Everywhere All at Once: Co-Location Attacks on Public Cloud FaaS

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To appear at ASPLOS'24

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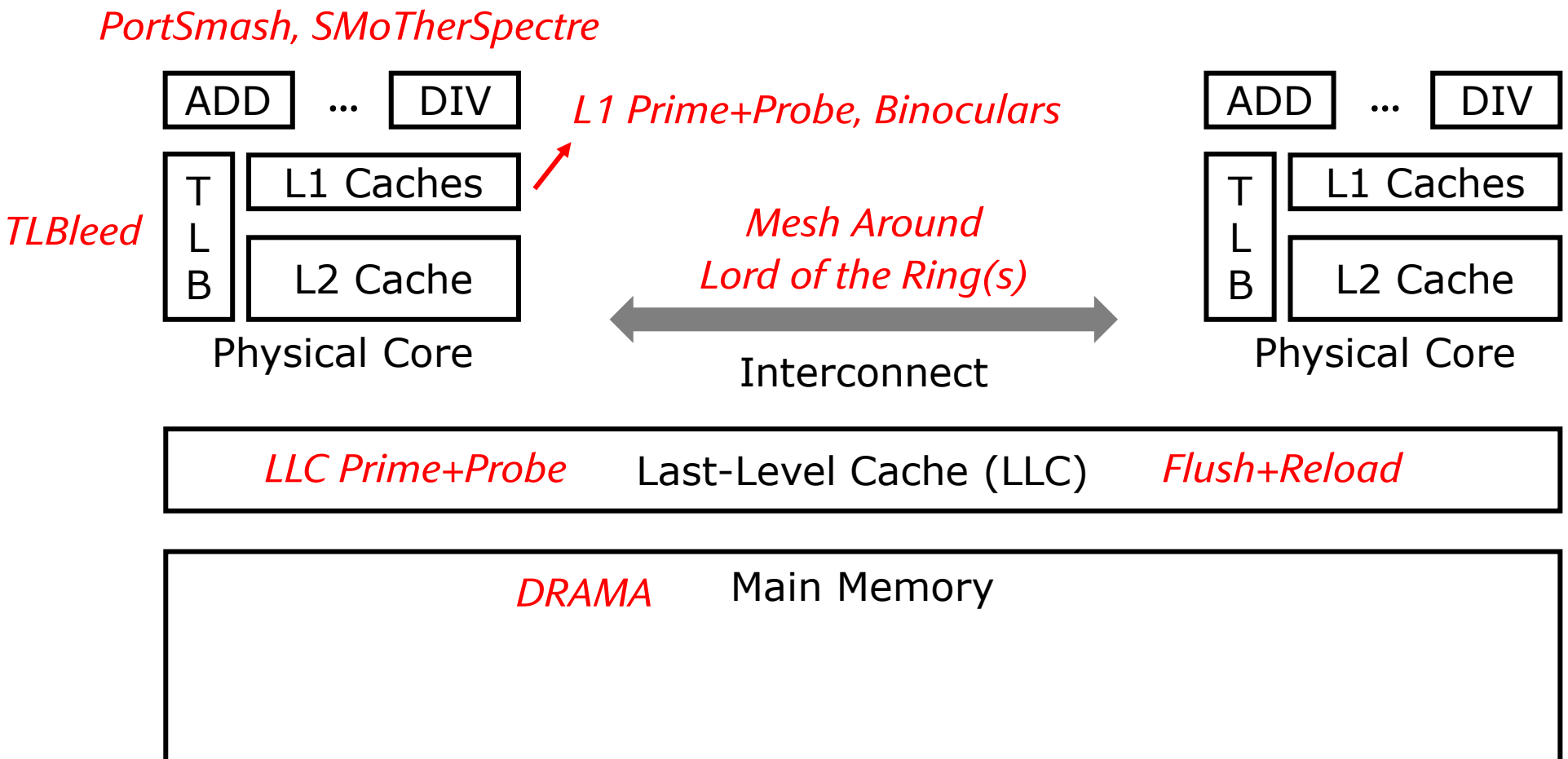
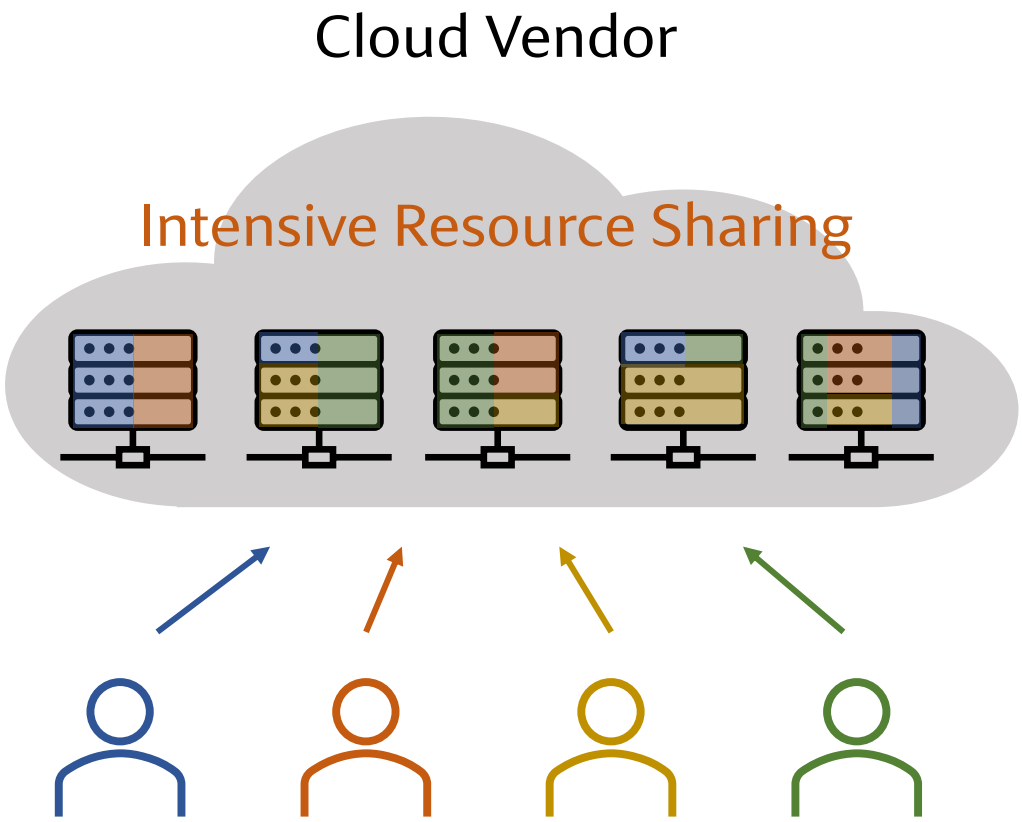
Ad *Will be on the job market this fall

Microarchitectural Side-Channel Attacks

Side channels exploit **shared resources** between attackers and victims

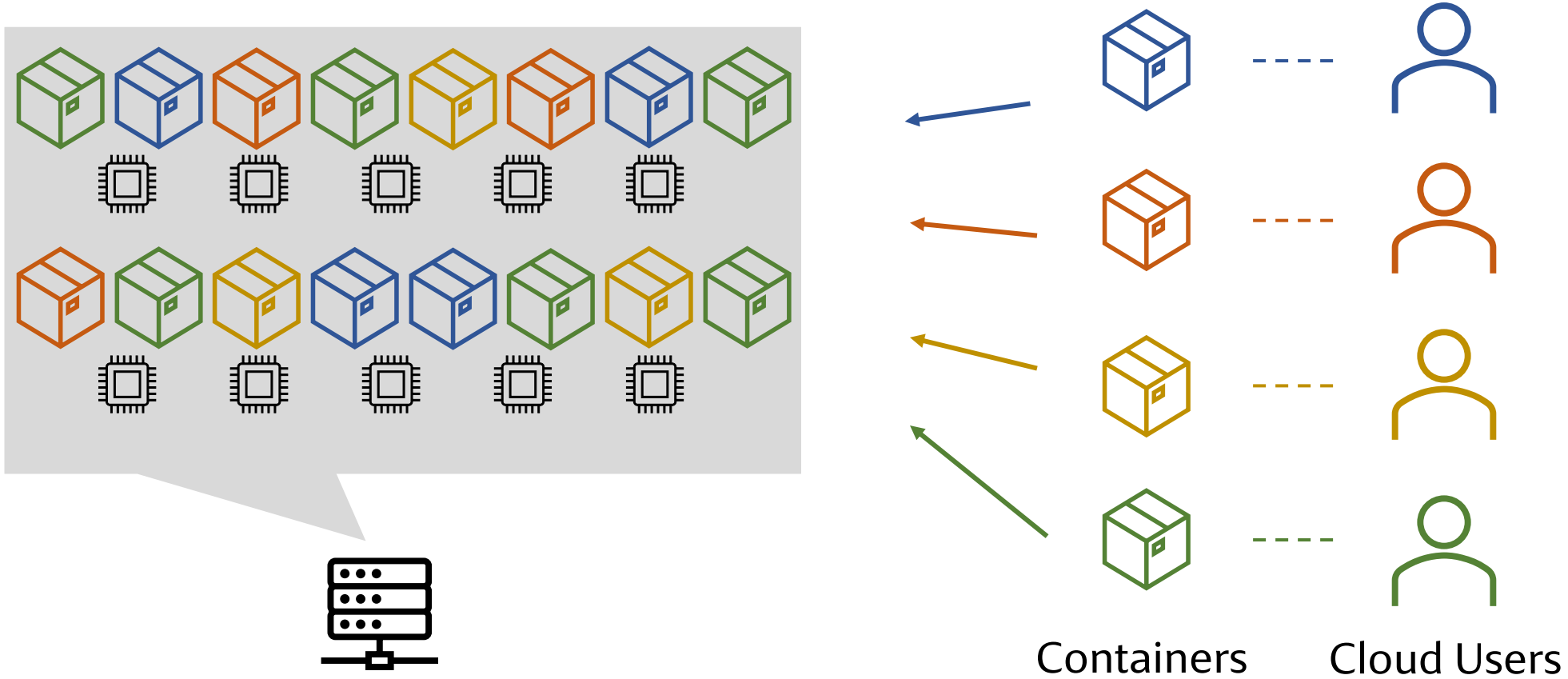


Cloud Computing: A Prime Target for Side Channels

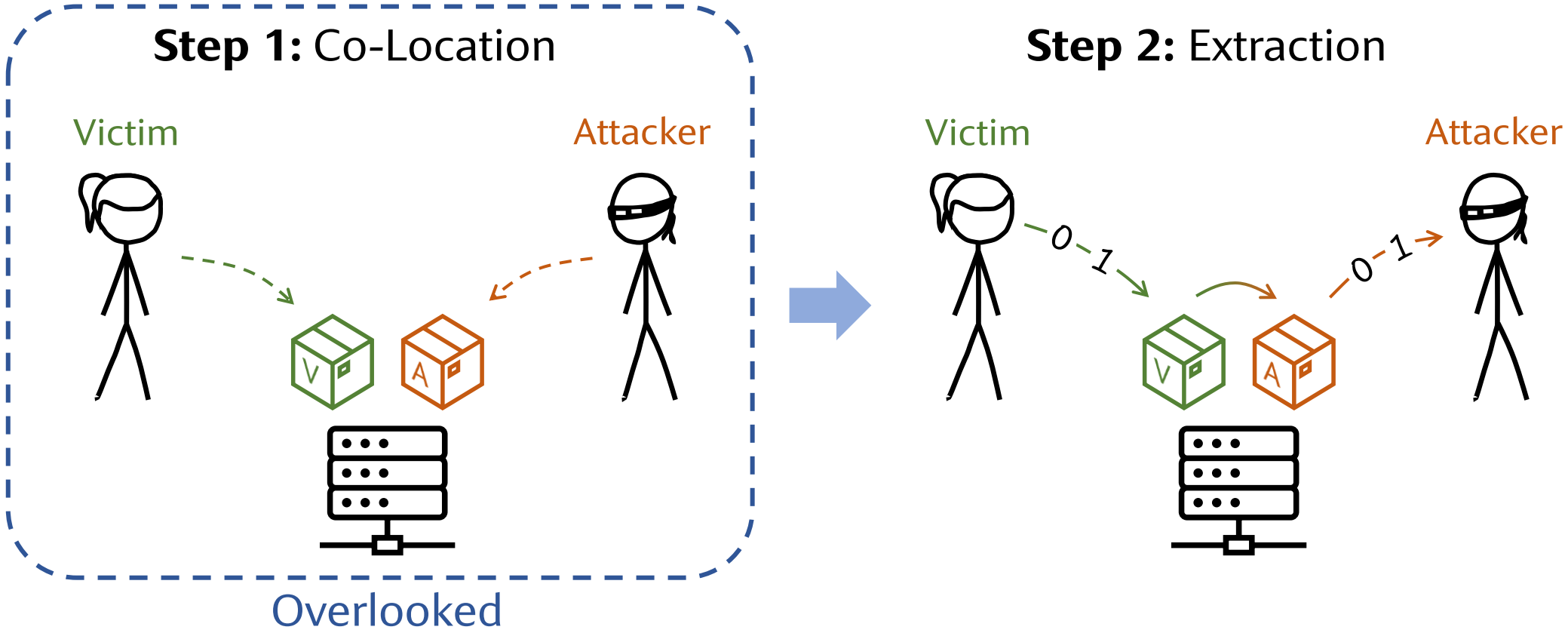


Emerging Cloud Computing Has Even More Sharing

Example: Function-as-a-Service (FaaS)



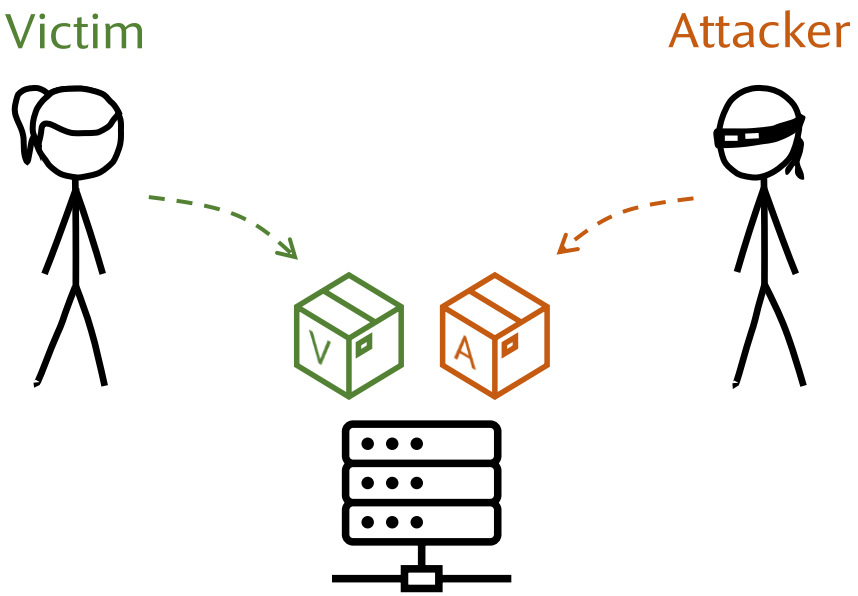
Steps of Side-Channel Attacks in the Wild



*Characters are based on https://xkcd.com/2176 and https://xkcd.com/1808/ (under a CC Attribution-NonCommercial 2.5 License)

Goal of This Work

Step 1: Co-Location

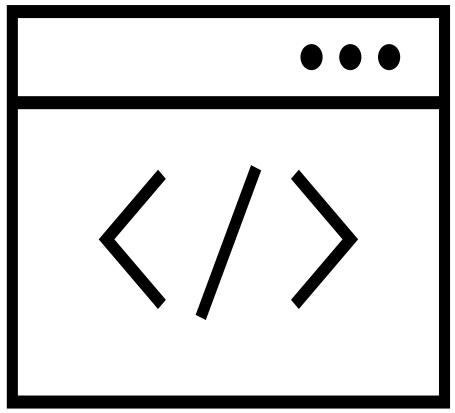


Goal: study how to achieve co-location in modern public clouds

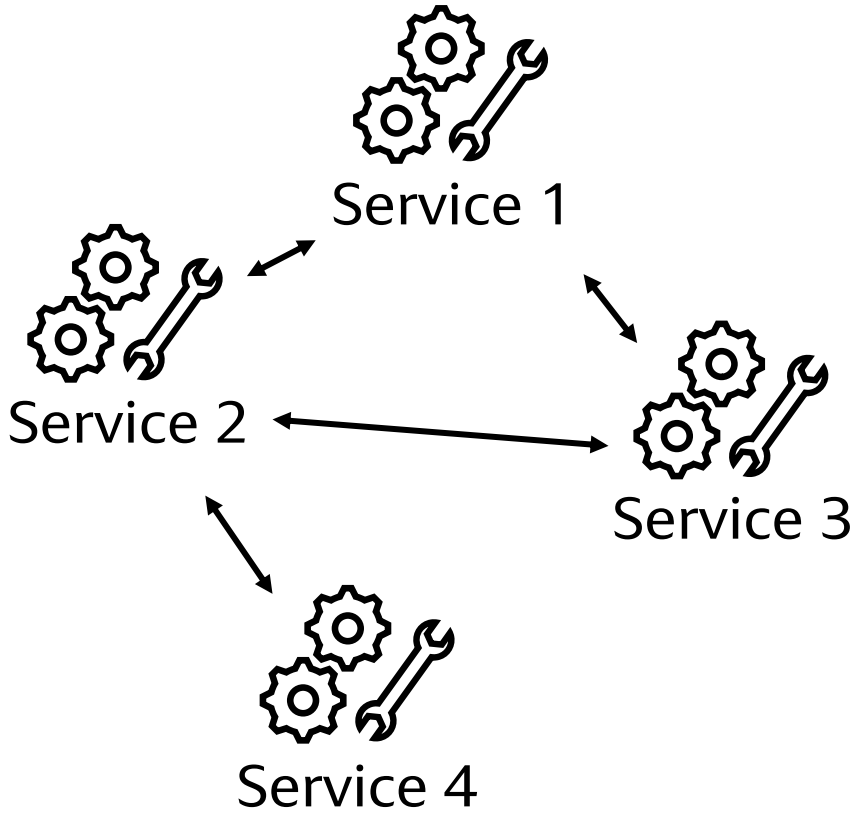
Target: Google Cloud Run

A production Function-as-a-Service platform from Google Cloud

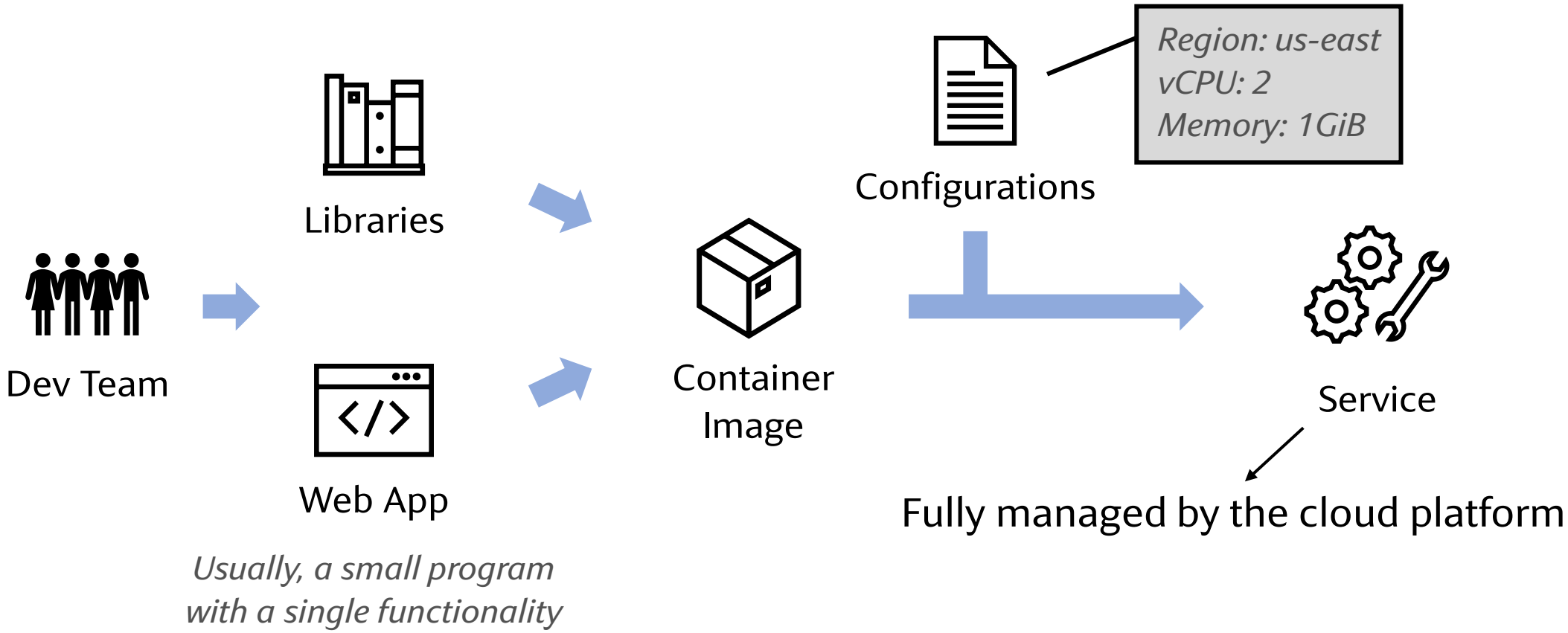
Background: Function-as-a-Service (FaaS)



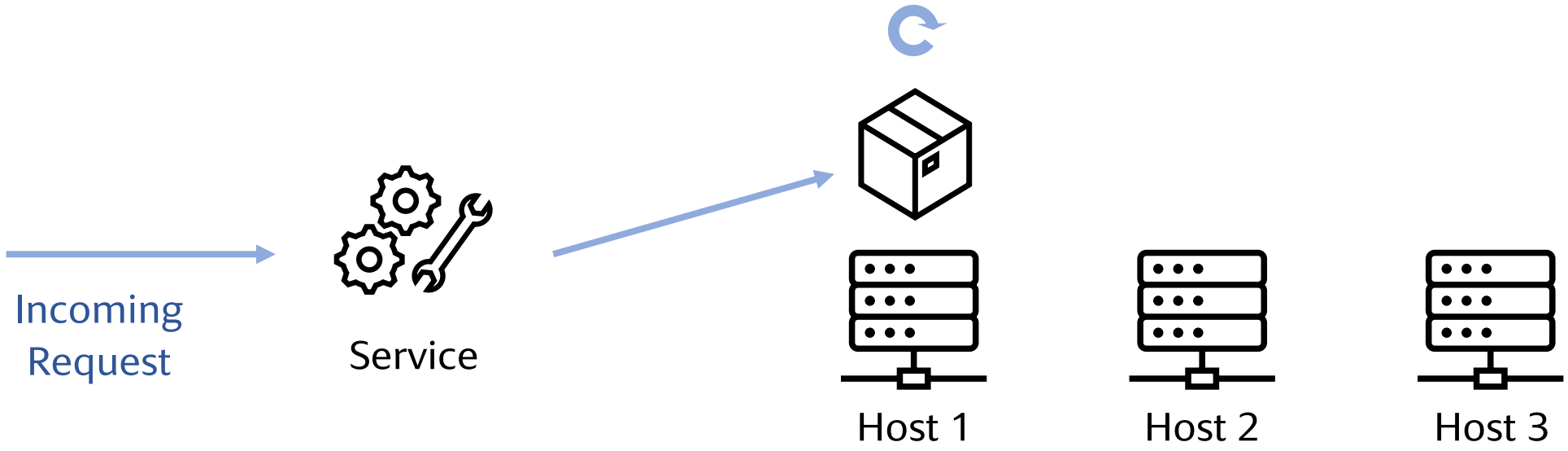
Monolithic App



Background: Function-as-a-Service (FaaS)

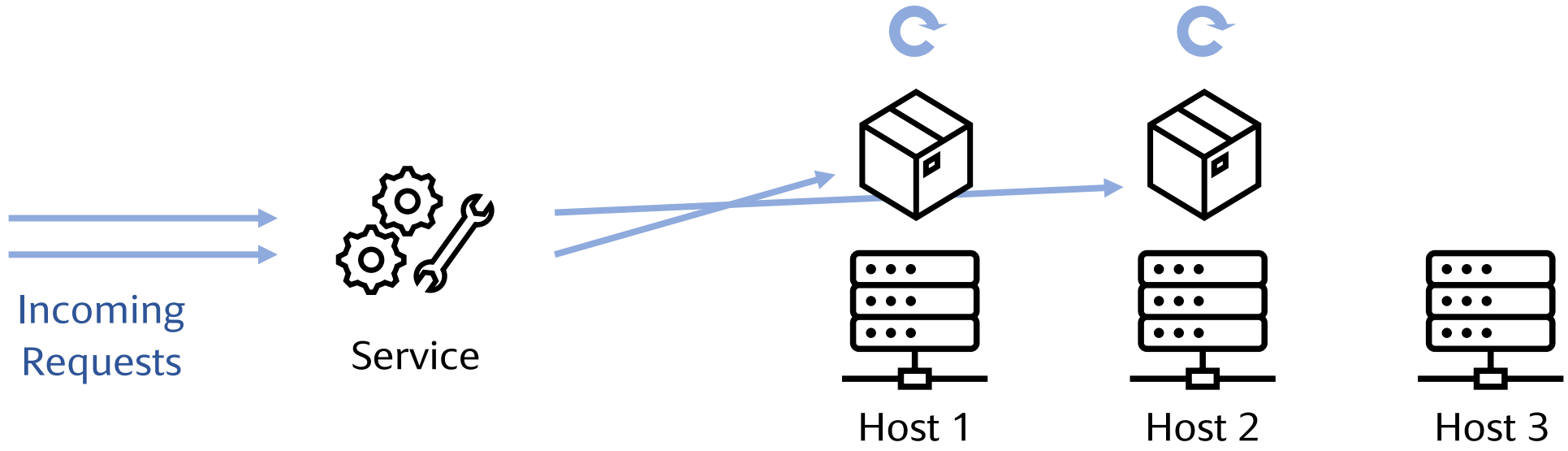


Background: Request Handling and Auto-Scaling



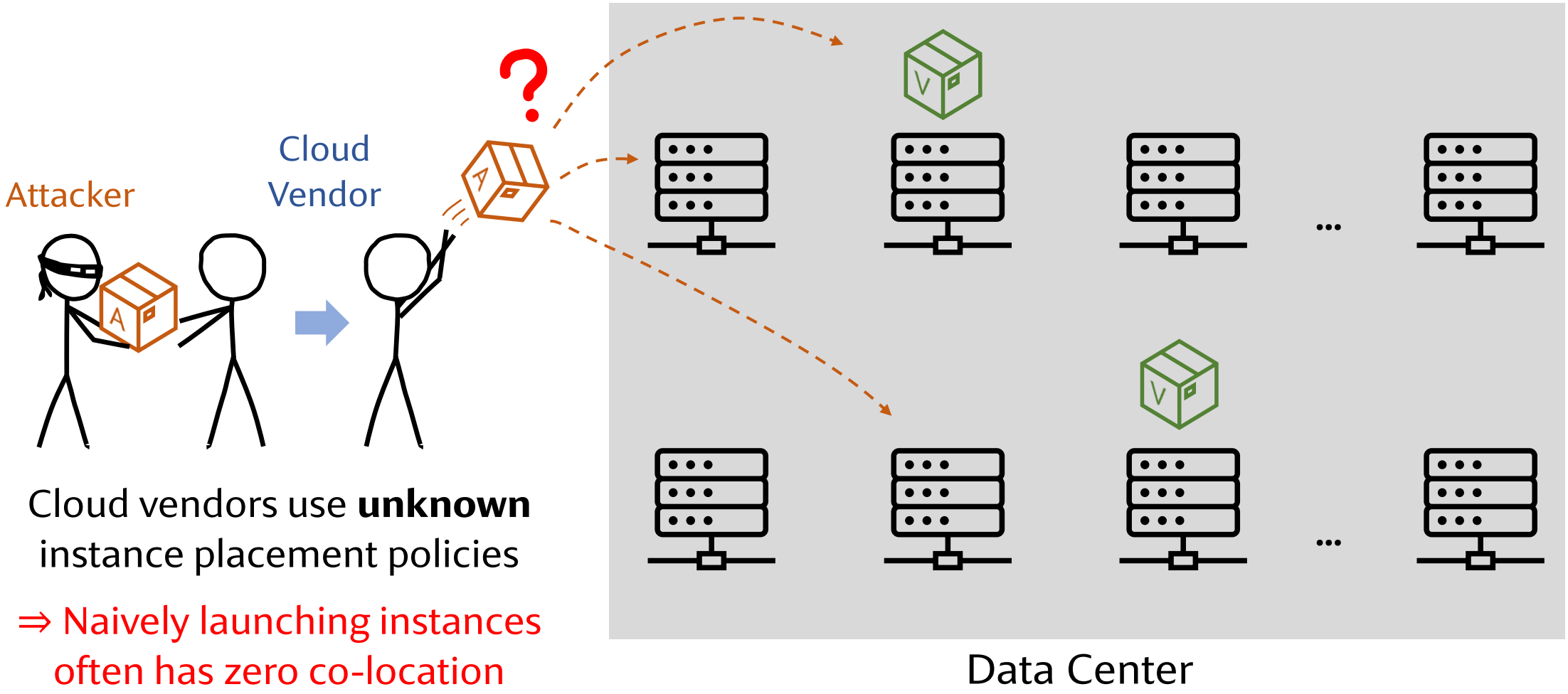
The instance launching process is fully managed by the cloud platform

Background: Request Handling and Auto-Scaling



Cloud platform launches more instances to handle traffic increases

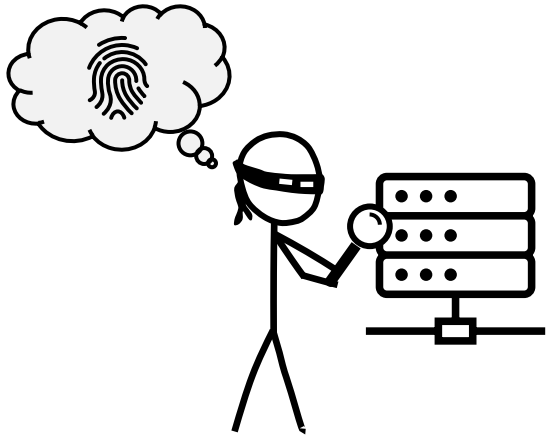
Fog of War: Container Instance Placement



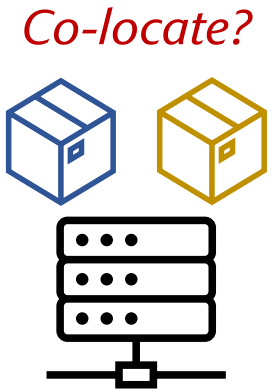
Cloud vendors use **unknown** instance placement policies

⇒ Naively launching instances often has zero co-location

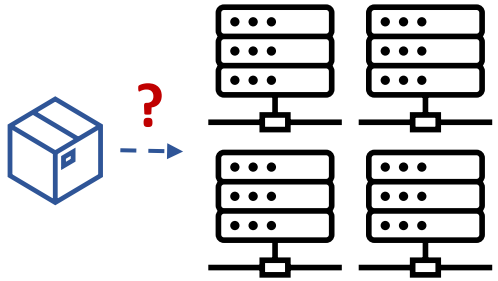
Main Contributions & Highlighted Results



1. Accurate
Host Fingerprinting



2. Inexpensive
Co-Location Test



3. Exploitable
Placement Behavior

100% probability of co-locating with at least one victim instance

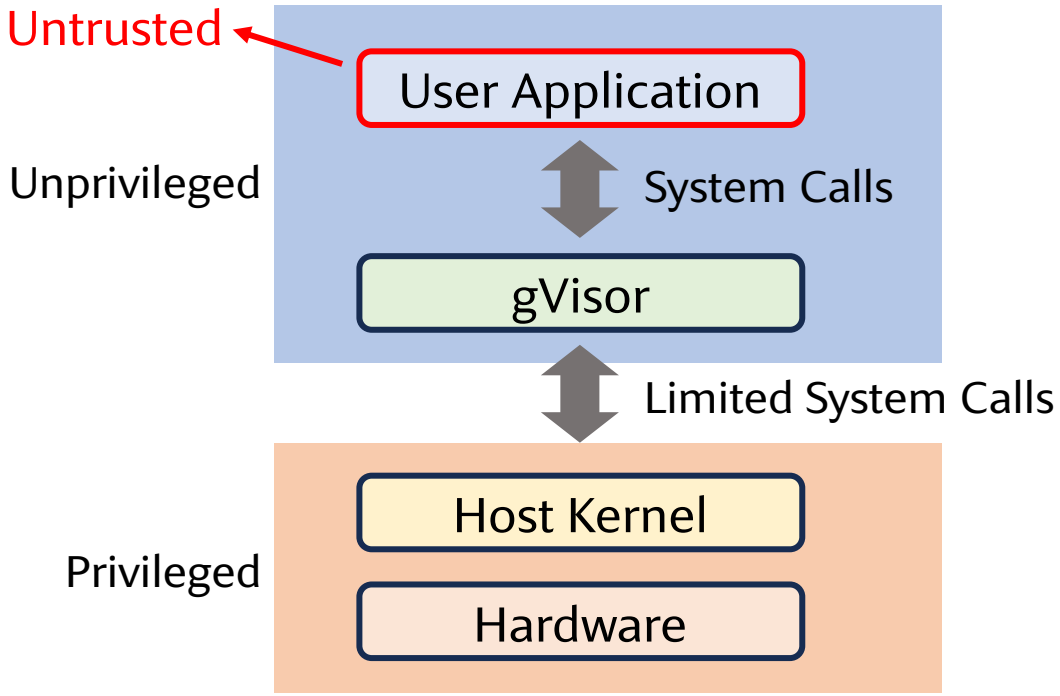
Co-locate with 61%-100% of victim instances in three major data centers

Threat Model

- An unprivileged attacker
- After co-location is achieved, the attacker can invoke the victim and exfiltrate information
- The attacker can execute arbitrary program inside the container

Securing the Cloud: Sandboxing Technologies

Linux Containers & gVisor

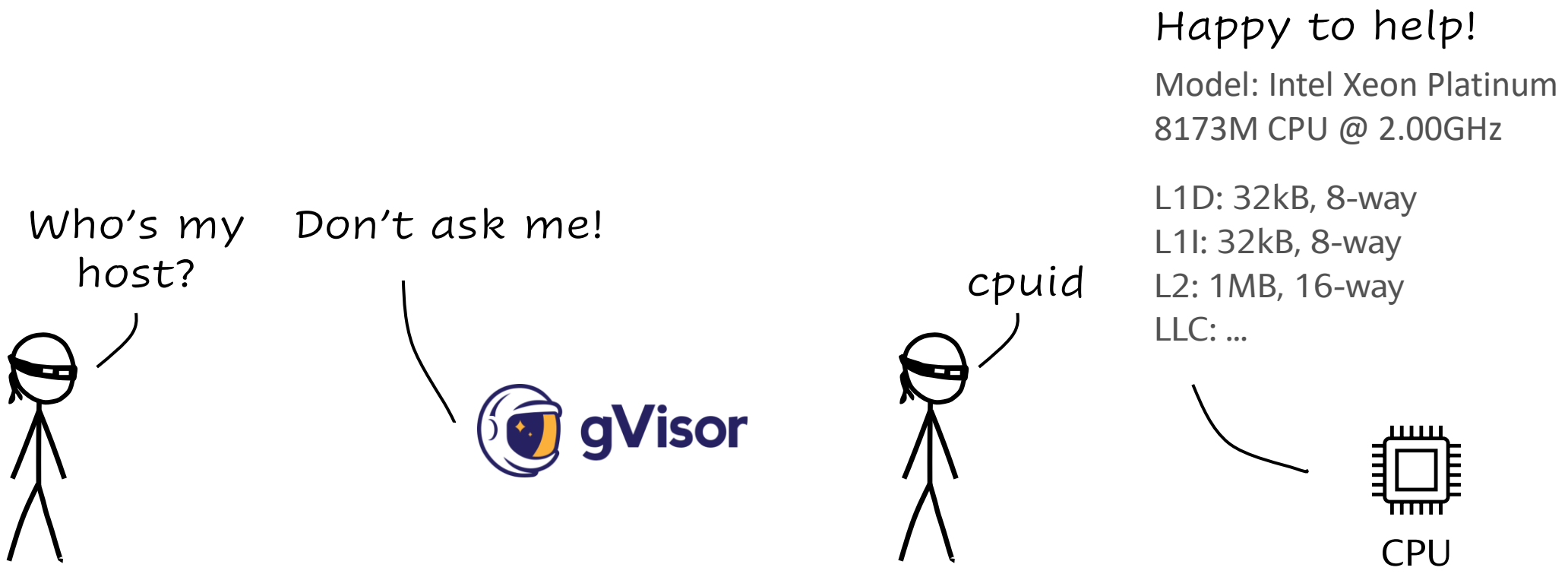


Non-virtualized, lightweight
Default environment for **web services**

gVisor Hides Sensitive Host Information

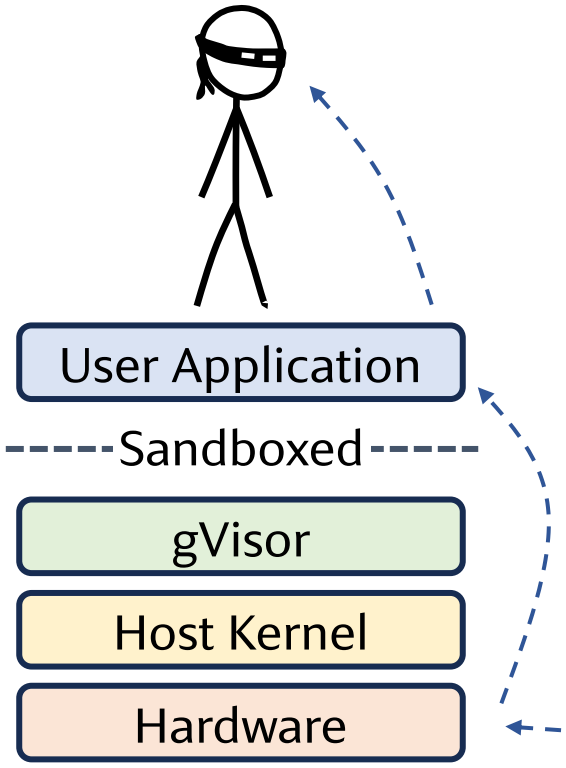
```
Attacker: CPU Model?
gVisor: unknown

Attacker: Boot log?
gVisor:
  Starting gVisor...
  Granting licence to kill(2)...
  Recruiting cron-ies...
  Creating process schedule...
  Checking naughty and nice process list...
  Gathering forks...
  Rewriting operating system in Javascript...
  Searching for needles in stacks...
  …
```

Physical Host Fingerprinting: Talk with the CPU



Insight: attacker can bypass software countermeasures by directly interacting with the shared underlying hardware

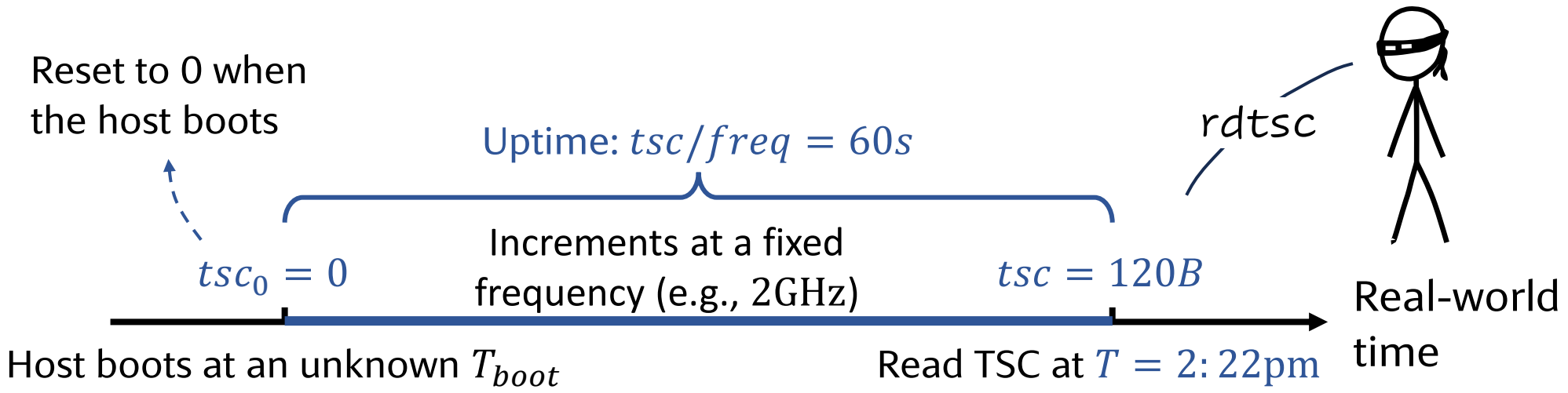
My Little Timestamp Counter (TSC)



The host's TSC is accessible through an unprivileged x86 instruction **`rdtsc`**

A high-resolution timer (frequency ~ a few GHz)

Deriving Host's Boot Time Using TSC

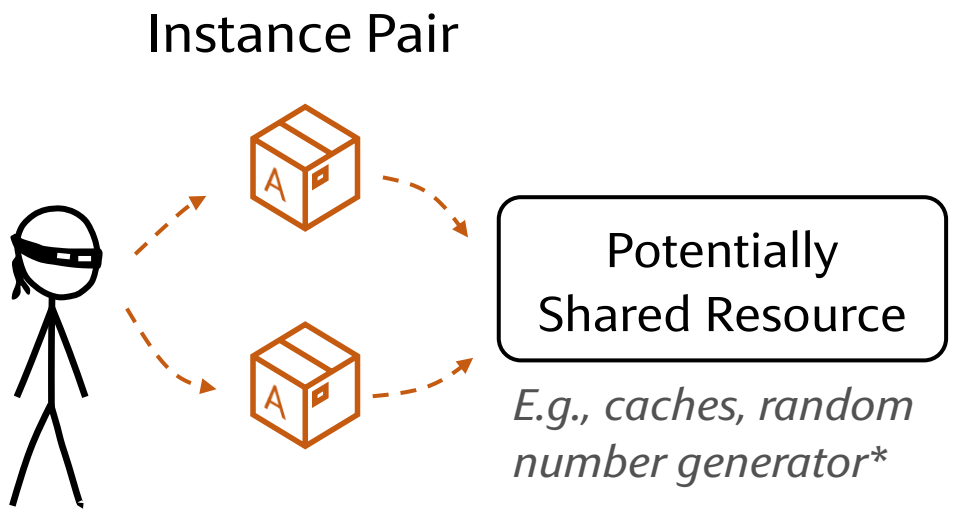


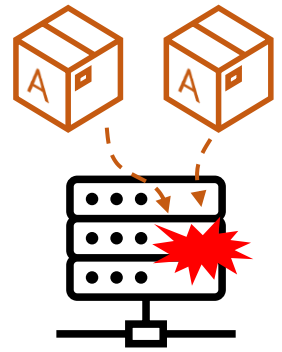
$$\Rightarrow T_{boot} = T - uptime = 2{:}21\text{pm}$$

Hypothesis: the boot time is likely unique for each physical host

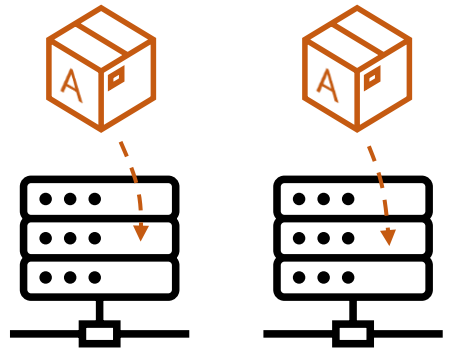
Host Fingerprint: $\mathbb{F} = T_{boot}$

Verifying Co-Location





Contention!
⇒ Co-Located

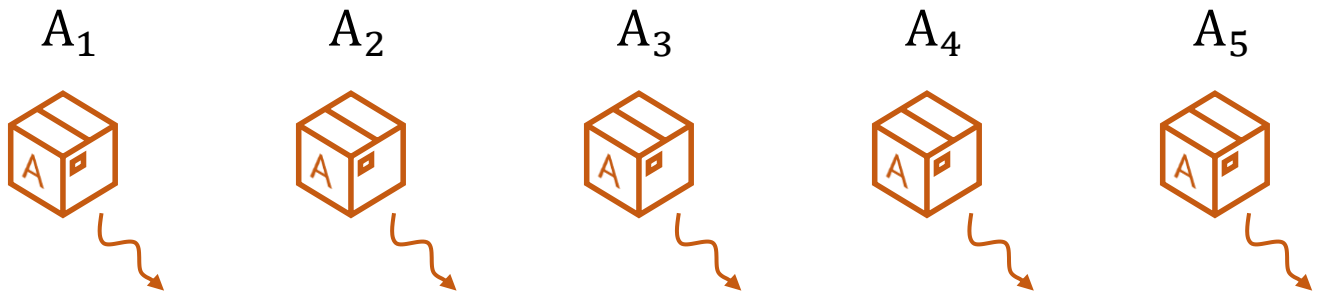


No Contention
⇒ Not Co-Located

Scalability Issue: it requires $O(N^2)$ pairwise tests to verify N containers

* Evtyushkin et al. Covert Channels through Random Number Generator: Mechanisms, Capacity Estimation and Mitigations

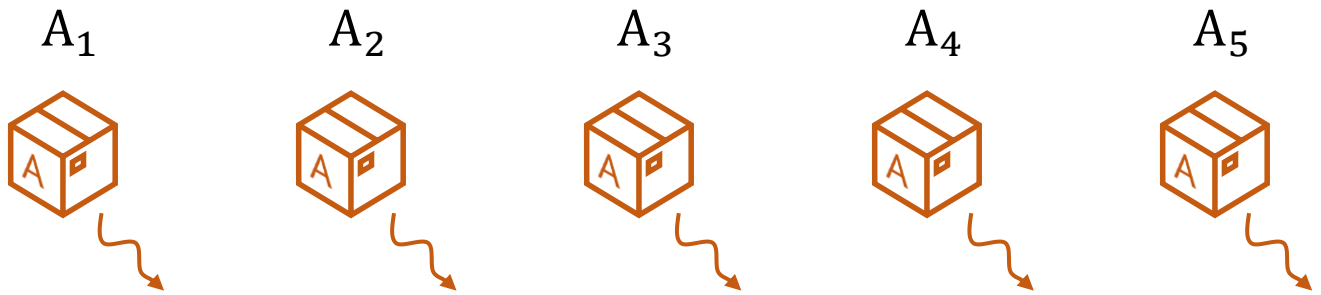
Go Beyond Pairwise Testing – Batch Testing



A_1, A_2, A_3 do not co-locate with any other instance
(i.e., they are *single instances*)

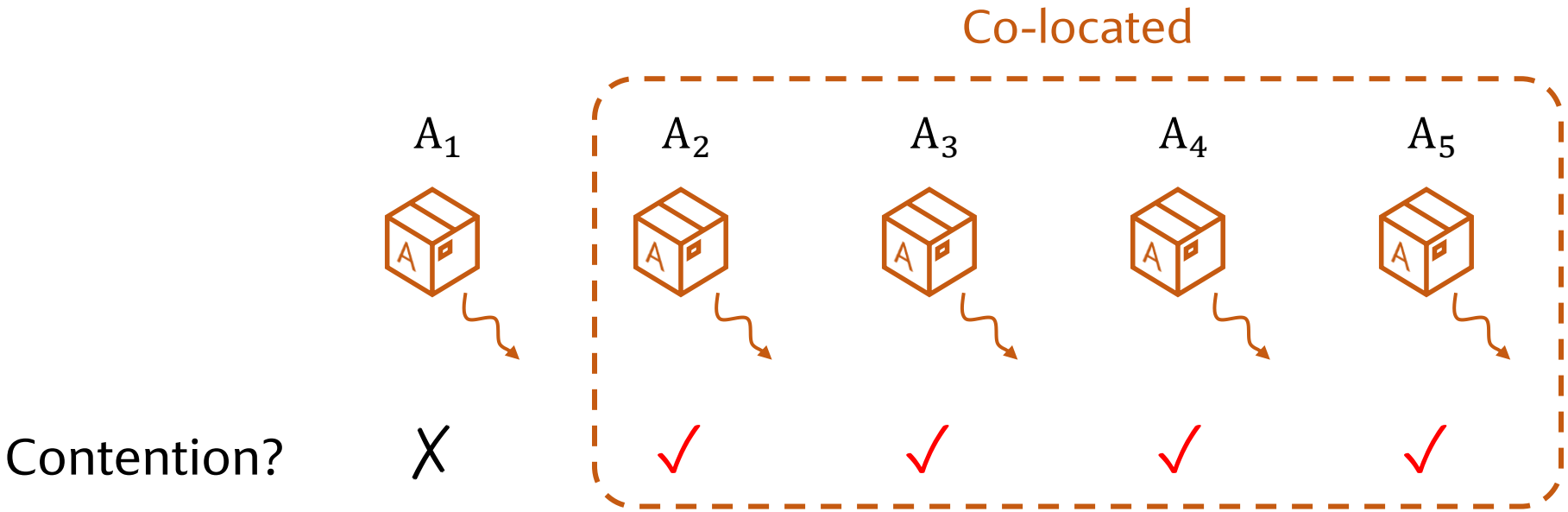
A_4 and A_5 are co-located

Go Beyond Pairwise Testing – Batch Testing



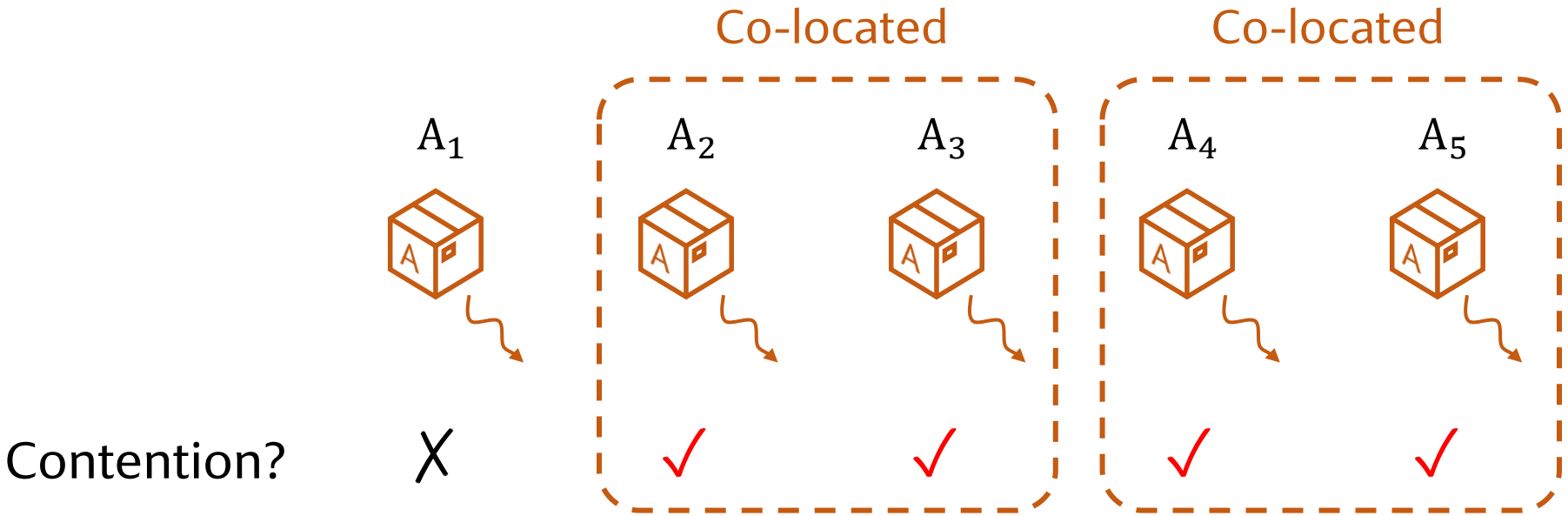
A_3, A_4, A_5 are co-located

Go Beyond Pairwise Testing – Batch Testing



A_2, A_3, A_4, A_5 are co-located? Not sure!

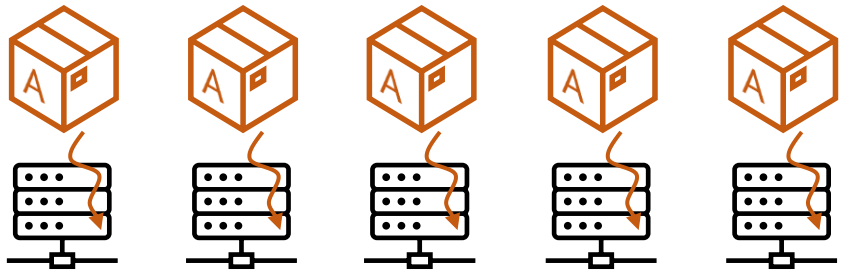
Go Beyond Pairwise Testing – Batch Testing



A_2, A_3, A_4, A_5 are co-located? Not sure!

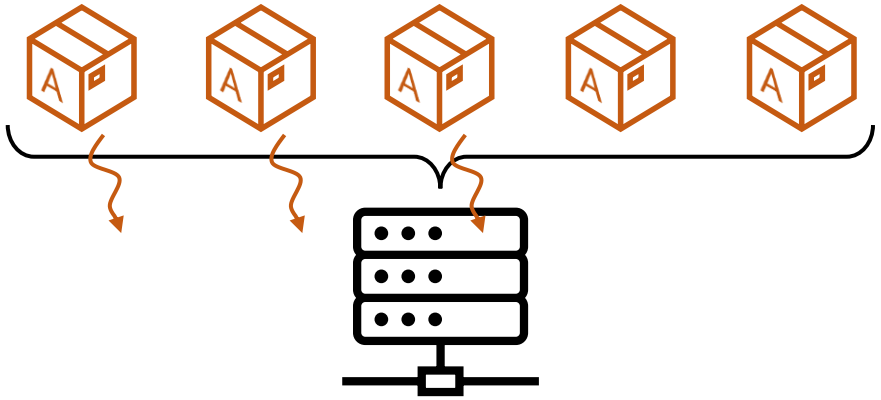
Batch Testing Strategies

Truly not co-located



Batch test all instances at once

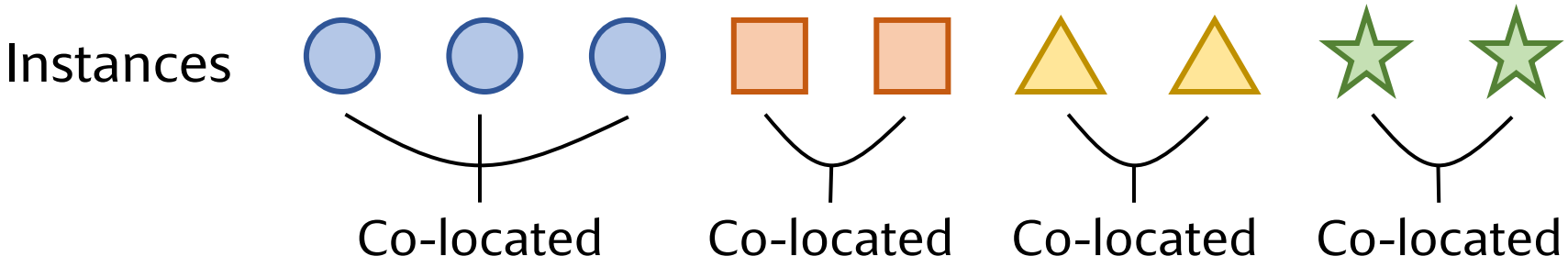
Truly co-located



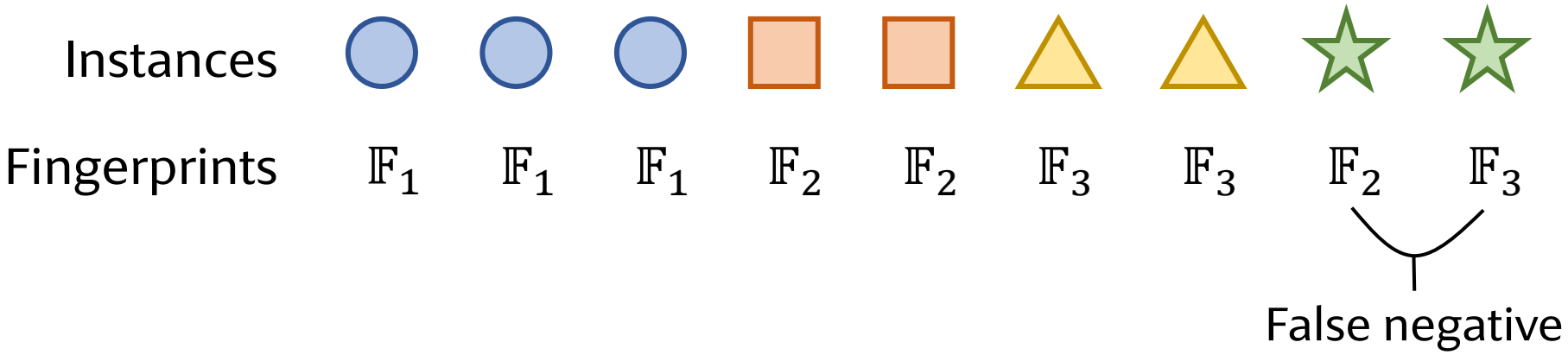
Batch test 3 instances at once

If fingerprints are accurate, they can provide hints on which instances are likely co-located

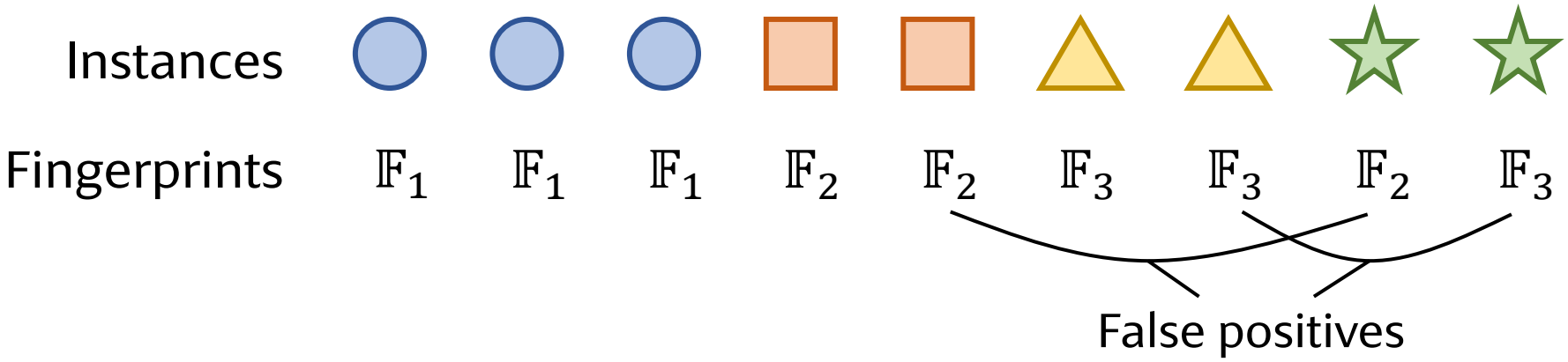
Fingerprint-Assisted Co-Location Verification



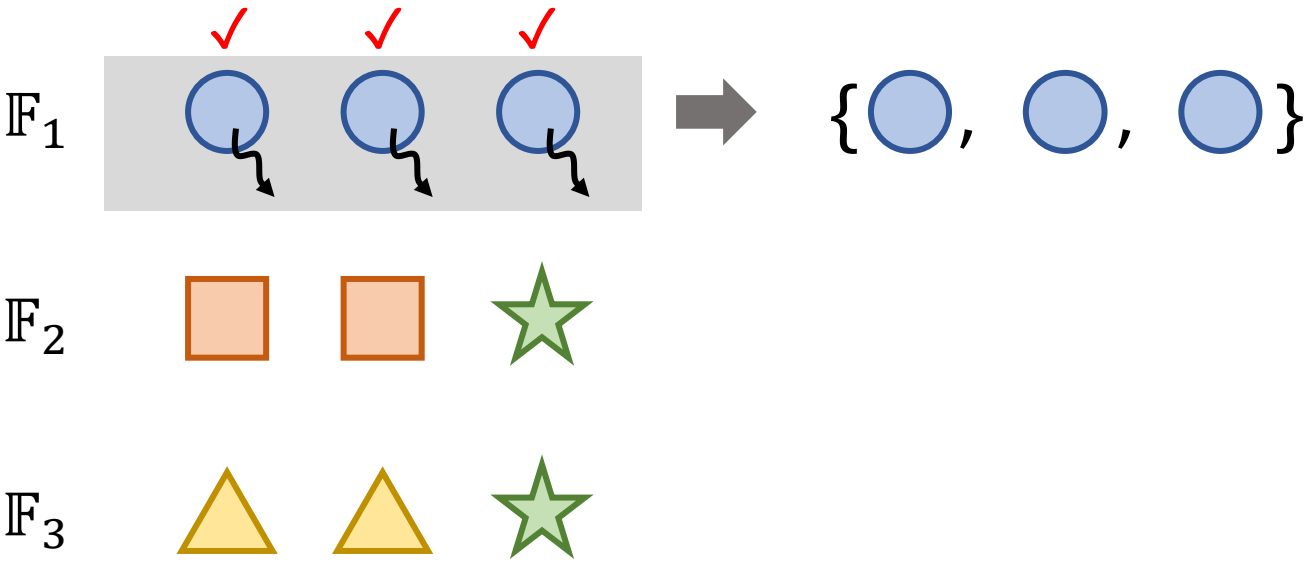
Fingerprint-Assisted Co-Location Verification



Fingerprint-Assisted Co-Location Verification



Fingerprint-Assisted Co-Location Verification



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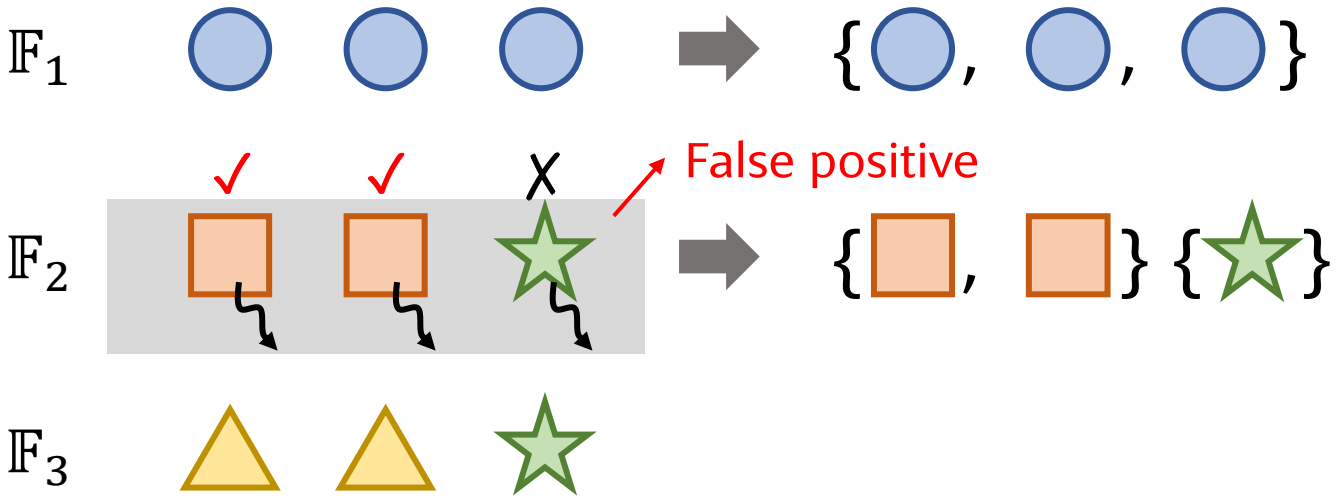

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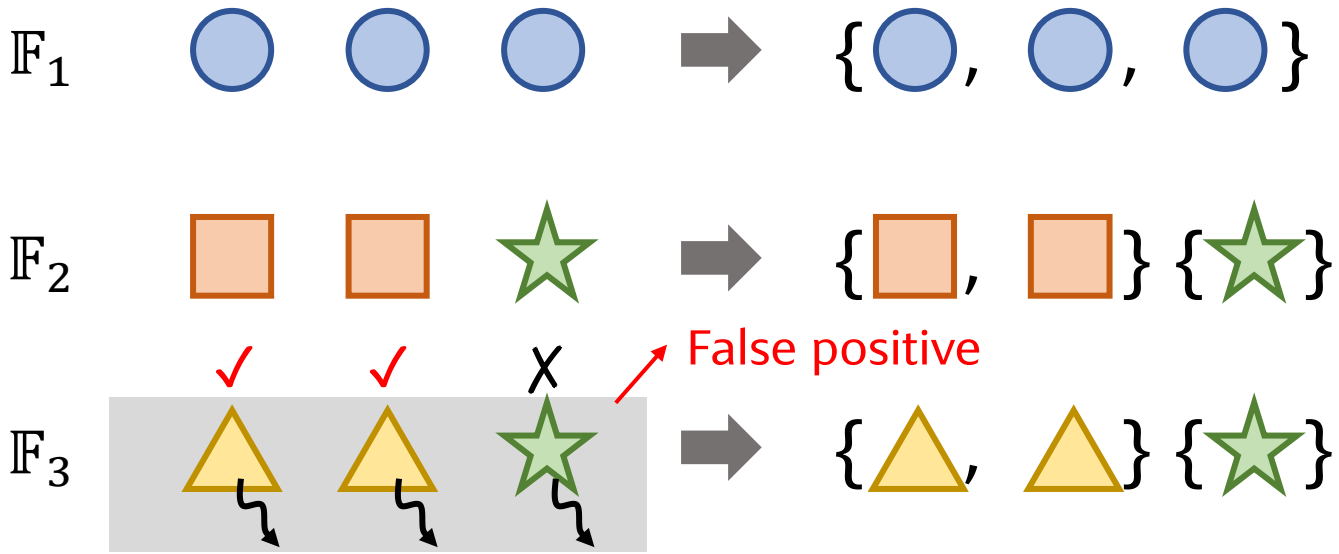

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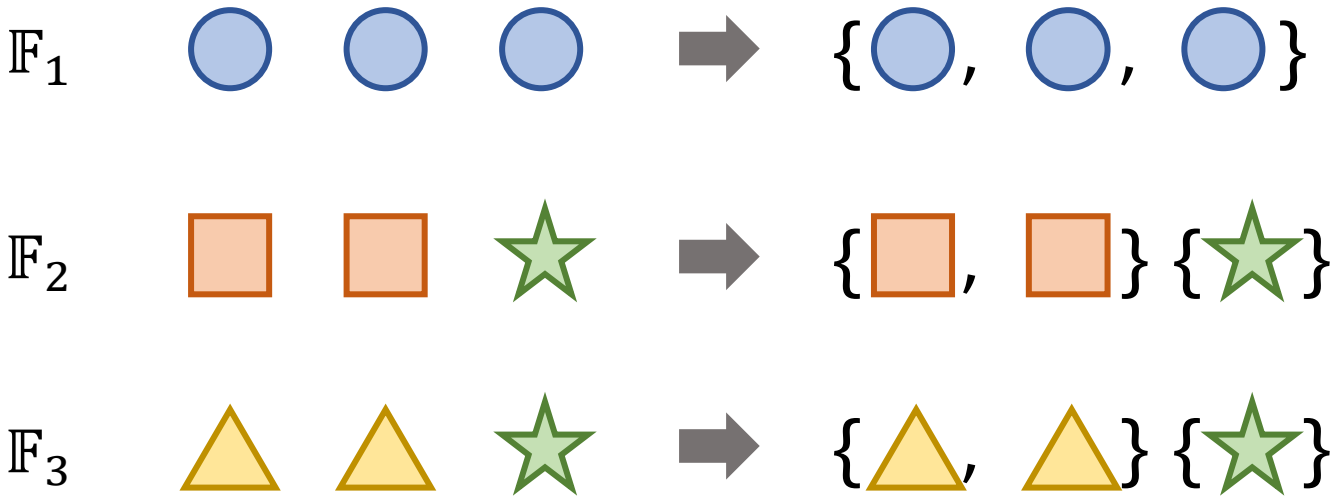
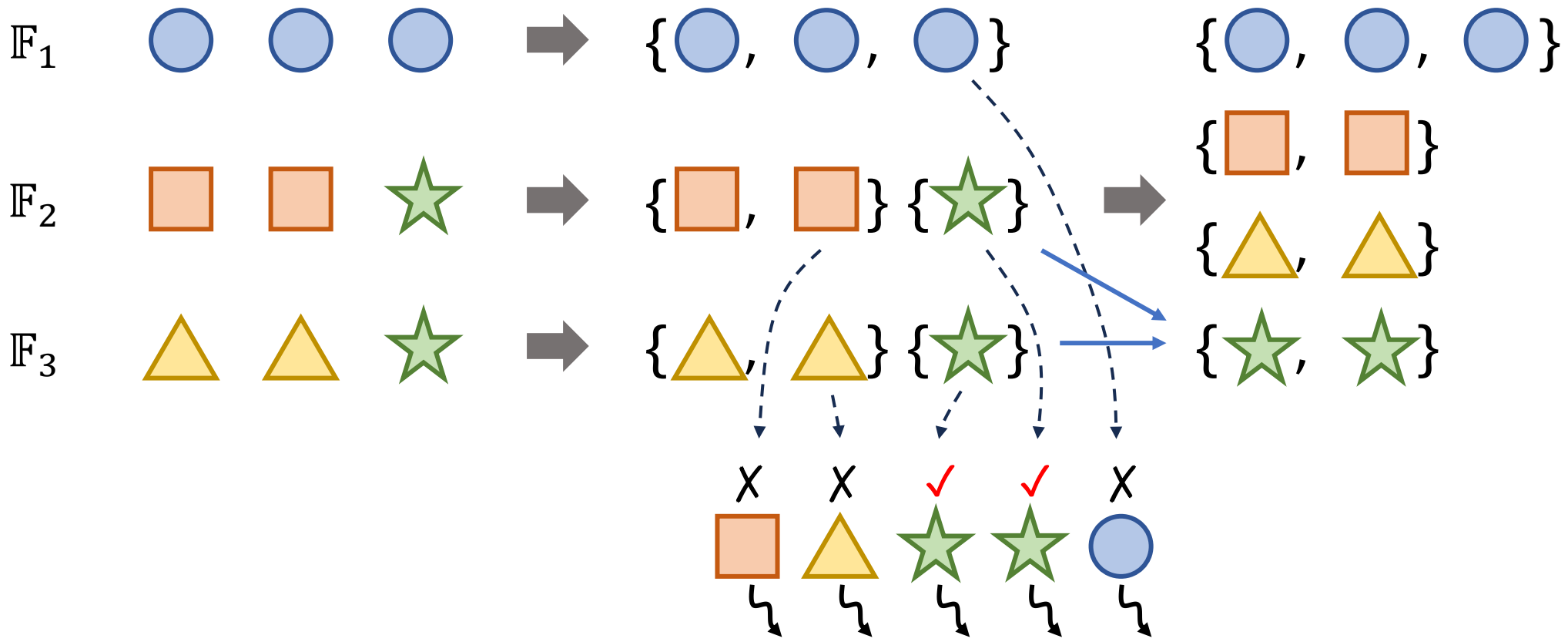


All false positives are identified, proceed to find false negatives

Fingerprint-Assisted Co-Location Verification



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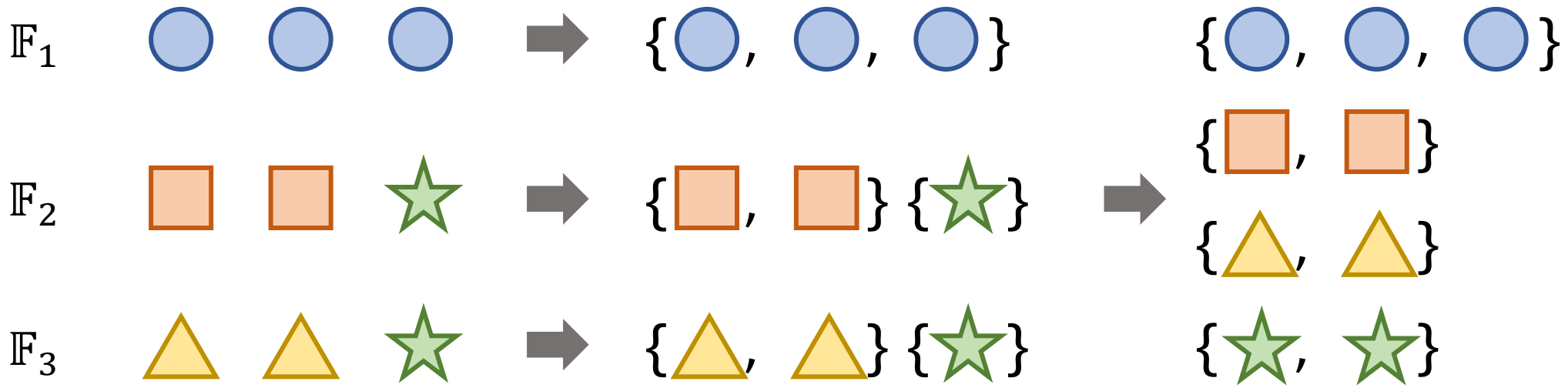

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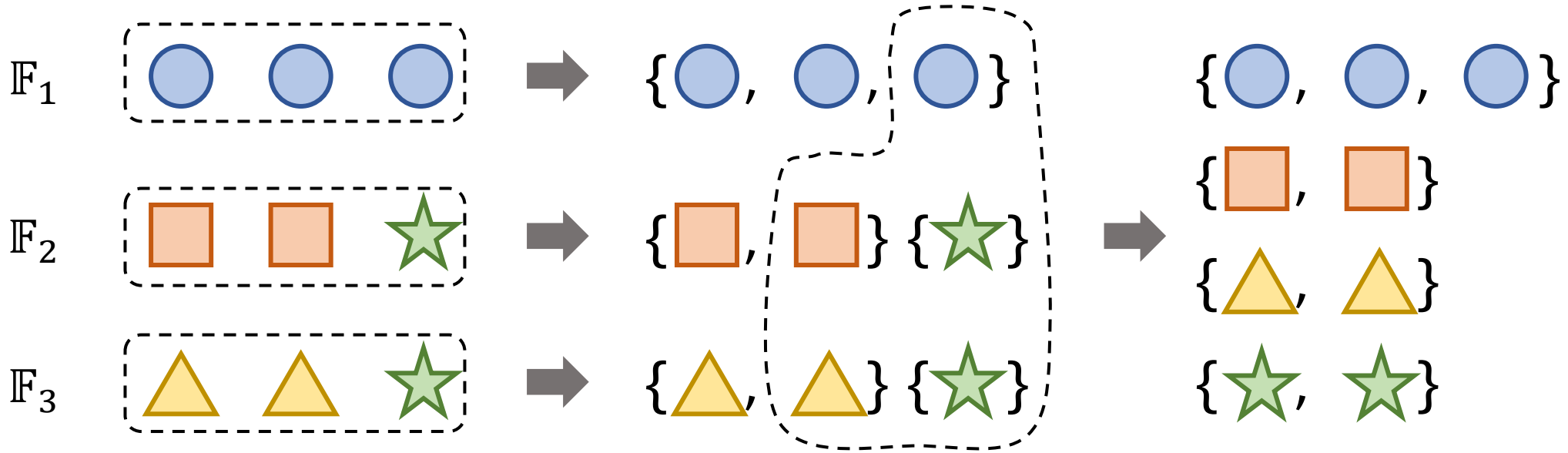


4 batch tests instead of $9 \times 8/2 = 36$ pairwise tests

More discussion in the paper

Host Fingerprints are Highly Accurate

- Gather fingerprints from 800 container instances
- Experiment is repeated 15 times in three data centers

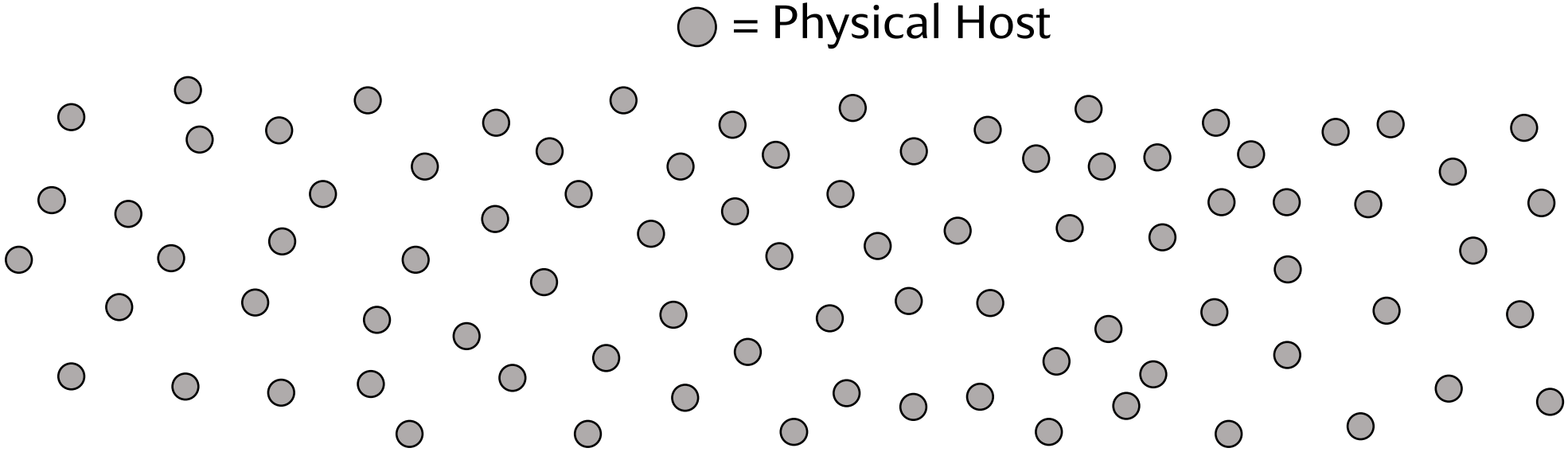
For each pair of container instances

- False positive (FP): same fingerprints but not co-located
- False negative (FN): different fingerprints but co-located

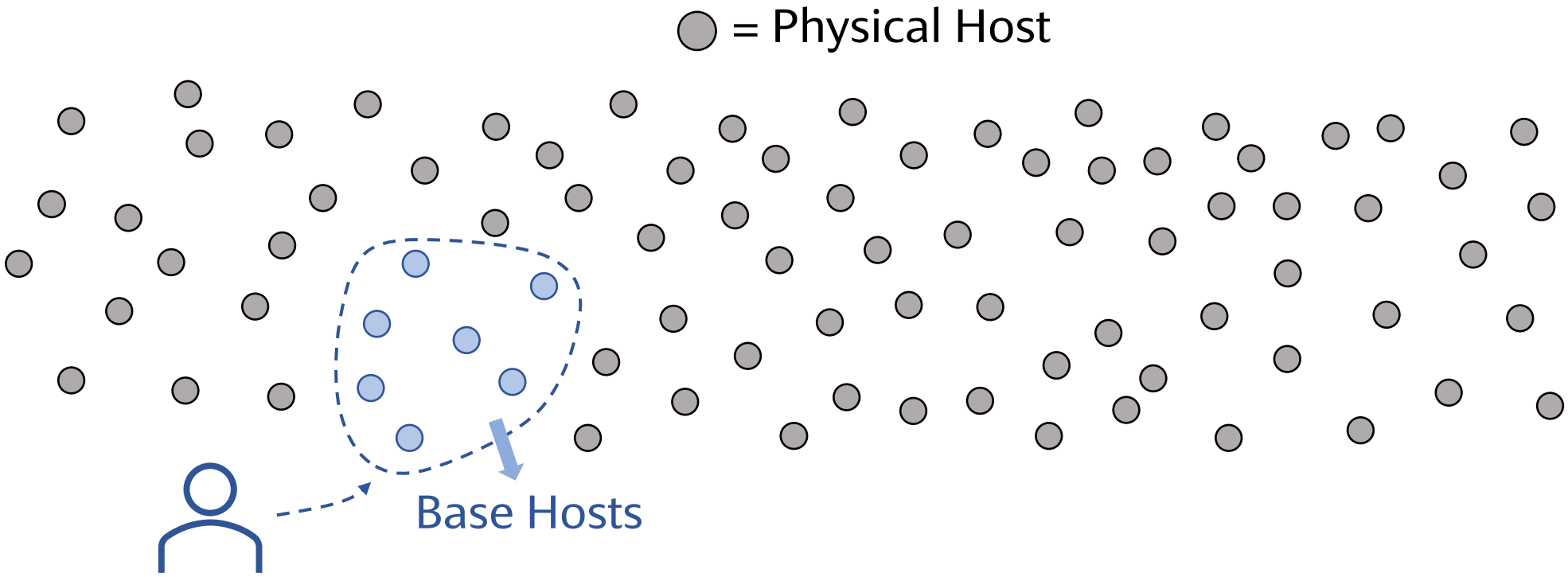
Average false negative rate: 0.00%
Average false positive rate: 0.02%

14 out of 15 measurements generate perfect fingerprints (no FP nor FN)

Understanding Instance Placement Policy



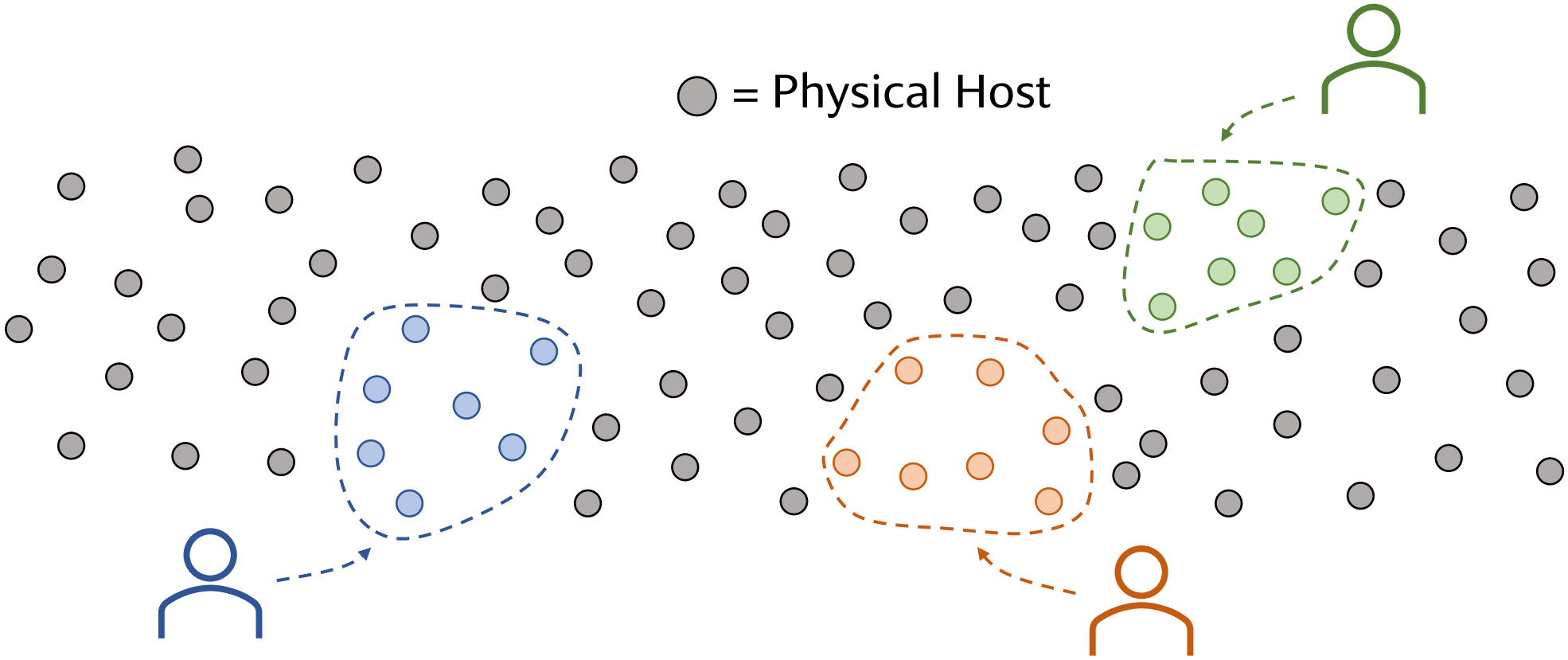
Base Hosts



Cloud Run prefers a specific set of hosts for instances owned by the same account

Possible cause: affinity scheduling to reduce communication overhead

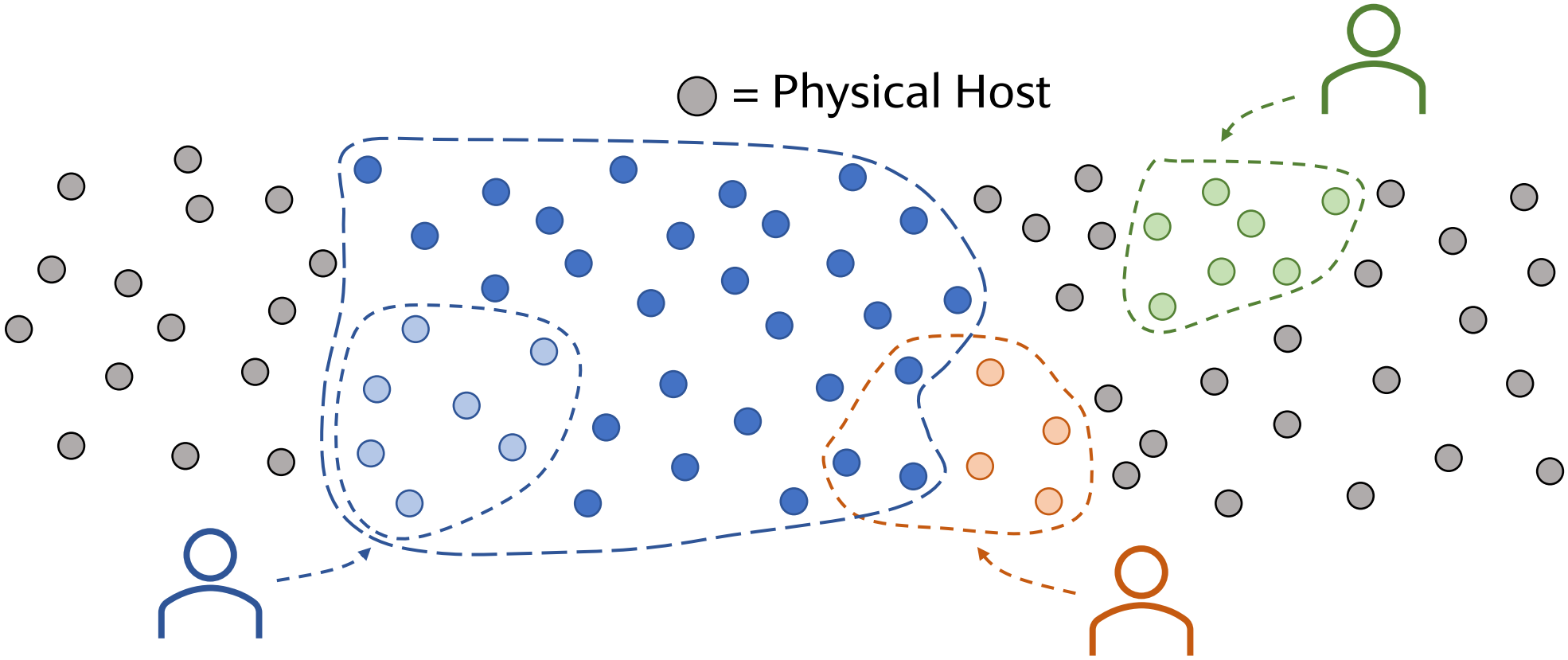
Different Accounts Have Different Base Hosts



Different accounts (usually) have different base hosts

Double-edged sword!

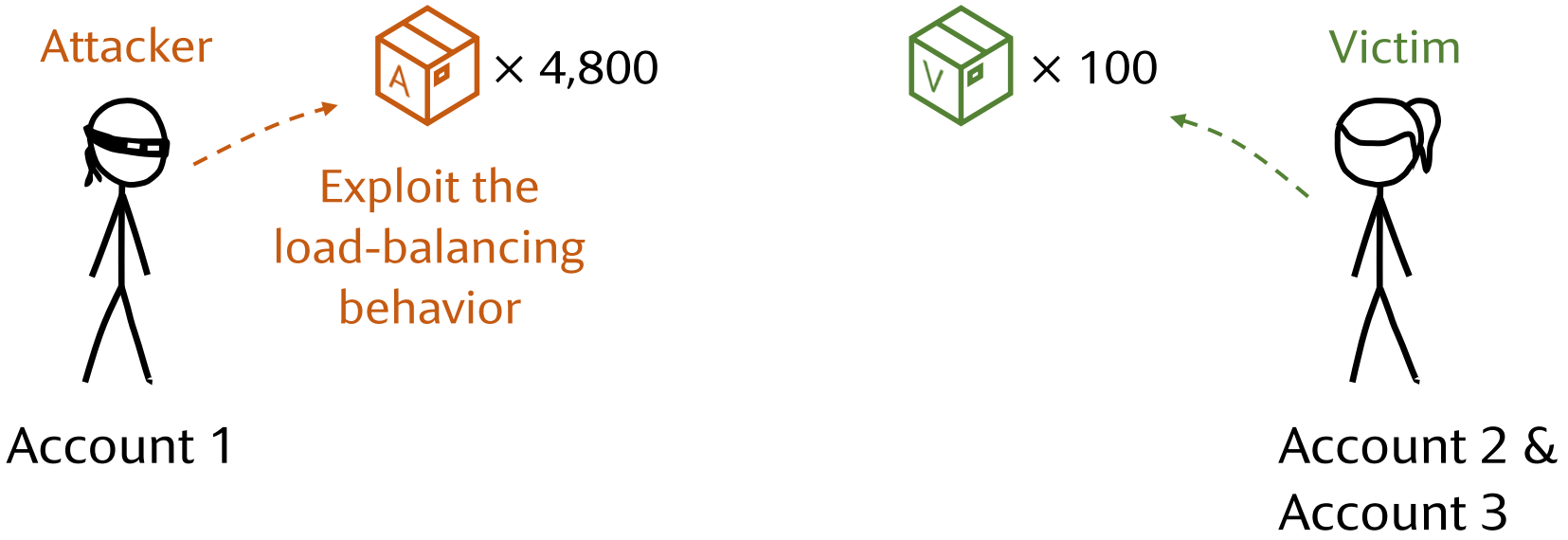
Load Balancing



High container usage can trick Cloud Run to spread instances across many hosts

☺ Allow attackers to go beyond their base hosts

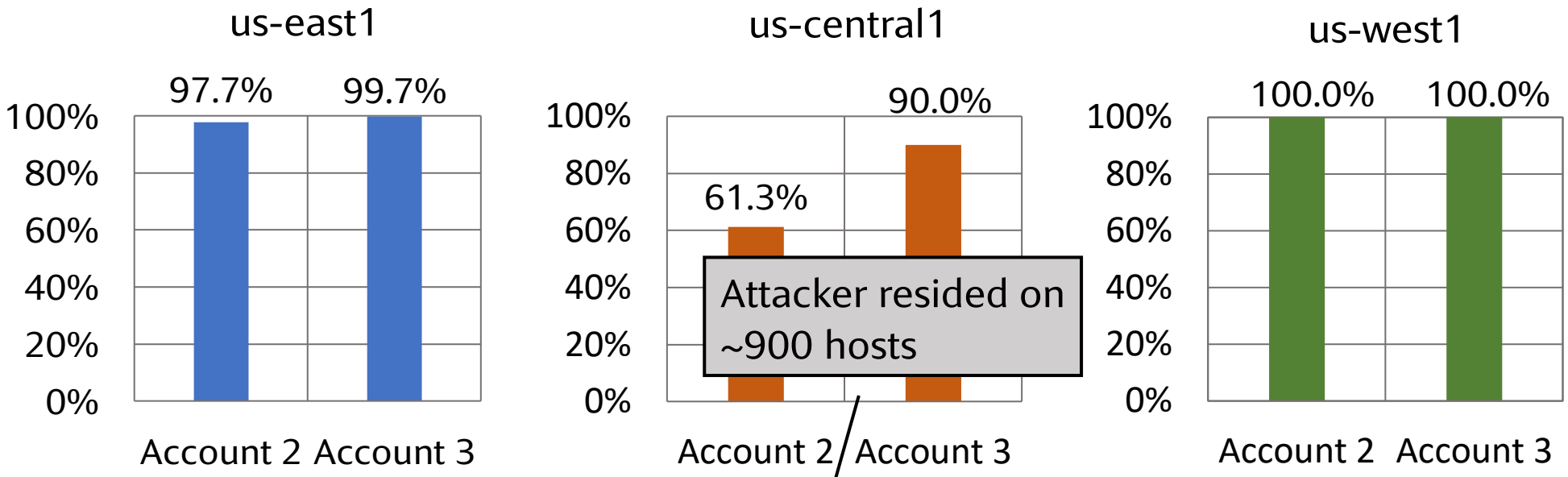
Co-Location with Victims



Victim Coverage: percentage of victim instances that are co-located with the attacker

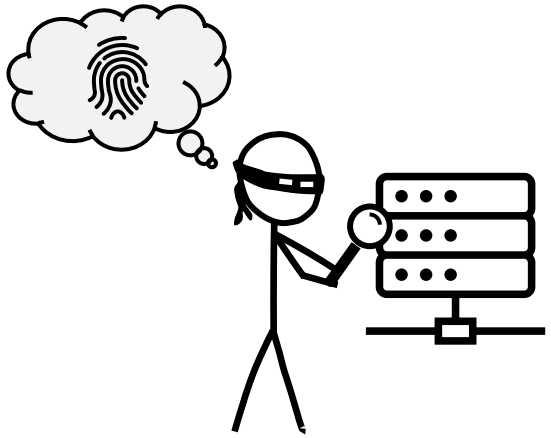
Co-Location with Victims

Average Victim Instance Coverage (3 repetitions in each region)



Attack Cost:	~24 USD	~23 USD	~27 USD

Conclusions



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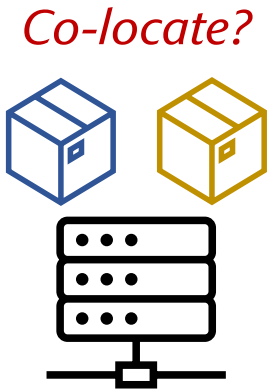

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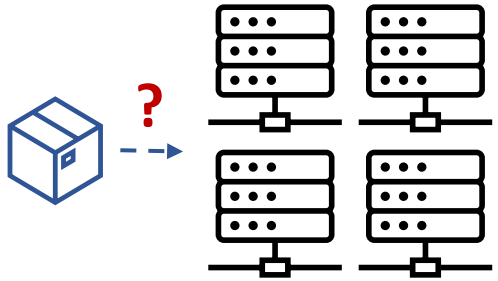

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Co-locate with 61%-100% of victim instances in three major data centers