Improving Application Migration to Serverless Computing Platforms:
Latency Mitigation with Keep-Alive Workloads

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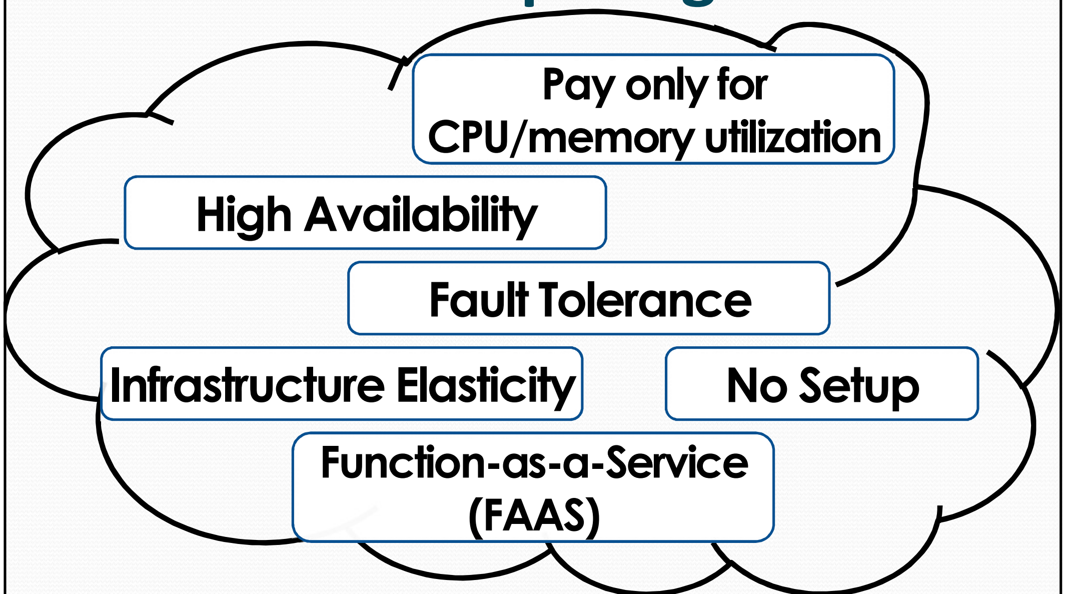
Outline

- Background
- Research Questions
- Experimental Workloads
- Experiments/Evaluation
- Conclusions

Serverless Computing



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Serverless Computing

Why Serverless Computing?

Many features of distributed systems, that are challenging to deliver, are provided automatically

…they are built into the platform

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Serverless Platforms

AWS Lambda
Azure Functions
IBM Cloud Functions
Google Cloud Functions
— *Commercial*

Open Source —
Apache OpenWhisk
Fn (Oracle)

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Serverless Computing

Research Challenges

Image from: https://mobisoftinfotech.com/resources/blog/serverless-computing-deploy-applications-without-fiddling-with-servers/

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Serverless Computing Research Challenges

- Memory reservation
- Infrastructure freeze/thaw cycle
- Vendor architectural lock-in
- Pricing obfuscation
- Service composition

Serverless Computing Research Challenges

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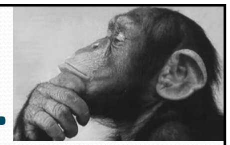
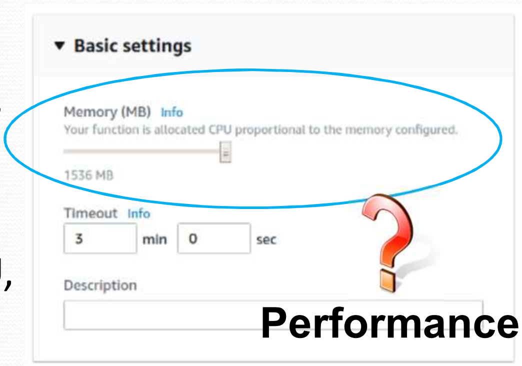
Memory Reservation Question…



- Lambda memory reserved for functions
- UI provides "slider bar" to set function's memory allocation
- Resource capacity (CPU, disk, network) coupled to slider bar: "*every **doubling** of memory, **doubles** CPU…*"



- **But how much memory do model services require?**

Infrastructure Freeze/Thaw Cycle

Performance

- Unused infrastructure is deprecated
  - ***But after how long?***
- AWS Lambda: Bare-metal hosts, firecracker micro-VMs
- Infrastructure states: https://firecracker-microvm.github.io/
- **Provider-COLD / Host-COLD**
  - Function package built/transferred to Hosts
- **Container-COLD (firecracker micro-VM)**
  - Image cached on Host
- **Container-WARM (firecracker micro-VM)**
  - "Container" running on Host

Image from: Denver7 – The Denver Channel News

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Research Questions

RQ1: **PERFORMANCE:** What are the performance implications for application migration? How does memory reservation size impact performance when coupled to CPU power?

RQ2: **SCALABILITY:** For application migration what performance implications result from scaling the number of concurrent clients? How is scaling affected when infrastructure is allowed to go cold?

Research Questions - 2

RQ3: **COST:** For hosting large parallel service workloads, how does memory reservation size, impact hosting costs when coupled to CPU power?

RQ4: **PERSISTING INFRSASTRUCTURE:** How effective are automatic triggers at retaining serverless infrastructure to reduce performance latency from the serverless freeze/thaw cycle?

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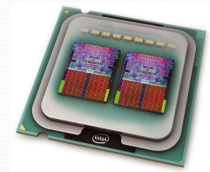
AWS Lambda PRMS Modeling Service



- PRMS: deterministic, distributed-parameter model
- Evaluate impact of combinations of precipitation, climate, and land use on stream flow and general basin hydrology (Leavesley et al., 1983)

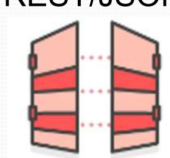
- Java based PRMS, Object Modelling System (OMS) 3.0
- Approximately ~11,000 lines of code
- Model service is 18.35 MB compressed as a Java JAR file
- Data files hosted using Amazon S3 (object storage)

Goal: quantify performance and cost implications of *memory reservation size* and *scaling* for model service deployment to AWS Lambda

PRMS Lambda Testing

REST/JSON

Images credit: aws.amazon.com



API GATEWAY

Client:
c4.2xlarge or c4.8xlarge
(8 core) (36 core)

BASH: GNU Parallel
Multi-thread client script
"partest"

Up to 100 concurrent synchronous requests

Results of each thread traced individually

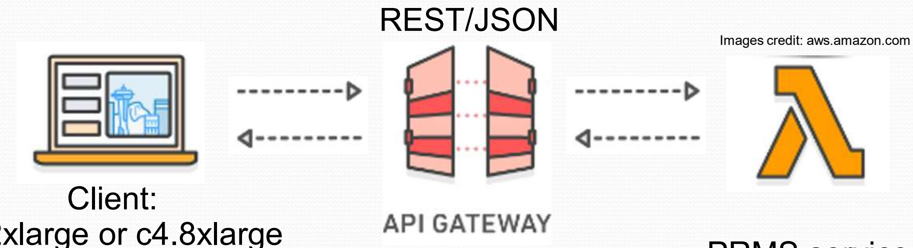
Fixed-availability zone:
EC2 client / Lambda server
us-east-1e

PRMS service

Max service duration: < 30 seconds

Memory: 256 to 3008MB

PRMS Lambda Testing - 2



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(8 core) (36 core)

PRMS service

Automatic Metrics Collection[1]:

New vs. Recycled Containers/VMs

\# of requests per container/VM

Avg. performance per container/VM

Avg. performance workload

Standard deviation of requests per container/VM

Container Identification
UUID → /tmp file

VM Identification
btime → /proc/stat

Linux CPU metrics

[1] Lloyd, W., Ramesh, S., Chinthalapati, S., Ly, L., & Pallickara, S. (April 2018). Serverless computing: An investigation of factors influencing microservice performance. In Cloud Engineering (IC2E), 2018 IEEE International Conference on (pp. 159-169). IEEE.

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RQ-1: Performance

Infrastructure

What are the performance implications of memory reservation size ?

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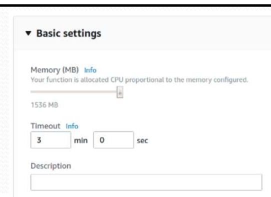
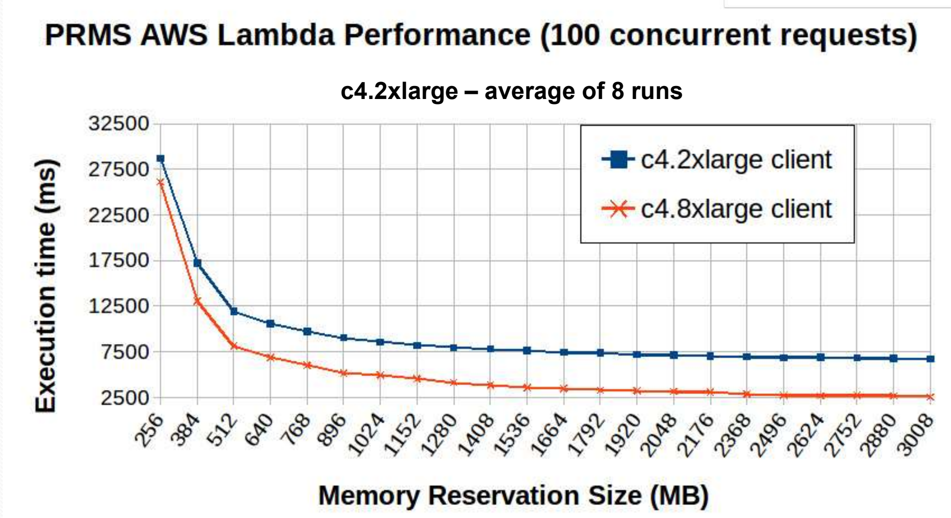
RQ-1: AWS Lambda Memory Reservation Size





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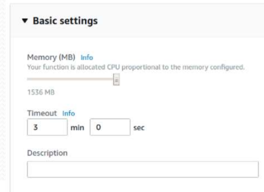
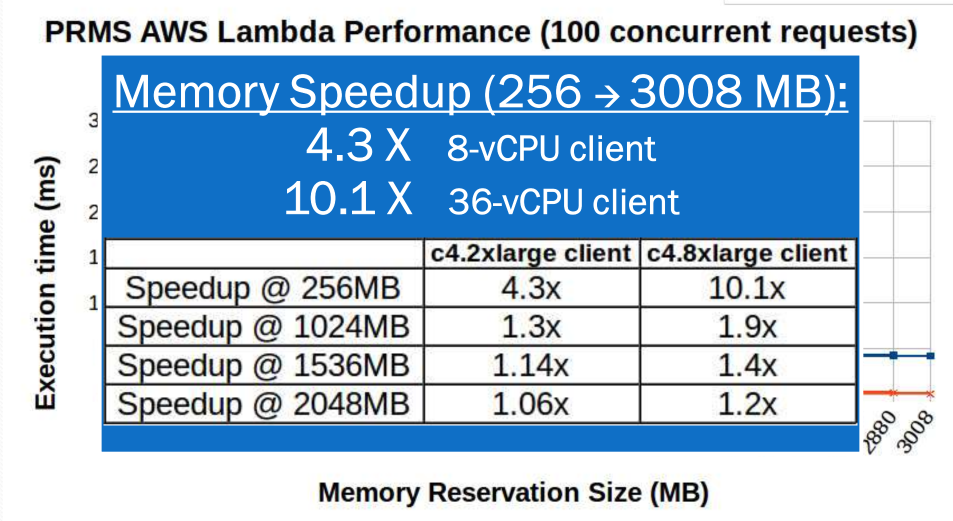
RQ-1: AWS Lambda Memory Reservation Size





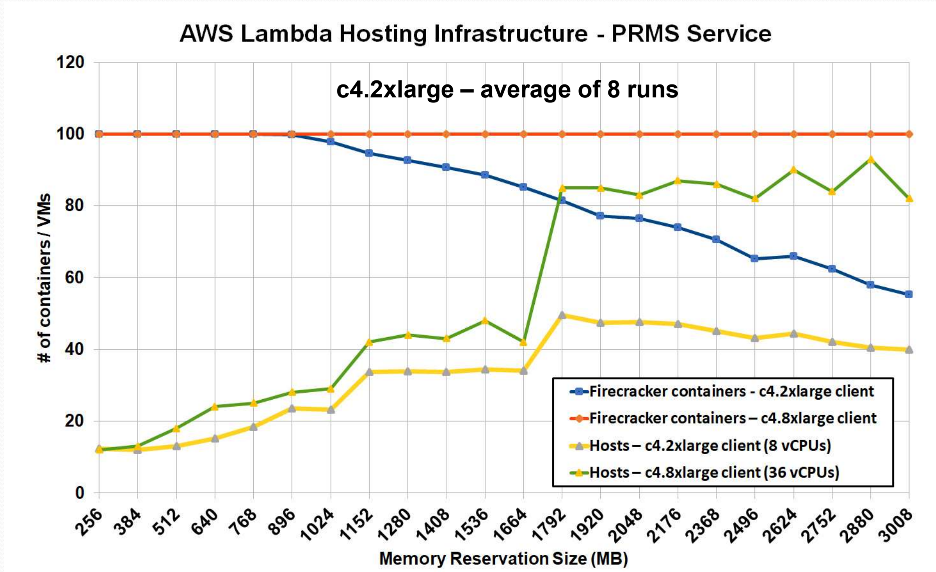
Memory Speedup (256 → 3008 MB):

4.3 X 8-vCPU client

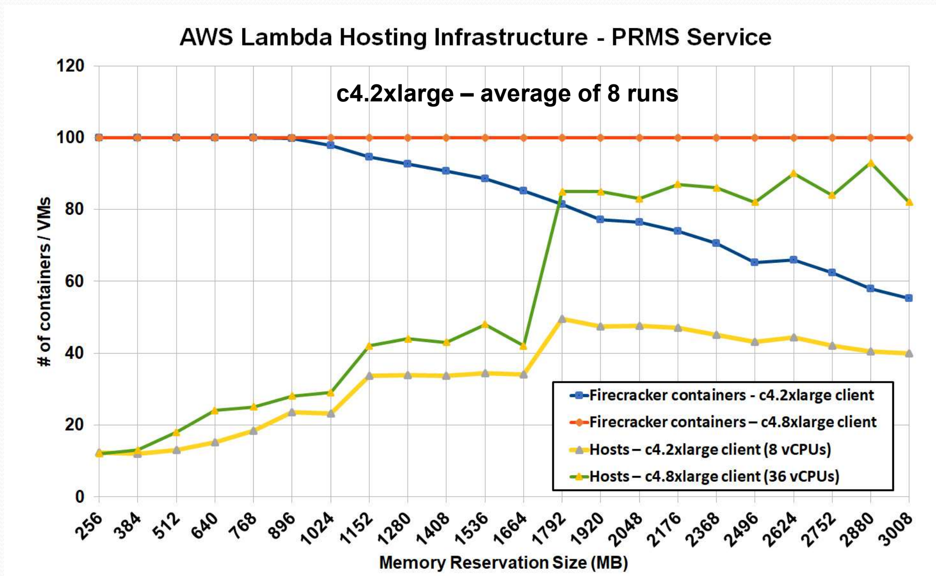
10.1 X 36-vCPU client

	c4.2xlarge client	c4.8xlarge client
Speedup @ 256MB	4.3x	10.1x
Speedup @ 1024MB	1.3x	1.9x
Speedup @ 1536MB	1.14x	1.4x
Speedup @ 2048MB	1.06x	1.2x

RQ-1: AWS Lambda Memory Reservation Size - Infrastructure



Many more Hosts leveraged when memory > 1536 MB



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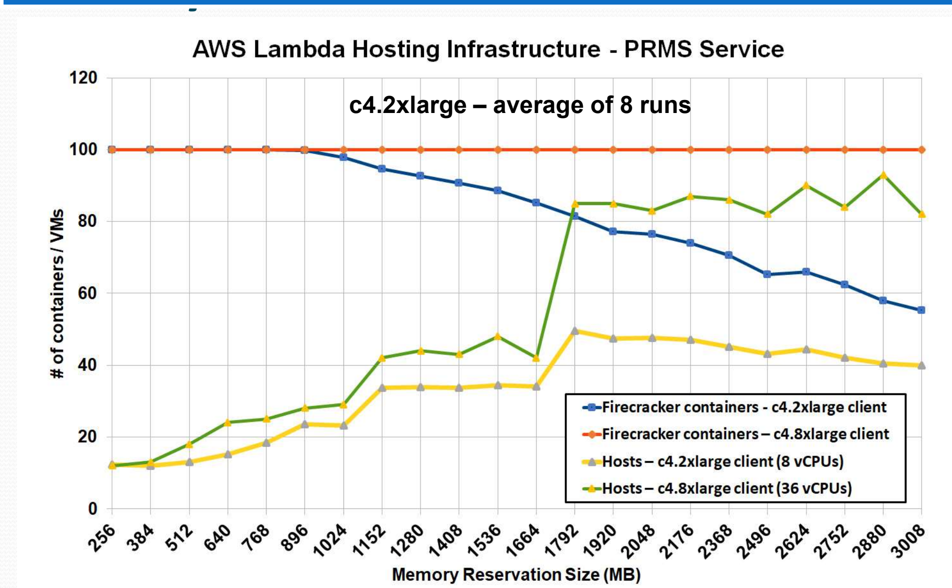
8 vCPU client struggles to generate 100 concurrent requests >= 1024MB



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RQ-2: Scalability

How does performance change when increasing the number of concurrent users ?

(scaling-up, totally cold, and warm)

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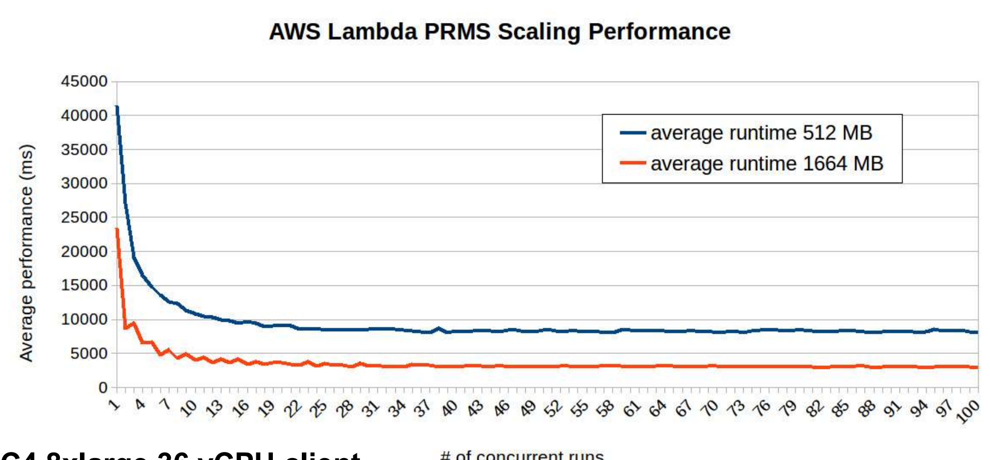
RQ-2: AWS Lambda PRMS Scaling Performance



C4.8xlarge 36 vCPU client

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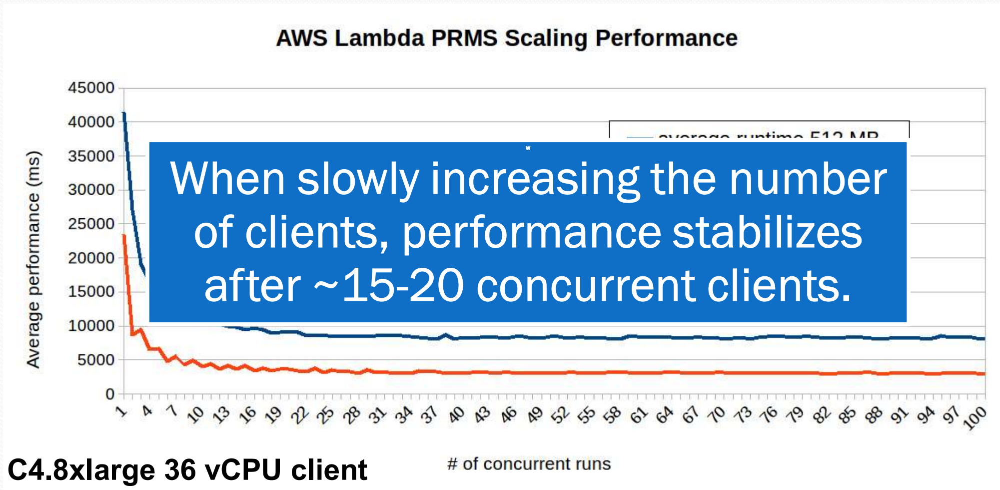
RQ-2: AWS Lambda PRMS Scaling Performance



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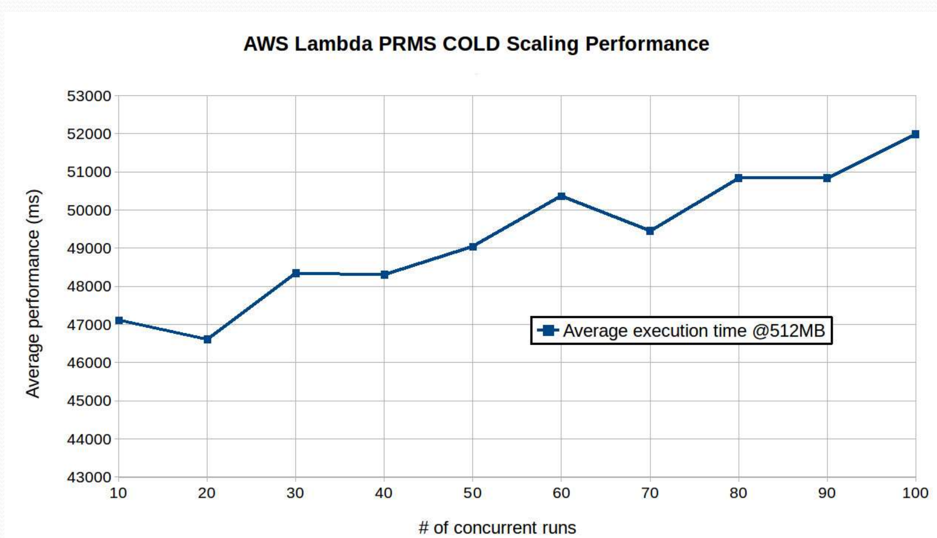
RQ-2: AWS Lambda Cold Scaling Performance



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RQ-3: Cost

What are the costs of hosting PRMS using a FaaS platform in comparison to IaaS?

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RQ-3: IaaS (EC2) Hosting Cost 1,000,000 PRMS runs

- Using a 2 vCPU c4.large EC2 VM
  - 2 concurrent client calls, no scale-up
- Estimated time: 347.2 hours, **14.46 days**
  - Assume average exe time of 2.5 sec/run
- Hosting cost @ 10¢/hour = **$34.72**

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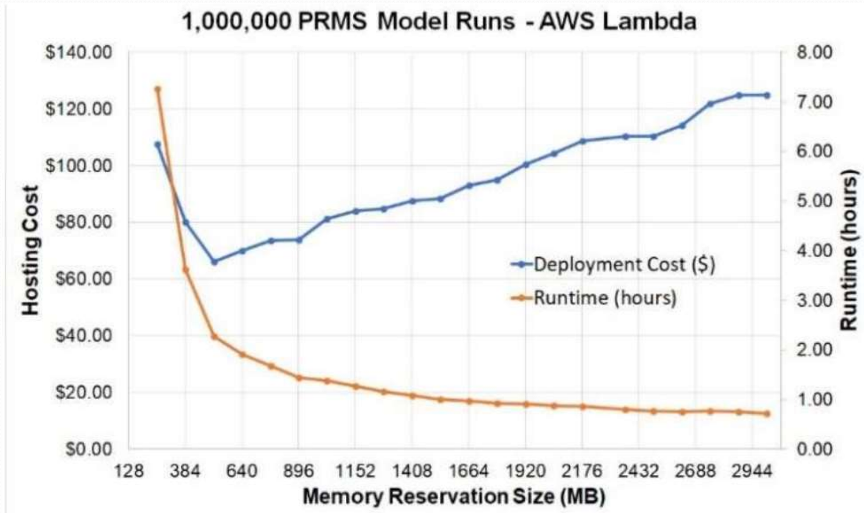
RQ-3: FaaS Hosting Cost 1,000,000 PRMS runs



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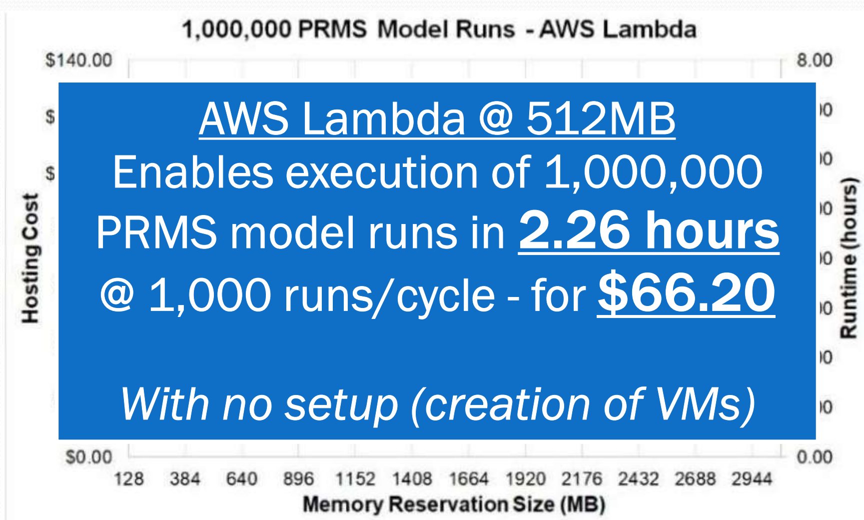

AWS Lambda @ 512MB
Enables execution of 1,000,000 PRMS model runs in **2.26 hours** @ 1,000 runs/cycle - for **$66.20**

With no setup (creation of VMs)

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RQ-4: Persisting Infrastructure

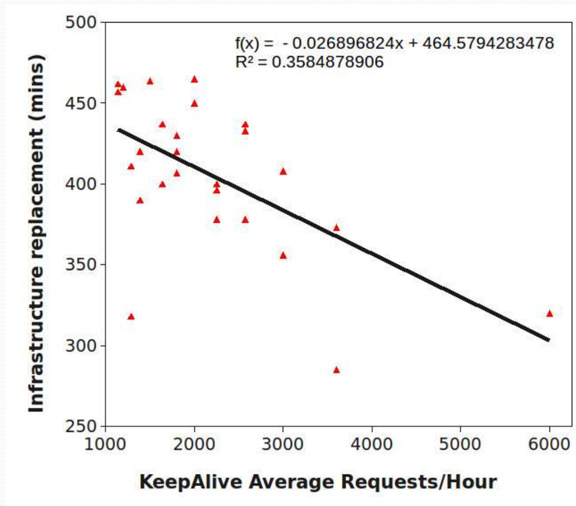
How effective are automatic triggers at retaining serverless infrastructure to reduce performance latency from the serverless freeze/thaw cycle?

RQ-4: Persisting Infrastructure

- Goal: preserve 100 firecracker containers for 24hrs
  - Mitigate cold start latency
- Memory: 192, 256, 384, 512 MB
- All initial host infrastructure replaced between ~4.75 – 7.75 hrs
- Replacement cycle (start→finish): ~2 hrs
- Infrastructure generations performance variance observed from: -14.7% to 19.4% (Δ 34%)
- Average performance variance larger for lower memory sizes: 9% (192MB), 3.6% (512MB)

RQ-4: Persisting Infrastructure

AWS Lambda: time to infrastructure replacement vs. memory reservation size



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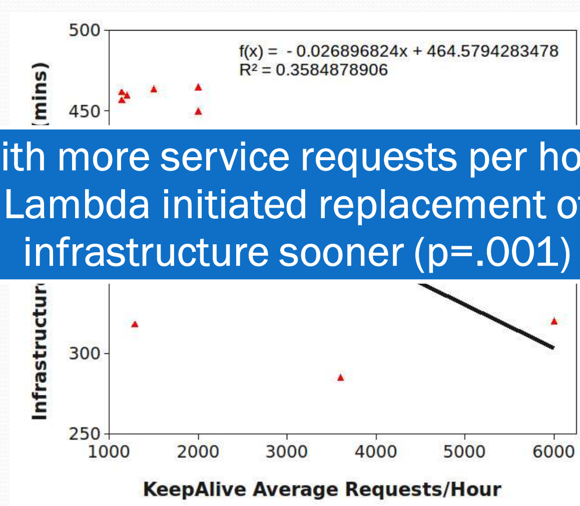
RQ-4: Persisting Infrastructure

AWS Lambda: time to infrastructure replacement vs. memory reservation size



With more service requests per hour, Lambda initiated replacement of infrastructure sooner (p=.001)

Memory sizes tested: 192, 256, 384, 512 MB

RQ-4: Persisting Infrastructure
Keep-Alive Infrastructure Preservation

- PRMS Service: parameterize for "ping"
  - Perform sleep (idle CPU) – do not run model
  - Provides delay to overlap (n=100) parallel requests to preserve infrastructure
- Ping intervals: tested 3, 4, and 5-minutes
- VM Keep-Alive client:
  c4.8xlarge 36 vCPU instance: ~4.5s sleep
- CloudWatch Keep-Alive client:
  100 rules x 5 targets: 5-s sleep

RQ-4: Keep-Alive Client Summary

Client type	c4.8xlarge VM	c4.8xlarge VM	CloudWatch	CloudWatch
Ping interval	5 min	3 min	5 min	4min
Keep-Alive calls/batch	100	100	500	500
Slowdown vs. WARM	13.3%	0.7%	11.6%	35.0%
Speedup vs. COLD	4.03x	4.53x	4.1x	3.4x
Test runs	32	32	26	17
Test duration (hrs)	24	24	18	12
Average new Lambda firecracker containers/test	2.41	0.38	5.42	14.71
Keep-Alive runtime avg (ms)	4492	4463	5200	5200
Memory (GB-sec/hour)	2695	4463	15600	19500
Keep-Alive cost/year	$4,484.00	$4,494.76	$2,278.06	$2,847.57

Keep-Alive clients can support trading off cost for performance for preserving FaaS infrastructure to mitigate cold start latency

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Conclusions

- **RQ-1 Memory Reservation Size**:
  - MAX memory: 10x speedup, 7x more hosts
- **RQ-2 Scaling Performance**:
  - 1+ scale-up near warm, COLD scale-up is slow
- **RQ-3 Cost**
  - m4.large $35 (14d), Lambda $66 (2.3 hr), $125 (42 min)
- **RQ-4 Persisting Infrastructure (Keep-Alive)**
  - c4.8xlarge VM $4,484/yr (13.3% slowdown vs warm, 4x ↑), CloudWatch $2,278/yr (11.6% slowdown vs warm, 4.1x ↑)

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Questions