Serverless in the Wild: Characterizing and Optimizing the Serverless Workload at a Large Cloud Provider

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What is Serverless?

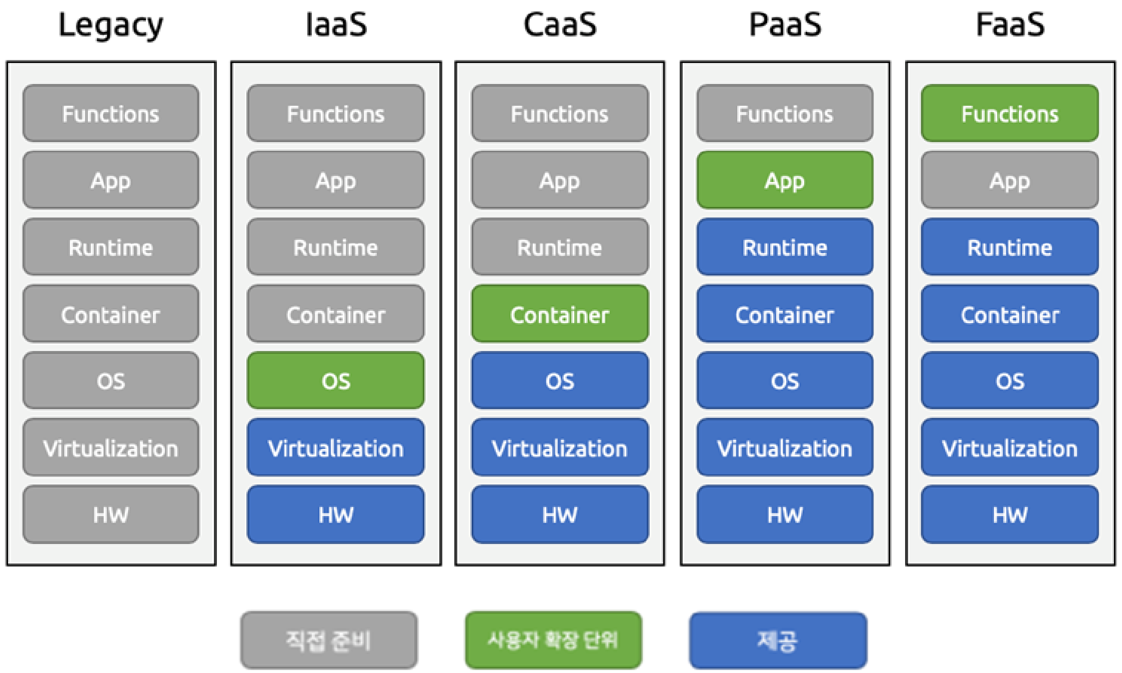
- Very attractive abtraction to users:
  - Pay for only usage
  - No worry about servers
    - Provisioning, reserving, configuring, patching, managing

- Most popular offering: Function-as-a-Service (FaaS)
  - Intuitive, event-based interface for developing cloud-based applications
  - Users upload the code, provider enables a handle for the code to run

serverless

FaaS

- FaaS (Function as a Service): users do not provision or configure resources
  - Function: basic unit of deployment
  - Application: consists of multiple functions, unit of resource allocation



(source: https://futurecreator.github.io/2019/03/14/serverless-architecture/)

Put yourself in provider's shoes..

- Challenges are:
  - You do worry about servers
    - Provisioning, scaling, allocating, securing, isolating
  - Optimize resource usage
  - Provide the illusion of always-available resources at the lowest cost
    - Fast function invocations without cold starts

Cloud Providers

Cold Starts

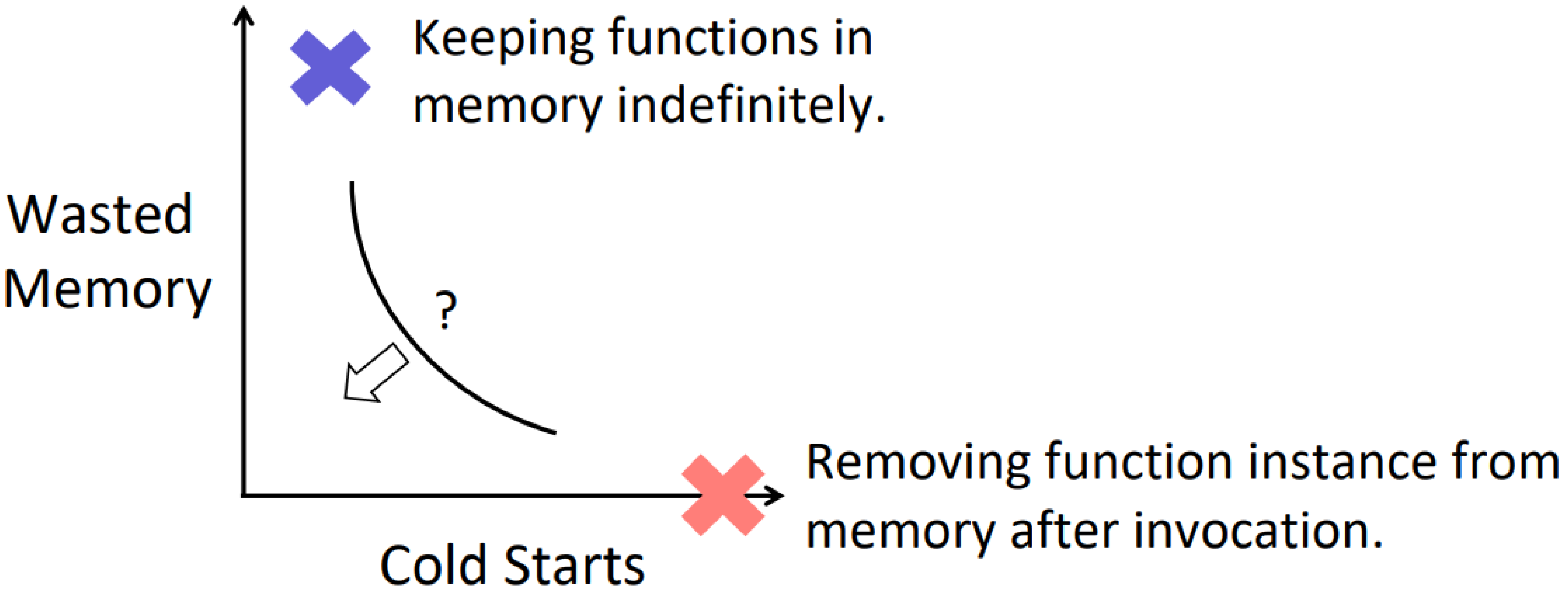
- Providers want to provide high function performance at the lowest cost
  - Function execution requires the needed code in memory
    - Warm start (from memory) vs **cold start** (from storage)
  - Keeping all resources in memory is prohibitively expensive
  - Functions have varying resource needs and invocation frequencies

☞ ***a comprehensive characterization of the FaaS workload is needed!!***

(Source: https://medium.com/ssense-tech/the-trade-offs-with-serverless-functions-71ea860d446d)

Problem: Cold Starts and Resource Wastage

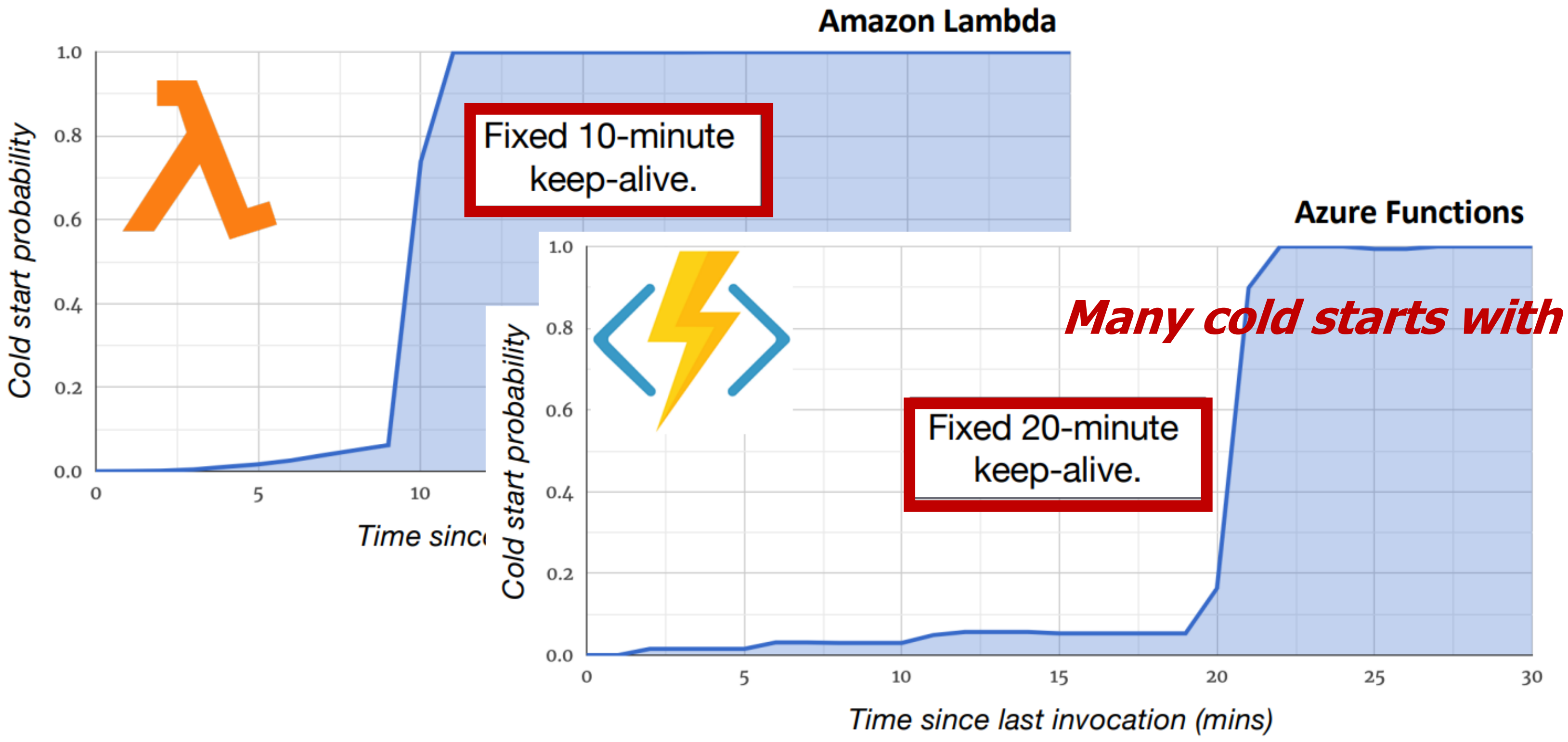
- Trade-off between reducing cold starts and the resources they need



(Source: https://www.usenix.org/system/files/atc20-paper593-slides-shahrad.pdf)

Problem: Fixed keep-alive policy

- Application instances are kept loaded in memory for a fixed time
  - It does not consider the wide variety of application behaviors



Many cold starts with wasting resources

(Source: https://www.usenix.org/system/files/atc20-paper593-slides-shahrad.pdf)

FaaS Workload

2 weeks of all invocations to Azure Functions in July 2019
First characterization of the workload of a large serverless provider

- Functions and applications
  - 54% applications only have one function and 95% applications have at most 10 functions

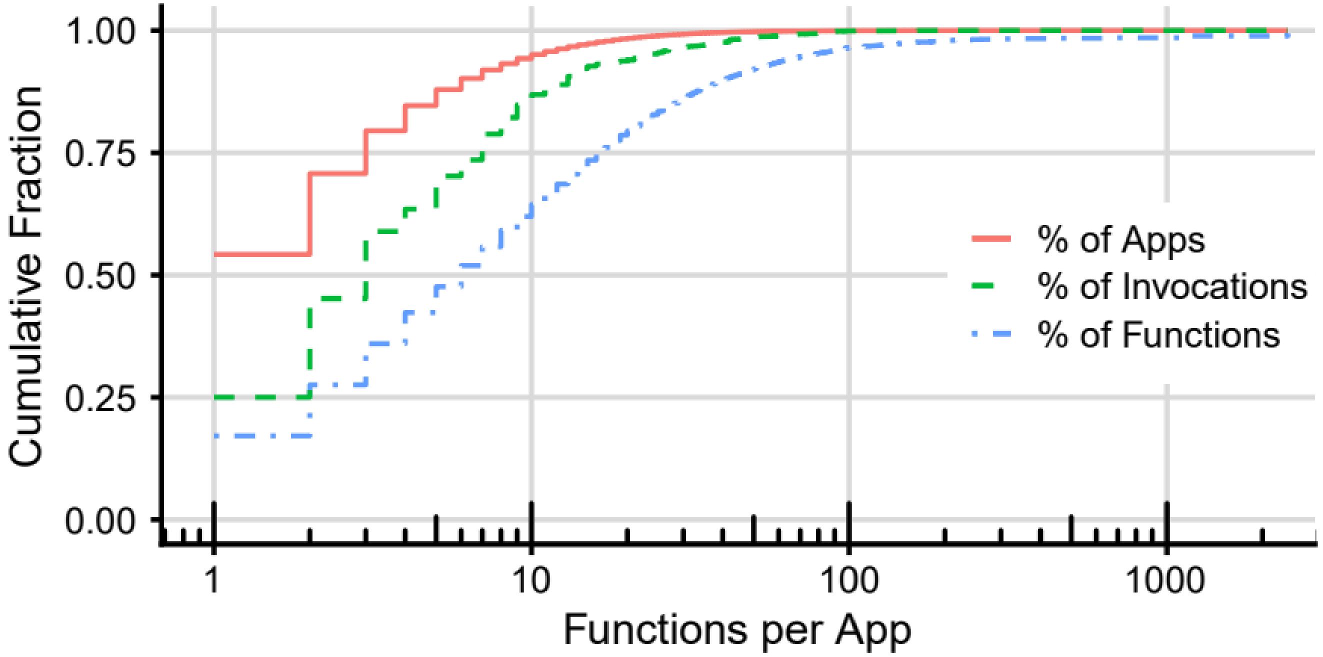


Figure 1: Distribution of the number of functions per app.

The number of functions in an applications is not useful in resource management

FaaS Workload

2 weeks of all invocations to Azure Functions in July 2019
First characterization of the workload of a large serverless provider

- Triggers and applications

Trigger	%Functions	%Invocations
HTTP	55.0	35.9
Queue	15.2	33.5
Event	2.2	24.7
Orchestration	6.9	2.3
Timer	15.6	2.0
Storage	2.8	0.7
Others	2.2	1.0

Figure 2: Functions and invocations per trigger type.

Trigger Type	% Apps
HTTP (H)	64.07
Timer (T)	29.15
Queue (Q)	23.70
Storage (S)	6.83
Event (E)	5.79
Orchestration (O)	3.09
Others (o)	6.28

(a) Apps with ≥ 1 of each trigger.

Trigger Types	Fraction of Apps (%)	Cum. Frac. (%)
H	43.27	43.27
T	13.36	56.63
Q	9.47	66.10
HT	4.59	70.69
HQ	4.22	74.92
E	3.01	77.92
S	2.80	80.73
TQ	2.57	83.30
HTQ	2.48	85.78
Ho	1.69	87.48
HS	1.05	88.53
HO	1.03	89.56

(b) Popular trigger combinations.

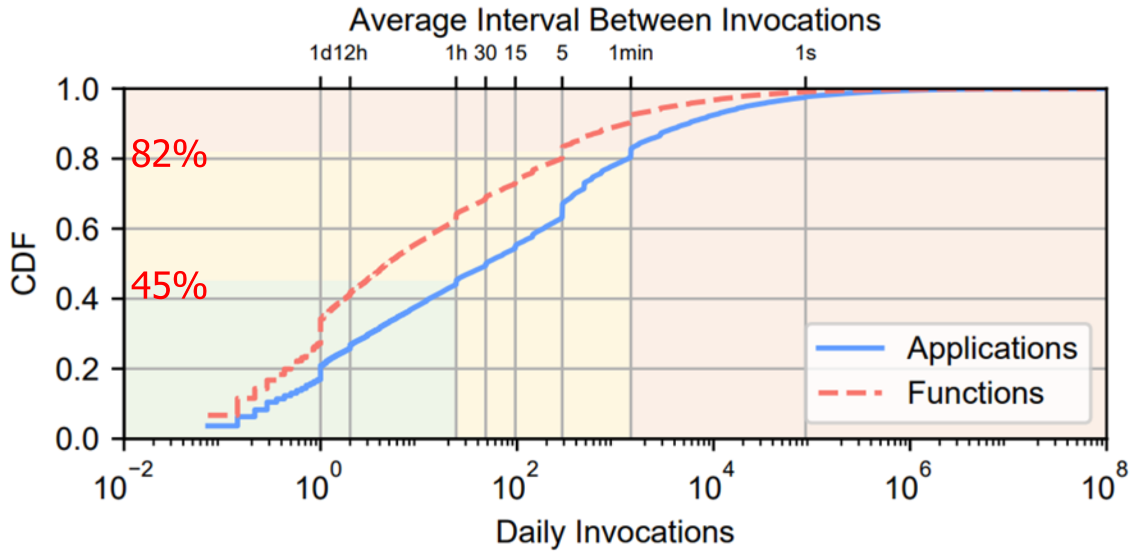
Figure 3: Trigger types in applications.

For predicting invocations: timers are very predictable, other applications with no timers aren't

FaaS Workload

2 weeks of all invocations to Azure Functions in July 2019
First characterization of the workload of a large serverless provider

- Invocations per application
  - Daily invocations varies by over 8 orders of magnitude
  - Vast majority of functions are invoked very infrequently



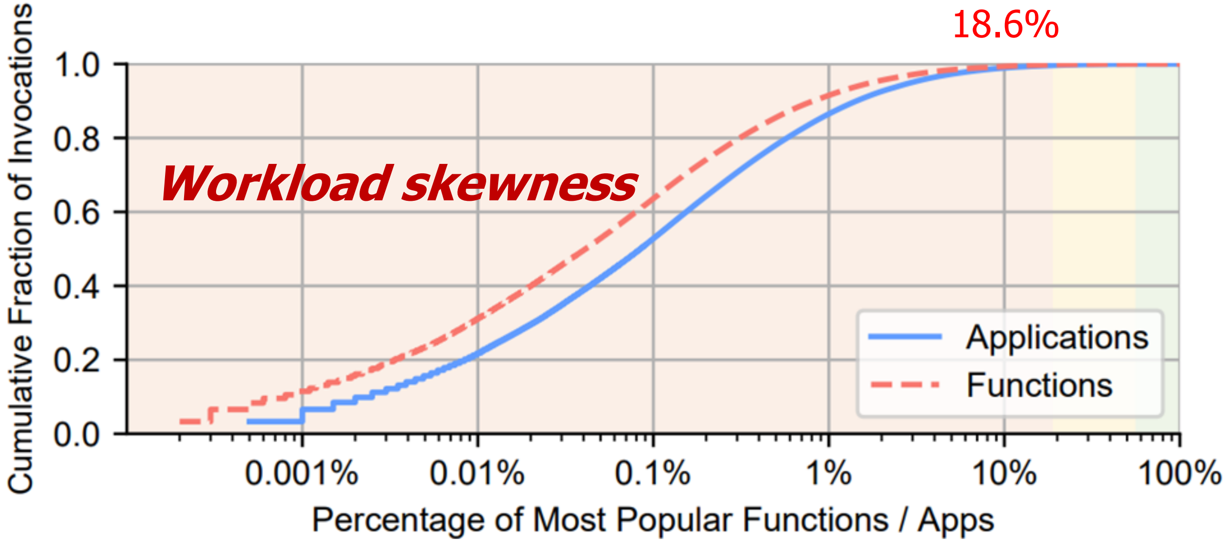


Figure 5: Invocations per application and per function for a representative sample of the dataset.

From IAT (Inter-arrival time) of invocation, we can pre-warming the application

FaaS Workload

2 weeks of all invocations to Azure Functions in July 2019
First characterization of the workload of a large serverless provider

- Function execution times
  - Same sale as the cold start times
  - Execution times are short

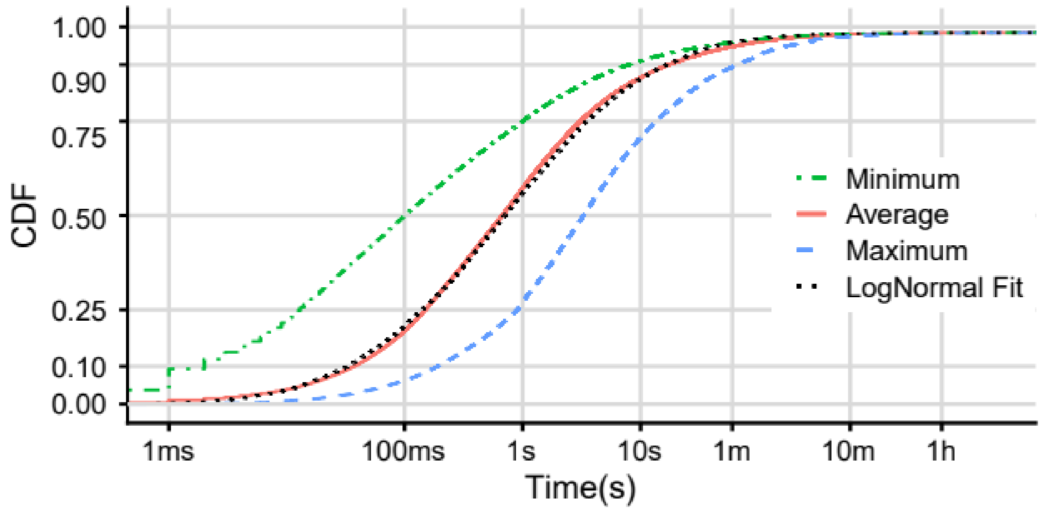


Figure 7: Distribution of function execution times. Min, avg, and max are separate CDFs, and use independent sorting.

Optimizing cold starts is important

- Memory Usage
  - Applications tend to remain memory resident for longer

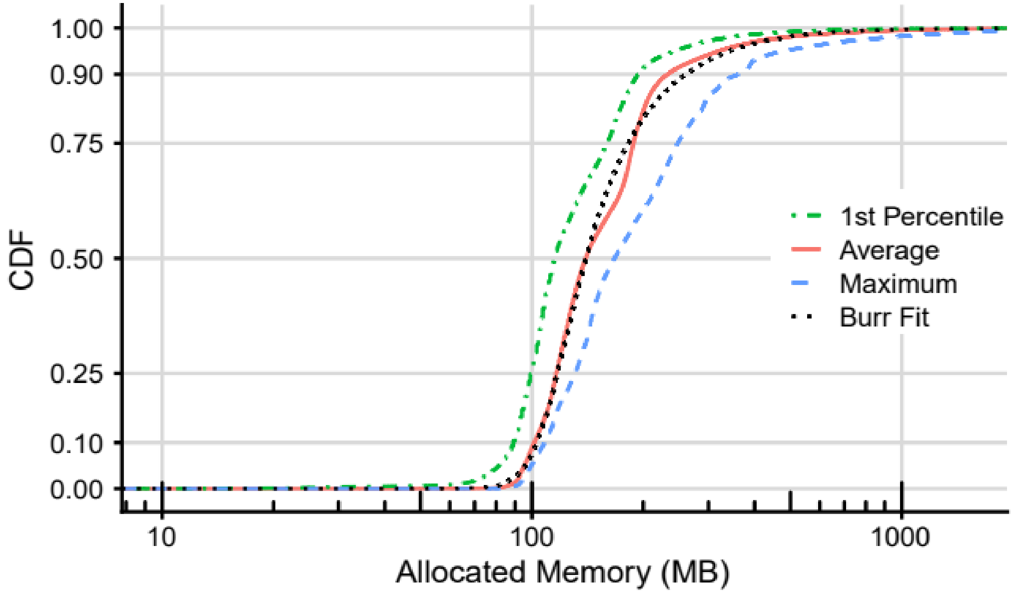
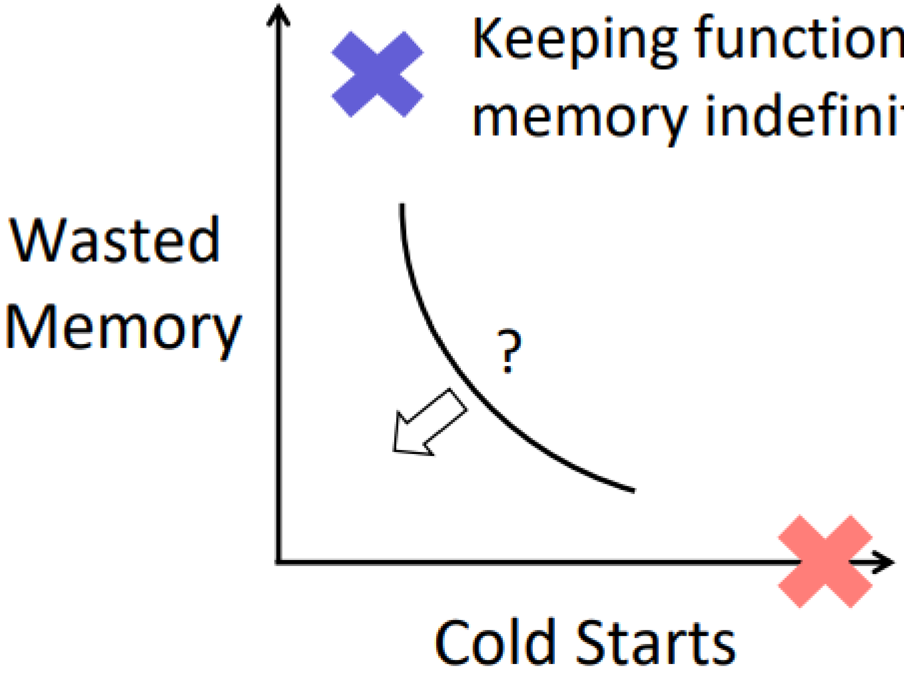


Figure 8: Distribution of allocated memory per application.

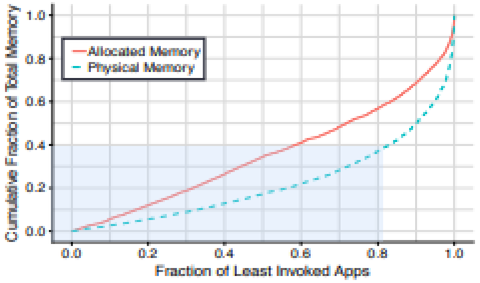
Memory is important in keep-alive decision for FaaS

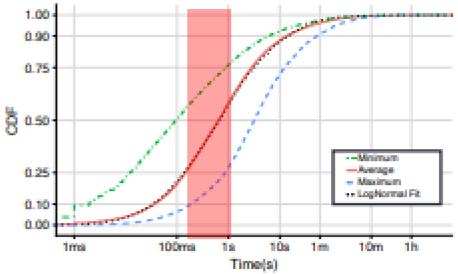
Cold Starts and Resource Wastage

- How to manage cold starts in FaaS?



Keeping functions in memory indefinitely.





Removing function instance from memory after invocation.

Hybrid Histogram Policy

- The policy of hybrid histogram
  - Pre-warming window / keep-alive window

* ARIMA: Autoregressive Integrated Moving Average

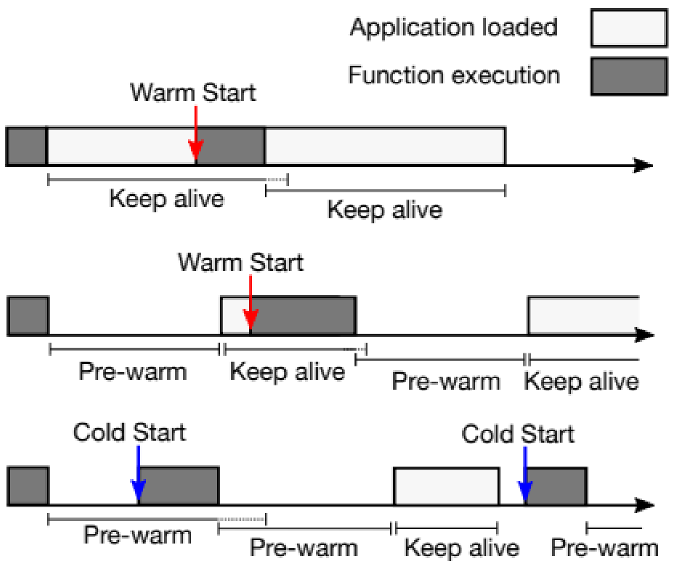


Figure 9: Timelines showing a warm start with keep alives and no pre-warming (top); a warm start following a pre-warm (middle); and two cold starts, before a pre-warm, and after a keep alive (bottom).

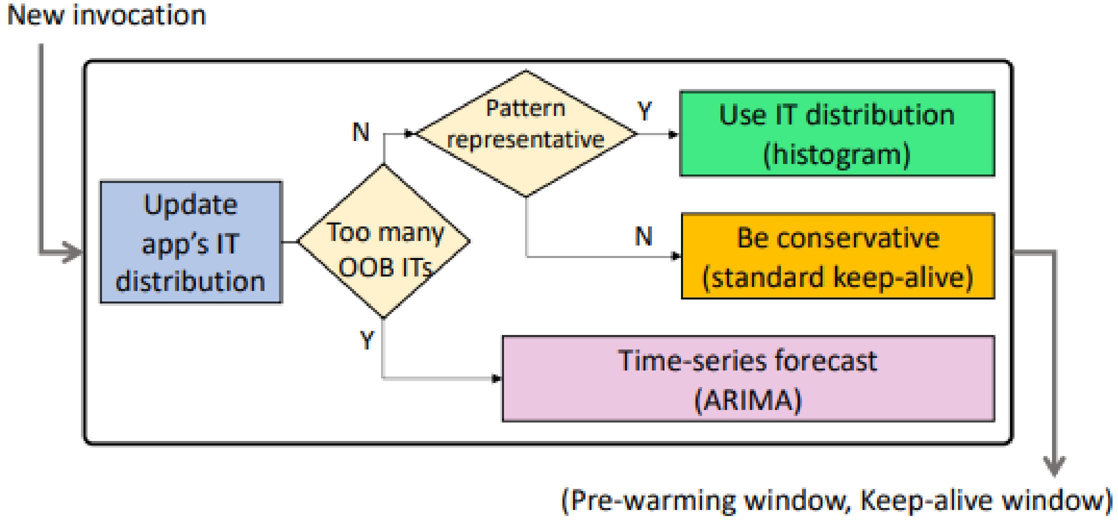


Figure 10: Overview of the hybrid histogram policy.

Hybrid Histogram Policy

- Three main components of the policy
  - A range-limited histogram
  - Standard keep-alive approach
  - Time-series forecast component

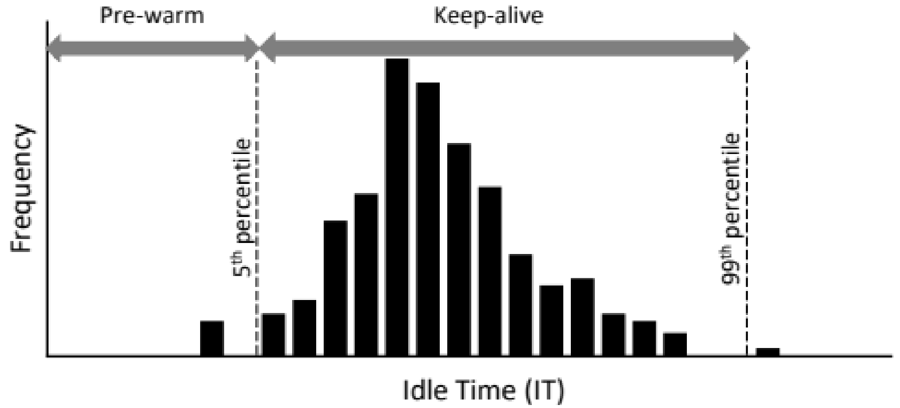


Figure 11: Example application idle time (IT) distribution used to select pre-warming times and keep-alive windows.

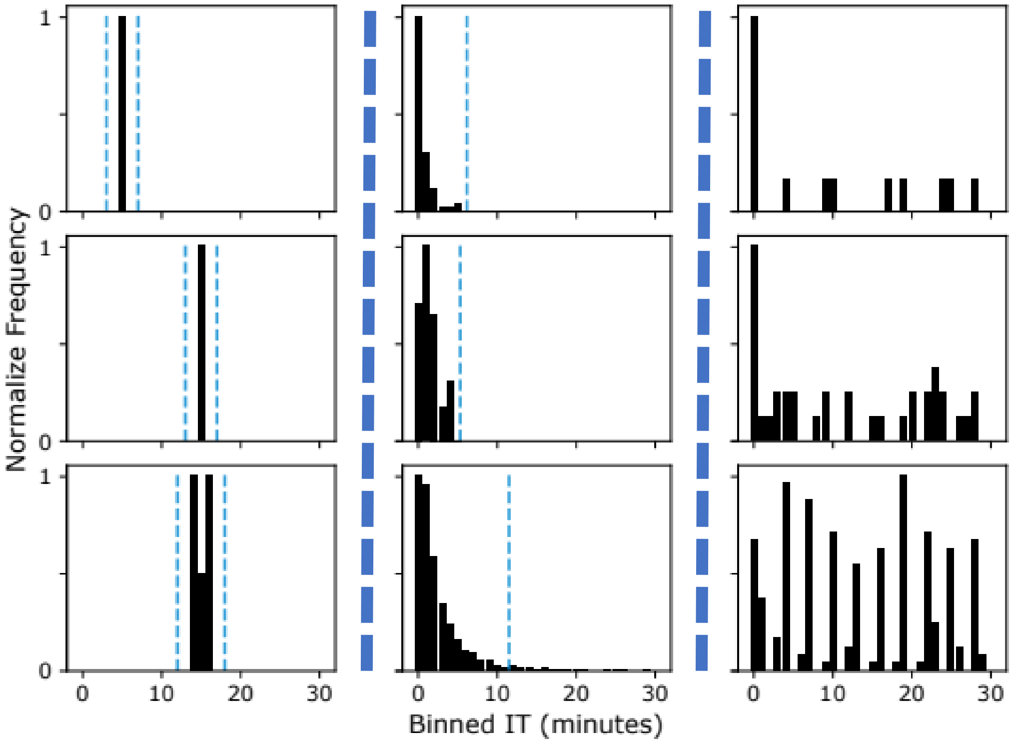


Figure 12: Nine normalized IT distributions from real FaaS workloads over a week.

Implementation in Apache OpenWhisk

- Apache OpenWhisk
  - Open-sourced industry-grade (IBM Cloud Functions)
  - Functions run in docker containers
  - Uses 10-minute fixed keep-alive
  - Built a distributed setup with 19 VMs

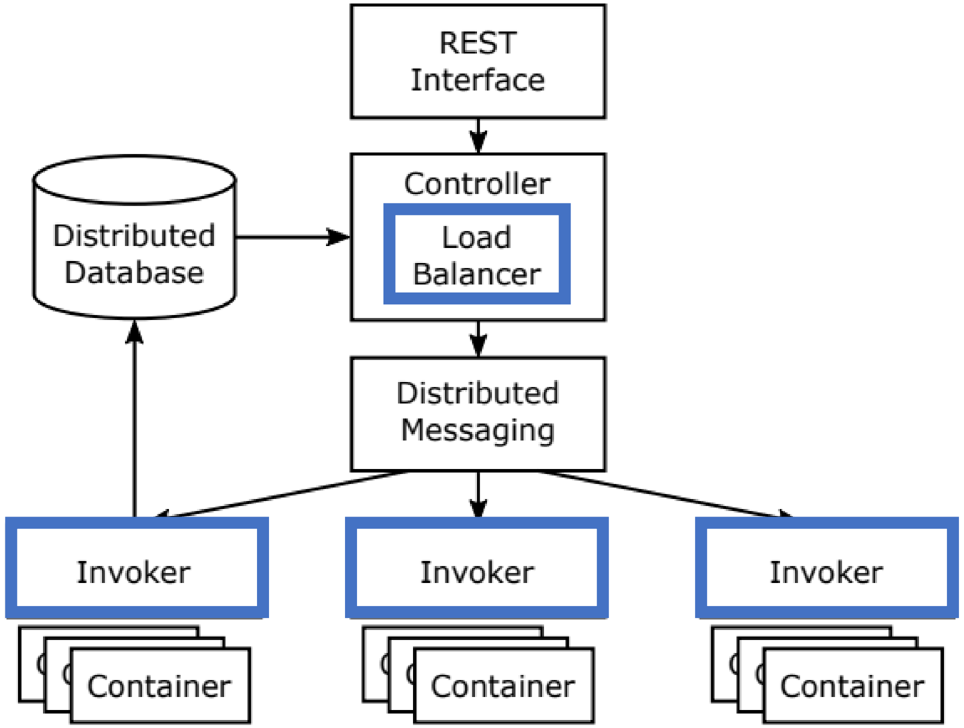


Figure 13: OpenWhisk architecture.

Evaluation

- Experiment Setup
  - Simulation
    - Workload: all function invocations across Azure between July 15th and Jylu 20th
    - Generates an array of invocation times and infer whether each invocation would be a cold start
  - Real experiments
    - Workload: scaled-down version of the trace
    - 19VM: One VM with 8 cores, 8GB of memory hosts / 18 VM with 2 cores, 4 GB of memory

☞ ***Simulation and experimental results show the same trends in both cold start and memory consumption behaviors***

Evaluation: simulation

- Fixed keep-alive policy

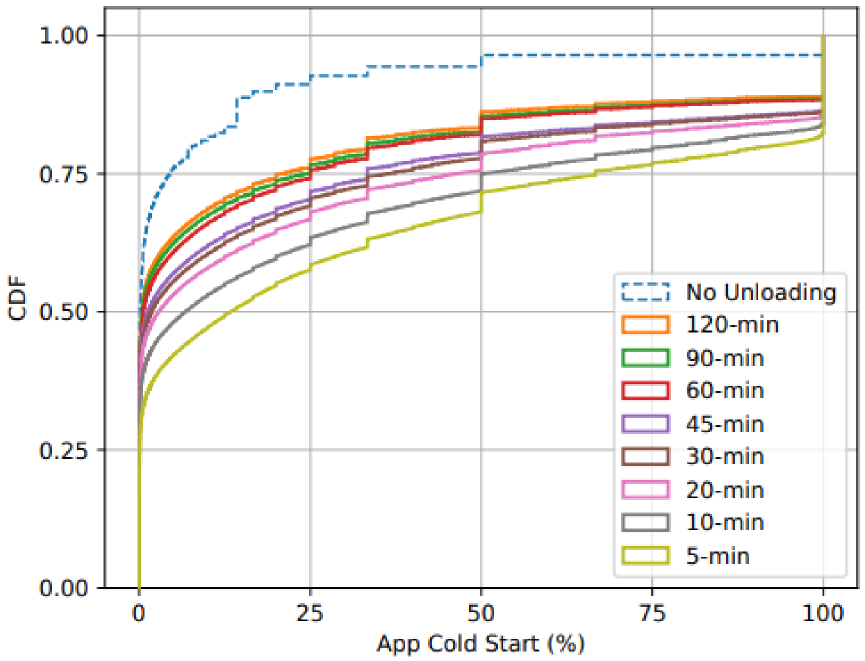


Figure 14: Cold start behavior of the fixed keep-alive policy, as a function of the keep-alive length.

Longer keep-alive reduces cold starts significantly

- Hybrid policy using a histogram

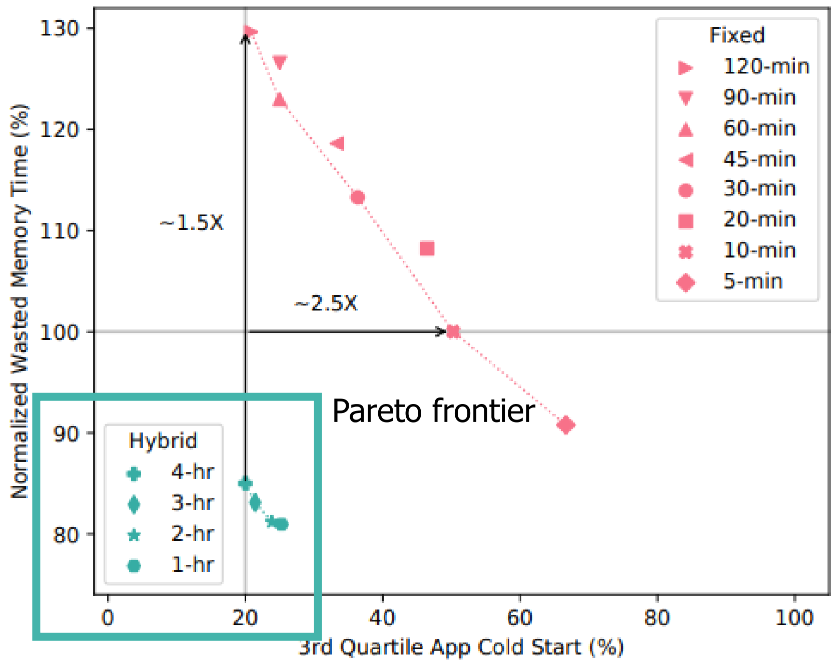


Figure 15: Trade-off between cold starts and wasted memory time for the fixed keep-alive policy and our hybrid policy.

Hybrid policies reduce cold starts significantly with lower memory waste

Evaluation: simulation

- Impact of the histogram cutoff percentiles

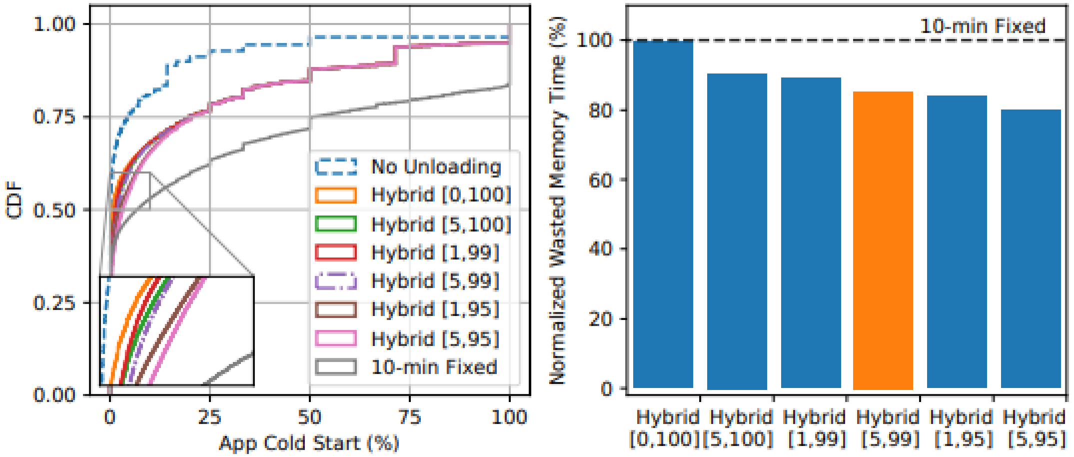


Figure 16: Wasted memory time can be significantly reduced by excluding outliers from the IT distribution.

wasted memory time goes down by 15%, compared to with no cutoff [0,100]

- Impact of unloading and pre-warming

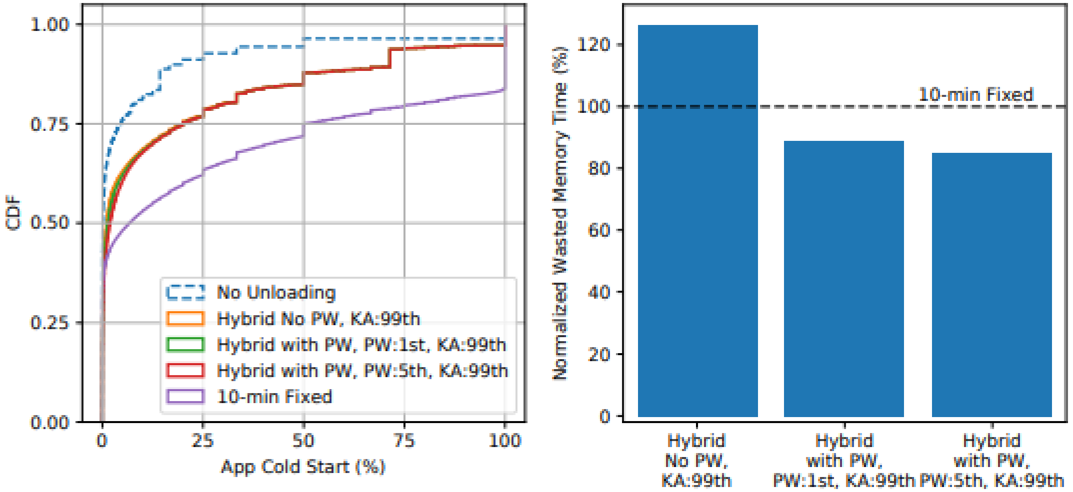
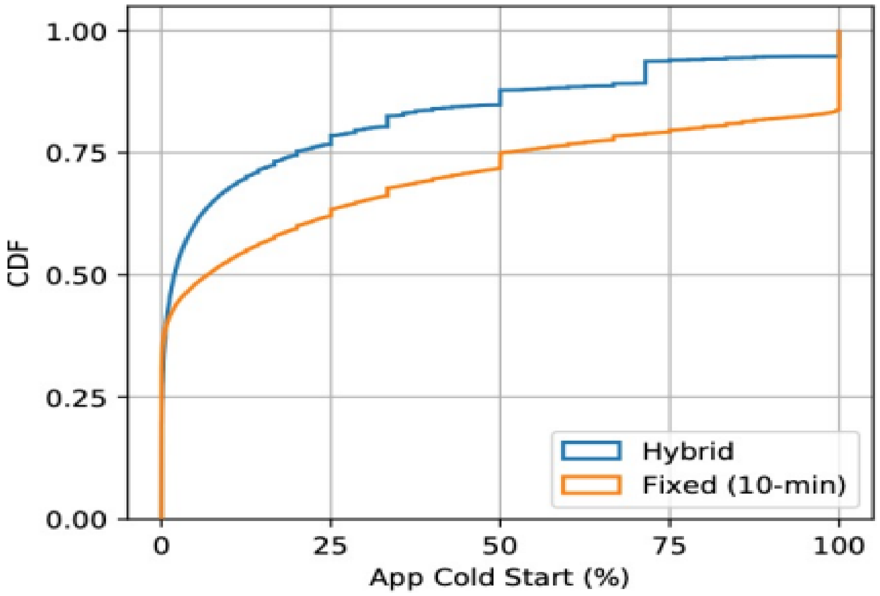


Figure 17: Pre-warming reduces the wasted memory time significantly. The cost is slight increase in cold starts.

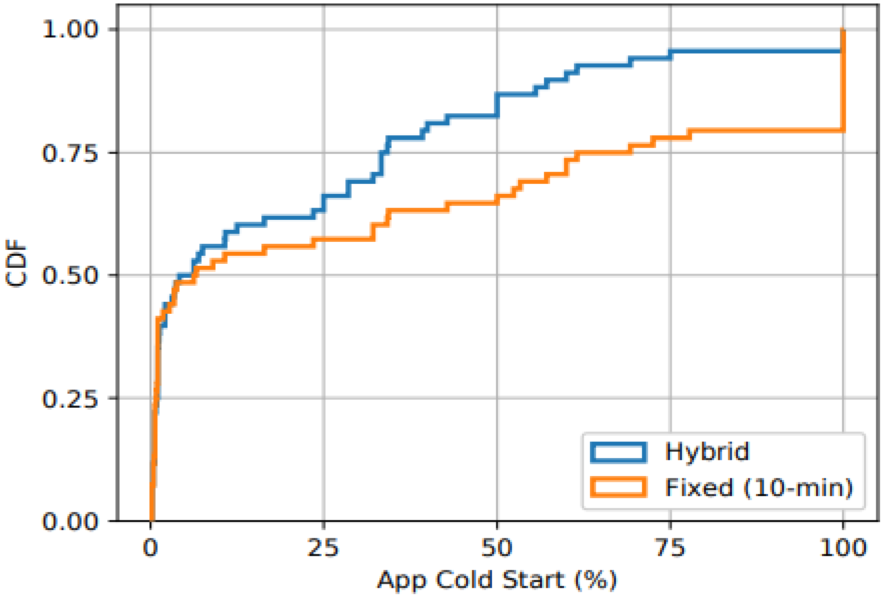
PW (Pre-warming) reduce the wasted memory time significantly

Evaluation: real experiment

- Simulation results



- Experimental results



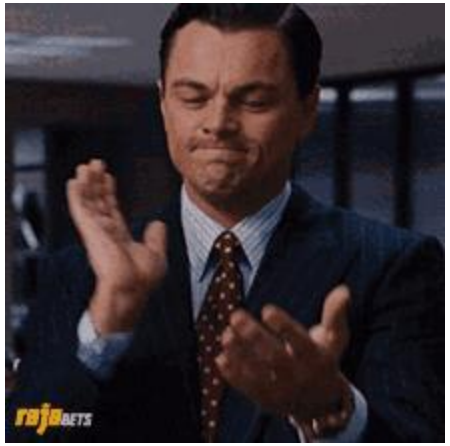
- ***Average exec time reduction: 32.5%***
- ***99th-percentile exec time reduction: 82.4%***

- ***Container memory reduction: 15.6%***
- ***Latency overhead: < 1ms (835.7us)***

Conclusion

Microsoft Azure Microsoft Research

- Characterize the users' real FaaS workloads of Azure Functions from provider's perspective
- A dynamic policy leveraging small histogram to reduce cold starts at a low resource cost
- Azure Functions sanitized traces available:
  https://github.com/Azure/AzurePublicDataset/blob/master/AzureFunctionsDataset2019.md



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Thank You !

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