



Security of Cloud Computing

Fabrizio Baiardi
f.baiardi@unipi.it



Syllabus

- Cloud Computing Introduction
 - Definitions
 - Economic Reasons
 - Service Model
 - Deployment Model
- Supporting Technologies
 - Virtualization Technology
 - Scalable Computing = Elasticity
- Security
 - New Threat Model
 - New Attacks
 - Countermeasures



Before the threats, the assets

- When moving your application and data to the cloud, you no longer have to protect resources (processor, memory, networks)
- Instead you have to protect your information
- Information-centric security binds security directly to information and the people who access it to ensure that they can access only the right information at the right time, when and where they need it
- All the assets you have to protect are virtual
- The cloud provider, instead, has to protect the physical assets
- No perimeter to be defended



Threat models and cloud migration: before

- They (evil, the external threat)
- Us (good ones)
- Us (the bad ones, insider threat)
- The defence is based upon
 - Preventing an attacker from entering into the system (firewall)
 - Discovering insider behaviours that violate the security policy or that have defeated the firewall (host & network IDS)
- The approach can be more detailed (e.g. defence in depth) but the distinction based upon a perimeter is always there



Threat models and cloud migration: after

- They (evil, the external threat)
- Us (good ones)
- Us (the bad ones, insider threat)
- We share the physical infrastructure, our application, our data with the evil, the cloud provider can be evil
- Every threat may become now also an insider threat
- The virtualization support has
 - to implement VMs
 - share physical resources among them
 - confine anomalous and dangerous users from good ones
- The attack surface of the cloud computing system increases at it includes
 - The VMM
 - The browser that is used to interact with the cloud.



How much control on them?

- Private cloud
 - used by a single organization eg a university, a company
 - good control
- Community cloud
 - Used by a set of organizations that share the same problems eg several hospitals
 - Acceptable control
- Public cloud
 - No control



Extended Attack Surface

- The attack surface of a system includes all the components that can be the target of an initial attack of a threat that enables the threat to reach some goals
 - Entry points
 - Exit points
 - Channels
- The notion of surface makes it possible to evaluate the percentage of a system that is exposed to threat attacks = how many initial attacks with respect to all attack
- The attack surface of a cloud system is larger than the one of an equivalent stand alone system



New classes of attacks

A system where legal user and attacker share the same architecture is the target of new attacks that

- discover and monitor the flows of information
 - among VMs, application, platforms
 - between the browser and the cloud
- discover the allocation of VMs onto physical nodes to deduce the physical resources shared among VMs =
cloud cartography
- control the user browser to control and manipulate the cloud resources with respect to those attacks that steal info of a browser and so on, now the goal is controlling those resources that are accessed through the browser

However, there is a much larger amount of cheap processing power, Can this power be helpful for the good guys? How?



SaaS Maturity Levels

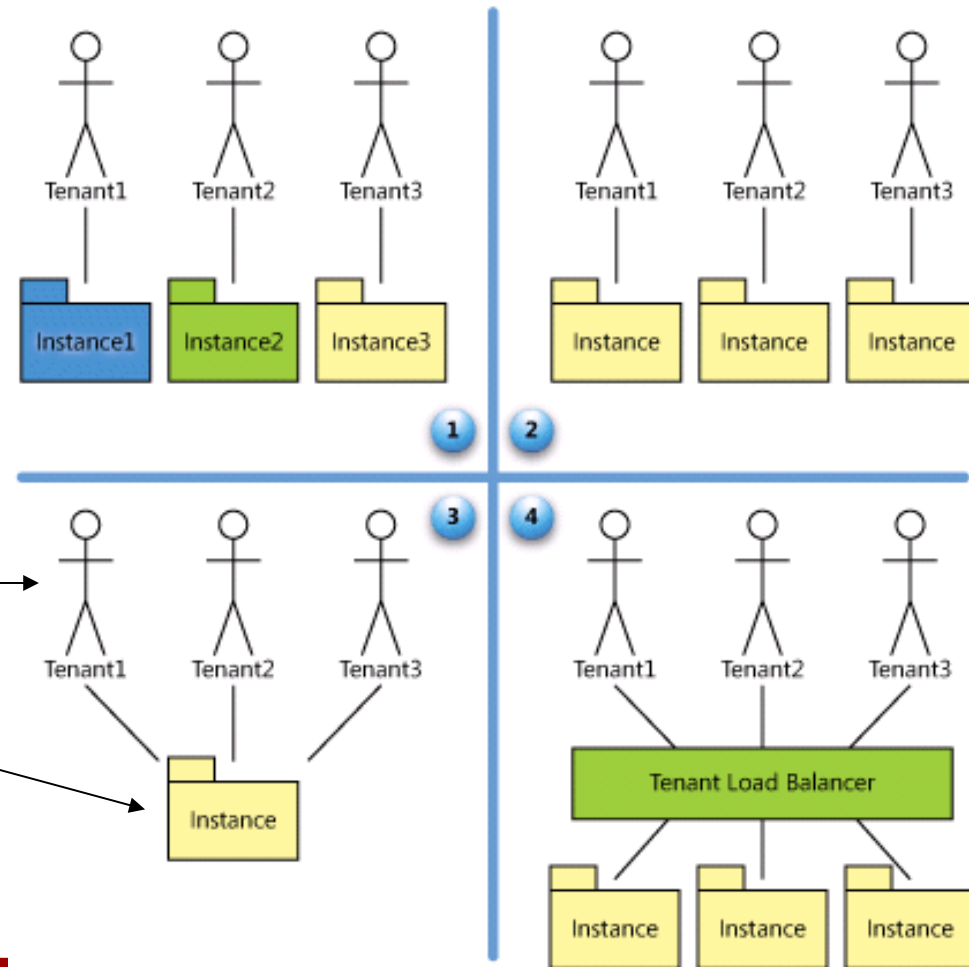
Level 1: Ad-Hoc/Custom

Level 2: Configurable

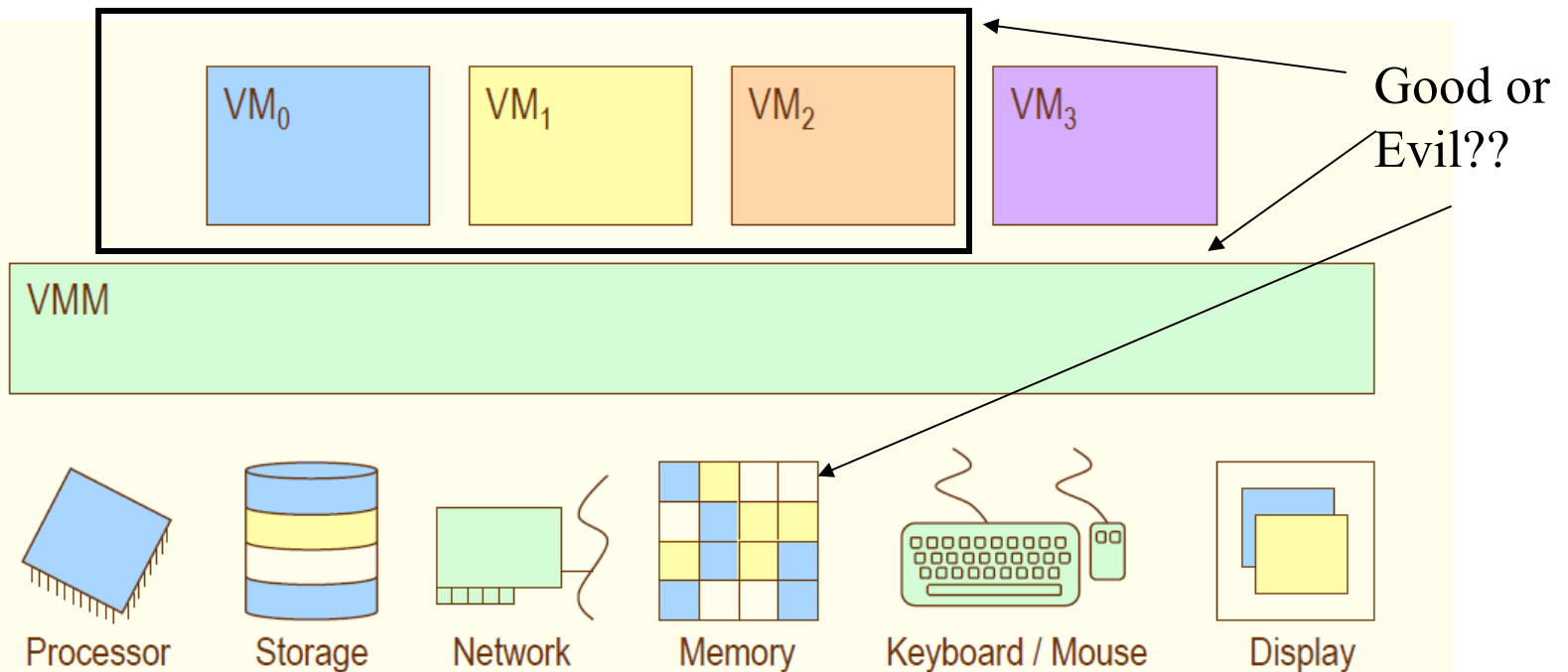
Level 3: Configurable, Multi-Tenant-Efficient

Level 4: Scalable, Configurable, Multi-Tenant-Efficient

Good or Evil?



All together ????



- ❑ **VMM applies all 3 sharing methods, as needed, to create illusion of platform ownership to each guest OS**



New resource availables for attacker

- A cloud is an interesting target for several threat such as terrorist or organized crime
- An agent attacking a cloud can access a much larger amount of resources, know how, processing power than typical attackers
- A SME that has to face a trade off
 - Better security offered by the provider
 - More powerful attackers
- The large amount of cheap processing power that cloud systems made available simplify the implementation of brute force attacks, e.g. exhaustive key searches



The cloud provider

- It is a new threat to be considered
- Why so few papers discuss this threat ??? :-D
- The impact of a provider attack is highly critical because of the kind of access to physical and logical resources
- There are problems to be considered independently of malicious planned attack
 - Lock in with a provider in the case of SaaS
 - It is almost impossible to have some assurance that data that has been stored by a provider have been erased
- With respect to other threat the provider is known, hence we simply need to prove a misbehavior rather than detailing which misbehaviour the provider has been involved in



The cloud provider

- A Service Level Agreement (contract) has to be signed to define
 - The amount of resources that will be available
 - Largest downtime that is acceptable
 - Geographical location of the data
 - Handling of sensible data
 - Use of encryption
 - Security policy of the provider
- It is important to include only those properties that can and will be checked
- Some checks should be automated to simplify their implementation and increase the number of checks



Cloud Vulnerabilities

What follows is a long(and tedious) list of vulnerabilities
Some of them will be discussed in the following, other ones
are to be remembered to check the provider since there are
no new countermeasures



Authentication Vulnerabilities

Access and Authentication

- Insecure storage of cloud access credentials by customer
- Insufficient roles available
- Credentials stored on a transitory machine
- Password-based authentication may become insufficient
 - Strong or two-factor authentication for accessing cloud resources will be necessary



Authentication Vulnerabilities

- Identity of customer or billing information is not adequately verified at registration
- Delays in synchronization between cloud system components
- Multiple, unsynchronized copies of identity data are made
- Credentials are vulnerable to interception and replay
- De-provisioned credentials are still valid due to time delays in roll-out of revocation



Resource Vulnerabilities

Inaccurate Modeling of Resource Usage

- Overbooking or over-provisioning
- Failure of resource allocation algorithms due to extraordinary events (e.g., outlying news events for content delivery).
- Failure of resource allocation algorithms using job or packet classification because resources are poorly classified.
- Failures in overall resource provisioning (as opposed to temporary overloads)

No resource capping

- If there is not a flexible and configurable way for the customer and/or the cloud provider to set limits on resources, this can be problematic when resource use is unpredictable.

Inadequate Resource Provisioning and Investments in Infrastructure

- Infrastructure investments take time. If predictive models fail, the cloud provider service can fail for a long period.



Vulnerabilities

Remote Access To Management Interface

- Allows vulnerabilities in end-point machines to compromise the cloud infrastructure (single customer or CP) through, for example, weak authentication of responses and requests

Hypervisor

- Exploiting the hypervisor potentially means exploiting every VM!
- Guest to host escape: A user defeat isolation and exit from a VM
- VM hopping: After leaving a VM other are attacked
- Virtual machine-based rootkits



Isolation Vulnerabilities

Lack of Resource Isolation

- Side channel attacks
- Shared storage
- Insecure APIs
- Lack of tools to enforce resource utilization

Lack of Reputation Isolation

- Activities from one customer impact the reputation of another customer and of the cloud provider

Communication Encryption

- Reading data in transit via MITM attacks
- Poor authentication
- Acceptance of self-signed certificates



Vulnerabilities

Weak or No Encryption Data in transit

- Data held in archives and databases
- Un-mounted virtual machine images
- Forensic images and data, sensitive logs and other data at rest put customer data at risk

Unable to Process Data in Encrypted Form

Poor Encryption Key Management

- Hardware security modules (HSM) required in multiple locations
- Key management interfaces which are accessible via the public Internet
- The rapid scaling of certificate authorities issuing key pairs to new virtual machines
- Revocation of keys for decommissioned virtual machines



Vulnerabilities

Low Entropy for Random Number Generation

- The combination of standard system images, virtualization technologies and a lack of input devices means that virtual systems have much less entropy than physical RNGs

No Control of Vulnerability Assessment Process

- Restrictions on port scanning and vulnerability testing are an important vulnerability which, combined with a AUP which places responsibility on the customer for securing elements of the infrastructure, is a serious security problem

Internal (Cloud) Network Probing

- Cloud customers can perform port scans and other tests on other customers within the internal network



Vulnerabilities

Co-residence Checks

- Side-channel attacks exploiting a lack of resource isolation allow attackers to determine which resources are shared by which customers

Lack of Forensic Readiness

- While the cloud has the potential to improve forensic readiness, many providers do not provide appropriate services and terms of use to enable this.



Vulnerabilities

Media Sanitization

- Shared tenancy of physical storage resources means that sensitive data may leak because data destruction policies may be impossible to implement
- Media cannot be physically destroyed because a disk is still being used by another tenant
- Customer storage cannot be located or tracked as it moves through the cloud

Service Level Agreement

- Clauses with conflicting promises to different stakeholders
- Clauses may also be in conflict with promises made by other clauses or clauses from other providers.



Vulnerabilities

Audit or Certification Not Available to Customers

- The CP cannot provide any assurance to the customer via audit certification.
- Open source hypervisors or customized versions of them (e.g., Xen) may not have Common Criteria certification, etc

Certification Schemes Not Adapted to Cloud

- Very few if any cloud-specific control, which means that security vulnerabilities are likely to be missed.



Vulnerabilities

Storage of Data in Multiple Jurisdictions

- Mirroring data for delivery by edge networks and redundant storage without real-time information available to the customer of where data is stored

Lack of Information on Jurisdictions

- Data may be stored and/or processed in high risk jurisdictions where it is vulnerable to confiscation by forced entry.



Vulnerabilities

Lack of Cloud Security Awareness

- Cloud customers and providers are not aware of the risks they could face when migrating into the cloud, particularly those risks that are generated from cloud specific threats, i.e. loss of control on data, cloud provider lock-in, exhausted resources of the cloud provider.

Lack of Vetting Processes (Personel Background Checks)

- Since there may be very high privilege roles within cloud providers, due to the scale involved, the lack or inadequate vetting of the risk profile of staff with such roles is an important vulnerability

Unclear Roles and Responsibilities

- Inadequate definition of roles and responsibilities in the cloud provider organization



Vulnerabilities

Poor Enforcement of Role Definitions

- Within the cloud provider, a failure to segregate roles may lead to excessively privileged roles which can make extremely large systems vulnerable

Need-to-know Principle Not Applied

- Poorly defined roles and responsibilities
- Parties should not be given unnecessary access to data

Inadequate Security Procedures

- Lack of physical perimeter controls (smart card authentication at entry);
- Lack of electromagnetic shielding for critical assets vulnerable to eavesdropping.
- Lack of policy or poor procedures for logs collection and retention
- Inadequate or misconfigured filtering resources



Os And Application Vulnerabilities

Mismanagement

- System or OS vulnerabilities
- Untrusted software
- Lack of - or a poor and untested - business continuity and disaster recovery plan
- Lack of - or incomplete or inaccurate - asset inventory
- Lack of - or poor or inadequate - asset classification
- Unclear asset ownership

Application Vulnerabilities and Poor Patch Management

- Bugs in the application code
- Conflicting patching procedures between provider and customer
- Application of untested patches
- Vulnerabilities in browsers
- Dormant virtual machines
- Outdated virtual machine templates



Cloud security ;-)

Information-centric security with one of

- Untrusted infrastructure IaaS
- Untrusted Platform PaaS
- Untrusted Software SaaS

and a larger attack surface



Cloud Computing Threat Model

ENISA

Cloud Computing Risk Assessment



Threat Model

- Risk 1: Resource Exhaustion
- Risk 2: Customer Isolation Failure
- Risk 3: Management Interface Compromise
- Risk 4: Interception of Data in Transmission
- Risk 5: Data leakage on Upload/Download, Intra-cloud
- Risk 6: Insecure or Ineffective Deletion of Data
- Risk 7: Distributed Denial of Service (DDoS)
- Risk 8: Economic Denial of Service
- Risk 9: Loss or Compromise of Encryption Keys
- Risk 10: Malicious Probes or Scans
- Risk 11: Compromise of Service Engine/Hypervisor
- Risk 12: Conflicts between customer hardening procedures and cloud environment



Threat Model

- Risk 13: Subpoena and E-Discovery
 - Risk 14: Risk from Changes of Jurisdiction
 - Risk 15: Licensing Risks
 - Risk 16: Network Failure
 - Risk 17: Networking Management
 - Risk 18: Modification of Network Traffic
 - Risk 19: Privilege Escalation
 - Risk 20: Social Engineering Attacks
 - Risk 21: Loss or Compromise of Operation Logs
 - Risk 22: Loss or compromise of Security Logs
 - Risk 23: Backups Lost or Stolen
 - Risk 23: Unauthorized Access to Premises, Including Physical Access to Machines and Other Facilities
 - Risk 25: Theft of Computer Equipment.
-



Threat Model Second Version

Policy Risk

- R.1 Lock-in
- R.2 Loss of governance
- R.3 Compliance challenges
- R.4 Loss of business reputation due to co-tenant activities
- R.5 Cloud service termination or failure
- R.6 Cloud provider acquisition
- R.7 Supply chain failure



Threat Model Second Version

Technical risks

- R.8 Resource exhaustion (under or over provisioning)
- R.9 Isolation failure
- R.10 Cloud provider malicious insider - abuse of high privilege roles
- R.11 Management interface compromise (manipulation, availability of infrastructure)
- R.12 Intercepting data in transit
- R.13 Data leakage on up/download, intra-cloud
- R.14 Insecure or ineffective deletion of data
- R.15 Distributed denial of service (DDoS)
- R.16 Economic denial of service (EDOS)
- R.17 Loss of encryption keys
- R.18 Undertaking malicious probes or scans
- R.19 Compromise service engine
- R.20 Conflicts between customer hardening procedures and cloud environment



Threat Model Second Version

Legal risks

- R.21 Subpoena and e-discovery
- R.22 Risk from changes of jurisdiction
- R.23 Data protection risks
- R.24 Licensing risks



Threat Model Second Version

Risks not specific to the cloud

- R.25 Network breaks
- R.26 Network management (ie, congestion / non-optimal use)
- R.27 Modifying network traffic
- R.28 Privilege escalation
- R.29 Social engineering attacks (ie, impersonation)
- R.30 Loss or compromise of operational logs
- R.31 Loss or compromise of security logs (manipulation of forensic investigation)
- R.32 Backups lost, stolen
- R.33 Unauthorized access to premises (including physical access to machines and other facilities)
- R.34 Theft of computer equipment
- R.35 Natural disasters



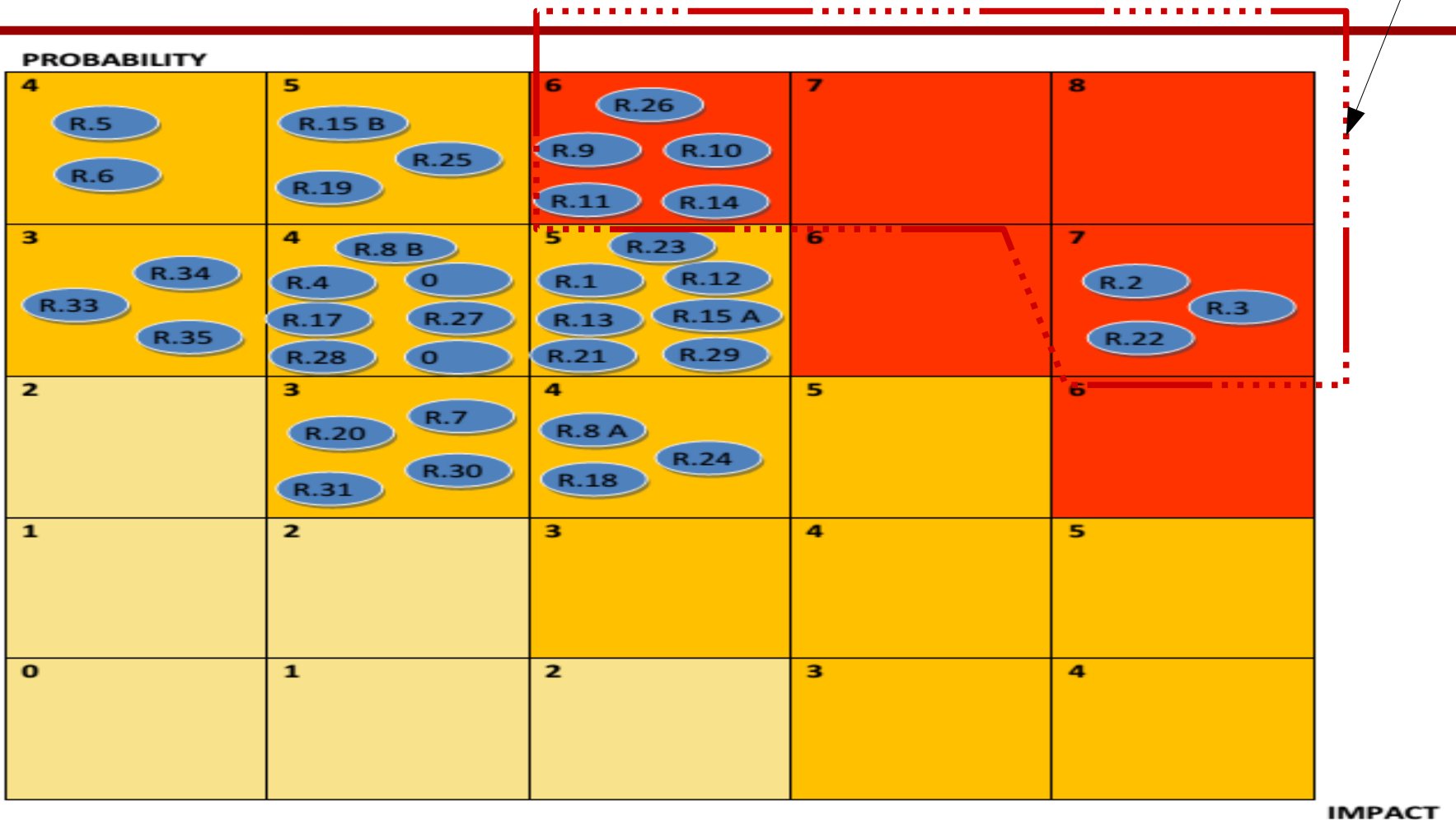
Risk Assessment

		Likelihood of incident scenario	Very Low (Very Unlikely)	Low (Unlikely)	Medium (Possible)	High (Likely)	Very High (Frequent)
		Business Impact	Very Low	0	1	2	3
Low	1		2	3	4	5	
Medium	2		3	4	5	6	
High	3		4	5	6	7	
Very High	4		5	6	7	8	



Risk Assessment

most dangerous are related to the provider



IMPACT



In the following...

- We will focus on technical risks and in some risks related to the provider
- A typical risk is the failure of isolation or the abuse of roles by the insider (working for the cloud provider)



References

- Chow, R.; Golle, P.; Jakobsson, M.; Shi, E.; Staddon, J.; Masuoka, R.; Molina, J. Controlling data in the cloud: outsourcing computation without outsourcing control. Proceedings of the 2009 ACM Workshop on Cloud Computing Security (CCSW 2009); 2009 November 13; Chicago, IL. NY: ACM; 2009; 85-90.
- Manadhata, P; Wing, J; , "An Attack Surface Metric," *Software Engineering, IEEE Transactions on* , vol.PP, no.99, pp.1, 0 doi: 10.1109/TSE.2010.60