Research in Cloud Security and Privacy

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"

From [1] NIST

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."

From [2] John McDermott, ACSAC 09

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.

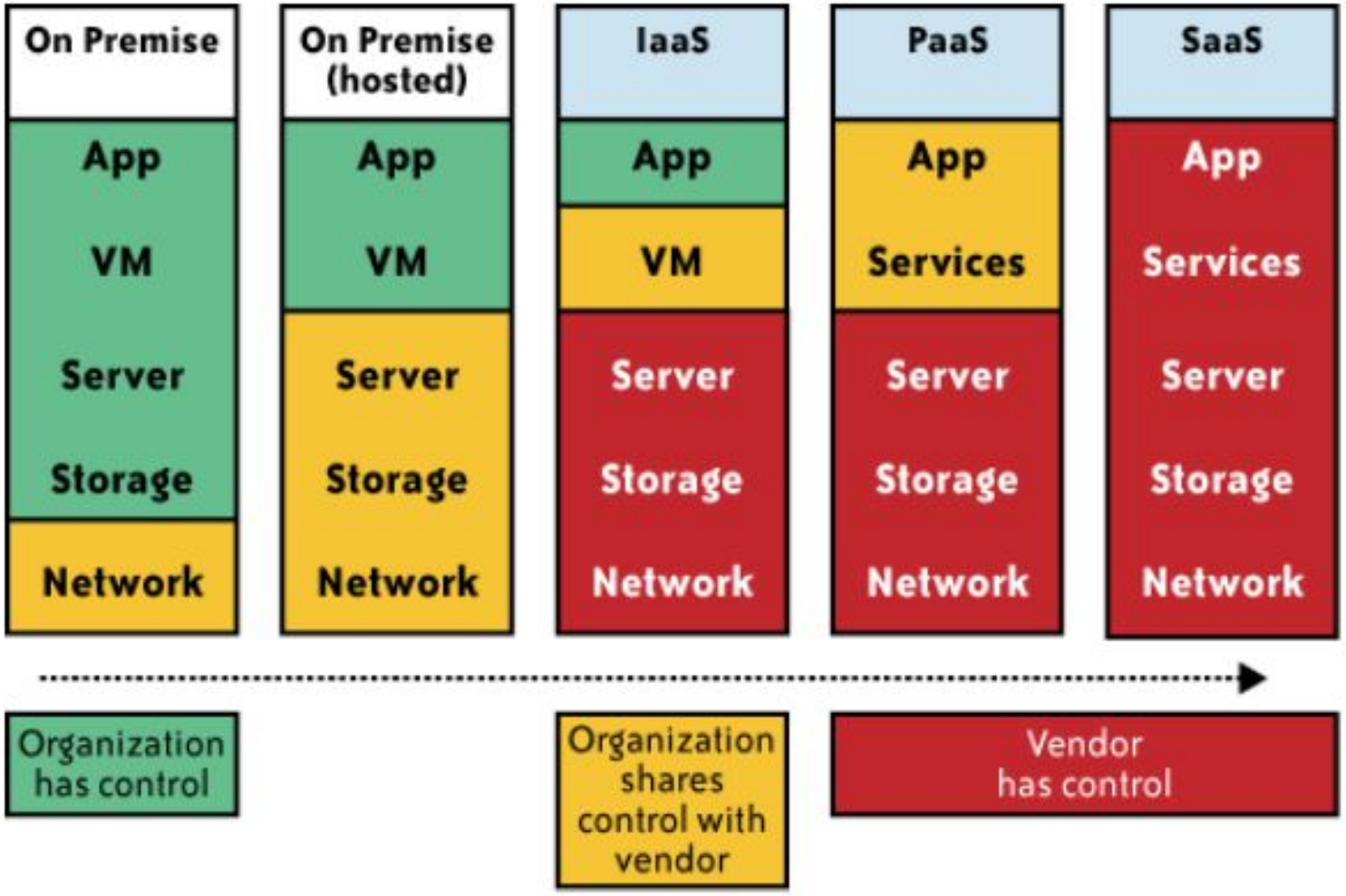
From [2] John McDermott, ACSAC 09

Cloud Models

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

From [1] NIST

Impact of cloud computing on the governance structure of IT organizations

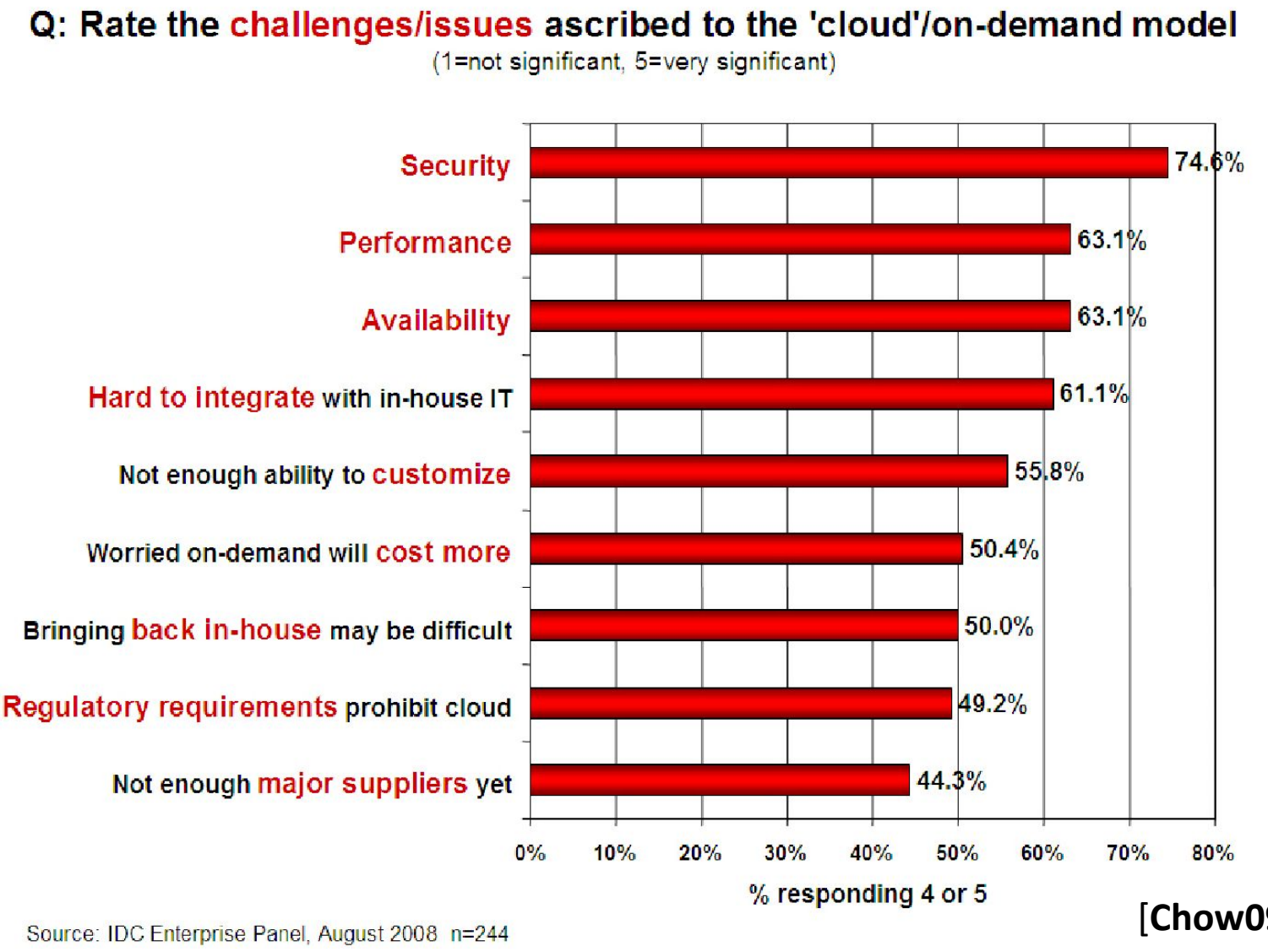


From [6] Cloud Security and Privacy by Mather and Kumaraswamy

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 afraid to use clouds



[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

- 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

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?

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

Taxonomy of Fear (cont.)

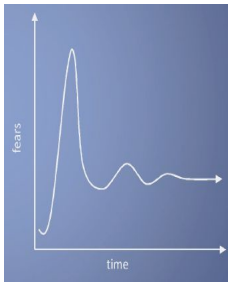
- Auditability and forensics (out of control of data)
  - Difficult to audit data held outside organization in a cloud
  - Forensics also made difficult since now clients don't maintain data locally
- Legal dilemma and transitive trust issues
  - Who is responsible for complying with regulations?
  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

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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 they fact that those outside of their cloud are evil, and those inside are good.
- But what if those inside are also evil?

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

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?

From [5] www.cs.jhu.edu/~ragib/sp10/cs412

PART II: SECURITY AND PRIVACY ISSUES IN CLOUD COMPUTING - BIG PICTURE

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?
  - Processing of data, including multitenancy
    - For any application to process data

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

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.compute2.amazonaws.com>
    - Restore <d3, t3, ex2.s3.amazonaws.com>
- Data provenance
  - Computational accuracy (as well as data integrity)
  - E.g., financial calculation: sum ((((2*3)*4)/6) -2) = $2.00 ?
    - How about dollars of different countries?
    - Correct exchange rate?
- Data remanence
  - Inadvertent disclosure of sensitive information is possible

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

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
- 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.

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

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?

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

PART III. POSSIBLE SOLUTIONS

Security Issues in the Cloud

- In theory, minimizing any of the issues would help:
  - Third Party Cloud Computing
  - 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)
  - 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

Third Party Cloud Computing

- Known issues: Already exist

- Confidentiality issues
- Malicious behavior by cloud provider
- Known risks exist in any industry practicing outsourcing
- Provider and its infrastructure needs to be trusted

New Vulnerabilities & Attacks

- Threats arise from other consumers
- Due to the subtleties of how physical resources can be transparently shared between VMs
- Such attacks are based on placement and extraction
- A customer VM and its adversary can be assigned to the same physical server
- Adversary can penetrate the VM and violate customer confidentiality

More on attacks…

- Collaborative attacks
- Mapping of internal cloud infrastructure
- Identifying likely residence of a target VM
- Instantiating new VMs until one gets co-resident with the target
- Cross-VM side-channel attacks
- Extract information from target VM on the same machine

More on attacks…

1. Can one determine where in the cloud infrastructure an instance is located?
2. Can one easily determine if two instances are co-resident on the same physical machine?
3. Can an adversary launch instances that will be co-resident with other user instances?
4. Can an adversary exploit cross-VM information leakage once co-resident?

Answer: Yes to all

Minimize Lack of Trust: Policy Language

- Consumers have specific security needs but don't have a say-so in how they are handled
  - 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
- Create policy language with the following characteristics:
  - Machine-understandable (or at least processable),
  - Easy to combine/merge and compare

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
- Risk assessment
  - Performed by certified third parties
  - Provides consumers with additional assurance

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
  - 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

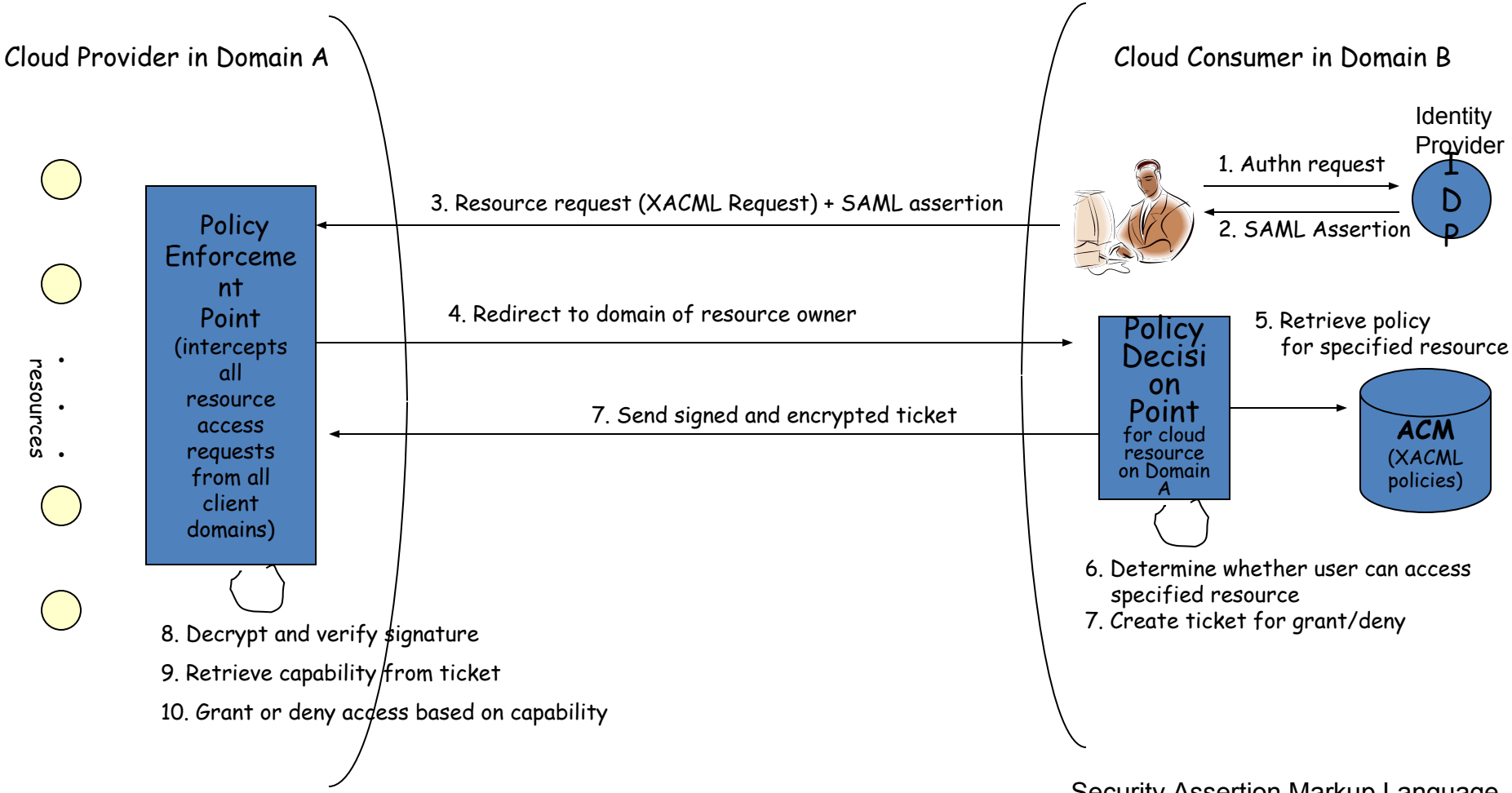
- Many possible layers of access control
  - E.g. access to the cloud, access to servers, access to services, access to databases (direct and queries via web services), access to VMs, and access to objects within a VM
  - Depending on the deployment model used, some of these will be controlled by the 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.)

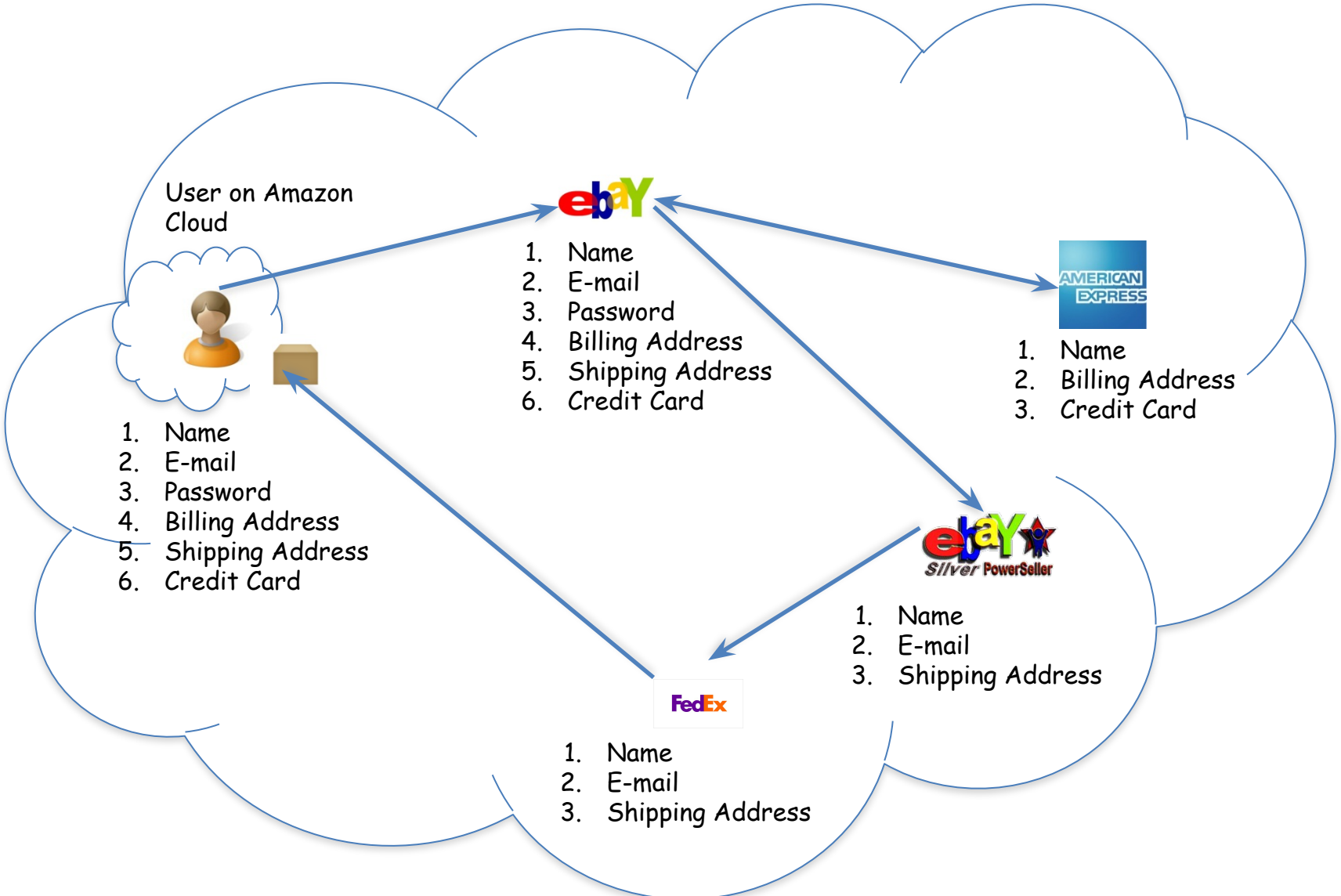
- Consumer-managed access control
  - Consumer retains decision-making process to retain some control, requiring less trust of the provider
  - Requires the client and provider to have a pre-existing trust relationship, as well as a pre-negotiated standard way of describing resources, users, and access 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.

Minimize Loss of Control: Access Control



Security Assertion Markup Language
eXtensible Access Control Markup Language

Minimize Loss of Control: IDM Motivation



Minimize Loss of Control: IDM Identity in the Cloud

Minimize Loss of Control: IDM Issues in Cloud Computing

- Cloud introduces several issues to IDM
  - Users have **multiple accounts** associated with **multiple service providers.**
  - Present IDMs require a **trusted third party** and do not work on an **untrusted host.**
  - Lack of trust
    - Use of Trusted Third Party is not an option
    - Cloud hosts are untrusted
  - Loss of control
    - Collusion between Cloud Services
      - Sharing sensitive identity information between services can lead to undesirable **mapping of the identities to the user.**

IDM in Cloud needs to be user-centric

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)
    - 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