Project Silver

Rethinking Security in the Era of Cloud Computing

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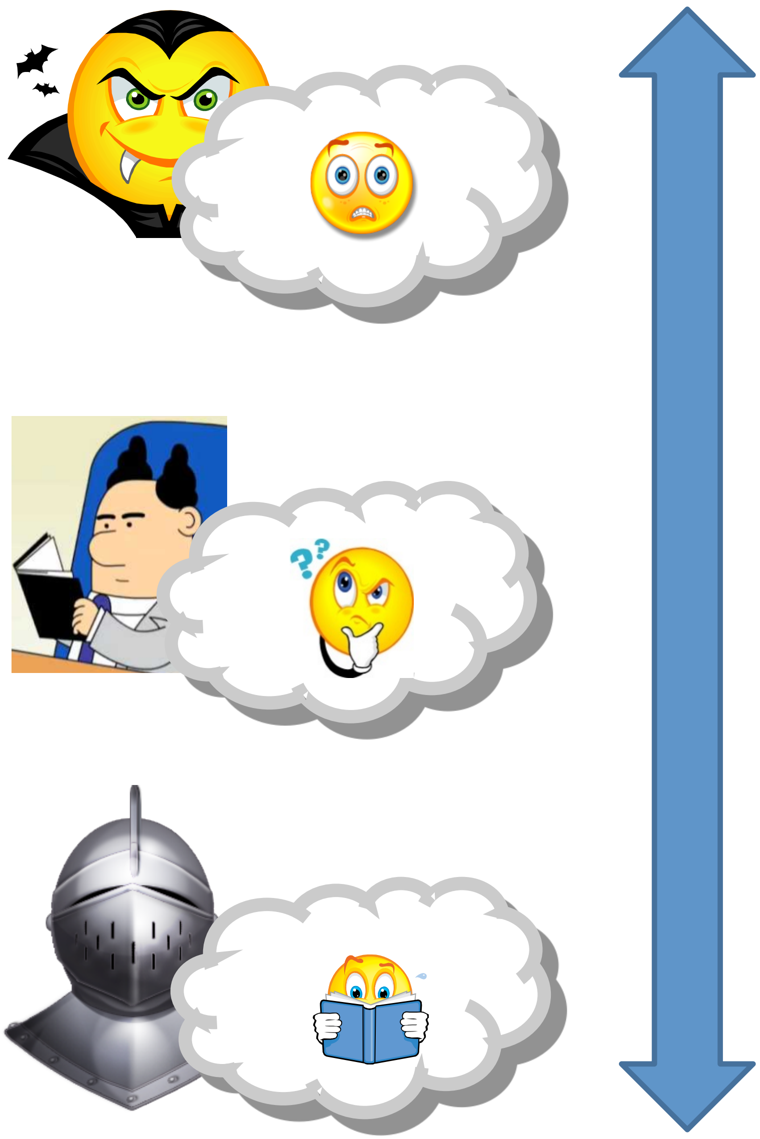
The Move to Cloud Computing

- >7% of the Alexa top 1M websites are tenants on EC2 or Azure
- Technical trends
  - Centralization in big providers
  - Clouds with more features

Threat Models



- The cloud *is* the adversary

  ⟹ e.g., virtualization secure against hypervisor, fully homomorphic encryption

- The cloud needs help

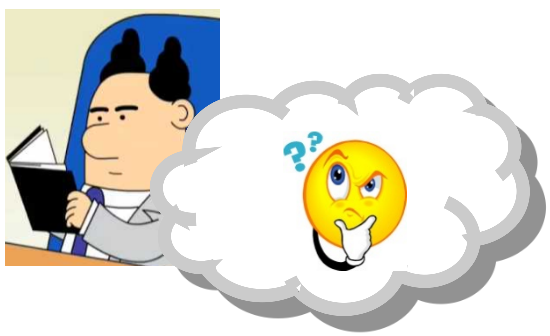
  ⟹ e.g., cycle stealing, colocation, cartography, side channels

- The cloud is an asset

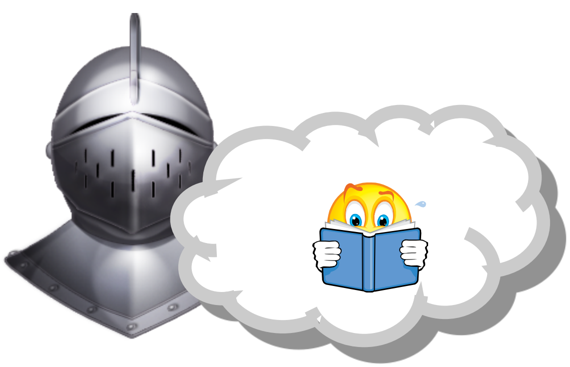
  ⟹ can be leveraged to do things that we couldn't do before

Reconsidering the Threat Model

"Most" academic research today is here …



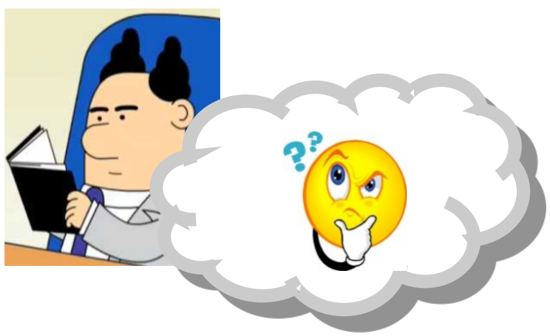
We want to be here …

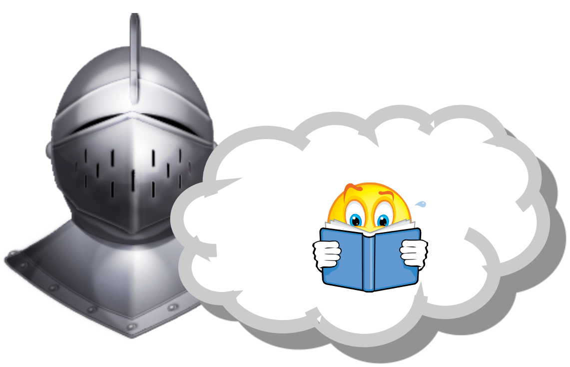


… and especially here.

Reconsidering the Threat Model

At odds with industry realities and incentives





- Better aligned with industry
- Easier deployment paths
- An understudied opportunity

The Driving Vision

- A "cloud control platform" that supports
  - Improved cloud and tenant security
  - Innovative services to enable new modes of tenant interaction

- … through new tech for better managing
  - Tenants' clients (credentials, protocols, …)
  - Tenant infrastructure (outsourced services, …)
  - Tenant-to-tenant ecosystem (trust management)

Cloud Security Horizons (CSH) Summits

- Three Cloud Security Horizon "summits"

- First CSH held in Feb 2014 in San Francisco
  - Co-located with the RSA Conference
- Second CSH held in Mar 2016 in New York City
- Last CSH Summit to be held in Spring 2018
  - Location TBD

Motivation for CSH

- Summits where we gather with industry stakeholders for technical exchange
  - Talks from both research team and industry
  - Facilitate technology flow and knowledge exchange
  - Focus discussions around the realities of cloud computing security
  - Familiarize industry partners with our tools and research directions
  - Industry partners serve an informal advisory role for our project

Cloud Security Curriculum Development Workshop

- 3-day curriculum workshop to help college teachers integrate cloud security into their courses

- Goal: curricular materials with integrated cloud security components …
  - From different perspectives
  - From different institutions
  - Within diverse courses

Cloud Security Curriculum Development Workshop

- First CSCD workshop held Jul 15-17, 2015 in Chapel Hill, NC
- Second CSCD workshop held Jul 13-15, 2016, also in Chapel Hill, NC

Cloud Security Curriculum Development Workshop

Day One (Wednesday, July 13)

- 08:30 – 09:00 Breakfast and Registration
- 09:00 – 09:40 Welcome, introductions, final agenda
- 09:40 – 10:00 Introduction to Cloud Computing and Cloud Security
- 10:00 – 10:45 Cloud 101 project – hands-on tutorial using **Amazon EC2**
- 11:00 – 12:00 Presentation of the Silver CSCW modules and their potential usage in classes (with examples for Distributed Systems, Introduction to Security, and Networking courses)
- 12:00 – 13:00 Lunch
- 13:00 – 15:00 **Cloud Security using GENI: demo and hands-on tutorial**
- 15:15 – 16:15 **GENI tutorial on OpenFlow and NAT devices** (continued)…
- 16:15 – 16:30 Agenda for tomorrow; and Q&A

Cloud Security Curriculum Development Workshop

Day Two (Thursday, July 14)

- 08:30 – 09:00 Breakfast
- 09:00 – 10:30 **CloudLab: demo and hands-on tutorial**
- 10:45 – 11:15 CloudLab tutorial (contd…)
- 11:00 – 12:00 Gary Bishop: My experience with Docker
- 12:00 – 14:00 Lunch (en route to IBM Data Center); Travel by pre-arranged vans
- 14:00 – 16:00 **IBM Data Center tour**
- 18:00 – 20:00 Working Dinner: Breakout sessions – pick your module and plan the implementation in your course(s)

Cloud Security Curriculum Development Workshop

Day Three (Friday, July 15)

- 09:00 – 09:30 Breakfast
- 09:30 – 09:45 Talk about a course experience by one of the participants
- 09:45 – 10:15 Mike Reiter – Side-channel attacks
- 10:15 – 10:30 Introduction to other Educational Resources
- 10:45 – 12:00 5 to 6-min presentations by each participant on how they plan to use our modules
- 12:00 – 13:00 Lunch – wrap-up, feedback, and next steps.

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  - Improved cloud and tenant security
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- … through new tech for better managing
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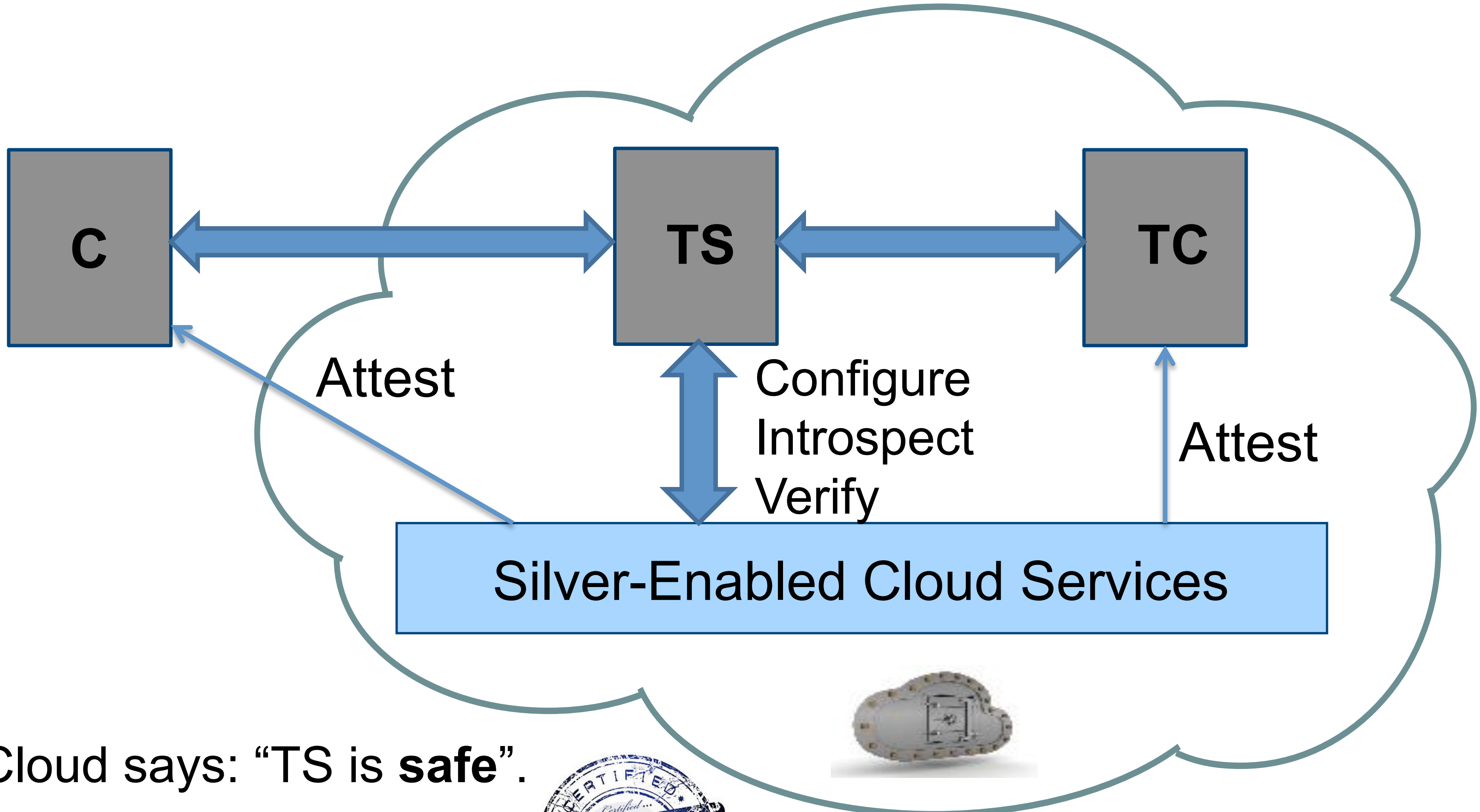
  - Tenant infrastructure (outsourced services, …)
  - Tenant-to-tenant ecosystem (trust management)

Strengthening Tenant Ecosystems

- **Focus**: New provider services to certify/attest tenant configurations and security properties.
  - **Leverage trust in cloud provider**
  - Broker trust among tenants
  - Evidence for regulatory/policy compliance
  - Practical code attestation → trusted instances
  - Extend authz for attribute-based access
  - Make trust relationships explicit
  - **Speculative**: requires new trust framework

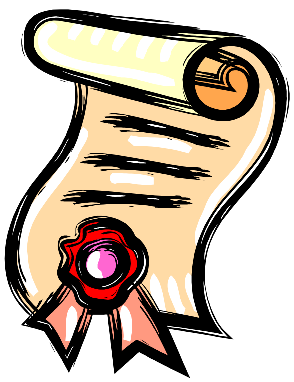
Attesting Security Properties



Cloud says: “TS is **safe**”.

Examples (Vision)

"TS is running ***SELinux*** version X.Y.Z, ***fully patched***"

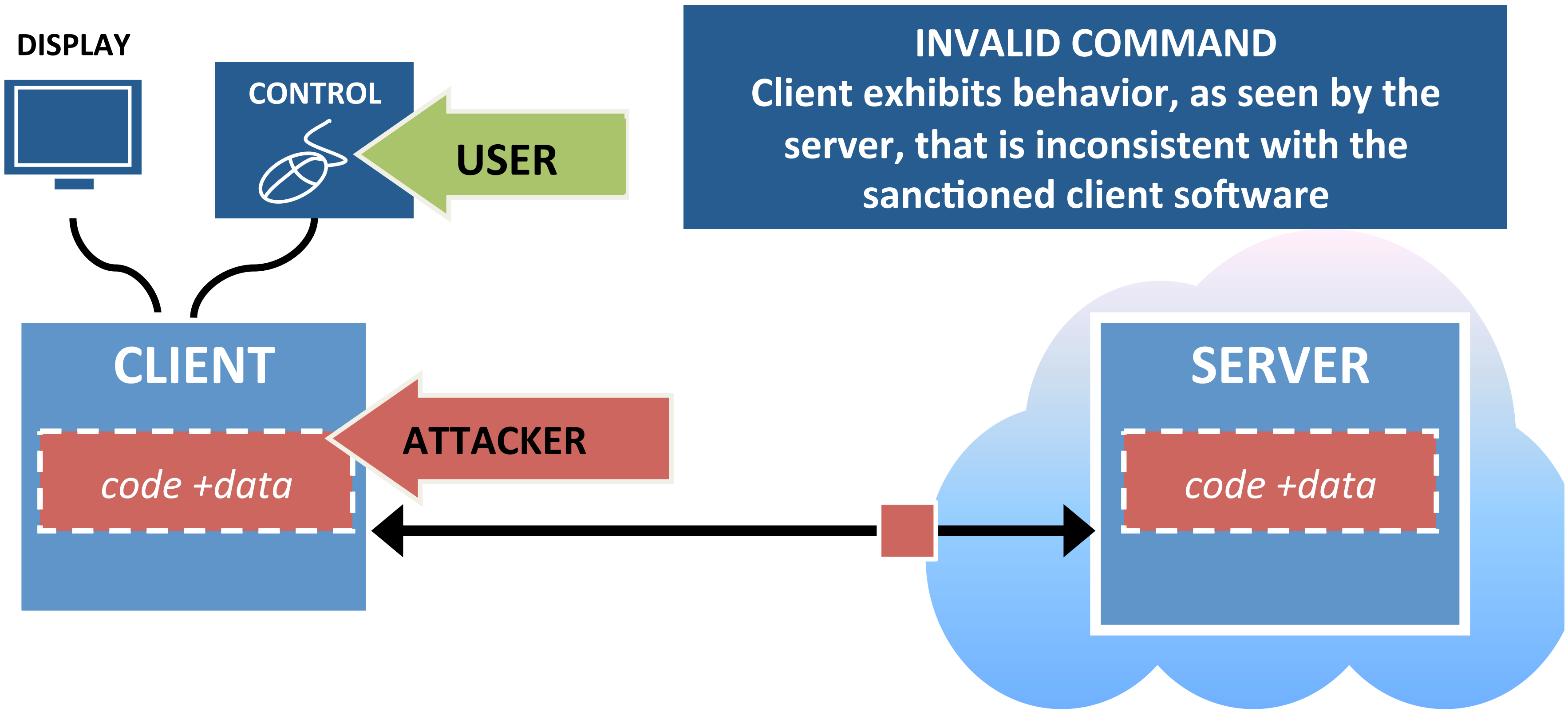


Proof of: "TS's security posture is ISO ***XYZ-compliant***"

"TS ***cannot leak data*** except via the approved output channel."

"TS is a ***sealed, immutable instance*** of application XYZ."

Invalid Command Attacks



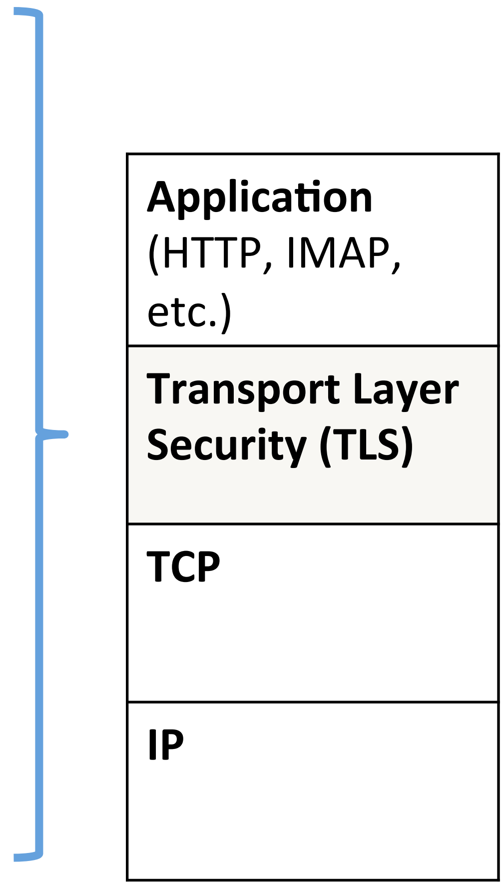
Invalid Command Attacks

- Tampering with clients in client-server protocols is an ingredient in numerous abuses
  - Exploits on the server directly
  - Manipulation of client state for which it is authoritative

- Exploits can take the form of …
  - Cleverly crafted malicious packets, or
  - Sequences of individually valid packets that exploit flaws in server logic or limitations in server visibility

Transport Layer Security (TLS)

- Handshake Protocol
  - Select cipher, authentication, key exchange
- Heartbeat Protocol
- Record Layer
  - Provides confidentiality and integrity
  - Encapsulates other protocols (above)

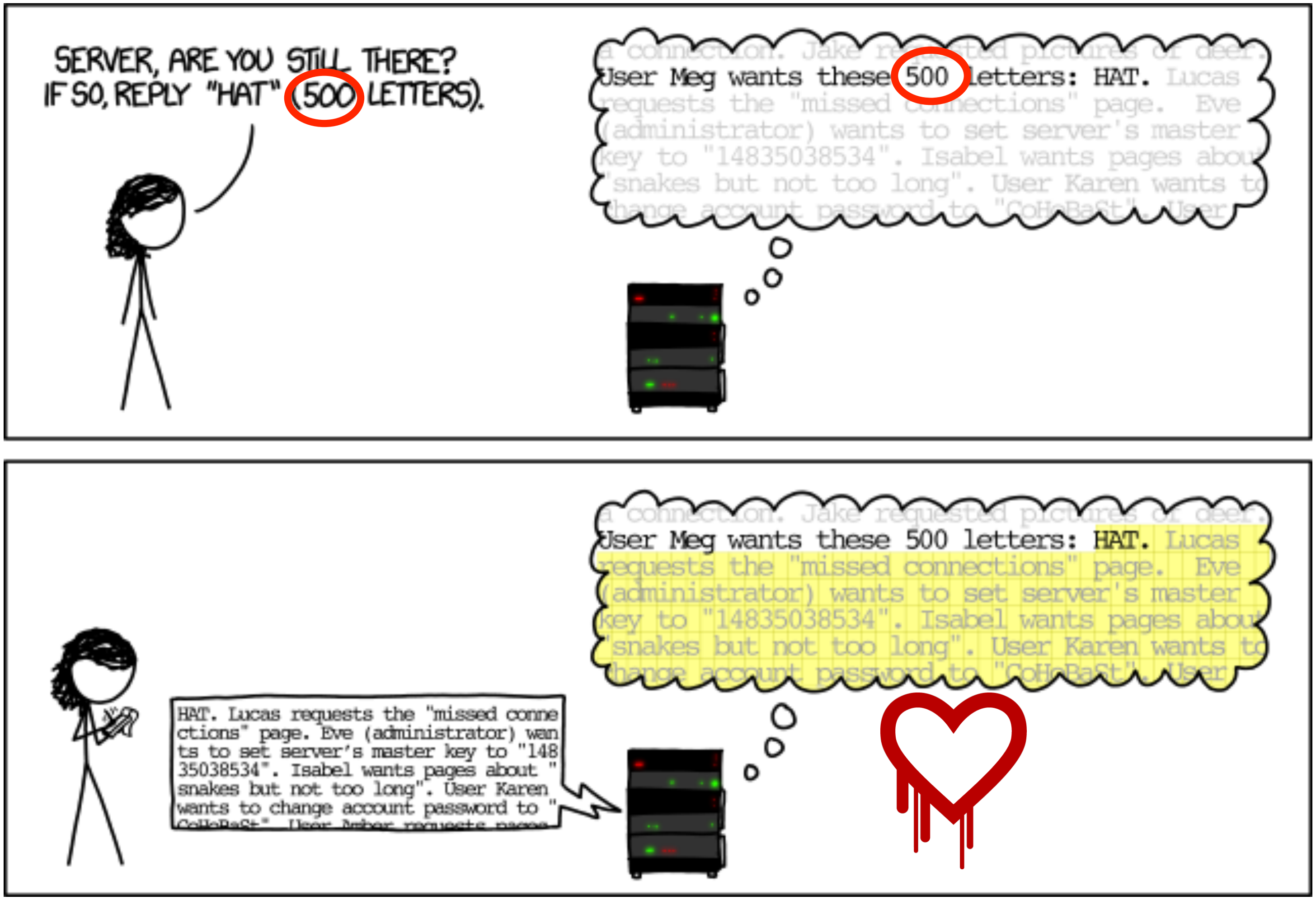


In 2014, critical vulnerabilities were discovered in all 5 major implementations of TLS (including OpenSSL).

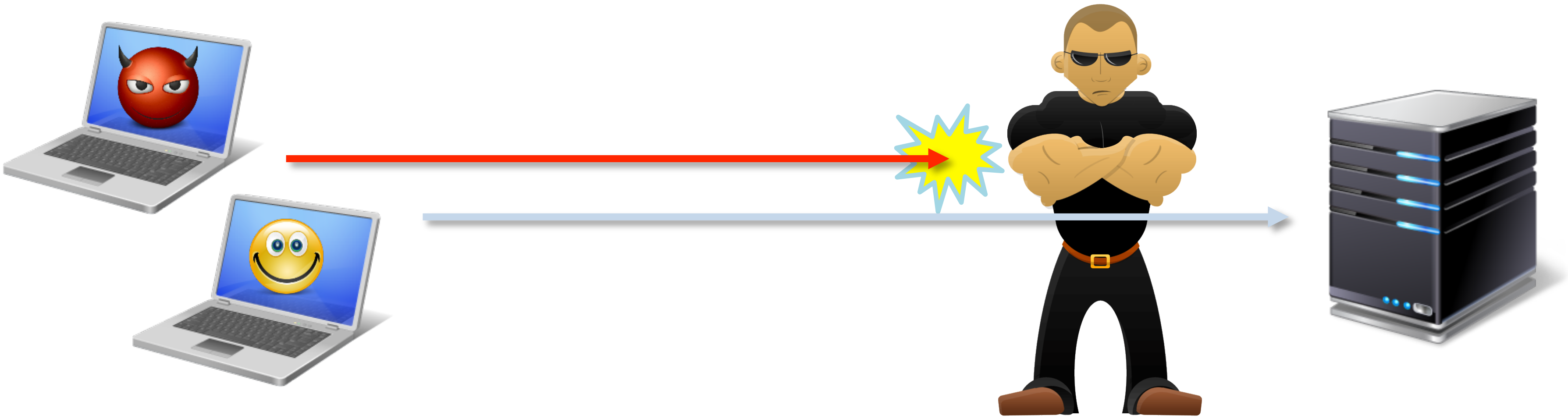
Heartbleed

- Implementation bug in OpenSSL (TLS Heartbeat handler)
- Nearly all OpenSSL applications vulnerable for 2 years
- 17% of the Internet's web servers (~500,000)
- Not just web: IMAP/SMTP, VPN, Android 4.1.1, etc.
- 4 months later, half remained unpatched (IBM, 3Q 2014)
- Even worse, patching is insufficient
  - Certificates must be revoked and reissued
  - Only 13% of vulnerable websites did so (Zhang et al., 2014)

Heartbleed (CVE-2014-0160)

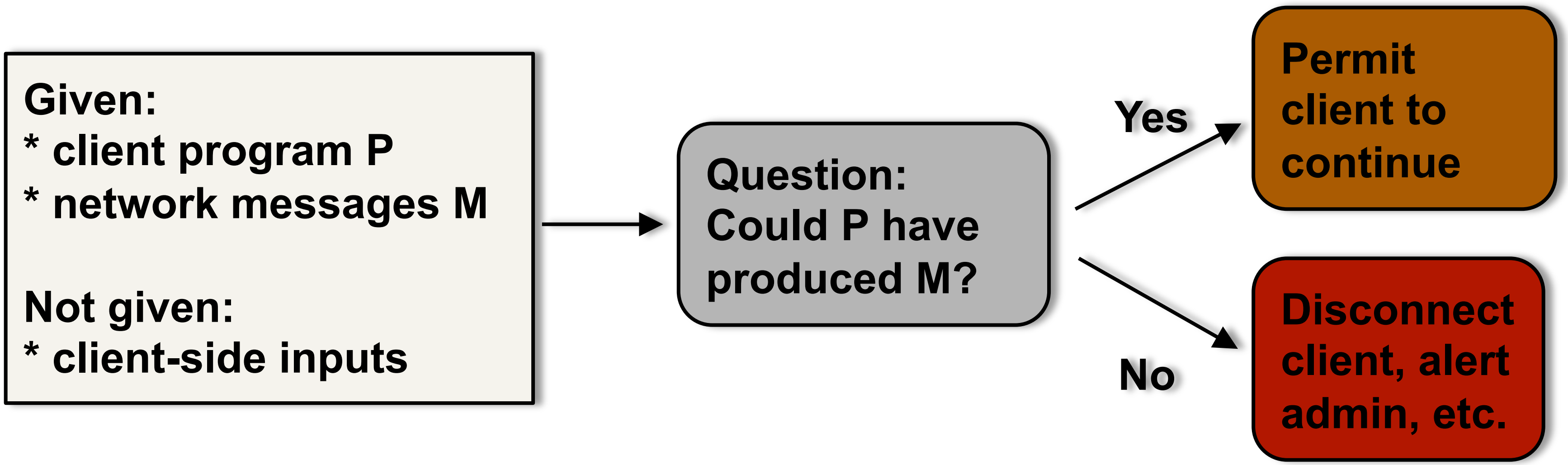


How Can We Defend Tenant Servers?



- Client validation: permit authorized client software only
  - Eliminates entire classes of attacks *without knowing about them*
  - Usually requires client modification or sending of client inputs
- Run for inline defense, or offline for rapid detection of exploit attempts

Client Behavior Validation
[Chi, Cochran, Nesfield, Reiter, Sturton; 2016]

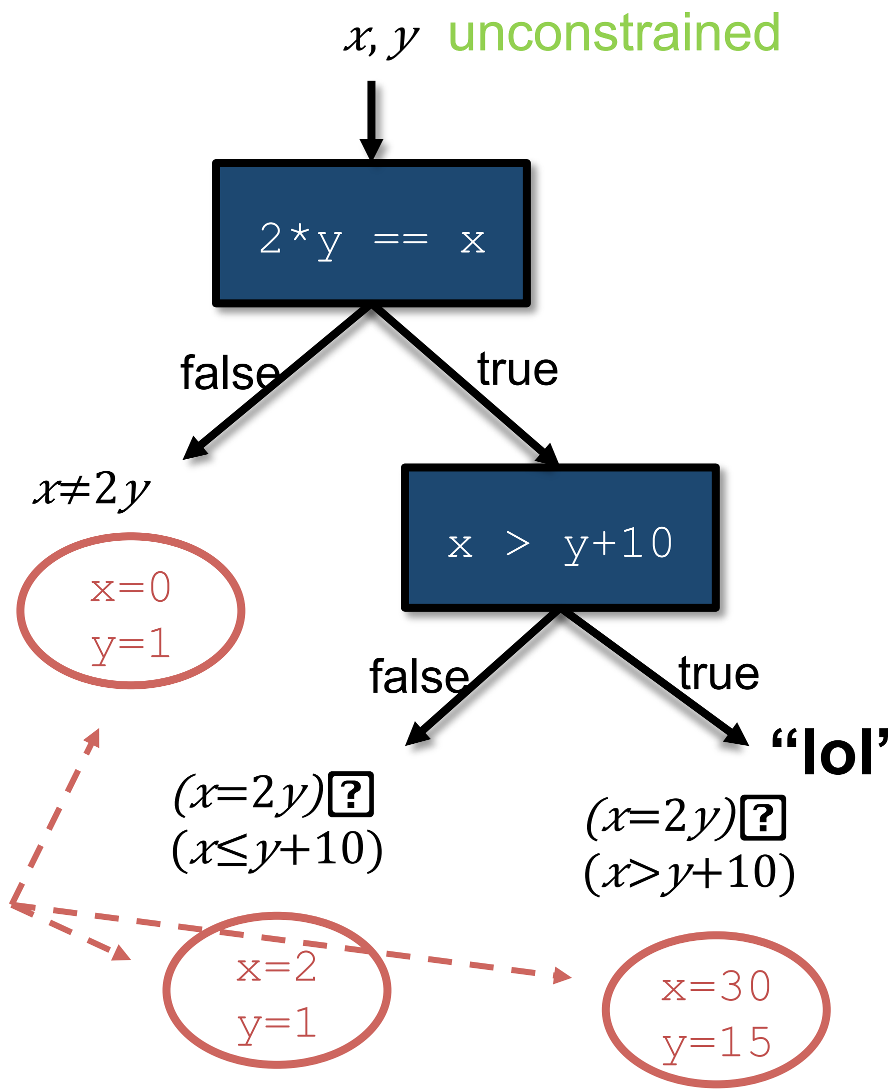


- General case: undecidable
- Specific instances may be practical

Symbolic Execution

```
x = sym_input();
y = sym_input();
testme(x,y);

void testme(int x, int y)
{
    int z = 2*y;
    if (z == x) {
       if (x > y+10)
           printf("lol");
    }
}
```



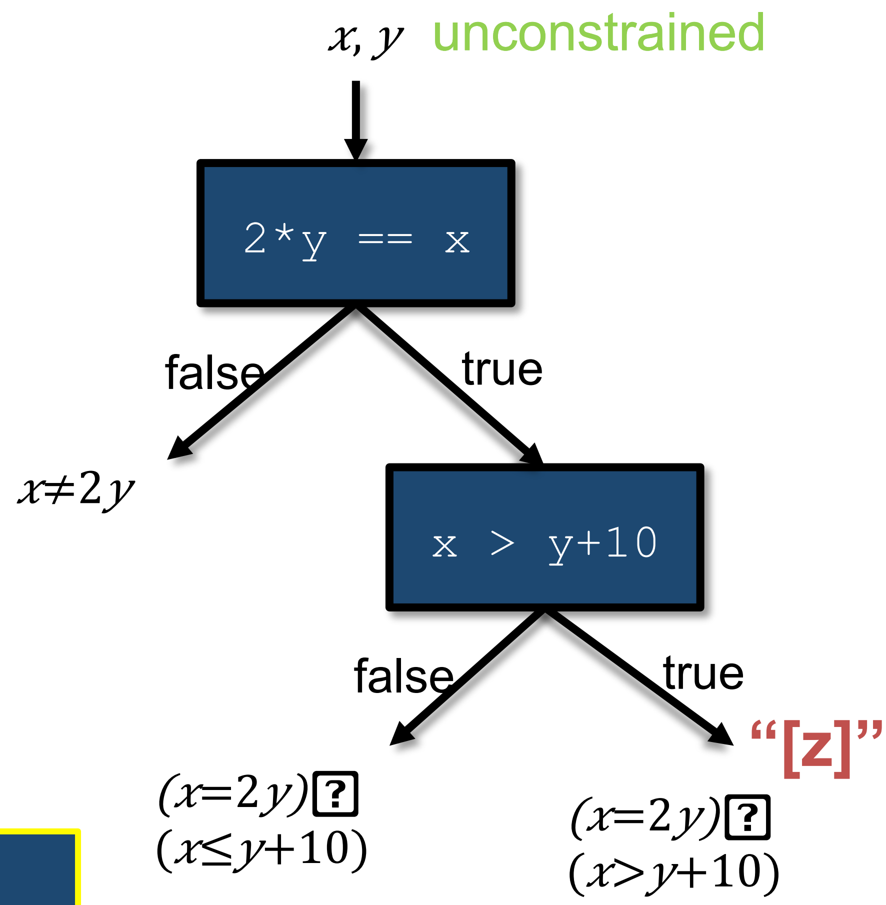
Apply SAT solver to obtain concrete test cases.

Example adapted from: Cristian Cadar, and Koushik Sen. "Symbolic execution for software testing: three decades later." Communications of the ACM 56.2 (2013): 82-90.

Symbolic Execution

```
x = sym_input();
y = sym_input();
testme(x,y);

void testme(int x, int y)
{
     int z = 2*y;
     if (z == x) {
        if (x > y+10)
             send(z);
     }
}
```

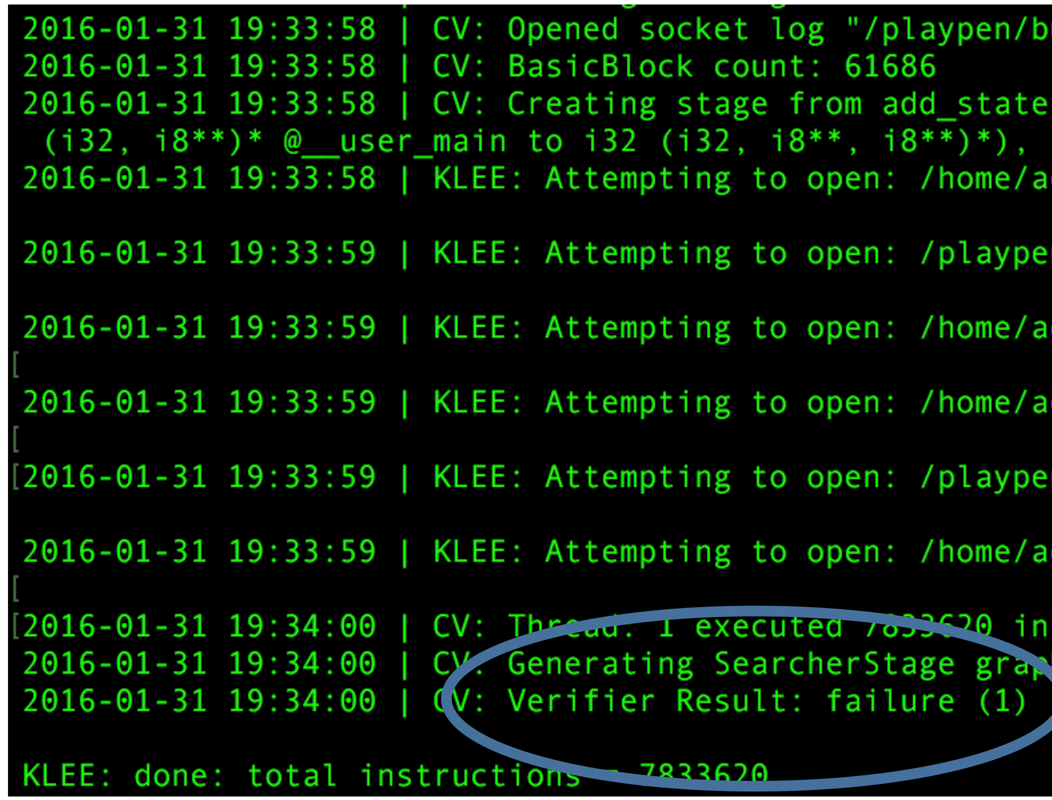


Can this program produce…

- **42?** **Yes** ($x=42$, $y=21$)
- **41?** **No** ($z=2y$ so it must be even)
- **2?** **No** ($x>y+10$ is violated)

Example: Detecting Heartbleed (Without Looking For It)

- Malicious s_client
  - performs handshake
  - sends Heartbleed exploit
- Validation
  - Handshake is verified
  - No explanation found for malicious Heartbeat



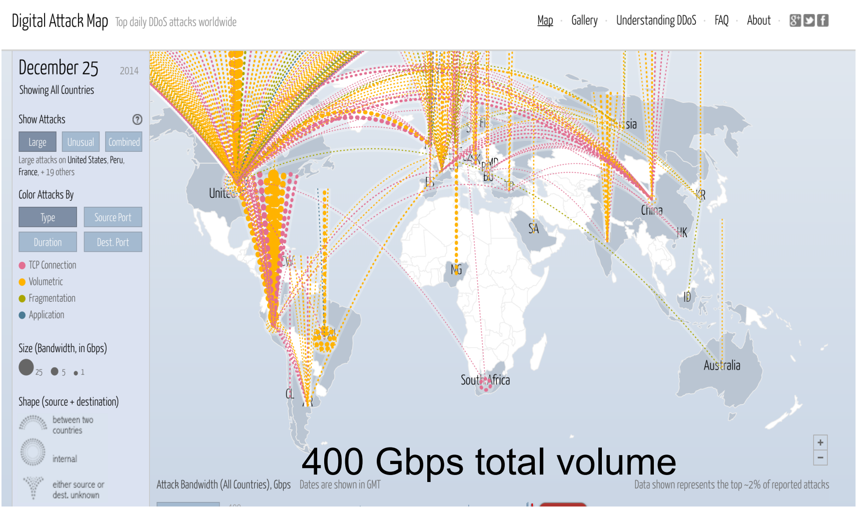
Detection in ~2s

Performance

- Verification latency is not (yet) fast enough for inline verification in latency-sensitive apps
- It can, however, keep pace with many common applications
  - Example: In our experience, OpenSSL and BoringSSL behavior in Gmail connections can be verified during the connection

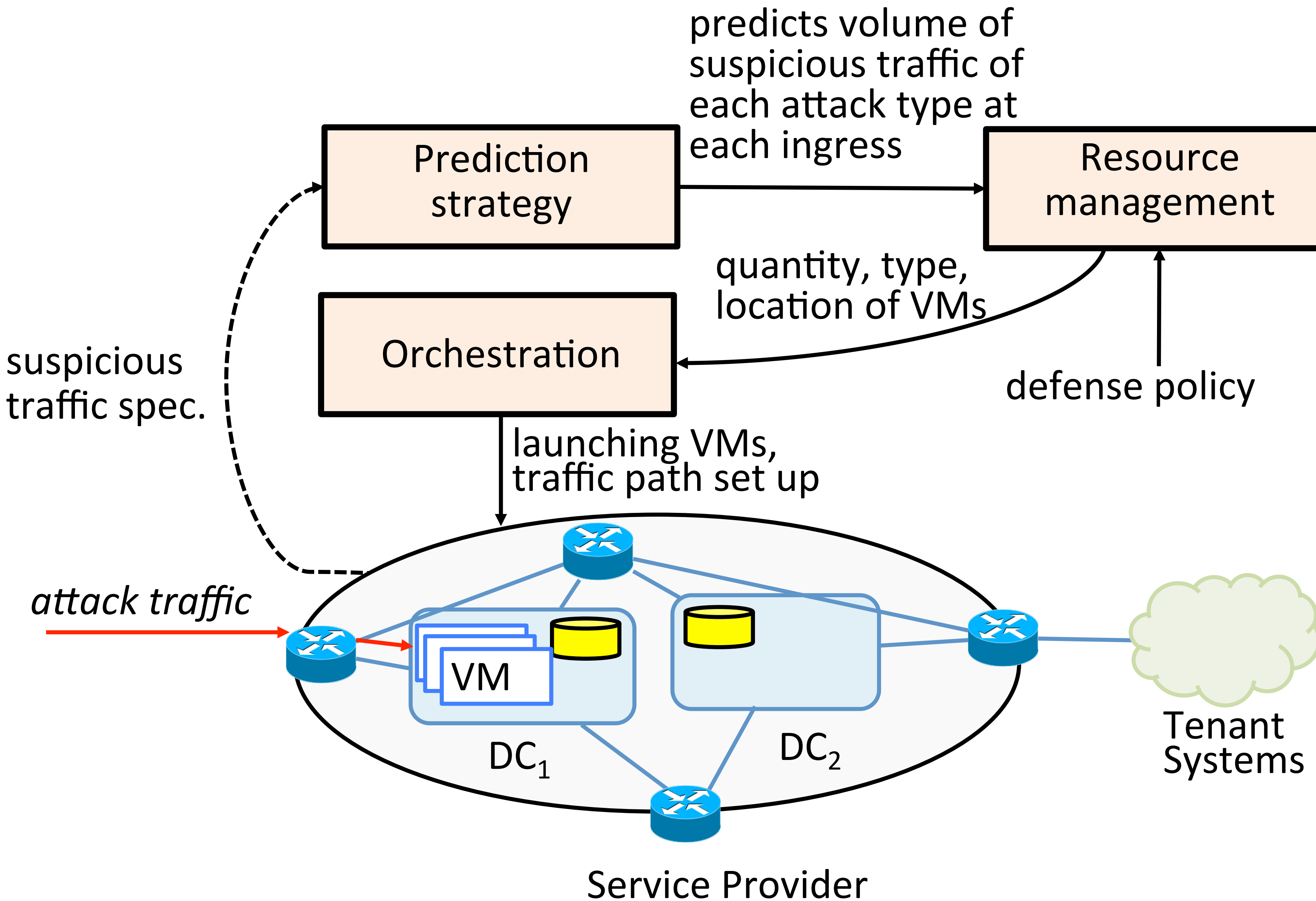
DDoS Defense: Bohatei
[Fayaz, Tobioka, Sekar, Bailey; USENIX Sec. 2015]

- DDoS attacks a persistent problem
- Today's defenses involve proprietary hardware
  - Expensive
  - Fixed: capacity, functionality, location

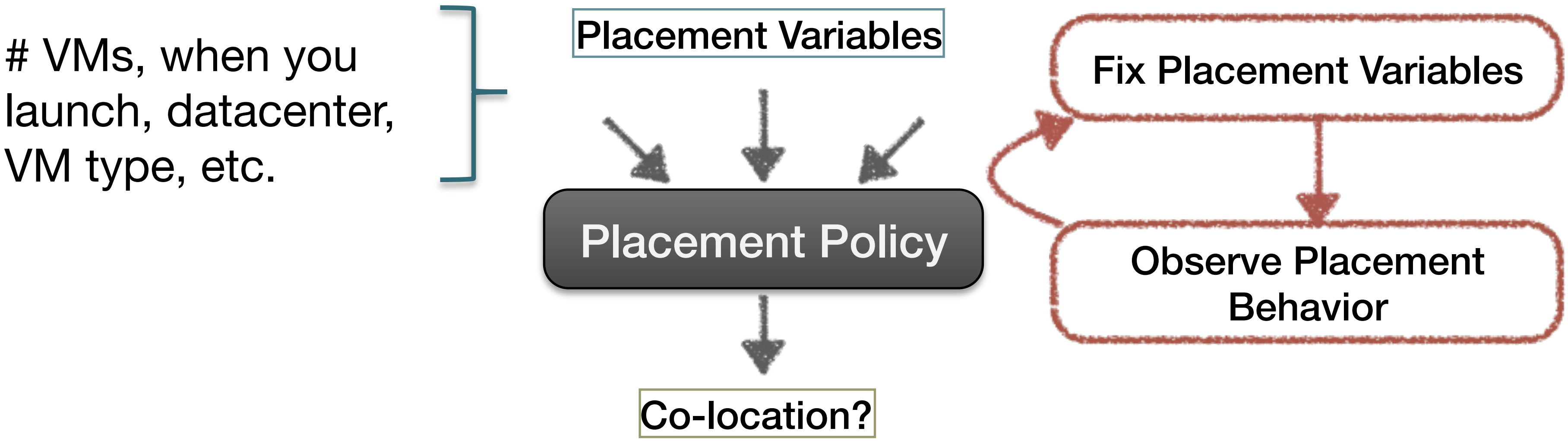


- Bohatei is a cost-effective, low-latency, agile DDoS defense by provider for tenants
  - manages dynamic 500 Gbps DDoS against tenant with < 1 min. reaction time

DDoS Defense: Bohatei
[Fayaz, Tobioka, Sekar, Bailey; USENIX Sec. 2015]



Side Channels: A Co-Location Vulnerability Study
[Varadharajan, Zhang, Ristenpart, Swift; USENIX Security 2015]



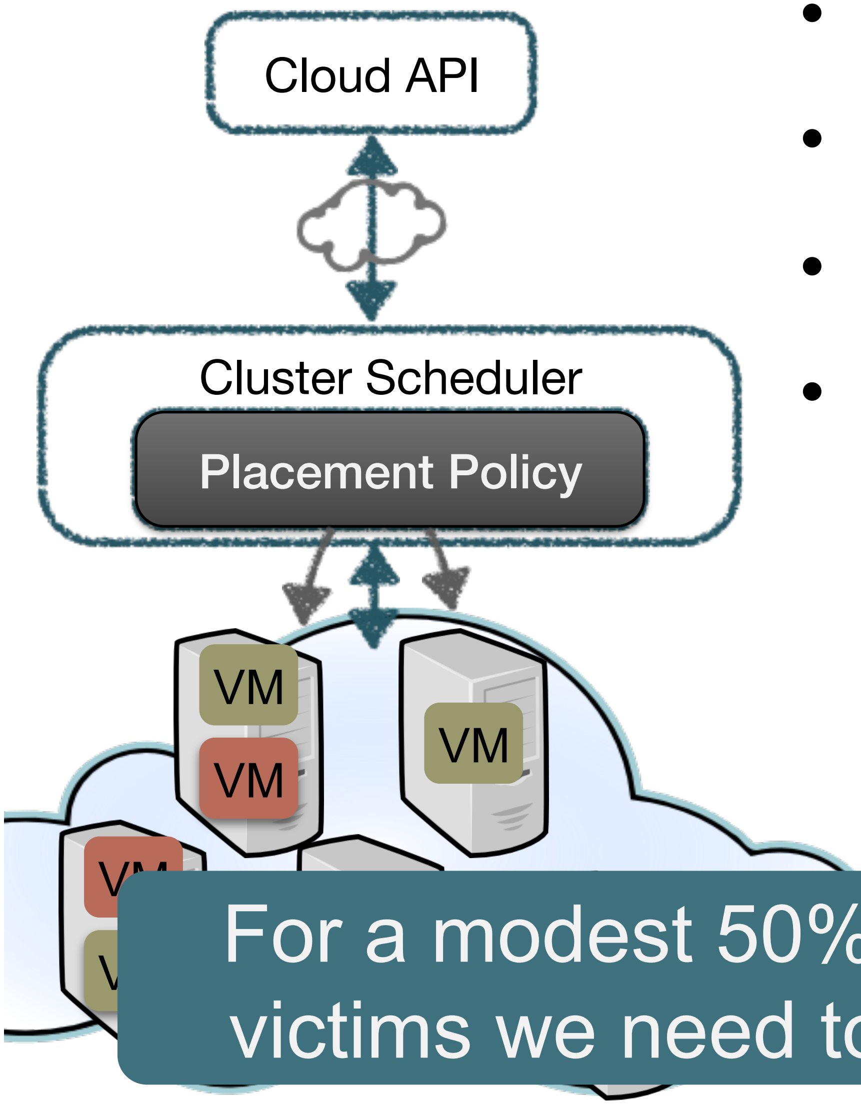
Study spanning 3 months & exploring 6 placement variables

Google Compute Engine amazon web services™ EC2 Microsoft Azure

Study Setup

- Two distinct accounts: proxy for victim and attacker
- 6 placement variables
  - # victim & attacker VMs, delay b/w launches, time of day, day of week, datacenter, cloud providers
  - Small instance type (EC2: t2.small, GCE: g1.small, Azure: Standard-A1)
  - Values for these variables form a launch strategy
- Execute a launch strategy from a workstation
  - detect and log co-location
- 9 samples per strategy with 3 runs per time of day & 2 days of week (weekday/weekend)

How Hard Should It Be To Achieve Co-location?

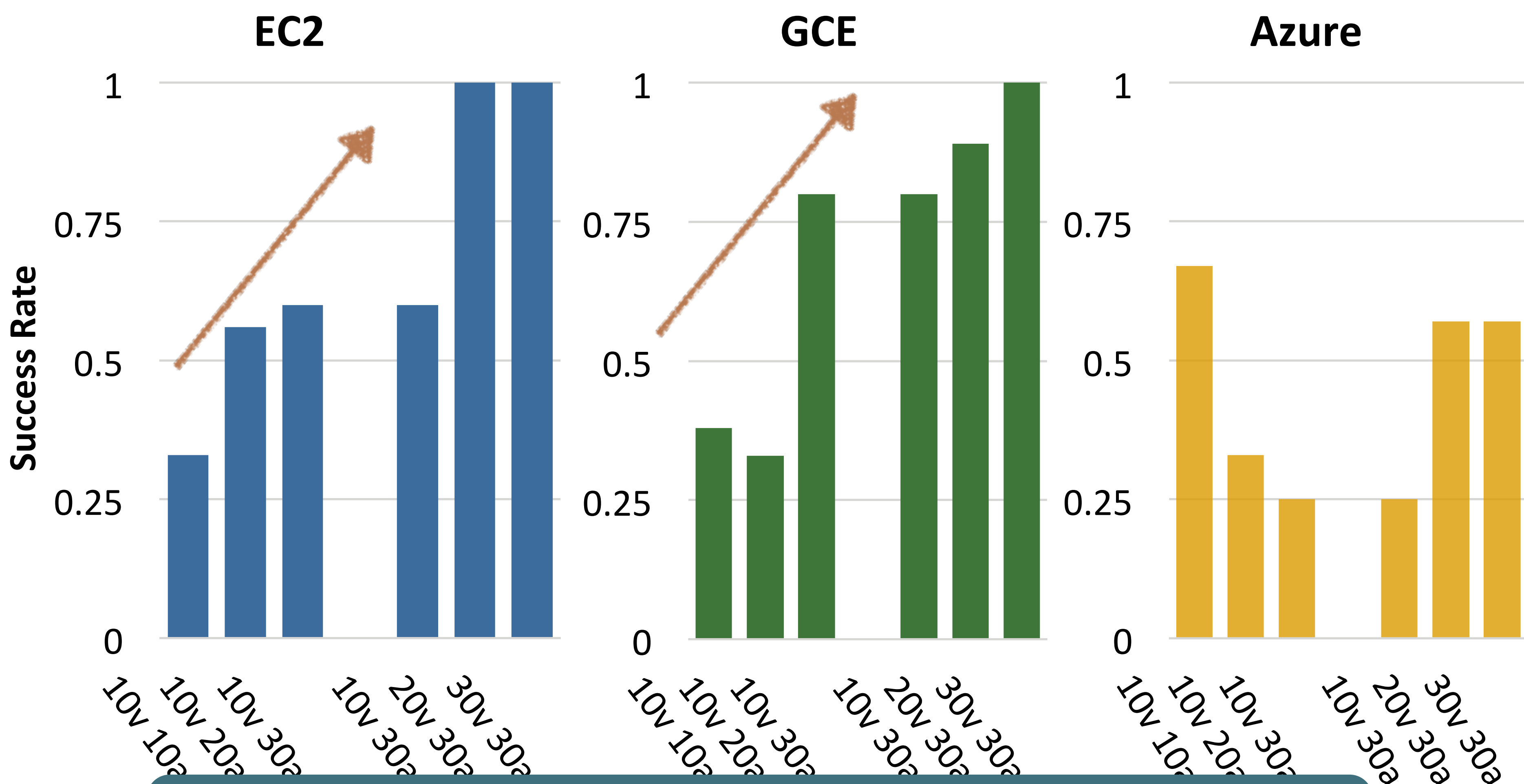


- Random placement policy
- N = 50,000 machines [re:Invent'14]
- *v* - victims and *a* - attacker VMs
- Probability of Collision:
  $P_c = 1 - (1 - v/N)^a$

v	a = ln(1− P_c)/ln(1−v/N); P_c= 0.5
10	3466

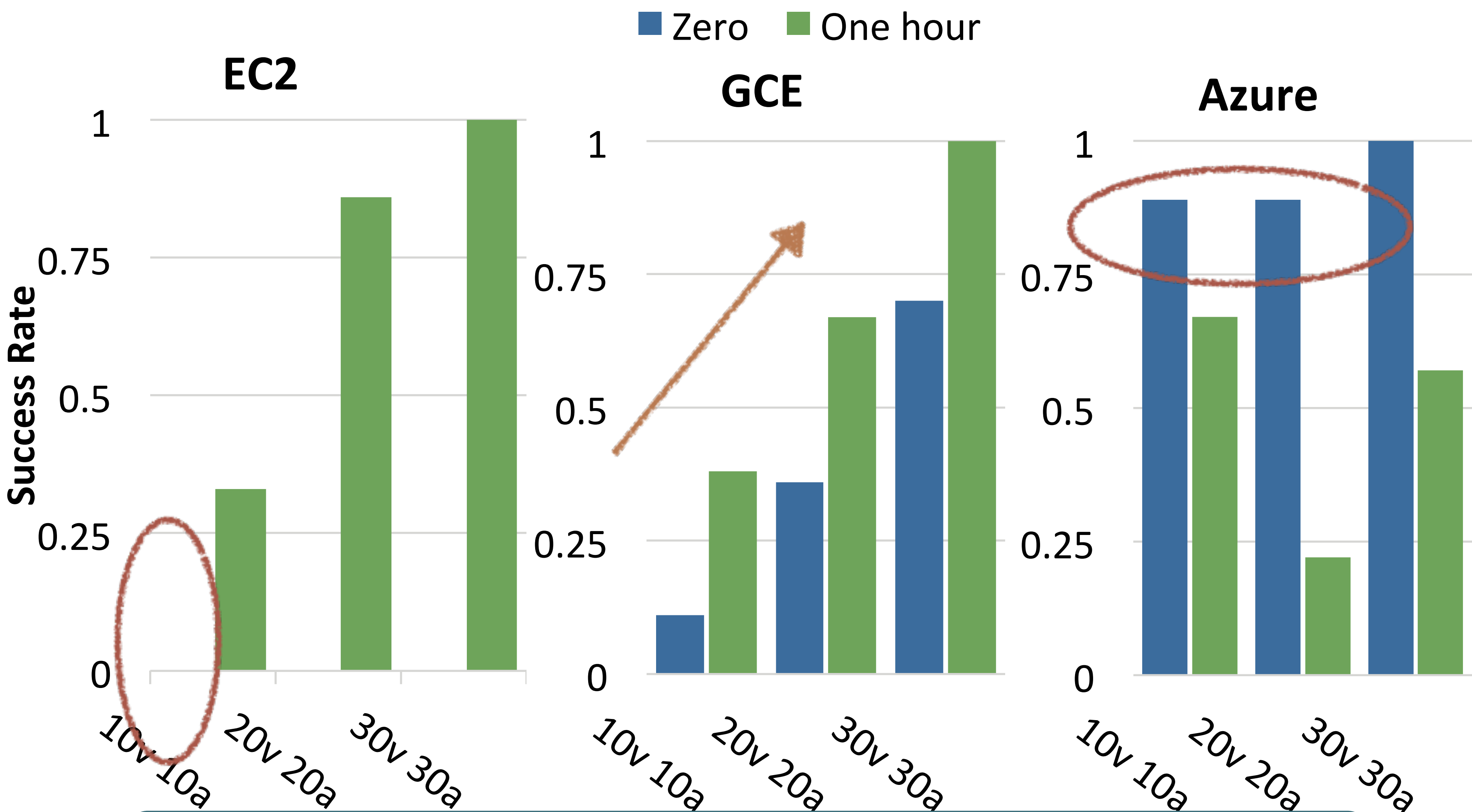
For a modest 50% success rate with 10-30 victims we need to launch 1000-3000 VMs

Results: Varying Number of VMs



Co-location is possible with as low as 10 VMs and always achieve co-location with 30 VMs

Results: Varying Delay between Launches



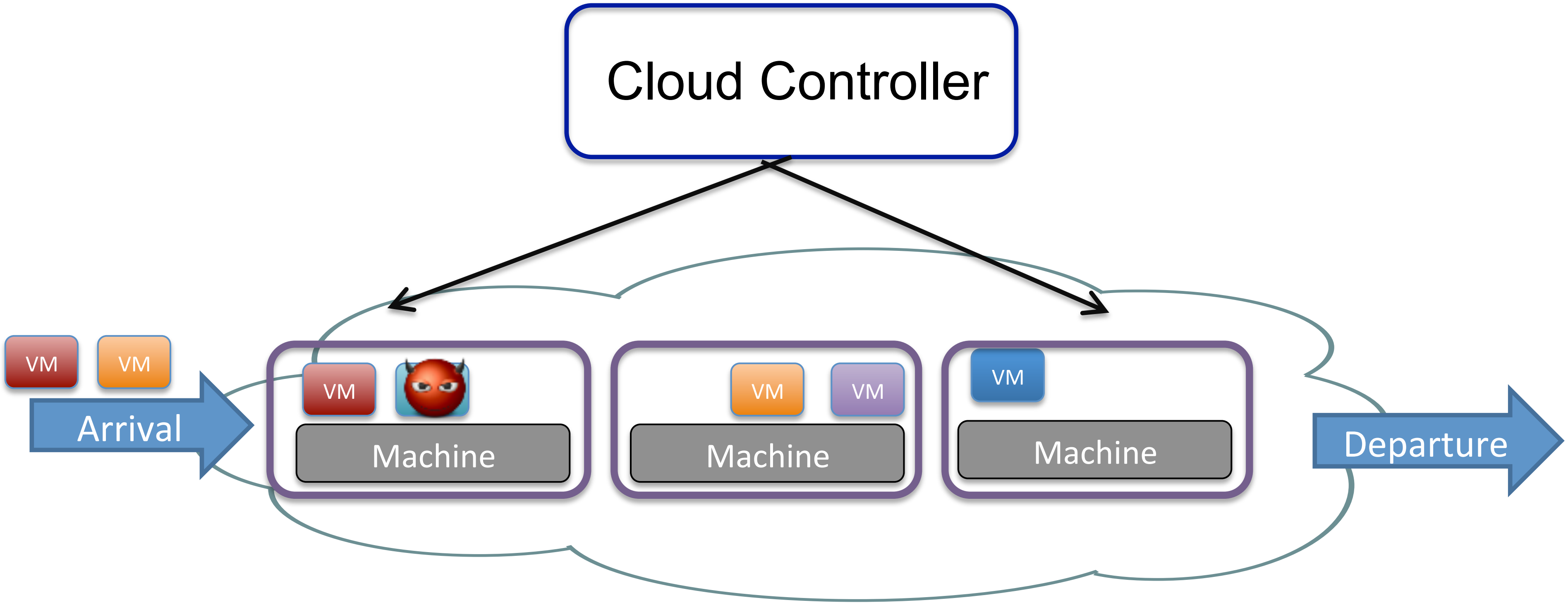
Placement policy for each cloud significantly varies

Side-Channel Defense

- A primary concern with co-location vulnerabilities is side channels
- Goal: a defense against side channels that is
  - *General* across a broad spectrum of side-channel attacks
  - *Immediately deployable* with minimal or no modifications to existing cloud hardware and software

Key idea: Migration

Tackle the *root cause* of side channels



Leverages the cloud provider as a trusted ally via an *opt-in* migration-as-a-service

Side-Channel Defense: Nomad

[Moon, Sekar, Reiter; CCS 2015]

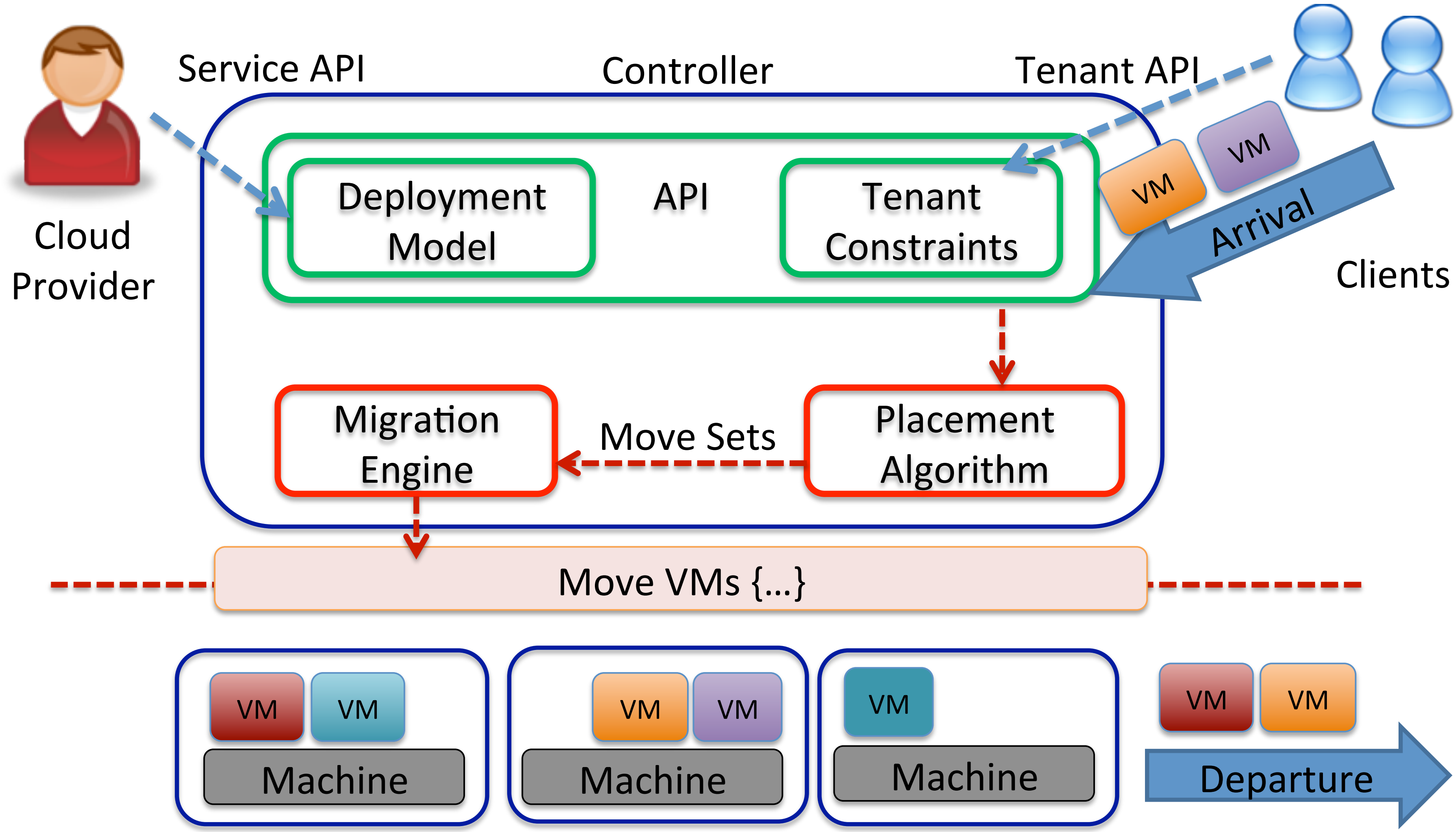
1) Vector-Agnostic Defense

Agnostic to the specific side-channel vector used

2) Minimal Modification

Can be deployed "out of the box"; requires only changing the VM placement algorithms

Nomad Overview

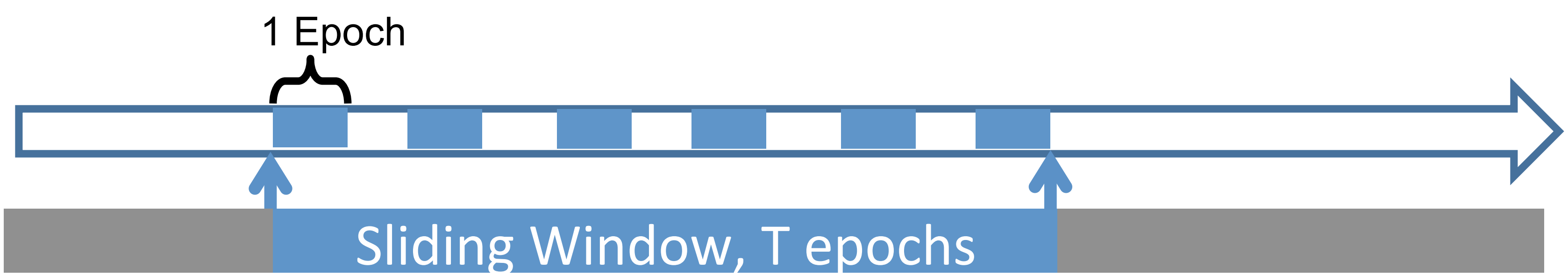


Threat Model

- Adversary capabilities
  - Identity unknown
  - Arbitrary side channels
  - Can identify targets
  - Arbitrary workloads
  - Efficient information collation
- Adversary limitations
  - No control over VM placement
  - No collusion among clients (i.e., Sybil attack)

Information Leakage Model

- What is the effect of co-residency on the amount of information leakage?
- Three dimensions
  1. Over time

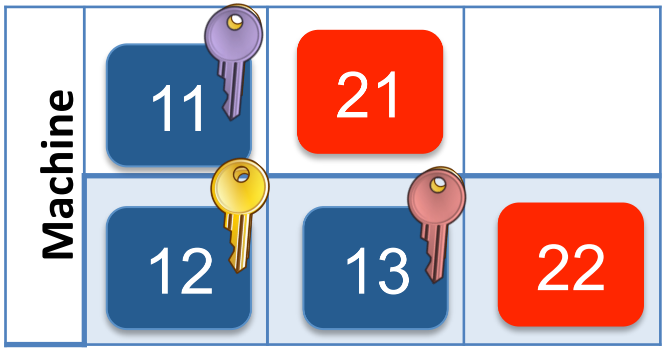


Extent of *information leakage* $\propto$ Number of epochs that VMs are co-resident in a sliding window of T epochs

Information Leakage Model

- What is the effect of co-residency on the amount of information leakage?
- Three dimensions
  2. Over victim VMs

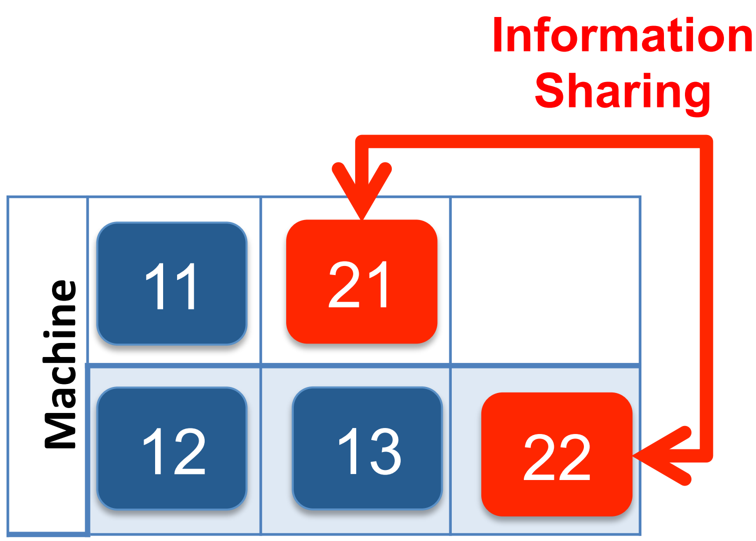
Replicated
vs.
Non-replicated



Information Leakage Model

- What is the effect of co-residency on the amount of information leakage?
- Three dimensions
  3. Over adversary VMs

Non-collaborating
vs.
Collaborating

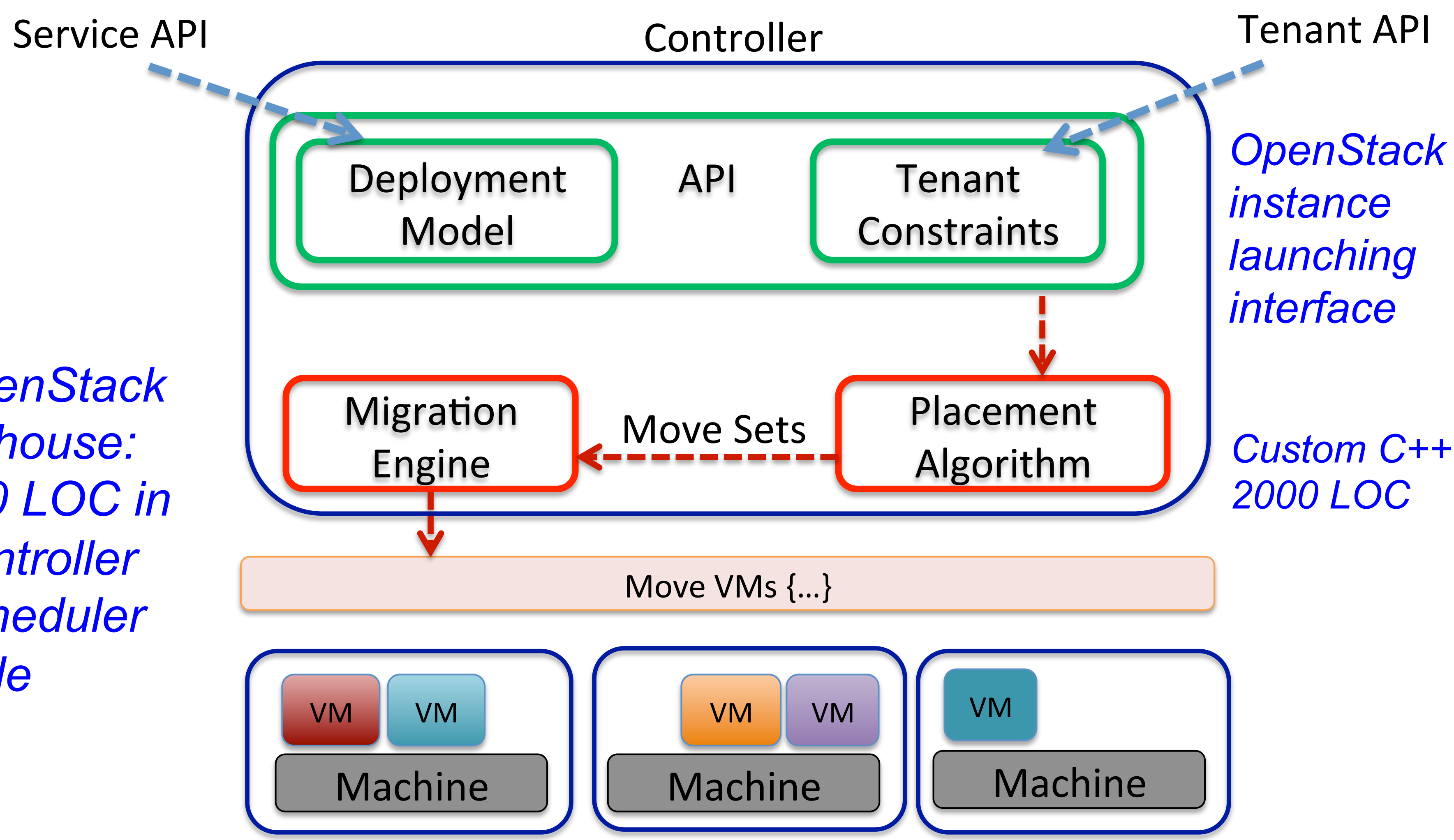


Nomad Placement Algorithm

- Nomad migrates VMs so as to (approximately) minimize information leakage over a sliding window
  - Subject to a fixed migration budget
  - Perfectly minimizing leakage isn't tractable (ILP)
- Nomad placement algorithm is greedy, but even then, requires a number of optimizations to be scalable
  - Limit migrations to free-inserts or 2-way swaps
  - Hierarchical placement: partition machines into clusters, and map tenants to clusters
  - Use lazy and incremental evaluation where possible

Nomad System Implementation

OpenStack Icehouse: 200 LOC in Controller Scheduler code



Nomad Evaluation Summary

- Greedy algorithm limits information leakage nearly optimally (albeit heuristically)
- Nomad is scalable
  - Cluster size can be 1,500 to handle 1 min goal
  - For cluster size of 20
    - Nomad takes 0.015s
    - ILP takes > 1 day
- Migrations do not substantially hurt job performance

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For more information, please see http://silver.web.unc.edu

Questions?