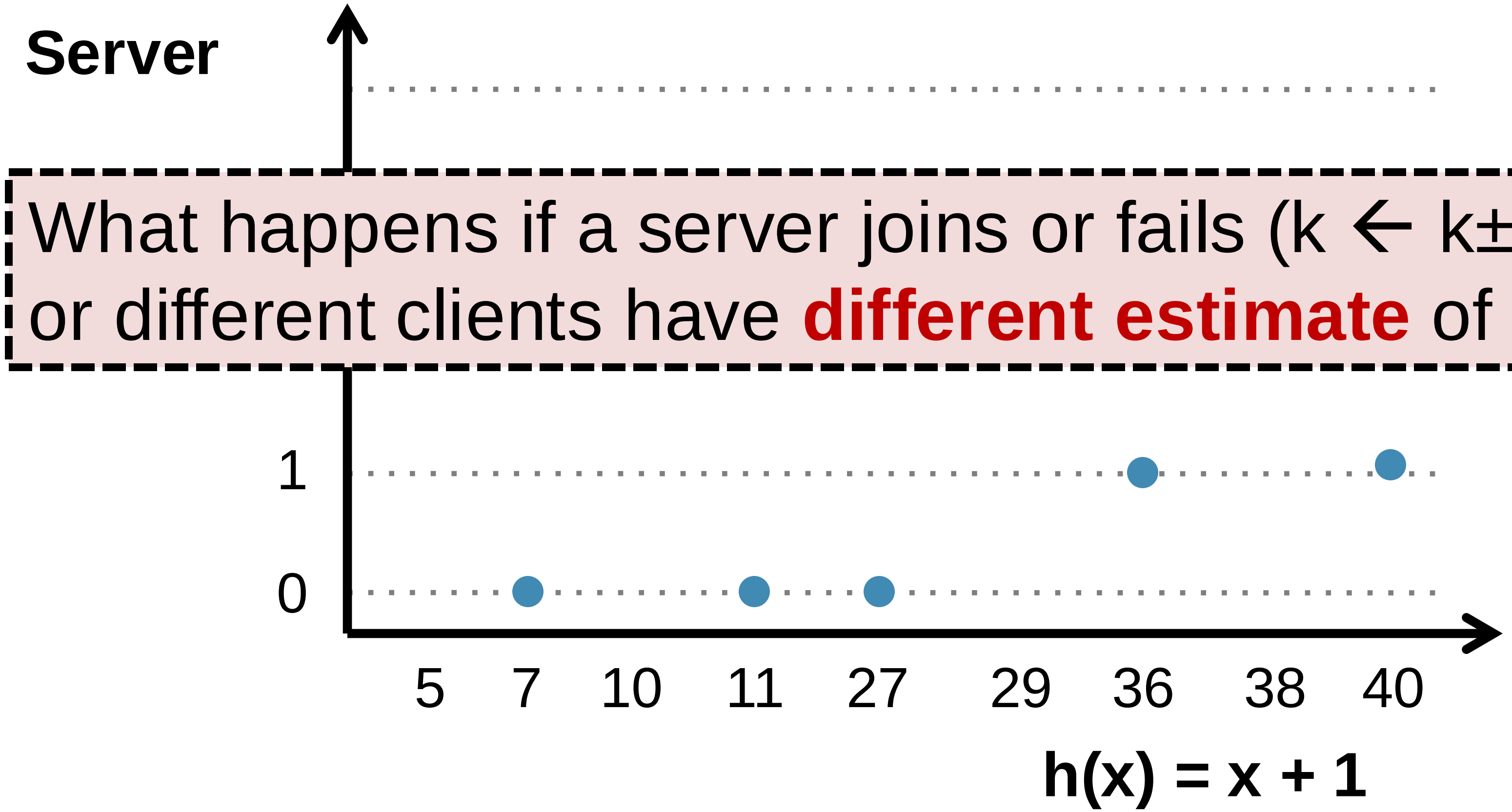
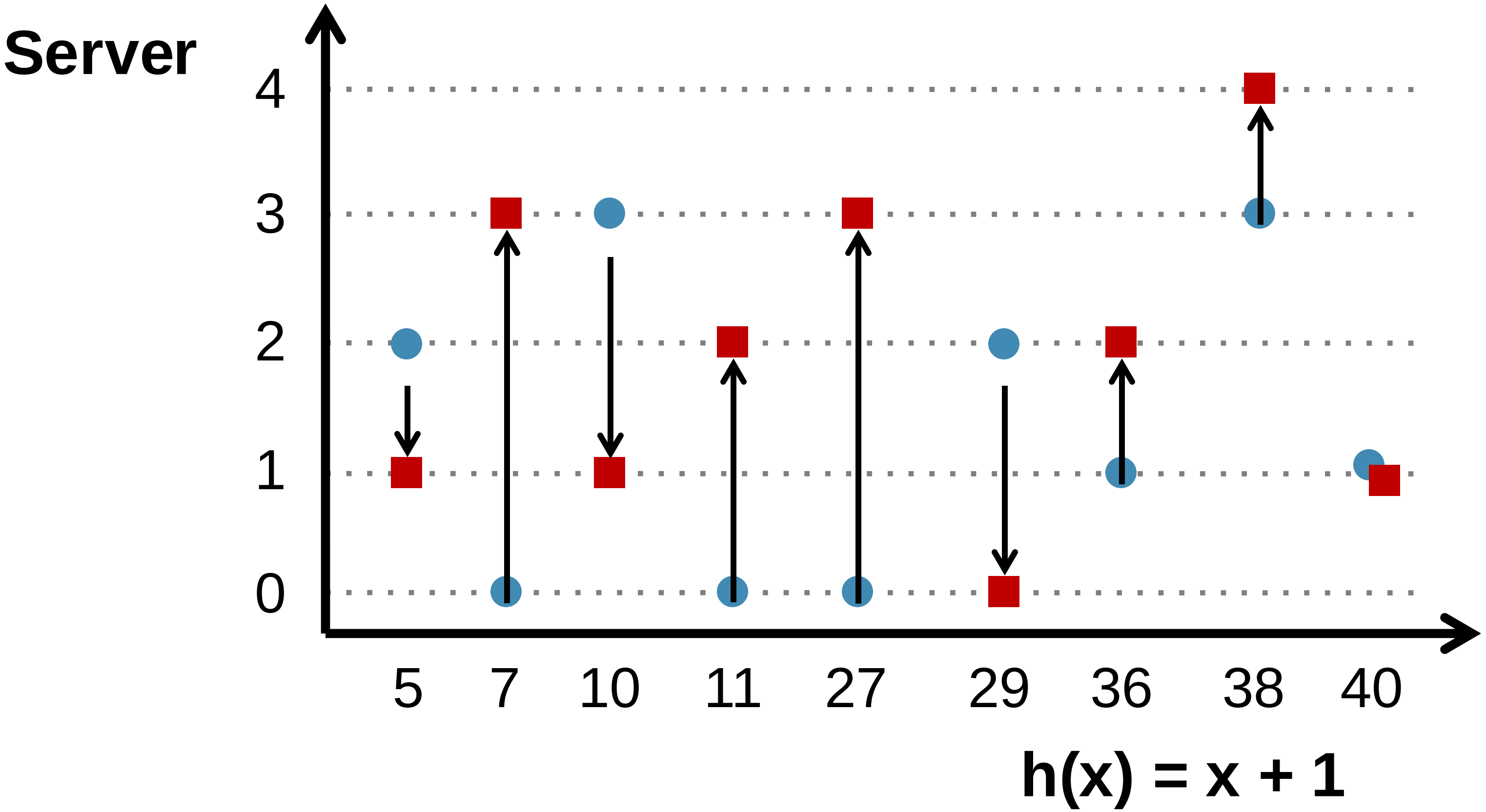


What happens if a server joins or fails (k ← k±1) or different clients have **different estimate** of k?

Problem for modulo hashing: Changing number of servers

i = h(*x*) mod 4

Add one machine: i = h(*x*) mod 5



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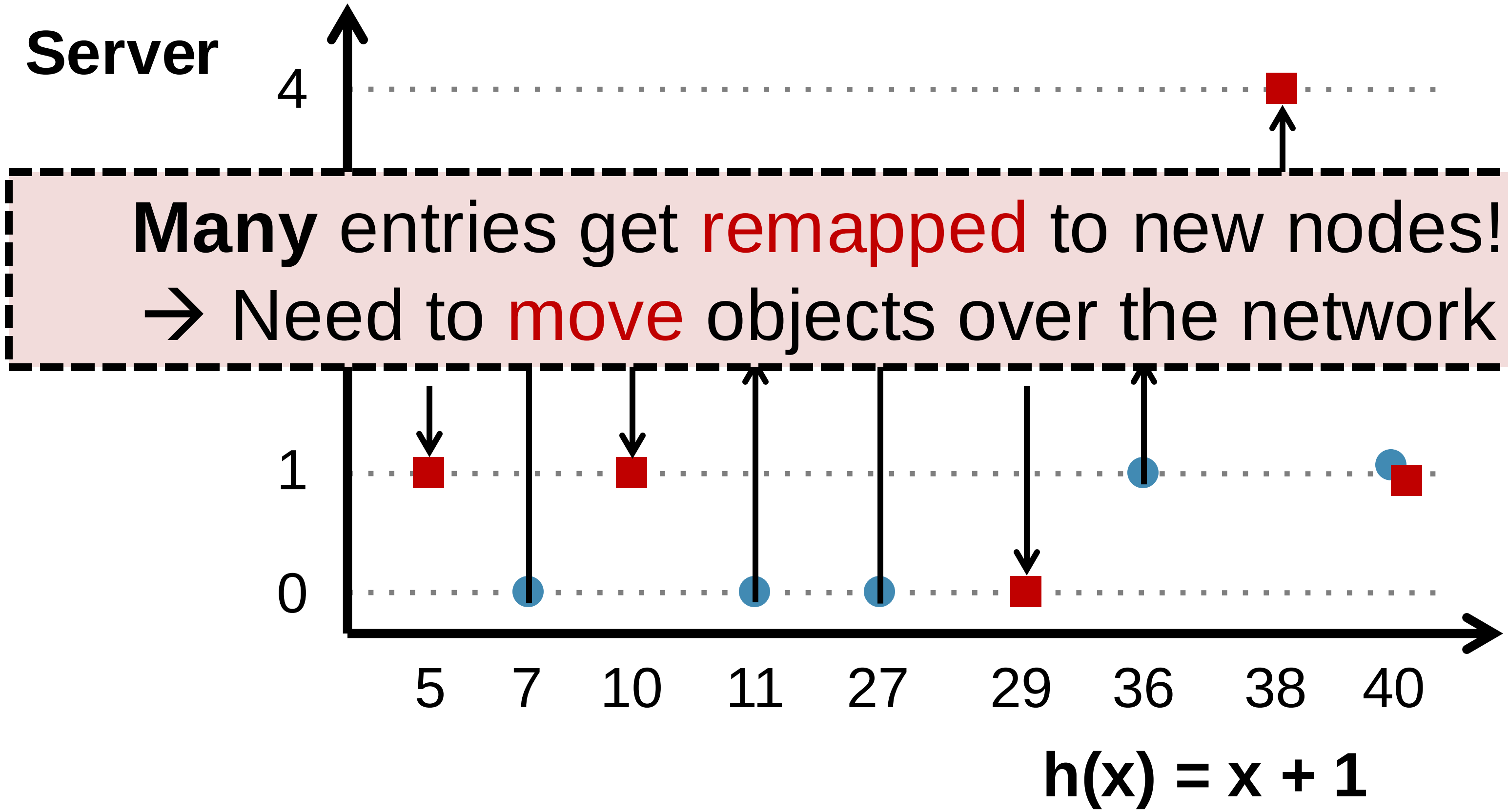
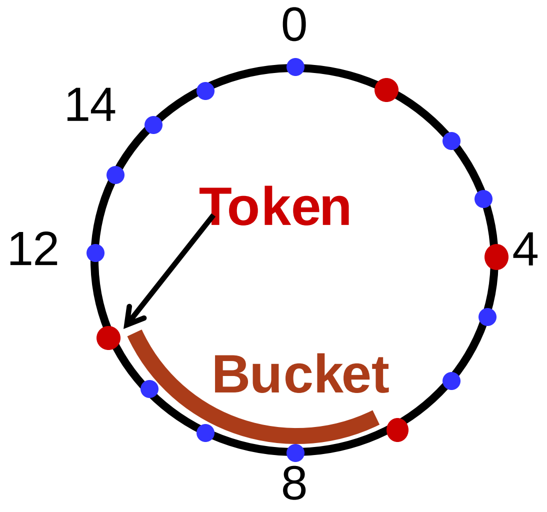


Many entries get remapped to new nodes!

→ Need to move objects over the network

Consistent hashing

- Assign n *tokens* to random points on mod 2^k circle; hash key size = k
- Hash object to random circle position
- Put object to **closest clockwise** bucket
  - *successor* (key) → bucket



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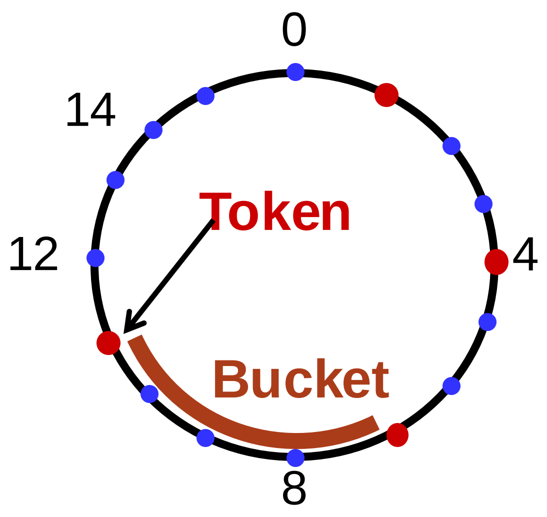
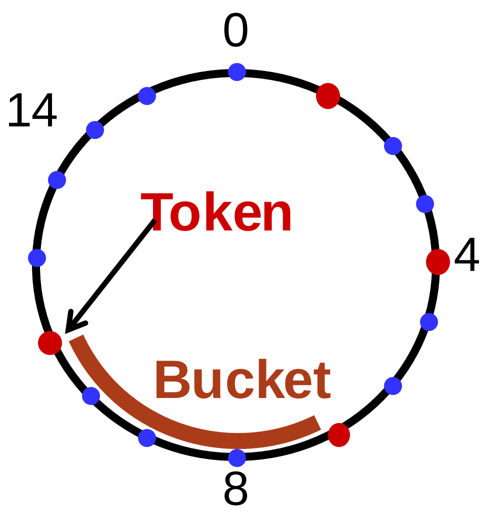


- **Desirable features:**
  - Balance: No bucket has "too many" objects; E(bucket size)=1/ n^{th}
  - Smoothness: Addition/removal of token minimizes object movements for other buckets

Consistent hashing's load balancing problem

- Each node owns 1/nth of the ID space in expectation
  - Hot keys → some buckets have higher request rate



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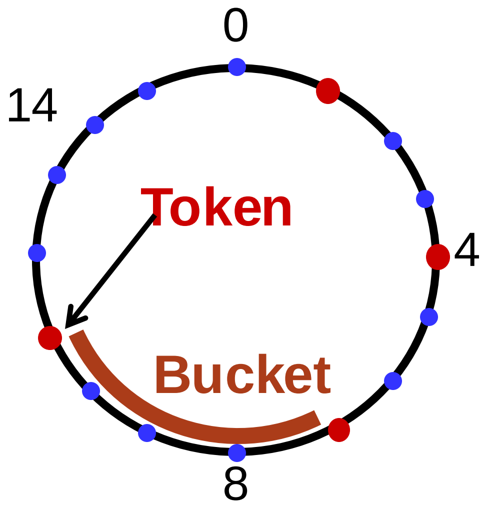

- If a node fails, its successor takes over bucket
  - Smoothness goal ✓: Only localized shift, not O(n)
  - But now successor owns **two** buckets: $2/n^{th}$ of key space
    - The failure has upset the load balance

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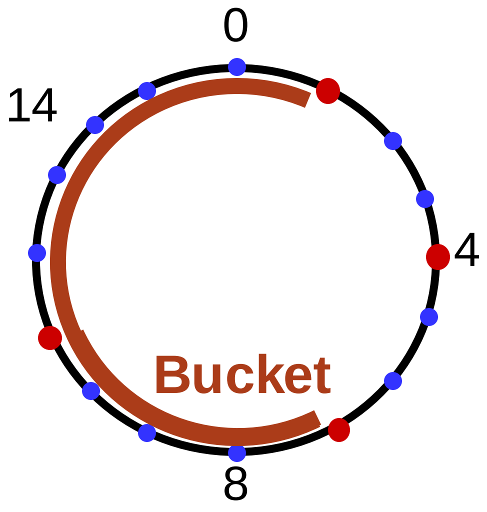

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Virtual nodes

- **Idea:** Each physical node implements v *virtual* nodes
  - Each **physical node** maintains **v > 1 token ids**
    - Each token id corresponds to a virtual node
    - Each **physical node** can have a different v based on strength of node (heterogeneity)

- Each virtual node owns an expected $1/(vn)^{th}$ of ID space

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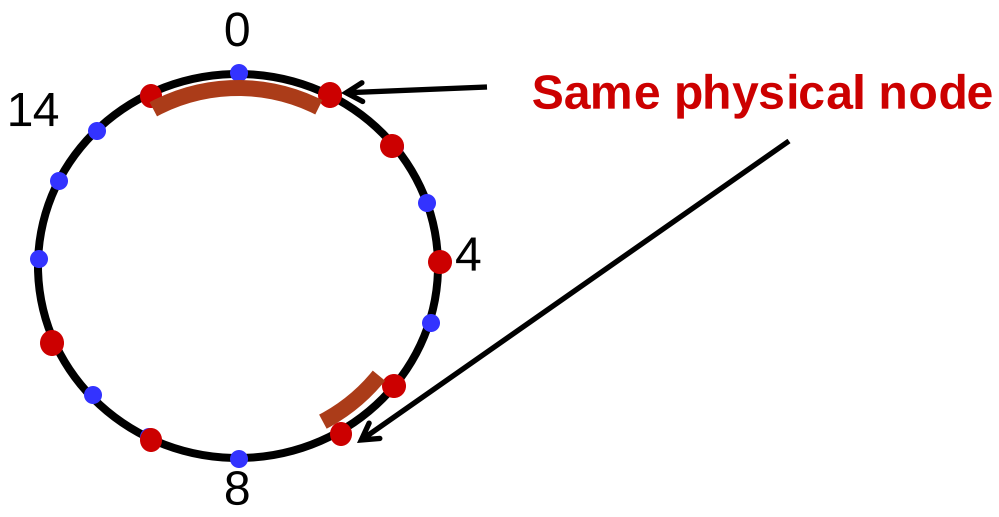
- Each virtual node owns an expected $1/(vn)^{th}$ of ID space

- **Upon a physical node's failure,** v virtual nodes fail
  - Their successors take over $1/(vn)^{th}$ more
    - Expected to be distributed across physical nodes

Virtual nodes: Example

4 Physical Nodes

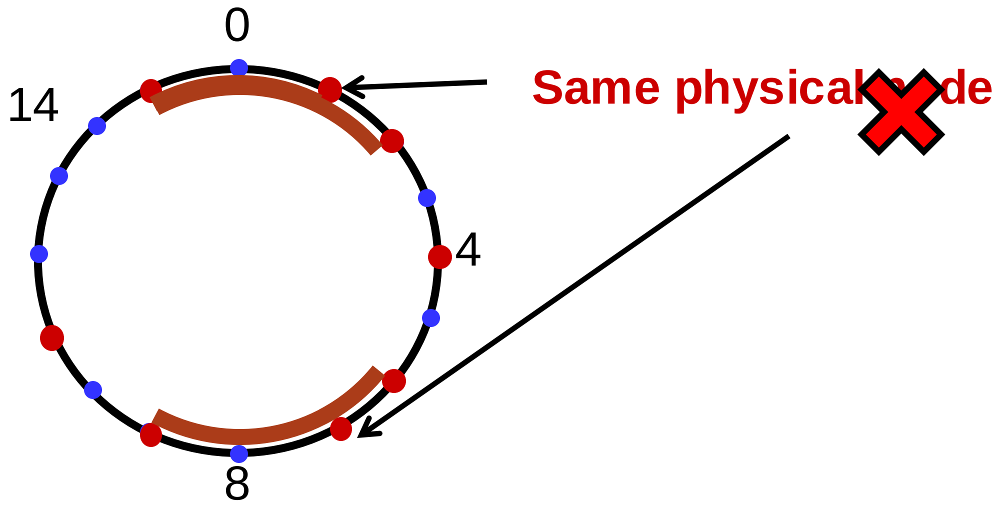
V=2



Virtual nodes: Example

4 Physical Nodes

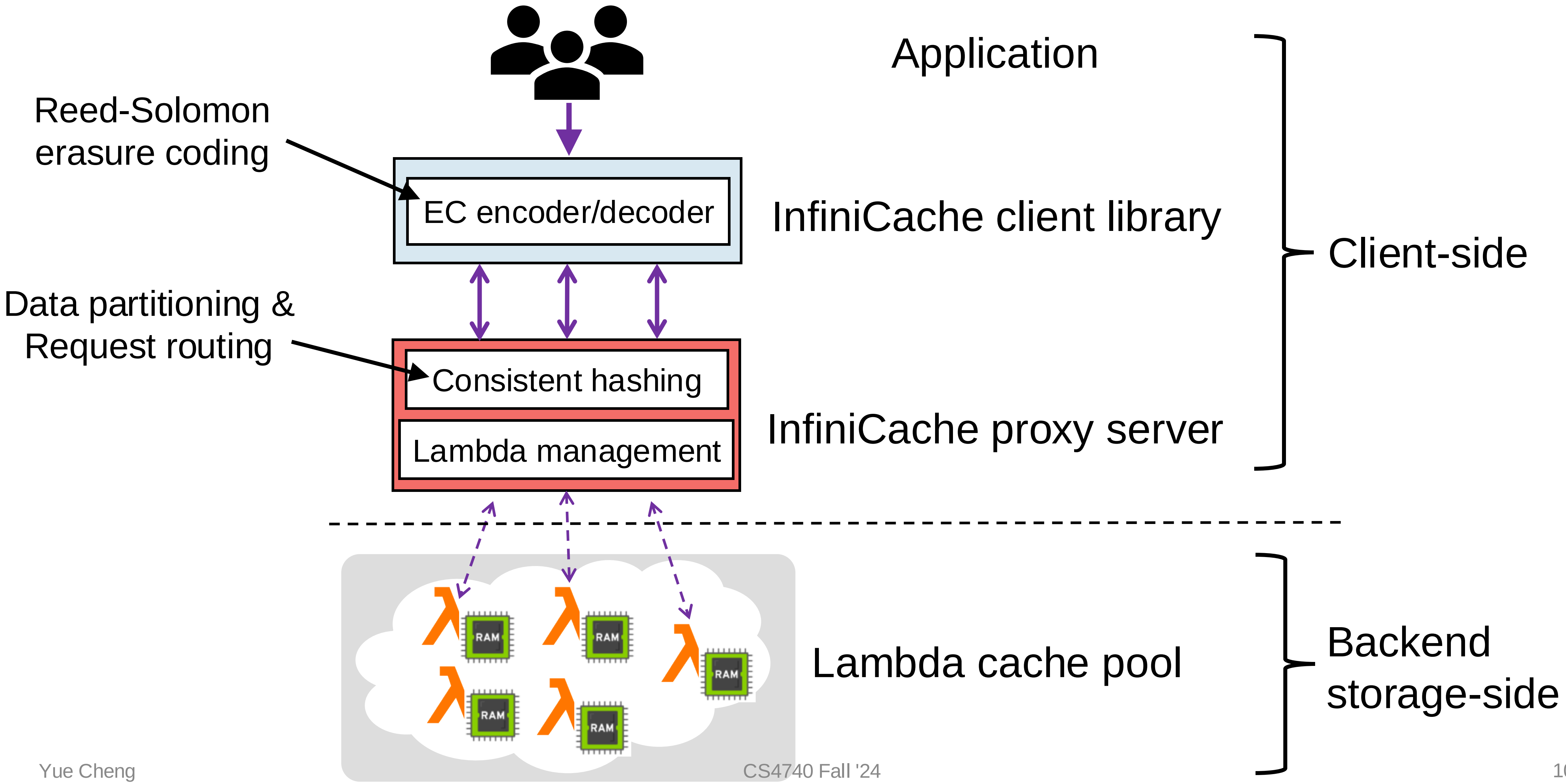
V=2



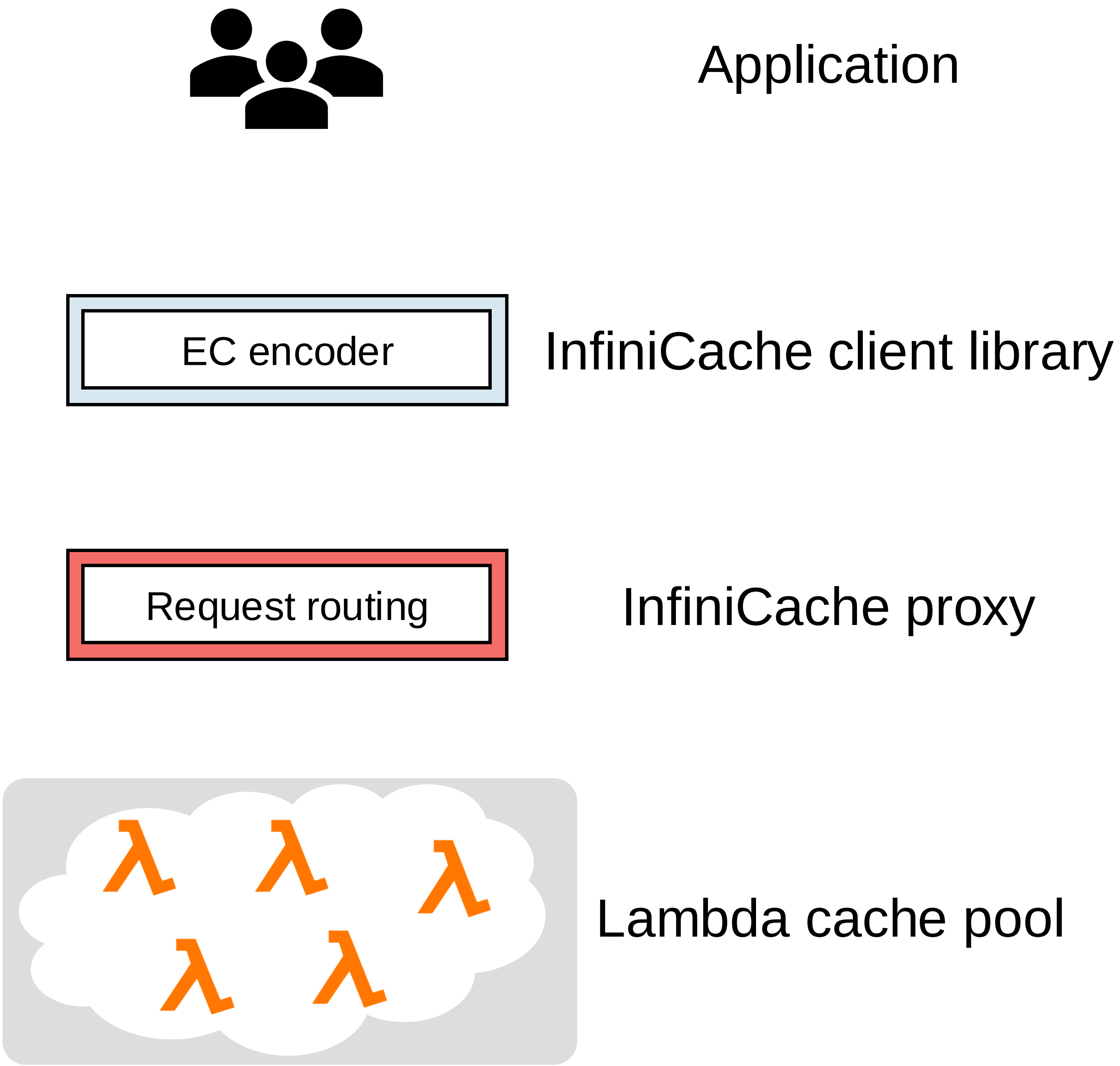
Result: Better load balance with larger v

Switching back to InfiniCache

InfiniCache bird's eye view



InfiniCache: PUT path



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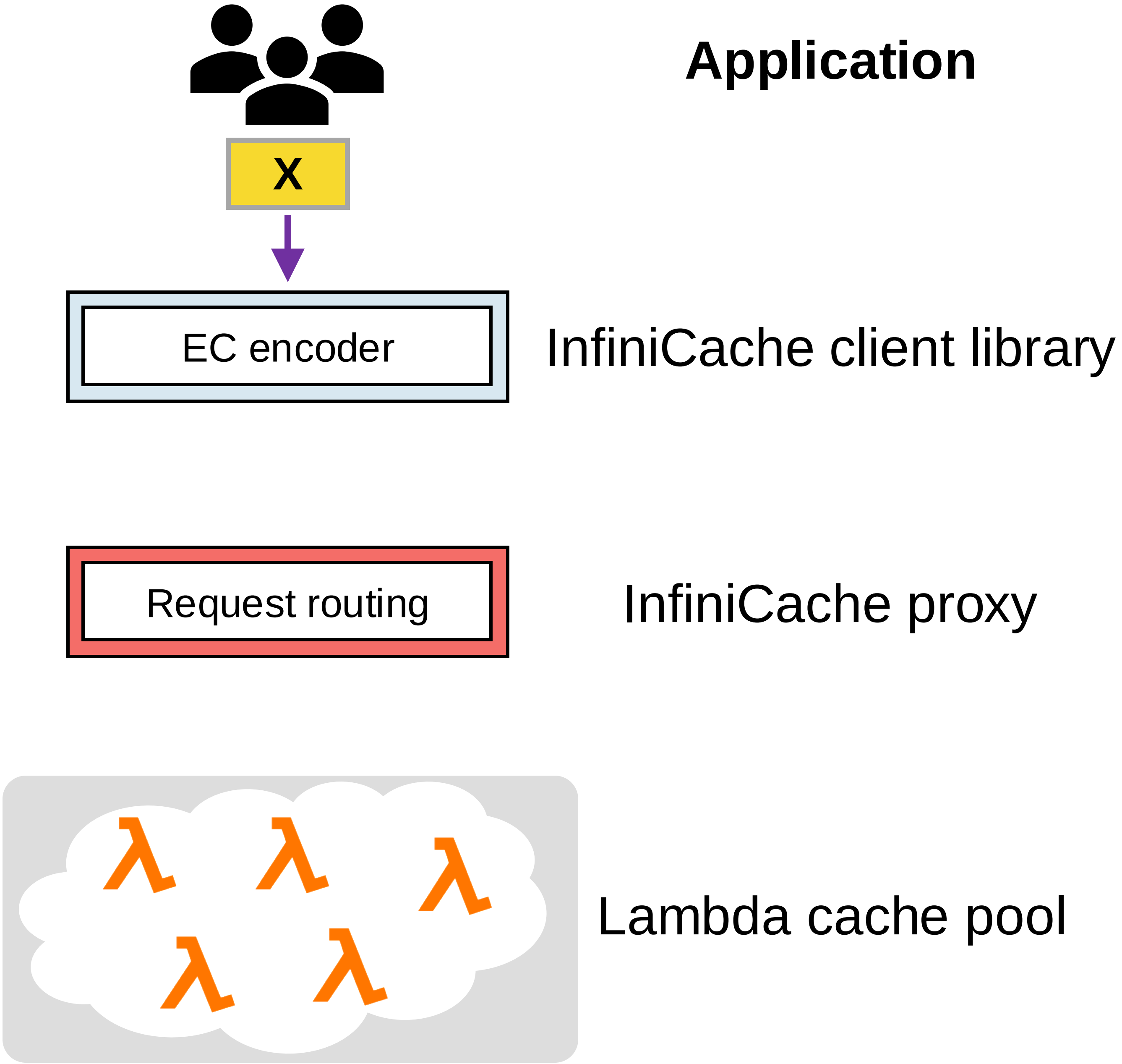
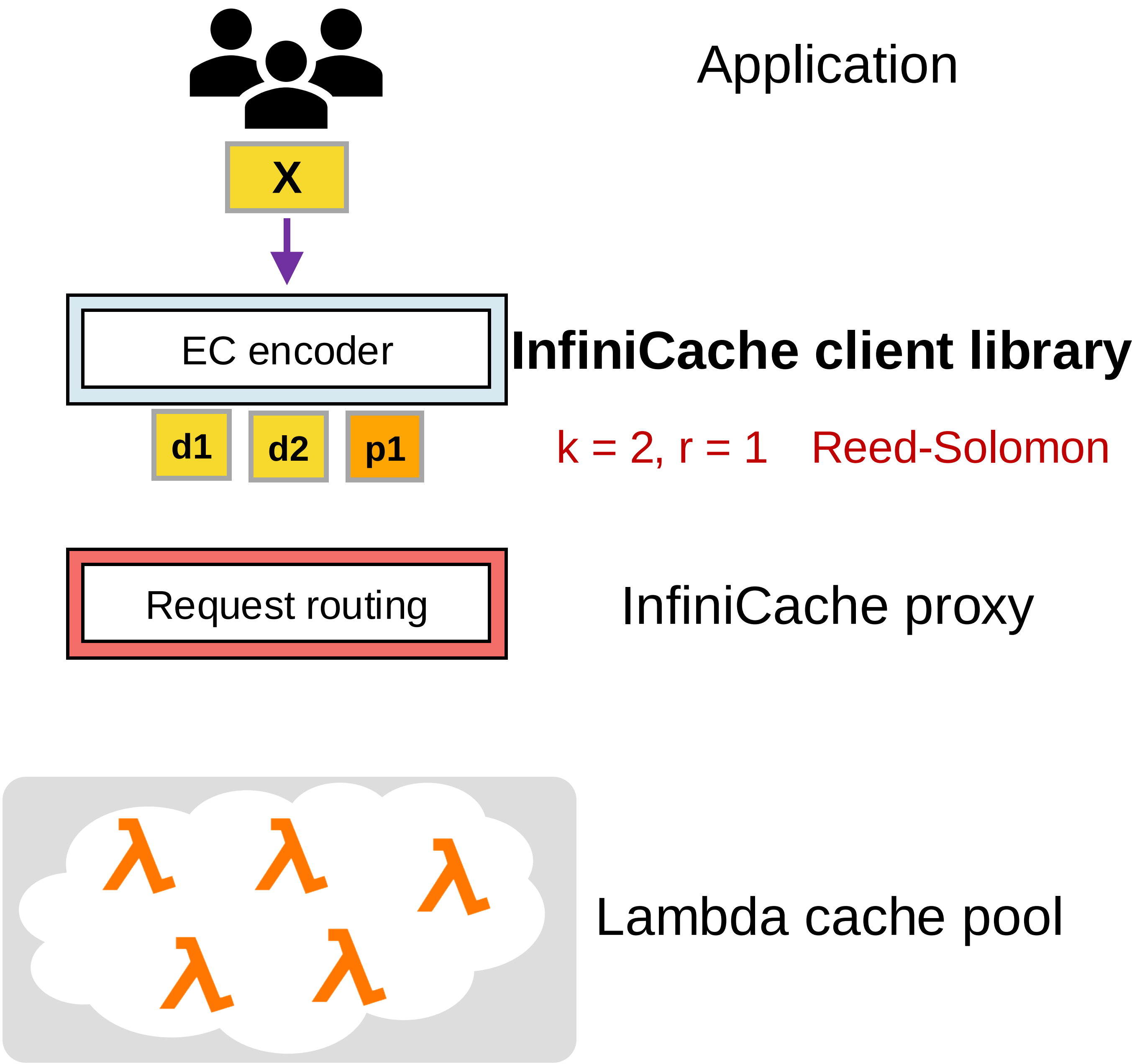


InfiniCache: PUT path

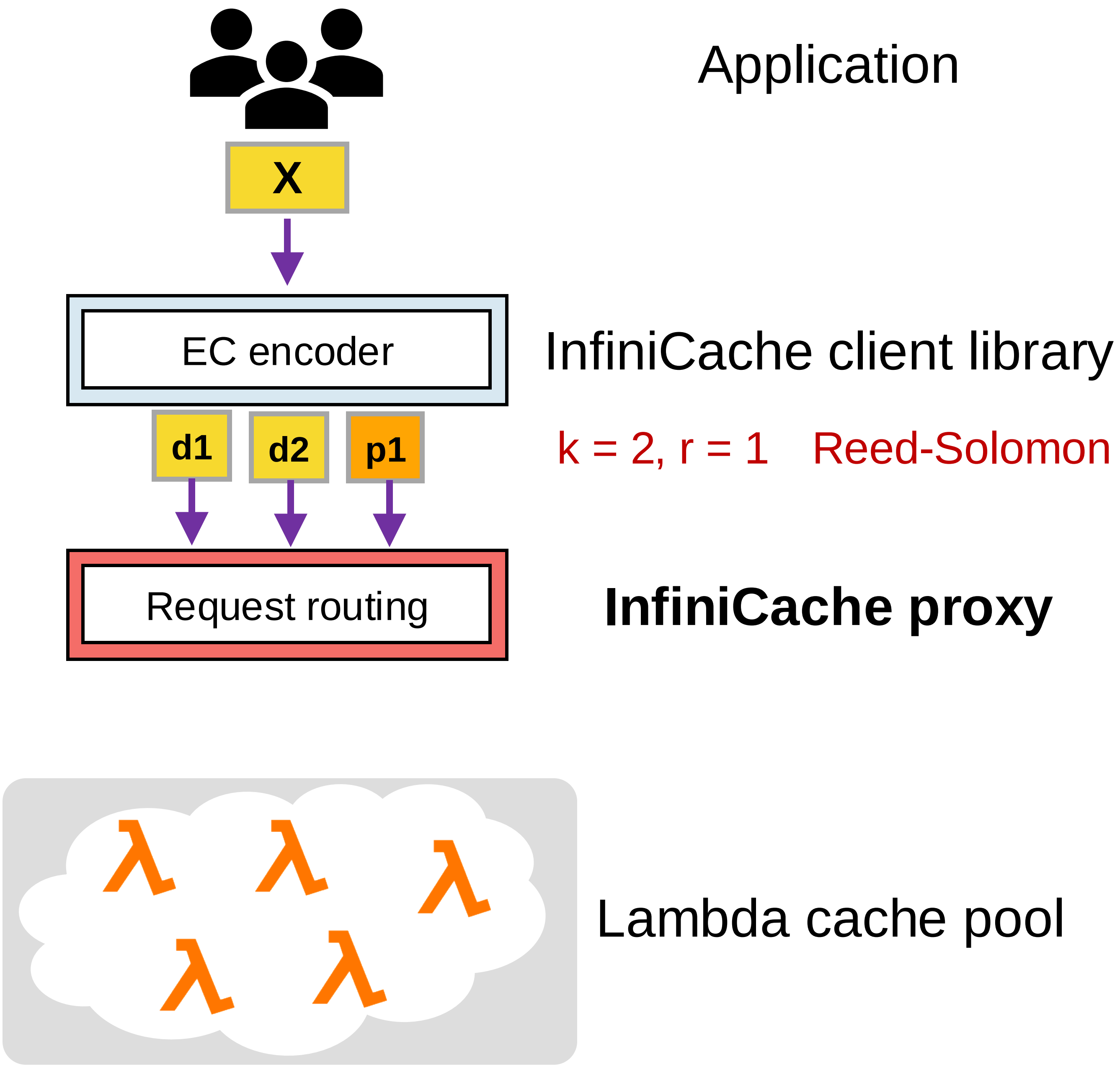
1. Object is split and encoded into k+r chunks



InfiniCache: PUT path

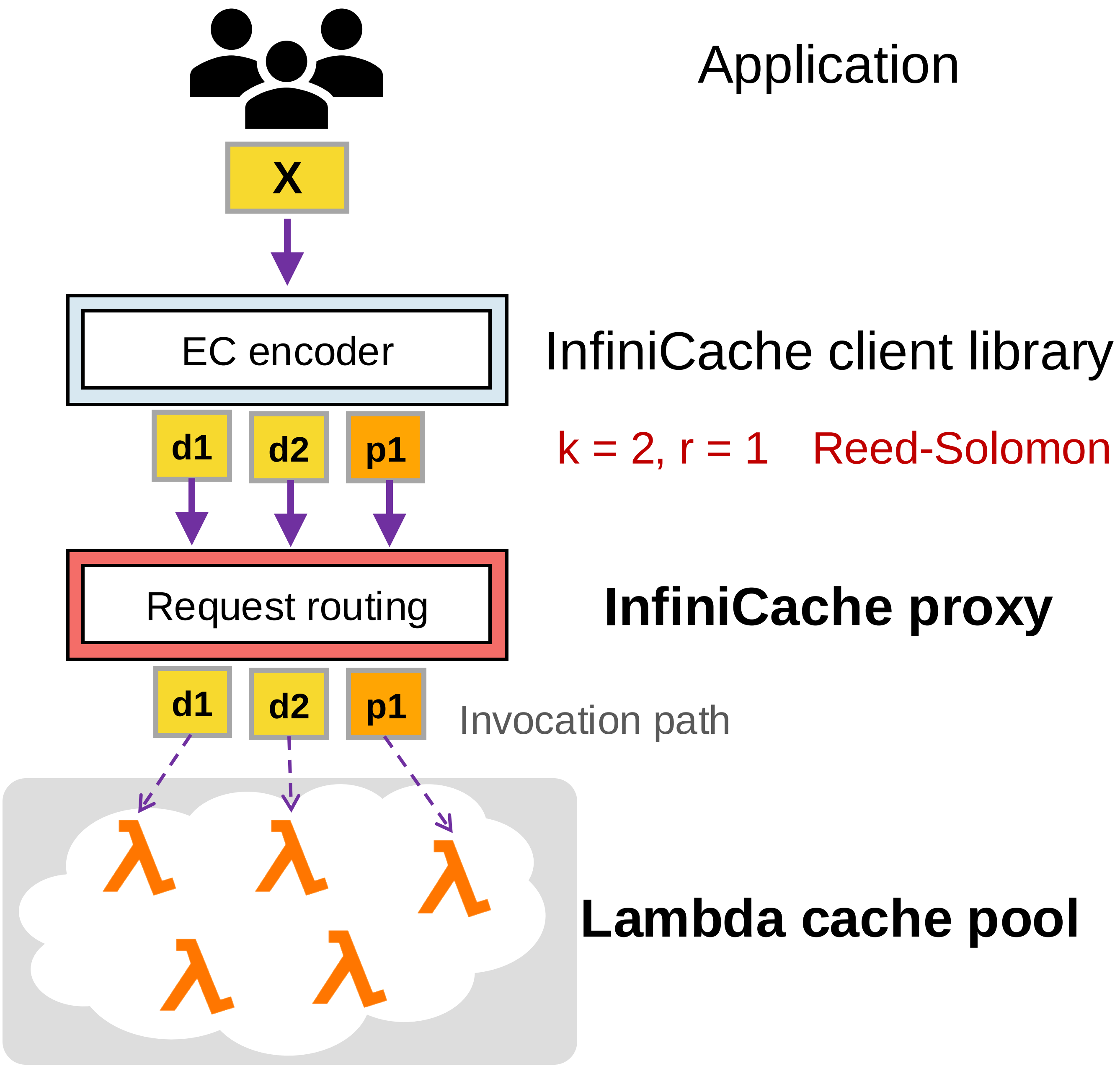
1. Object is split and encoded into k+r chunks

2. Object chunks are sent to the proxy in parallel



InfiniCache: PUT path

1. Object is split and encoded into k+r chunks
2. Object chunks are sent to the proxy in parallel
3. Proxy invokes Lambda cache nodes



InfiniCache: PUT path

1. Object is split and encoded into k+r chunks
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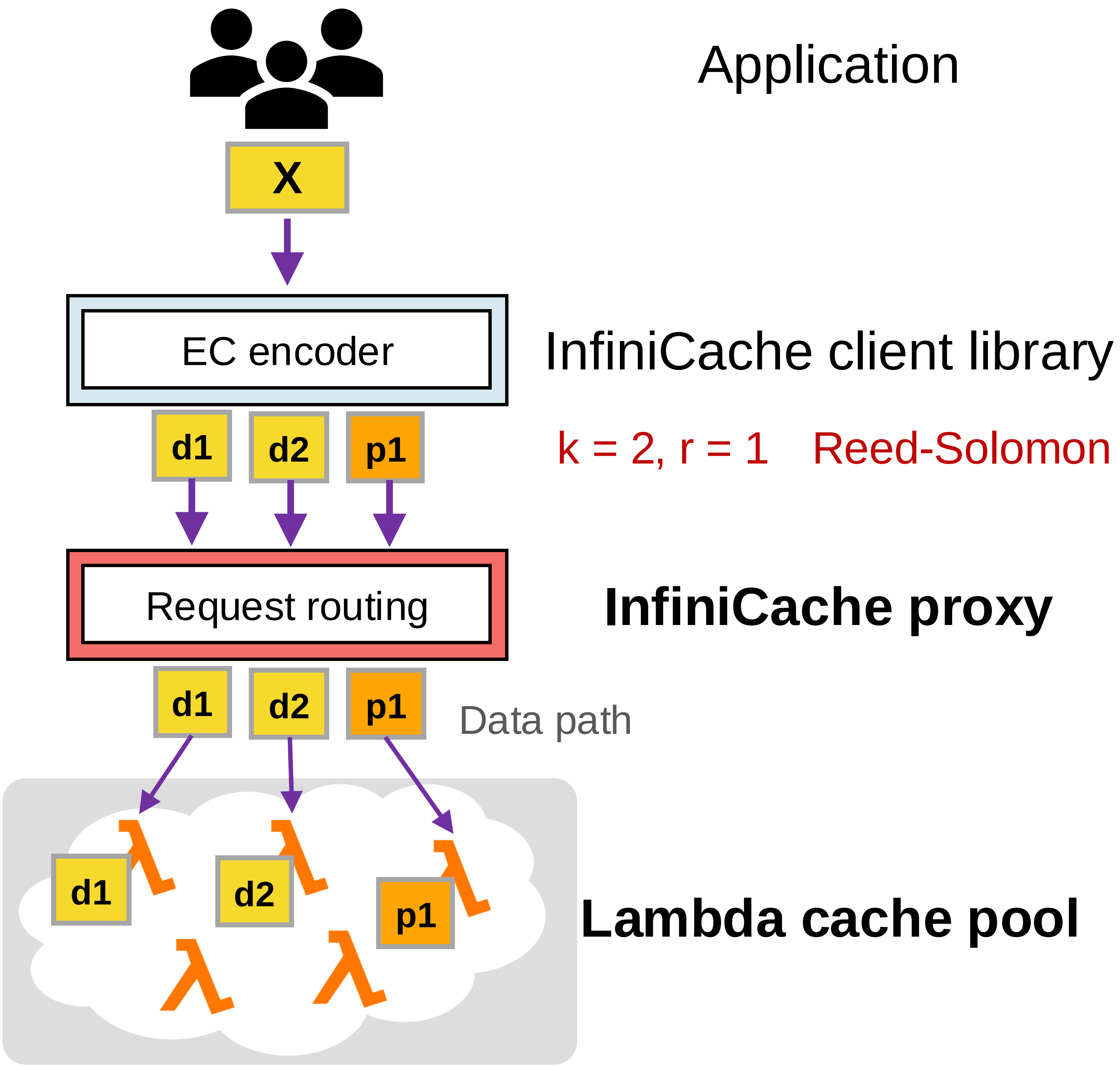
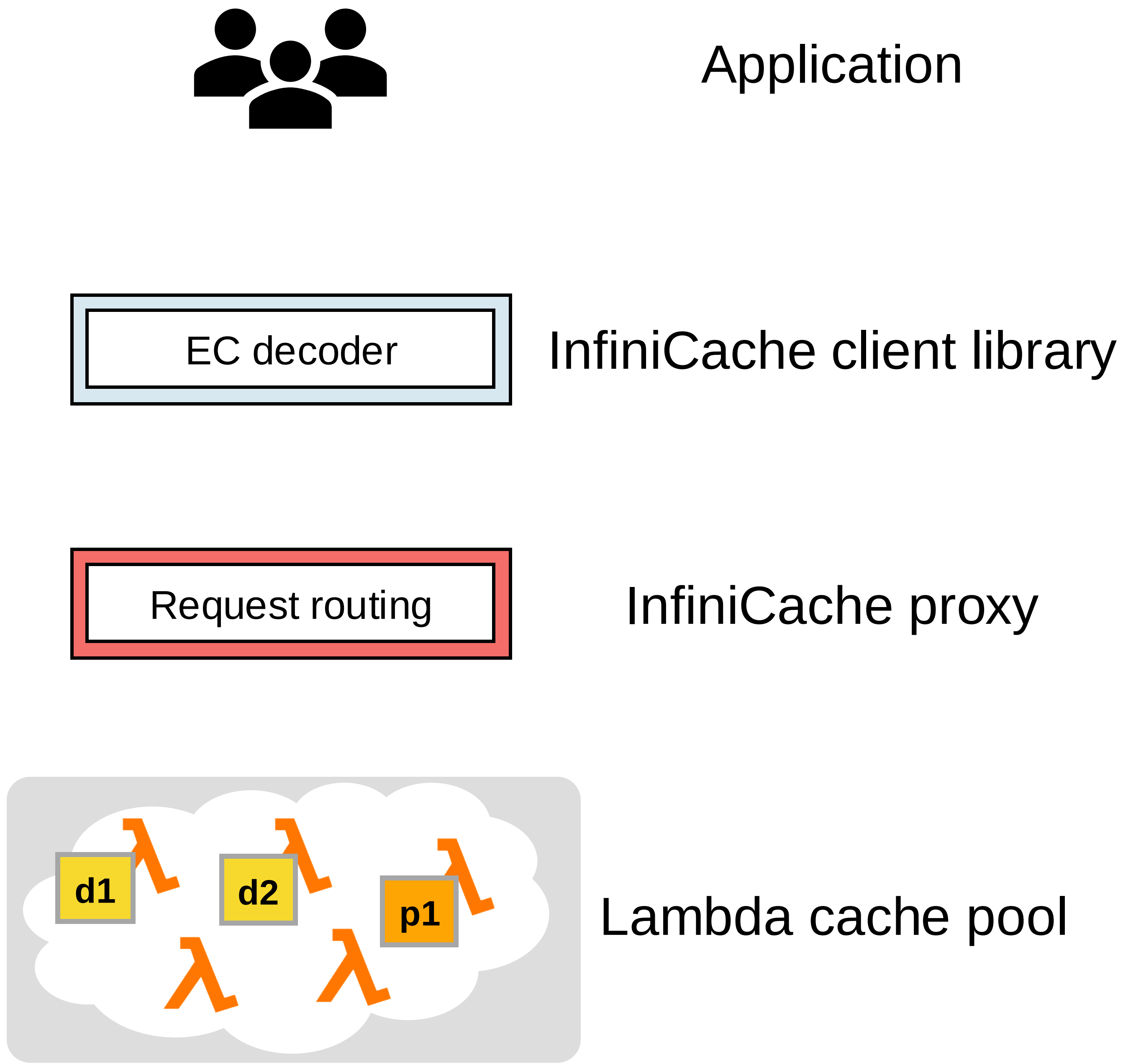
3. Proxy invokes Lambda cache nodes
4. Proxy streams object chunks to Lambda cache nodes

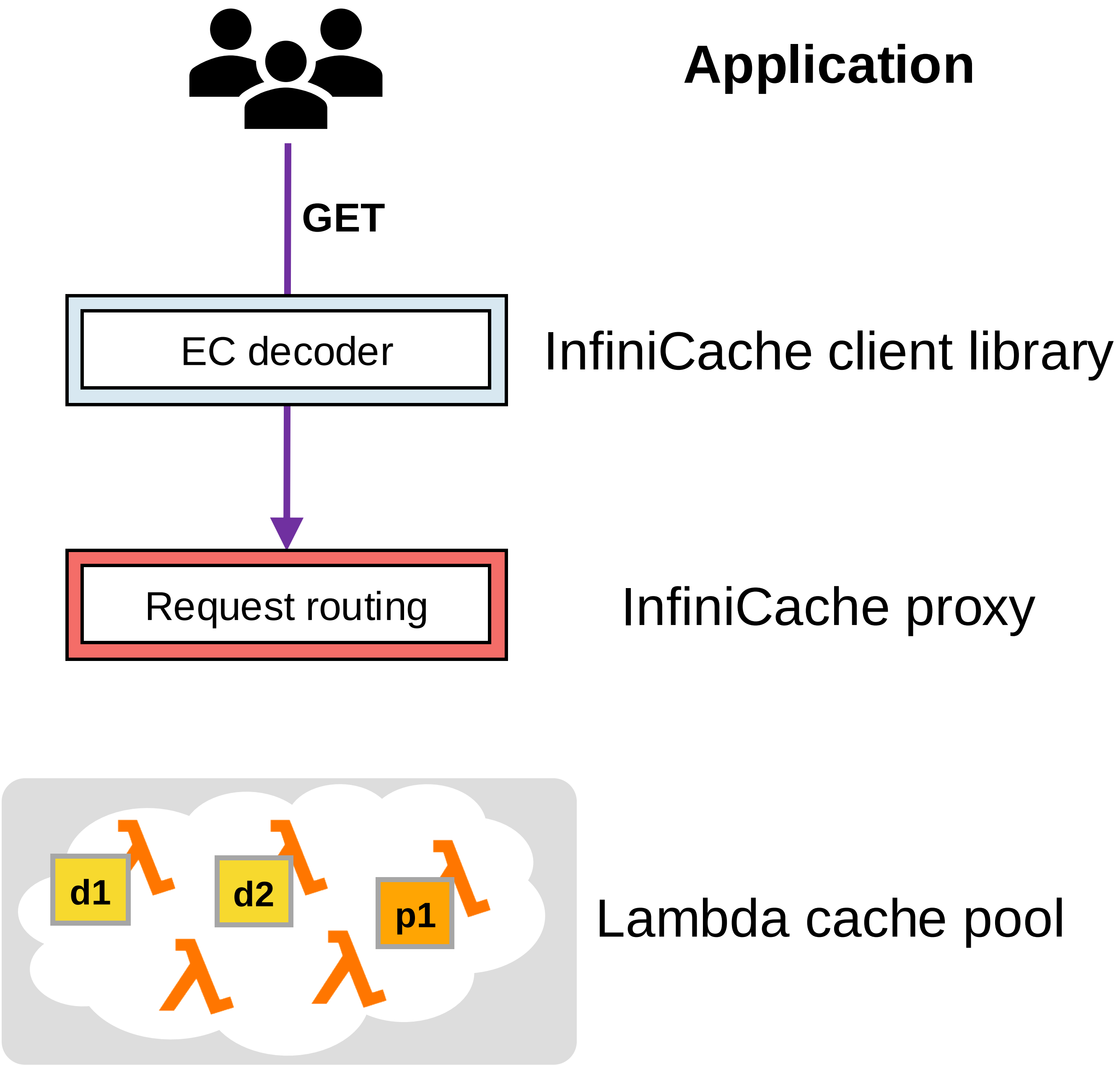


InfiniCache: GET path



InfiniCache: GET path

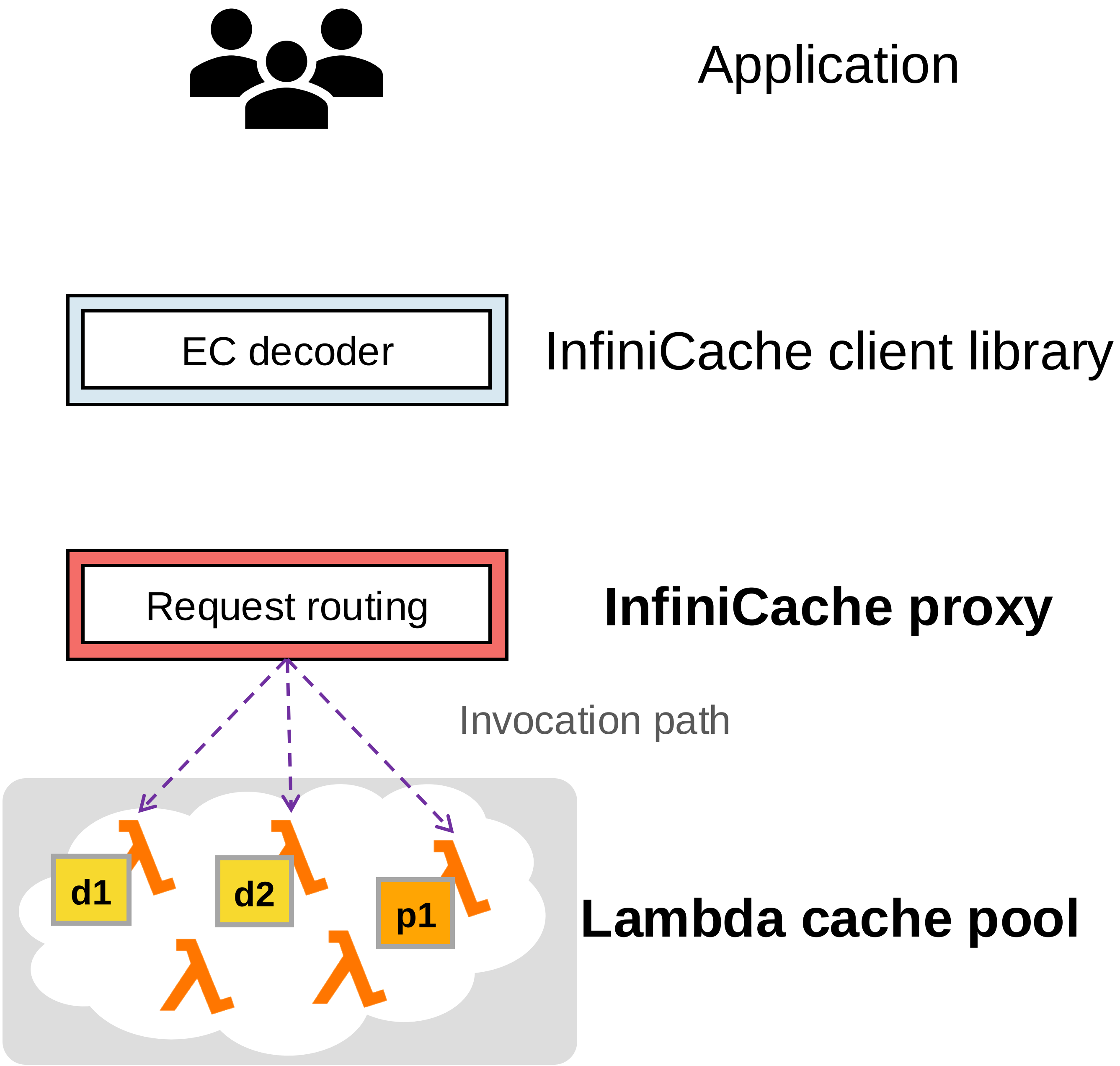
1. Client sends GET request



InfiniCache: GET path

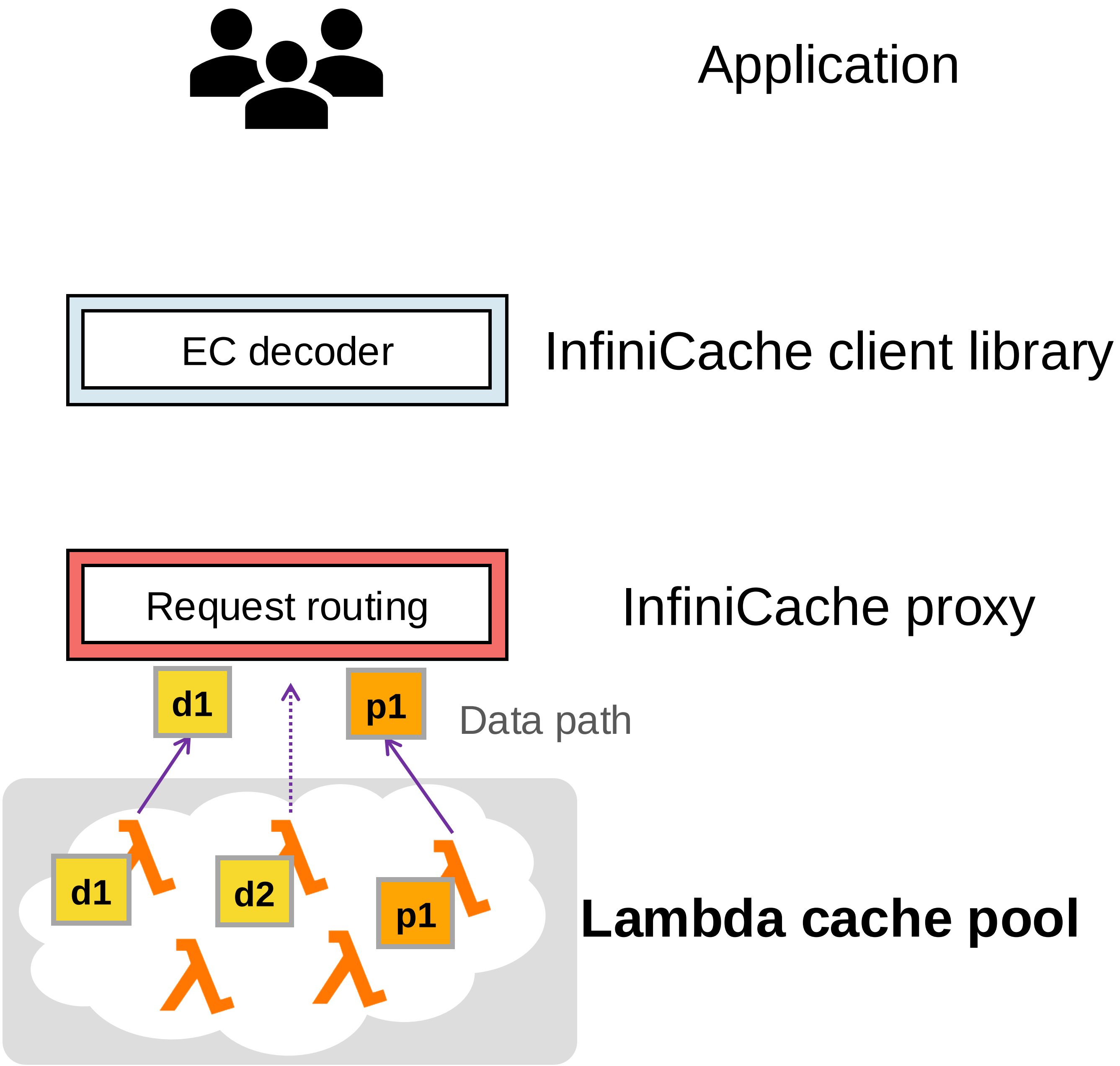
1. Client sends GET request

2. Proxy invokes associated Lambda cache nodes



InfiniCache: GET path

1. Client sends GET request
2. Proxy invokes associated Lambda cache nodes
3. Lambda cache nodes transfer object chunks to proxy



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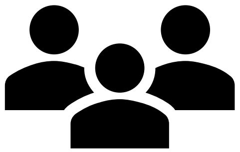

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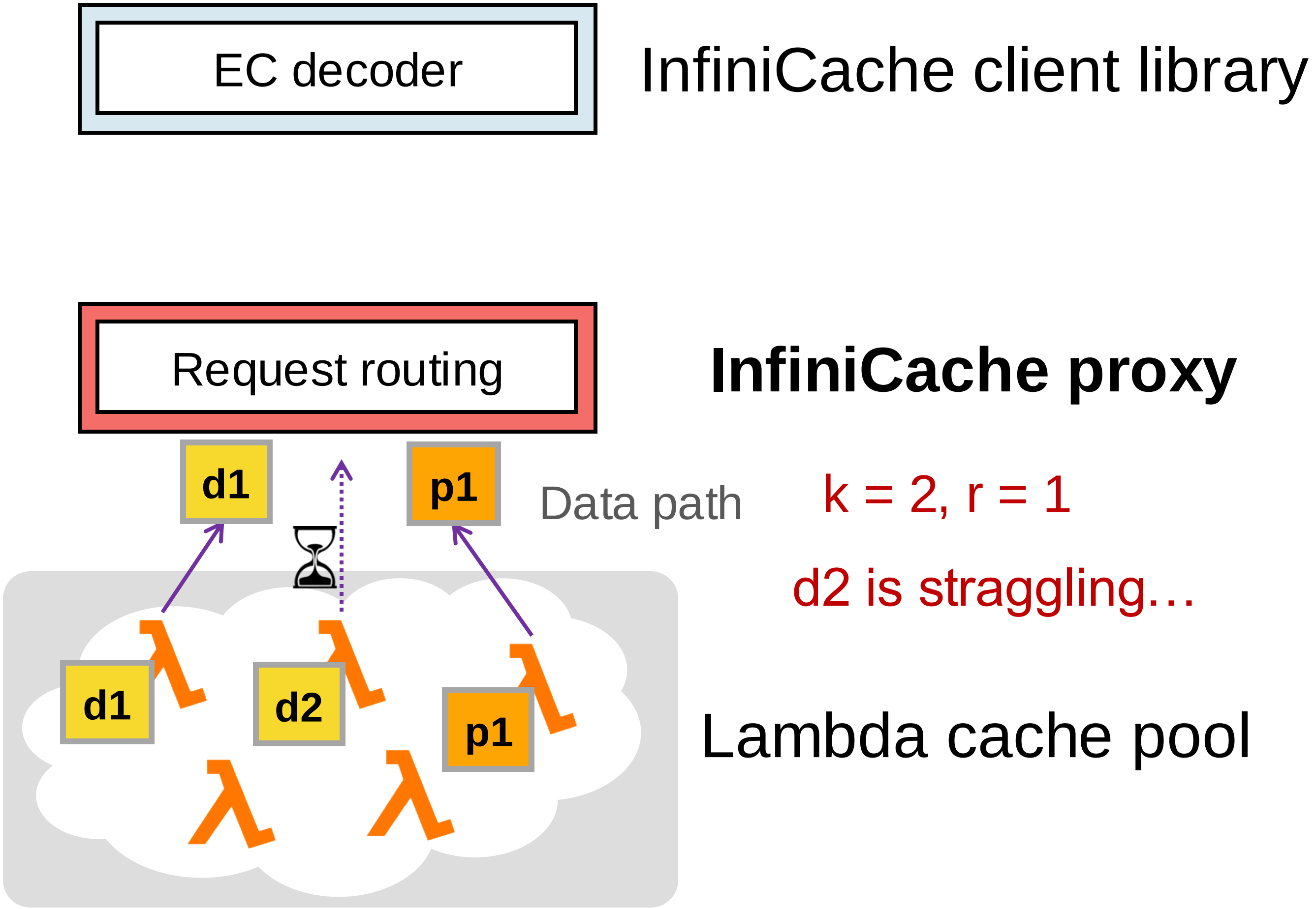
   - **First-d optimization:** Proxy drops **straggler** Lambda



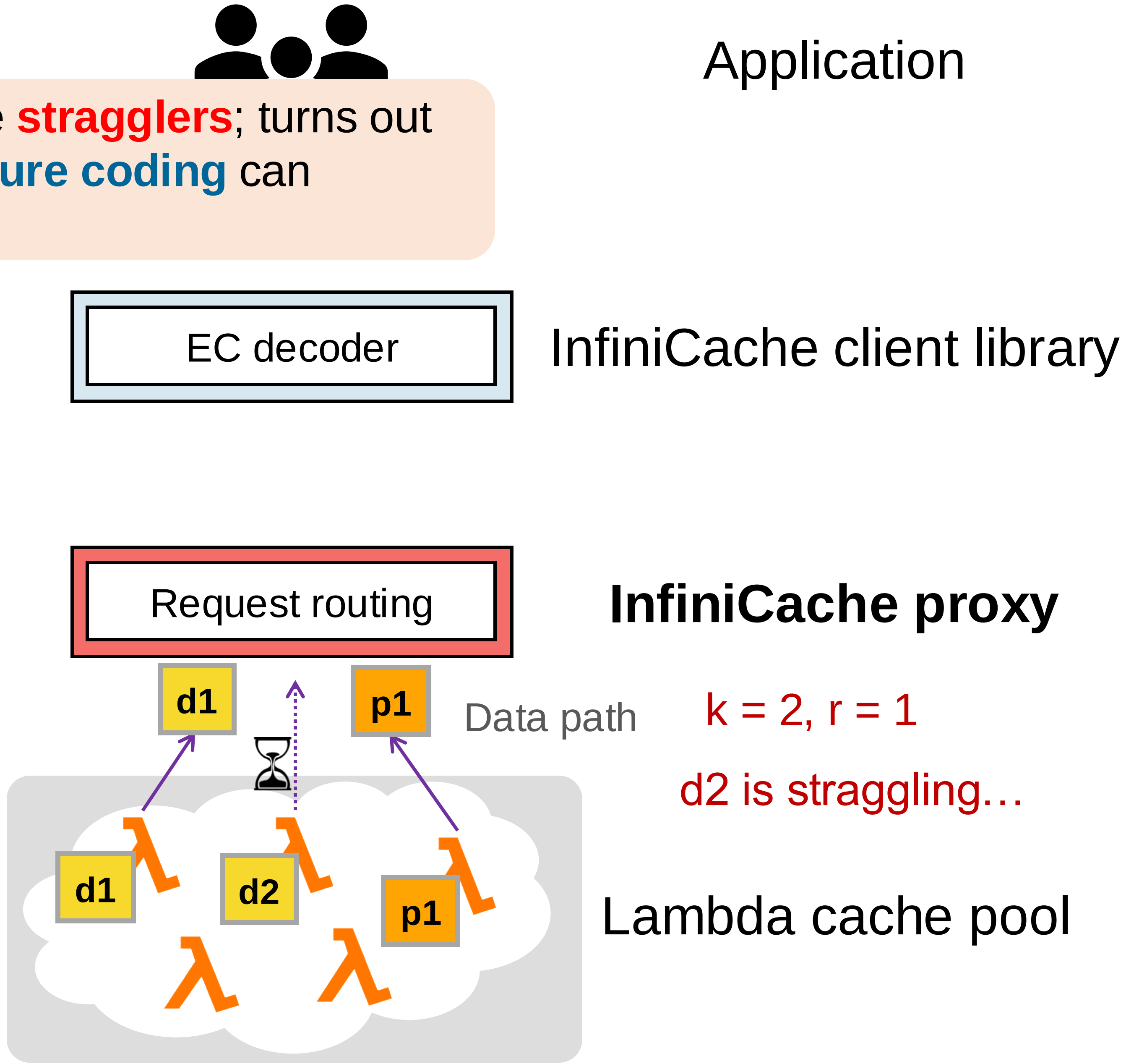
InfiniCache: GET path

Recall MapReduce uses replication to tackle **stragglers**; turns out storage-efficient redundancy technique **erasure coding** can achieve the same goal.

1. Client s quest

2. Proxy inv ociated Lambda ca des

3. Lambda cach odes transfer object chunks proxy
    - **First-d opti mization:** Proxy drops **straggler** Lambda



InfiniCache: GET path

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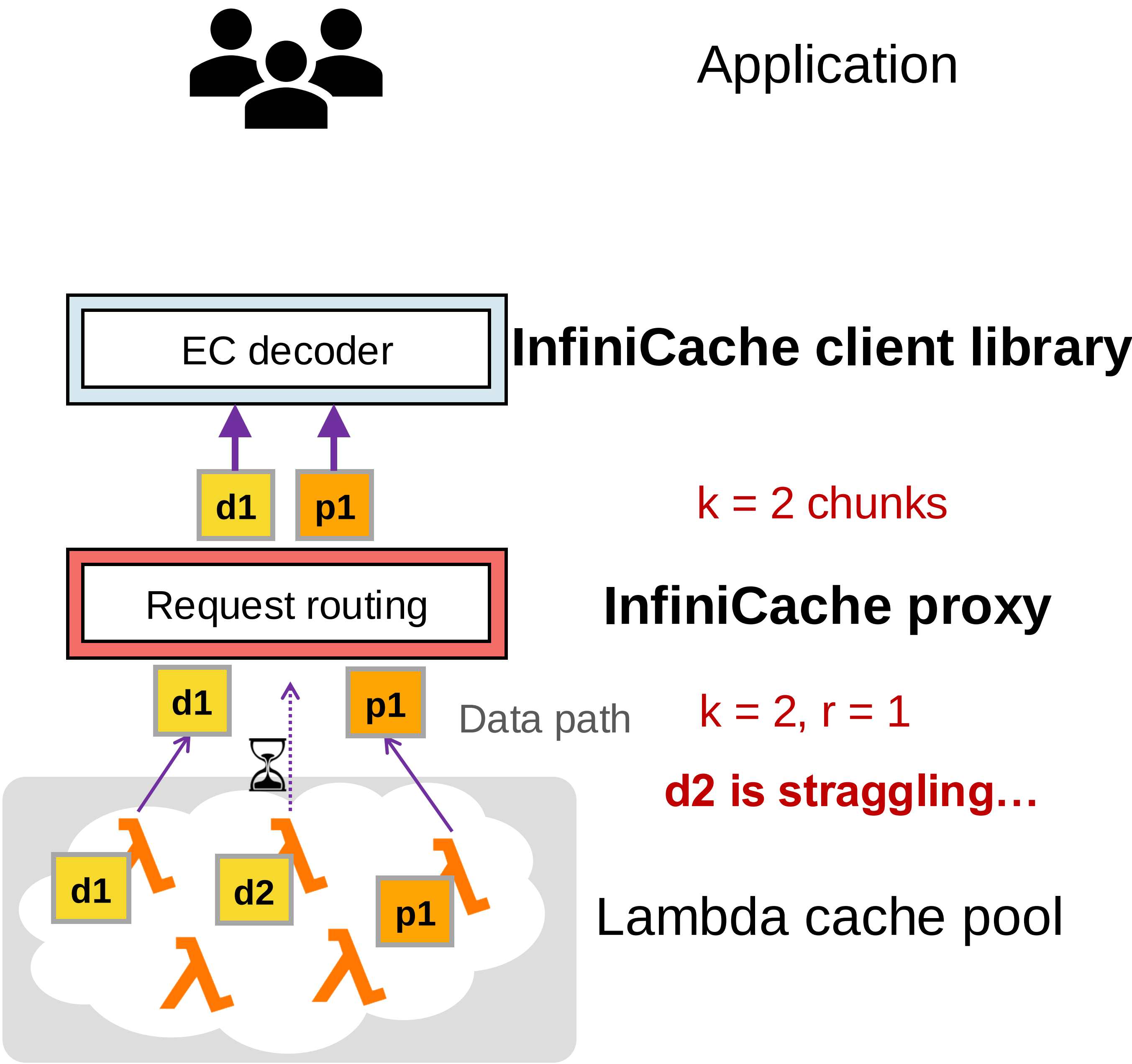
4. Proxy streams k=2 chunks in parallel to client



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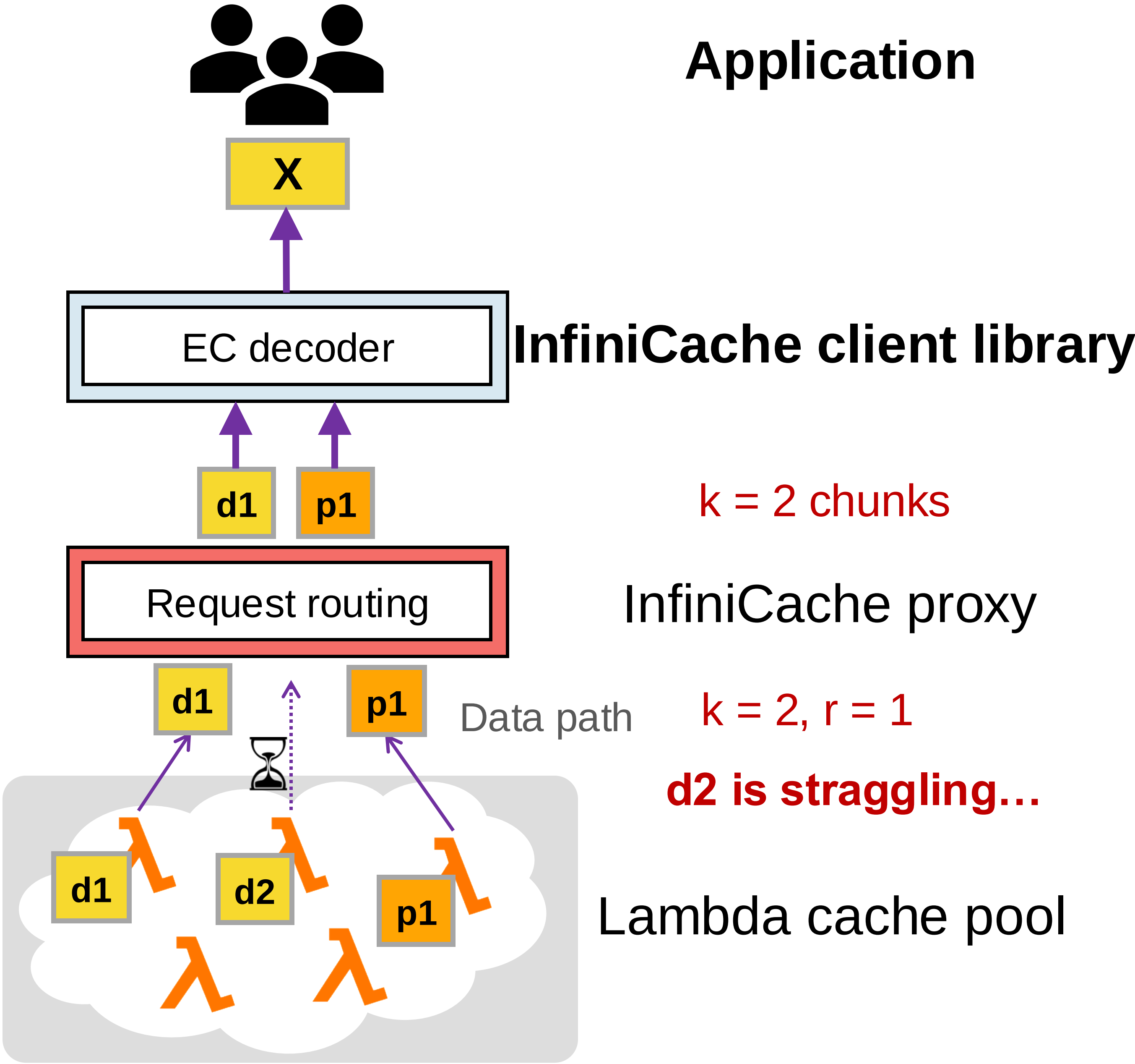

InfiniCache: GET path

Application

Tradeoff: Computational cost of EC decoding **vs.** delay waiting for the straggler (typically, **computational cost < straggler delay**, thanks to the efficient implementation of modern EC libraries)

1. Client sen

2. Proxy invoke
   Lambda cach

3. Lambda cache ansfer
   object chunks to

4. Proxy streams k=2 unks in
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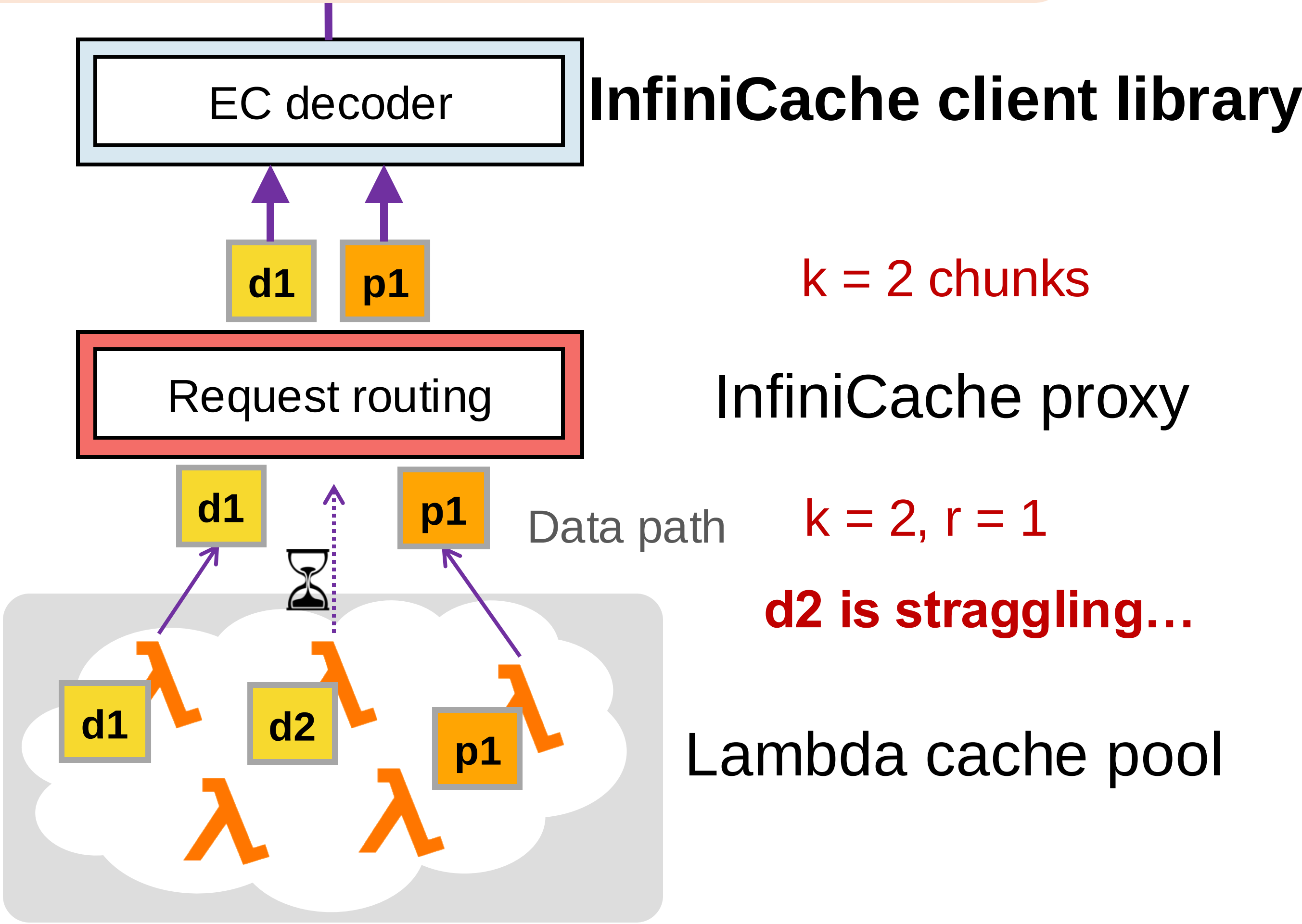
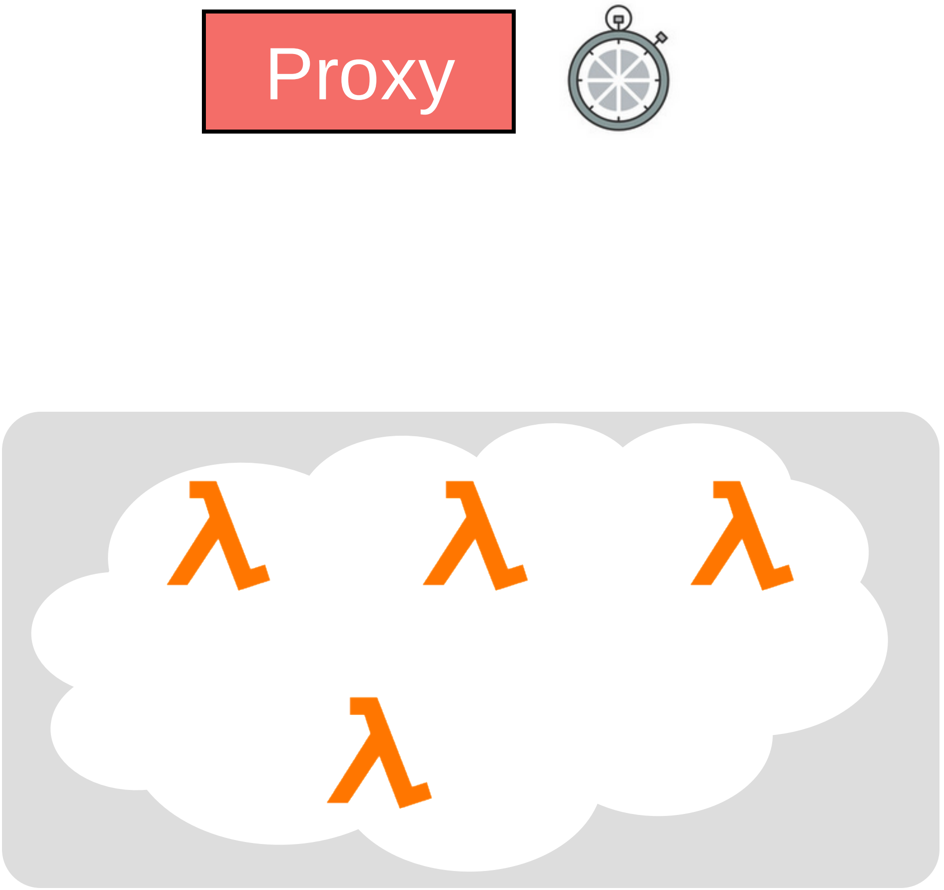


Maximizing data availability

- Erasure-coding
- Periodic warm-up
- Smart delta-sync backup

Maximizing data availability: Periodic warm-up

1. Lambda nodes are cached by AWS when not running



Maximizing data availability: Periodic warm-up

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    - AWS may reclaim cold Lambda functions after they are idling for a period

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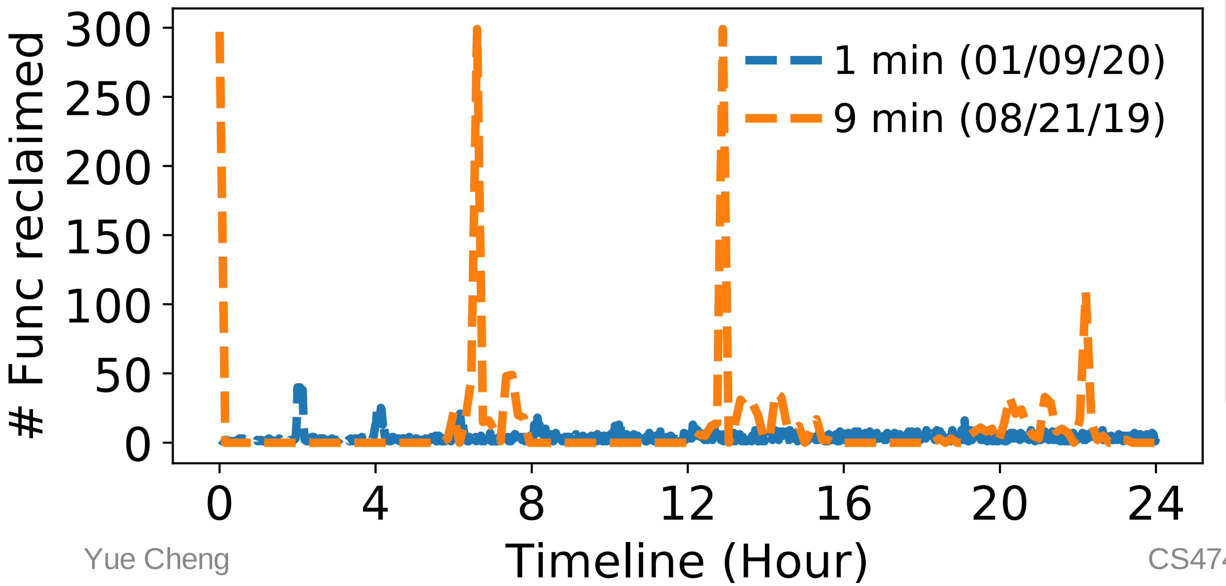

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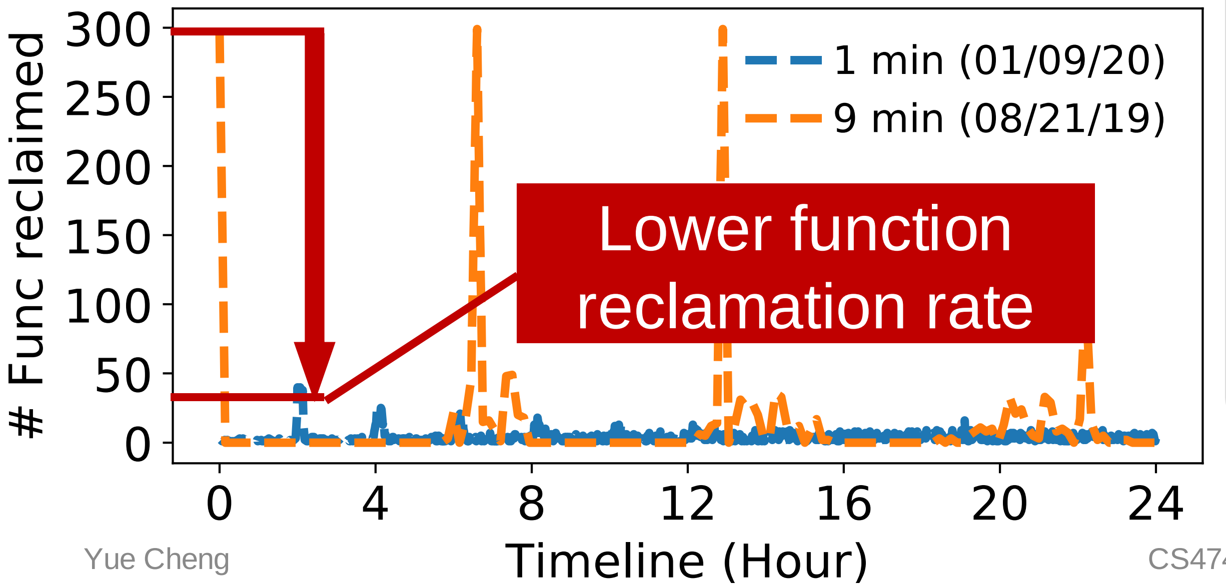
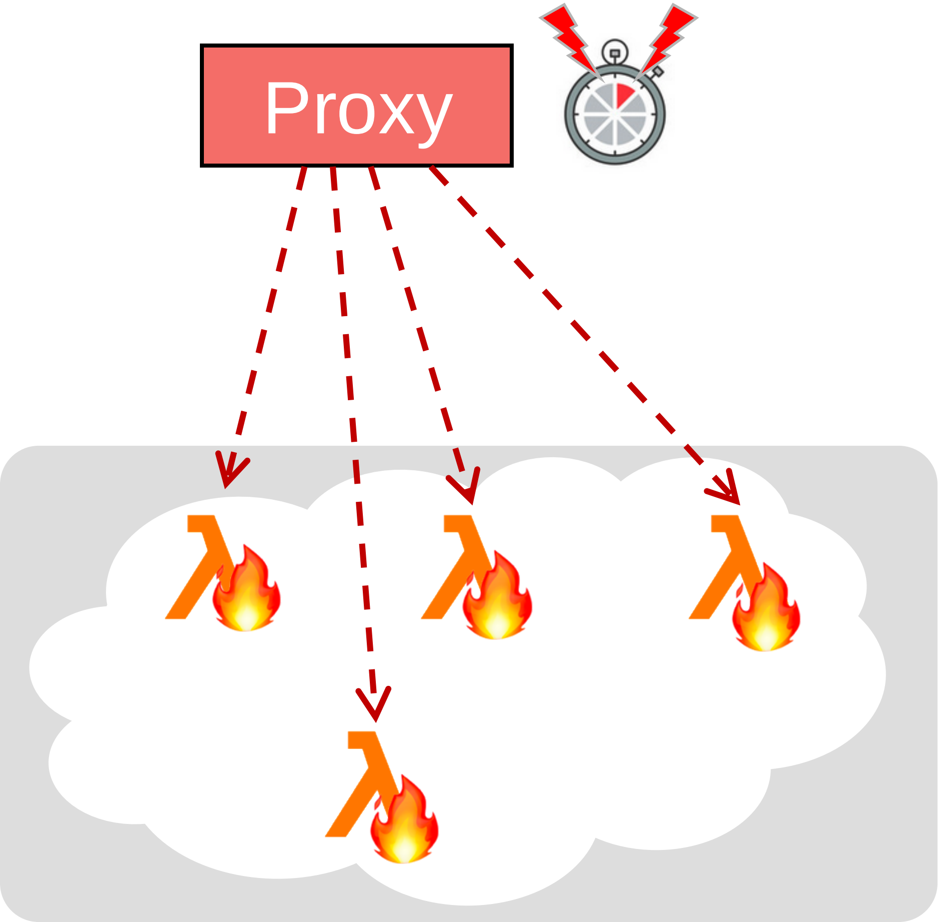


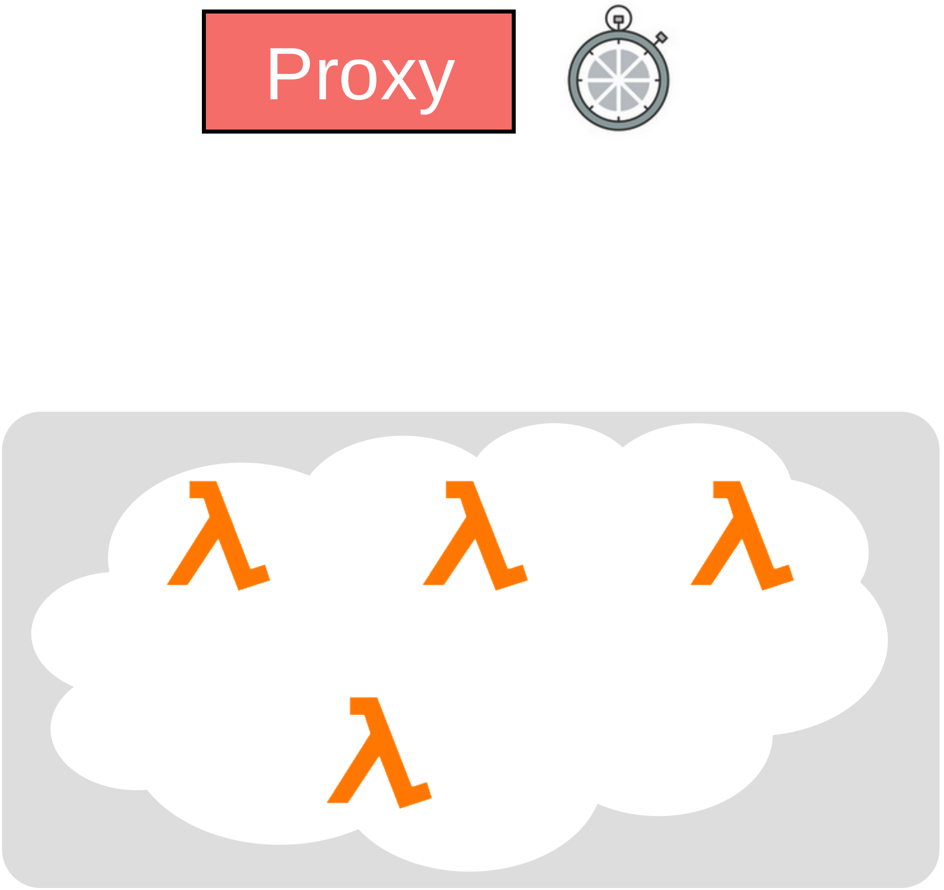
Maximizing data availability: Periodic warm-up

1. Lambda nodes are cached by AWS when not running

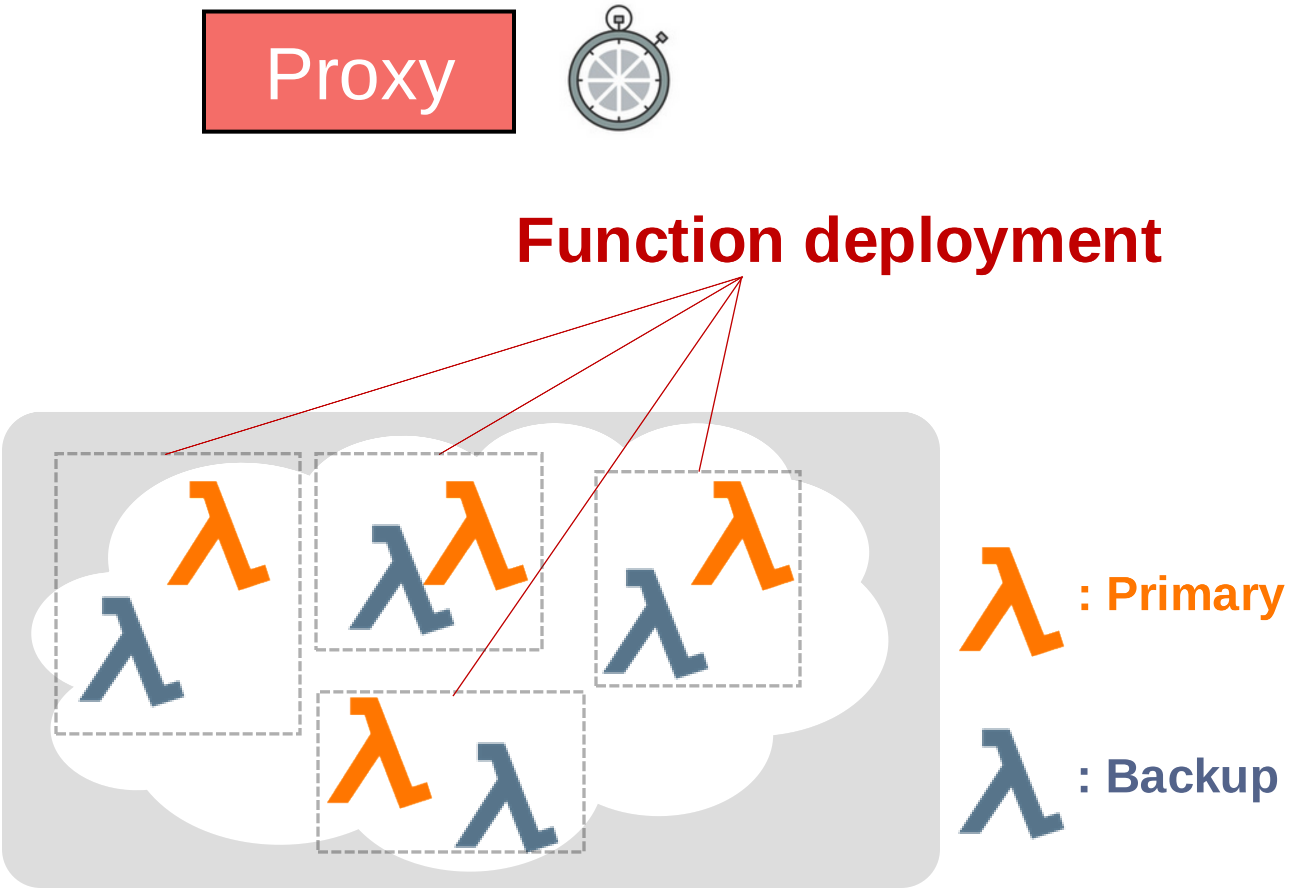
2. Proxy periodically invokes sleeping Lambda cache nodes to extend their lifespan



Maximizing data availability: Periodic backup

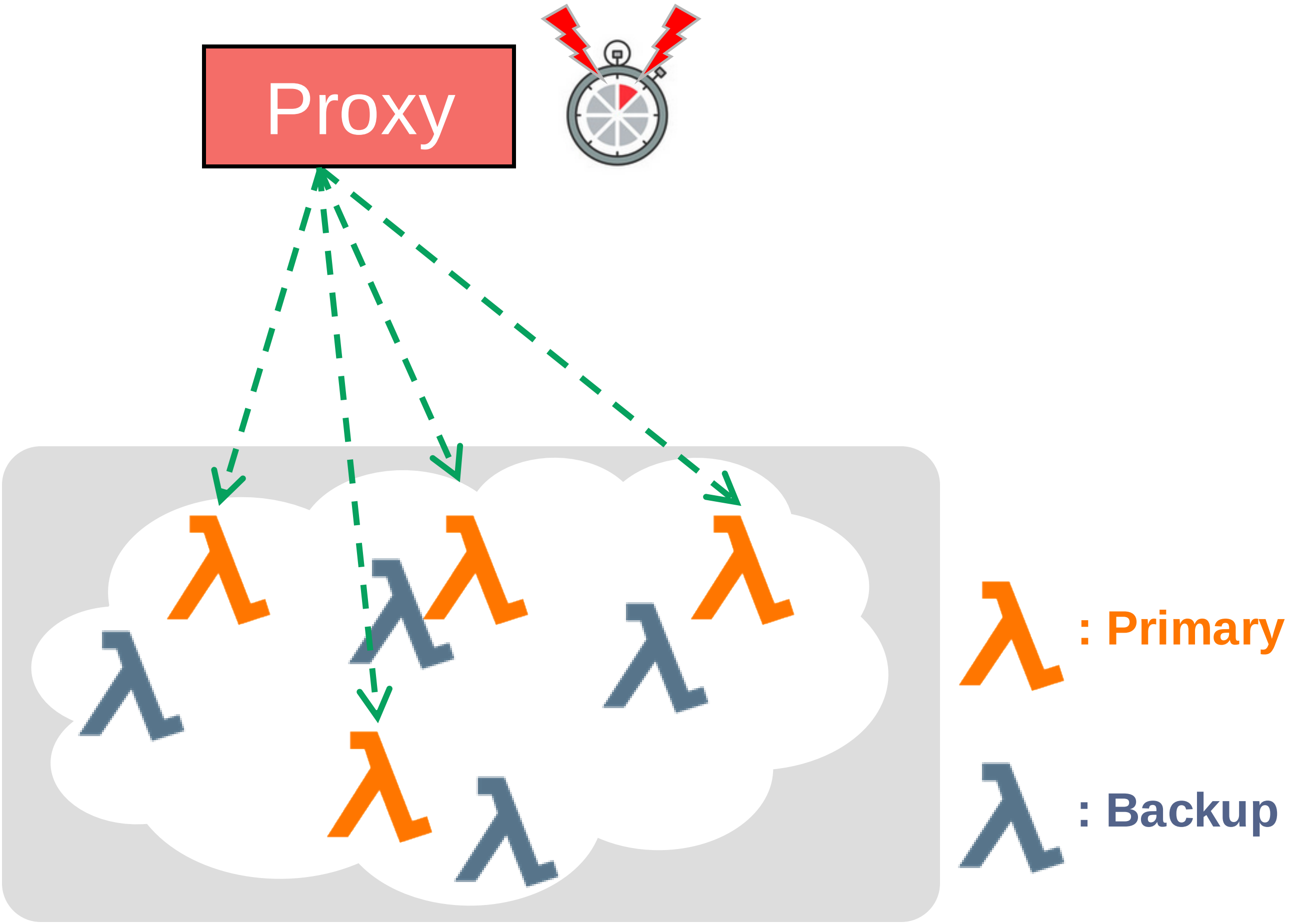


Maximizing data availability: Periodic backup



Maximizing data availability: Periodic backup

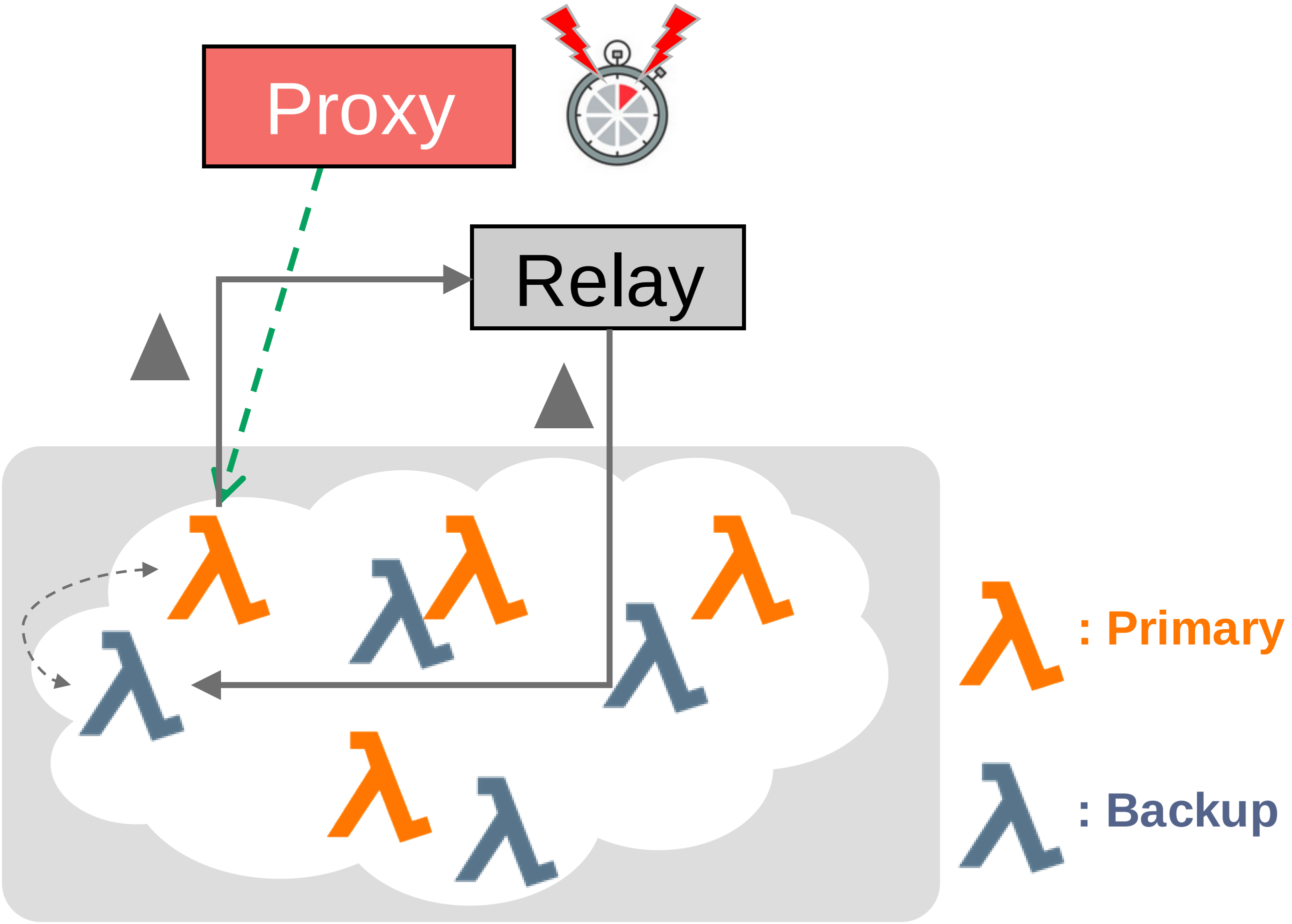
1. Proxy periodically sends out backup commands to Lambda cache nodes



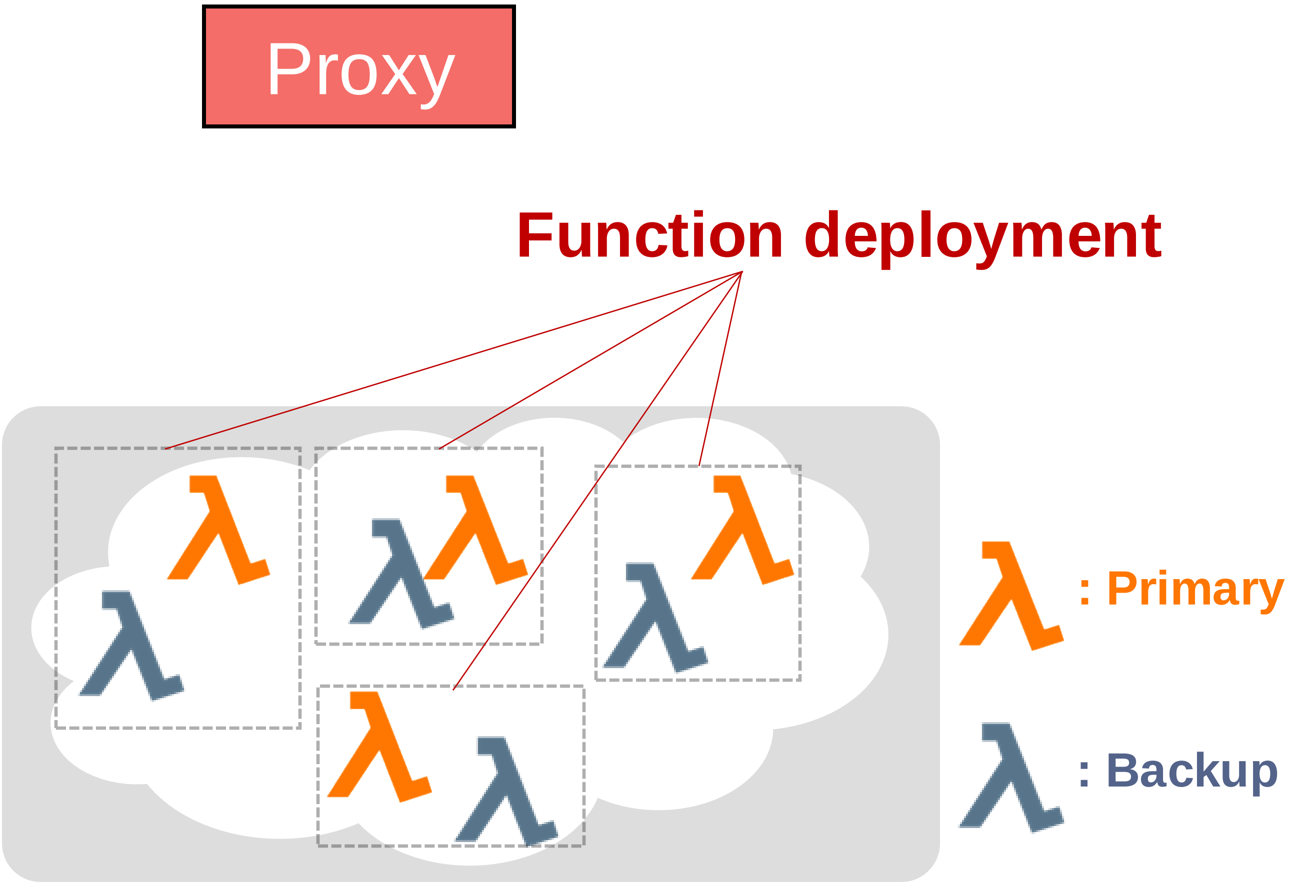
Maximizing data availability: Periodic backup

1. Proxy periodically sends out backup commands to Lambda cache nodes

2. Lambda node performs delta-sync with its peer replica
   - Source Lambda propagates delta-update ▲ to destination Lambda

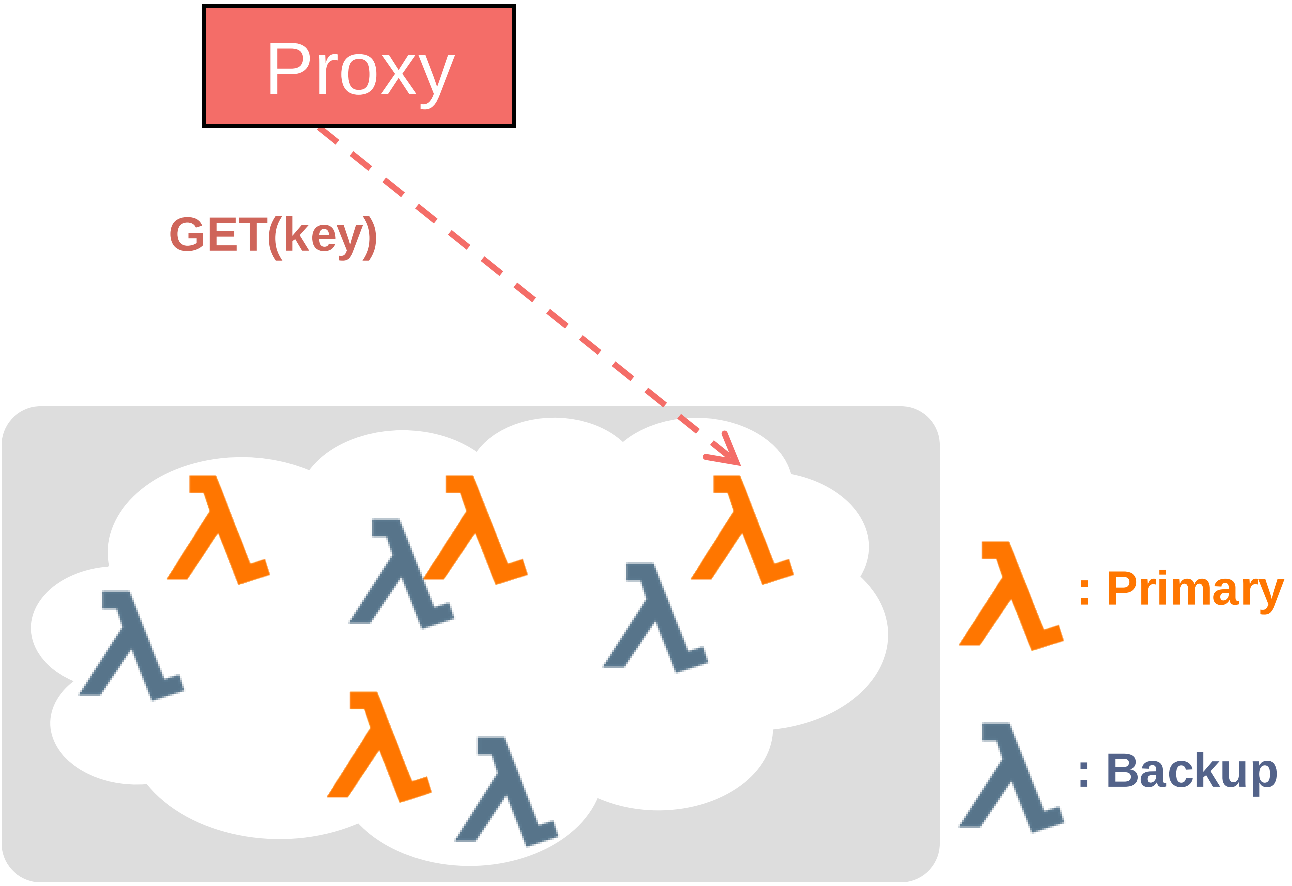


Seamless failover



Maximizing data availability: Seamless failover

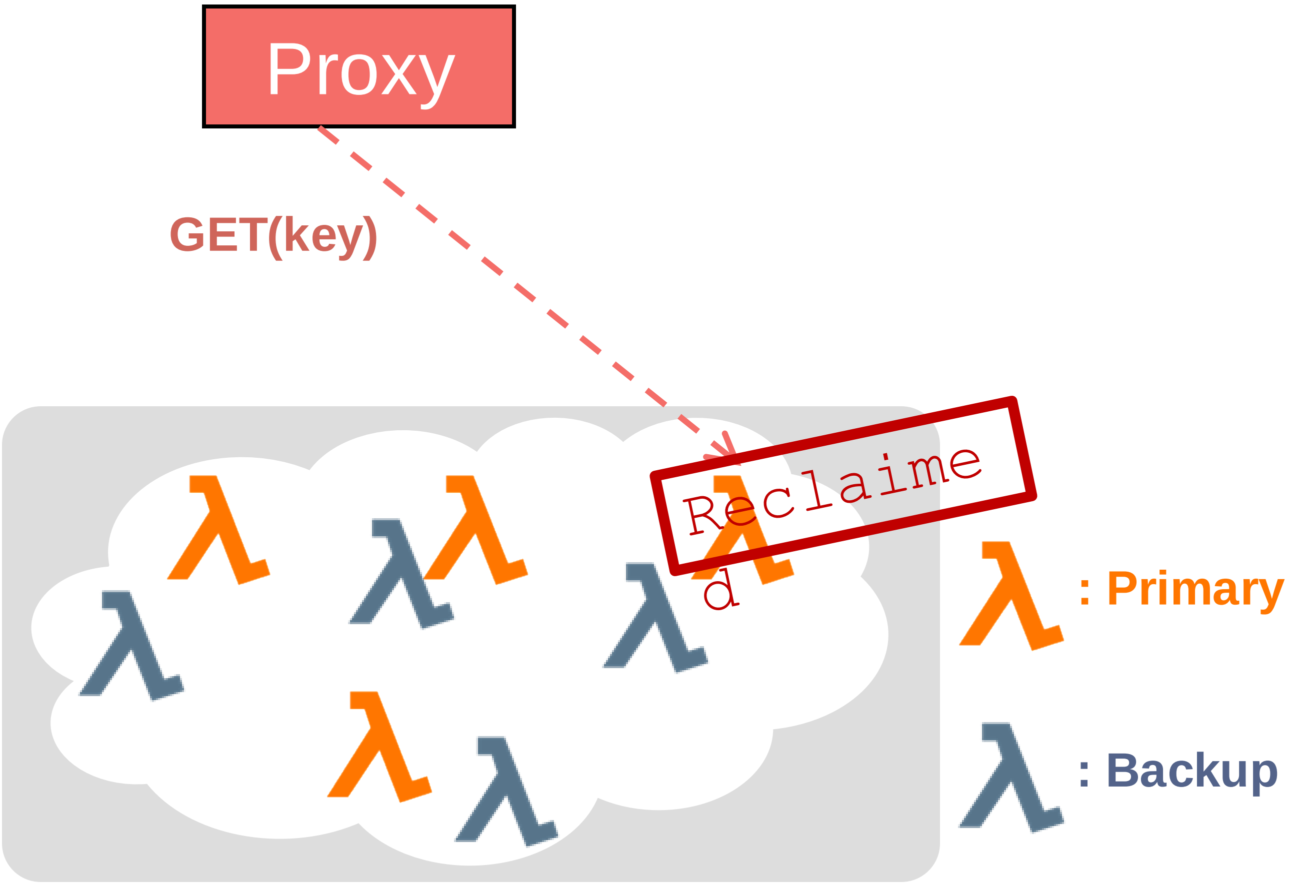
1. Proxy invokes a Lambda cache node with a GET request



Maximizing data availability: Seamless failover

1. Proxy invokes a Lambda cache node with a GET request

2. Source Lambda gets reclaimed

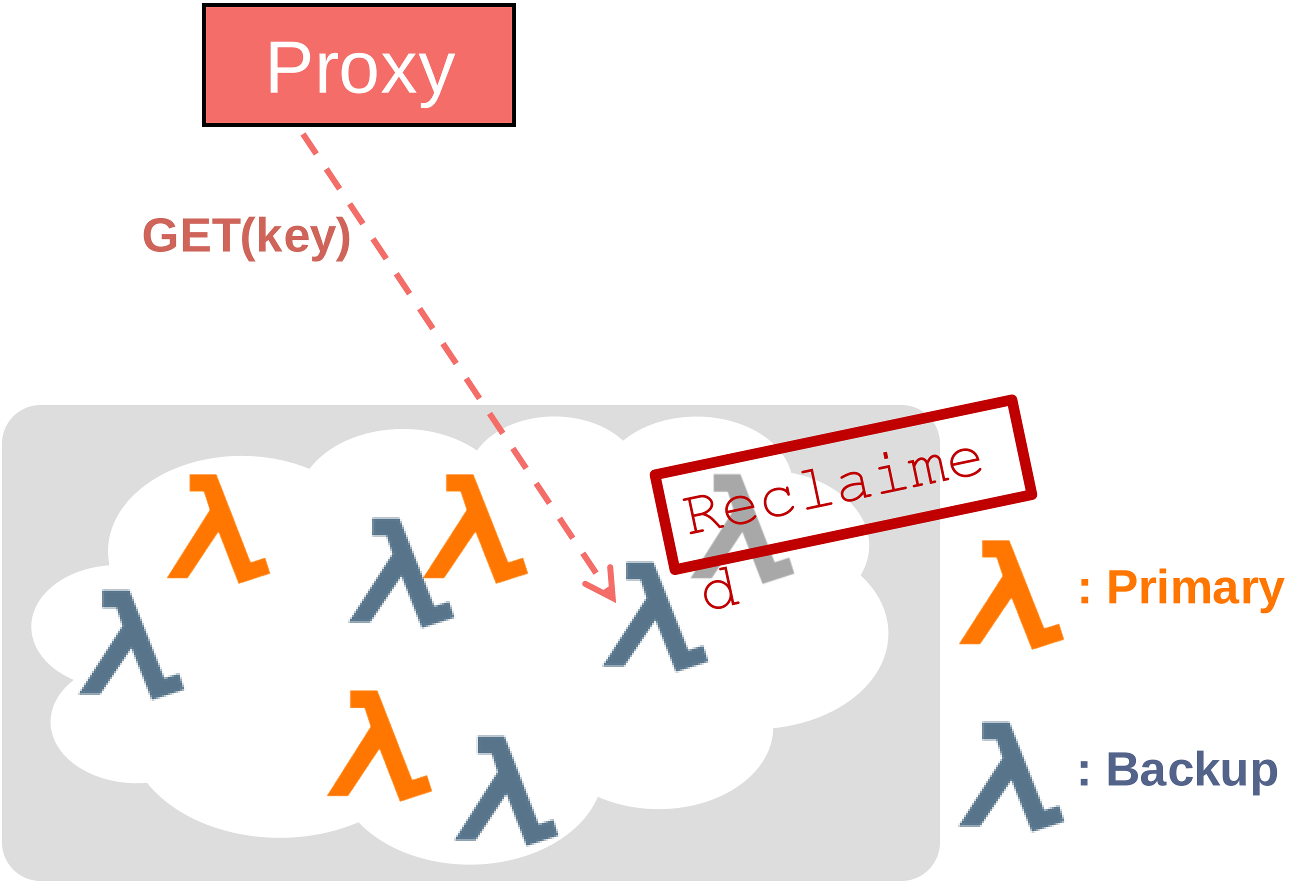


Maximizing data availability: Seamless failover

1. Proxy invokes a Lambda cache node with a GET request

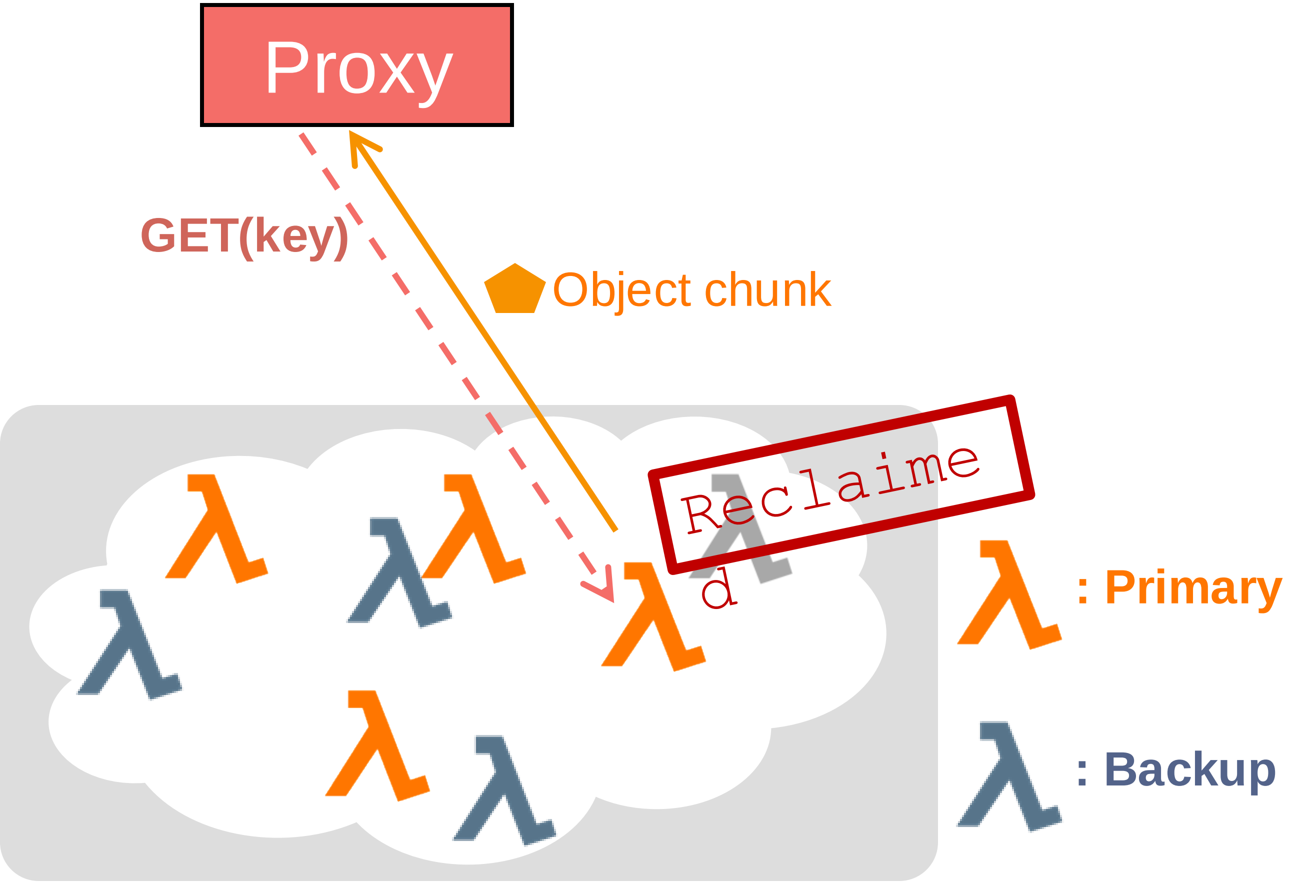
2. Source Lambda gets reclaimed

3. The invocation request gets seamlessly redirected to the backup Lambda

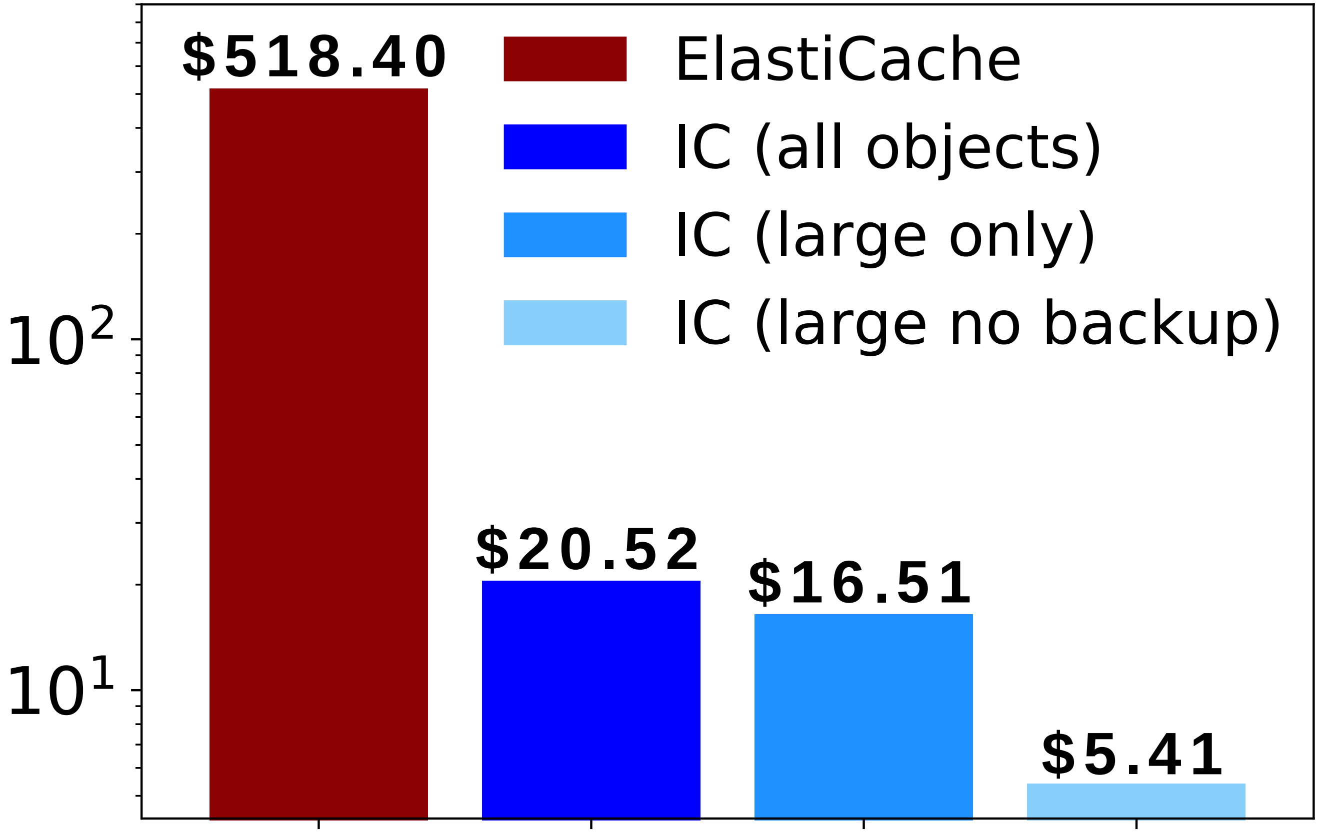


Maximizing data availability: Seamless failover

1. Proxy invokes a Lambda cache node with a GET request
2. Source Lambda gets reclaimed
3. The invocation request gets seamlessly redirected to the backup Lambda
   - Failover gets **automatically** done and the backup becomes the primary
   - By exploiting the **auto-scaling** feature of AWS Lambda



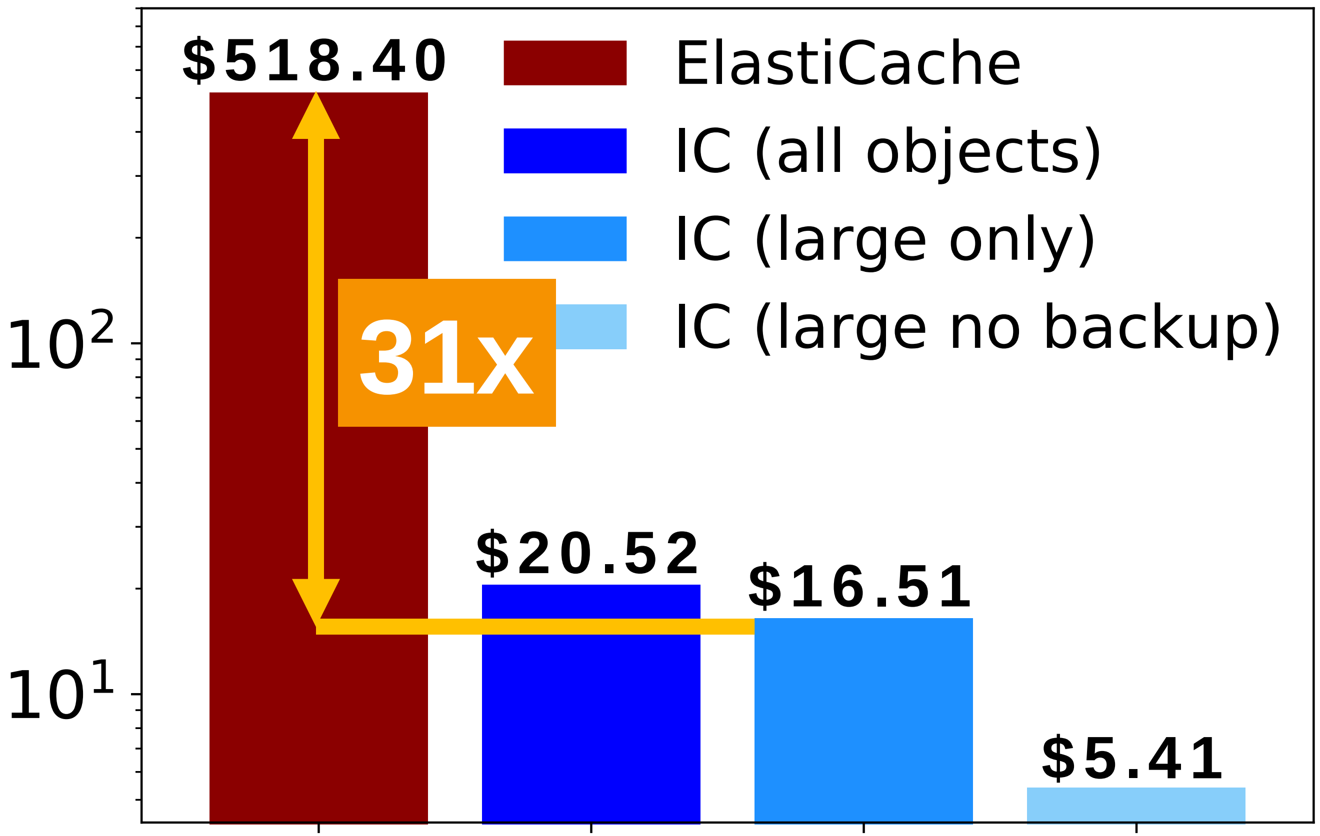
Cost effectiveness of InfiniCache



Workload setup

- All objects
- Large object only
  - Object larger than 10MB
- Large object w/o backup

Cost effectiveness of InfiniCache



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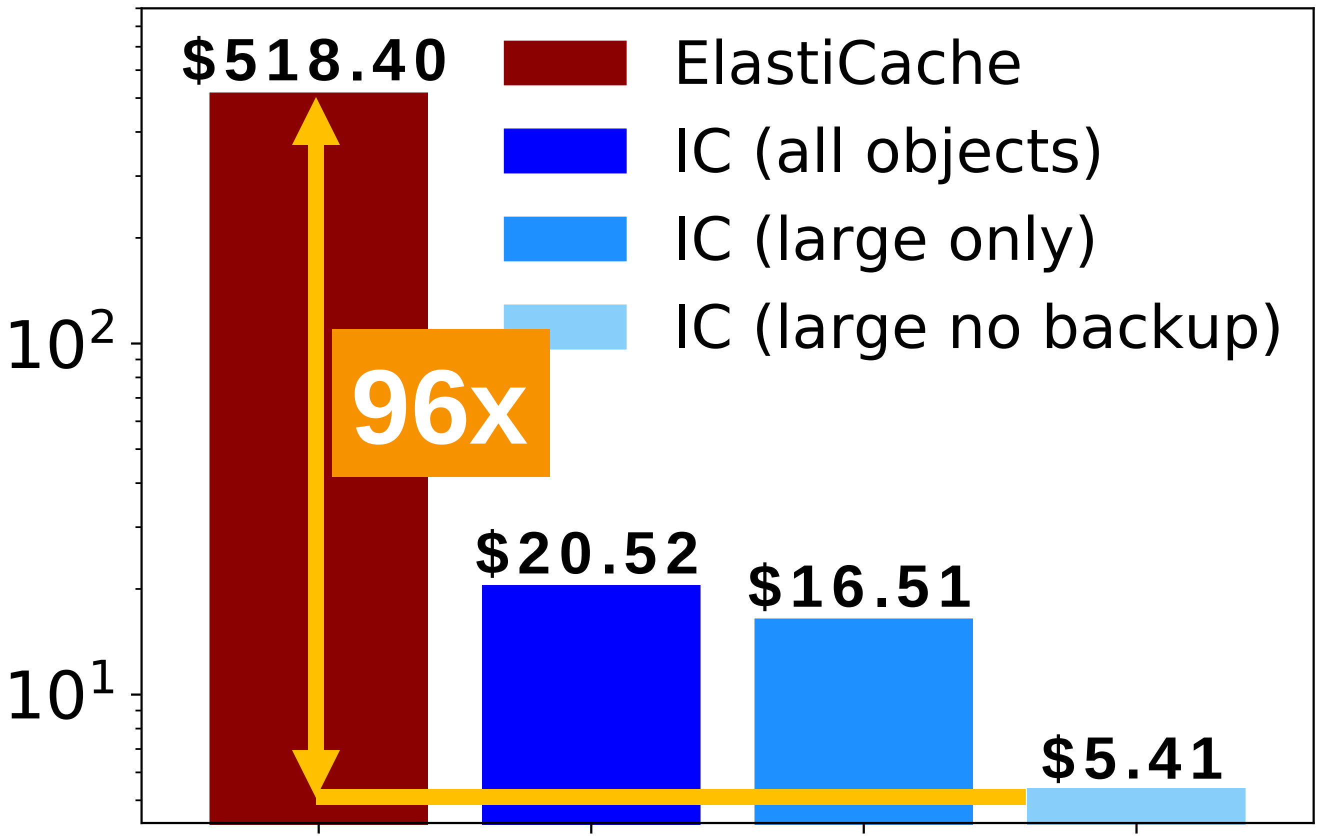
Cost effectiveness of InfiniCache



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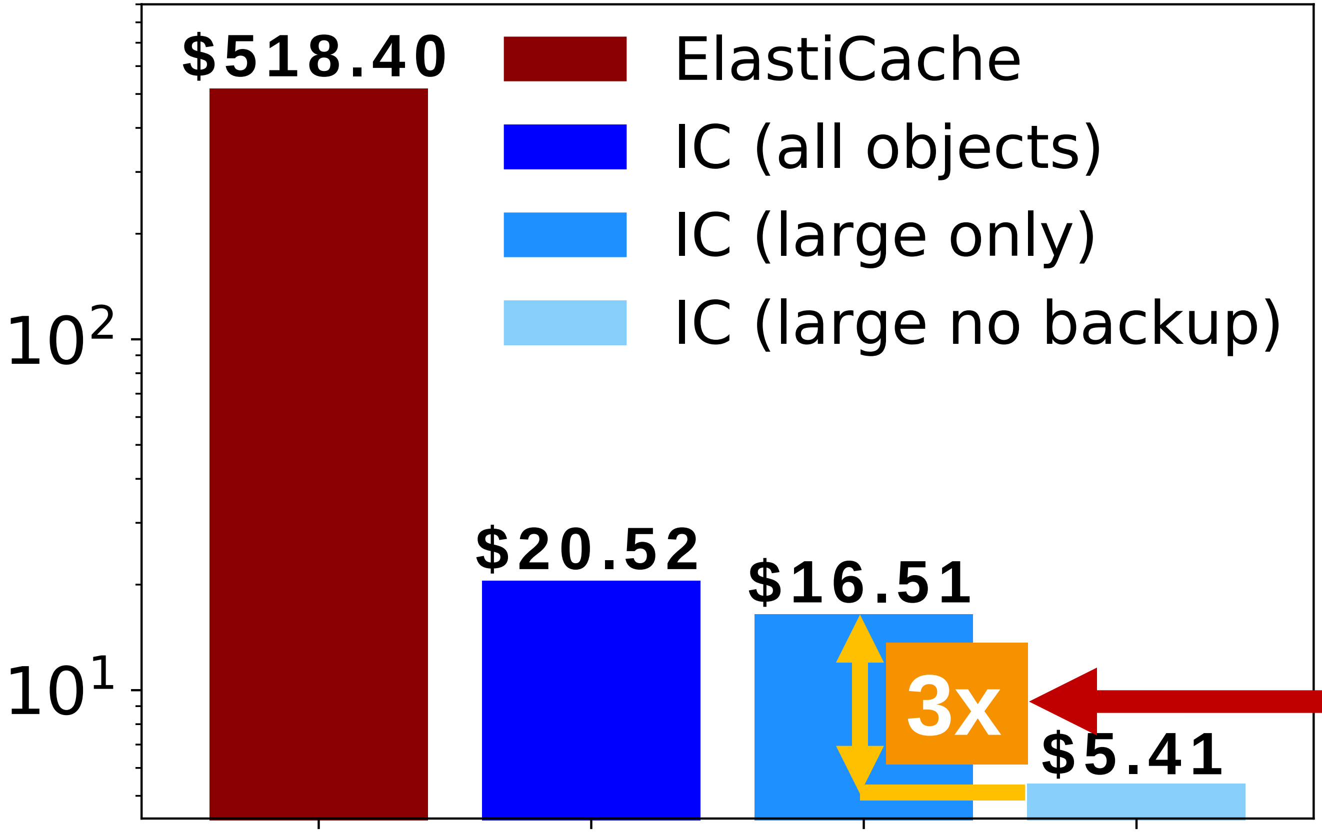


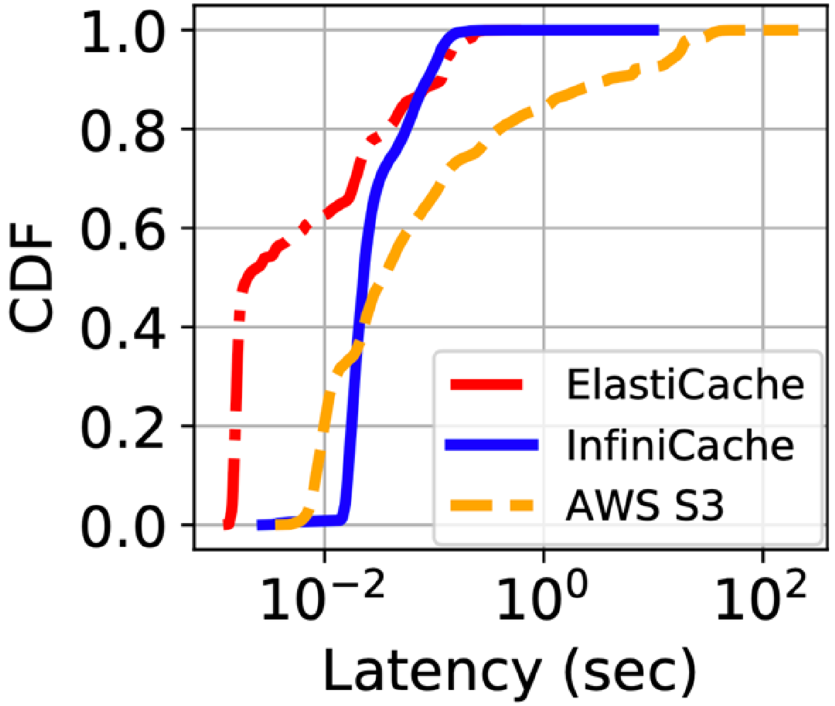
Workload setup

- All objects
- Large object only
  - Object larger than 10MB
- **Large object w/o backup**

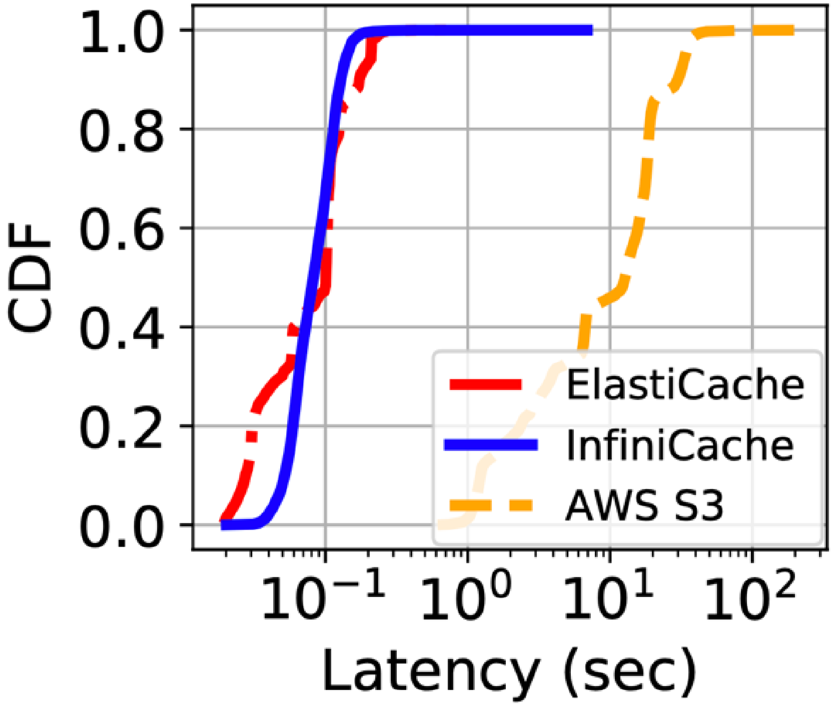
Hit ratio and $$ cost tradeoff

Workload	ElastiCache	InfiniCache	InfiniCache w/o backup
All objects	67.9%	64.7%	---
Large object only	65.9%	63.6%	56.1%

Performance of InfiniCache



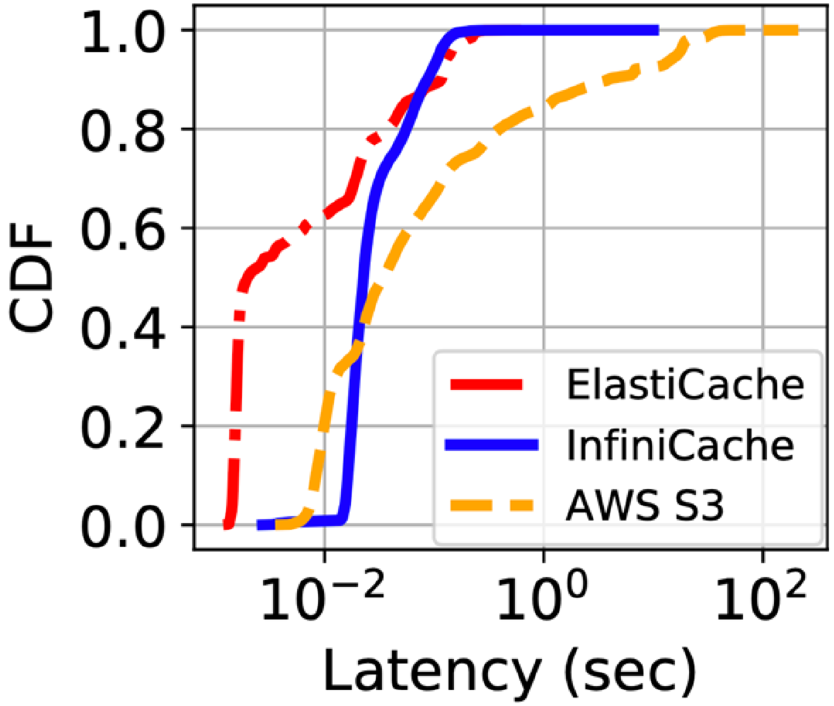
All objects



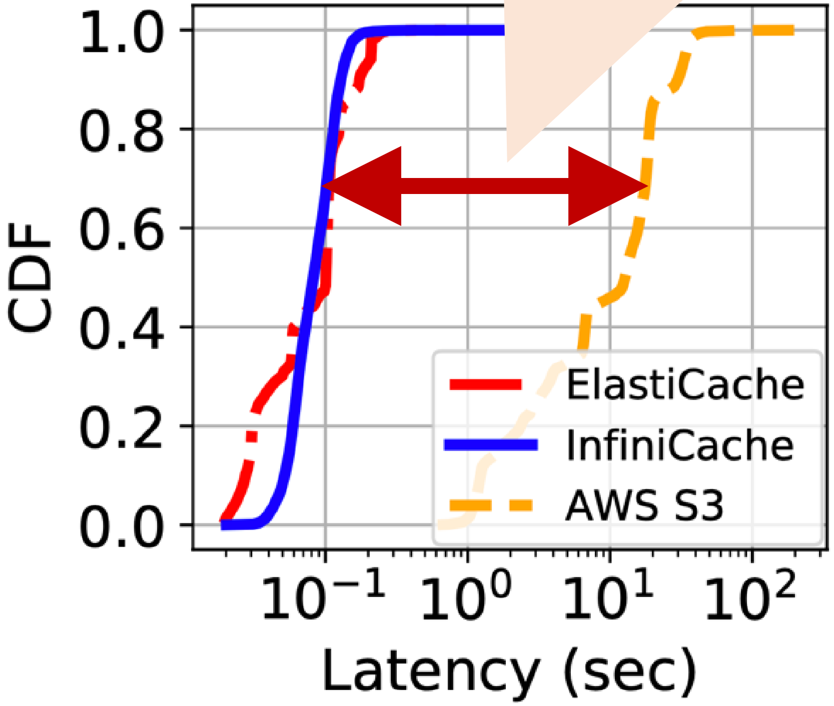
Large objects only

Performance of InfiniCache

> 100 times improvement



All objects



Large objects only

Discussion

- InfiniCache's cost saving benefits have conditions
  - The same condition holds for many different types of serverless/FaaS apps

- Unit time $ cost increases with the access rate