Serverless Functions Made Confidential and Efficient with Split Containers

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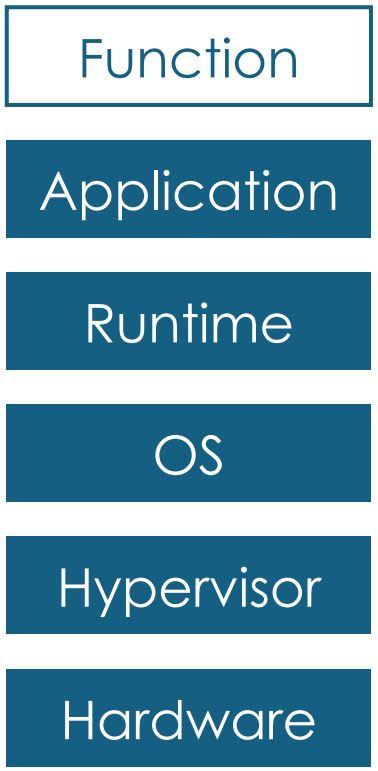
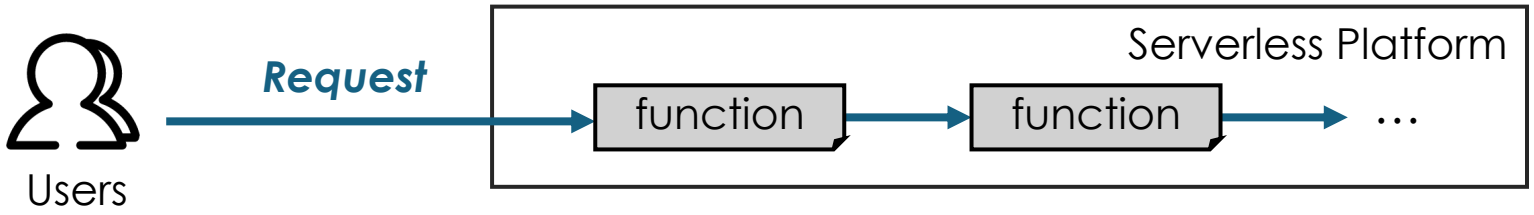
Serverless Requires Security

Function-as-a-Service





Simple DevOps *Auto-scaling* *Pay-as-you-go*

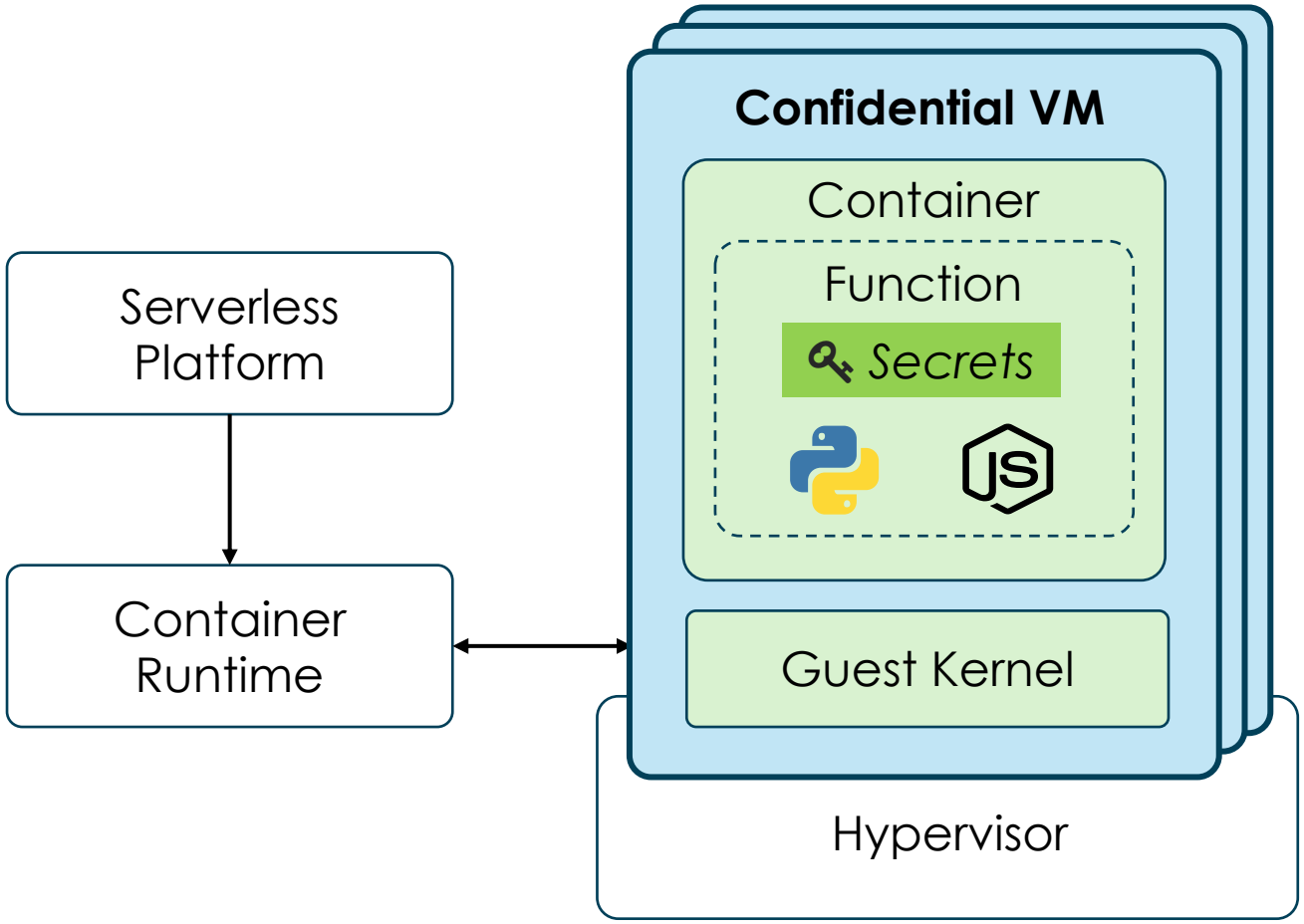
Serverless has been adopted in security-critical scenarios


Facial recognition


Healthcare


Finance

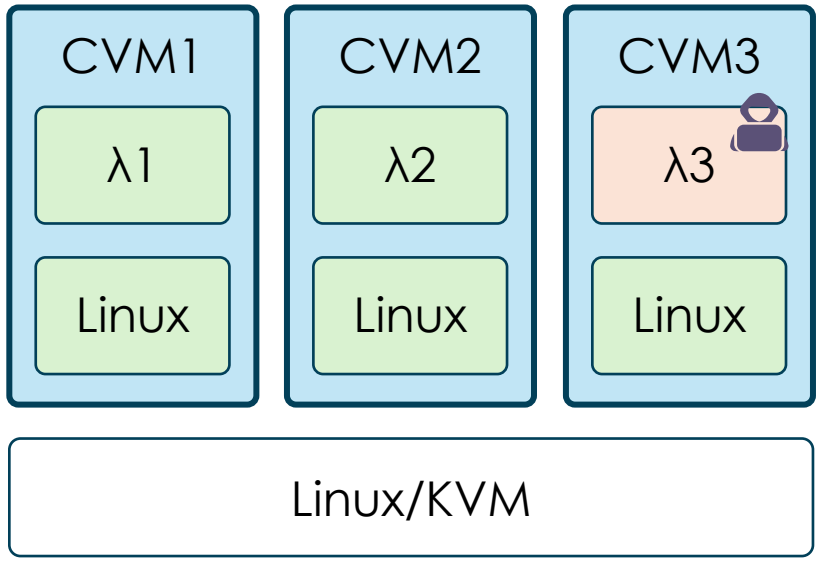
Confidential Containers



- Functions run in containers
- **TCB of containers is huge**
  - Compromised host OS
  - Compromised hypervisor
  - Compromised cloud stack
  - Malicious cloud insiders
- **Run containers in CVMs**
  - CVM protects a whole VM from external attacks

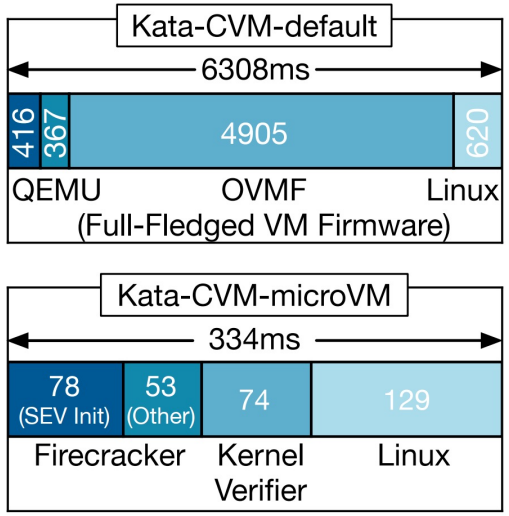
Mismatch: CVM and Serverless

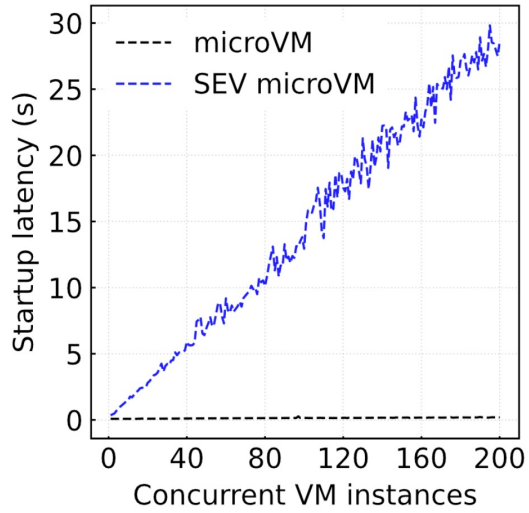
Design choice 1 (Kata-Containers)
Per-Container-CVM



Strong inter-function isolation

Cold start: Large startup latency (CVM init + attest)





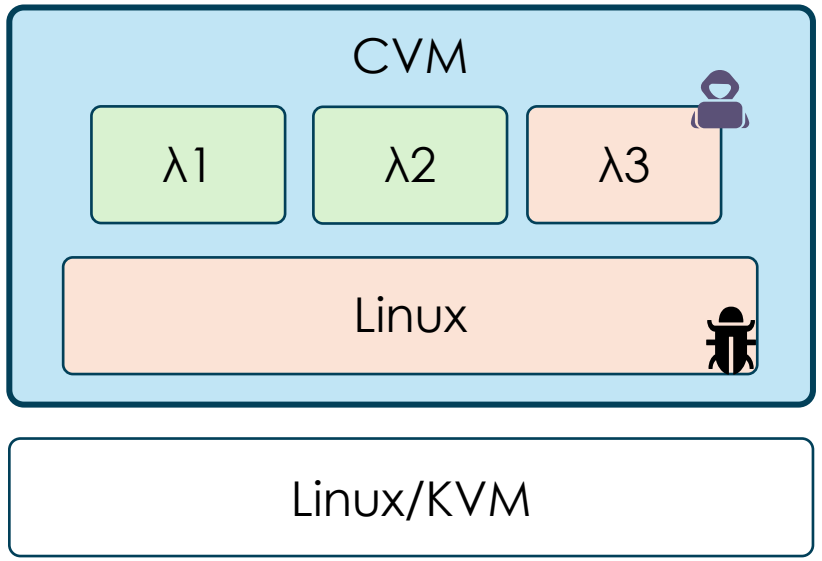
Single microVM: 334ms 200 concurrency: 28.5s

Warm start: Large memory consumption

Caching 500 CVMs: 42.5GB
(No cross-CVM memory-sharing)

Mismatch: CVM and Serverless

Design choice 2
Single-CVM-Multiple-Containers



Eliminate CVM cold start overhead
Enable cross-function memory-sharing

Weak inter-function isolation

Large TCB: CVM guest Linux kernel

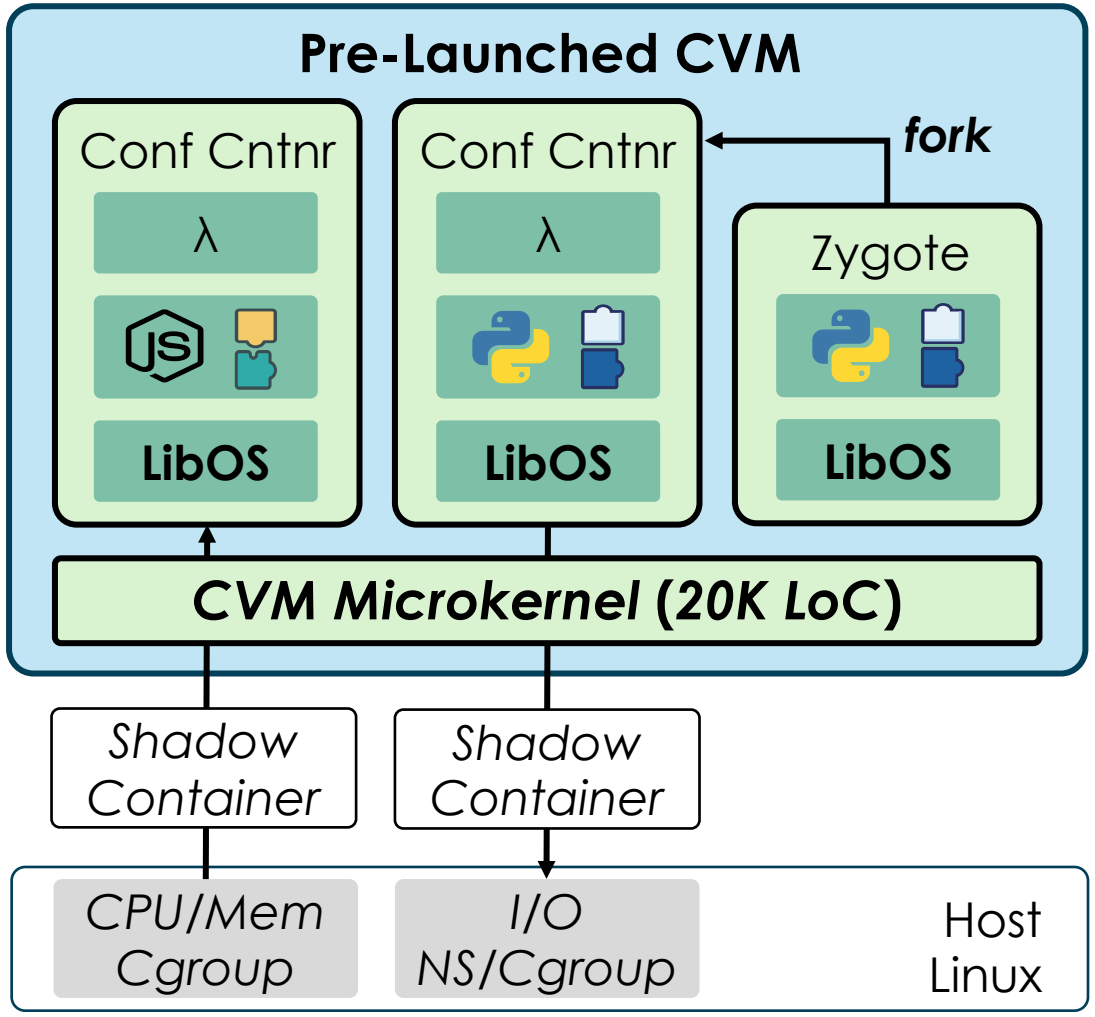
Serverless functions do not require a full-fledged Linux kernel

Single-Process Data-Plane Stateless

System calls used by 150+ functions

Syscall	Number	Syscall	Number
FS	26	Event	4
Network	12	Misc	5
Memory	6	Dummy	15
Sync	3		
Thread	3	Total	**74**

Split Container Architecture



Performance: multiple containers in one CVM

Security: isolated with a ***microkernel***

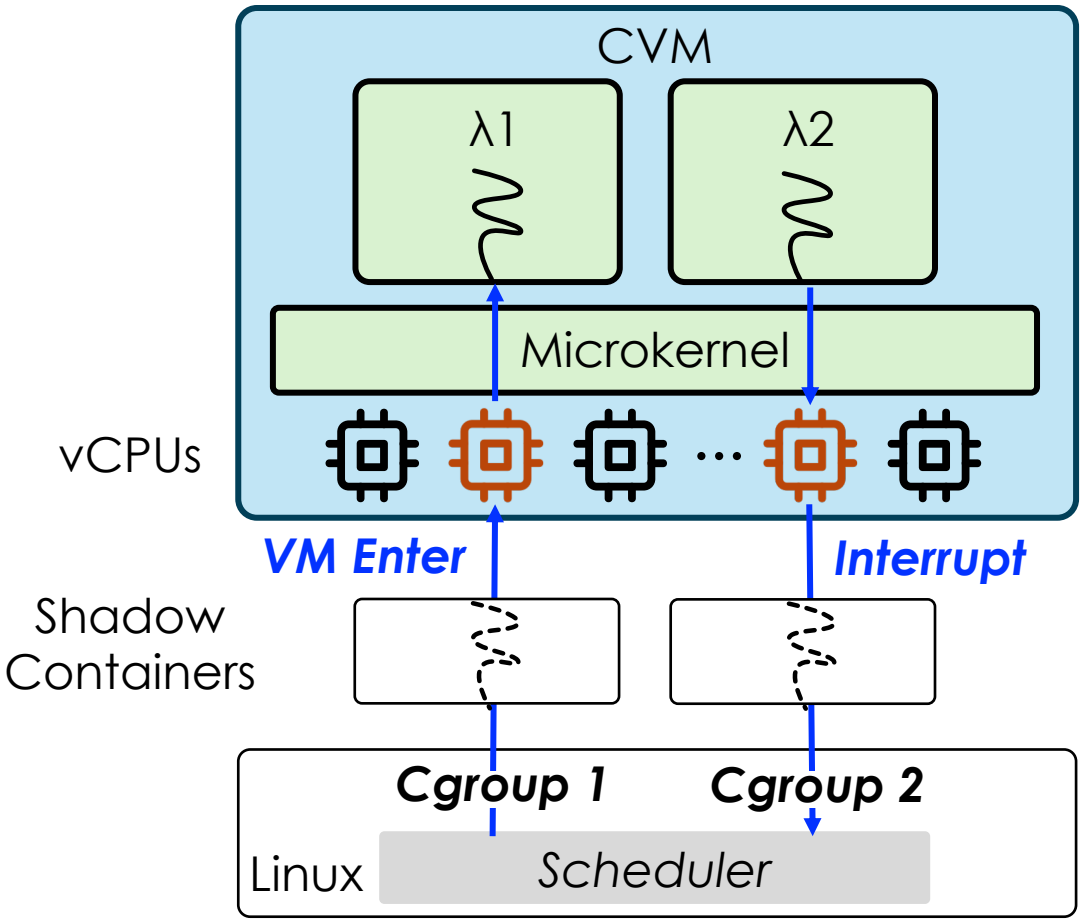
Decouple security from management

- Reuse host cgroups and namespaces
  - Shadow container: ***resource granting*** and ***I/O delegation***
  - Confidential container: secure execution context

- Microkernel + libOS in the CVM

Fast container startup
copy-on-write fork and ***split-attestation***

CPU Resource Granting



One-to-one thread mapping

Shadow Thread – vCPU – Confidential Thread

Cgroup Accounting

Host Scheduler

Allocate a time slice to a shadow thread

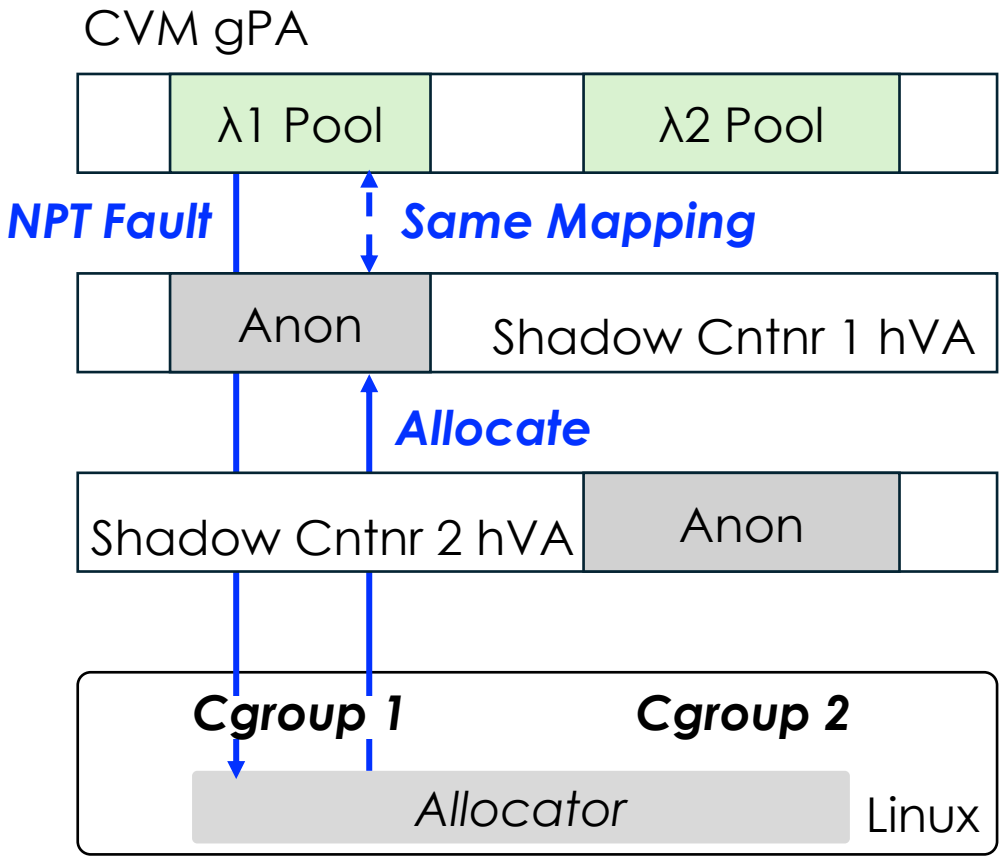
Shadow thread

Activate the confidential thread with VM enter

Confidential thread

Run with the allocated time slice (until interrupted)

Memory Resource Granting



Per-container gPA pool

Same PA mapping: gPA Pool – shadow hVA Pool

Guest Allocator

Conf. cntnr. pgfault → Allocate from gPA pool

gPA not mapped → pvalidate (NPT fault)

Host Allocator

Find gPA-to-hVA mapping

Allocate pages for the hVA

Map the same pages to the CVM NPT

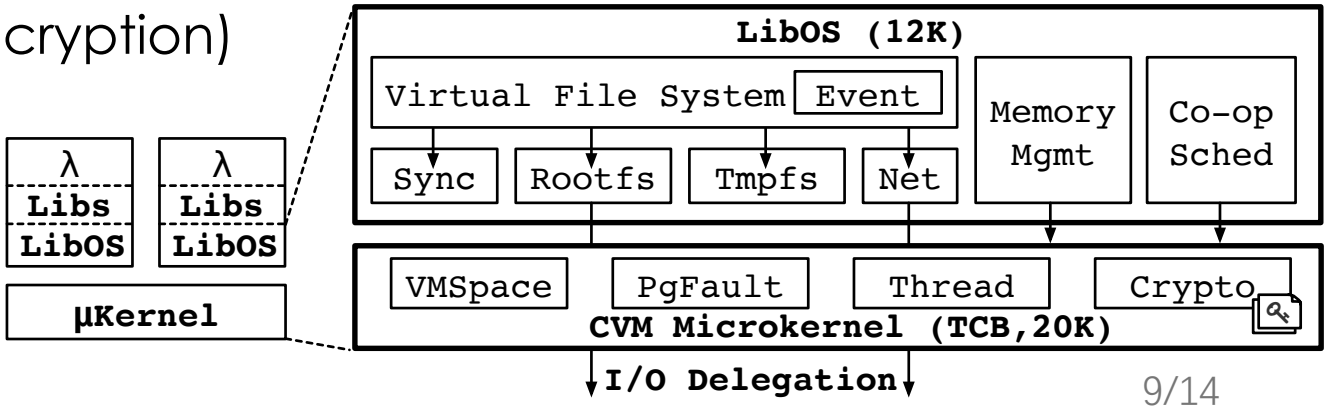
Cgroup Accounting

CVM OS Implementation

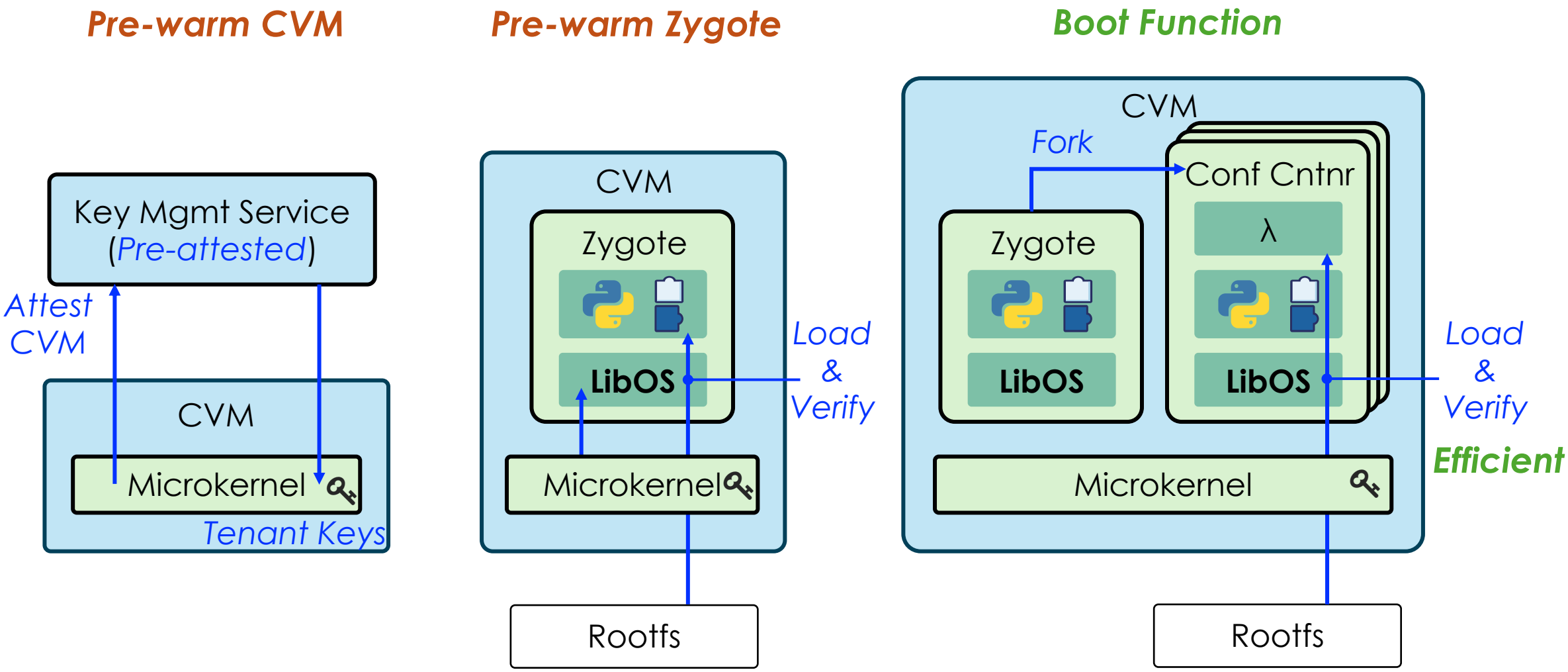
- **Microkernel**: Security-critical components
  - Page table update, crypto library (tenant keys)
- **libOS**: System call functionalities
  - Virtual memory management, VFS, tmpfs, sync. primitives, event, …
- **I/O delegation** with data protection
  - FS: rootfs read (w/ verification)
  - Network: socket syscalls (w/ encryption)

Microkernel (Isolation TCB)
20K Lines-of-Code

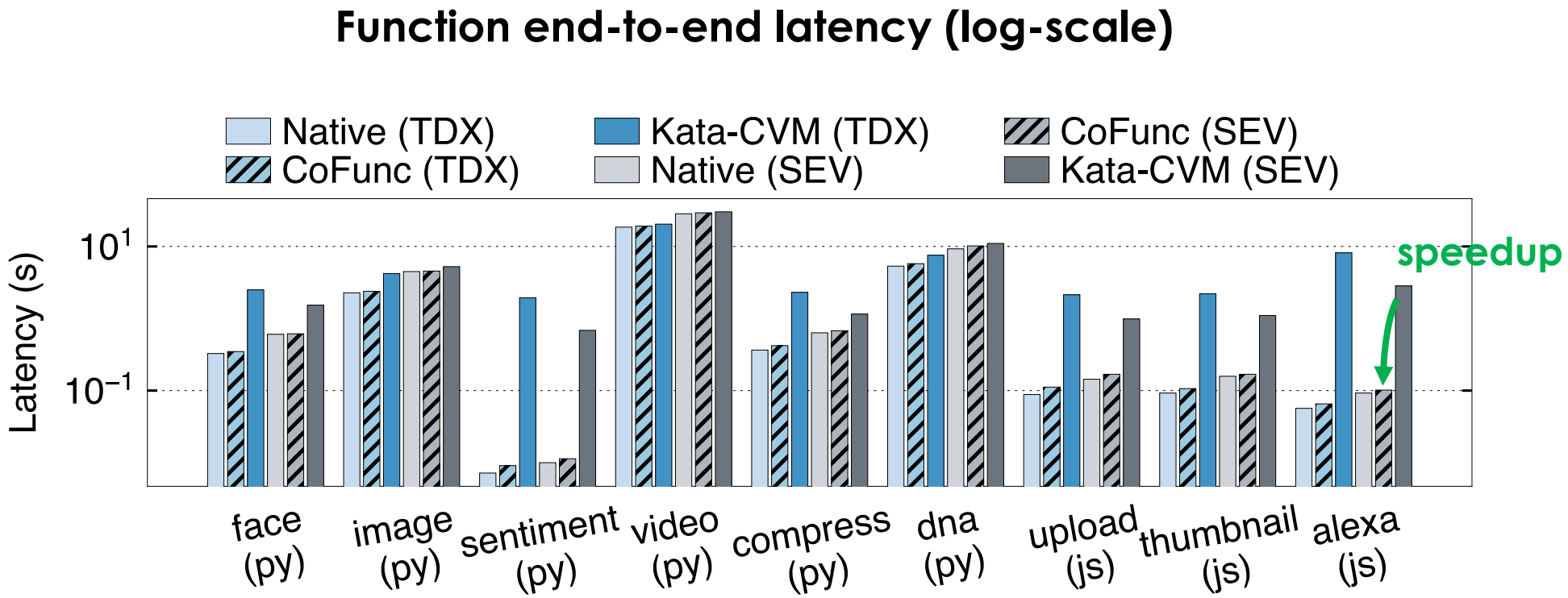
Implemented based on ***ChCore***



Fast Function Boot



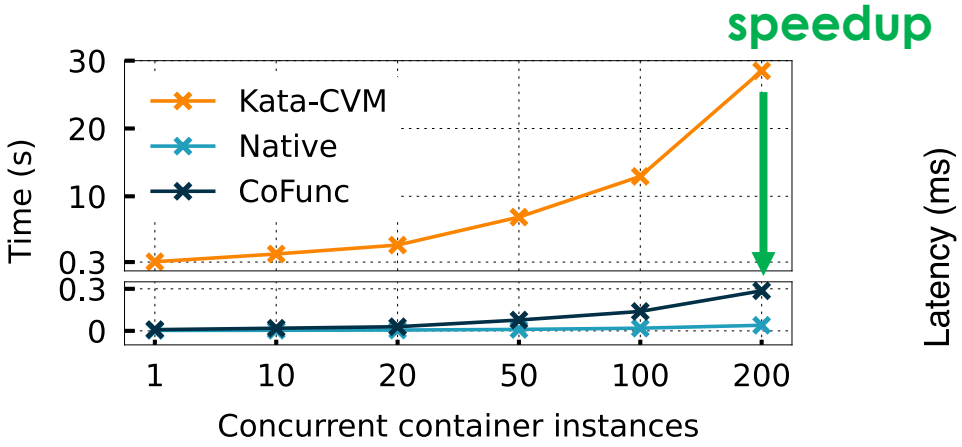
Evaluation: End-to-End Latency



Split-Container (CoFunc**)** v.s. **Per-Container-CVM (**Kata-Containers**)**:
TDX: **1.06×~215× speedup**; SEV (optimized Kata): **1.02×~60× speedup**

Evaluation: Startup Latency

Containerization

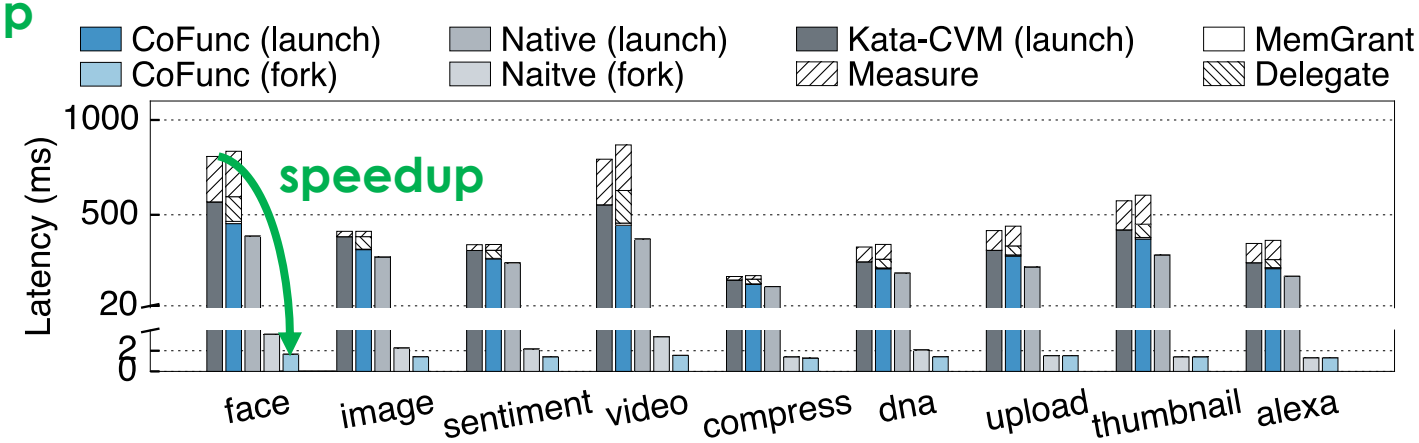


CoFunc v.s. **Kata-Containers**

Single: **120× (TDX), 22.3× (SEV) speedup**

200 concurrent: **100× (SEV) speedup**

Code Loading and Initialization



CoFunc v.s. **Kata-Containers**

148×~499× (TDX), 134×~513× (SEV) speedup

Evaluation

- **Overhead (v.s. native containers)**
  - End-to-end latency (single request): **<14%** on average
  - Startup stage: measurement of function-specific code
  - Execution stage: I/O delegation, encryption, memory granting
- **Reduce memory consumption (v.s. Kata-Containers)**
  - 200 containers w/ Python and libraries: **20×~56× reduction**
- **Function chain optimization (v.s. Kata-Containers)**
  - Communication: network + encryption → shared memory
  - FINRA application: **31× end-to-end latency reduction**

Summary

- **Serverless + CVM**: Enable fast boot of confidential containers while ensuring resource efficiency
- **Split Container**: Securely isolate multiple confidential containers in one CVM with a microkernel
  - Transparently pass through containerization offered by the host kernel into the CVM
  - A new non-Linux CVM OS (microkernel + libOS)