Serverless Object Caching

DS 5110: Big Data Systems (Spring 2023)

Lecture 7c

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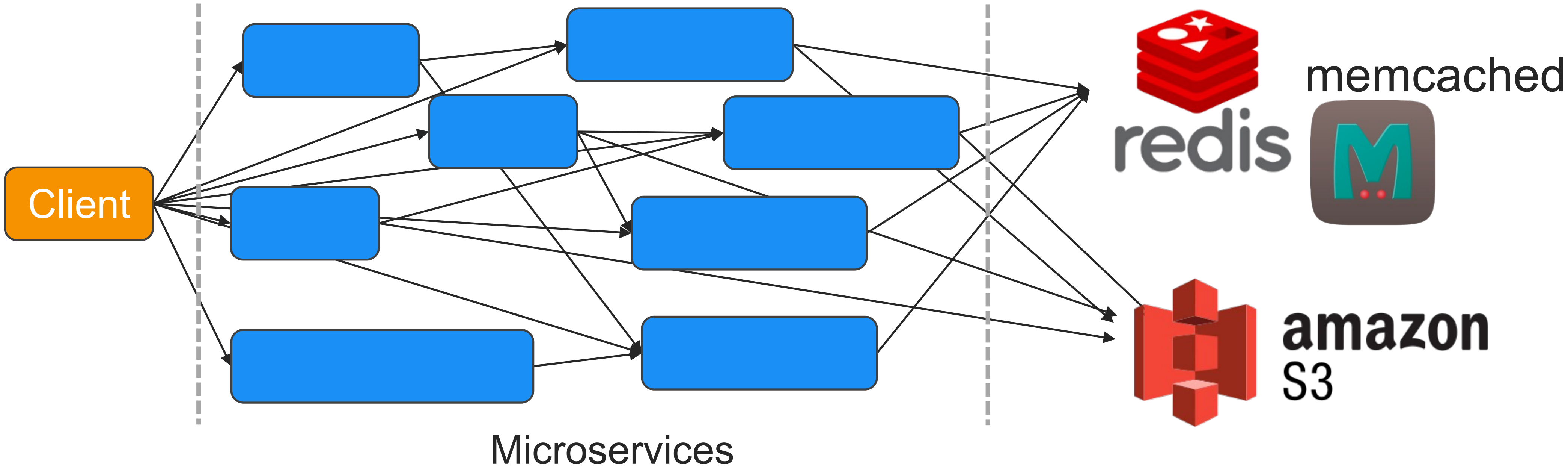
Challenges of supporting stateful apps on FaaS

Research Question: Is FaaS poorly suited for stateful applications because these applications share state?

Case studies:

1. **[Programming model]** How to design FaaS-centric parallel computing to **enable easy programming of 10,000 CPU cores and 15,000 GBs of RAM**?
2. **[Data storage]** How to exploit FaaS **elasticity and pay-per-use** to reduce the $$ cost by **100X**?

Internet-scale web apps are storage-intensive



Example app: IBM Cloud Container Registry workloads

- 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 workloads

- Object size distribution

- Large objects’ reuse patterns

- Storage footprint

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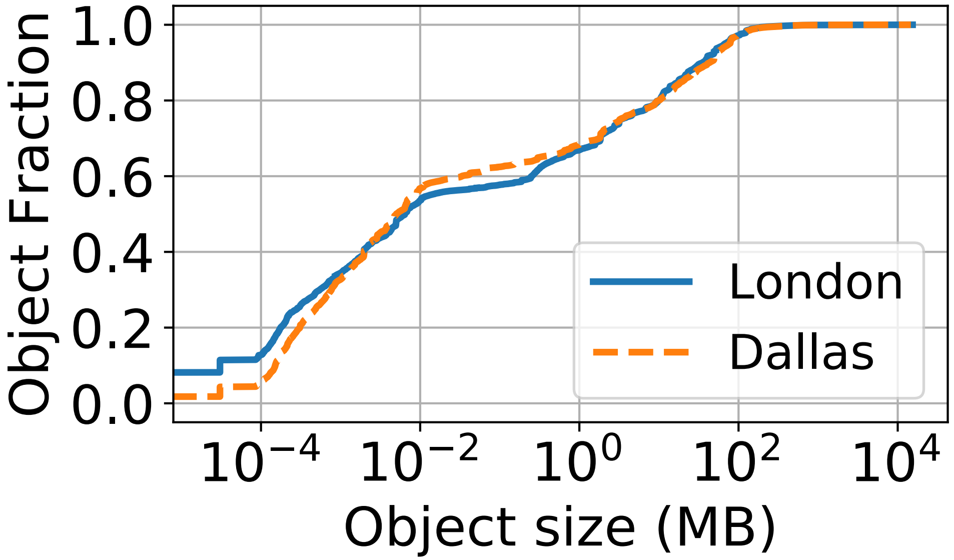

Extreme variability in object sizes:

➢ Object sizes span over 9 orders of magnitude

➢ 20% of objects > 10MB

Example app: IBM Cloud Container Registry workloads

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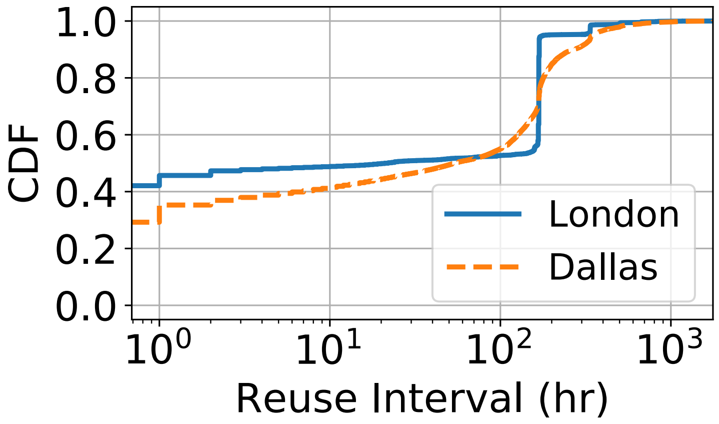
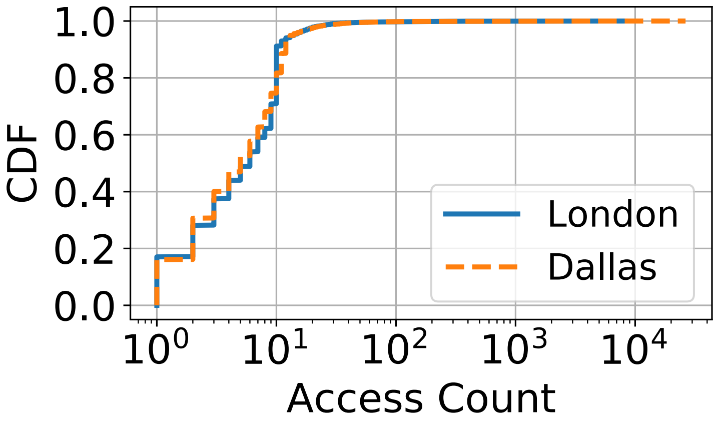
- Storage footprint





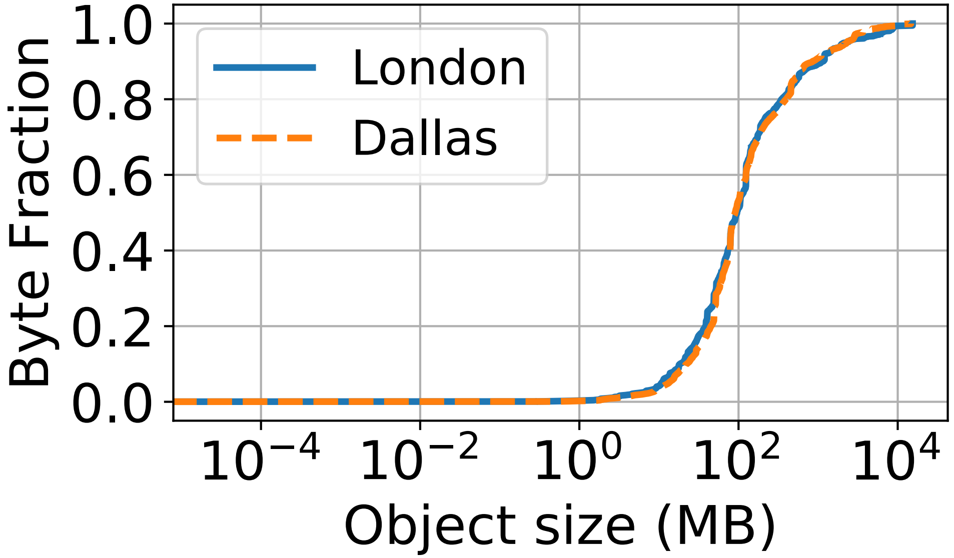
Caching large objects is beneficial:

➢ > 30% large object being accessed 10+ times

➢ Around 45% of them get reused within 1 hour

Example app: IBM Cloud Container Registry workloads

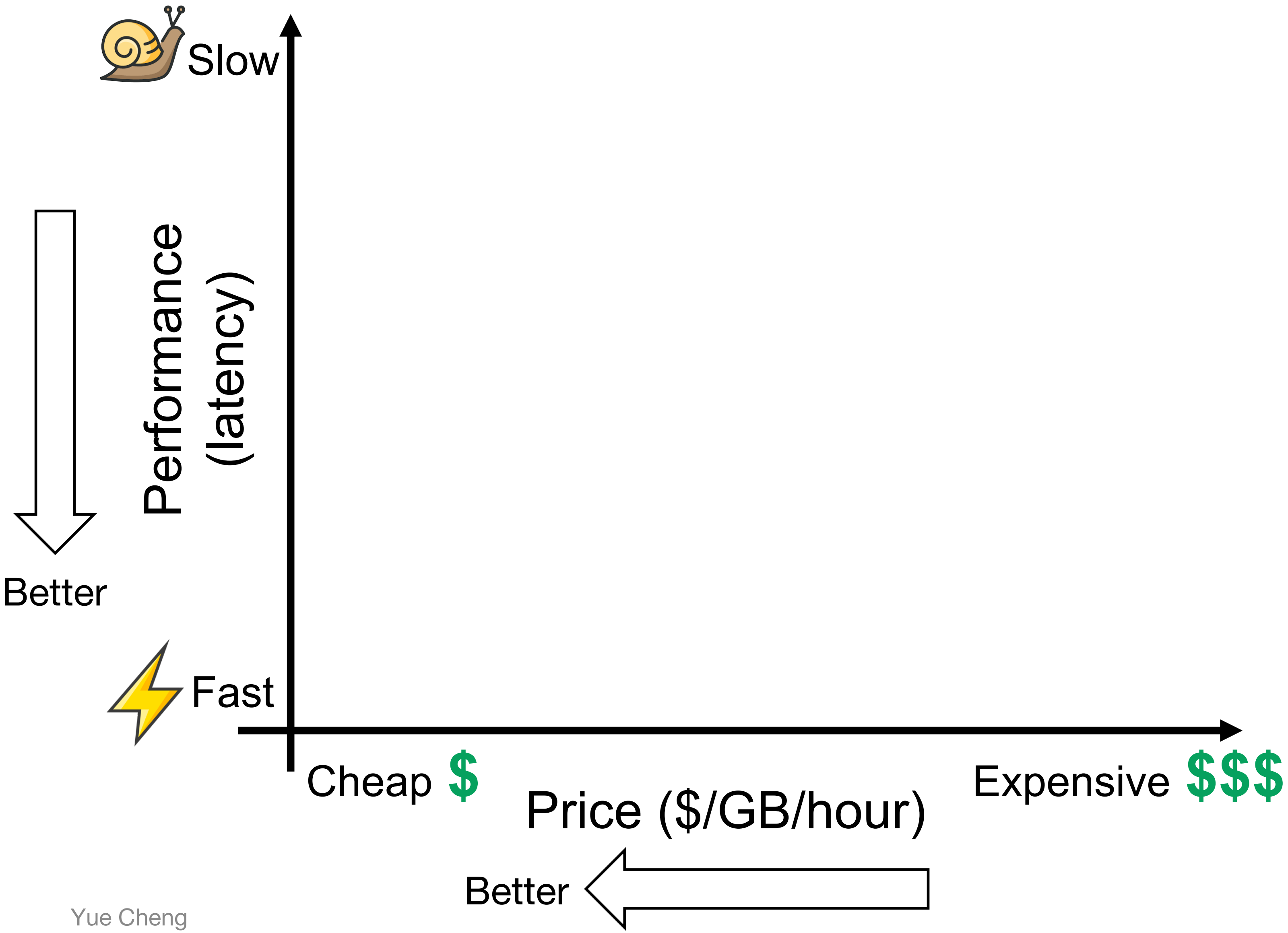
- Object size distribution
- Large objects' reuse patterns
- Storage footprint



Extreme tension between small and large objects:

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

Today's cloud storage landscape



Slow

Performance (latency)

Better

Fast

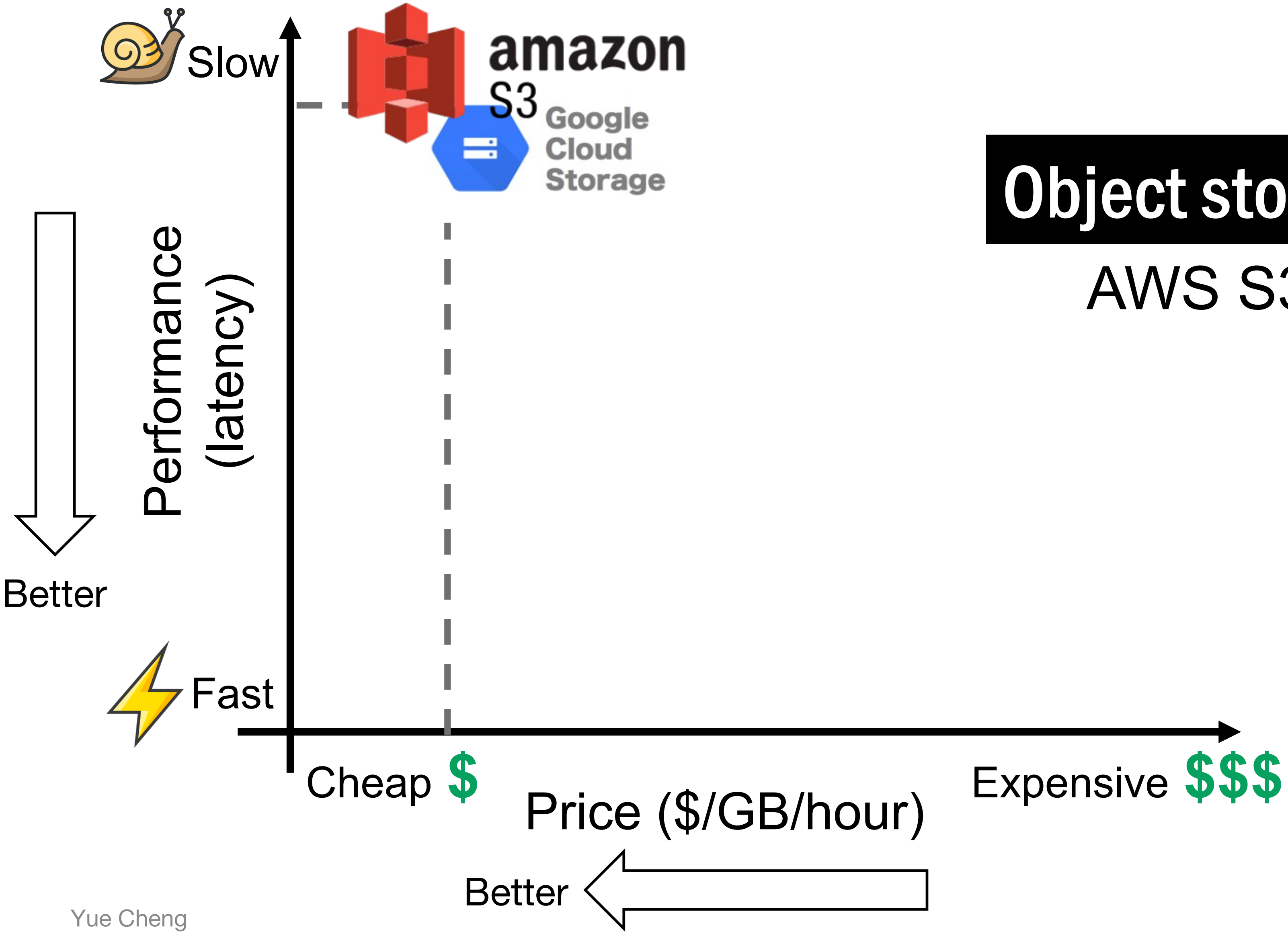
Cheap $

Price ($/GB/hour)

Expensive $$$

Better

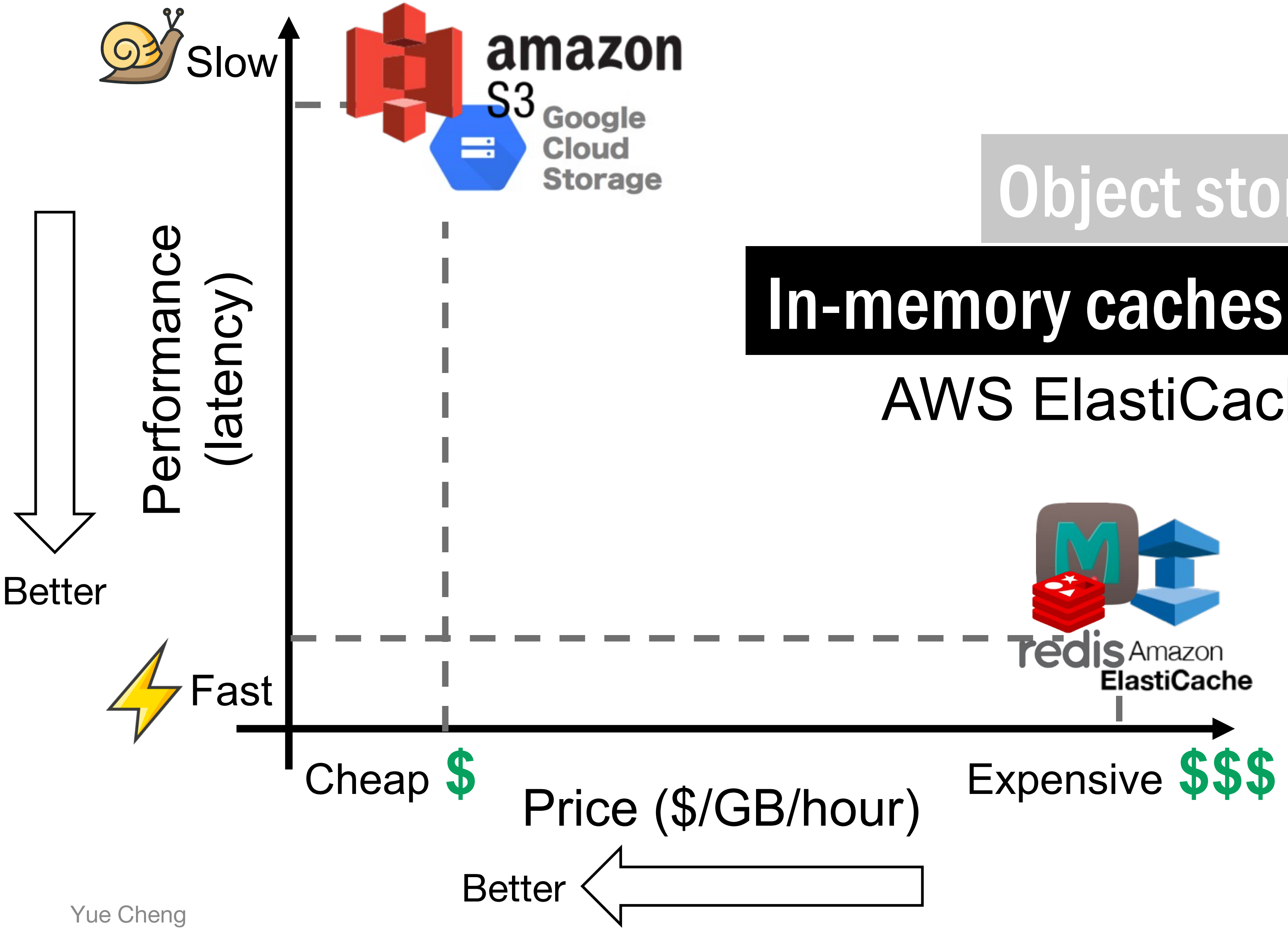
Today’s cloud storage landscape



Object stores are cheap but too slow

AWS S3: $0.023 per GB per month

Today’s cloud storage landscape

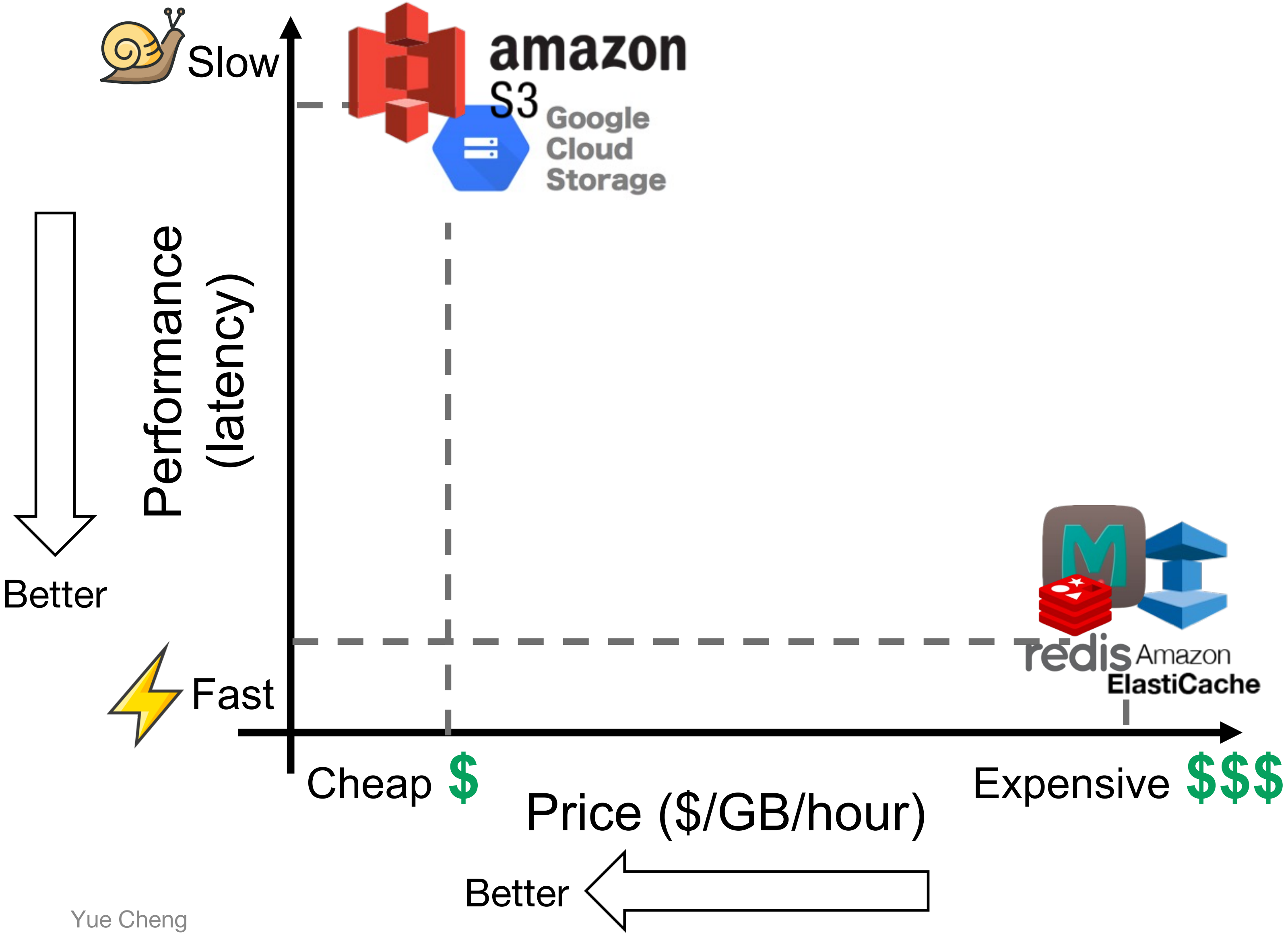


Object stores are cheap but too slow

In-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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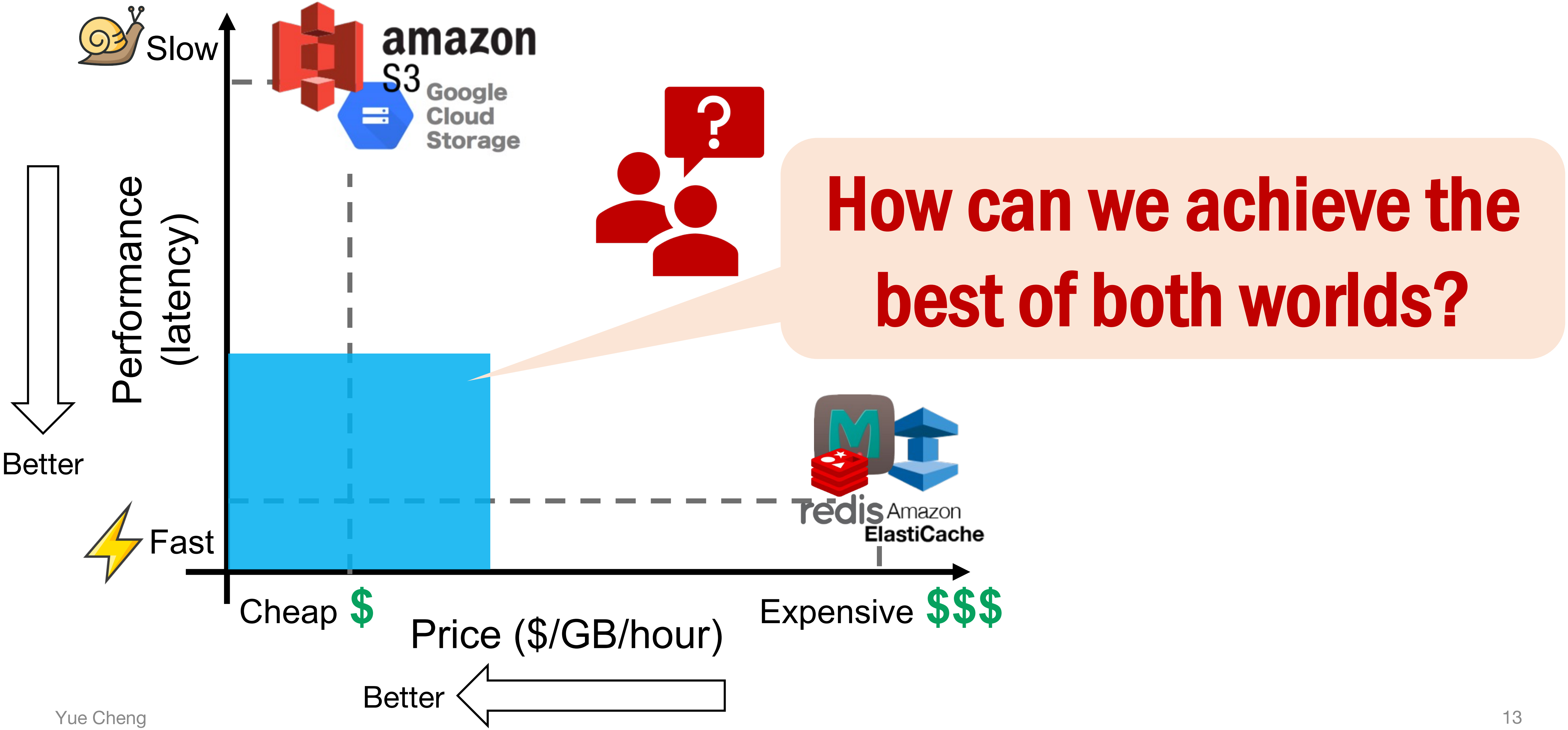


InfiniCache: A cost-effective and high-performance in-memory caching system built atop FaaS

- **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 in-memory caching system 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

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

Our contribution: InfiniCache

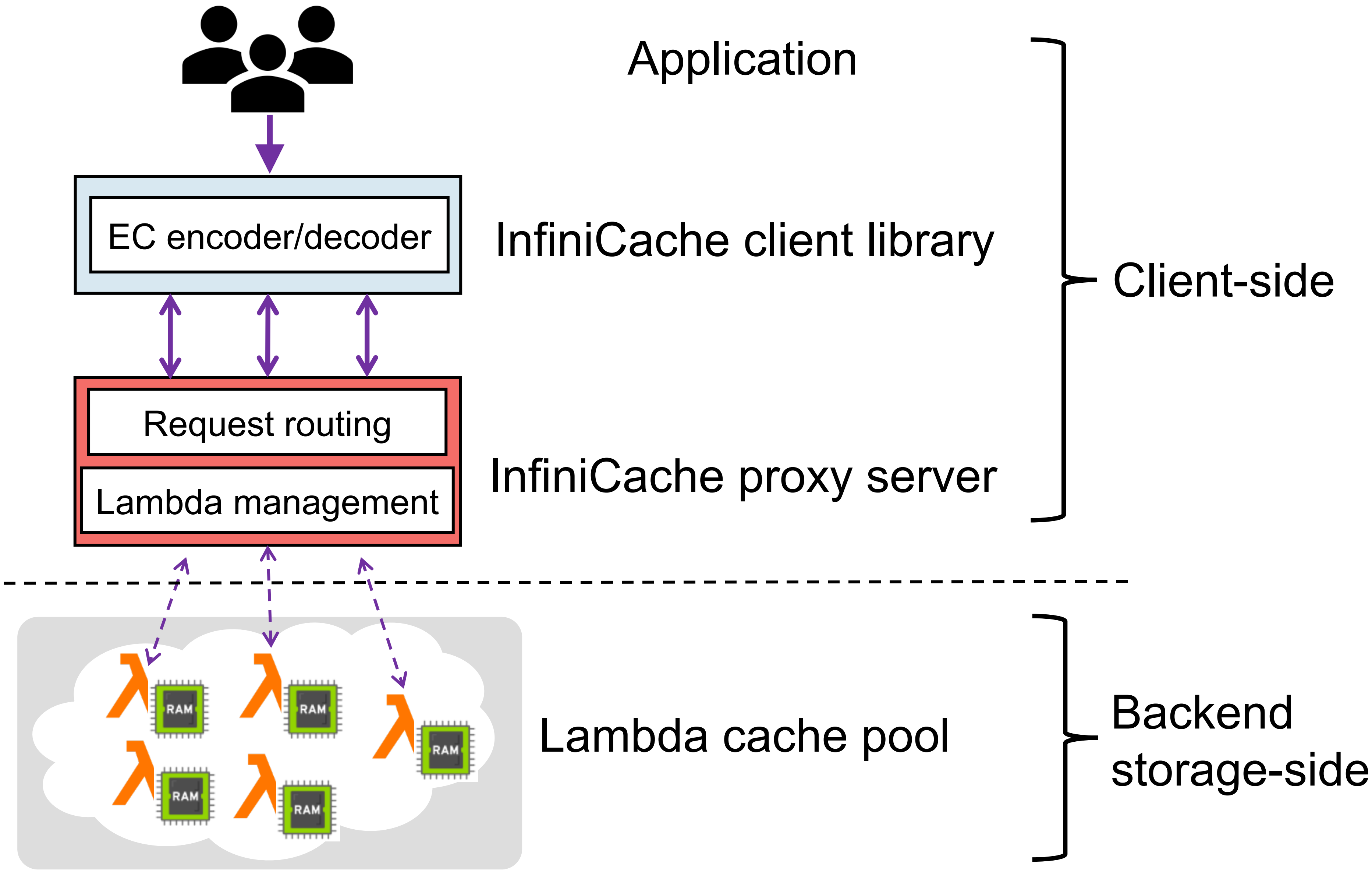
The first in-memory caching system built atop FaaS

- 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 network bandwidth of multiple functions in parallel
- InfiniCache achieves similar performance to AWS ElastiCache while improving the cost-effectiveness by 31-96X

Background of RAID and erasure coding (RS)

Switch to note

InfiniCache bird’s eye view



Application

EC encoder/decoder

InfiniCache client library

Request routing

Lambda management

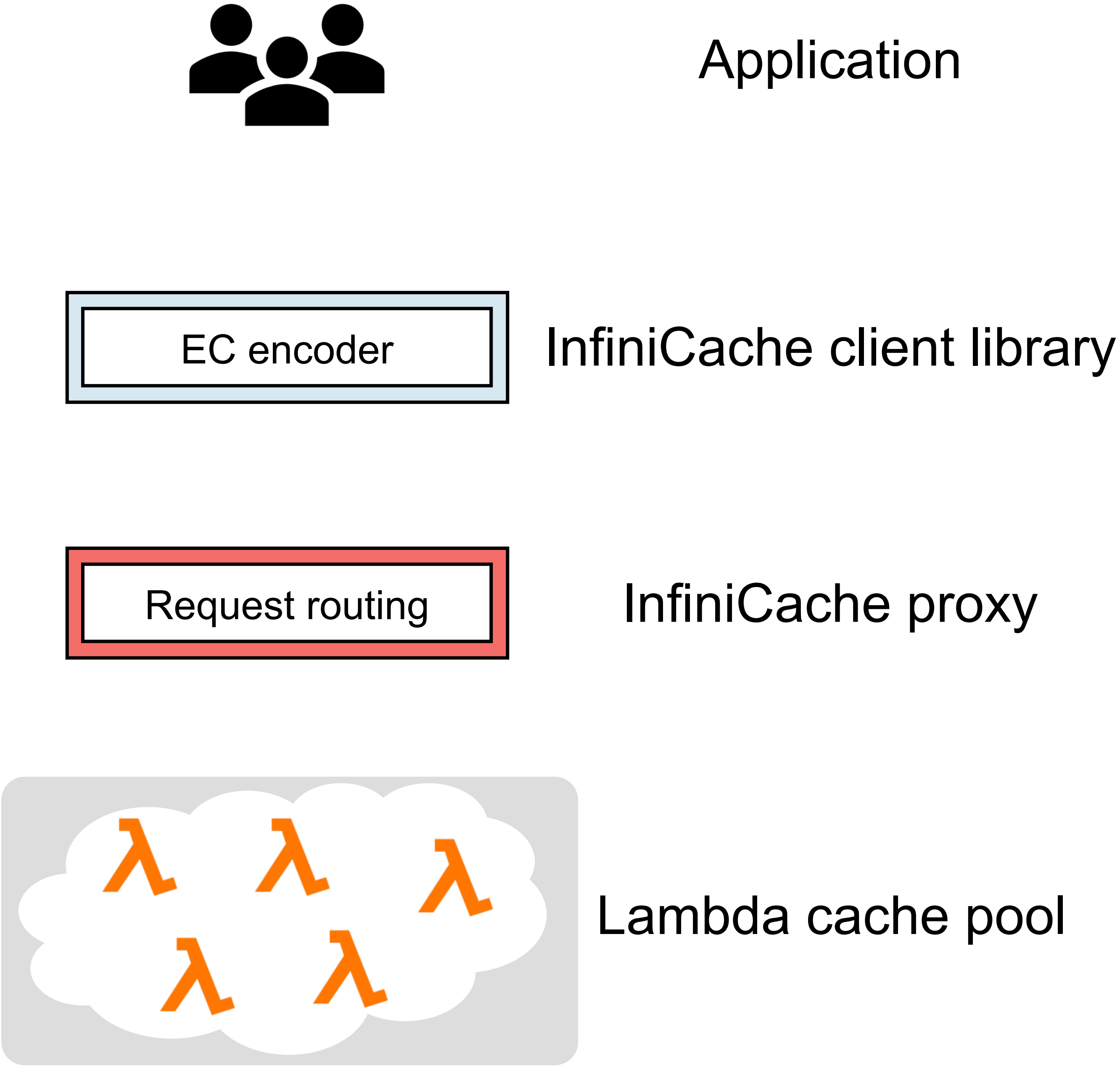
InfiniCache proxy server

Client-side

Lambda cache pool

Backend storage-side

InfiniCache: PUT path



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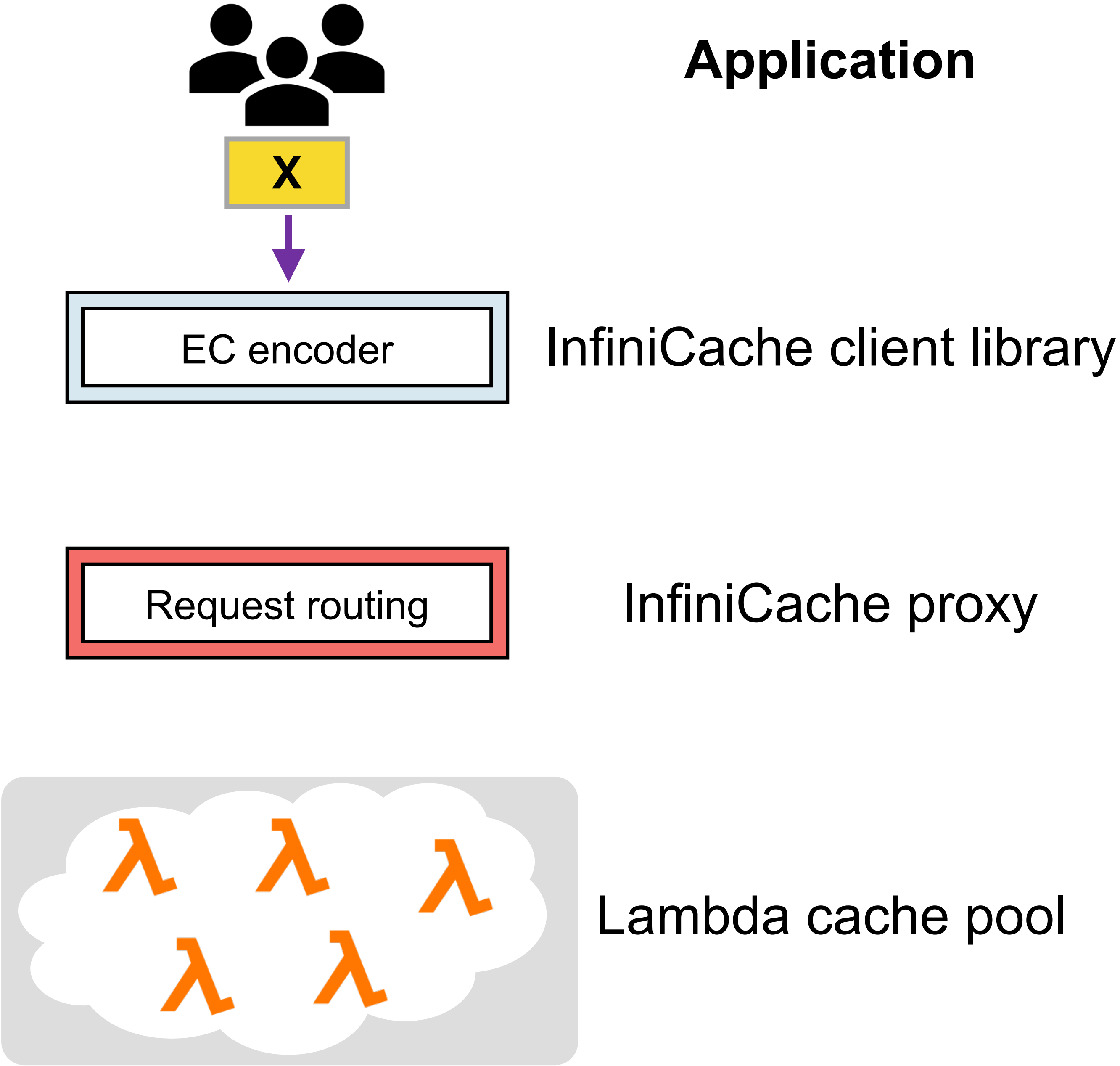
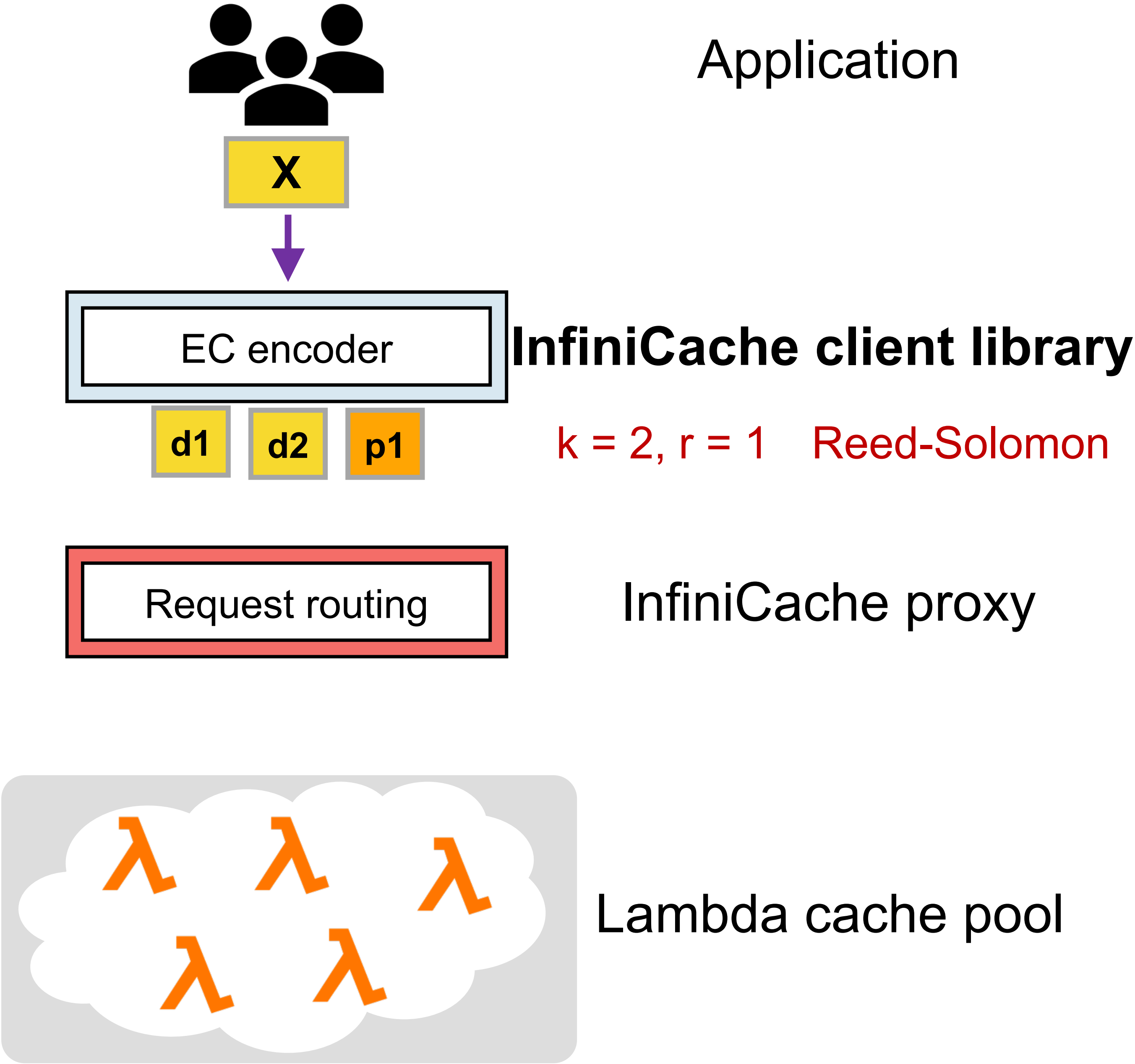


InfiniCache: PUT path

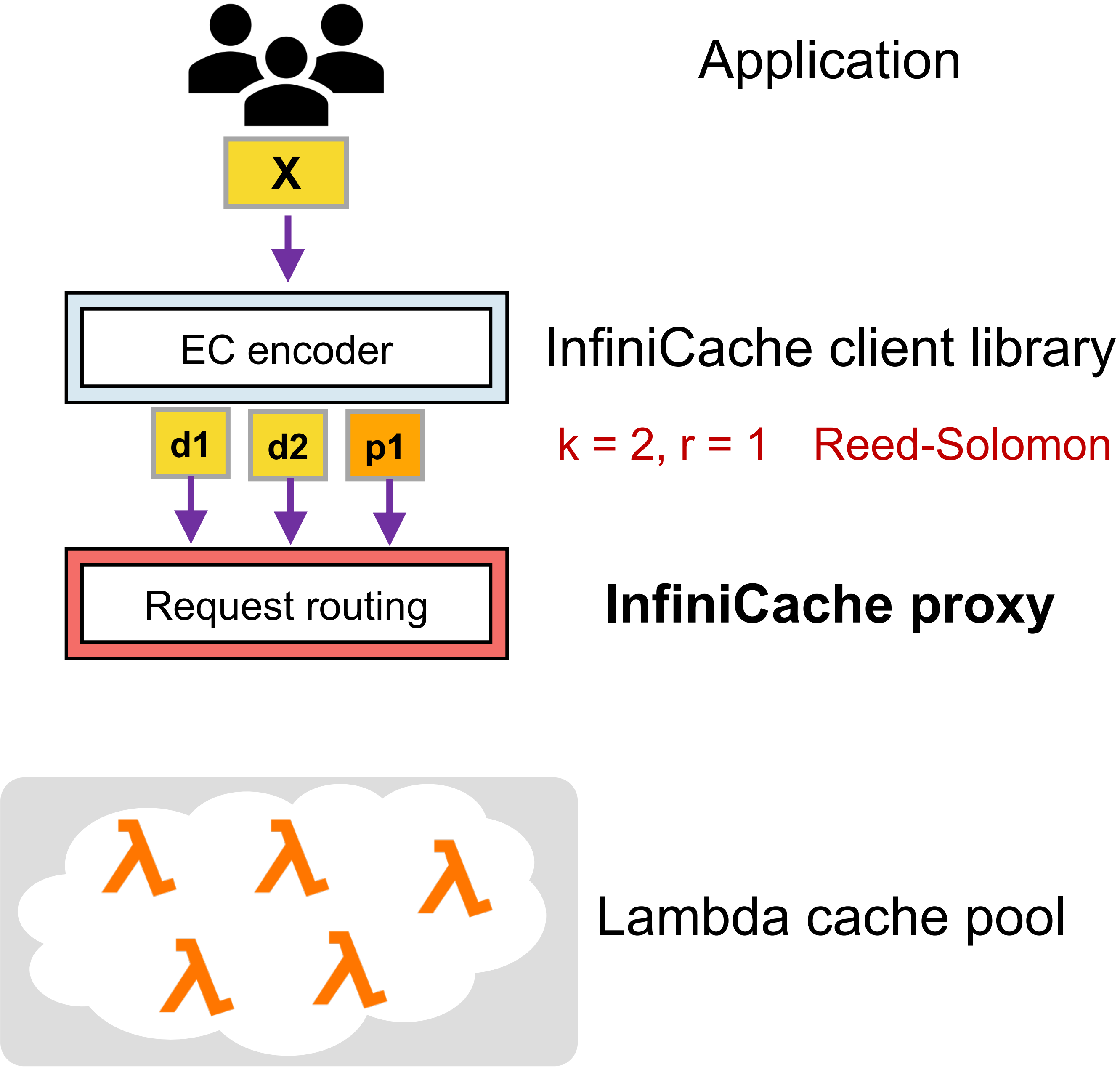
1. Object is split and encoded into k+r chunks



InfiniCache: PUT path

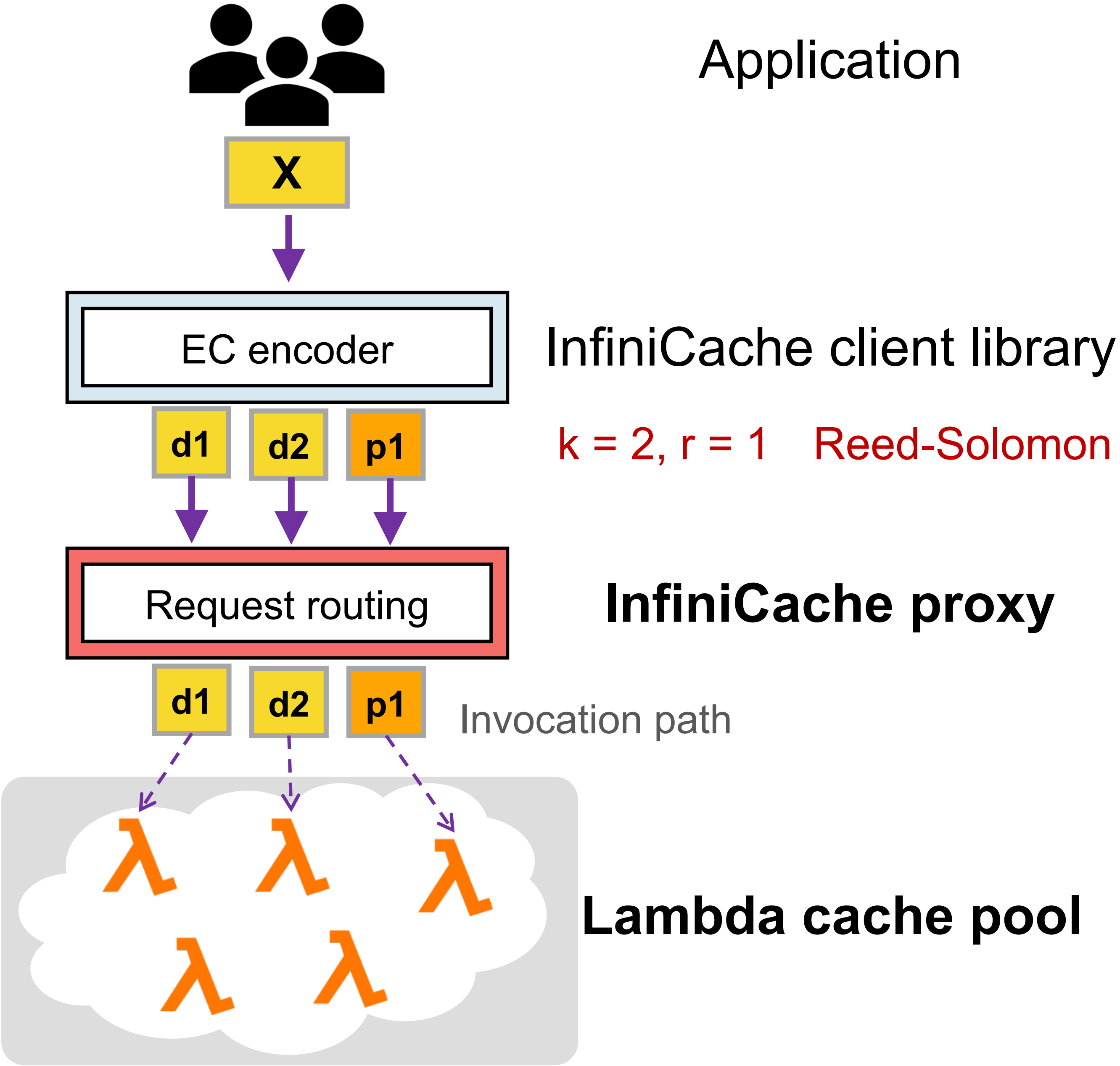
1. Object is split and encoded into k+r chunks

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



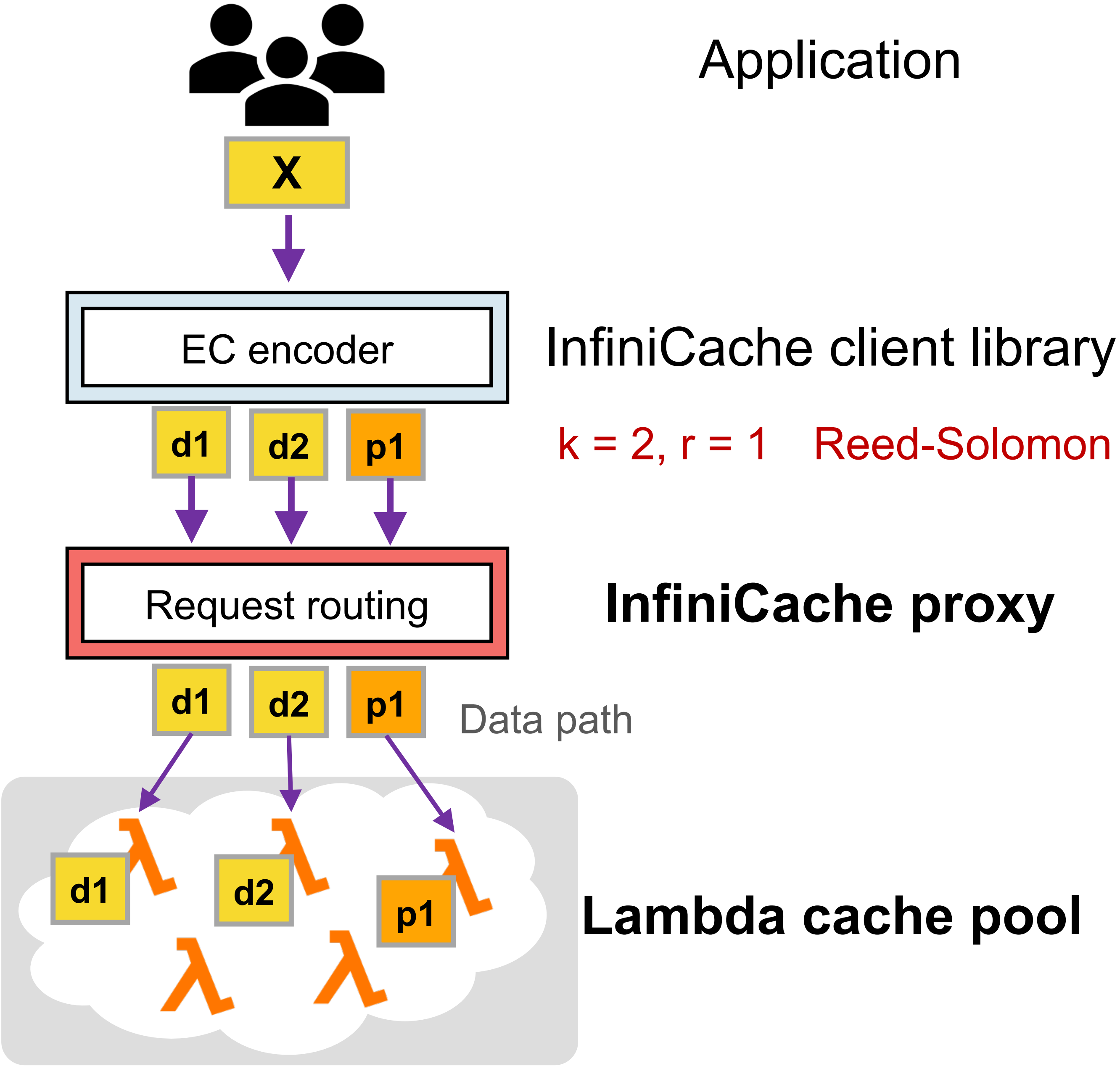
InfiniCache: PUT path

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

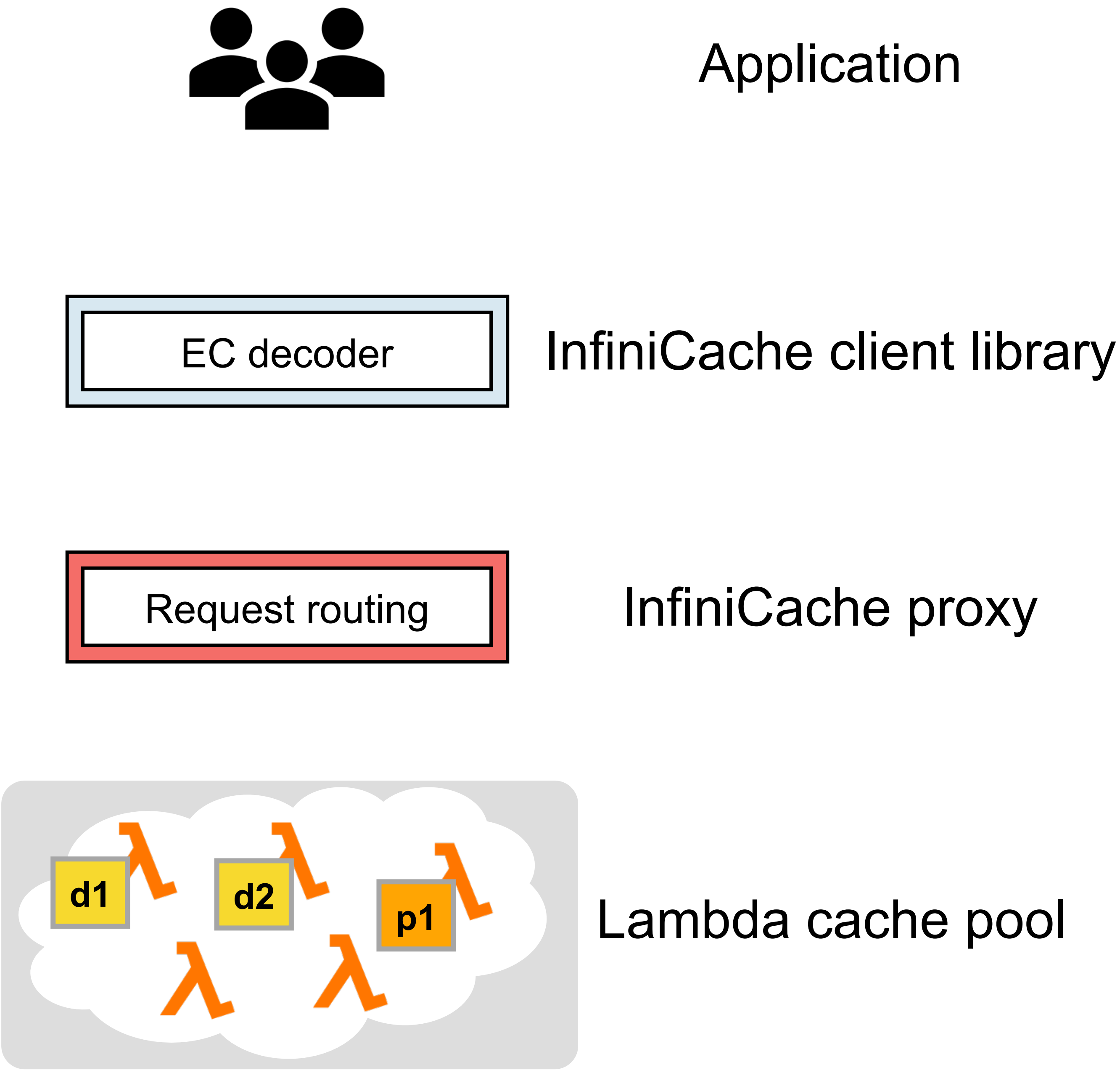
2. Object chunks are sent to the proxy in parallel

3. Proxy invokes Lambda cache nodes

4. Proxy streams object chunks to Lambda cache nodes



InfiniCache: GET path



Application

EC decoder

InfiniCache client library

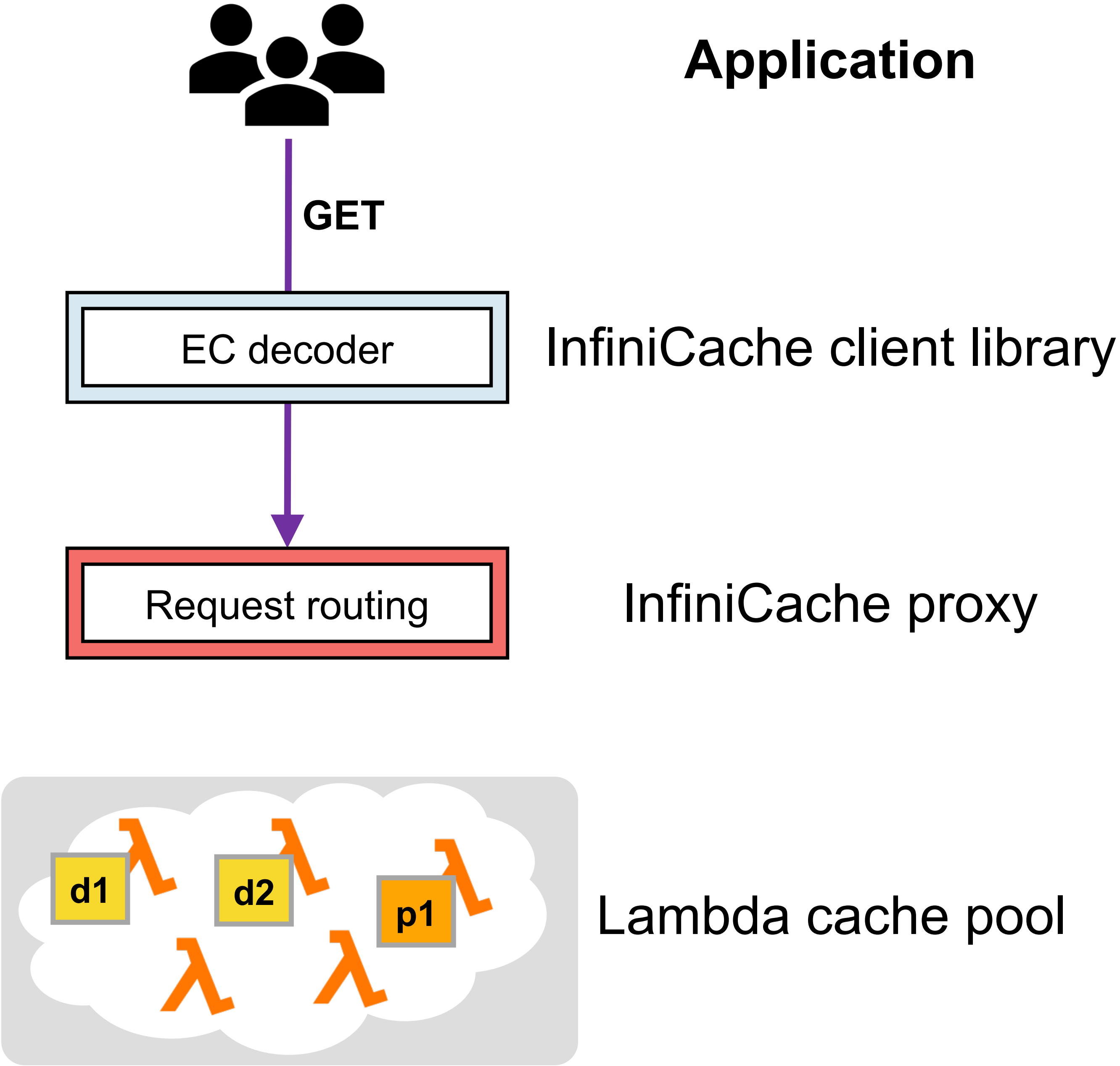
Request routing

InfiniCache proxy

Lambda cache pool

InfiniCache: GET path

1. Client sends GET request



InfiniCache: GET path

1. Client sends GET request

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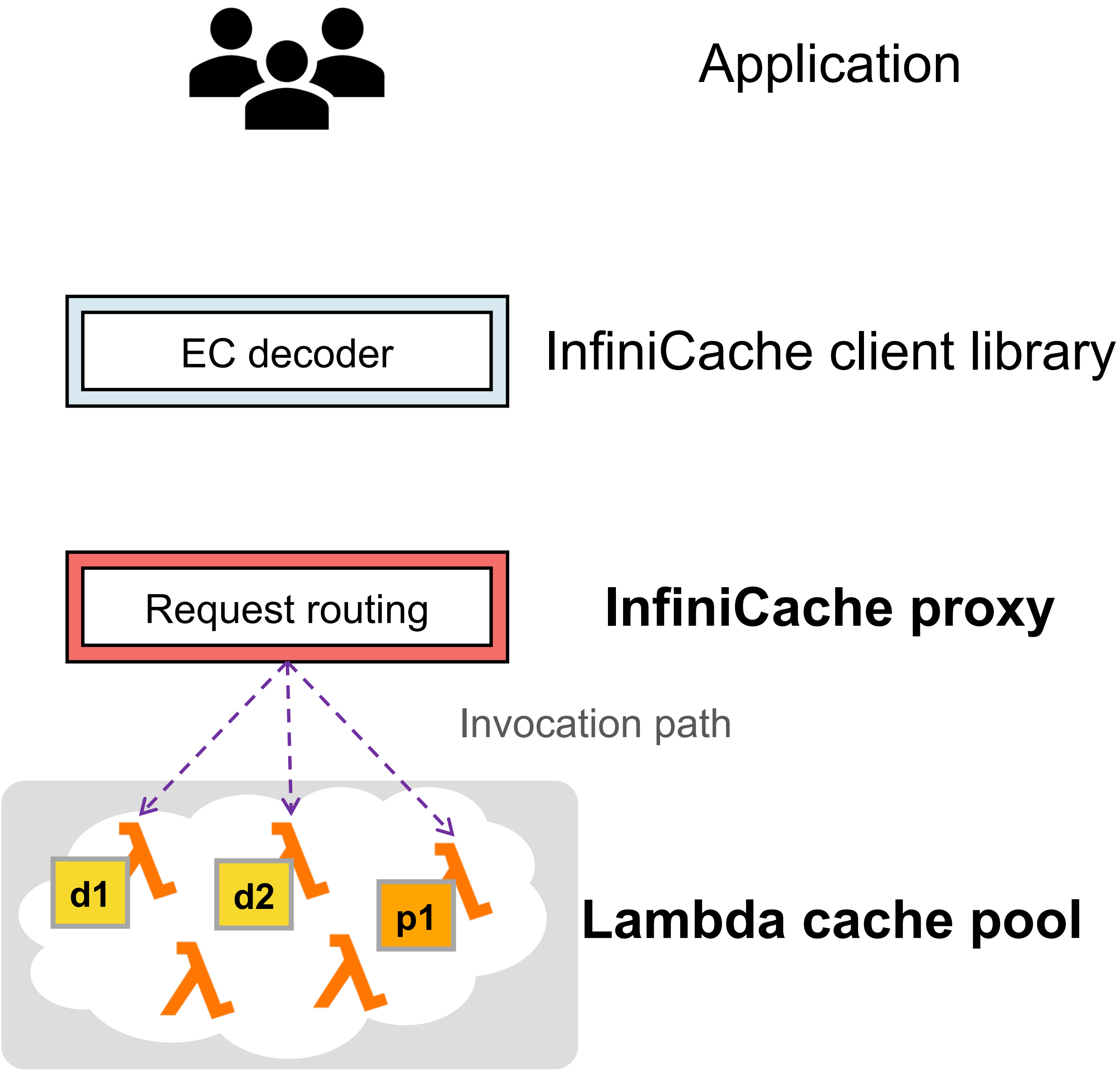
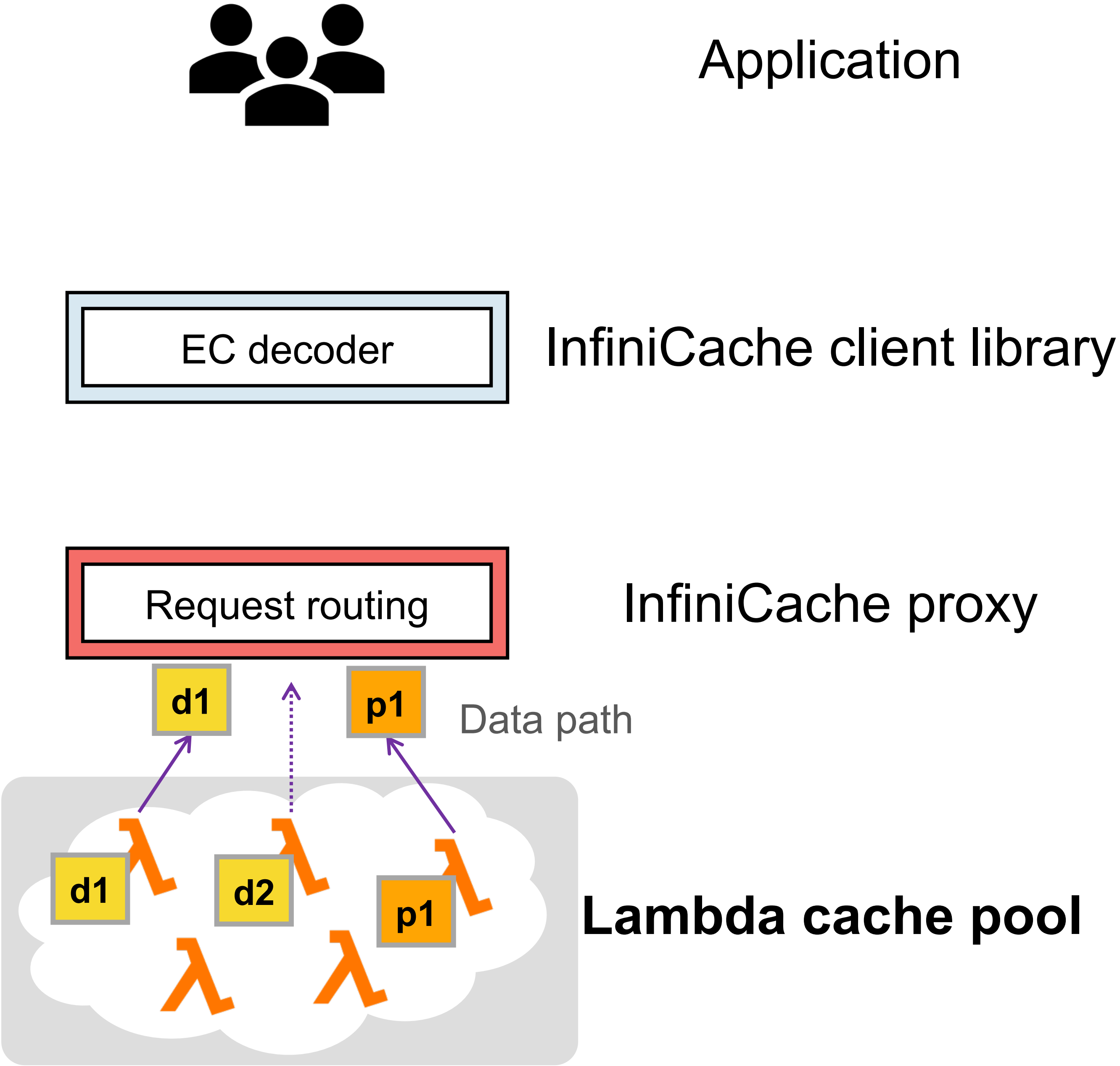


InfiniCache: GET path

1. Client sends GET request

2. Proxy invokes associated Lambda cache nodes

3. Lambda cache nodes transfer object chunks to proxy



InfiniCache: GET path

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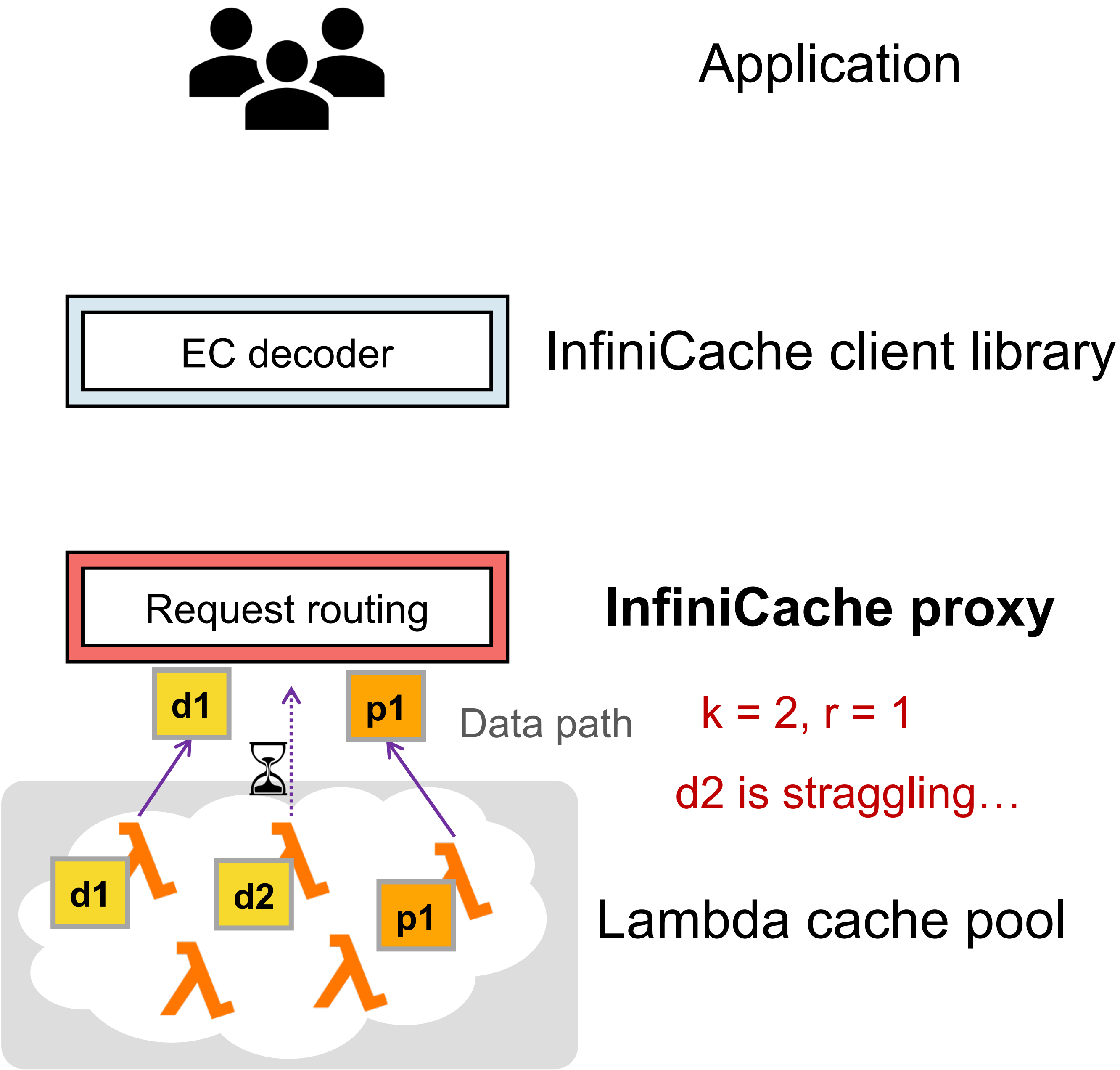
3. Lambda cache nodes transfer object chunks to proxy
   - **First-d optimization:** Proxy drops straggler Lambda



InfiniCache: GET path

1. Client sends GET request

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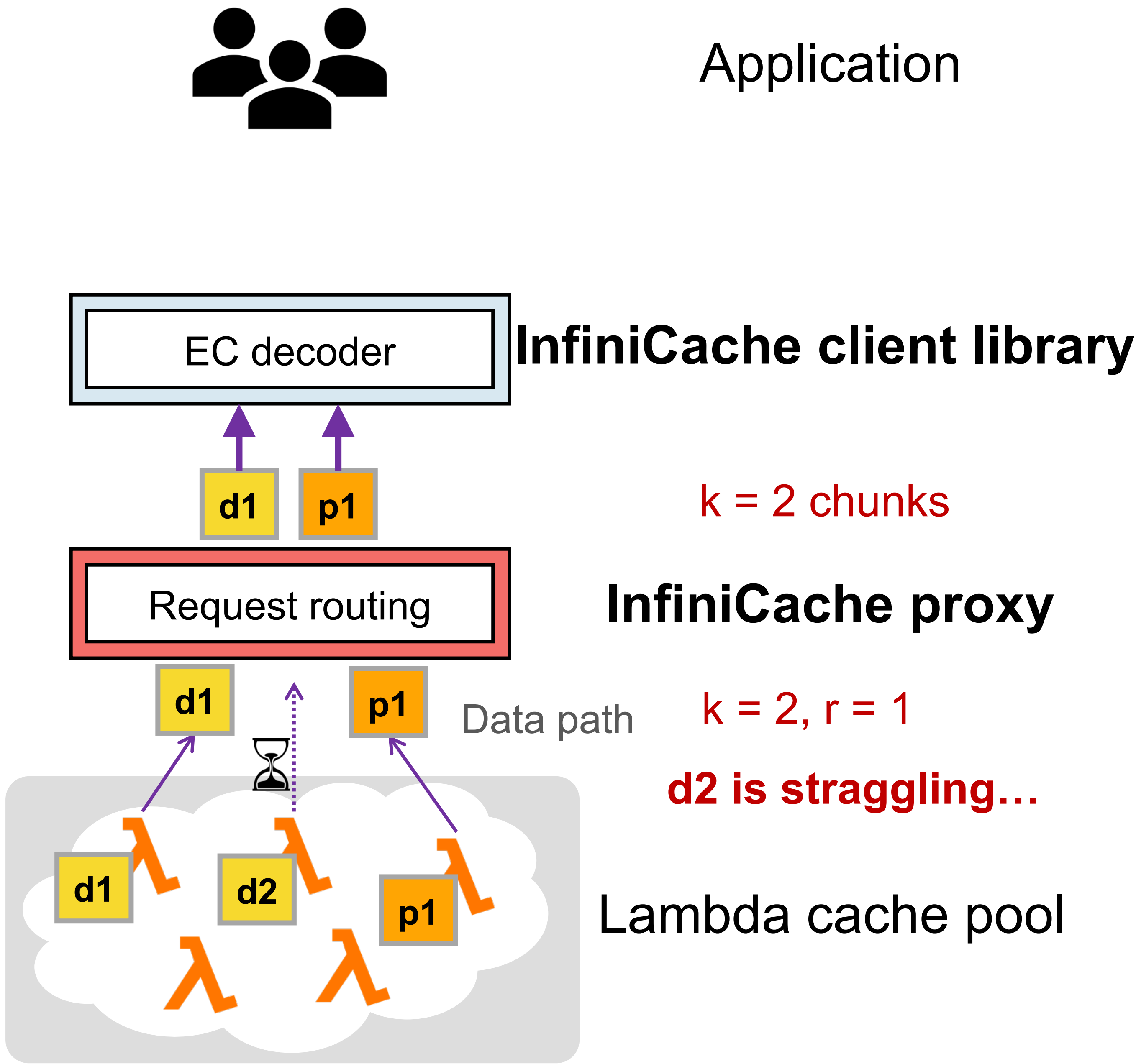
4. Proxy streams k=2 chunks in parallel to client



Application

EC decoder

InfiniCache client library

d1 p1

k = 2 chunks

Request routing

InfiniCache proxy

d1 p1

Data path

k = 2, r = 1

d2 is straggling…

d1 d2 p1

Lambda cache pool

InfiniCache: GET path

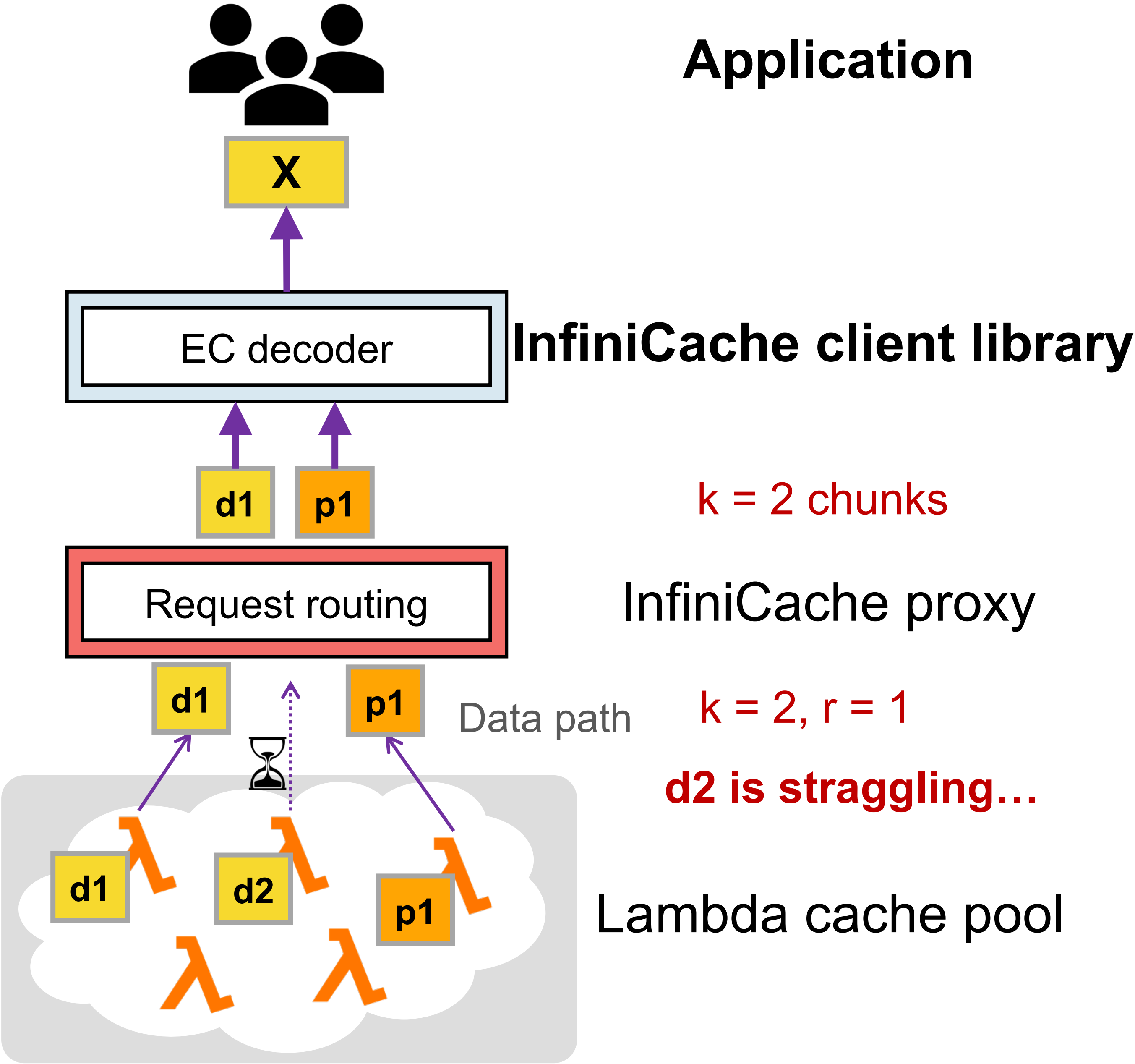
1. Client sends GET request

2. Proxy invokes associated Lambda cache nodes

3. Lambda cache nodes transfer object chunks to proxy

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

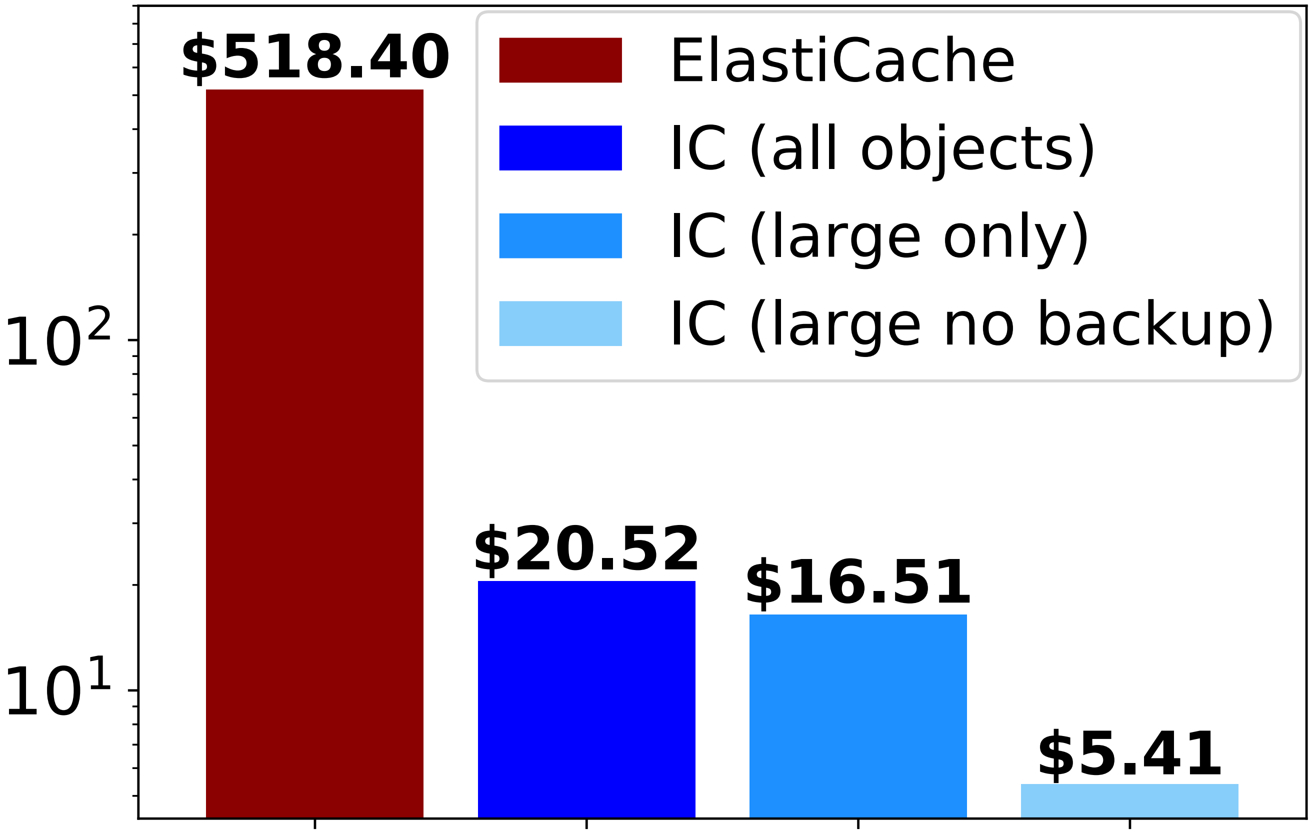
5. Client library decodes k chunks



Maximizing data availability

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

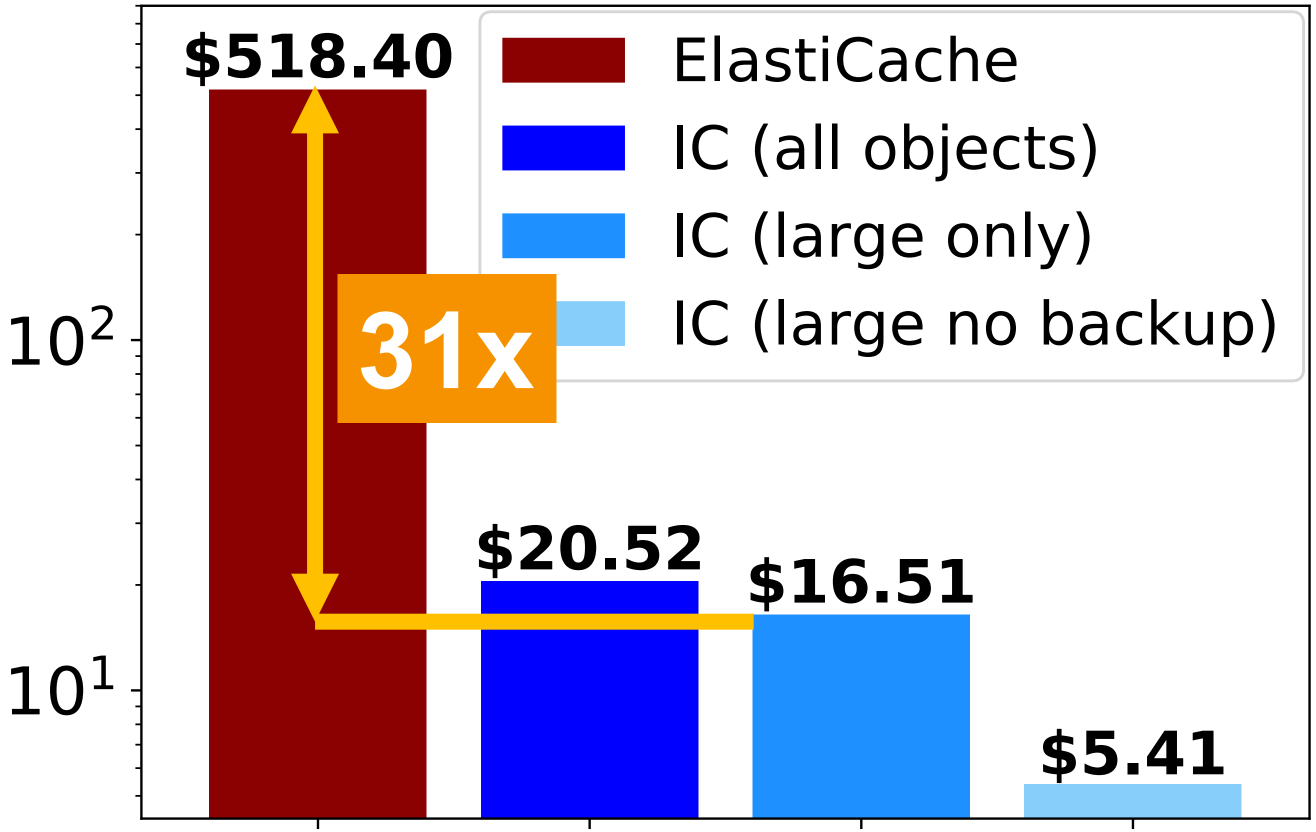
Cost effectiveness of InfiniCache



Workload setup

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

Cost effectiveness of InfiniCache



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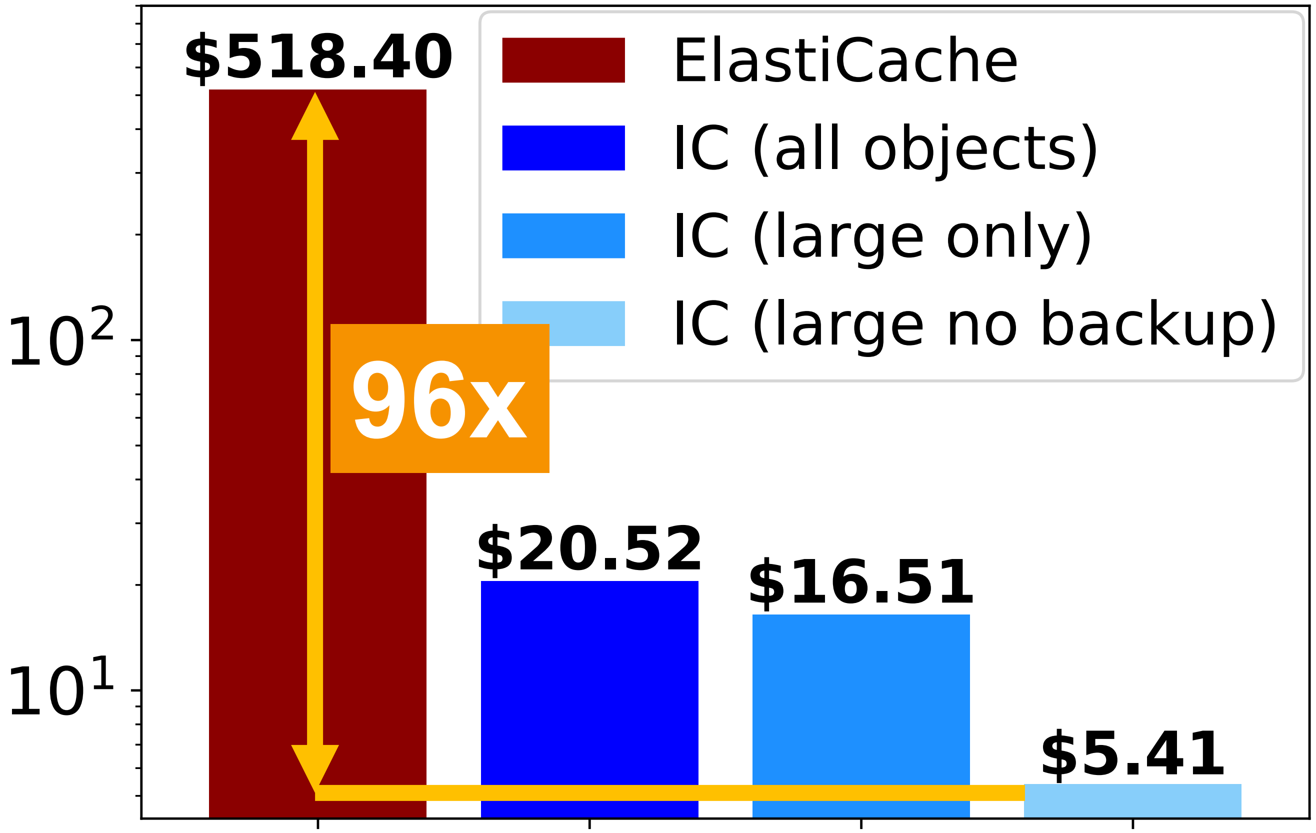

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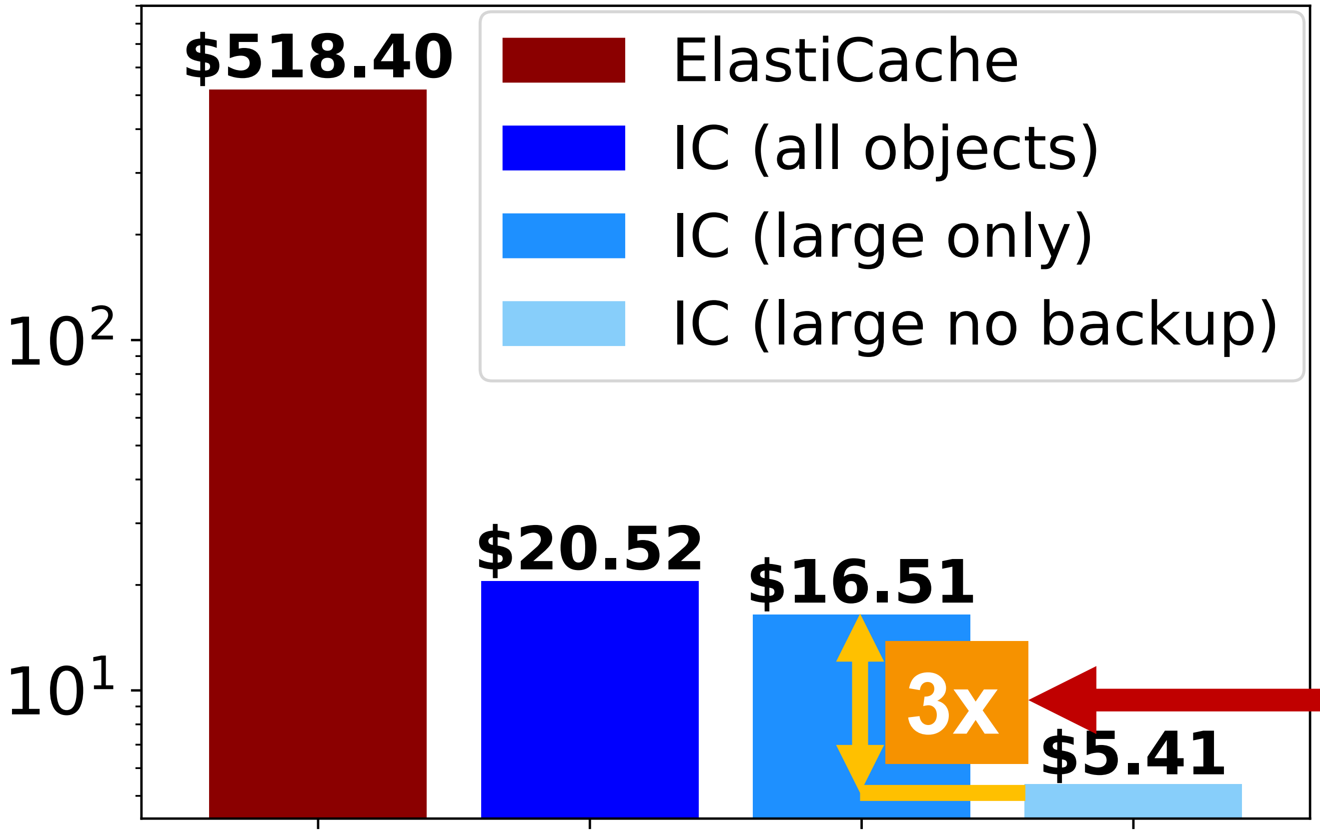
Cost effectiveness of InfiniCache



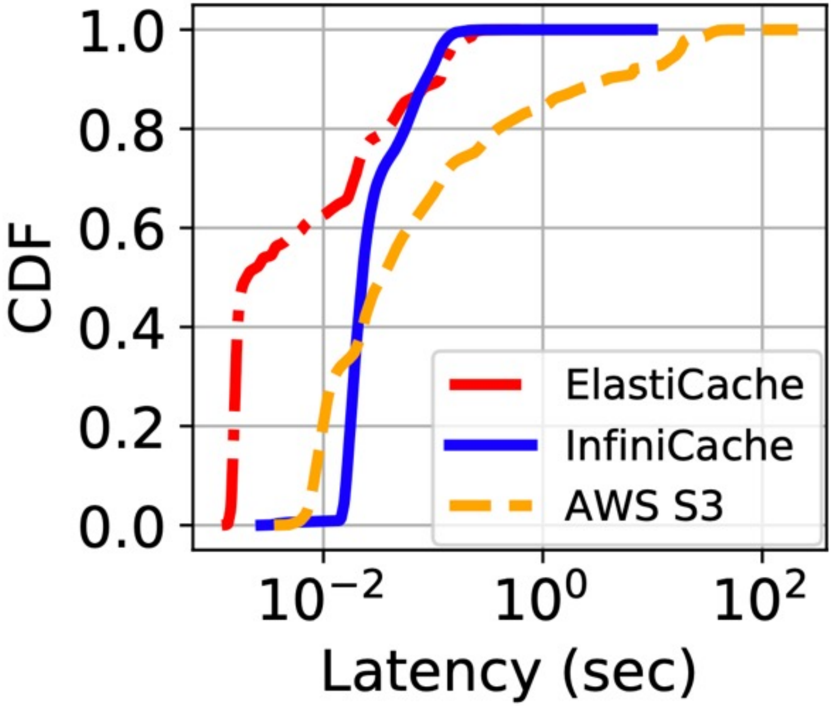
Hit ratio and $$ cost tradeoff

Workload setup

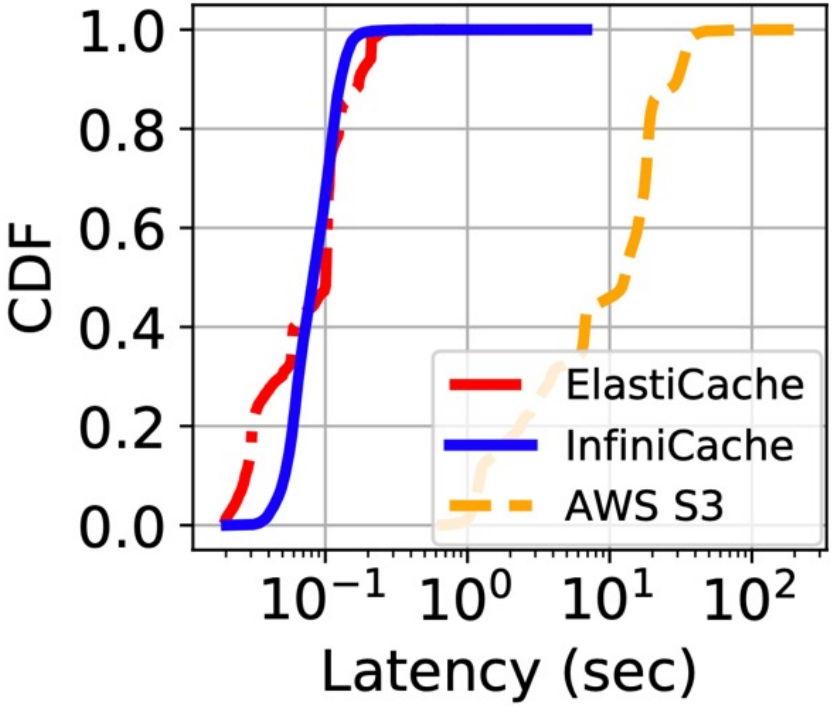
- All objects
- Large object only
  - Object larger than 10MB
- **Large object w/o backup**

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

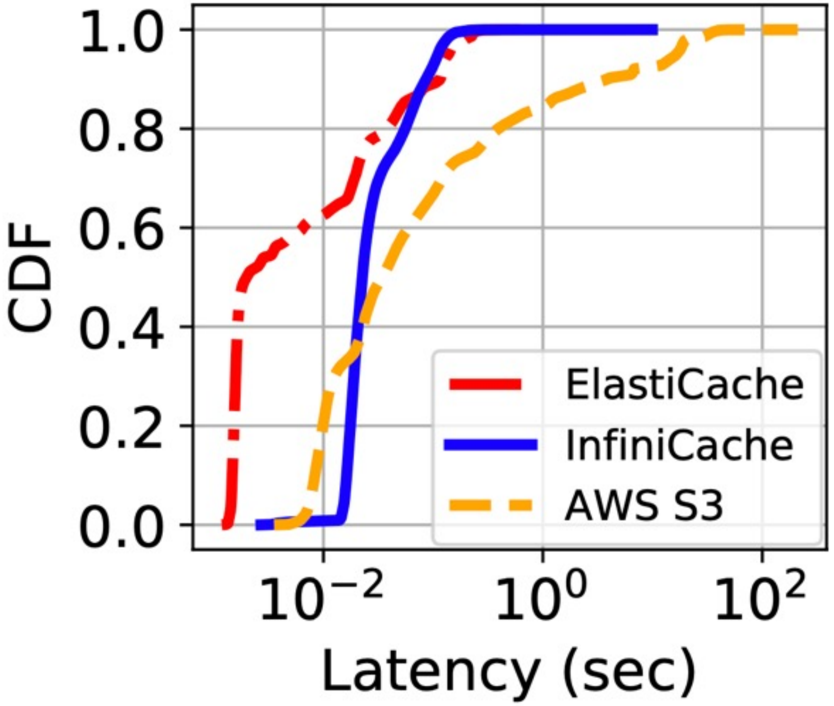


All objects

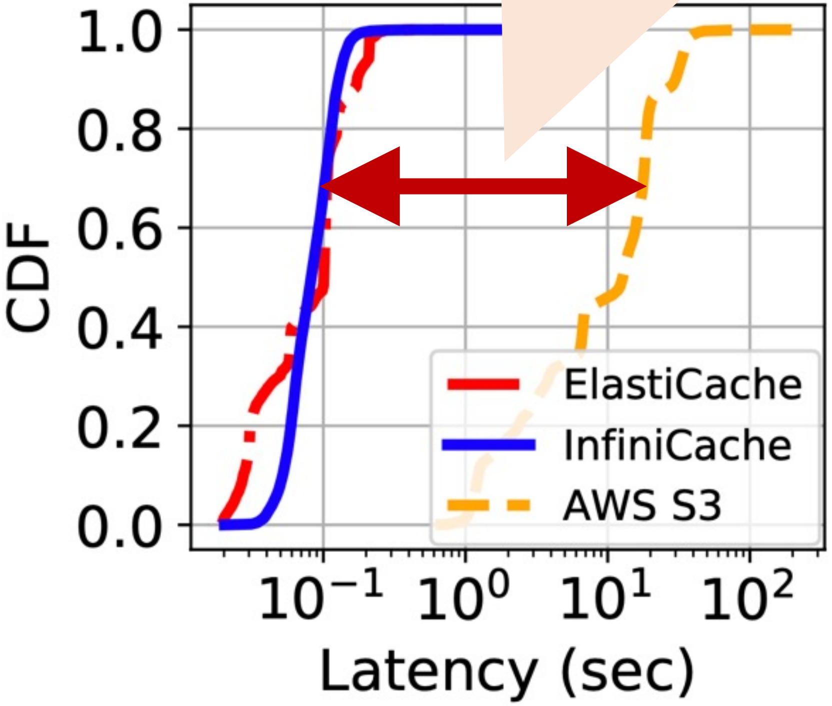


Large objects only

Performance of InfiniCache



All objects



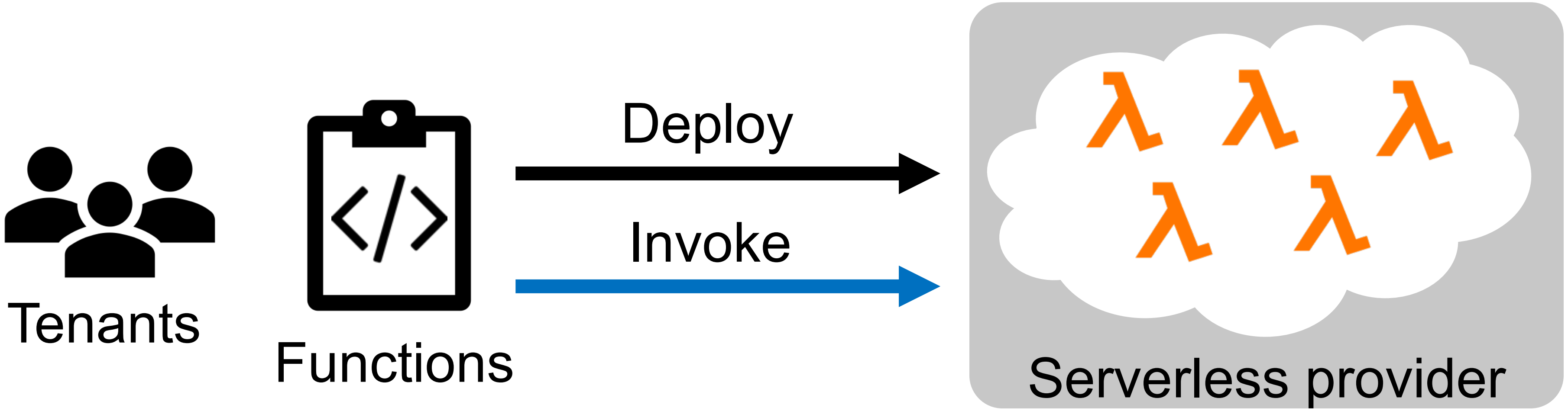
Large objects only

> 100 times improvement

Backup slides

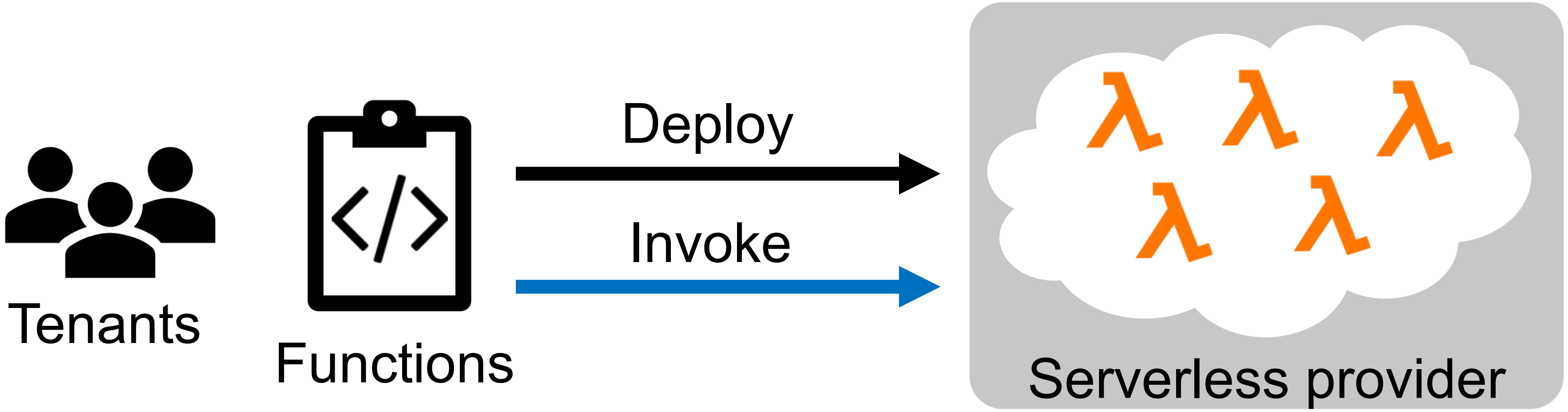
A primer on Serverless Computing

- Serverless computing enables cloud tenants to launch short-lived tasks (i.e., Lambda functions) with high elasticity and fine-grained resource billing



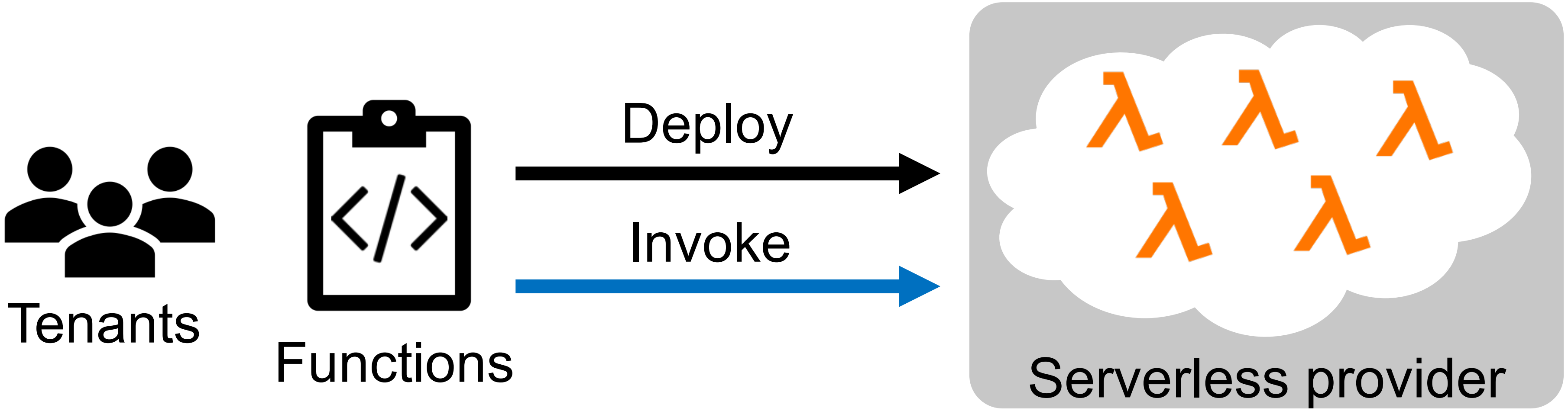
A primer on Serverless Computing

- Serverless computing enables cloud tenants to launch short-lived tasks (i.e., Lambda functions) with high elasticity and fine-grained resource billing
- Function: basic unit of deployment. Application consists of multiple serverless functions



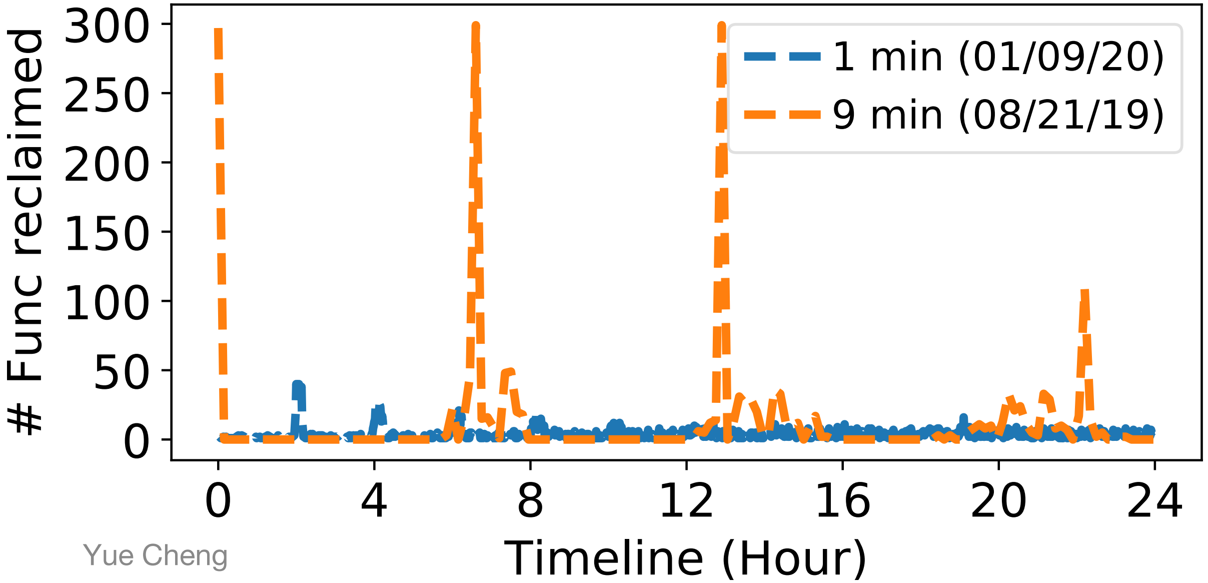
A primer on Serverless Computing

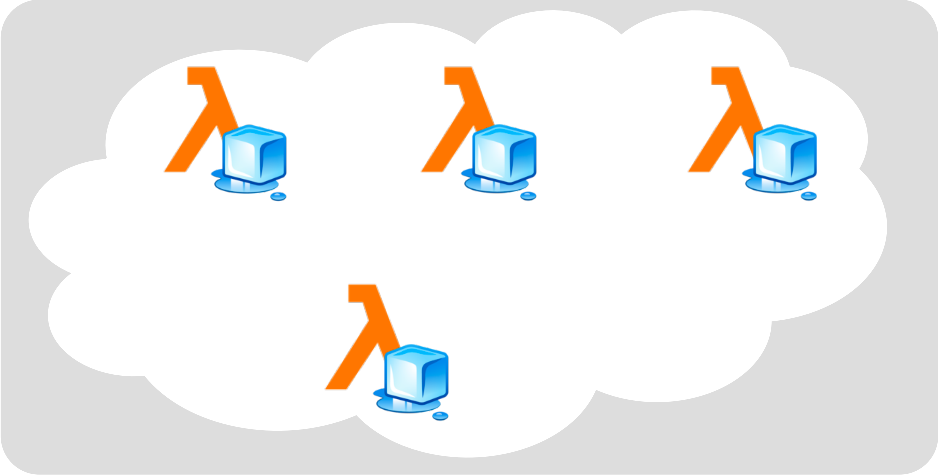
- Serverless computing enables cloud tenants to launch short-lived tasks (i.e., Lambda functions) with high elasticity and fine-grained resource billing
- Function: basic unit of deployment. Application consists of multiple serverless functions
- Popular use cases: Backend APIs, data processing…



Maximizing data availability: Periodic warm-up

1. Lambda nodes are cached by AWS when not running
   - AWS may reclaim cold Lambda functions after they are idling for a period





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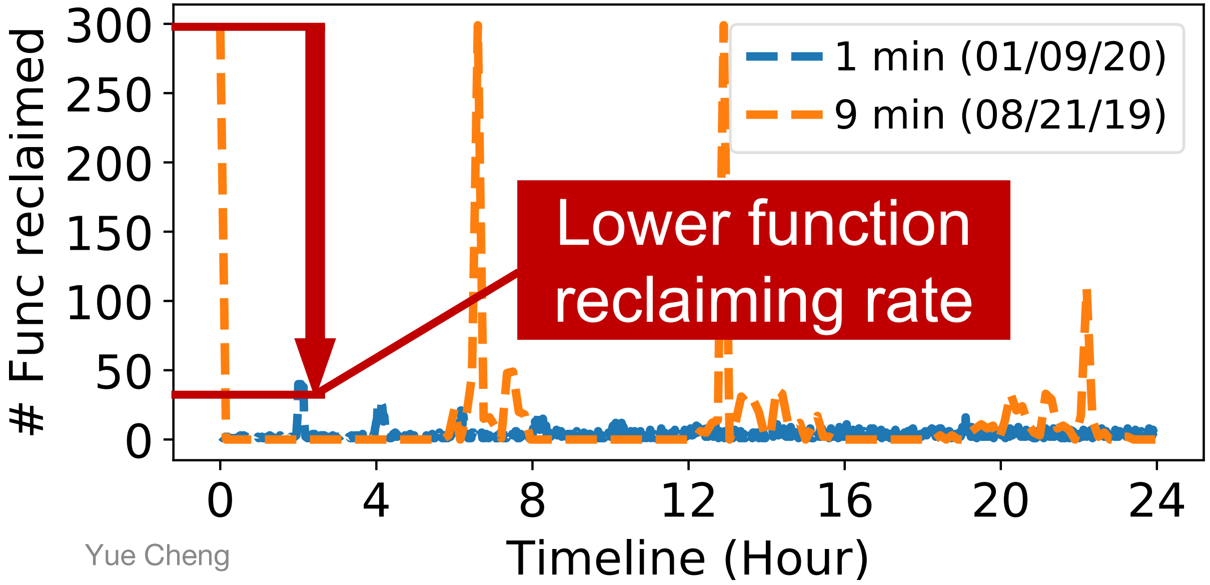
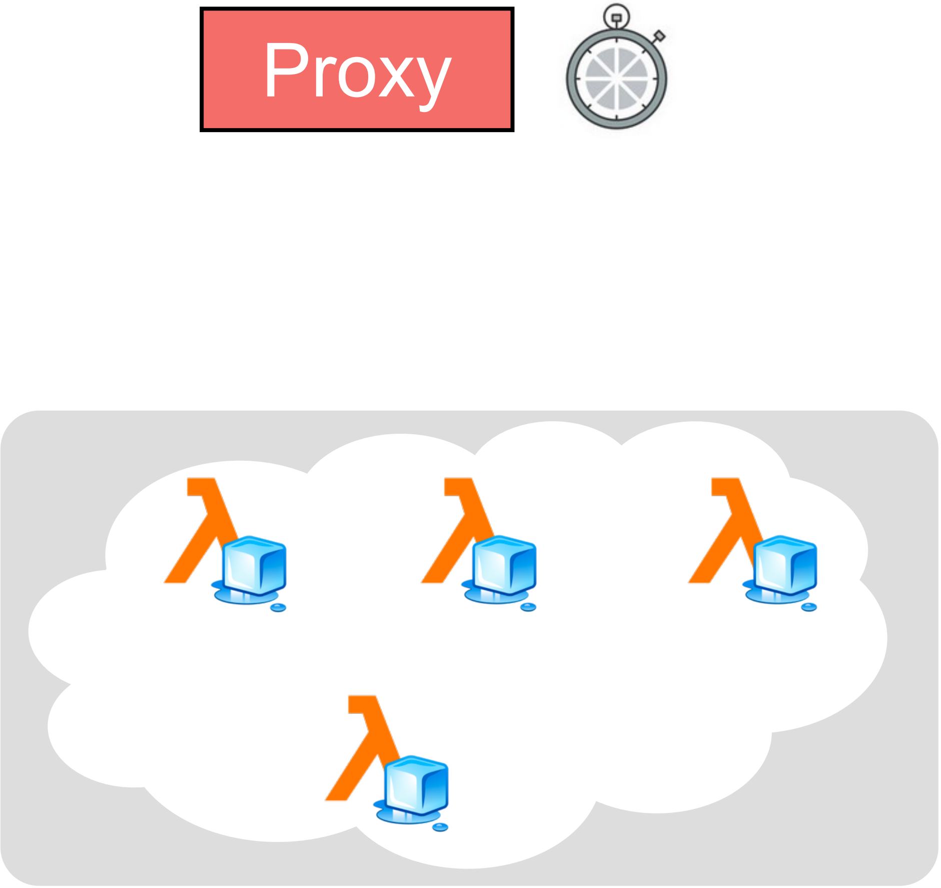


Lower function reclaiming rate



Proxy

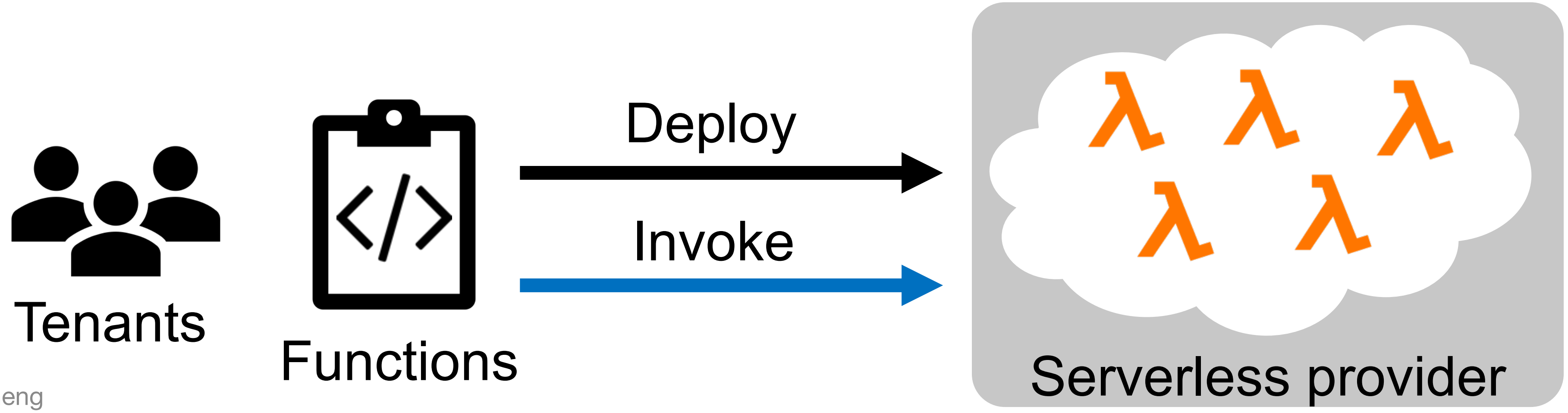
Experimental setup

- InfiniCache
  - 400 1.5GB Lambda cache nodes
  - Client running on one `c5n.4xlarge` EC2 VM
  - Warm-up interval: 1 minute; backup interval: 5 minutes
  - Under one AWS VPC

- Production workloads
  - The first 50 hours of the Dallas datacenter traces from IBM Docker registry workloads
  - All objects: including small and large objects
  - Large object only: objects > 10MB

FaaS is desirable

- Pay-per-use pricing model
  - AWS Lambda: $0.2 per 1M invocations
    $0.00001667 for every GB-sec



FaaS is desirable

- Pay-per-use pricing model
  - AWS Lambda: $0.2 per 1M invocations
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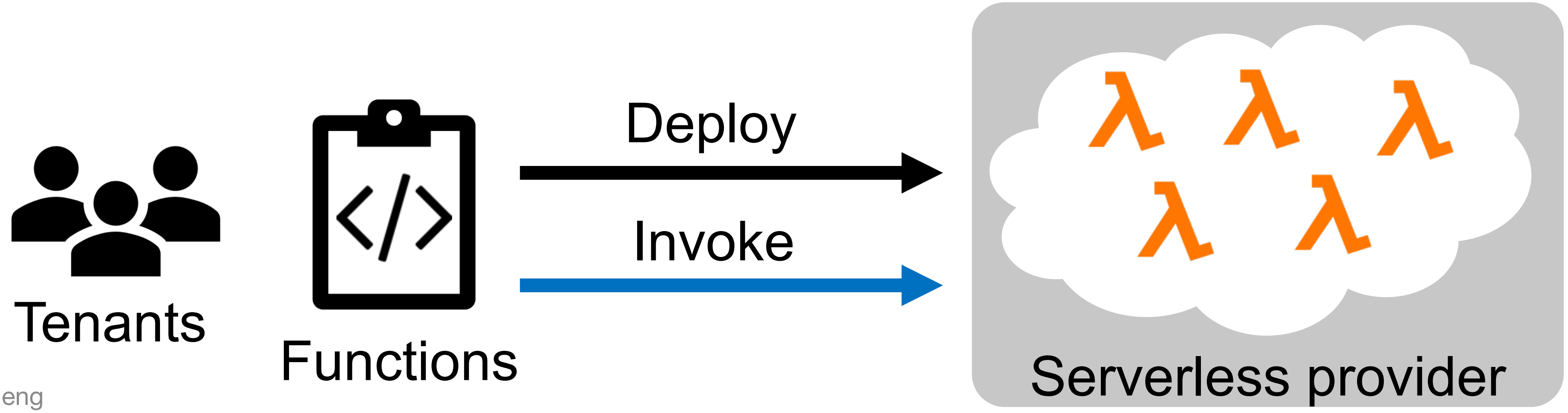
- Short-term function caching
  - Provider caches triggered functions in memory without charging tenants



FaaS is desirable

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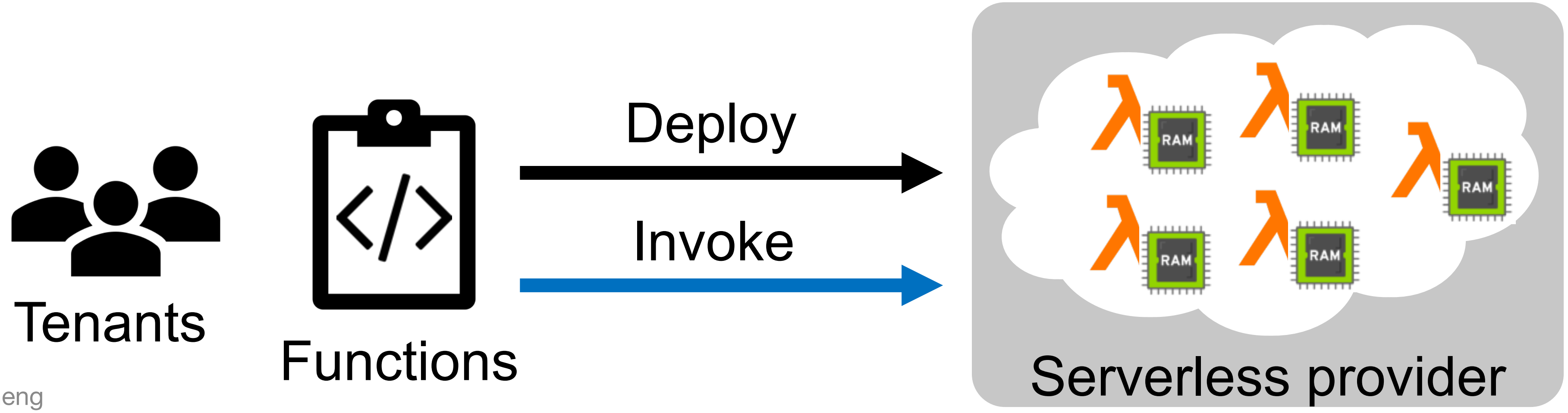
Goal: Build a cost-effective, high-performance memory cache that exploits the FaaS features

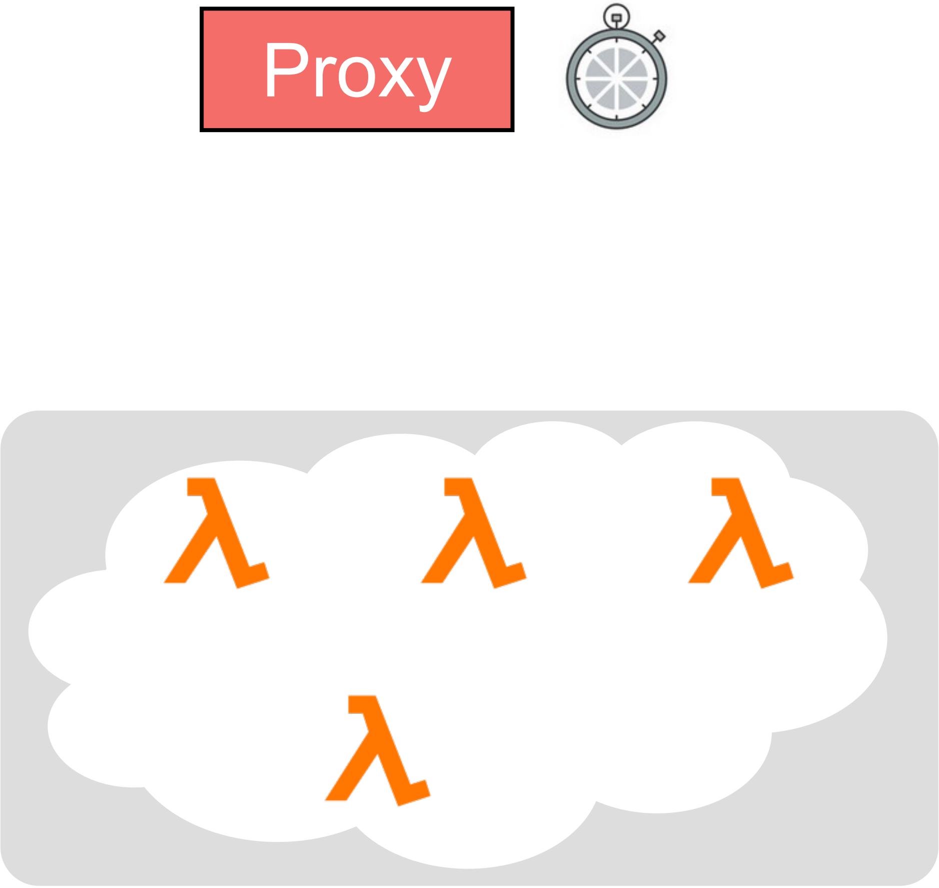


Maximizing data availability

- Erasure-coding
- Periodic warm-up
- Periodic 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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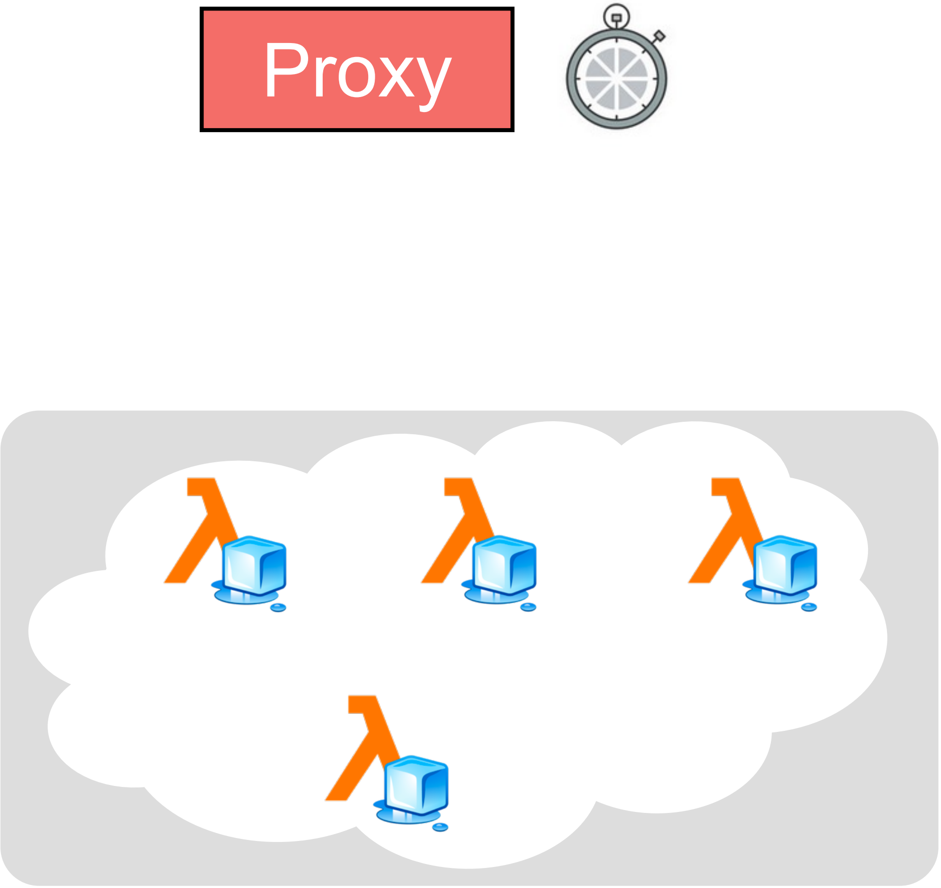
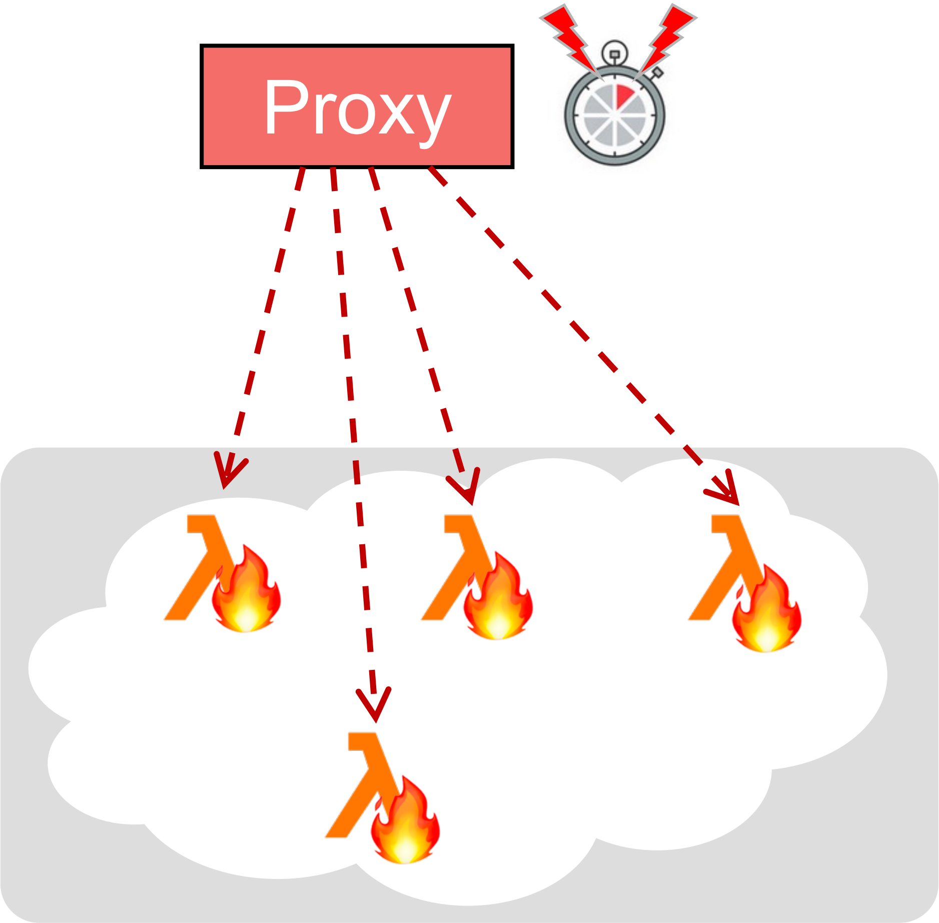


Proxy

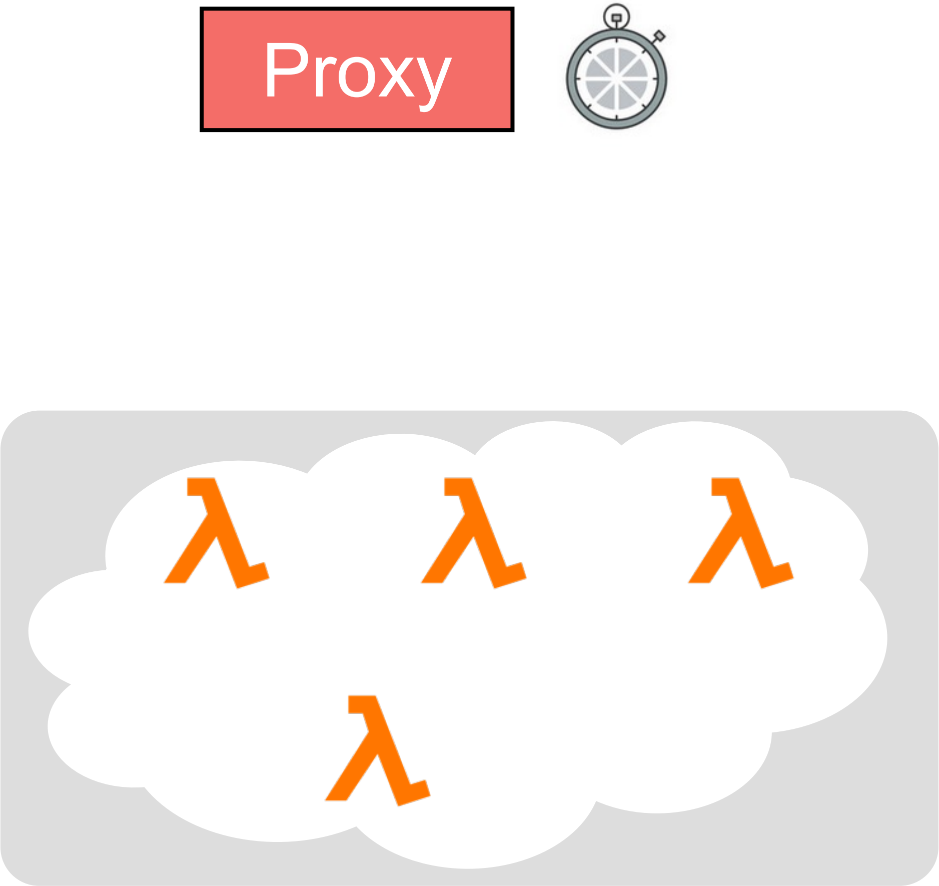
Maximizing data availability: Periodic warm-up

1. Lambda nodes are cached by AWS when not running

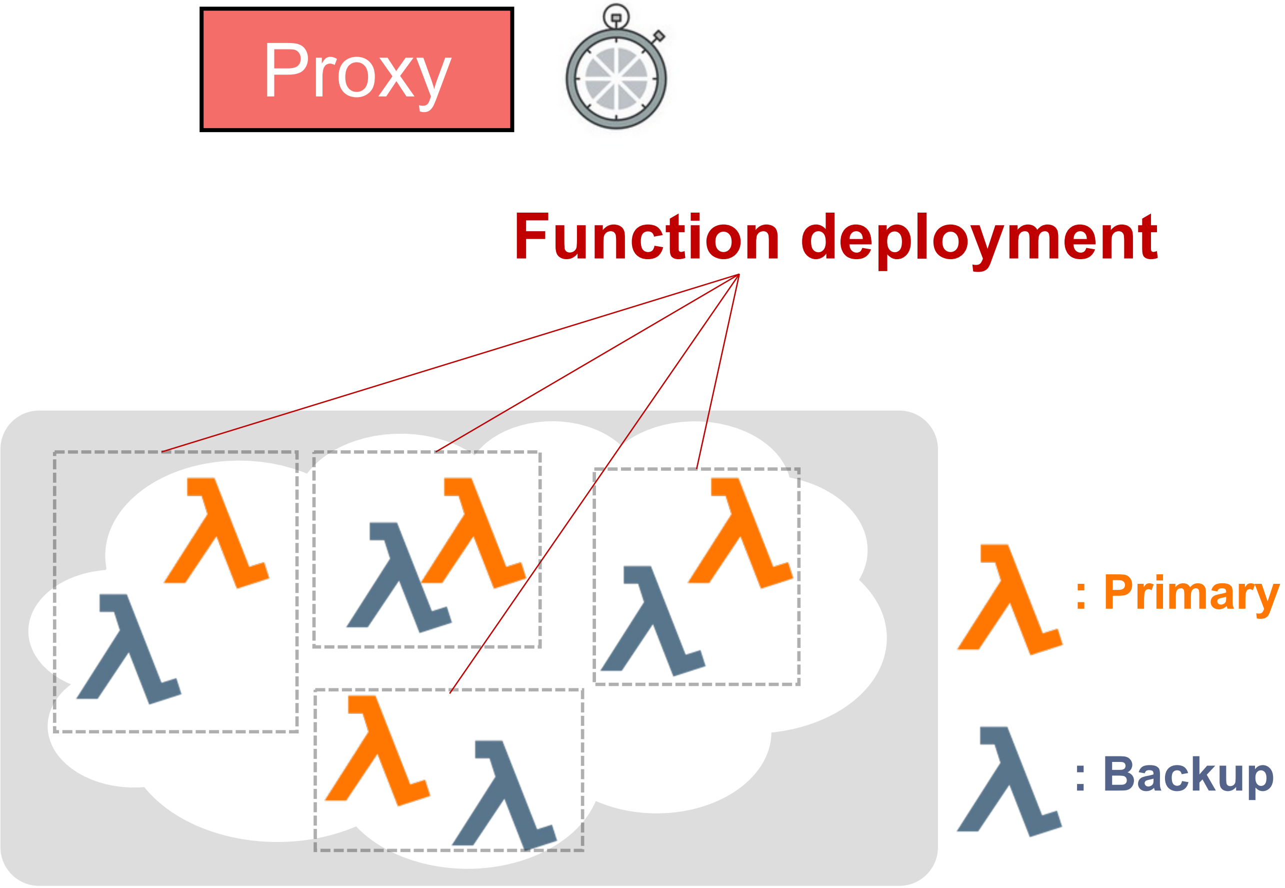
2. Proxy periodically invokes sleeping Lambda cache nodes to extend their lifespan



Maximizing data availability: Periodic backup



Maximizing data availability: Periodic backup



Proxy

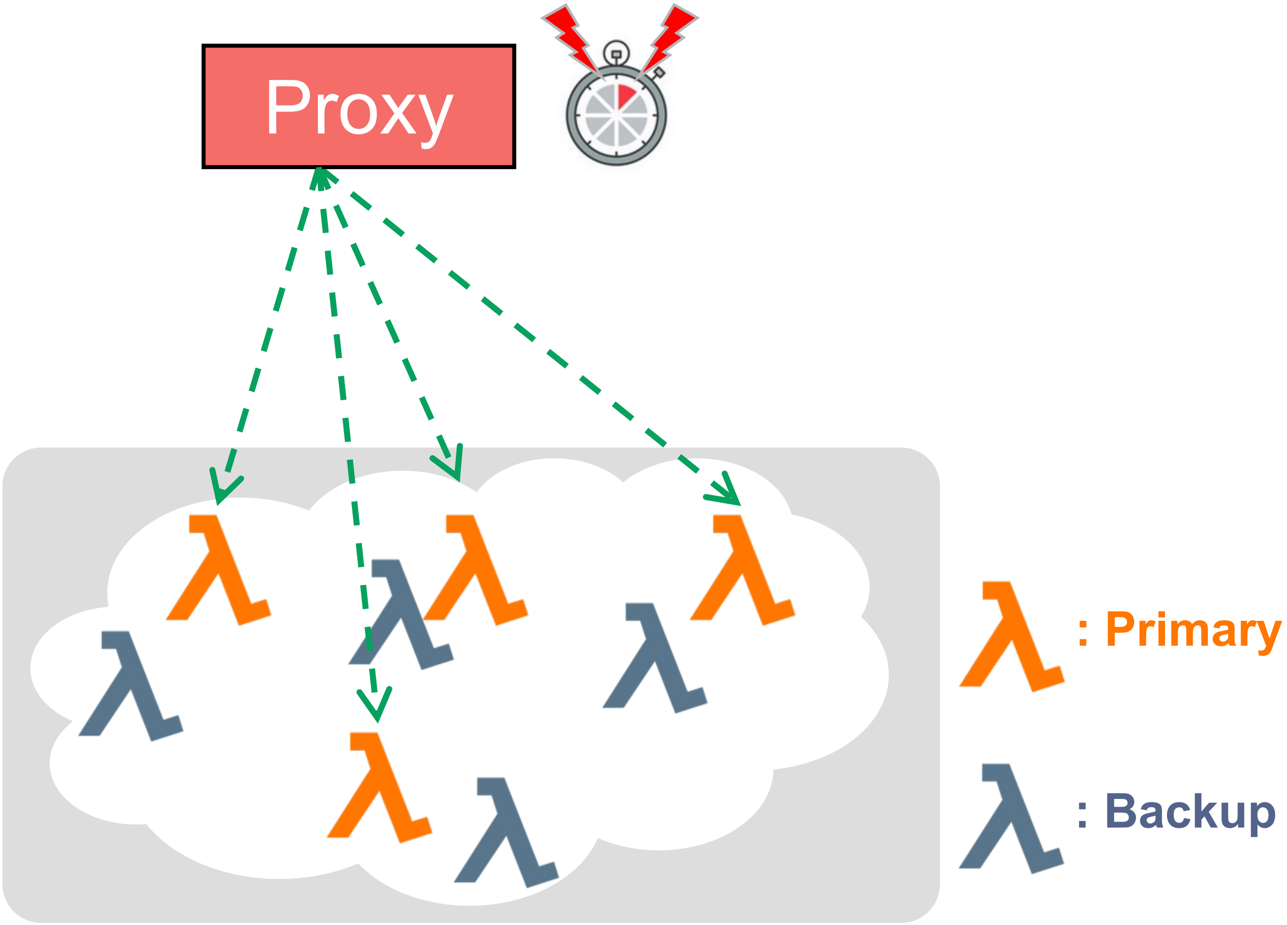
Function deployment

λ : Primary

λ : Backup

Maximizing data availability: Periodic backup

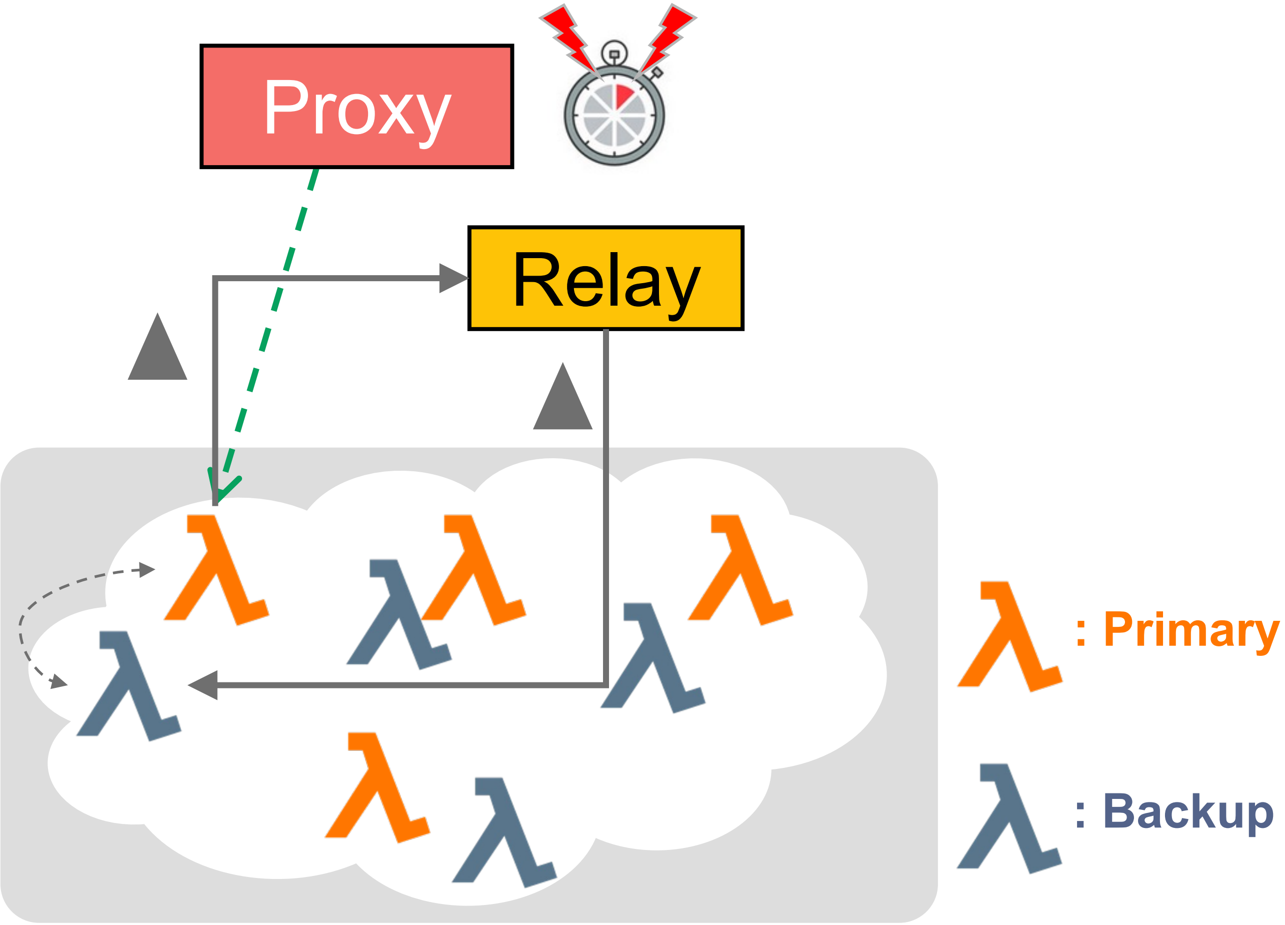
1. Proxy sends out backup commands to Lambda cache nodes periodically



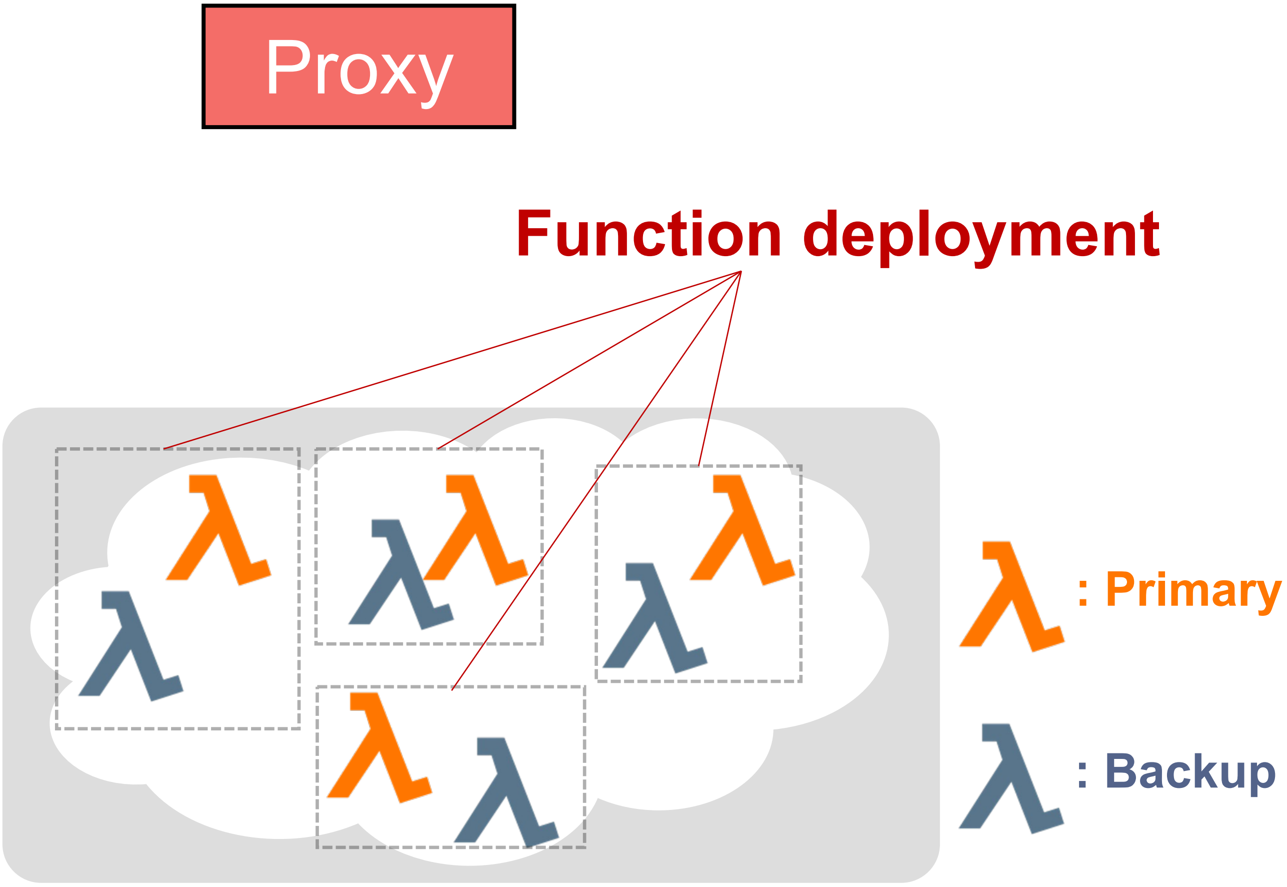
Maximizing data availability: Periodic backup

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

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

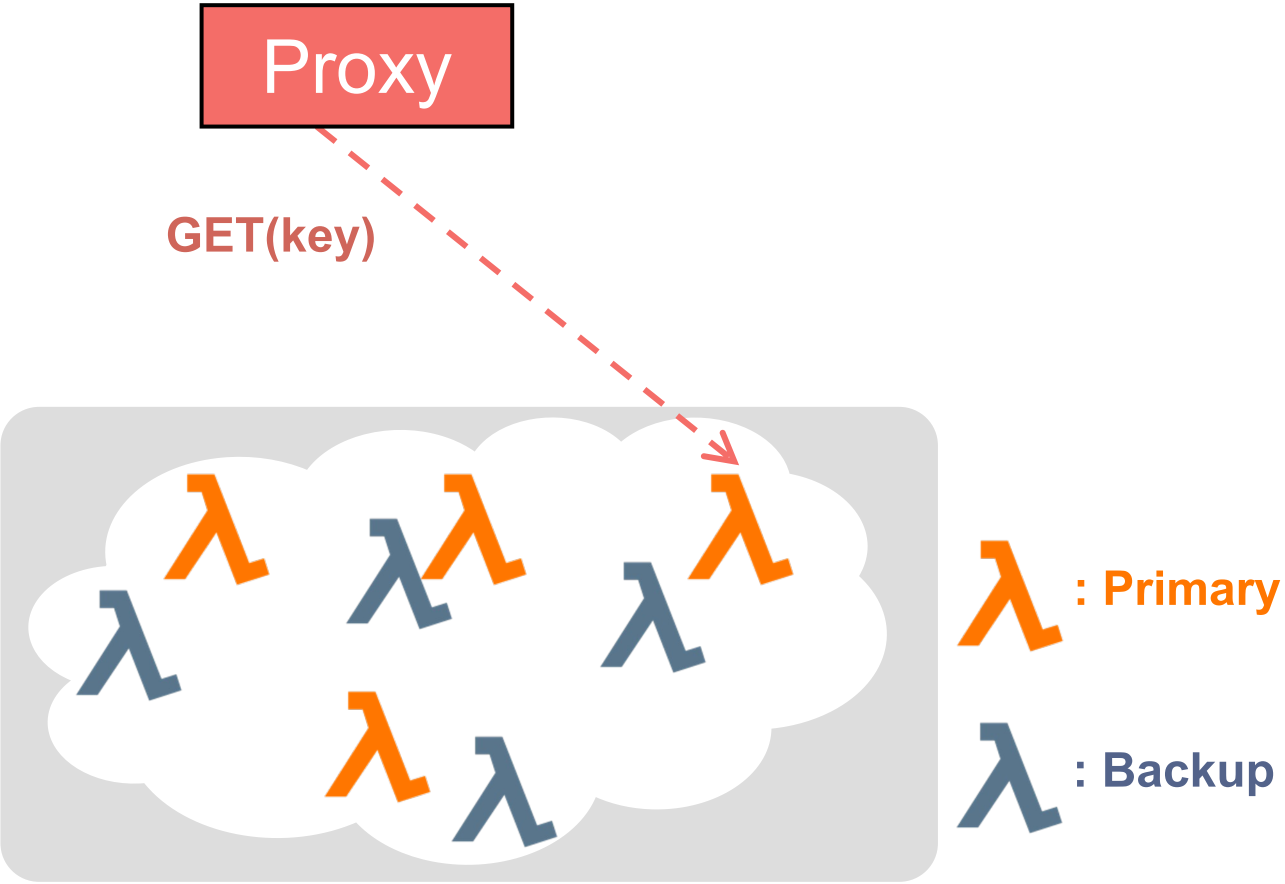


Maximizing data availability: Seamless failover



Maximizing data availability: Seamless failover

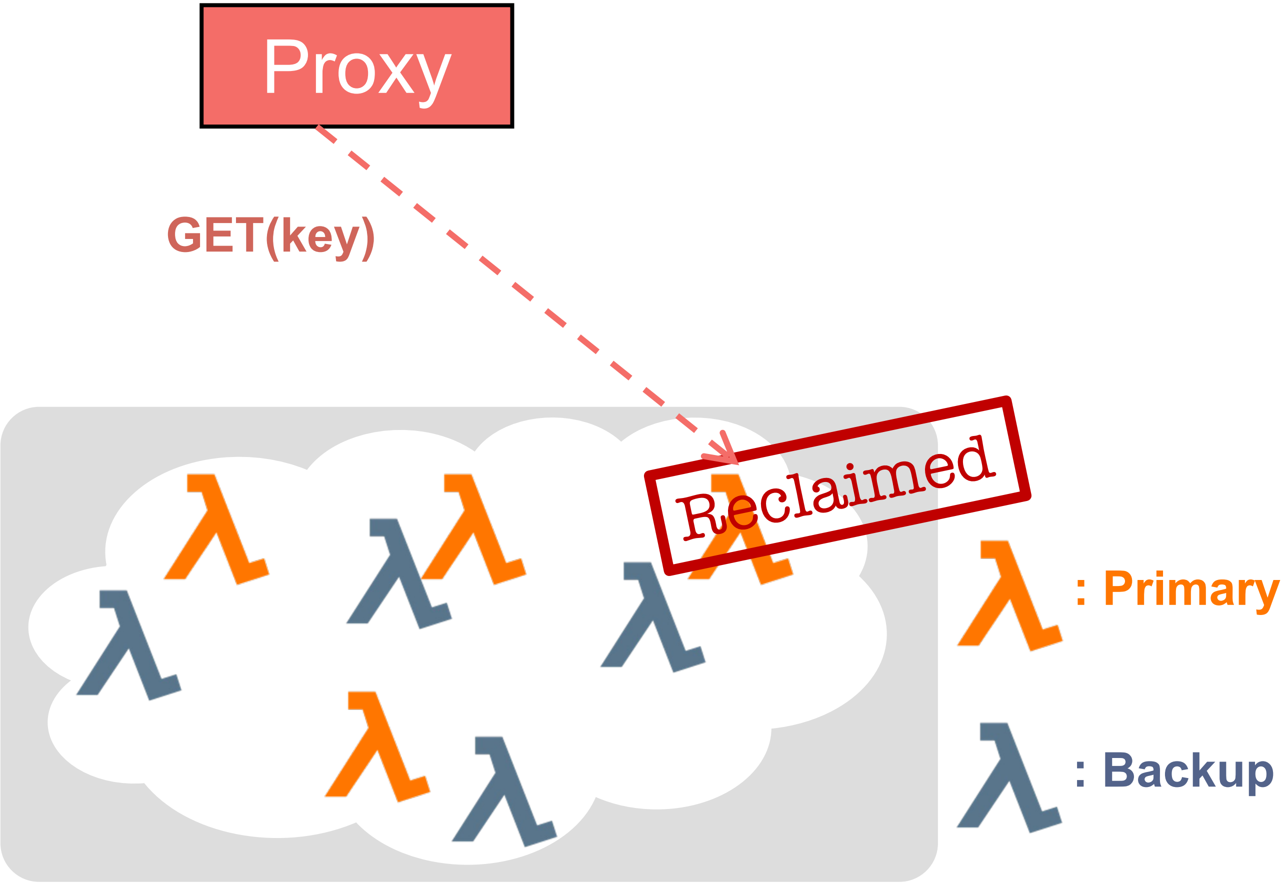
1. Proxy invokes a Lambda cache node with a GET request



Maximizing data availability: Seamless failover

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

2. Primary Lambda gets reclaimed



Maximizing data availability: Seamless failover

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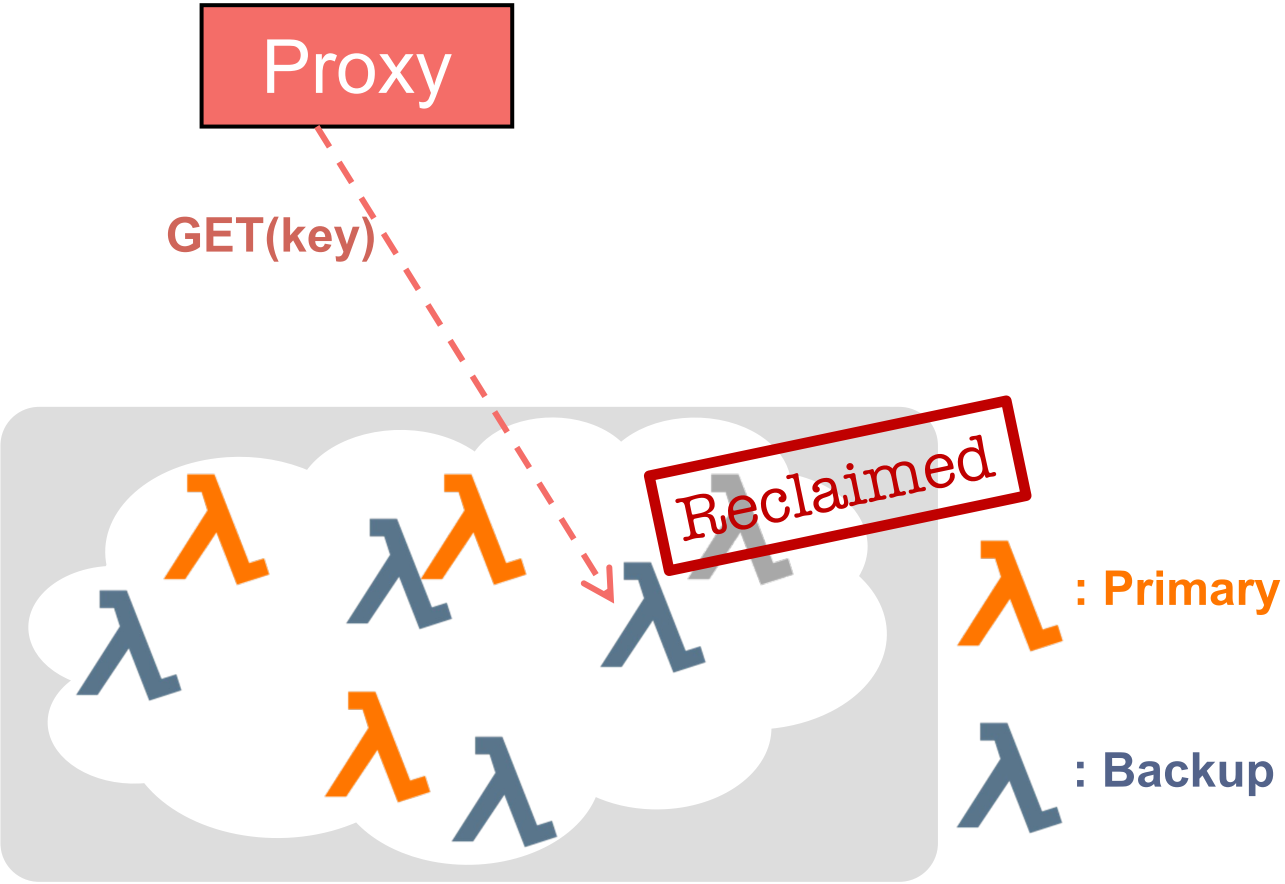
3. The invocation request gets seamlessly redirected to the backup Lambda

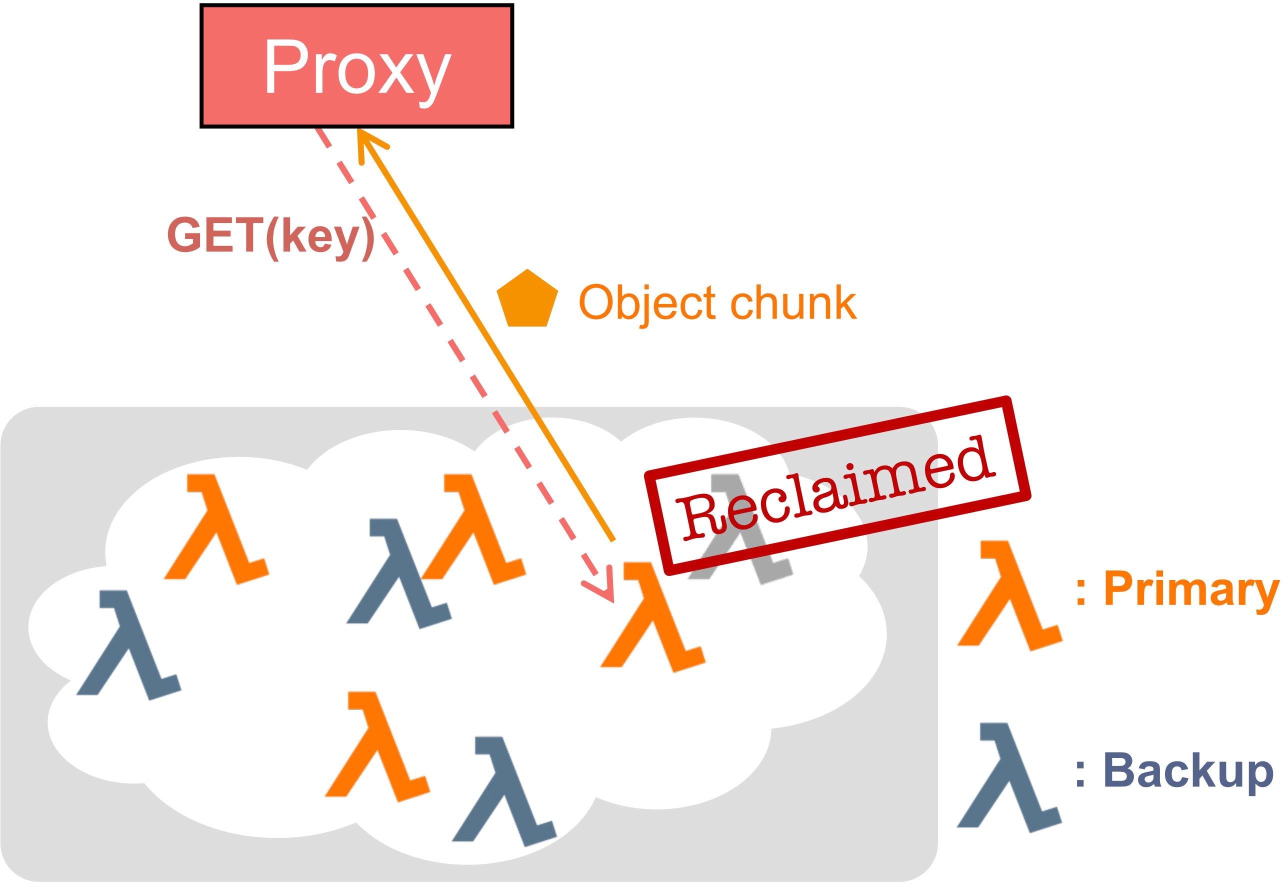


Maximizing data availability: Seamless failover

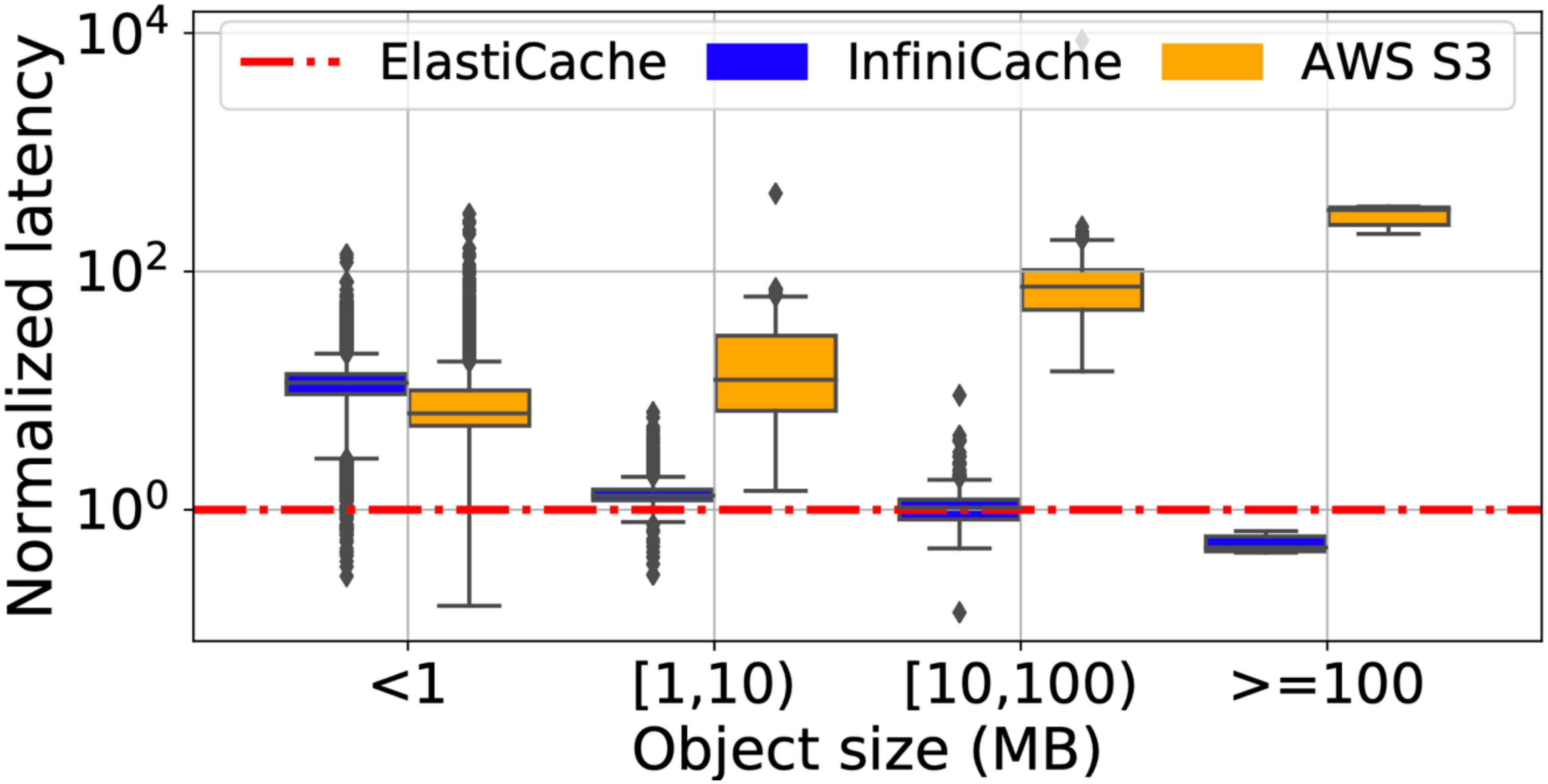
1. Proxy invokes a Lambda cache node with a GET request

2. Primary Lambda gets reclaimed

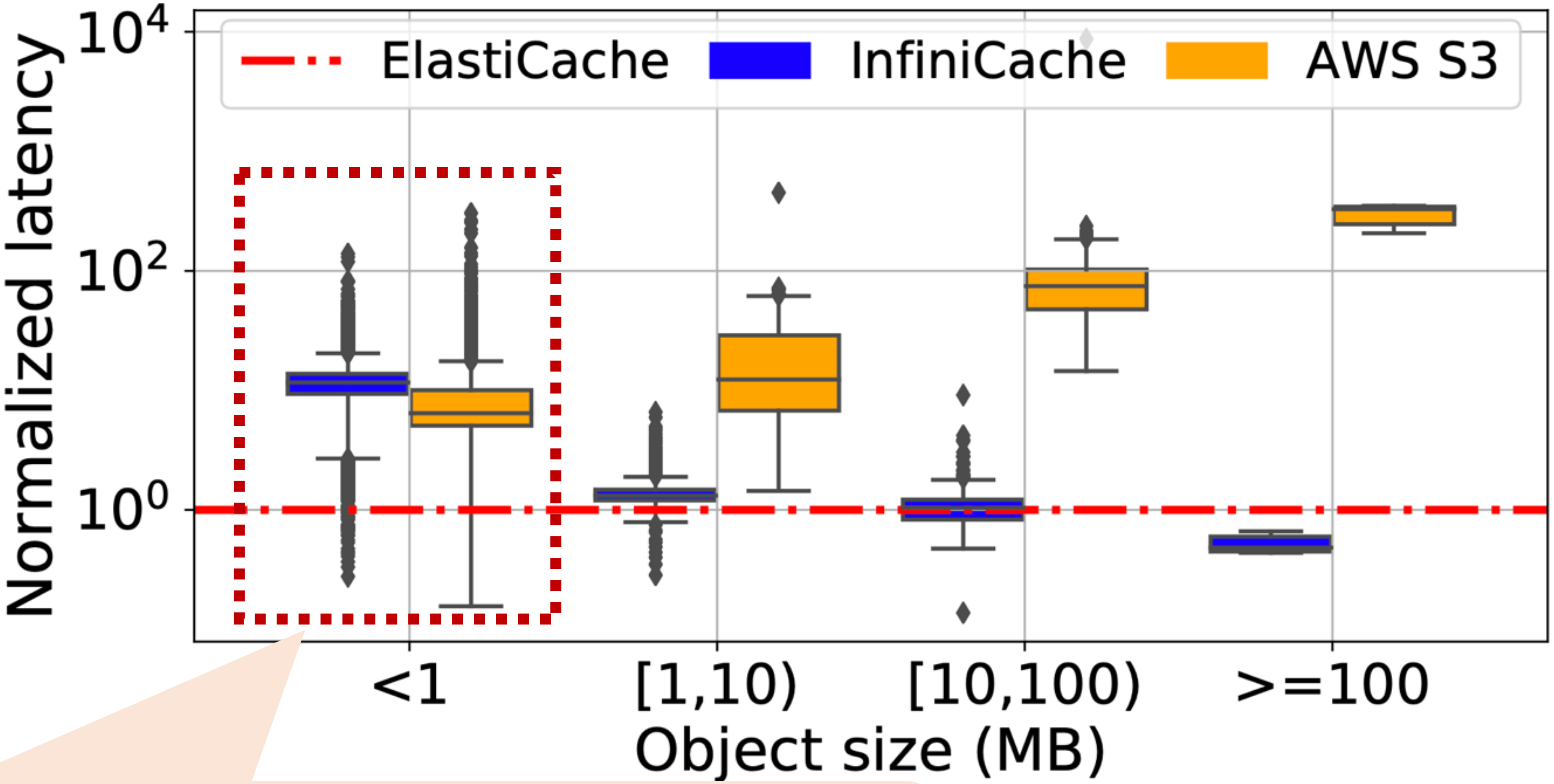
3. The invocation request gets seamlessly redirected to the backup Lambda
    - Backup Lambda becomes the primary
    - Achieves automatic failover by exploiting FaaS **auto-scaling**



Performance of InfiniCache

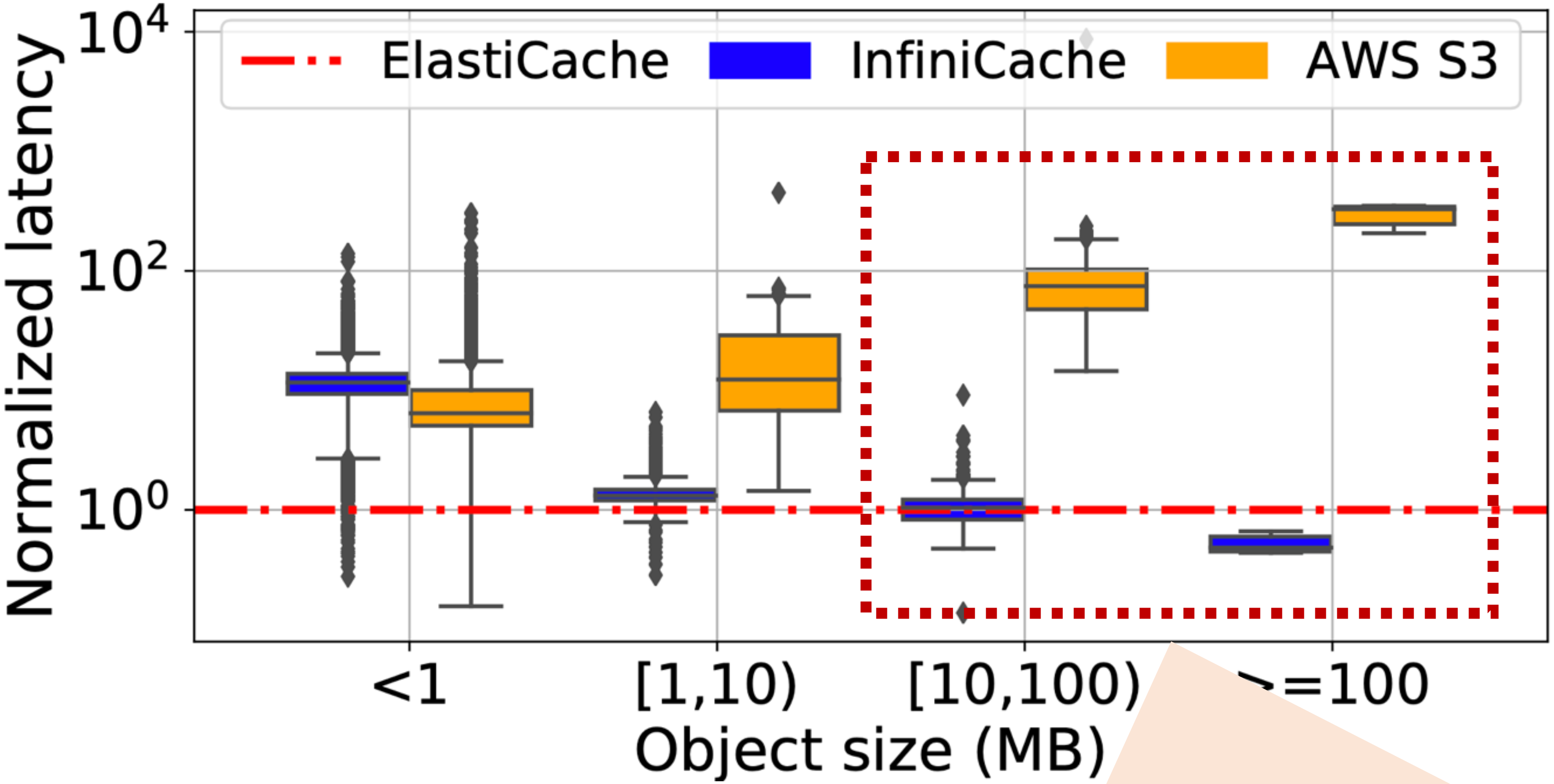


Performance of InfiniCache



Lambda invocation overhead (~13ms) dominates when fetching small objects

Performance of InfiniCache



InfiniCache achieves same or higher performance than ElastiCache for large objects