Cloud security

CS642: Computer Security

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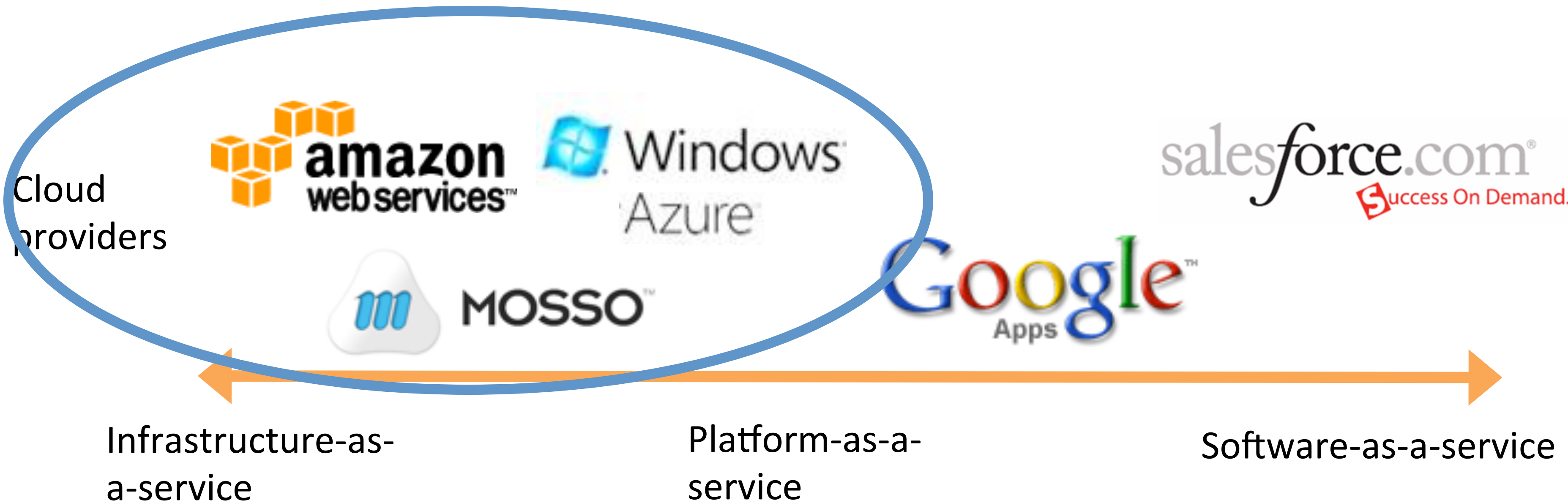
Announcements

- No office hour today
  - Extra TA office hour tomorrow (10-11am or 3-4pm?)
- No class Wednesday
- Homework 3 due Wednesday
- Homework 4 later this week
- Project presentations Dec 10 and 12
- Take-home final handed out Dec 12
  - Due one week later

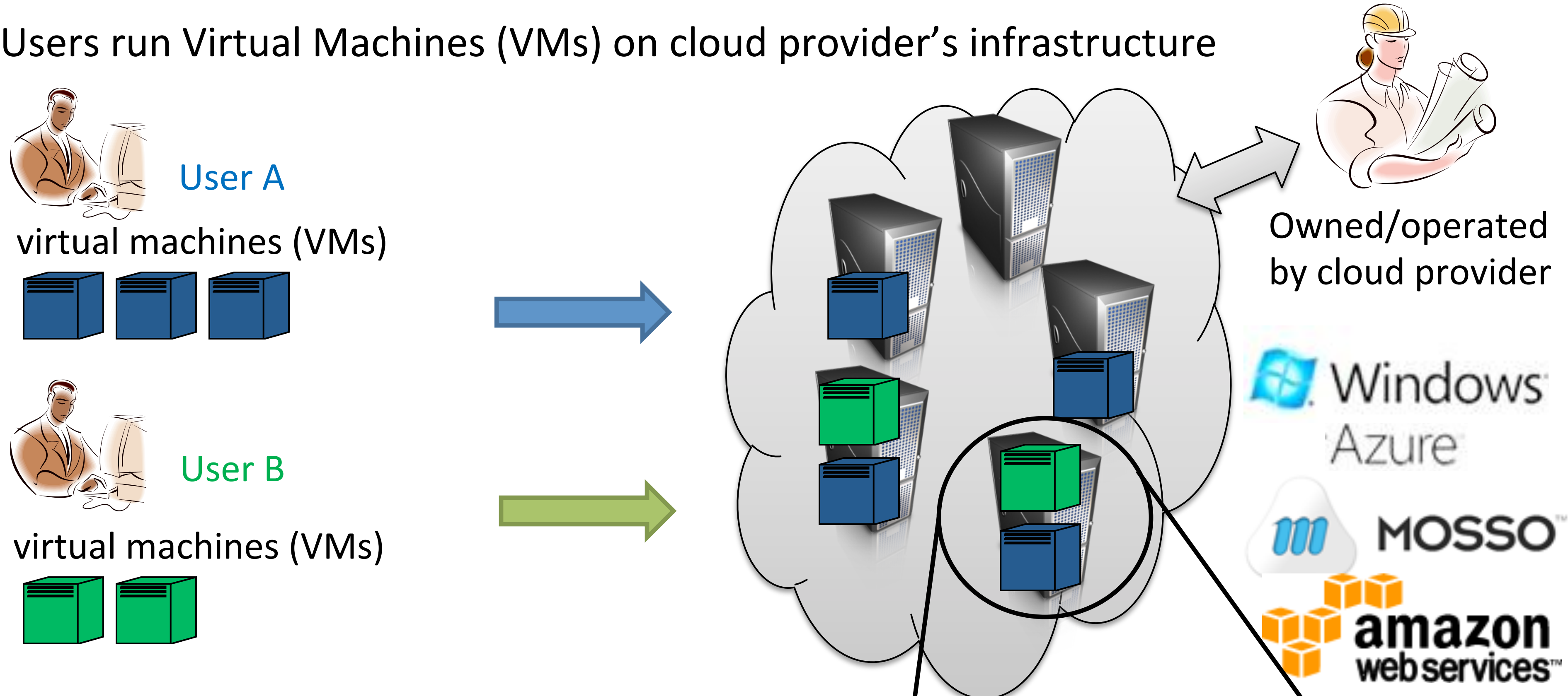
Cloud computing

NIST: Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.



A simplified model of public cloud computing

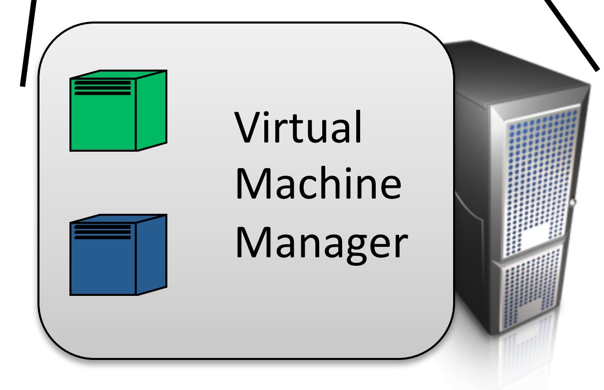
Users run Virtual Machines (VMs) on cloud provider's infrastructure



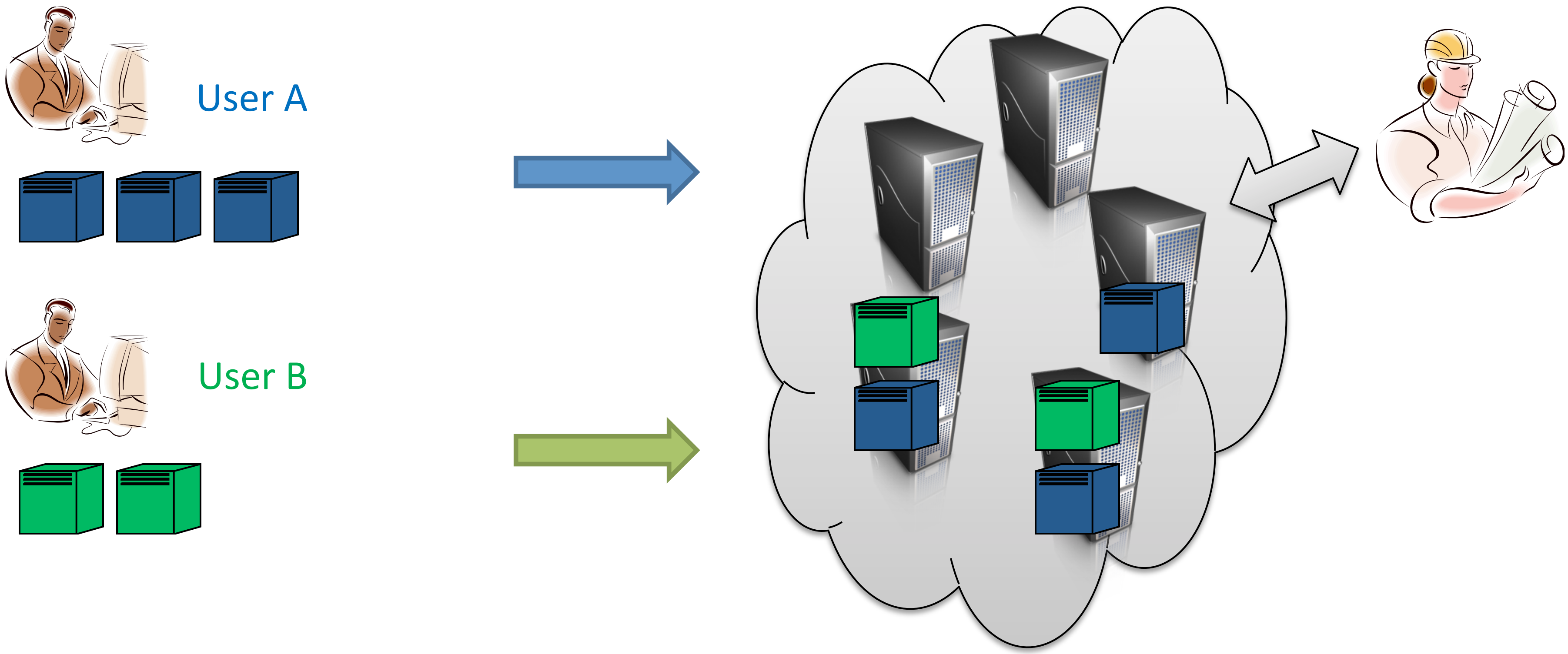
Multitenancy (users share physical resources)

Virtual Machine Manager (VMM) manages physical server resources for VMs

To the VM should look like dedicated server



Trust models in public cloud computing



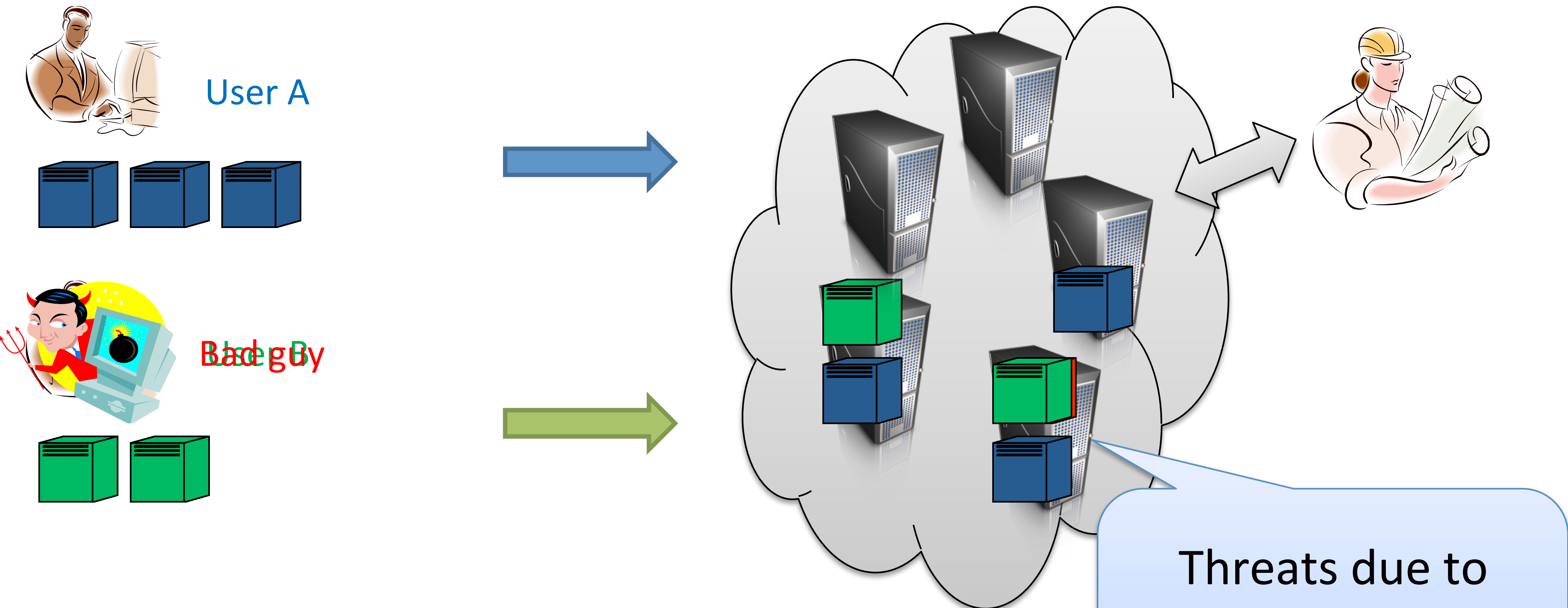
Users must trust third-party provider to

not spy on running VMs / data

secure infrastructure from external attackers

secure infrastructure from internal attackers

Trust models in public cloud computing

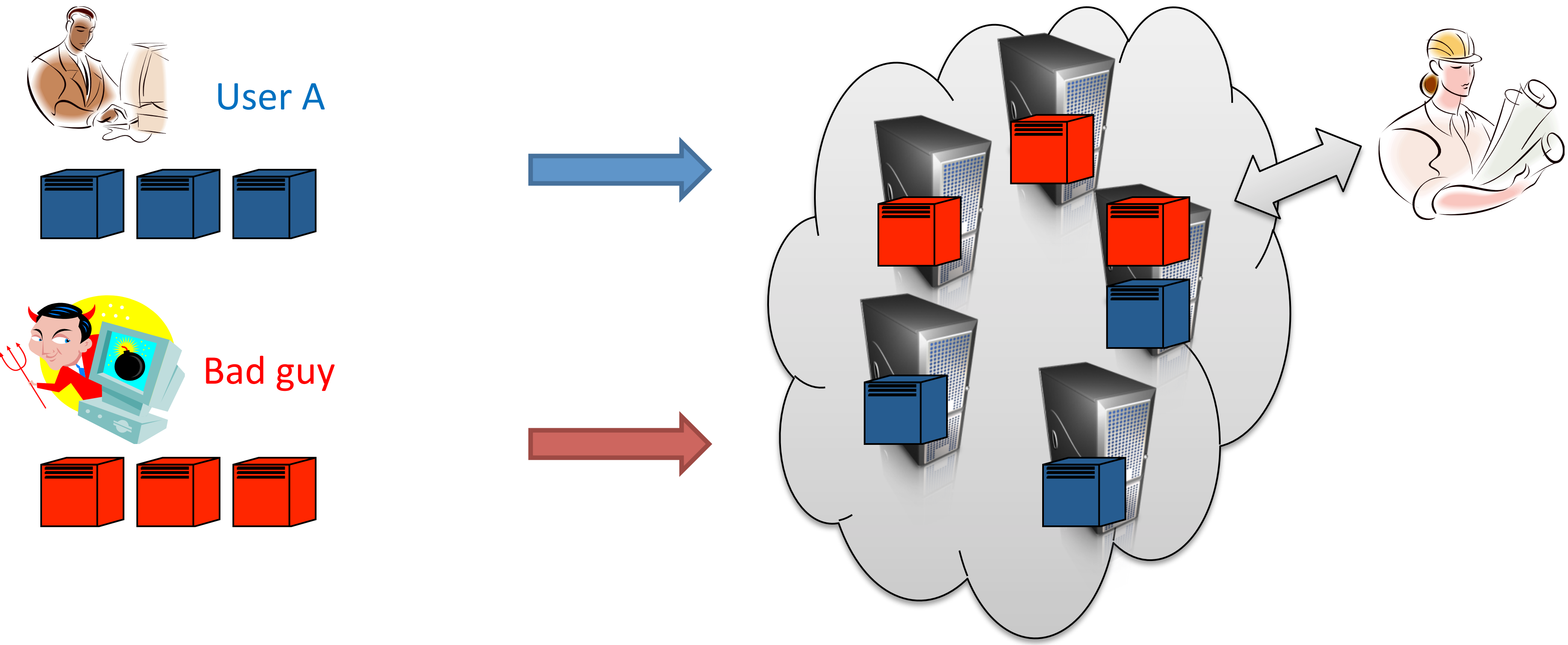


Threats due to sharing of physical infrastructure ?

Users must trust third-party provider to

- not spy on running VMs / data
- secure infrastructure from external attackers
- secure infrastructure from internal attackers
  - Your business competitor
  - Script kiddies
  - Criminals
  - …

A new threat model:



Attacker identifies one or more victims VMs in cloud

1) Achieve advantageous placement via launching of VM instances

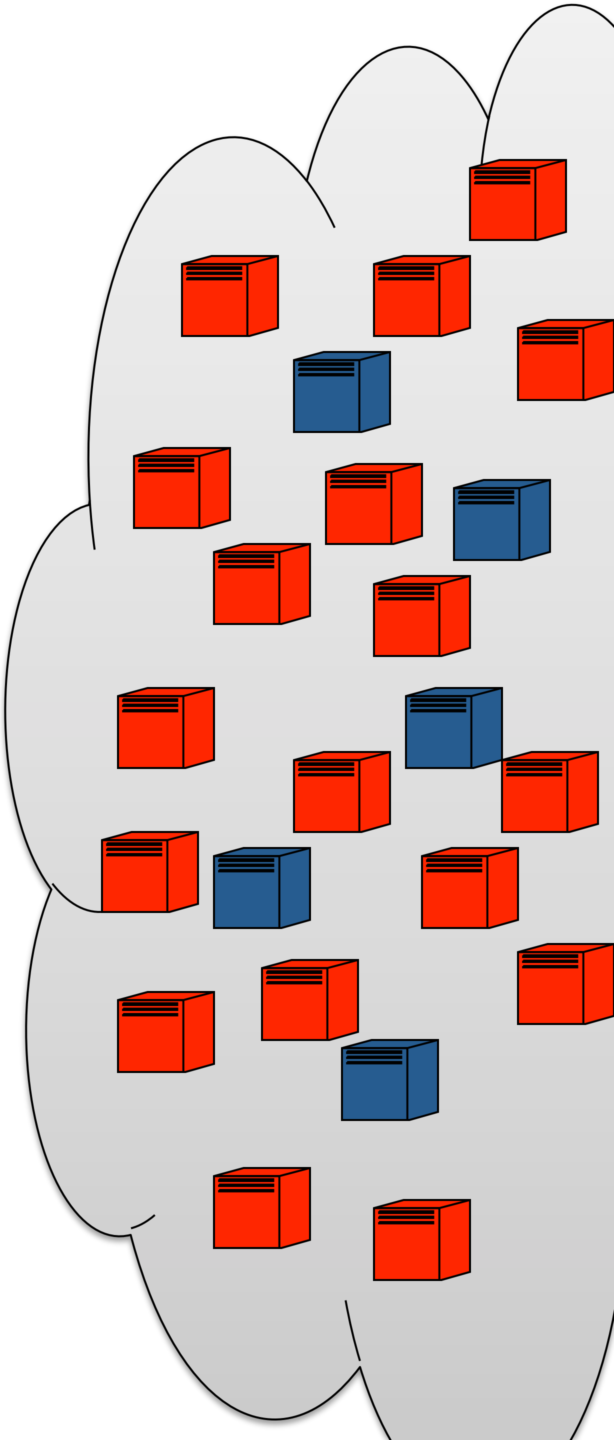
2) Launch attacks using physical proximity

Exploit VMM vulnerability DoS Side-channel attack

1 or more targets in the cloud and we want to attack them from same physical host

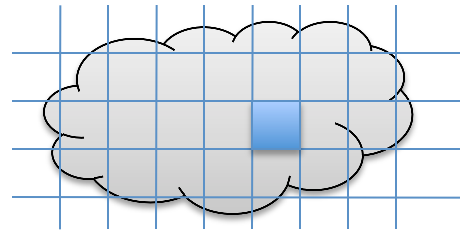
Launch lots of instances (over time), with each attempting an attack

Can attackers do better?



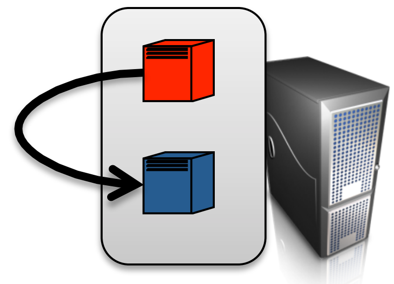
Outline of a more damaging approach:

1) Cloud cartography



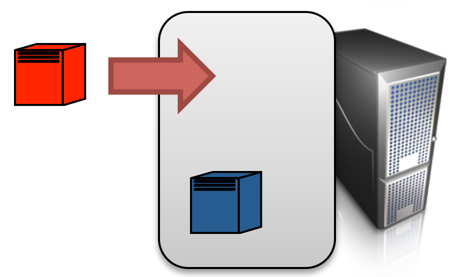
map internal infrastructure of cloud
map used to locate targets in cloud

2) Checking for co-residence



check that VM is on same server as target
- network-based co-residence checks
- efficacy confirmed by covert channels

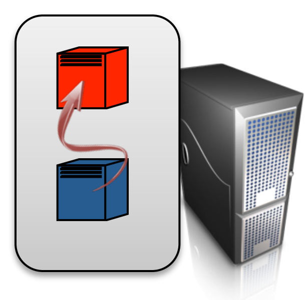
3) Achieving co-residence



brute forcing placement
instance flooding after target launches

Placement vulnerability: attackers can knowingly achieve co-residence with target

4) Location-based attacks



side-channels, DoS, escape-from-VM

Case study with Amazon's EC2

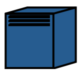
1) given no insider information

2) restricted by (the spirit of) Amazon's acceptable use policy (AUP)

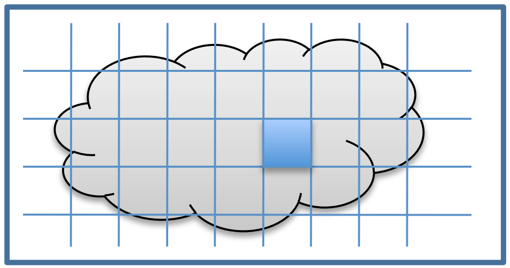
(using only Amazon's customer APIs and very restricted network probing)

We were able to:

Pick target(s)

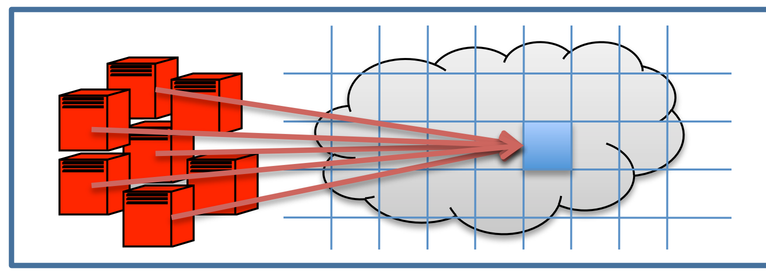


"Cloud cartography"



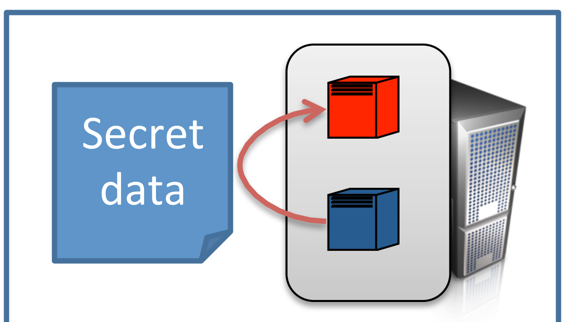
Choose launch parameters for malicious VMs

Each VM checks for co-residence



Frequently achieve advantageous placement

Cross-VM side channel attacks to spy on victim's computational load



Some info about EC2 service (at time of study)

Linux-based VMs available
Uses Xen-based VM manager

launch parameters

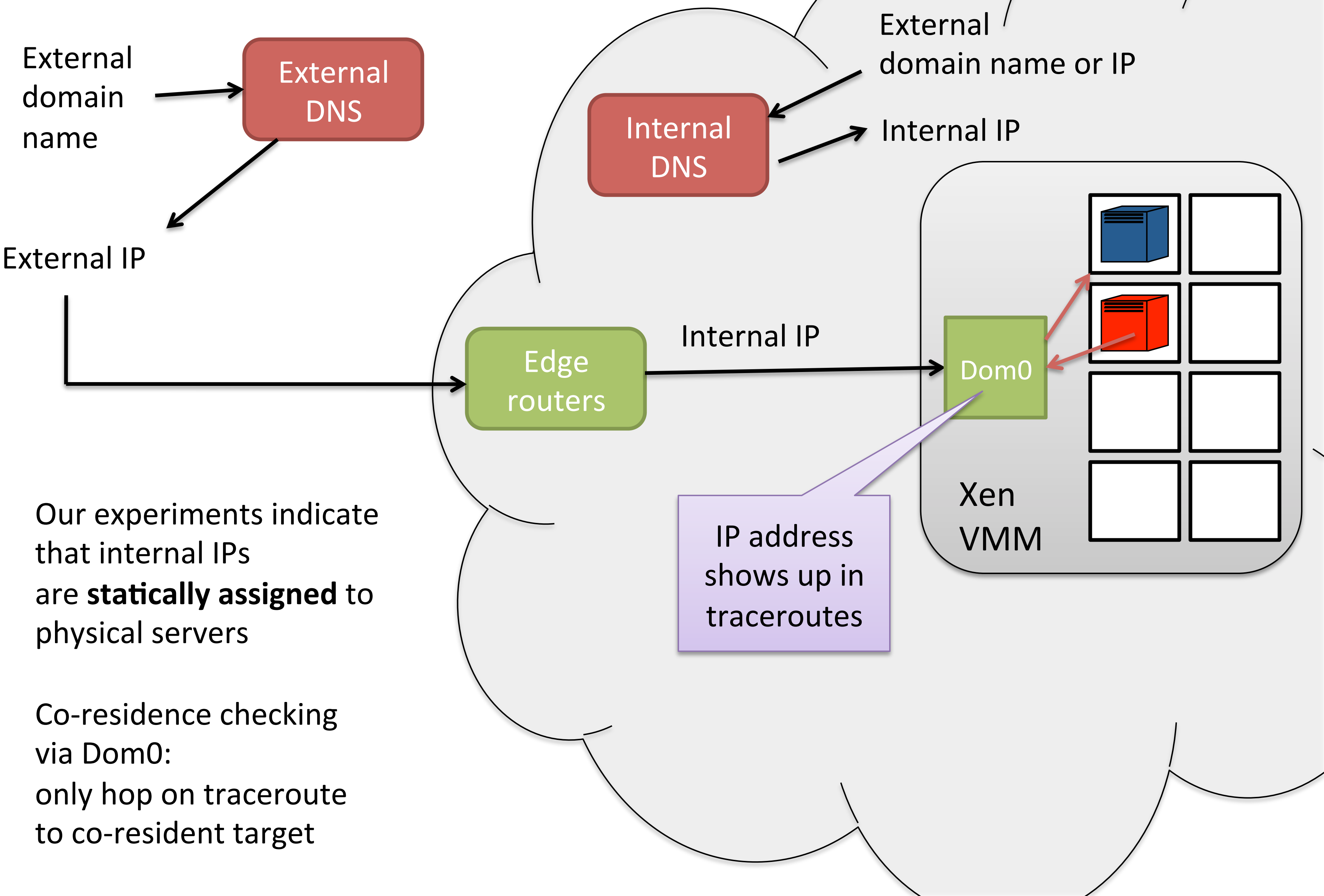
- User account
- 3 “availability zones” (Zone 1, Zone 2, Zone 3)
- 5 instance types (various combinations of virtualized resources)

Type	gigs of RAM	EC2 Compute Units (ECU)
m1.small (default)	1.7	1
m1.large	7.5	4
m1.xlarge	15	8
c1.medium	1.7	5
c1.xlarge	7	20

1 ECU = 1.0-1.2 GHz 2007 Opteron or 2007 Xeon processor

Limit of 20 instances at a time per account.
Essentially unlimited accounts with credit card.

(Simplified) EC2 instance networking

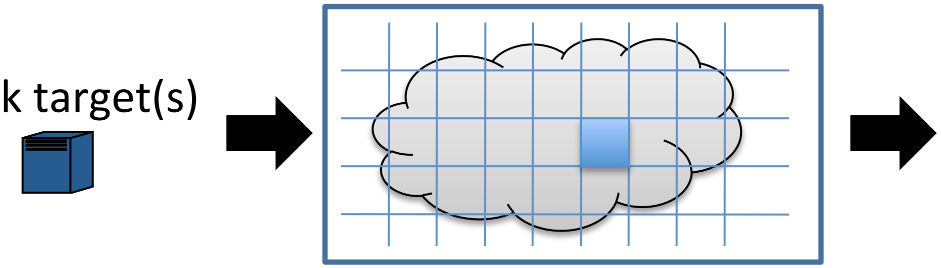


Our experiments indicate that internal IPs are **statically assigned** to physical servers

Co-residence checking via Dom0:
only hop on traceroute to co-resident target

Cloud cartography

Pick target(s)



Choose launch parameters for malicious VMs

launch parameters

3 "availability zones"
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5 instance types
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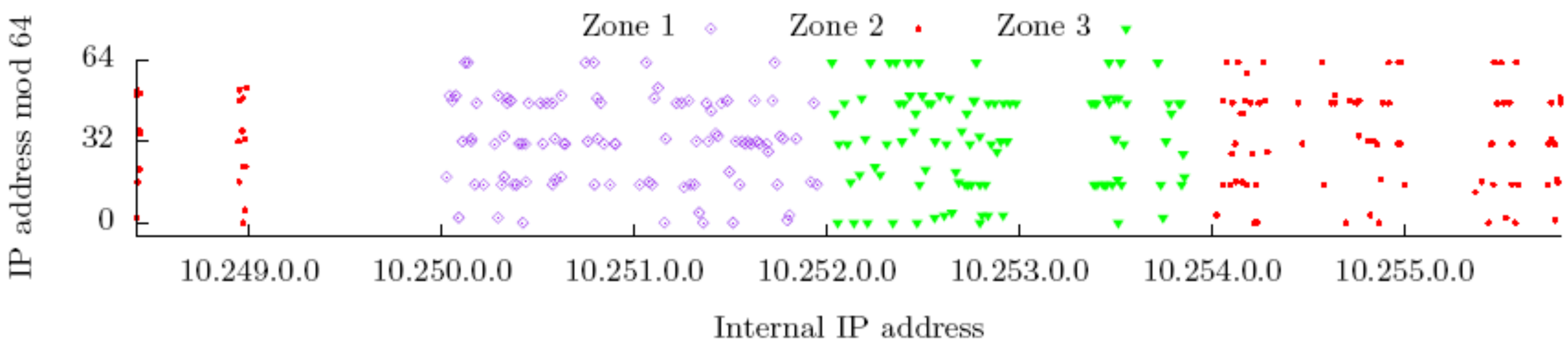
User account



Cloud cartography

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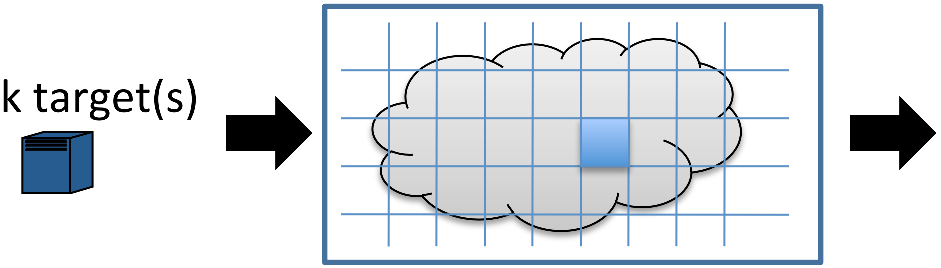

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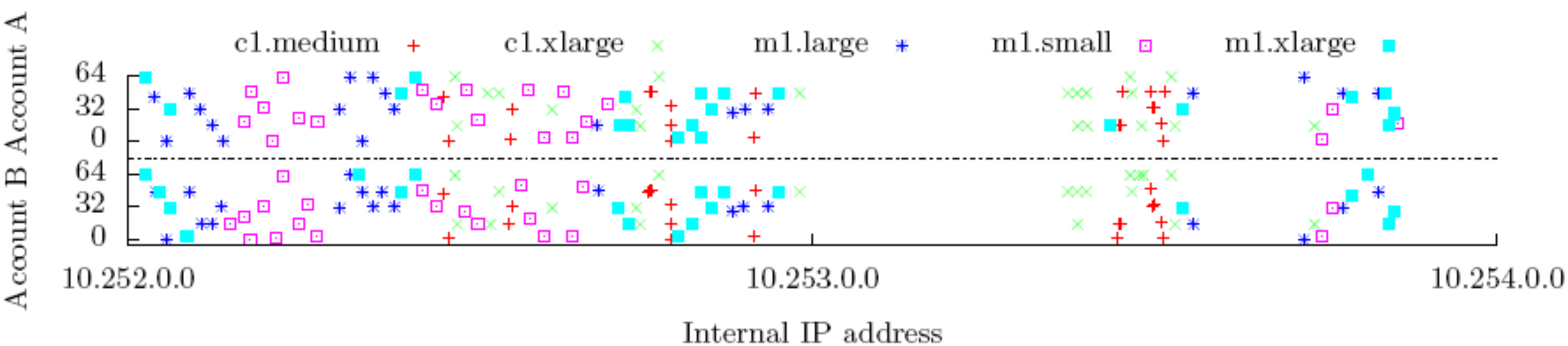
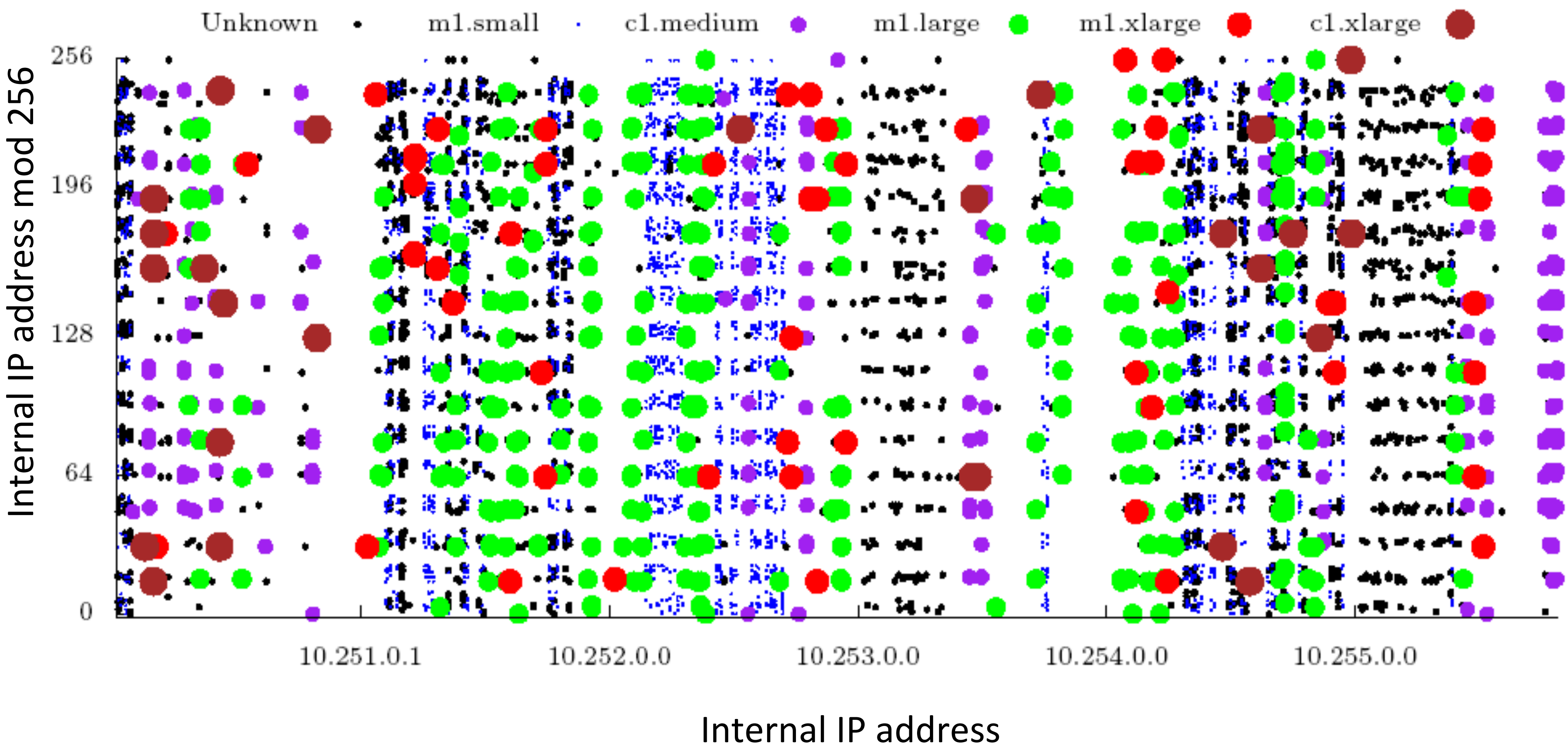


Associate to each /24 an estimate of Availability zone and Instance Type

External IP → (DNS) → Internal IP → (/24) → Availability zone / Instance Type

Mapping 6,577 public HTTP servers running on EC2 (Fall 2008)



Achieving co-residence

"Brute-forcing" co-residence

Attacker launches many VMs over a relatively long period of time in target's zone and of target type

Experiment:

1,686 public HTTP servers as stand-in "targets" running m1.small and in Zone 3 (via our map)

1,785 "attacker" instances launched over 18 days

Each checked co-residence against all targets using Dom0 IP

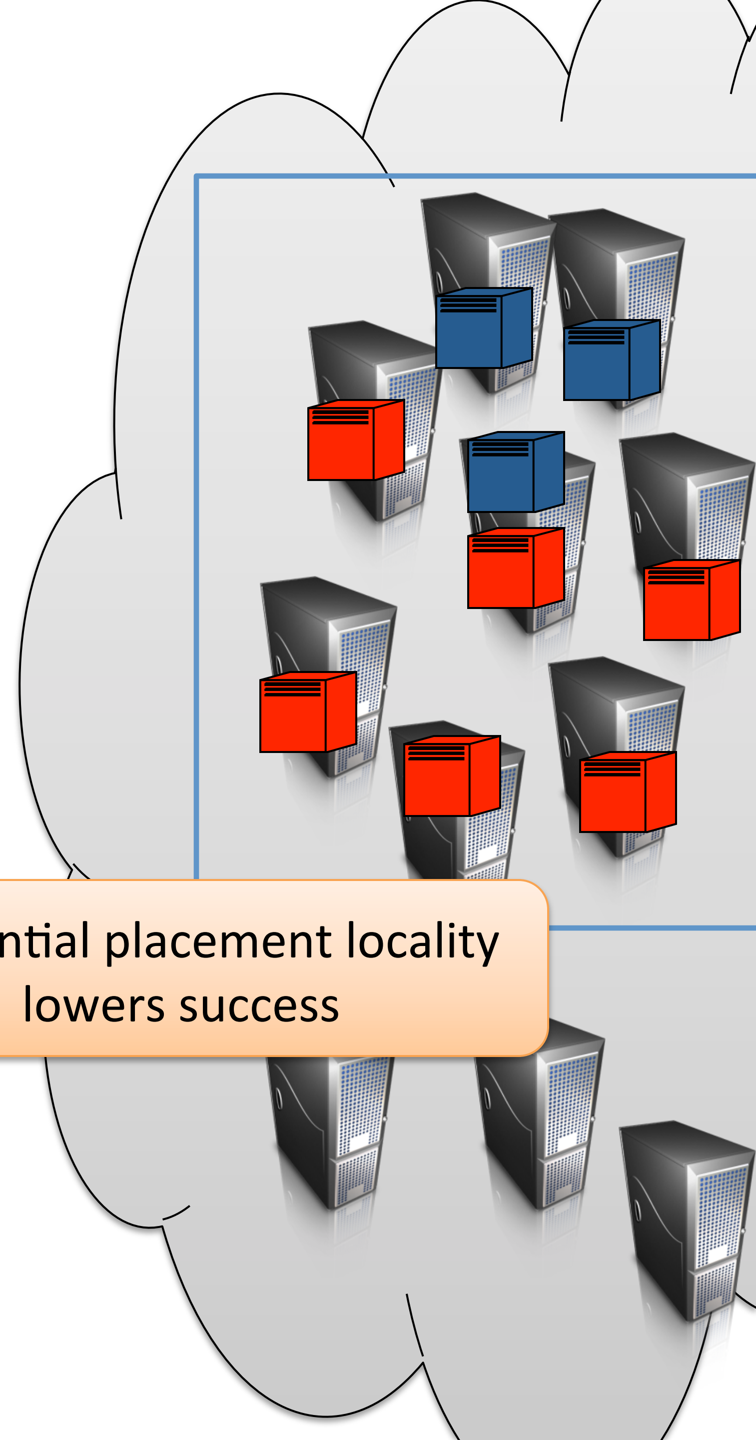
Results:

78 unique Dom0 IPs

141 / 1,686 (8.4%) had attacker co-resident

Sequential placement locality lowers success

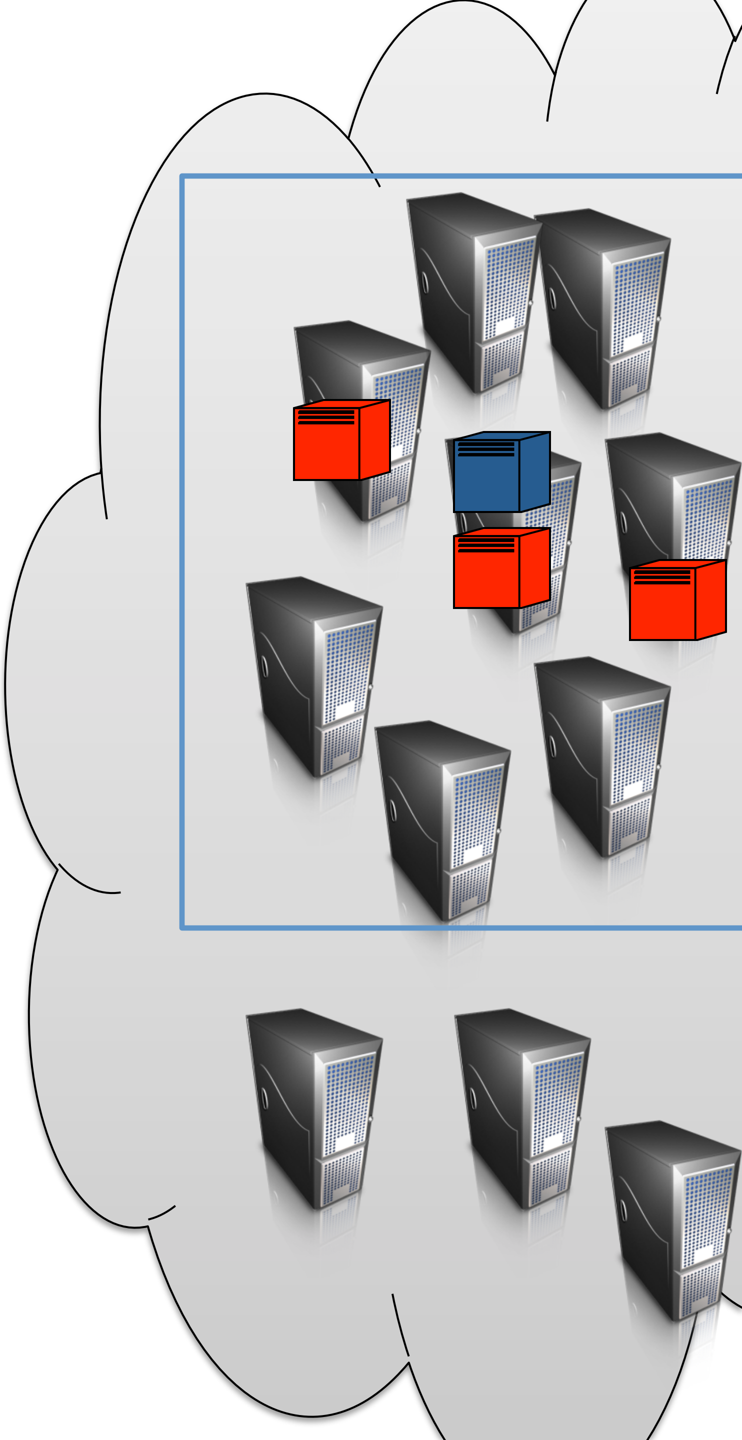
Lower bound on true success rate



Achieving co-residence

Instance flooding near target launch abuses parallel placement locality

Launch many instances in parallel near time of target launch



Achieving co-residence

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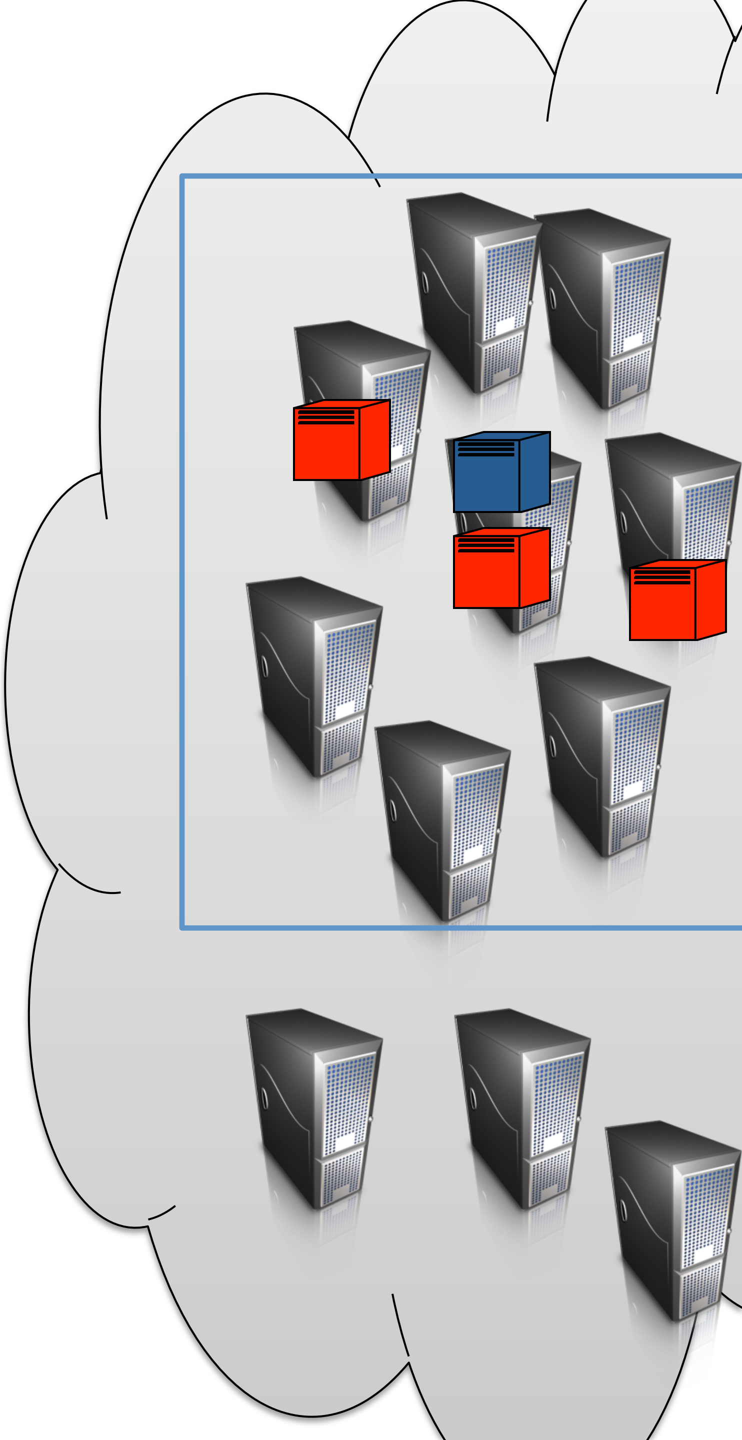


Experiment:

Repeat for 10 trials:

1) Launch 1 target VM (Account A)

2) 5 minutes later, launch 20 "attack" VMs (alternate using Account B or C)

3) Determine if any co-resident with target using Dom0 IP

4 / 10 trials succeeded

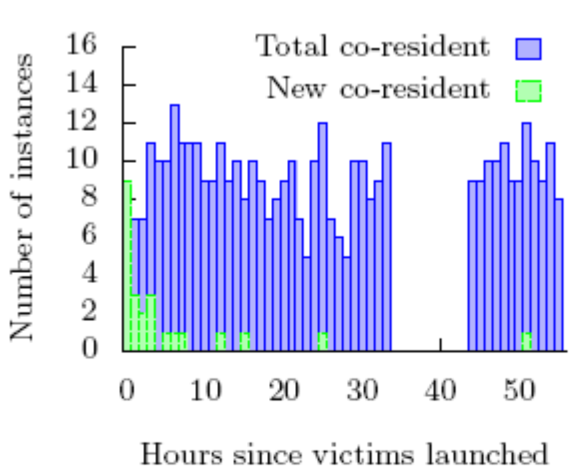
Achieving co-residence

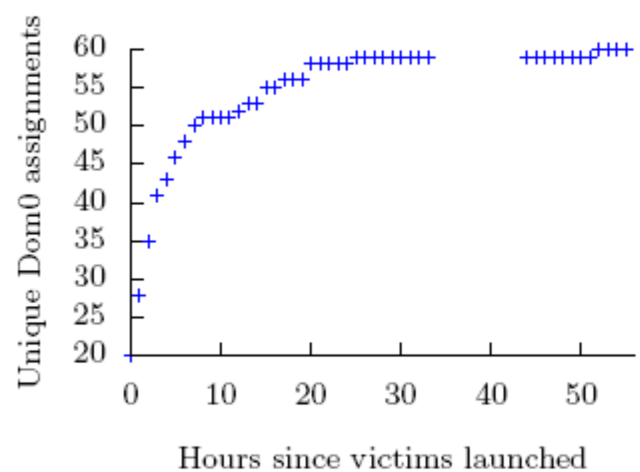
Instance flooding near target launch abuses
parallel placement locality

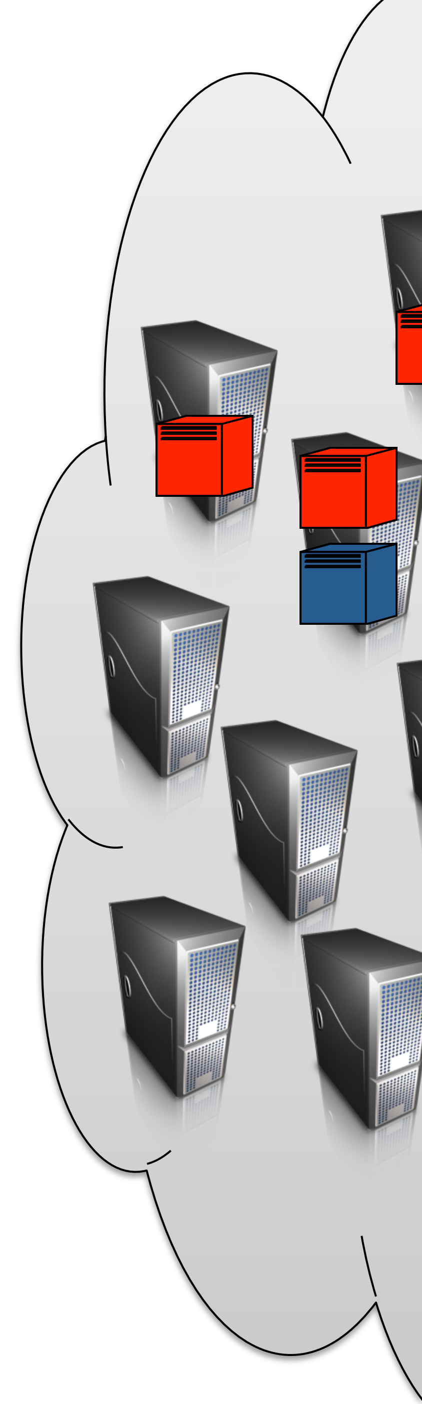
How long is parallel placement locality good for?

Experiment:

40 “target” VMs (across two accounts)
20 “attack” VMs launched hourly







Achieving co-residence

Instance flooding near target launch abuses
parallel placement locality

What about commercial accounts?

RightScale

2 attempts

1^{st} – coresident
w/ 40 VMs

2^{nd} – 2 VMs coresident
w/ 40 launched

rPath

Several attempts

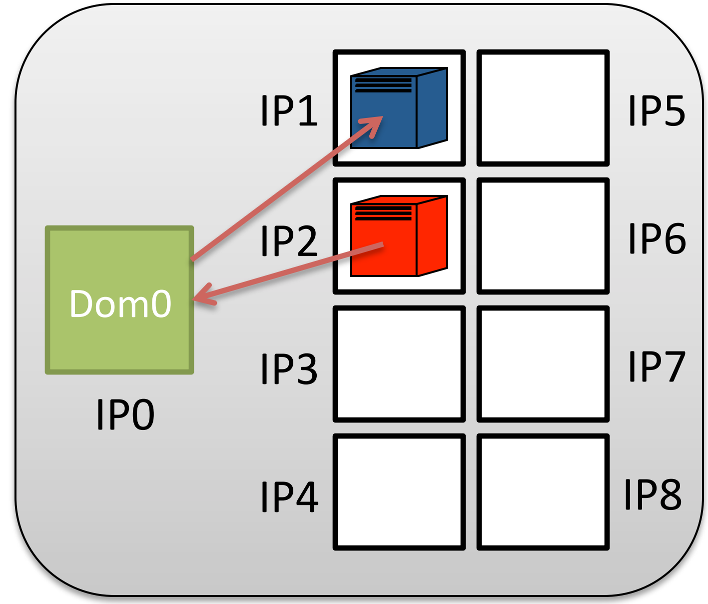
1^{st} – coresident
w/ 40 VMs

Subsequent
attempts
failed

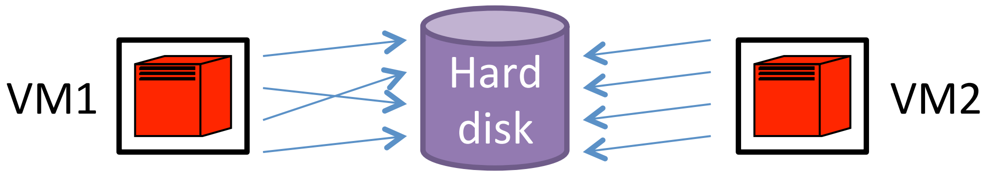
Free demos
of Internet appliances
powered by EC2

Checking for co-residence

How do we know Dom0 IP is valid co-residence check?



Use simple covert channel as ground truth:



Sender transmits ‘1’ by franticly reading random locations

Receiver times reading of a fixed location

Sender transmits ‘0’ by doing nothing

Covert channels require control of both VMs:
we use only to **verify** network-based co-residence check

Checking for co-residence

Experiment

Repeat 3 times:

1) 20 m1.small Account A
2) 20 m1.small Account B
3) All pairs w/ matching Dom0 → send 5-bit message across HD covert channel

Dom0 check works

Ended up with 31 pairs of co-resident instances as indicated by Dom0 IPs

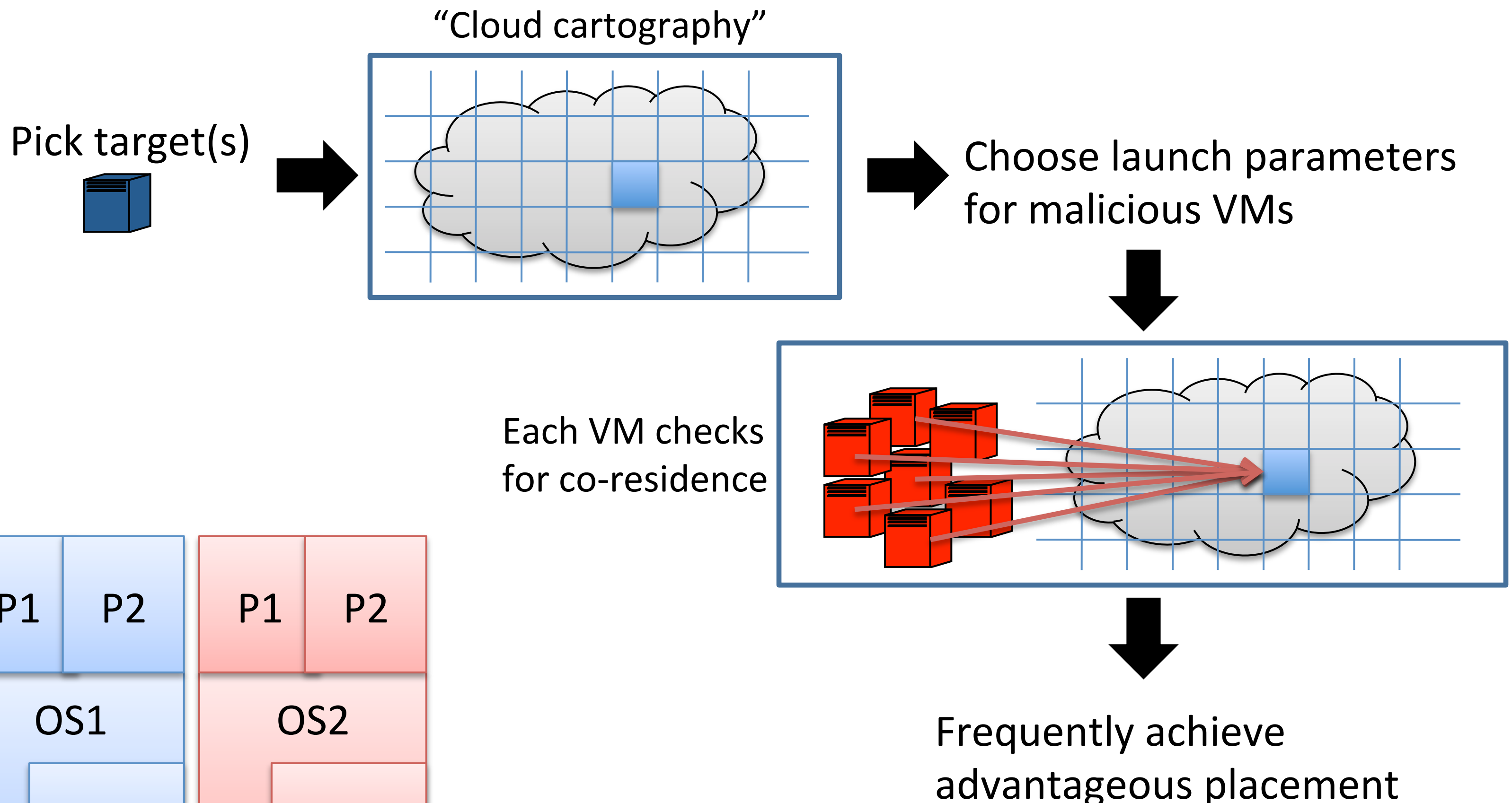
Result: a correctly-received message sent for every pair of instances

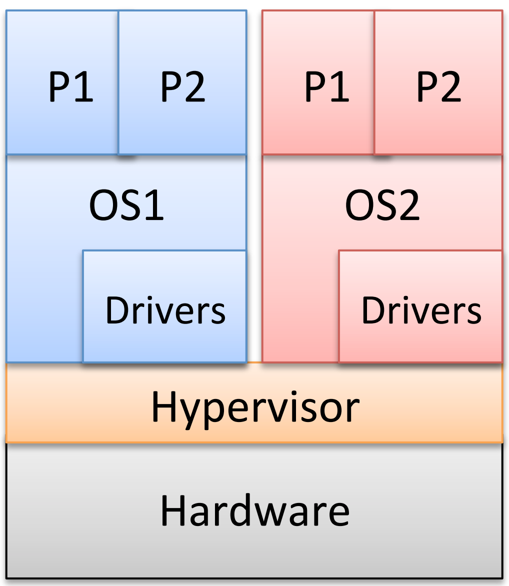
During experiment also performed pings to:
* 2 control instances in each zone
* co-resident VM

RTT times also indicate co-residence

	Median RTT (ms)
Zone 1 Control 1	1.164
Zone 1 Control 2	1.027
Zone 2 Control 1	1.113
Zone 2 Control 2	1.187
Zone 3 Control 1	0.550
Zone 3 Control 2	0.436
Co-resident VM	0.242

So far we were able to:

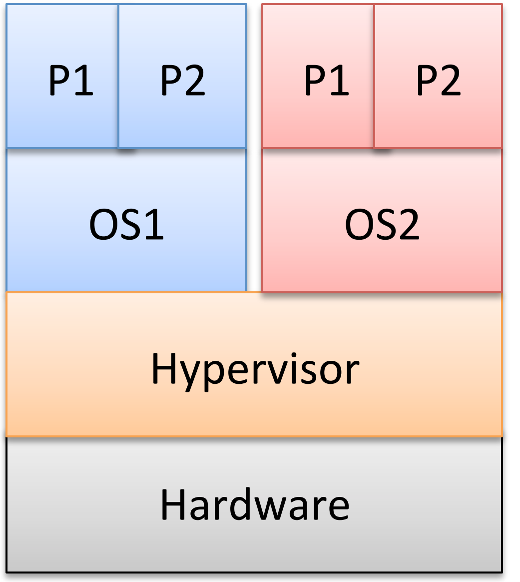




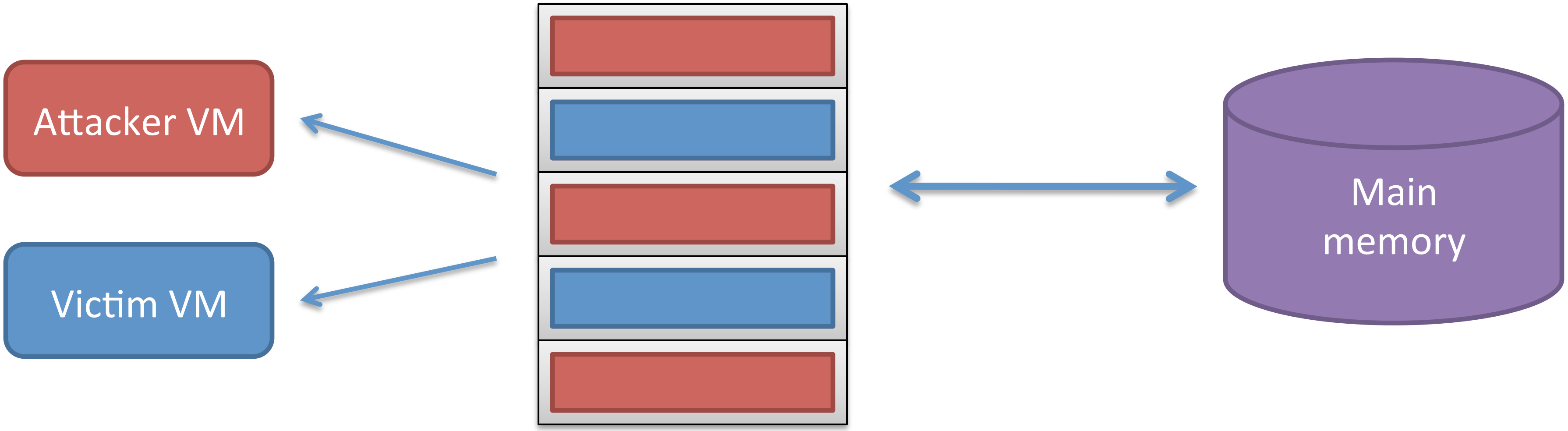
This shouldn't matter if VMM provides good isolation!

Violating isolation

- Hard drive covert channel used to validate Dom0 co-residence check already violated isolation
- Degradation-of-Service attacks
  - Guests might maliciously contend for resources
  - Xen scheduler vulnerability
- Escape-from-VM vulnerabilities
- Side-channel attacks



Cross-VM side channels using CPU cache contention



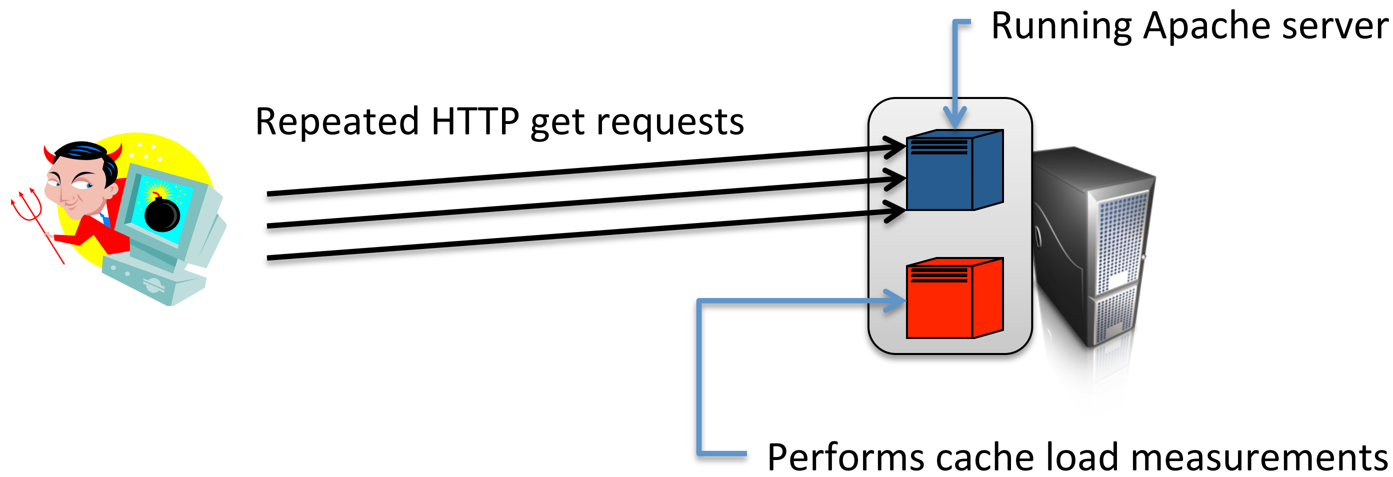
CPU data cache

1) Read in a large array (fill CPU cache with attacker data)

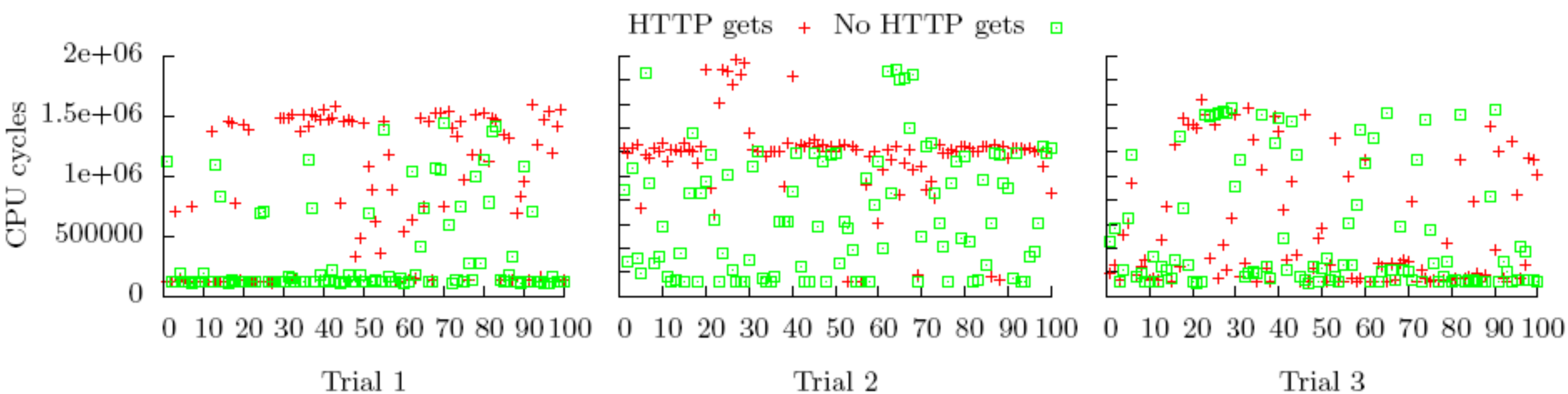
2) Busy loop (allow victim to run)

3) Measure time to read large array (the load measurement)

Cache-based cross-VM load measurement on EC2

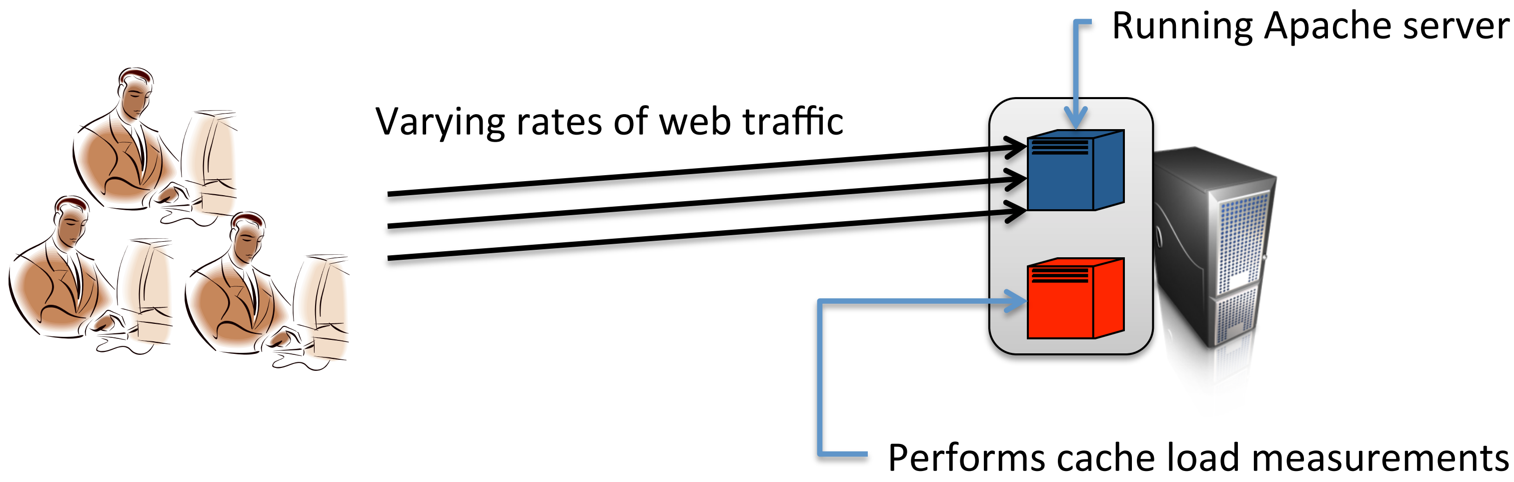


3 pairs of instances, 2 pairs co-resident and 1 not
100 cache load measurements during **HTTP gets** (1024 byte page) and with **no HTTP gets**

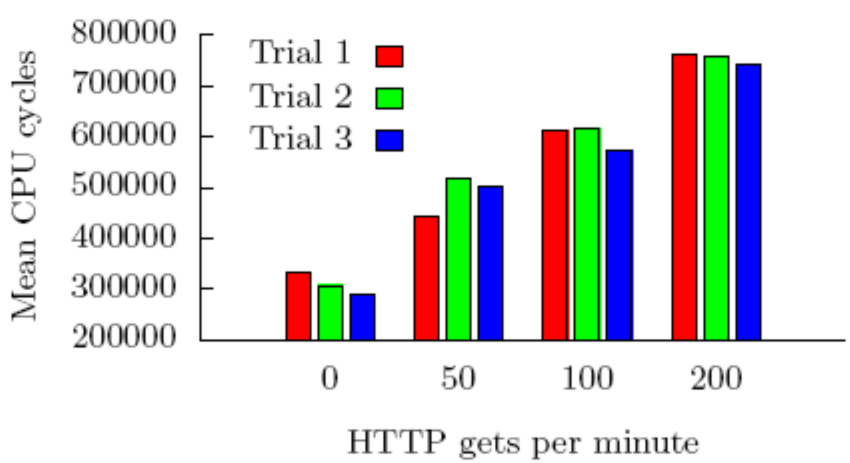


Instances co-resident | Instances co-resident | Instances NOT co-resident

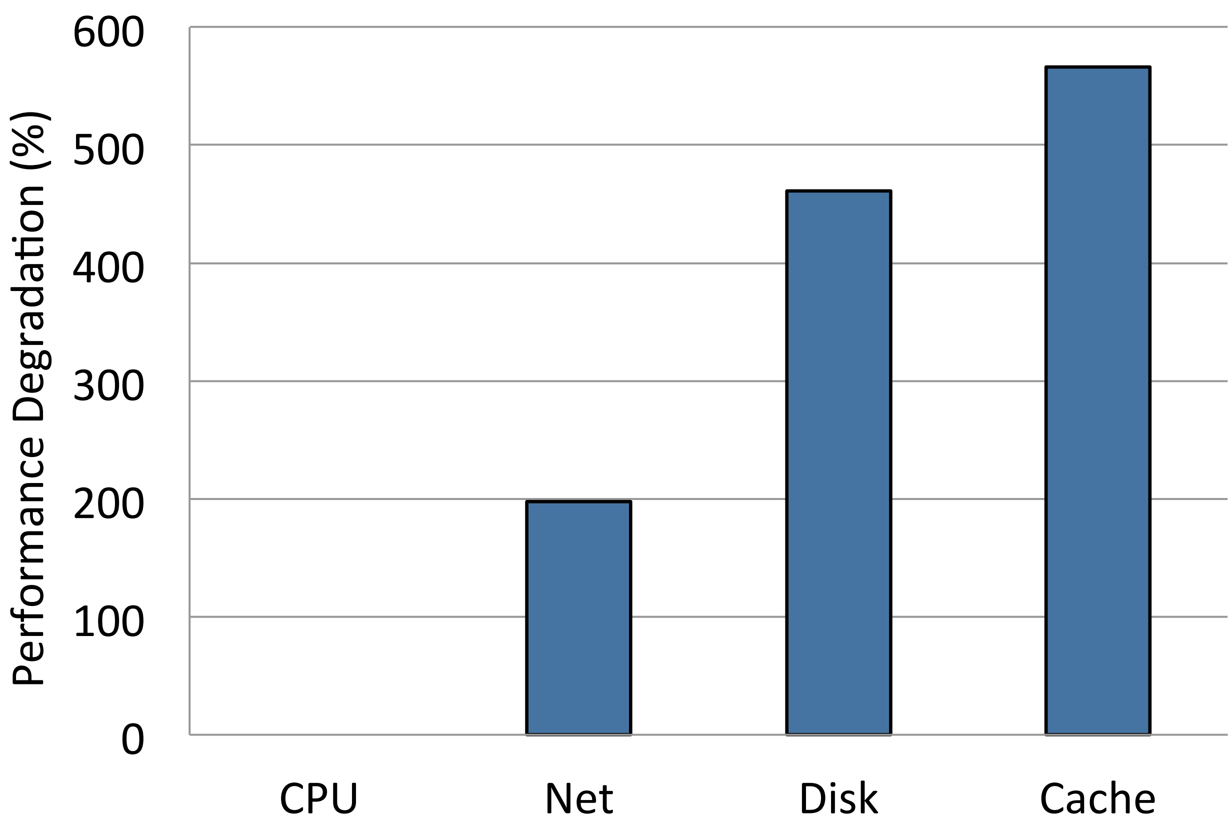
Cache-based load measurement of traffic rates on EC2

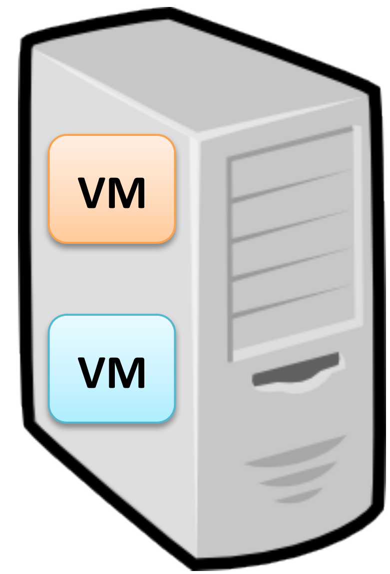


3 trials with 1 pair of co-resident instances:
1000 cache load measurements during
0, 50, 100, or 200 **HTTP gets** (3 Mbyte page) per minute for ~1.5 mins



Performance Loss from Contention





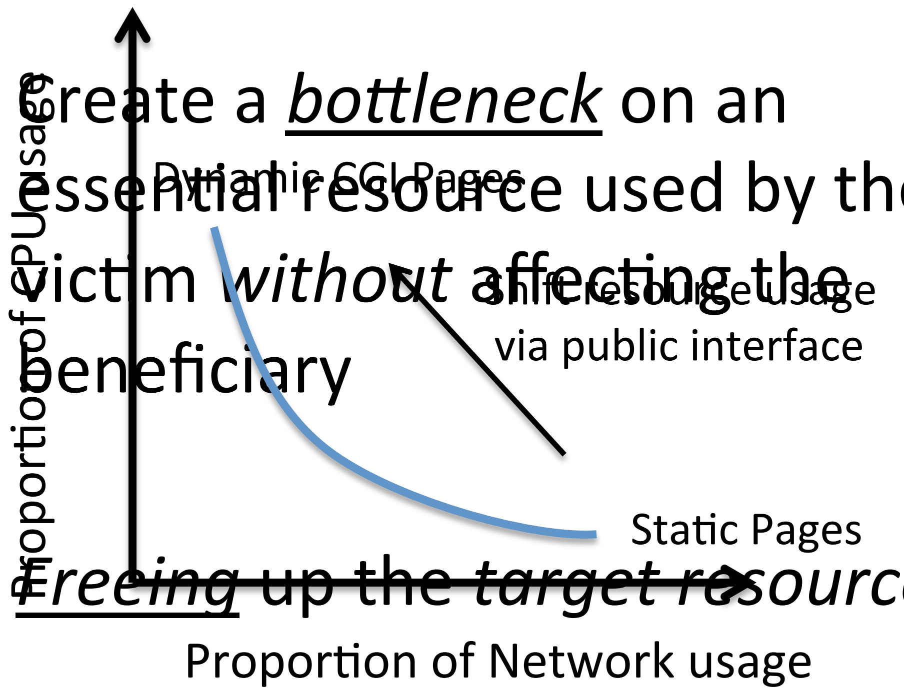
Local Xen Testbed	
Machine	Intel Xeon E5430, 2.66 Ghz
CPU	2 packages each with 2 cores
LLC Size	6MB per package

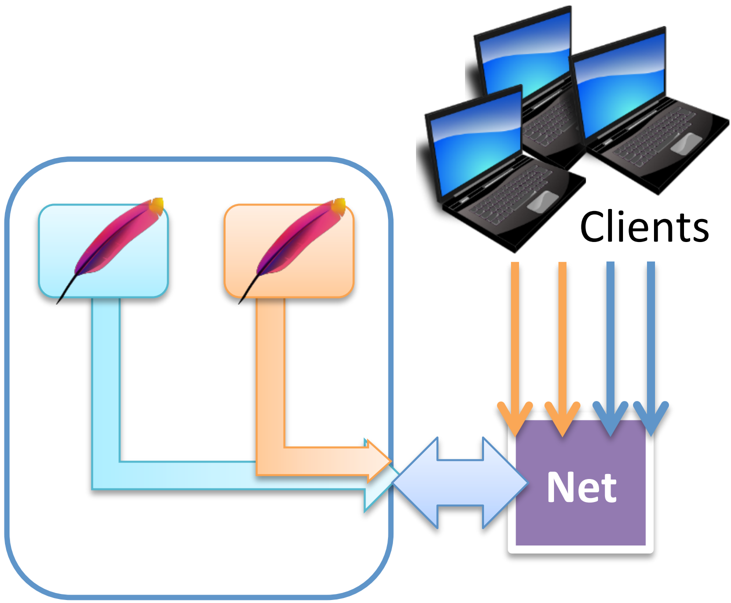
Resource Freeing Attacks (RFAs)

- Goal:
  - Reduce performance loss from contention
- Intuition:
  - Performance suffers from contention for a *target resource*
  - Introducing new workload on a victim can shift their usage away from target

Ingredients for a successful RFA

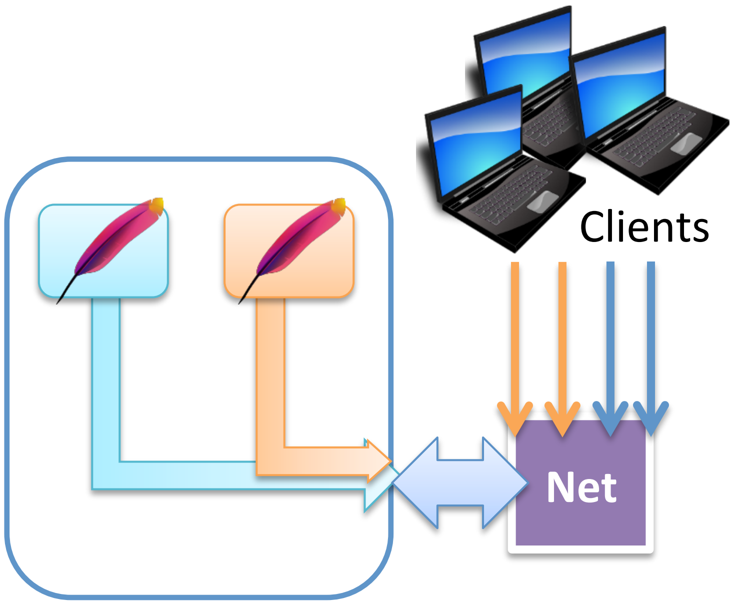
- *Shift* resource away from the *target resource*
- Create a *bottleneck* on an essential resource used by the victim *without* affecting the beneficiary
- *Freeing* up the *target resource*





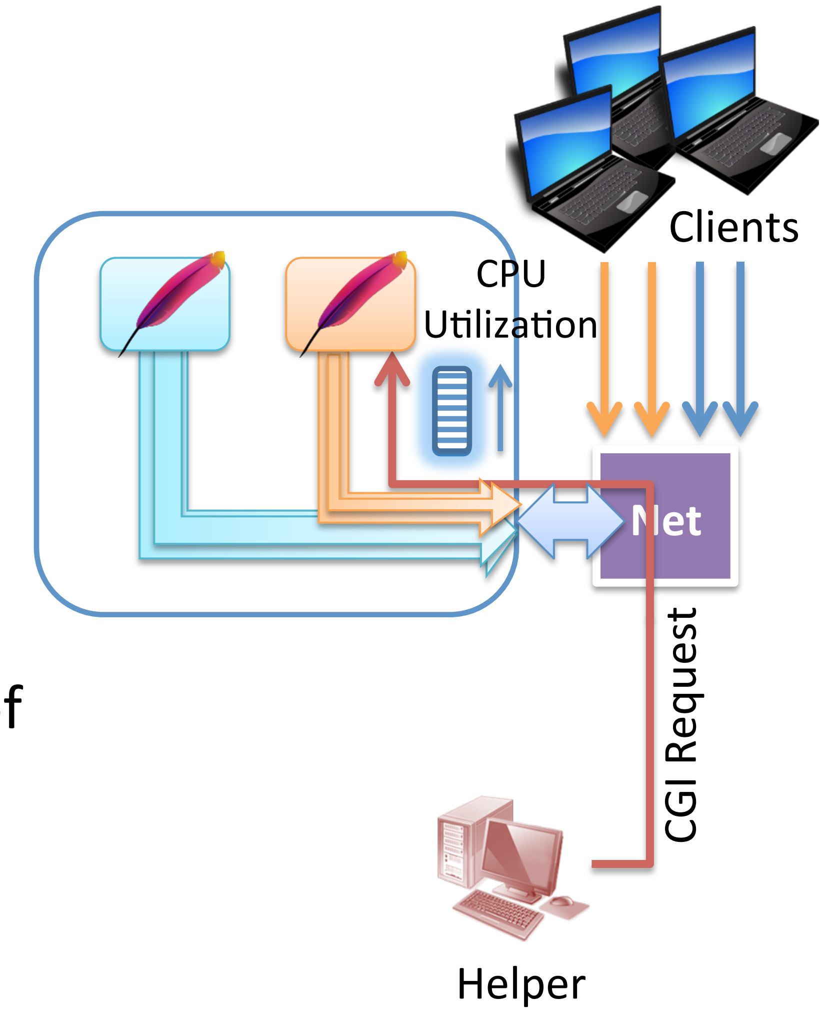
Example RFA: Network bandwidth

- *Victim* runs Apache webserver hosting static and dynamic content (CGI pages)
- *Beneficiary* also runs Apache webserver hosting static content
- Contending for network bandwidth



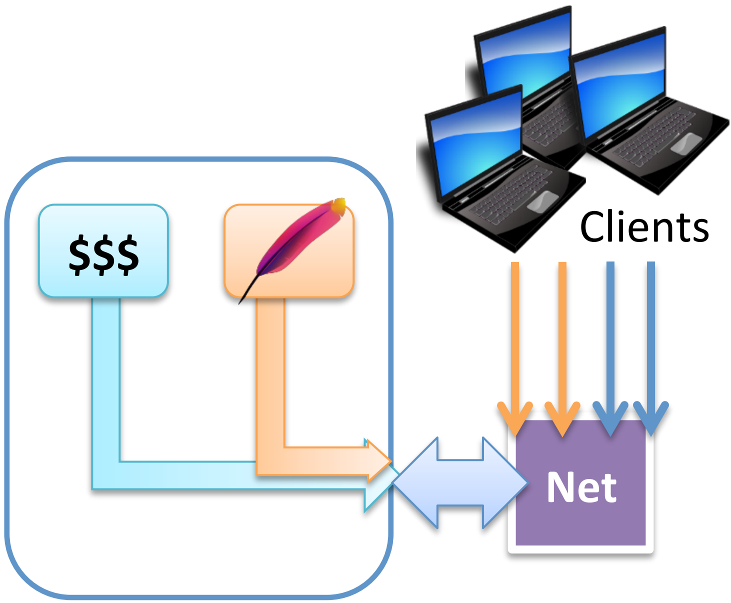
Example RFA: Network bandwidth

- *Helper* sends CPU-intensive CGI requests
- Creates CPU *bottleneck* on victim
- *Frees up* bandwidth
  - Increasing beneficiary's share of bandwidth from 50 to 85%



Example RFA: Cache contention

- *Victim* runs Apache webserver hosting static and dynamic content (CGI pages)
- *Beneficiary* runs Apache cache-sensitive workload
- Contending for cache



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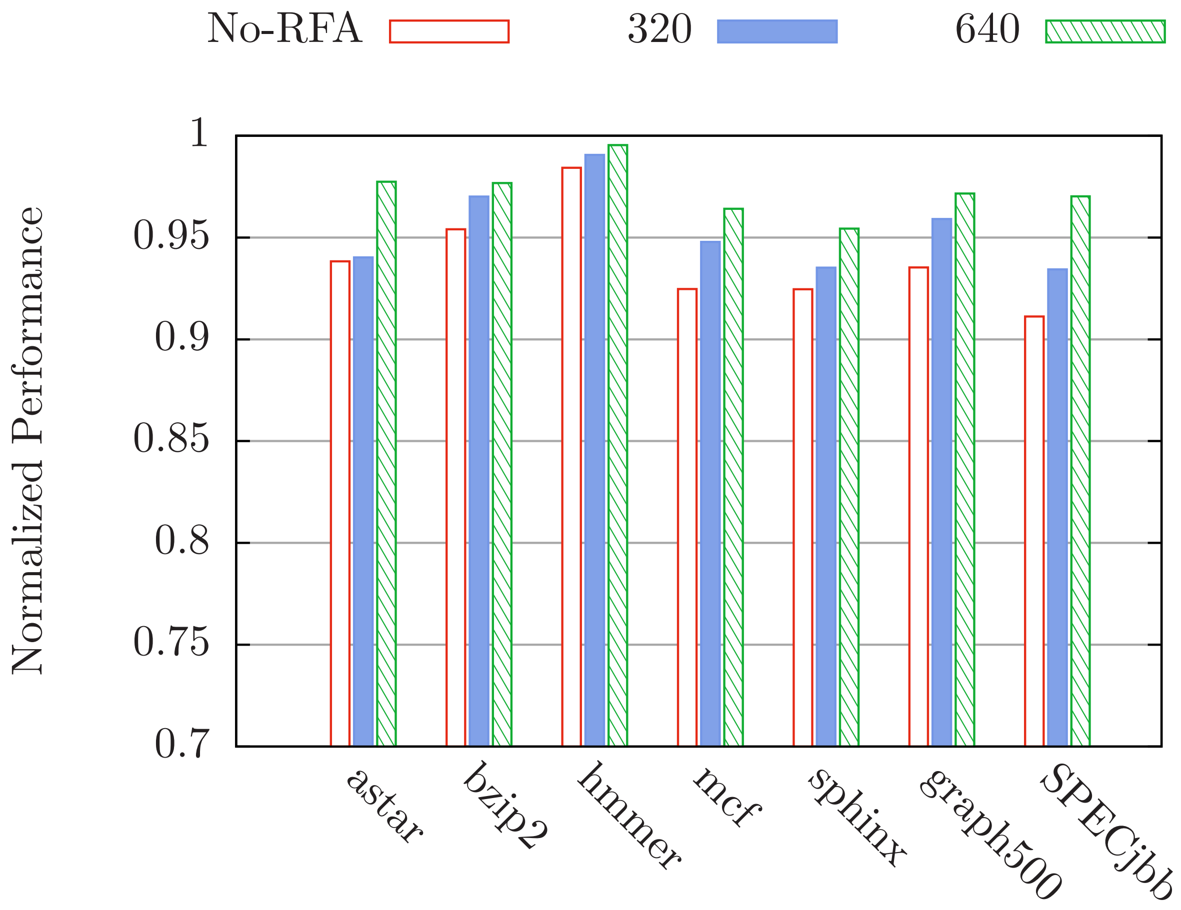


Experiments on EC2

Arranged for co-resident placement of m1.small instances from accounts under our control

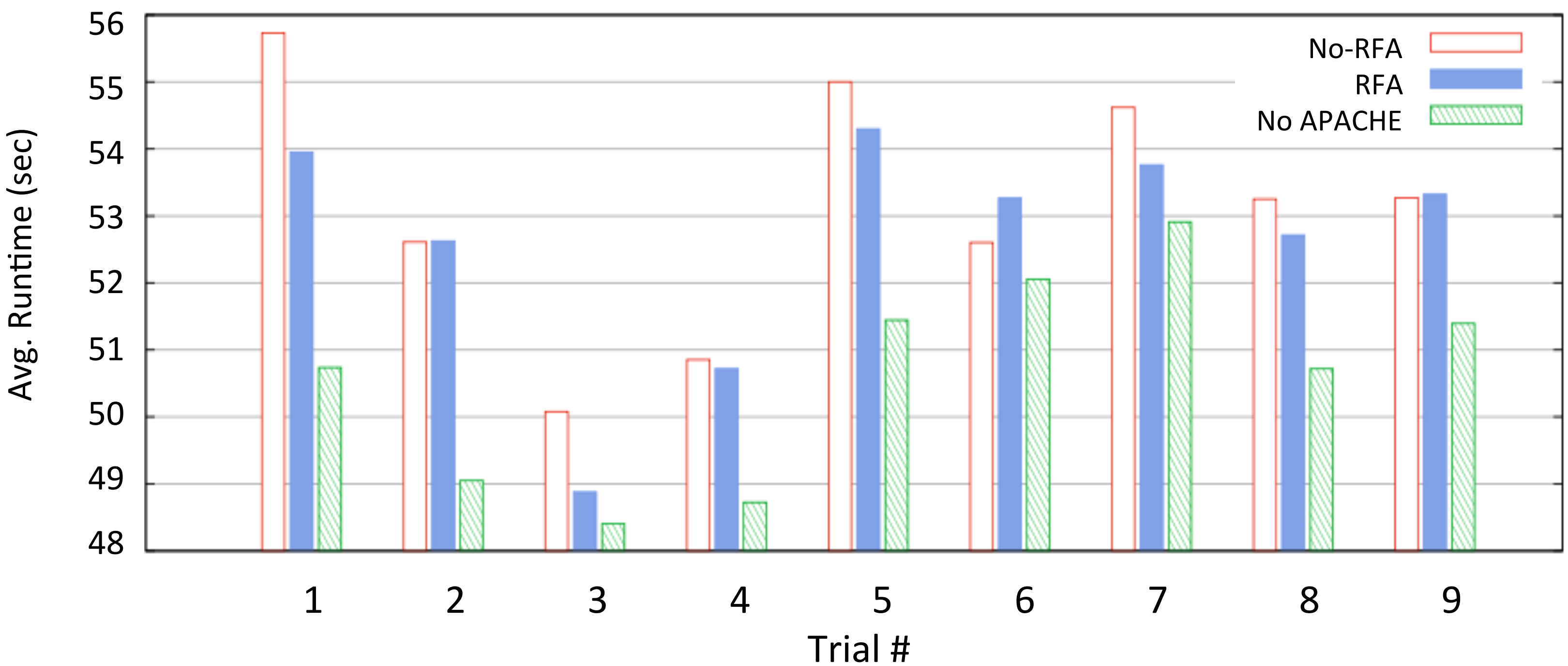
Pair of co-resident instances used as stand-ins for victim and beneficiary

Machine	#	Machine	#	Machine	#
E5507-1	4	E5507-4	3	E5507-7	2
E5507-2	2	E5507-5	2	E5507-8	3
E5507-3	2	E5507-6	2	E5507-9	3

Figure 9: Summary of EC2 machines and number of co-resident m1.small instances running under our accounts.

Demonstration on Amazon EC2

- *MCF: cache bound*
- *Apache: interrupts/data pollute cache*



What can cloud providers do?

1) Clo

2) Ch
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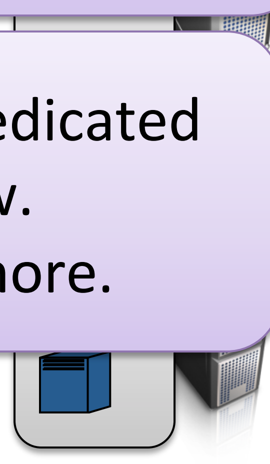
Amazon doesn’t report Dom0 in traceroutes anymore



3) A
co-r

Amazon provides dedicated instances now.
They cost a lot more.

4) Side-channel information leakage
Resource-freeing attacks

Possible counter-measures:

- Random Internal IP assignment
- Isolate each user’s view of internal address space
- Hide Dom0 from traceroutes
- Allow users to opt out of multitenancy
- Hardware or software countermeasures to stop leakage [Ber05,OST05,Page02,Page03, Page05,Per05]
- Improved performance isolation

Untrusted provider

- A lot of work aimed at untrustworthy provider
- Attestation of cloud:
  - Homealone: use L2 cache side-channels to detect presence of foreign VM
  - RAFT: Remote Assessment of Fault Tolerance to infer if data stored in redundant fashion
  - Keep data private: searchable or fully-homomorphic encryption

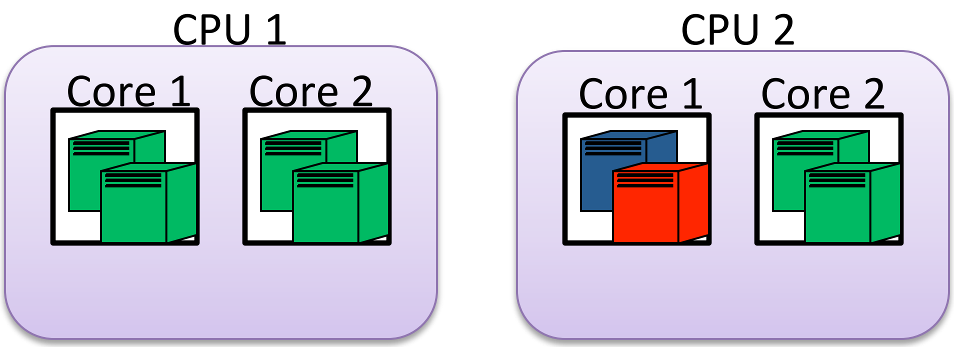
More on cache-based physical channels

Prime+Trigger+Probe combined with differential encoding technique gives high bandwidth cross-VM covert channel on EC2

See [Xu et al., "An Exploration of L2 Cache Covert Channels in Virtualized Environments", CCSW 2011]

Keystroke timing in experimental testbed similar to EC2 m1.small instances

AMD Opterons



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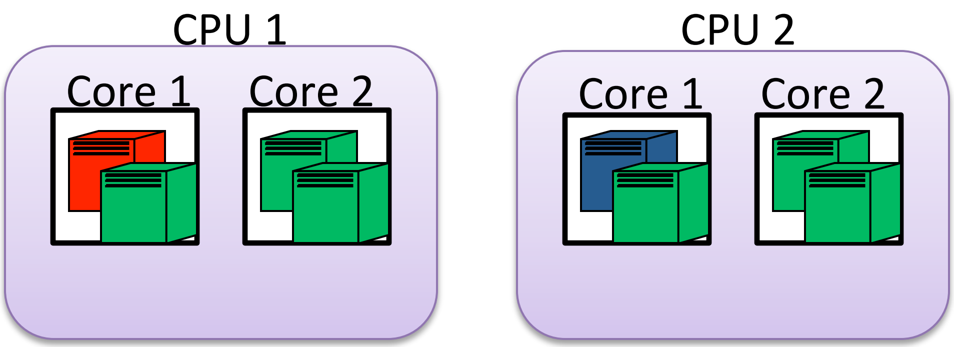
See [Xu et al., "An Exploration of L2 Cache Covert Channels in Virtualized Environments", CCSW 2011]

Keystroke timing in experimental testbed similar to EC2 m1.small instances

AMD Opterons



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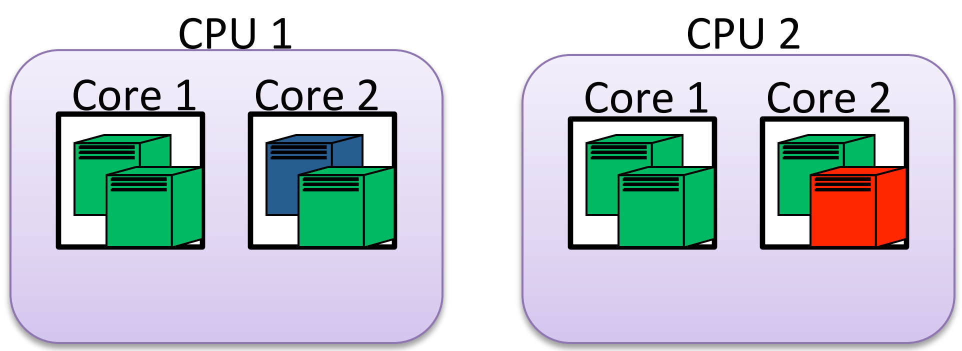

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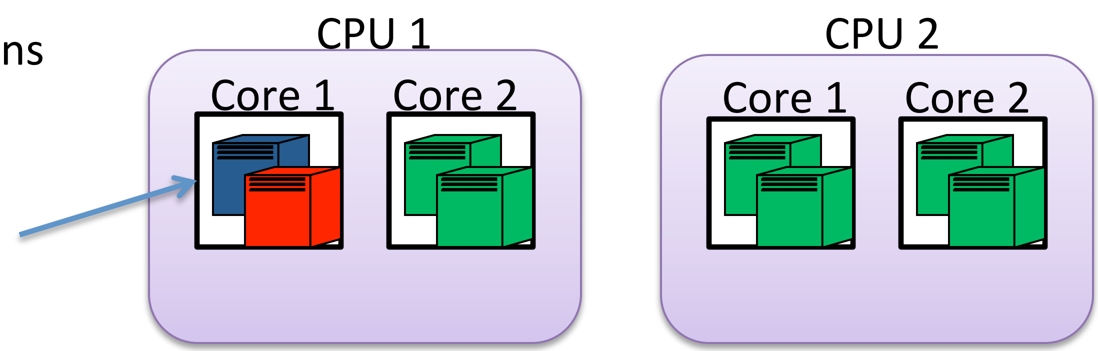
AMD Opterons

VMs pinned to core



We show that cache-load measurements enable cross-VM keystroke detection

Keystroke timing of this form might be sufficient for the password recovery attacks of [Song, Wagner, Tian 01]