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

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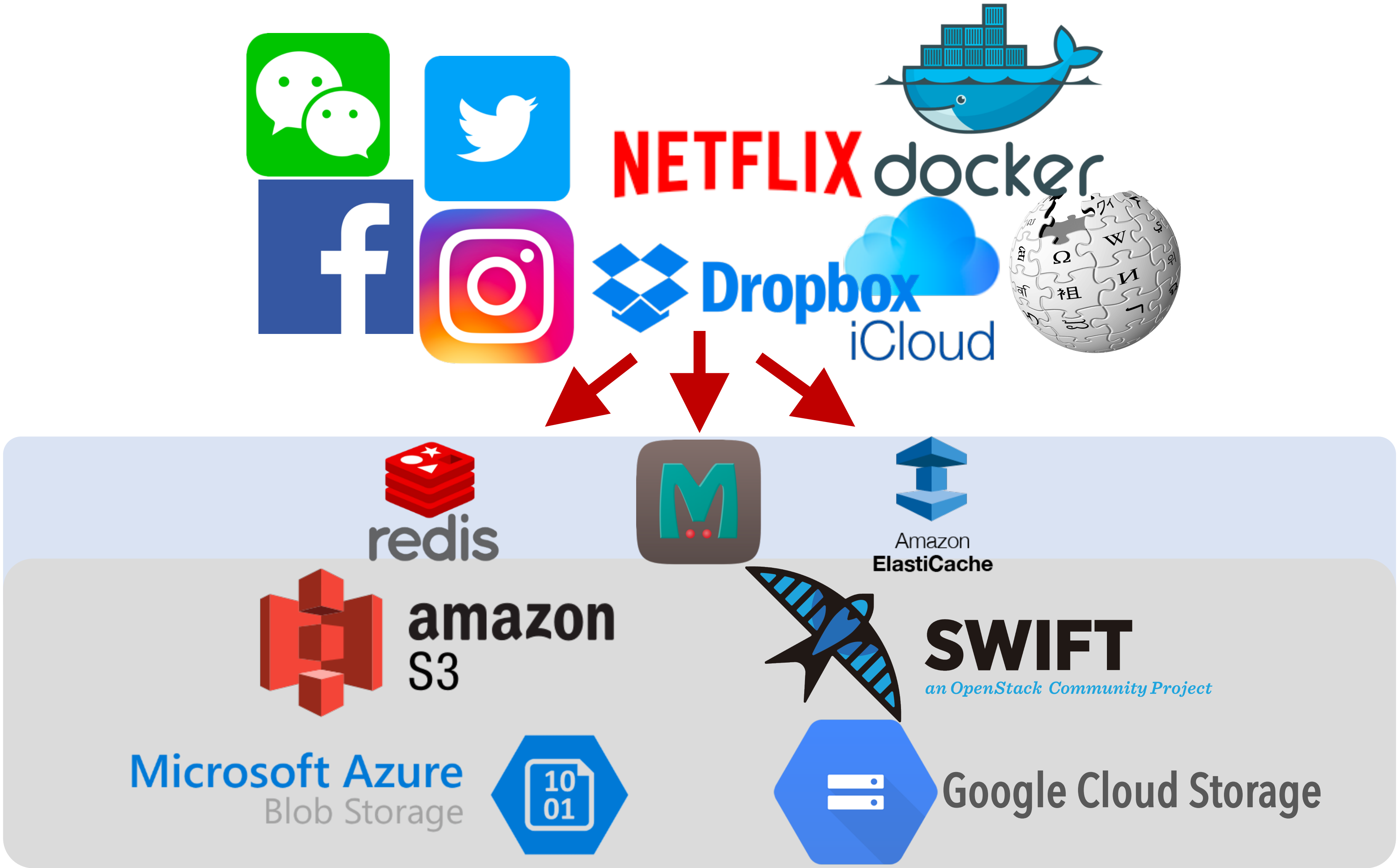
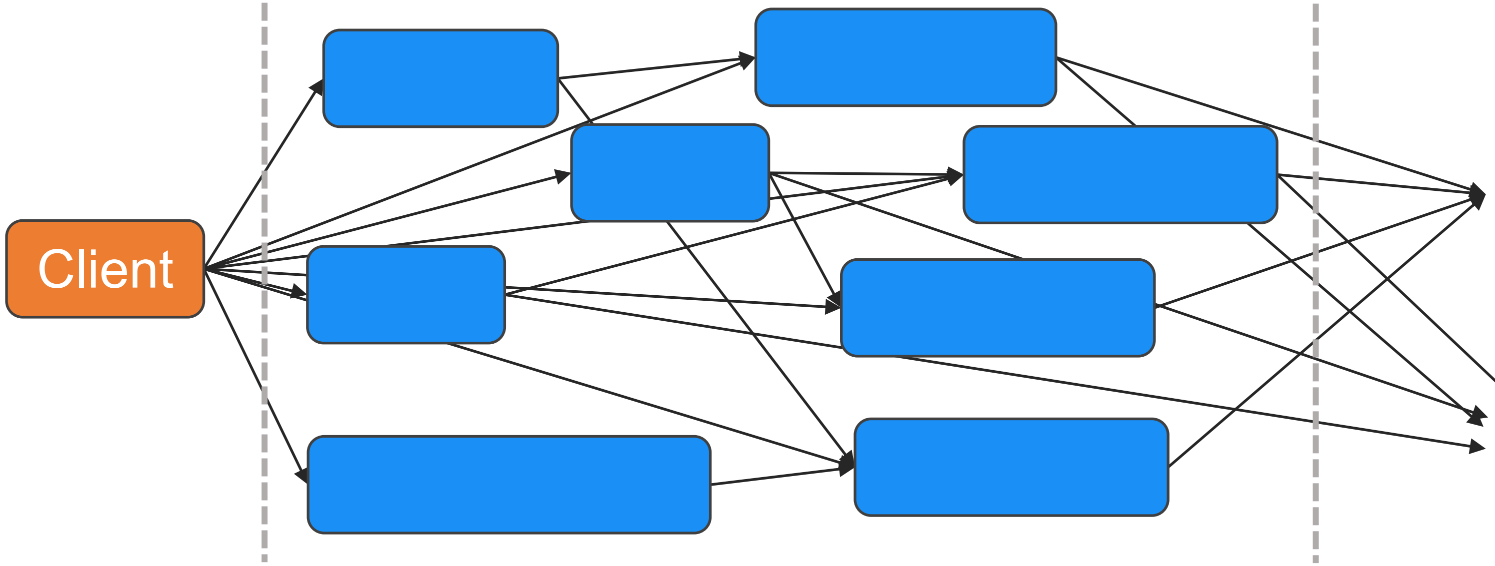
Web applications are storage-intensive



Web applications – heterogeneous I/O



Microservices

Case study: IBM Docker registry workloads

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

Case study: IBM Docker registry workloads

- Object size distribution
- Large object reuse patterns
- Storage footprint

Case study: IBM Docker registry workloads

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Extreme variability in object sizes:

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

Case study: IBM Docker registry workloads

- Object size distribution
- Large object reuse patterns
- Storage footprint

Caching large objects is beneficial:

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

Case study: IBM Docker registry workloads

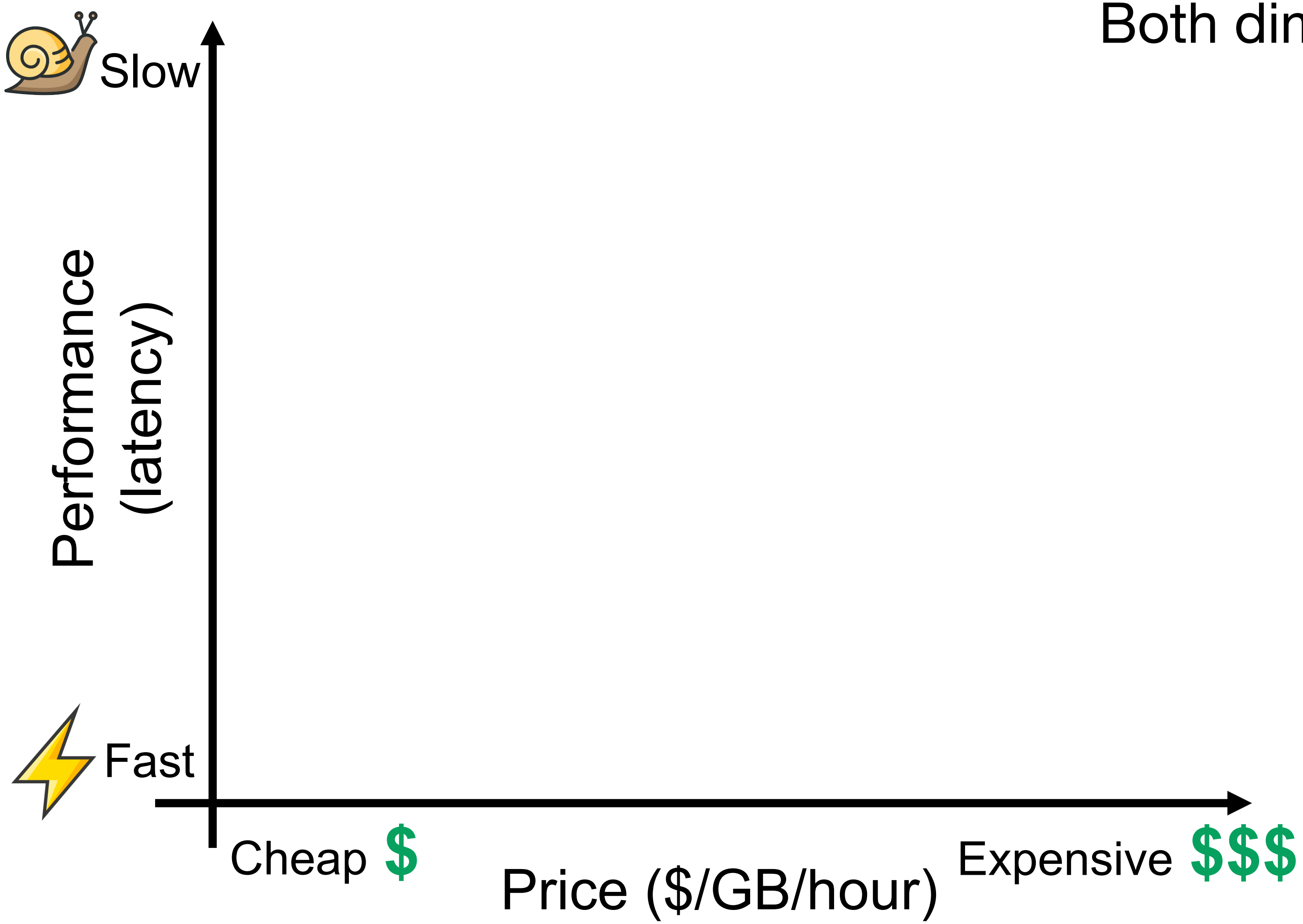
- Object size distribution
- Large object reuse patterns
- Storage footprint

Extreme tension between small and large objects:

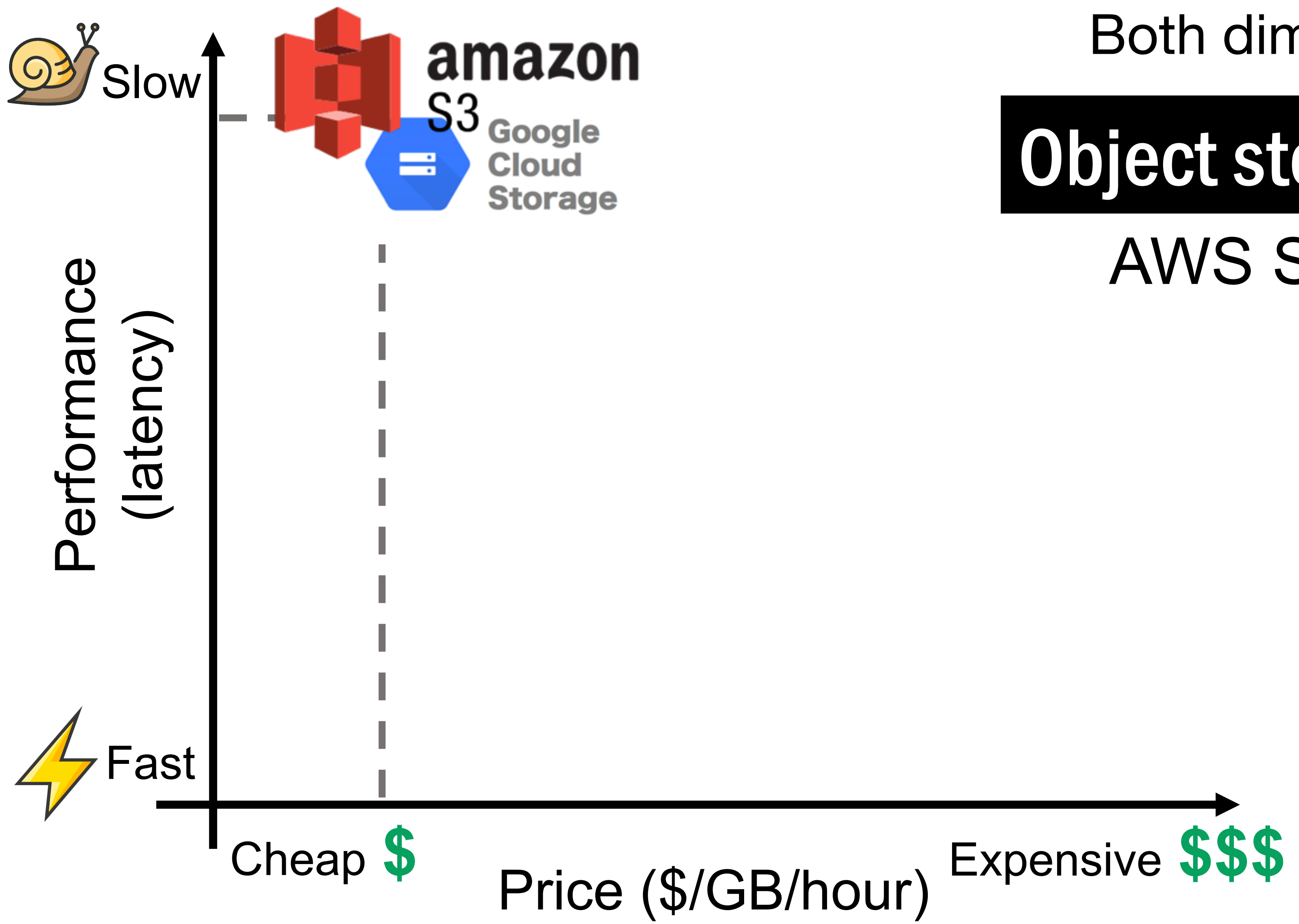
➢ Large objects (>10MB) occupy 95% storage footprint

Existing cloud storage solutions

Both dimensions: the lower the better



Large objects managed by cloud object stores

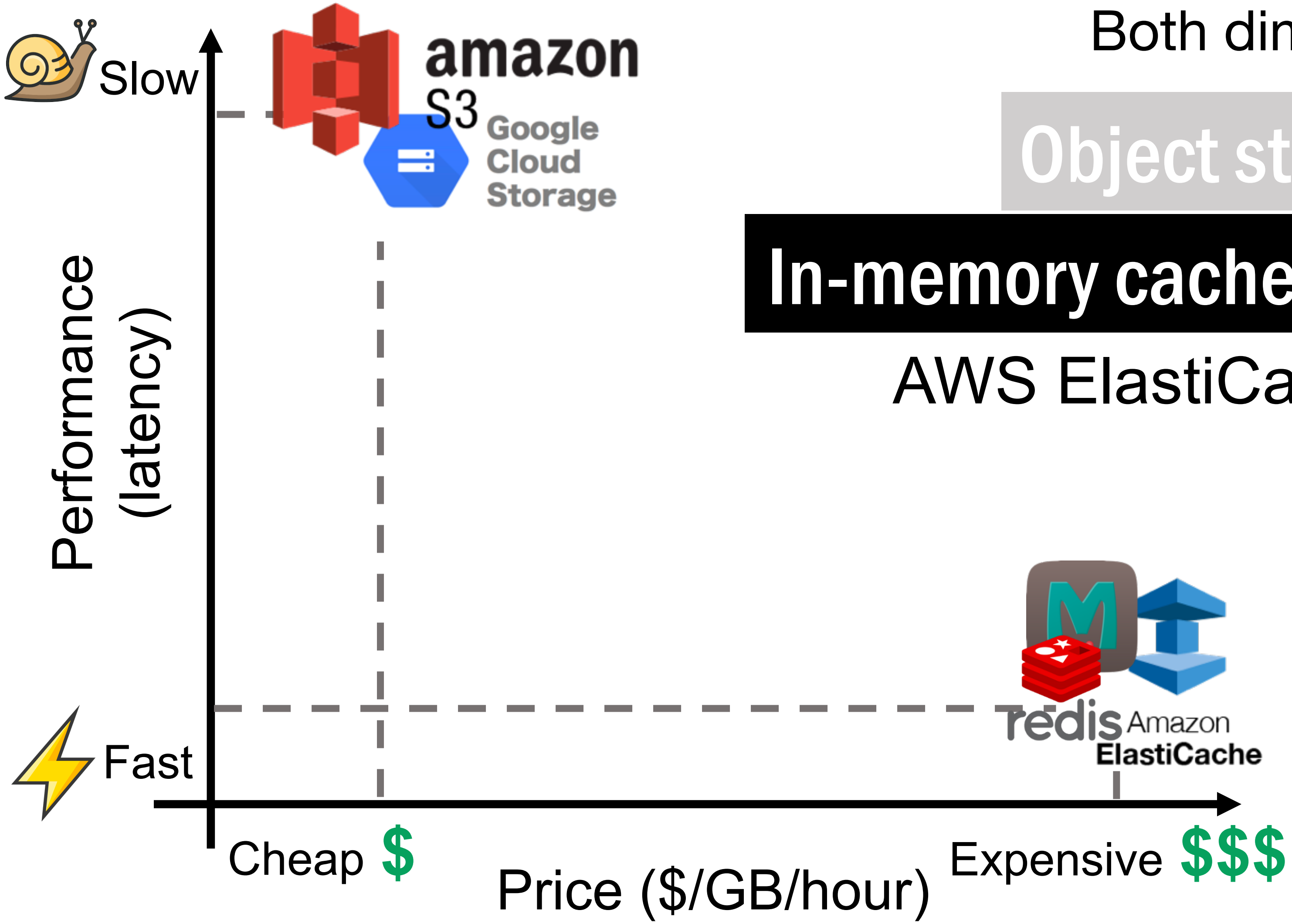


Both dimensions: the lower the better

Object stores are cheap but too slow

AWS S3: $0.023 per GB per month

Small objects accelerated by in-memory caches



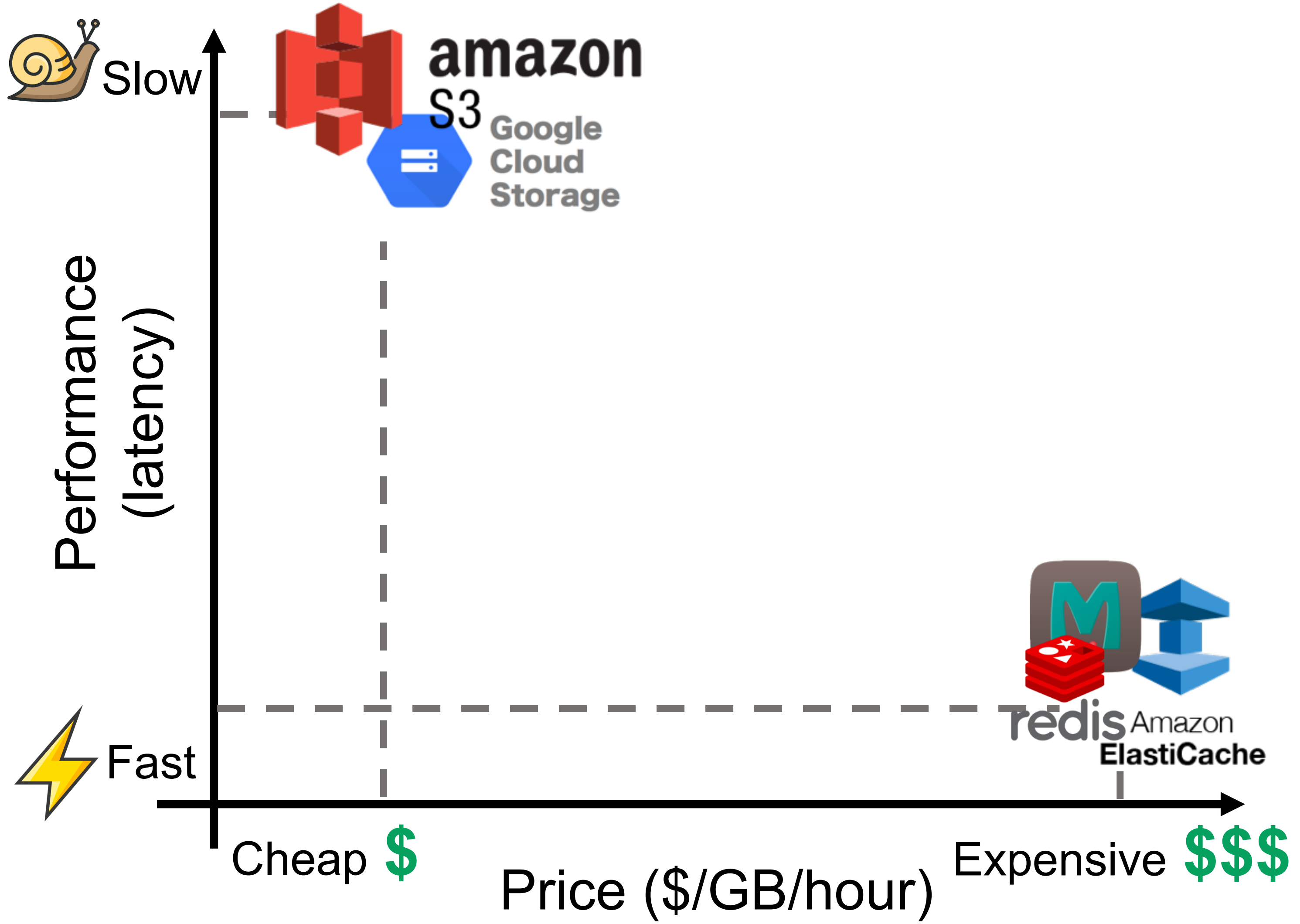
Both dimensions: the lower the better

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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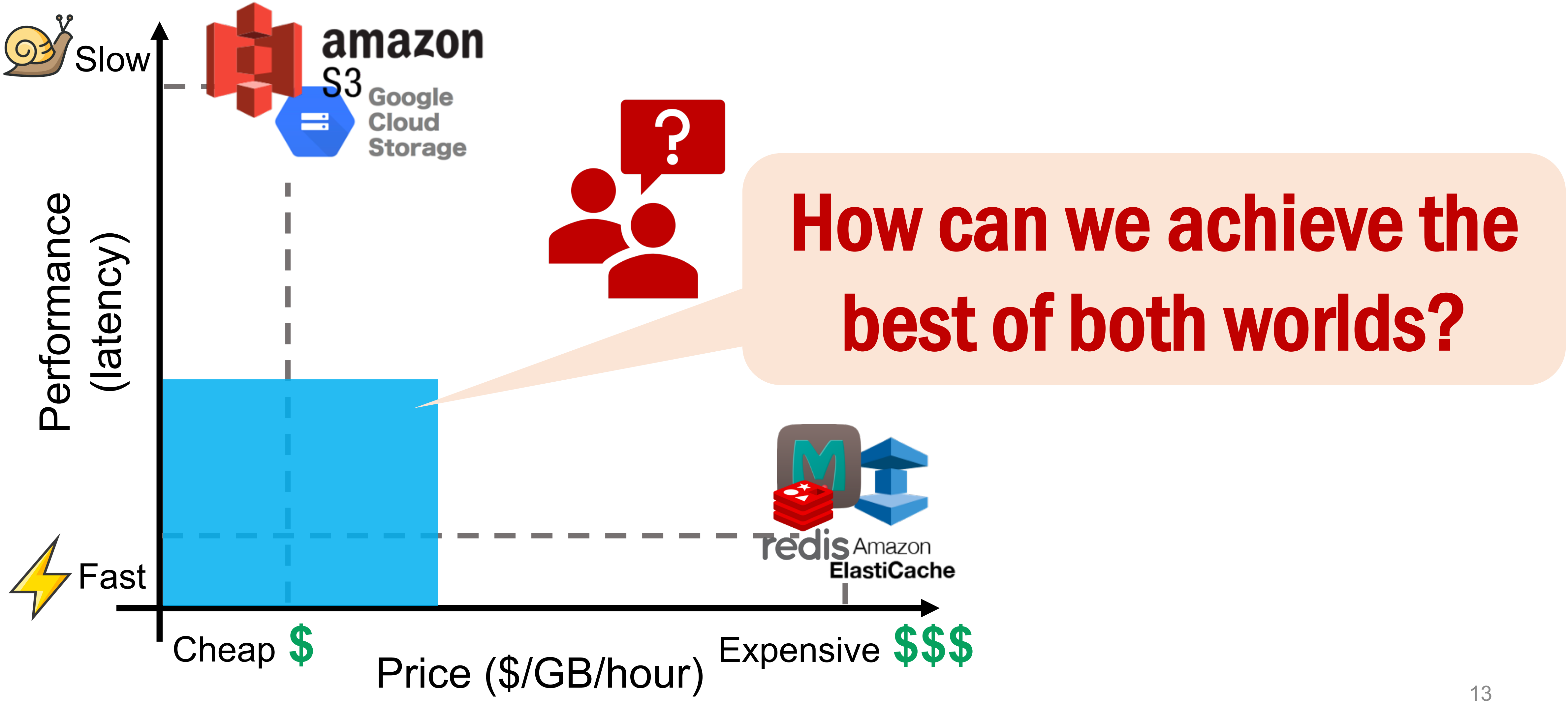


- **Caching both small and large objects** is challenging
- Existing solutions are **either too slow or expensive**

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

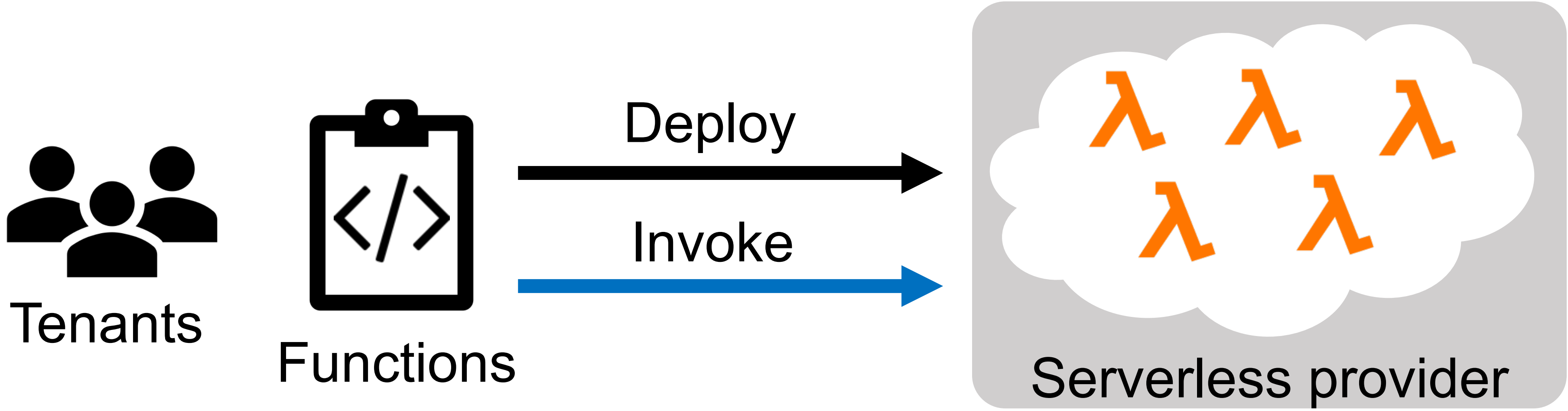
- **Insight #1:** Serverless functions’ <CPU, Mem> resources are pay-per-use
- **Insight #2:** Serverless providers offer “free” function caching for tenants

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

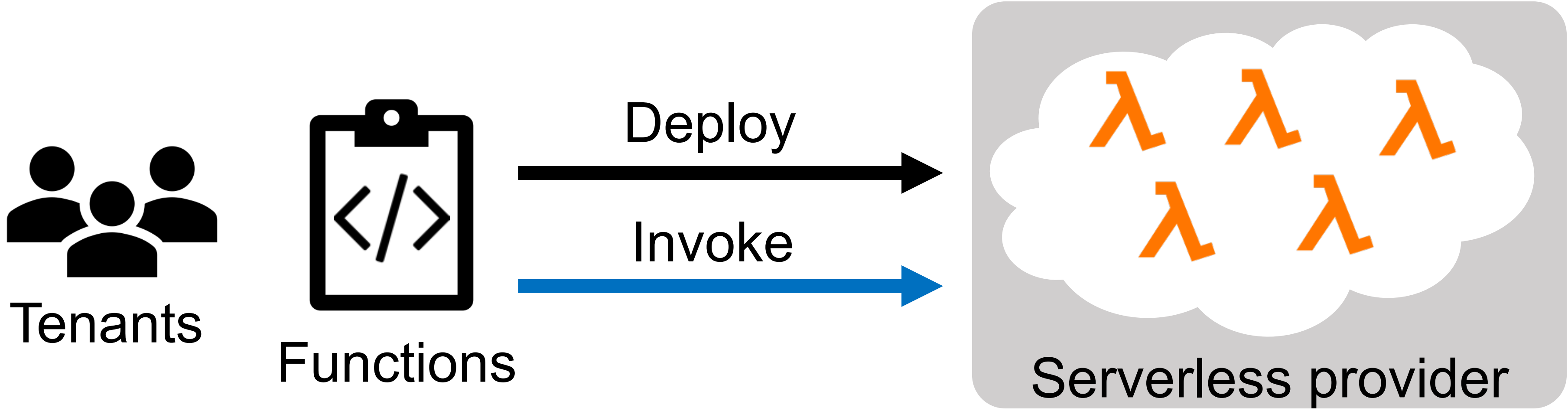
A primer on Serverless Computing

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



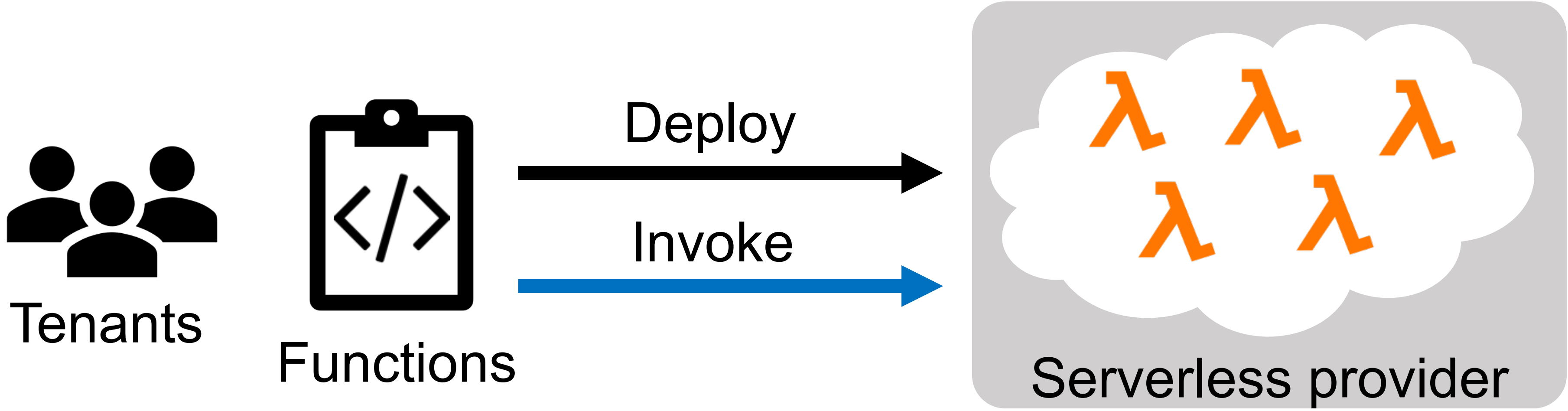
A primer on Serverless Computing

- 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



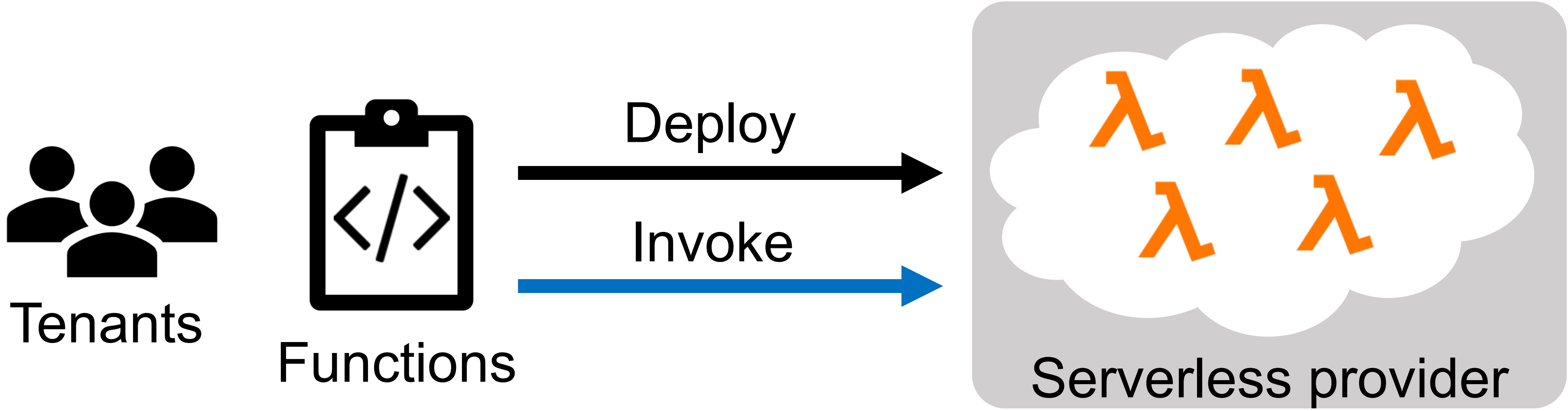
A primer on Serverless Computing

- 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…



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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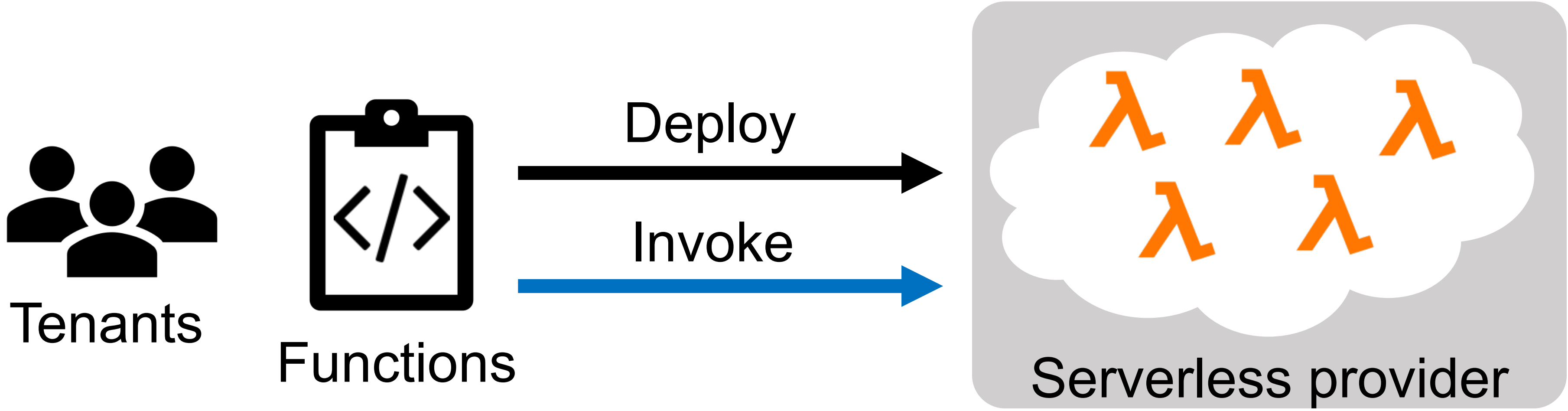
- Short-term function caching
  - Provider caches triggered functions in memory without charging tenants



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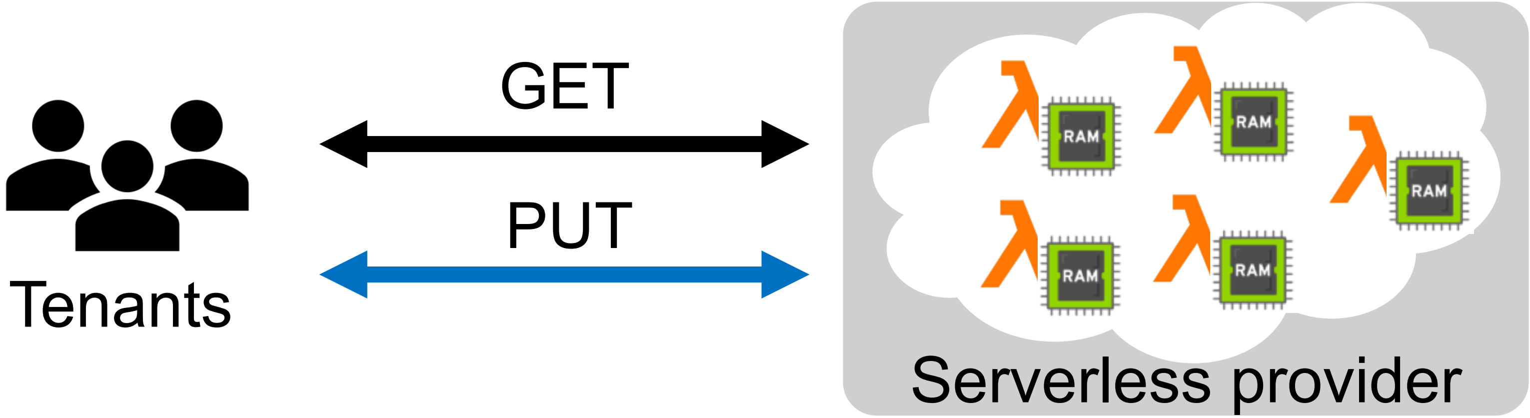
Goal: Exploit the serverless computing model to build a cost-effective, high-performance in-memory cache



Challenges: to build a memory cache with serverless functions

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

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

⚠️ Serverless functions could be reclaimed any time

⚠️ In-memory state is lost

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

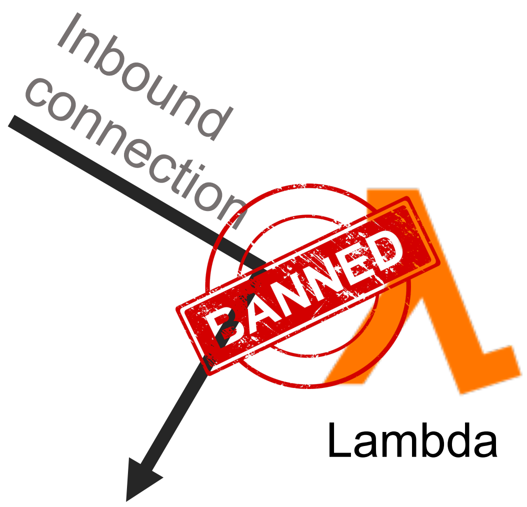
Challenges: to build a memory cache with serverless functions

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

- No data availability guarantee

⚠️ Serverless functions cannot run as a server

- Banned inbound network



- Limited per-function resources

Challenges: to build a memory cache with serverless functions

- A strawman proposal
  - Directly cache the objects in serverless functions' memory?
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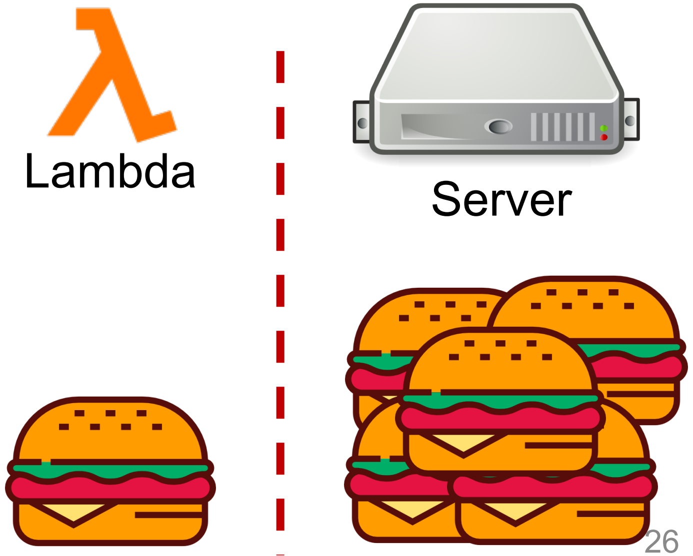
⚠️ Memory up to 3 GB

⚠️ CPU up to 2 cores



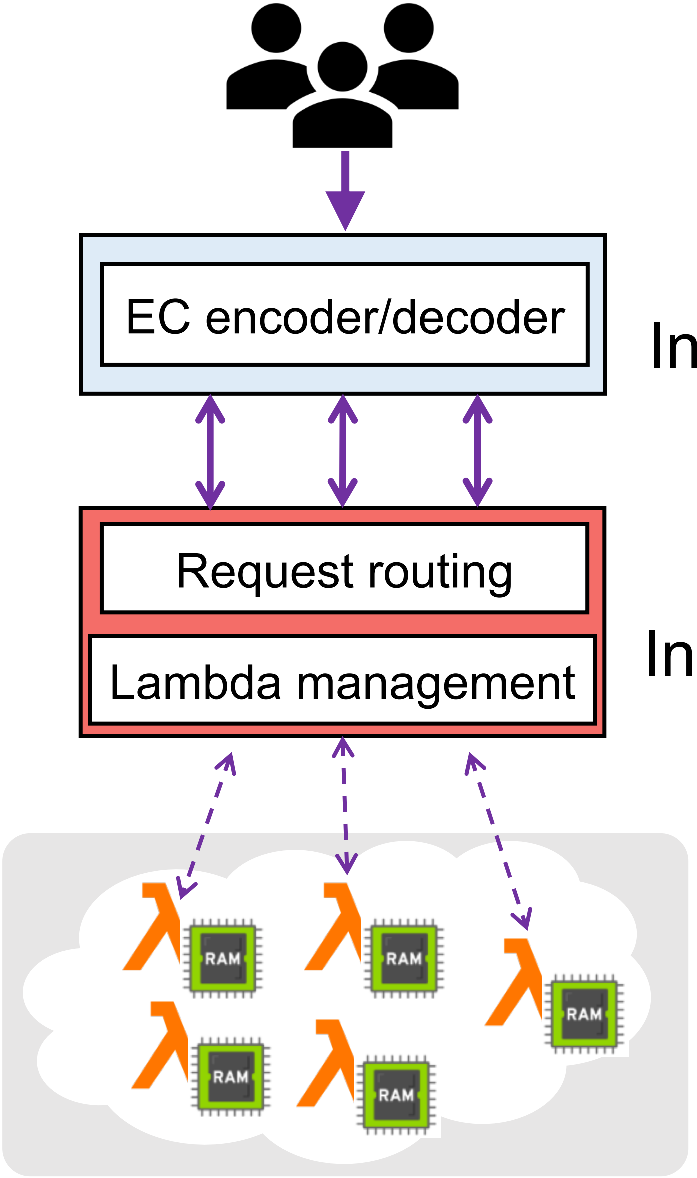
Our contribution: InfiniCache

- **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



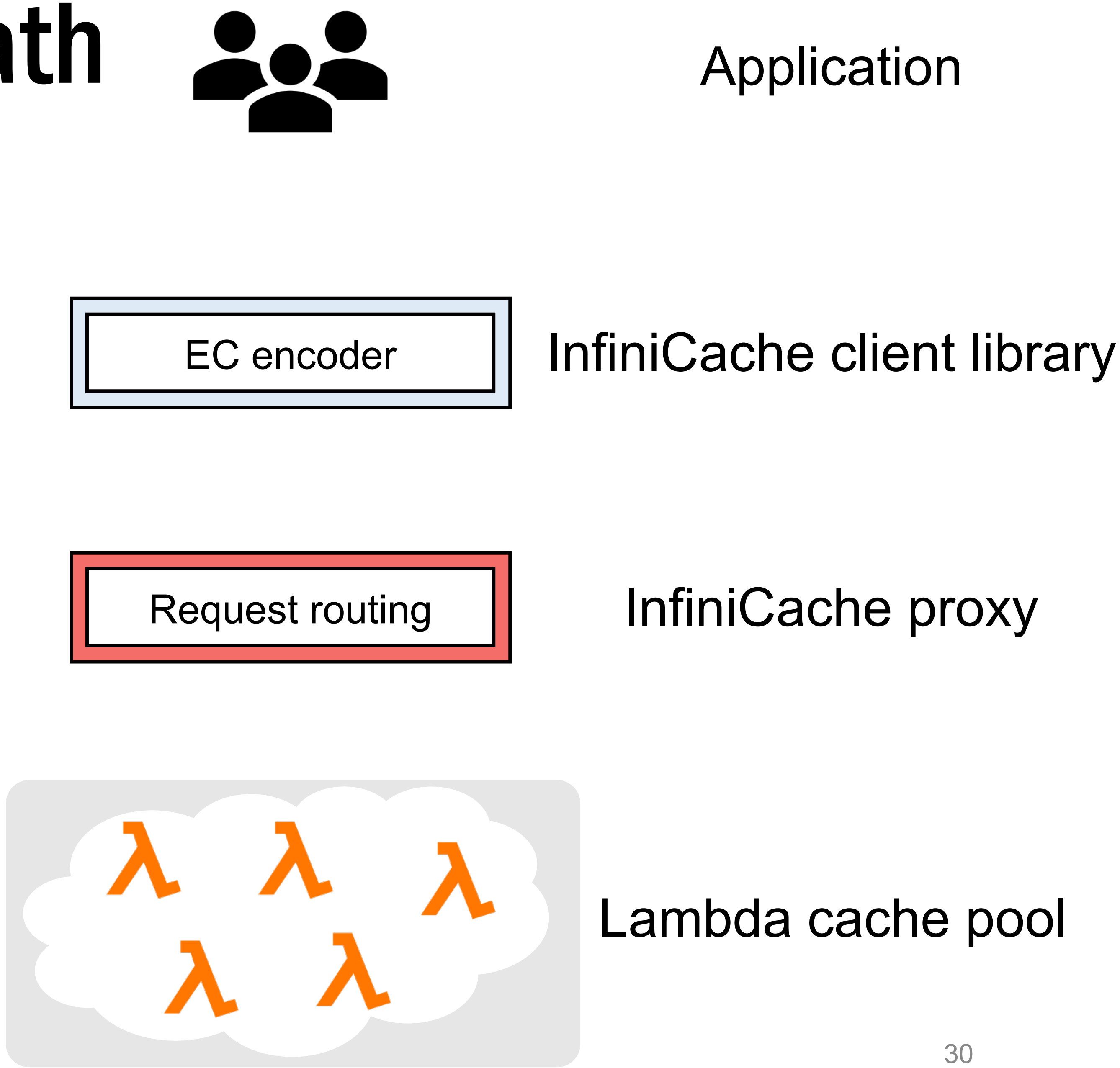
Application

InfiniCache client library

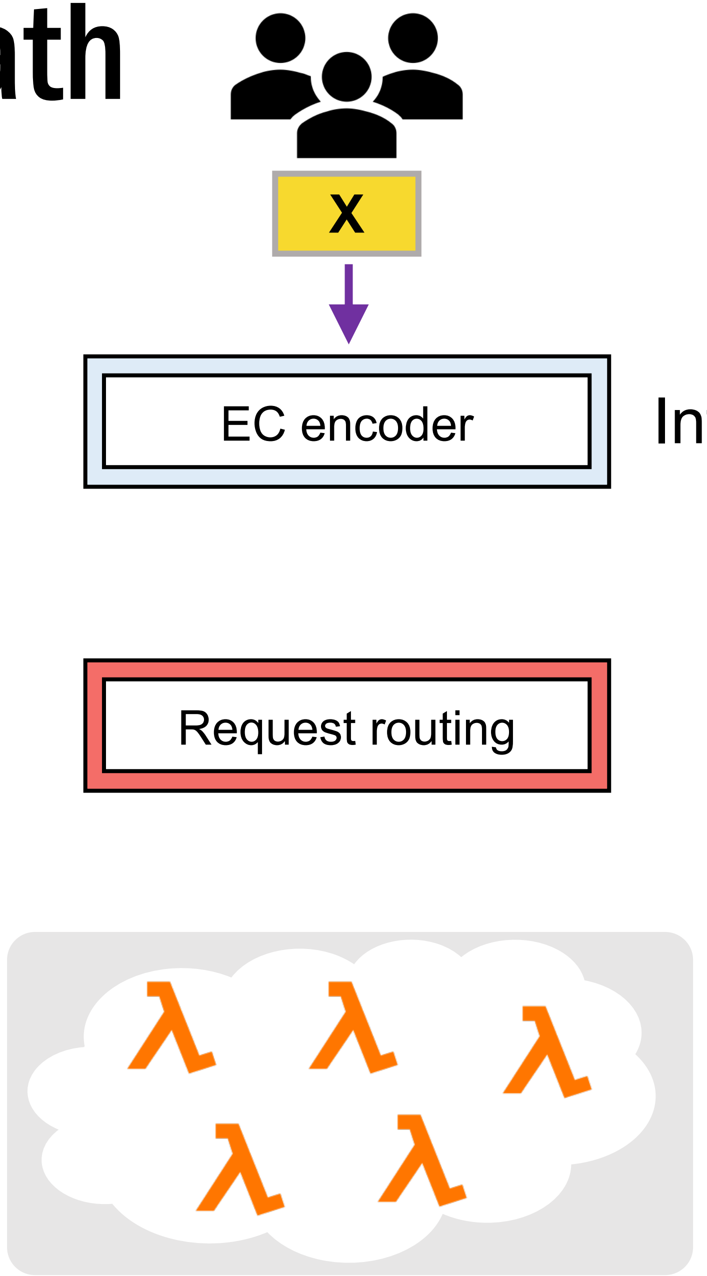
InfiniCache proxy server

Lambda cache pool

InfiniCache: PUT path



InfiniCache: PUT path



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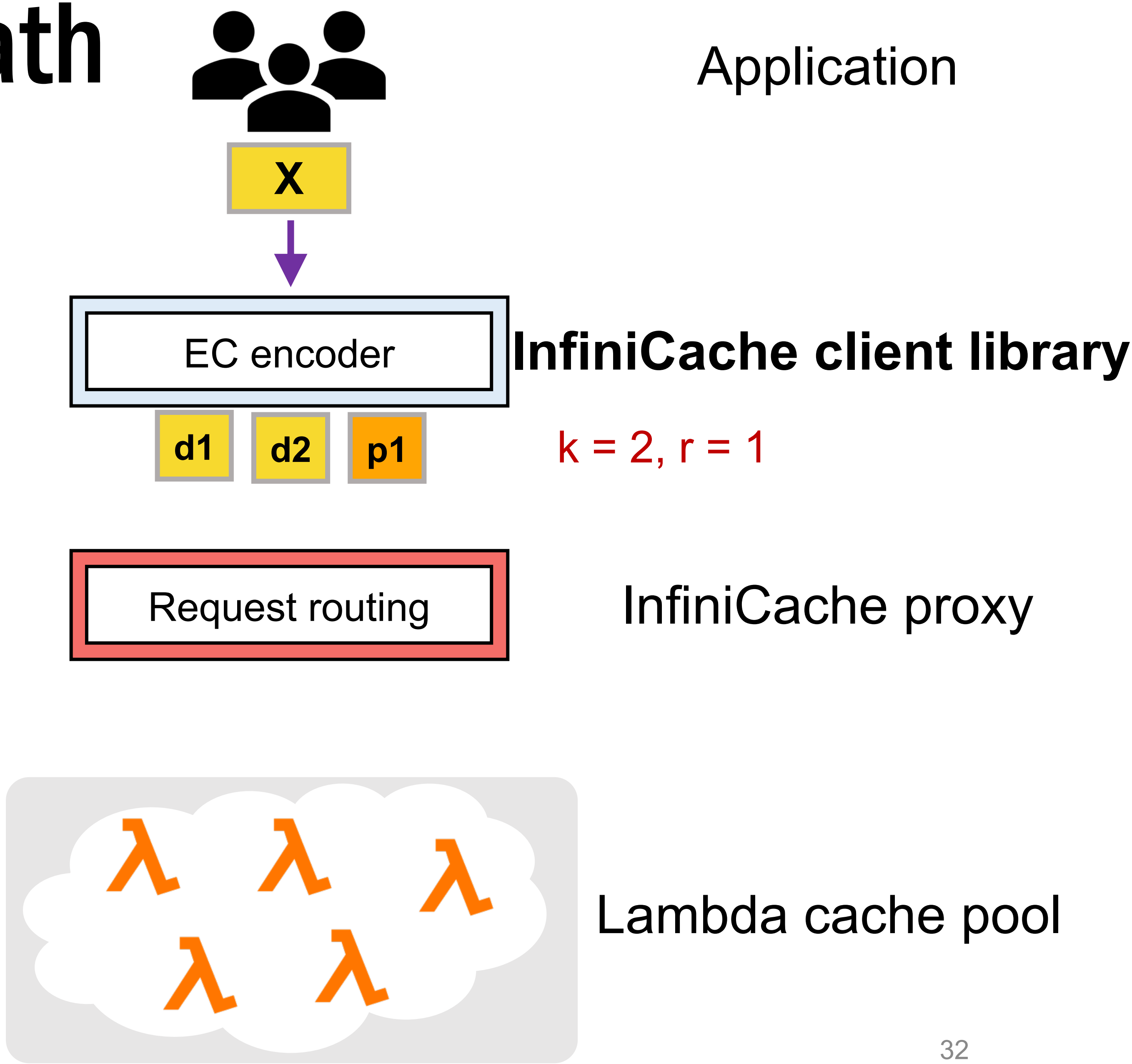
InfiniCache: PUT path

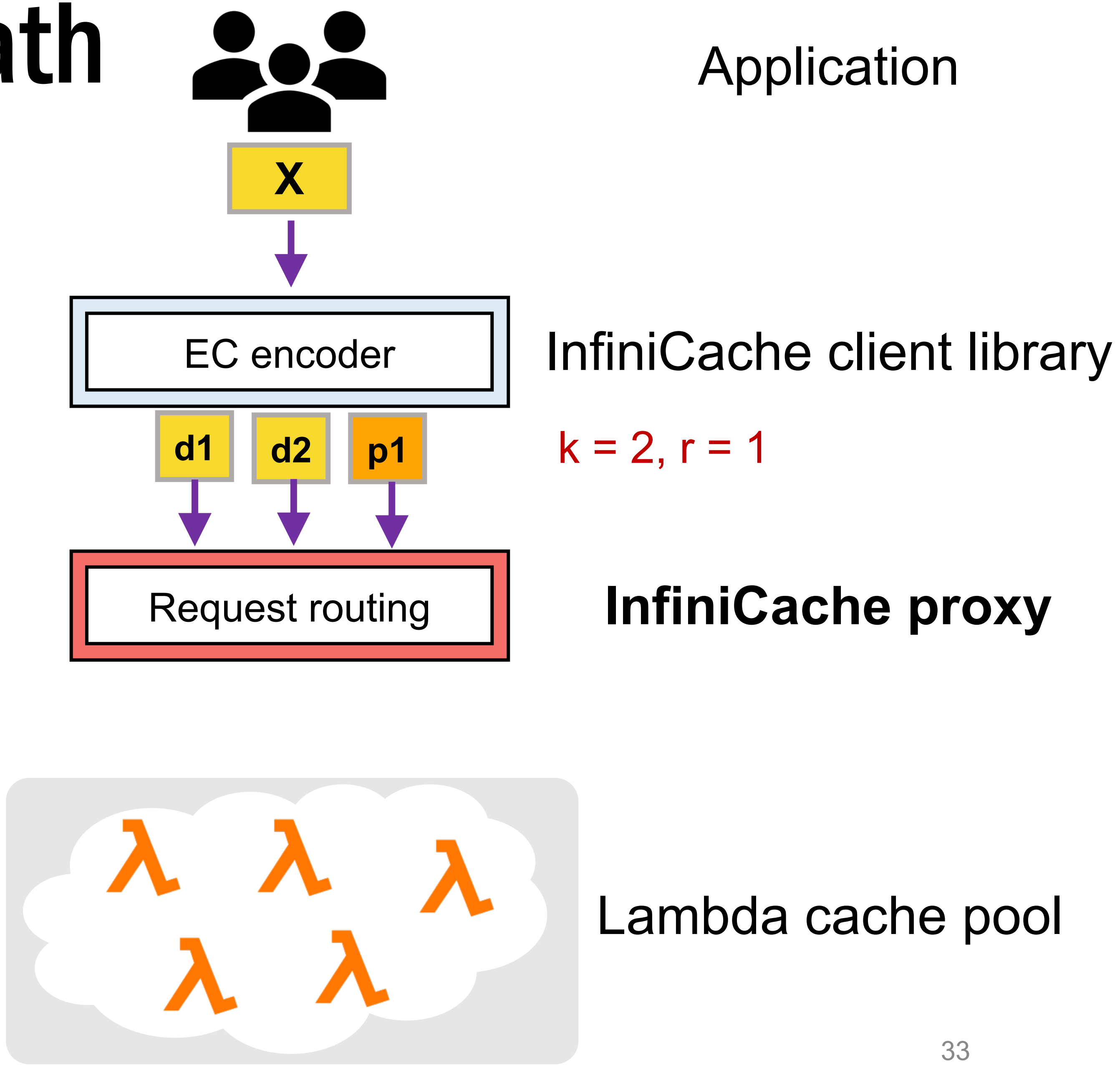
1. Object is split and encoded into k+r chunks



InfiniCache: PUT path

1. Object split and encode into k+r chunks

2. Object chunks are sent to the proxy in parallel



InfiniCache: PUT path

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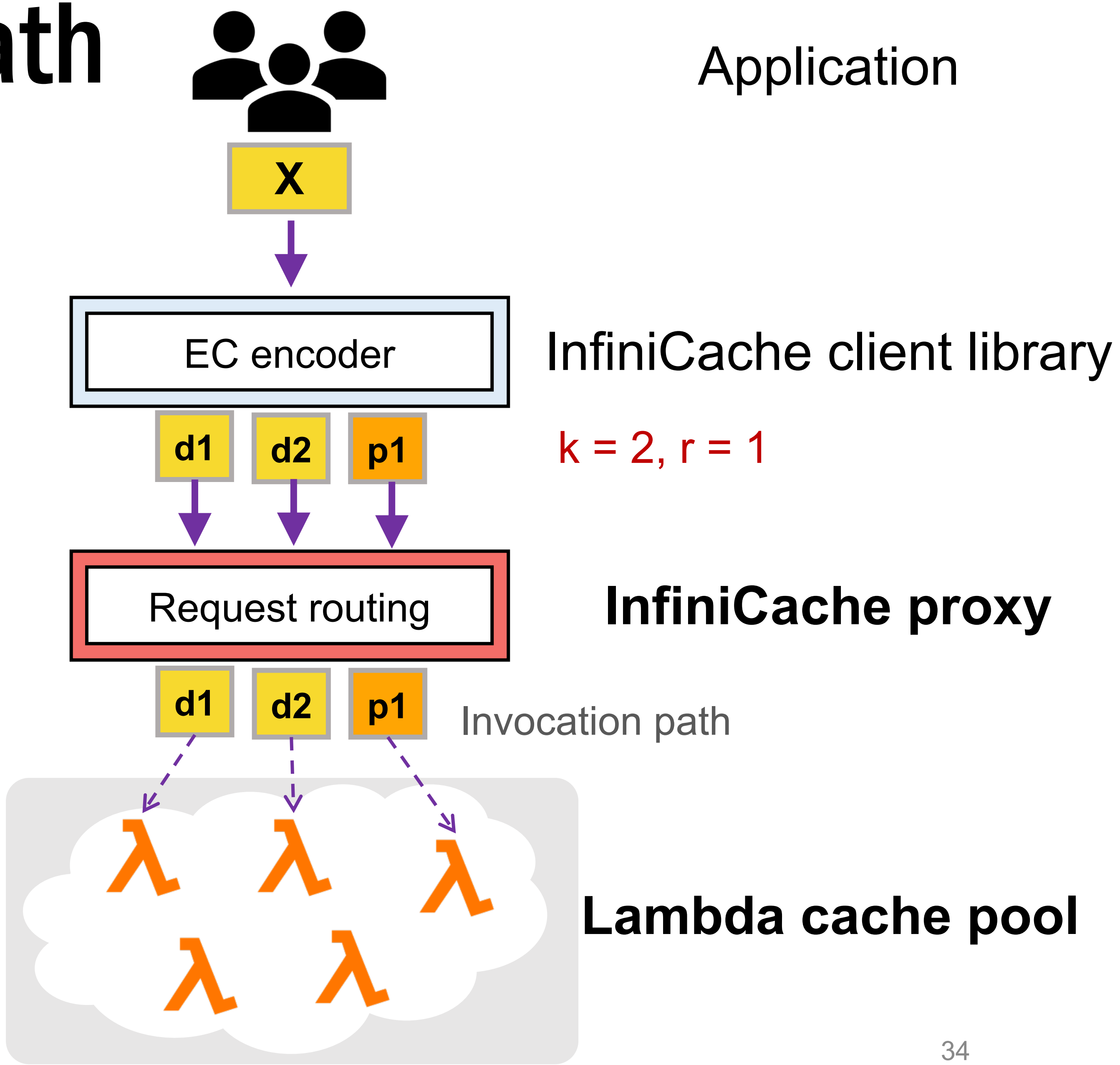
3. Proxy invoke Lambda cache nodes



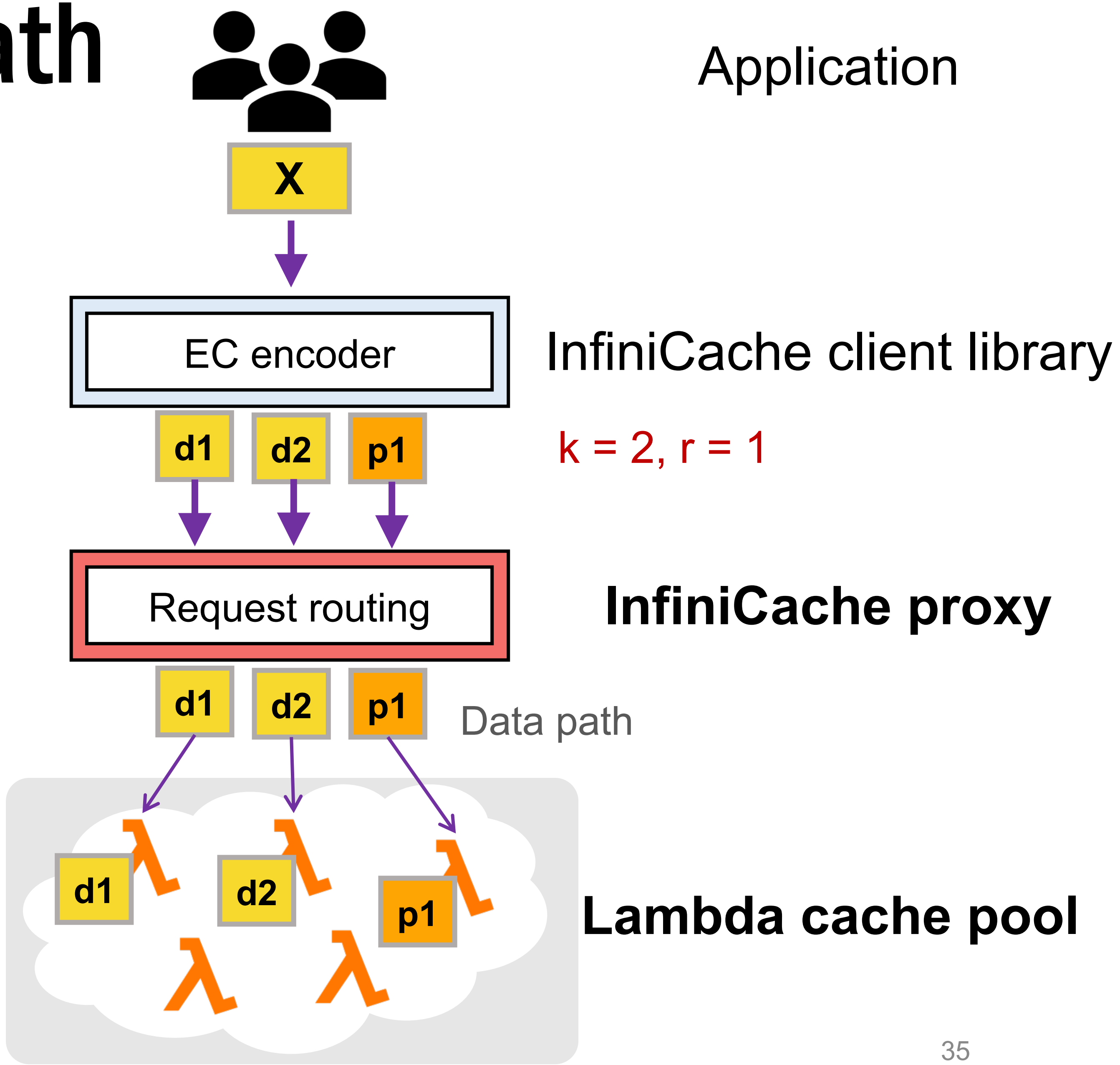
InfiniCache: PUT path

1. Object split and encode into k+r chunks

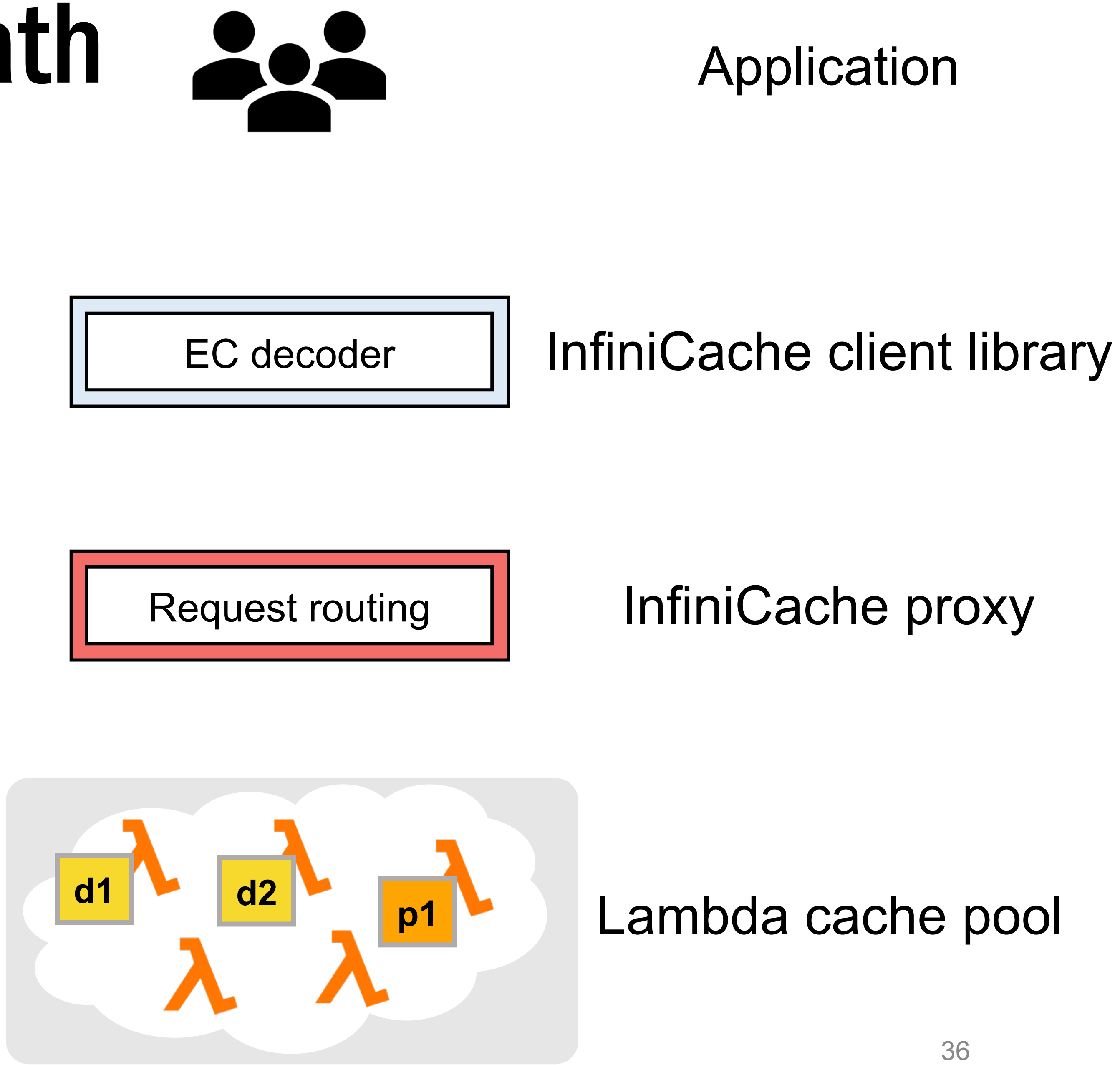
2. Object chunks are sent to the proxy in parallel

3. Proxy invoke Lambda cache nodes

4. Proxy streams object chunks to Lambda cache nodes

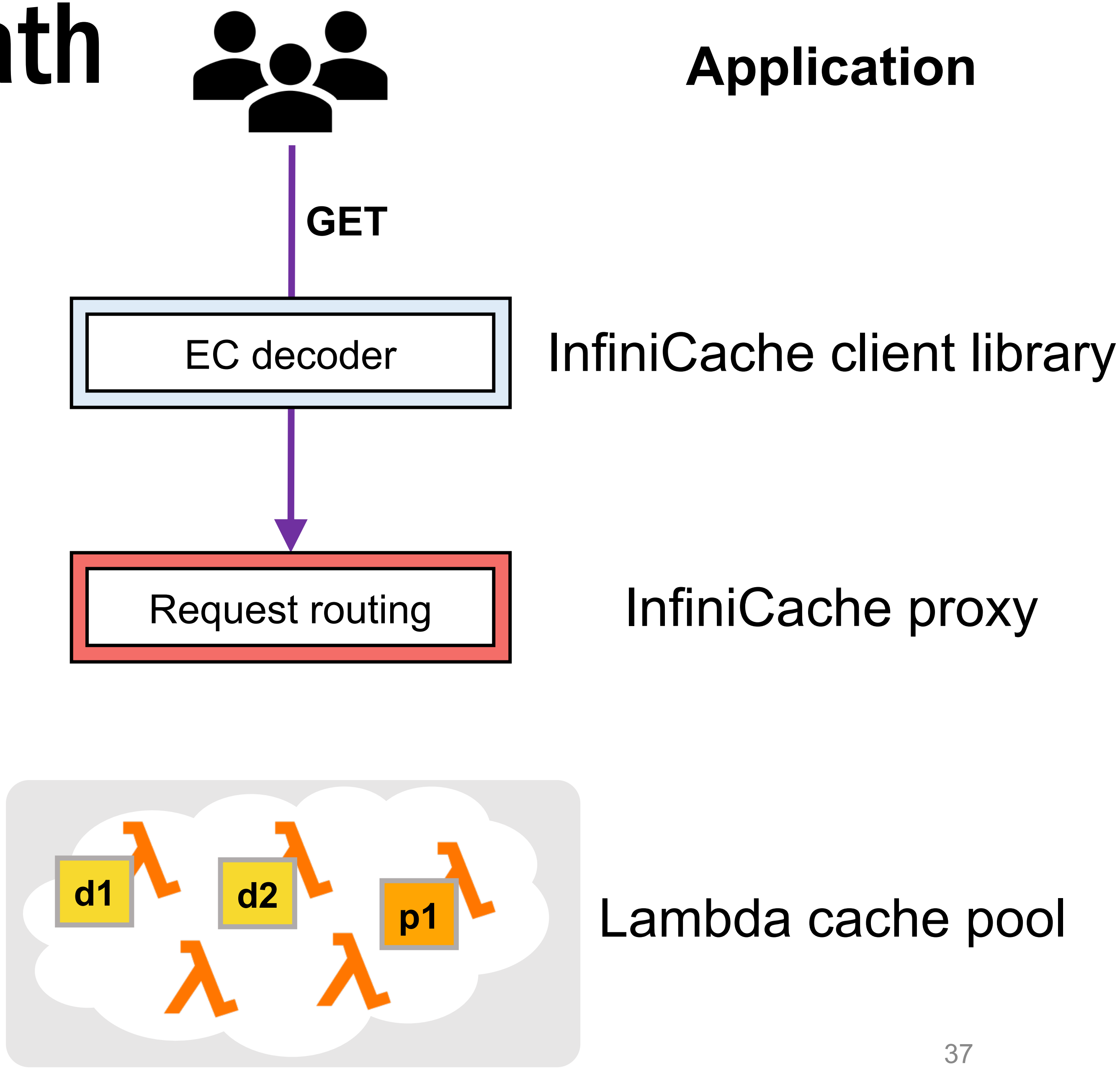


InfiniCache: GET path



InfiniCache: GET path

1. Client sends GET request

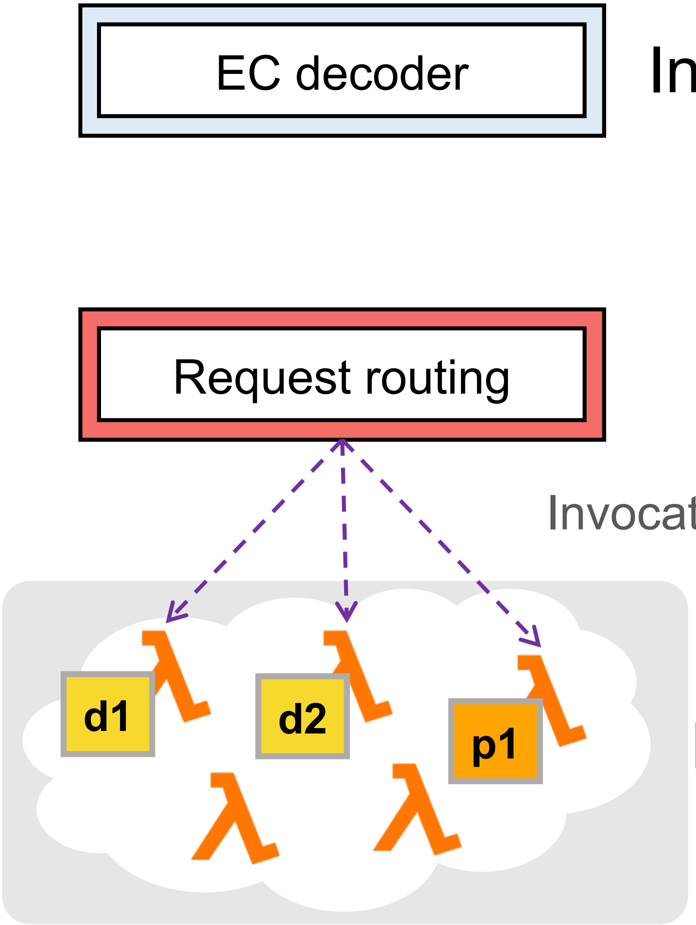


InfiniCache: GET path

Application

1. Client sends GET request

2. Proxy invokes associated
   Lambda cache nodes



InfiniCache client library

InfiniCache proxy

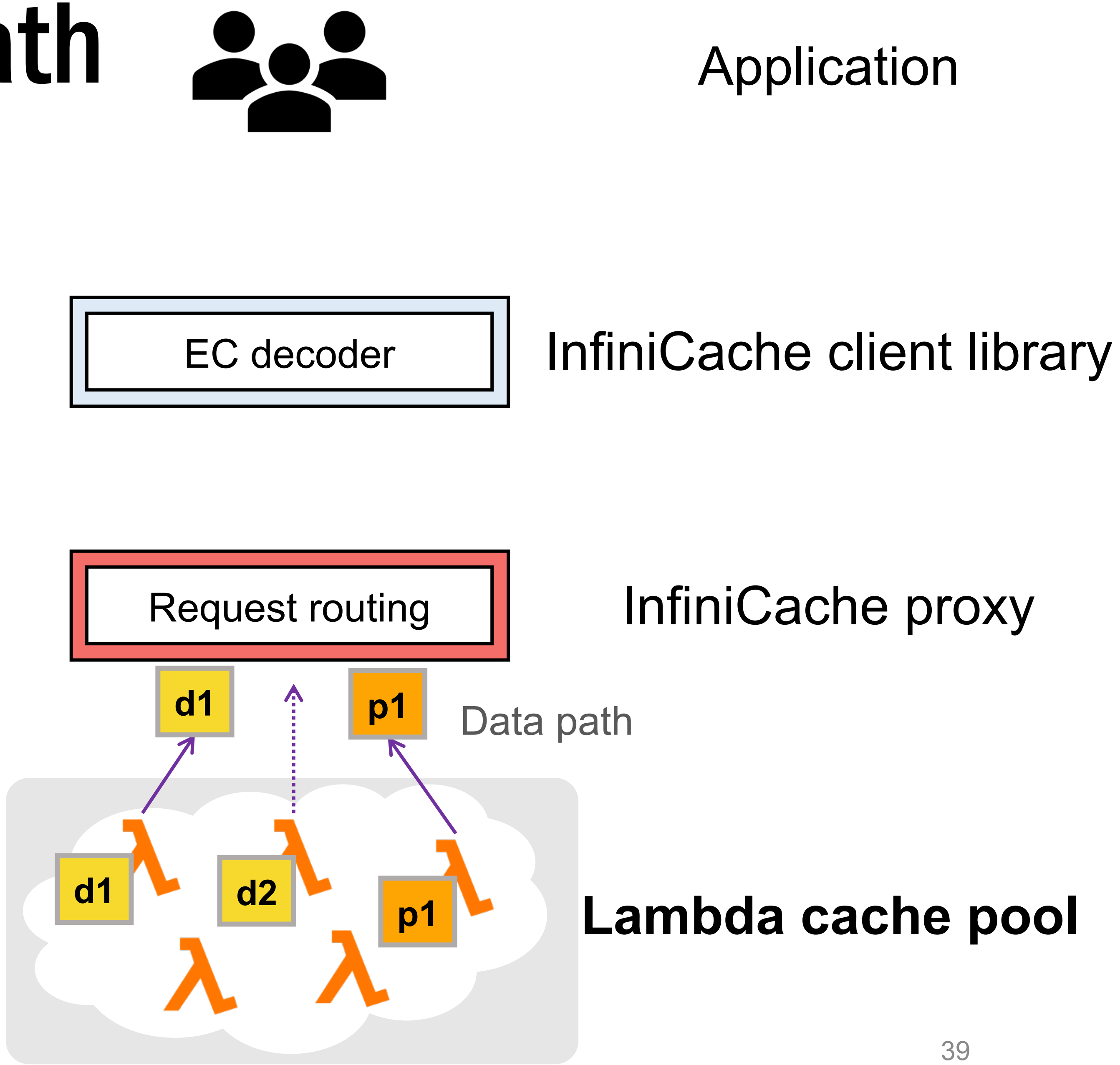
Lambda cache pool

InfiniCache: GET path

1. Client sends GET request

2. Proxy invokes associated Lambda cache nodes

3. Lambda cache nodes transfer object chunks to proxy



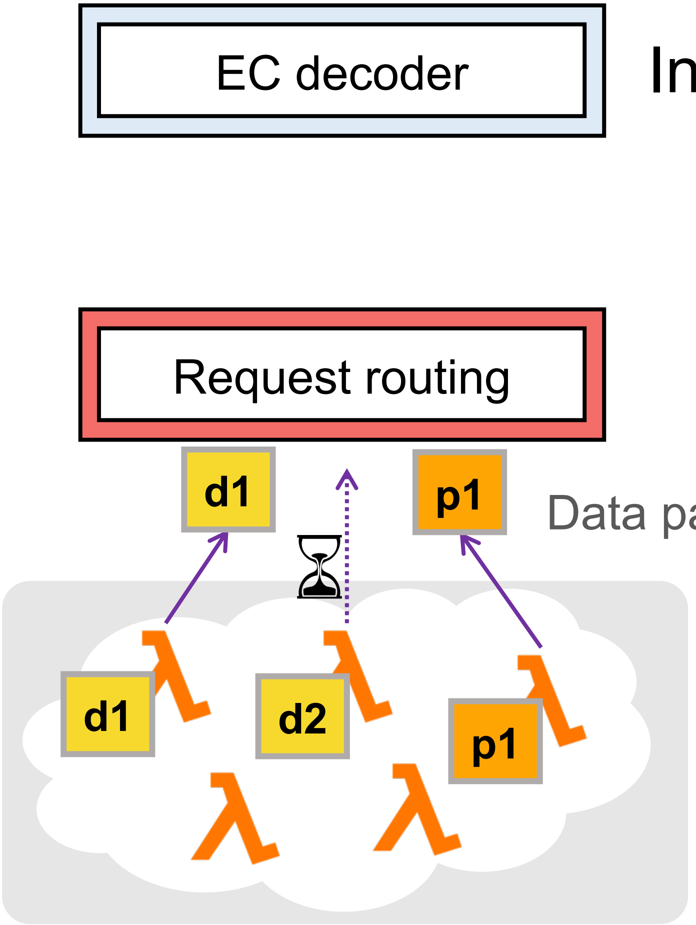
InfiniCache: GET path

Application

1. Client sends GET request

2. Proxy invokes associated Lambda cache nodes

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



InfiniCache client library

InfiniCache proxy

Data path

k = 2, r = 1

d2 is straggling…

Lambda cache pool

InfiniCache: GET path

1. Client sends GET request
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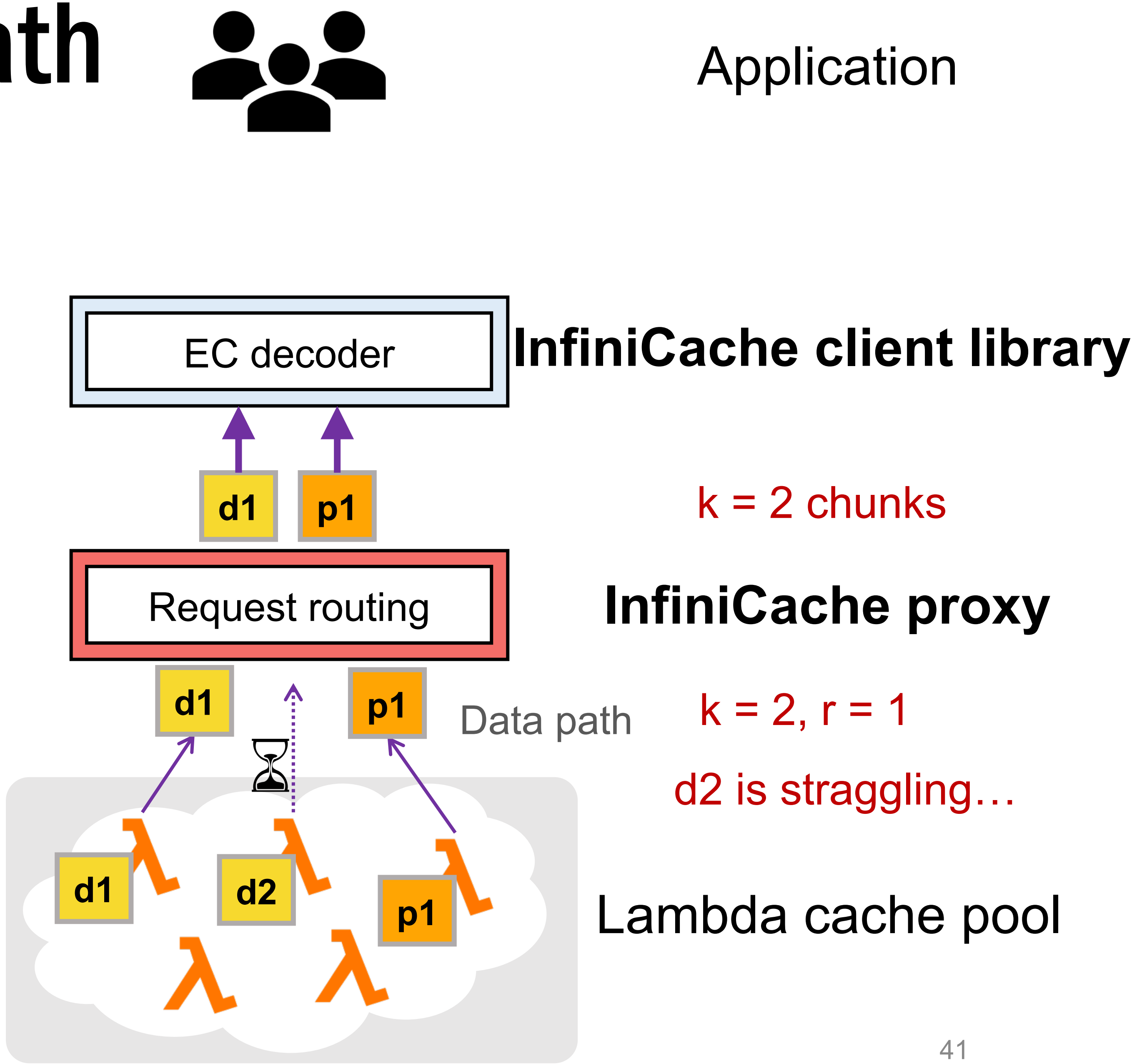
3. Lambda cache nodes transfer object chunks to proxy
4. Proxy streams k chunks in parallel to client



InfiniCache: GET path

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2. Proxy invokes associated Lambda cache nodes
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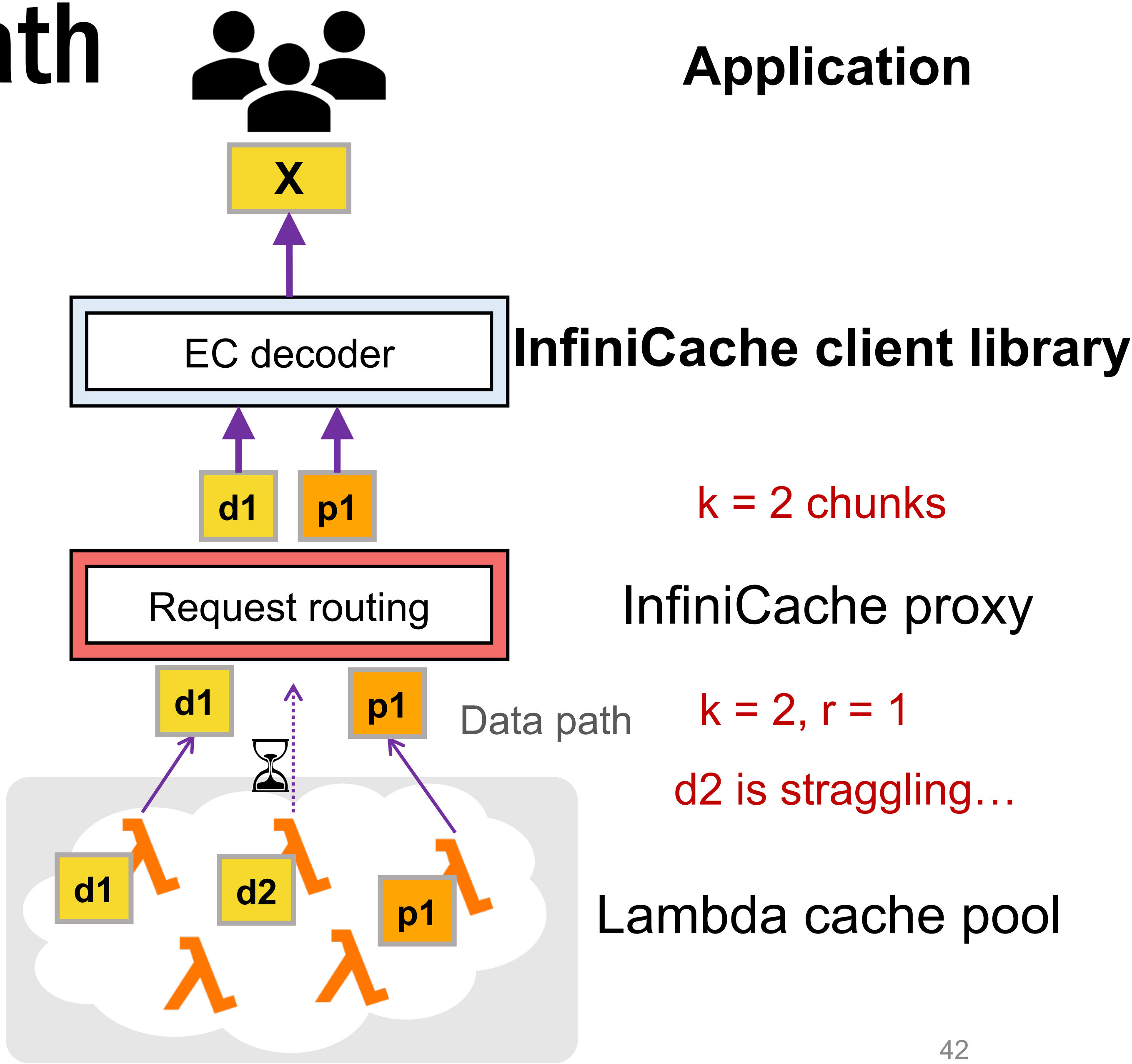
4. Proxy streams k chunks in parallel to client
5. Client library decodes k chunks



Maximizing data availability

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

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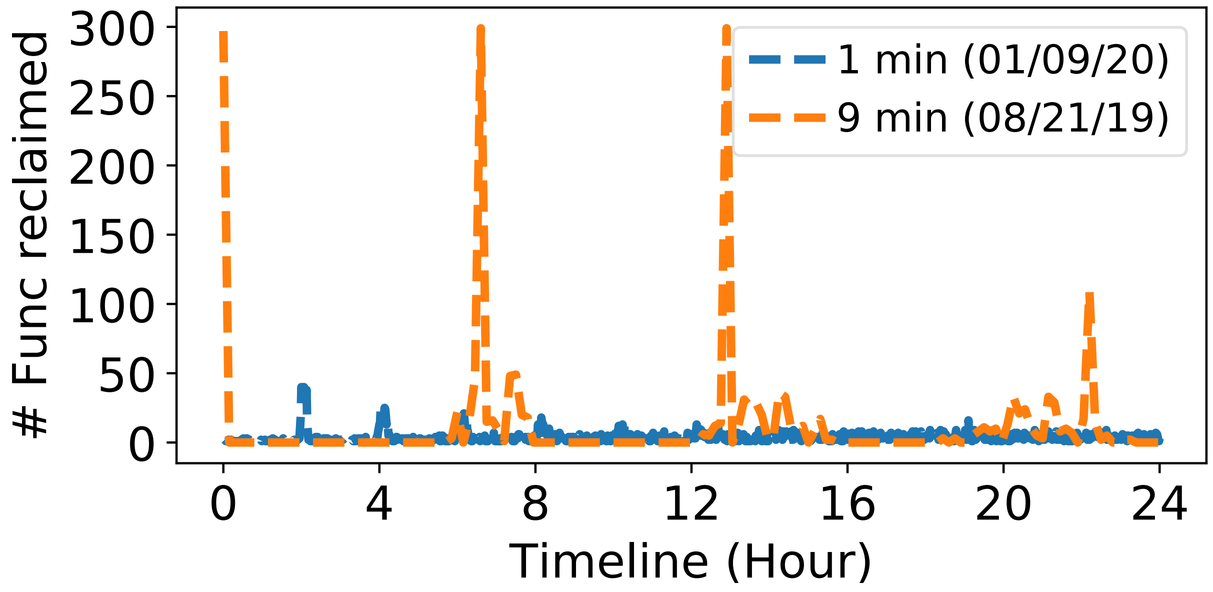
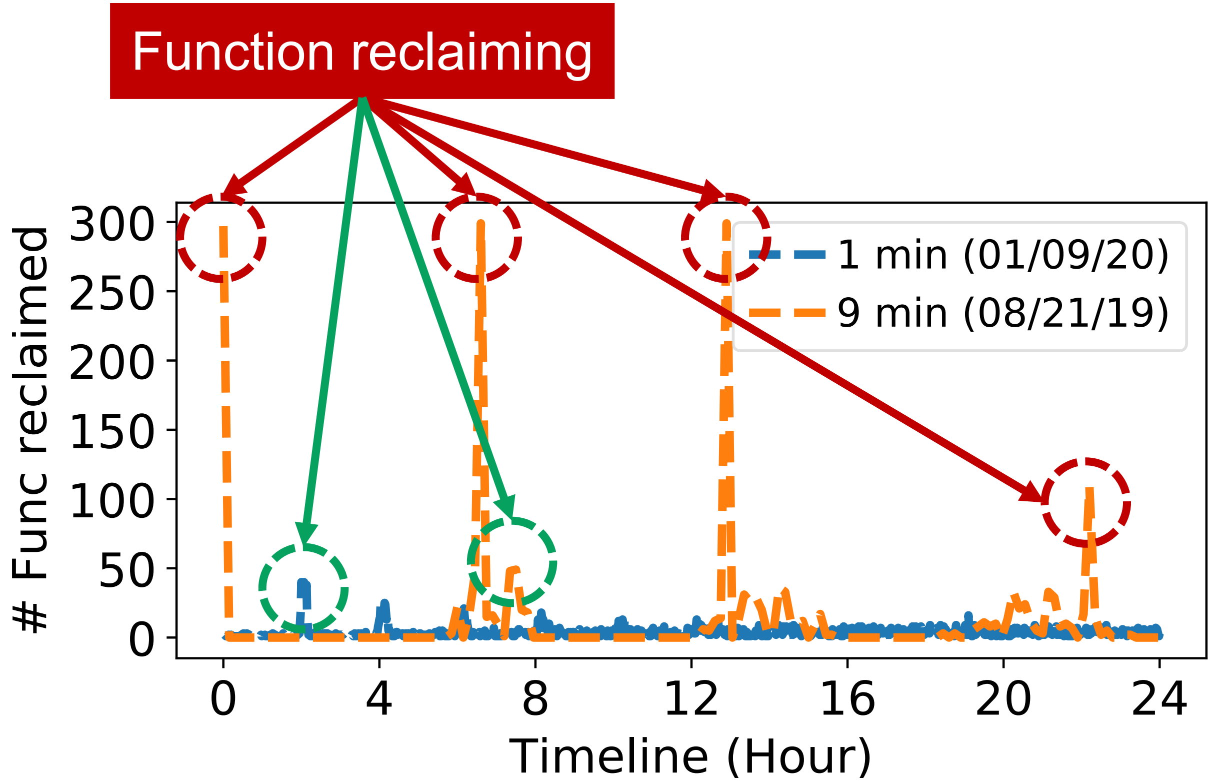
Maximizing data availability: Periodic warm-up

AWS Lambda reclaiming policy



Maximizing data availability: Periodic warm-up

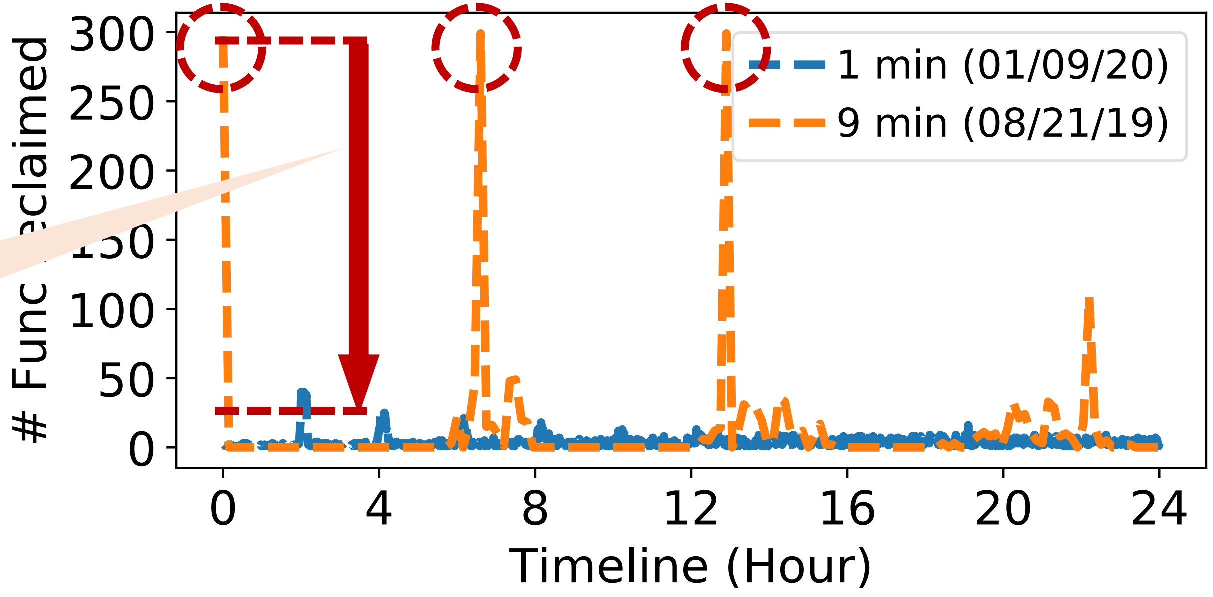
AWS Lambda reclaiming policy



Maximizing data availability: Periodic warm-up

AWS Lambda reclaiming policy

- Shorter triggering interval will lower the function reclaiming rate



1min interval significantly reduce function reclaiming rate

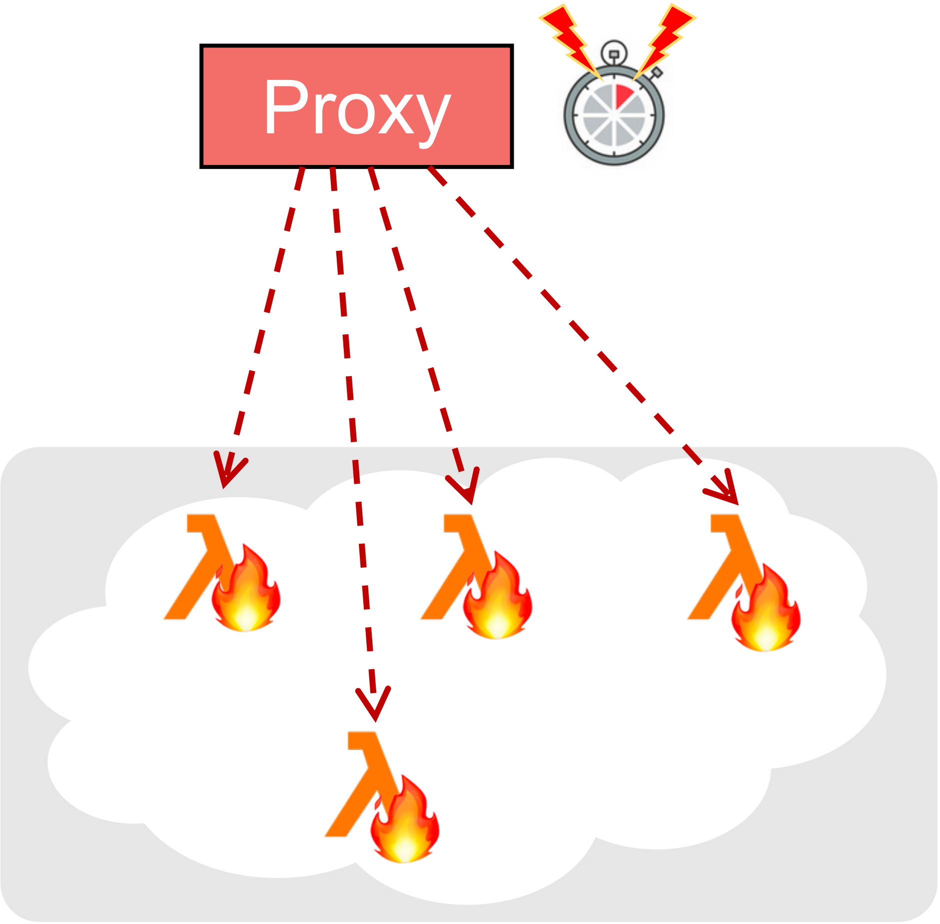
Maximizing data availability: Periodic warm-up

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

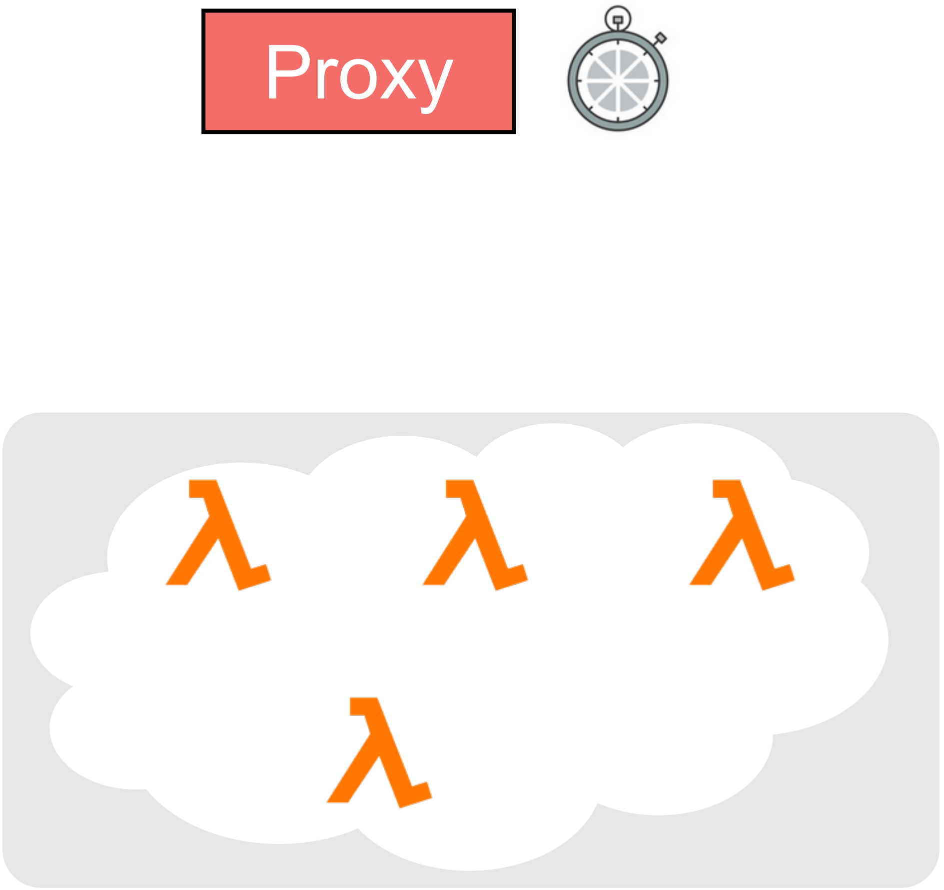
Maximizing data availability: Periodic warm-up

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

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



Maximizing data availability: Periodic backup



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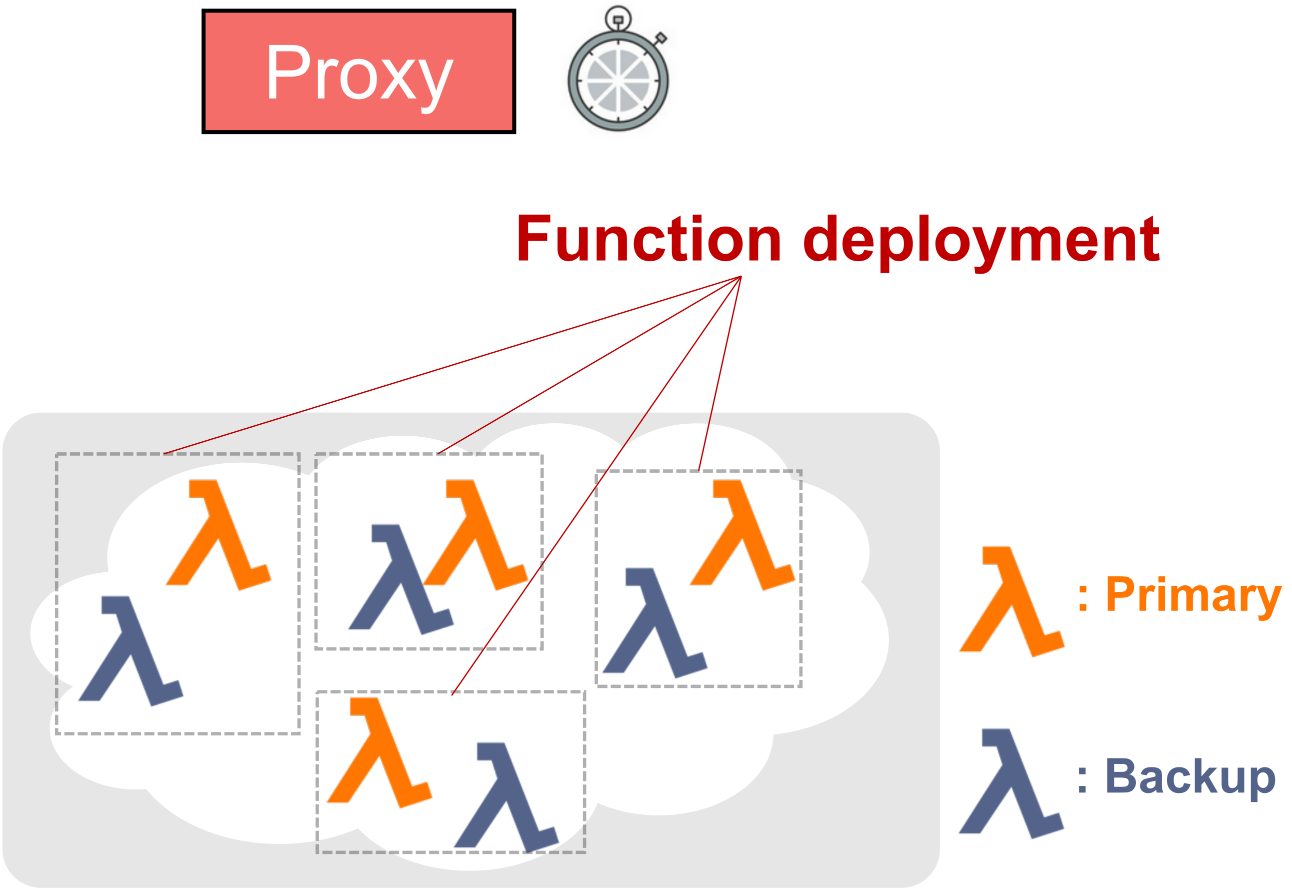
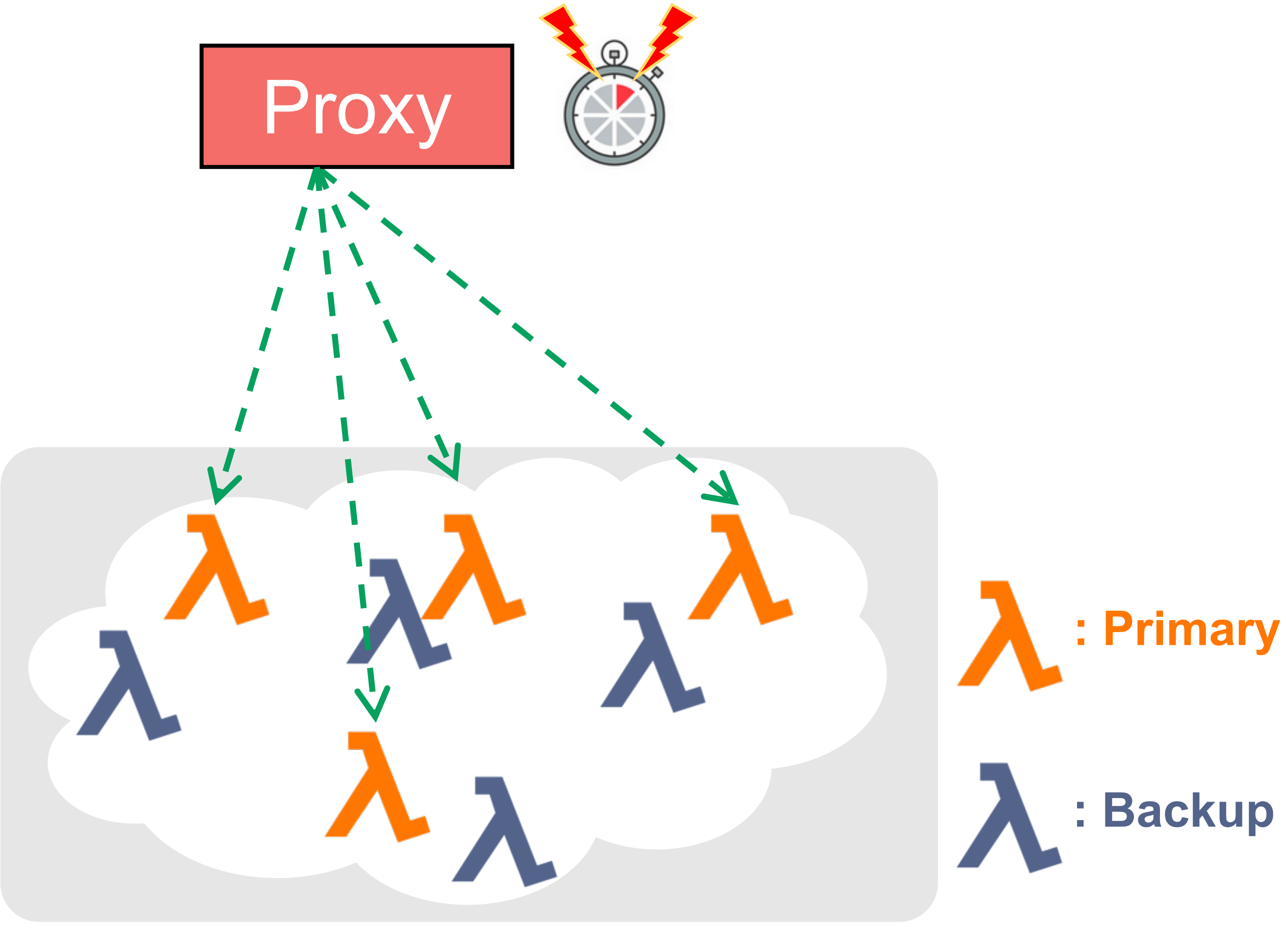


Maximizing data availability: Periodic backup

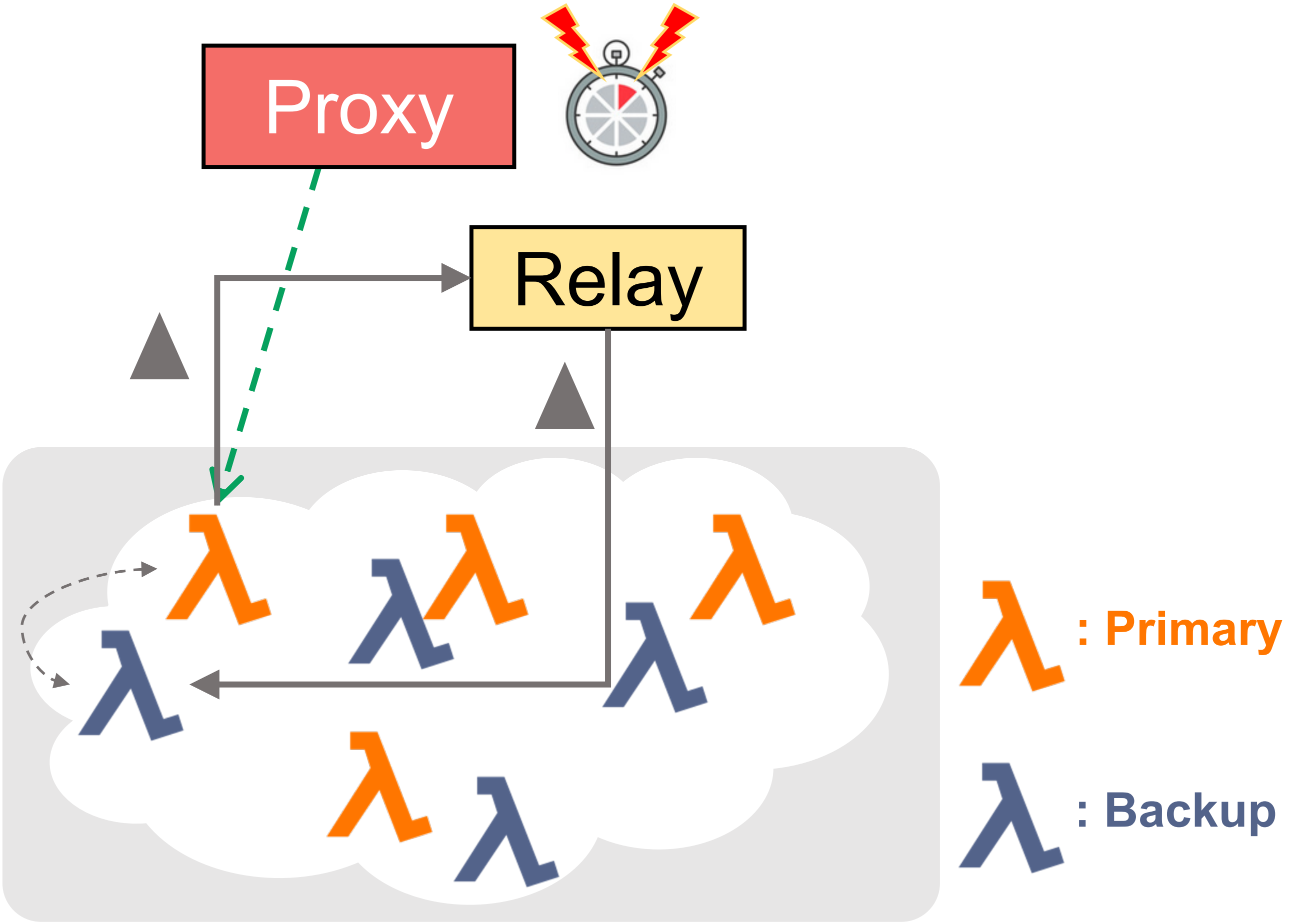
1. Proxy periodically sends out backup commands to Lambda cache nodes



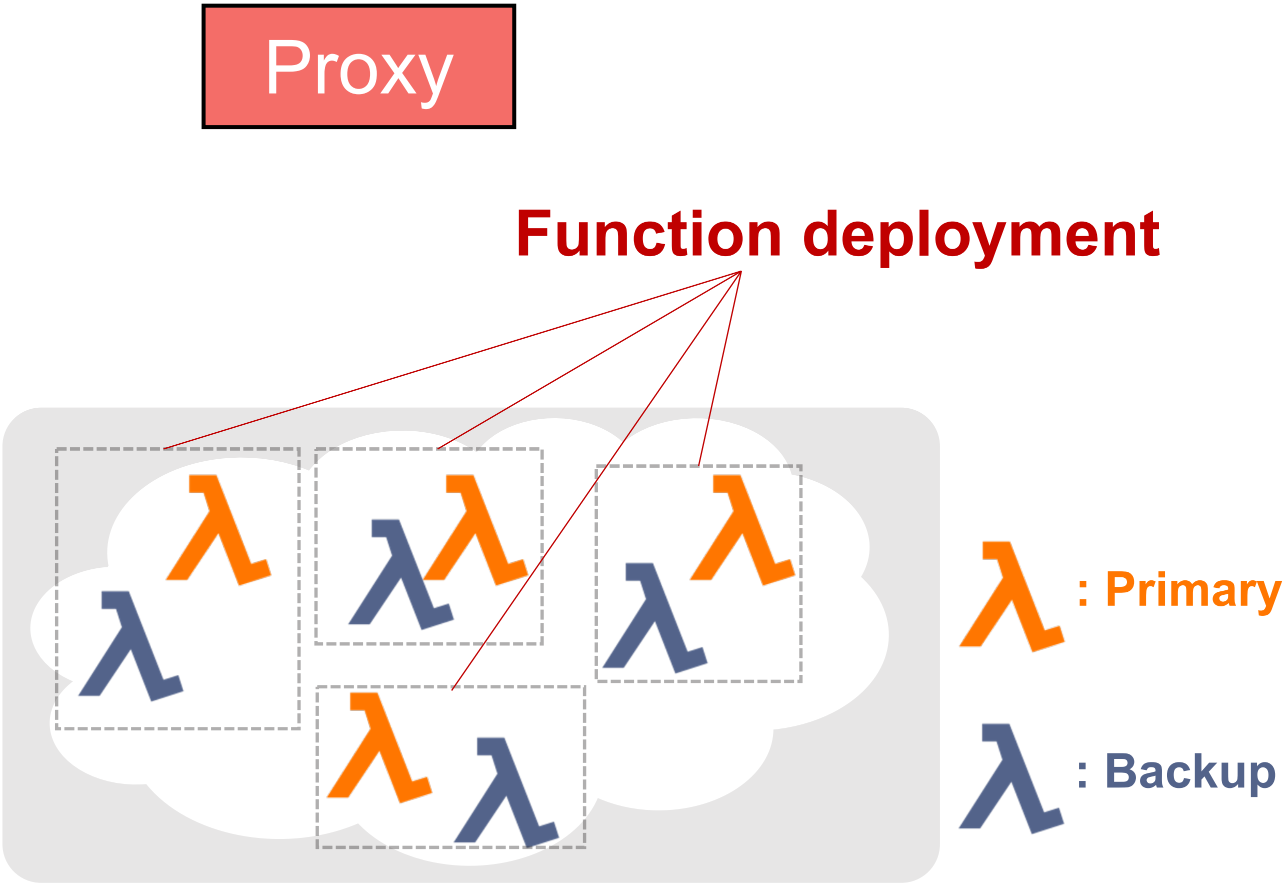
Maximizing data availability: Periodic backup

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

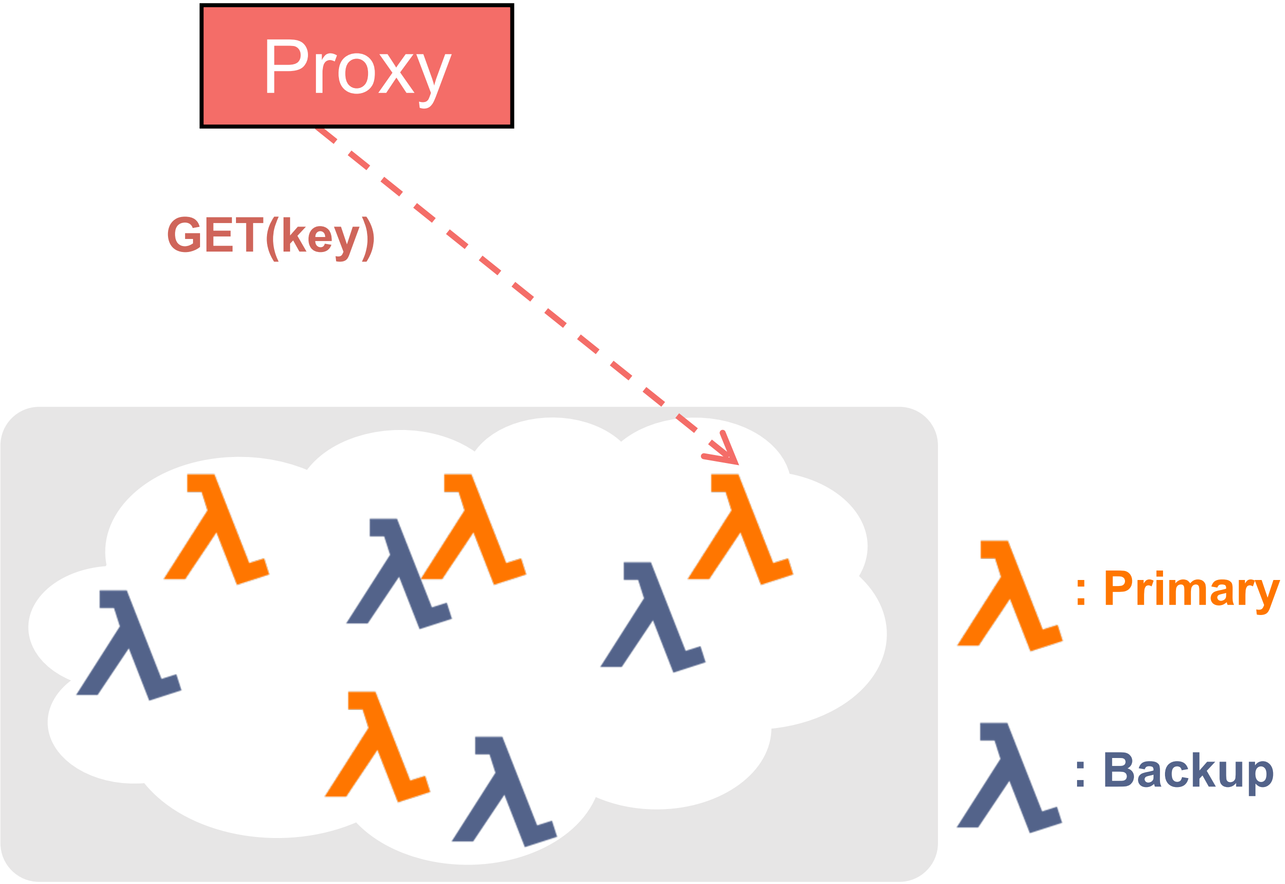


Seamless failover



Maximizing data availability: Seamless failover

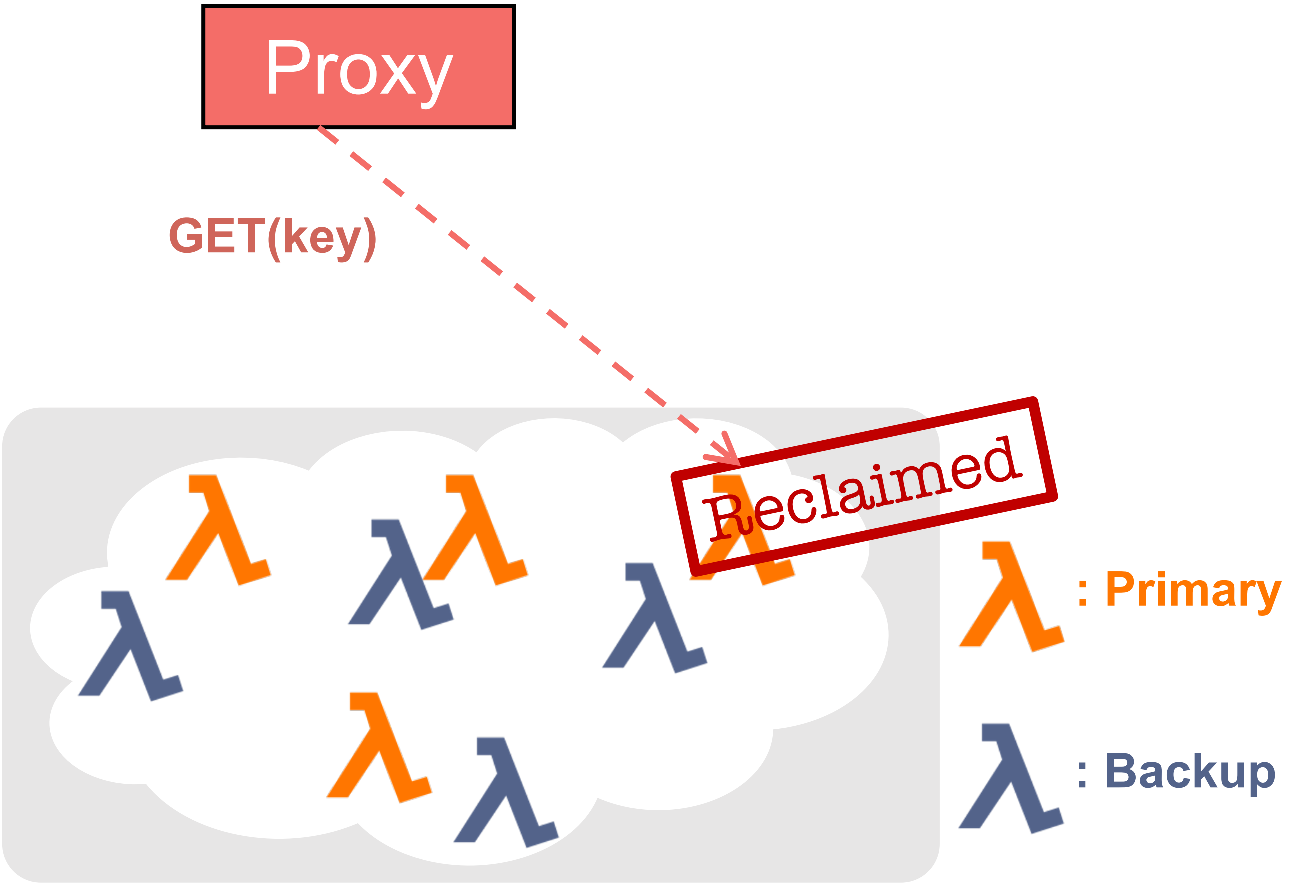
1. Proxy invokes a Lambda cache node with a GET request



Maximizing data availability: Seamless failover

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

2. Primary Lambda gets reclaimed



Maximizing data availability: Seamless failover

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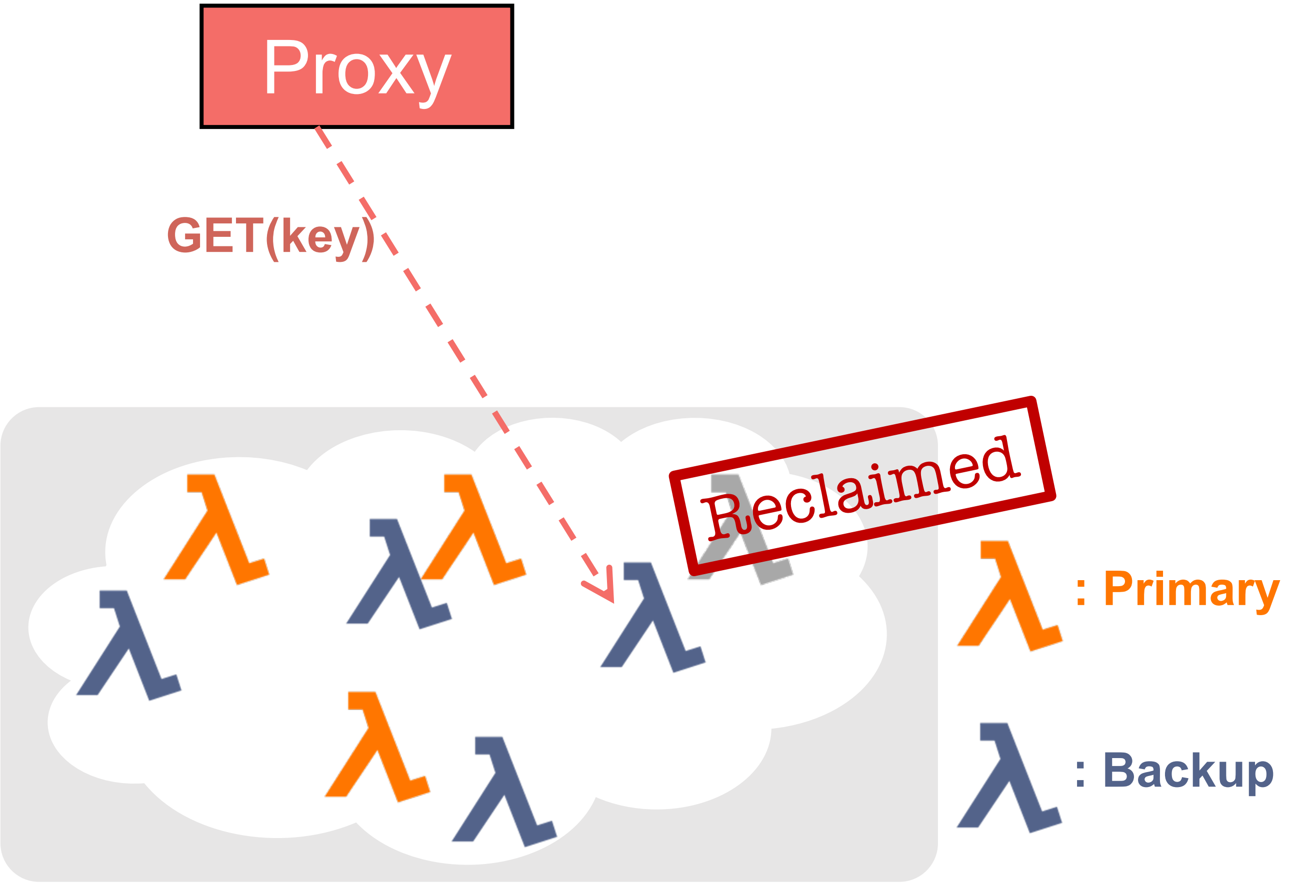
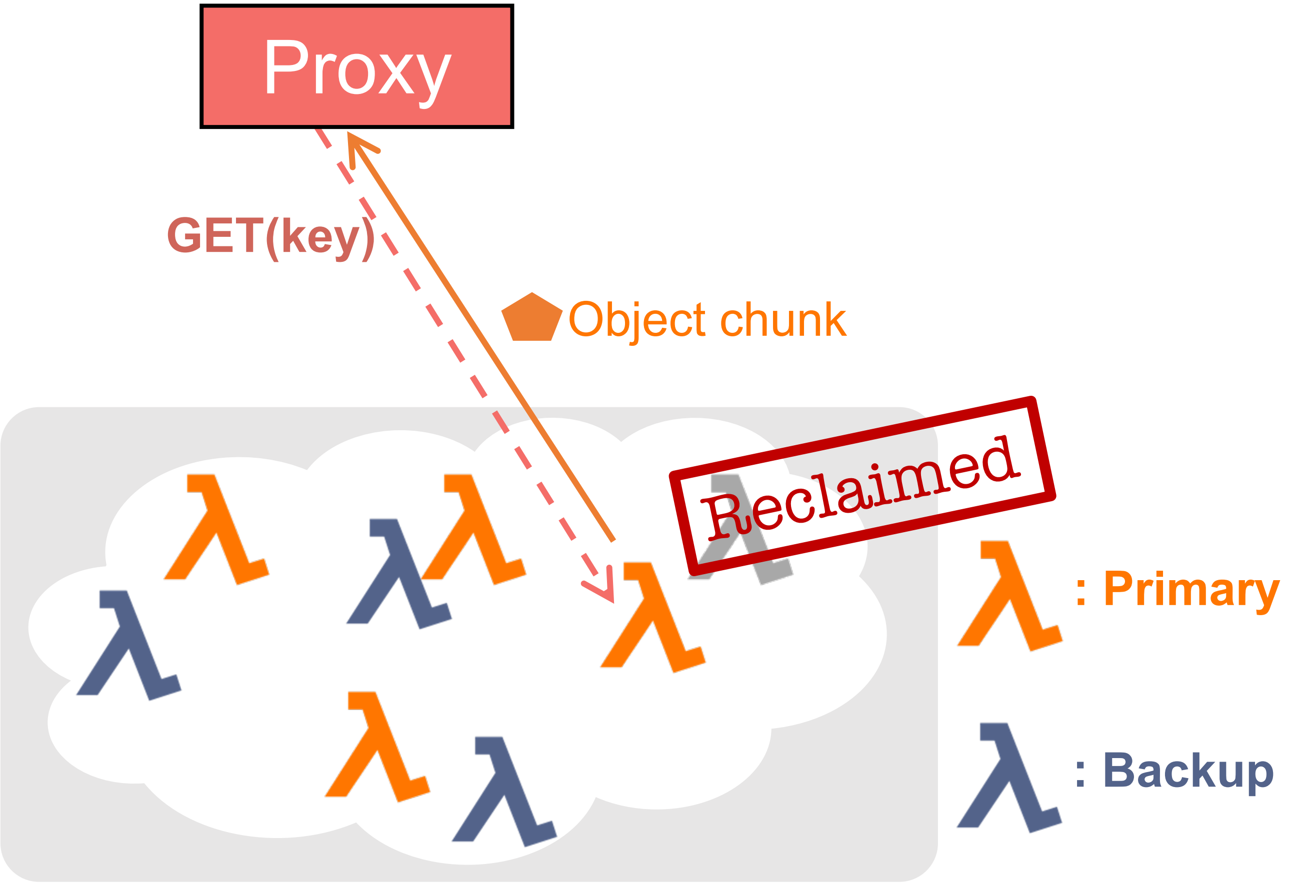


Maximizing data availability: Seamless failover

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

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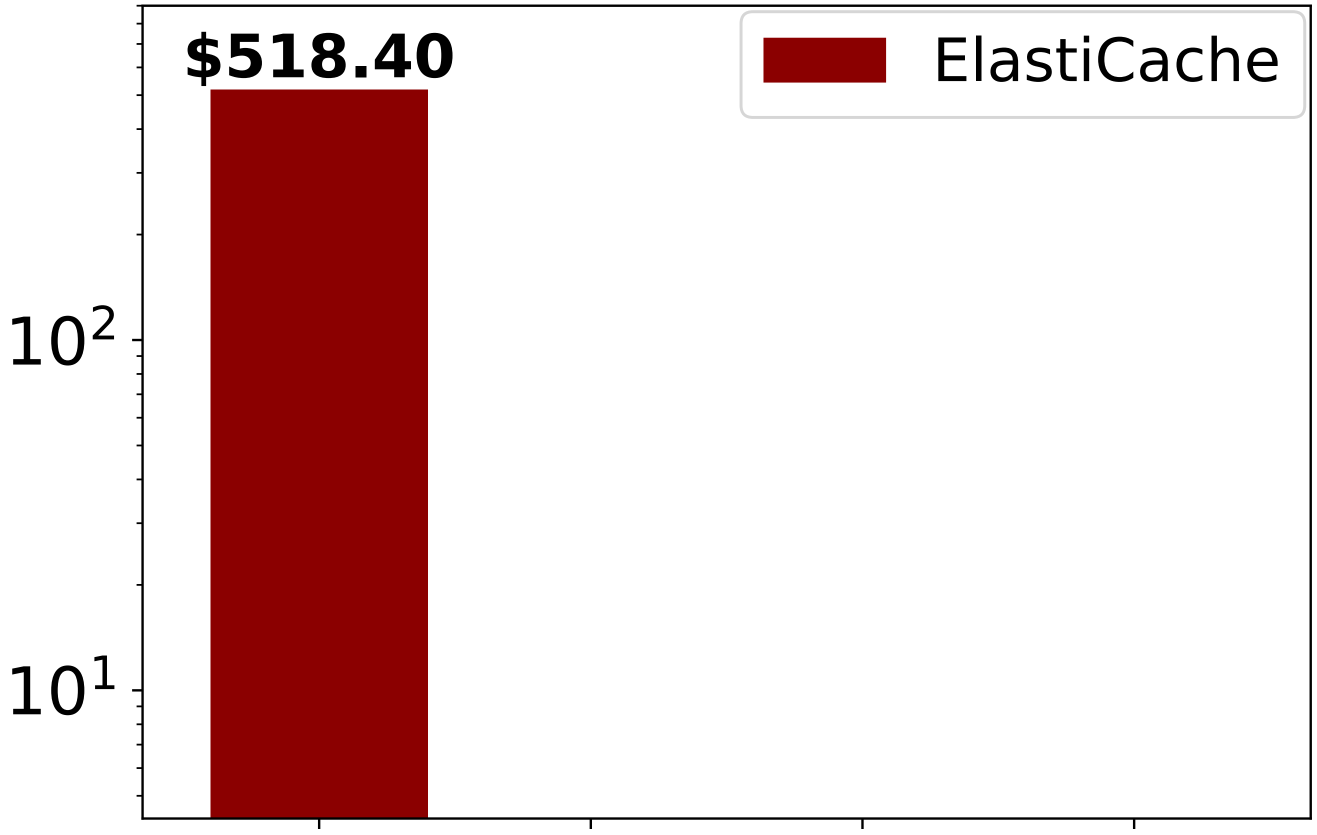
Experimental setup

- 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

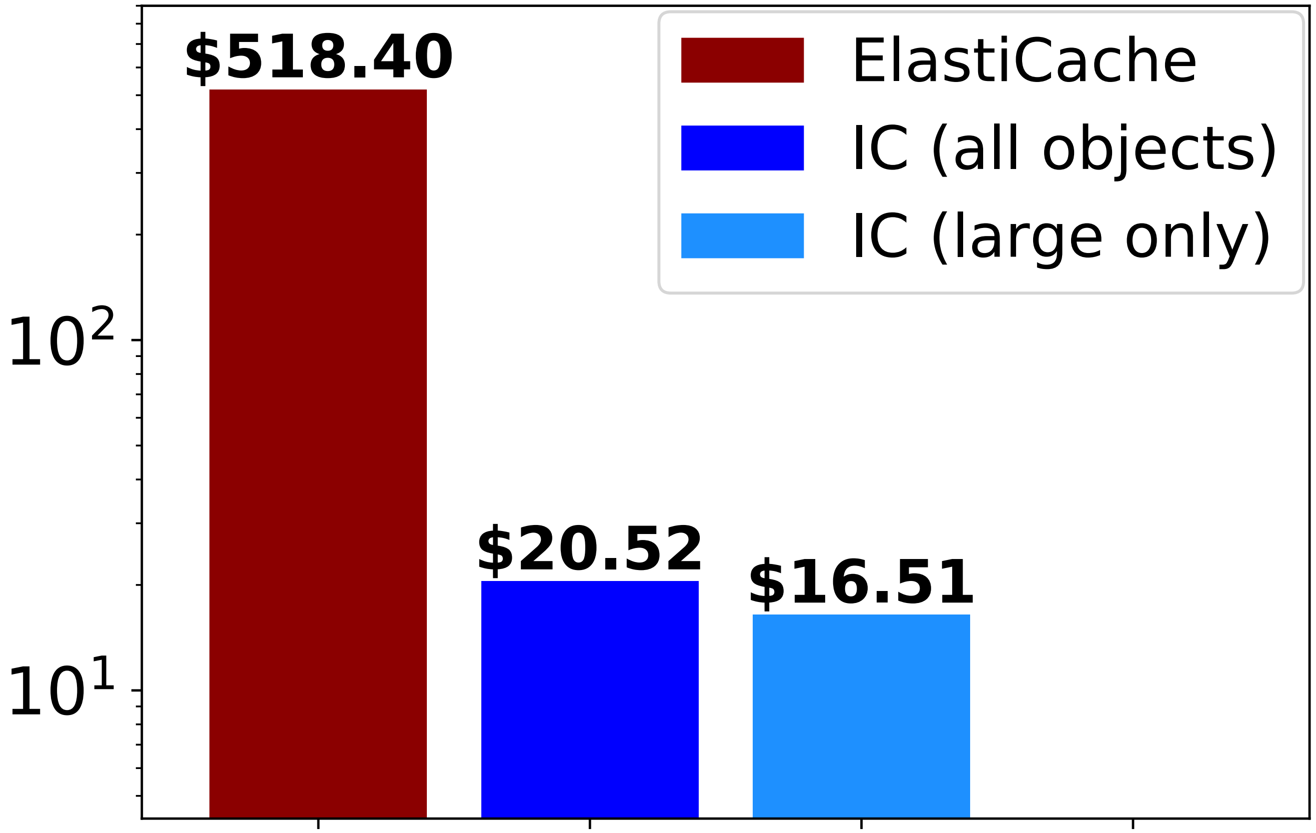
Cost effectiveness of InfiniCache



AWS ElastiCache

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

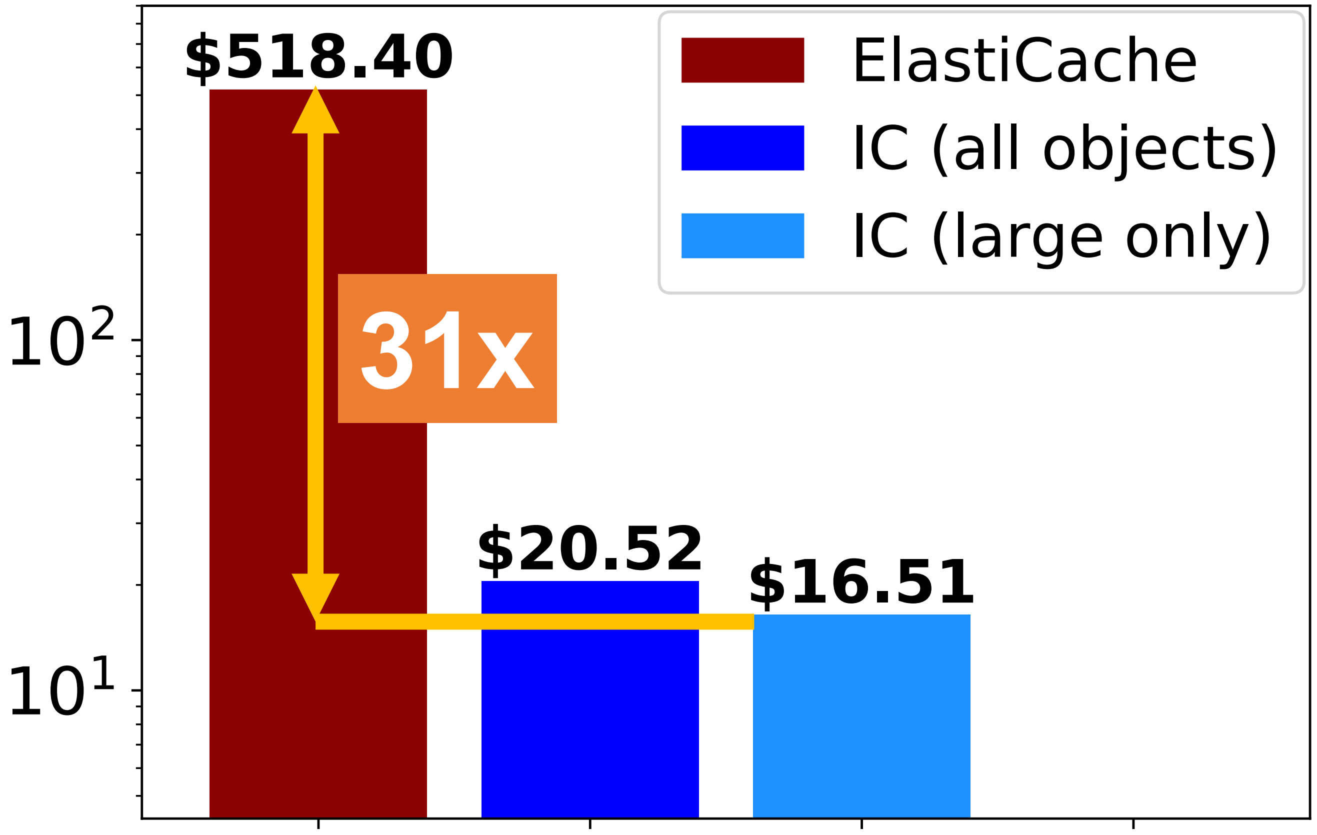
Cost effectiveness of InfiniCache



Workload setup

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

Cost effectiveness of InfiniCache



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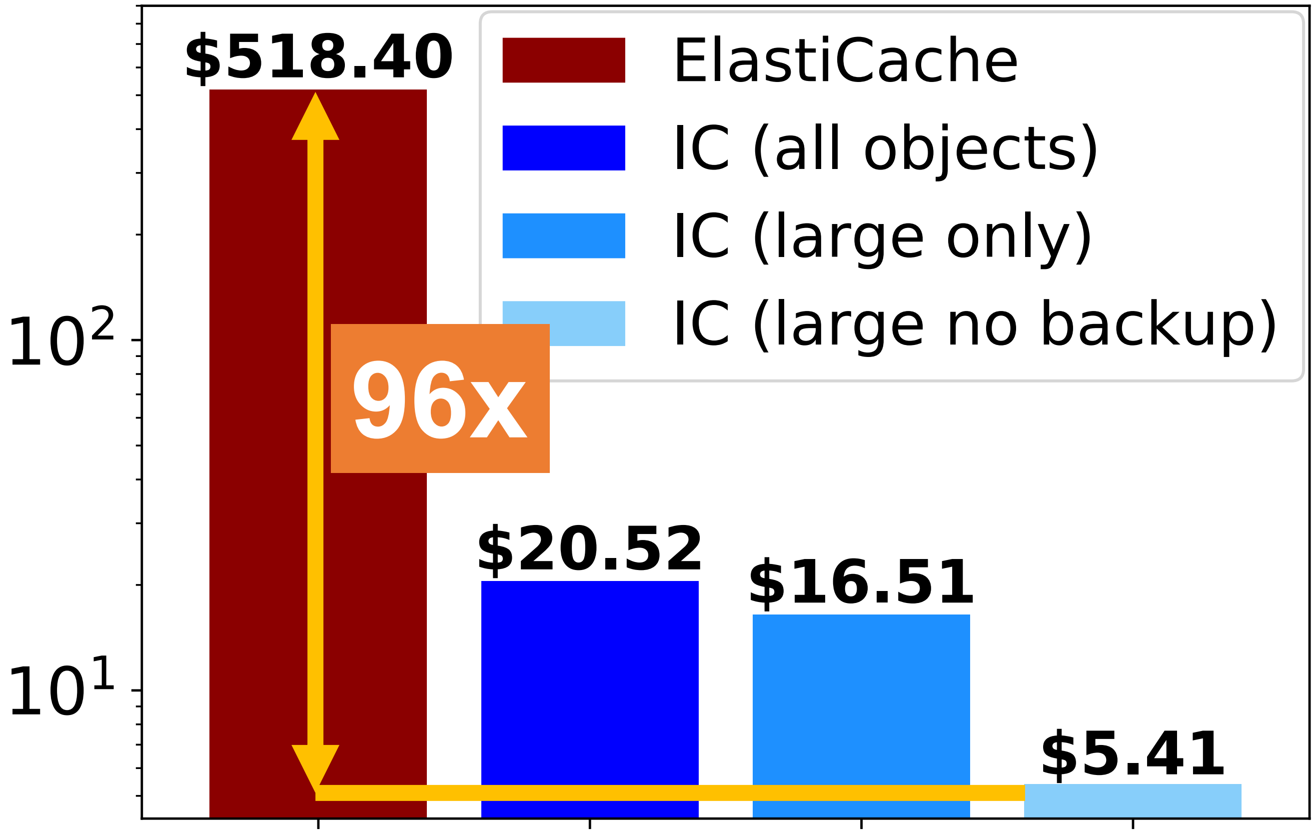
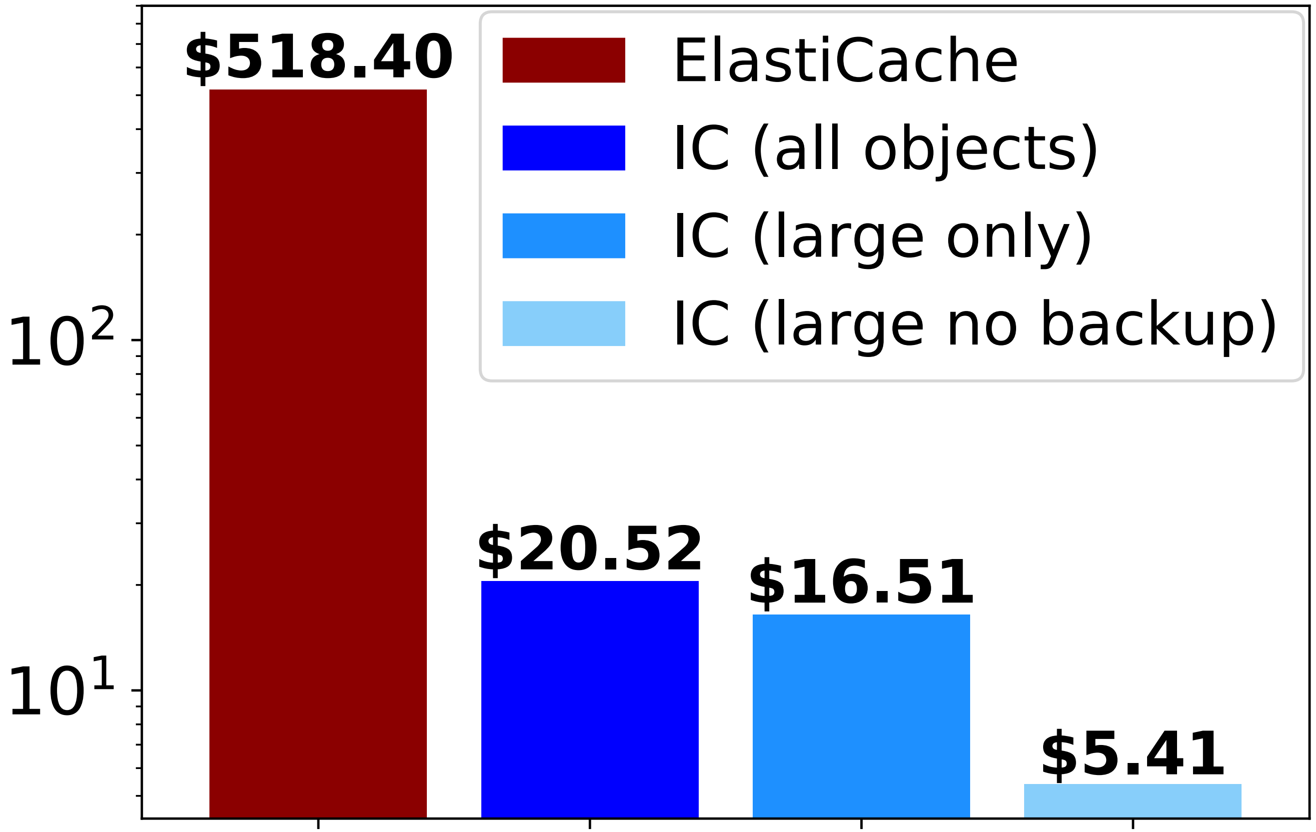


Workload setup

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

Cost effectiveness of InfiniCache



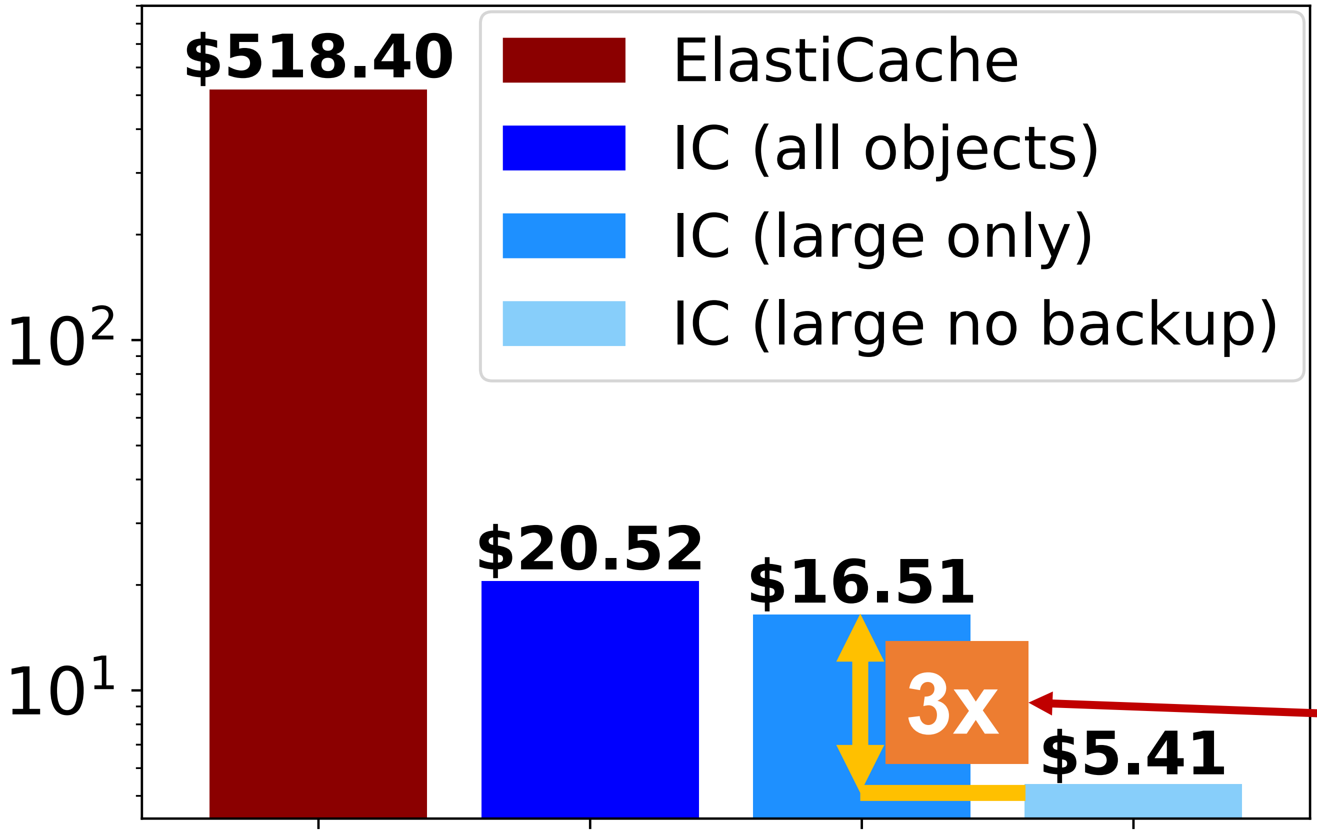
Workload setup

- 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



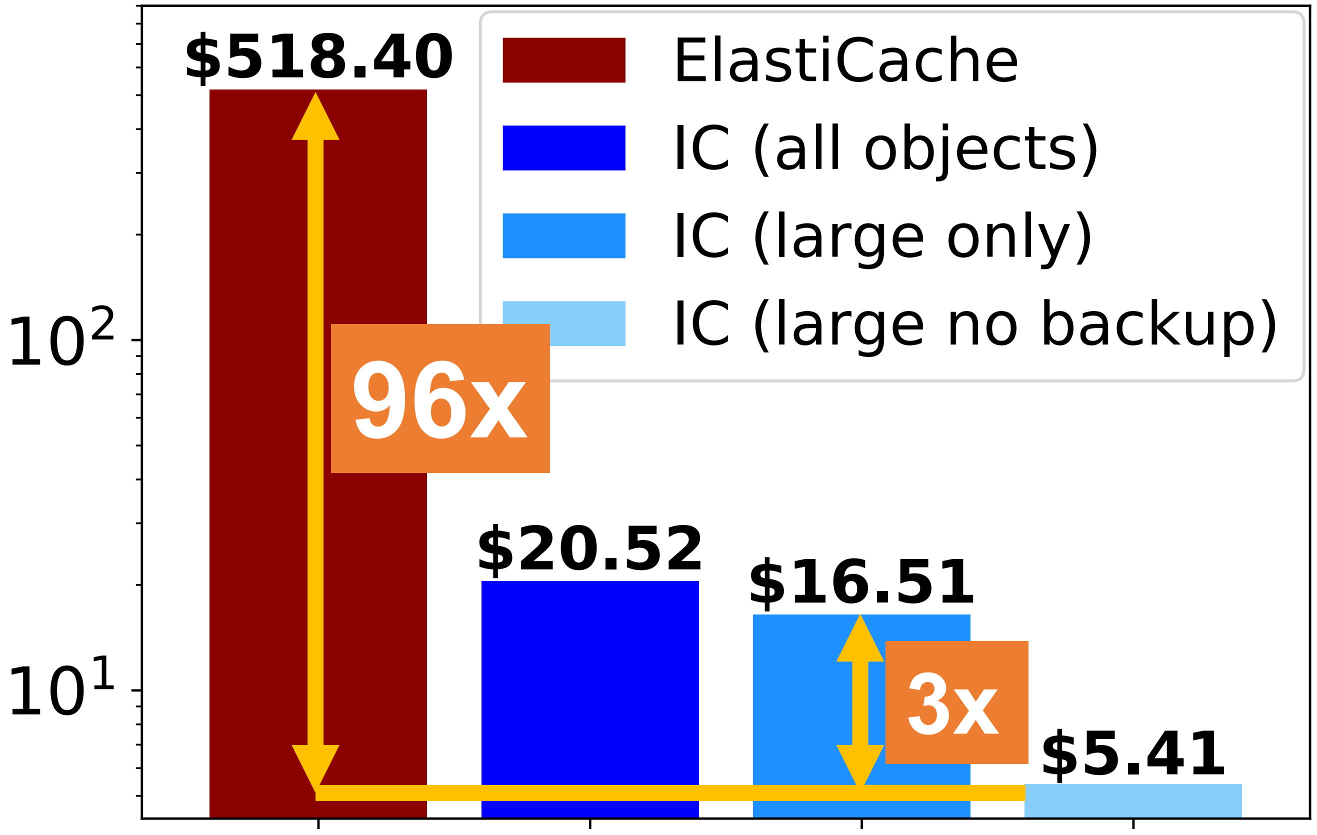
Workload setup

- 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

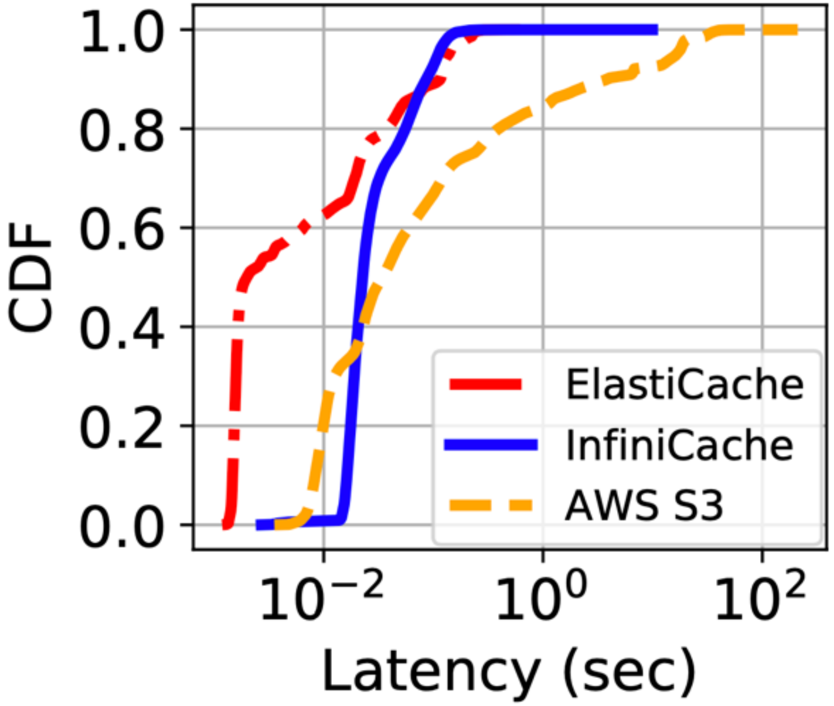


Workload setup

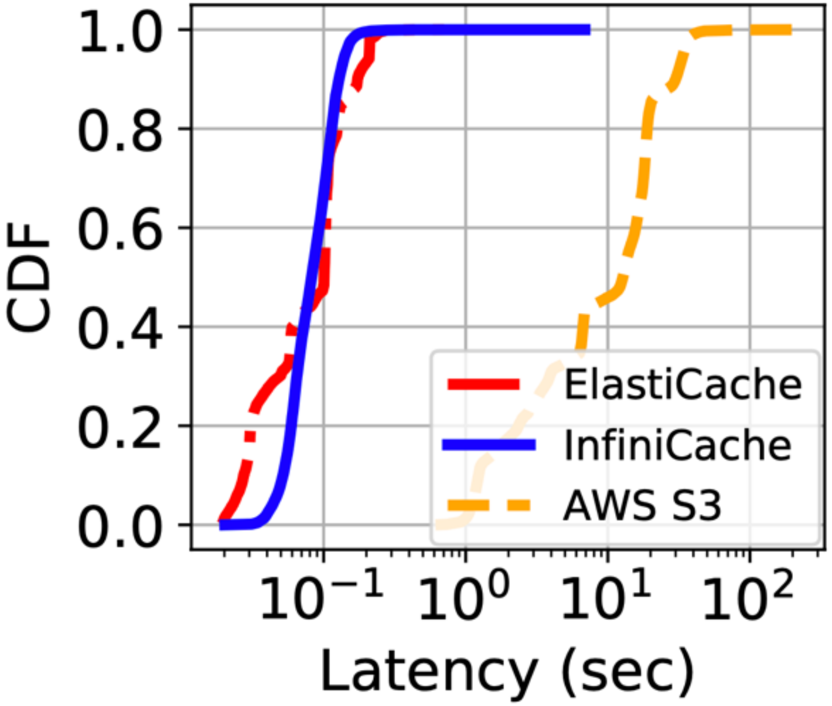
- All objects
- Large object only
  - Object larger than 10MB
- Large object w/o backup

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

Performance of InfiniCache



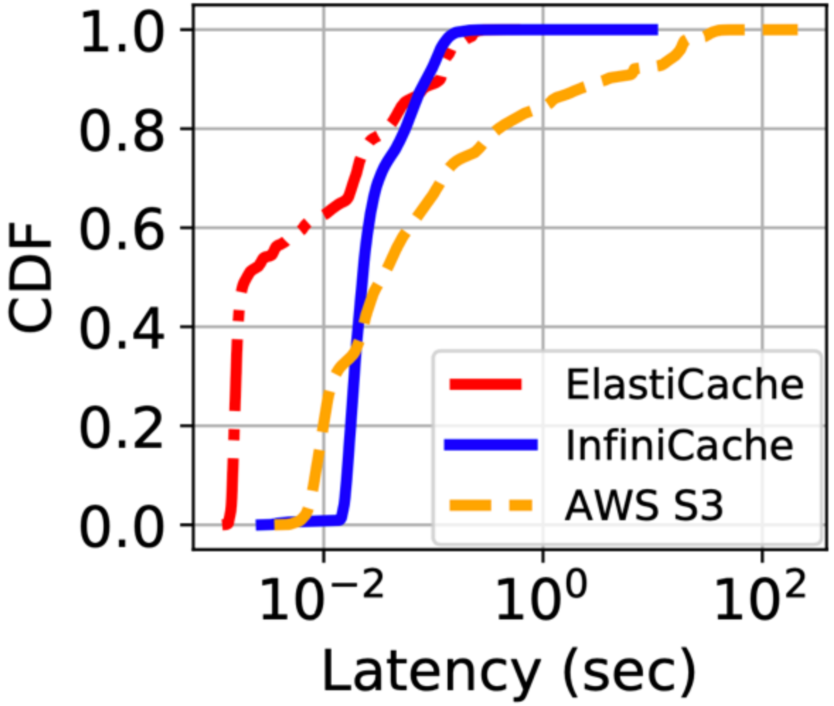
All objects



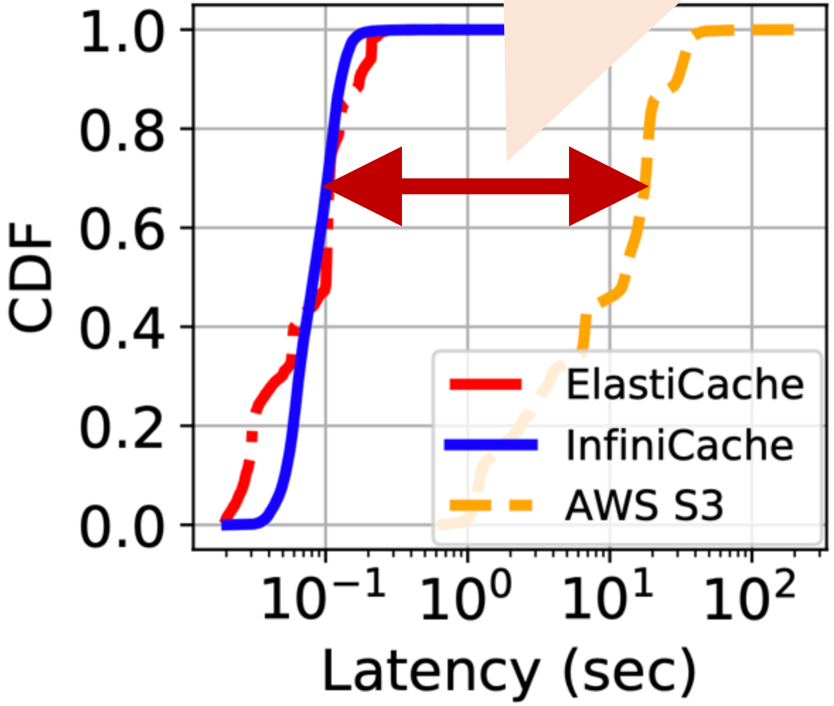
Large objects only

Performance of InfiniCache

> 100 times improvement

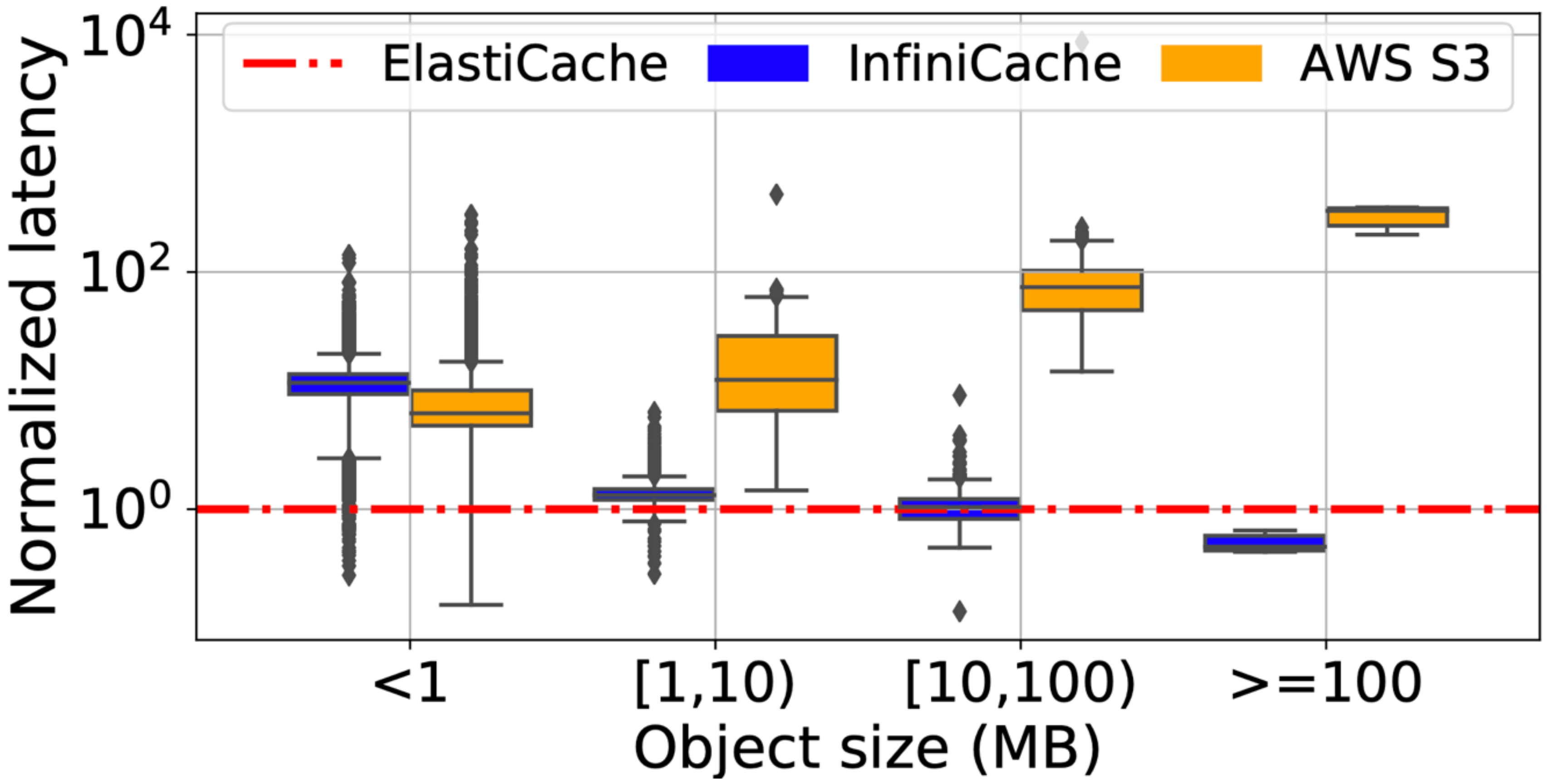


All objects

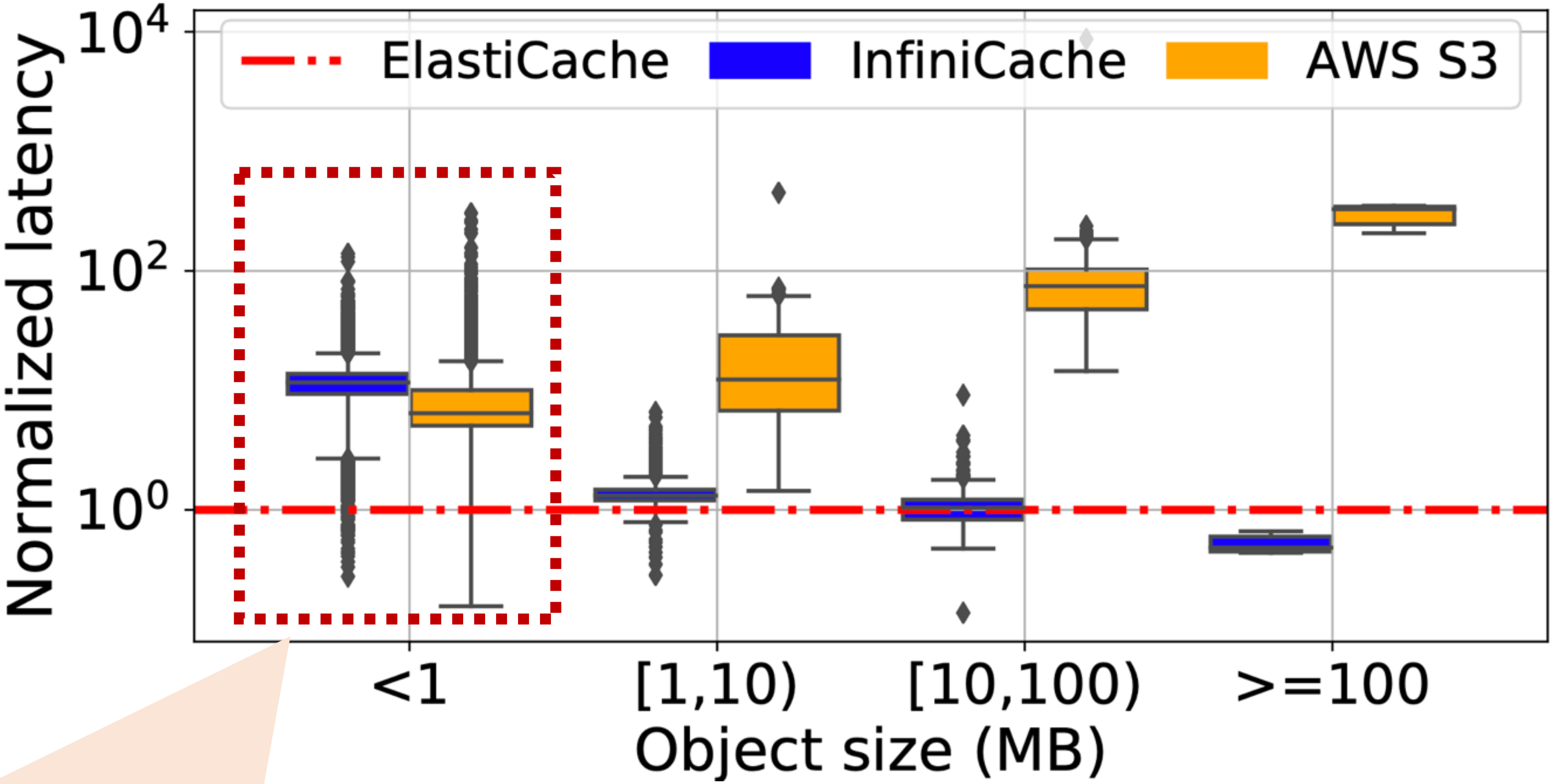


Large objects only

Performance of InfiniCache

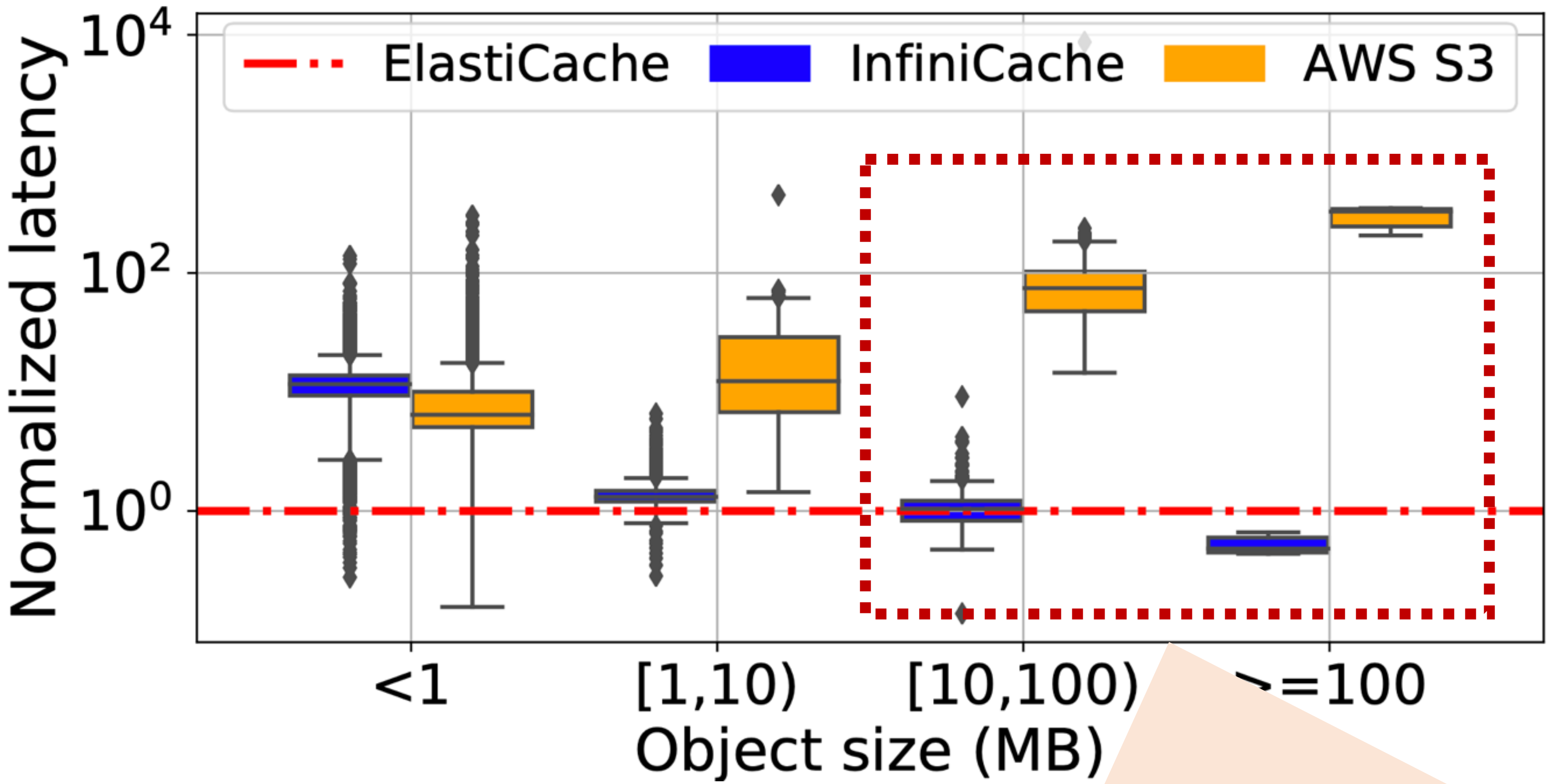


Performance of InfiniCache



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!

FORK ME ON GITHUB!

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