Data Confidentiality in the Cloud: Laser Gunfight at the O.K. Corral?

Approaches to stopping the malicious insider at the cloud provider

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Cloud computing in a nutshell

- Computing as a utility
- Pay-as-you-go / pay-per-use
- Resource pooling
- Elasticity
- Large-scale datacenters

Microsoft's Chicago datacenter

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Talk is about IaaS and public clouds

- Infrastructure as a Service (IaaS): the service provided are virtual machines, storage
  - e.g., Amazon EC2, Amazon S3
- Public cloud: the cloud provider and cloud user are different companies

Security in the cloud (from the user viewpoint)

- Challenges
  - The system is no longer in the user premises
  - The infrastructure is shared with other users
  - The access is made through the internet
- The three classical security attributes can be jeopardized: confidentiality, integrity, availability

Outline

- How to steal data in the cloud
- Approach 1: improve the infrastructure
- Approach 2: build a cloud-of-clouds

How to steal data in the cloud

Malicious insider and confidentiality

- The data is in the cloud and the malicious insider is a real problem
  - CyberLynk (March'09) and Google (early'10) events

CRIMINAL JUSTICE

Producer Sues ISP and its Fired Employee, Saying Hack Destroyed Season of Kids' TV Series

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hacked into his former company's networked computers and
n of a syndicated children's TV show.

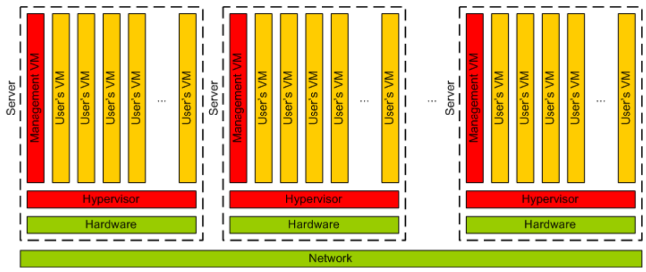
EXCLUSIVE

GCreep: Google Engineer Stalked Teens, Spied on Chats (Updated)

We entrust Google with our most private communications because we assume the company takes every precaution to safeguard our data. It doesn't. A Google engineer spied on four underage teens for months before the

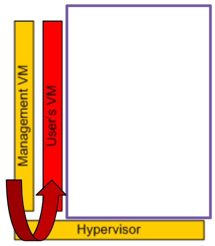
Basic cloud architecture (IaaS)

- Service provided is the execution of Virtual Machines (VMs): full sw stack, including OS
- Servers run an Hypervisor (or VMM) that supports the execution of several VMs



Experiments

- We played the role of a malicious insider with access to the management VM
- The “cloud” was just a single machine
  - Hypervisor was Xen
  - Management VM was Xen Dom 0 with Linux (Ubuntu)
  - 1 user VM (victim) with Linux and an Apache server



Attack 1: steal passwords in memory

- Trivial: take mem snapshot, look for passwords

```
$ xm dump-core 2 -L lucidomu.dump
Dumping core of domain: 2 ...
$ cat lucidomu.dump | strings | grep loginpwd
loginpwd
loginpwd
$ cat lucidomu.dump | strings | grep apachersapwd
apachersapwd
apachersapwd
apachersapwd
```

Attack 2: steal private keys in memory

- Trivial: they're in a standard format in memory

```
$ xm dump-core 2 -L lucidomu.dump
Dumping core of domain: 2 ...
$ rsakeyfind lucidomu.dump
found private key at 1b061de8
version = 00
modulus = 00 d0 66 f8 9d e2 be 4a 2b 6d be 9f de
  46 db 5a
...
publicExponent = 01 00 01
privateExponent = ...
prime1 = ...
prime2 = ...
```


Attack 3: steal files in file system

- Trivial: essentially mounting a drive (with LVM)

```
$ lvcreate -L 2G -s -n lv_st /dev/main_vol/domu
Logical volume 'lv_st' created        Snapshot victim's VM drive
$ kpartx -av /dev/main_vol/lv_st
                                      Add partition map to the new vol.
...
$ vgscan     Search for LVM volumes
Found volume group 'LucidDomU'
$ vgchange -ay LucidDomU   Activate the snapshot volume
$ mount /dev/LucidDomU/root /mnt/
```

Current solutions?

- “Cloud Computing Roundtable” (Nov/Dec 2010)
  - senior staff from: Google, Microsoft, Cisco, Amazon, Cloud Security Alliance
- “We have very strict procedures in place for when our employees are allowed to [physically] access the machines the customer data resides on.”
  - But the attacks we saw can be done remotely
- “We keep track of every action that they take on those machines, and we log all that information for later audits”
  - But detecting later can be too late
- “We have zero tolerance for insiders abusing that trust”

Cryptography?

- Obvious solution: simply encrypt the data
- But what is data in IaaS?
  - User files, web pages, databases, variables, data structures, etc.
  - Is it possible to modify applications to handle encrypted data? An application server (Tomcat, JBoss,…)?
  - Where do we store the encryption keys safely?
- Moreover applications often manipulate data
  - Manipulate encrypted data: fully homomorphic encryption
  - Slow and does not work with data from several clients

Approach 1: improve the infrastructure

Key idea

- To prove to the cloud user that its data is in a server with a “good” software configuration
  - e.g., in which the management VM has no snapshot function
- Do it with the Trusted Platform Module (TPM)
  - a security chip designed by the Trusted Computing Group, now shipping with common PC hardware

TPM basic functions

- Two basic functions:
- Storage of cryptographic keys – e.g. to protect RSA private keys from disclosure
- System software integrity measurement – to do certain operations (or not) depending on the software running

Measurements and PCRs

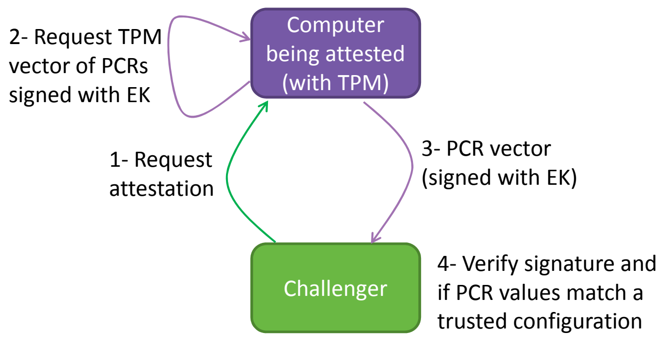
- TPM has at least 16 Platform Configuration Registers (PCR)
- A PCR stores (typically) a measurement of a software block, i.e., its cryptographic hash
  - During system boot, the i^{th} module to run stores the hash of the $(i+1)^{th}$ module in PCR_{i-1}
  - Example: BIOS stores *hash(boot loader)* in PCR_0; boot loader stores *hash(hypervisor)* in PCR_1
- A vector of PCR values gives a trusted measurement of the software configuration

Measurements and PCRs (cont)

- Can't the 1st module provide a false hash of the 2nd?
- We assume we can trust the 1st module, thus called the Static Root of Trust for Measurement (SRTM)
- Can't a PCR be overwritten at any time?
- No, there is no *write* operation, only extend
  - $PCR_i \leftarrow H(PCR_i \,||\, h)$ (the 1st time, PCR_i=0)
  - After the 1st extend, it's infeasible to store exactly 0||h in PCR_i (due to properties of cryptographic hash functions)

Remote attestation

- Computer gives to challenger a measurement of the software configuration, i.e., a vector of PCR values
  - Challenger has the Endorsement Key Certificate, signed by the TPM vendor (means it's a real TPM!)



Solution overview

- Servers run a Trusted Virtualization Environment (TVE), formed by hypervisor + management VM that the user trusts
- TVE does not provide dangerous operations to administrators: snapshot, volume mount
- TVE provides only trusted versions of certain operations: launch, migrate, backup, terminate VMs
- VMs enter and leave a TVE encrypted
- Users do remote attestation of TVEs/operations to be sure that their VMs are either in a TVE or encrypted

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Trusted virtualization environment

- The virtualization environment is measured
  - At boot time, hashes of the software components that are loaded are stored in PCRs
  - At least: boot record, hypervisor, management VM (kernel, management software)
- The environment is a TVE if its measurements (PCR values) fall in a set of TVE-configurations

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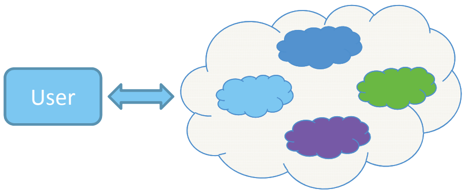
Open problems

- Gap between checking a measurement (just a hash) and trusting a complex software module
  - How can we know that there aren't vulnerabilities, undesirable functionality or malware inside?
- Putting this solution in production is far from simple
  - Short time to market and too many players: cloud provider, software producers, assurance labs

Approach 2: build a cloud-of-clouds

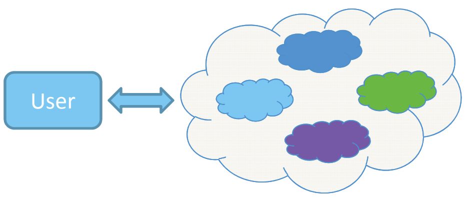
Securing the cloud

- 1st solution: improve the cloud infrastructure with trusted computing ✓
- 2nd solution: build a (virtual) cloud-of-clouds based on a few clouds – DepSky system
- First can be implemented by providers, second by users



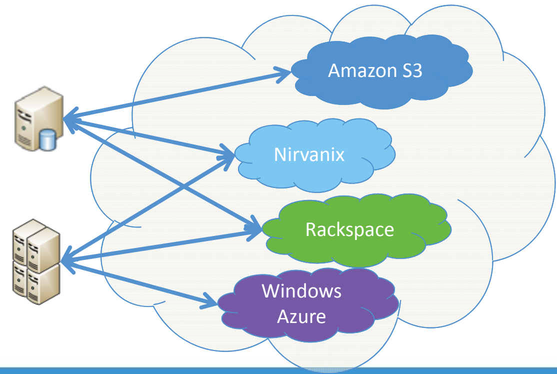
Cloud-of-clouds' benefits

- Can tolerate data corruption
  - Due to malicious insiders, other attacks, accidental faults (e.g., due to bugs)
- Can tolerate datacenter and cloud outages
- No vendor lock-in
- Faster read access
- Confidentiality…

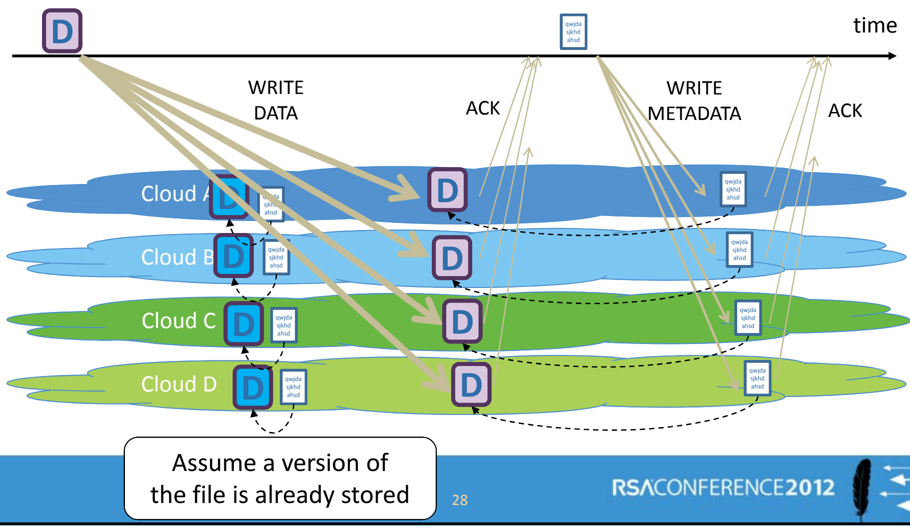


Cloud-of-clouds object storage

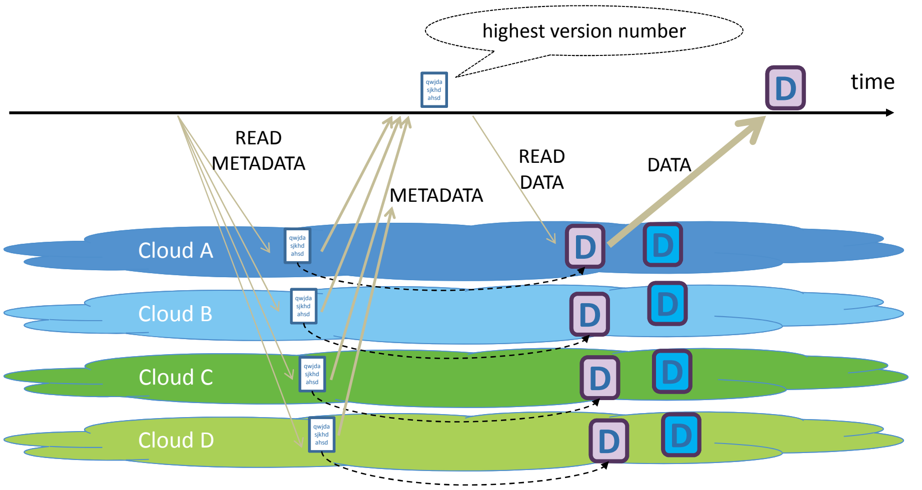
- No longer IaaS cloud computing, (only) storage
- Cloud-of-clouds provides the same service as single cloud: read data, write data, etc.



Write protocol



Read protocol

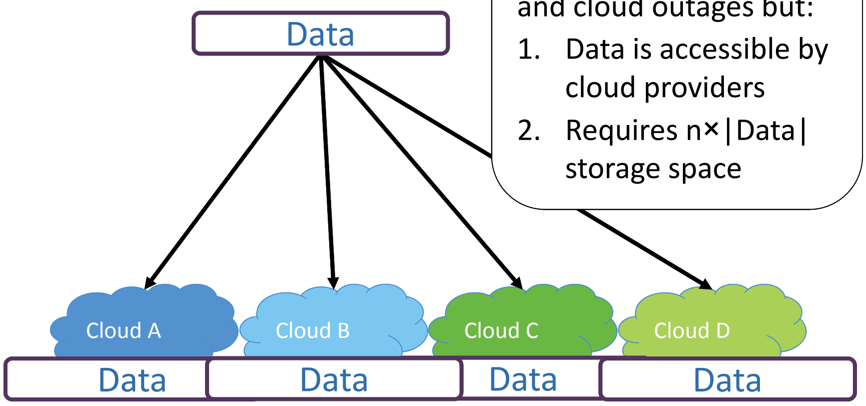


Data is fetched from other clouds if needed

Solution so far

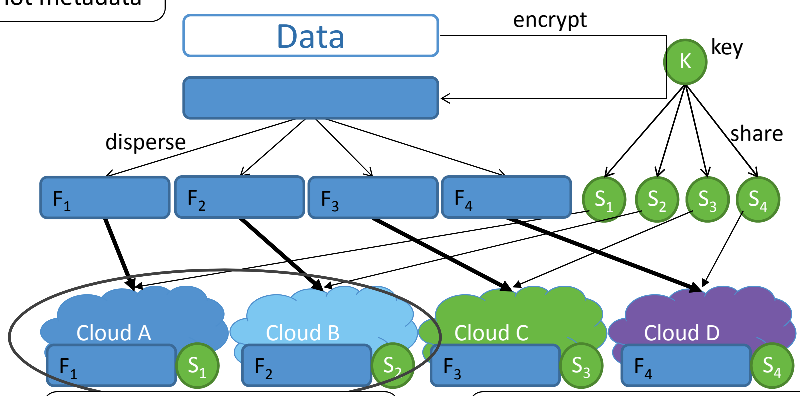
Provides availability despite data corruption and cloud outages but:

1. Data is accessible by cloud providers
2. Requires n×|Data| storage space



Combining erasure codes and secret sharing

Only for data, not metadata



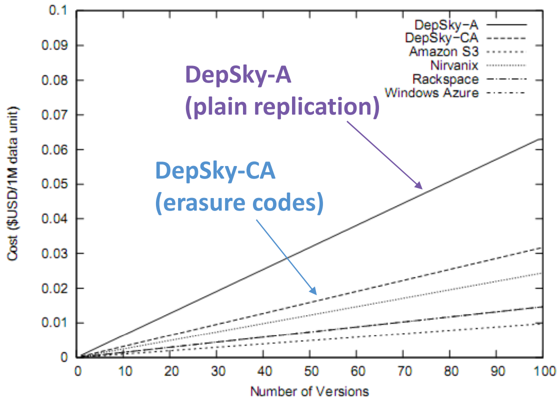
Encrypted so data can't be read at a cloud!

Only twice the size of storage, not 4 times!

Performance evaluation setup

- Prototype: 3K LOCs (Java), REST/HTTPS
- Experimental setup
  - 2 DepSky versions: A (availability), CA (availability+ confidentiality)
  - 4 commercial storage clouds: S3 (Amazon S3), WA (Windows Azure), NX (Nirvanix SDN) and RS (Rackspace)
  - Clients in 8 sites around the world (PlanetLab)
  - 437K+ reads/writes in Sep./Oct. 2010

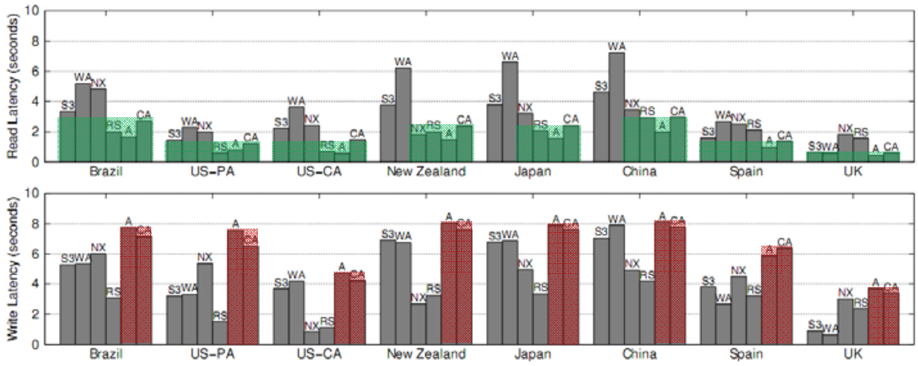
DepSky storage costs ($)



DepSky-CA storage cost (1M DU) ≈ 2 × (average cloud cost)

DepSky latency (100KB DU)

DepSky **read** latency is close to the cloud with the **best** latency



DepSky **write** latency is close to the cloud with the **worst** latency

Conclusions

Conclusions (1)

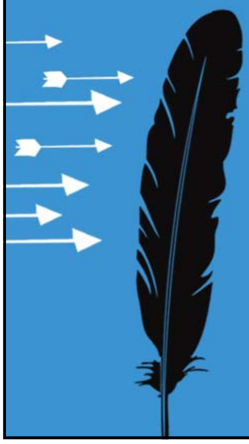
- Cloud security undeniable problem for organizations that want to use it for critical systems/data
- The malicious insider is an especially hard problem
- Two approaches, but not exactly for the same problem

Conclusions (2)

- Approach 1 – improve the cloud infrastructure with trusted computing
  - Cloud providers may implement something of the kind
  - But too many open problems yet
- Approach 2 – build a storage cloud-of-clouds based on a few clouds – DepSky system
  - A user-side solution, so easier to deploy
  - More expensive than single cloud, but not excessively

Apply Slide

- In the next <u>three months</u> you should:
- Identify critical data yr company has in the cloud
- If your company uses the cloud for computing
  - Identify hypervisor/management VM used
  - Ask provider operations supported by the mgmt VM
  - Ask provider what protections from admins are used
- If you company uses storage clouds
  - Consider encrypting data and using two clouds
- In <u>one year</u>: follow cloud evolution; use DepSky?



Thank you!

More info:
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