Server Virtualization and Private Cloud Management

CSYE 6225: Network Structure & Cloud Computing
Northeastern University

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M4: Overview

Topics include:

- Introduction to Virtualization and Cloud Computing.
- Hypervisor Architecture and Types (Type-1 vs Type-2).
- Virtual Machines (VMs) vs Containers.
- Private Cloud Management Platforms (Proxmox, VMware vSphere, Nutanix).
- Hands-On Lab: Working with Virtualization and Containerization Tools.

Private Cloud Computing

Server Virtualization Management

Objectives:

- Understand the Concept of Virtualization and Its Role in Cloud Computing.
- Differentiate Between Hypervisor Types.
- Compare Virtual Machines (VMs) and Containers.
- Understand Private Cloud Management Platforms.
- Engage in Hands-On Work with Containerization and Virtualization Software.

What is Server Virtualization?

Server virtualization is the abstraction of physical servers to run multiple isolated virtual machines (VMs) on the same hardware. This allows better utilization of resources, improved scalability, cost efficiency, and flexibility in both private and public cloud environments.

Benefits of Virtualization

Consolidation: Reduces the number of physical servers by consolidating multiple VMs on fewer machines.

Isolation: Each virtual machine operates in complete isolation with its own operating system and applications.

Improved Resource Utilization: Hypervisors optimize the allocation of CPU, memory, and network resources to VMs dynamically based on workload needs.

Agility and Flexibility: Easy to provision, manage, and decommission virtualized environments, supporting DevOps and CI/CD pipelines.

Cost Reduction: Reduces capital expenditure (CapEx) by decreasing the number of physical machines required and lowering operational expenditure (OpEx) by improving energy efficiency and space utilization.

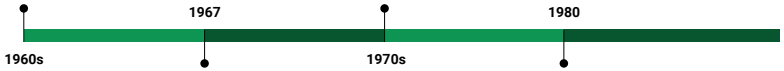
High Availability and Fault Tolerance: Virtual machines can easily be migrated between hosts, and redundant configurations ensure that workloads continue in case of hardware failures.

Disaster Recovery (DR): Virtualization simplifies disaster recovery with features such as snapshotting, backup, and easy replication across geographic regions.

Timeline: History of Server Virtualization

Concept of Time-Sharing: Introduced by IBM during the mainframe era

IBM VM/370 (1972): OS capable of running multiple instances of various operating systems simultaneously



IBM CP-40 and CP-67: early virtual machine operating systems that allowed multiple users to share computing resources. Basis for **VM/370** OS allows users to run multiple virtual machines on a single physical mainframe.

Shift Toward x86 Architecture and PC Computing

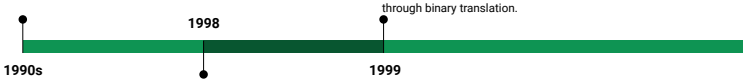
Early experiments with Software virtualization due to lack of Virtualization support of x86 instruction set.

Timeline: History of Server Virtualization

Commercialization and Software-based Virtualization: Introduced by IBM during the mainframe era

VMware Workstation: Multiple operating systems on a single personal computer.

VMware achieved x86 virtualization through binary translation.



VMware's Founding (1998): Brought server virtualization to the **x86 architecture.** Multiple OS on one physical device.

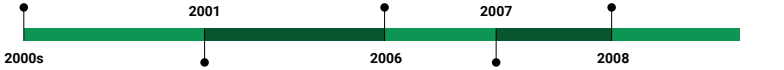
Timeline: History of Server Virtualization

Widespread Adoption and Cloud Computing.

Public Cloud Virtualization (AWS) Launch.

Microsoft Hyper-V: Built -in feature for MS Servers.

Became foundation for Microsoft-Based Data Centers

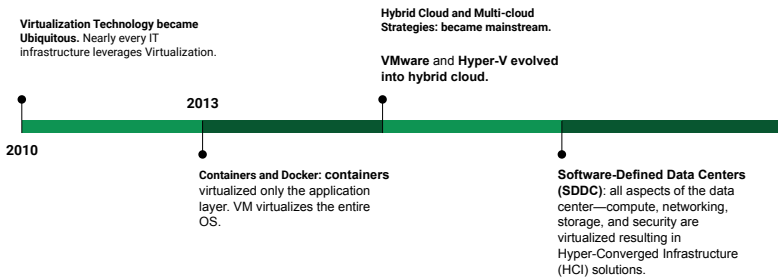


VMware ESX Server (2001): Type-1 Hypervisor.

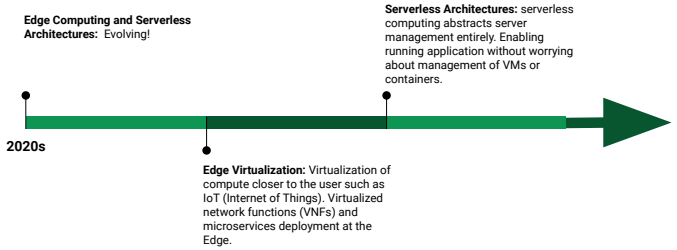
ESX became the foundation of Data centers.

Open Source VM solutions (Xen, KVM which became part of Linux).

Timeline: History of Server Virtualization



Timeline: History of Server Virtualization



Hypervisor Types

A Hypervisor is the **software** that creates and runs virtual machines.

Type-1 Hypervisor (**Bare Metal** Hypervisor):

- Runs directly on the physical hardware without a host operating system.
- Examples: VMware ESXi, Microsoft Hyper-V, and Xen.
- Used for enterprise-level virtualization as it provides better performance, efficiency, and direct access to hardware resources.

Example use case: Large data centers and cloud providers use Type-1 hypervisors to run large-scale virtualization environments with multiple VMs for customers or internal services.

Type-2 Hypervisor (**Hosted** Hypervisor):

- Runs on a host operating system and uses the system's resources to manage VMs.
- Examples: VMware Workstation, Oracle VirtualBox.
- Typically used for development, testing, or personal use on desktops or laptops.

Example use case: A software developer using VirtualBox on their laptop to run multiple operating systems for testing and development.

Virtualization Types

Desktop Virtualization: Running multiple desktop environments on a single machine. Useful for VDI (Virtual Desktop Infrastructure) solutions, which allow remote desktop access from anywhere.

Network Virtualization: Abstracts network resources such as switches, routers, and firewalls to allow easier configuration, scaling, and management. Software-Defined Networking (SDN) is a common implementation.

VMware Horizon® Red Hat Virtualization Parallels

Storage Virtualization: Pools storage resources to create a unified storage infrastructure, improving redundancy and scalability.

Application Virtualization: Allows applications to run in isolated containers without the need for installation on physical hardware. Docker is a popular example.

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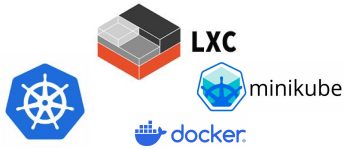
VM vs Containers

Virtual Machines (VMs): Full operating system instances running in isolation. They include virtualized hardware components such as CPU, memory, and network interfaces. VMs are resource-heavy and require more overhead but provide full isolation.

Containers: Lightweight, share the host OS kernel, and use less overhead compared to VMs. Containers are faster to start and stop and are ideal for microservices architectures. Docker (2008) and Kubernetes (K8 by Google 2014) are widely used container platforms.



Private Cloud Platforms

Private cloud platforms allow organizations to manage their **own cloud infrastructure**, providing the benefits of cloud computing within their own data centers.

These platforms give more **control**, customization, and **security** compared to public cloud offerings.

Proxmox (Open Source):

- Open-source virtualization platform that combines KVM hypervisor and LXC containers.
- Key features: High availability, backup and restore, live migration, and easy-to-use web interface.
- Example: A research lab setting up a private cloud for running multiple isolated virtual machines for data processing and storage using Proxmox to manage compute and storage resources.

Private Cloud Platforms

VMware vCenter/vSphere:

- Industry-standard for enterprise-grade virtualization, vSphere manages VMs, networking, and storage.
- vCenter provides centralized management, automation, and orchestration of VMs and other resources.
- Example: A corporation managing its virtualized infrastructure with VMware for data center operations, high availability, and disaster recovery.

Nutanix:

- Hyper-converged infrastructure platform that integrates compute, storage, and networking into a single software solution.
- Nutanix provides a highly scalable, flexible cloud-like experience for private cloud deployments.
- Example: A hospital managing patient data securely within its private cloud using Nutanix to ensure compliance with healthcare regulations and privacy laws.

Public Cloud Virtual Compute

AWS EC2 (Elastic Compute Cloud)

Provides resizable compute capacity in the cloud.

Autoscaling groups (ASG) allow automatic scaling of resources based on demand, ensuring cost efficiency and availability.

Security Groups act as virtual firewalls to control inbound and outbound traffic to instances.

Example: A media streaming company autoscaling its EC2 instances during peak viewing hours to handle increased demand.

Azure Virtual Machines

Similar to AWS EC2, providing scalable virtual machines with various configurations to meet different workloads.

Built-in features for high availability, disaster recovery, and scaling.

Example: A finance firm using Azure VMs for running sensitive financial calculations with enhanced security and compliance features.

Key AWS Virtual Compute Components

EC2 (Elastic Compute Cloud):

- Virtual servers that can be scaled up or down based on demand.
- Supports multiple OS, networking configurations, and custom images (

EBS (Elastic Block Store):

- Persistent block storage for EC2 instances.
- Allows snapshots and backups for data durability.

ELB (Elastic Load Balancing):

- Distributes incoming application traffic across multiple EC2 instances to ensure high availability and fault tolerance.

ASG (Auto Scaling Groups):

- Automatically adjusts the number of EC2 instances in response to traffic demand.
- Example: A web application scaling out during peak traffic hours and scaling in during off-peak hours to optimize costs.

Horizontal vs Vertical Scaling

Horizontal Scaling (Scaling out): Adding more instances (or nodes) to distribute the load.

Example: Increasing the number of EC2 instances to handle web traffic during Black Friday sales.

Vertical Scaling (Scaling up): Increasing the resources (CPU, memory) of a single instance.

Example: Upgrading an EC2 instance to a larger instance type (from t2.medium to m5.large) to handle more intensive processing.

Software-Defined Data Centers (SDDC)

Definition:

- A Software-Defined Data Center (SDDC) virtualizes all elements of the infrastructure—compute, networking, and storage—into software, which is then managed through a single control plane.
- SDDC enables automation, scalability, and flexibility within a private cloud environment.

Advanced Use Case:

- A financial institution implementing SDDC to ensure rapid deployment of networking and storage resources, scaling dynamically during trading peaks without the need for additional hardware.

Key Components:

- Software-Defined Networking (SDN): Network management that is decoupled from hardware using platforms such as VMware NSX or Cisco ACI.
- Software-Defined Storage (SDS): Storage is managed independently from the underlying hardware, using systems such as Nutanix Distributed Storage Fabric (DSF) or VMware vSAN.
- Hypervisor-agnostic Management: SDDC platforms such as Nutanix allow private cloud management across multiple hypervisors (AHV, ESXi, Hyper-V).

Multi-Cloud and Hybrid Cloud Integration

Definition:

- Private clouds often need to be integrated with public clouds (AWS, Azure) to leverage a hybrid cloud model, where workloads can be migrated between on-premises and cloud environments based on demand or cost considerations.

Advanced Use Case:

- Healthcare organizations utilizing hybrid cloud architecture to securely manage patient data on private clouds while performing computationally intensive tasks (e.g., AI/ML) in the public cloud.

Key Concepts:

- Hybrid Cloud Management Platforms: Tools such as VMware Cloud on AWS, Microsoft Azure Arc, or Google Anthos enable seamless integration between on-prem and public cloud environments.
- Workload Migration: Leveraging platforms such as Nutanix or VMware vCenter to migrate virtualized workloads between private and public clouds, without disruption.
- Disaster Recovery in Hybrid Cloud: Tools such as VMware Site Recovery allow organizations to use the public cloud as a failover target for their private cloud workloads.

Hyperconverged Infrastructure (HCI)

Definition:

- Hyperconverged infrastructure simplifies the management of a private cloud by integrating compute, storage, and networking into a single platform. Nutanix, VMware vSAN, and HPE SimpliVity are leading HCI solutions.

Advanced Use Case:

- A media company using Nutanix's hyperconverged infrastructure to support rapid editing and storage of high-definition video content, while benefiting from simplified management.

Key Benefits:

- Consolidation of Resources: Unified management of hardware reduces the complexity of managing separate compute, storage, and networking resources.
- Scaling: Horizontal scaling by adding nodes rather than upgrading individual hardware components.
- Reduced Latency: Since all components are tightly integrated, latency between storage and compute is minimized.

Infrastructure as Code (IaC) for Private Clouds

- Infrastructure as Code (IaC) enables the automated deployment and management of private cloud resources using configuration files. Popular tools include Terraform, and Ansible.

Red Hat Ansible Automation Platform

Terraform

Key Components:

- Automated Provisioning: Using IaC to define virtualized resources (VMs, networks, firewalls) programmatically.
- Consistency and Version Control: IaC ensures consistent deployments and enables tracking of infrastructure changes through version control.
- State Management: Tools like Terraform manage the desired state of infrastructure, automatically applying changes when new resources or configurations are needed.

Advances in Private Cloud Management and Virtualization

Advanced Security: Zero Trust Architecture (ZTA)

Definition

Zero Trust is a security model where no entity (internal or external) is trusted by default. It focuses on continuous verification, least-privilege access, and network segmentation.

Key Concepts

- **Microsegmentation:** With tools like VMware NSX or Nutanix Flow, microsegmentation is used to isolate workloads within the private cloud, ensuring each segment of the network is independently secured.
- **Identity and Access Management (IAM)**: Implement advanced IAM strategies to enforce strict access controls and multi-factor authentication across the private cloud.
- **Behavioral Analytics**: Using machine learning-based security platforms like Nutanix Prism Pro or VMware Carbon Black to detect and mitigate insider threats based on deviations in normal user behavior.

Container Orchestration in Private Clouds

Overview

VMs are common in private clouds. However, containerization (such as Docker, Kubernetes) is becoming more prevalent due to its lightweight and flexible nature.

Orchestrating containers in a private cloud requires integrating Kubernetes or similar platforms.

Key Components

- **Kubernetes on Private Cloud:** Use of platforms like VMware Tanzu, Rancher, or OpenShift to manage Kubernetes clusters.
- **Multi-Cluster Management:** Tools like Nutanix Karbon simplify the management of multiple Kubernetes clusters running in a private cloud.
- **Security and Isolation:** Containers can be isolated via Kubernetes namespaces or pod security policies, enhancing security in private cloud environments.

AI and Machine Learning Workloads in Private Clouds

Overview

Private clouds are increasingly being used to run AI/ML workloads due to the need for data privacy and high-performance computing.

Platforms like NVIDIA DGX, VMware Bitfusion, and Nutanix Era support AI/ML workloads in private cloud environments.

Key Components

- **GPU Virtualization:** Platforms like NVIDIA GRID allow for the sharing of GPU resources across multiple virtual machines, optimizing hardware utilization for AI/ML workloads.
- **Machine Learning Pipelines:** Kubeflow or MLflow can be used in Kubernetes clusters to manage end-to-end ML workflows (data ingestion, model training, deployment).
- **Data Management:** Ensure proper management of large datasets (e.g., using Nutanix Objects for object storage) and reduce storage costs for AI/ML models.

Private Cloud Cost Optimization Strategies

Overview

Managing costs in private clouds can be challenging, as resources are dedicated, and inefficient use can lead to significant overhead. Strategies for optimizing costs include resource optimization, rightsizing, and dynamic provisioning.

Key Concepts

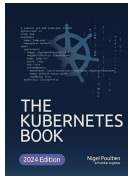
- **Capacity Planning and Rightsizing:** Continuously monitor usage patterns to adjust VM sizes and avoid over-provisioning resources. Tools such as VMware vRealize or Nutanix Prism Pro can provide insights into optimal resource allocation.
- **Dynamic Resource Allocation:** Automatically scale resources based on demand. Implementing Elastic Private Clouds that grow or shrink based on business needs ensures efficient resource utilization.
- **Chargeback and Showback:** Implement chargeback or showback models to allocate private cloud costs to business units, fostering accountability for resource consumption.

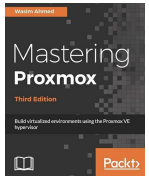
Hand-on

- Objective:
  - work on creation of containers and VMs using any of these technologies.
  - Understand private cloud management with hands-on experience.
- Containerization and VMs:
  - Docker: https://docs.docker.com/engine/install/
  - Minikube: https://minikube.sigs.k8s.io/docs/
  - LXC: https://linuxcontainers.org/lxc/introduction/
- Private Cloud Management:
  - Proxmox: https://www.proxmox.com/en/proxmox-virtual-environment/overview

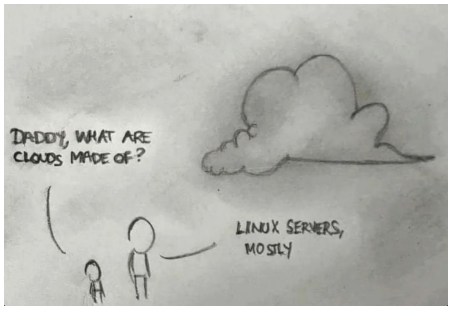
Recommended Readings

1. Mastering Proxmox - Third Edition: Build virtualized environments using the Proxmox VE hypervisor.
2. The Kubernetes Book.





Clouds



Module 4 Conclusion

- Overview of Virtualization and Cloud Computing.
- Understand the hypervisor and its types.
- Understand the difference between Virtual Machines (VMs) and Containers.
- Obtain hands-on experience with various virtualization technologies such as Minikube and Docker.
- Obtain hands-on experience in private cloud management with platforms like Proxmox.