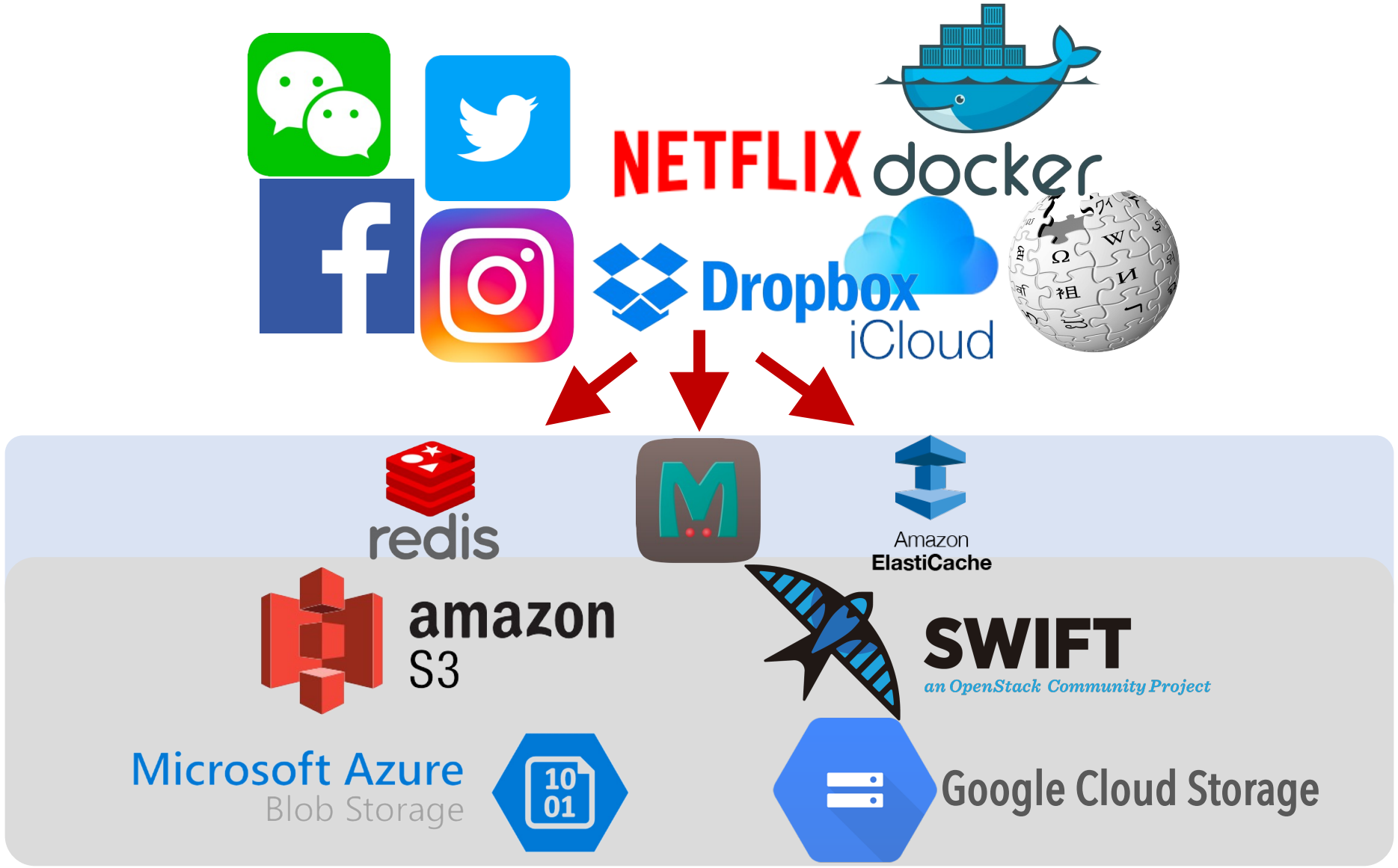
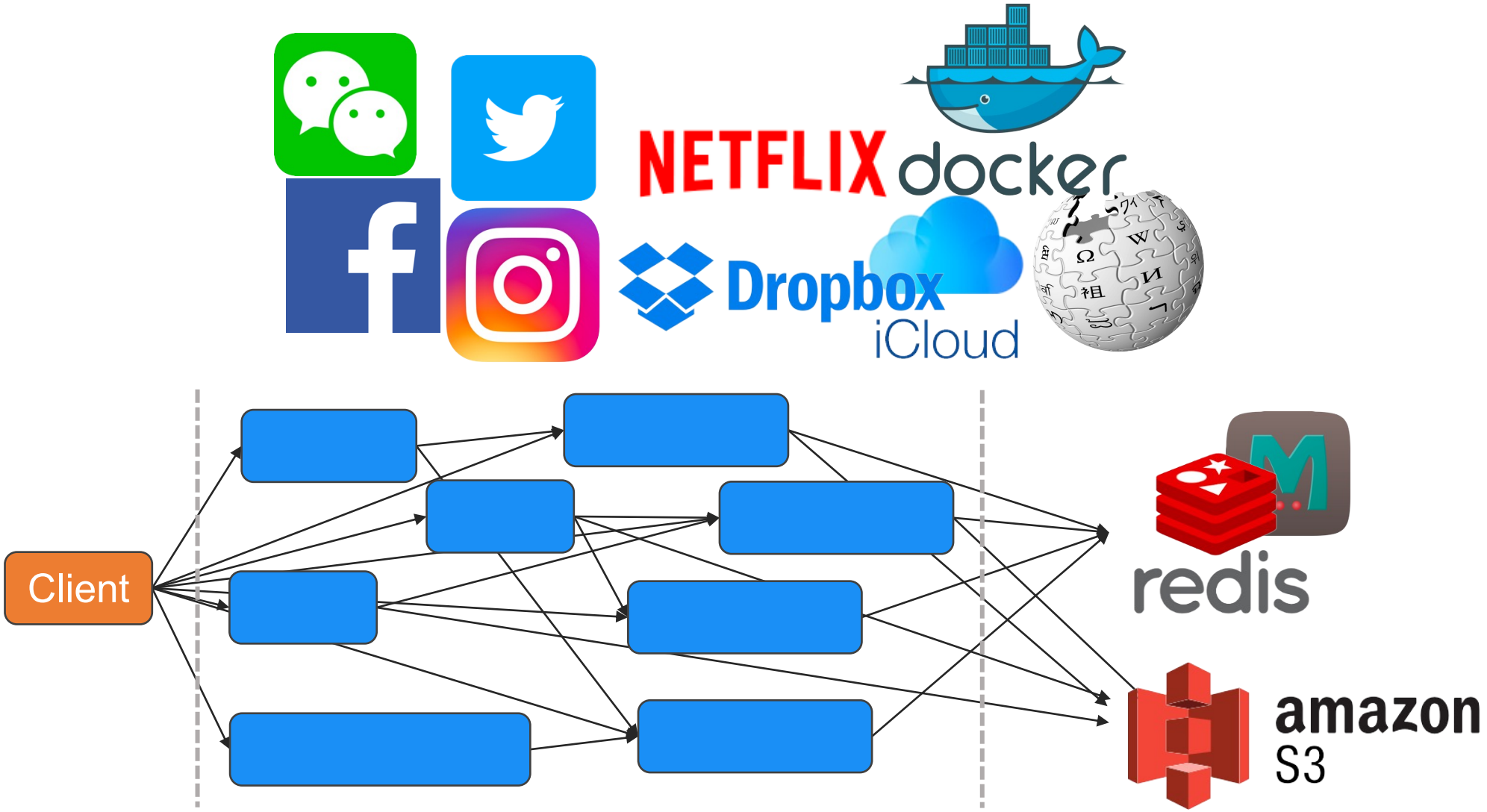
# InfiniCache: Exploiting Ephemeral Serverless Functions to Build a Cost-Effective Memory Cache

Yue Cheng

# Web applications are storage-intensive



# Web applications — heterogeneous I/O



# Case study: IBM Docker registry workloads

- IBM Cloud container registry service across 75 days during 2017
- Selected data centers: Dallas & London

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- Object size distribution
- Large object 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

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Caching large objects is beneficial:

- > 30% large object access 10+ times
- Around 45% of them got reused within 1 hour

# Case study: IBM Docker registry workloads

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- Large object reuse patterns
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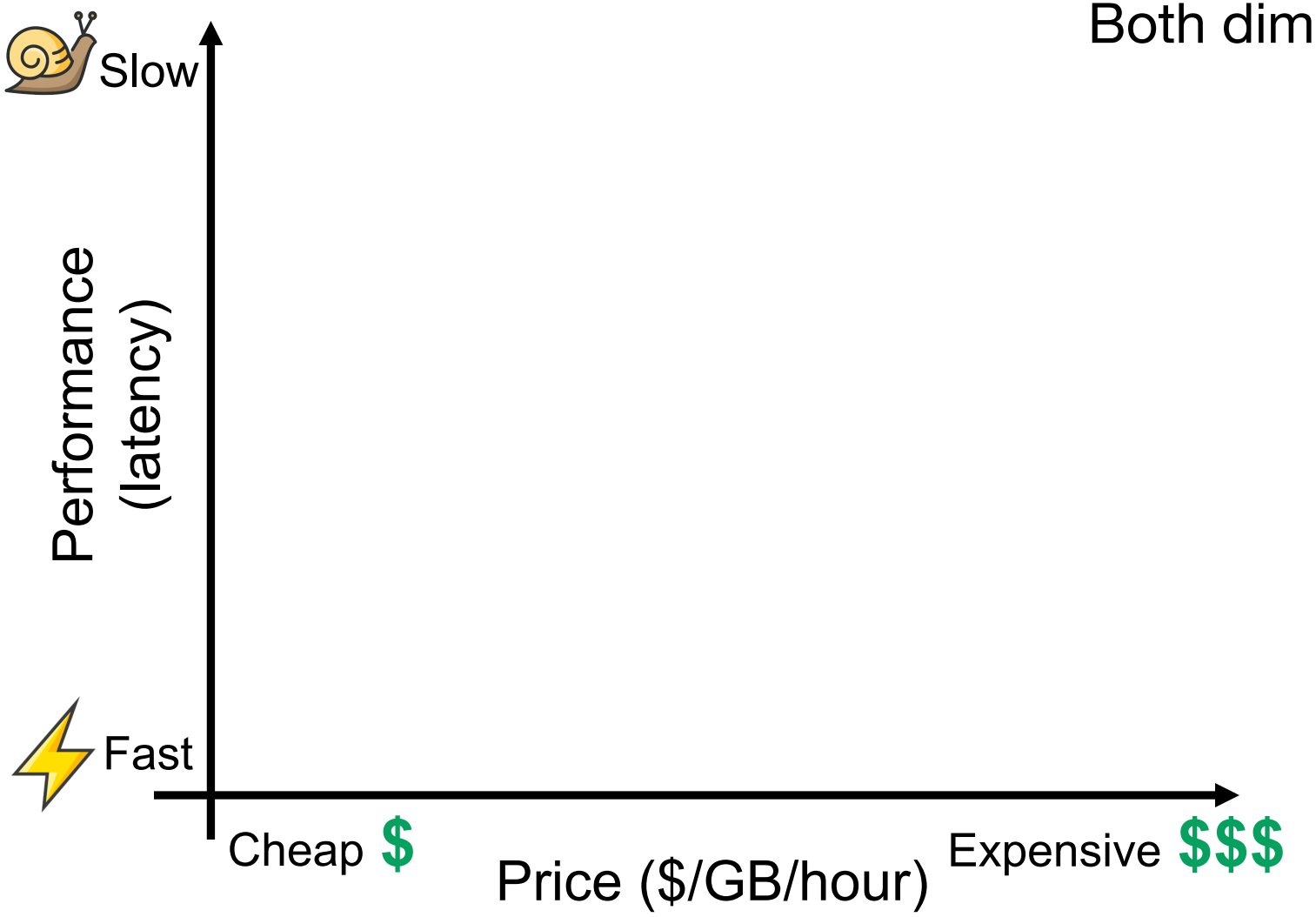
Extreme tension between small and large objects:

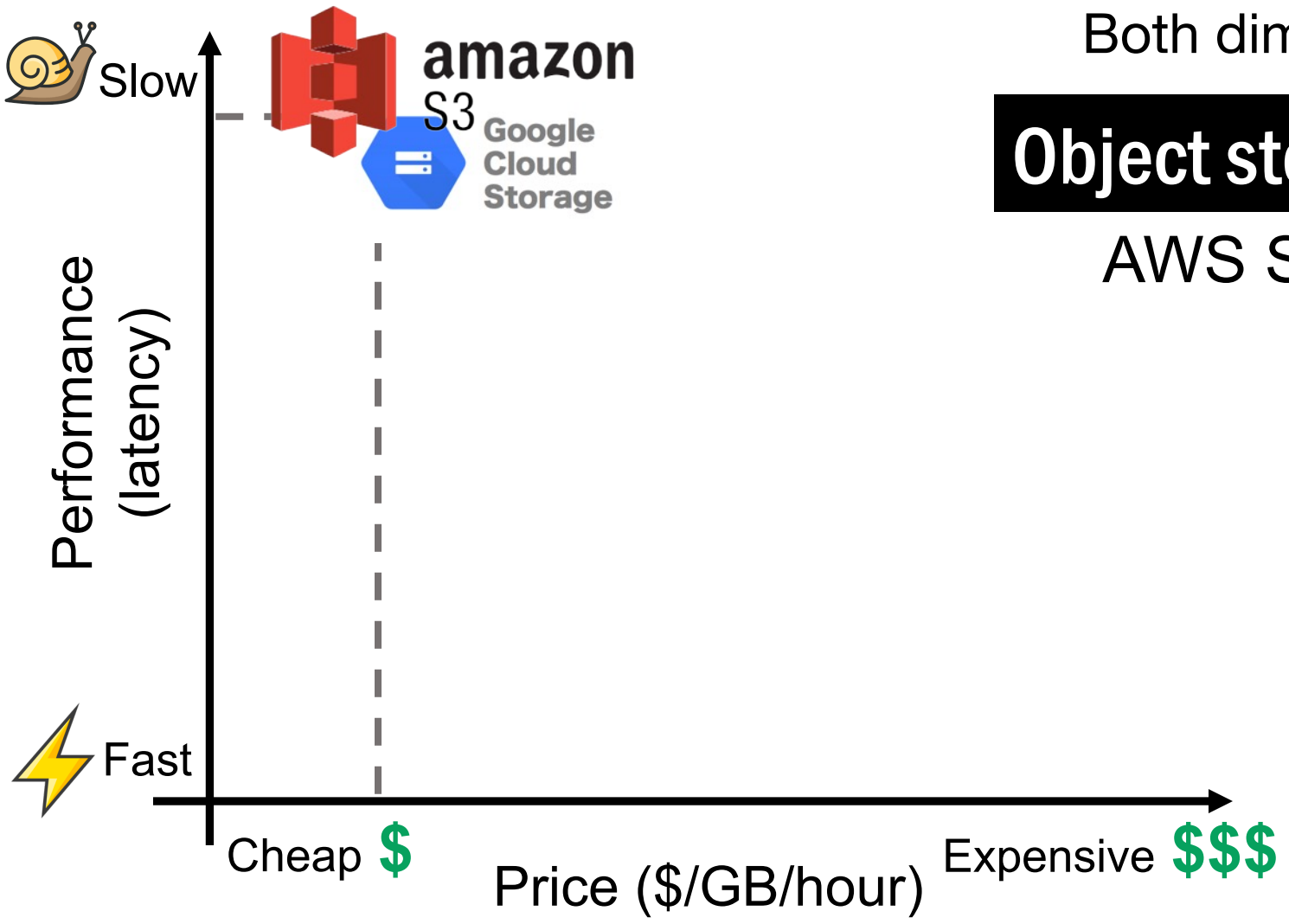
➢ Large objects (>10MB) occupy 95% storage footprint

# Existing cloud storage solutions

Both dimensions: the lower the better



# Large objects managed by cloud object stores

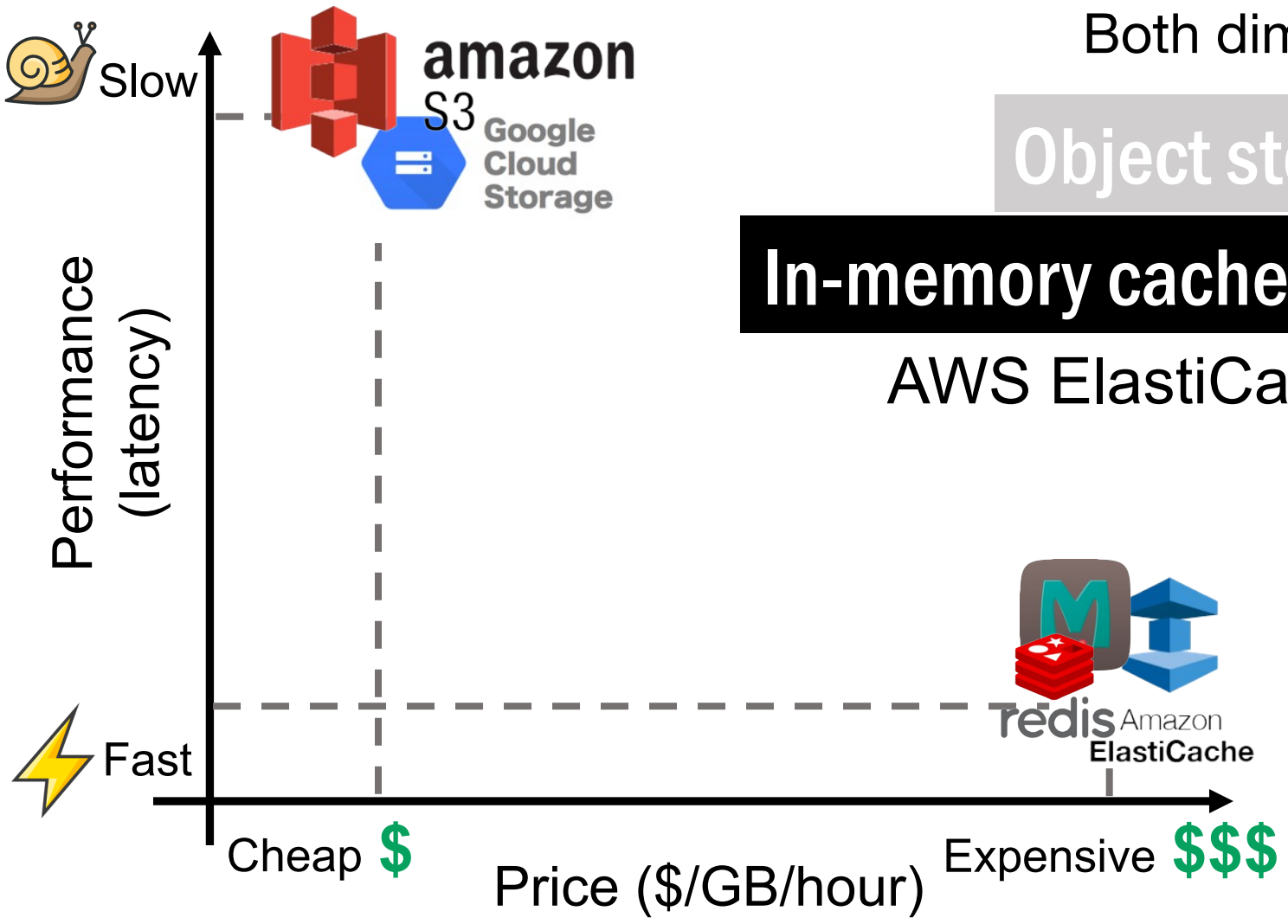



Both dimensions: the lower the better

**Object stores are cheap but too slow**

AWS S3: $0.023 per GB per month

# Small objects accelerated by in-memory caches



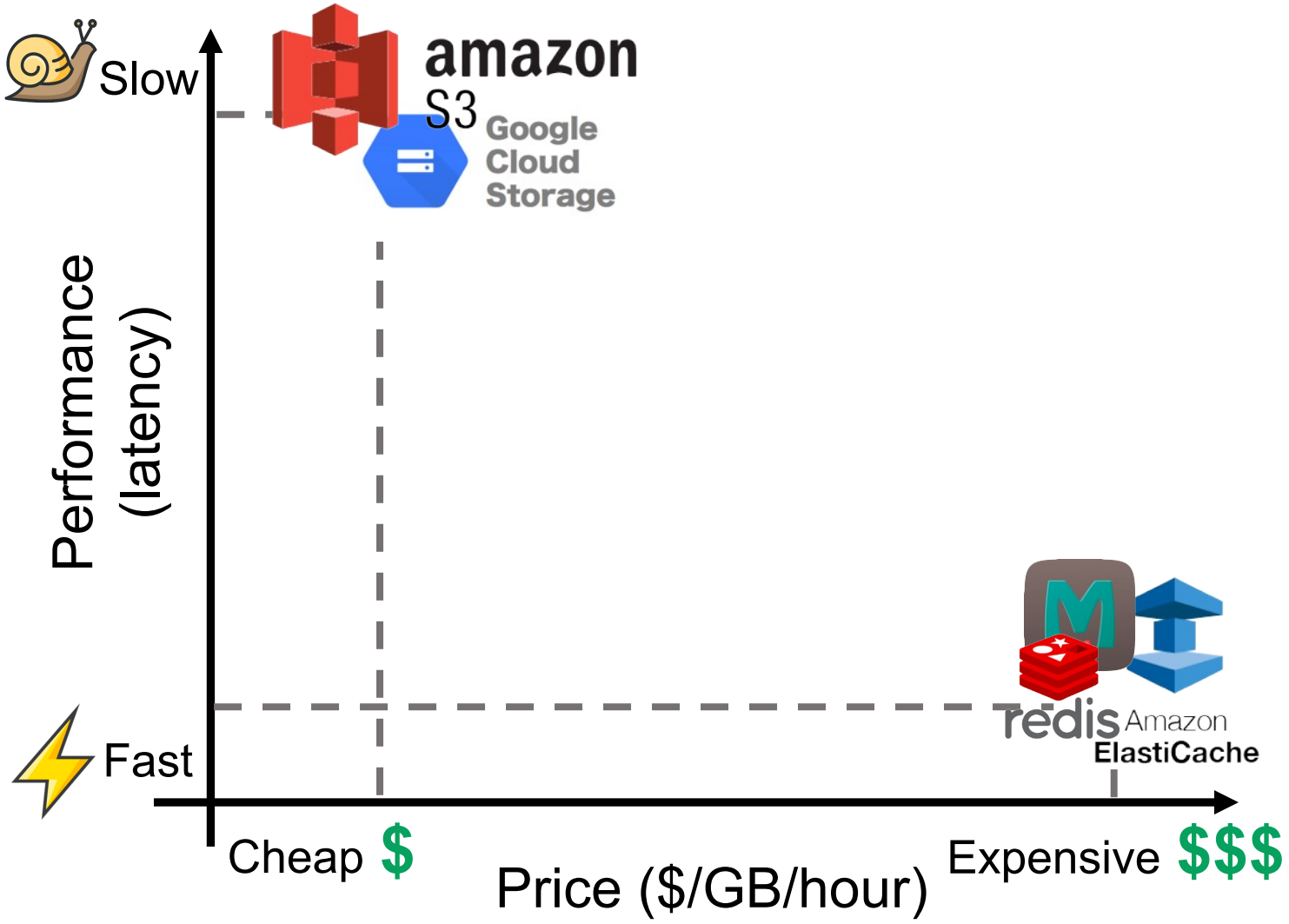

Both dimensions: the lower the better

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 are **either too slow or expensive**



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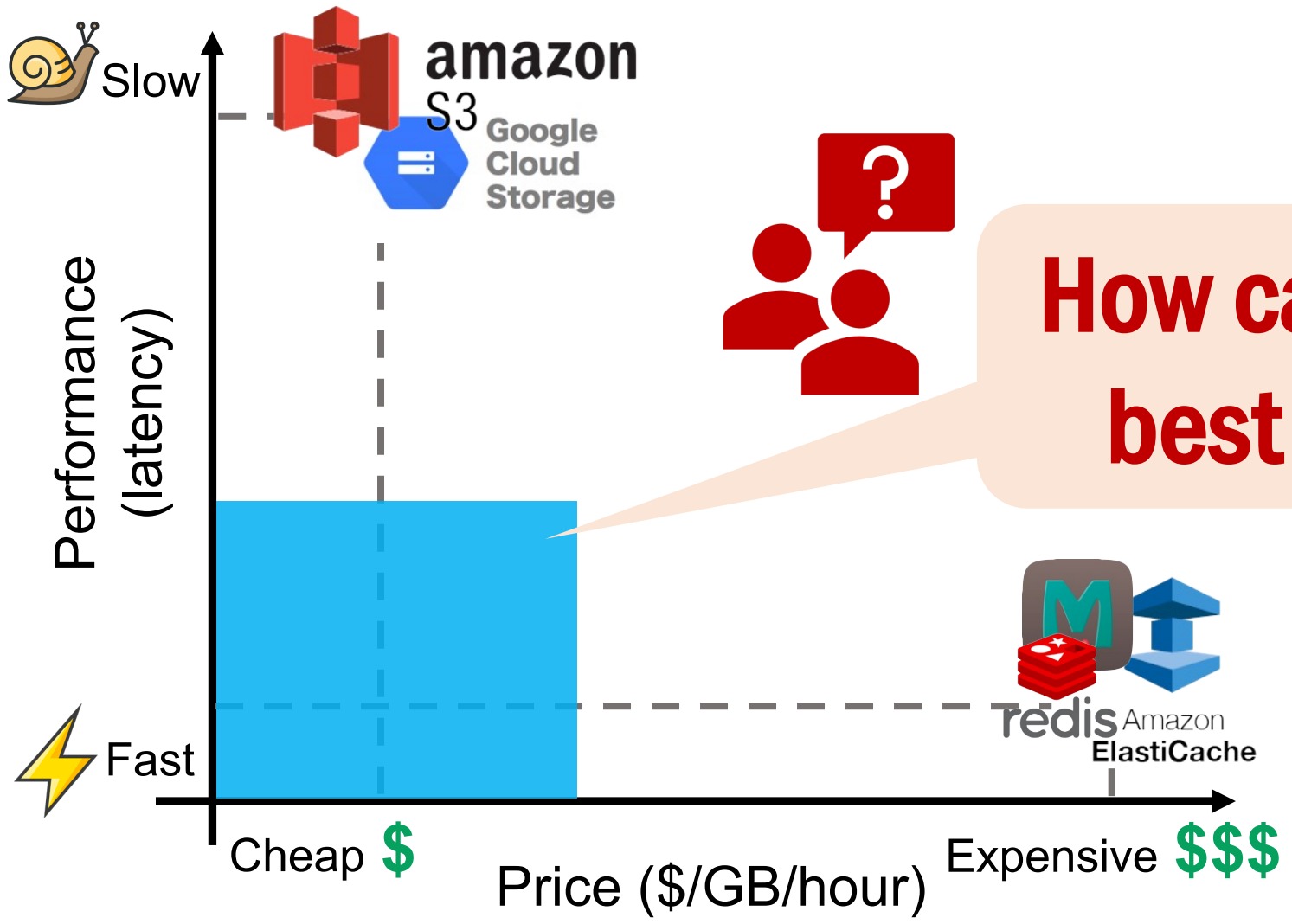



**How can we achieve the best of both worlds?**

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

***Requires rethinking about a new cloud cache/storage model that achieves both cost effectiveness and high-performance!***

# *InfiniCache: A cost-effective and high-performance in-memory caching solution atop Serverless Computing platform*

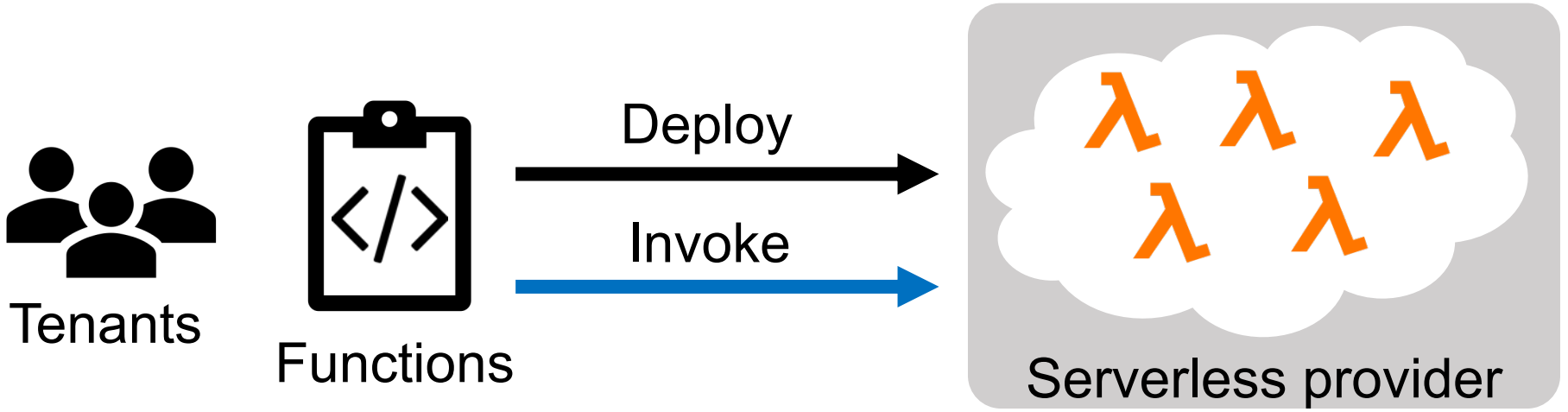
- **Insight #1:** Serverless functions' <CPU, Mem> resources are **pay-per-use**
- **Insight #2:** Serverless providers offer **"free"** function caching for tenants

# *InfiniCache: A cost-effective and high-performance in-memory caching solution atop Serverless Computing platform*

- **Insight #1:** Serverless functions' <CPU, Mem> resources are pay-per-use → **Cost-effectiveness**
- **Insight #2:** Serverless providers offer "free" function caching for tenants → **High-performance**

# 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

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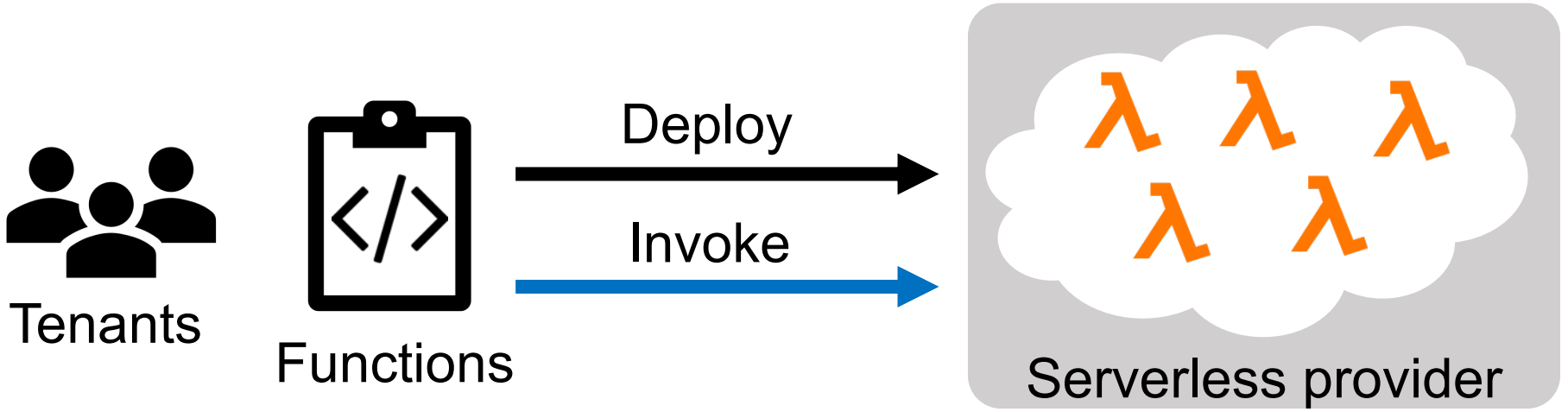
- Function: basic unit of deployment. Application consists of multiple serverless functions



# A primer on Serverless Computing

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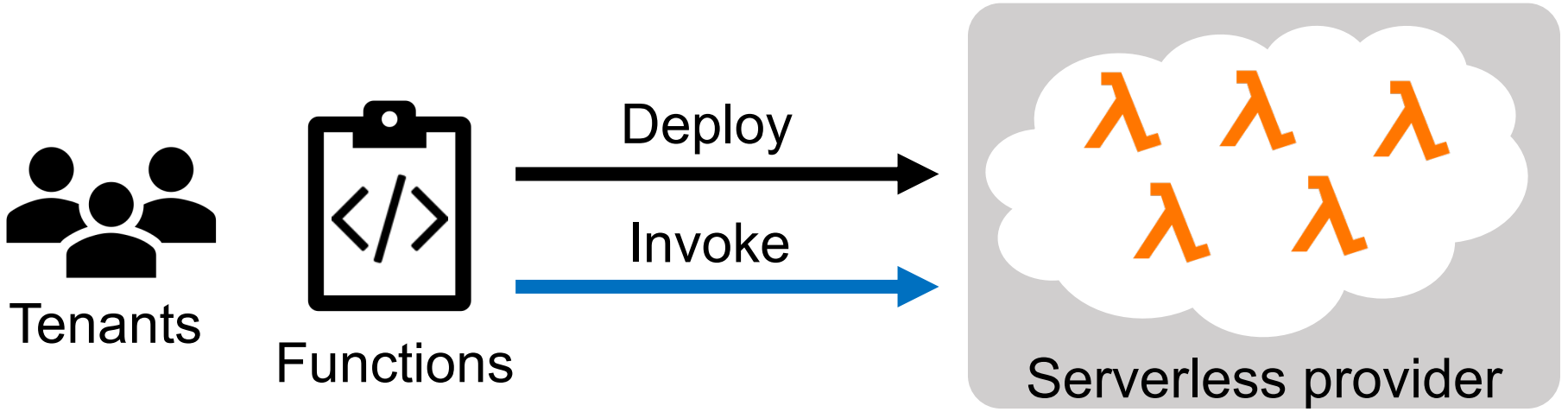
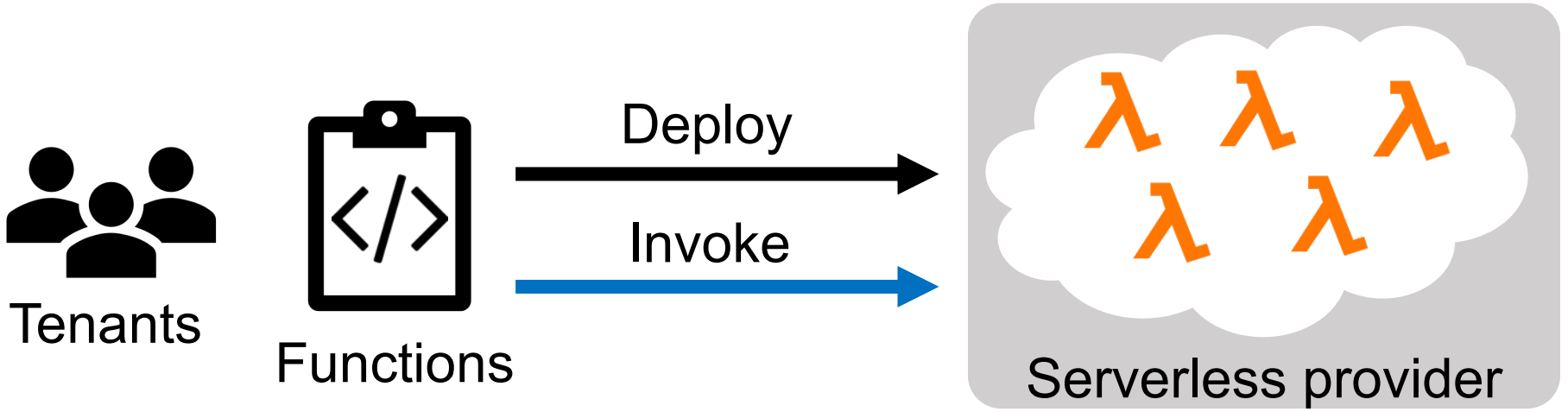
- Function: basic unit of deployment. Application consists of multiple serverless functions
- Popular use cases: data processing, cron, …



# Serverless Computing is desirable

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



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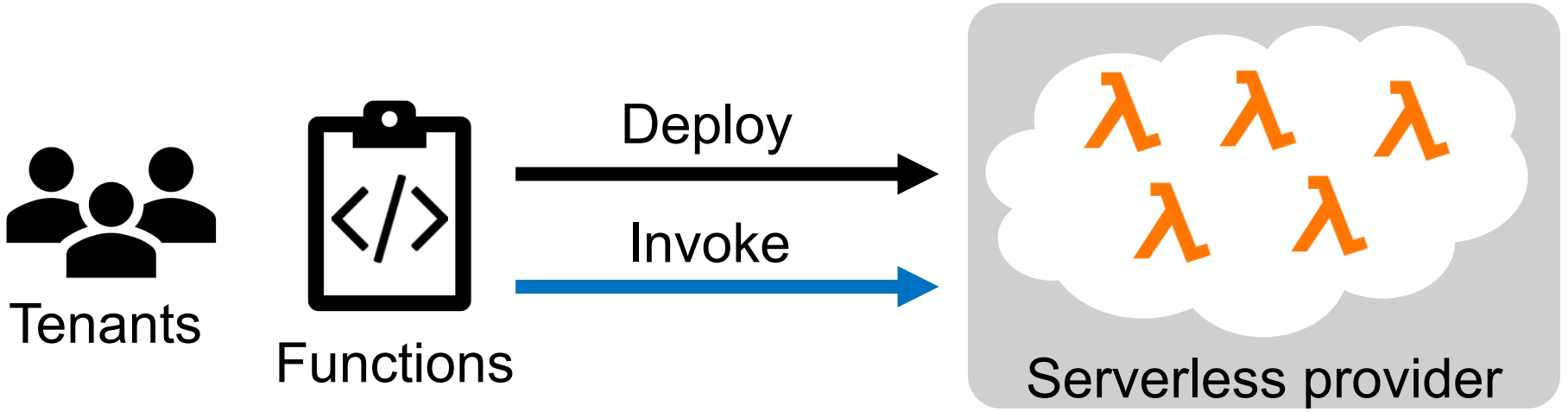
  - Provider caches triggered functions in memory without charging tenants



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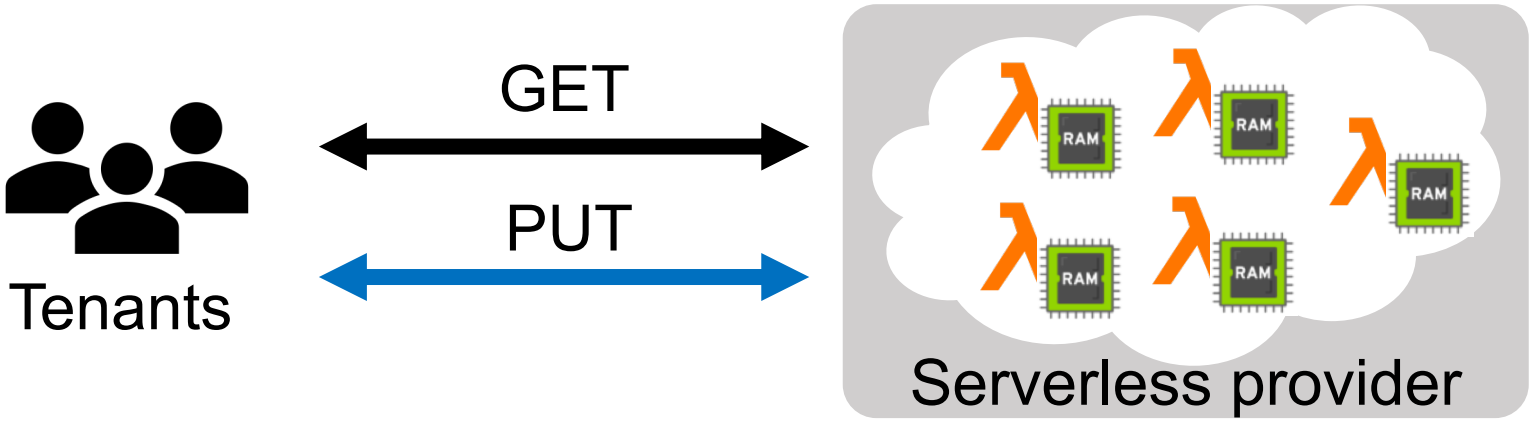
**Goal: Exploit the serverless computing model to build a cost-effective, high-performance in-memory cache**



# Challenges: to build a memory cache with serverless functions

- A strawman proposal
  - Directly cache the objects in serverless functions' memory?

- Cannot guarantee data availability

- Banned inbound network

- Limited per-function resources

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- No data availability guarantee

- Banned inbound network

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⚠ Serverless functions could be reclaimed any time

⚠ In-memory state is lost

# Challenges: to build a memory cache with serverless functions

- A strawman proposal
  - Directly cache the objects in serverless functions' memory?
- No data availability guarantee
- Banned inbound network
- Limited per-function resources

⚠ Serverless functions cannot run as a server

# Challenges: to build a memory cache with serverless functions

- A strawman proposal
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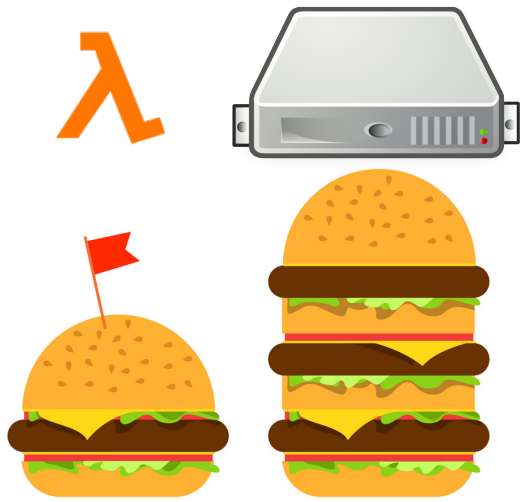
⚠ Memory up to 3 GB

⚠ CPU up to 2 cores



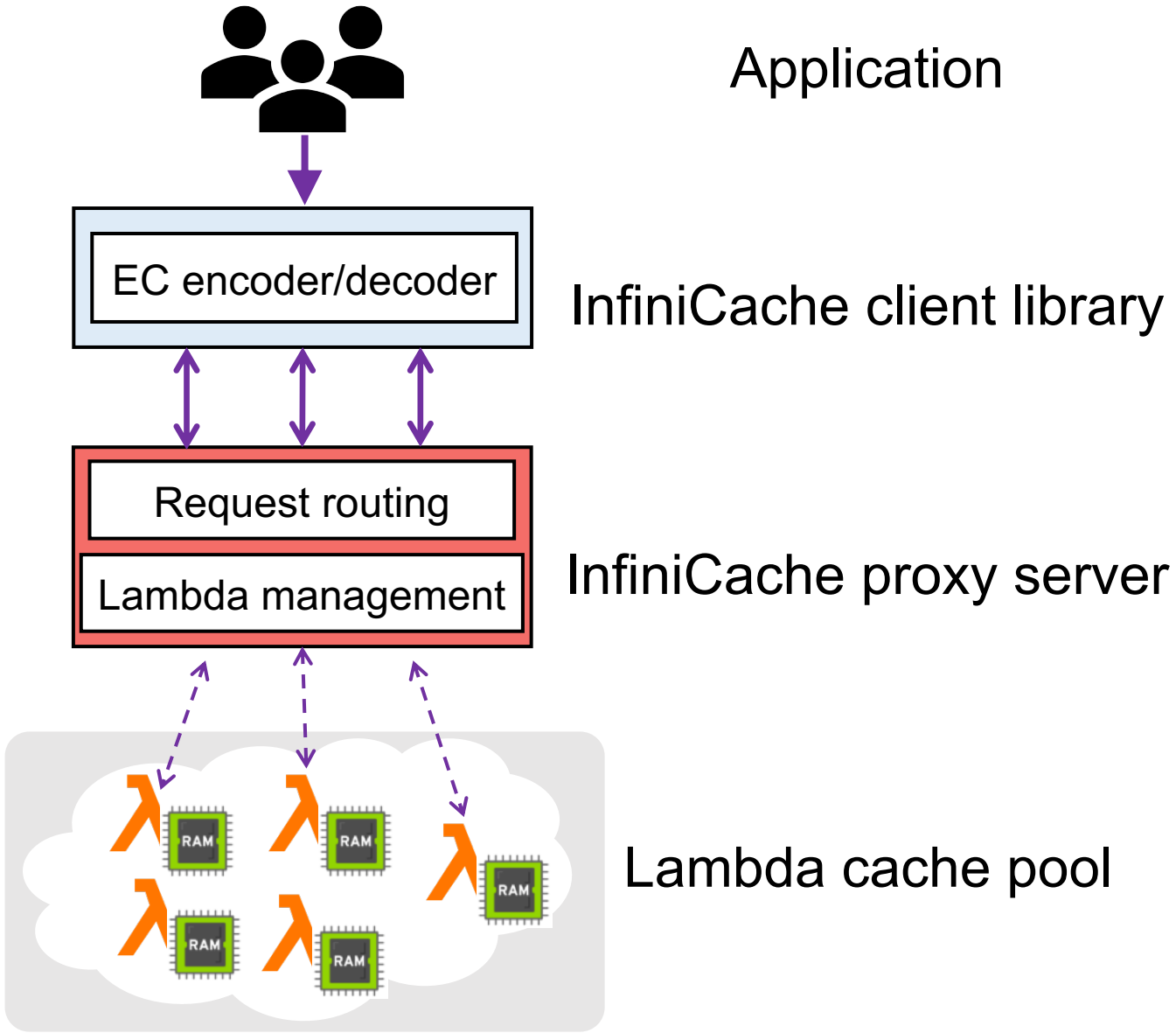
# Our contribution: InfiniCache

- **The first in-memory cache system built atop serverless functions**
- InfiniCache achieves high data availability by leveraging 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

# Outline

- InfiniCache Design
- Evaluation
- Conclusion

# InfiniCache bird's eye view



# InfiniCache: PUT path

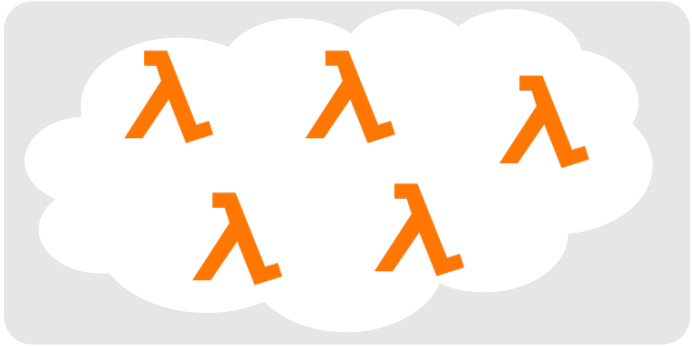
Application

EC encoder

InfiniCache client library

Request routing

InfiniCache proxy




Lambda cache pool

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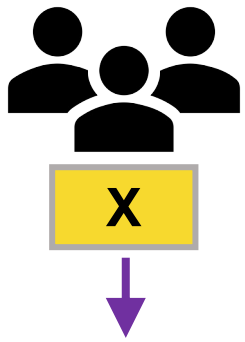


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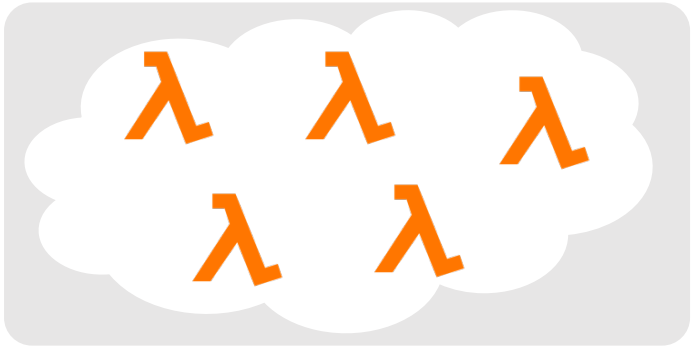

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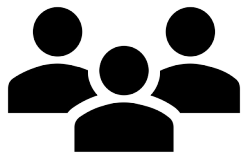
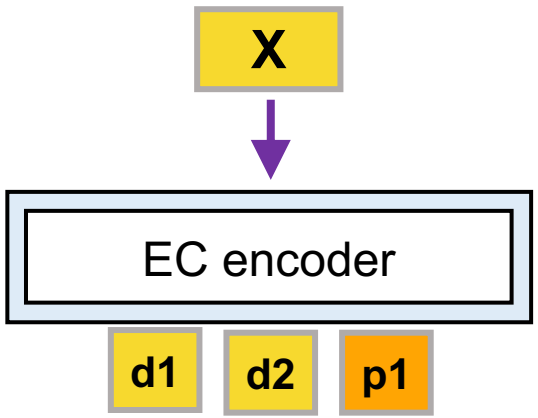


Application

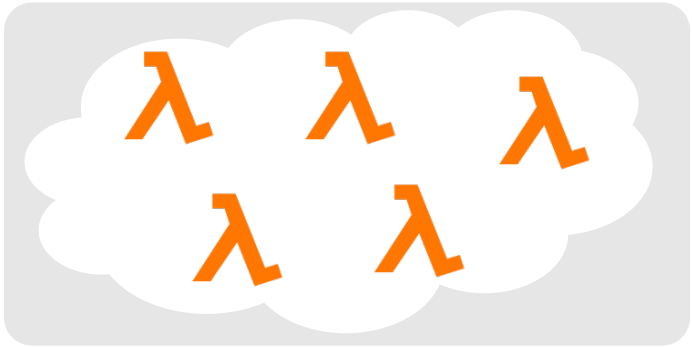
1. Object is split and encoded into k+r chunks




**InfiniCache client library**

k = 2, r = 1

InfiniCache proxy



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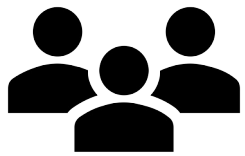
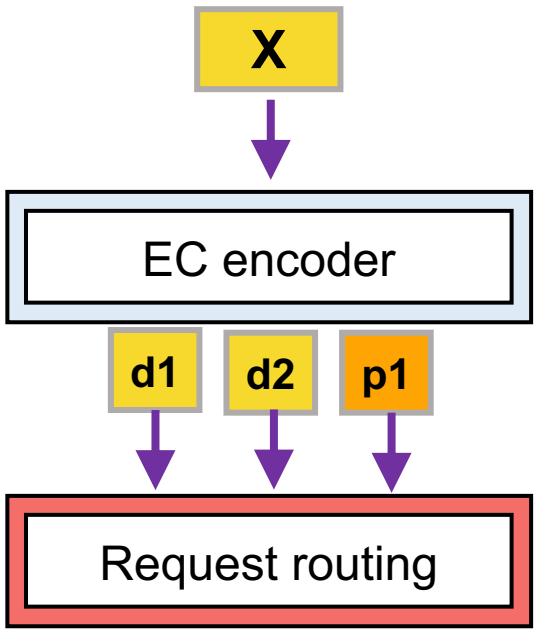


Application

1. Object split and encode into k+r chunks
2. Object chunks are sent to the proxy in parallel

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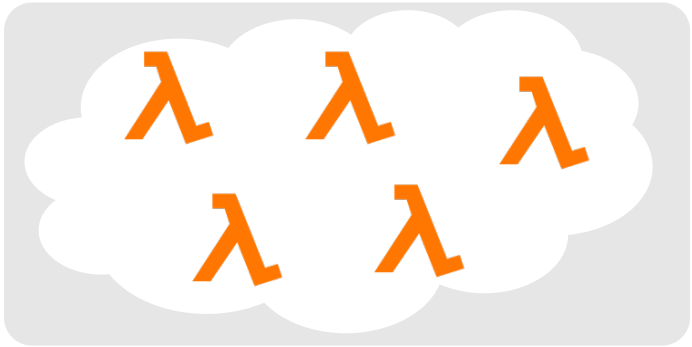


Lambda cache pool

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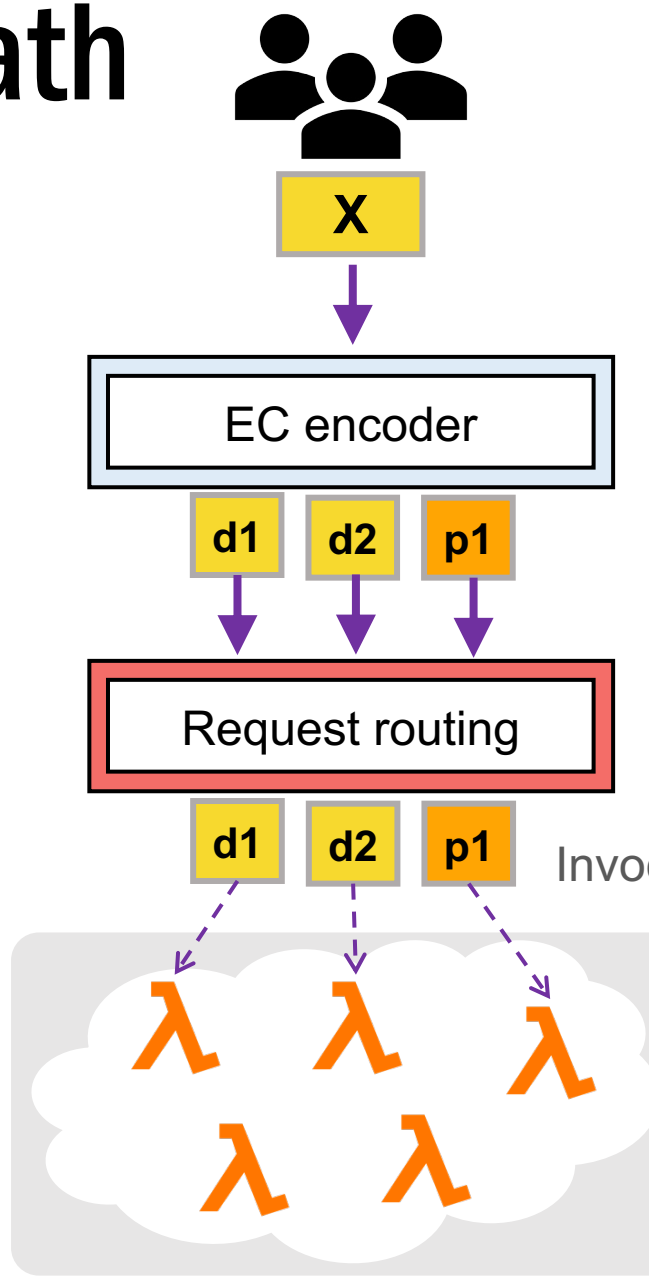


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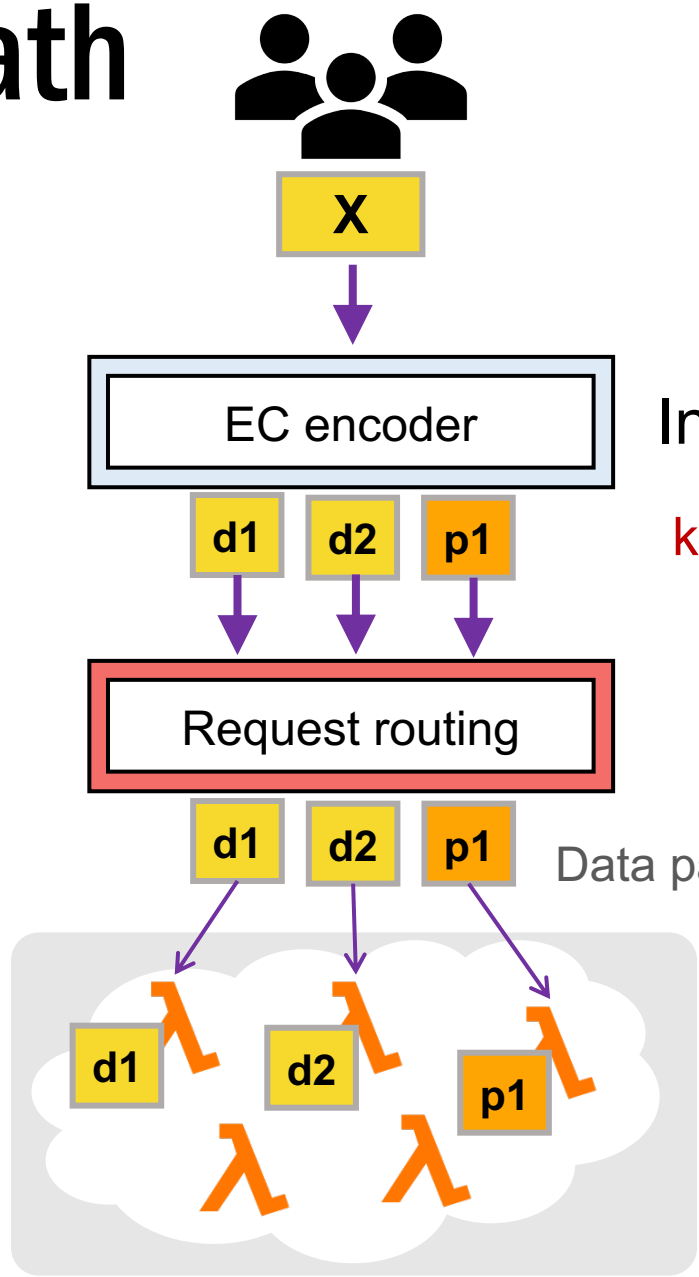

# InfiniCache: GET path

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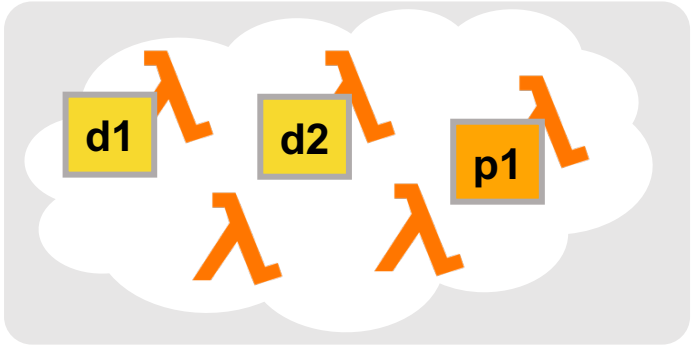
EC decoder

InfiniCache client library

Request routing

InfiniCache proxy

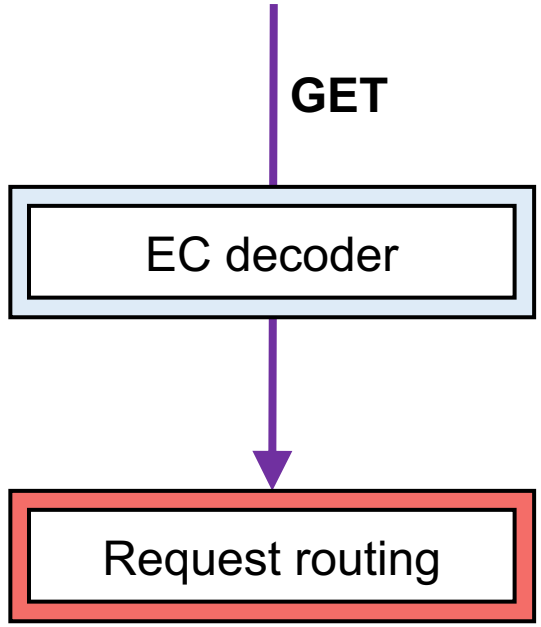



Lambda cache pool

# InfiniCache: GET path

1. Client sends GET request

**Application**

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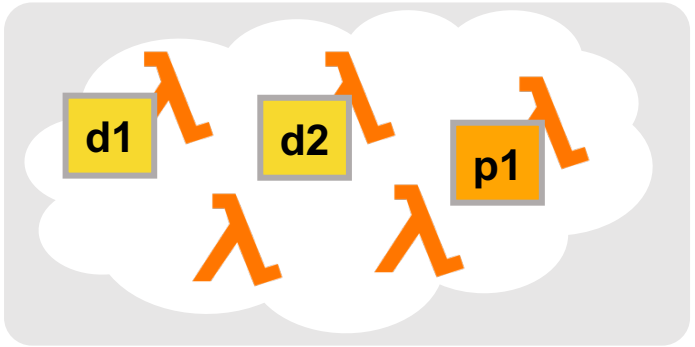


Lambda cache pool

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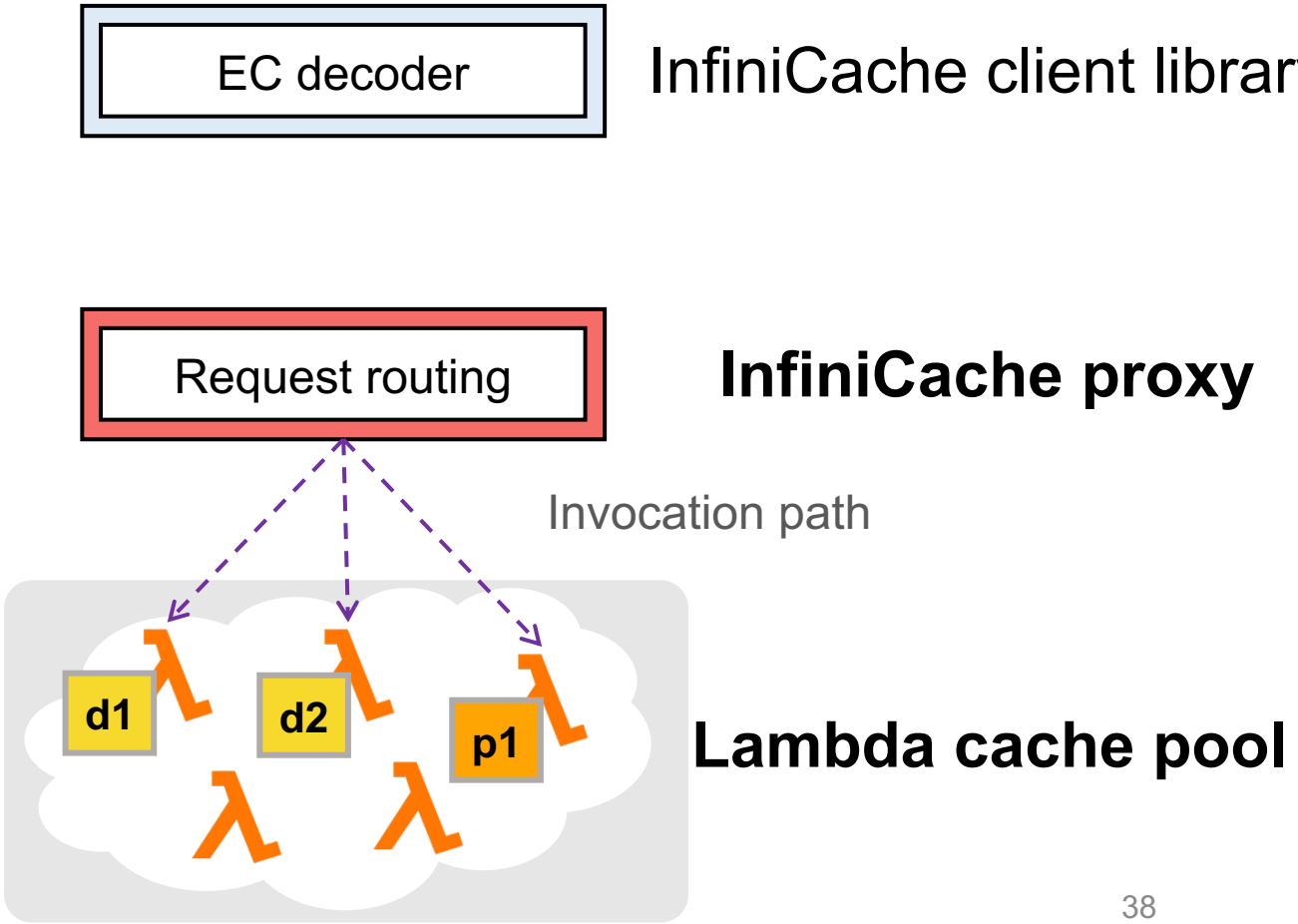

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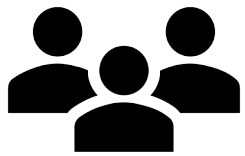

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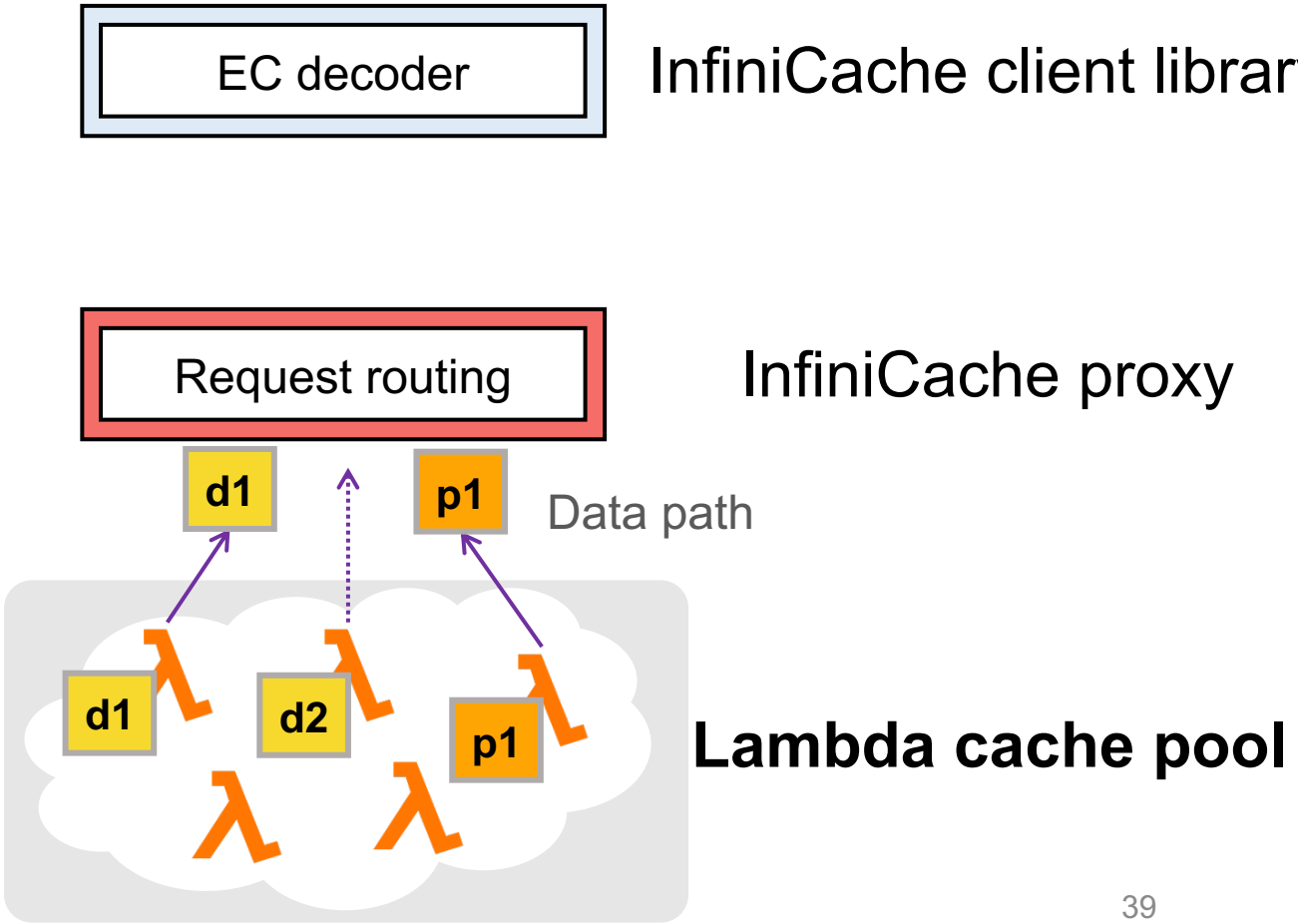

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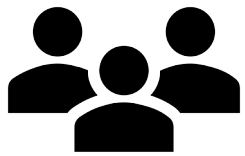

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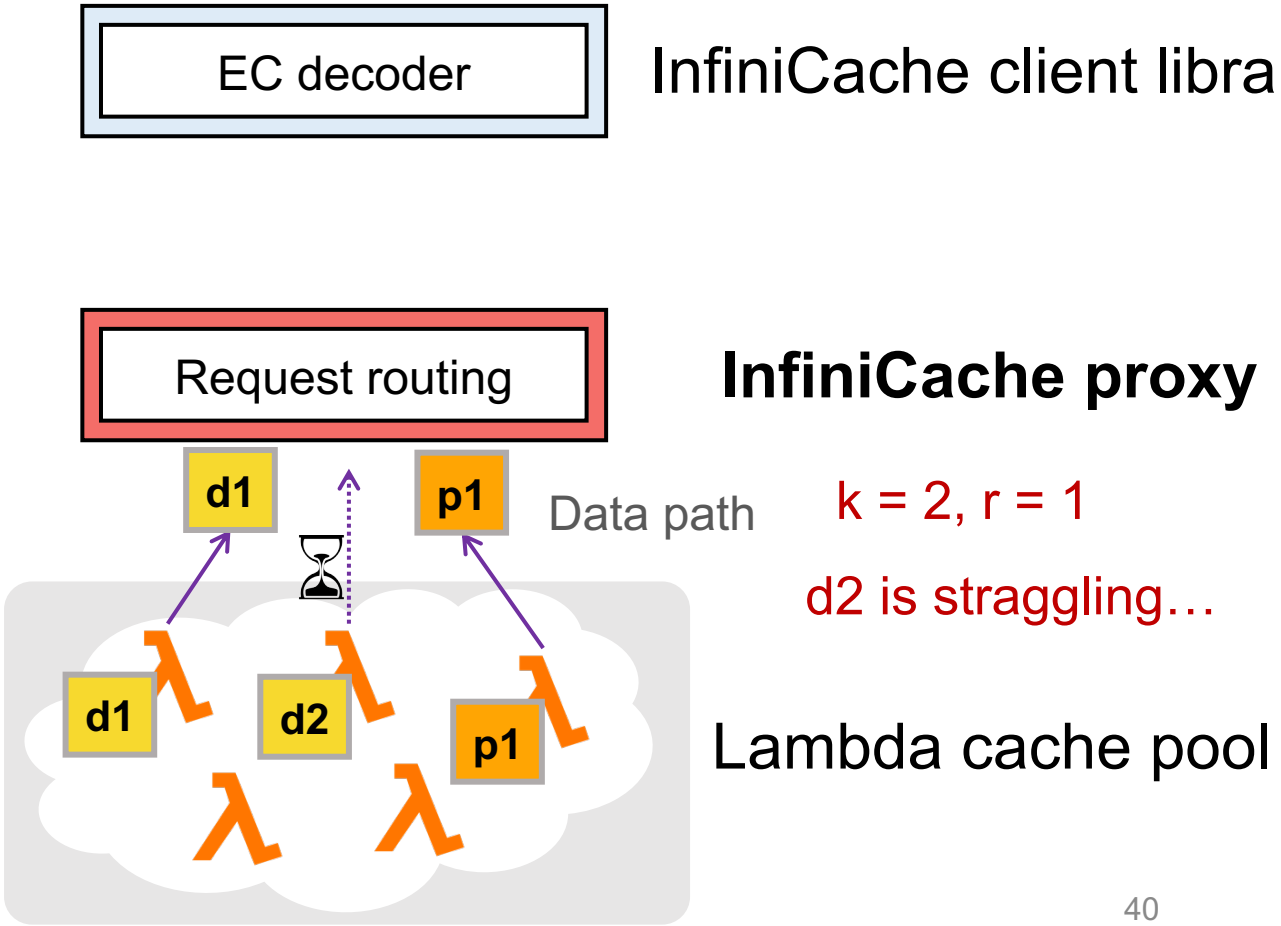
   - **First-d optimization:** Proxy drops straggler Lambda



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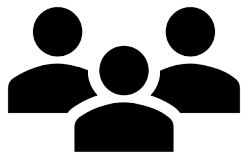

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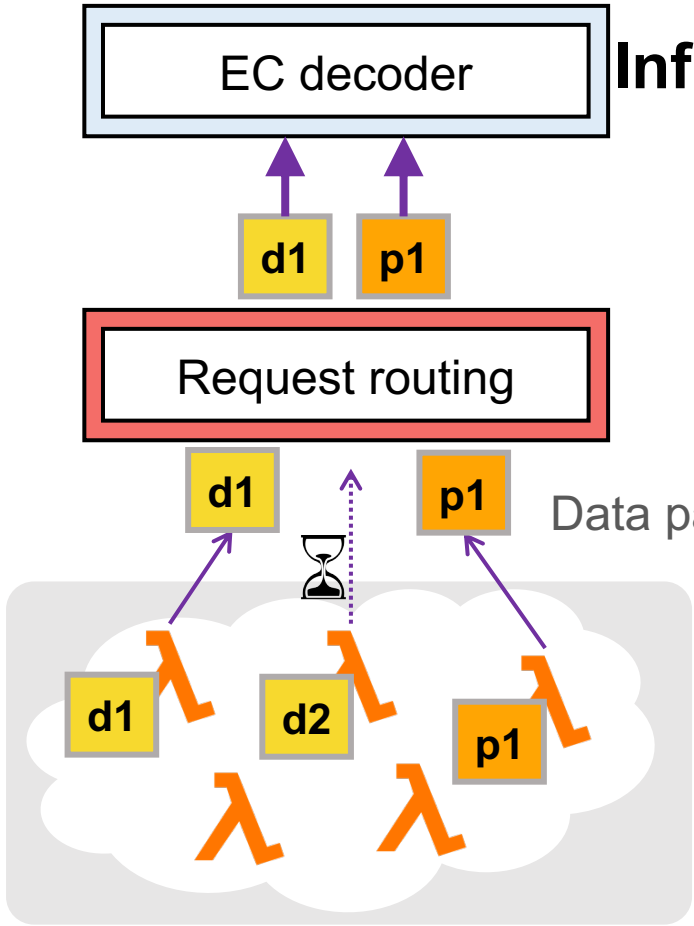


**InfiniCache client library**

k = 2 chunks

**InfiniCache proxy**

k = 2, r = 1

d2 is straggling…

Lambda cache pool

# InfiniCache: GET path

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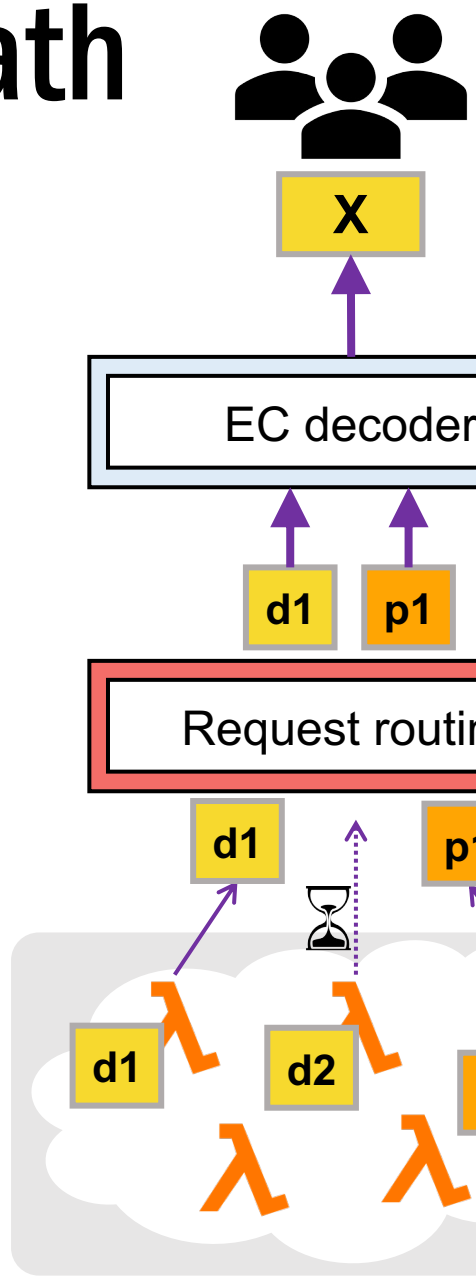
5. Client library decodes k chunks

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Data path

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# Maximizing data availability

- Erasure-coding
- Periodic warm-up
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# Maximizing data availability: Periodic warm-up

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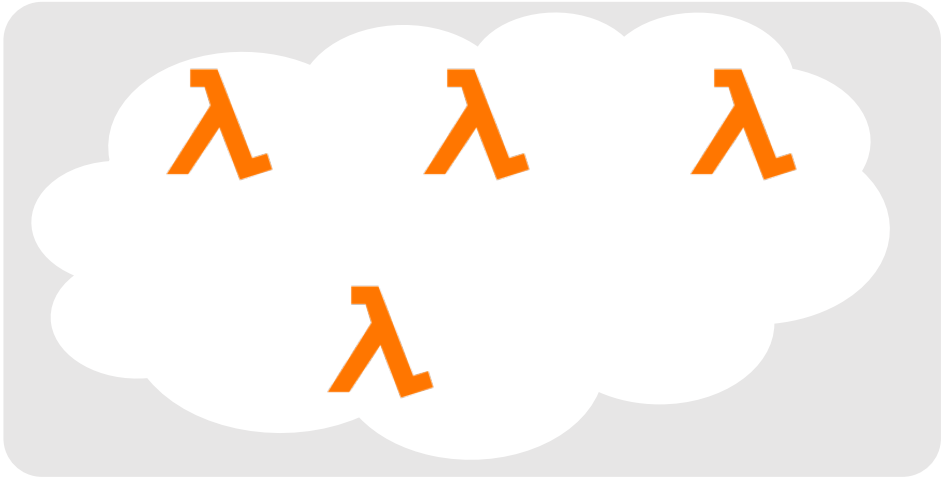

# Maximizing data availability: Periodic warm-up

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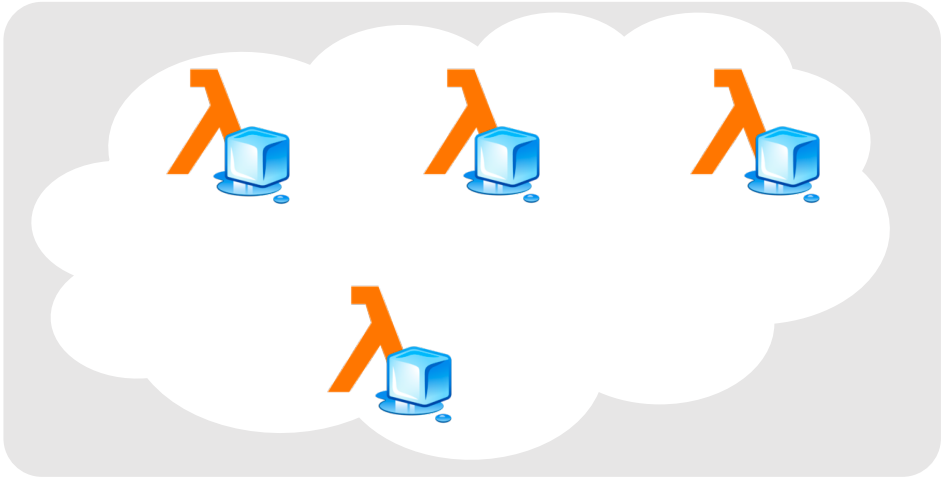

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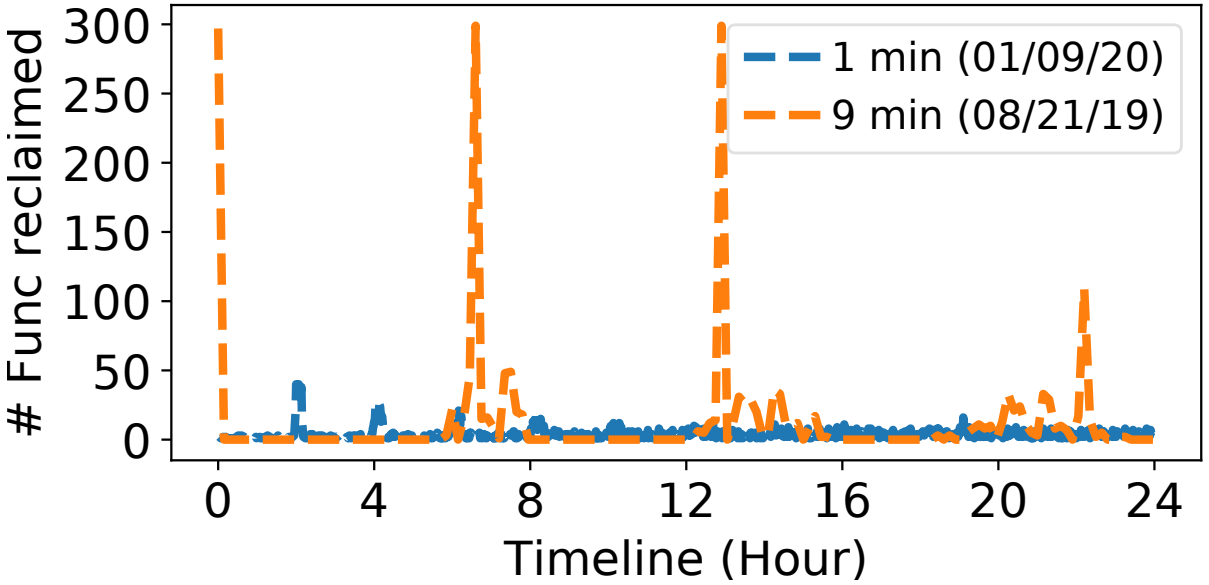



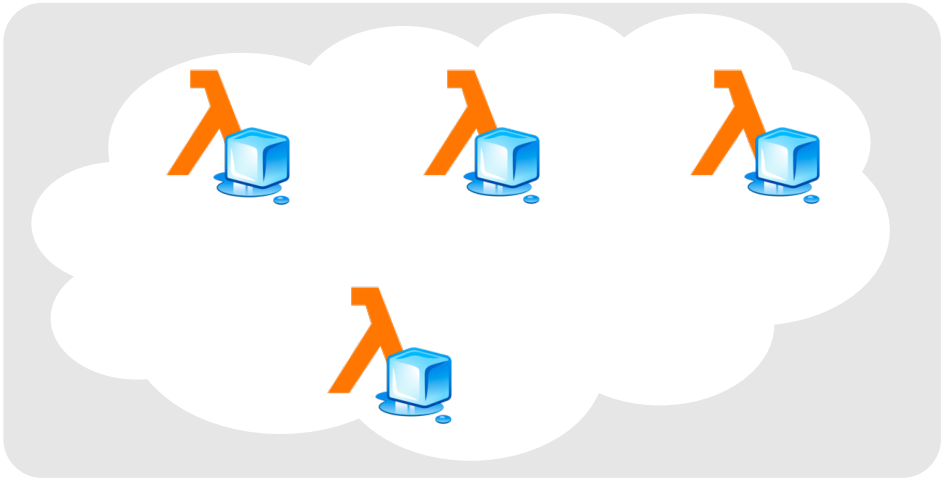

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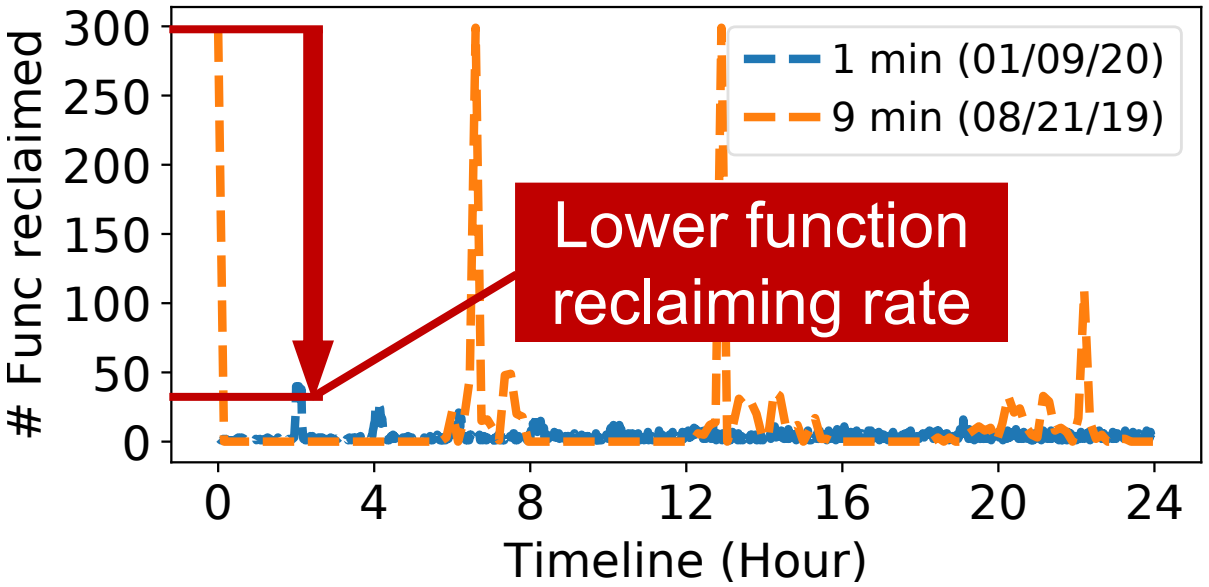
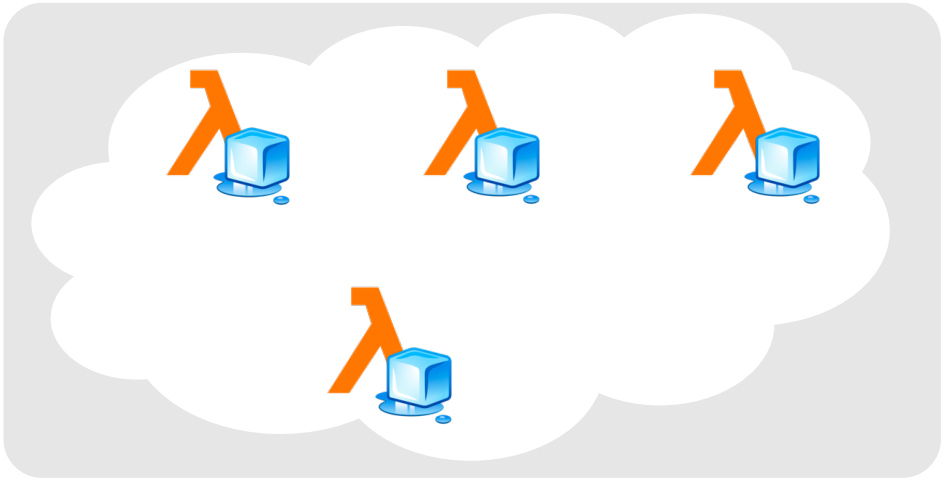


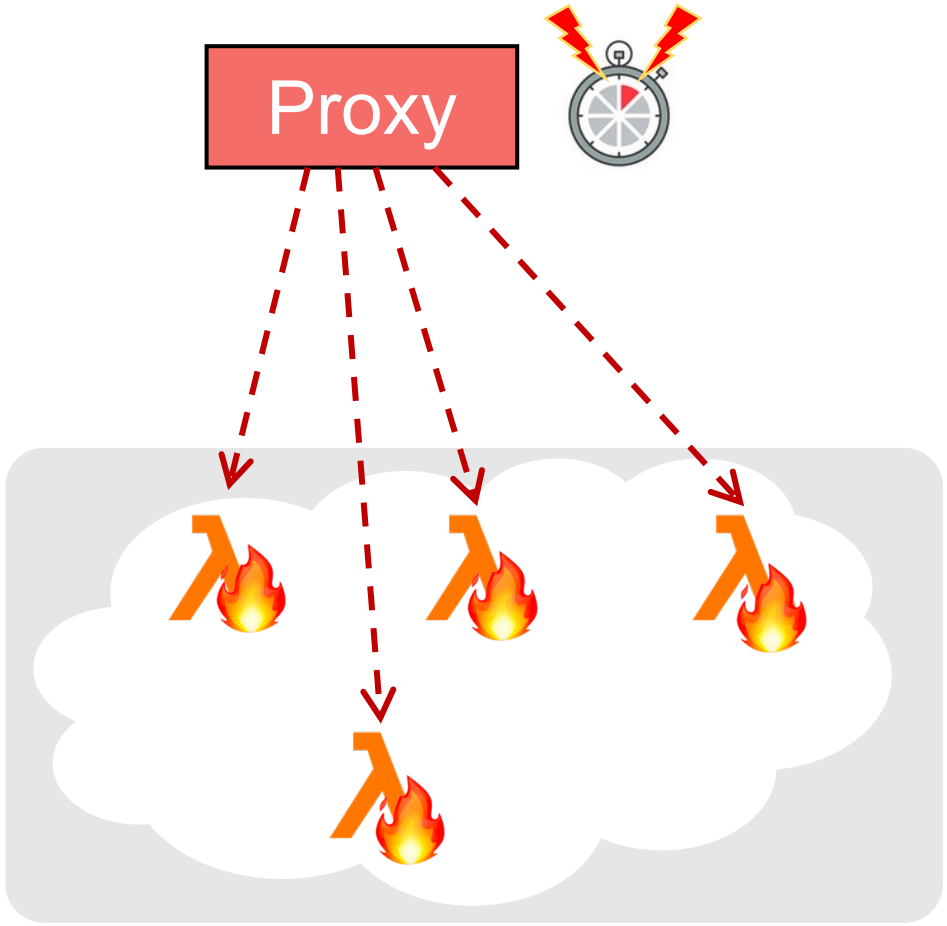




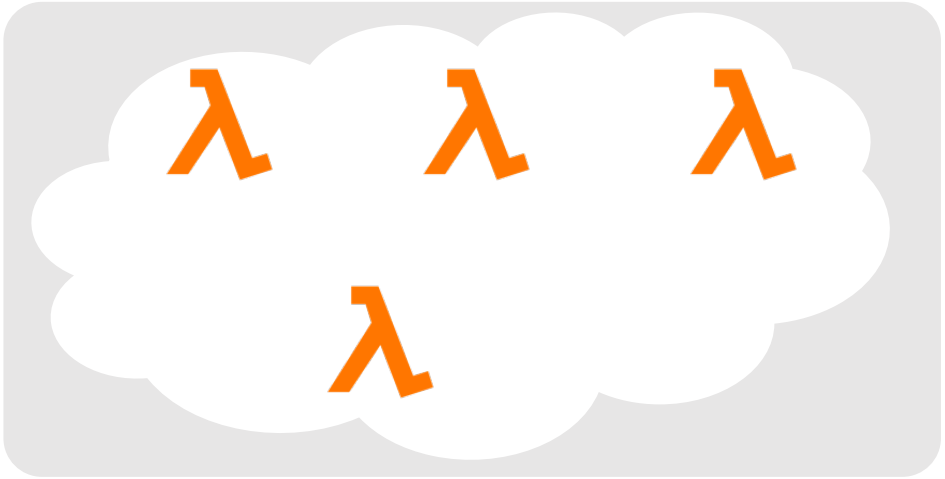
# Maximizing data availability: Periodic warm-up

1. Lambda nodes are cached by AWS when not running

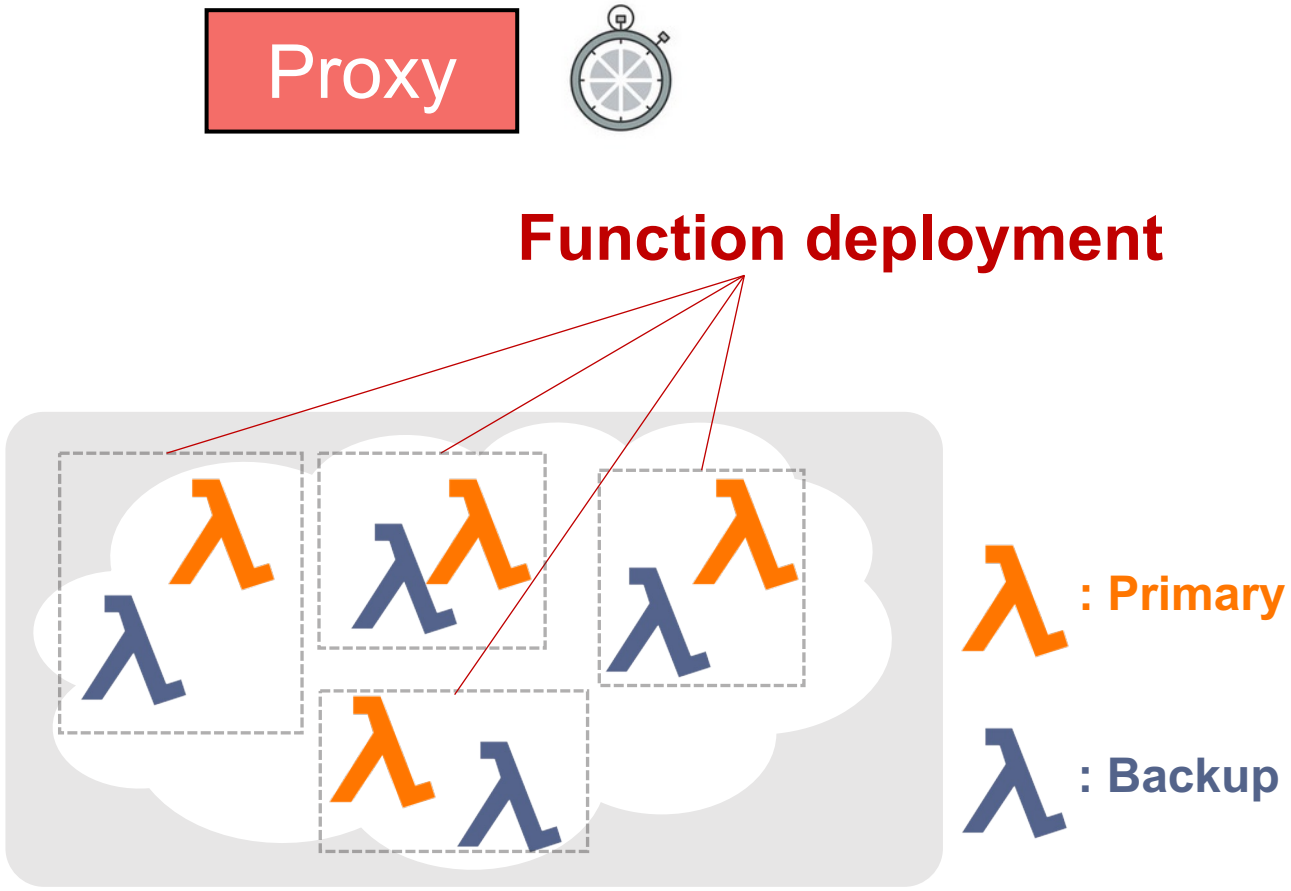
2. Proxy periodically invokes sleeping Lambda cache nodes to extend their lifespan



# Maximizing data availability: Periodic backup

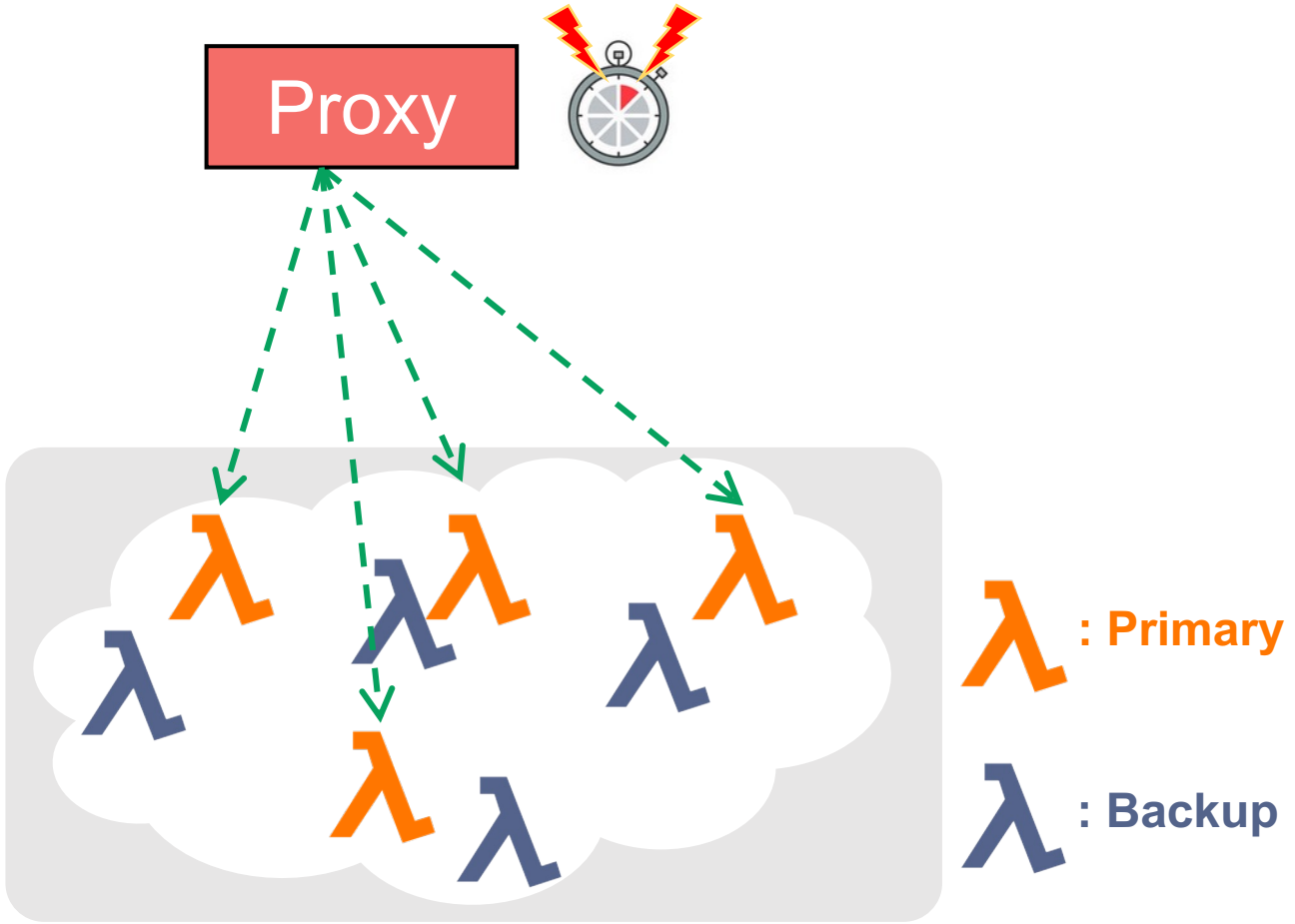



# Maximizing data availability: Periodic backup



# Maximizing data availability: Periodic backup

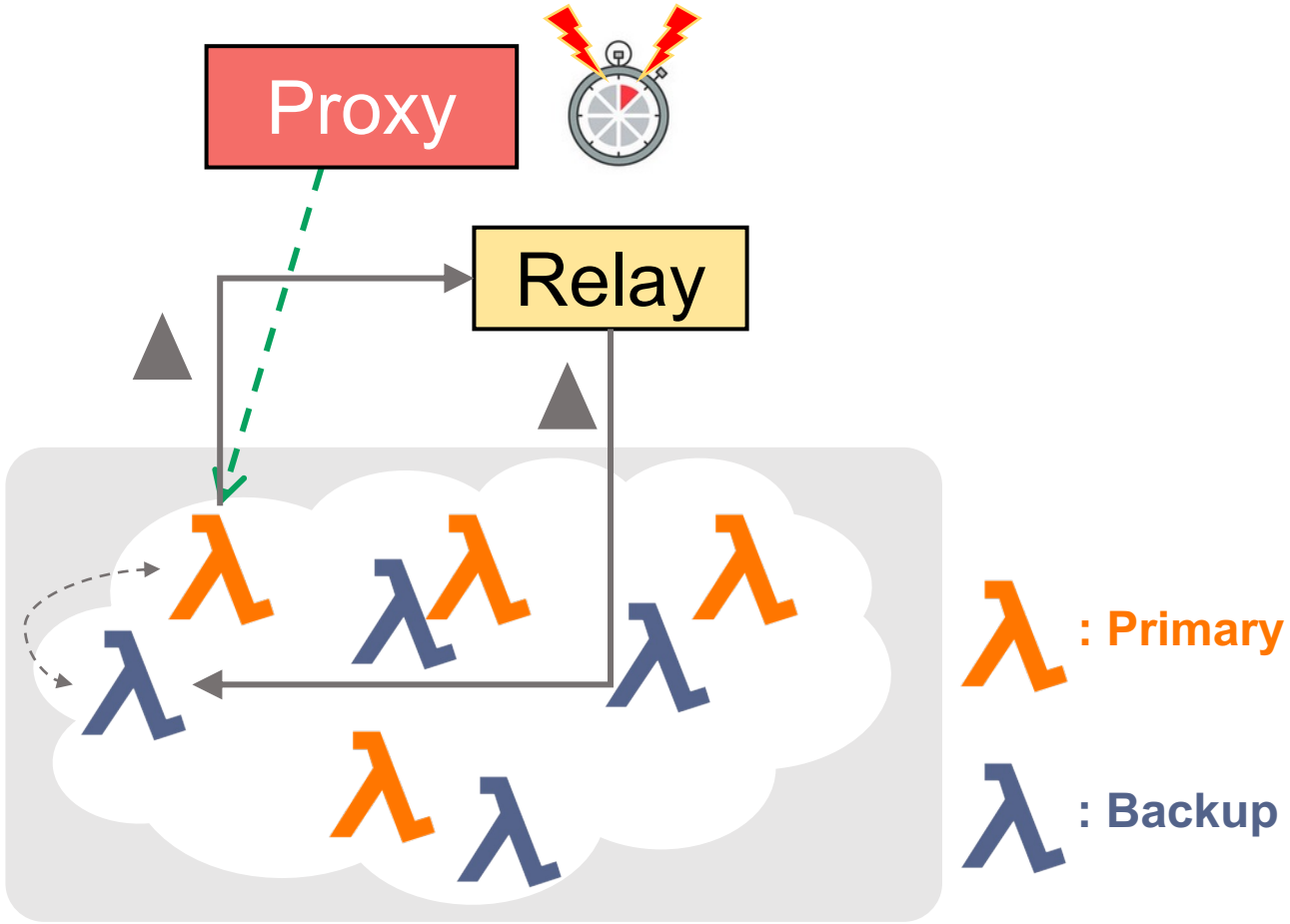
1. Proxy periodically sends out backup commands to Lambda cache nodes



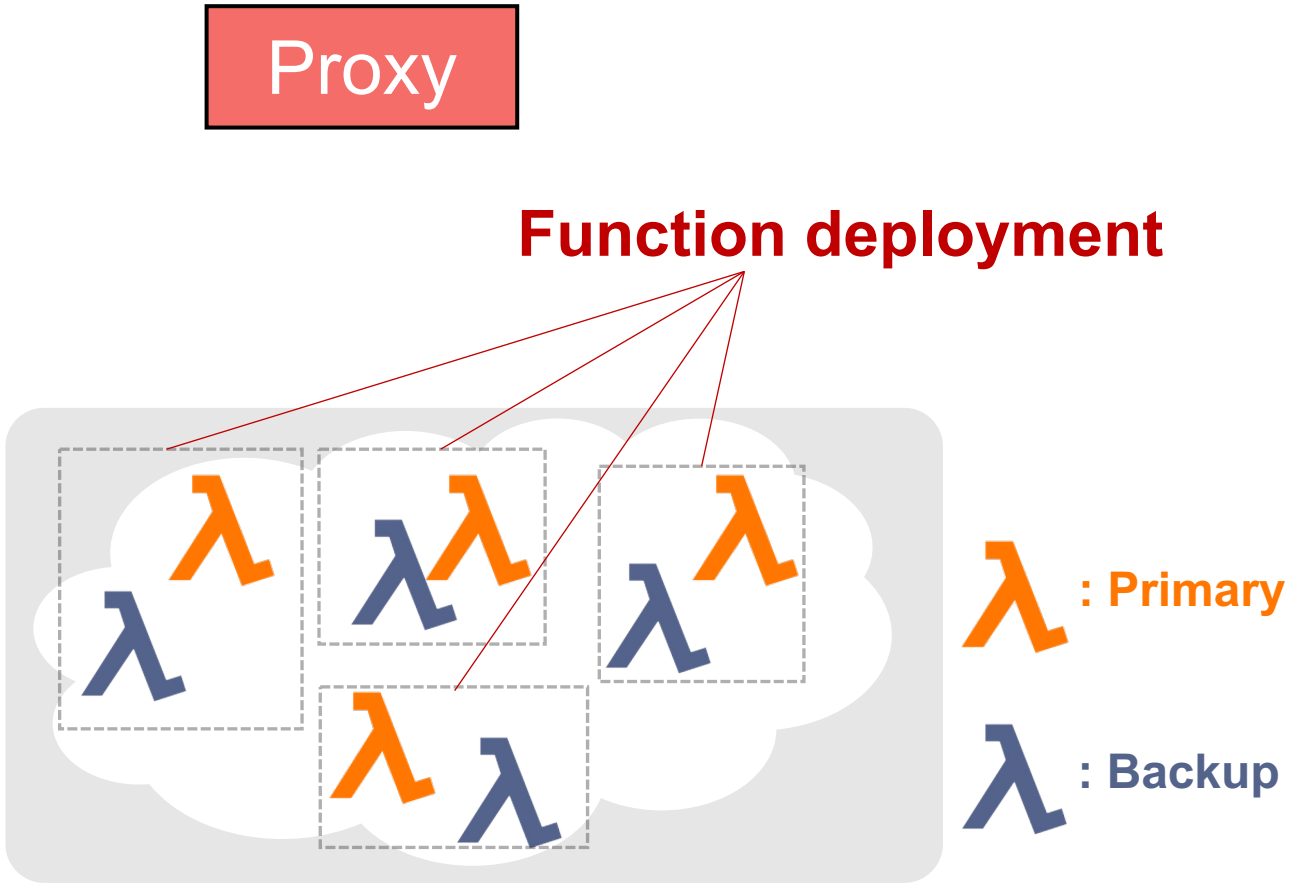
# Maximizing data availability: Periodic backup

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

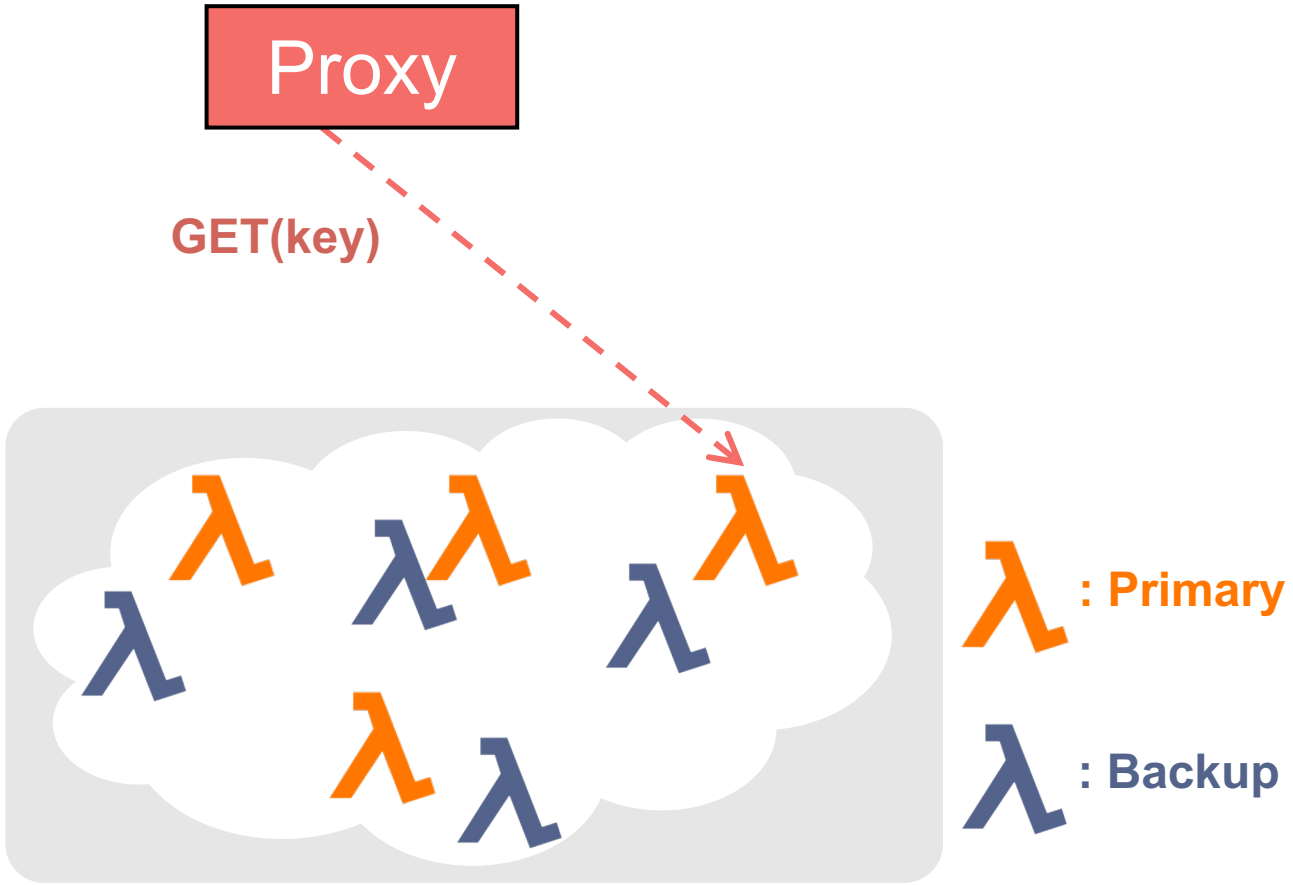


# Seamless failover



# Maximizing data availability: Seamless failover

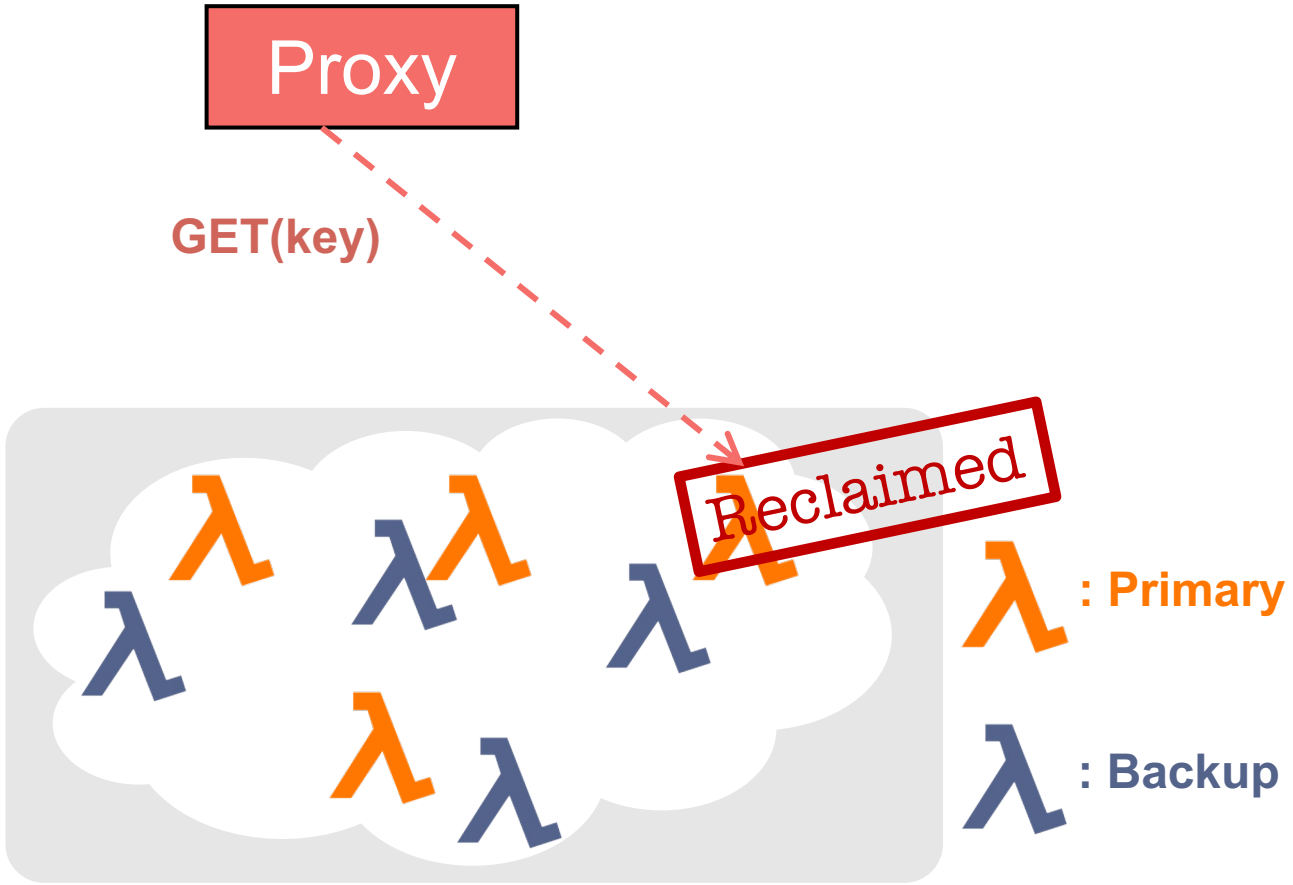
1. Proxy invokes a Lambda cache node with a GET request



# Maximizing data availability: Seamless failover

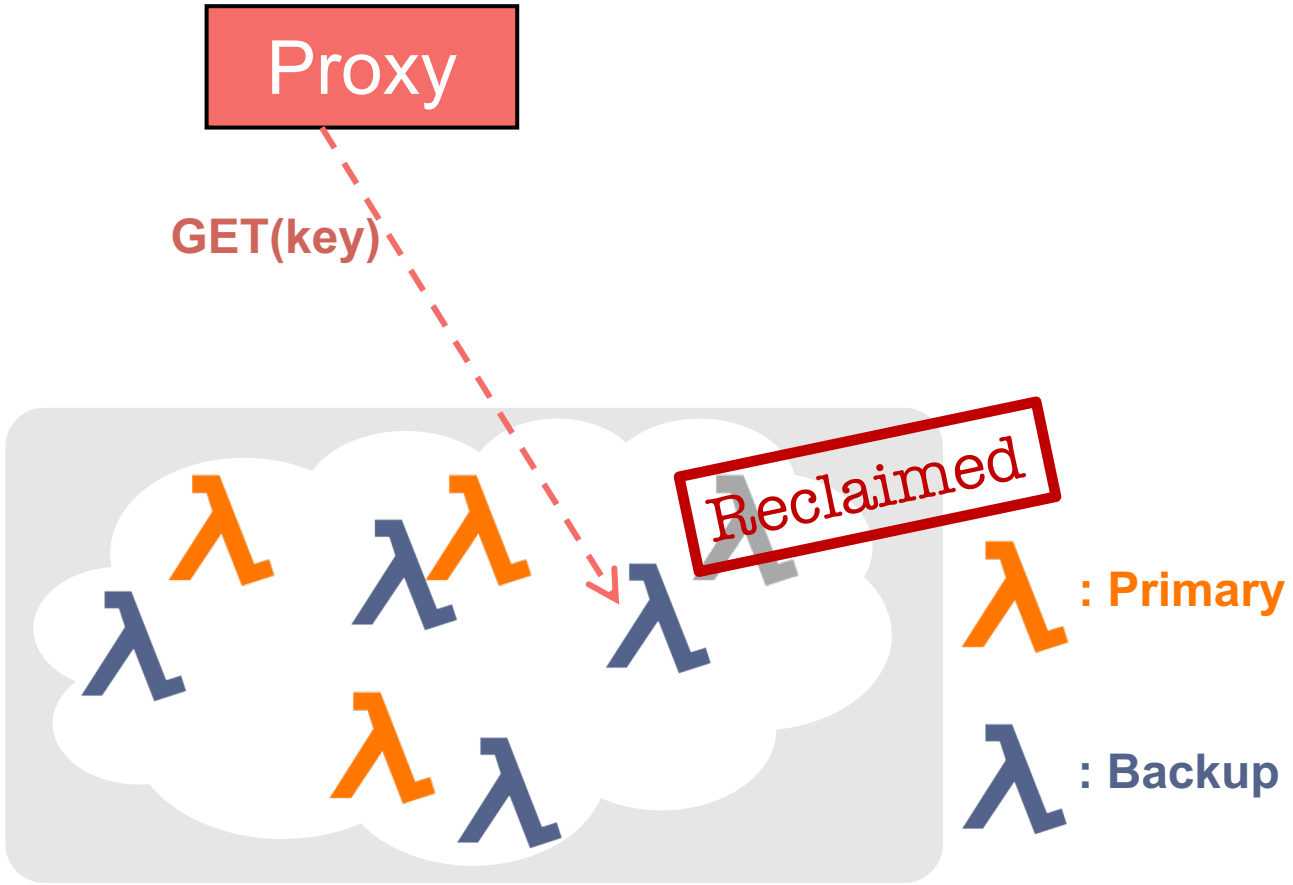
1. Proxy invokes a Lambda cache node with a GET request

2. Source Lambda gets reclaimed



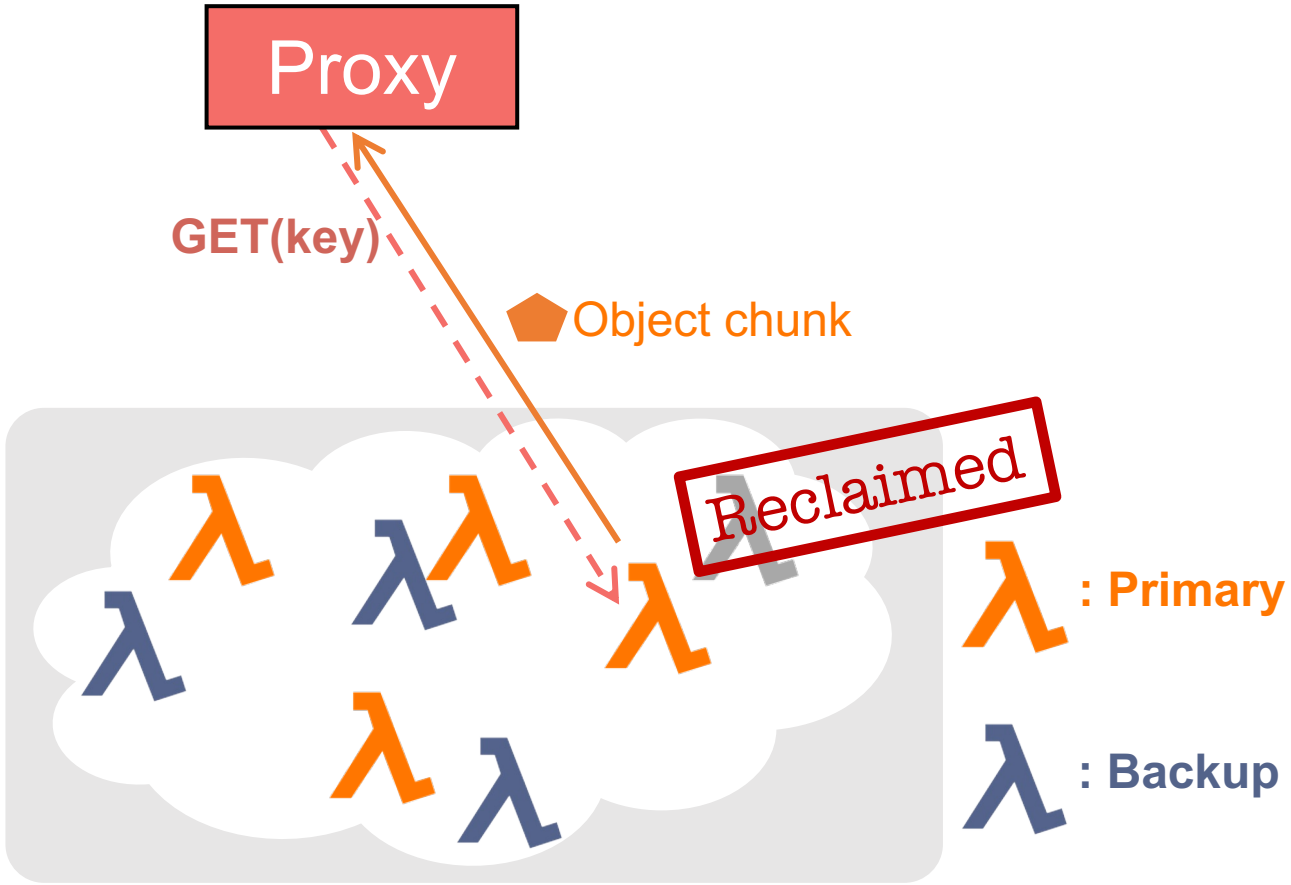
# Maximizing data availability: Seamless failover

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



# Outline

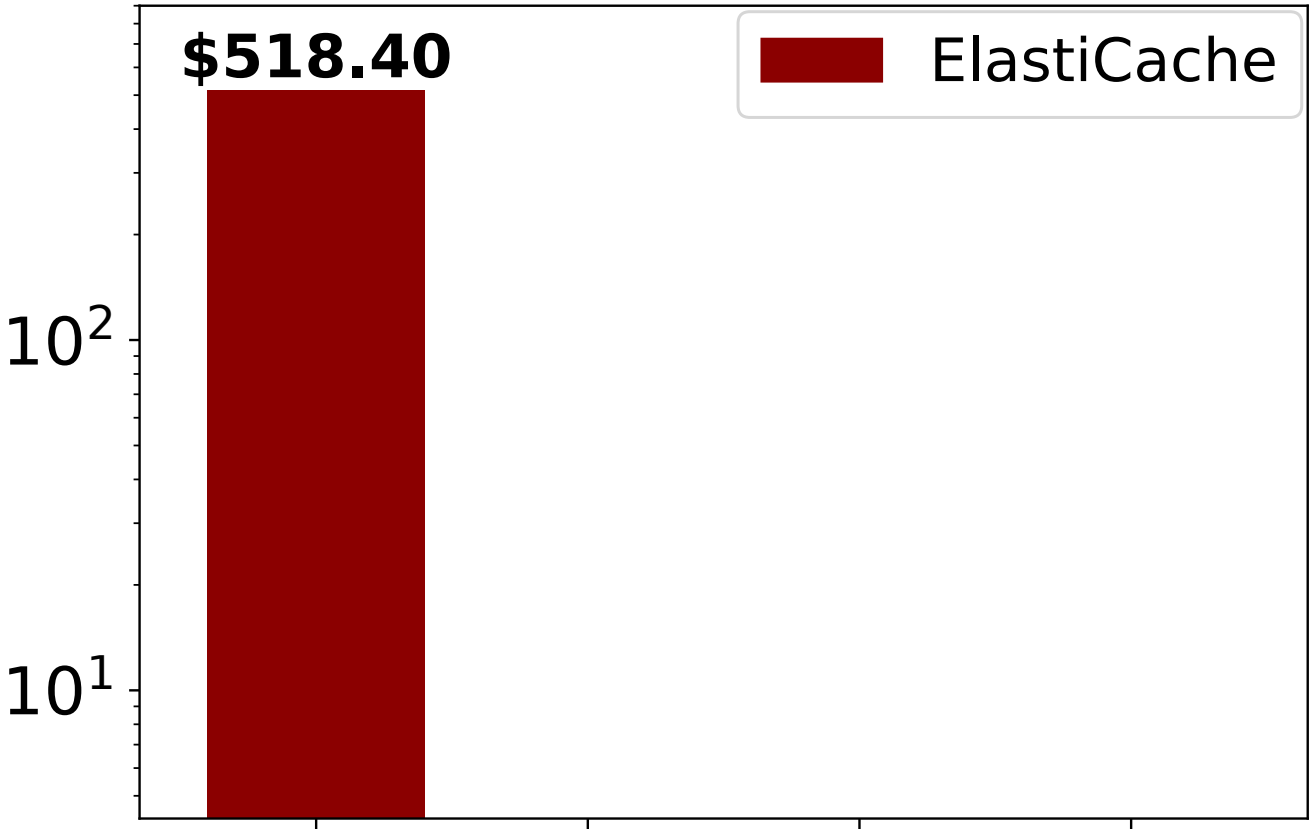
- InfiniCache Design
- Evaluation
- Conclusion

# 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

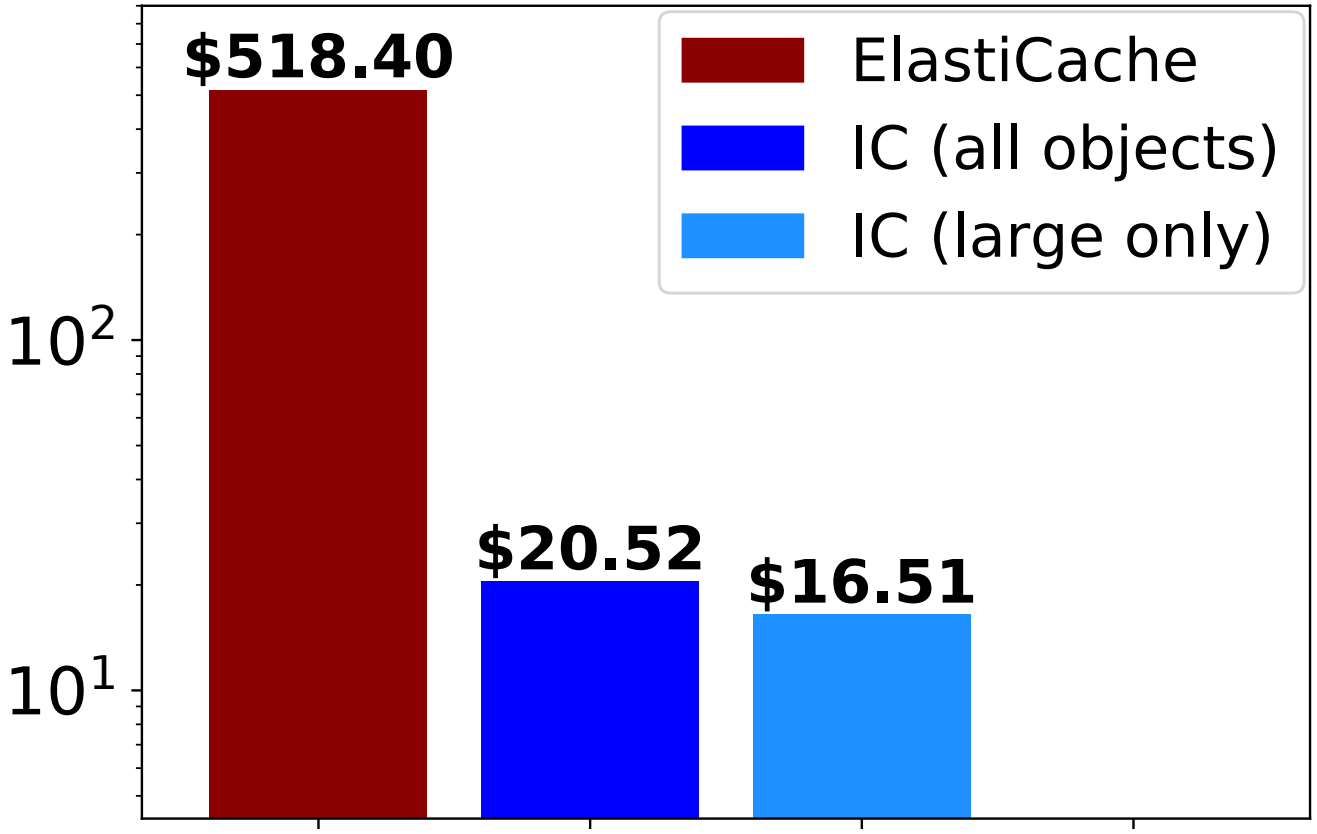
# Cost effectiveness of InfiniCache




AWS ElastiCache

- One `cache.r5.24xlarge` with 600GB memory
- $10.368 per hour

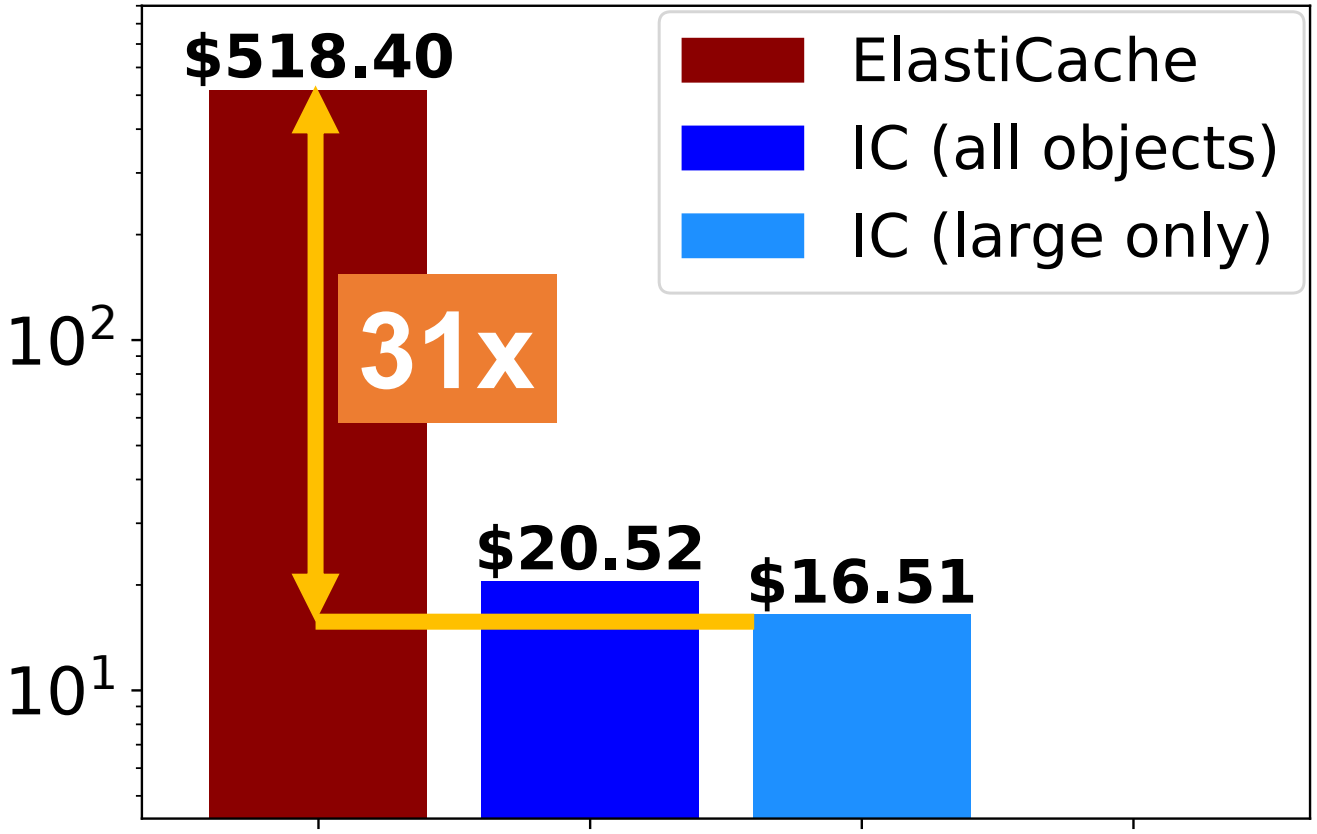
# Cost effectiveness of InfiniCache




Workload setup

- All objects
- Large object only
  - Object larger than 10MB

# Cost effectiveness of InfiniCache




Workload setup

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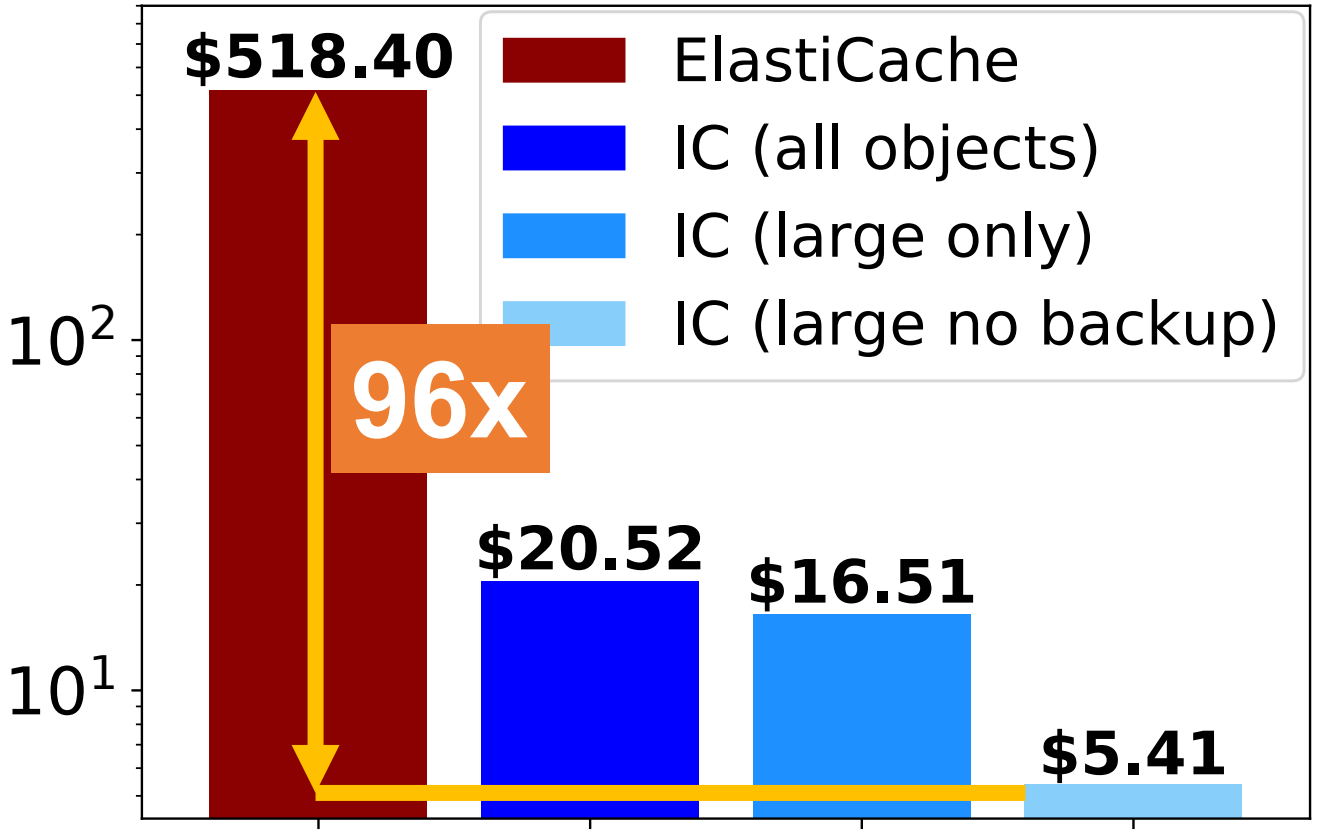
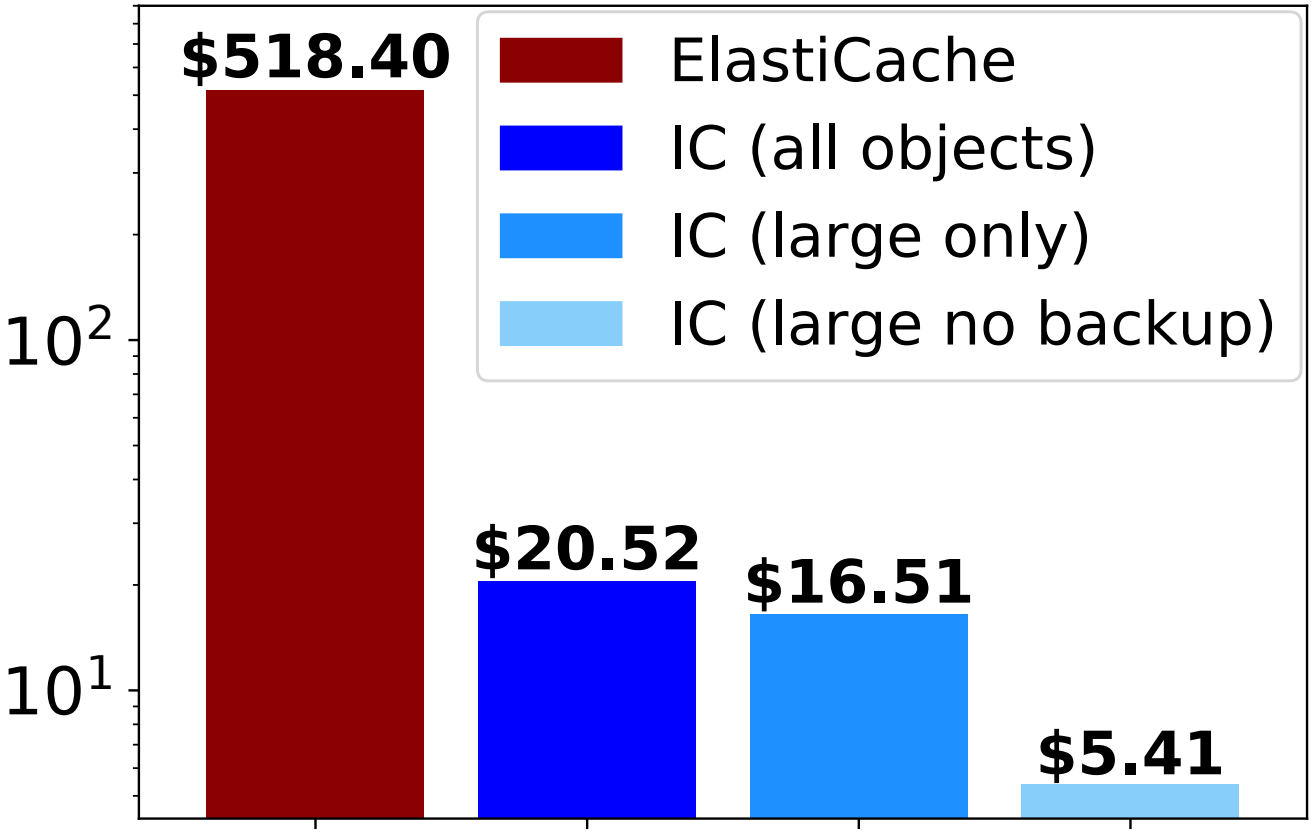
# Cost effectiveness of InfiniCache




Workload setup

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

# Cost effectiveness of InfiniCache



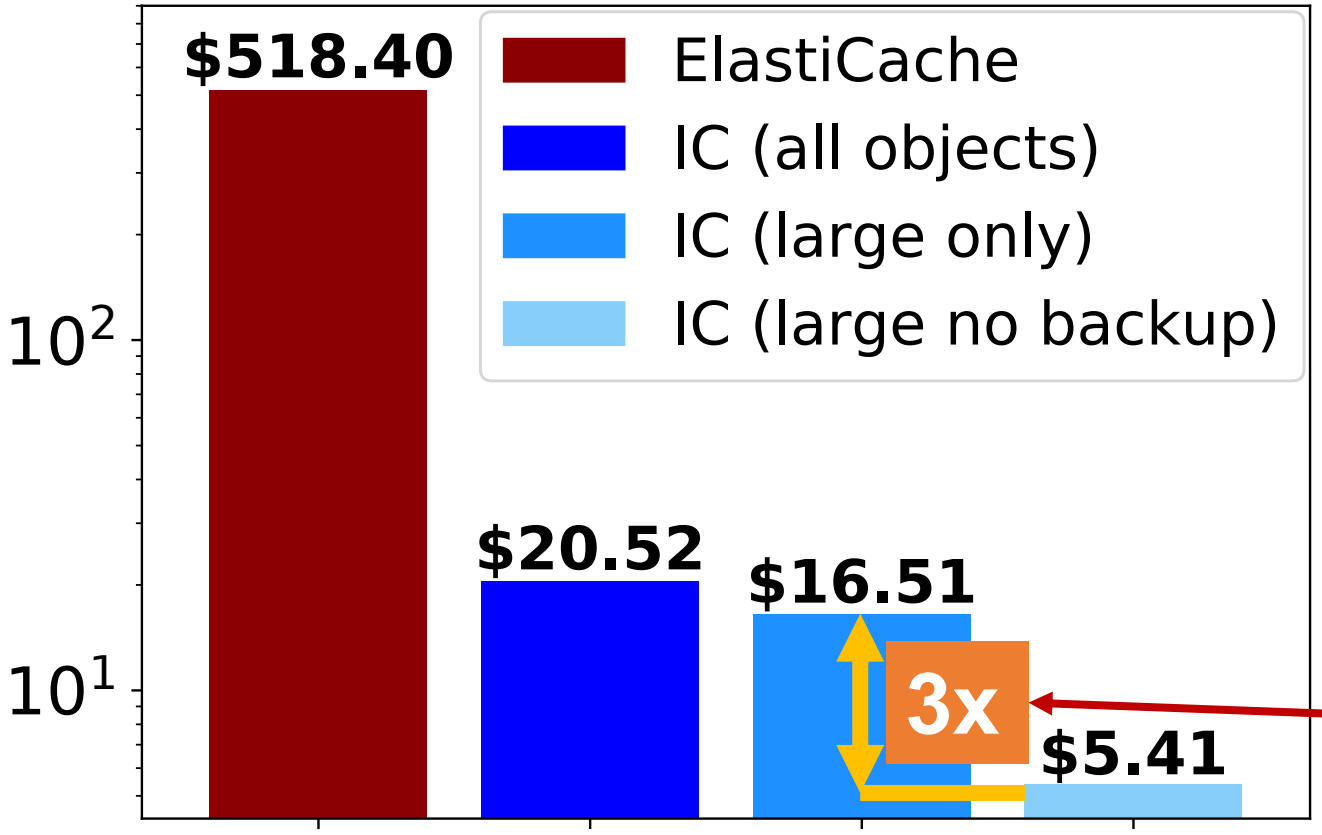

Workload setup

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

Hit ratio

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

# Cost effectiveness of InfiniCache



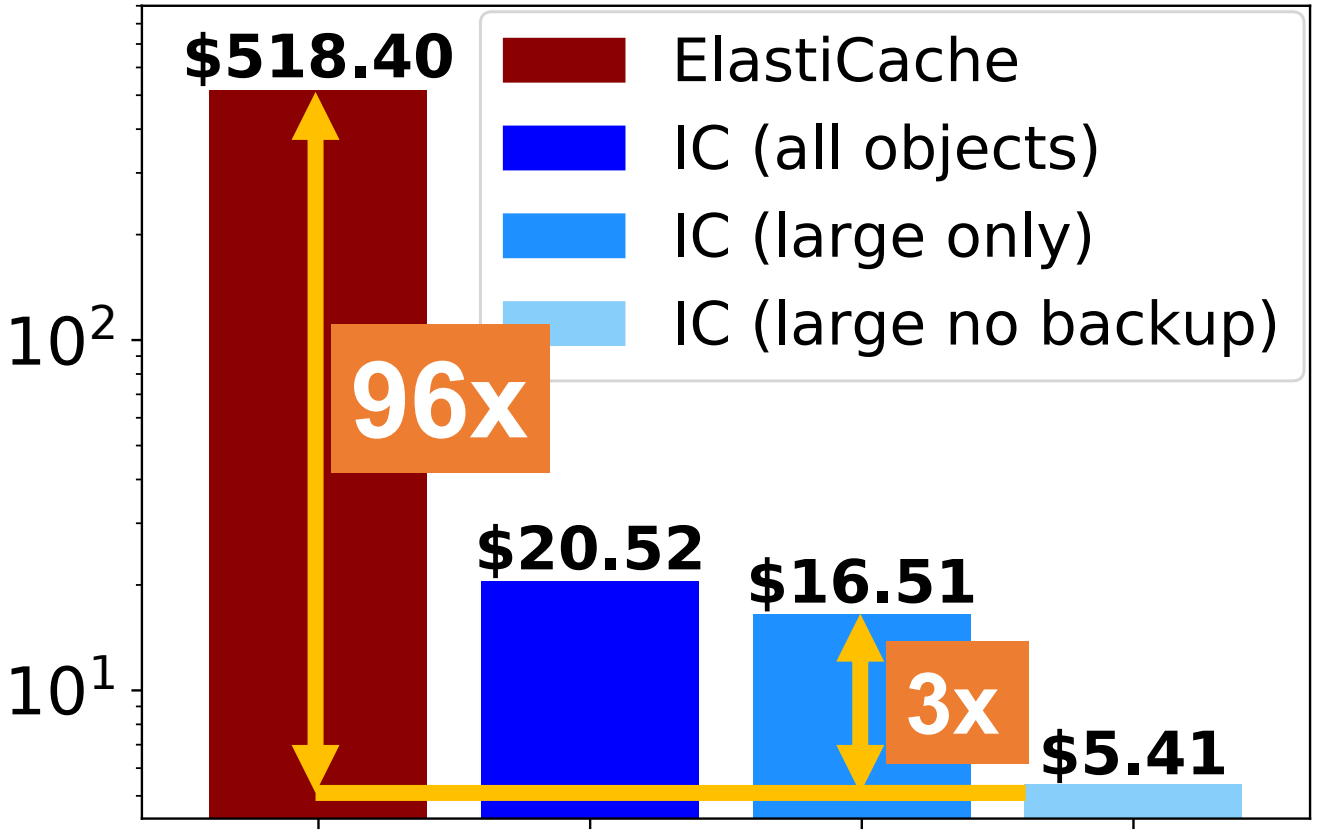

Workload setup

- 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% |

# Cost effectiveness of InfiniCache

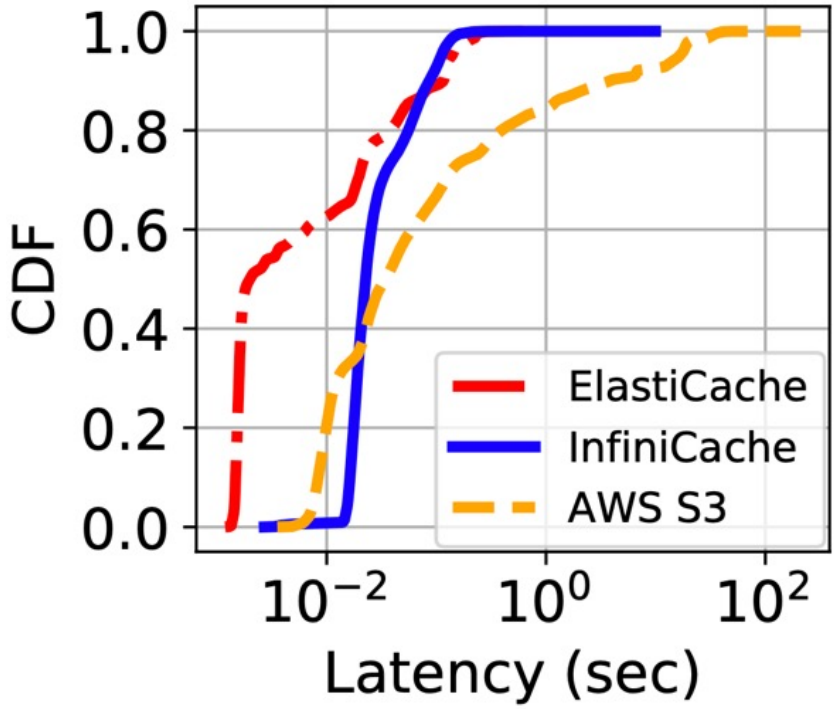



Workload setup

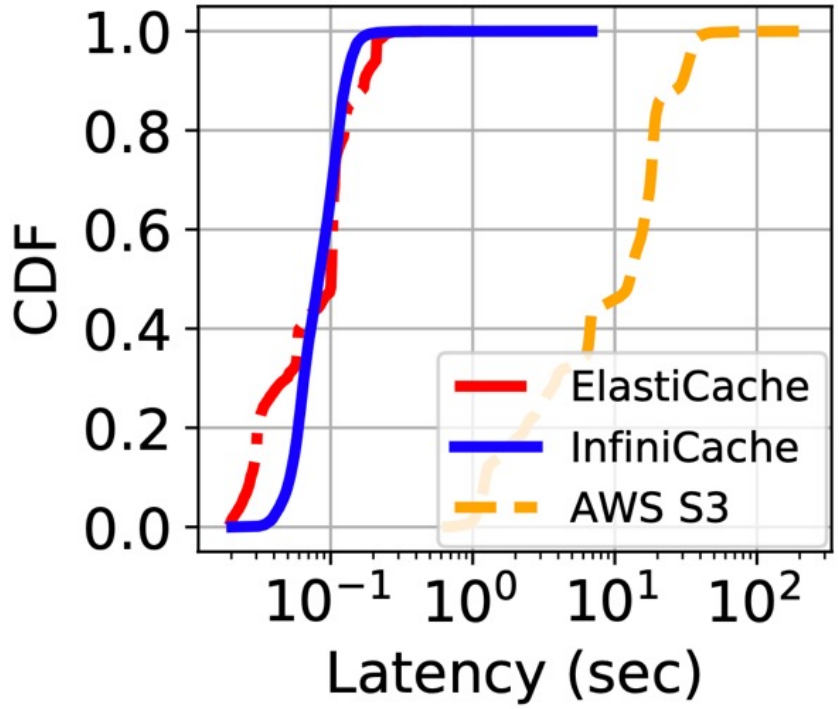
- All objects
- Large object only
  - Object larger than 10MB
- Large object w/o backup

**InfiniCache is 31 – 96x cheaper than ElastiCache because tenant does not pay when Lambdas are not running**

# Performance of InfiniCache

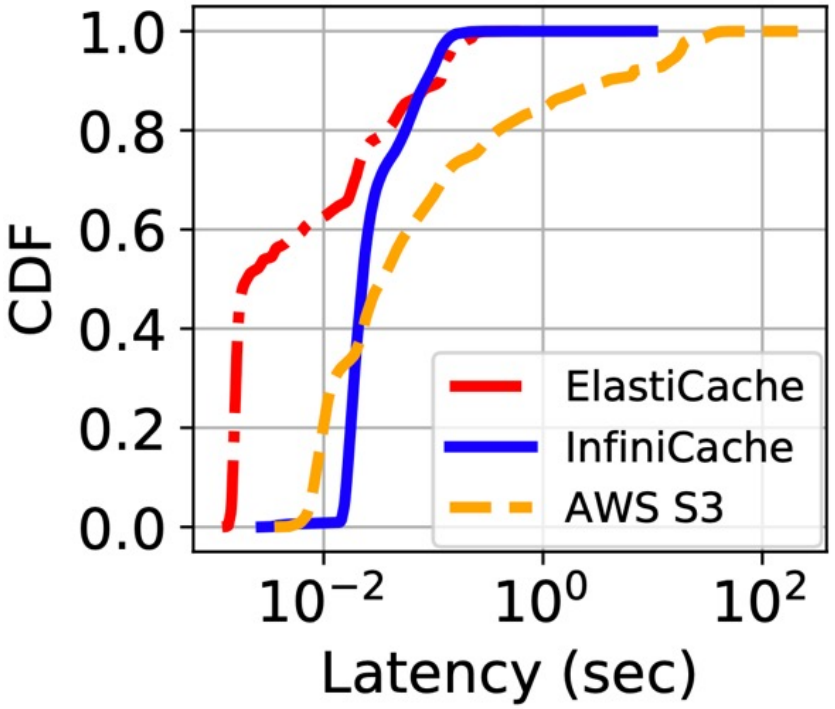



All objects



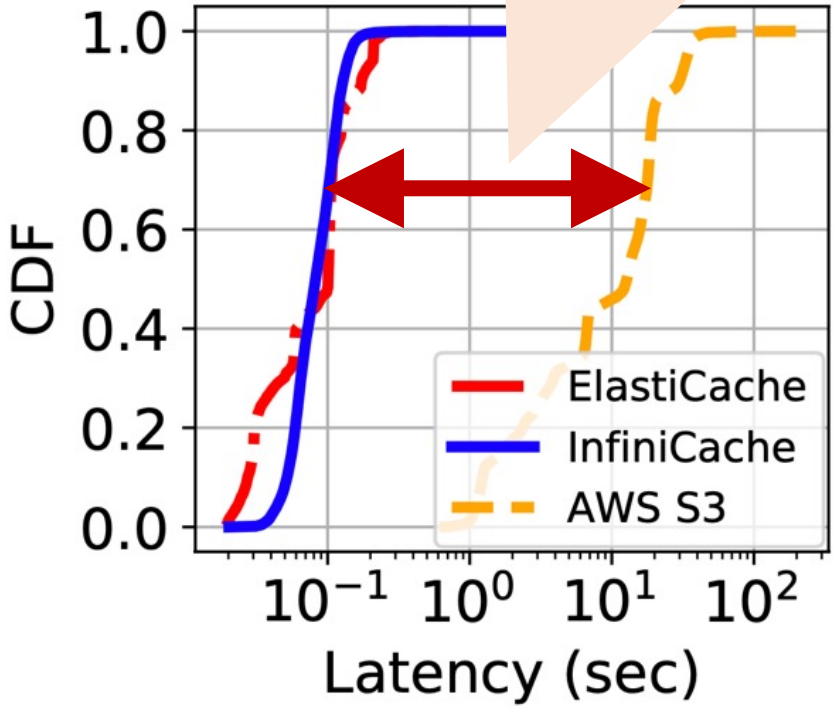

Large objects only

# Performance of InfiniCache



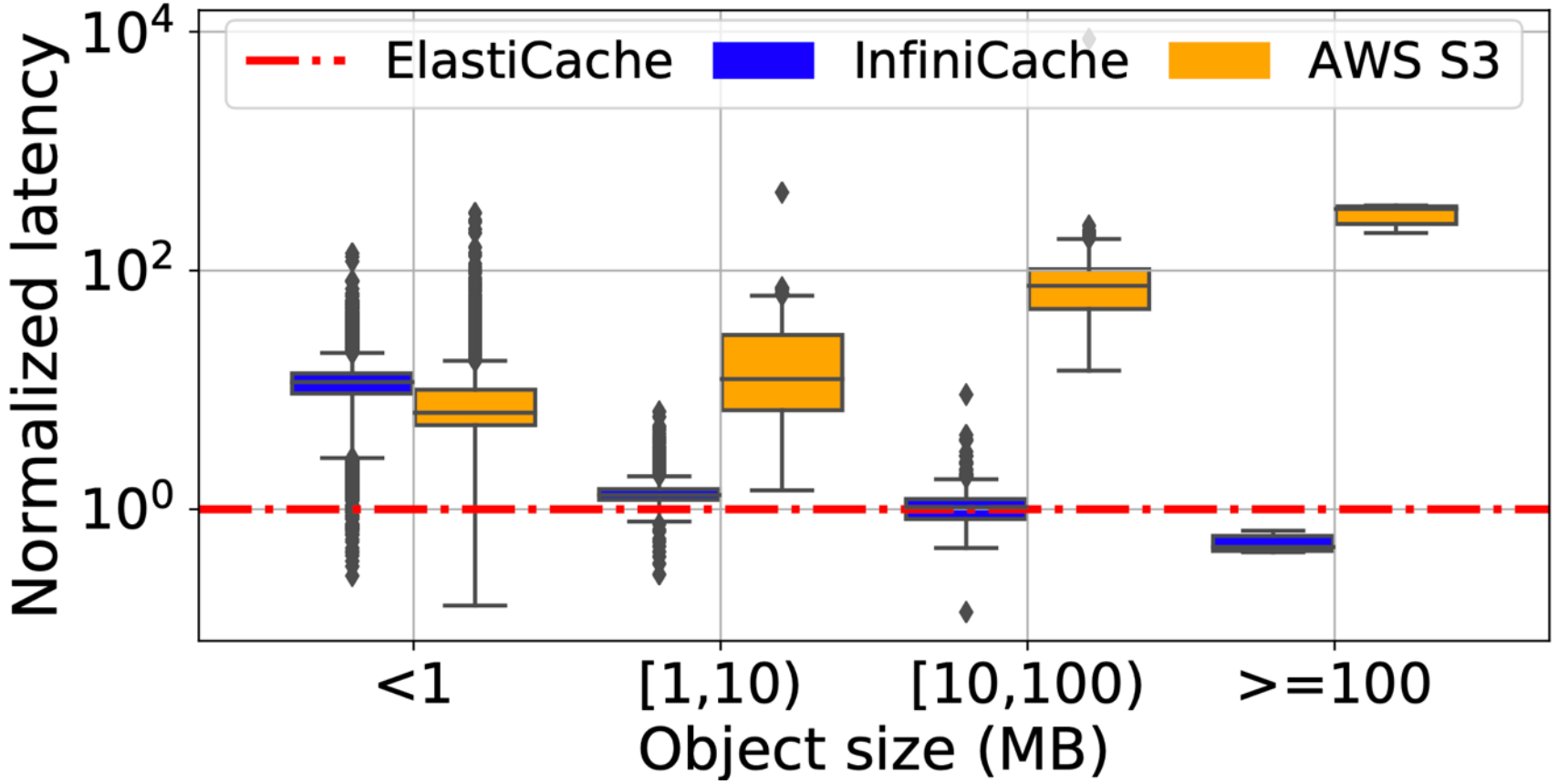

All objects

> 100 times improvement

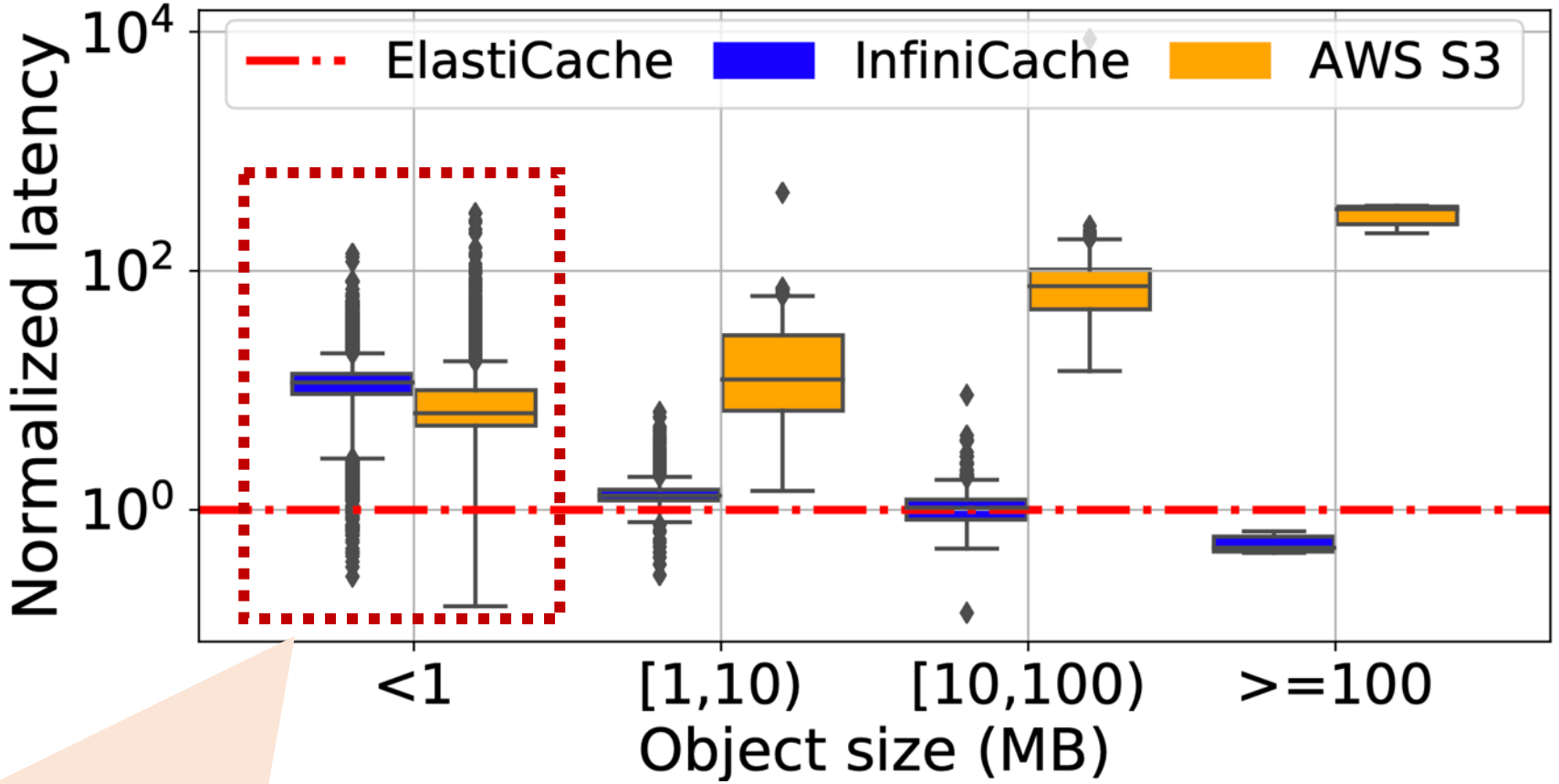



Large objects only

# Performance of InfiniCache

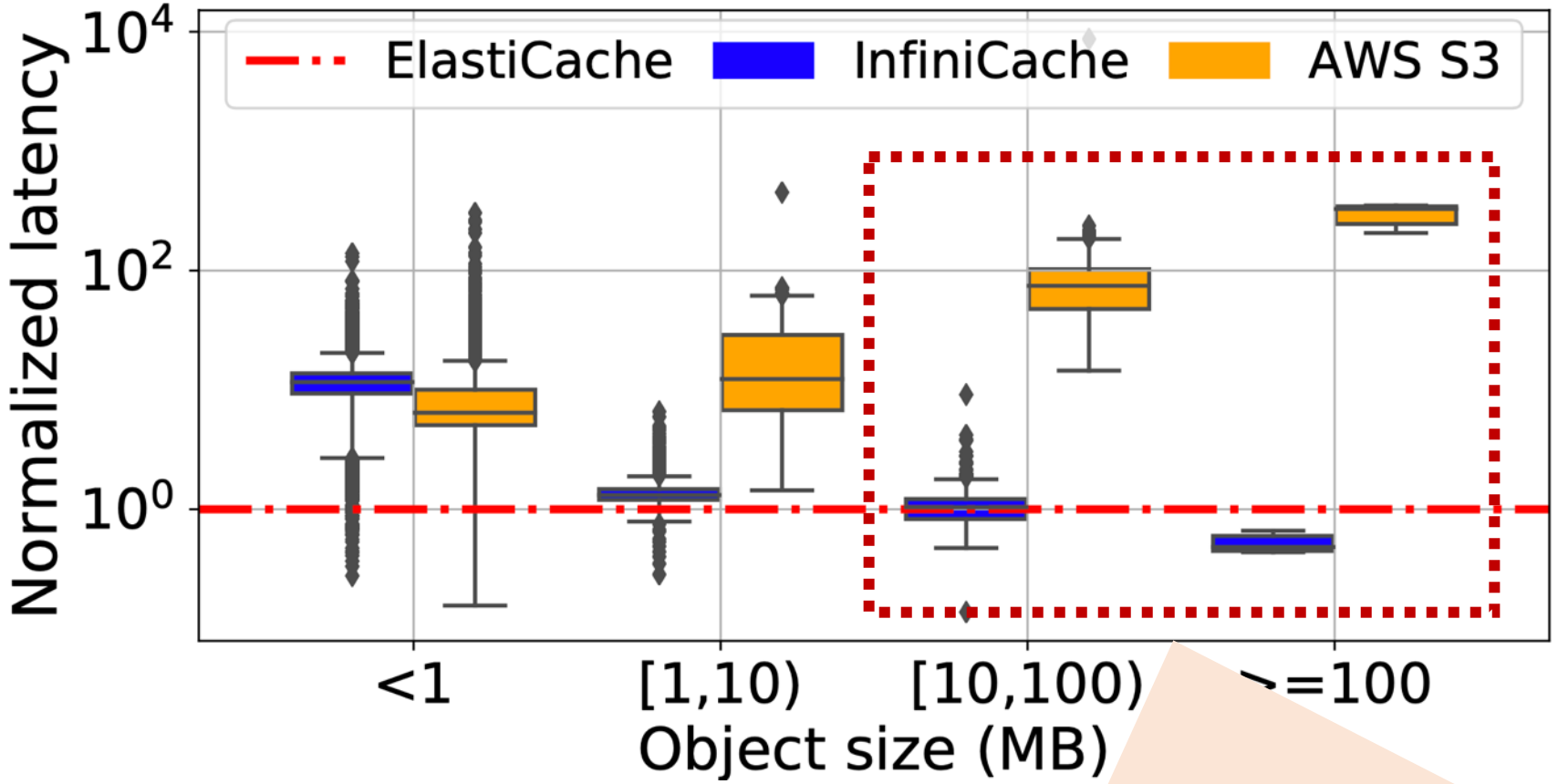


# Performance of InfiniCache




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

# Performance of InfiniCache




**InfiniCache achieves same or higher performance than ElastiCache for large objects**

# Conclusion

- InfiniCache is the first in-memory cache system built atop a serverless computing platform (AWS  )
- InfiniCache synthesizes a series of techniques to achieve high performance while maintaining good data availability
- InfiniCache improves the cost-effectiveness by 31-96x compared to AWS ElastiCache

# Thank you!




- Contact: Ao Wang – awang24@gmu.edu,

  Jingyuan Zhang – jzhang33@gmu.edu


- https://github.com/mason-leap-lab/infinicache 


University of Nevada, Reno