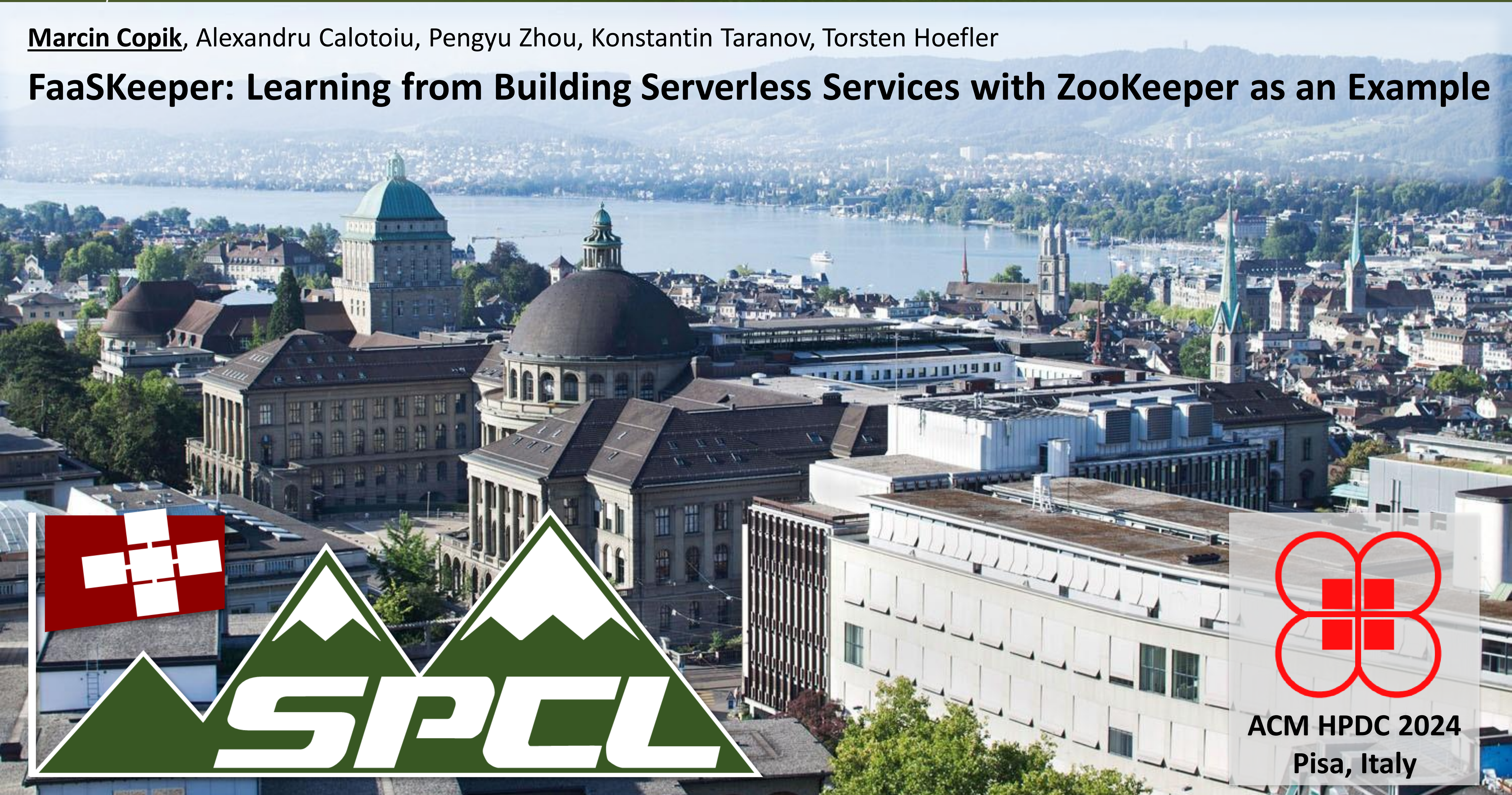
Marcin Copik, Alexandru Calotoiu, Pengyu Zhou, Konstantin Taranov, Torsten Hoefler

FaaSKeeper: Learning from Building Serverless Services with ZooKeeper as an Example



ACM HPDC 2024
Pisa, Italy

What is ZooKeeper?

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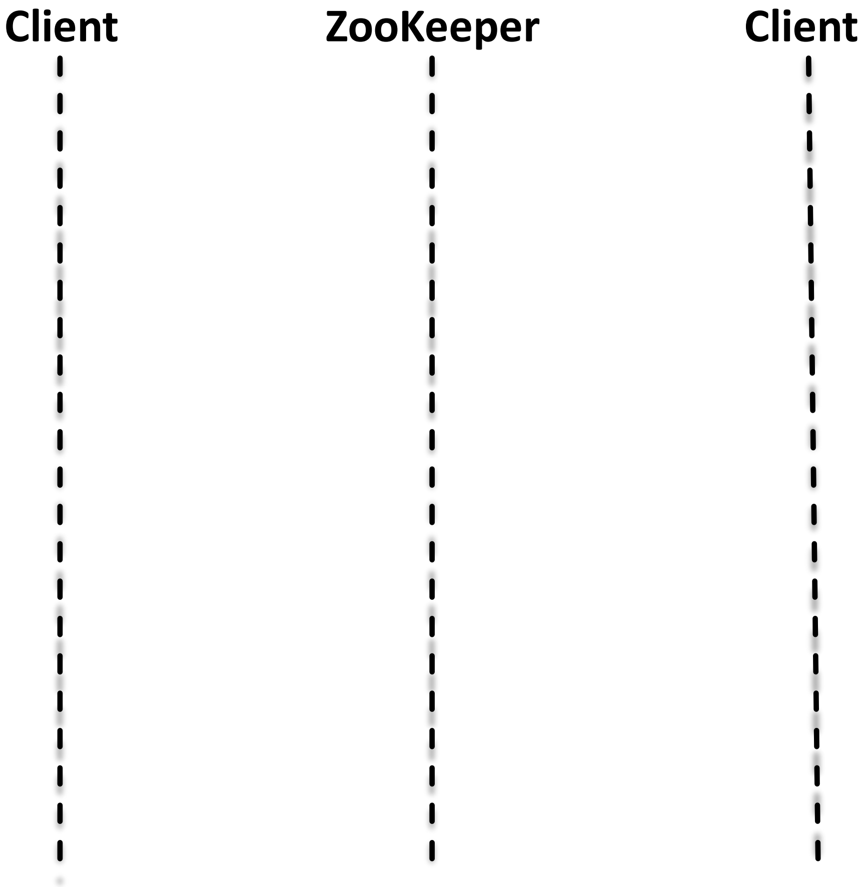
What is ZooKeeper? How it’s used in practice?



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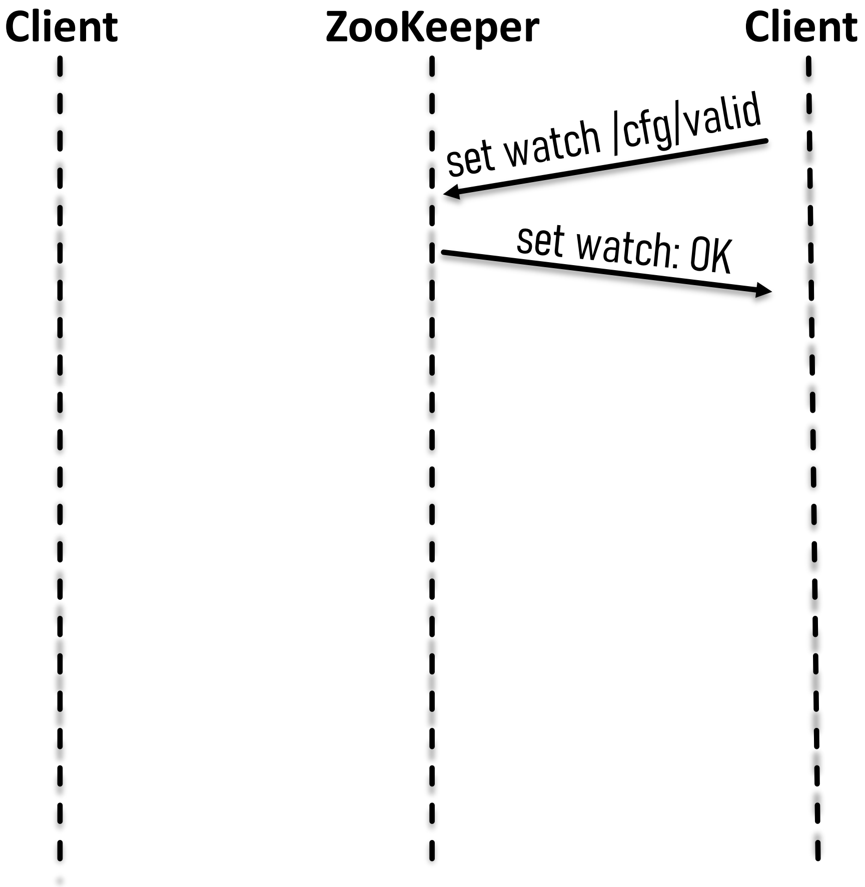

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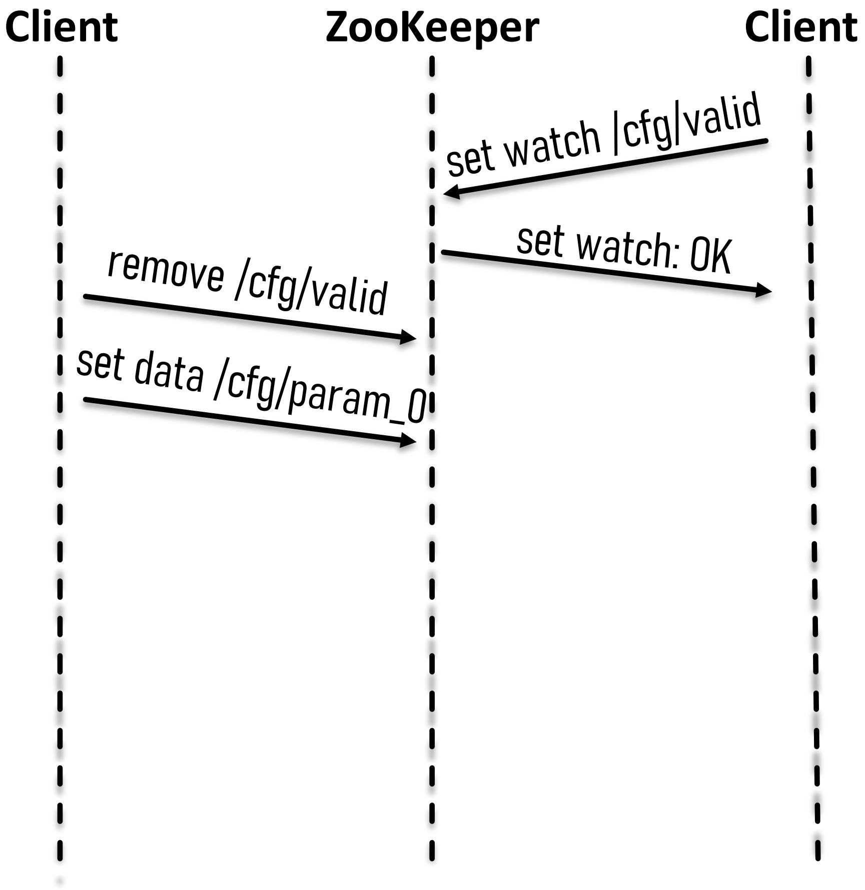

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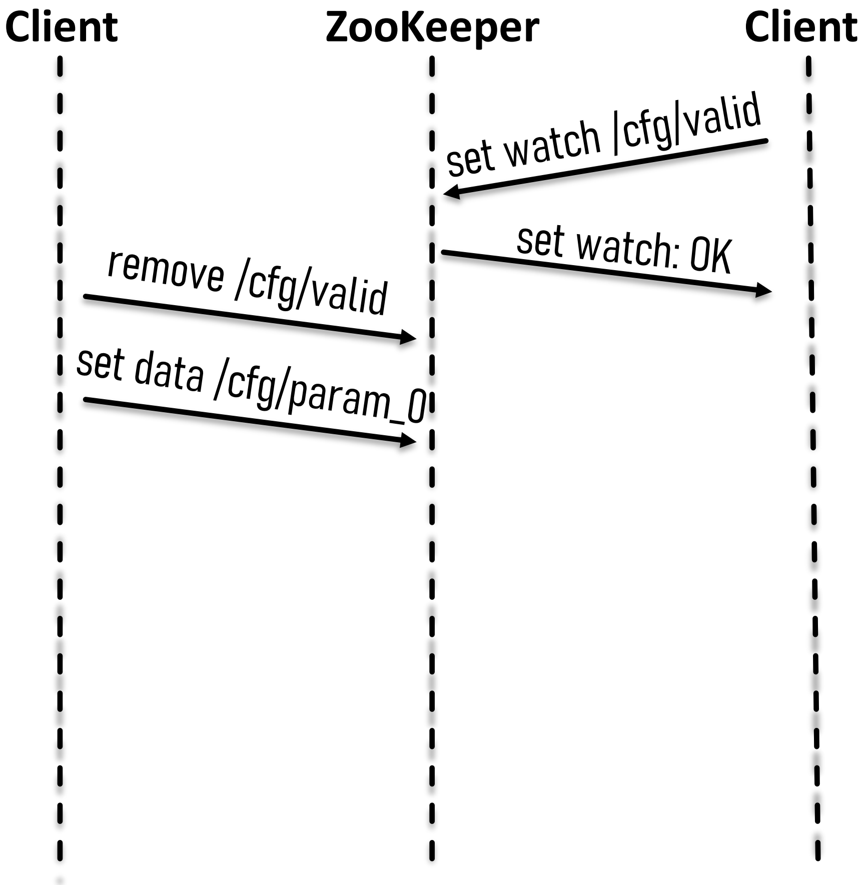
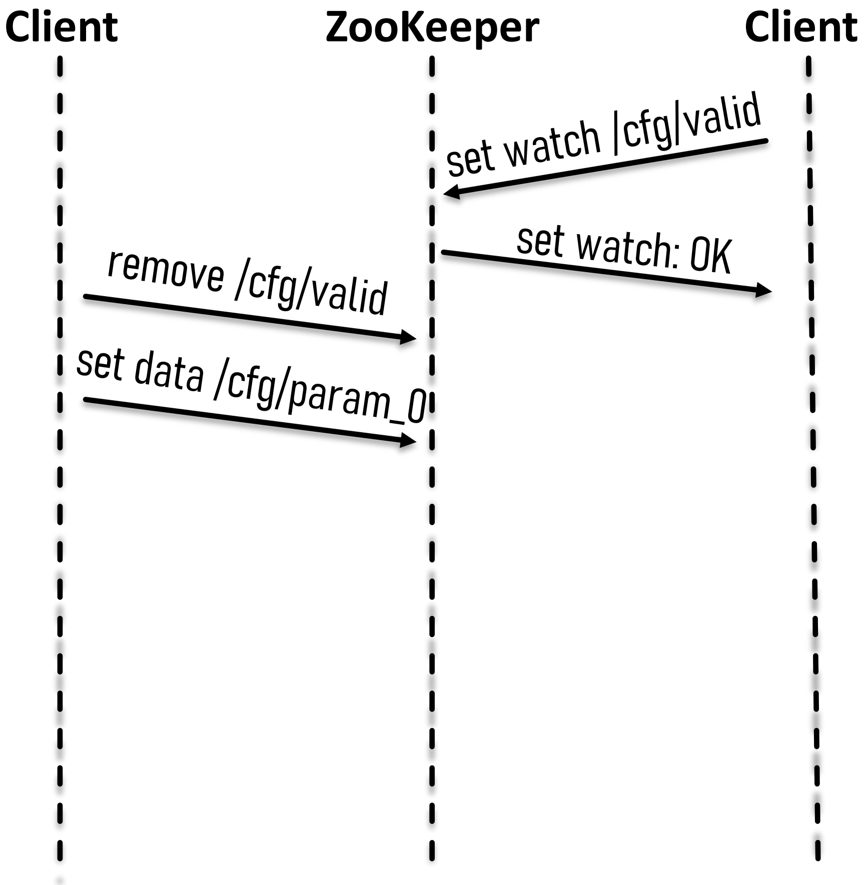


1 **Atomicity**

What is ZooKeeper? How it's used in practice?



1. **Atomicity**
2. **Linearized Writes**

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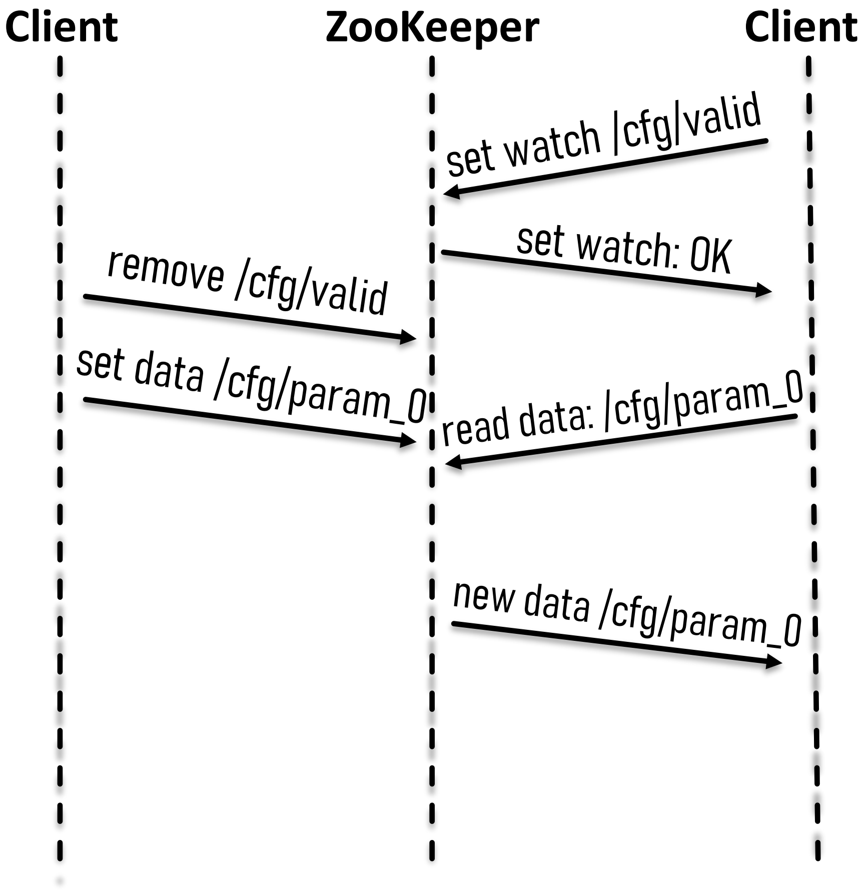

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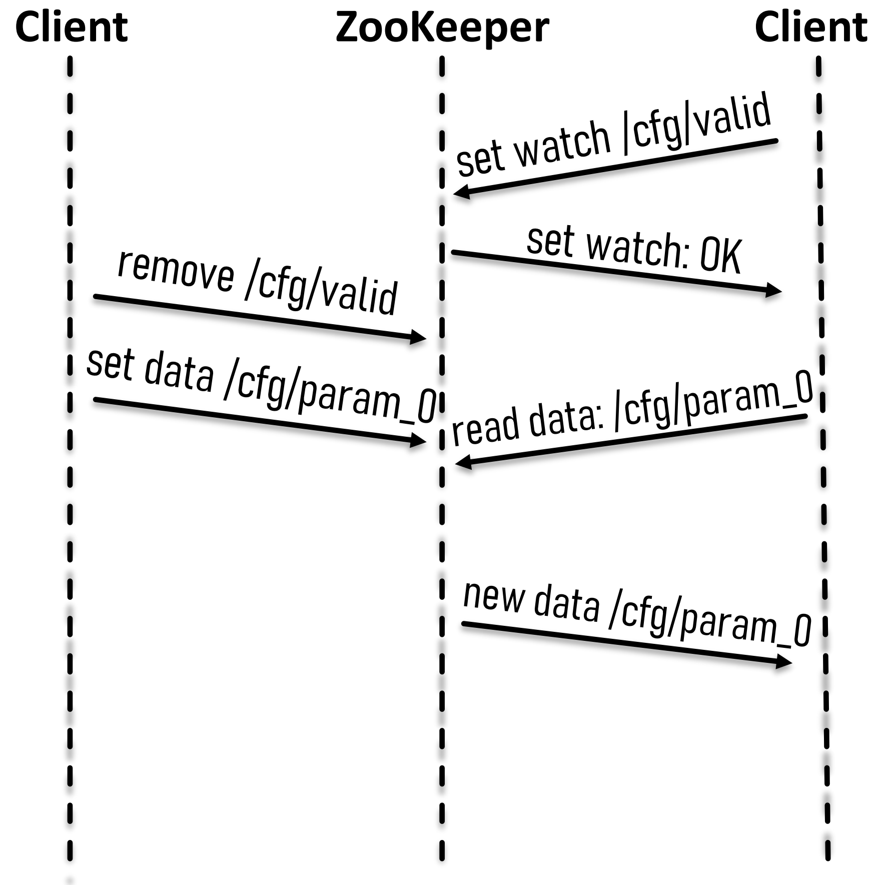

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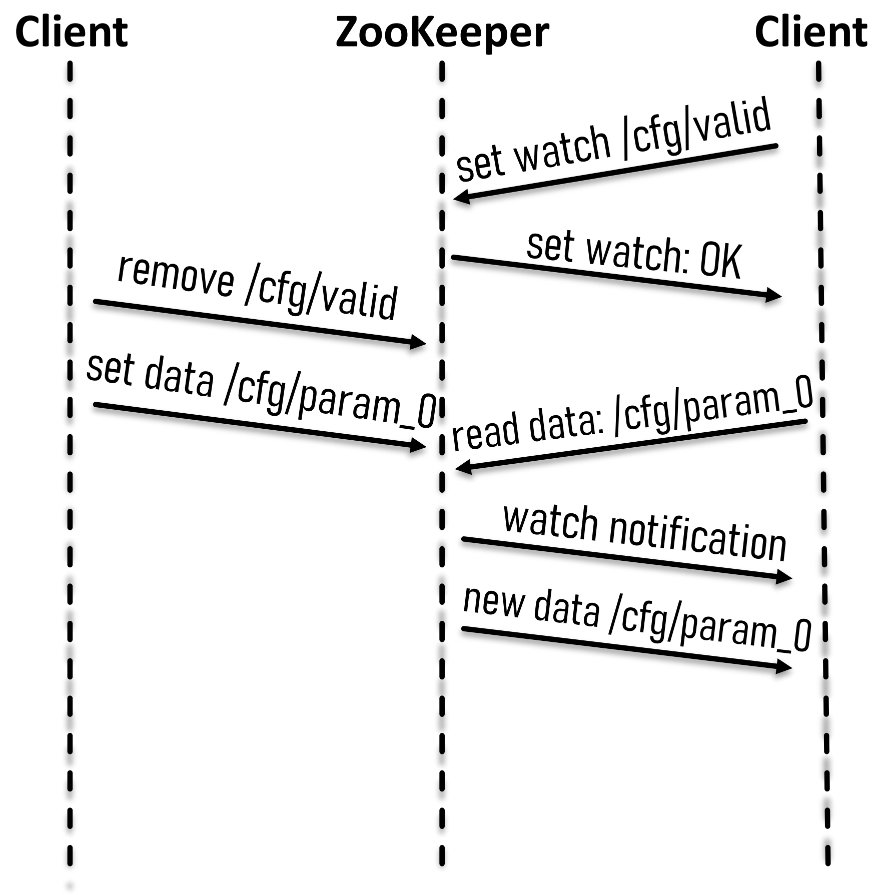

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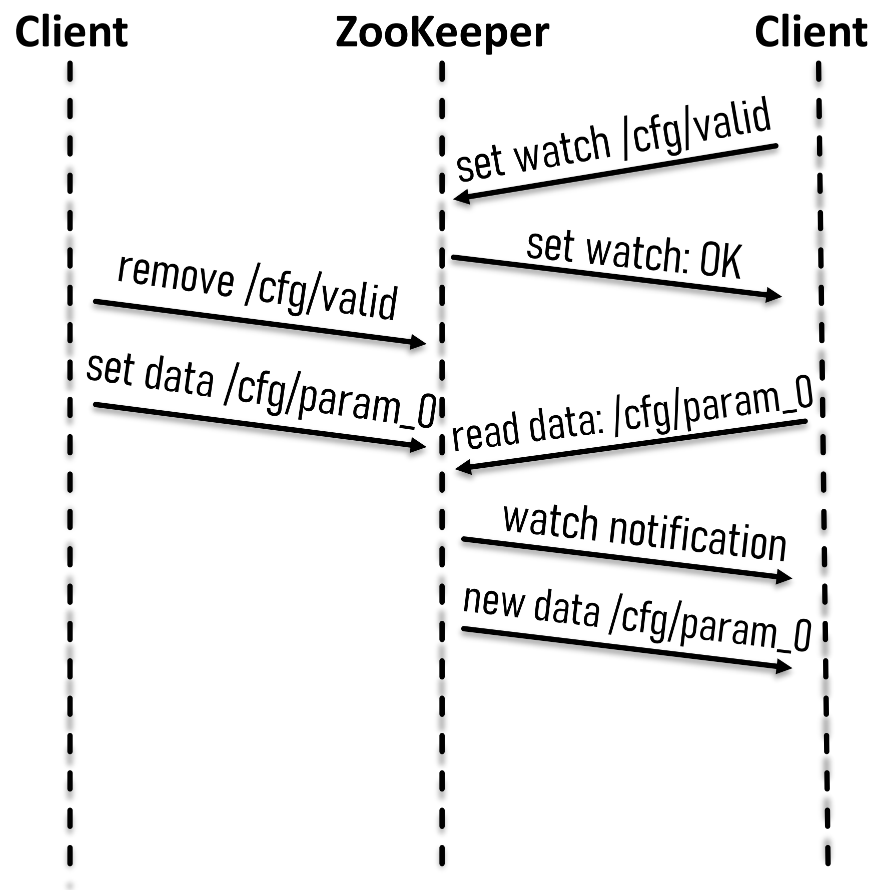
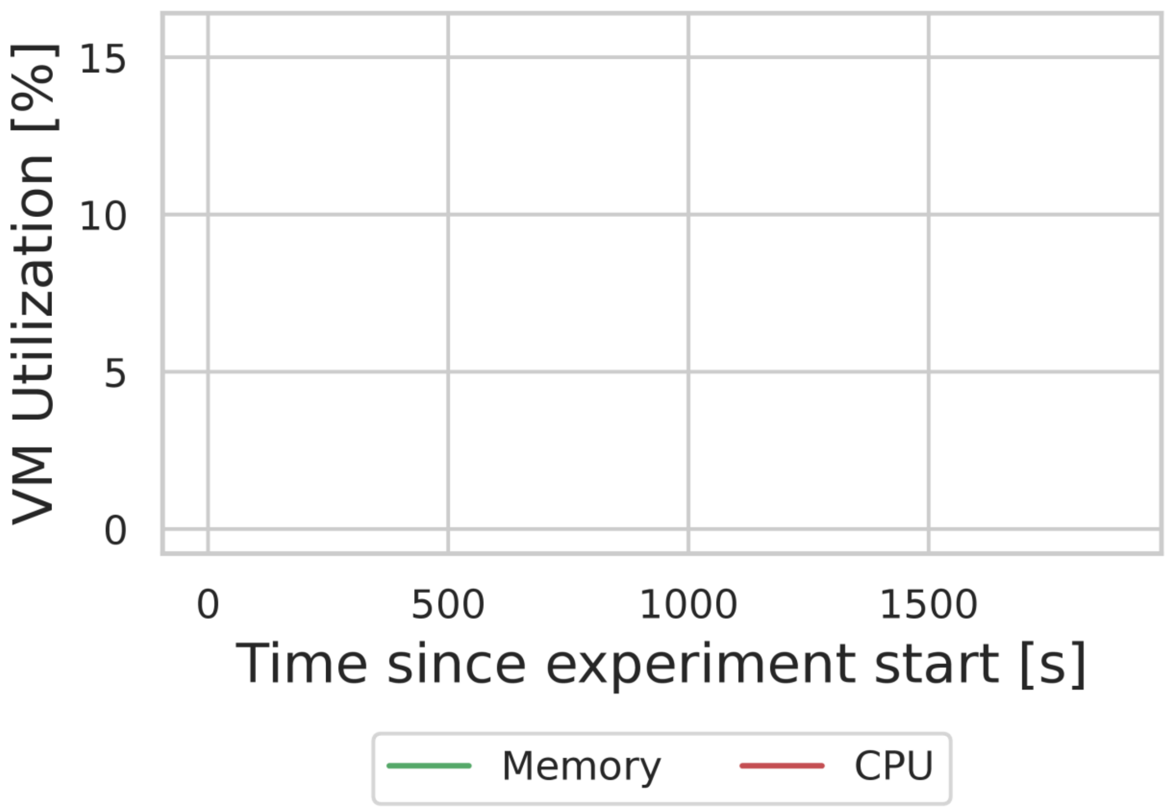
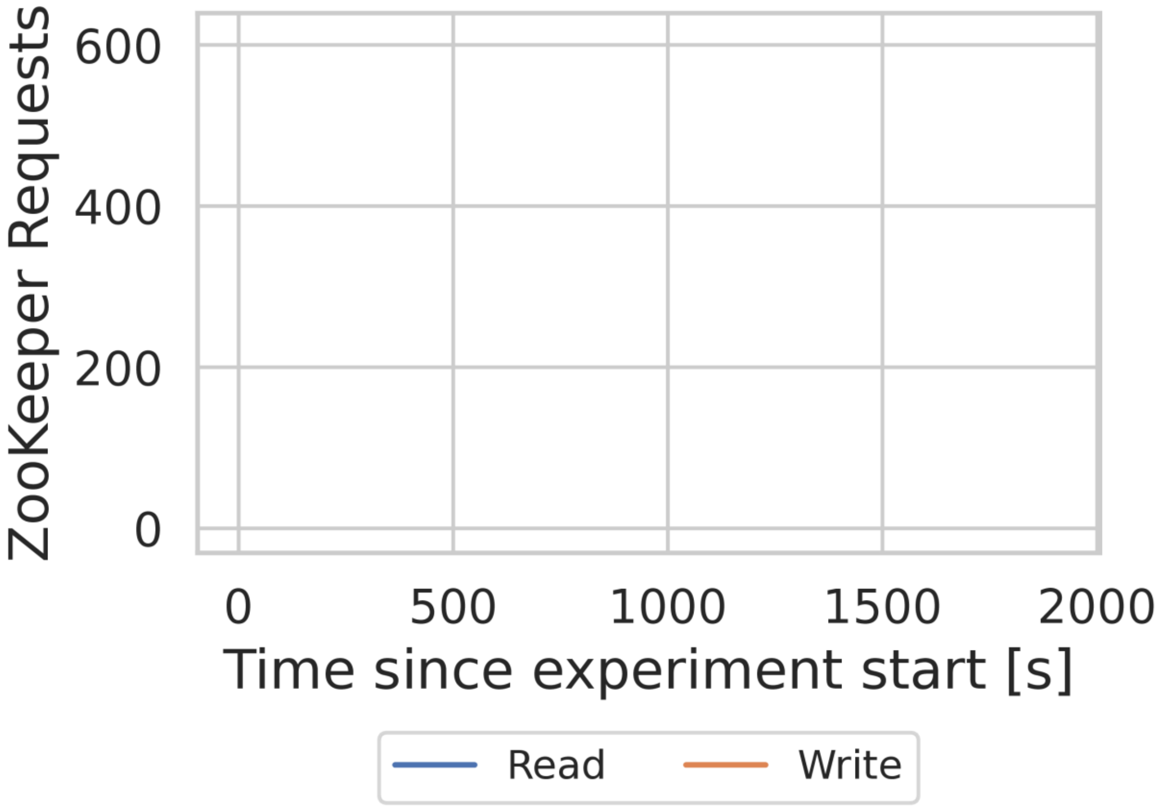


1. Atomicity
2. Linearized Writes
3. Single System Image
4. Ordered Notifications

ZooKeeper Utilization in Practice: APACHE HBASE





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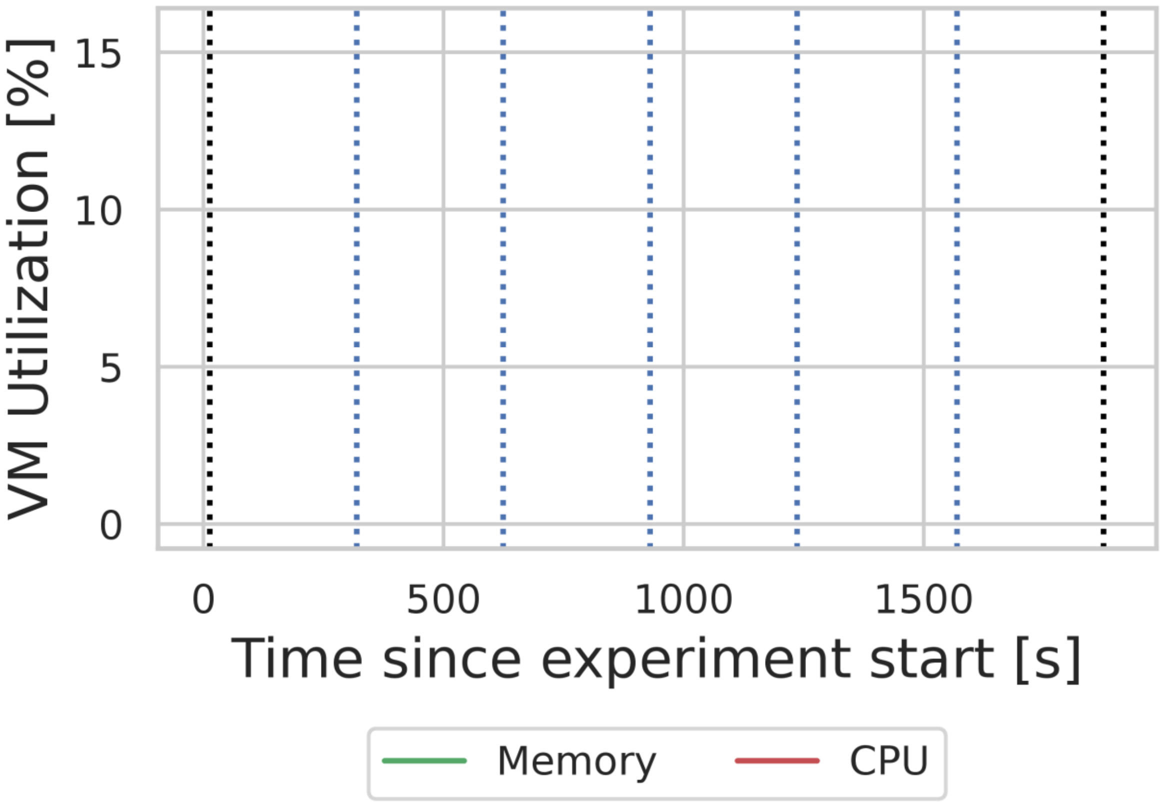

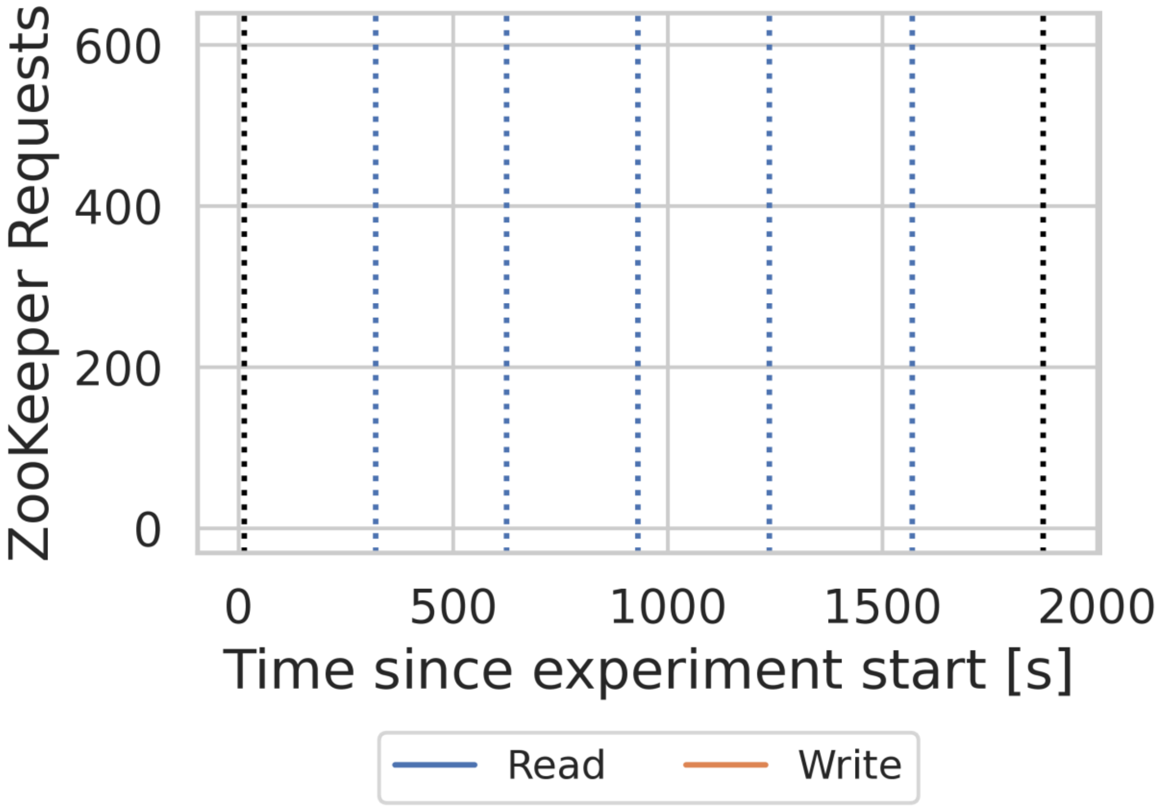

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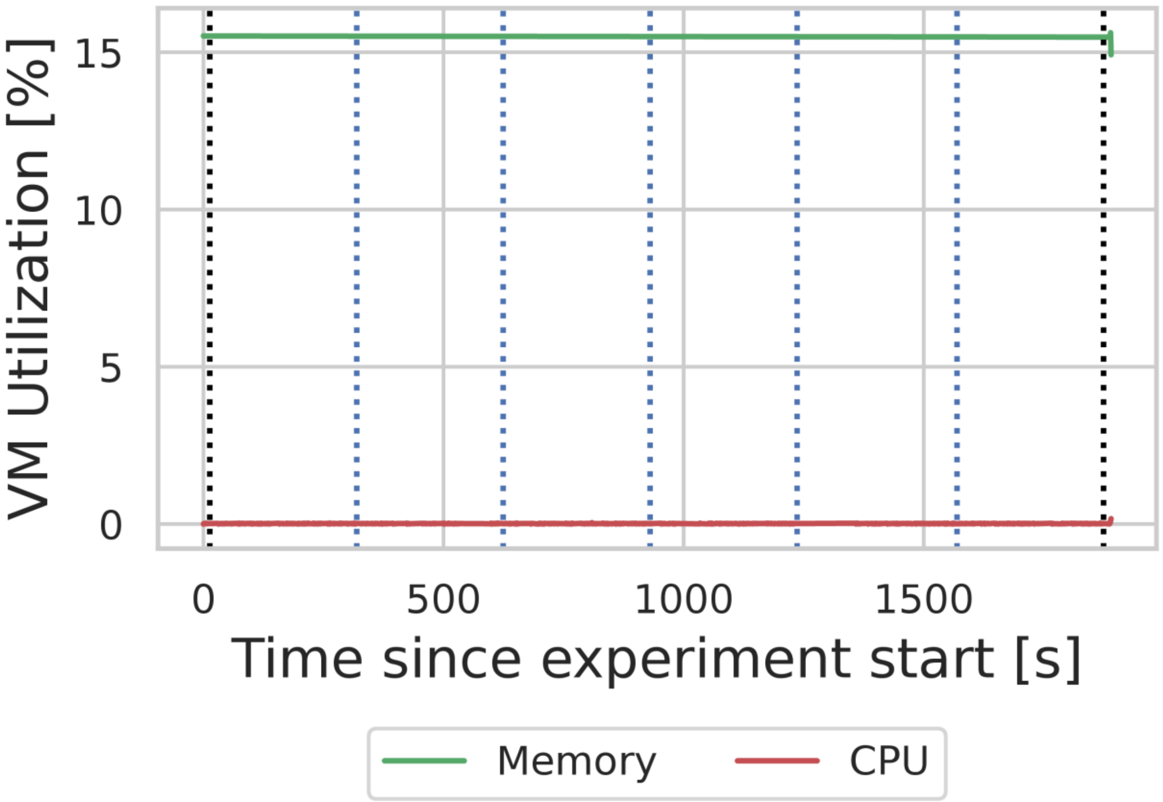

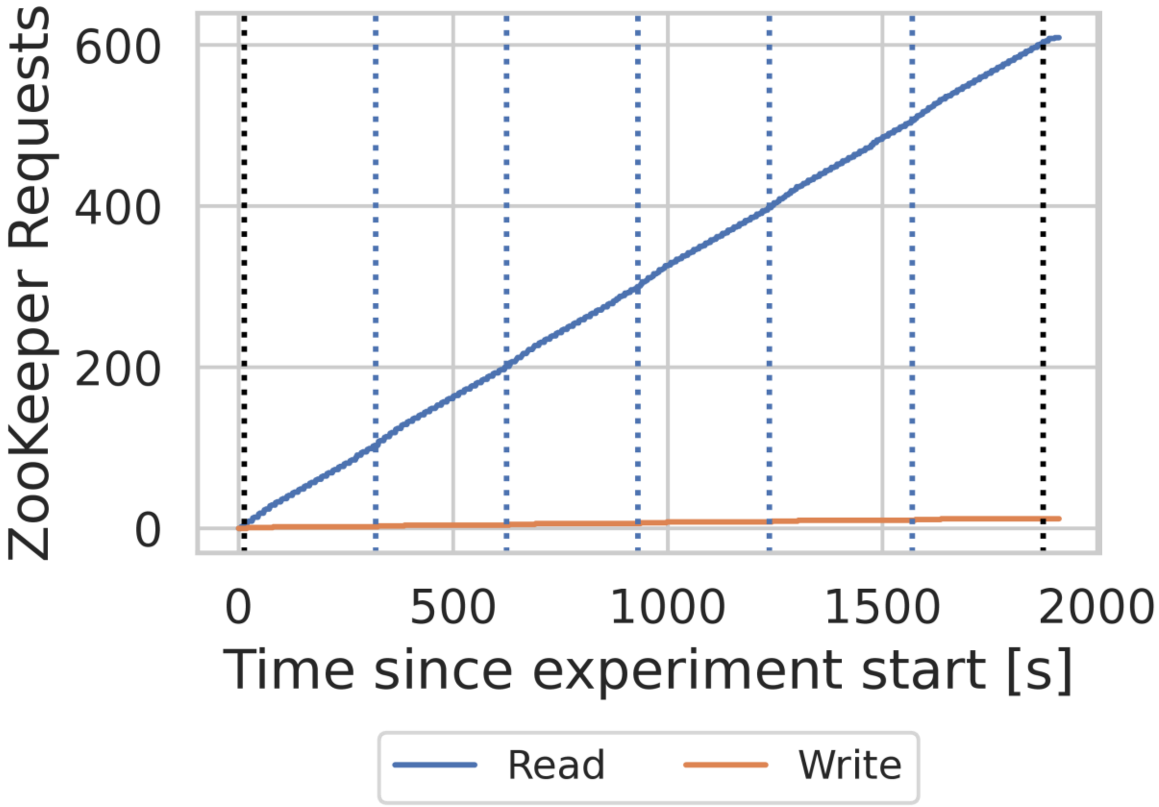

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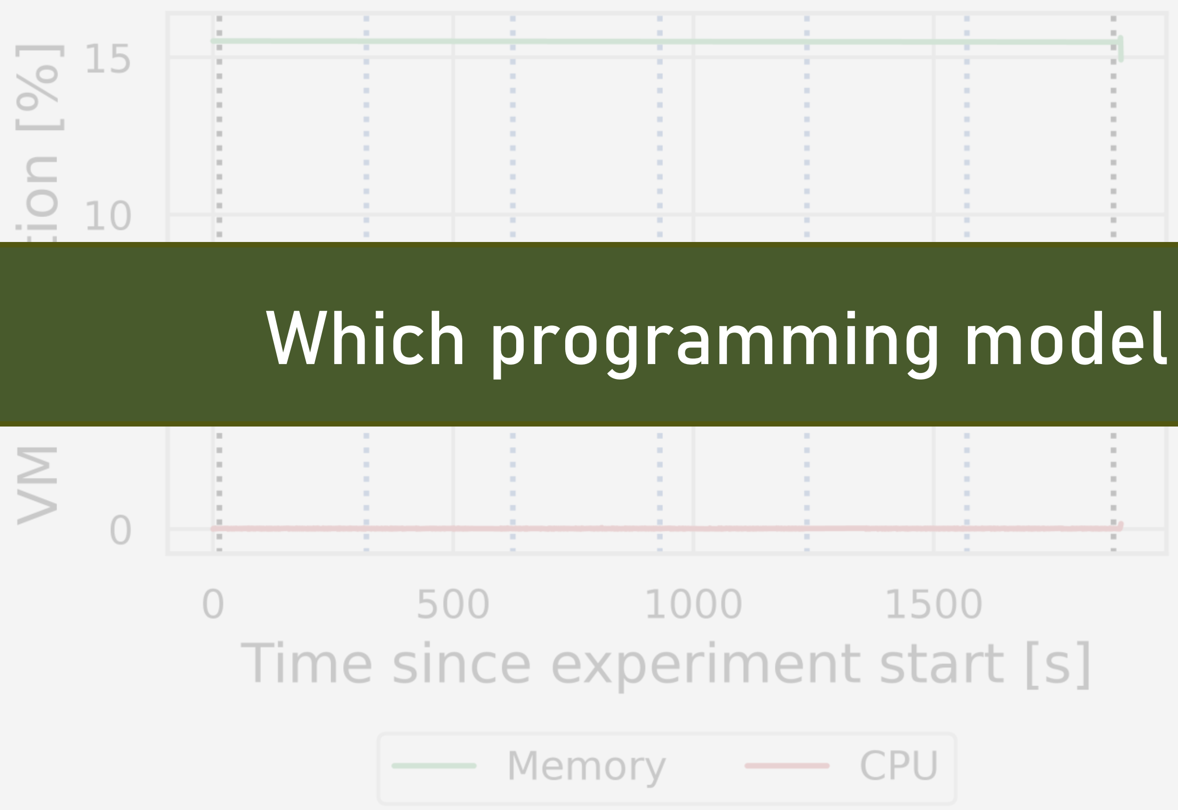

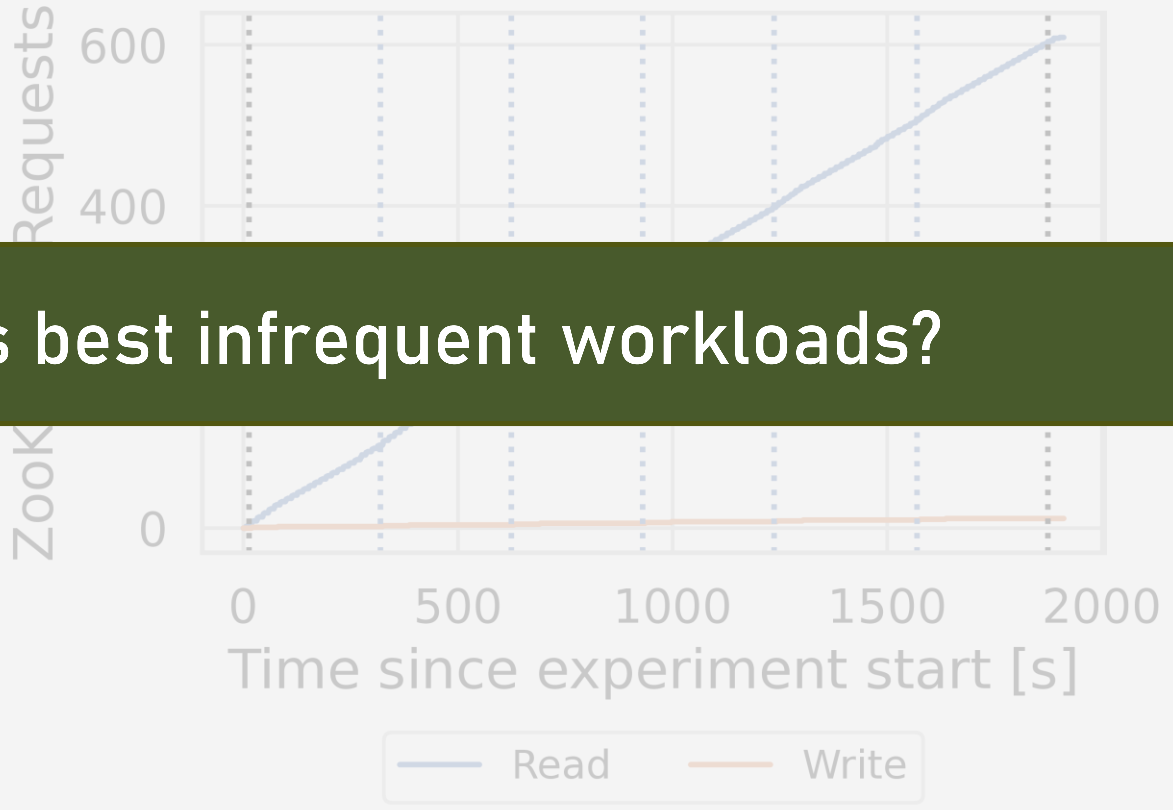

Which programming model fits best infrequent workloads?

How does Function-as-a-Service (FaaS) work?

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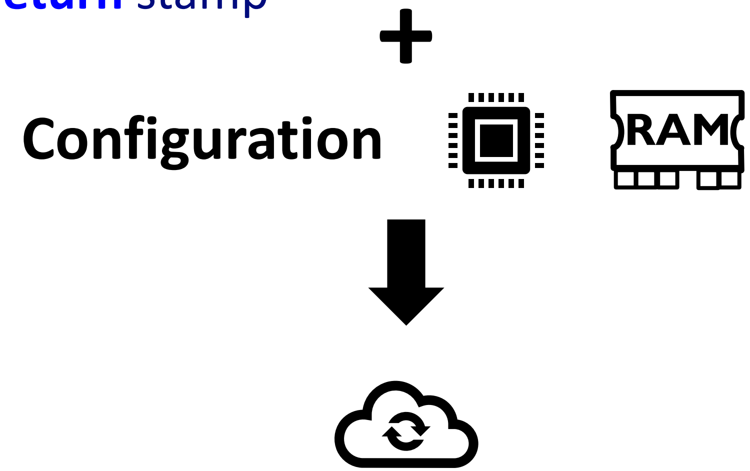

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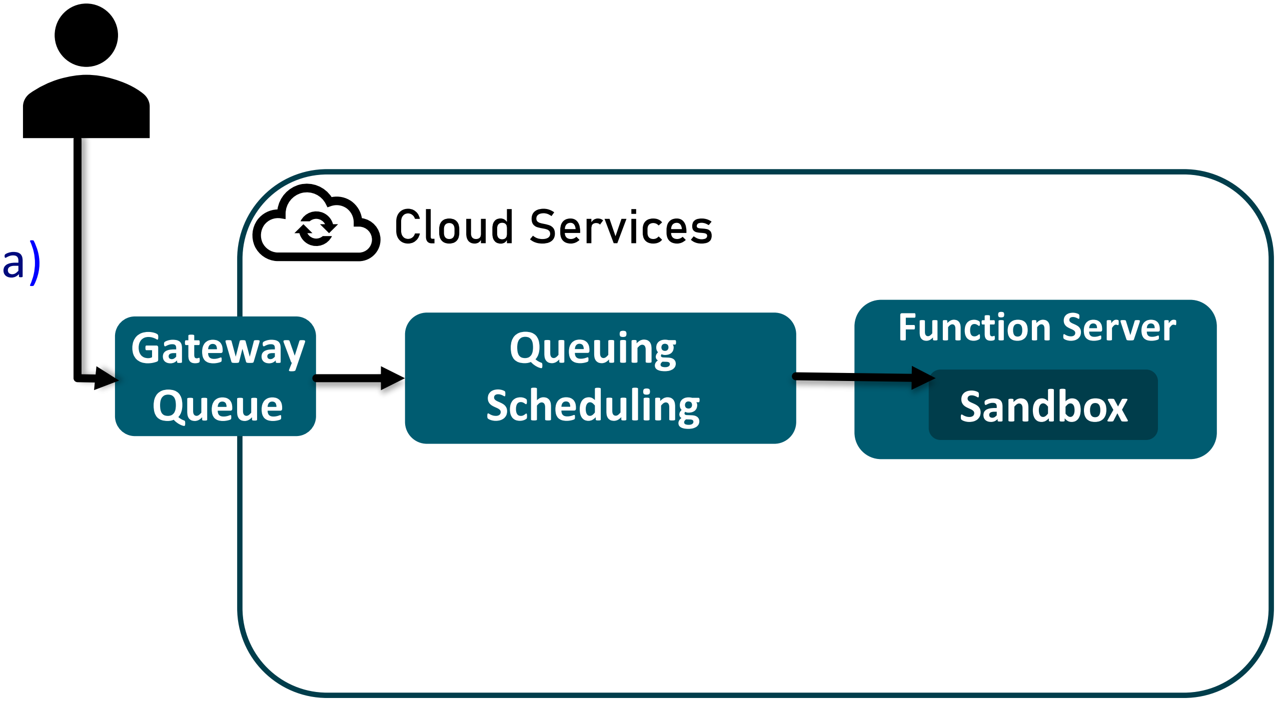

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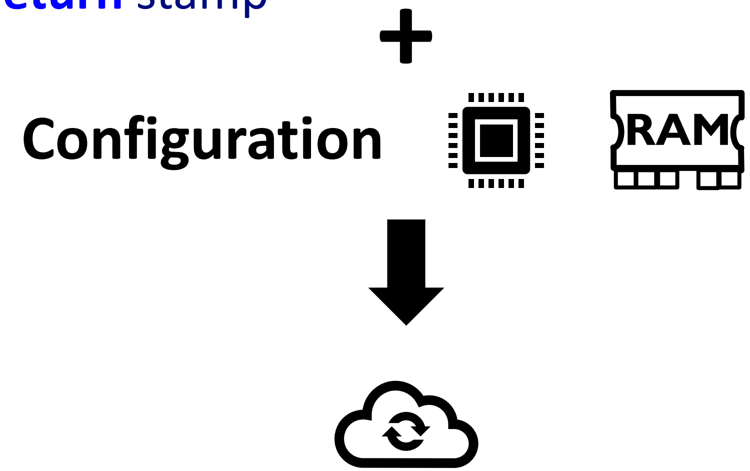

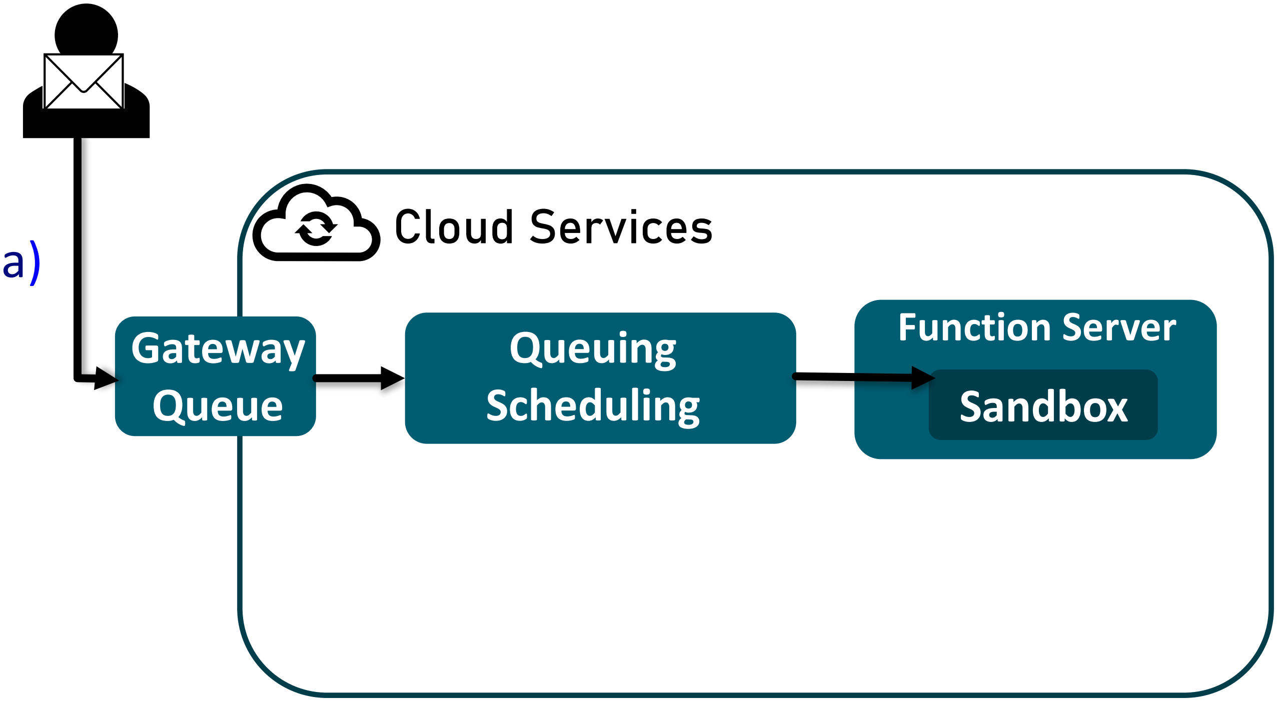

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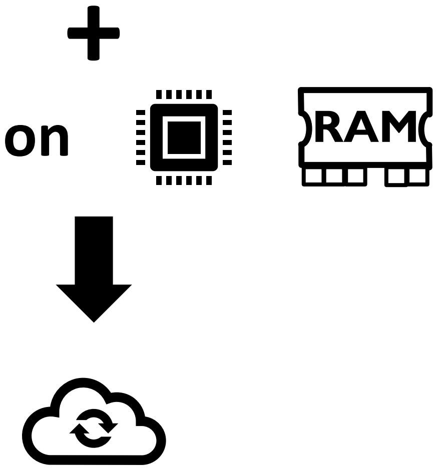

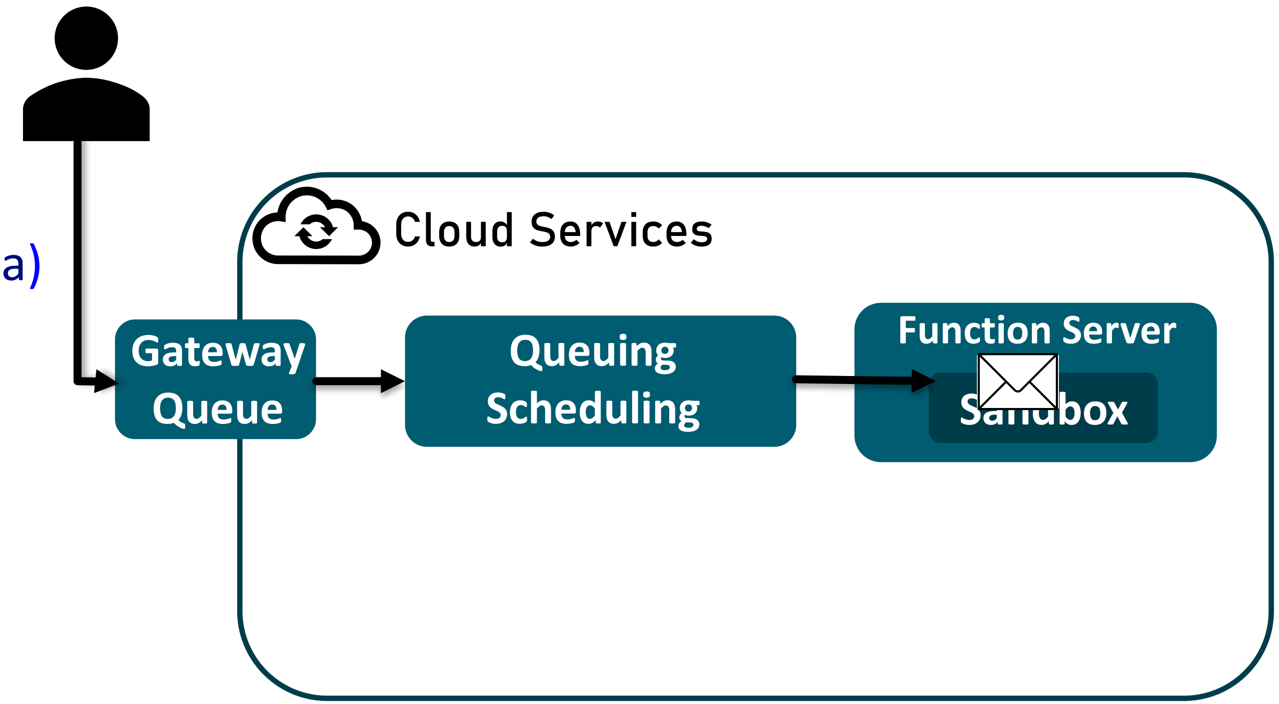

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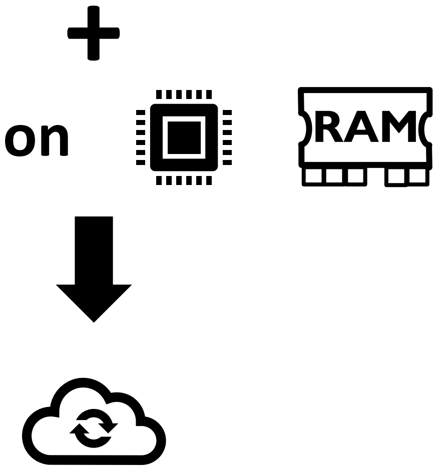

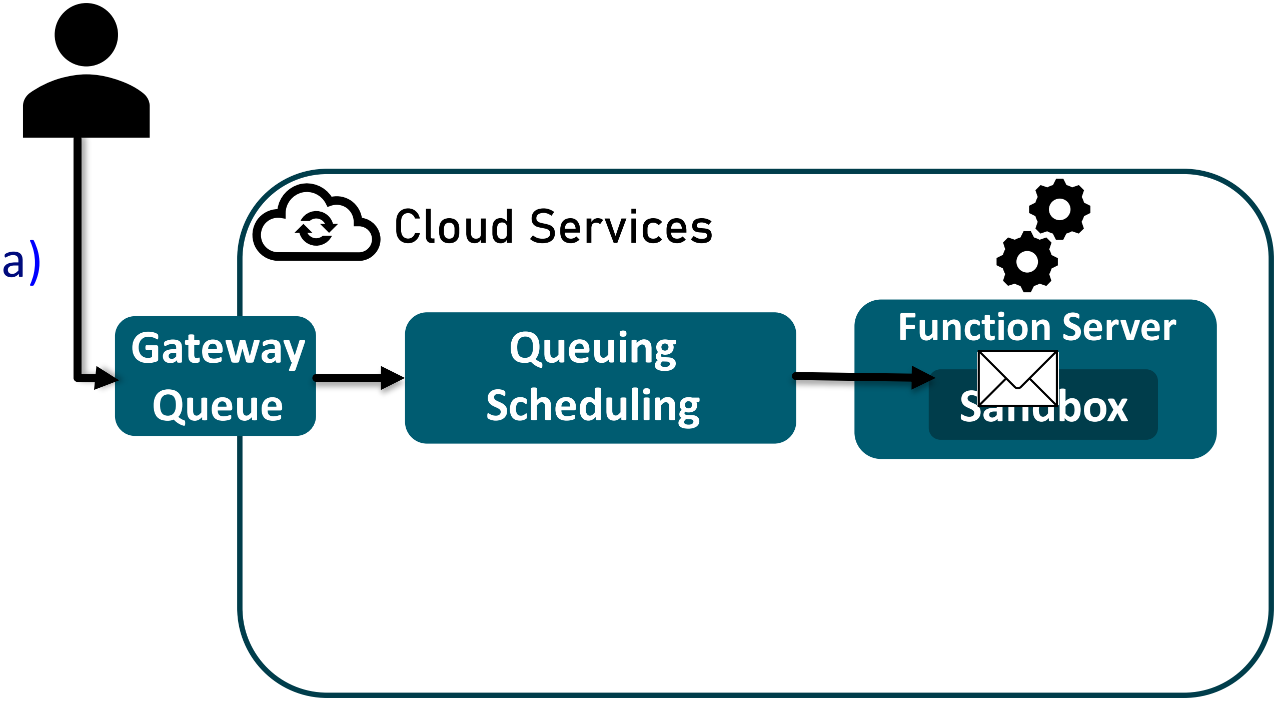

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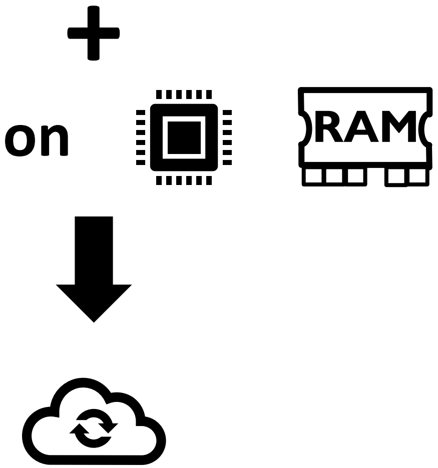

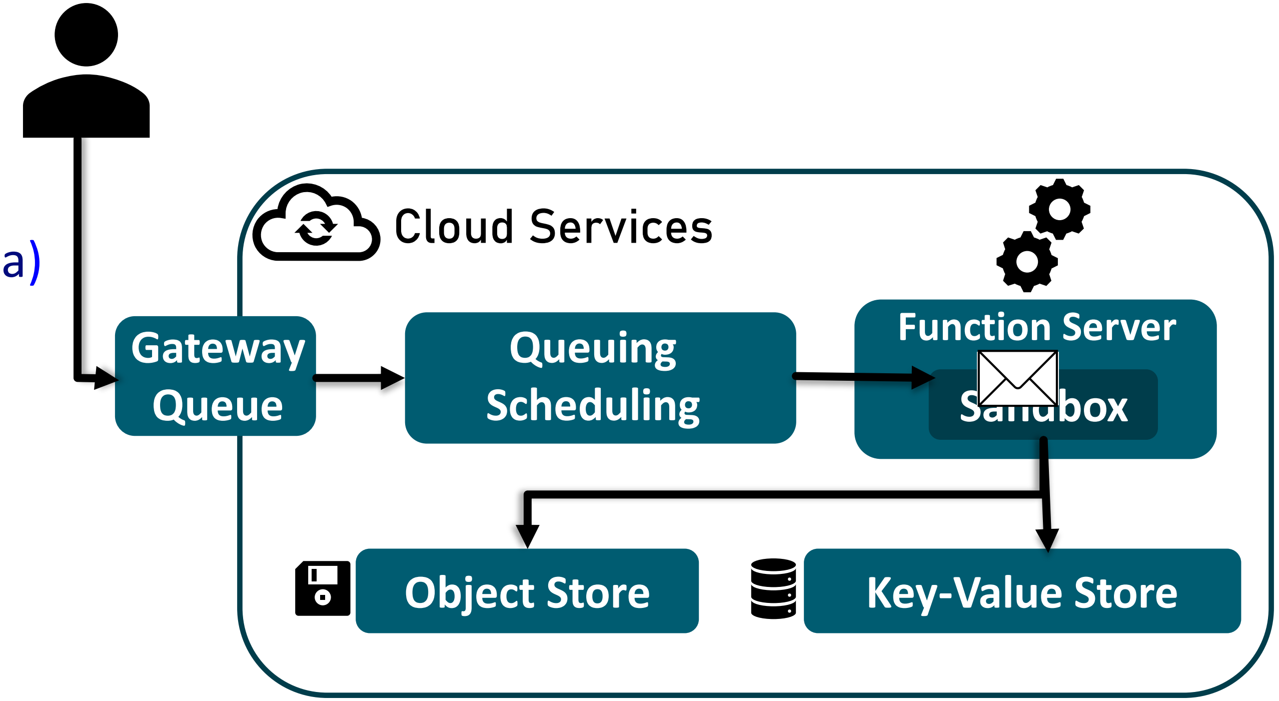

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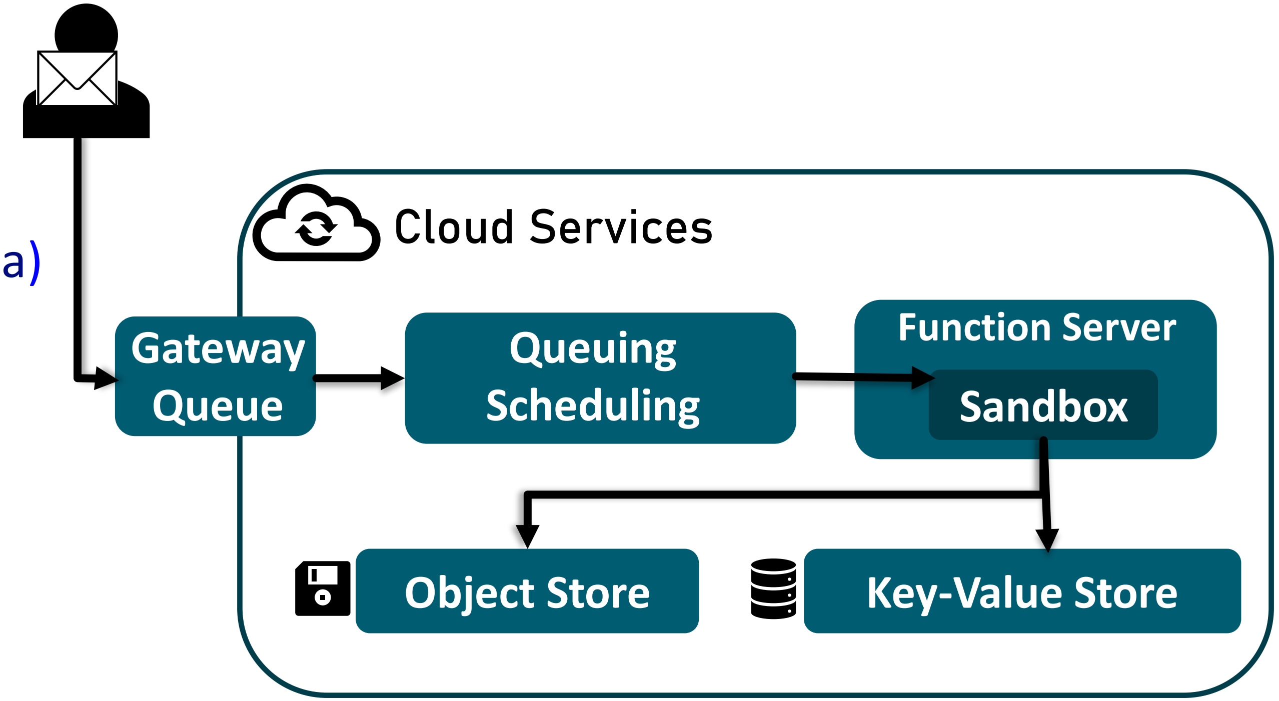

Serverless ZooKeeper: Why and Why Not?

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Benefit from pay-as-you-go billing.

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ZooKeeper relies on warm TCP connections.

Complex Data Model

Linearized writes with ordered notifications.

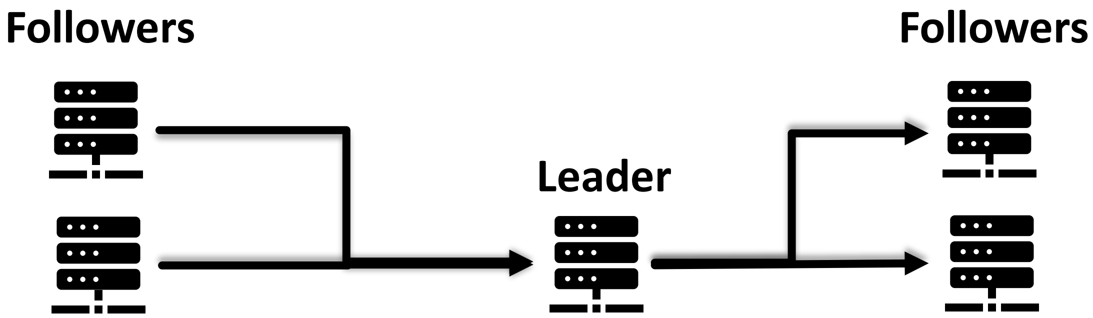
From ZooKeeper to FaaSKeeper

From ZooKeeper to FaaSKeeper

APACHE ZooKeeper™

Leader

From ZooKeeper to FaaSKeeper



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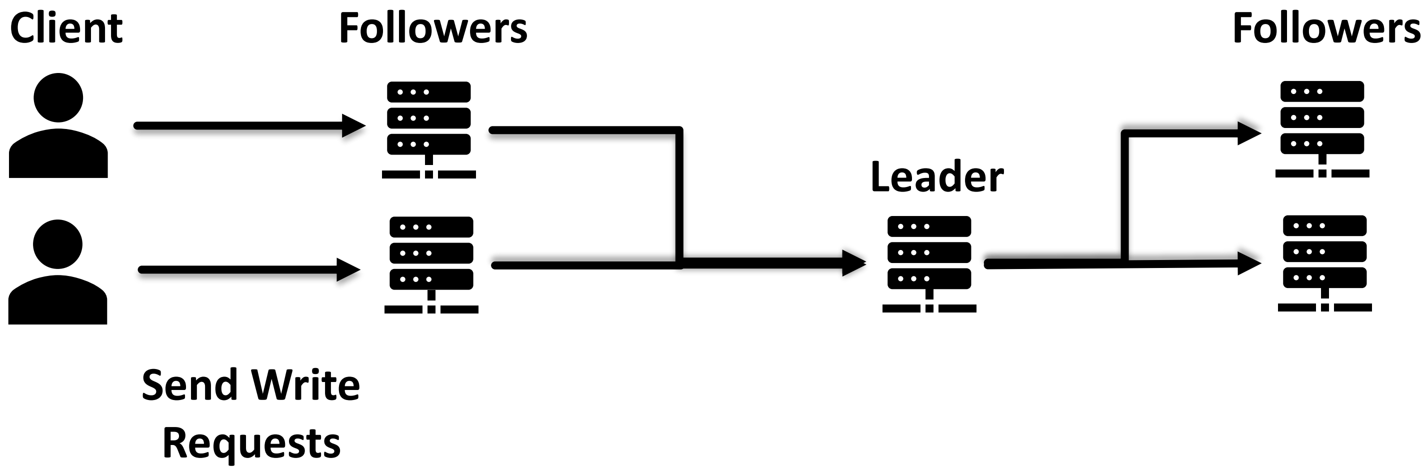

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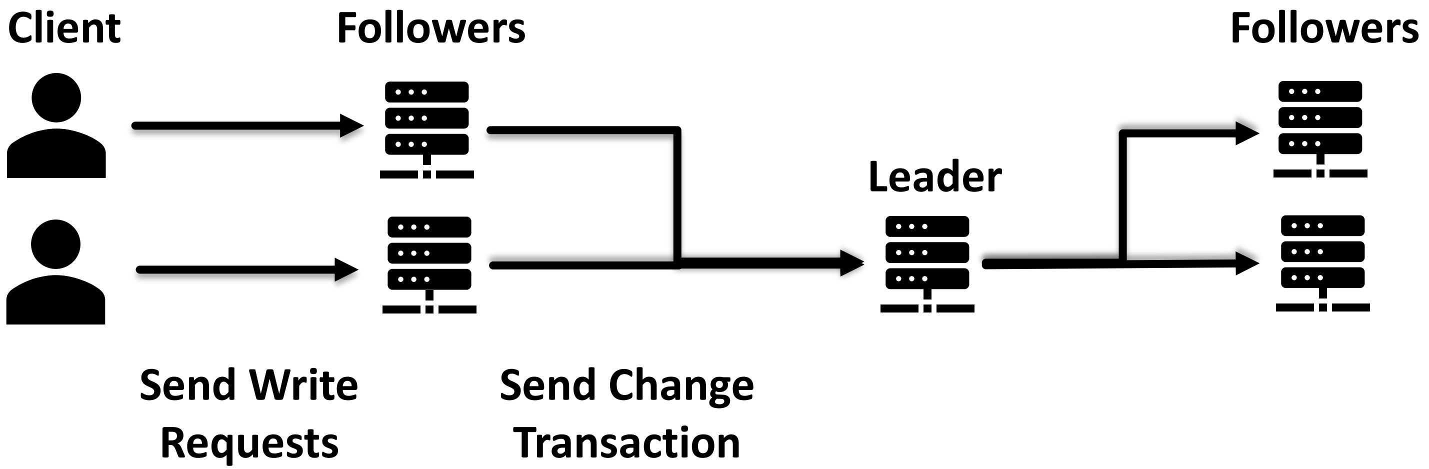

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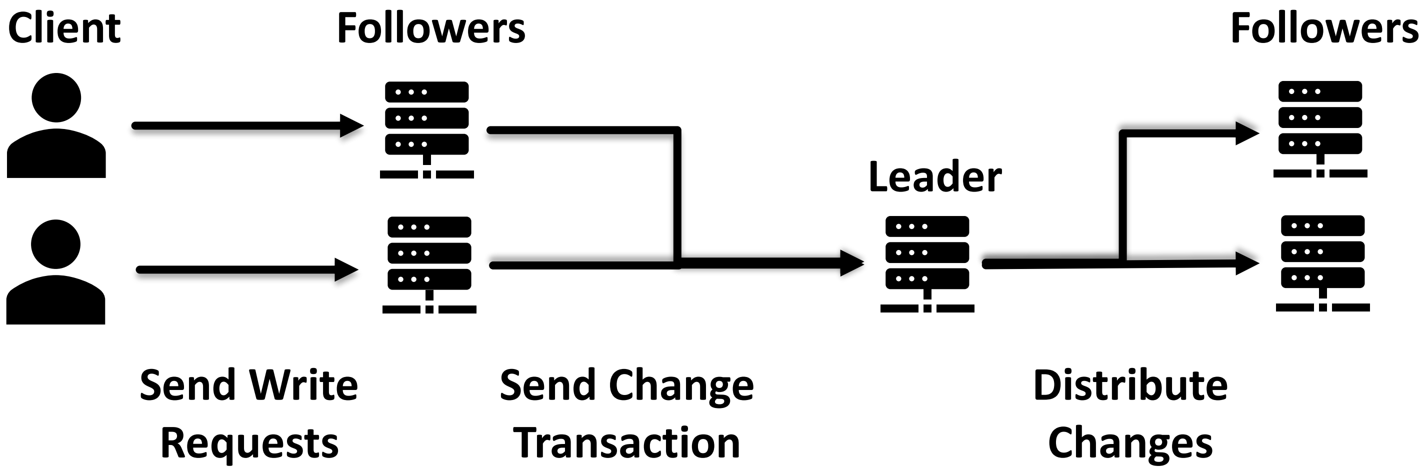


Client

Followers

Followers

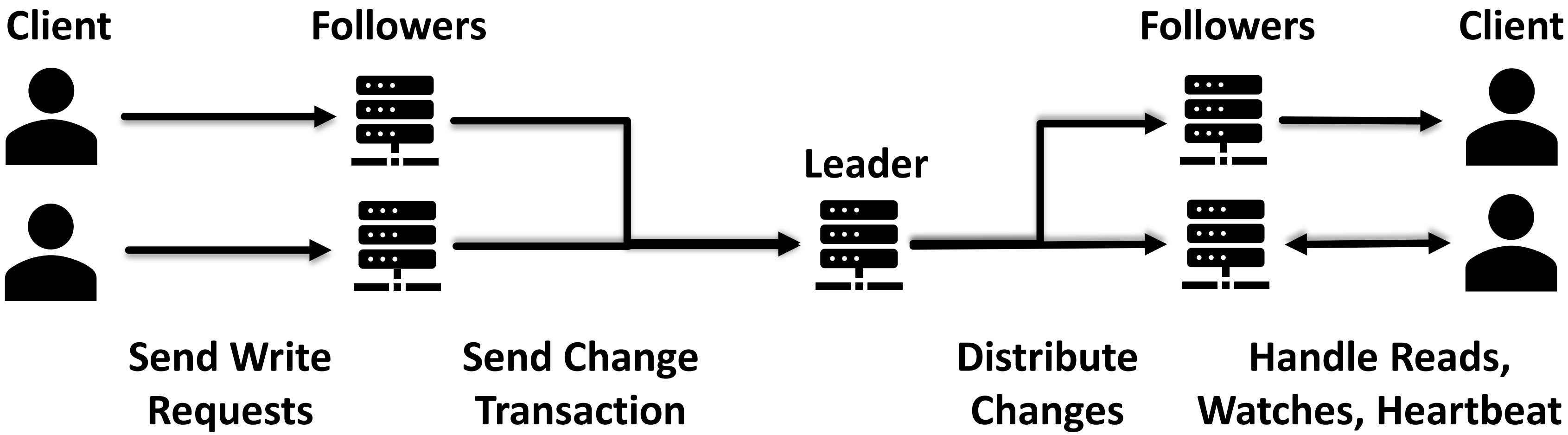
Leader

Send Write Requests

Send Change Transaction

Distribute Changes

From ZooKeeper to FaaSKeeper



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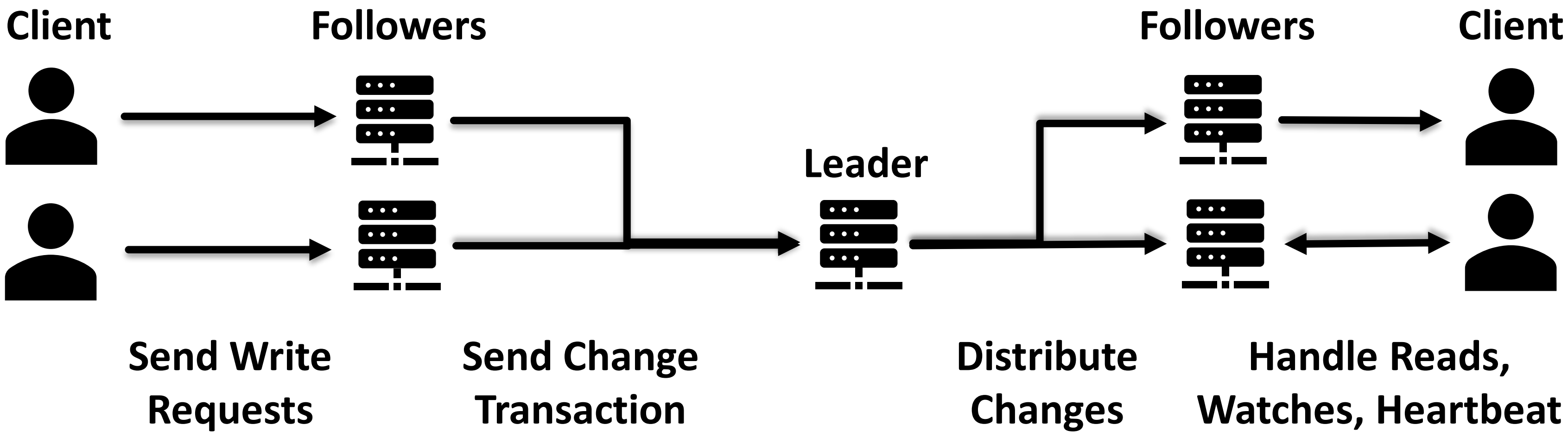

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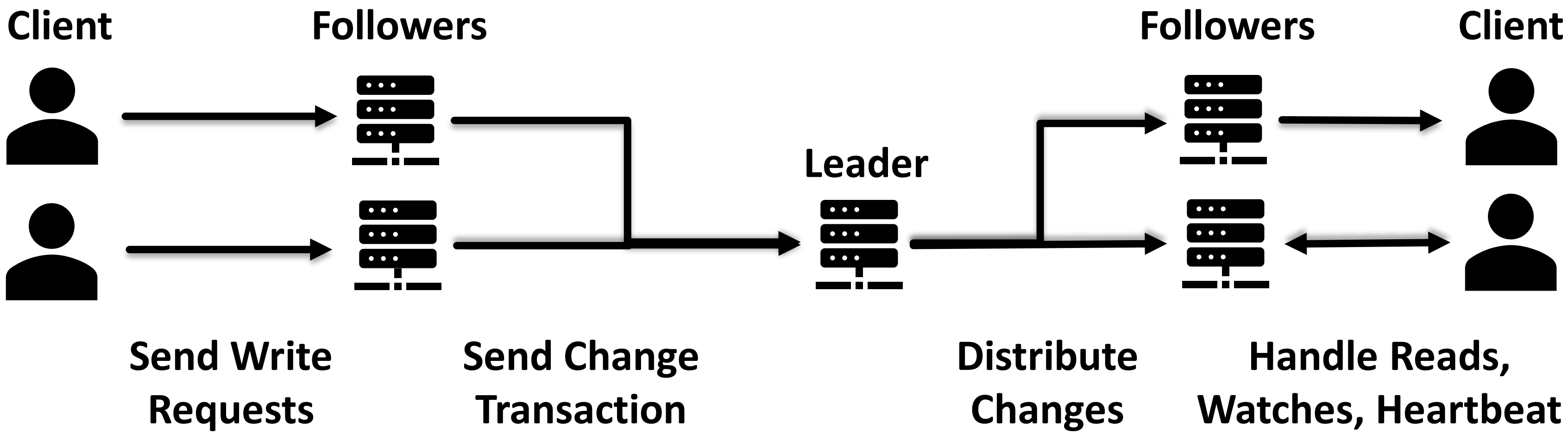
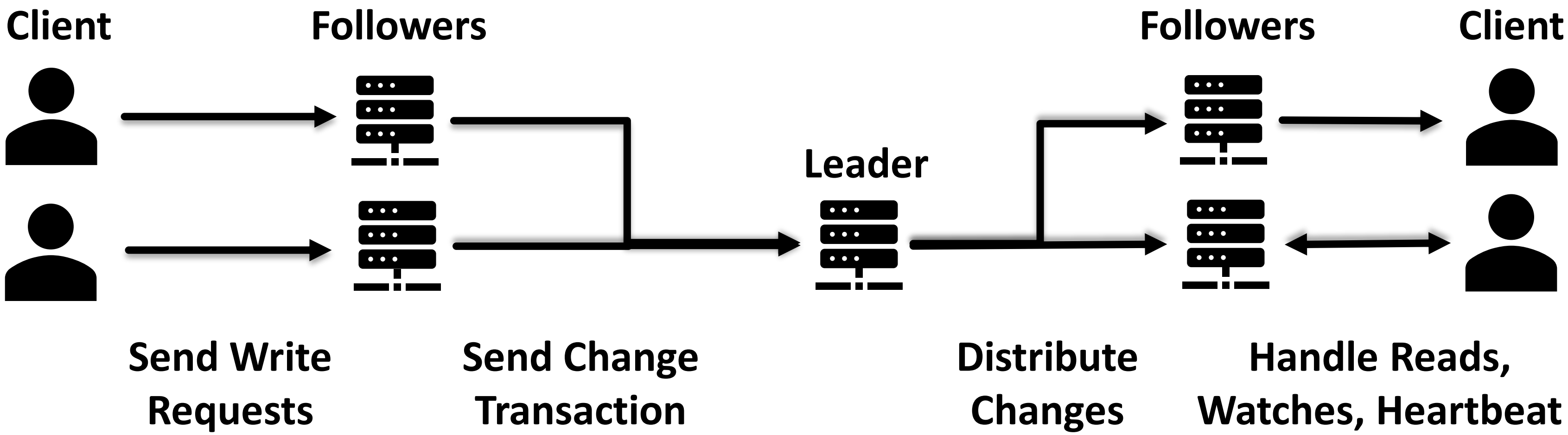
Handle Reads, Watches, Heartbeat

From ZooKeeper to FaaSKeeper



Cloud-Native

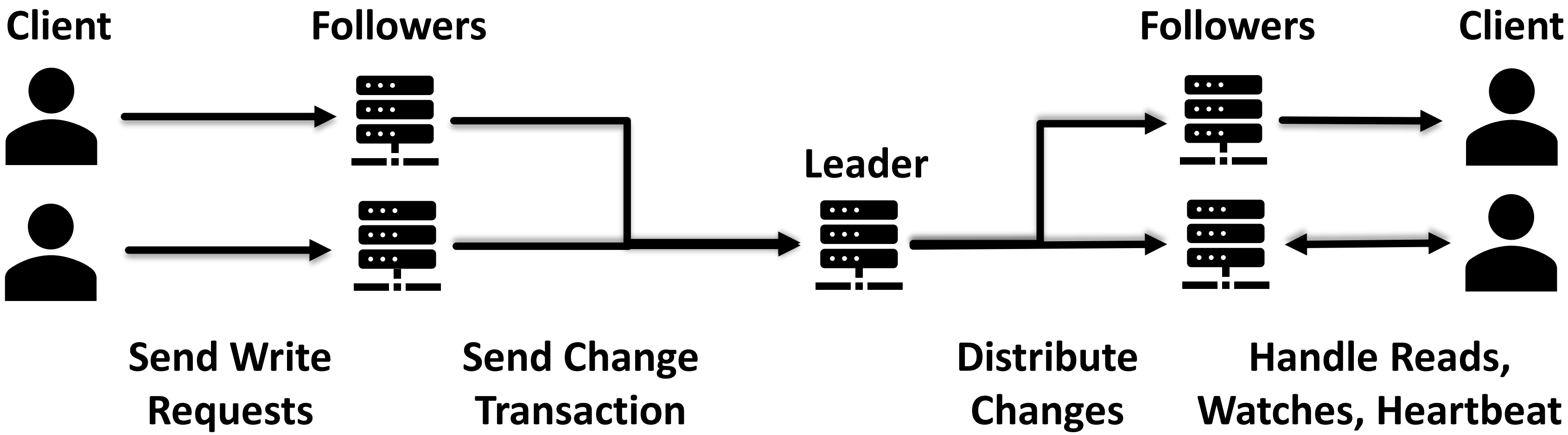
From ZooKeeper to FaaSKeeper



Cloud-Native

100% Serverless

From ZooKeeper to FaaSKeeper



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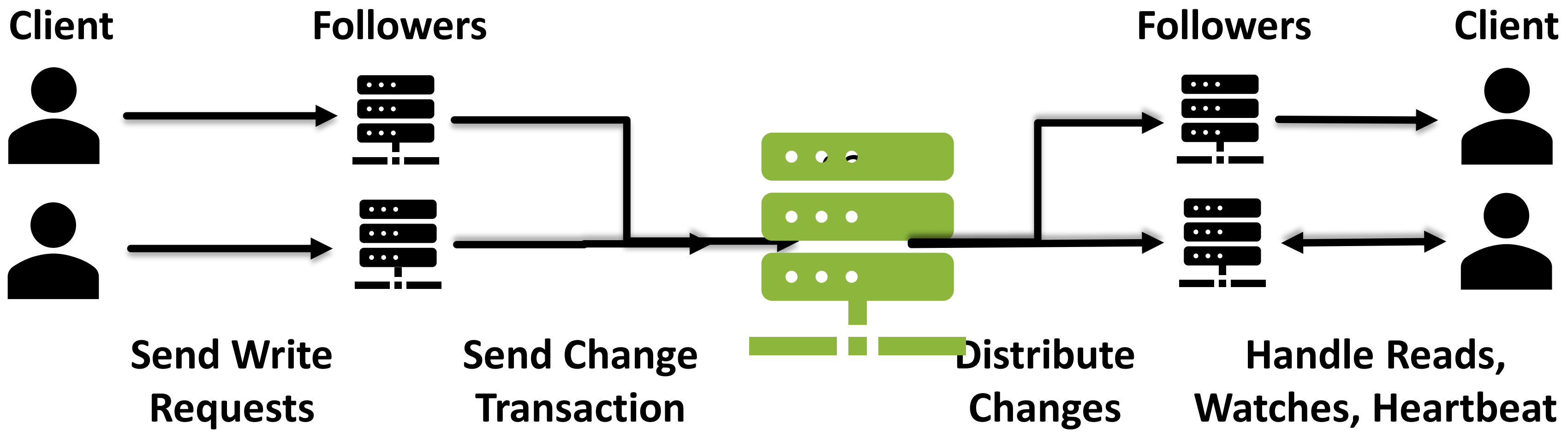

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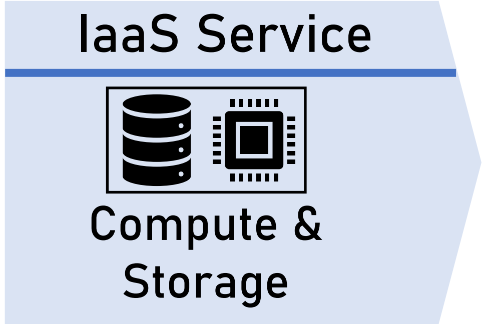

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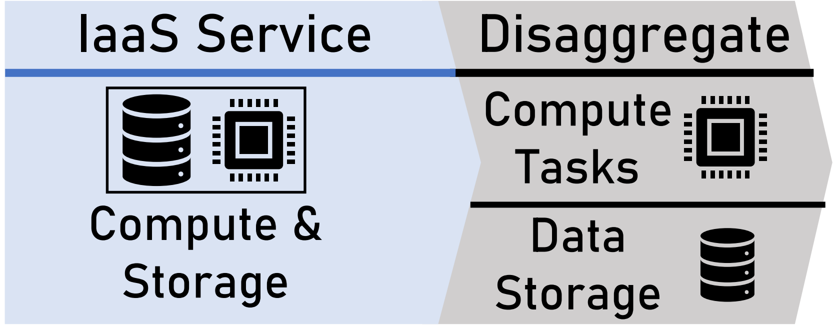

Disaggregate Compute & Storage

Building Serverless Services - Disaggregate

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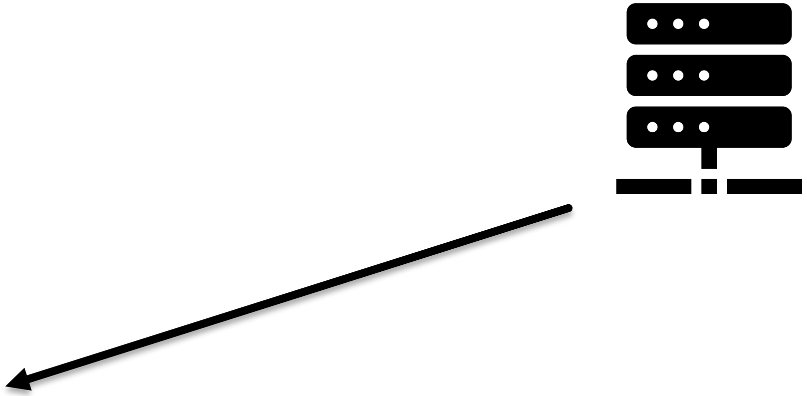
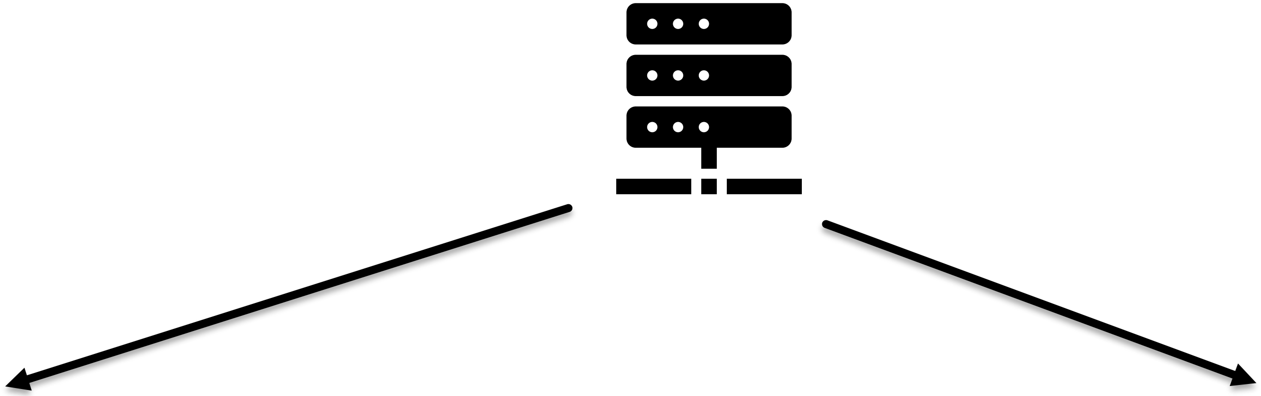


λ **Writing**

Custom logic

Building Serverless Services - Disaggregate



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Bandwidth-scalable data access

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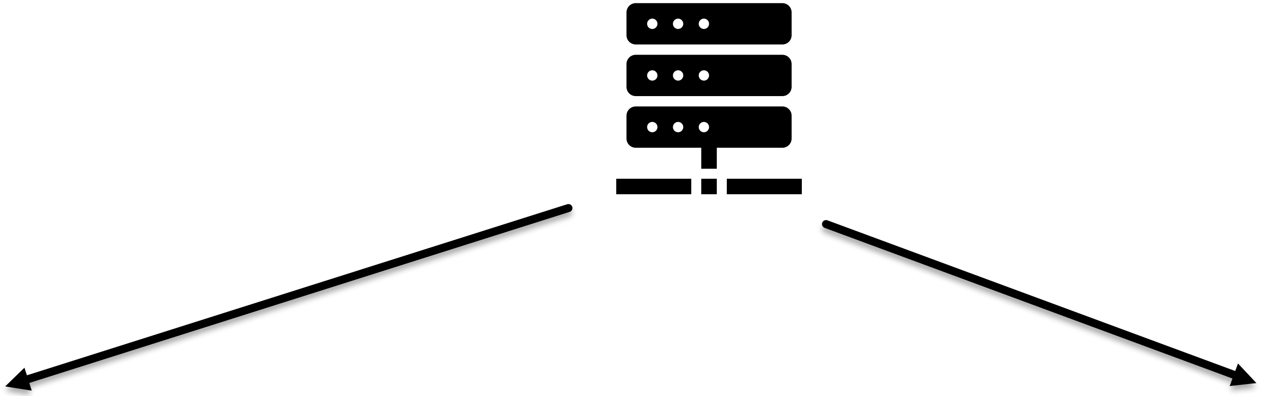

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10M read requests to DynamoDB: $2.5

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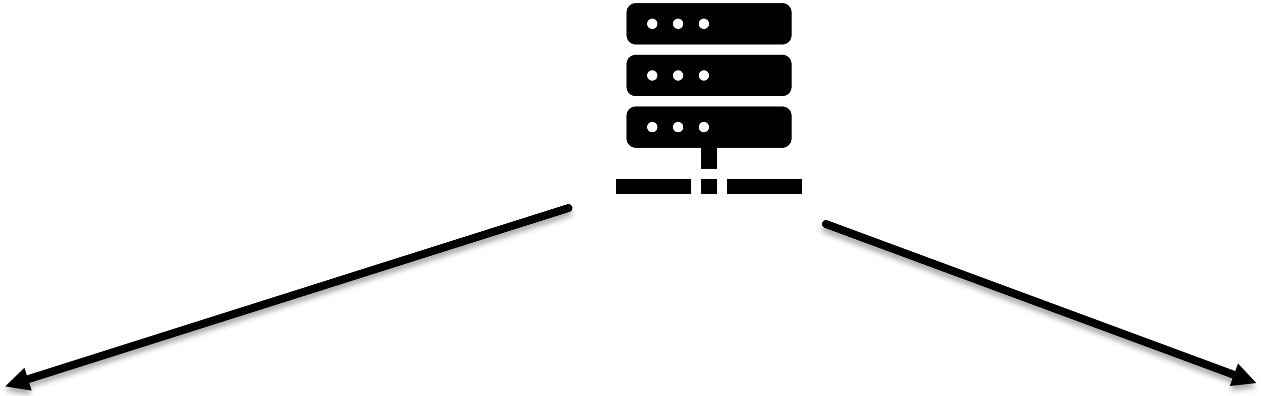

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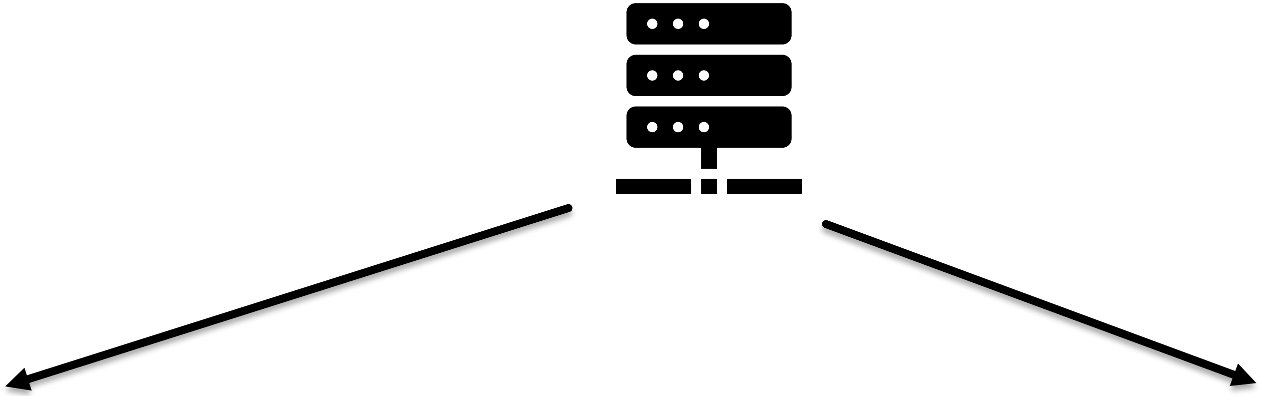

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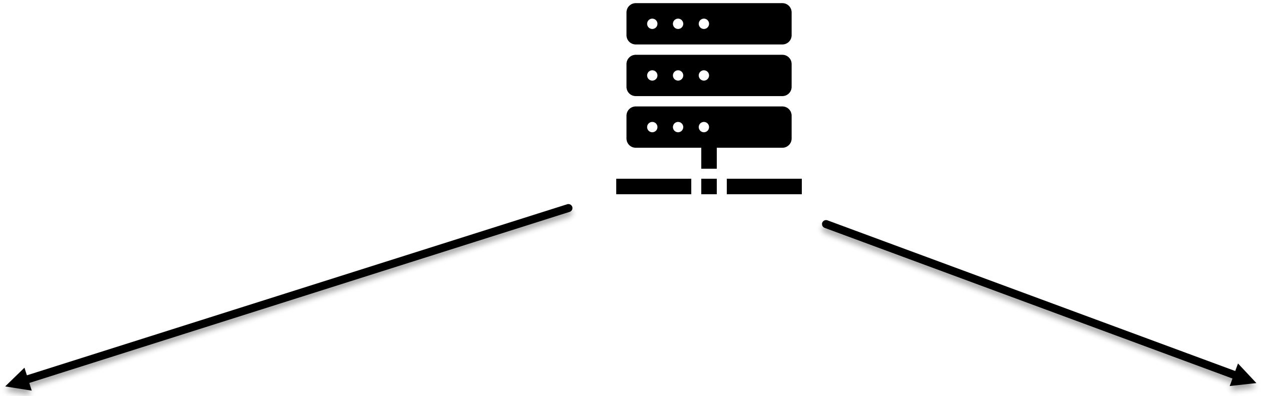

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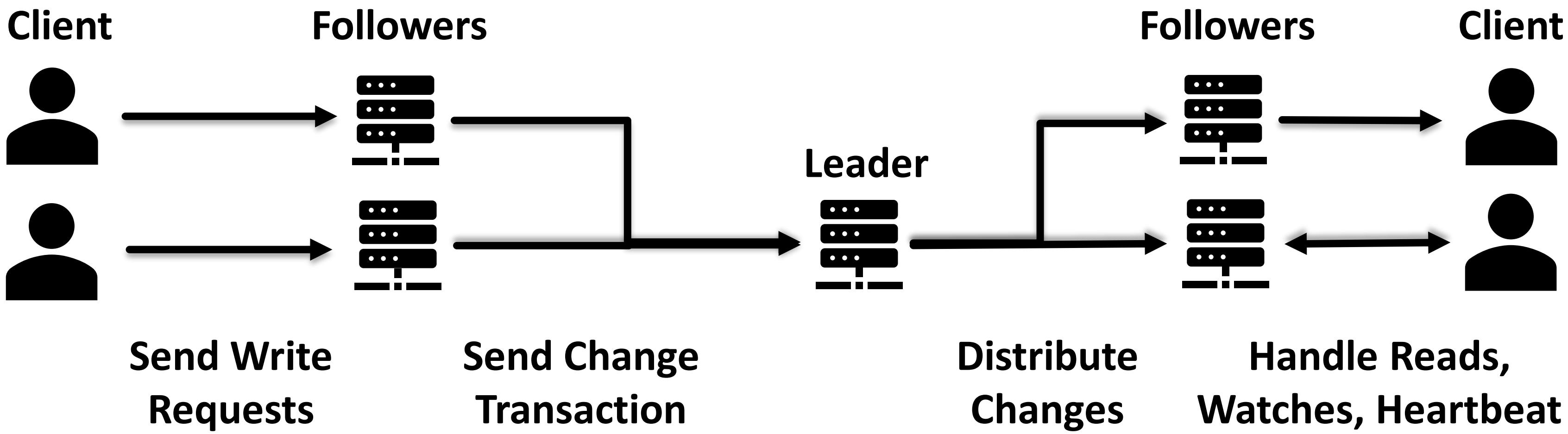

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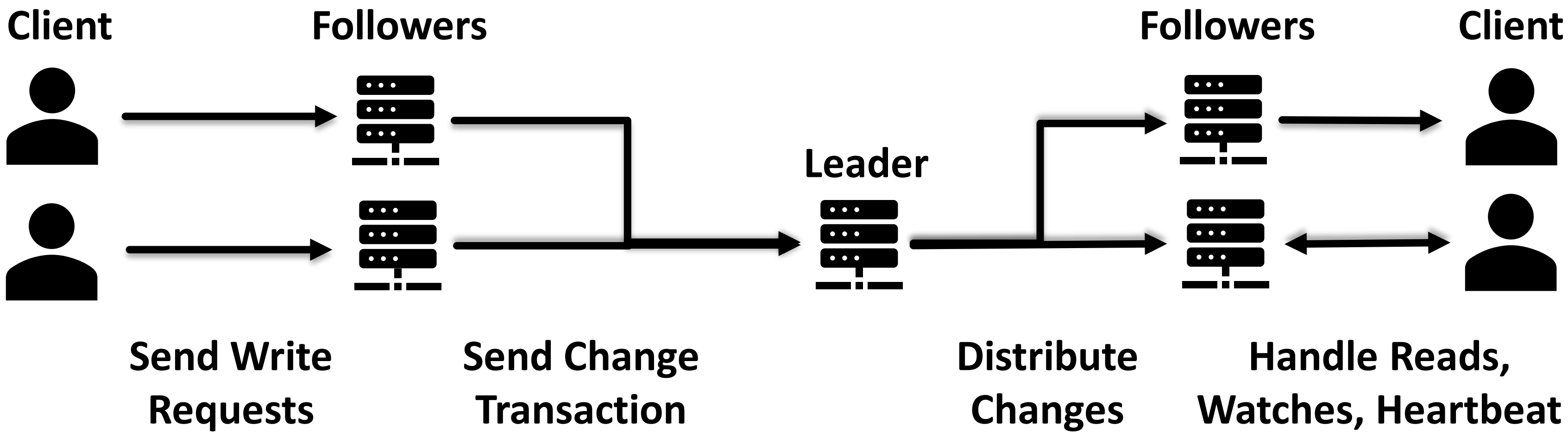
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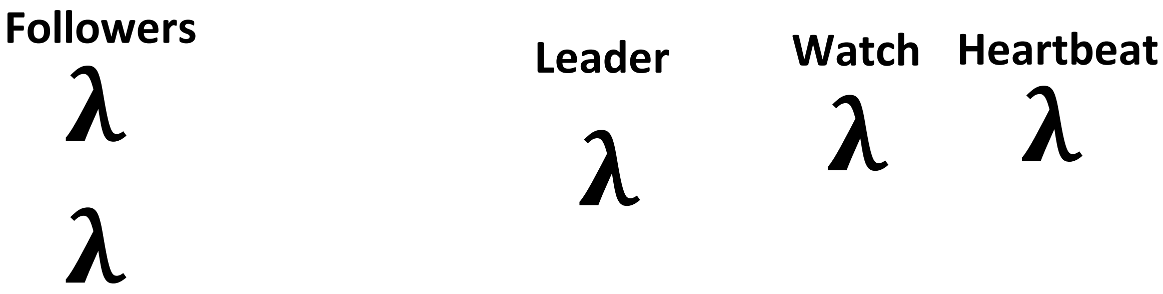
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λ

Watch

λ

Heartbeat

λ

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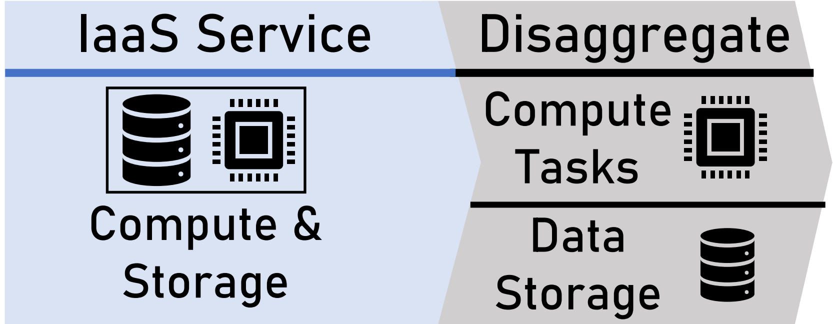

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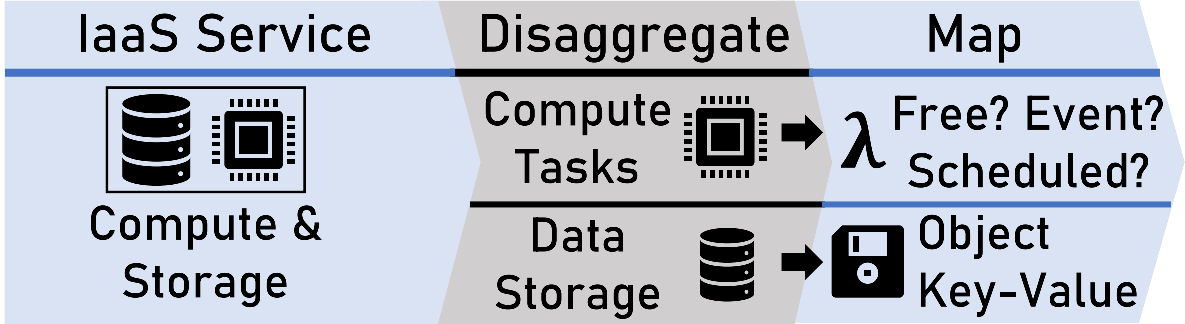

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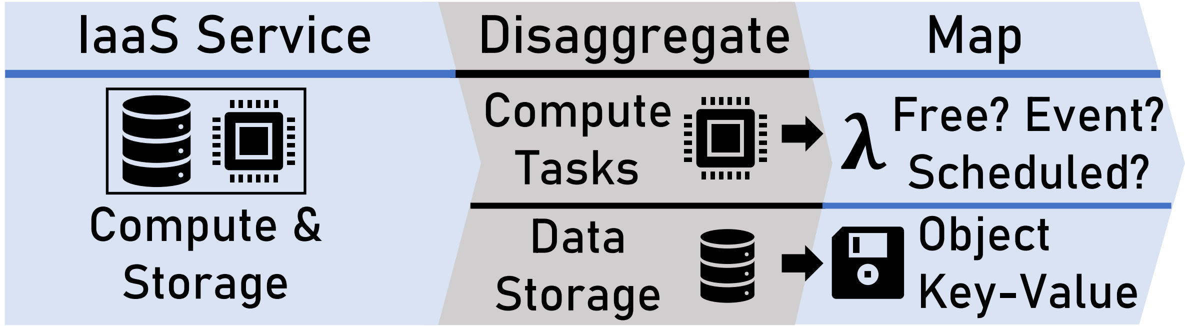


Map to Cloud Services

Building Serverless Services – Map Storage

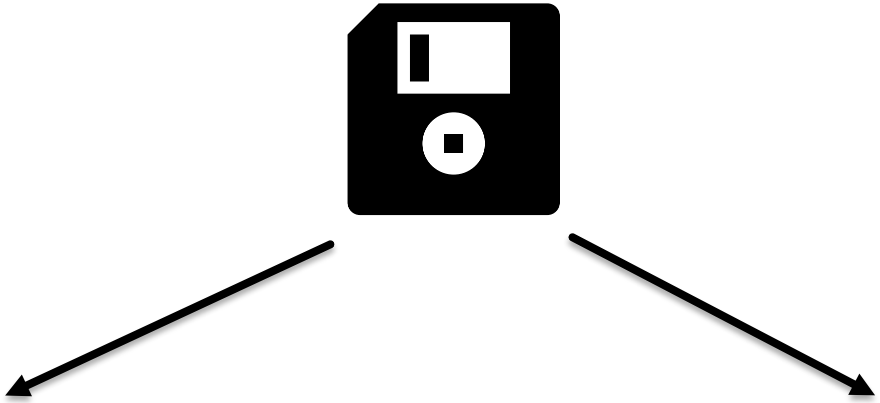
Building Serverless Services – Map Storage

System

Mostly write operations

Synchronization primitives

Building Serverless Services – Map Storage



System

Mostly write operations

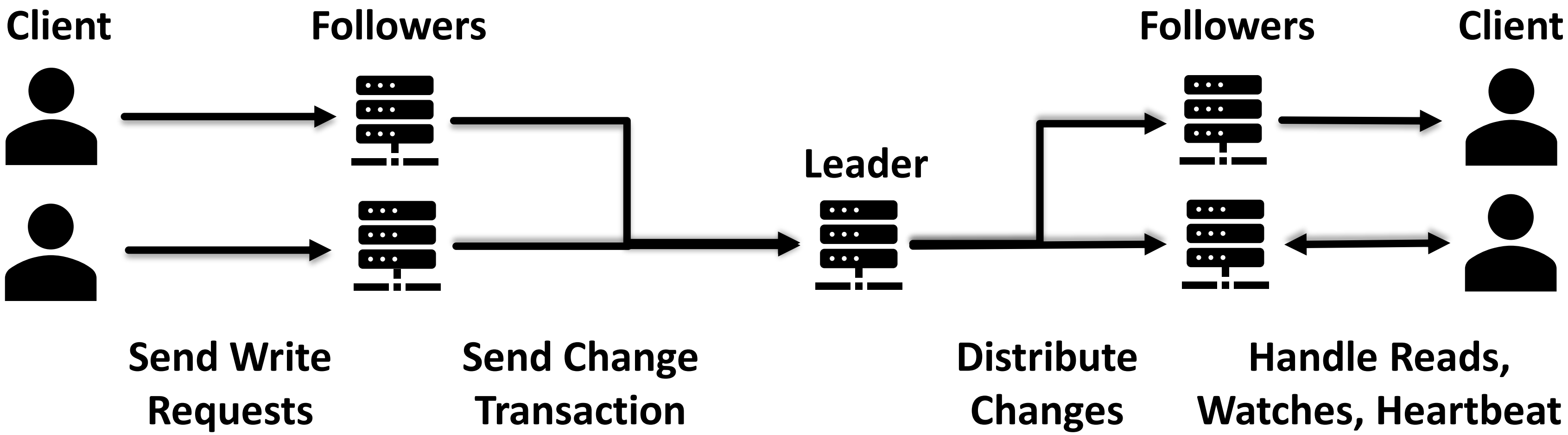
Synchronization primitives

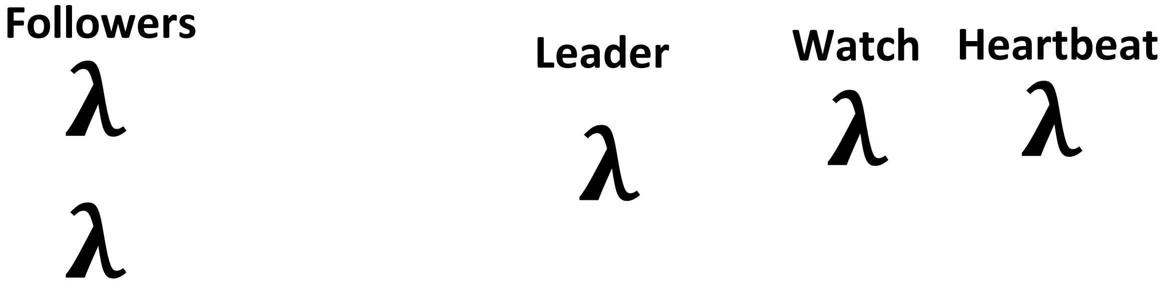
User

Frequent reading

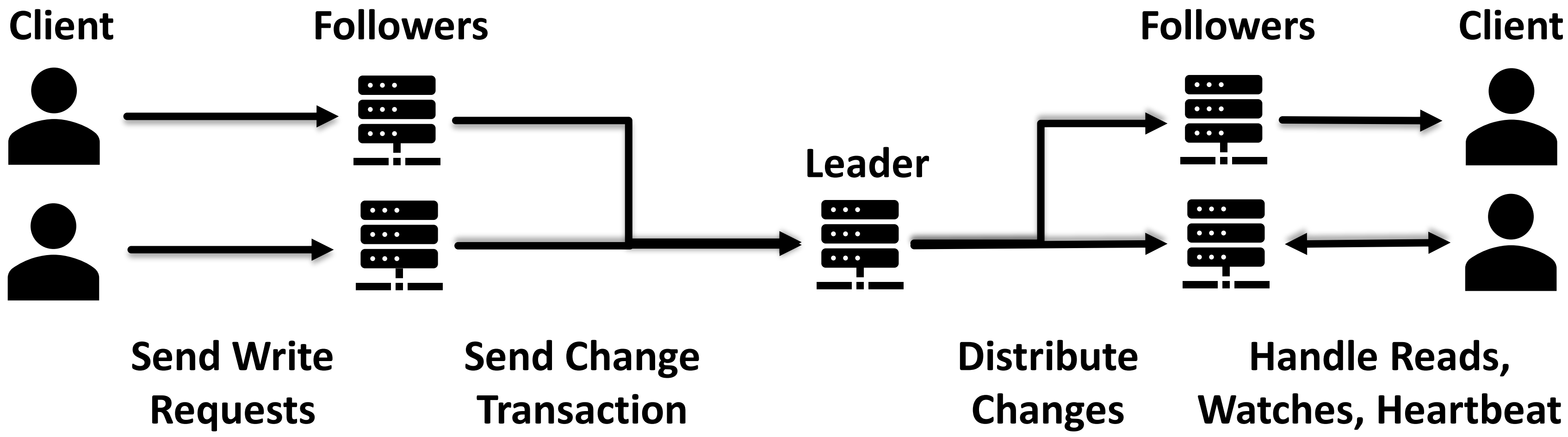
Cost efficient

From ZooKeeper to FaaSKeeper





From ZooKeeper to FaaSKeeper


Client

Followers

Leader

Followers

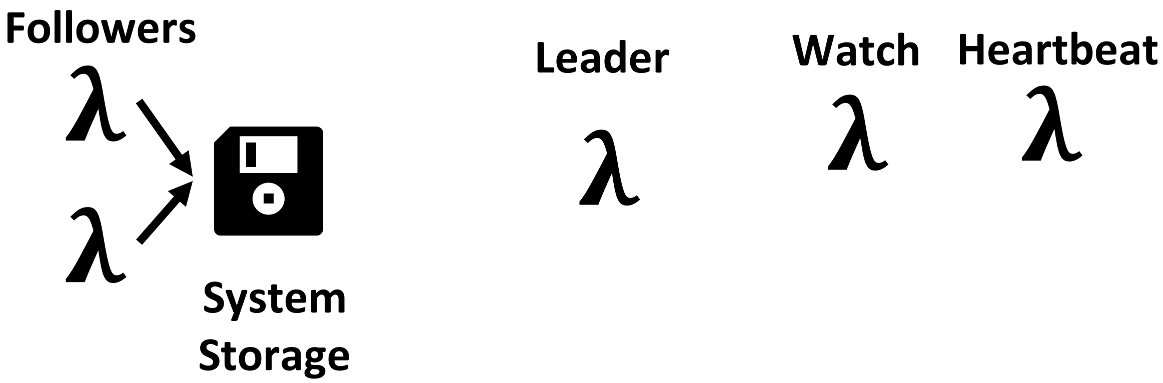
Client

Send Write Requests

Send Change Transaction

Distribute Changes

Handle Reads, Watches, Heartbeat


Followers

λ

λ

System Storage

Leader

λ

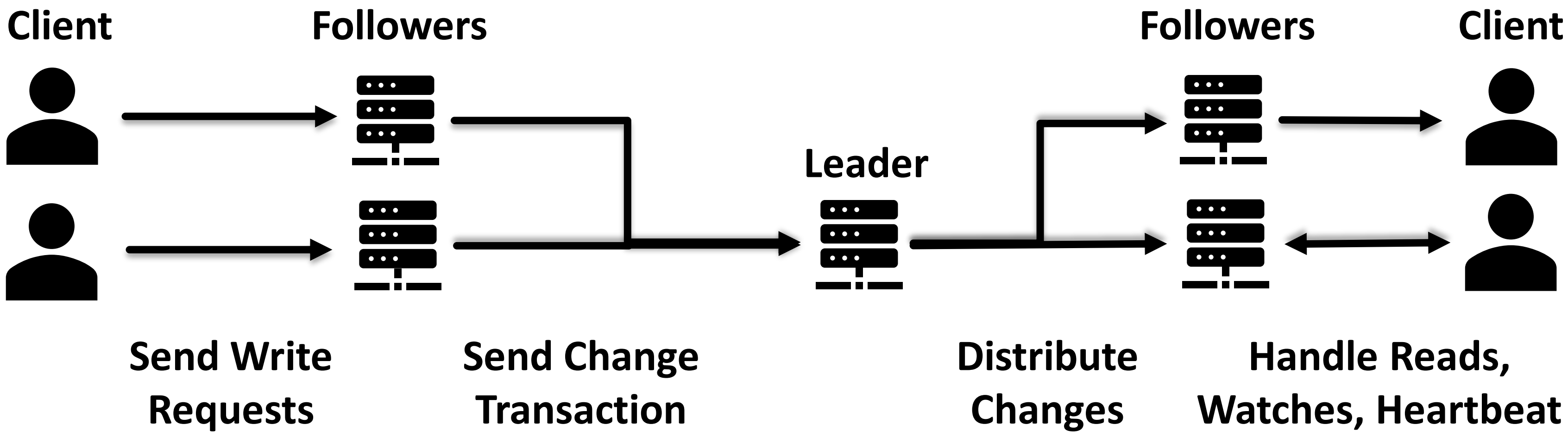
Watch

λ

Heartbeat

λ

From ZooKeeper to FaaSKeeper



Client

Followers

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Followers

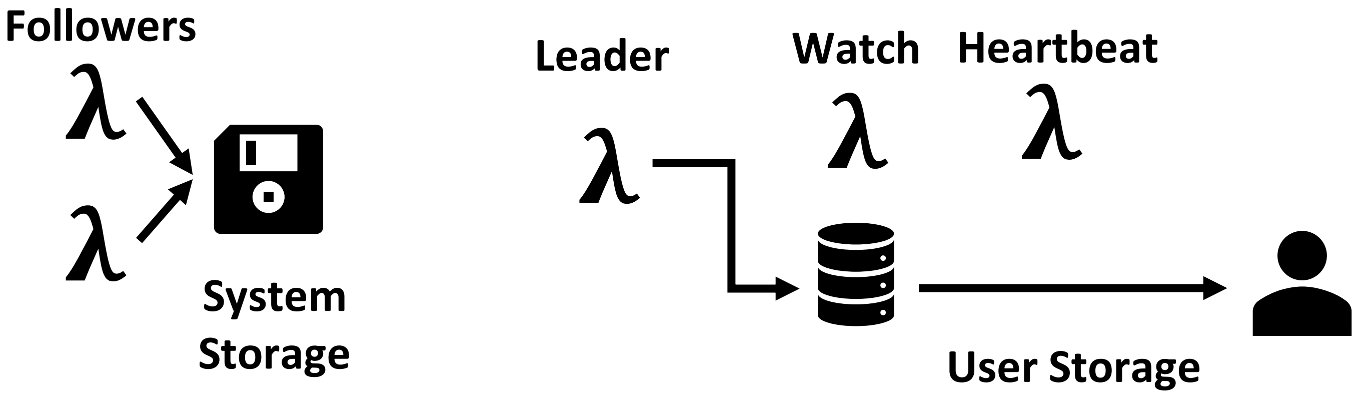
Client

Send Write Requests

Send Change Transaction

Distribute Changes

Handle Reads, Watches, Heartbeat



Followers

System Storage

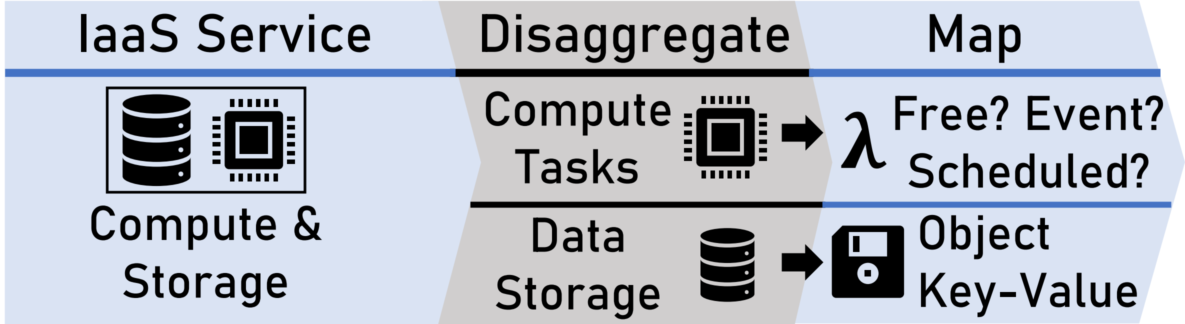
Leader

Watch

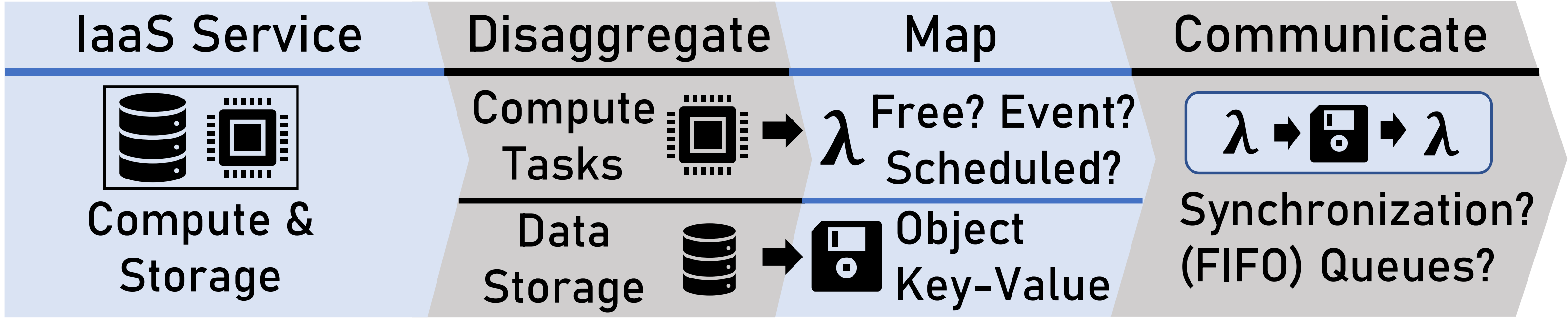
Heartbeat

User Storage

From ZooKeeper to FaaSKeeper



From ZooKeeper to FaaSKeeper



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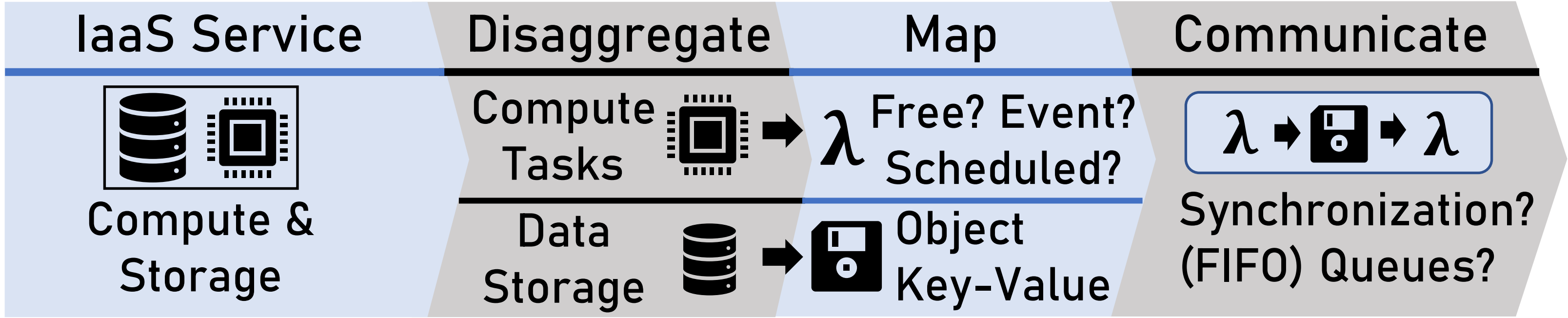
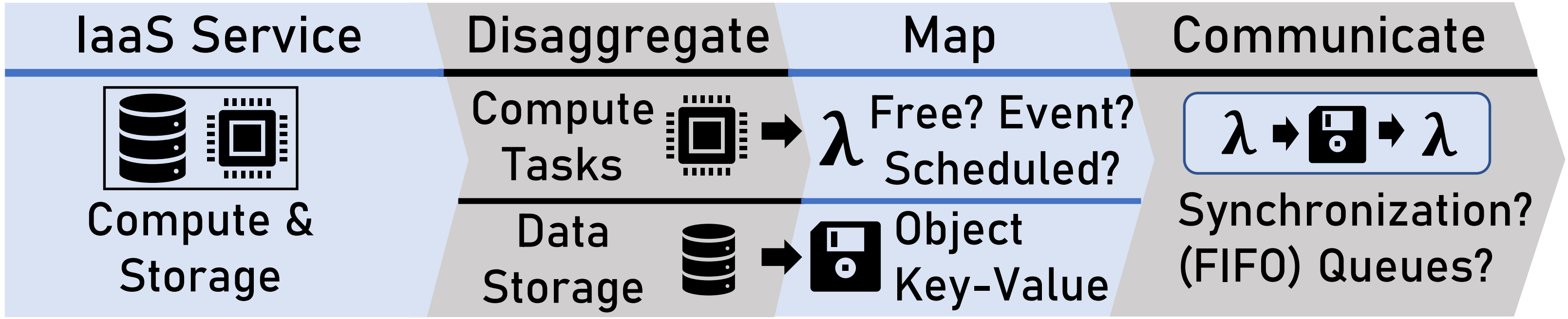


Event Ordering on Client

From ZooKeeper to FaaSKeeper



IaaS Service

Compute & Storage

Disaggregate

Compute Tasks →

Data Storage →

Map

λ Free? Event? Scheduled?

Object Key-Value

Communicate

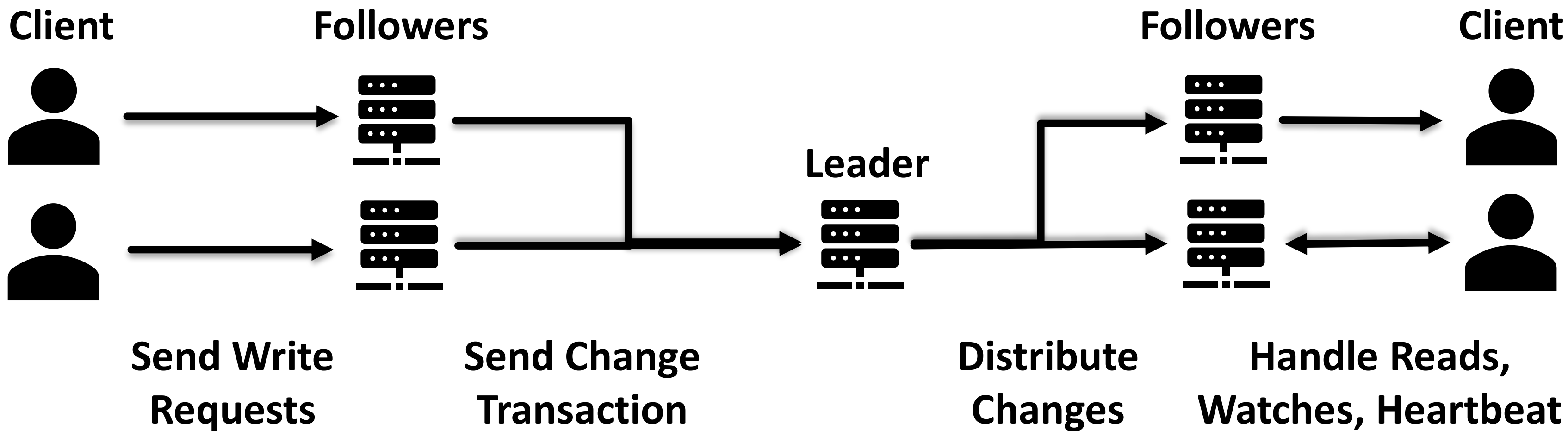
λ → 🖫 → λ

Synchronization? (FIFO) Queues?

Event Ordering on Client

Epoch Counters for Watches

From ZooKeeper to FaaSKeeper



Client

Followers

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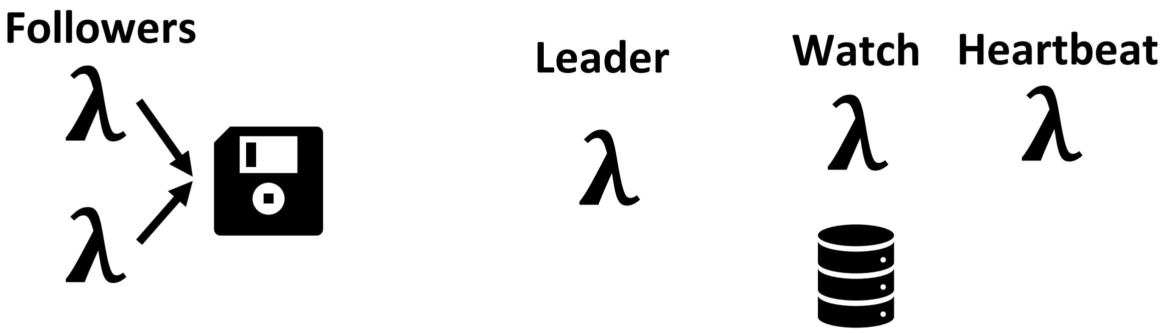
Handle Reads, Watches, Heartbeat



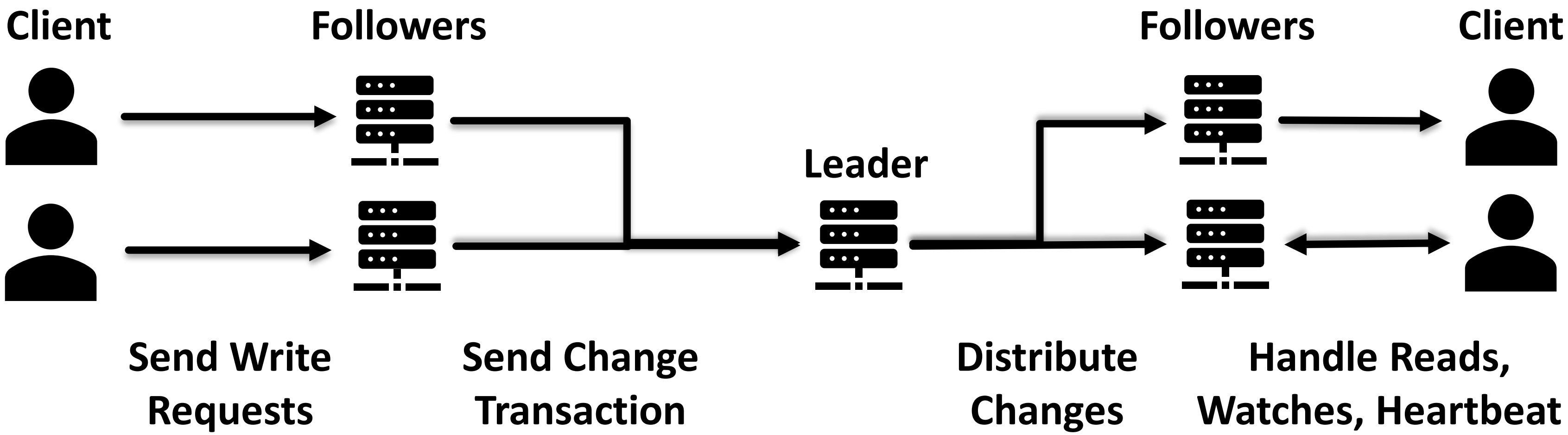
Followers

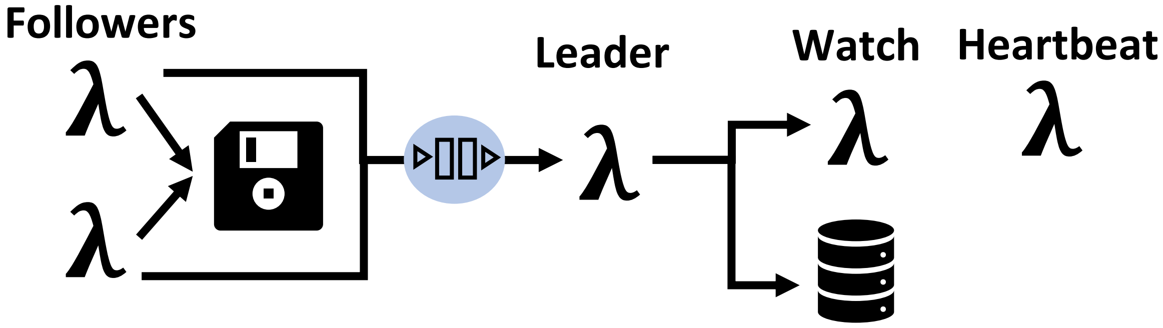
Leader

Watch

Heartbeat

From ZooKeeper to FaaSKeeper





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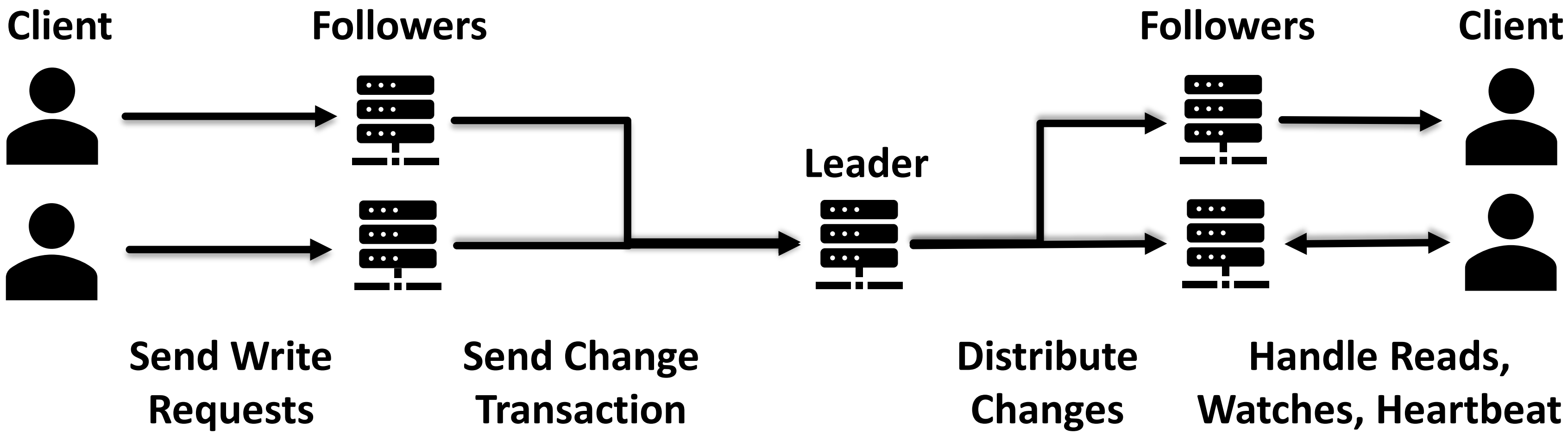

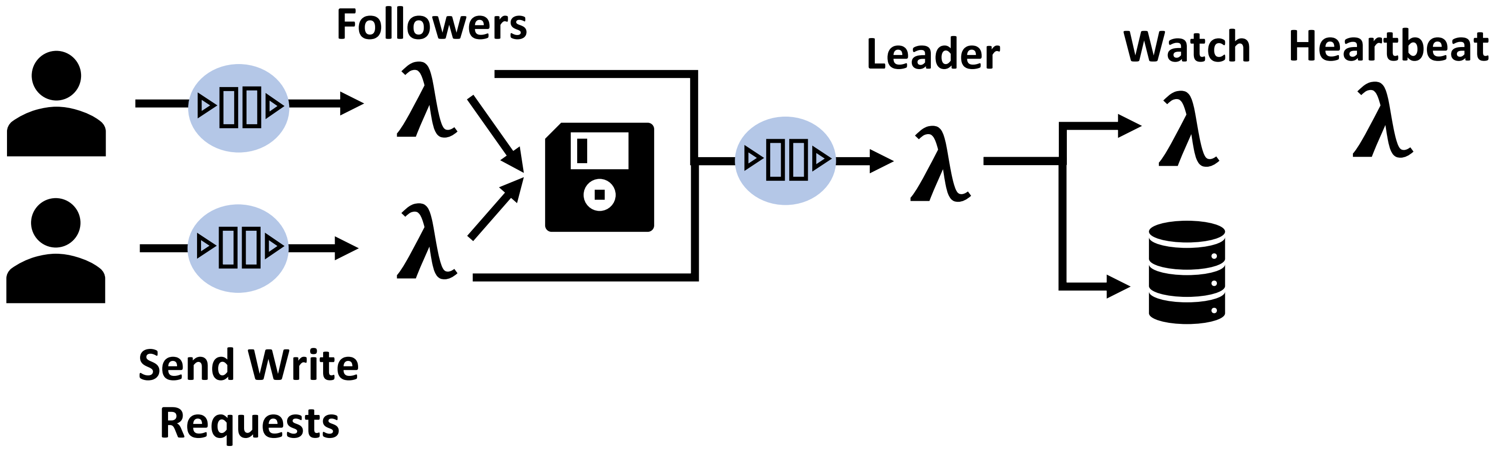

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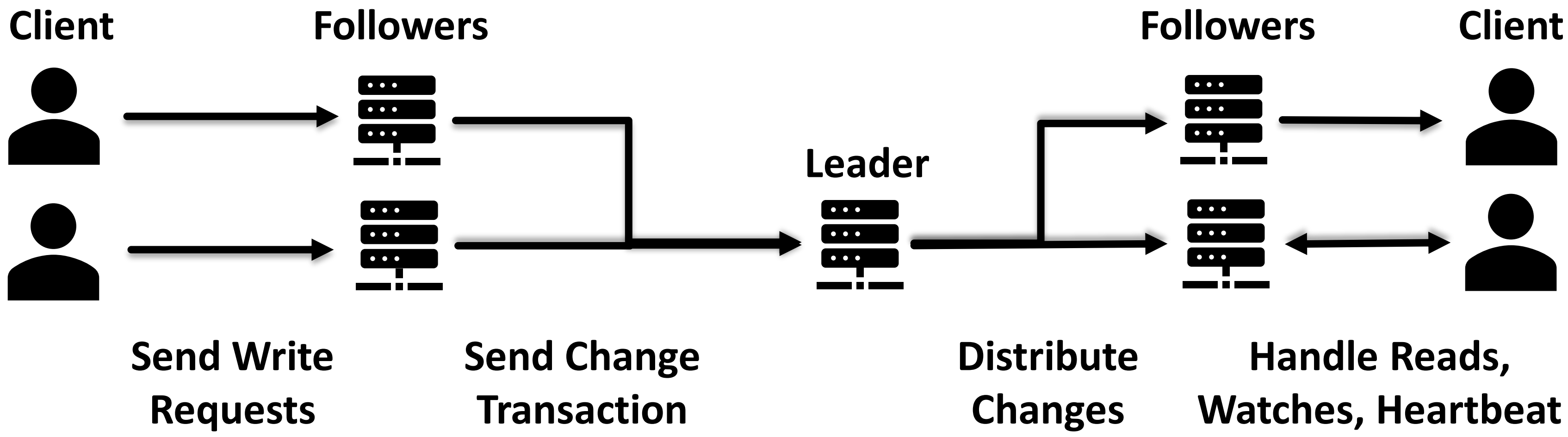

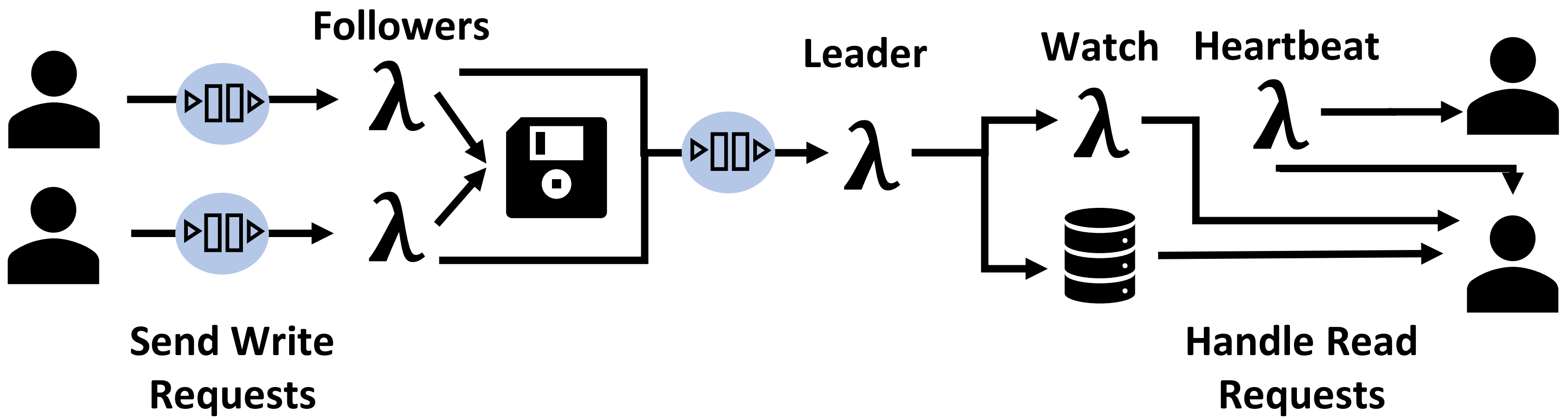

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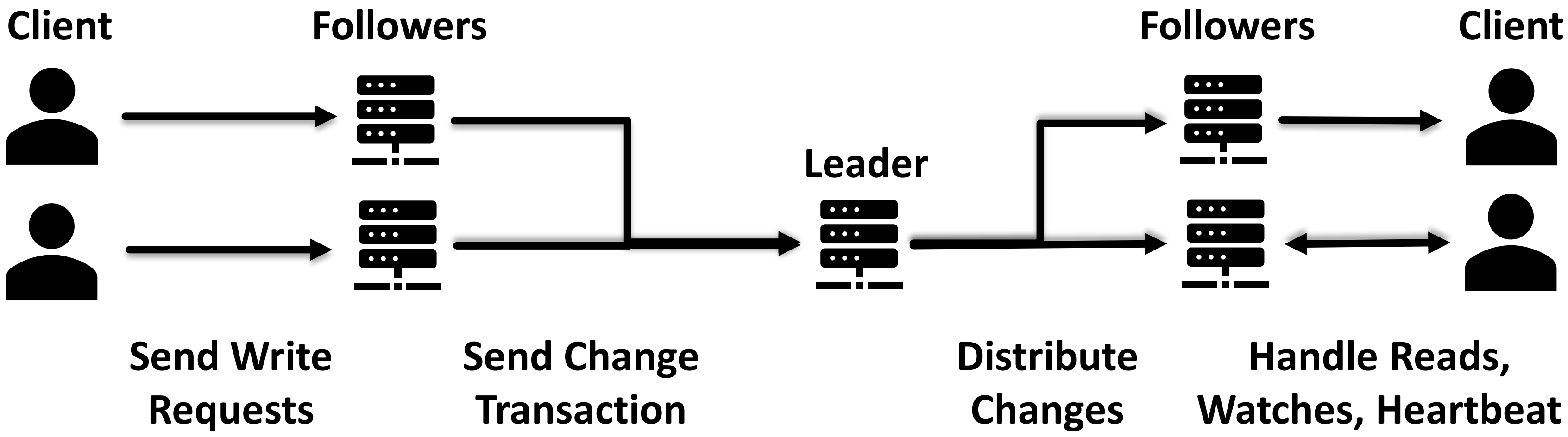

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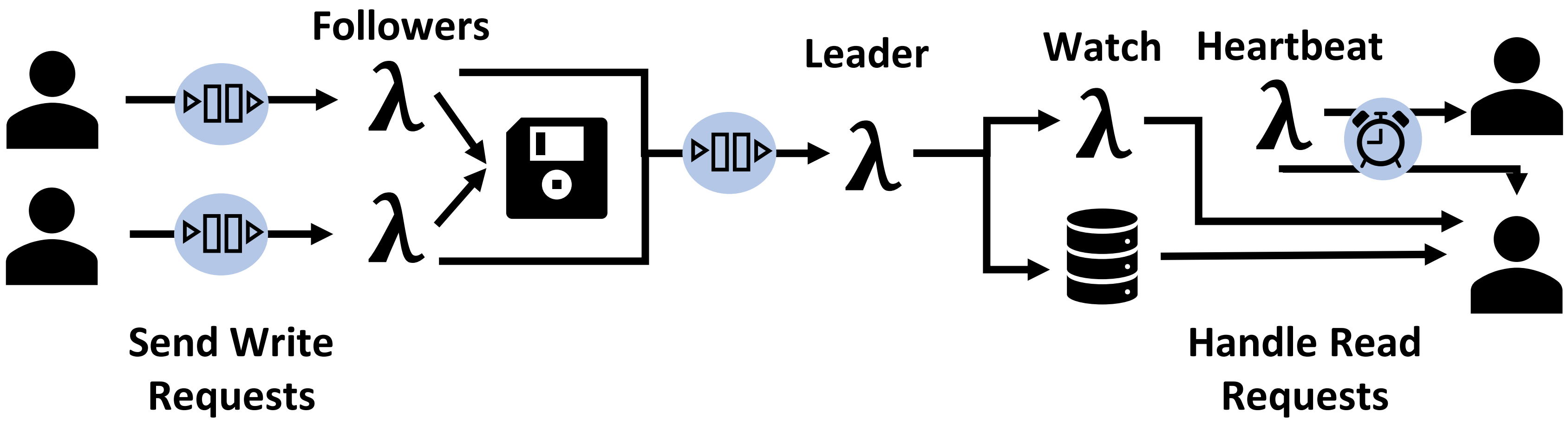


Followers

Leader

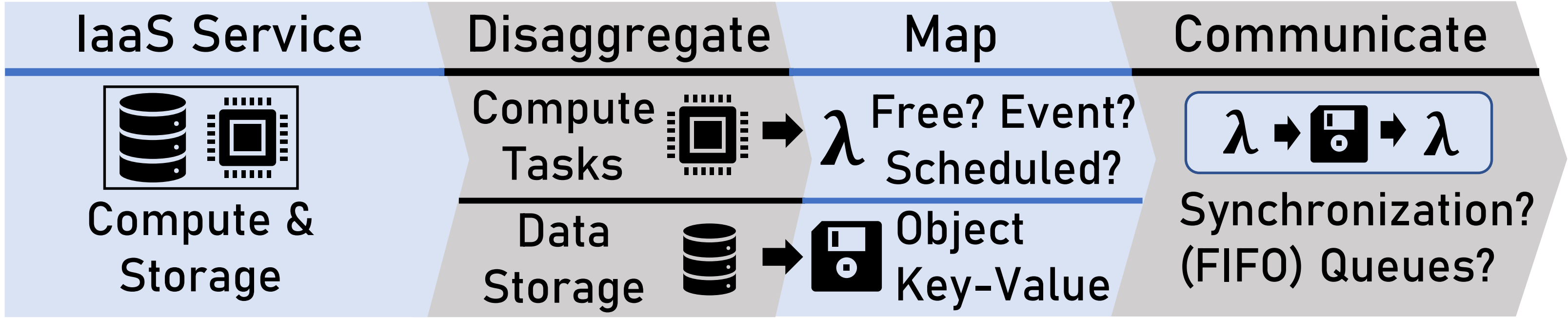
Watch

Heartbeat

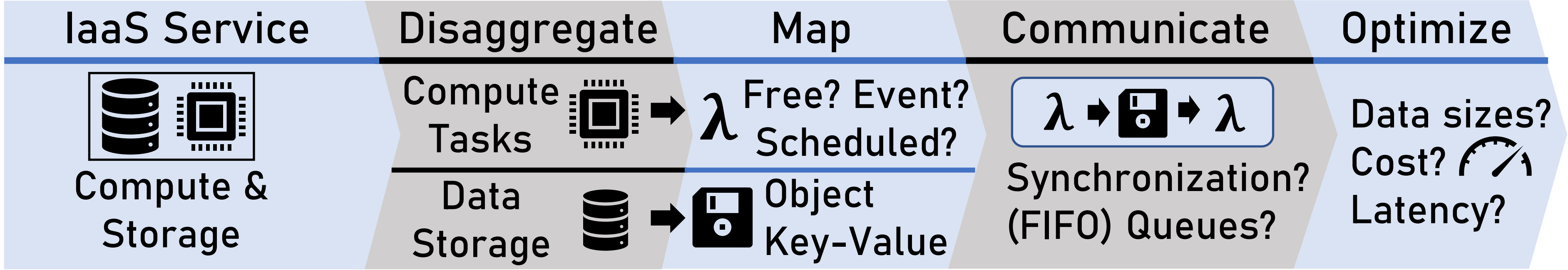
Send Write Requests

Handle Read Requests

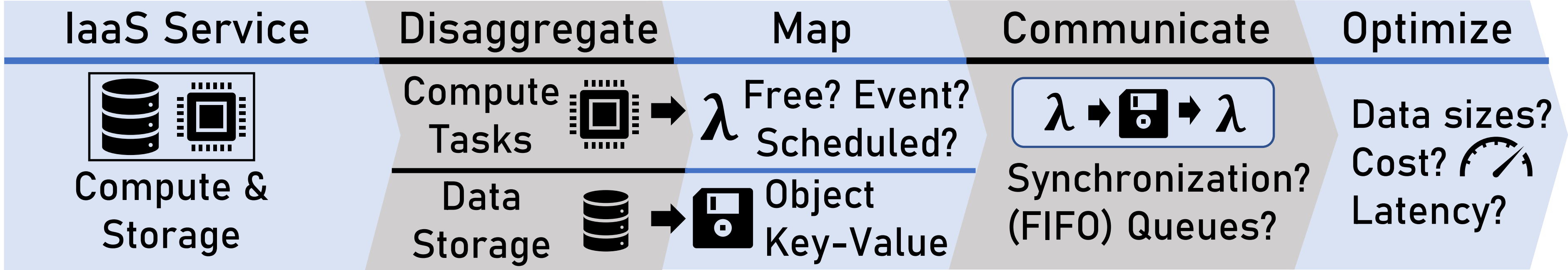
From ZooKeeper to FaaSKeeper



From ZooKeeper to FaaSKeeper



From ZooKeeper to FaaSKeeper



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Disaggregate

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Data Storage

Map

λ Free? Event? Scheduled?

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Communicate

λ → → λ

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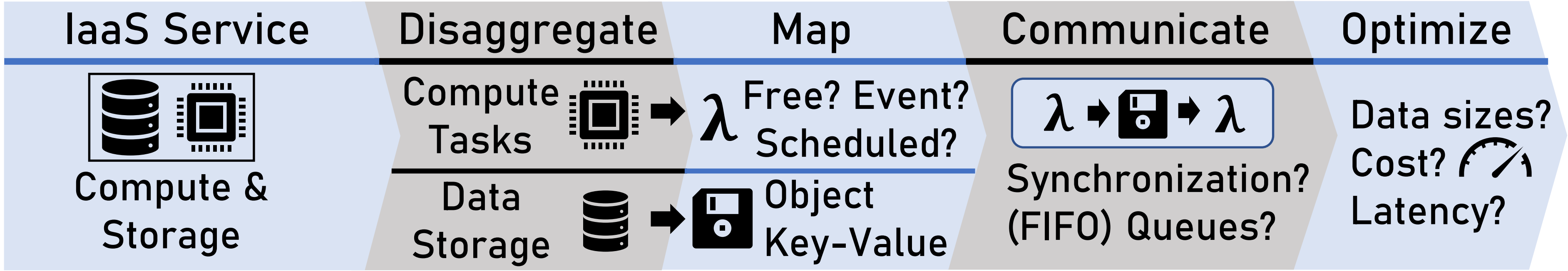
Optimize

Data sizes? Cost? Latency?

Hybrid Storage

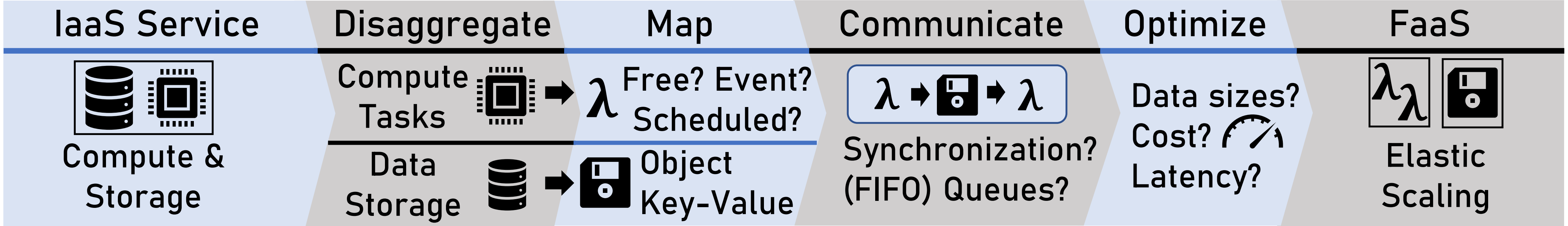
From ZooKeeper to FaaSKeeper



Hybrid Storage

Decoupled Heartbeats

From ZooKeeper to FaaSKeeper



Hybrid Storage

Decoupled Heartbeats

Consistency Model

Consistency Model

❶ **Atomicity**

Atomic updates to cloud storage

Consistency Model

APACHE ZooKeeper™

FAASKEEPER

1 **Atomicity** — **Atomic updates to cloud storage**

2 **Linearized Writes** — **Single leader with ordered queues**

Consistency Model

APACHE ZooKeeper™	FAASKEEPER
1 Atomicity	Atomic updates to cloud storage
2 Linearized Writes	Single leader with ordered queues
3 Single System Image	Strongly consistent cloud storage

Consistency Model

APACHE ZooKeeper™	FAASKEEPER
1 Atomicity	Atomic updates to cloud storage
2 Linearized Writes	Single leader with ordered queues
3 Single System Image	Strongly consistent cloud storage
4 Ordered Notifications	Watch notifications with epoch counters

Implementation & Evaluation

Implementation & Evaluation

Proof of Concept Implementation

1,350 LoC for FaaSKeeper

1,400 LoC for client library

Implementation & Evaluation

Proof of Concept Implementation

1,350 LoC for FaaSKeeper

1,400 LoC for client library

aws

Google Cloud

Implementation & Evaluation

Proof of Concept Implementation
1,350 LoC for FaaSKeeper
1,400 LoC for client library

aws

Google Cloud

1. **How does read performance compare to ZooKeeper?**

2. **How does write performance compare to ZooKeeper?**

Implementation & Evaluation

Proof of Concept Implementation
1,350 LoC for FaaSKeeper
1,400 LoC for client library

aws

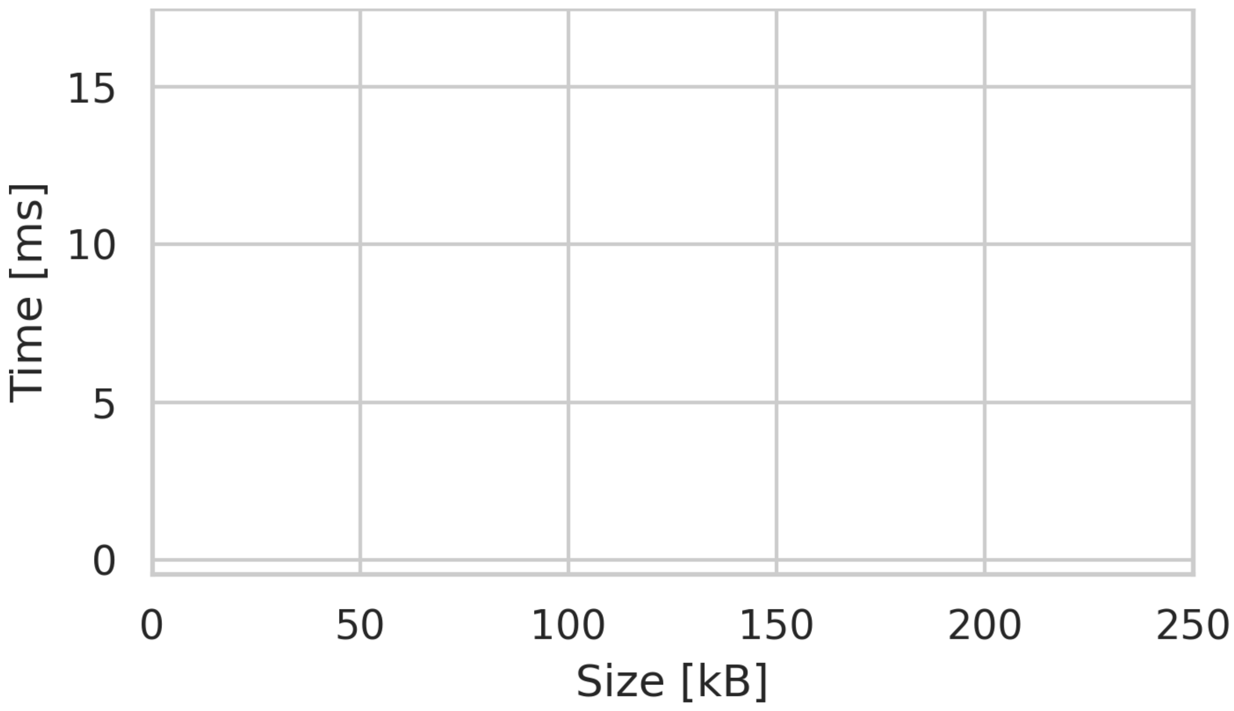
Google Cloud

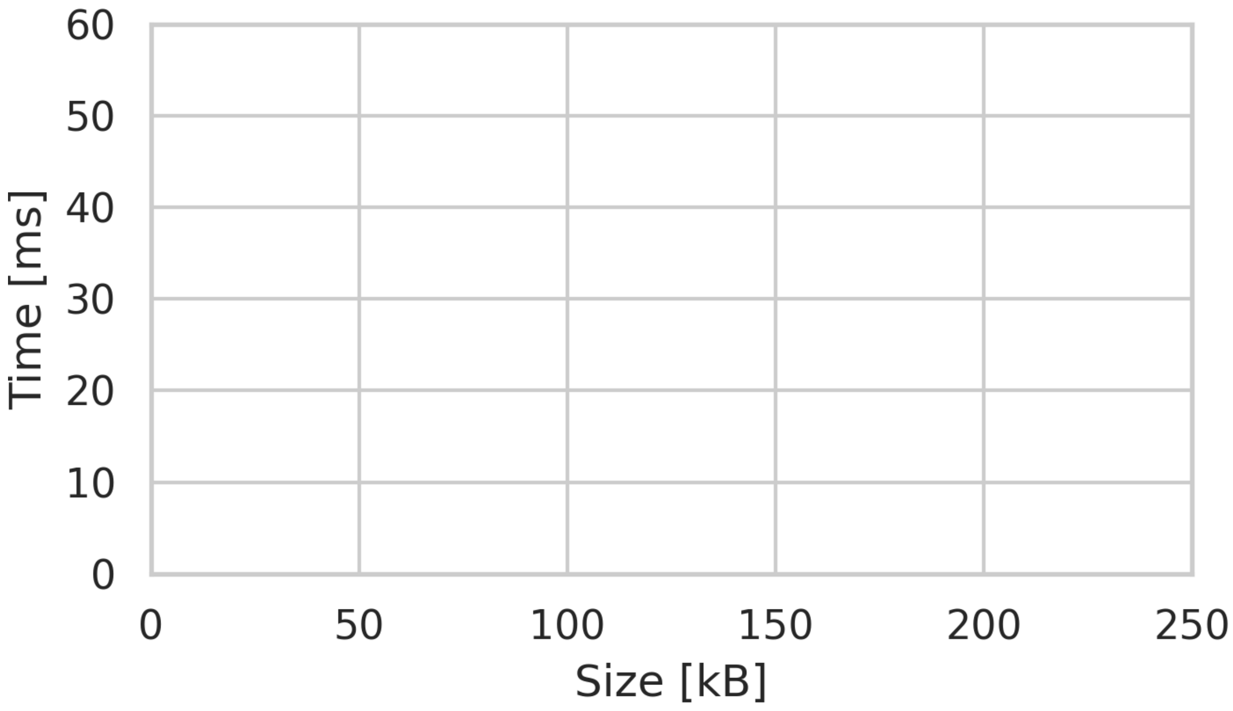
1. **How does read performance compare to ZooKeeper?**
2. **How does write performance compare to ZooKeeper?**
3. **By how much can FaaSKeeper decrease costs?**

Evaluation: Read Performance 1

aws

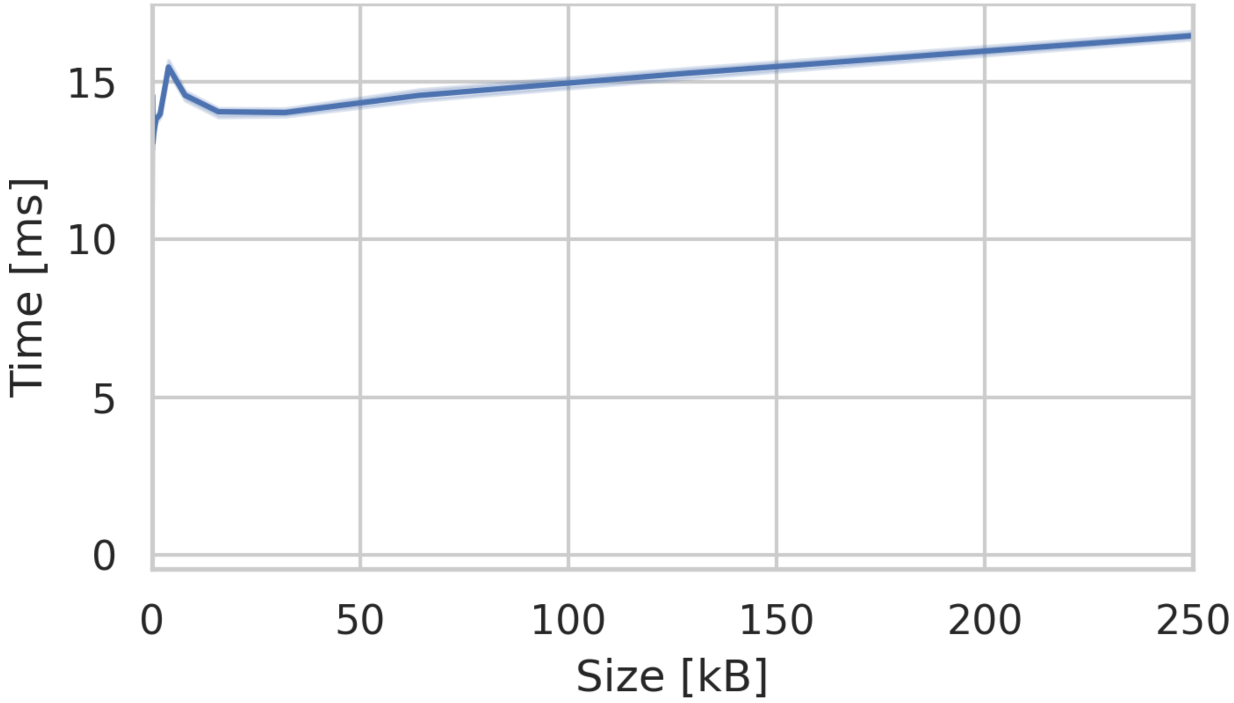
Google Cloud



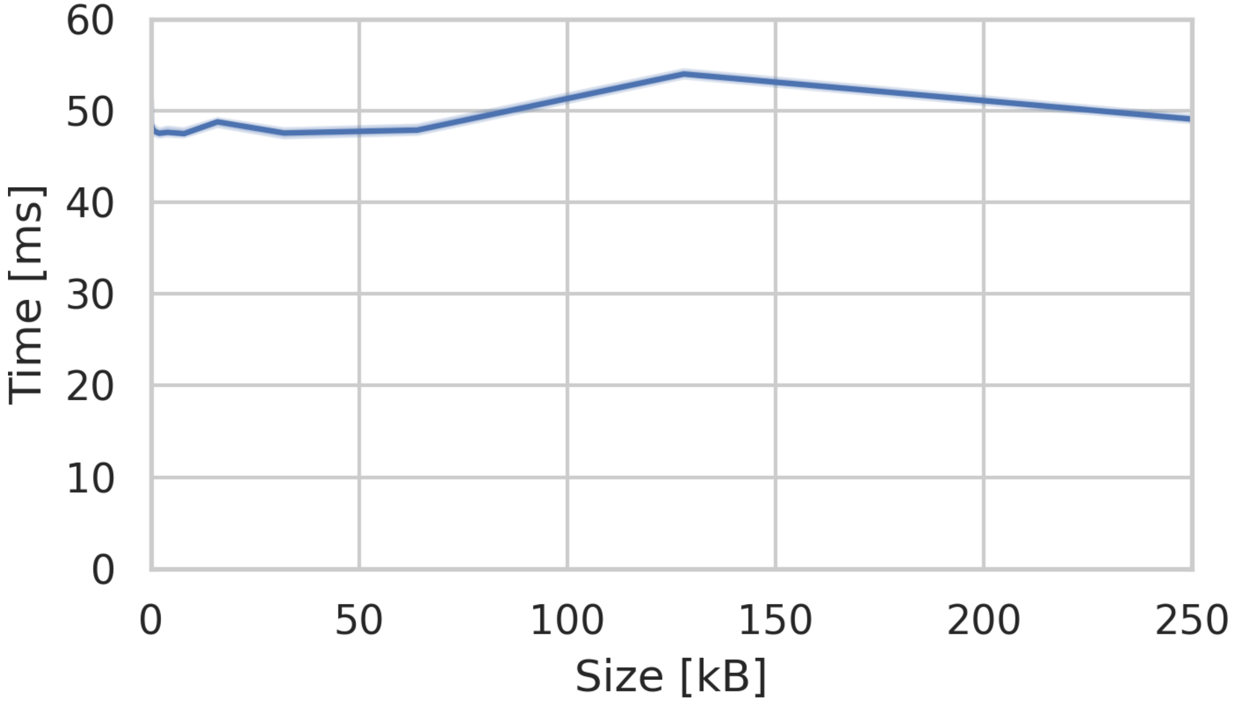


Evaluation: Read Performance 1

aws

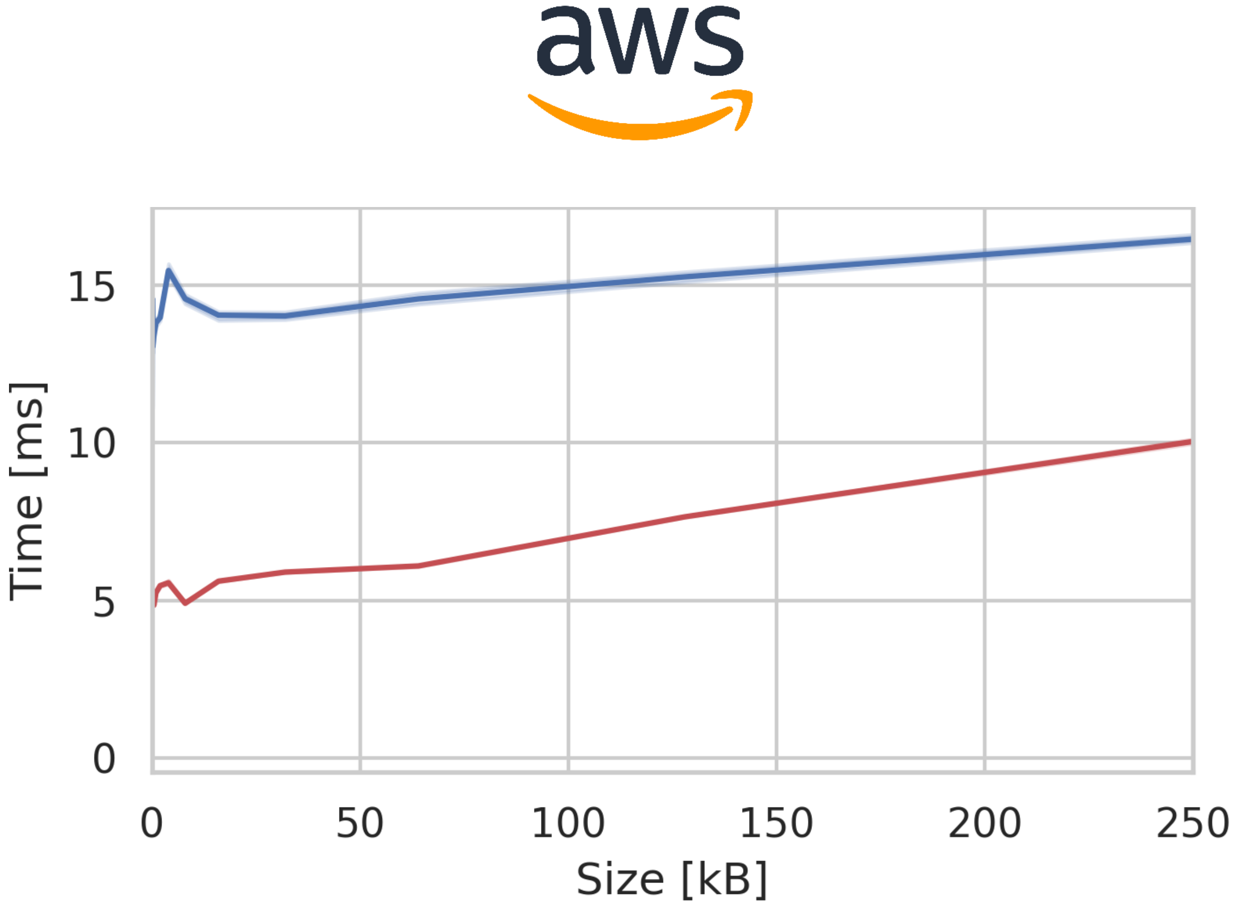


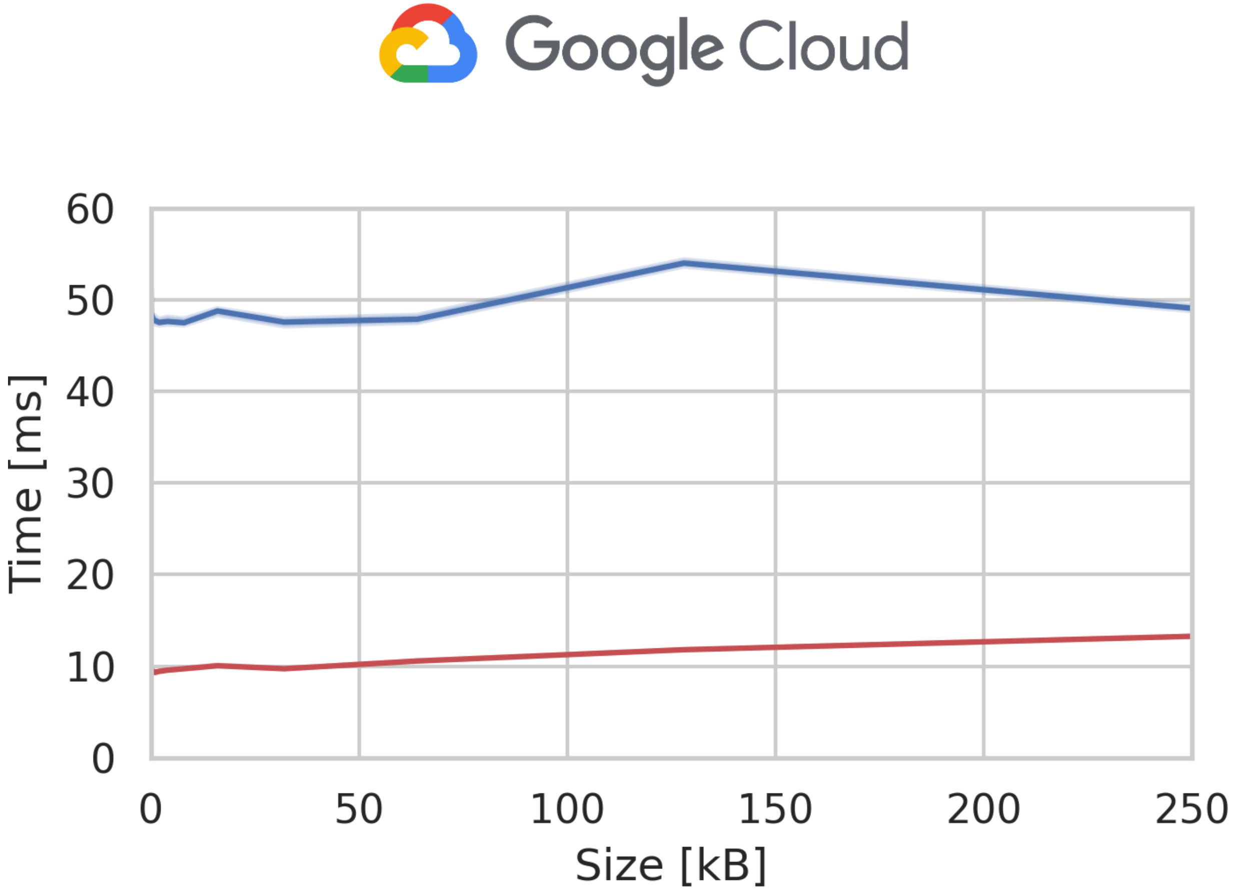
Google Cloud



FaaSKeeper
Object Storage

Evaluation: Read Performance 1



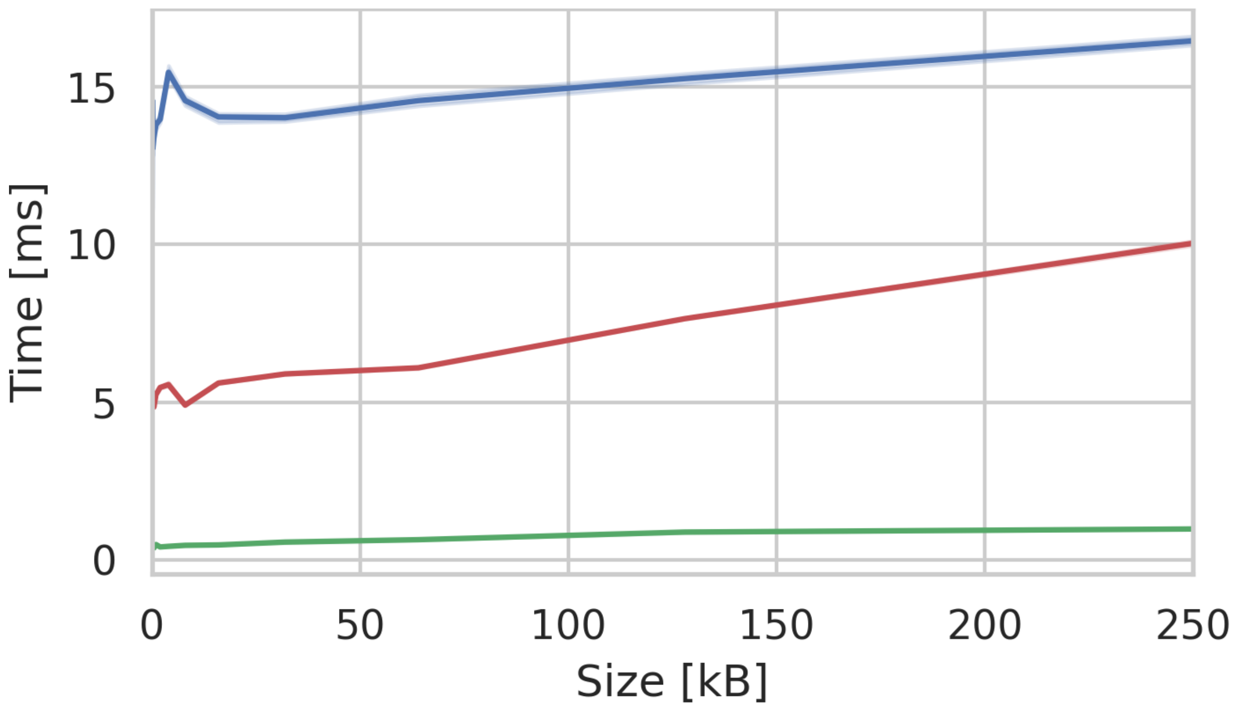


FaaSKeeper Object Storage

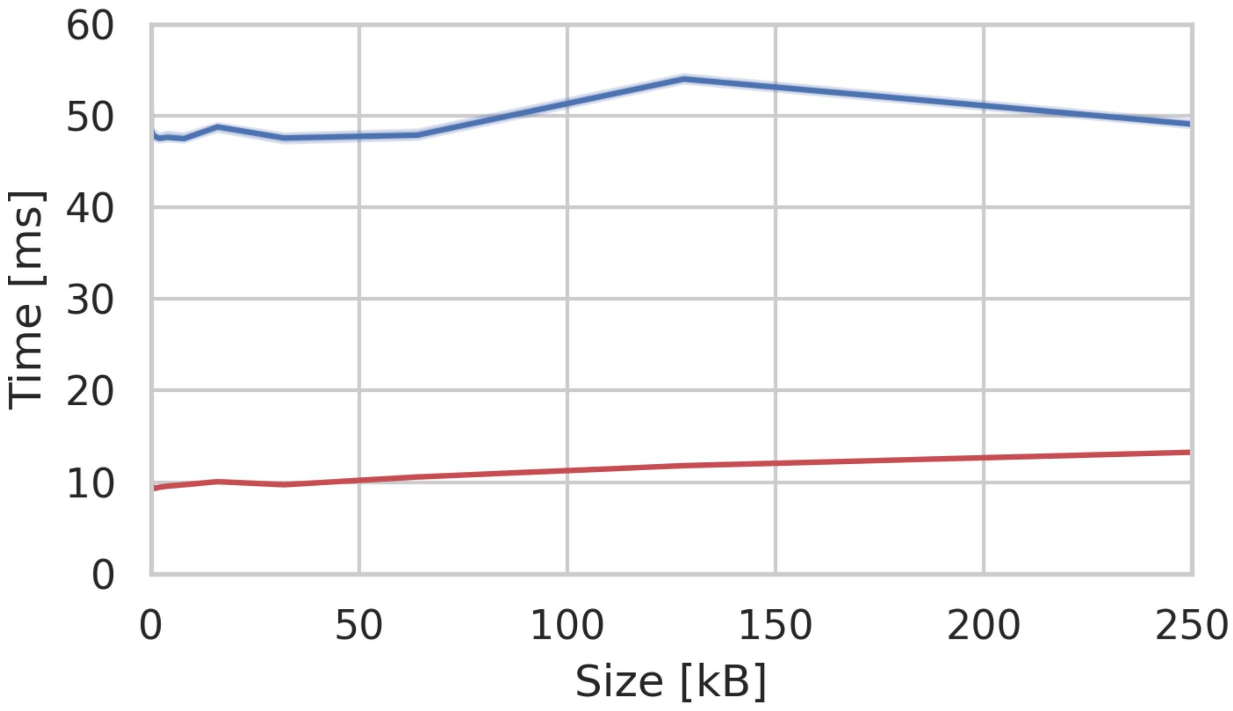
FaaSKeeper Key-Value Storage

Evaluation: Read Performance 1

aws



Google Cloud

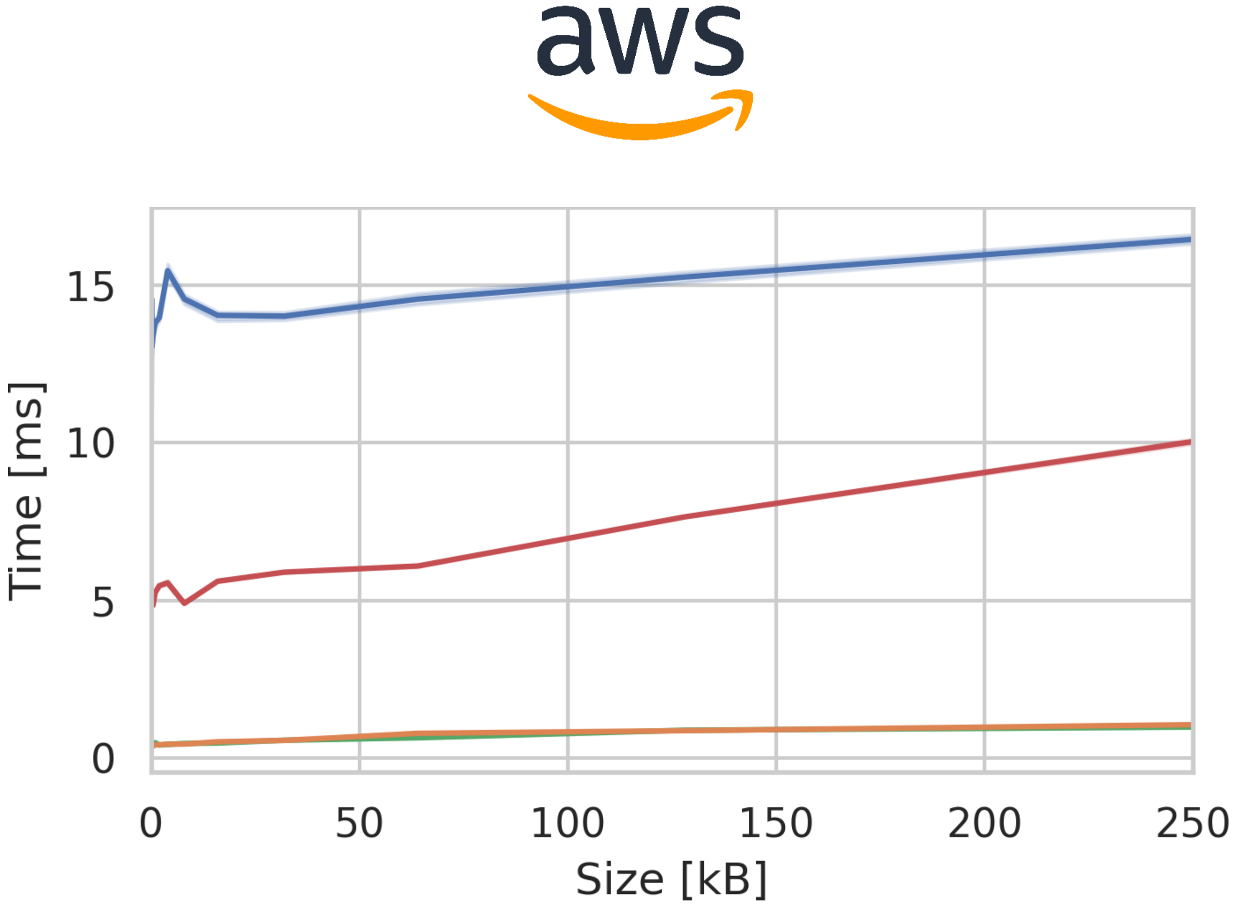


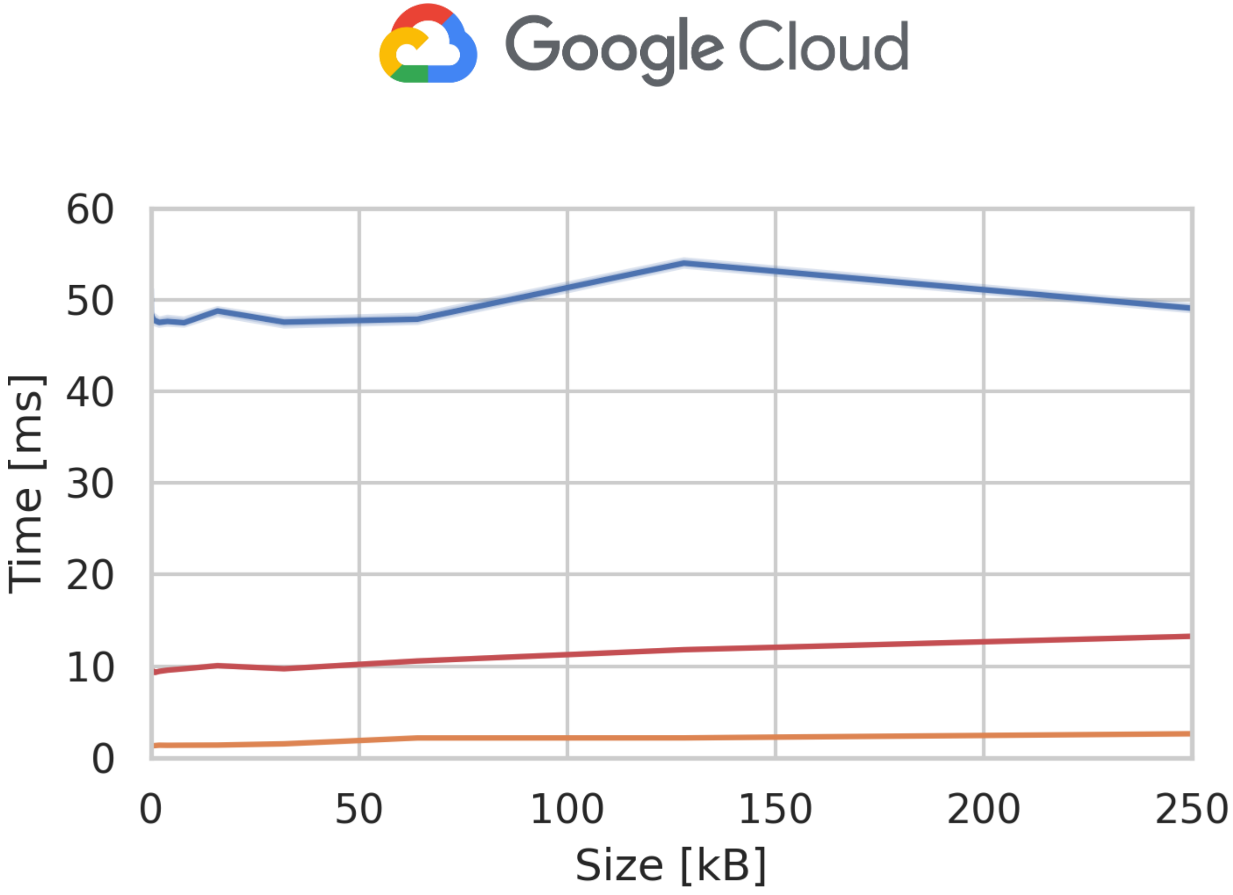
FaaSKeeper Object Storage

FaaSKeeper Key-Value Storage

FaaSKeeper Redis

Evaluation: Read Performance 1





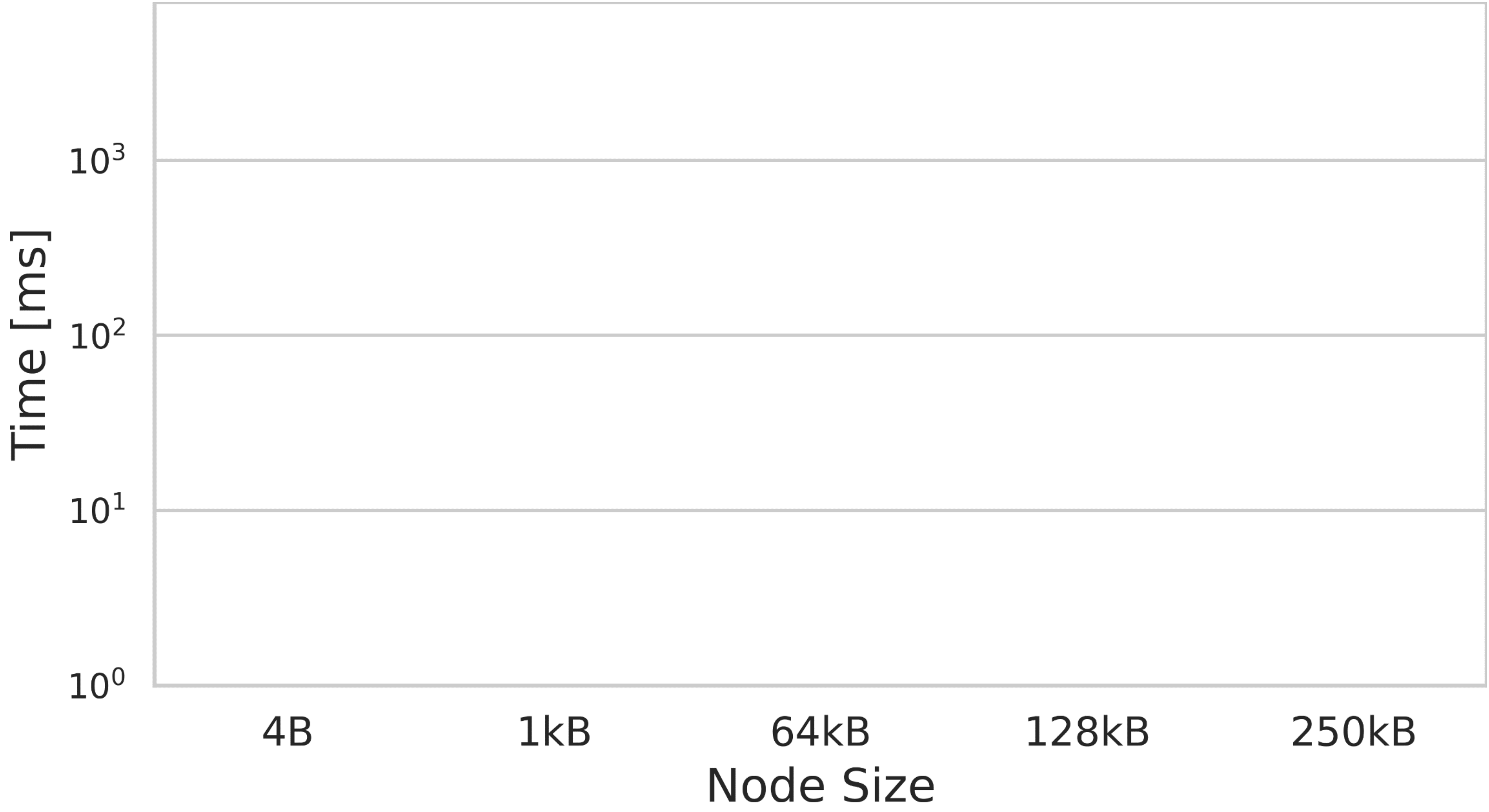
FaaSKeeper Object Storage

FaaSKeeper Key-Value Storage

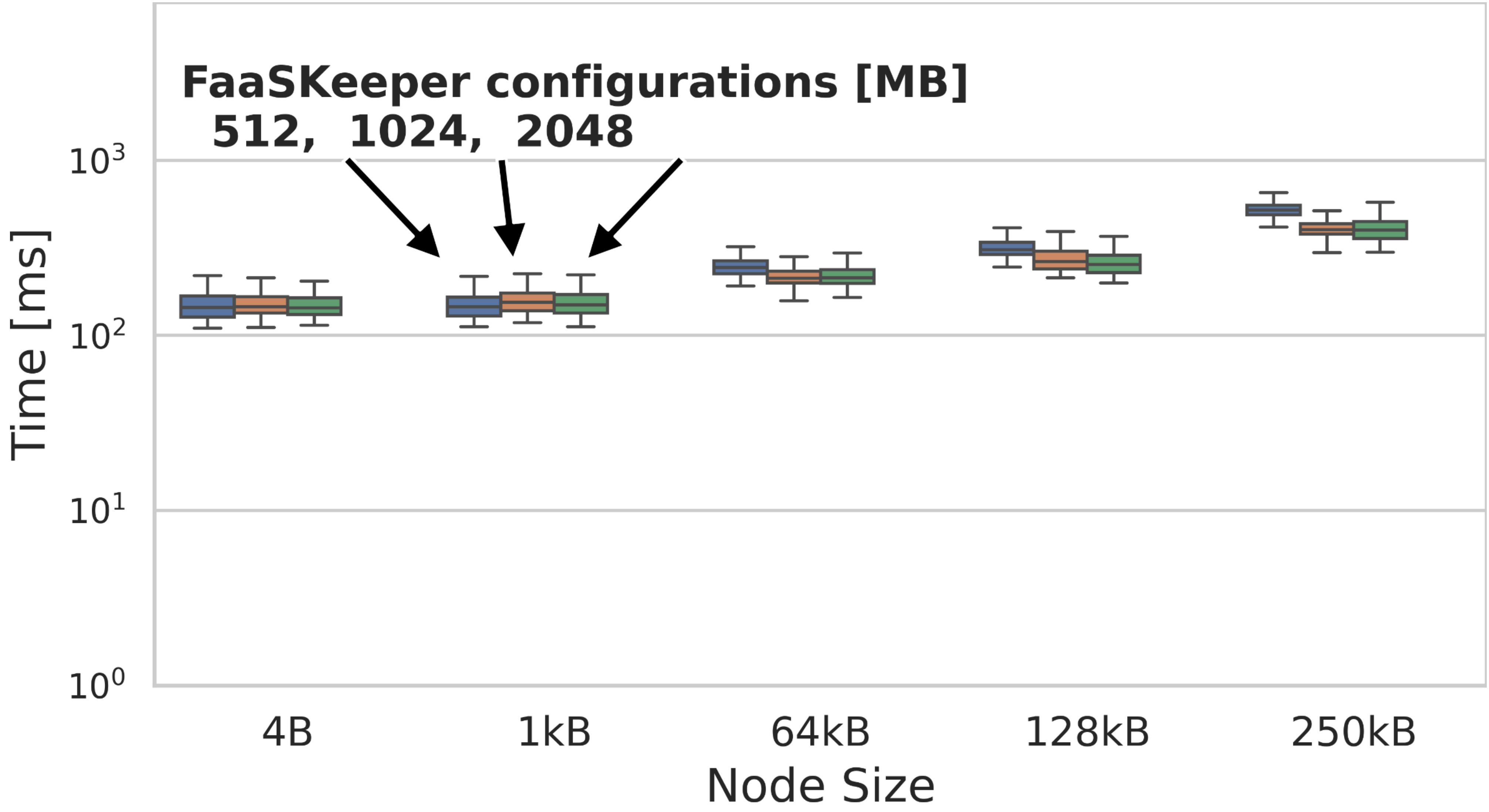
FaaSKeeper Redis

ZooKeeper

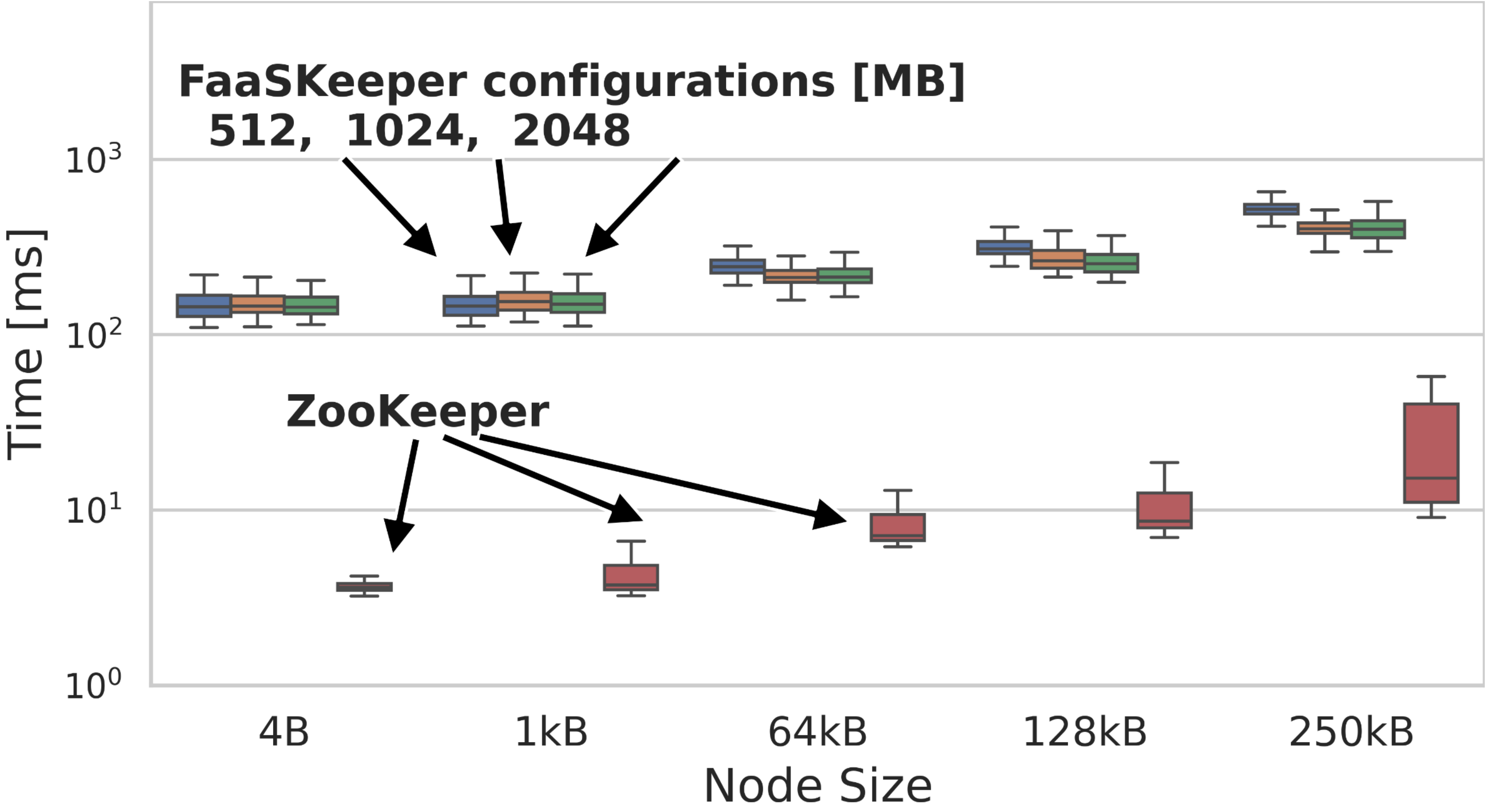
Evaluation: Write Performance 2



Evaluation: Write Performance 2



Evaluation: Write Performance 2



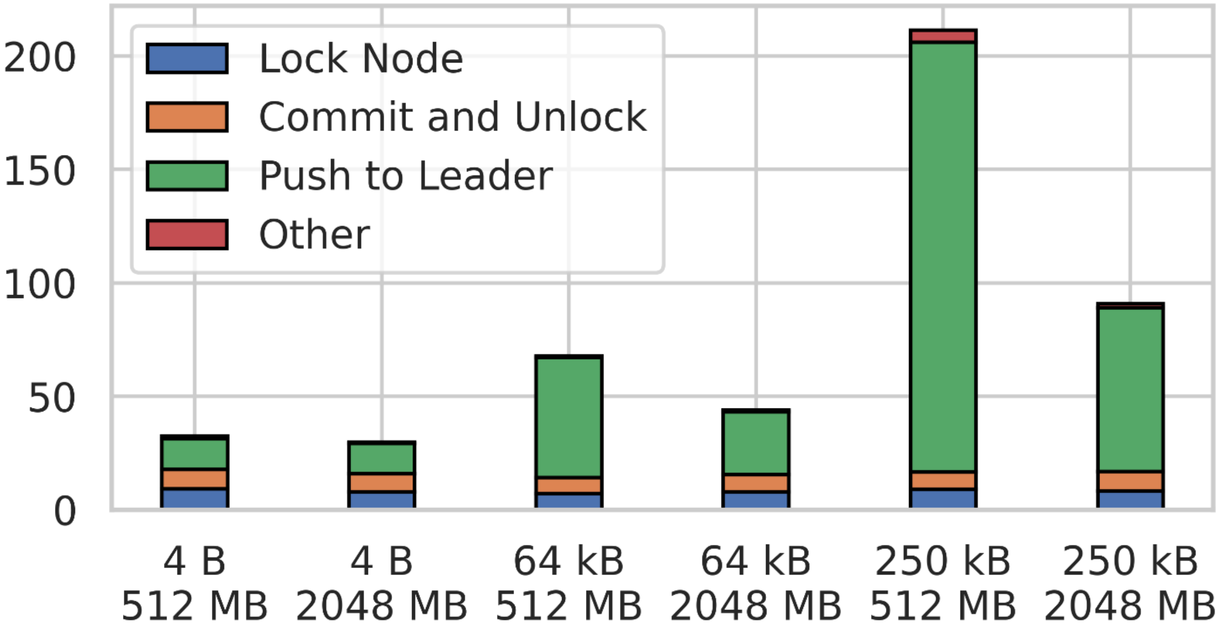
Evaluation: Write Performance 2

Follower Function

Leader Function

Evaluation: Write Performance 2

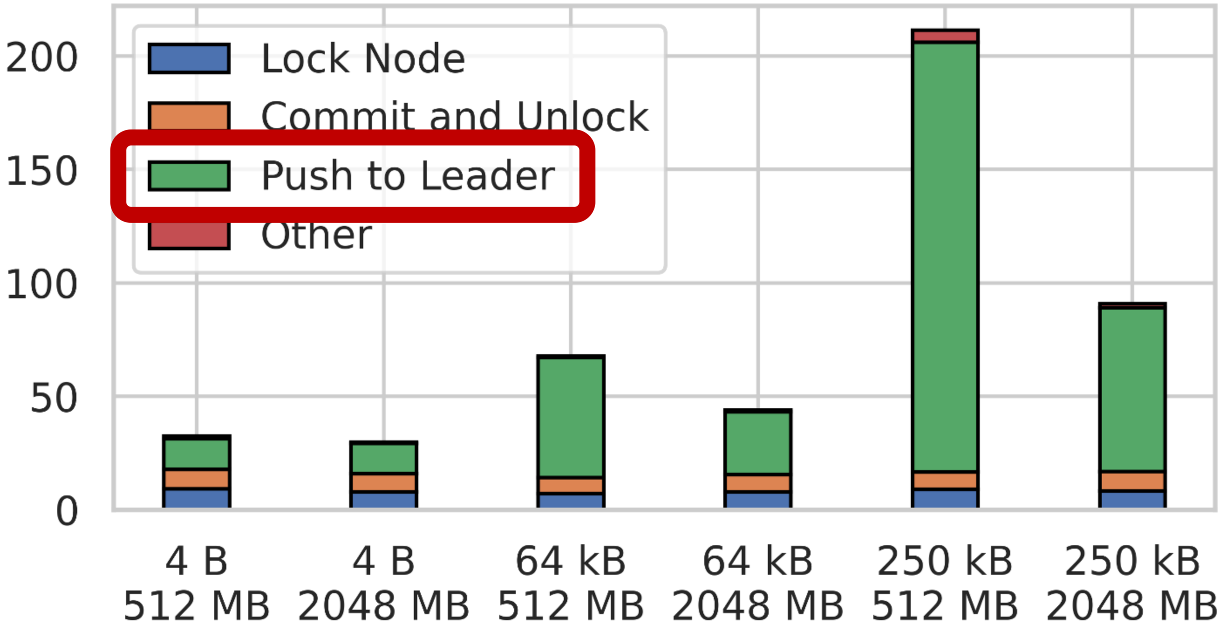
Follower Function



Leader Function

Evaluation: Write Performance 2

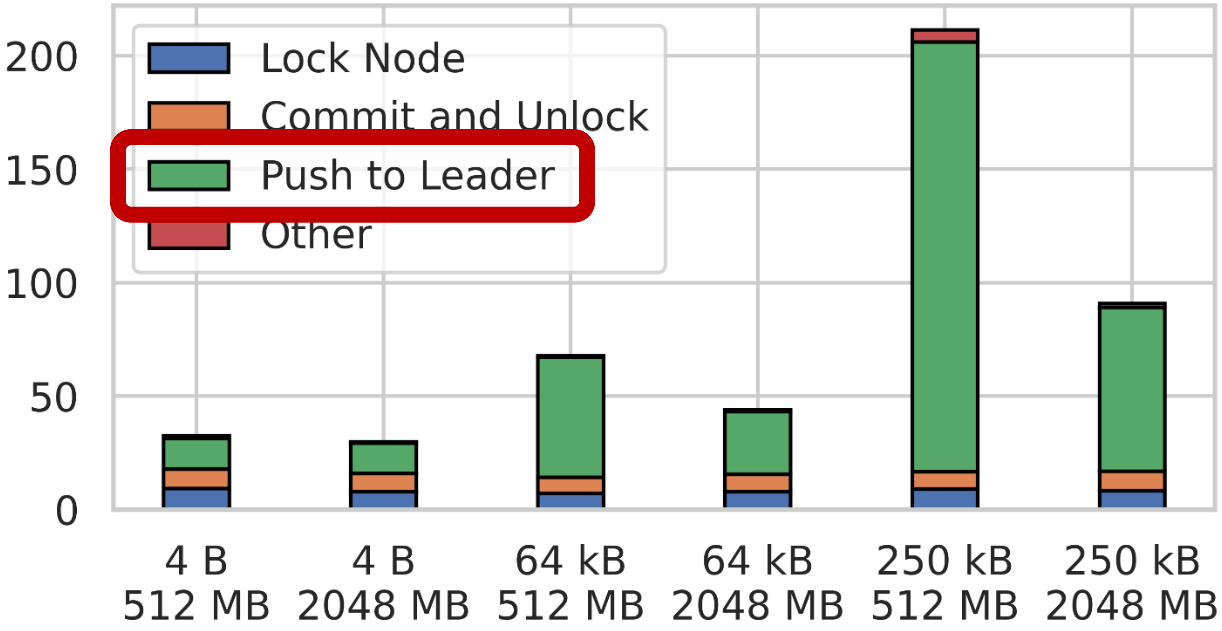
Follower Function



Leader Function

Evaluation: Write Performance 2

Follower Function



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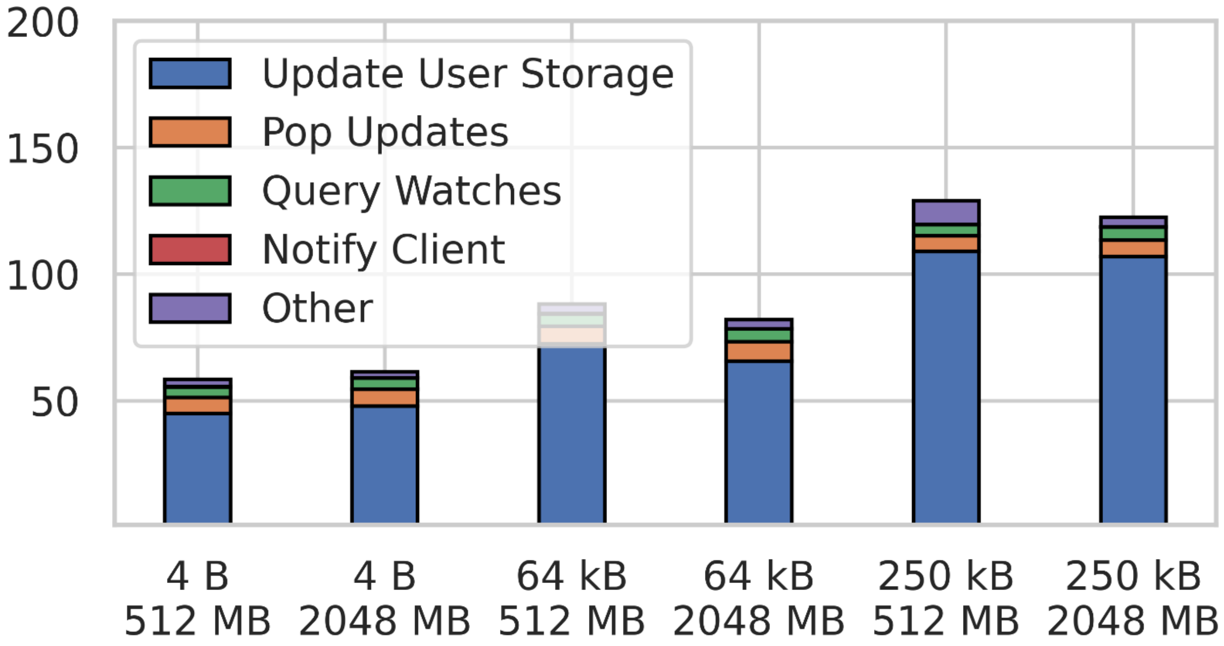

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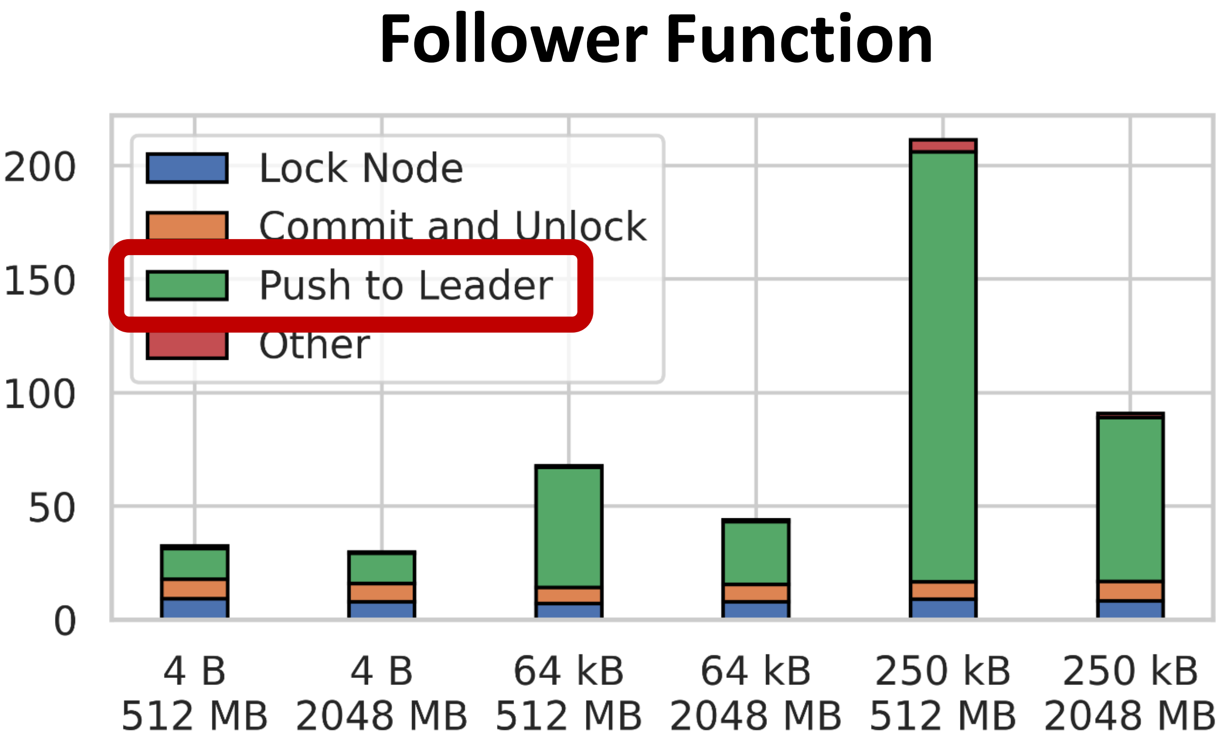
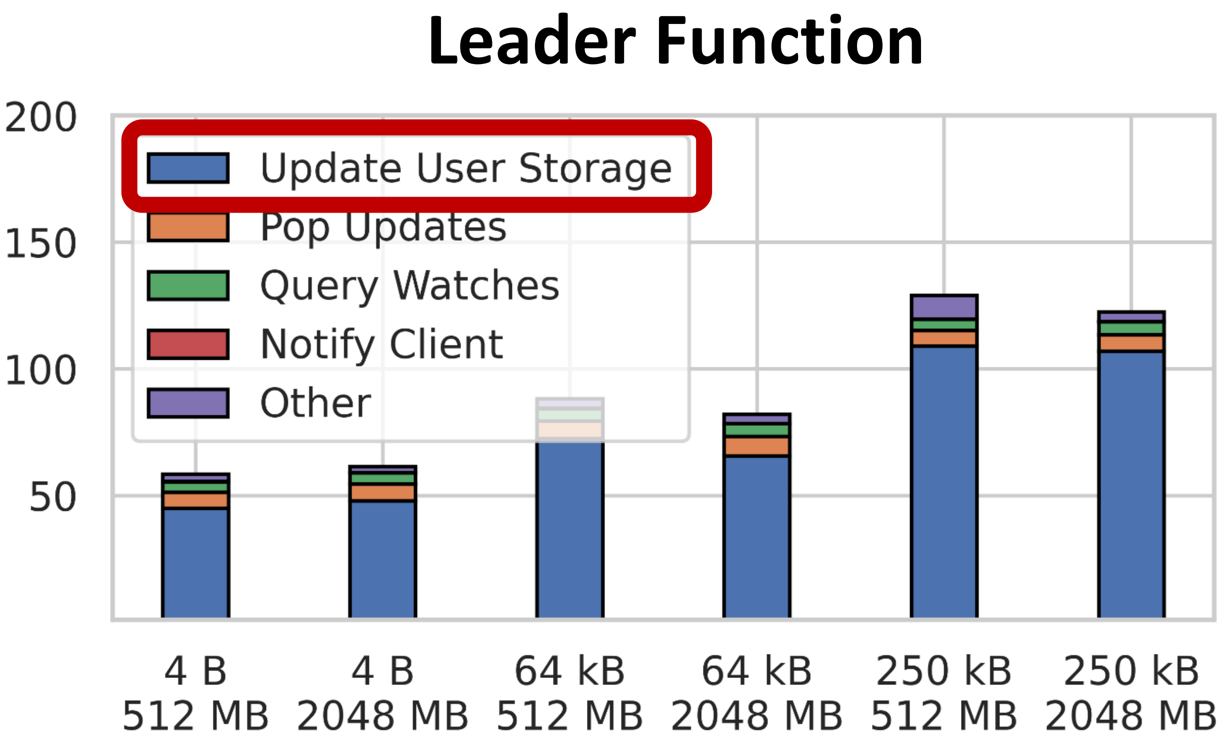




Evaluation: Cost Efficiency

3

Cost ratio of ZooKeeper and FaaSKeeper, 90% reads.

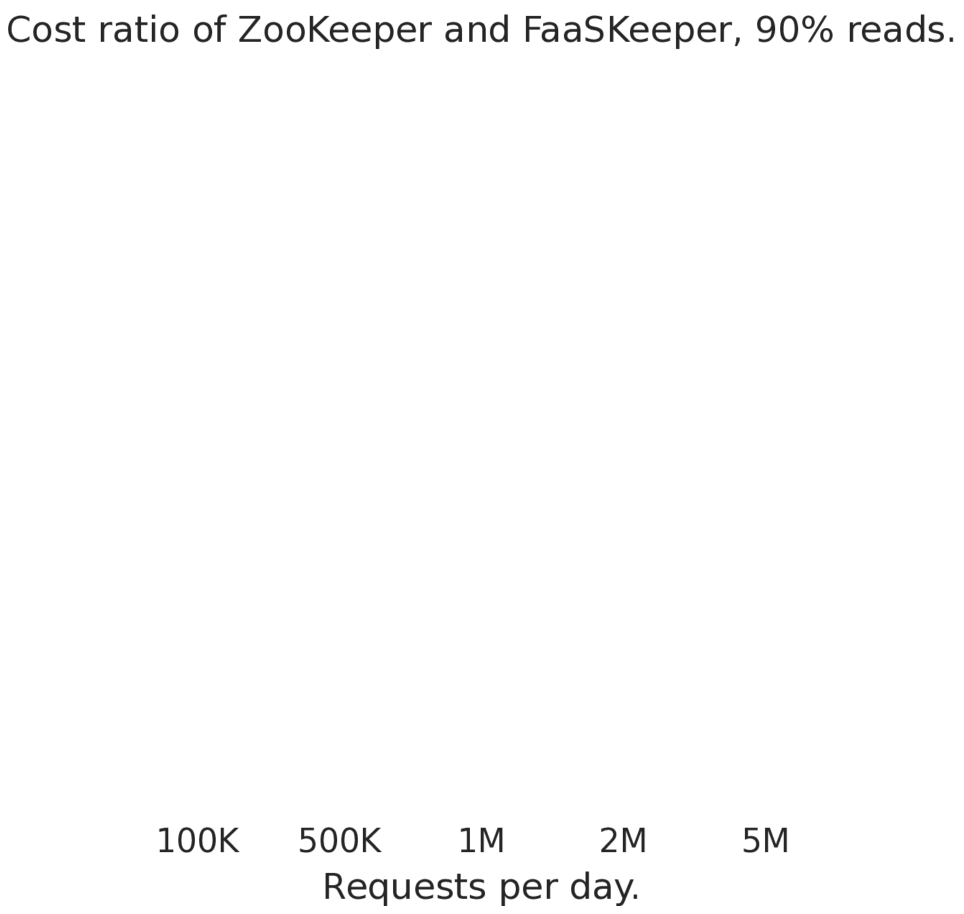
Cost ratio of ZooKeeper and FaaSKeeper, 80% reads.

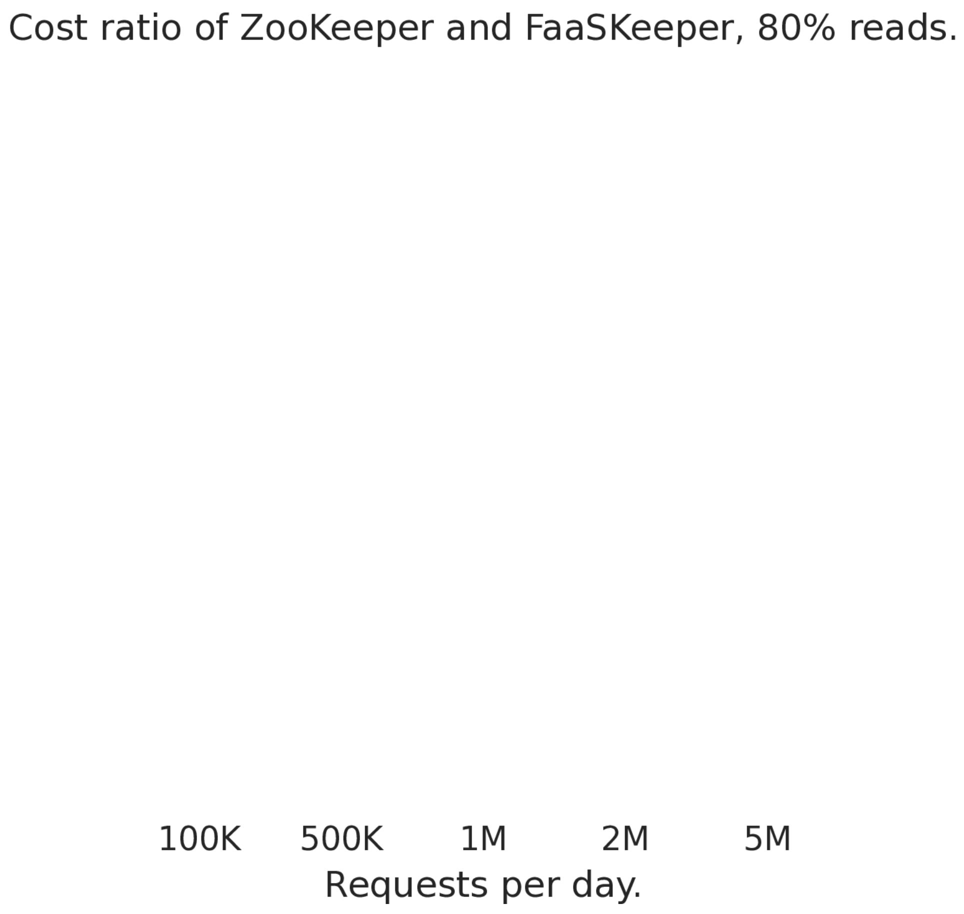
ZooKeeper – constant cost for VMs.
FaaSKeeper – pay per each request.

Set node data of 1 kB, no watches, single request per invocation.

Evaluation: Cost Efficiency

3





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Evaluation: Cost Efficiency

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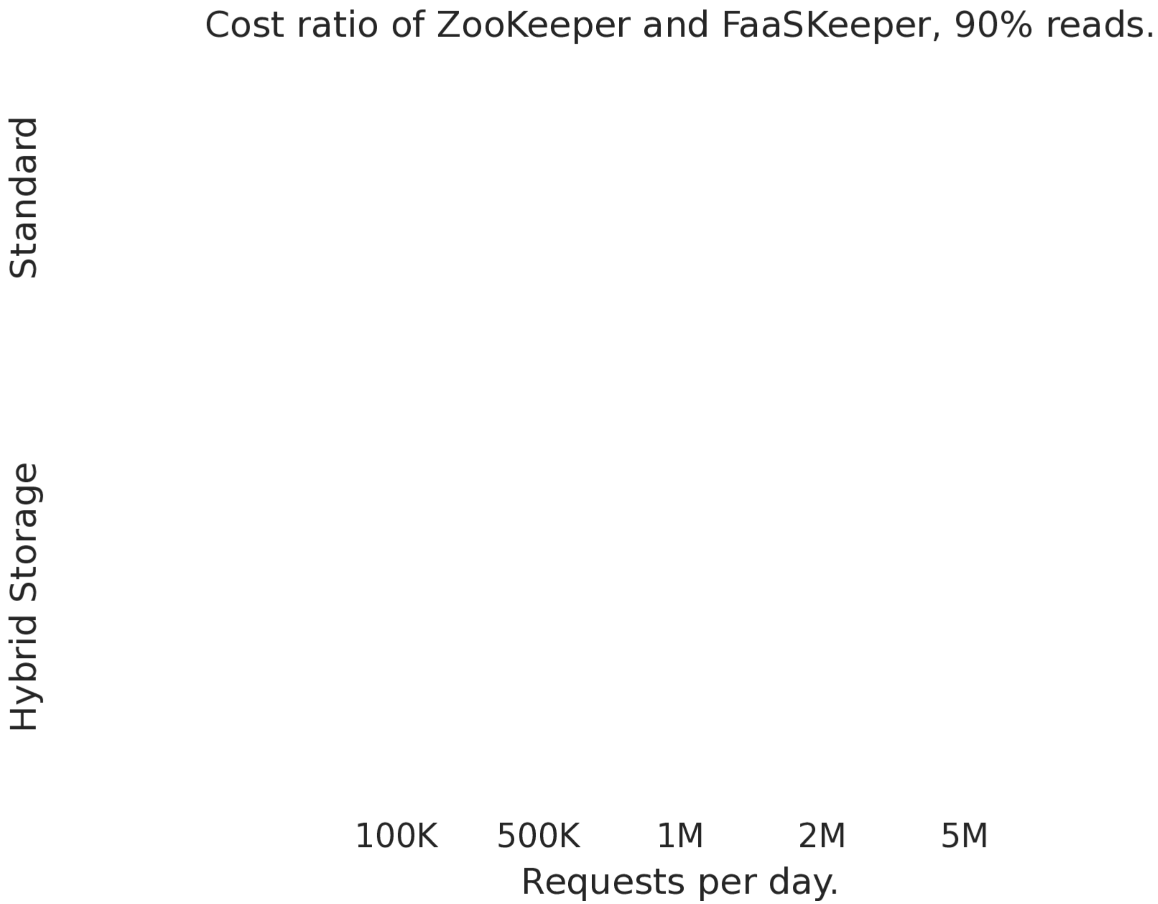

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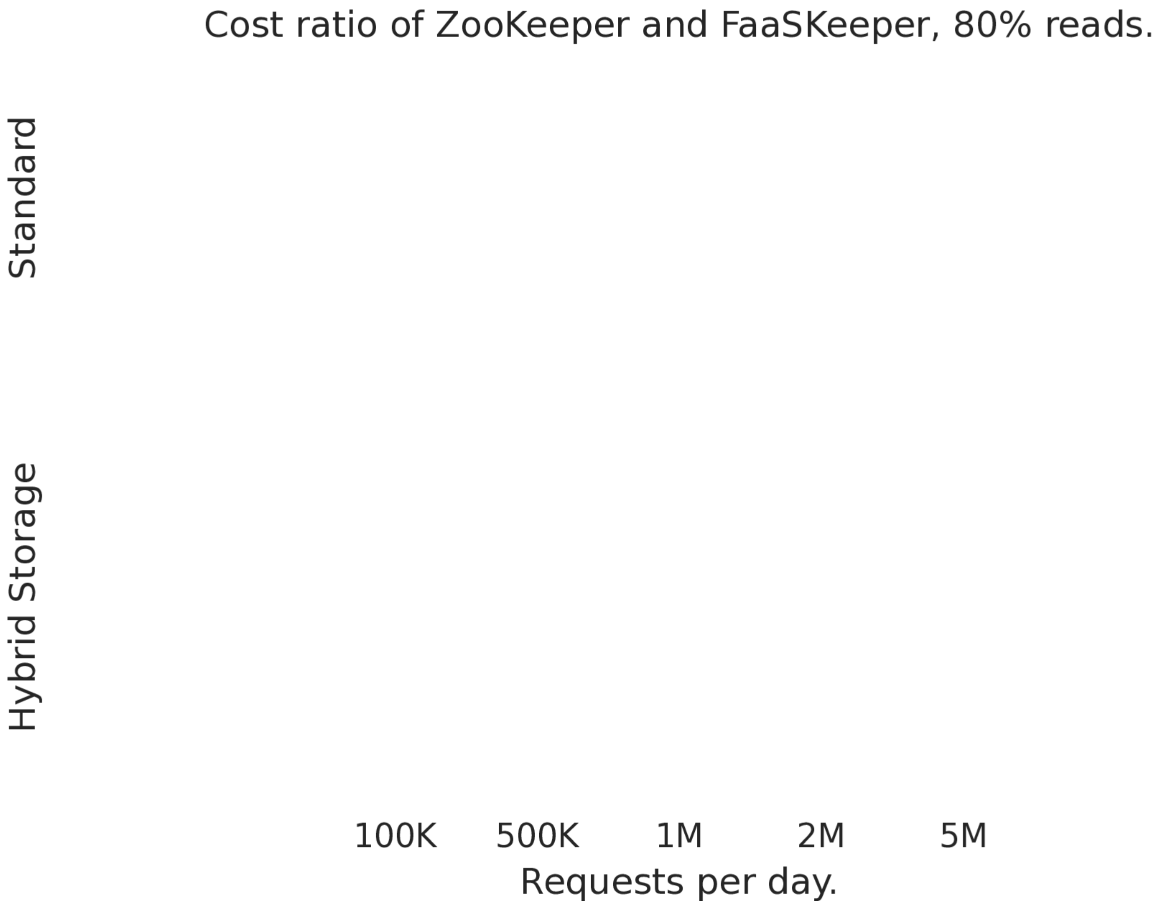

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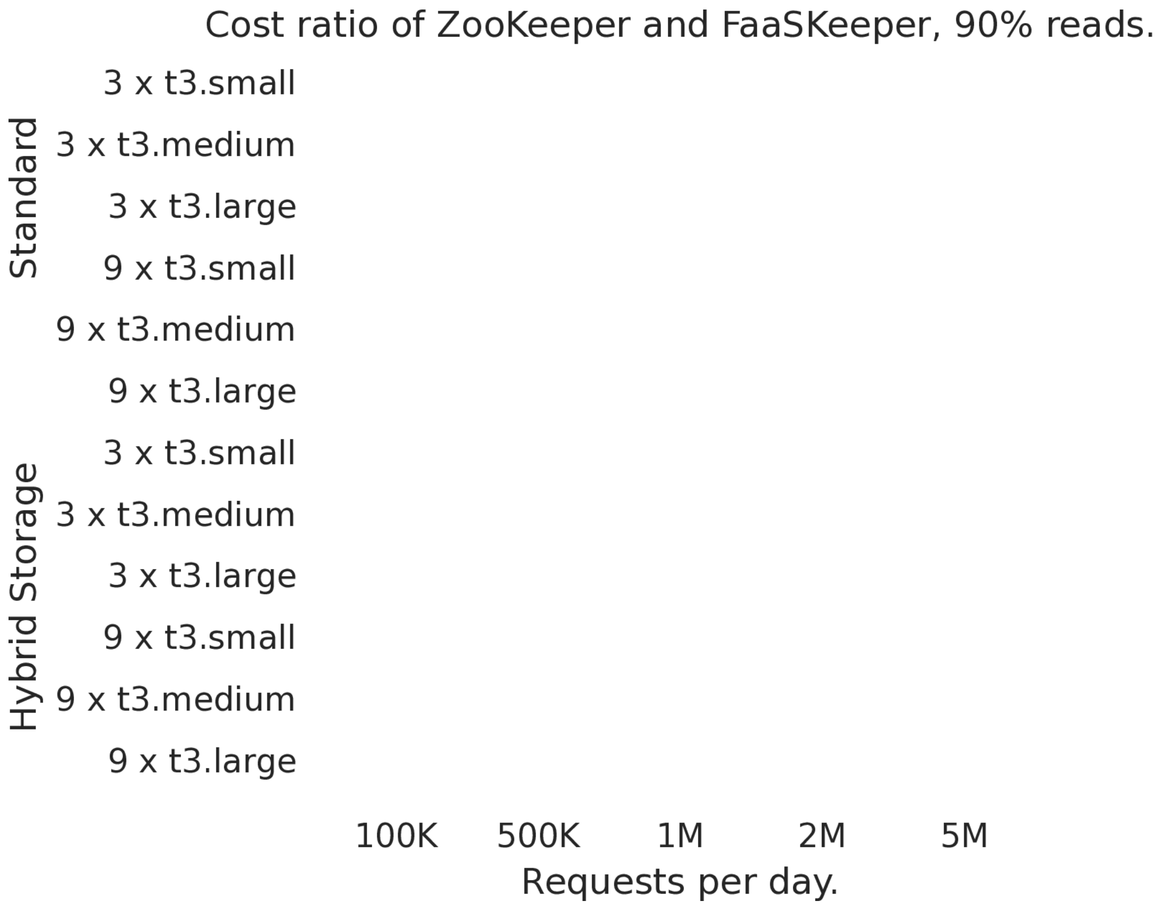
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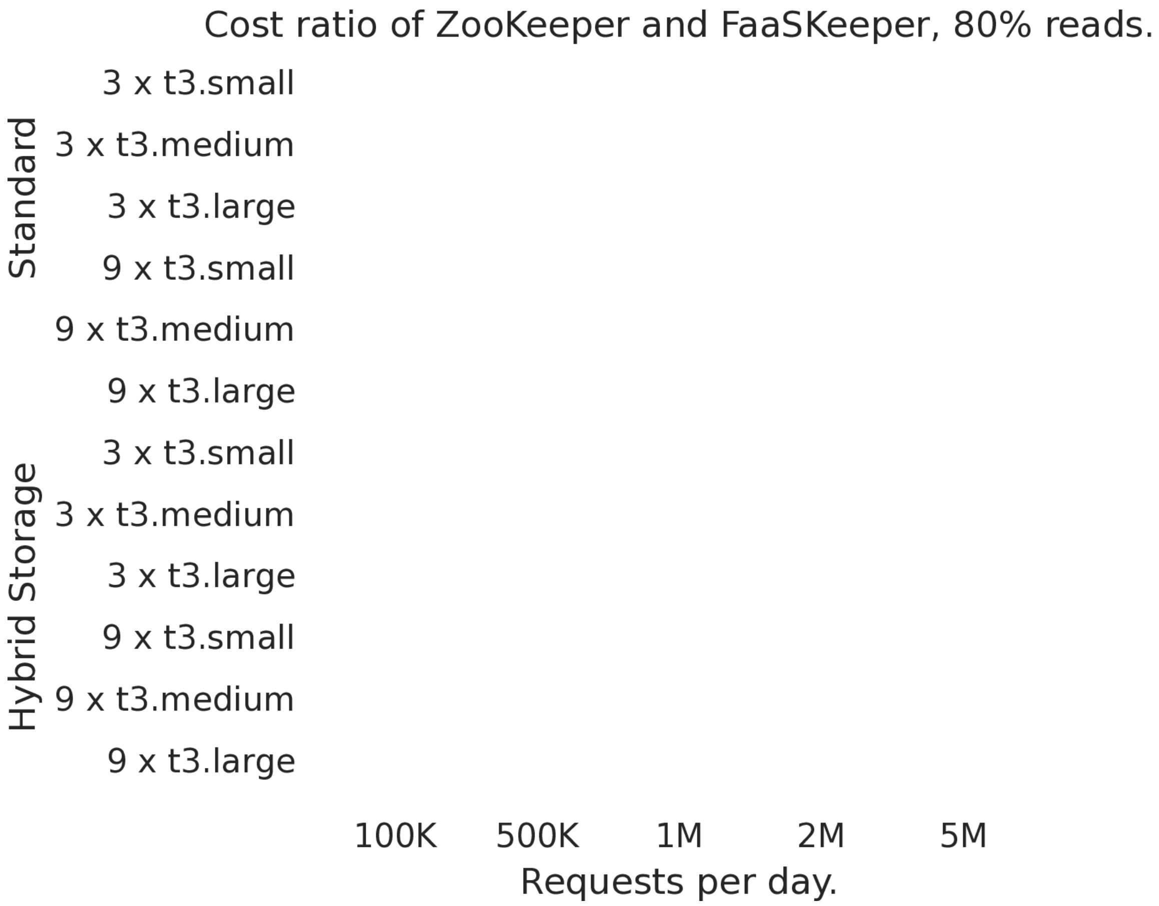
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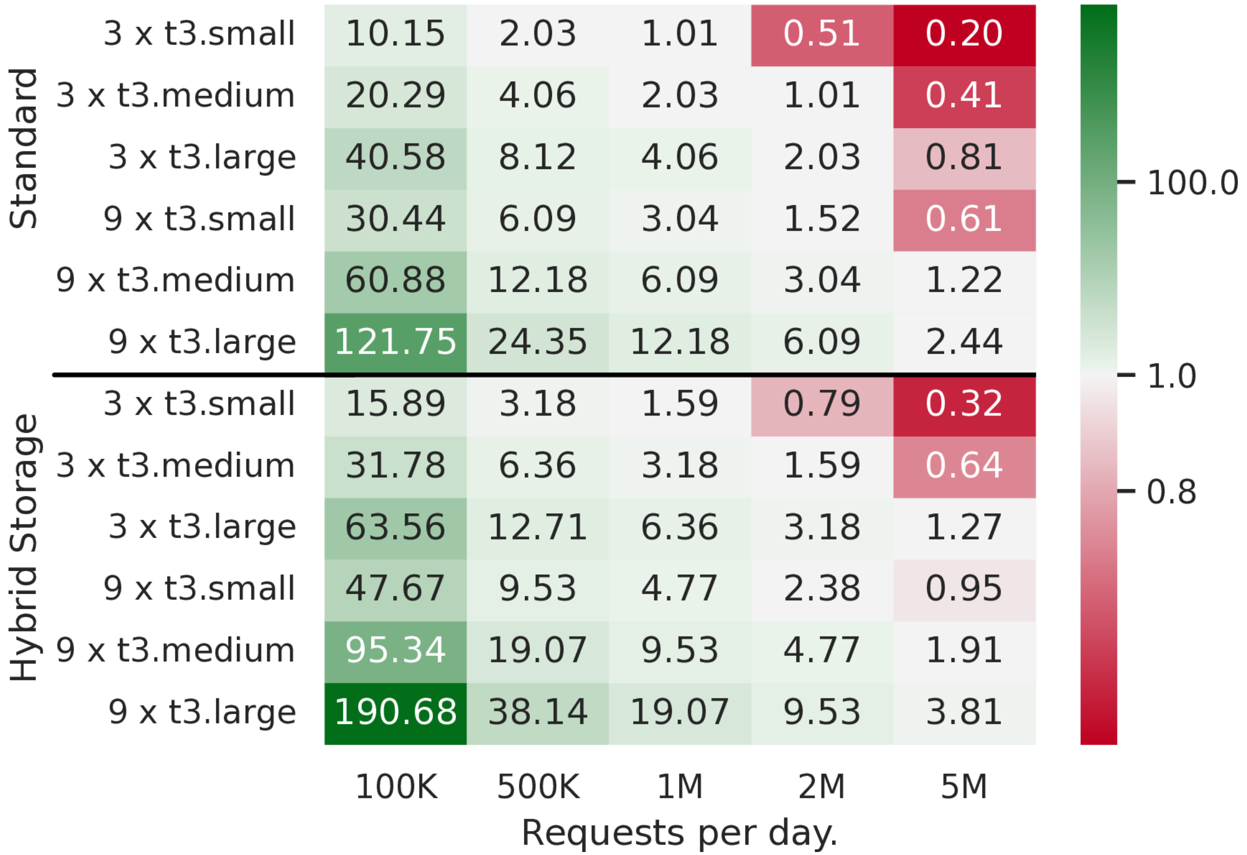

		100K	500K	1M	2M	5M
Standard	3 x t3.small	10.15	2.03	1.01	0.51	0.20
	3 x t3.medium	20.29	4.06	2.03	1.01	0.41
	3 x t3.large	40.58	8.12	4.06	2.03	0.81
	9 x t3.small	30.44	6.09	3.04	1.52	0.61
	9 x t3.medium	60.88	12.18	6.09	3.04	1.22
	9 x t3.large	121.75	24.35	12.18	6.09	2.44
Hybrid Storage	3 x t3.small	15.89	3.18	1.59	0.79	0.32
	3 x t3.medium	31.78	6.36	3.18	1.59	0.64
	3 x t3.large	63.56	12.71	6.36	3.18	1.27
	9 x t3.small	47.67	9.53	4.77	2.38	0.95
	9 x t3.medium	95.34	19.07	9.53	4.77	1.91
	9 x t3.large	190.68	38.14	19.07	9.53	3.81

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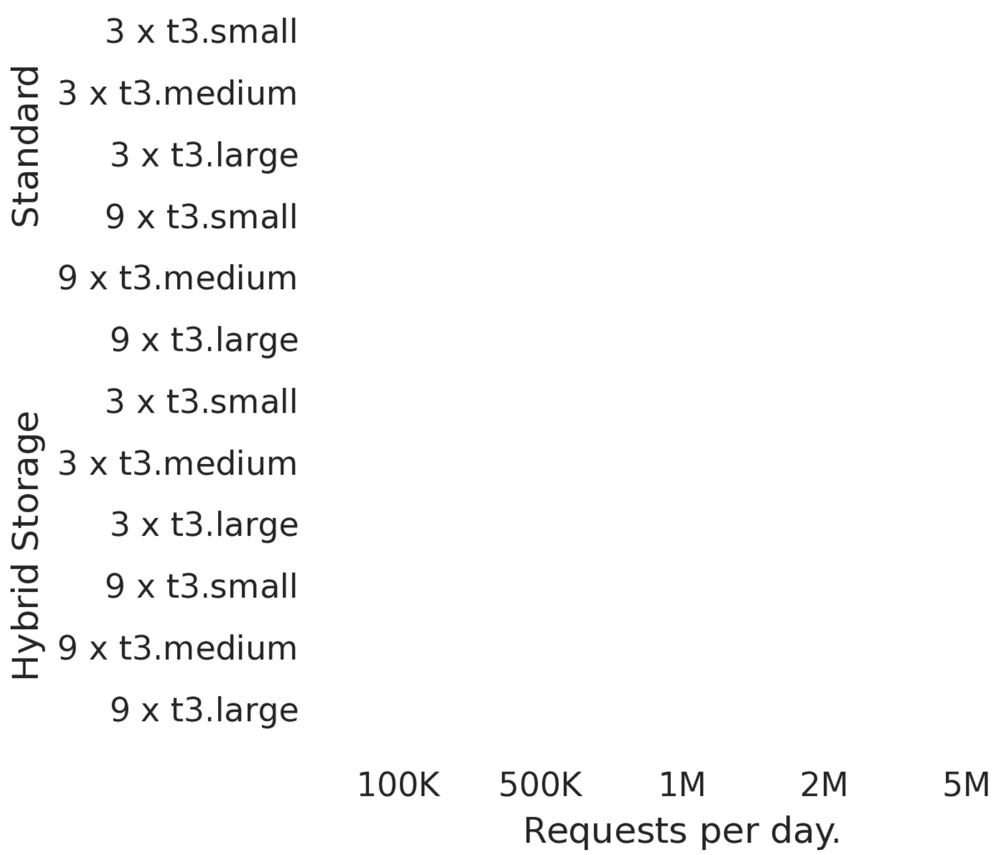

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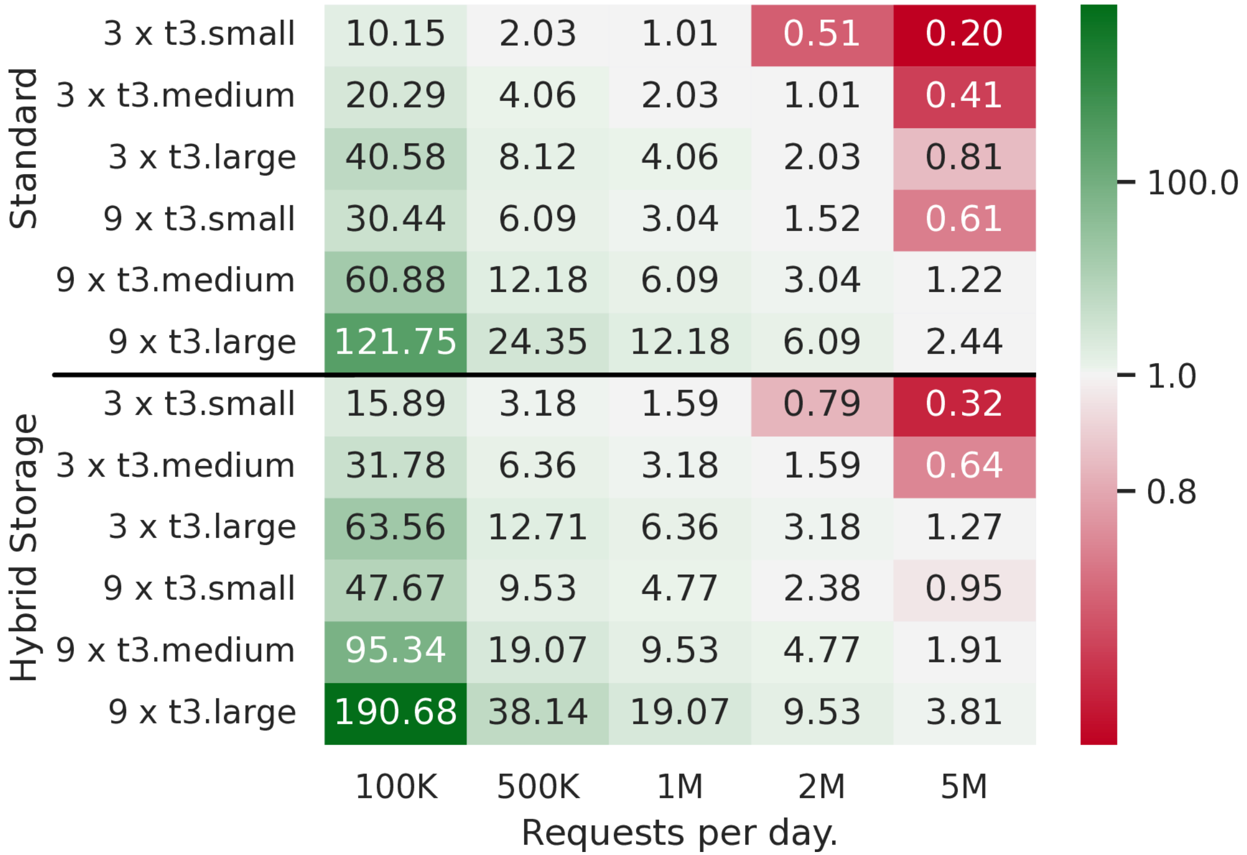

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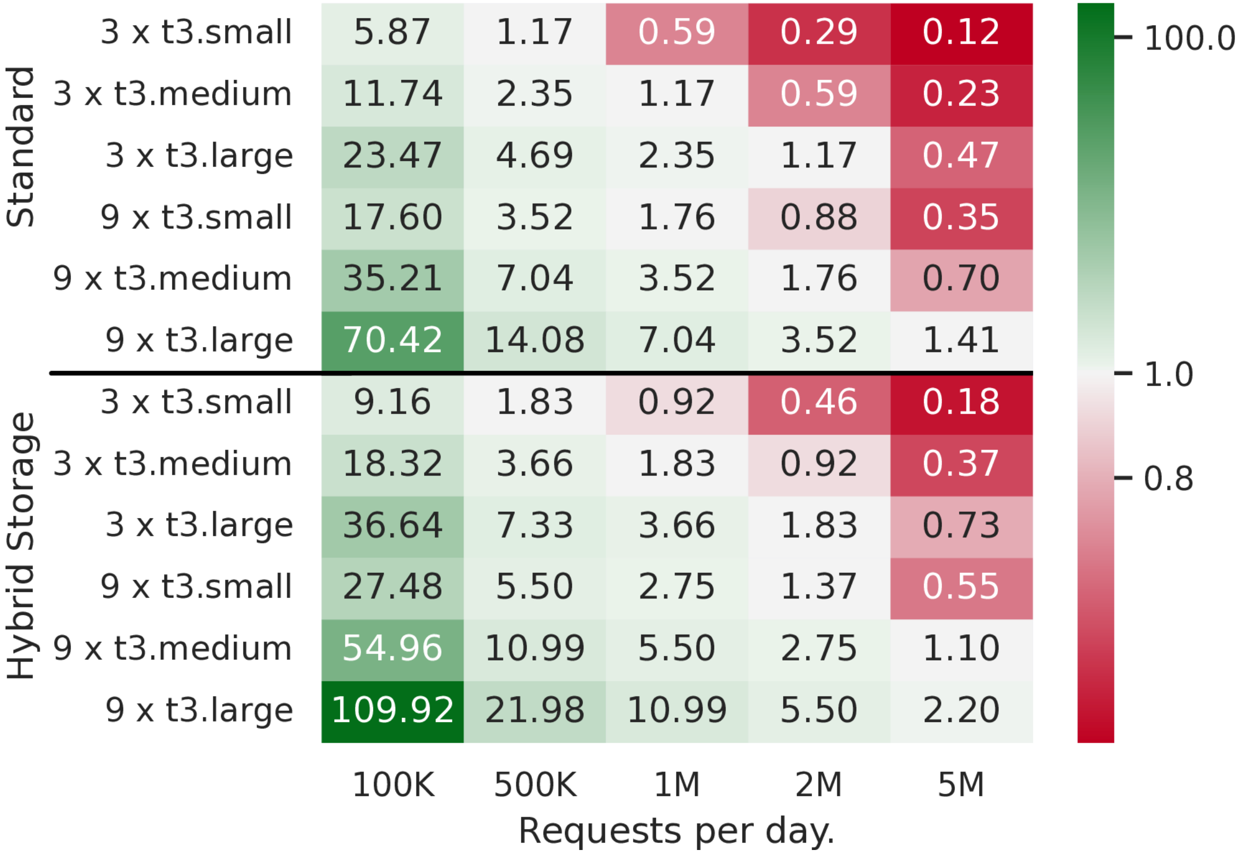

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Standard	3 x t3.small	5.87	1.17	0.59	0.29	0.12
	3 x t3.medium	11.74	2.35	1.17	0.59	0.23
	3 x t3.large	23.47	4.69	2.35	1.17	0.47
	9 x t3.small	17.60	3.52	1.76	0.88	0.35
	9 x t3.medium	35.21	7.04	3.52	1.76	0.70
	9 x t3.large	70.42	14.08	7.04	3.52	1.41
Hybrid Storage	3 x t3.small	9.16	1.83	0.92	0.46	0.18
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	3 x t3.large	36.64	7.33	3.66	1.83	0.73
	9 x t3.small	27.48	5.50	2.75	1.37	0.55
	9 x t3.medium	54.96	10.99	5.50	2.75	1.10
	9 x t3.large	109.92	21.98	10.99	5.50	2.20

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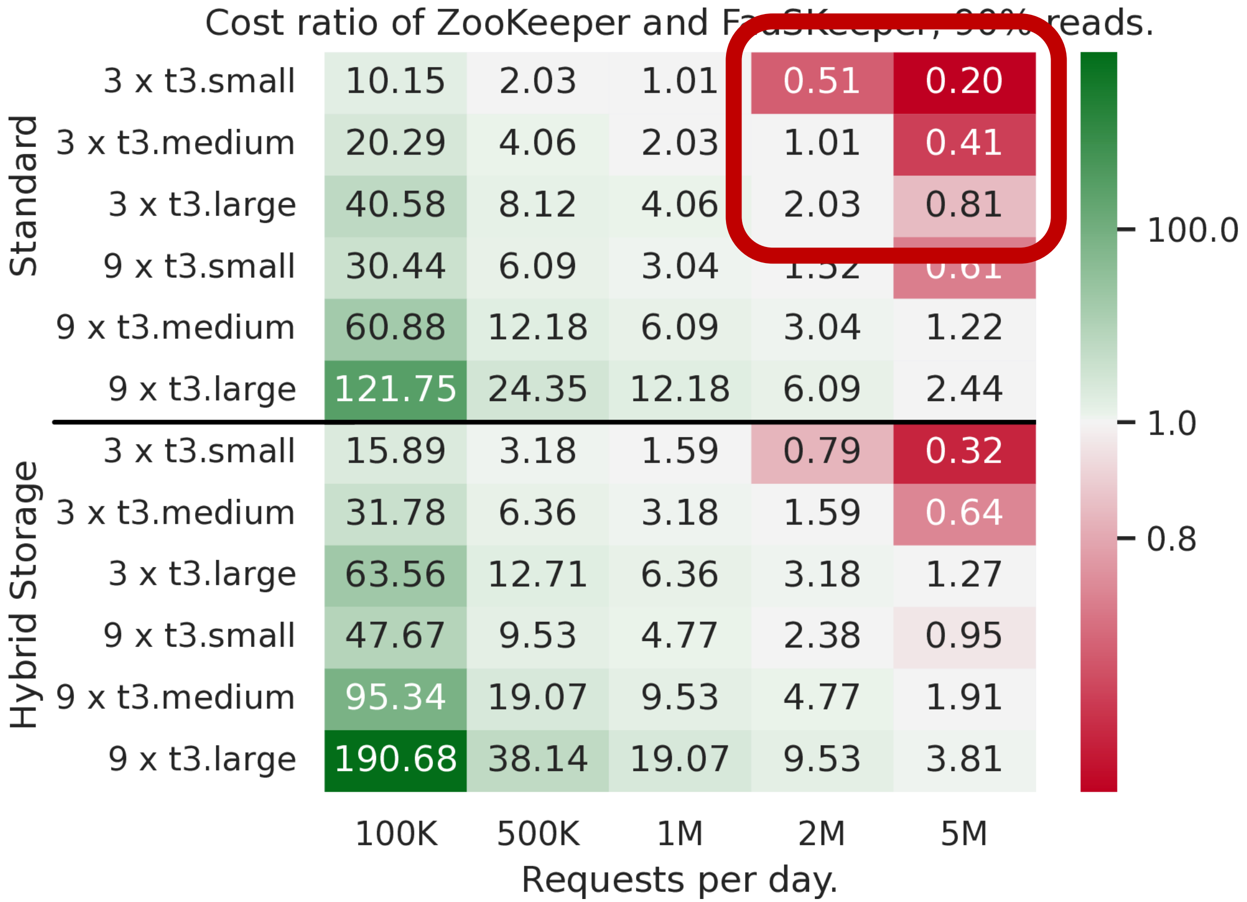
Set node data of 1 kB, no watches, single request per invocation.

Evaluation: Cost Efficiency

3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	9 x t3.small	30.44	6.09	3.04	1.52	0.61
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	9 x t3.large	121.75	24.35	12.18	6.09	2.44
Hybrid Storage	3 x t3.small	15.89	3.18	1.59	0.79	0.32
	3 x t3.medium	31.78	6.36	3.18	1.59	0.64
	3 x t3.large	63.56	12.71	6.36	3.18	1.27
	9 x t3.small	47.67	9.53	4.77	2.38	0.95
	9 x t3.medium	95.34	19.07	9.53	4.77	1.91
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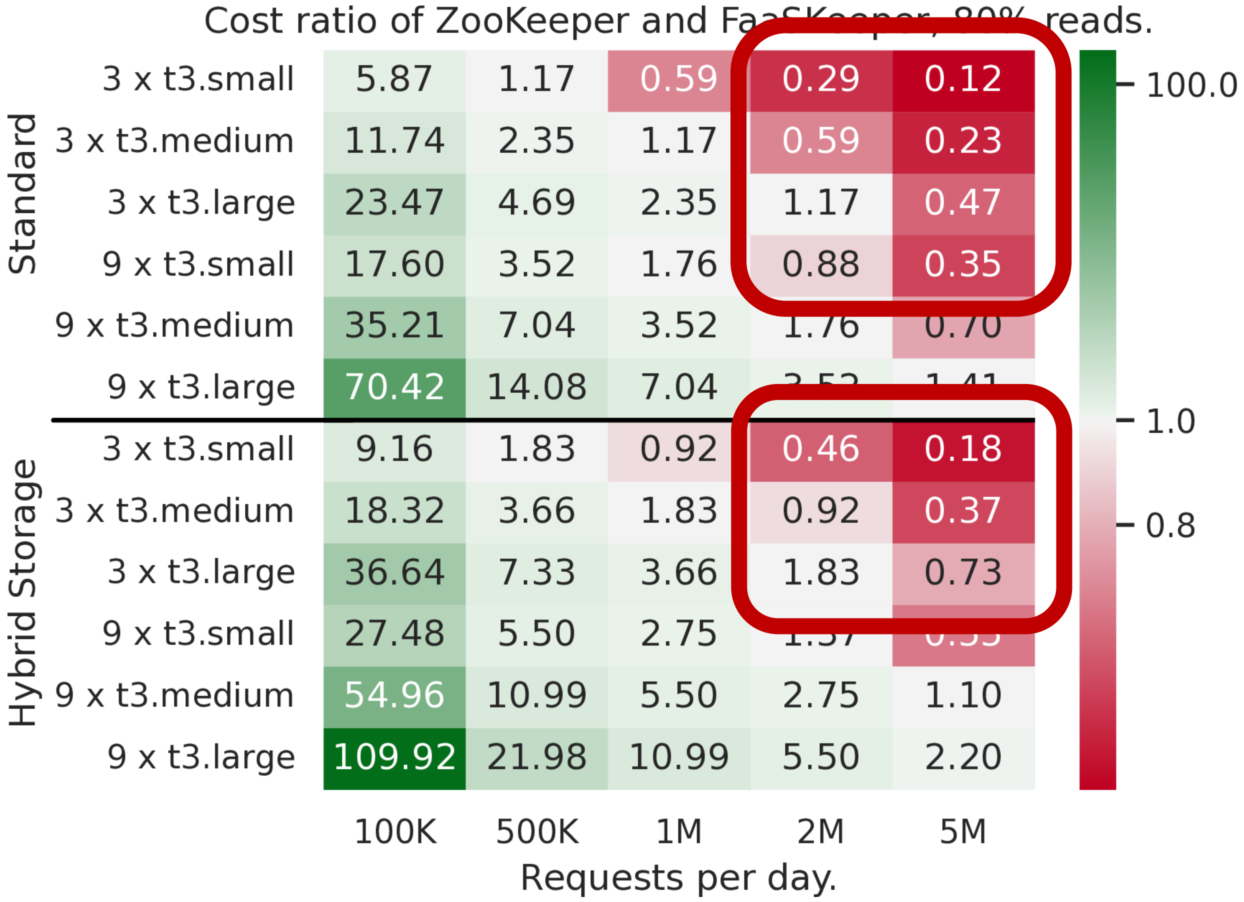
Requests per day.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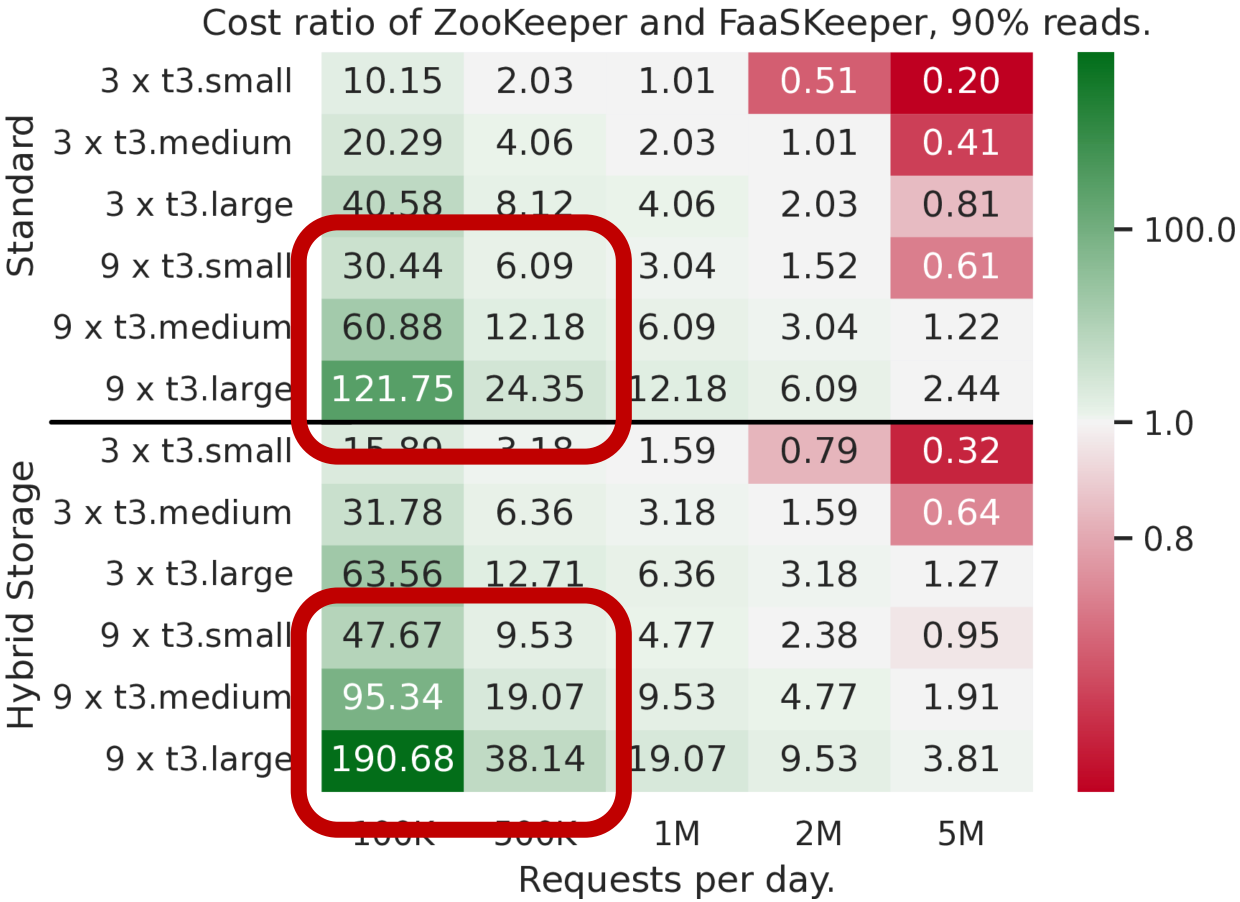

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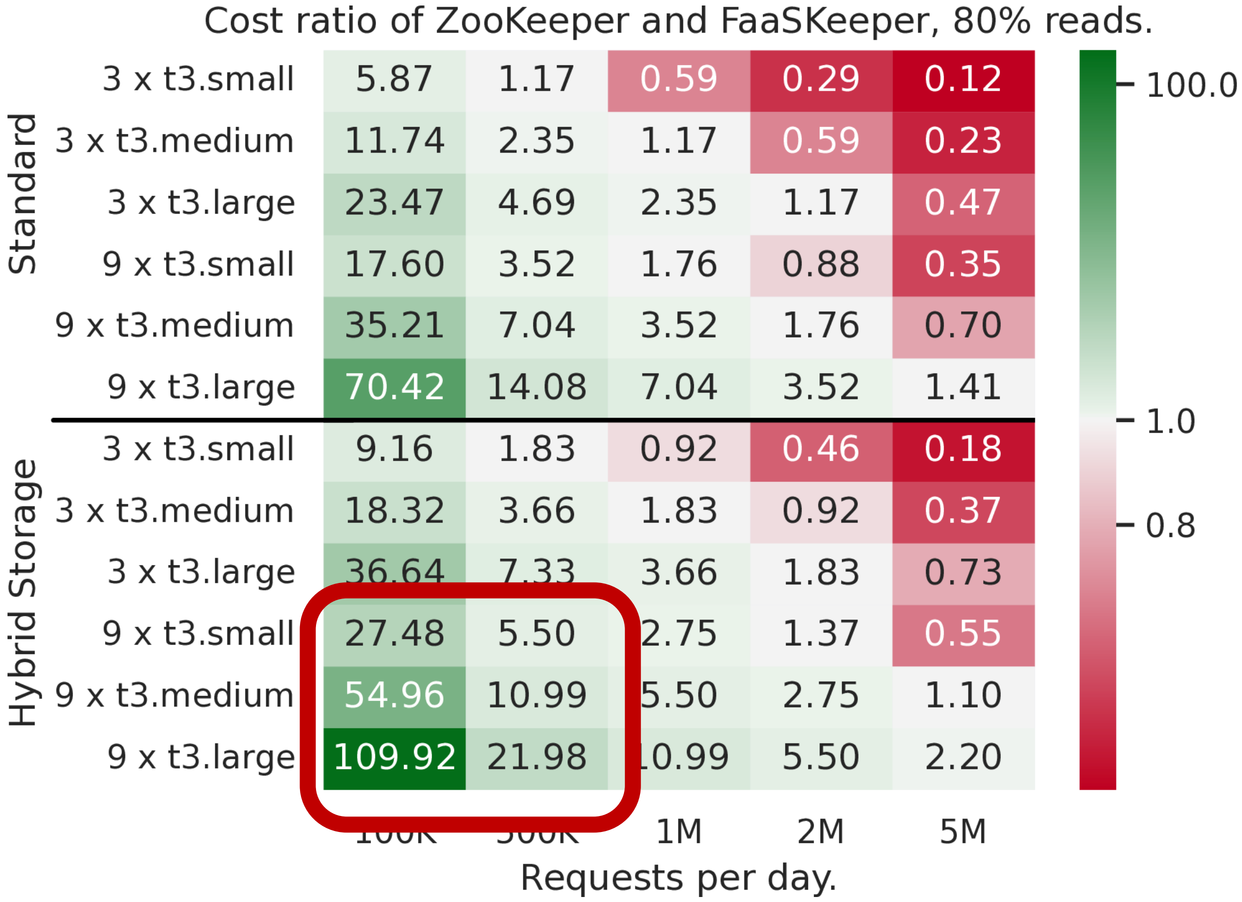

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spcl/FaaSKeeper

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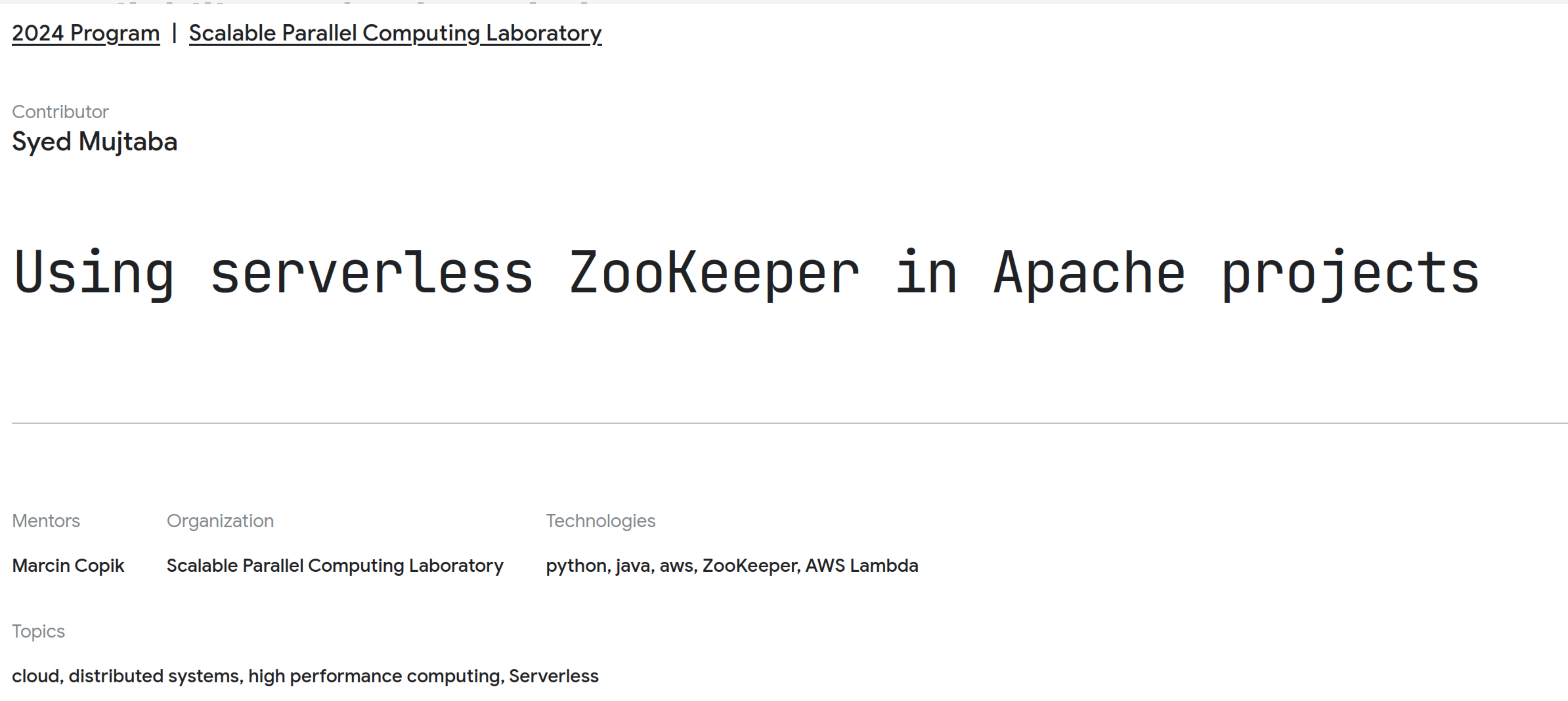
aws Google Cloud Google Summer of Code



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Contributor

Syed Mujtaba

Using serverless ZooKeeper in Apache projects

Mentors	Organization	Technologies
Marcin Copik	Scalable Parallel Computing Laboratory	python, java, aws, ZooKeeper, AWS Lambda

Topics

cloud, distributed systems, high performance computing, Serverless

Conclusions

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What is ZooKeeper?

APACHE ZooKeeper™

APACHE HBASE

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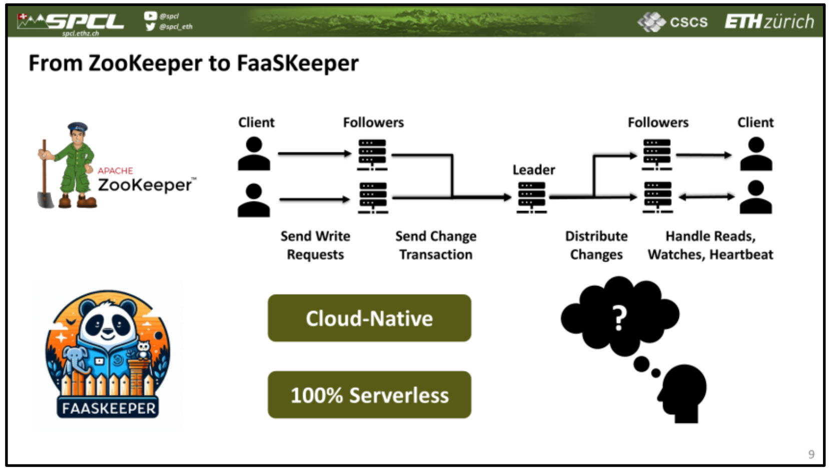

From ZooKeeper to FaaSKeeper

Cloud-Native

100% Serverless

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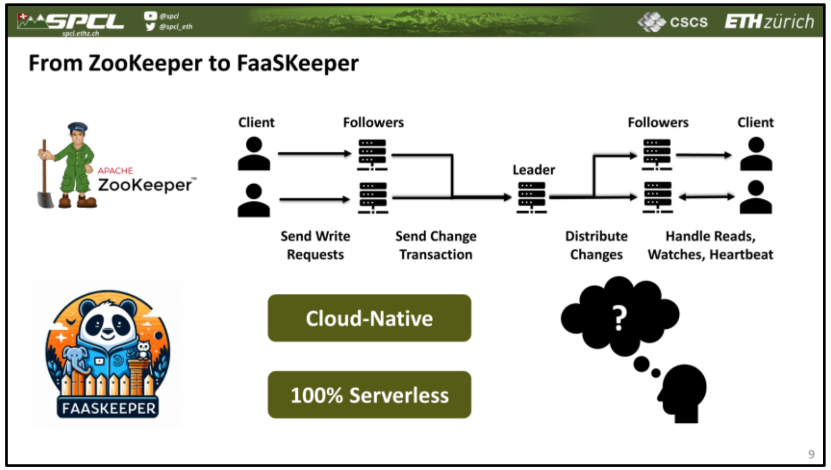

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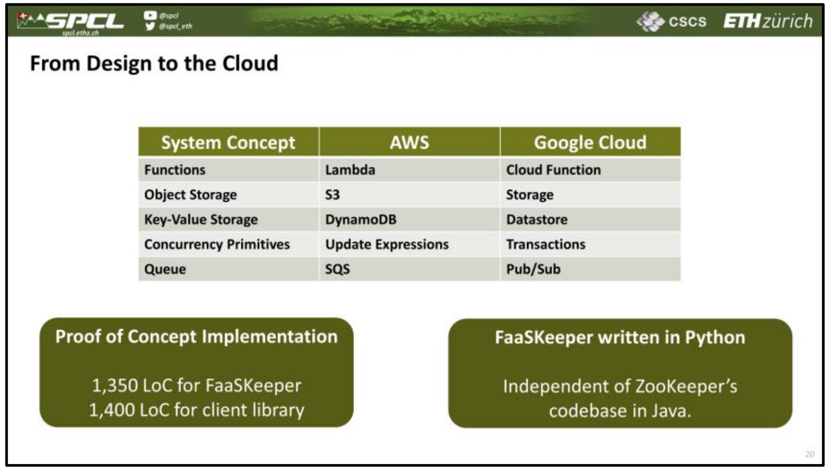

From Design to the Cloud

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Functions	Lambda	Cloud Function
Object Storage	S3	Storage
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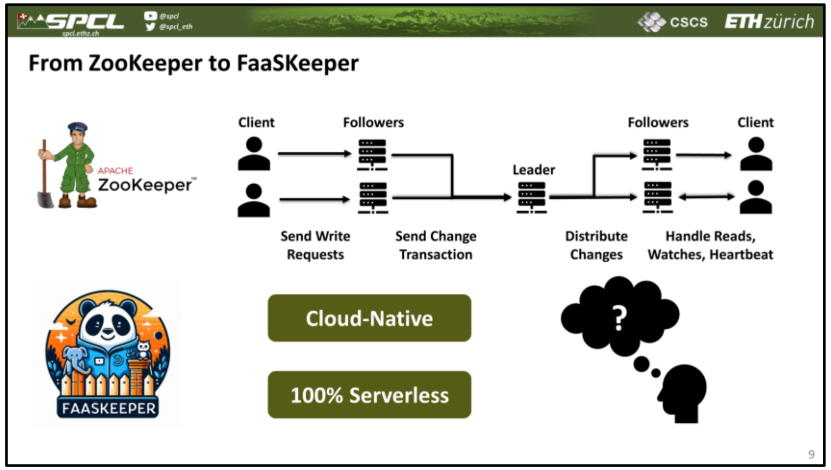

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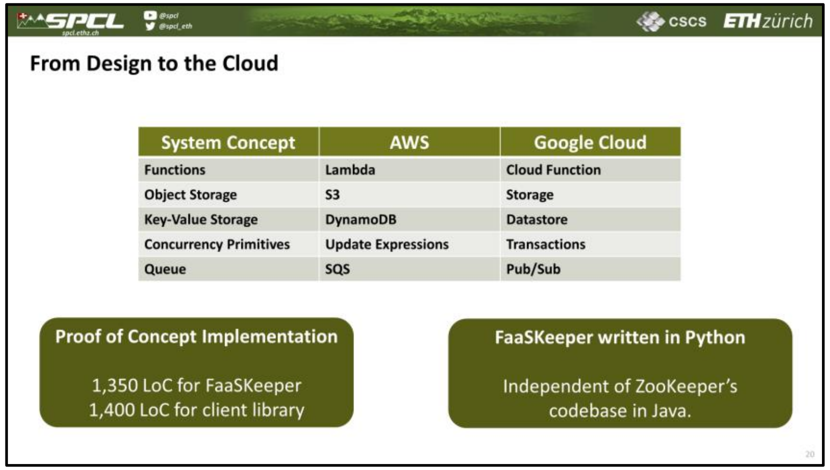

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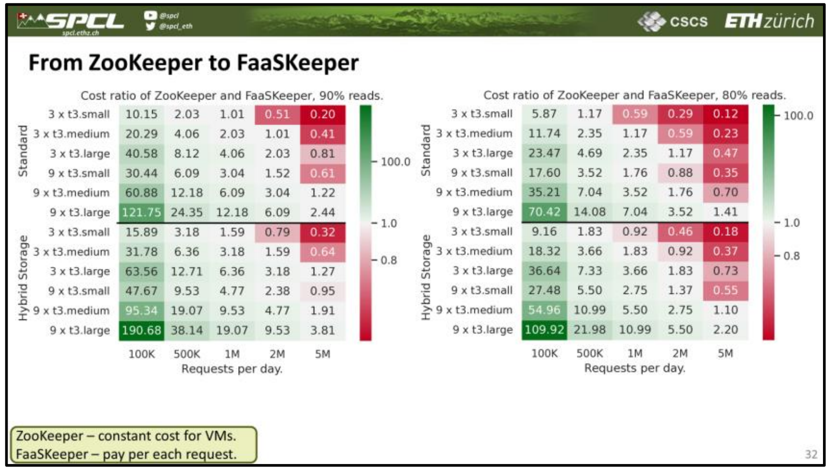

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