Virtualization

CS642: Computer Security

Professor Ristenpart

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Virtualization and cloud security

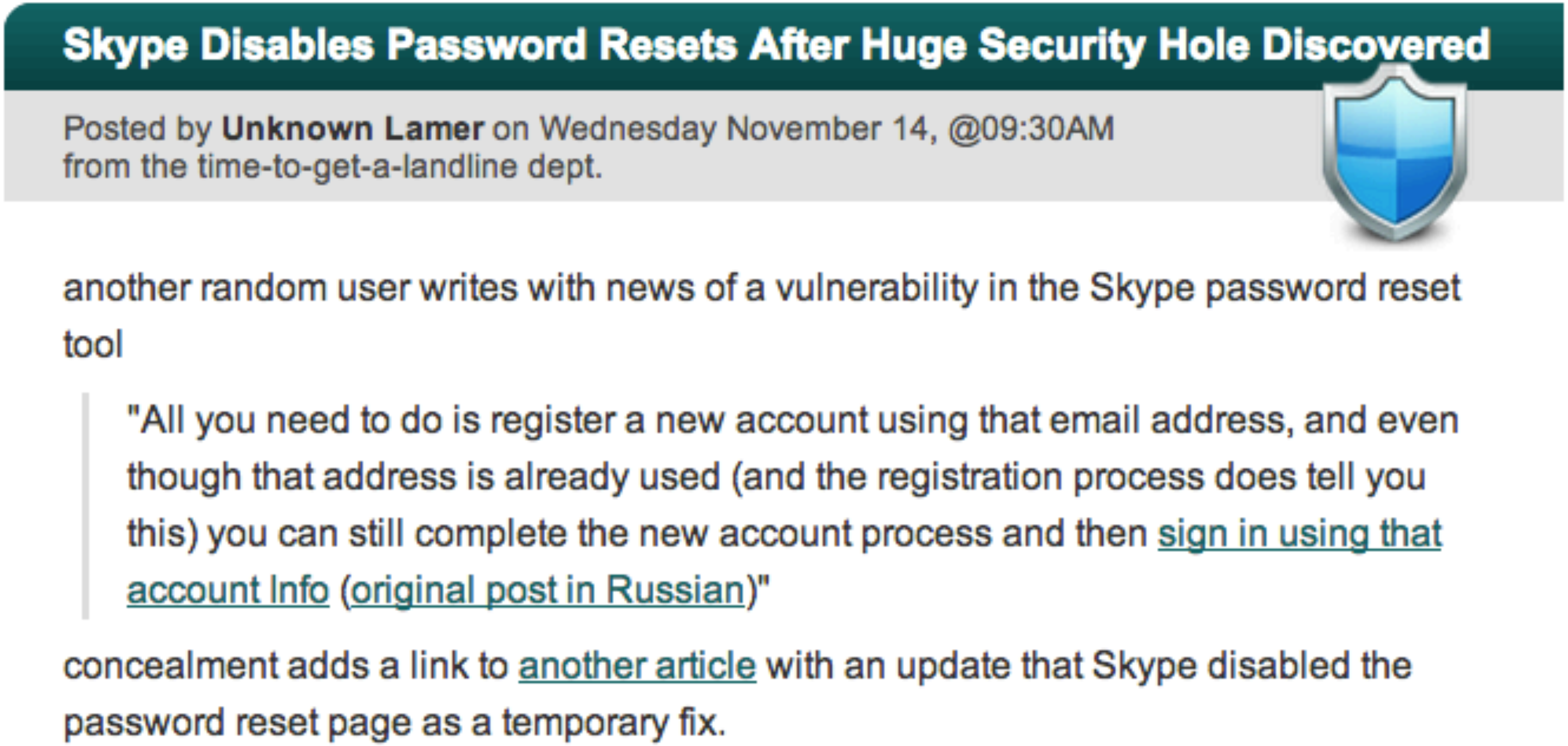
VMs

Cloud computing paradigms

VM image security issues

VM Introspection

Introspection



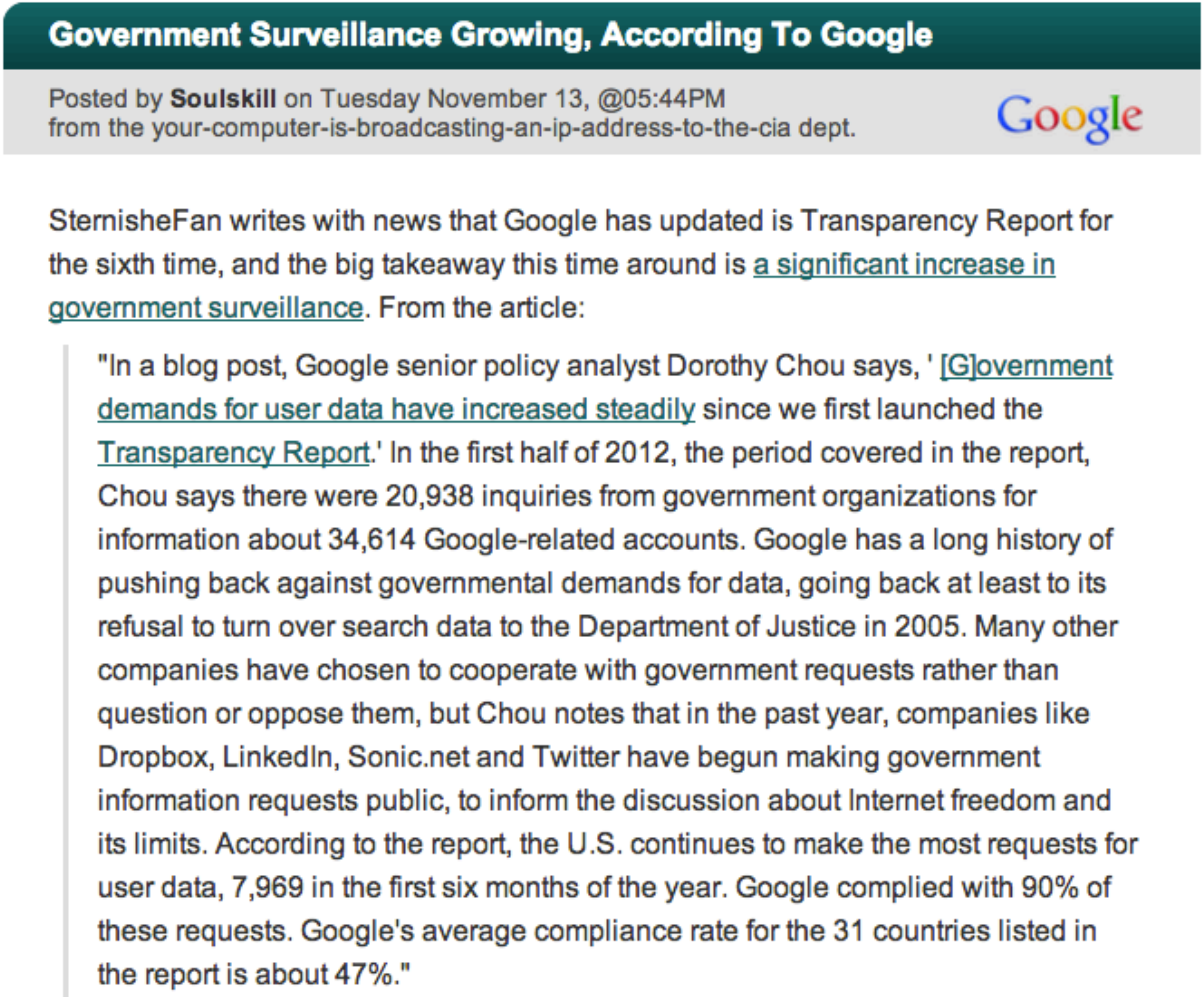
Skype Disables Password Resets After Huge Security Hole Discovered

Posted by **Unknown Lamer** on Wednesday November 14, @09:30AM
from the time-to-get-a-landline dept.

another random user writes with news of a vulnerability in the Skype password reset tool

> "All you need to do is register a new account using that email address, and even though that address is already used (and the registration process does tell you this) you can still complete the new account process and then sign in using that account Info (original post in Russian)"

concealment adds a link to another article with an update that Skype disabled the password reset page as a temporary fix.



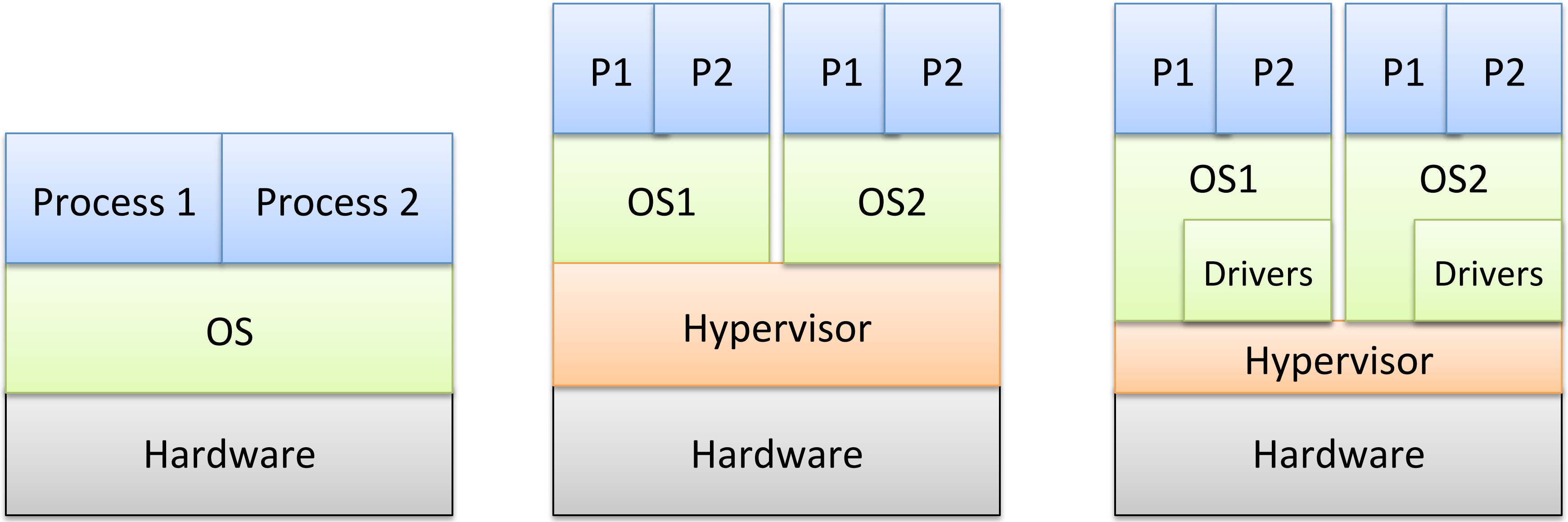
Government Surveillance Growing, According To Google

Posted by **Soulskill** on Tuesday November 13, @05:44PM
from the your-computer-is-broadcasting-an-ip-address-to-the-cia dept.

SternisheFan writes with news that Google has updated is Transparency Report for the sixth time, and the big takeaway this time around is a significant increase in government surveillance. From the article:

> "In a blog post, Google senior policy analyst Dorothy Chou says, ' [G]overnment demands for user data have increased steadily since we first launched the Transparency Report.' In the first half of 2012, the period covered in the report, Chou says there were 20,938 inquiries from government organizations for information about 34,614 Google-related accounts. Google has a long history of pushing back against governmental demands for data, going back at least to its refusal to turn over search data to the Department of Justice in 2005. Many other companies have chosen to cooperate with government requests rather than question or oppose them, but Chou notes that in the past year, companies like Dropbox, LinkedIn, Sonic.net and Twitter have begun making government information requests public, to inform the discussion about Internet freedom and its limits. According to the report, the U.S. continues to make the most requests for user data, 7,969 in the first six months of the year. Google complied with 90% of these requests. Google's average compliance rate for the 31 countries listed in the report is about 47%."

Virtualization



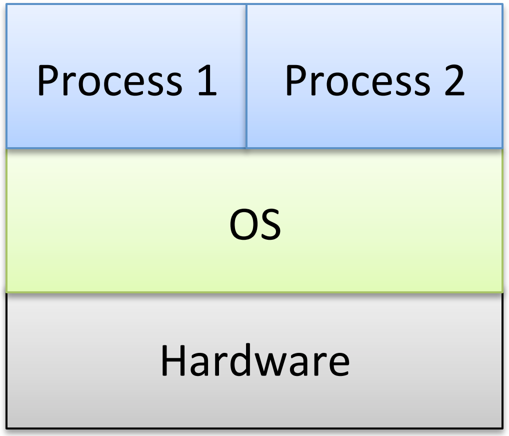
No virtualization

Full virtualization

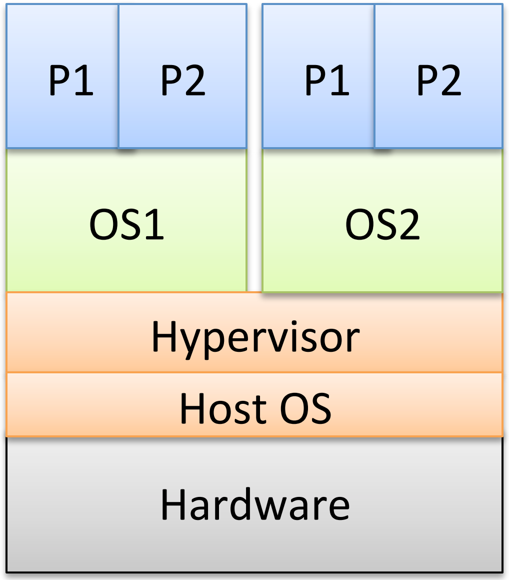
Paravirtualization

Type-1: Hypervisor runs directly on hardware

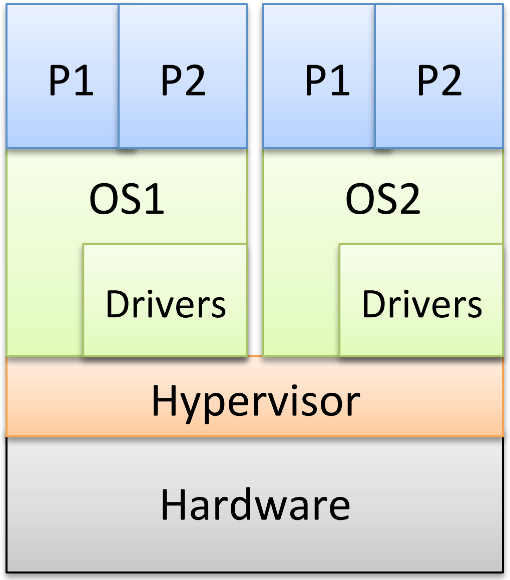
Virtualization



No virtualization



Full virtualization



Paravirtualization

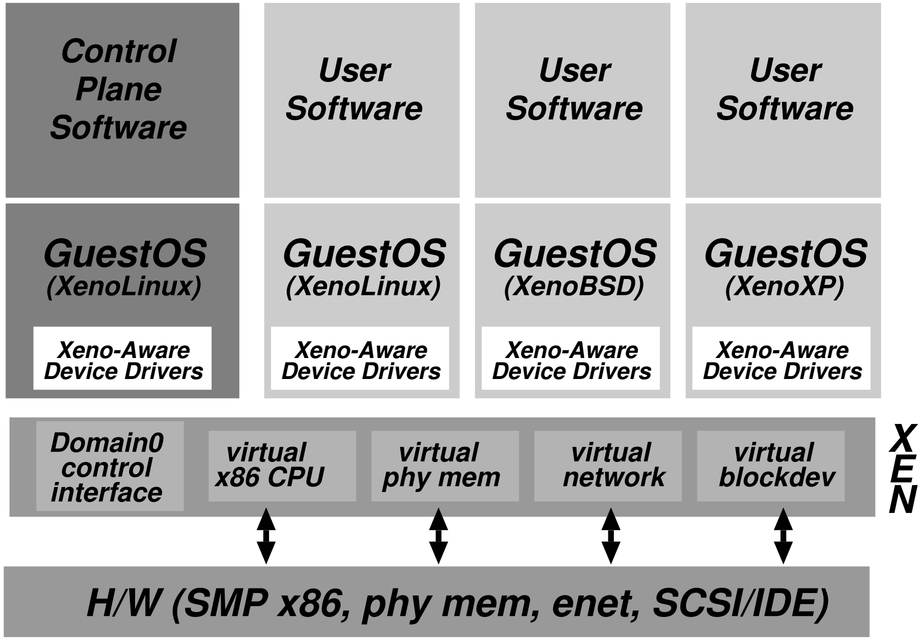
Type-1: Hypervisor runs directly on hardware
Type-2: Hypervisor runs on host OS

IBM VM/370

- Released in 1972
  - Used with System/370, System/390, zSeries mainframes
  - Full virtualization
- Supported CP/CMS operating system
  - Initial application was to support legacy OS
- z/VM is newer version, most recent version 2010
  - Better use of 64-bit mainframes

Xen

- 2003: academic paper
  - “Xen and the Art of Virtualization”
- Paravirtualization
  - Hypercalls vs system calls
  - Modified guest OS
  - Each guest given 1 or more VCPUs
- Why?



Other VM solutions

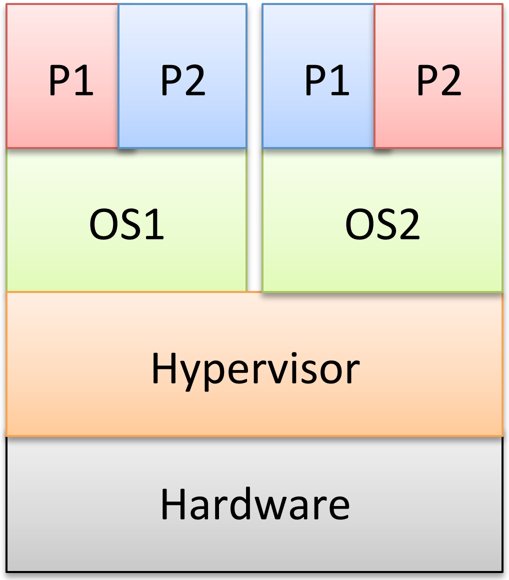
- VMWare
- Virtual Box
- KVM

Example VM Use Cases

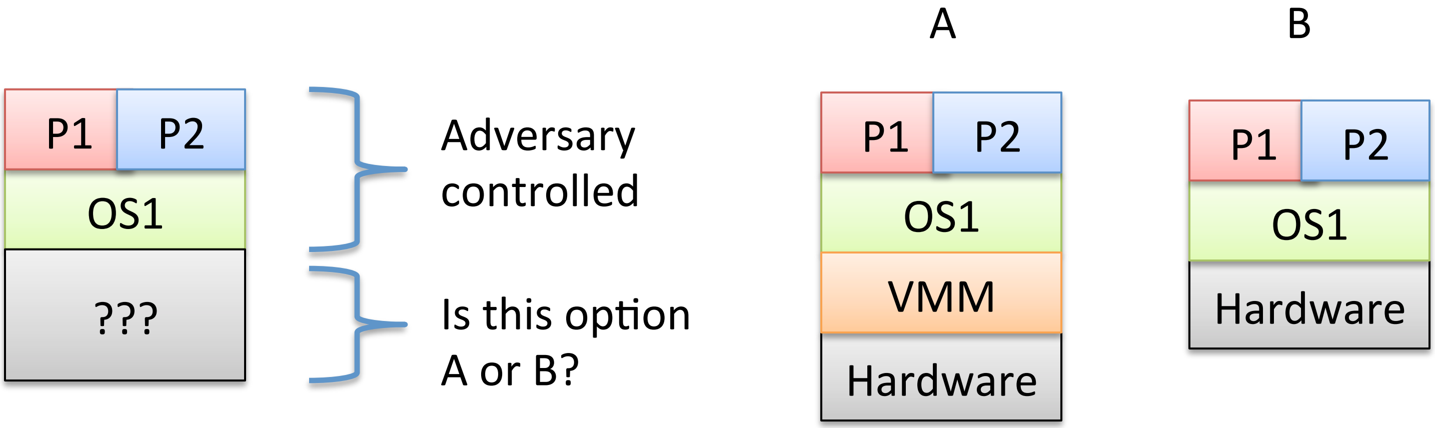
- Legacy support (e.g., VM/370)
- Development
- Server consolidation
- Cloud computing Infrastructure-as-a-Service
- Sandboxing / containment

Study of malware

- Researchers use VMs to study malware
- Example of VM sandboxing
  - Hypervisor must contain malicious code
- Introspection
- How would you evade analysis as a malware writer?
  - split personalities



VMM Transparency



Adversary controlled

Is this option A or B?

- Adversary can detect if:
  - Paravirtualization
  - Logical discrepancies
    - Expected CPU behavior vs virtualized
    - Red pill (Store Interrupt Descriptor Table instr)
  - Timing discrepancies
    - Slower use of some resources

Garfinkel et al.
“Compatibility
is not transparency:
VMM Detection
Myths and Reality”

Detection of VMWare

```
MOV EAX,564D5868 <-- "VMXh"
MOV EBX,0
MOV ECX,0A
MOV EDX,5658 <-- "VX"
IN EAX,DX <-- Check for VMWare
CMP EBX,564D5868
```

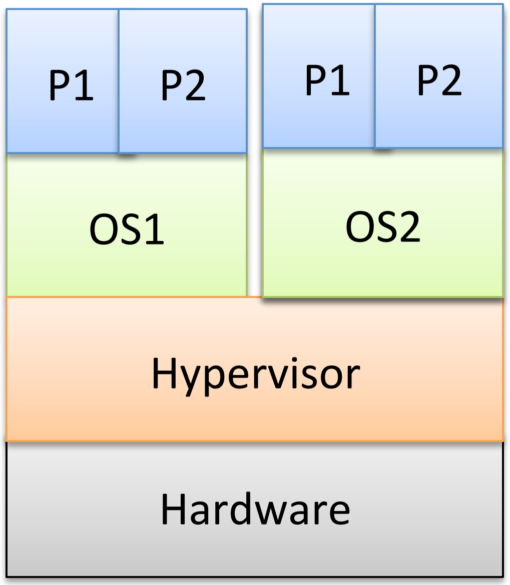
IN instruction used by VMWare to facilitate host-to-guest communication

VMWare:
	places VMXh in EBX
Physical:
	processor exception

From
http://handlers.sans.org/tliston/ThwartingVMDetection_Liston_Skoudis.pdf

Server consolidation

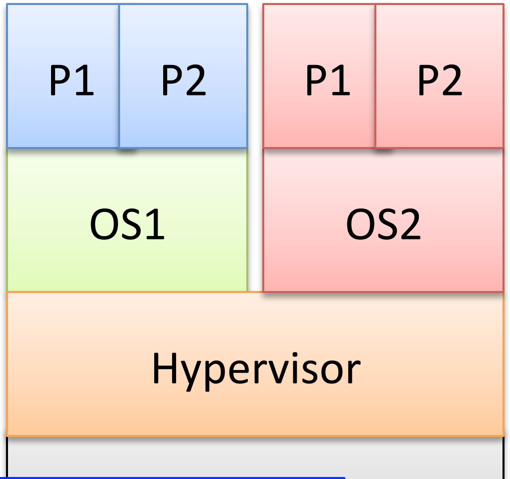
- Consolidation
  - Use VMs to optimize use of hardware
  - Pack as many VMs onto each server as possible
  - Turn off other servers

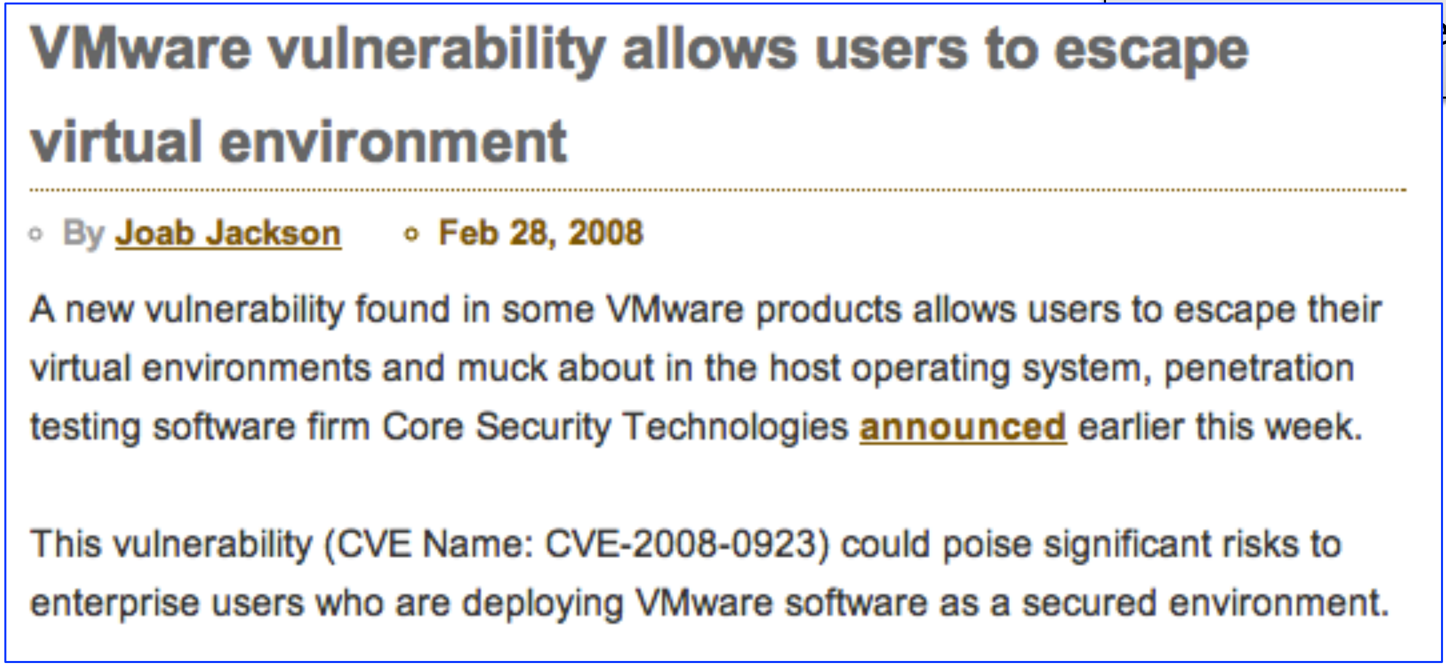


- Threat model?
  - Containment
  - Isolation
  - Assume guests are/can be compromised

Violating containment

- Escape-from-VM
  - Vulnerability in VMM or host OS (e.g., Dom0)
  - Seemingly rare, but exist





VMware vulnerability allows users to escape virtual environment

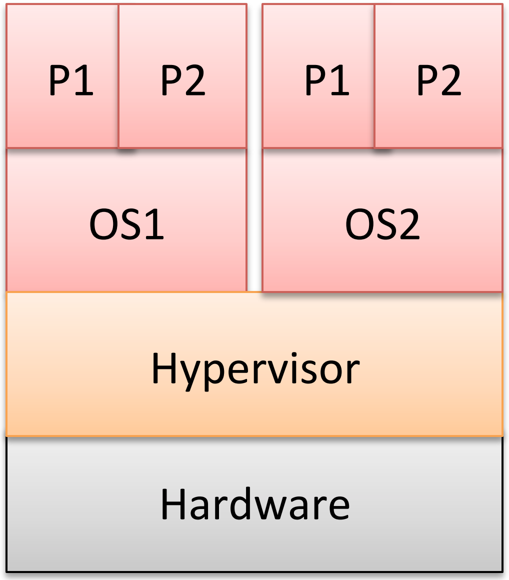
- By Joab Jackson
- Feb 28, 2008

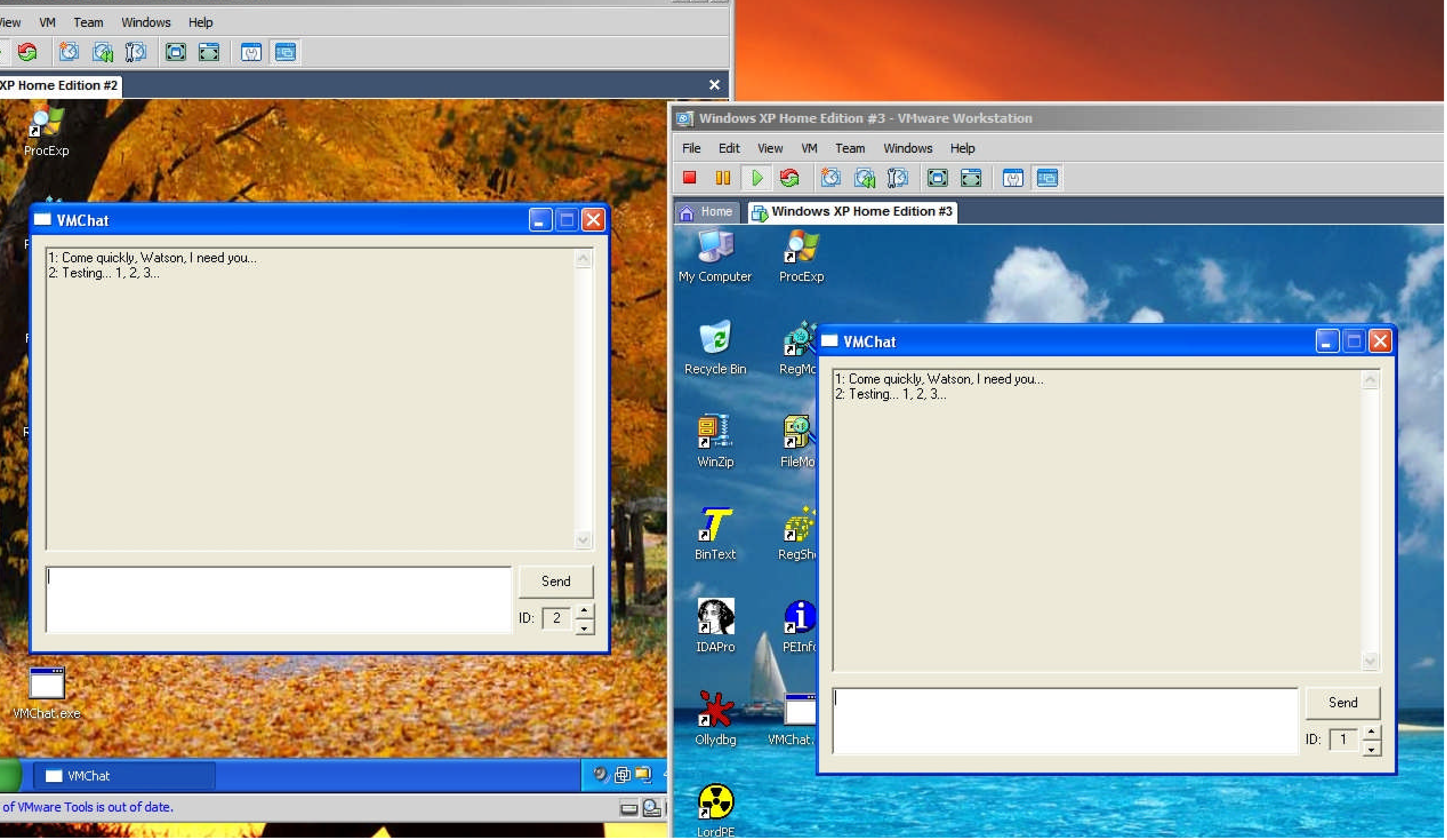
A new vulnerability found in some VMware products allows users to escape their virtual environments and muck about in the host operating system, penetration testing software firm Core Security Technologies announced earlier this week.

This vulnerability (CVE Name: CVE-2008-0923) could poise significant risks to enterprise users who are deploying VMware software as a secured environment.

Violating isolation

- Covert channels between VMs circumvent access controls
  - Bugs in VMM
  - Side-effects of resource usage





VMChat (left window, ID: 2)

1: Come quickly, Watson, I need you...
2: Testing... 1, 2, 3...

ID: 2

of VMware Tools is out of date.

VMChat (right window, ID: 1)

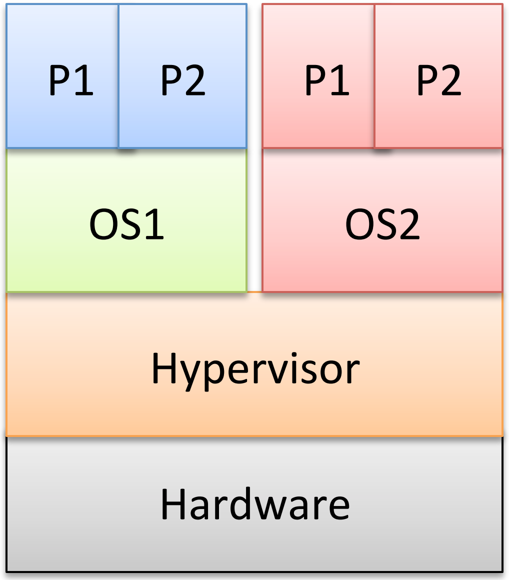
1: Come quickly, Watson, I need you...
2: Testing... 1, 2, 3...

ID: 1

http://handlers.sans.org/tliston/ThwartingVMDetection_Liston_Skoudis.pdf

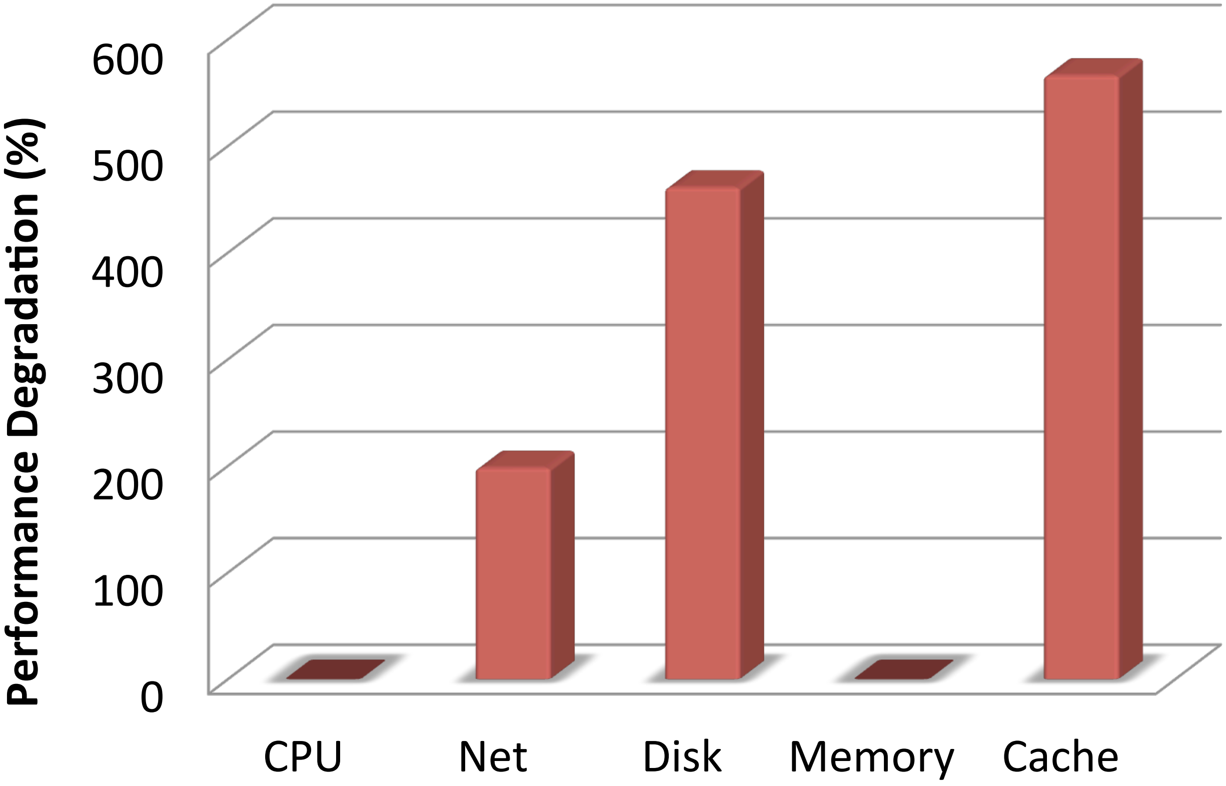
Violating isolation

- Covert channels between VMs circumvent access controls
  - Bugs in VMM
  - Side-effects of resource usage
- Degradation-of-Service attacks
  - Guests might maliciously contend for resources
  - Xen scheduler vulnerability



Measuring Resource Contention

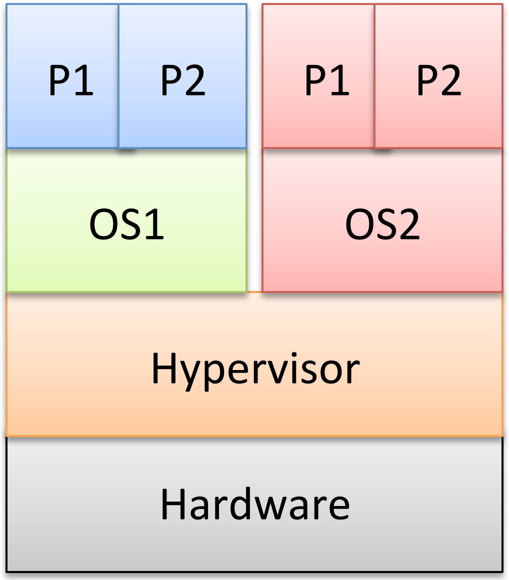
- Contention for the same resource



Local Xen Testbed	
Machine	Intel Xeon E5430, 2.66 Ghz
Packages	2, 2 cores per package
LLC Size	6MB per package

Violating isolation

- Covert channels between VMs circumvent access controls
  - Bugs in VMM
  - Side-effects of resource usage
- Degradation-of-Service attacks
  - Guests might maliciously contend for resources
  - Xen scheduler vulnerability
- Side channels
  - Spy on other guest via shared resources



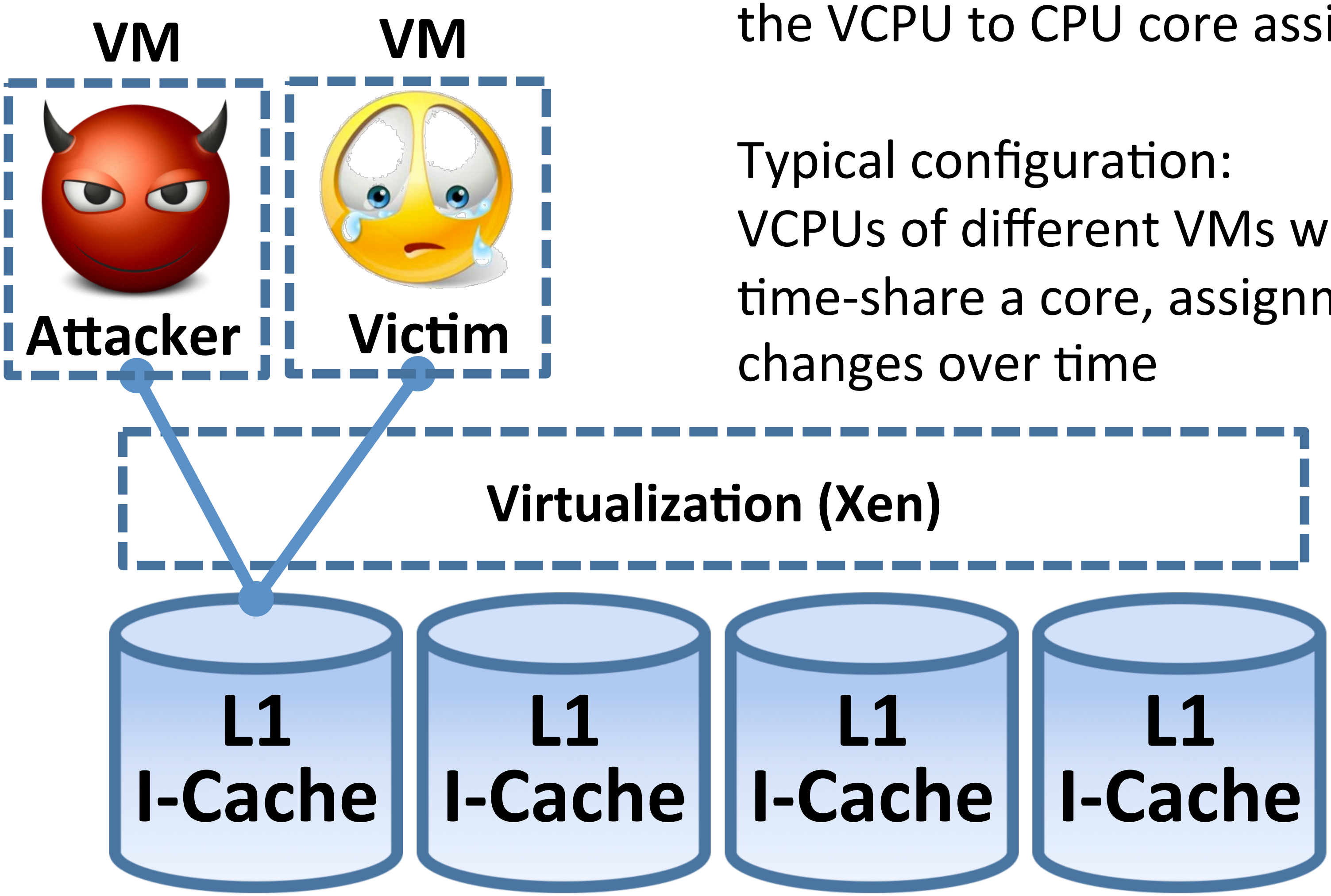
Square-and-Multiply

```
/* $y = x^e \bmod N$ , from **libgcrypt***/
**Modular Exponentiation** (x, e, N):
    let $e_n \ldots e_1$ be the bits of e
    $y \leftarrow 1$
    for $e_i$ in $\{e_n \ldots e_1\}$
        $y \leftarrow$ **Square**(y)                (S)
        $y \leftarrow$ **Reduce**(y, N)             (R)
        if  $e_i = 1$ then
            $y \leftarrow$ **Multi**(y, x)      (M)
            $y \leftarrow$ **Reduce**(y, N)   (R)
```

$e_i = 1$ → SRMR
$e_i = 0$ → SR

Control flow (sequence of instructions used) leaks secret

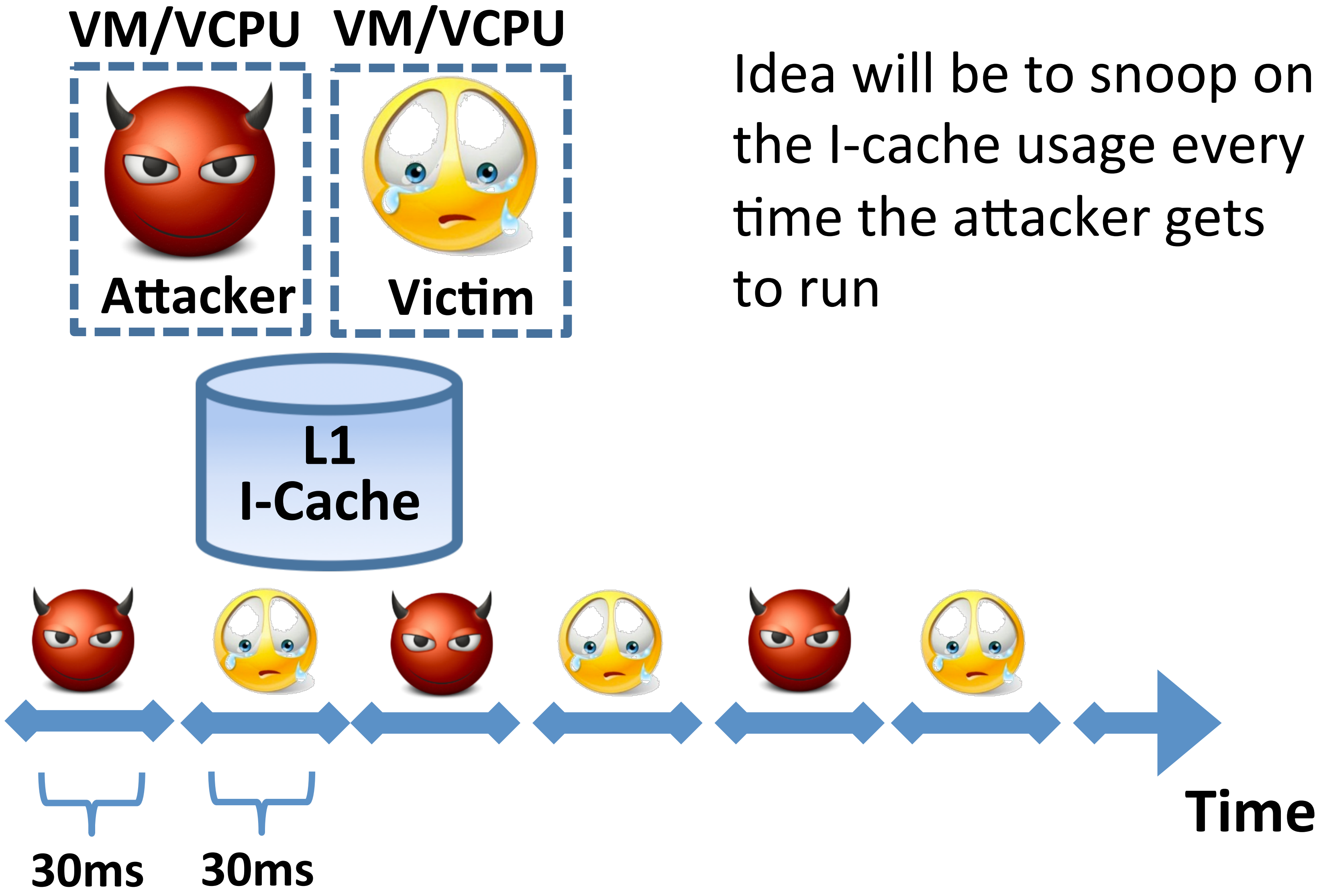
Xen core scheduling



Xen core scheduler determines the VCPU to CPU core assignment

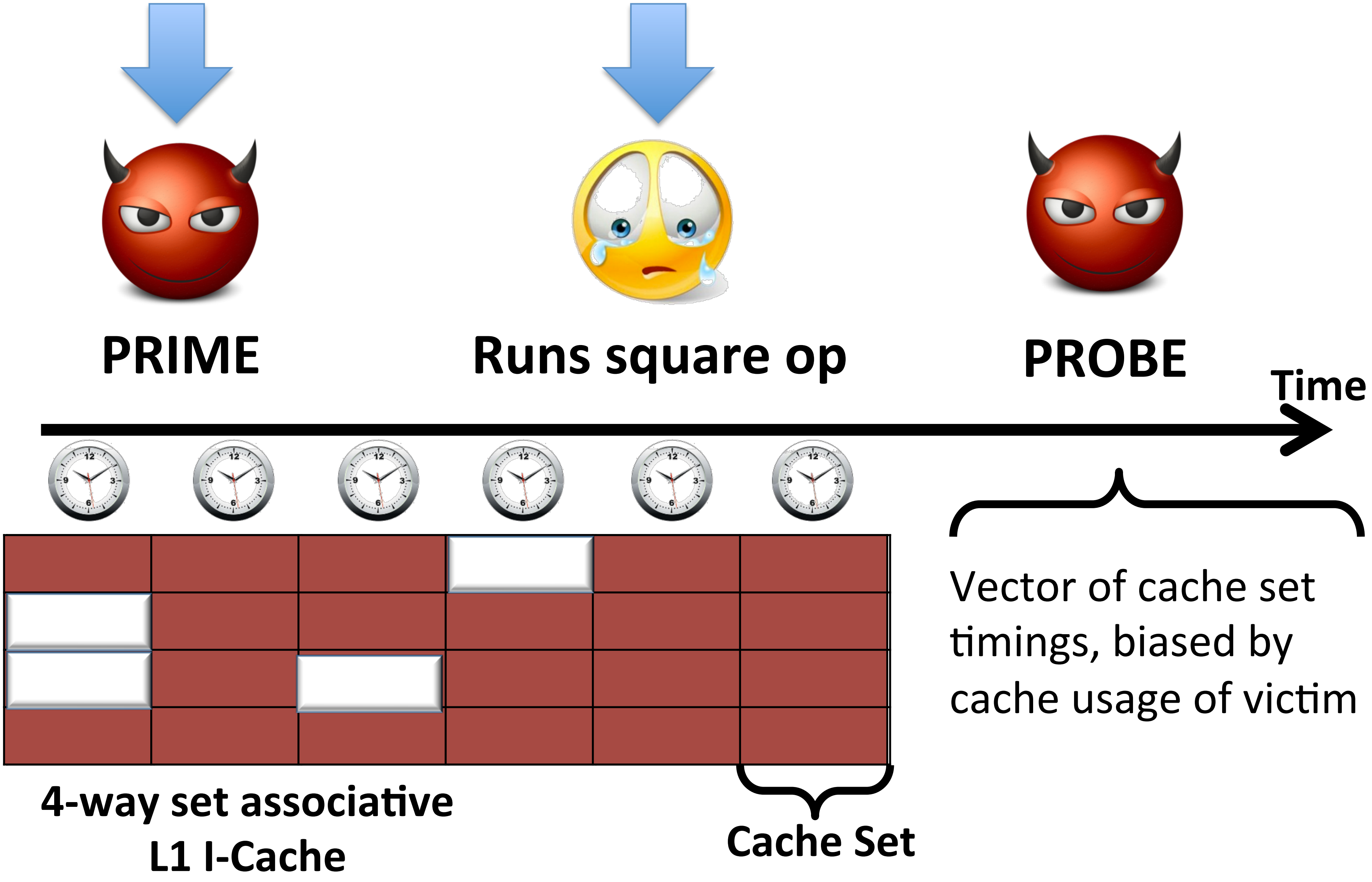
Typical configuration:
VCPUs of different VMs will often time-share a core, assignment changes over time

Time-sharing a core



Idea will be to snoop on the I-cache usage every time the attacker gets to run

Prime-Probe Protocol



PRIME

Runs square op

PROBE

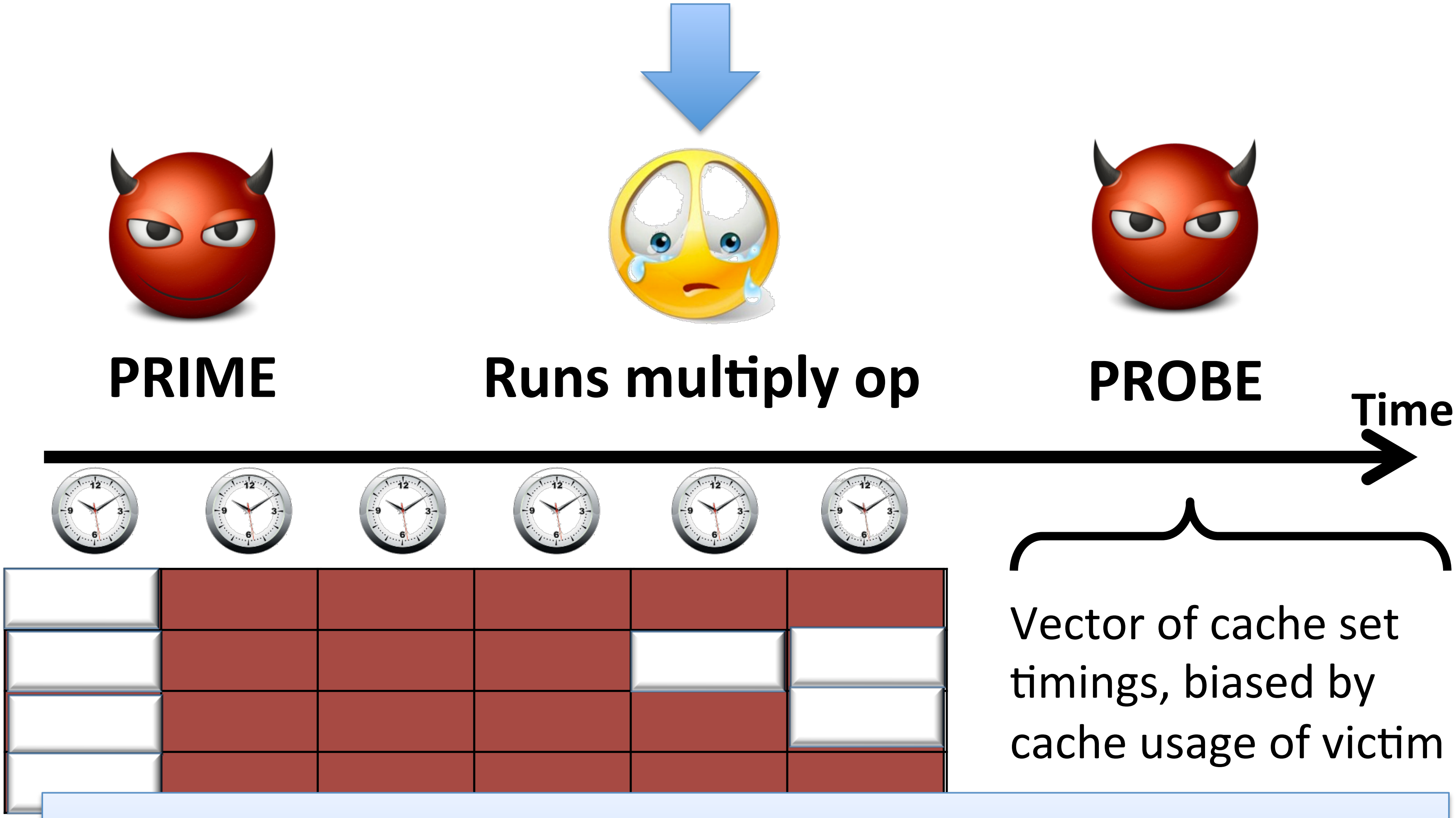
Time

Vector of cache set timings, biased by cache usage of victim

4-way set associative L1 I-Cache

Cache Set

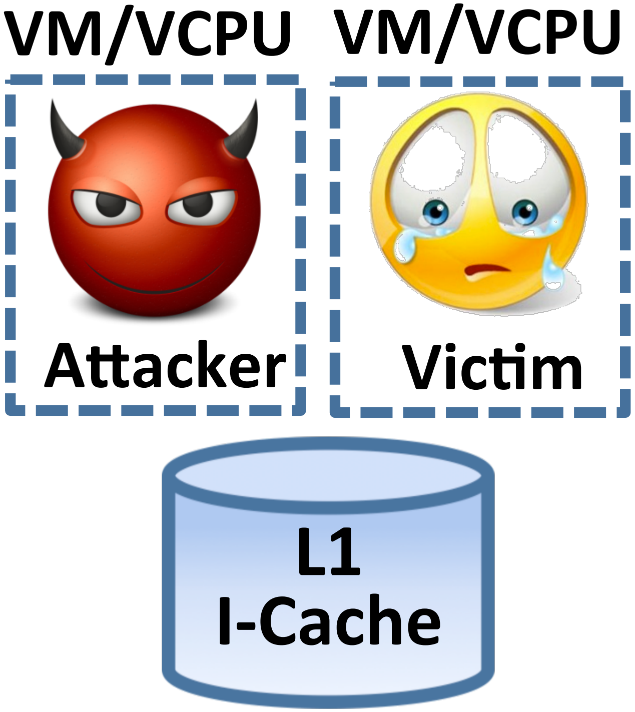
Prime-Probe Protocol



Vector of cache set timings, biased by cache usage of victim

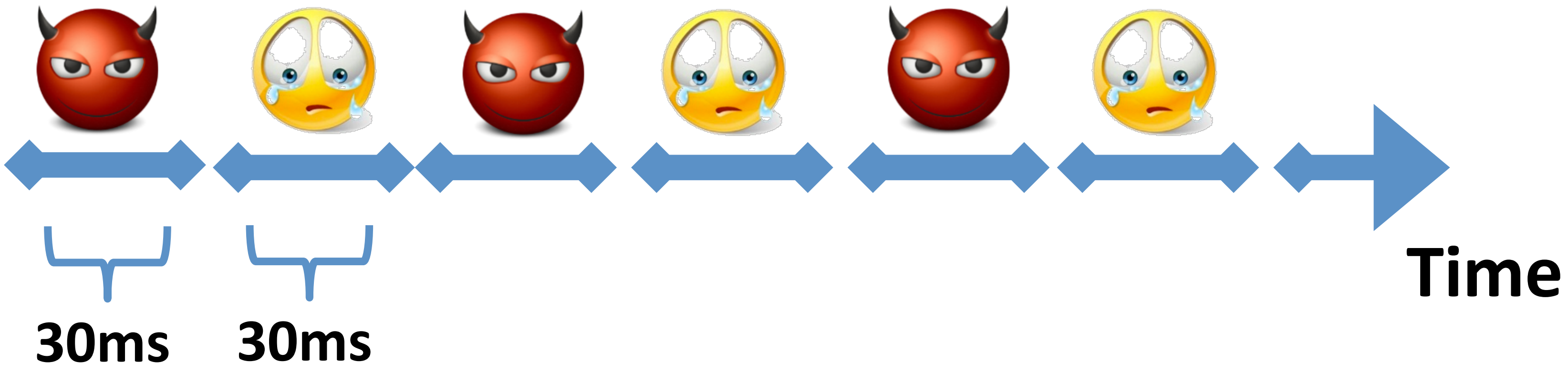
Square and Multiply give different-looking timing vectors (in the absence of noise)

Time-sharing a core

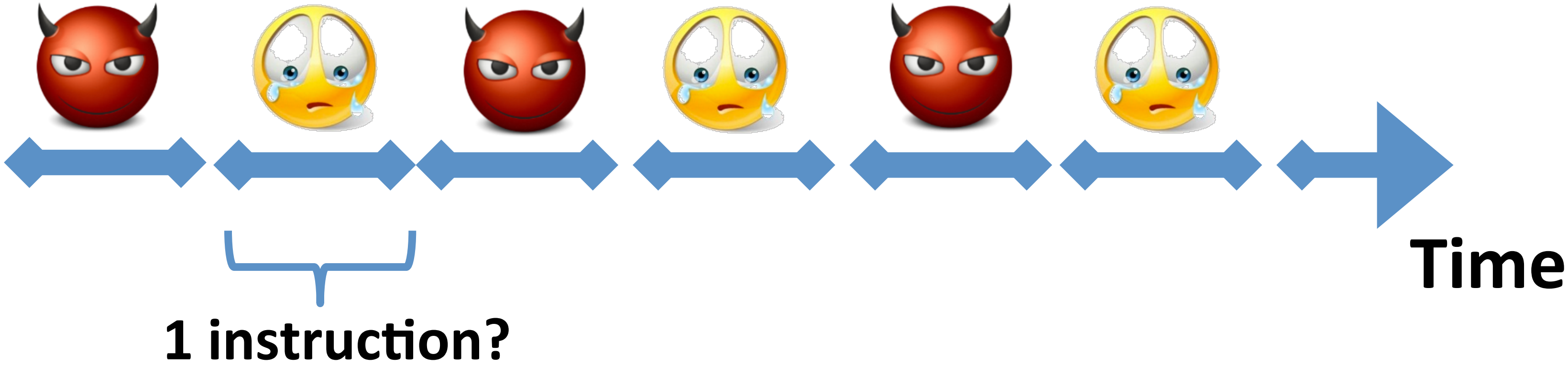


Problem:
Default scheduling quantum is 30ms in Xen

Exponentiation for 4096-bit modulus takes about 200ms to complete

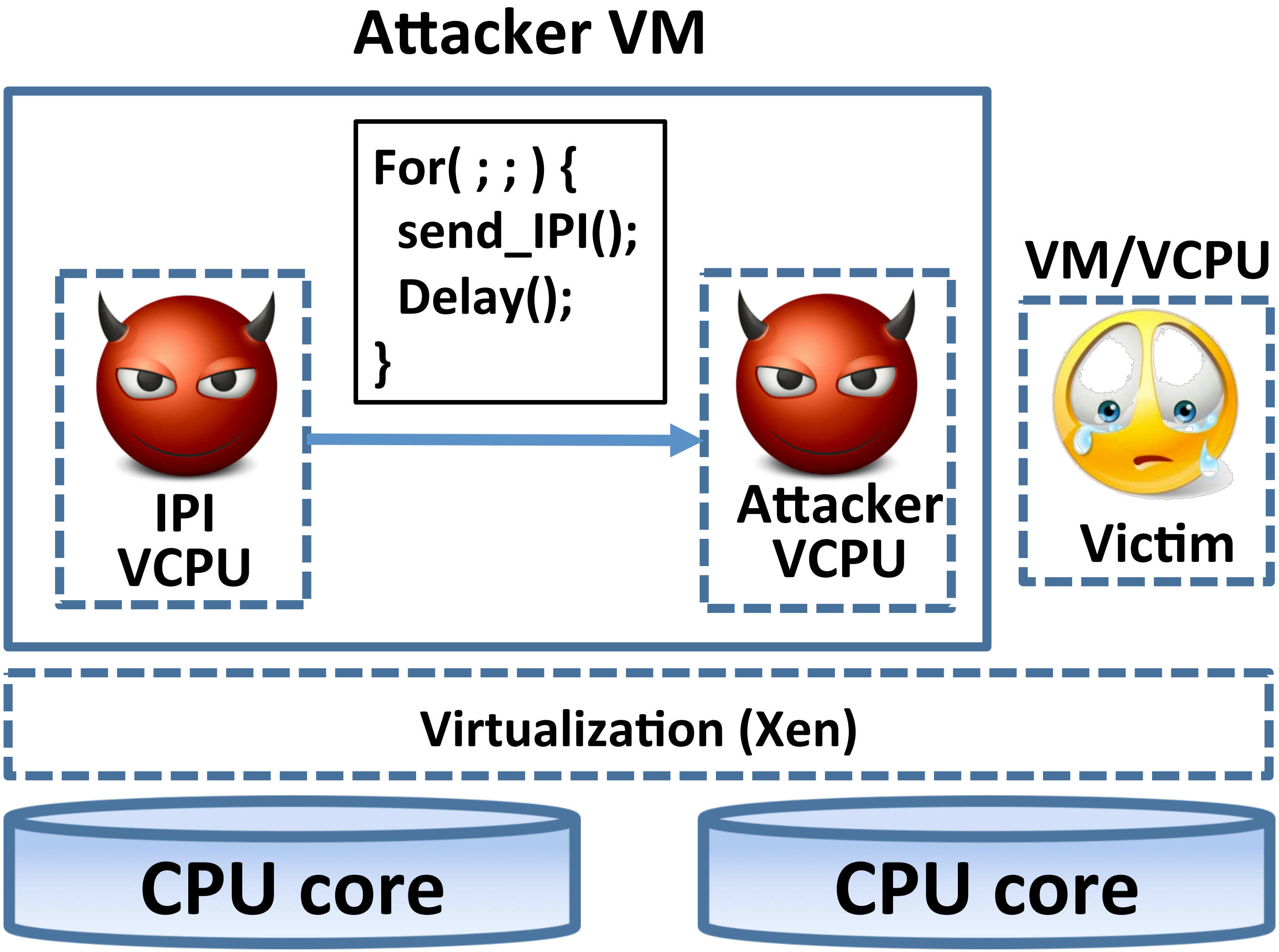


Ideally …



- Use **Interrupts** to preempt the victim:
  - Timer interrupts?
  - Network interrupts?
  - HPET interrupts?
  - **Inter-Processor interrupts (IPI)!**

Inter-Processor Interrupts



Attacker VM

```
For( ; ; ) {
  send_IPI();
  Delay();
}
```

IPI VCPU

Attacker VCPU

VM/VCPU

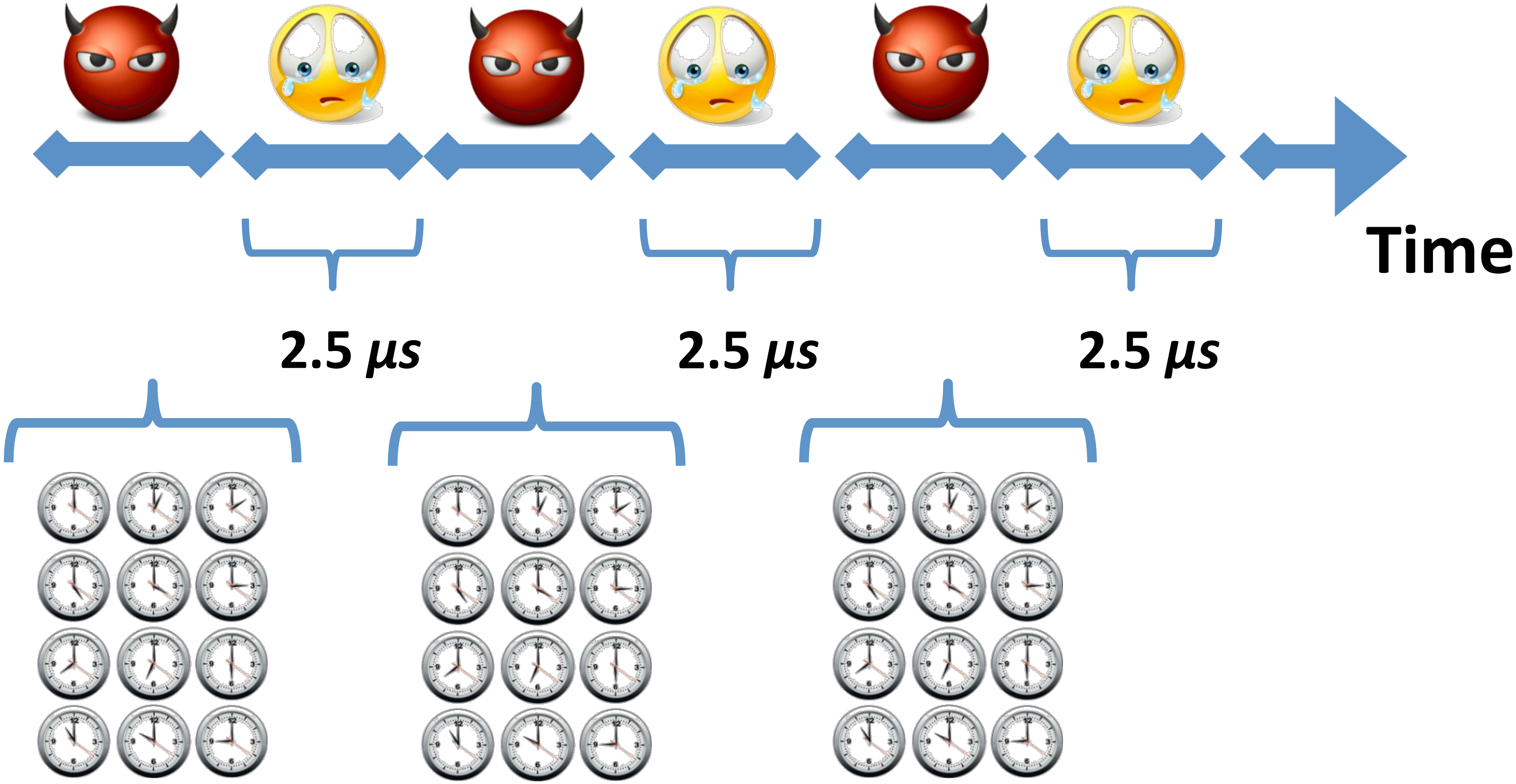
Victim

Virtualization (Xen)

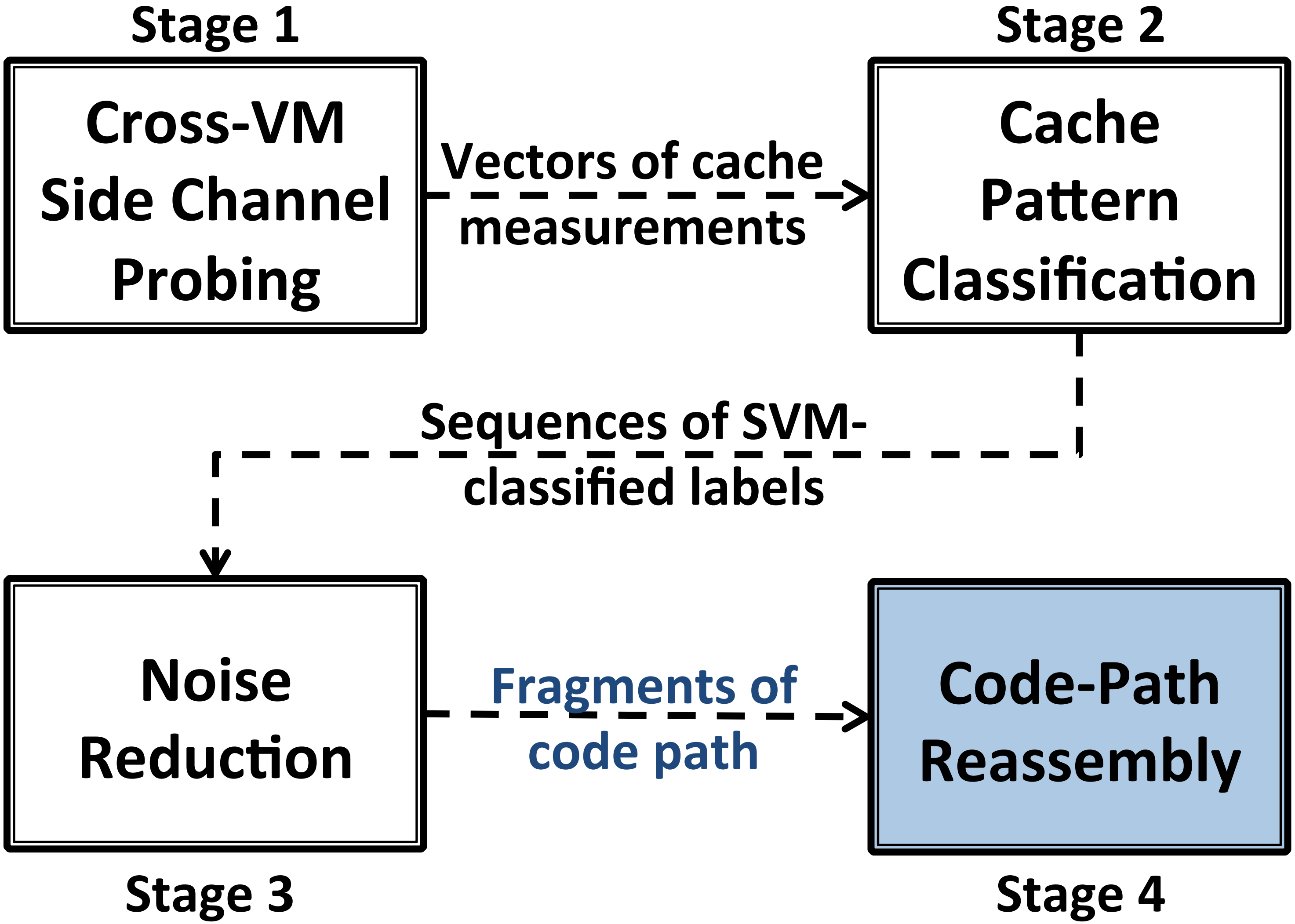
CPU core

CPU core

Cross-VM Side Channel Probing



Outline



Stage 1

Cross-VM Side Channel Probing

Vectors of cache measurements

Stage 2

Cache Pattern Classification

Sequences of SVM-classified labels

Noise Reduction

Stage 3

Fragments of code path

Code-Path Reassembly

Stage 4

Evaluation

- Intel Yorkfield processor
  - 4 cores, 32KB L1 instruction cache
- Xen + linux + GnuPG + libgcrypt
  - Xen 4.0
  - Ubuntu 10.04, kernel version 2.6.32.16
  - Victim runs GnuPG v.2.0.19 (latest)
  - libgcrypt 1.5.0 (latest)
  - ElGamal decryption, 4096 bits

Results

- **Work-Conserving Scheduler**
  - 300,000,000 prime-probe results (6 hours)
  - Over 300 key fragments
  - Brute force the key in ~9800 guesses

- **Non-Work-Conserving Scheduler**
  - 1,900,000,000 prime-probe results (45 hours)
  - Over 300 key fragments
  - Brute force the key in ~6600 guesses

Lessons

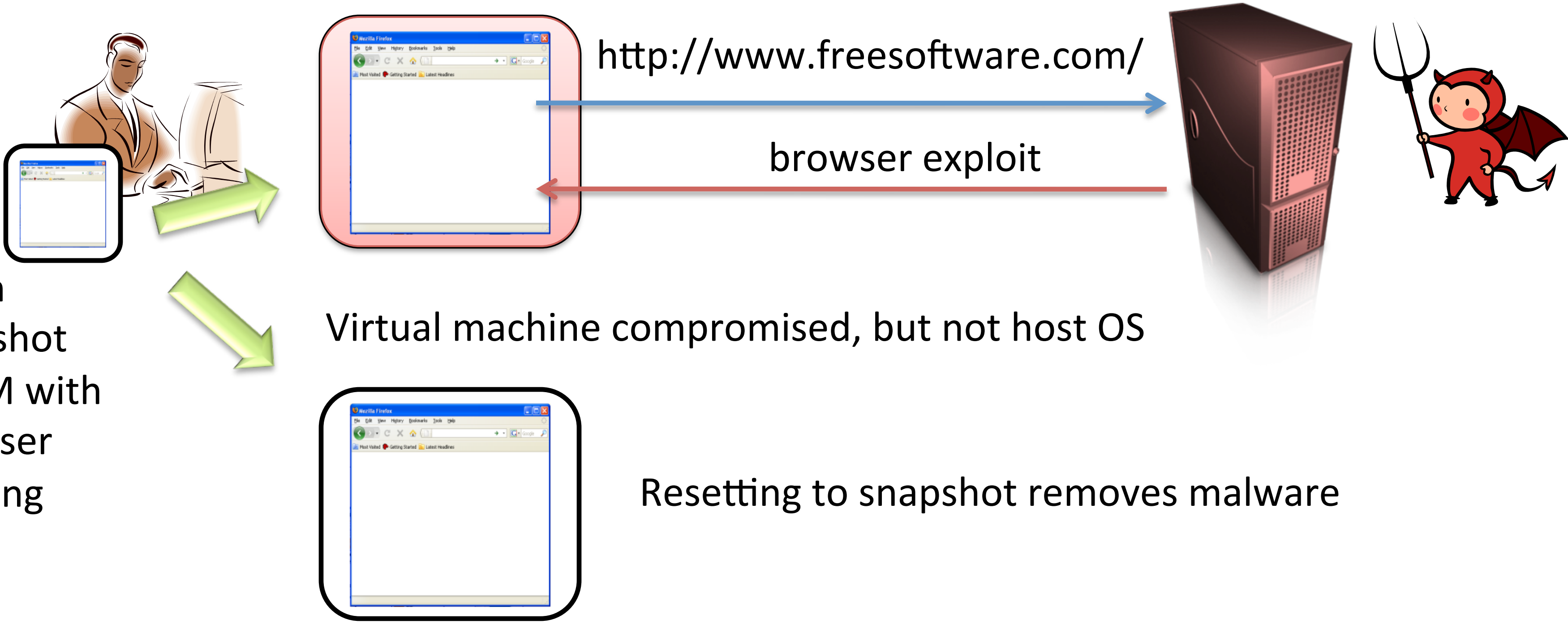
- Don’t rely on:
  - VMM transparency
  - Containment
  - Strong isolation (side channels exist)
- Securing guest OS and host OS still very important

Virtual Machine Management

- Snapshots
  - Volume snapshot / checkpoint
    - persistent storage of VM
    - must boot from storage when resuming snapshot
  - Full snapshot
    - persistent storage and ephemeral storage (memory, register states, caches, etc.)
    - start/resume in between (essentially) arbitrary instructions
- VM image is a file that stores a snapshot

Virtual machines and secure browsing

"**Protect Against Adware and Spyware:** Users protect their PCs against adware, spyware and other malware while browsing the Internet with Firefox in a virtual machine."
[http://www.vmware.com/company/news/releases/player.html]



http://www.freesoftware.com/

browser exploit

Clean snapshot of VM with browser running

Virtual machine compromised, but not host OS

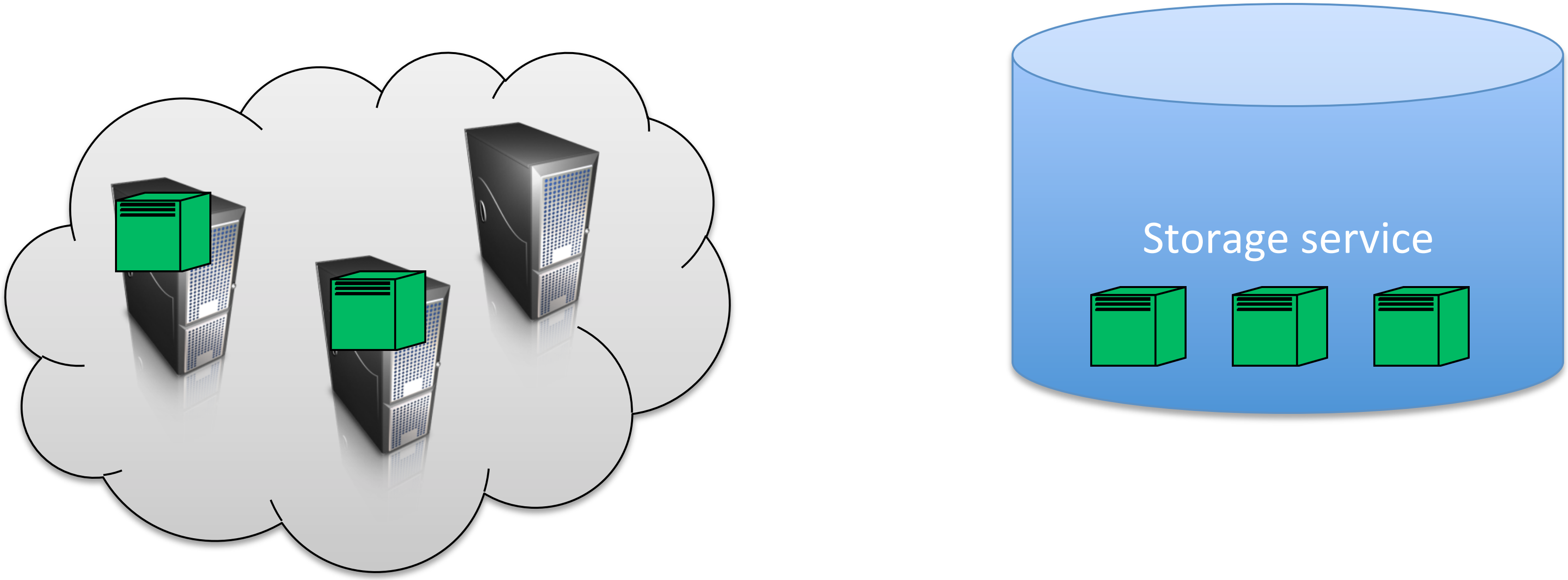
Resetting to snapshot removes malware

VM Management issues

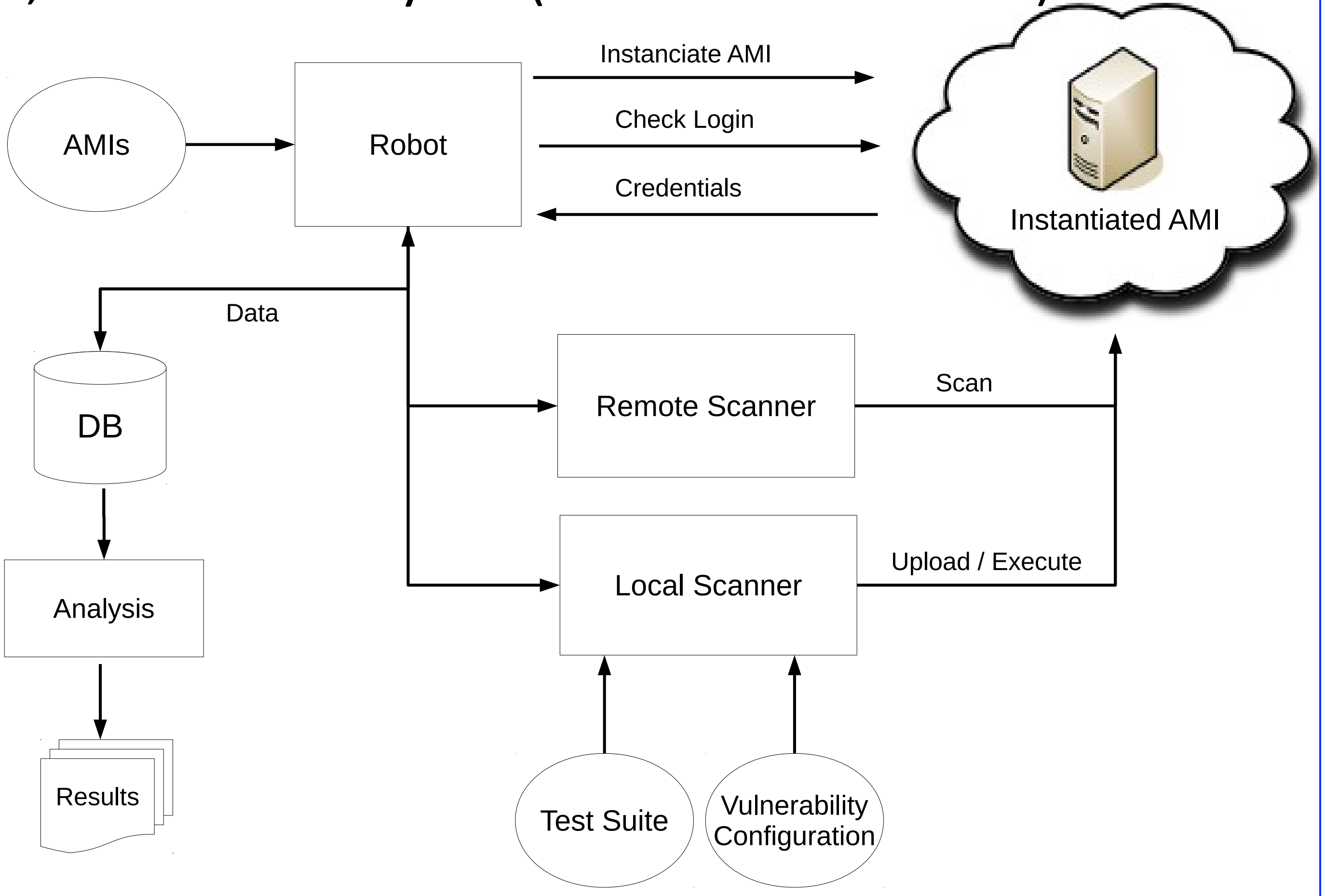
- Reset vulnerabilities
  - We saw crypto/RNG related vulnerabilites last week (reuse of randomness)
  - Guest OS and application quiescing
- Lack of diversity
- Identity management / credentials

Amazon Machine Images (AMIs)

- Users set up volume snapshots / checkpoints that can then be run on the Elastic Compute Cloud (EC2)
- Can be marked as public and anyone can use your AMI

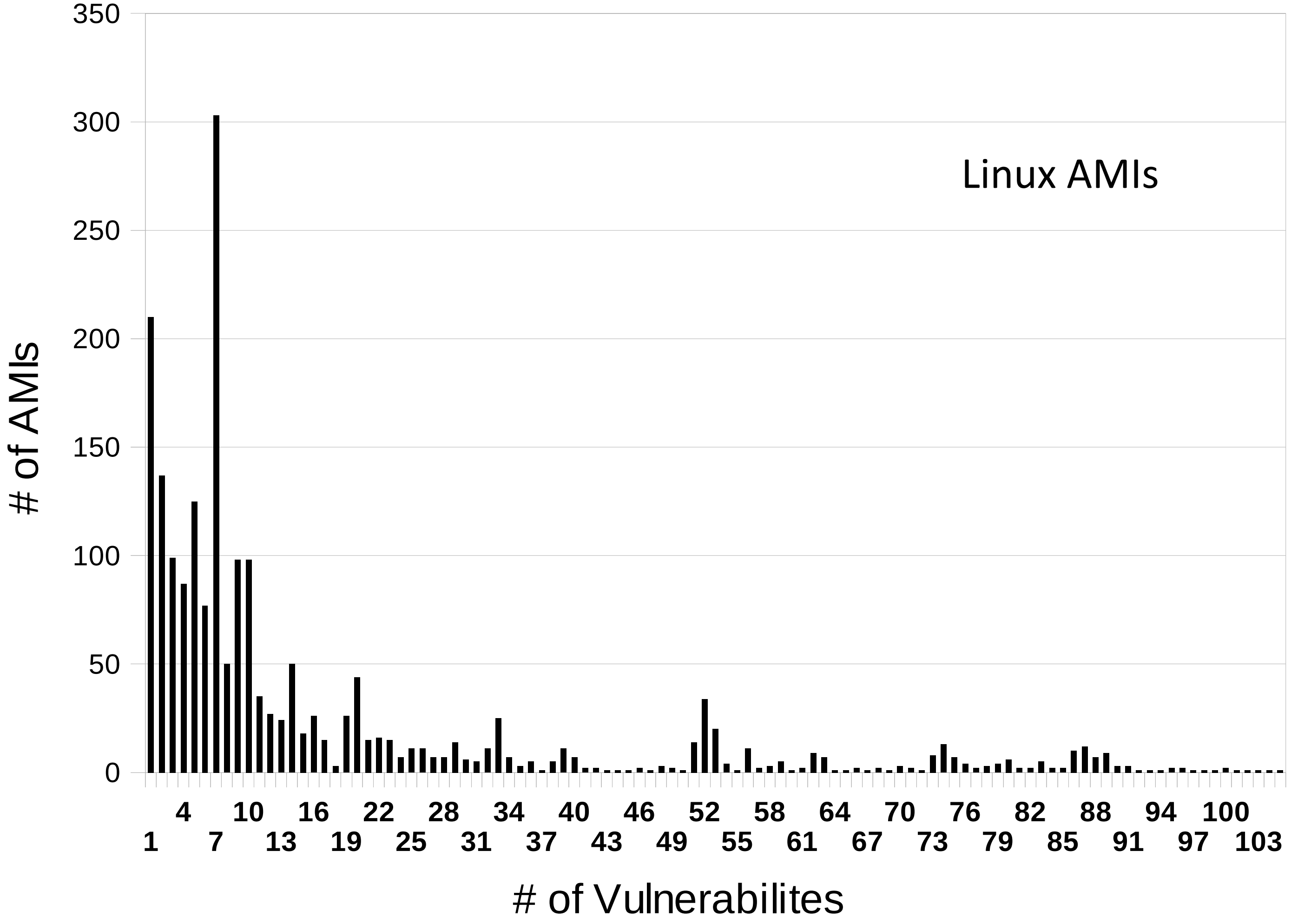


5,303 AMIs analyzed (Linux and Windows)



Balduzzi et al. "A Security Analysis of Amazon's Elastic Compute Cloud Service – Long Version –", 2011

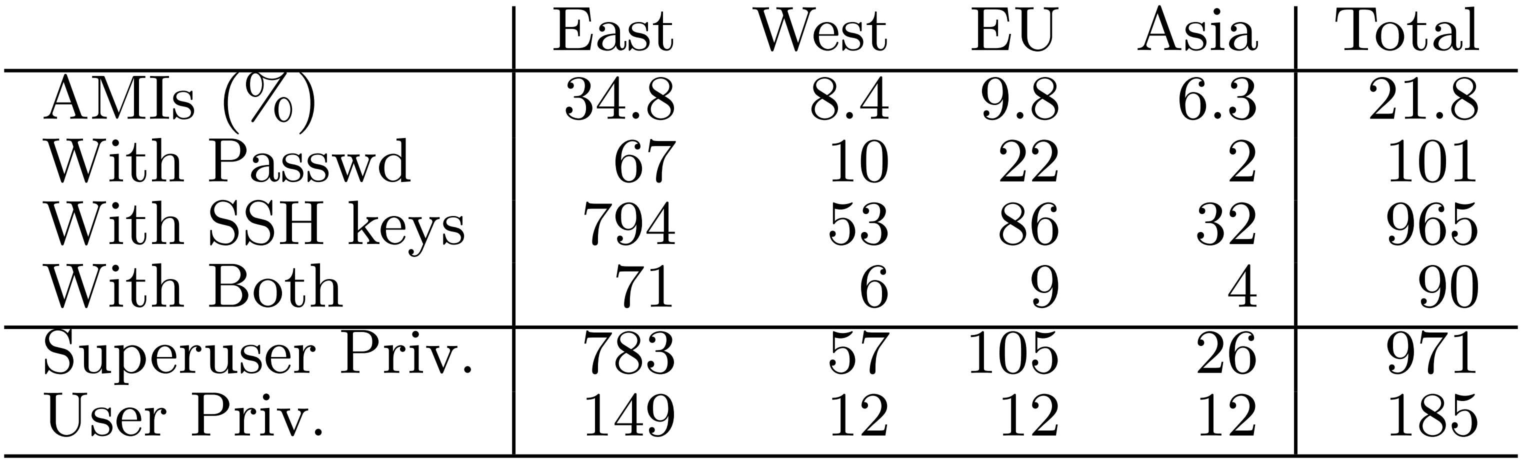
See also Bugiel et al., "AmazonIA: When Elasticity Snaps Back", 2011



Also: Malware found on a couple AMIs

Balduzzi et al. analysis

- Backdoors
  - AMIs include SSH public keys within authorized_keys
  - Password-based backdoors

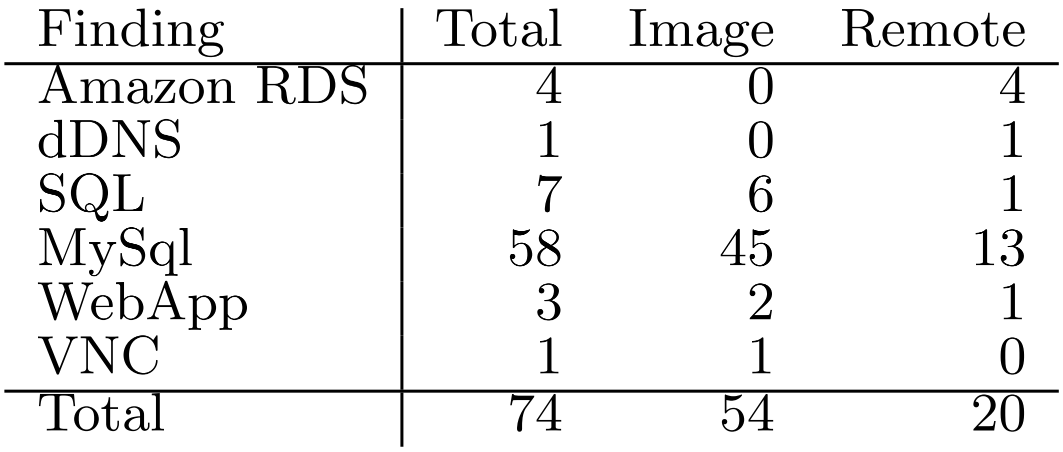


	East	West	EU	Asia	Total
AMIs (%)	34.8	8.4	9.8	6.3	21.8
With Passwd	67	10	22	2	101
With SSH keys	794	53	86	32	965
With Both	71	6	9	4	90
Superuser Priv.	783	57	105	26	971
User Priv.	149	12	12	12	185

Table 2: Left credentials per AMI

Balduzzi et al. analysis

- Credentials for other systems
  - AWS secret keys (to control EC2 services of an account): 67 found
  - Passwords / secret keys for other systems: 56 found

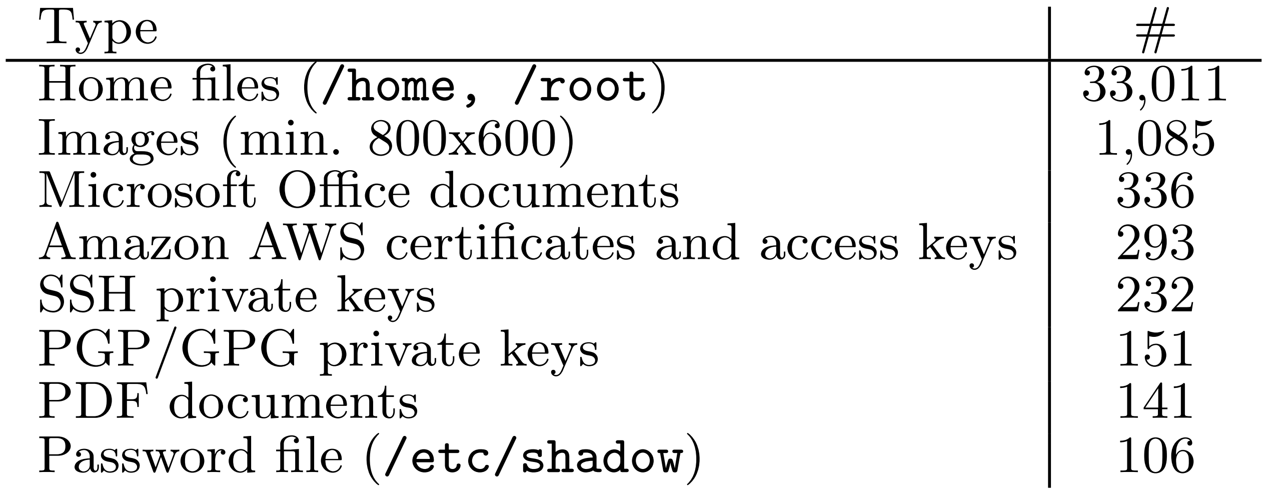


Finding	Total	Image	Remote
Amazon RDS	4	0	4
dDNS	1	0	1
SQL	7	6	1
MySql	58	45	13
WebApp	3	2	1
VNC	1	1	0
Total	74	54	20

Table 3: Credentials in history files

Balduzzi et al. analysis

- Deleted files
  - – One AMI creation method does block-level copying



Type	#
Home files (`/home, /root`)	33,011
Images (min. 800x600)	1,085
Microsoft Office documents	336
Amazon AWS certificates and access keys	293
SSH private keys	232
PGP/GPG private keys	151
PDF documents	141
Password file (`/etc/shadow`)	106

Table 5: Recovered data from deleted files

Response

> “They told me it’s not their concern, they just provide computing power,” Balduzzi says. “It’s like if you upload naked pictures to Facebook. It’s not a good practice, but it’s not Facebook’s problem.”

http://www.forbes.com/sites/andygreenberg/2011/11/08/
researchers-find-amazon-cloud-servers-teeming-with-backdoors-and-other-peoples-data/

- Amazon notified customers with vulnerable AMIs
- Made private AMIs of non-responsive customers
- New tutorials for bundling systems
- Working on undelete issues…

Lessons

- New software management practices needed with VM snapshots
- Discussion:
  - New tool support?
  - How much worse is this than non-cloud server deployments?
- We have about ~1600 AMIs downloaded ourselves. Research project ideas?