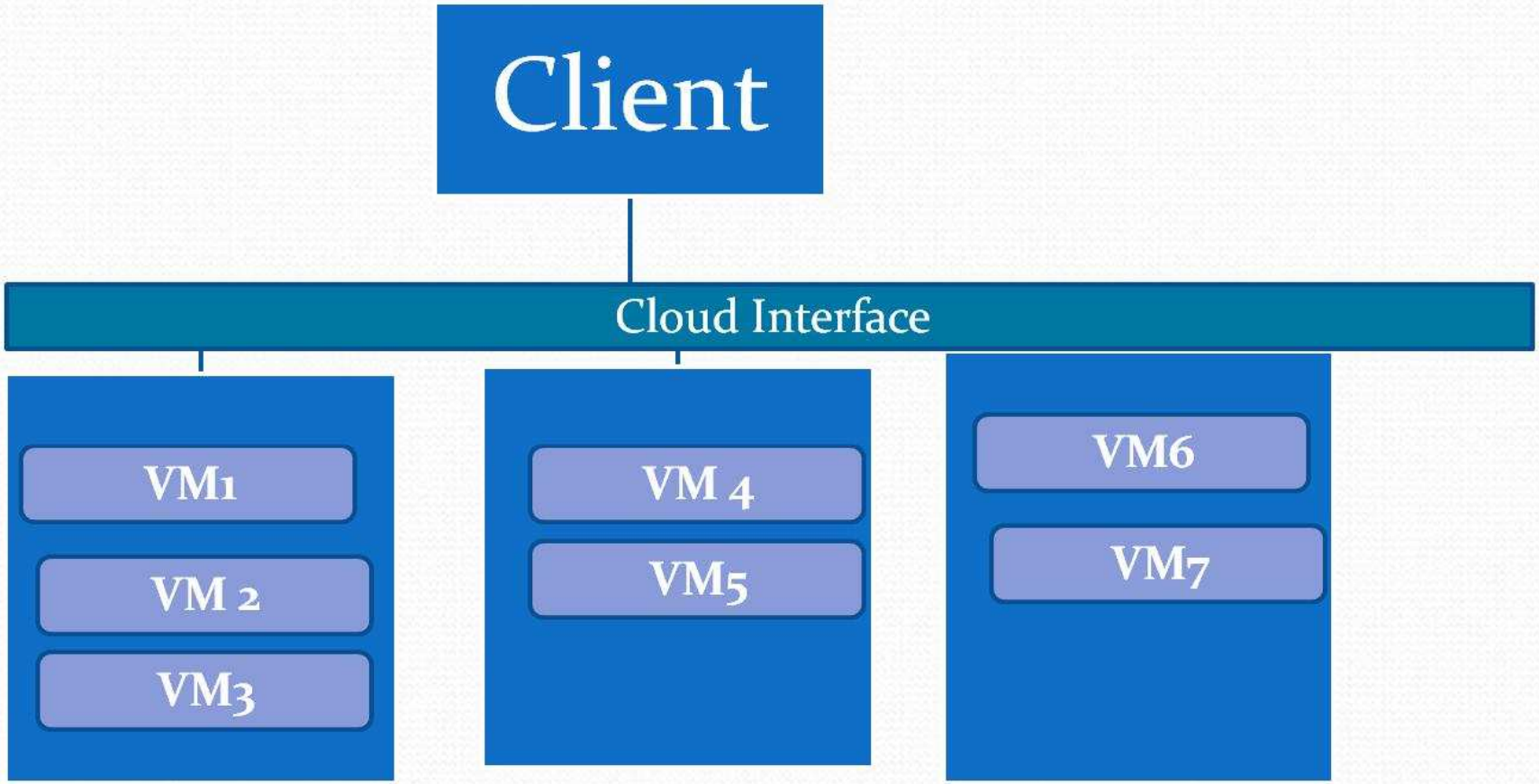
Chapter Four

Migration
In Cloud Computing

Prepared By: Dr. Fatma Omara

Hand-Book of Cloud: Chapters 1- 8
CLOUD COMPUTING Principles and Paradigms: Chapter 1
Other Materials from different sites

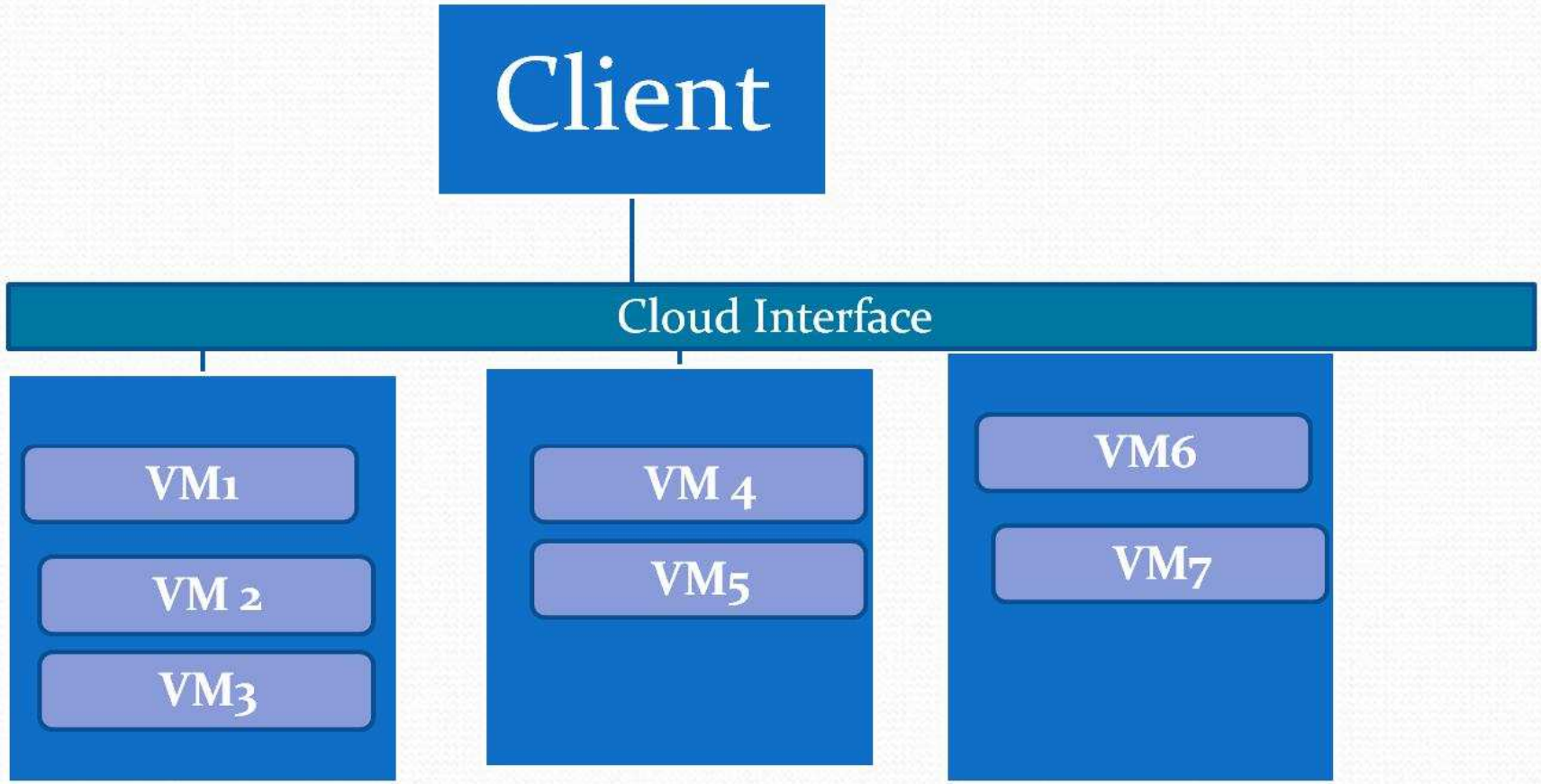
Migration Services



Help to :

- Utilize Resources
- Load Balance
- Safe Power (Green ICT)

Migration Services



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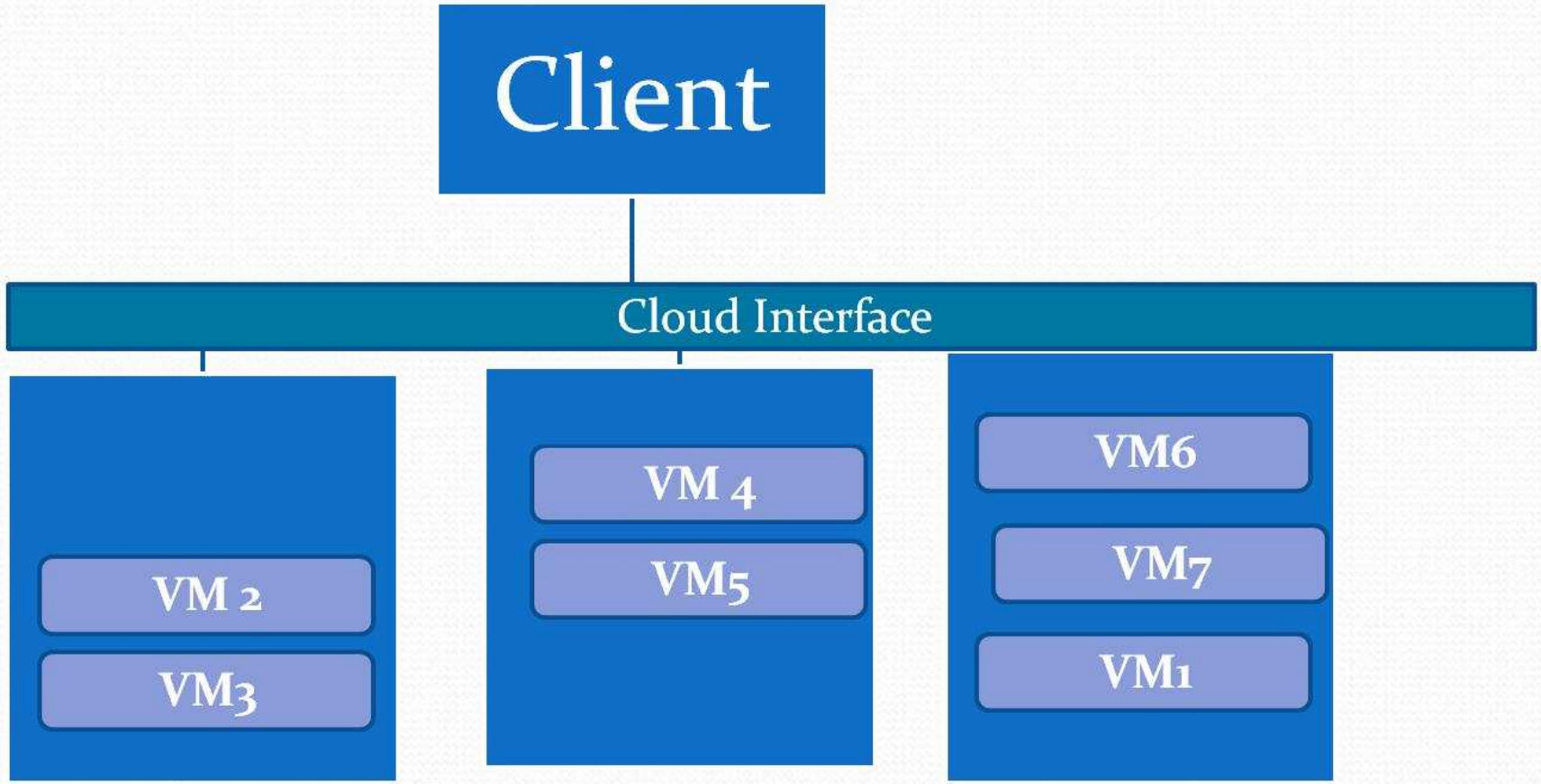

Help to :

- Utilize Resources
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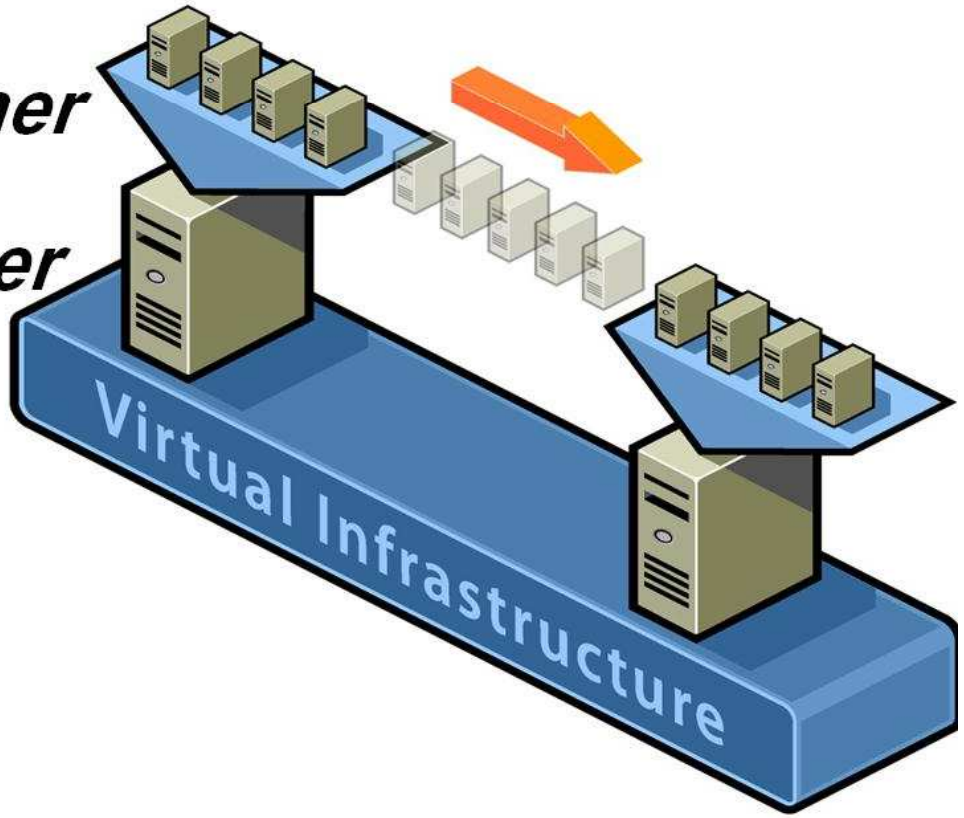
Virtual Machine Migration Services

- Migration service in the context of virtual machines, is ***the process of moving a virtual machine from:***
  - ***One host server to another***
  - ***Storage location to another***
  - ***One data center to another***



Migration Services

- All keys of Virtual Machine's components such as ***CPU***, ***storage disks***, ***networking*** and ***memory*** are completely virtualized.
  - This facilitates the entire state of the virtual machine to be captured and moved by a *set of easily moved data files*.

Various techniques:

- **Live (hot or real time) migration** : VM is powered on
- **Worm migration**: VM is suspend
- **Regular (cold) migration**: VM is powered off
- **Live Storage migration**

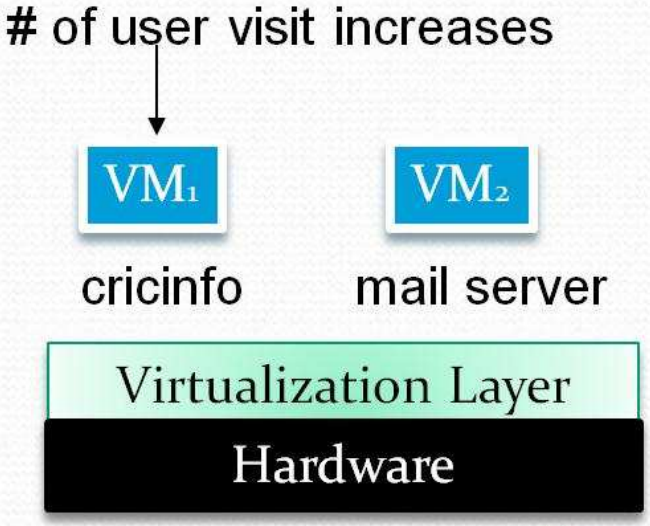
IaaS

VMs Migration, Why?

- **Load balancing**
  - Move ***VMs*** to a less busy host
  - Make use of newly-added capacity
- **Maintenance**
  - Move ***VMs*** off a host before it is shut down
- **Recovery from host failure**
  - Restart ***VM*** on a different host

Motivation

- Consider a data center consisting of ***"n"*** physical machines (***PM***) hosting ***"m" VMs*** implementing one customer application each
- Resources(CPU, Network, Memory, I/O) are allocated to each VM to handle the workload and operate at certain performance level (**SLA**)
- Each VM sees workload fluctuation from time to time => resource requirement changes



PM Capacity

Network Bandwidth	= 10 Gbps
Memory	= 16 GB
CPU	= 8 cores

Resource Allocation

	VM1	**VM2**
	N = 5Gbps	N = 5Gbps
	M = 8GB	M = 8GB
	C = 4 cores	C = 4 cores

Motivation- Cont..

- An increase in workload can be handled by allocating more resources to ***VM***, if idle resources (***Where!!!***) are available
- Main Issues:
  - What if ***PM*** does not have (enough or no) idle resources to satisfy ***VM's*** requirement?
    - Performance of the application degrades
    - SLA violation occurs
- Key Ideas
  - Replication ***VMs***
  - Migrating ***VMs***

Virtual Machine Migration

- Why we need migration?
- When we need to migrate?
- How migration is done?
- Issues in ***long distance migration*** (across data centers)
  - ***VM*** migration can be used to ***reduce power consumption in cloud data centers (i.e., VM Consolation)***
    - ***Support Green ICT***

When we need to migrate?

- Hotspots can cause SLA violations
  - Burden some Virtual or Physical Machines are called **hotspots**
    - **Hotspot:** any resource exceeds a threshold(or SLA violation) for a sustain period
- Hotspot Detection (Sandpiper)
  - **Black-box Monitoring**
    - CPU /processes
    - Network (/processes/network/devices)
    - Memory (swap)
  - **Gray-box Monitoring**
    - Gather OS level statistics and application logs
- A ***hotspot*** is ***flagged*** only if ***thresholds are exceeded*** or ***SLAs violation*** for a sustained time.

Wood T et al (2007) Black-box and gray-box strategies for virtual machine migration. In: Proc of NSDI

Determine:
What virtual servers should migrate
Where to move them
How much of a resource to allocate the virtual servers after migration

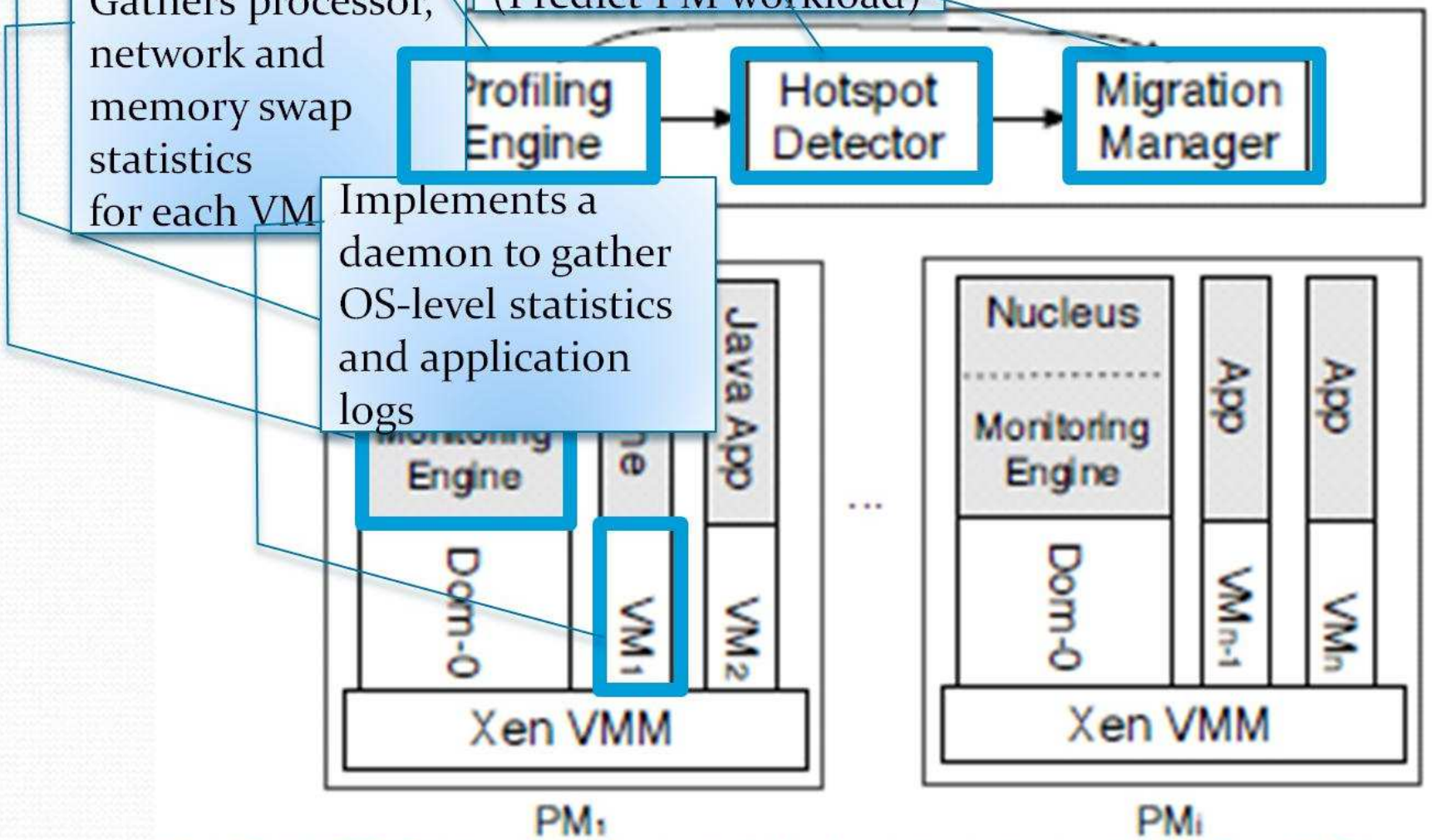
Construct reso
usage profiles f
each virtual serve
(Predict PM workload)

sustain period

Gathering resource usage

Gathers processor, network and memory swap statistics for each VM

Implements a daemon to gather OS-level statistics and application logs



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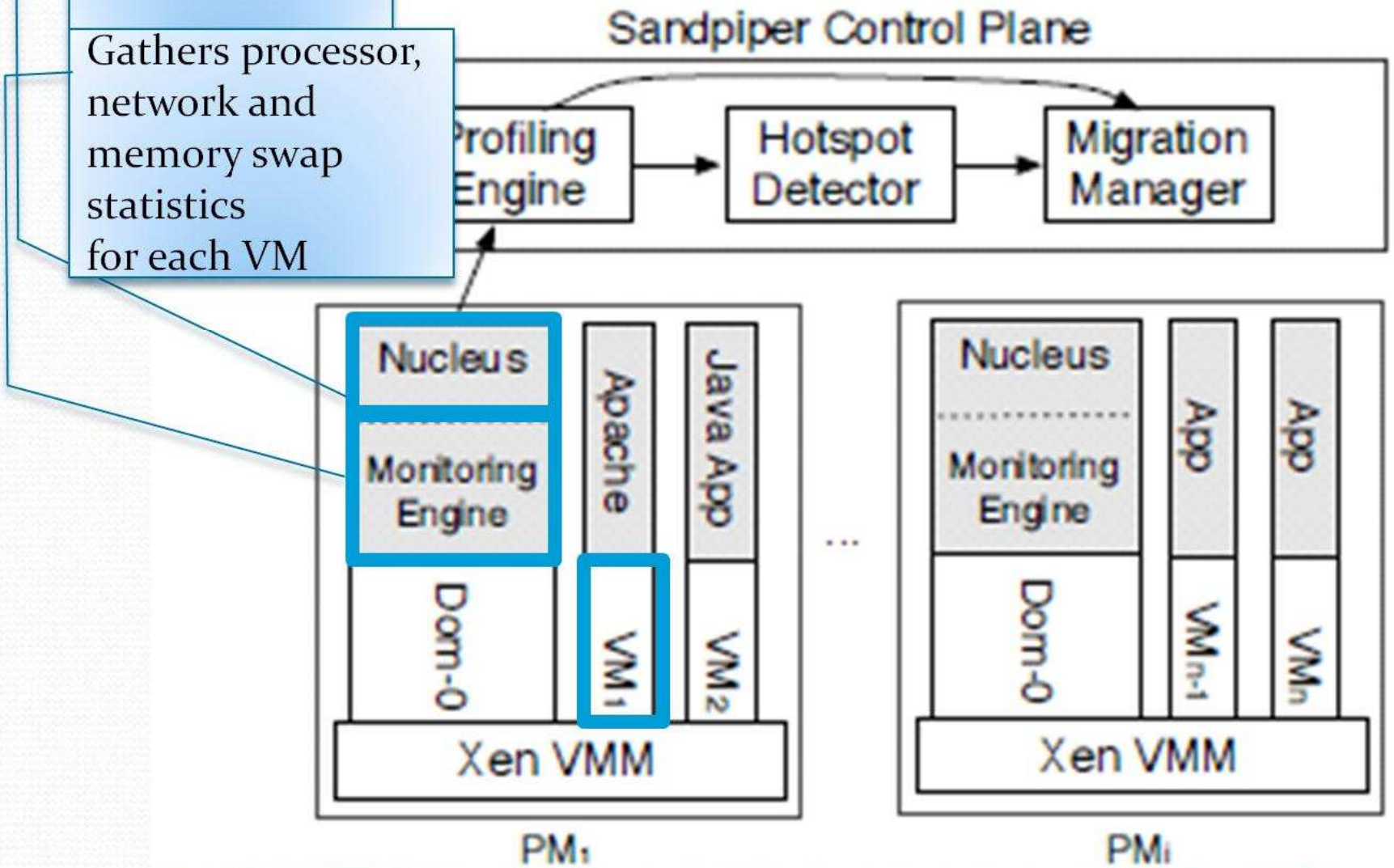
Gathering resource usage statistics on that server

Gathers processor, network and memory swap statistics for each VM



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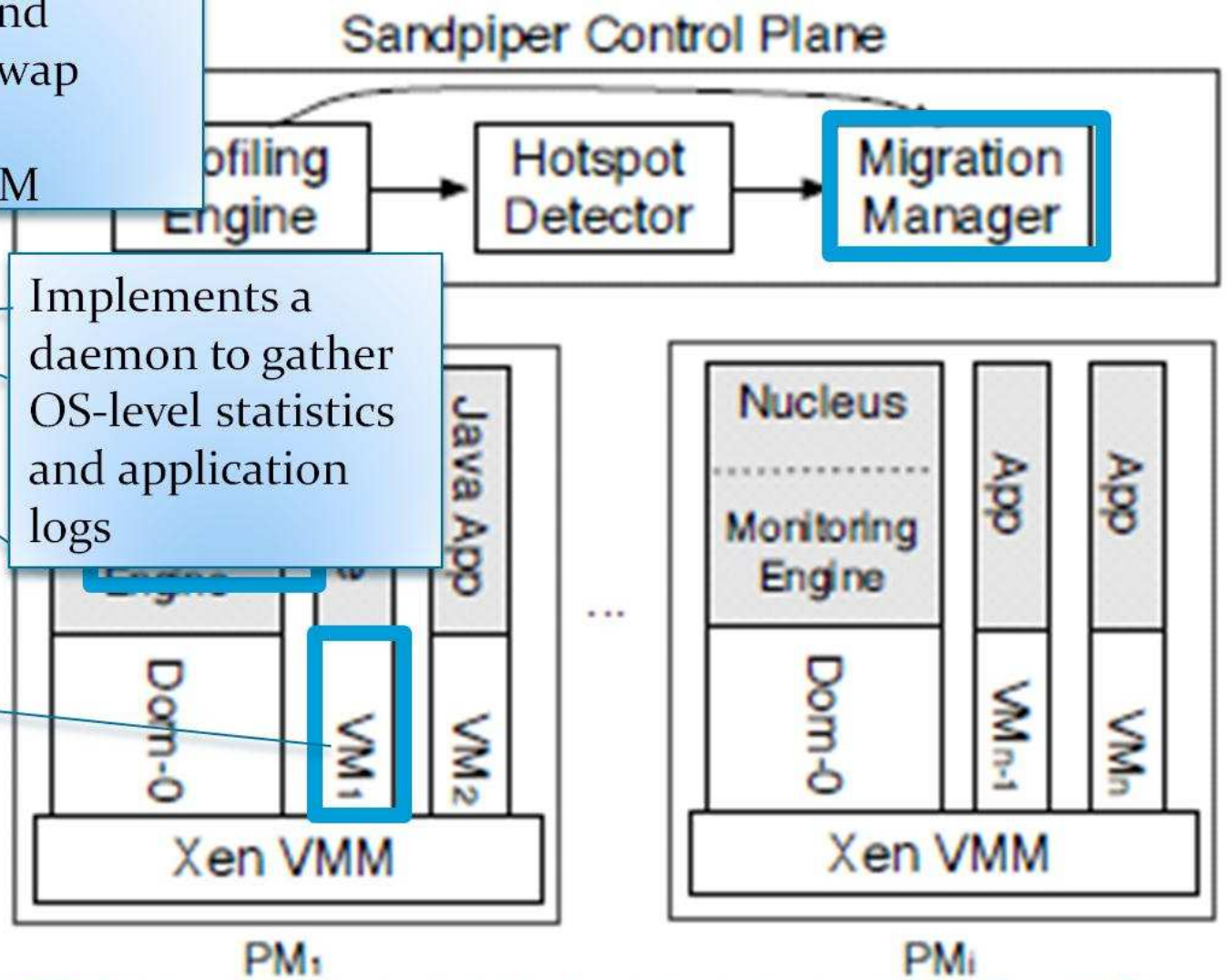

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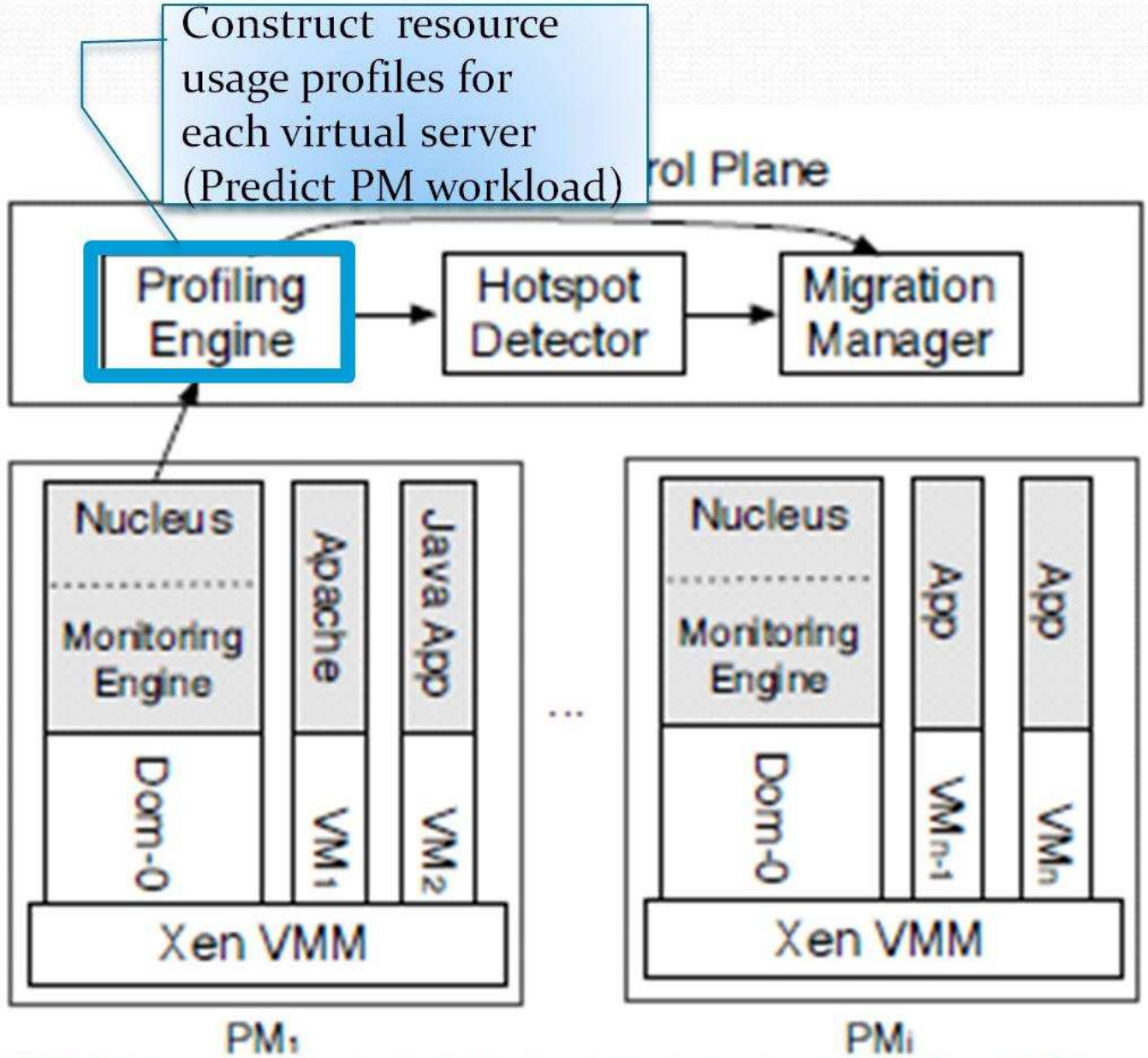

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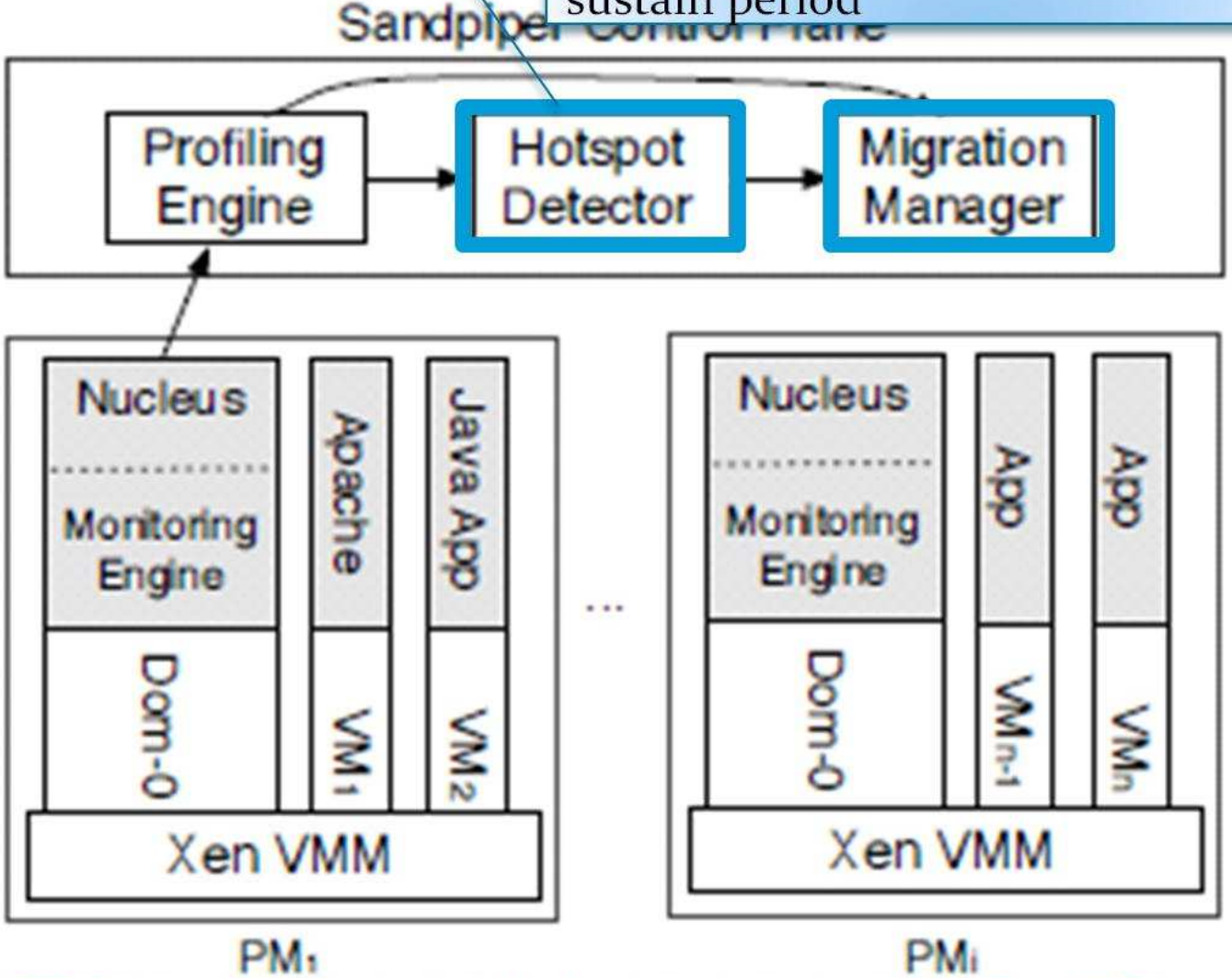
Monitors usage profiles to detect hotspots.

Hotspot: any resource exceeds a threshold(or SLA violation) for a sustain period



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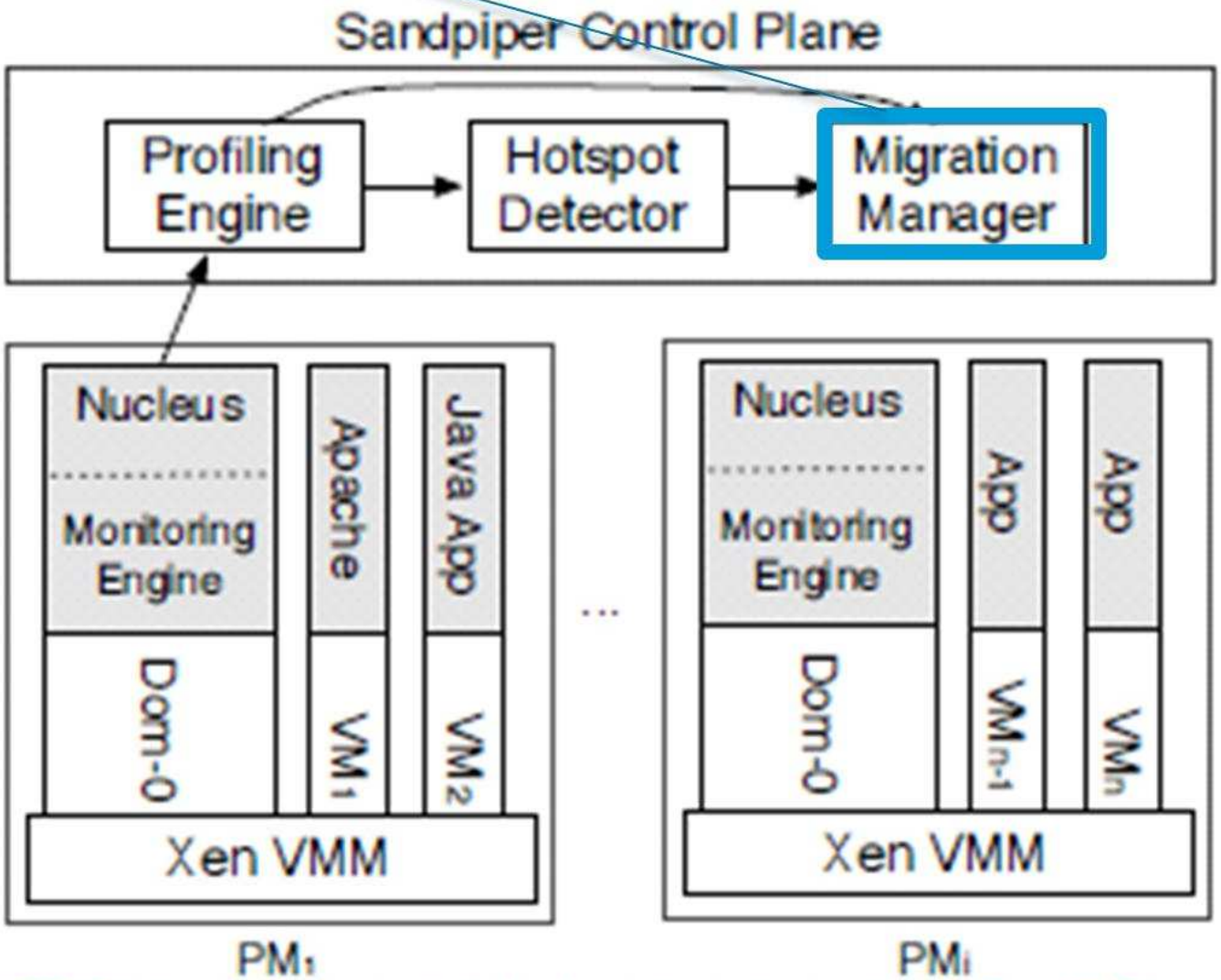

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When we need to migrate? – Cont..

- SLA violation detection
  1. Mapping *low-level resource metrics* to *high-level SLAs*
  2. Crude data maps to user requirements such as
     - **CPU speed** maps *to Response Time*
     - Occupied *memory size* maps to *number of concurrent clients*
  3. Predictive Strategy for detection of possible SLA violations
- Detection interval
  - ***Short measurement intervals*** may ***degrade performance***
  - ***Long measurement intervals*** may ***cause ignorance of heavy SLA violations***

Why

?

Towards autonomic detection of SLA violations in Cloud infrastructures, Future Generation Computer Systems, 2012

How migration is done?

- Transferring a ***VM*** refers to the transfer of its state include:
  - **its memory**, **internal state of the virtual CPU**, **network**, and **storage disk**
  - Among these, the most Time-Consuming one is the ***memory transfer***.
- **Memory Migration**
  - Pre-Copy
    - Warm-Up
    - Stop-and-Copy
  - Post-Copy
- **File System Migration**
  - In case of distributed file system, there is no need to copy
  - Alternatively, ***copy only changed local files*** to the destination using Virtual Machine Manager's API.

S. Venkatesha, S. Sadhu, S. Kintali, and S. Barbara, "Survey of virtual machine migration techniques" - Memory, 2009

How migration is done?-Cont..

- **Network Migration**
  - If both source and destination are **on same LAN switch**
    - an Address Resolution Protocol (ARP) reply from the migrating host is provided
  - If both source and destination are **on a switched network**
    - The migrating OS can keep its original Ethernet MAC address, relying on the network switch to detect its move to a new port

S. Venkatesha, S. Sadhu, S. Kintali, and S. Barbara, "Survey of virtual machine migration techniques" - Memory, 2009

Migration across Data Centers

- Need for ***VM*** mobility across data centers
  - Data center maintenance without downtime
  - Disaster avoidance
  - Data center migration/expansion
  - Workload balancing across multiple sites

Downtime

Time during which the VM on the source host is suspended (not available)

- Issues should be considered for VM mobility across data centers:
  - Trust to a remote execution environment
  - Interoperability at the level of Web Services, Java etc..
  - Migration across multiple domains are vulnerable to security exploits

Migration Process Goals

- **Migration Time**
  - Minimize total end-to-end migration time
  - Predictability of migration time
  - Keep the total migration time manageable
- **Guest Penalty**
  - Minimize performance loss
  - Minimize downtime (maximize availability)
- **Atomicity**
  - Avoid dependence on multiple volumes (for replication fault domains)

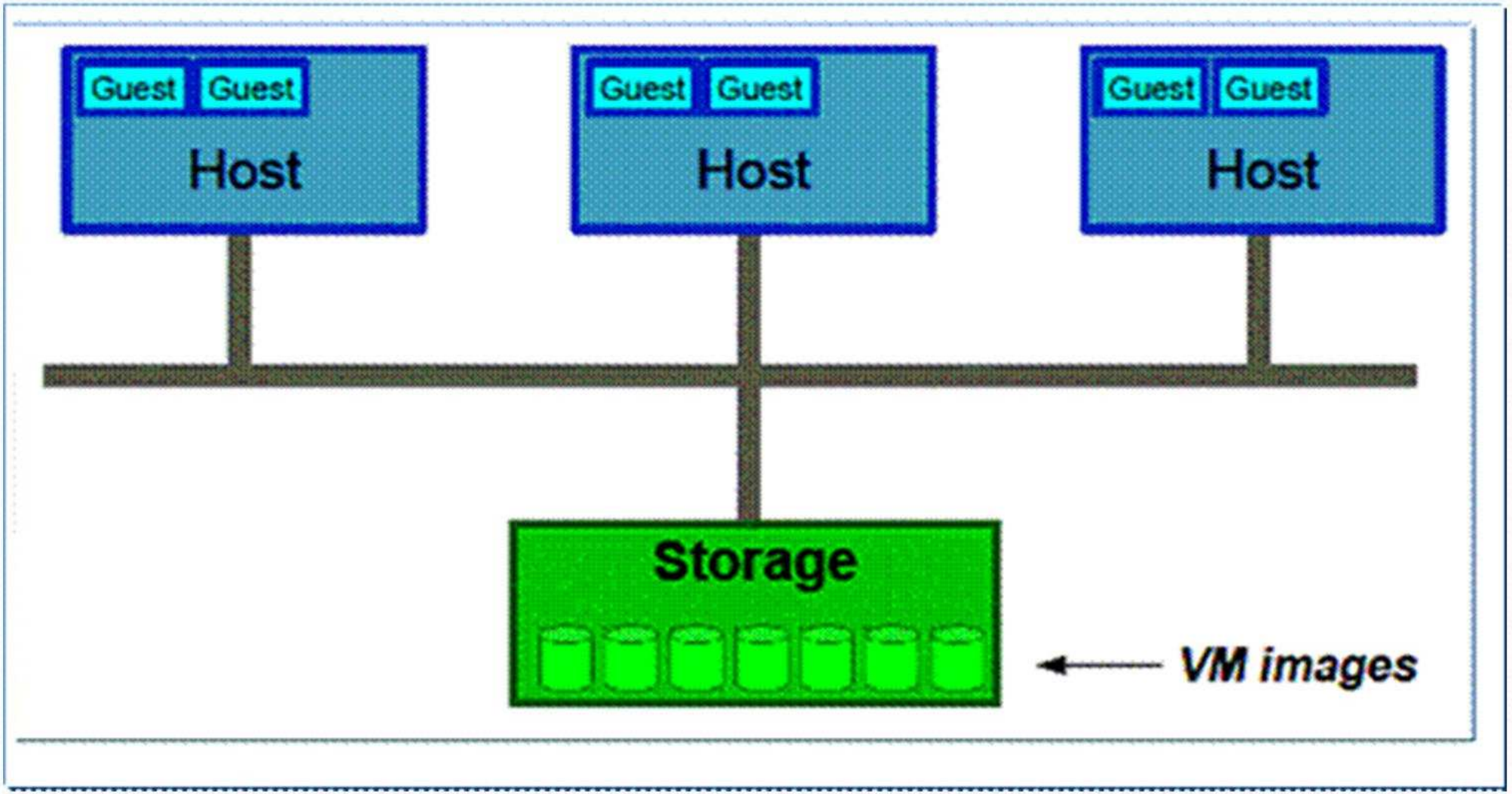
Guarantee That: ***Ideally,*** we want migrations to:

- ***Complete successfully***
- ***Limit the impact of migration*** on ***both the Guest*** and ***the local network***

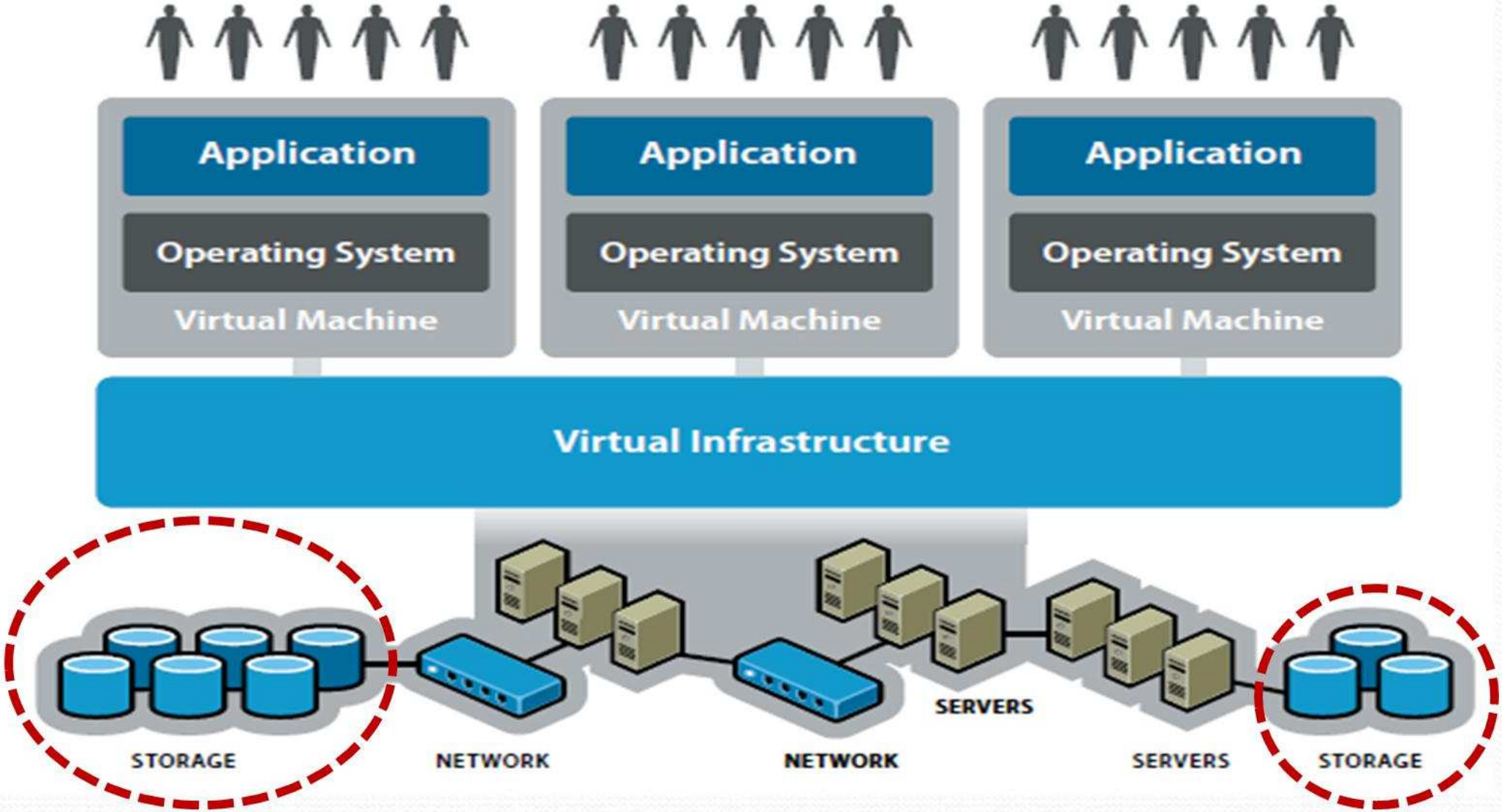
***Migration and Storage

- The **VM** disk image has to be accessible from the new host after the migration
- Just copy the disk image across?
  - **Slow**
    - Fine for a ***cold migration*** though
- Can we do a "***live migration***" of storage?
  - ***Yes*** (e.g. very recent versions of KVM can do this)
    - **Risky**
    - **Doesn't help recover from node failure**
- Kernel-Based Virtual Machine (KVM)
  - It is virtualization module in the Linux kernel that allows the kernel to function as a hypervisor.

Traditional Solution Migration of Storage:
Shared Storage



Shared Storage



Advantages of Shared Storage

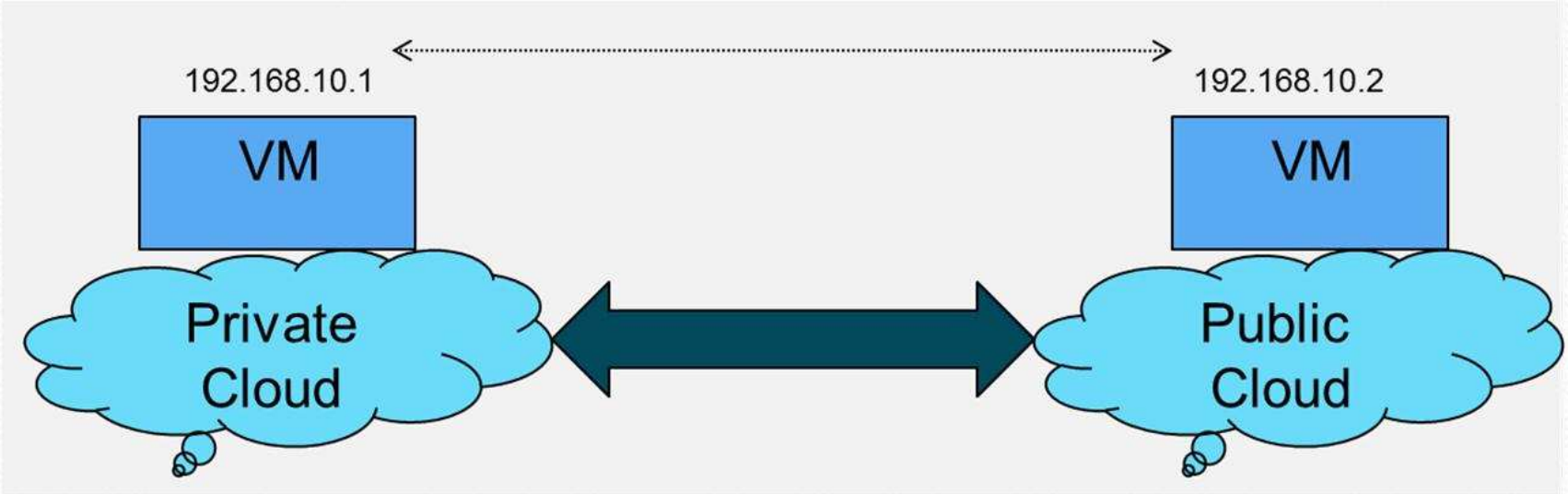
- Complete mobility of **VMs** with ***live migration***
- Can scale the ***compute nodes*** and the ***storage nodes*** independently
- Simpler compute nodes
  - little or no local storage required
- Central point of volume management
- Central point of backup / Data Recovery

Disadvantages of Shared Storage

- Storage becomes ***single point of failure***
- Network becomes ***single point of failure***
- Network bandwidth can be a ***bottleneck***
- Network ***latency*** can impact performance
- Network ***security***
- Risk of accidentally starting two **VMs** using the same disk image!

VM Burst migration Benefits

- Benefits provided by **VM** Migration from **Private Cloud** to **Public Cloud (Burst Migration)** are:
  - ✓ Load balancing
  - ✓ Disaster recovery
  - ✓ Hardware maintenance
  - ✓ Fault takeover

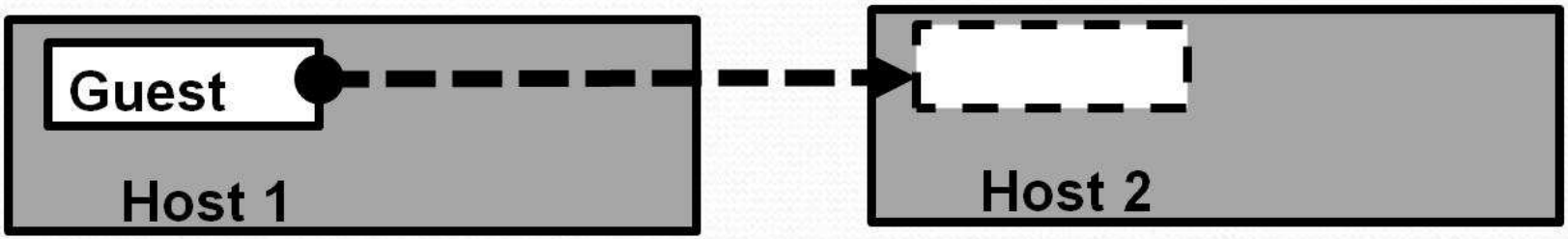


VM Migration Techniques

Cold (Regular) Migration

Principles:

- It is also know as ***offline migration***.
- In this category, **VM** is ***completely power off*** before its migration to remote end.
- Shutdown **VM** on **Host 1**, restart on **Host 2**



Regular/Cold Migration- Cont..

- Cold Migration of a **powered-off** virtual machine.
- With Cold Migration:
  - You have options to move associated disks from one data store to another.
- The virtual machines are ***not required to be on a shared storage.***

Regular/Cold Migration- Cont..

- The cold migration process is simple to implement (as the case for the **VMware** product):

1. Shut Down Virtual Machine
2. The ***configuration files***, including the ***NVRAM file*** (BIOS settings), ***log files***, as well as, the ***disks*** of the virtual Machine, are moved from the source host to the destination host's associated storage area.
3. The Virtual Machine is registered with the new host.
4. After the migration is completed, the old version of the Virtual Machine is deleted from the source host.

Warm (Suspended/Paused) Migration:

- Transfer **VM** from one physical server to another ***without shutting down*** it .

1. State of **VM** saved in ***hard disk*** or ***RAM*** for short time.
2. Suspend **VM** on **Host 1**, copy across ***RAM*** and ***CPU registers***
3. Continue on **Host 2** (some seconds later)

Hot (Live) (Real Time) Migration

- The movement of a virtual machine from one physical host to another while being powered on.
- ***Requires shared memory between VMs***
- The goal of live migration is to find a ***quick*** and ***efficient*** way to transfer services between physical servers
- Two parameters are considered while performing live VM migration are:
  - **Down Time**
    - ❖ Time during which the service of the VM is not available.
  - **Migration Time**
    - ❖ Total amount of time required to transfer a virtual machine from source to destination node ***without affecting its availability.***

Hot (Live) (Real Time) Migration- Cont..

- Live migration is a technology used for:
  - ***load balancing,*** and ***optimization of VM deployment*** in data centers.
- In live migration process, the ***state of a VM*** to migrate is transferred.
  - Its memory contents and local file system.
- Live migration is classified into two steps :

I. Control is switched to the destination.

II. Data Transferring (memory/disk) to the destination

Hot (Live) (Real Time) Migration

- ✓ Live Memory Migration (only shared storage)/ Live Block Migration
  - It is used to minimize the ***downtime*** of **VM** migration between servers.

Why not through CPU Registers??

1. **VM** is powered on
2. Copy ***state of VM*** across **RAM** ***while VM continues to run on Host 1***
3. Mark "dirty" (changed) RAM pages and re-copy
4. Brief suspension ***VM*** for final copy (<< 1 sec)

Hot (Live) (Real Time) Migration- Cont..

- Measured metrics of live migration performance

1. **Preparation Time**
   - Resources are reserved on the destination which performed various operations.
2. **Down Time**
   - Time during which the ***VM*** on the source host is suspended (not available)
3. **Resume Time**
   - The instantiation of ***VM*** on the destination with the same state as suspended source.
4. **Pages Transferred**
   - Total amount of memory "dirty" pages transferred
5. **Total Migration Time**
   - The total time taken in completion of all these phases
6. **Application Degradation**
   - When ***VM*** migrated from one host to another, the application performance is degraded which is running on that VM.

Advantages of Live Migration

- Allows ***High Availability*** (because of minimum ***Down Time*** in Guest)
- It facilitates ***proactive maintenance*** in case of failure, because the potential problem can be resolved before the disruption of service occurs.
- Can be used for ***load balancing*** in which job is shared among computers in order ***to optimize the utilization of available CPU resources.***
  - Load balancing for long-lived jobs (***why not short lived***?)
- Migration takes place without any noticeable effect from the end user's point of view (a matter of ***milliseconds***).
- ***Energy efficiency***: rearrange loads to reduce A/C needs

Live Migration Challenges

GENERALLY!!!!

- Minimizing ***down time***
- Keeping ***total migration time down***.
- Avoid disrupting (Degrade Performance) active services.

Memory Transfer Approaches

- Two major approaches are used to data transferring
  - ***Pre-Copy,***
  - ***Post-Copy***

Pre-Copy Memory Transfer Approach

- **Two techniques, *Warm-Up* and *Stop-and-Copy***
- ***Warm-Up Technique***
  1. Transferring memory pages to the destination host over a number of iterations ***without stopping the execution of the VM in the source***.
  2. Then, VM is transferred to the destination
  3. ***Dirty Pages*** must sent again to the destination host.

The Dirty Pages,

- ❖ Memory pages that have been modified in the source host since last page transfer.
- ❖ If the rate of updating of pages is very high, migration time will rise to a very high value.

Pre-Copy Memory Transfer Approach

- ***Stop-and –Copy Technique***
  1. Transferring memory pages to the destination host over a number of iterations ***without stopping the execution of the VM in source***.
  2. The VM will suspend in source and the remaining ***dirty pages*** will be copied to the destination,
  3. Then, VM will be resumed in destination.

Pre-Copy Memory Transfer Approach

Advantage of Pre-Copy

- All updating are available at the destination host.
- It can be activated any time.

Disadvantage of Pre-Copy

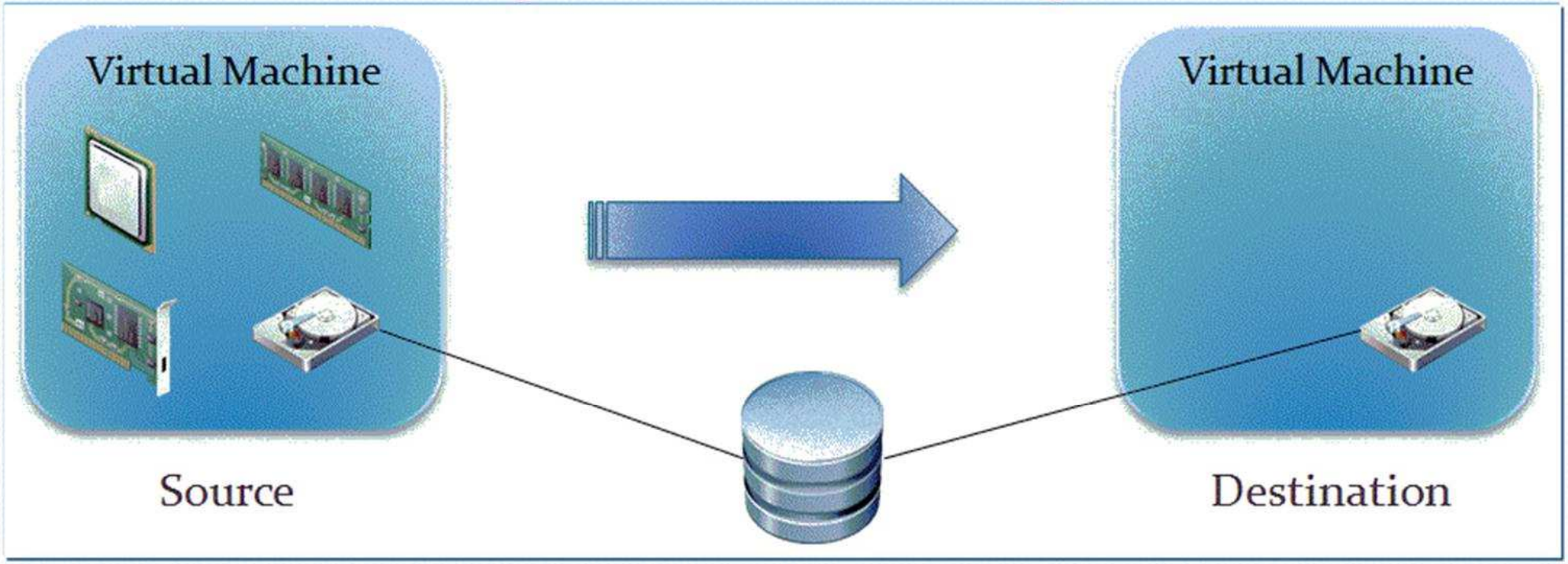
- For VM has some set of ***pages update very frequently***, they are poor candidates for pre-copy migration.

Post-Copy Memory Transfer Approach

1. Suspend the migrating of ***VM*** at the source side
2. Copy ***minimal subset of the execution state*** of the ***VM (CPU state, registers and, optionally non-pageable memory) state*** to the destination host
3. Resuming ***VM*** migration
4. ***Concurrently***, the source actively pushes the remaining memory pages of the VM to the target.

- At the target, if the VM tries to access a page that has not yet been transferred, it generates a ***page-fault*** (known as **network fault**), and ***trapped*** at the target and redirected to the source, which responds with the faulted page.
  - Too many ***network faults*** can degrade performance of applications running inside the VM.

Generally, Live Migration



- Disk is placed on a **shared volume** (100GBs-1TBs)
- CPU and Device State are copied (MBs)
- Memory is copied (GBs)
  - Large and it changes often → Iteratively copy

Live Storage Migration of Virtual Machine

- It Constitutes moving the ***virtual disks*** or ***configuration file*** of a running virtual machine to a new data store,
  - Without any interruption in the availability of the virtual machine's service (***How??!***)

Cold Migration Versus Live Migration

1) Live migrations needs to ***a shared storage*** for virtual machines in the server's pool, but cold migration does not.
2) In live migration for a virtual machine between two hosts, there should be ***certain CPU compatibility checks***, but in cold migration this checks do not apply
   - ***because of VM restart on the destination in live migration, while VM shutdown and switch on in cold migration***).

Regular/Cold Migration Comparison with Live Migration

Regular/Cold	Live
Host is powered off	Hosts are powered on
The virtual machines are not required to be on a shared storage.	Needs a shared storage for virtual machines in the server's pool
Not apply CPU compatibility checks	Apply certain CPU compatibility checks between hosts
Simple Process	Less Simple Process

**Live Migration Vendor Implementation

- **VMware Vmotion**: ***allows users*** to
  - A. *Automatically optimize* and *allocate* an entire pool of resources for *maximum hardware utilization*, *flexibility*, and *availability* , and
  - B. Perform hardware's maintenance without scheduled downtime
  - C. *In addition, migrating virtual machines away from failing or underperforming servers*
- **Citrix XenServer XenMotion.**
  - Provides ***IT administrator*** with the *facility to move a running VM* from one XenServer to another in the same pool *without interrupting the service* (hypothetically for zero-downtime server maintenance, which actually takes minutes), making it a highly available service.
  - A good feature to balance the workloads on the virtualized environment

Virtual Machine Migration

Main advantages

- Enabling virtual machine migration to ***balance load*** across the data centers.
- Enabling ***robust*** and ***highly responsive provisioning*** in data centers.
- Avoid ***hotspots***.

Challenges

- Currently, ***detecting workload hotspots and initiating a migration lacks*** the agility to respond to ***sudden workload changes***.
- Moreover, ***memory state should be transferred consistently*** and ***efficiently***, with integrated consideration of resources for applications and physical servers.

Relation ship

VM Migration & SLA

- **Virtual machines' migration** plays an important role in data centers by making it easy to adjust resource's priorities ***to match resource's demand conditions***
  - It is completely going in the direction of meeting ***SLAs***:
    - If a particular *VM* is consuming more than its fair share of resources at the expense of other ***VMs*** on the ***same host***, it will be eligible, for this machine, to either:
      - be moved to another underutilized host, or
      - assign more resources for it, in case that the host machine still has resources

VM Migration & On-Demand Computing

- Fulfill the requirements of ***on-demand computing*** resources
  - There should be an integration between ***virtualization's management tools*** (with its migrations and performance's monitoring capabilities), and ***SLA's management tools*** to ***achieve balance in resources*** by ***monitoring and migrating the workloads***, and accordingly, ***meeting the SLA***

Migration of Virtual Machines to Alternate Platforms

- There are different ways for achieving this, such as;
  - ***Depending on the source and target virtualization's platforms,*** and
  - ***Depending vendor's tools that manage this facility***
- **For example**
  - **VMware converter**
    - ✓ Handles migration between ESX hosts, VMware server, and VMware workstation
    - ✓ Can import from other virtualization platforms, such as Microsoft virtual server machines

Virtual Machine Consolidation

- By 2014, energy costs contribute **75%** by the data centers because of ***insufficient hardware usage*** and ***inefficient resource usage***
- Consequently, energy costs for ***operating*** and ***cooling*** the equipment of data centers have increased significantly up to a point where they are able to ***surpass the hardware acquisition costs***
- For ***each watt*** consumed by the ***computing resources*** an additional ***0.5-1 watt*** is required by the ***cooling systems*** and ***CO2 emission*** increases and affect ***Greenhouse***
- A study has revealed that ***energy consumption*** of ***Cloud*** causes ***more carbon emission*** to that of two countries, Netherlands and Argentina

Virtual Machine Consolidation-Cont..

- According to McKinsey report on ***"Revolutionizing Data Center Energy Efficiency"***:
  - A typical data center uses as much energy as ***25,000*** households uses.
  - Energy costs in a typical data center ***doubles*** every ***five years***
  - About ***50%*** of power in the data center is consumed by the servers/storage, and
  - Computer AC room consumes about ***34%*** of power
- The solution is ***Green Computing !!!!***

Virtual Machine Consolidation- Cont..

- ***VM consolidation*** concerns about reducing the number of active Physical Machine (PM) by migrating VMs into lesser number of active Physical Machines (PMs), so that PMs with no VM can be converted into ***sleep state to reduce energy consumption***.
  - Energy consumption of PM in ***sleep state*** is lower than the energy consumption of PM in ***active state***, therefore,
  - **E**nergy **C**onsumption of **C**loud **D**ata **C**enters (CDCs) minimizes.
- VM Consolidation includes:
  - VM Placement
  - VM Migration

VM Placement Types

Application QoS Based Approach

- ***VM Placement*** is the process of selecting the appropriate host for the given VM with considering maximizing resource utilization and QoS of this host.
- Then, next step is ***VM Migration***

Power Based Approach

- ***VM placement*** is the process of ***saving energy conservation*** by shutting down some severs.

VM Migration

- ***VM Migration*** is carried out after the ***initial VM placement*** in order to reduce the number of running physical machines by ***migration of few VMs*** and ***consolidate them into reduced number of PMs***
- Four steps are involved in the VM machine migration process
  1. Select the PM which is under loaded
  2. Select one or more VMs from under loaded server
  3. Select the appropriate destination PM where selected VMs can be placed, and
  4. Transfer/ migrate the VMs to destination PM
- Selecting the suitable host is one of the challenging task in the migration process, because wrong selection of host can ***increase number of migration***, ***resource wastage*** and ***energy consumption***

Consolidation

- VMs hosted in a PM share its underlying physical resources of that PM.
- Therefore, by increasing number of VMs sharing underlying resources of a single PM, waiting time for a VM prior receiving its required resources becomes higher.
- Thus, if more VMs are placed in a single PM, resource contention may arise which would lead towards poor QoS.
  - Consequently, possibility of Service Level Agreement (SLA) violation arises.

VM Consolidation- Cont....

Before VM Consolidation:
VMs are scattered in multiple PMs

After VM Consolidation:
VMs are now placed/migrated in lesser number of PMs than before

Both of SERVER 2 and SERVER 3 can now be switched off, as no VMs are using the servers

VM Consolidation

Types Of Consolidation

VM Consolidation is of two types:

- ✓ **Static consolidation, and**
- ✓ **Dynamic consolidation**

- In ***static consolidation***, a new VM is placed to PM for processing and no migration takes place here
- In ***dynamic consolidation***, the VMs are migrated from one PM to another whenever a necessity occurs

VM Consolidation – Cont..

Advantages

- Reduce the amount of hardware,
- Reduce the data center footprints,
- Indirectly reduce power consumption,
  - Grantee ***Green ICT***
- Cost reduction and
- Reduce staffing needs

Consolidation Challenge

- How accurately to characterize an application's resource requirements and resource usage over a time period

VM Consolidation- Cont....

- To balance the tradeoff between ***QoS*** and ***energy-efficiency***, it is extremely challenging to design ***VM Consolidation algorithm*** which satisfy the following aspects:
  - Maximize Resource Utilization,
  - Maximize Energy-efficiency by minimizing energy consumption
  - Maximize Cloud profit
- Designing efficient VM Consolidation algorithms is challenging as it needs to be:
  - ***Scalable***, to the ***millions*** of ***VMs*** and ***PMs***, as well as
  - ***Robust***, such that the performance does not degrade with the fluctuation in resource demand of VMs.