Cloud-specific Architecture Issues

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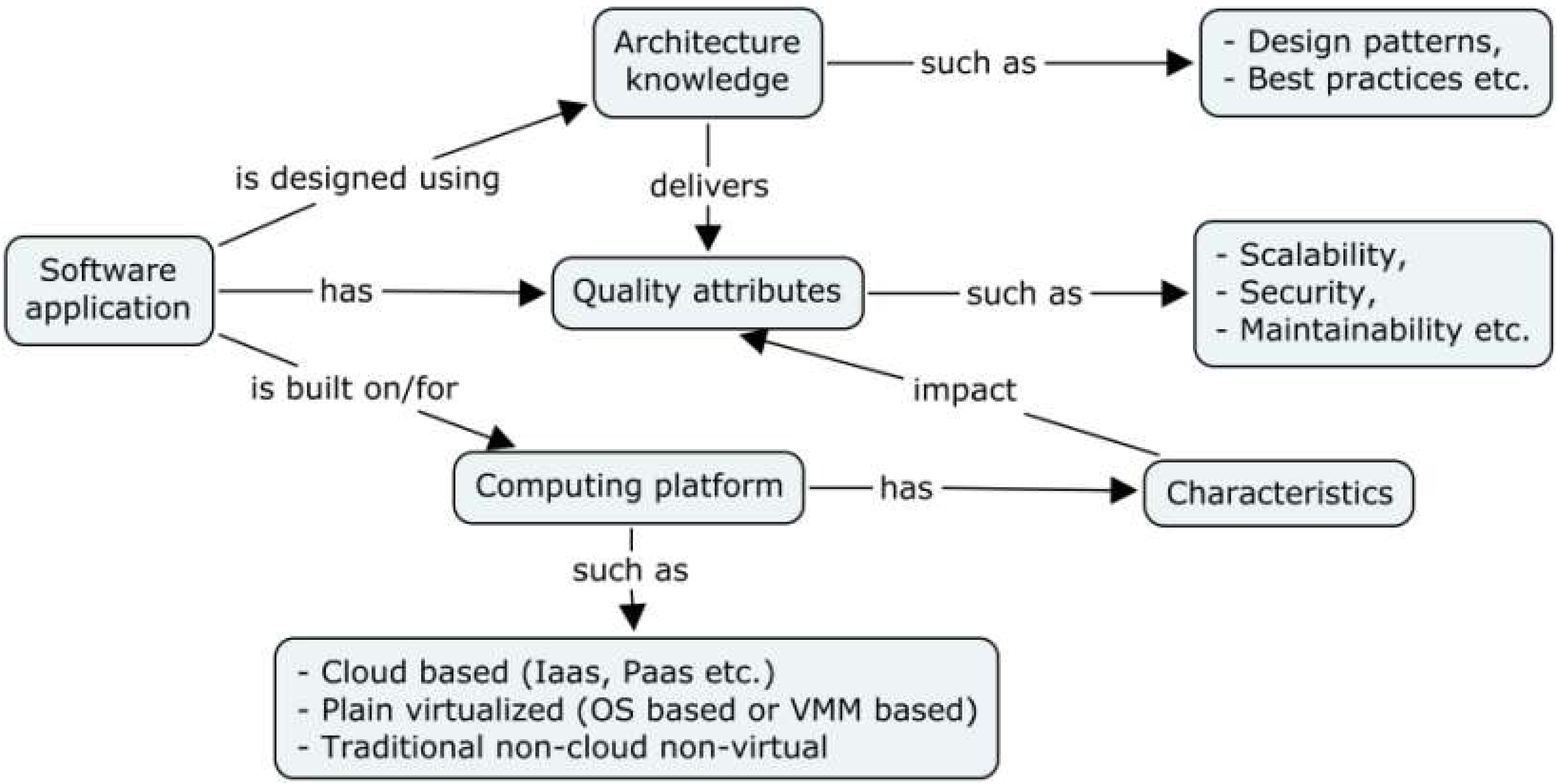
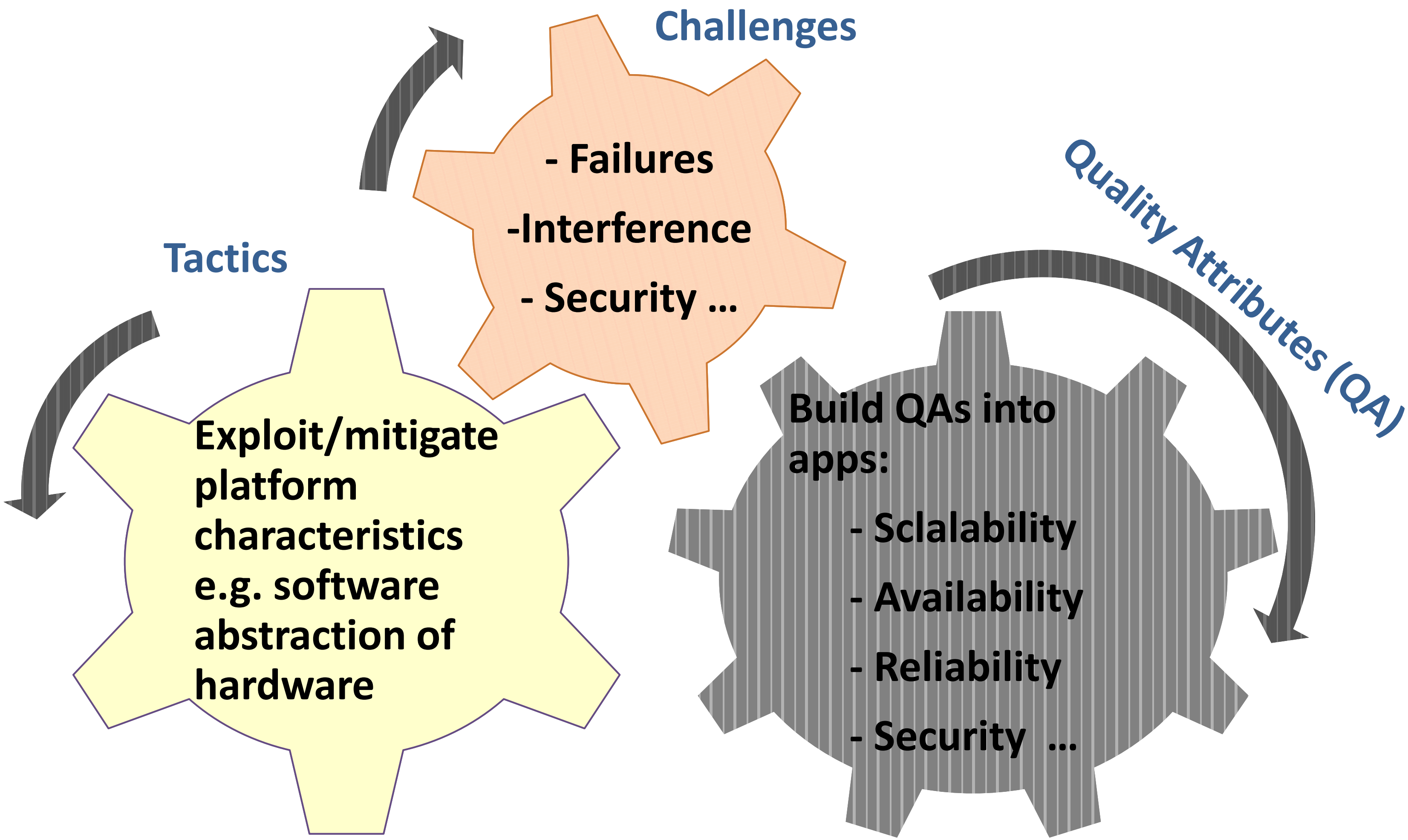
Platforms & Applications Architecture



Building *Quality* Into Cloud Apps



Cloud vs. Non-cloud

- Cloud vendors address some issues faced by non-cloud data centers
  - Provisioning of server resources
  - Physical security
  - Hiring/training data center personnel
- Several other issues still remain the same
  - Network intrusion threats from outside
  - Isolating and managing production/test environments
  - Installation of updates/patches
- Some new or now-changed issues have arisen
  - These are the issues that we bring out

Key Issues Specific To Cloud

- Security/privacy
  - Multi-tenancy
  - Access keys/credentials
  - Dependency on geographic/legal jurisdiction
- Failure
  - Failure of VM instances
  - Data consistency failures
  - Software upgrade error

Key Issues Specific To Cloud

- Performance
  - Network latency
  - How fast can you provision
  - Elasticity → Over/under provisioning
  - Performance interference due to VM co-location

Details about Key Issues

Failure Defined

- *A system failure occurs when the delivered service no longer complies with the specifications, the latter being an agreed description of the system's expected function and/or service*
- Related terms:
  - Faults (defects or bugs)
  - Errors (expected and actual behavior differs)
- Faults and errors *may* lead to failure

Failure Rates Get Amplified In Cloud

- Failure rates
  - Servers experience 2-4% annual failure rates (AFR)
  - Disk drives have about 4-6% AFR
- For server AFR of 3% MTBF is about 292000hrs
  - More than 30 years
- In a datacenter having 64000 servers having 2 disks each
  - Daily, more than 5 servers and 15 disks can fail

Handling Failure In Cloud

- Before you handle a failure you must detect it
- *Heartbeat* remains the key tactic for identifying failures
- Must have a *monitor* that watches aliveness of VMs
  - A monitor can be in: infrastructure, client or part of the application
- A VM must periodically show its aliveness to the monitor
  - By responding to some query
  - Sending some message

Stateful vs. Stateless Instances

- Applications can be stateful or stateless
- Stateful applications
  - Remember information across requests
  - State information kept in memory or external
- Stateless applications
  - Require that requests carry necessary information needed for understanding the context
- Failure recovery is different in stateful and stateless cases

Recovery For Stateful Instance

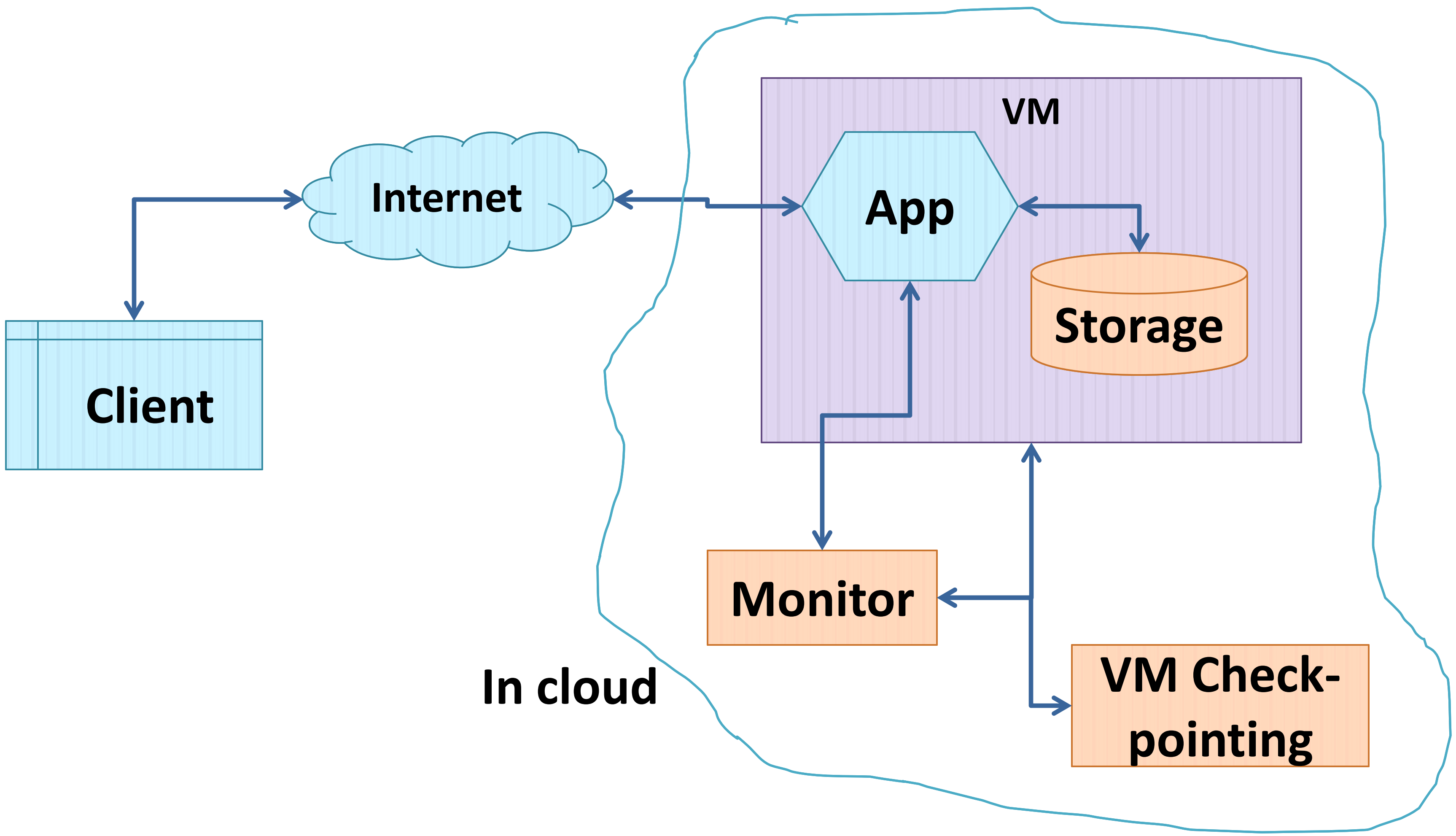
- Multiple tactics are possible depending upon
  - Whether application stored state in the VM itself or on external device
  - Application’s tolerance for loss of computation
  - Availability of VM check-pointing
- Basic tactic is to:
  - Keep saving most recent state data somewhere safely
  - Restore back to last saved state on detecting failure

Stateful Recovery | Tactic 1

- Assumes that application keeps state in VM itself
  - No state dependency on external device
- Works for cloud only
- *Check-point VM state on regular intervals
- On detection of failure, restore and start from last check-pointed VM image
  - Requests arriving between time of failure until restoring to last checkpoint get lost

*** Sodhi & Prabhakar, "Cloud-oriented platforms: Bearing on Application Architecture and Design patterns" in IEEE Services 2012**

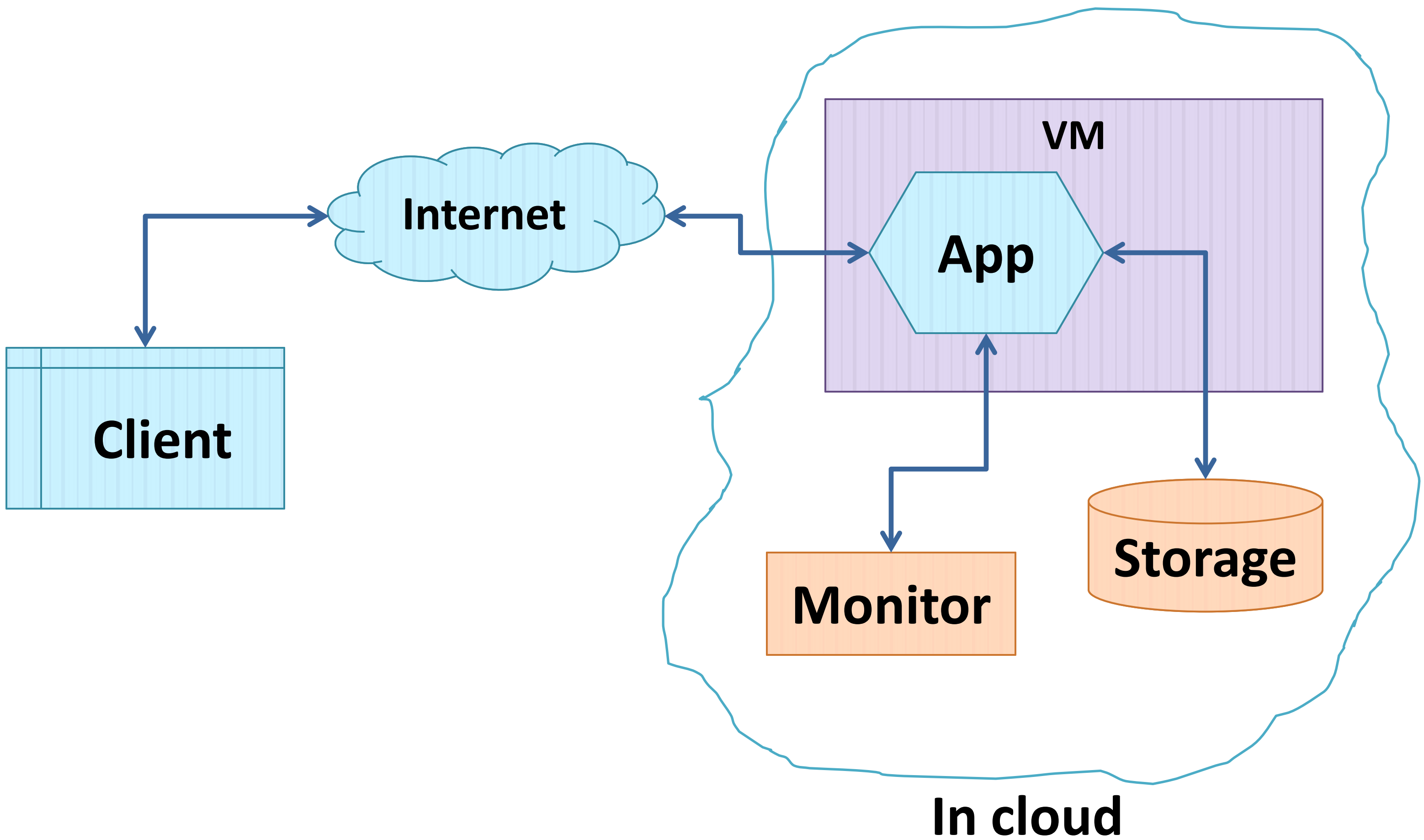
Stateful Recovery | Tactic 1



Stateful Recovery | Tactic 2

- Application saves recent state on external device
  - Done at regular intervals
- On detection of failure:
  - Check for recent state saved on external device
  - Resume from state restored from external device
- Requests arriving between time of failure until restoring to last saved state get lost
- Recovery mechanism needs to be coded into application itself

Stateful Recovery | Tactic 2



Avoiding Lost Requests In Tactic 2

- Application logs incoming request as well to external device
- On detection of failure:
  - Resume from state restored from external device
  - Read and play logged requests that arrived during down time
- No requests are lost if logging to external device and acknowledgement to client is atomic

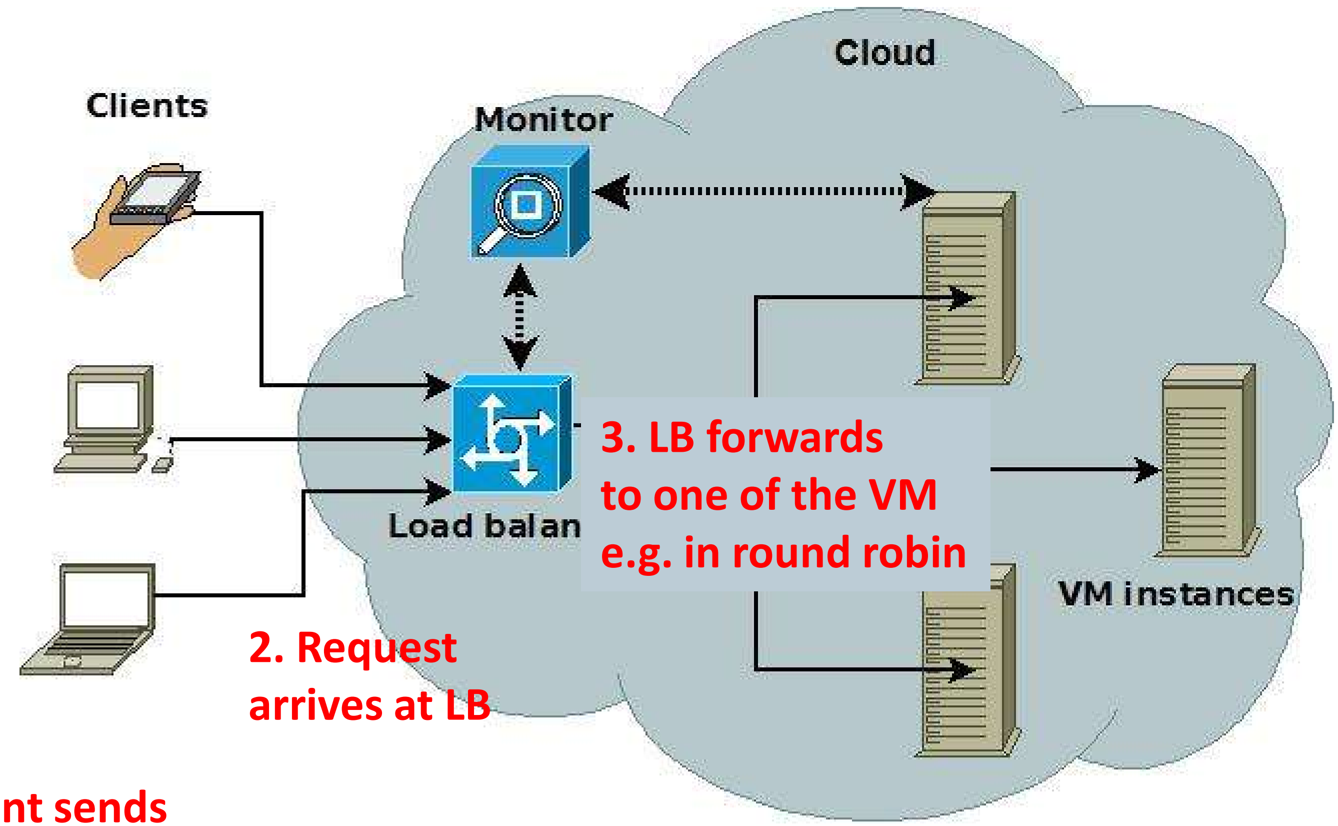
Stateless Applications | Requests Flow

- A request can be received by any instance
- New VMs can be created to meet QoS demands
  - Performance, reliability etc.
- Requests are routed to instances by a load balancer component

Routing Requests To Instances

- Decided by load balancer (LB)
  - LB policies take failures into account
  - LB is augmented by a monitor component
- Tactic has two flavors:
  - Push: LB decides which instance gets to serve a request
  - Pull: Instances pull the requests from a queue maintained by the LB

Architecture Of Push Based LB



1. Client sends request

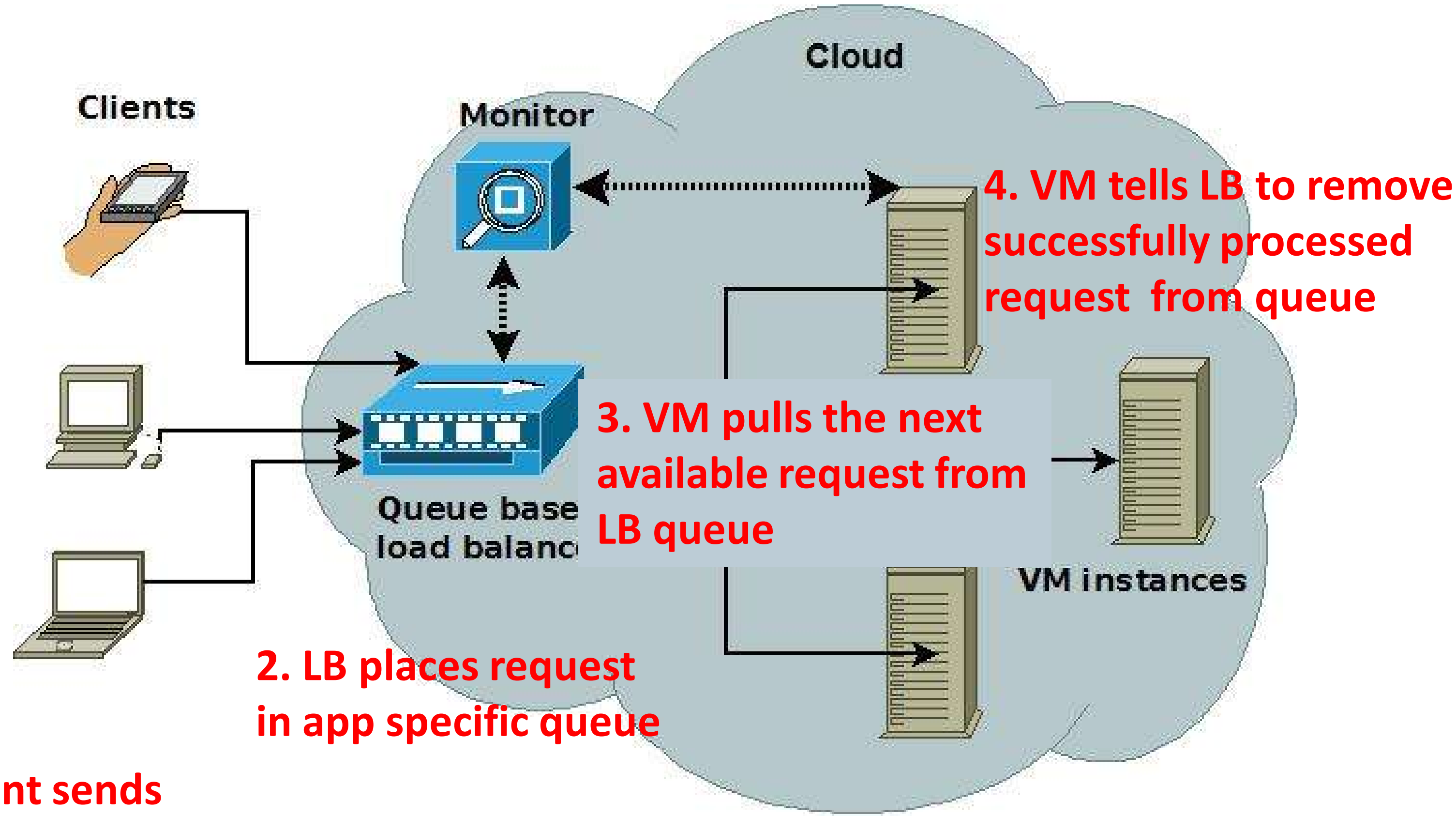
Role Of Monitor

- Observes the VMs
  - Resource (CPU, memory etc.) utilization
  - Requests load
  - Quality of service violations etc.
- Sends VM stats to load balancer
  - Include failures info
- Decides, based on some rules, when more resources are required

Working Of Push LB Pattern

- Monitor detects VM failure
  - E.g. when VM becomes non-responding
- LB gets to know this and stops sending requests to the failed VM
- Current in-progress requests handled by VM are lost
  - Client needs to detect this possibly via timeout
  - Client should resend the lost requests

Architecture Of Pull Based LB



1. Client sends request

Role Of Monitor

- Watch the application specific queues on LB
  - Waiting time for requests in a queue
  - Length of the queue
- Infer load on a VM from queue stats
- Decides, based on some rules, when more resources are required

Working Of Pull LB Pattern

- LB knows when a request has been processed by a VM
- Requests that remain unhandled until a time limit get reassigned by LB
- A failed VM won't pick requests from it queue
  - This automatically takes a failed VM out of service
- Requests trapped in failed VMs
  - Can get processed when VM recovers
  - Application must handle duplicate processing scenario

VM Cleanup On IaaS Cloud

- When a VM fails:
  - It is not automatically de-allocated
  - It needs to be de-allocated by consumer
  - Cloud provider continue to charge until VM is de-allocated
- On de-allocation of a VM:
  - Its public and private IP addresses become available for reassignment
  - Infrastructure can be told to assign released public IP address to replacement VM

Summary

- LB and monitor are key components
  - LB policies take failures into account
  - LB is augmented by a monitor component
- Tactic has two flavors:
  - Push: LB decides which instance gets to serve a request
  - Pull: Instances pull the requests from a queue maintained by the LB

Data storage issues on cloud

Data Storage

- Provides ability to persists digitized information
  - e.g. plain text files, binary files containing photos
- Retains data for an interval of time
  - Length of time depends on storage type
    - e.g. RAM contents don’t survive machine restart, whereas hard disk contents can

Data Storage Components

- Can be have different categories, for example:
  - Raw files on a file systems (FS) on the operating system
  - Data stores such as RDBMS engines, key-value stores etc.
- Characteristics/behavior of each category can vary significantly
- An application can use multiple types of data storage components
  - E.g. can write to both the raw FS and a database table

Data Storage And Cloud

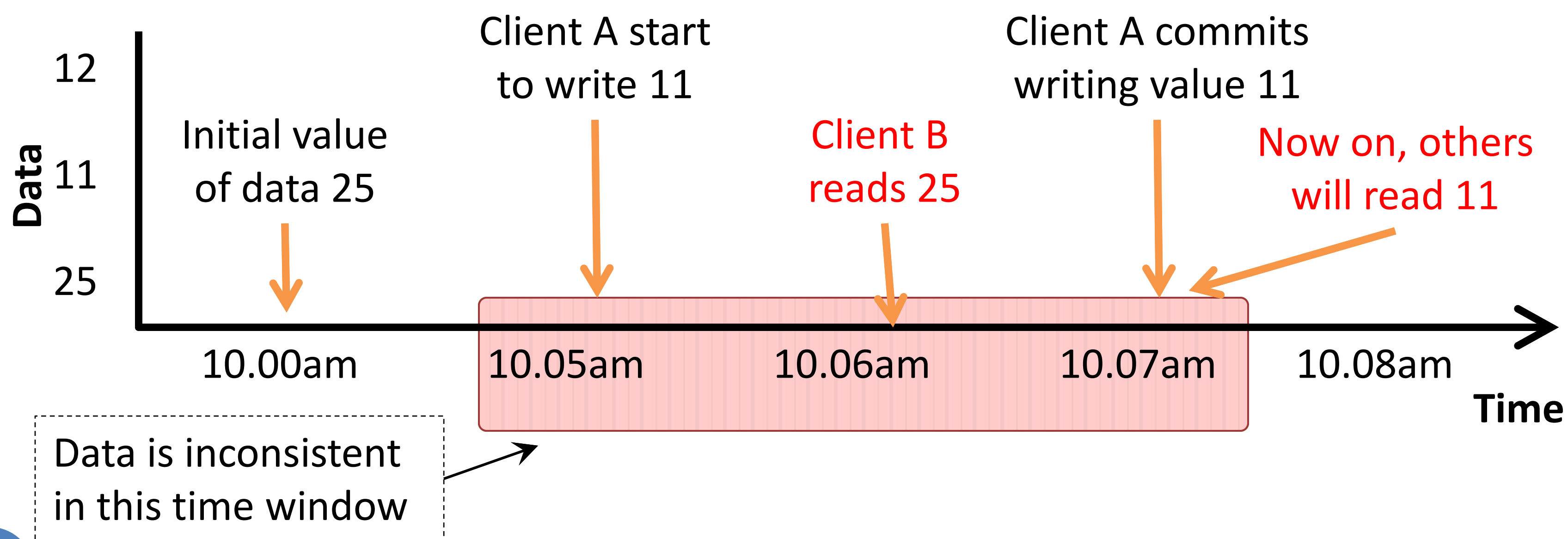
- Mainly we are concerned about data storage on:
  - IaaS cloud
  - PaaS cloud
- IaaS cloud because:
  - Cloud user has to manage the resources including storage
- PaaS cloud because:
  - As a developer you need to handle data storage from within the applications you write
- SaaS cloud case is not interesting
  - Because as a user you don’t write any software here

Data Storage On Cloud

- IaaS cloud vendors offer two data storage types:
  - Ephemeral
  - Persistent
- Ephemeral storage doesn’t survive instances failure
  - Typically available as a block device attached to the VM instance
- Persistent storage is long lived
  - Cloud vendor automatically replicates
  - Geographically distributed replicas
- Storage failures can lead to data consistency issues
  - Application needs to be prepared for this

Data Consistency In Applications

- Consistency
  - Disallow multiple values of same piece of data when seen by different clients at the same point in time



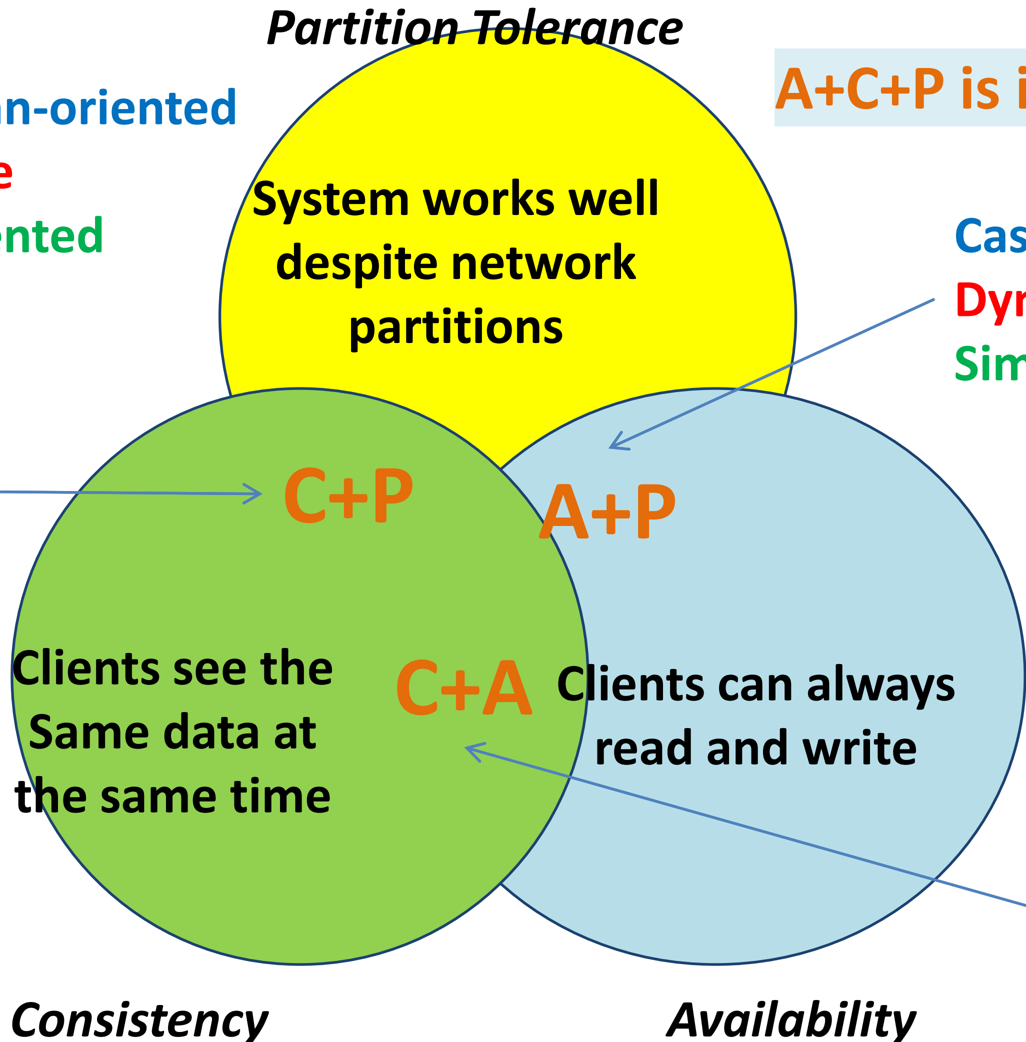
Data Partition Tolerance

- Partitioning of data means:
  - Placing parts or copies of data on multiple nodes
    - A “node” here may mean a physical machine or just a different database server instance
  - Often needed to achieve massive scalability
- Tolerance for data partitioning means:
  - Application should not respond incorrectly even in the presence of data partitioning
  - i.e. data *consistency* is maintained in presence of partitions

Data Consistency | CAP Theorem

Data Model

- Relational
- Tabular/Column-oriented
- Key-value store
- Document oriented



A+C+P is impossible!

C+P: BigTable, Redis, MongoDB

A+P: Cassandra, Dynamo, SimpleDB

C+A: MySQL, Vertica

Data Consistency In Cloud

- Replication is a key mechanism
- Replicating data is time consuming
  - Replicas may not be in sync immediately
  - Clients may see inconsistent data for a tiny duration
- Typically, cloud vendors offer "consistent reads"
  - But there may be latency issues
- E.g. AWS S3 today offers read-after-write consistency for PUTs of new objects
  - But gives only eventual consistency for overwrite PUTS and DELETES

Why Is It Important?

- Because users needs to be happy
  - "500 Internal Server Error" is the last thing I want to see after punching in my credit card details
    - Next time I'll shop elsewhere
- It impacts* the businesses too
  - Extra 0.1s in response time costs Amazon 1% in sales
  - Google found that 0.5s jump in latency leads to 20% drop in traffic

* http://highscalability.com/latency-everywhere-and-it-costs-you-sales-how-crush-it

How To Address It

- You need to choose any two from among:
  - Availability, consistency and partition tolerance
- Drop availability
  - Services are unavailable until data is consistent on all nodes
- Drop partition tolerance
  - Avoid partitions from happening
- Drop consistency
  - Expect that data becomes consistent eventually

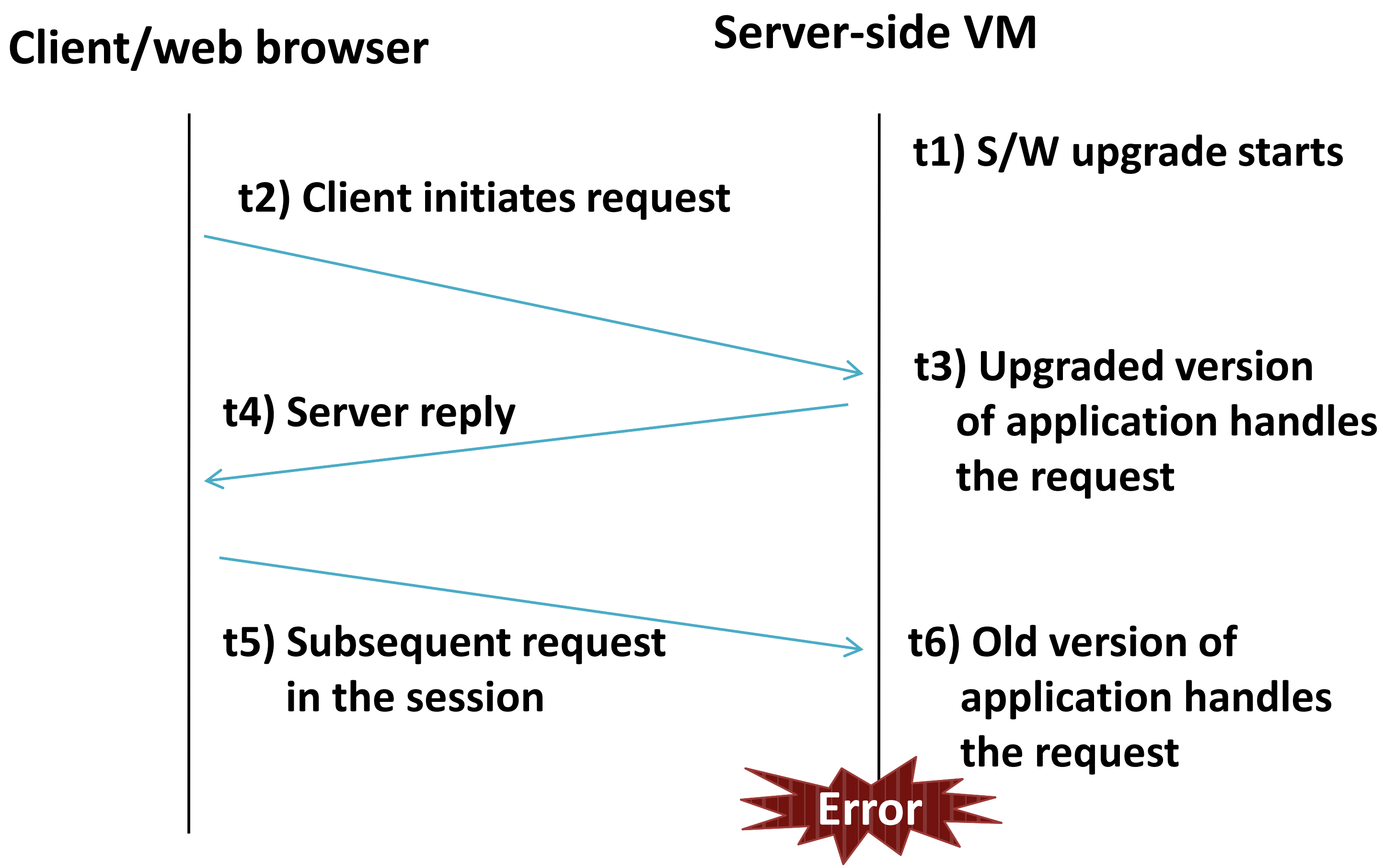
Summary

- It is important to understand characteristics of data storage mechanisms on cloud
  - Different storage services may behave differently
- Data consistency in applications
  - Cannot achieve all three at the same time:
    - Consistency of data
    - Availability of data/services
    - Partition tolerance

Software Upgrade Induced Failures

- Upgrading and patching software is common
- Main reasons for upgrades and patching
  - Releasing new features
  - Fixing defects
- Users may experience failures during such upgrades and patching of software applications
  - How to avoid such failures?

An Example Scenario



Handling S/W Upgrade Failures

- What do we need from the solution
  - Clients should always interact with latest application version on server side
  - Requests should get load balanced regardless of active application versions on server side
- We need to make some assumptions:
  - Backward compatibility of application versions
  - Clients can be dynamically told about latest application version number available

A Solution Idea

- Treat each application version as a separate destination for requests
- Client knows the latest version number that it has interacted with
- Load balancer routes requests based on version number present in request header
  - A version xxx in the header is routed to instance whose version is ≥ xxx
  - Route normally if no version number found in request header

Security and privacy

Information Security

- "Information security means protecting information and information systems from unauthorized access, use, disclosure, disruption, modification, perusal, inspection, recording or destruction"

  (From 44 US Code § 3542)
  http://www.law.cornell.edu/uscode/text/44/3542

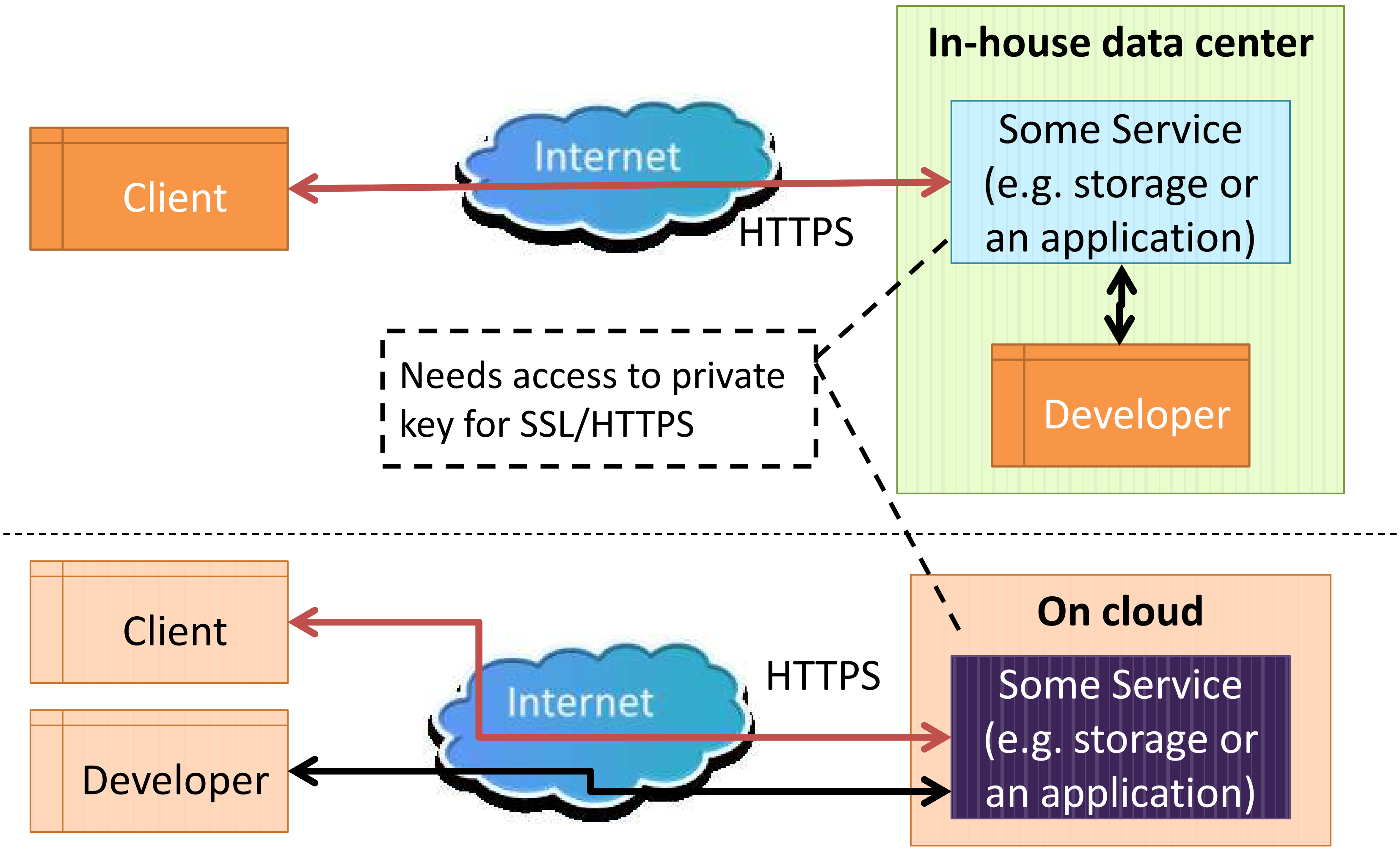
Core Artifacts: Credentials and Keys

- Credentials in IT are typically, a combination of login ID and password
  - Identify the user holding them
- Mainly credentials are used for controlling access to IT resources
  - Authentication: you are who you say you are
  - Authorization: you have the rights to perform certain actions
  - Non-repudiation: you cannot deny you did something
- A key is a number used in cryptography for
  - Encrypting/decrypting data
  - Digital credentials

Some Common Security Measures

- Encrypting sensitive data
- Checking for buffer overruns
- Input validation
- Role based access to data and functionality
- Transaction monitoring and auditing
- Limiting access to servers (close unnecessary ports)
- etc.

Security Scenario | In-house vs. Cloud



Important Security Aspects On Cloud

- Central issue:
  - Data and applications being in 3rd party (cloud vendor) custody
  - Lack of trust on the cloud service provider
- Access credentials and encryption keys
  - Management of keys and credentials
- Privacy and security in multi-tenant environment
- Dependency on legal/geographical jurisdiction
  - Local laws governing a cloud service provider

Bank vs. At-home | A Metaphor

Bank **At-home**

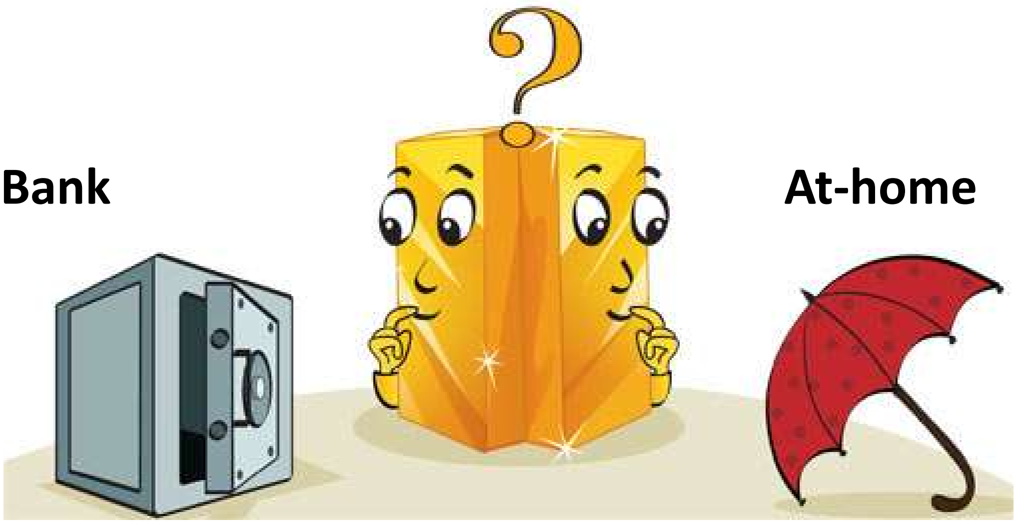
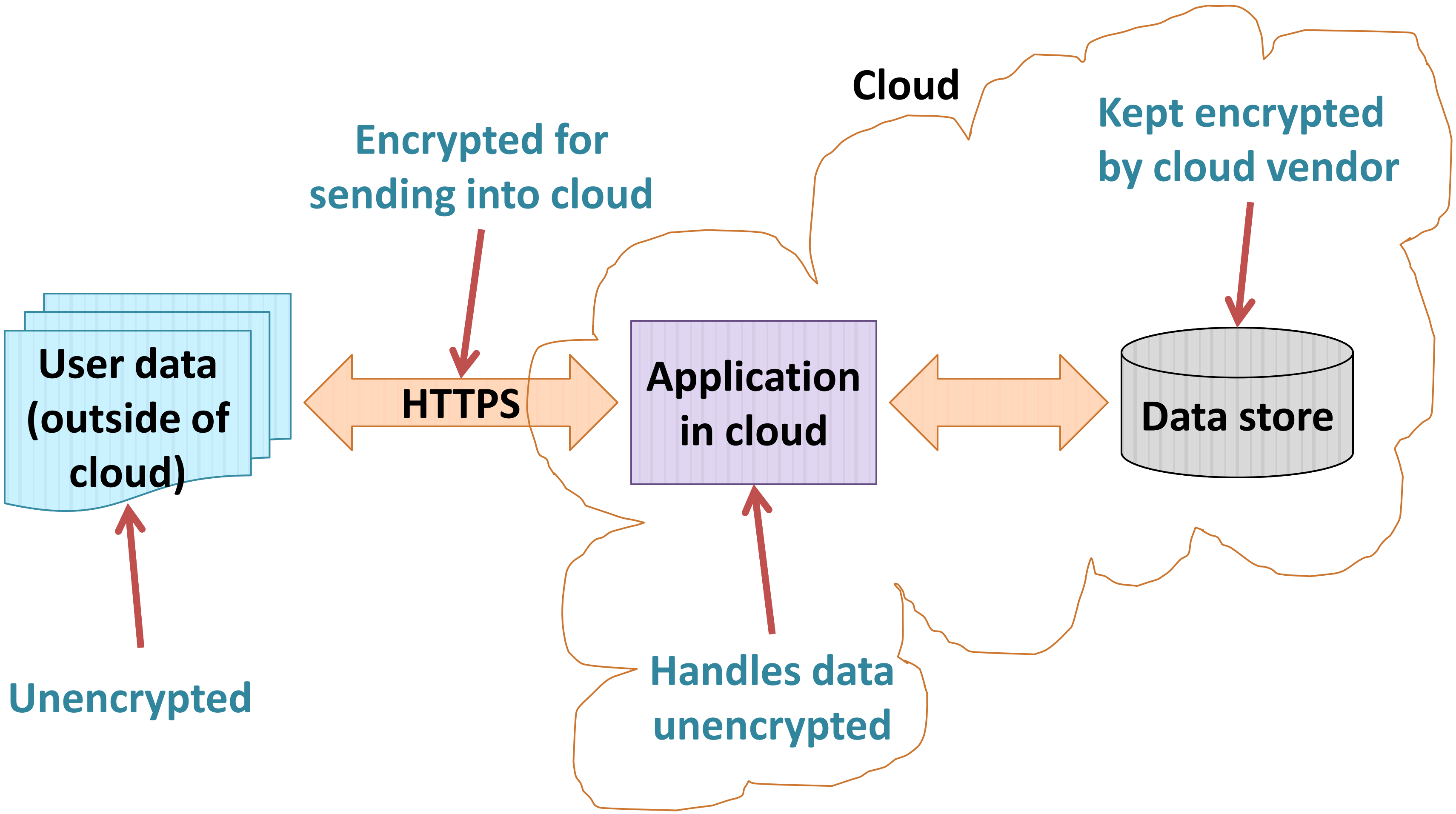


Image credit: Business Today

Elementary Data Security



Issues With Elementary Data Security

- A cloud provider responding to a legal order may:
  - Potentially share your data with govt. agencies
  - Have to provide decrypted data
- To address the above you can encrypt your data before sending to cloud
  - Thus cloud provider can share only encrypted data
- However, if legal orders are directed at you then you need to comply with decrypted data

Credentials Management For Cloud

- Important considerations:
  - Who has/needs access to credentials?
  - Will you need to change credentials? When?
  - Storage and automated provisioning of credentials
- Some options for providing credentials in cloud
  - Build into the VM image
  - Supply as parameter during instance launch
  - Keep in some persistent storage
  - Send from client every time a new instance starts

Summary

- Several security aspects remain same on cloud as they were in-house
  - e.g. from tightening of firewall rules to input validation in you application
- Few things have changed
  - Data/apps now lives in a 3rd party custody
  - It is cloud consumer's responsibility to protect its sensitive data
    - Can use encryption technologies to achieve this

Geo/Legal Jurisdiction Dependency

- Requirements related to storage of personal information (PI)
  - The EU mandates that PI can leave the EU only for jurisdictions that guarantee equivalent privacy
- Some jurisdictions claim access rights on all data stored inside their borders
  - US Patriot Act allows any data stored in US to be examined by US govt.

Impact On Cloud Consumers

- Awareness of cloud vendor data centers location
  - Some do not provide locations of its data centers
- Backup locations may be chosen by the vendor
  - For optimization of its resources etc.
- Abilities to allow users to control data locations
  - Based on type of the data
  - Every vendor may not offer

How To Deal With It?

- Use anonymization techniques for securing PI
  - E.g. replace PI with tokens and keep the PI ↔ token mapping locally
- Example:
  - Original data:
    - Shiva Kumar → {Sensitive data}, e.g., bank account number
  - Anonymization tokens (kept locally)
    - Shiva Kumar → {Token}, e.g., a number
  - Data stored in cloud:
    - Token
    - Sensitive data
  - Restore original data by taking join of token table and cloud data table

performance

Performance Of A System

- Characterized by quantum of useful work done by a system for a given amount of time and computing resources
- Often measured by
  - Response time (smaller the better)
  - Latency (smaller the better)
  - Throughput (higher the better)
  - Resource utilization (higher the better)

Achieving Better Performance

- System should do:
  - more work
  - at a faster rate
  - by consuming less computing resources
- Time-proven design principles apply on cloud as well
  - Exploit parallelism
  - Pooling of shared resources
  - Put processing near the data/resources it needs
  - Minimizing round trips

  … and rest of the good stuff

Key Points For Cloud

- Consolidation of computing resources
  - Improves overall utilization in a data center
  - Use virtualization to achieve this
- Rapid elasticity
  - On-demand provisioning of resources
  - Fast scaling of applications
  - Latencies can still be an issue
- Multi-tenancy
  - May result in performance interference

Elasticity On Cloud Platforms

- Elasticity: provision computing resources on demand
- Consumers can define auto-scaling rules
  - E.g. on an existing VM when CPU usage remains above 80% for 10 minutes, launch a new VM
  - Eliminates manual intervention for provisioning
- Auto-scaling strategies
  - A matter of research
  - Provisioning a VM and starting the apps on it takes time

Provisioning Latency: An Important Issue

- Small Instance
  - 1 EC2 Compute Unit (1 virtual core with 1 EC2 Compute Unit), 1.7 GB of memory, 160 GB of instance storage, 32-bit platform with a base install of CentOS 5.3 AMI
  - Can take 5 to 6 minutes us-east-1c from launch to availability
- Large Instance
  - 4 EC2 Compute Units (2 virtual cores with 2 EC2 Compute Units each), 7.5 GB of memory, 850 GB of instance storage, 64-bit platform with a base install of CentOS 5.3 AMI
  - Can take 11 to 18 minutes us-east-1c

[http://www.philchen.com/2009/04/21/how-long-does-it-take-to-launch-an-amazon-ec2-instance]

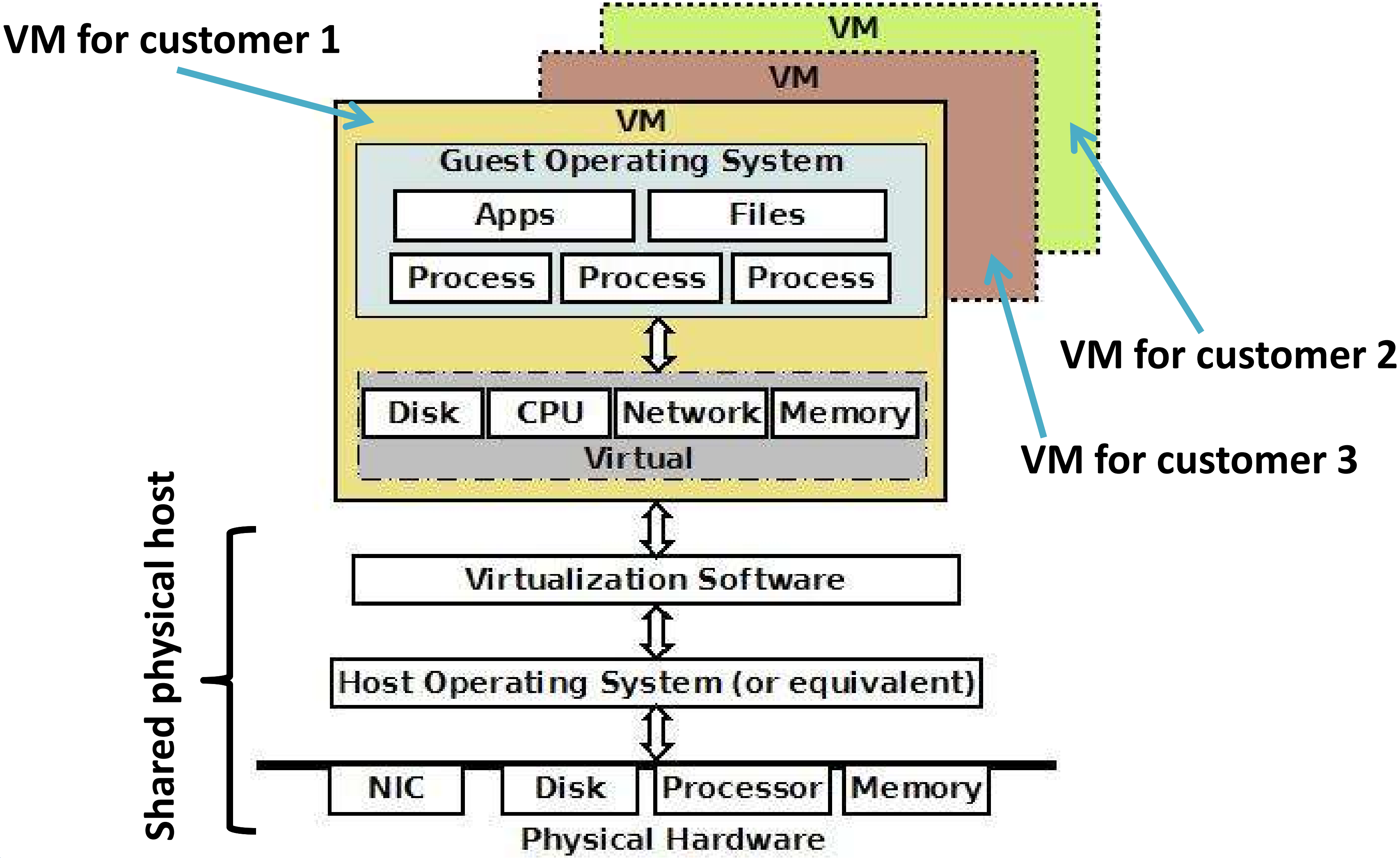
Addressing Provisioning Latency Issue

- You need to forecast the number of resources needed for optimal service
- Basic idea is to:
  - Watch for events that may indicate potential surge in load
  - Calculate the amount of additional resources needed to handle load
- Success depends on:
  - How well you pick right events that indicate load surge
  - Accuracy of calculating needed resources

Multi-tenancy On Cloud

- Different consumer's applications and data hosted on shared infrastructure
  - e.g. Single physical disk holding data from different consumers
- Needed for optimizing resource utilization
  - Allows cloud provider to leverage economies of scale
- Consumers can assume they are sandboxed
  - i.e. their apps and data is isolated from other's

Multi-tenancy On Cloud

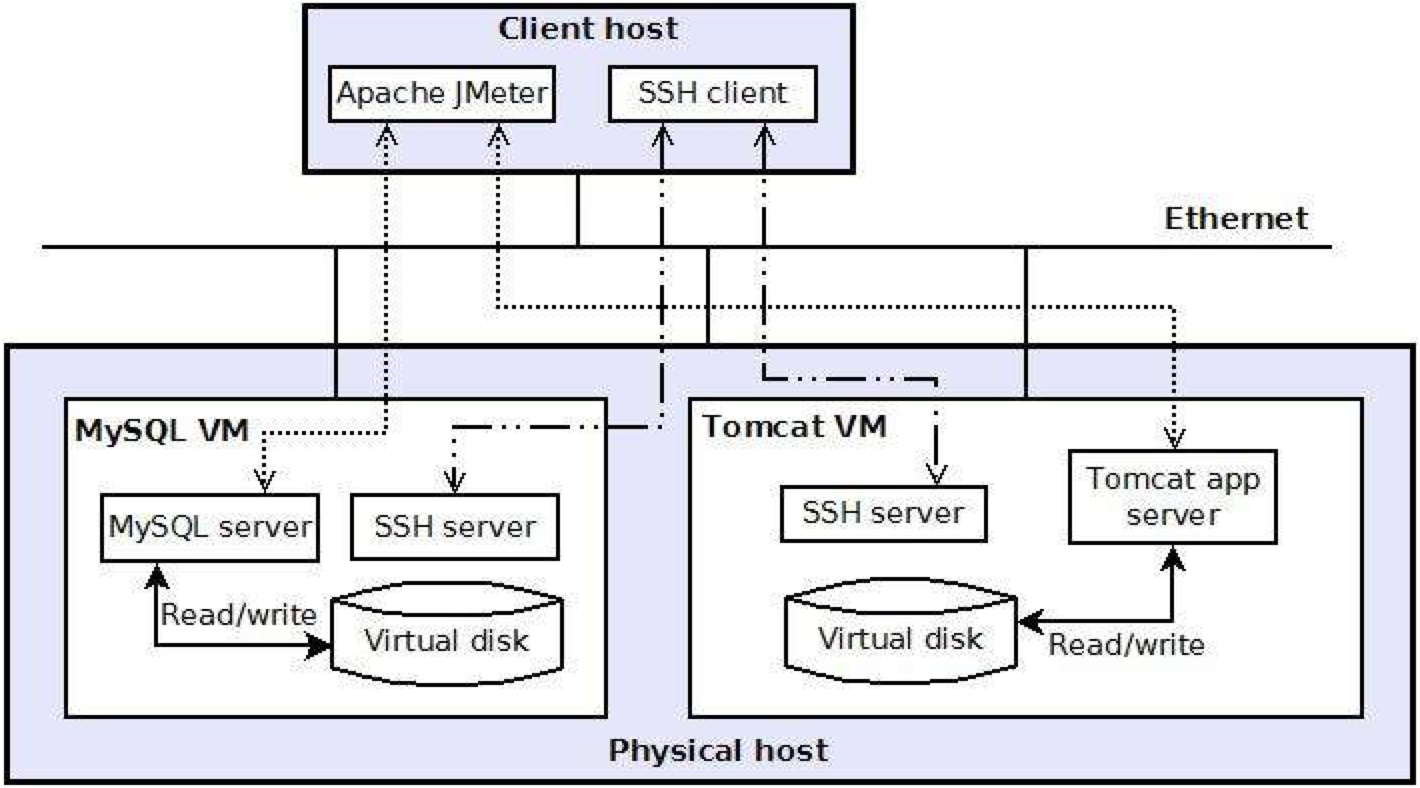


Issues Arising Due To Multi-tenancy

- Performance interference
  - VMs co-located on same physical host may affect each other's performance
  - E.g. simply forcing expensive cache invalidation on the host CPU
- Potential for one VM breaking into another
  - Bugs in virtualization software
  - Encrypting data by user can help

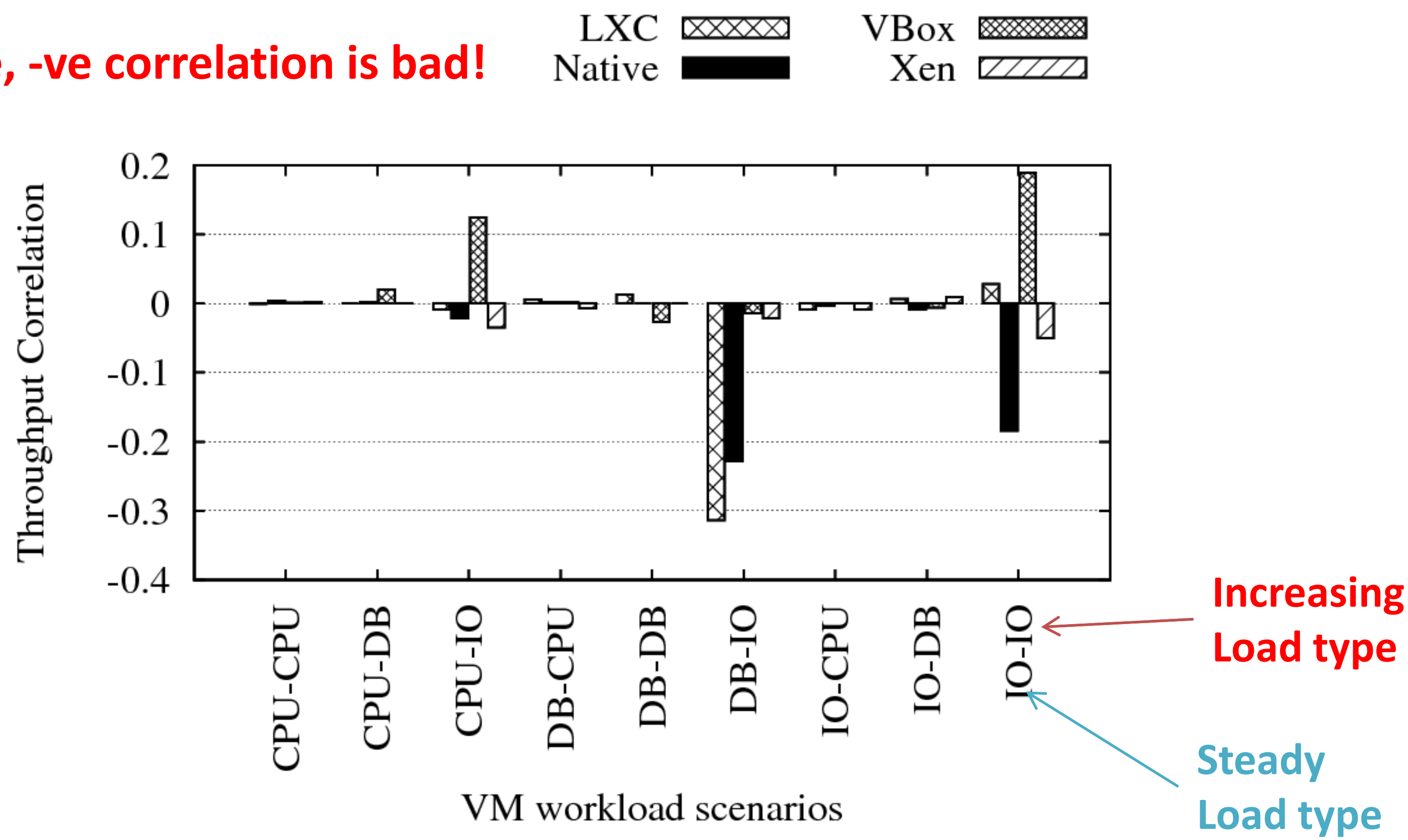
Sodhi & Prabhakar, "Cloud Platforms: Impact on Guest Application Quality Attributes" in IEEE APSCC 2012

Measuring Interference



Performance Interference (Throughput)

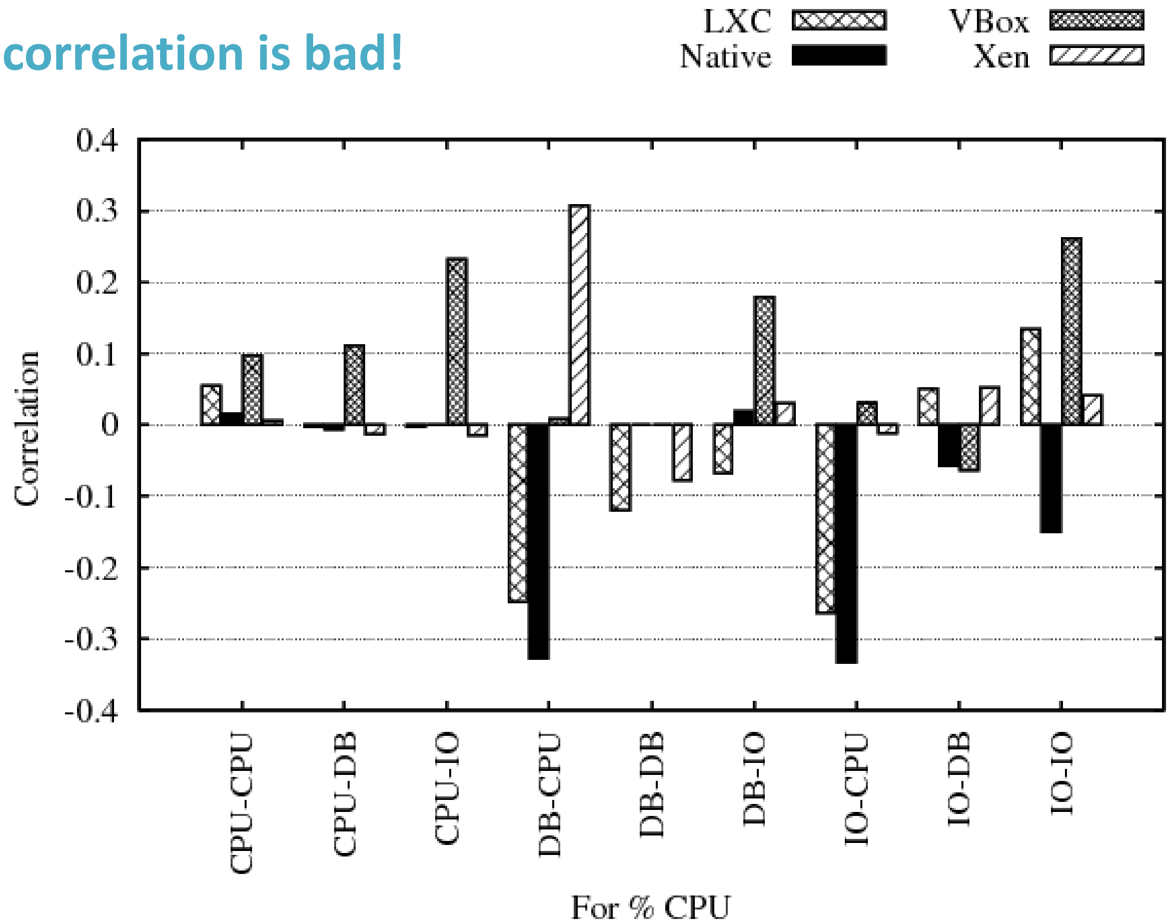
Here, -ve correlation is bad!



Sodhi & Prabhakar, "Performance Characteristics of Virtualized Platforms from Applications Perspective" in GLOBE 2012 (Springer LNCS)

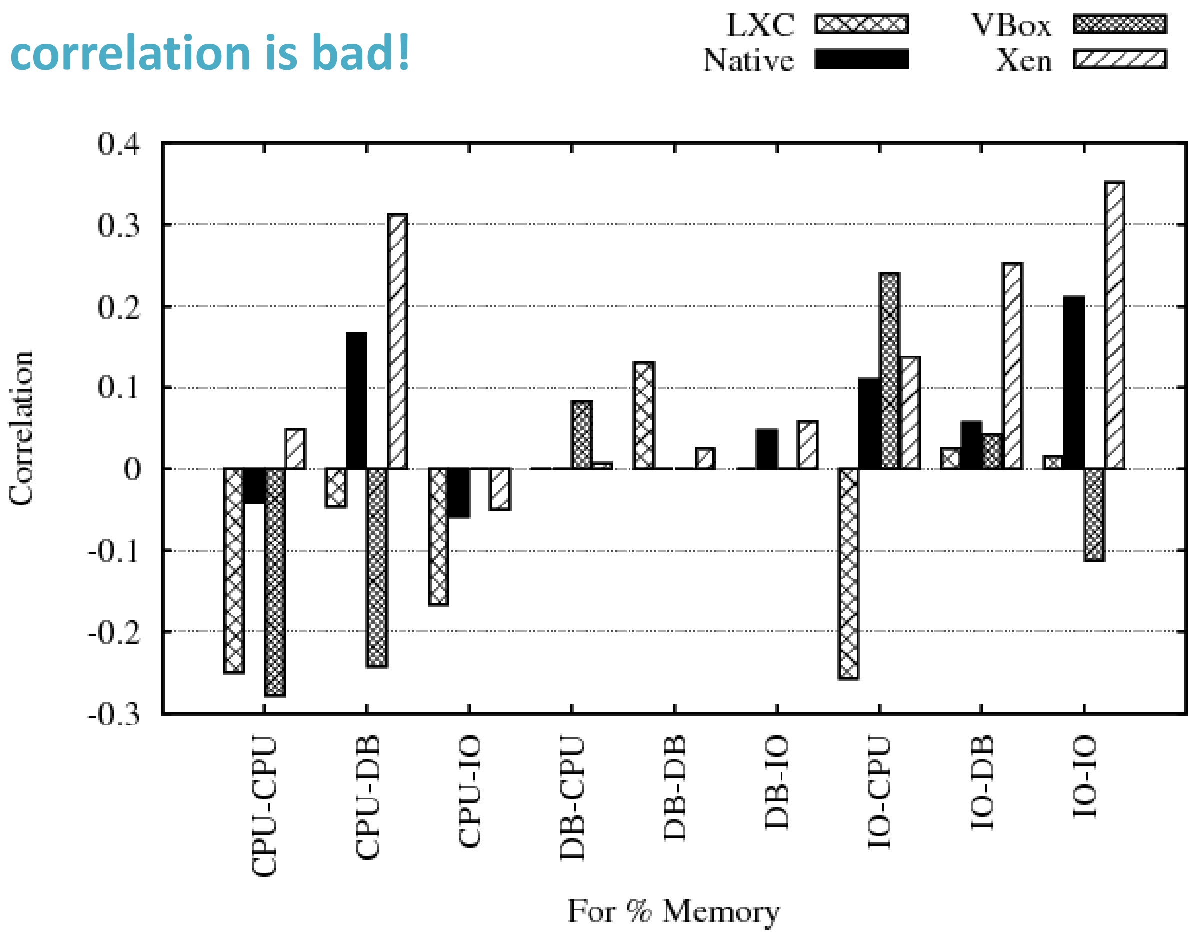
Performance Interference (CPU)

Here, +ve correlation is bad!



Performance Interference (Memory)

Here, +ve correlation is bad!



Summary

- Performance best practice from non-cloud environments continue to apply on cloud
- But you can leverage cloud specific characteristics
  - Elasticity of computing resources
  - Virtual nature of resources
  - On-demand provisioning
- Performance remains a design issue on cloud as well
  - One has to design performance into the application
    - It does not come automatically!

Impact Of Platform Characteristics

Platform Characteristics

- A computing platform (?aaS) carries characteristics unique to it
  - Chars. = {Functional + non-functional attributes of platform}
- For example:
  - Software abstraction of hardware resources (V12N)
  - Coarse-grained multi-tenancy (IaaS/PaaS)
  - Limited control of underlying infrastructure (PaaS)
  - Location transparency (XaaS)
- They impact guest application architecture
  - E.g ability of a guest app to achieve certain QAs

Finding Impact on Application Architecture

- Examine platform characteristics in light of architecture knowledge and reverse-engineer the tactics and patterns

QA (Possible tactic for it)	Remarks
Reliability (State checkpoint)	On finding a failure, the system can be restored to a prior check-pointed consistent state.
Performance (Add concurrency)	Processing different sets of tasks in parallel by creating additional threads.
Security (Limit exposure)	Services are deployed on hosts in a manner that reduces overall damage when the host is compromised.

Sodhi & Prabhakar, "Cloud Platforms: Impact on Guest Application Quality Attributes" in IEEE APSCC 2012

Characteristics' Impact on QAs

- Some examples:

Characteristic	Impacted QA
Software abstraction of hardware	DR, Efficiency (+)
Programmatic self-serviced provisioning	Deployability, Scalability (+)
VM/resource check-pointing and snap shots	Availability, DR, Reliability (+)
Lack of computing assets custody	Privacy, Security (-)
Relative anonymity behind subscription and usage	Security (-)

Sodhi & Prabhakar, "Cloud Platforms: Impact on Guest Application Quality Attributes" in IEEE APSCC 2012

How To Make Use Of This?

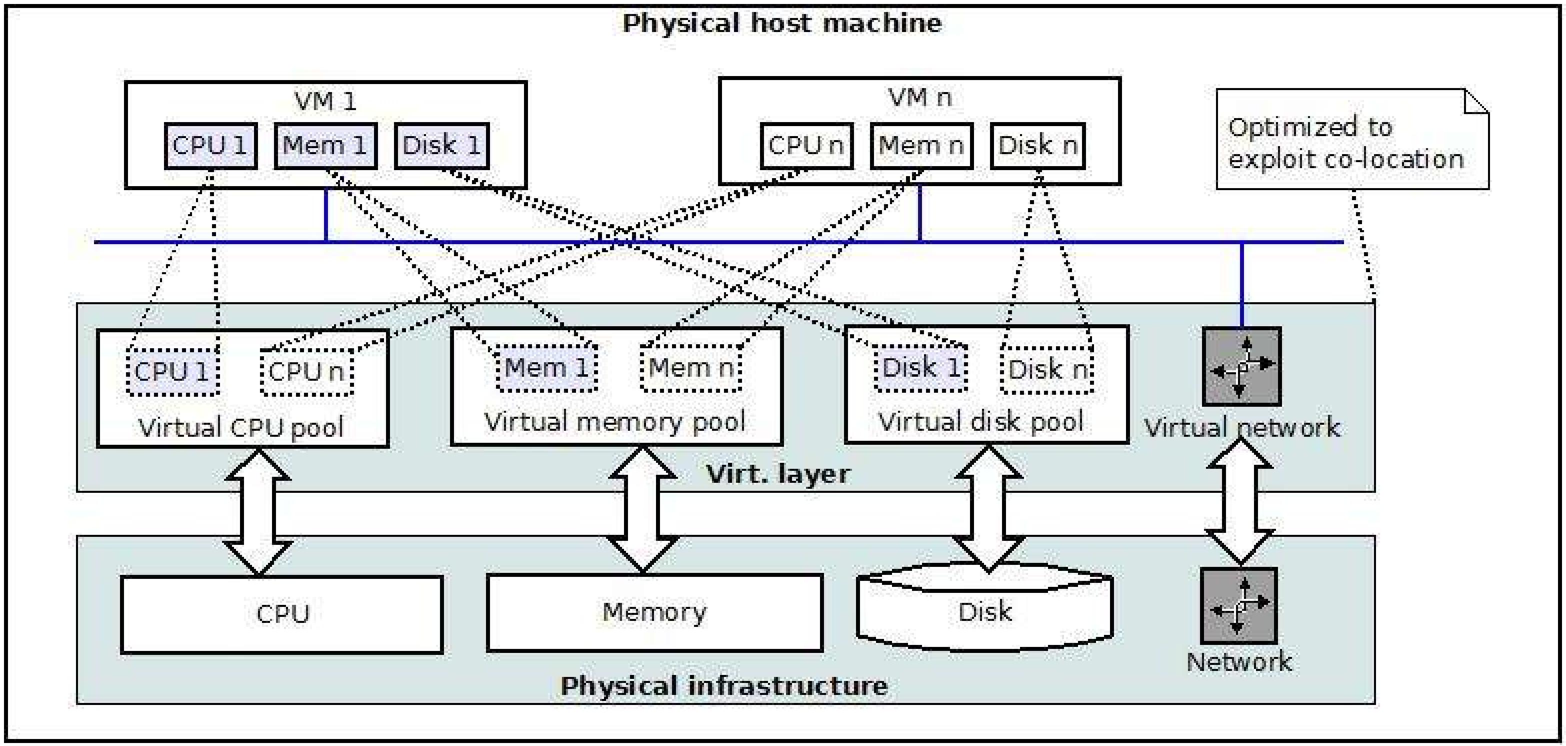
- Can be used address different types of application scenarios
  - Implement failure recovery at platform level
  - Co-locate different tiers on same host keeping them isolated
  - Selective request/computation transfer

Sodhi & Prabhakar, "Cloud-oriented platforms: Bearing on Application Architecture and Design patterns" in IEEE Services 2012

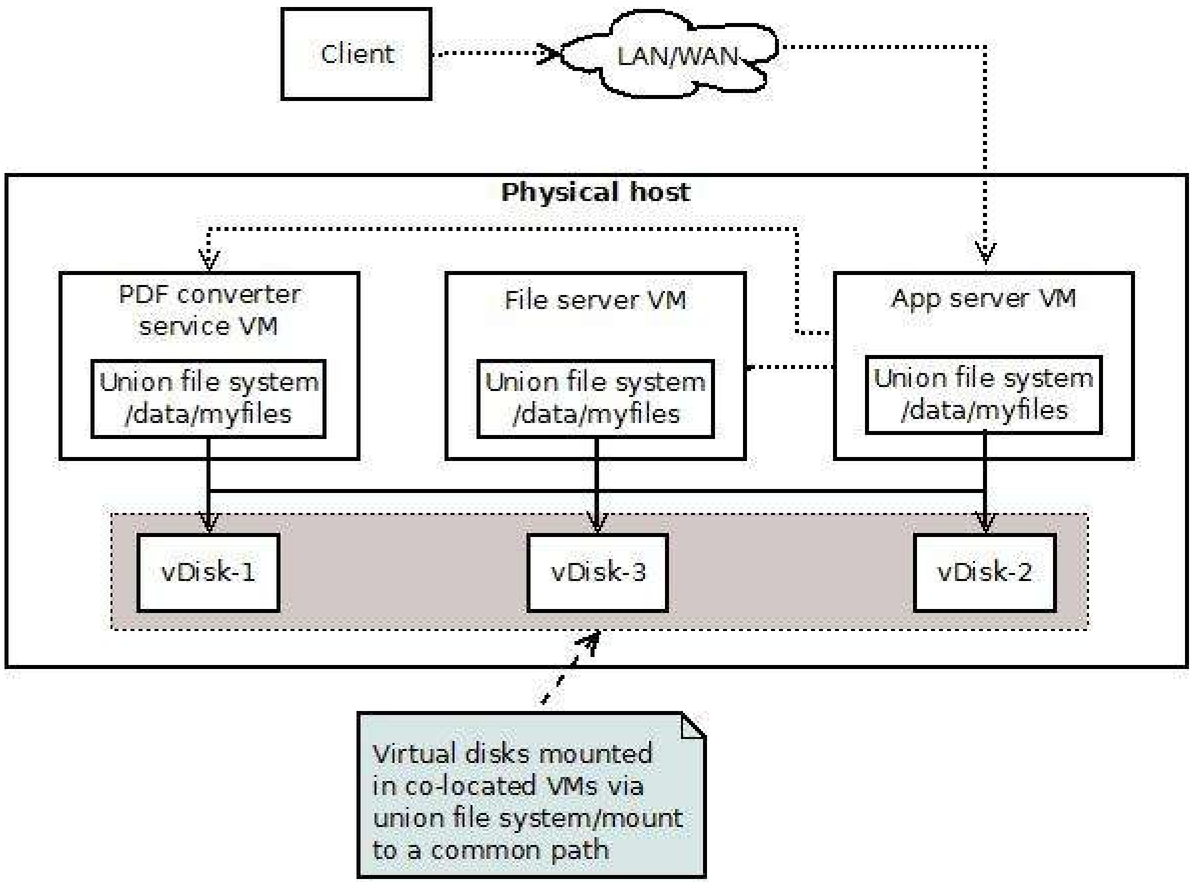
Tier Co-location: Problem Scenario

- Application consisting of multiple tiers
  - e.g. a N-tier web application
- There is some over-the-wire data exchanged among tiers
  - This is costly!
- You want to retain tier isolation, but still minimize inter-tier communication overheads

Tier Co-location: Logical View



Tier Co-location: Example

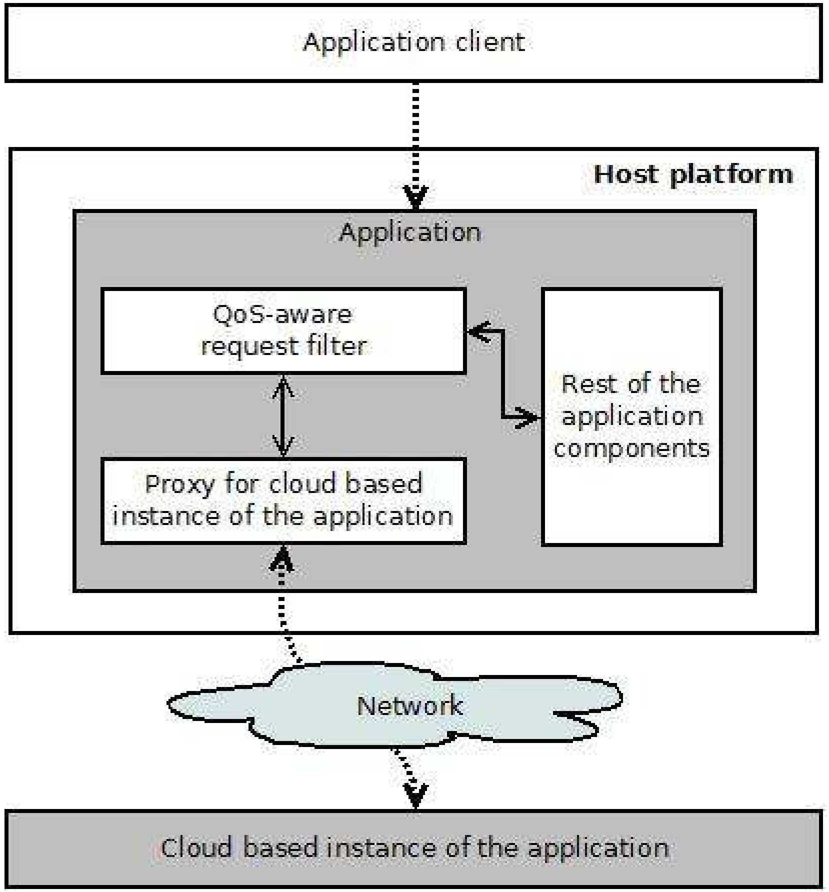


Selective Computation Transfer

- Problem context:
  - An application functionality is such that:
    - Different requests may take different amount of resources to process
    - Some requests may require execution of privileged components
    - Majority of requests can be served from normal deployment environment
  - You want to maintain certain QoS for *ALL* requests

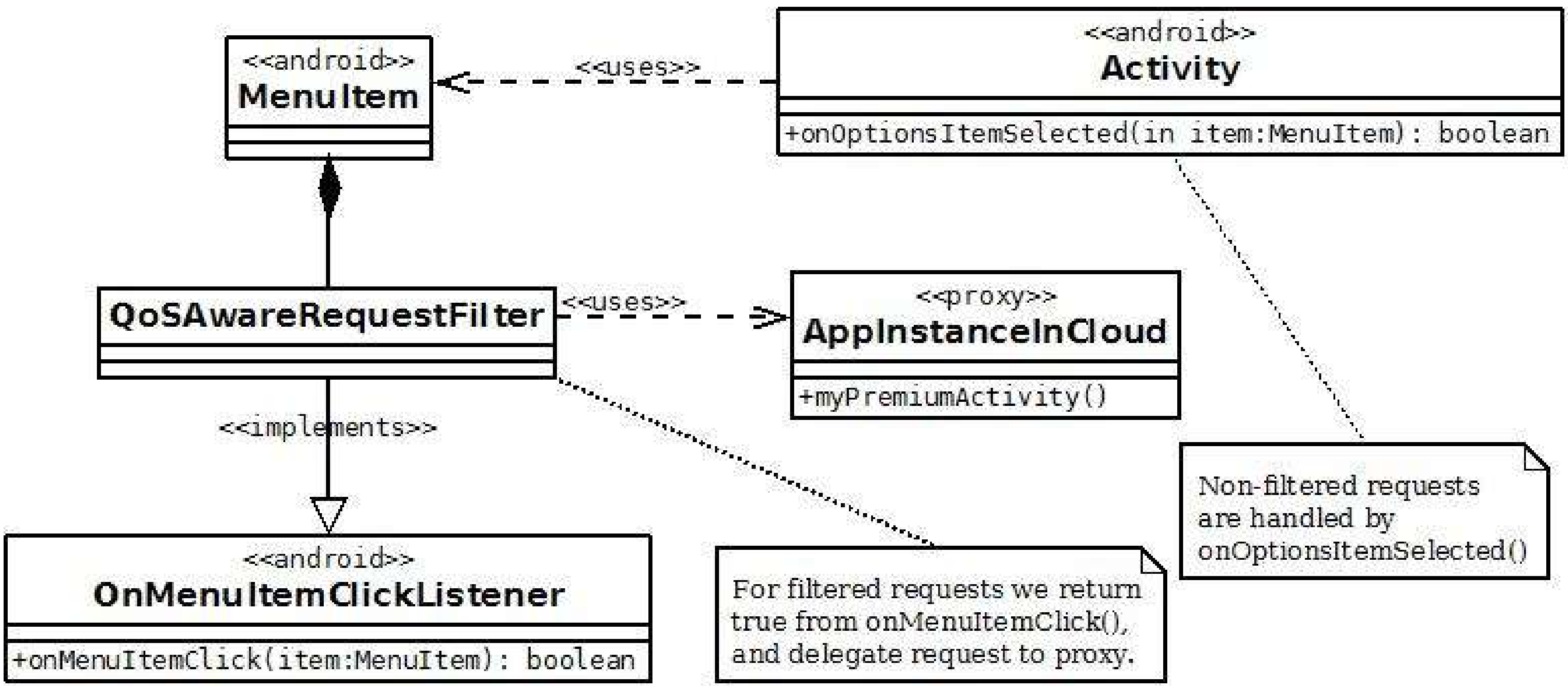
Selective Computation Transfer

Architecture



Selective Computation Transfer

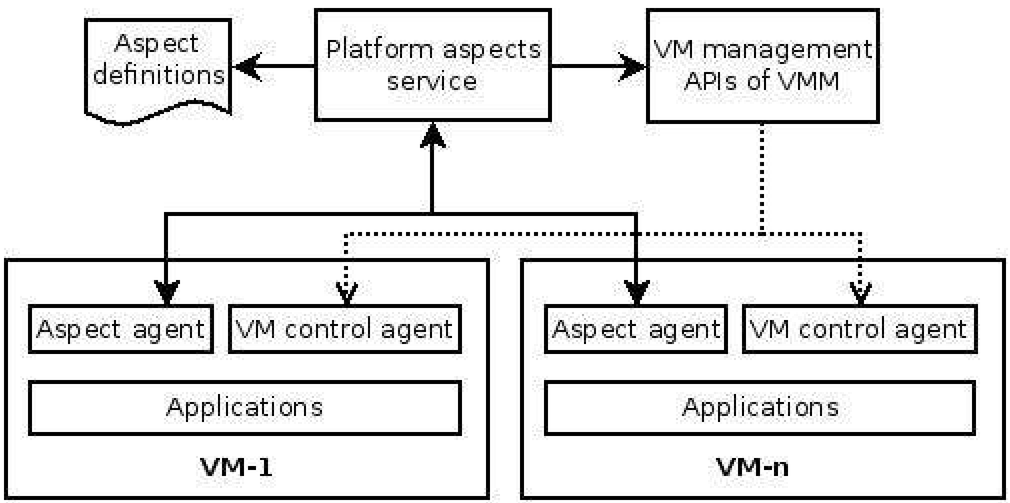
- Example implementation



Aspect-orientation at Platform-level

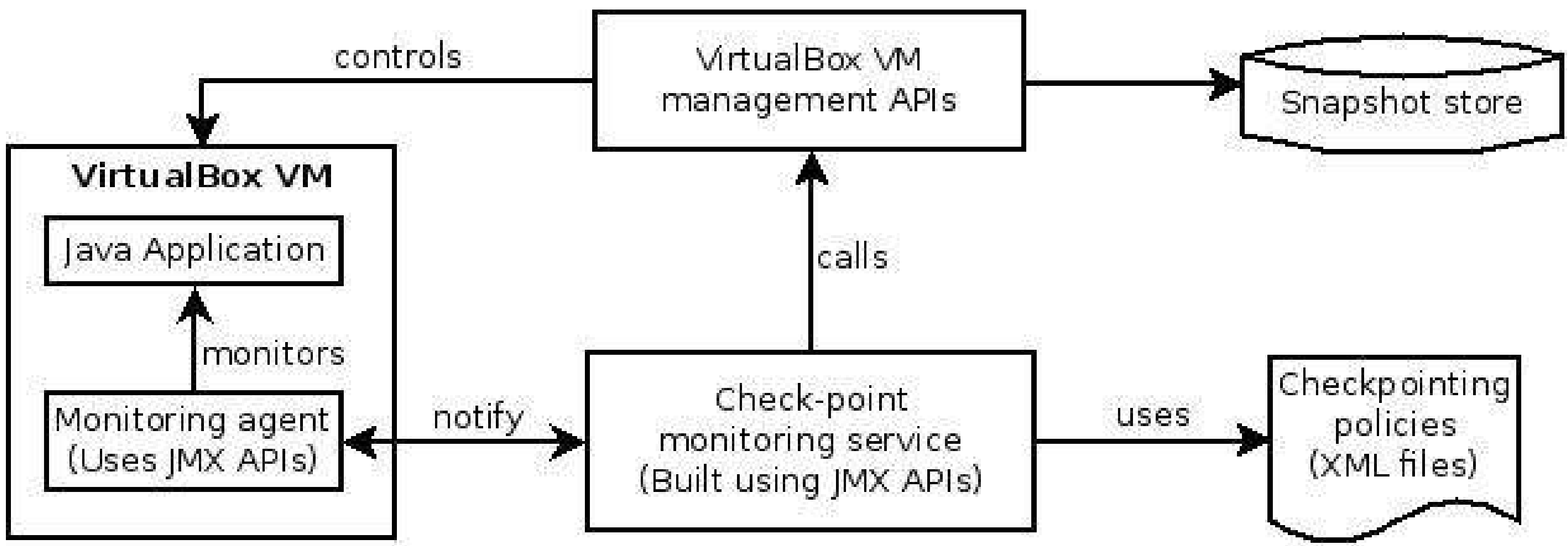
- Problem context:
  - There are software design and implementation concerns which apply at the coarse grained computing environment/platform level, and they cut across the applications
    - E.g. monitoring and reacting to platform level events

Aspect-orientation at Platform-level



Aspect-orientation at Platform-level

- Example implementation



Summary

- It is important to determine and understand platform characteristics
  - Cloud and virtualization based platforms have several unique characteristics
- Devise solutions to application scenarios
  - Leverage platform characteristics