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FIREWORKS: A Fast, Efficient, and Safe Serverless Framework using VM-level post-JIT Snapshot

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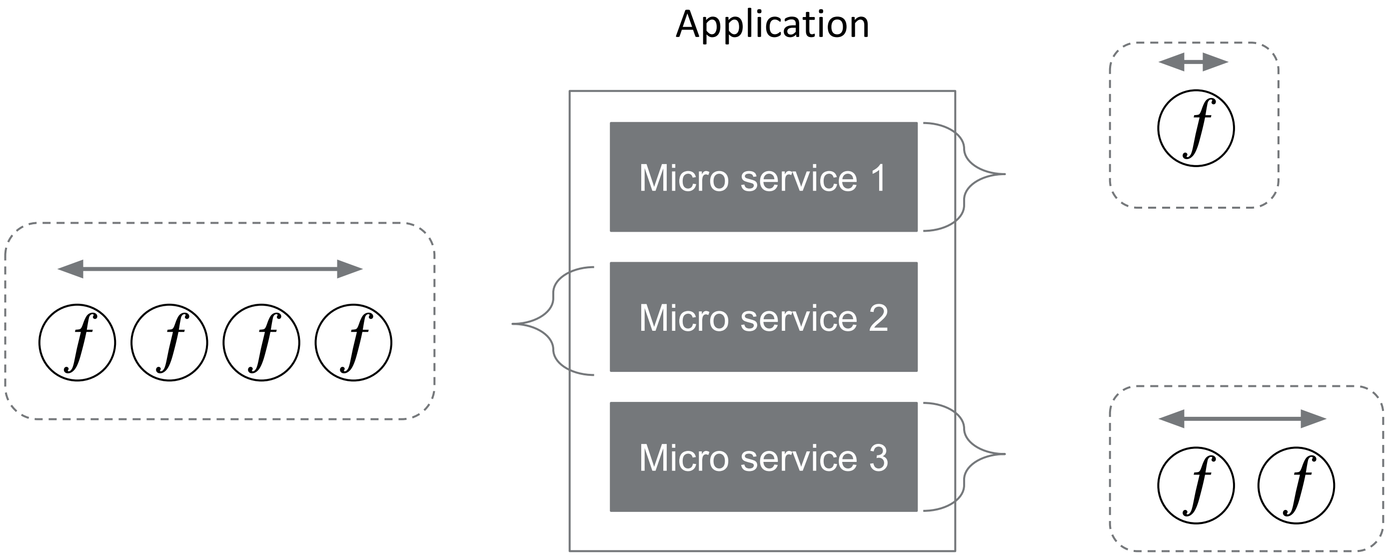
Here is Serverless Computing!

- Serverless computing is now mainstream in the cloud era
- Amazon Lambda, Microsoft Azure, Google Cloud, IBM Cloud Functions provide their serverless computing models
- Developers **do not need to effort** into administration
- It offers significant **scalability** for the resource provisioning
- The serverless introduces **pay-as-you-go**

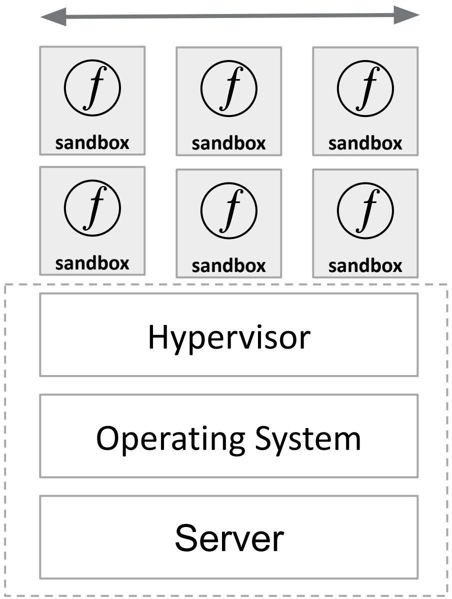
What is Serverless Computing?

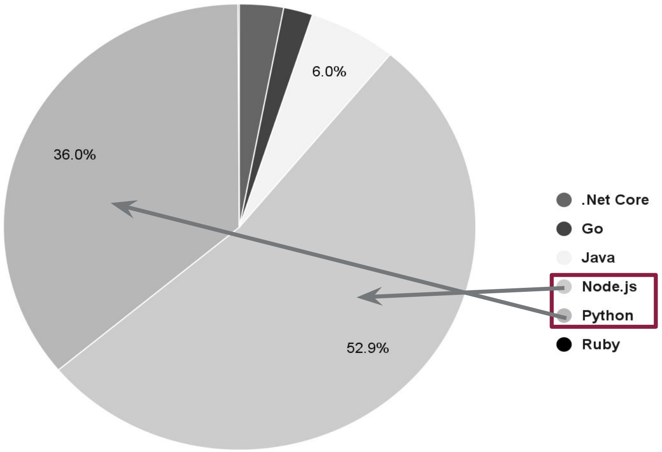
- Application can consist of small serverless functions
- Serverless computing is Function-as-a-Service (**FaaS**)



What is Serverless Computing?

- Inside the serverless, each function runs **in its own sandbox**
- **Cloud operator** manages functions flexibly for users
- In function, most used languages and runtime(**90%**) is **interpreter language**





* serverless benchmark report AWS lambda 2020

Characteristics of Serverless Computing

- **On-demand execution**
  - The resources for functions are created on-demand when invoked
- **Shorter execution time**
  - Functions on the serverless run in a short span
- Cloud operators aim to **consolidate a large number of serverless functions** in a few machines to utilize server's resources more efficiently

Problems

(1) Long startup time penalty

- Long booting time of VM, OS, container and runtime
- 1st request = cold start, subsequent requests = warm start(can be expired)
- In some cases, startup time > execution time of function

(2) Unpredictability in Just-In-Time(JIT) compilation of interpreter language

- Short execution time of the function is not suitable for JIT compilation

(3) Memory is bottleneck in the consolidation

- Cloud operators retain the functions in memory for a while waiting

(4) Security challenge

- High consolidated serverless environment needs robust isolation

Our approach

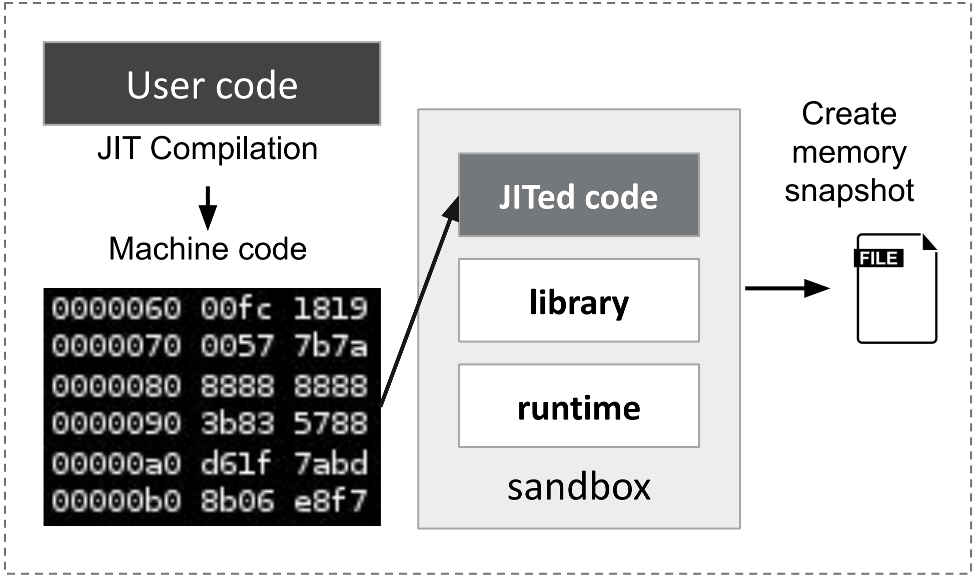
- **Low-latency start up time** → Snapshot
- **Fast execution time** → Post-JIT, Snapshot
- **Memory efficiency** → Sharing, Post-JIT, Snapshot
- **Robust isolation** → Sharing, VM-level, Post-JIT, Snapshot

Our approach : VM-level post-JIT snapshot

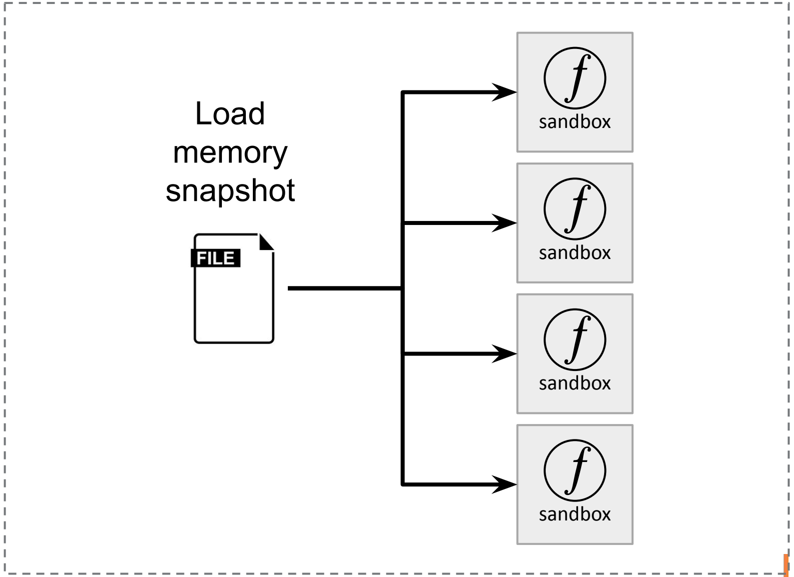
Installation phase : create a memory snapshot with JIT compilation

Invocation phase : load the memory snapshot on a sandbox as a new function

Installation phase



Invocation phase



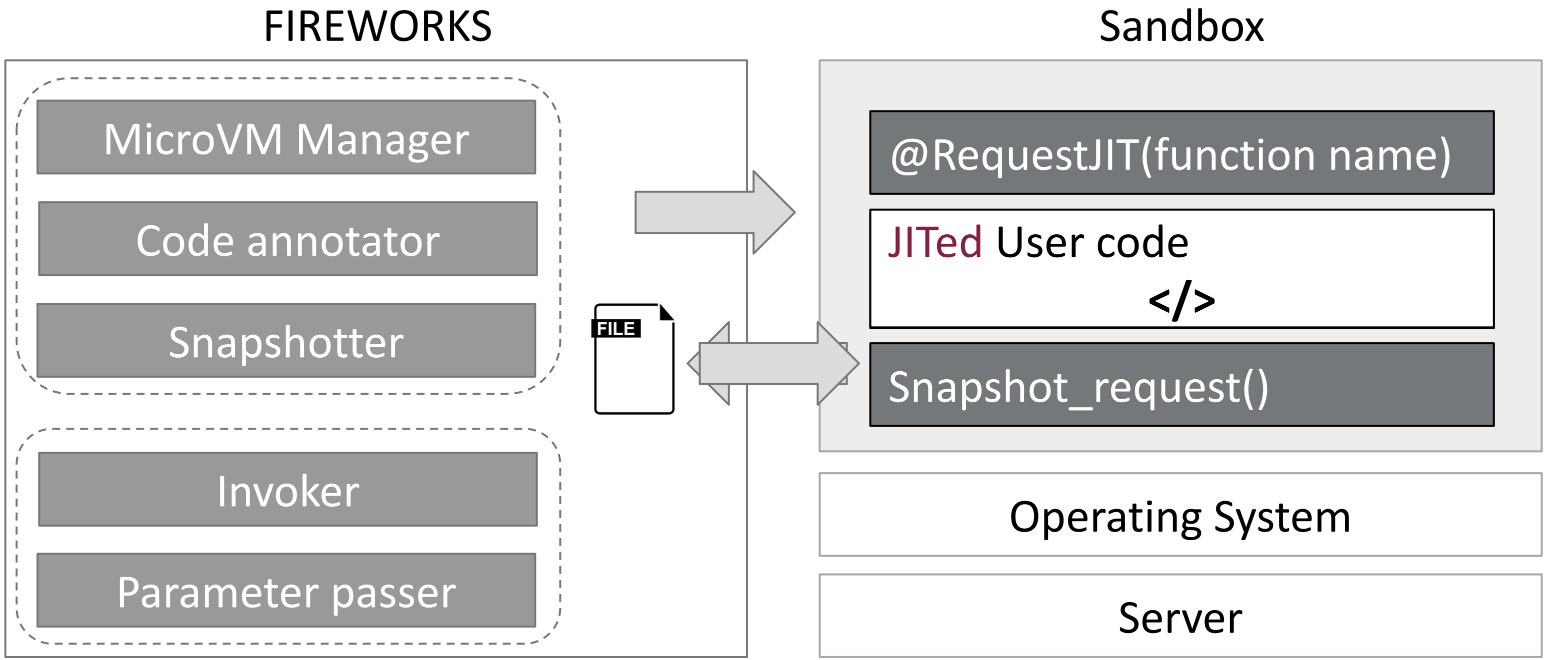
Challenges

- Installation phase
  - How can we manipulate JIT compilation?
  - Do we know when creating a snapshot?

- Invocation phase
  - How we can reduce a memory footprint?
  - How to solve the problem of duplicated IP and MAC using the same snapshot?
  - How can we pass multiple users' arguments to the same running state of a memory snapshot?

Our solution : FIREWORKS

We suggest **FIREWORKS**, a way to solve the challenges and realize a post-JIT snapshot



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How can we manipulate JIT compilation?

Use source code annotation

- Modern highly-optimized language runtimes already support **annotation to trigger JIT** at the program loading time.
- We re-purpose this feature to create a post-JIT VM-level snapshot

```javascript
function optfn() {
  try {
    %OptimizeFunctionOnNextCall(main);
  }
  catch (e) {
    console.log(e);
  }
}
```

Node.js

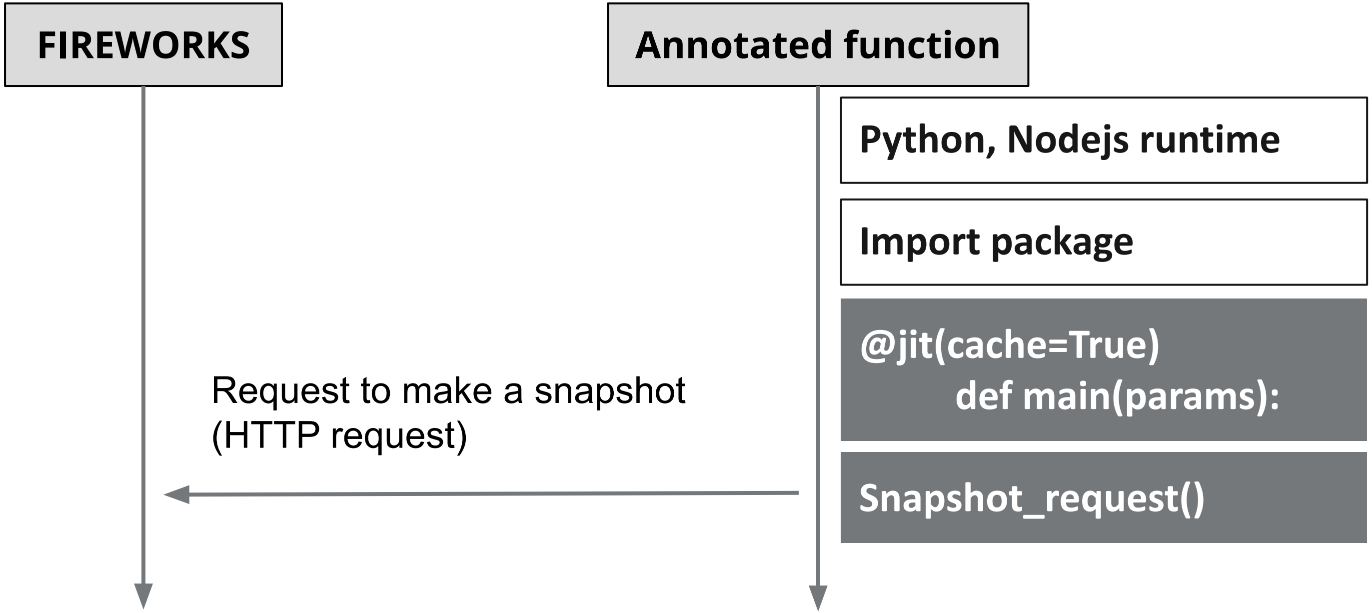
```python
@jit(cache=True)
def f(x, y):
      return x + y
```

Python

Do we know when to create a snapshot?

Place a trigger of making a snapshot in **user code**

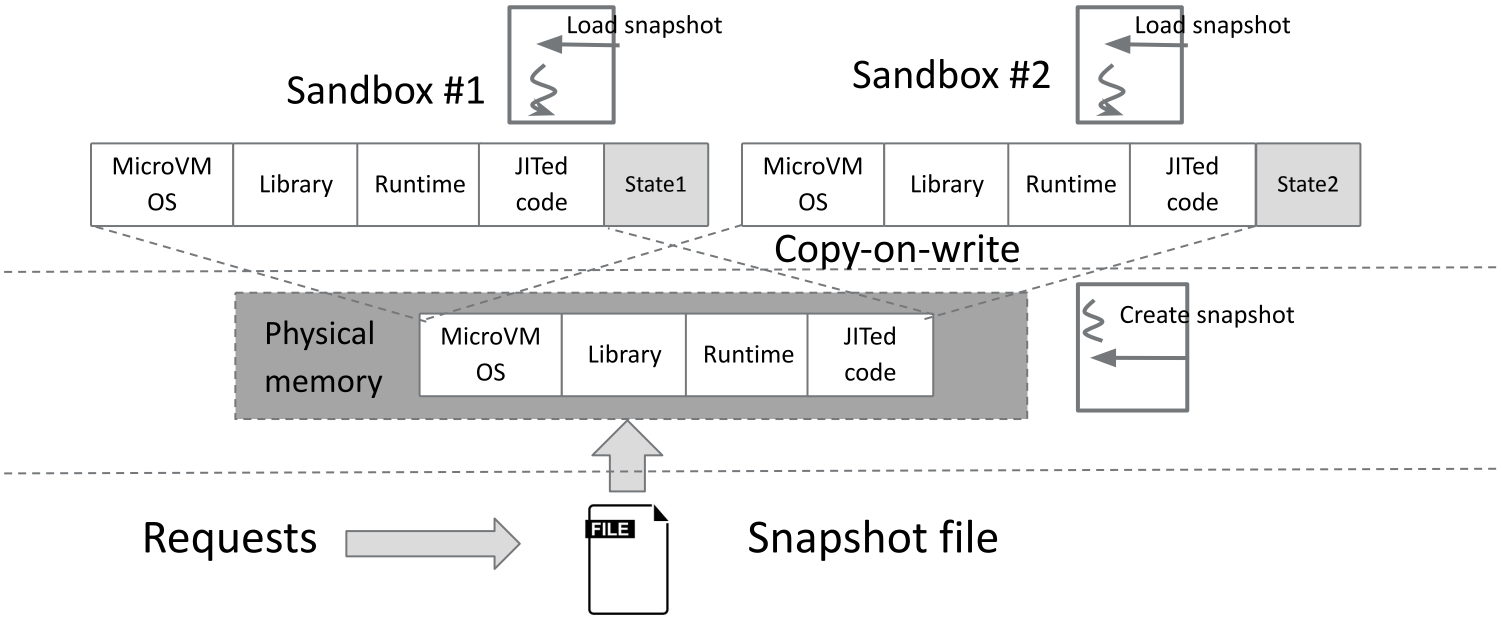
- **Only a function knows** that the code is optimized and ready to run, rather than the environment that manages it



How we can reduce memory footprint?

Redefine Running a function as loading a memory snapshot file

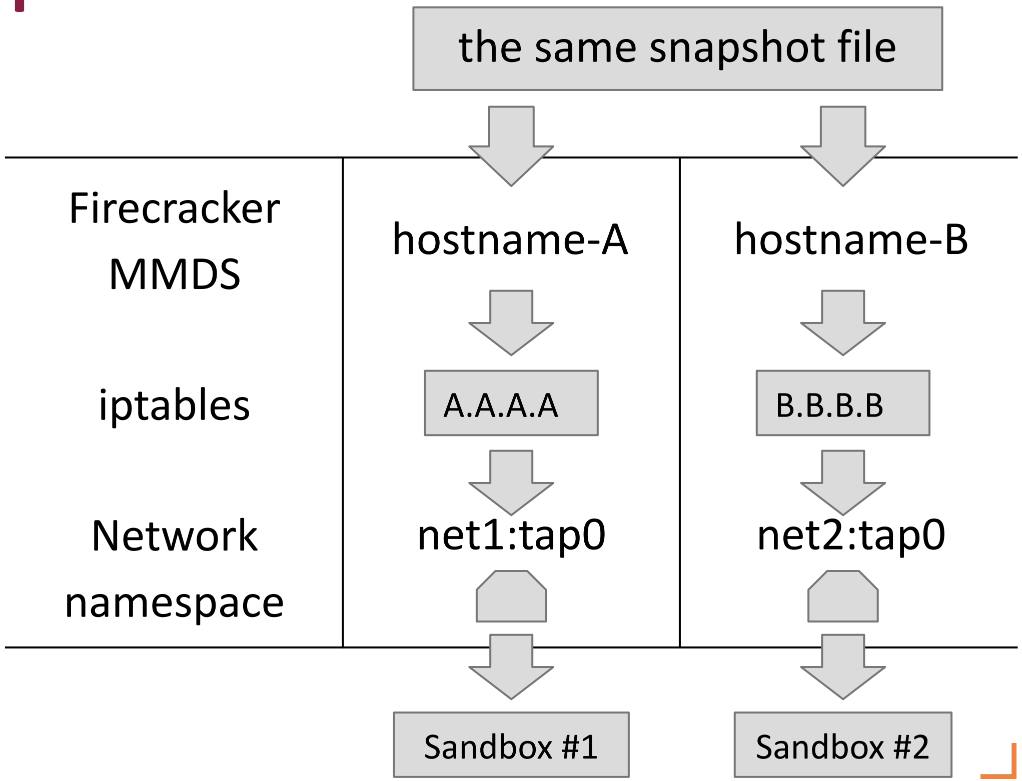
- Sandbox #1 runs by loading the memory snapshot file
- Sandbox #2 can share the memory in a copy-on-write manner



How to solve the problem of duplication IP and MAC using the same snapshot?

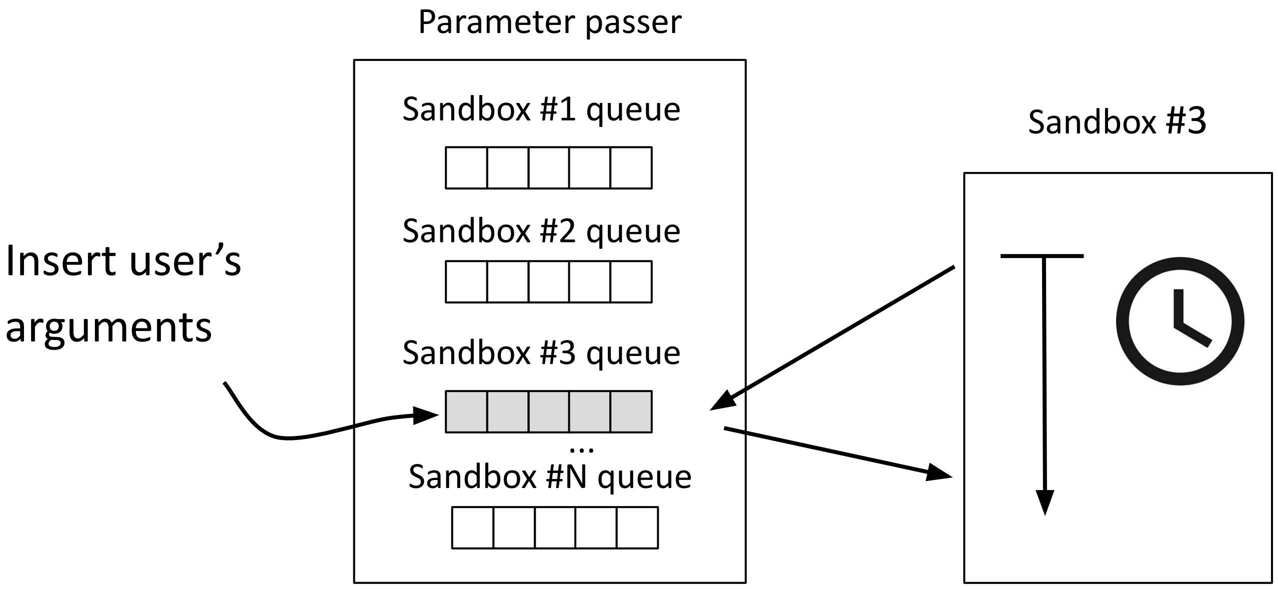
Take advantage of MMDS, iptables NAT and network namespace

- **MicroVM metadata service (MMDS)** inserts unique information of the microVM
- **iptables NAT** map the same ip to different exposed IP
- conflict for the same device.
  ⇒ own **network namespace.**

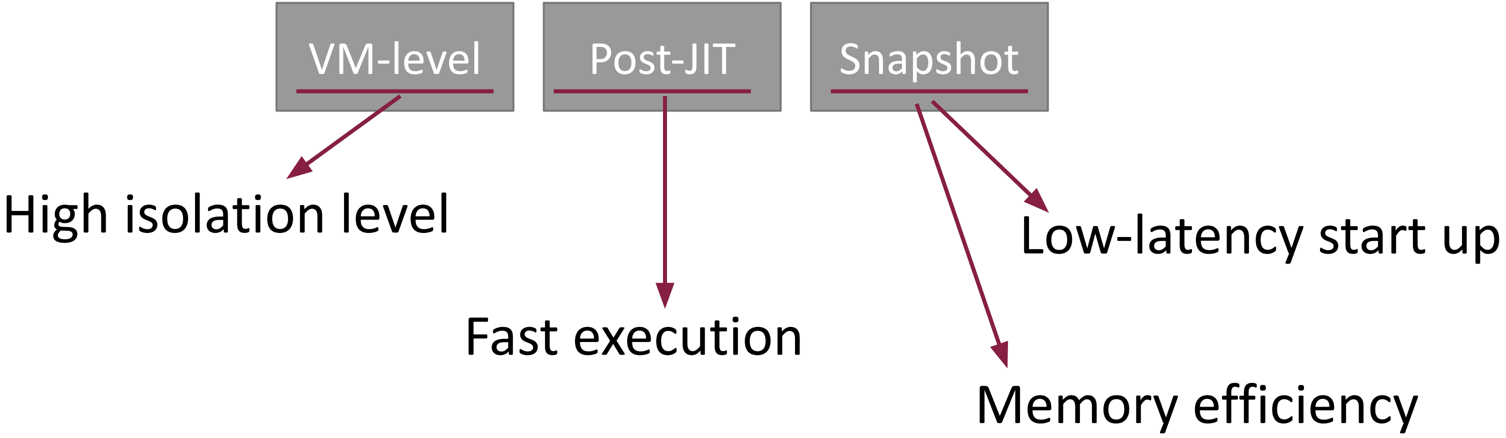


How can we pass multiple users' arguments to the same running state of a memory snapshot?

Create a repository that can be delivered between users and functions in the sandbox, and add logic to check it



FIREWORKS



Code annotation

Argument passing

Request snapshot from a function

Multiple sandboxes from one memory snapshot

Implementation & Evaluation Methodology

Implementation

- Firecracker v0.24.0
- 3,000 lines of Bash code for microVM manager, Invoker, Code annotator
- 500 lines of Node.js, Python for Snapshotter, Parameter passer
- 40 lines of C++ for Node.js V8 Source
- 17,480 lines of Node.js, Python borrowed code with modification from FaasDom and SeverlessBench Benchmark

Evaluation Methodology

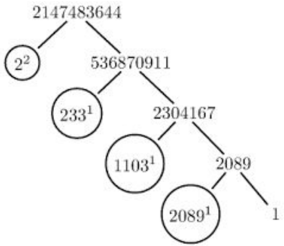
- **FaaSdom Benchmark**[*1] represents basic performance in serverless
- **ServerlessBench**[*2] measures the real-world serverless application performance

***1** [DEBS20] Faasdom: a benchmark suite for serverless computing
***2** [SoCC20] Characterizing serverless platforms with serverlessbench.

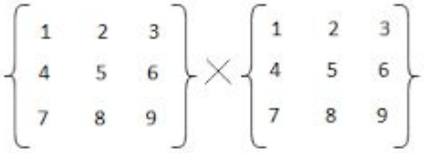
Evaluation

- How much can FIREWORKS reduce **start-up time and function execution time** of various serverless applications?
- How effective are FIREWORKS's **design choices (VM-level snapshot, post-JIT snapshot)** in improving performance and saving memory usage?
- How much memory can Fireworks save by **sharing memory snapshots** across sandboxes?

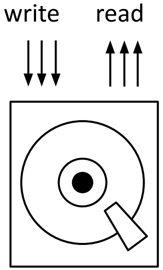
Microbenchmark : Python



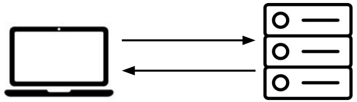
faas-fact



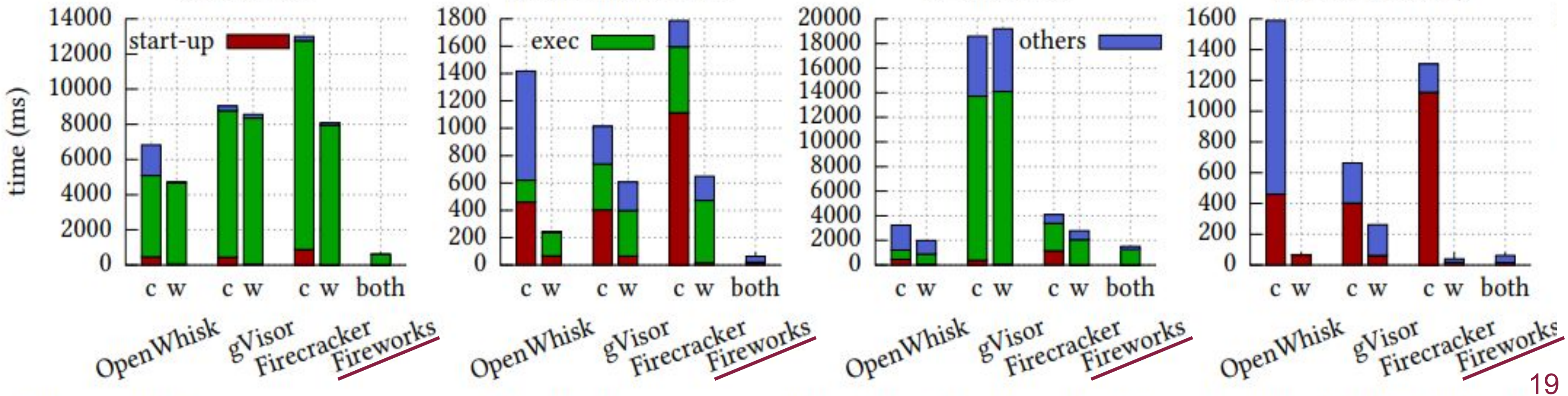
faas-matrix-mult



faas-diskio

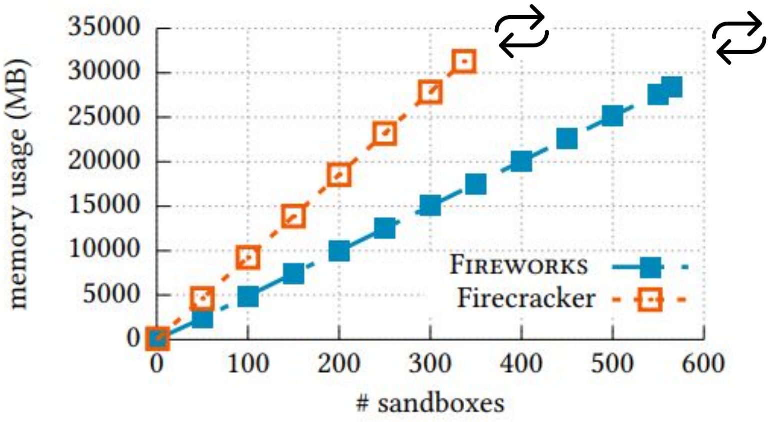


faas-netlatency



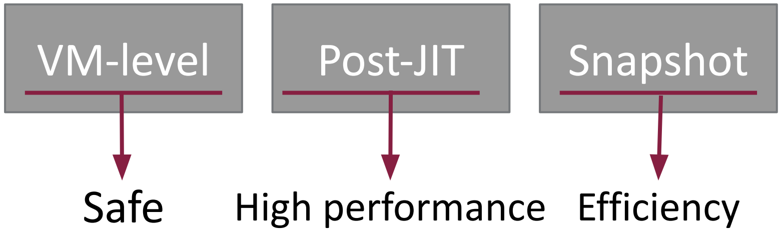
Memory Usage

- FIREWORKS can make **565 sandboxes**, and Firecracker can make **337 sandboxes** without the swap memory
- It allows FIREWORKS to consolidate **167%** more sandbox than Firecracker



Conclusion

- Seeking a **safe, efficient, high performance** serverless framework continues.
- **FIREWORKS** can get **all three:**



- We **designed**, **implemented**, and **evaluated new serverless framework** by using VM-level snapshots and JIT-based snapshots
  - 20 time shorter (cold) startup time, 7 times lower memory footprint
  - The achievements give a ***guidance*** to utilize **JIT** and **Snapshot** in the serverless computing.