

Security and Privacy in Cloud Computing

Outline

- Part I: Introduction
- Part II: Security and Privacy Issues in Cloud Computing
- Part III: Possible Solutions

Part I. Introduction

- Cloud Computing Background
- Cloud Models
- Why do you still hesitate to use cloud computing?
- Causes of Problems Associated with Cloud Computing
- Taxonomy of Fear
- Threat Model

Cloud Computing Background

- Features
 - Use of internet-based services to support business process
 - Rent IT-services on a utility-like basis
- Attributes
 - Rapid deployment
 - Low startup costs/ capital investments
 - Costs based on usage or subscription
 - Multi-tenant sharing of services/ resources
- Essential characteristics
 - On demand self-service
 - Ubiquitous network access
 - Location independent resource pooling
 - Rapid elasticity
 - Measured service
- “Cloud computing is a compilation of existing techniques and technologies, packaged within a new infrastructure paradigm that offers improved scalability, elasticity, business agility, faster startup time, reduced management costs, and just-in-time availability of resources”

A Massive Concentration of Resources

- Also a massive concentration of risk
 - expected loss from a single breach can be significantly larger
 - concentration of “users” represents a concentration of threats
- “Ultimately, you can outsource responsibility but you can’t outsource accountability.”

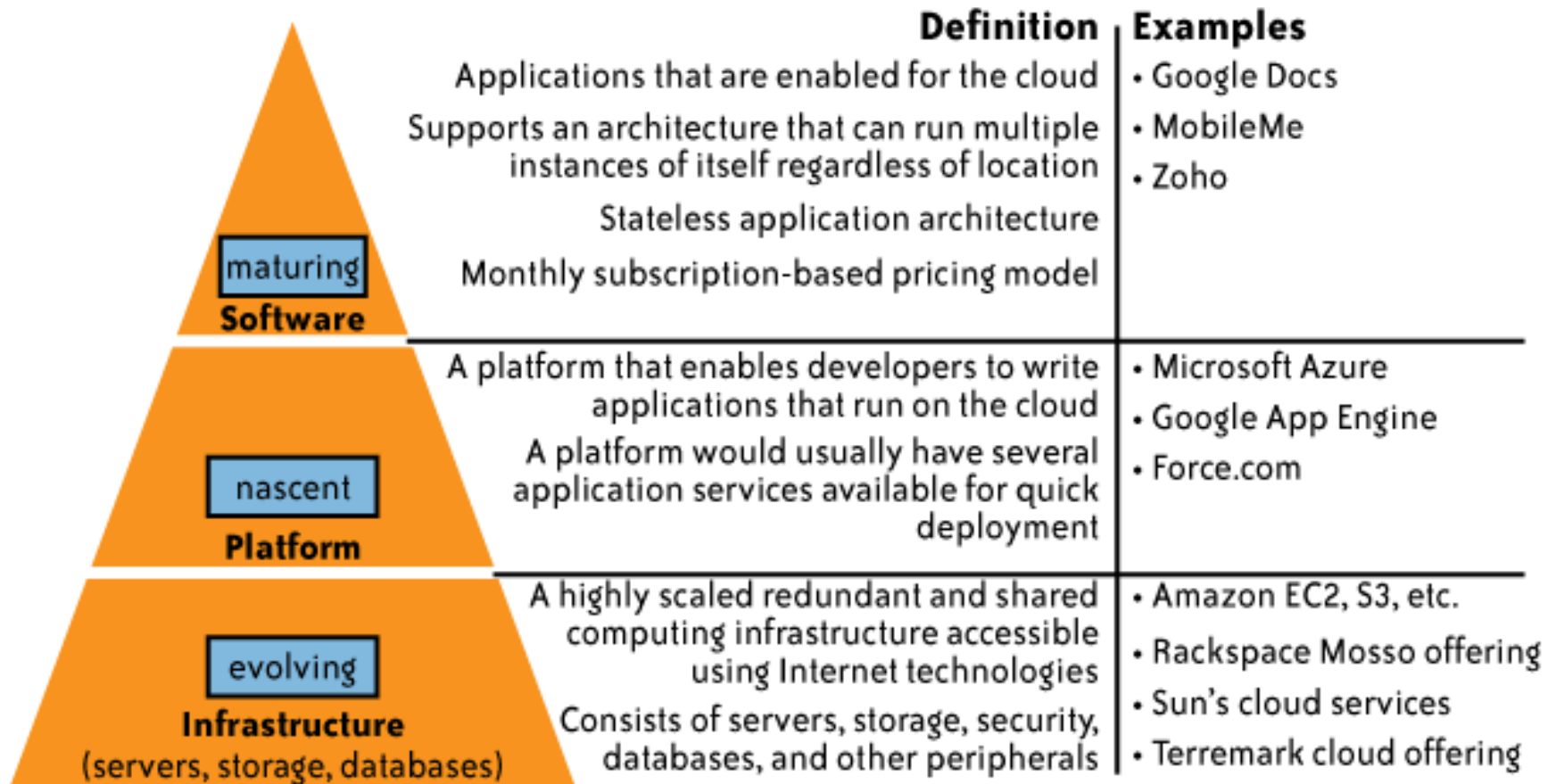
Cloud Computing: who should use it?

- Cloud computing definitely makes sense if your own security is weak, missing features, or below average.
- Ultimately, if
 - the cloud provider's security people are "better" than yours (and leveraged at least as efficiently),
 - the web-services interfaces don't introduce too many new vulnerabilities, and
 - the cloud provider aims at least as high as you do, at security goals,then cloud computing has better security.

Cloud Models

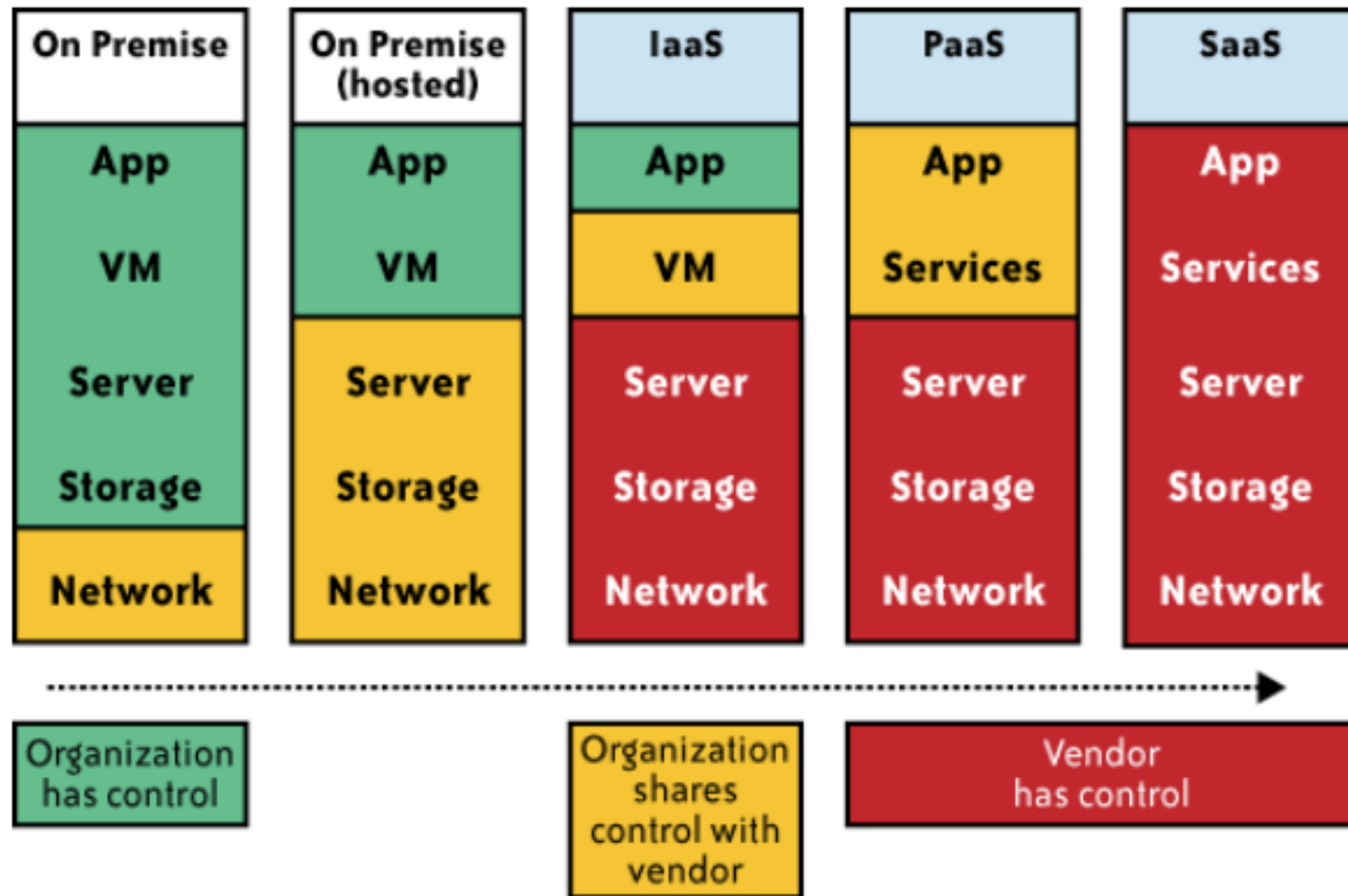
- Delivery Models
 - SaaS
 - PaaS
 - IaaS
- Deployment Models
 - Private cloud
 - Community cloud
 - Public cloud
 - Hybrid cloud
- We propose one more Model: Management Models (trust and tenancy issues)
 - Self-managed
 - 3rd party managed (e.g. public clouds and VPC)

Delivery Models



While cloud-based software services are maturing,
Cloud platform and infrastructure offering are still in their early stages !

Impact of cloud computing on the governance structure of IT organizations



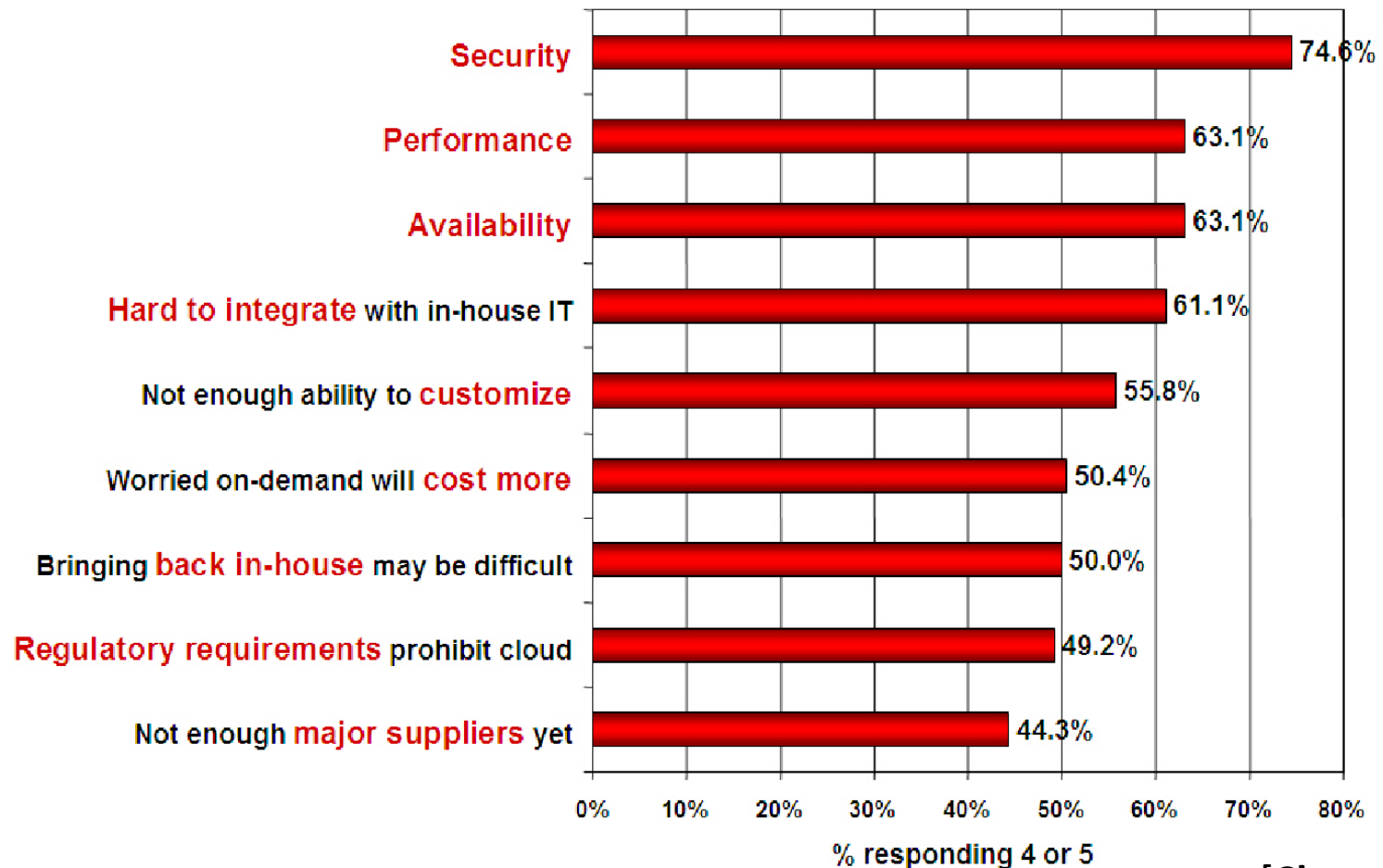
If cloud computing is so great, why isn't everyone doing it?

- The cloud acts as a big black box, nothing inside the cloud is visible to the clients
- Clients have no idea or control over what happens inside a cloud
- Even if the cloud provider is honest, it can have malicious system admins who can tamper with the VMs and violate confidentiality and integrity
- Clouds are still subject to traditional data confidentiality, integrity, availability, and privacy issues, plus some additional attacks

Companies are still afraid to use clouds

Q: Rate the **challenges/issues** ascribed to the 'cloud'/on-demand model

(1=not significant, 5=very significant)



Source: IDC Enterprise Panel, August 2008 n=244

[Chow09ccsw]

Causes of Problems Associated with Cloud Computing

- Most security problems stem from:
 - Loss of control
 - Lack of trust (mechanisms)
 - Multi-tenancy
- These problems exist mainly in 3rd party management models
 - Self-managed clouds still have security issues, but not related to above

Loss of Control in the Cloud

- Consumer's loss of control
 - Data, applications, resources are located with provider
 - User identity management is handled by the cloud
 - User access control rules, security policies and enforcement are managed by the cloud provider
 - Consumer relies on provider to ensure
 - Data security and privacy
 - Resource availability
 - Monitoring and repairing of services/resources

Lack of Trust in the Cloud

- A brief deviation from the talk
 - (But still related)
 - Trusting a third party requires taking risks
- Defining trust and risk
 - Opposite sides of the same coin (J. Camp)
 - People only trust when it pays (Economist's view)
 - Need for trust arises only in risky situations
- Defunct third party management schemes
 - Hard to balance trust and risk
 - e.g. Key Escrow (Clipper chip)
 - Is the cloud headed toward the same path?

Multi-tenancy Issues in the Cloud

- Conflict between tenants' opposing goals
 - Tenants share a pool of resources and have opposing goals
- How does multi-tenancy deal with conflict of interest?
 - Can tenants get along together and 'play nicely' ?
 - If they can't, can we isolate them?
- How to provide separation between tenants?
- Cloud Computing brings new threats
 - Multiple independent users share the same physical infrastructure
 - Thus an attacker can legitimately be in the same physical machine as the target

Security concepts

Confidentiality: Preserving authorized restrictions on information access

Integrity: The assurance that data received are exactly as sent by an authorized entity (i.e., contain no modification, insertion, deletion, or replay).

Availability: Ensuring timely and reliable access to and use of information.

Taxonomy of Fear

- Confidentiality
 - Fear of loss of control over data
 - Will the sensitive data stored on a cloud remain confidential?
 - Will cloud compromises leak confidential client data
 - Will the cloud provider itself be honest and won't peek into the data?
- Integrity
 - How do I know that the cloud provider is doing the computations correctly?
 - How do I ensure that the cloud provider really stored my data without tampering with it?

Taxonomy of Fear (cont.)

- Availability
 - Will critical systems go down at the client, if the provider is attacked in a Denial of Service attack?
 - What happens if cloud provider goes out of business?
 - Would cloud scale well-enough?
 - Often-voiced concern
 - Although cloud providers argue their downtime compares well with cloud user's own data centers

Taxonomy of Fear (cont.)

- Privacy issues raised via massive data mining
 - Cloud now stores data from a lot of clients, and can run data mining algorithms to get large amounts of information on clients
- Increased attack surface
 - Entity outside the organization now stores and computes data, and so
 - Attackers can now target the communication link between cloud provider and client
 - Cloud provider employees can be phished

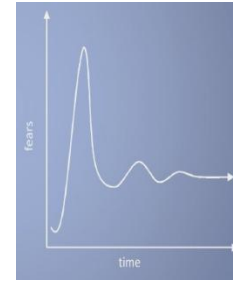
Taxonomy of Fear (cont.)

- Auditability and forensics (out of control of data)
 - Difficult to audit data held outside organization in a cloud
 - Forensics also made difficult since now clients don't maintain data locally
- Legal quagmire and transitive trust issues
 - Who is responsible for complying with regulations?
 - e.g., SOX, HIPAA, GLBA ?
 - If cloud provider subcontracts to third party clouds, will the data still be secure?

Taxonomy of Fear (cont.)



Cloud Computing is a **security nightmare** and it can't be handled in traditional ways.
John Chambers
CISCO CEO



- Security is one of the most difficult task to implement in cloud computing.
 - Different forms of attacks in the application side and in the hardware components
- Attacks with catastrophic effects only needs one security flaw

(<http://www.exforsys.com/tutorials/cloud-computing/cloud-computing-security.html>)

Threat Model

- A threat model helps in analyzing a security problem, design mitigation strategies, and evaluate solutions
- Steps:
 - Identify attackers, assets, threats and other components
 - Rank the threats
 - Choose mitigation strategies
 - Build solutions based on the strategies

Threat Model

- Basic components
 - Attacker modeling
 - Choose what attacker to consider
 - insider vs. outsider?
 - single vs. collaborator?
 - Attacker motivation and capabilities
 - Attacker goals
 - Vulnerabilities / threats

What is the issue?

- The core issue here is the levels of trust
 - Many cloud computing providers trust their customers
 - Each customer is physically commingling its data with data from anybody else using the cloud while logically and virtually you have your own space
 - The way that the cloud provider implements security is typically focused on the fact that those outside of their cloud are evil, and those inside are good.
- But what if those inside are also evil?

Attacker Capability: Malicious Insiders

- At client
 - Learn passwords/authentication information
 - Gain control of the VMs
- At cloud provider
 - Log client communication
 - Can read unencrypted data
 - Can possibly peek into VMs, or make copies of VMs
 - Can monitor network communication, application patterns
 - Why?
 - Gain information about client data
 - Gain information on client behavior
 - Sell the information or use itself

Attacker Capability: Outside attacker

- What?
 - Listen to network traffic (passive)
 - Insert malicious traffic (active)
 - Probe cloud structure (active)
 - Launch DoS
- Goal?
 - Intrusion
 - Network analysis
 - Man in the middle
 - Cartography

Challenges for the attacker

- How to find out where the target is located?
- How to be co-located with the target in the same (physical) machine?
- How to gather information about the target?

Part II: Security and Privacy Issues in Cloud Computing - Big Picture

- Infrastructure Security
- Data Security and Storage
- Identity and Access Management (IAM)
- Privacy
- And more...

From [6] Cloud Security and Privacy by Mather and Kumaraswamy

Infrastructure Security

- Network Level
- Host Level
- Application Level

The Network Level

- Ensuring confidentiality and integrity of your organization's data-in-transit to and from your public cloud provider
- Ensuring proper access control (authentication, authorization, and auditing) to whatever resources you are using at your public cloud provider
- Ensuring availability of the Internet-facing resources in a public cloud that are being used by your organization, or have been assigned to your organization by your public cloud providers
- Replacing the established model of network zones and tiers with domains

From [6] Cloud Security and Privacy by Mather and Kumaraswamy

The Network Level - Mitigation

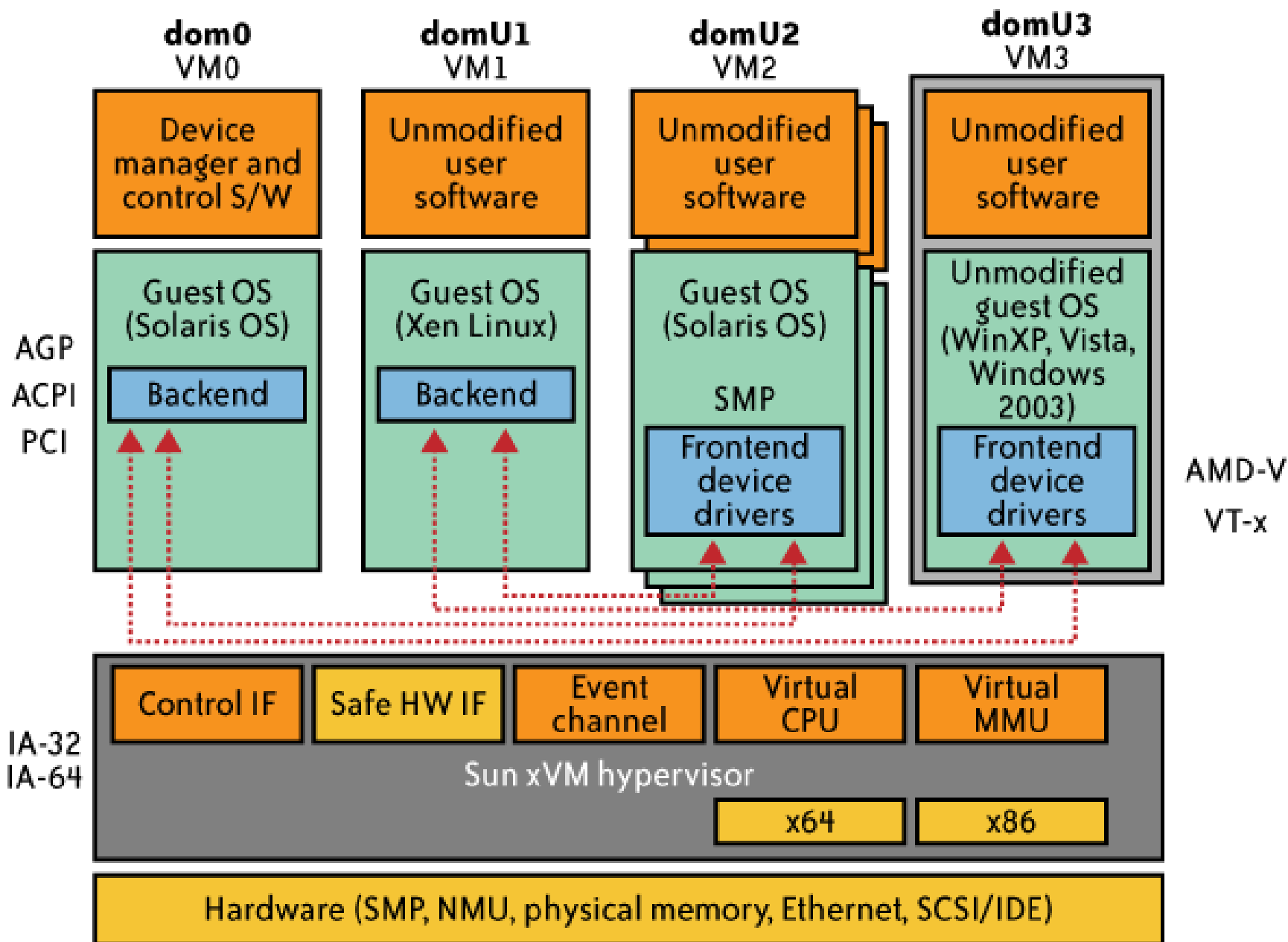
- Note that network-level risks exist regardless of what aspects of “cloud computing” services are being used
- The primary determination of risk level is therefore not which *aaS is being used,
- But rather whether your organization intends to use or is using a public, private, or hybrid cloud.

From [6] Cloud Security and Privacy by Mather and Kumaraswamy

The Host Level

- SaaS/PaaS
 - Both the PaaS and SaaS platforms abstract and hide the host OS from end users
 - Host security responsibilities are transferred to the CSP (Cloud Service Provider)
 - You do not have to worry about protecting hosts
 - However, as a customer, you still own the risk of managing information hosted in the cloud services.

From [6] Cloud Security and Privacy by Mather and Kumaraswamy



Case study: Amazon's EC2 infrastructure

- "Hey, You, Get Off of My Cloud: Exploring Information Leakage in Third-Party Compute Clouds"
 - Multiple VMs of different organizations with virtual boundaries separating each VM can run within one physical server
 - "virtual machines" still have internet protocol, or IP, addresses, visible to anyone within the cloud.
 - VMs located on the same physical server tend to have IP addresses that are close to each other and are assigned at the same time
 - An attacker can set up lots of his own virtual machines, look at their IP addresses, and figure out which one shares the same physical resources as an intended target
 - Once the malicious virtual machine is placed on the same server as its target, it is possible to carefully monitor how access to resources fluctuates and thereby potentially glean sensitive information about the victim

Local Host Security

- Are local host machines part of the cloud infrastructure?
 - Outside the security perimeter
 - While cloud consumers worry about the security on the cloud provider's site, they may easily forget to harden their own machines
- The lack of security of local devices can
 - Provide a way for malicious services on the cloud to attack local networks through these terminal devices
 - Compromise the cloud and its resources for other users

Local Host Security (Cont.)

- With mobile devices, the threat may be even stronger
 - Users misplace or have the device stolen from them
 - Security mechanisms on handheld gadgets are often times insufficient compared to say, a desktop computer
 - Provides a potential attacker an easy avenue into a cloud system.
 - If a user relies mainly on a mobile device to access cloud data, the threat to availability is also increased as mobile devices malfunction or are lost
- Devices that access the cloud should have
 - Strong authentication mechanisms
 - Tamper-resistant mechanisms
 - Strong isolation between applications
 - Methods to trust the OS
 - Cryptographic functionality when traffic confidentiality is required

The Application Level

- DoS
- EDoS(Economic Denial of Sustainability)
 - An attack against the billing model that underlies the cost of providing a service with the goal of bankrupting the service itself.
- End user security
- Who is responsible for Web application security in the cloud?
- SaaS/PaaS/IaaS application security
- Customer-deployed application security

From [6] Cloud Security and Privacy by Mather and Kumaraswamy

Data Security and Storage

- Several aspects of data security, including:
 - Data-in-transit
 - Confidentiality + integrity using secured protocol
 - Confidentiality with non-secured protocol and encryption
 - Data-at-rest
 - Generally, not encrypted , since data is commingled with other users' data
 - Encryption if it is not associated with applications?
 - But how about indexing and searching?
 - Then homomorphic encryption vs. predicate encryption?
 - Processing of data, including multitenancy
 - For any application to process data, not encrypted

Data Security and Storage (cont.)

– Data lineage

- Knowing when and where the data was located w/i cloud is important for audit/compliance purposes

- e.g., Amazon AWS

- Store <d1, t1, ex1.s3.amazonaws.com>
- Process <d2, t2, ec2.compute.amazonaws.com>
- Restore <d3, t3, ex2.s3.amazonaws.com>

Where is (or was) that system located?
What was the state of that physical system?
How would a customer or auditor verify that info?

– Data provenance

- Computational accuracy (as well as data integrity)
- E.g., financial calculation: $\text{sum}(((2*3)*4)/6) - 2 = \$2.00 ?$
 - Correct : assuming US dollar
 - How about dollars of different countries?
 - Correct exchange rate?

Data Security and Storage

- Data remanence
 - Inadvertent disclosure of sensitive information is possible
- Data security mitigation?
 - Do not place any sensitive data in a public cloud
 - Encrypted data is placed into the cloud?
- Provider data and its security: storage
 - To the extent that quantities of data from many companies are centralized, this collection can become an attractive target for criminals
 - Moreover, the physical security of the data center and the trustworthiness of system administrators take on new importance.

Why IAM?

- Organization's trust boundary will become dynamic and will move beyond the control and will extend into the service provider domain.
- Managing access for diverse user populations (employees, contractors, partners, etc.)
- Increased demand for authentication
 - personal, financial, medical data will now be hosted in the cloud
 - S/W applications hosted in the cloud requires access control
- Need for higher-assurance authentication
 - authentication in the cloud may mean authentication outside F/W
 - Limits of password authentication
- Need for authentication from mobile devices

From [6] Cloud Security and Privacy by Mather and Kumaraswamy

Early this morning, at 3:30am PST, we started seeing elevated levels of authenticated requests from multiple users in one of our locations. While we carefully monitor our overall request volumes and these remained within normal ranges, we had not been monitoring the proportion of authenticated requests. Importantly, these cryptographic requests consume more resources per call than other request types.

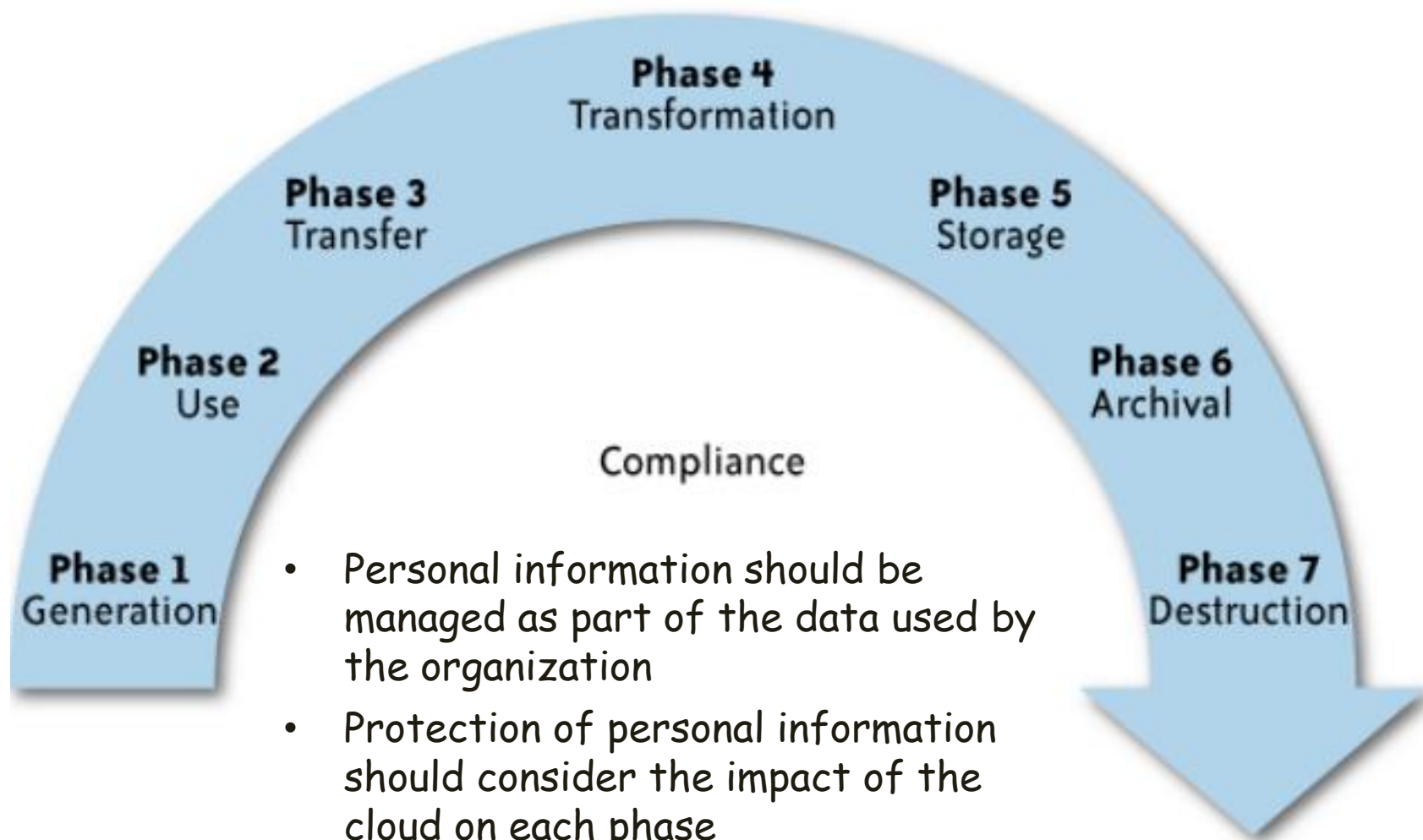
- Shortly before 4:00am PST, we began to see several other users significantly increase their volume of authenticated calls. The last of these pushed the authentication service over its maximum capacity before we could complete putting new capacity in place. In addition to processing authenticated requests, the authentication service also performs account validation on every request Amazon S3 handles. This caused Amazon S3 to be unable to process any requests in that location, beginning at 4:31am PST. By 6:48am PST, we had moved enough capacity online to resolve the issue.

- As we said earlier today, though we're proud of our uptime track record over the past two years with this service, any amount of downtime is unacceptable. As part of the post mortem for this event, we have identified a set of short-term actions as well as longer term improvements. We are taking immediate action on the following: (a) improving our monitoring of the proportion of authenticated requests; (b) further increasing our authentication service capacity; and (c) adding additional defensive measures around the authenticated calls. Additionally, we've begun work on a service health dashboard, and expect to release that shortly.

What is Privacy?

- The concept of privacy varies widely among (and sometimes within) countries, cultures, and jurisdictions.
- It is shaped by public expectations and legal interpretations; as such, a concise definition is elusive if not impossible.
- Privacy rights or obligations are related to the collection, use, disclosure, storage, and destruction of personal data (or Personally Identifiable Information—PII).
- At the end of the day, privacy is about the accountability of organizations to data subjects, as well as the transparency to an organization's practice around personal information.

What is the data life cycle?



What Are the Key Privacy Concerns?

- Typically mix security and privacy
- Some considerations to be aware of:
 - Storage
 - Retention
 - Destruction
 - Auditing, monitoring and risk management
 - Privacy breaches
 - Who is responsible for protecting privacy?

Storage

- Is it commingled with information from other organizations that use the same CSP?
- The aggregation of data raises new privacy issues
 - Some governments may decide to search through data without necessarily notifying the data owner, depending on where the data resides
- Whether the cloud provider itself has any right to see and access customer data?
- Some services today track user behaviour for a range of purposes, from sending targeted advertising to improving services

Retention

- How long is personal information (that is transferred to the cloud) retained?
- Which retention policy governs the data?
- Does the organization own the data, or the CSP?
- Who enforces the retention policy in the cloud, and how are exceptions to this policy (such as litigation holds) managed?

Destruction

- How does the cloud provider destroy PII at the end of the retention period?
- How do organizations ensure that their PII is destroyed by the CSP at the right point and is not available to other cloud users?
- Cloud storage providers usually replicate the data across multiple systems and sites—increased availability is one of the benefits they provide.
 - How do you know that the CSP didn't retain additional copies?
 - Did the CSP really destroy the data, or just make it inaccessible to the organization?
 - Is the CSP keeping the information longer than necessary so that it can mine the data for its own use?

Auditing, monitoring and risk management

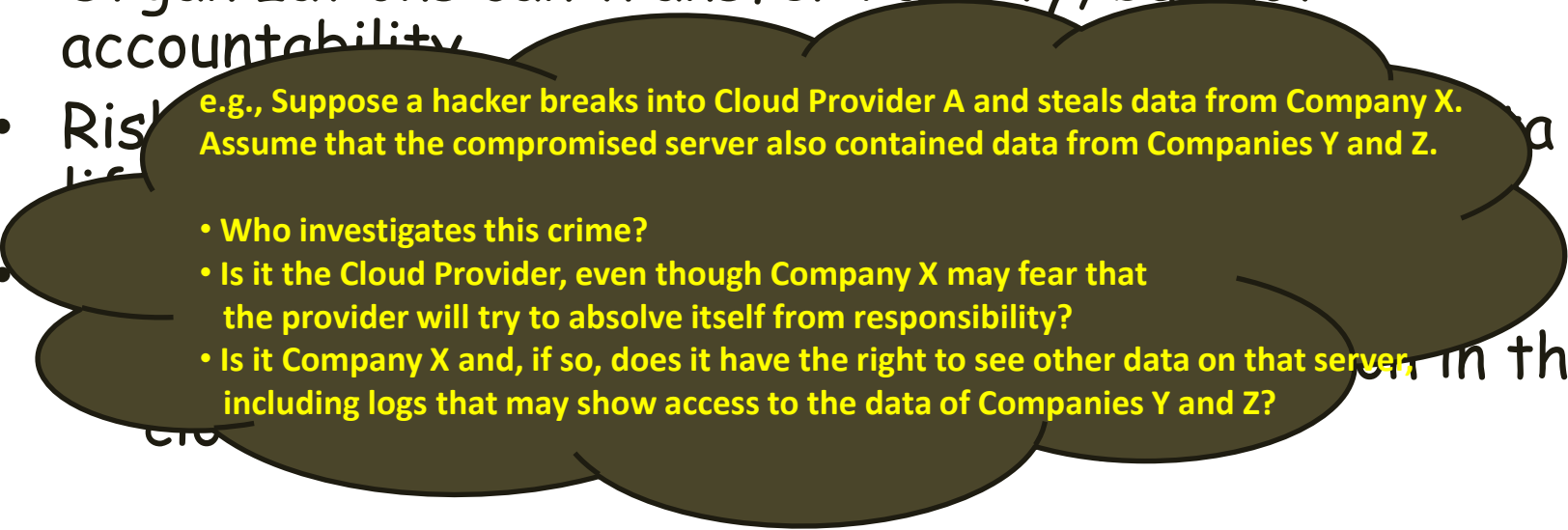
- How can organizations monitor their CSP and provide assurance to relevant stakeholders that privacy requirements are met when their PII is in the cloud?
- Are they regularly audited?
- What happens in the event of an incident?
- If business-critical processes are migrated to a cloud computing model, internal security processes need to evolve to allow multiple cloud providers to participate in those processes, as needed.
 - These include processes such as security monitoring, auditing, forensics, incident response, and business continuity

Privacy breaches

- How do you know that a breach has occurred?
- How do you ensure that the CSP notifies you when a breach occurs?
- Who is responsible for managing the breach notification process (and costs associated with the process)?
- If contracts include liability for breaches resulting from negligence of the CSP?
 - How is the contract enforced?
 - How is it determined who is at fault?

Who is responsible for protecting privacy?

- Data breaches have a cascading effect
- Full reliance on a third party to protect personal data?
- In-depth understanding of responsible data stewardship
- Organizations can transfer liability, but not accountability

- Risk 

e.g., Suppose a hacker breaks into Cloud Provider A and steals data from Company X. Assume that the compromised server also contained data from Companies Y and Z.

- Who investigates this crime?
 - Is it the Cloud Provider, even though Company X may fear that the provider will try to absolve itself from responsibility?
 - Is it Company X and, if so, does it have the right to see other data on that server, including logs that may show access to the data of Companies Y and Z?

Part III. Possible Solutions

- Minimize Lack of Trust
 - Policy Language
 - Certification
- Minimize Loss of Control
 - Monitoring
 - Utilizing different clouds
 - Access control management
 - Identity Management (IDM)
- Minimize Multi-tenancy

Security Issues in the Cloud

- In theory, minimizing any of the issues would help:
 - Loss of Control
 - Take back control
 - Data and apps may still need to be on the cloud
 - But can they be managed in some way by the consumer?
 - Lack of trust
 - Increase trust (mechanisms)
 - Technology
 - Policy, regulation
 - Contracts (incentives): topic of a future talk
 - Multi-tenancy
 - Private cloud
 - Takes away the reasons to use a cloud in the first place
 - VPC: its still not a separate system
 - Strong separation

Minimize Lack of Trust

- **POLICY LANGUAGE**
- **CERTIFICATION**

Minimize Lack of Trust: Policy Language

- Consumers have specific security needs but don't have a say-so in how they are handled
 - What the heck is the provider doing for me?
 - Currently consumers cannot dictate their requirements to the provider (SLAs are one-sided)
- Standard language to convey one's policies and expectations
 - Agreed upon and upheld by both parties
 - Standard language for representing SLAs
 - Can be used in a intra-cloud environment to realize overarching security posture

Minimize Lack of Trust: Policy Language (Cont.)

- Create policy language with the following characteristics:
 - Machine-understandable (or at least processable),
 - Easy to combine/merge and compare
 - Examples of policy statements are, “requires isolation between VMs”, “requires geographical isolation between VMs”, “requires physical separation between other communities/tenants that are in the same industry,” etc.
 - Need a validation tool to check that the policy created in the standard language correctly reflects the policy creator’s intentions (i.e. that the policy language is semantically equivalent to the user’s intentions).

Minimize Lack of Trust: Certification

- Certification
 - Some form of reputable, independent, comparable assessment and description of security features and assurance
 - Sarbanes-Oxley, DIACAP, DISTCAP, etc (are they sufficient for a cloud environment?)
- Risk assessment
 - Performed by certified third parties
 - Provides consumers with additional assurance

Minimize Loss of Control

- MONITORING
- UTILIZING DIFFERENT CLOUDS
- ACCESS CONTROL MANAGEMENT
- IDENTITY MANAGEMENT (IDM)

Minimize Loss of Control: Monitoring

- Cloud consumer needs situational awareness for critical applications
 - When underlying components fail, what is the effect of the failure to the mission logic
 - What recovery measures can be taken (by provider and consumer)
- Requires an application-specific run-time monitoring and management tool for the consumer
 - The cloud consumer and cloud provider have different views of the system
 - Enable both the provider and tenants to monitor the components in the cloud that are under their control

Minimize Loss of Control: Monitoring (Cont.)

- Provide mechanisms that enable the provider to act on attacks he can handle.
 - infrastructure remapping (create new or move existing fault domains)
 - shutting down offending components or targets (and assisting tenants with porting if necessary)
 - Repairs
- Provide mechanisms that enable the consumer to act on attacks that he can handle (application-level monitoring).
 - RAdAC (Risk-adaptable Access Control)
 - VM porting with remote attestation of target physical host
 - Provide ability to move the user's application to another cloud

Minimize Loss of Control: Utilize Different Clouds

- The concept of 'Don't put all your eggs in one basket'
 - Consumer may use services from different clouds through an intra-cloud or multi-cloud architecture
 - Propose a multi-cloud or intra-cloud architecture in which consumers
 - Spread the risk
 - Increase redundancy (per-task or per-application)
 - Increase chance of mission completion for critical applications
 - Possible issues to consider:
 - Policy incompatibility (combined, what is the overarching policy?)
 - Data dependency between clouds
 - Differing data semantics across clouds
 - Knowing when to utilize the redundancy feature (monitoring technology)
 - Is it worth it to spread your sensitive data across multiple clouds?
 - Redundancy could increase risk of exposure

Minimize Loss of Control:

Access Control

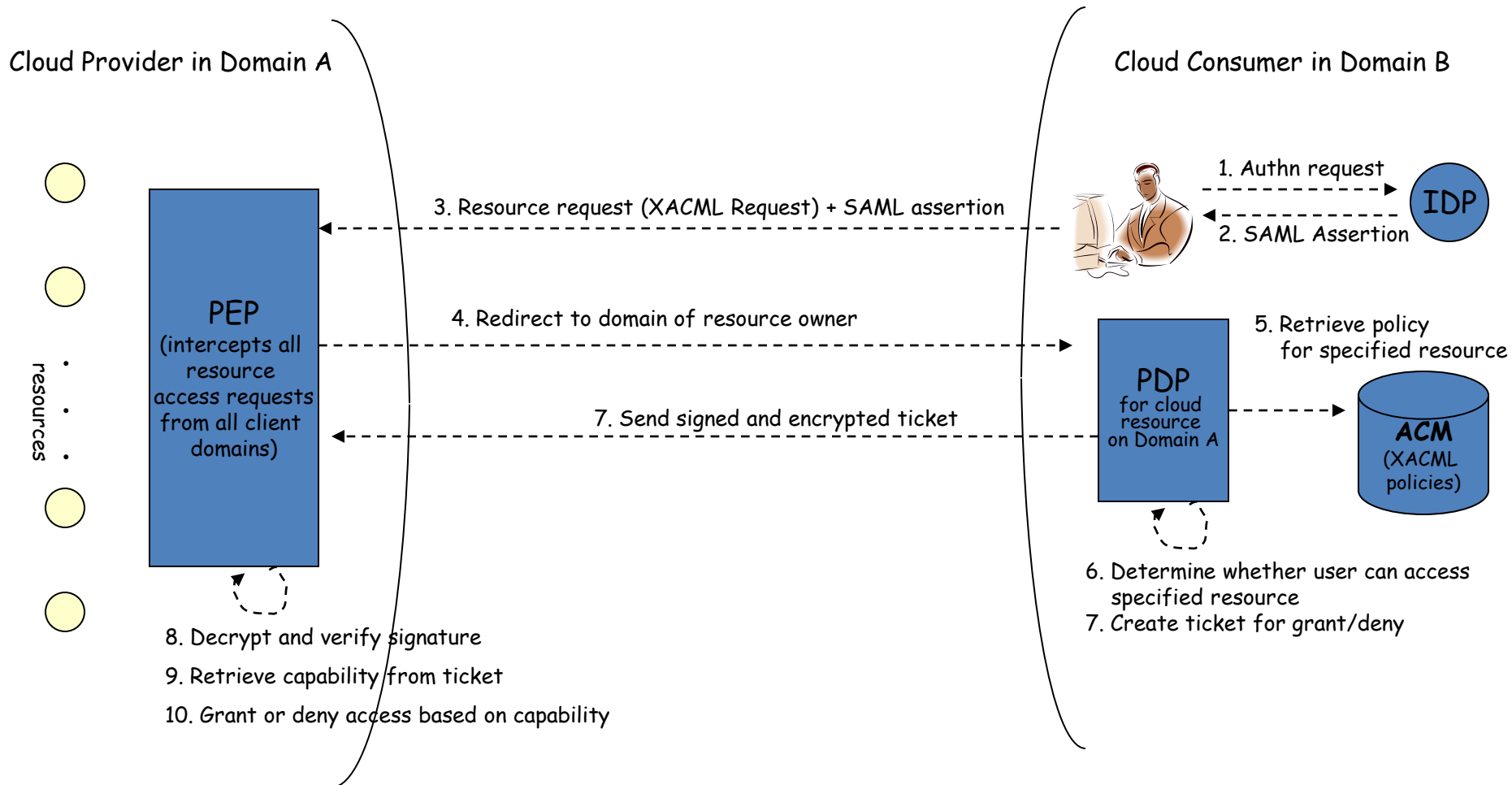
- Many possible layers of access control
 - E.g. access to the cloud, access to servers, access to services, access to databases (direct and queries via web services), access to VMs, and access to objects within a VM
 - Depending on the deployment model used, some of these will be controlled by the provider and others by the consumer
- Regardless of deployment model, provider needs to manage the user authentication and access control procedures (to the cloud)
 - Federated Identity Management: access control management burden still lies with the provider
 - Requires user to place a large amount of trust on the provider in terms of security, management, and maintenance of access control policies. This can be burdensome when numerous users from different organizations with different access control policies, are involved

Minimize Loss of Control:

Access Control (Cont.)

- Consumer-managed access control
 - Consumer retains decision-making process to retain some control, requiring less trust of the provider
 - Requires the client and provider to have a pre-existing trust relationship, as well as a pre-negotiated standard way of describing resources, users, and access decisions between the cloud provider and consumer. It also needs to be able to guarantee that the provider will uphold the consumer-side's access decisions.
 - Should be at least as secure as the traditional access control model.
 - Facebook and Google Apps do this to some degree, but not enough control
 - Applicability to privacy of patient health records

Minimize Loss of Control: Access Control



IDENTITY MANAGEMENT (IDM)

- Identity management (IdM) describes
 - the management of individual identities,
 - their authentication, authorization, roles and privileges within or across system and enterprise boundaries
 - with the goal of increasing security and productivity while decreasing cost, downtime, and repetitive tasks.

Minimize Multi-tenancy

Minimize Multi-tenancy

- Can't really force the provider to accept less tenants
 - Can try to increase isolation between tenants
 - Strong isolation techniques (VPC to some degree)
 - C.f. VM Side channel attacks (T. Ristenpart et al.)
 - QoS requirements need to be met
 - Policy specification
 - Can try to increase trust in the tenants
 - Who's the insider, where's the security boundary? Who can I trust?
 - Use SLAs to enforce trusted behavior

Conclusion

- Cloud computing is sometimes viewed as a reincarnation of the classic mainframe client-server model
 - However, resources are ubiquitous, scalable, highly virtualized
 - Contains all the traditional threats, as well as new ones
- In developing solutions to cloud computing security issues it may be helpful to identify the problems and approaches in terms of
 - Loss of control
 - Lack of trust
 - Multi-tenancy problems

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