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STUDY NOTES

CLOUD COMPUTING

Unit II — Virtualization in Cloud Computing

Topics Covered (09 Hours)

Introduction to Virtualization: Concept and Core Benefits
Understanding Hypervisors: Type-1 (Bare-metal) vs. Type-2 (Hosted)
Processor / CPU Virtualization (Binary Translation, Hardware-Assist)
Memory Virtualization (Page Tables, Shadow Page Tables)
Full Virtualization vs. Para-Virtualization Mechanisms
Device and I/O Virtualization Strategies
Virtual Clustering & Cloud Computing Implementations
Virtualization Architectures & Infrastructure Management
Containerization vs. Virtualization & Orchestration Ecosystems
Common Issues, Security Vulnerabilities, & Overhead
Network (SDN) and Storage Virtualization Architectures

Compiled in a simple, easy-to-understand, book style format
for students of Computer Science and Engineering

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2.1 Virtualization Fundamentals & Hypervisors

Virtualization is the fundamental technology that enables cloud computing. It refers to the abstraction of physical IT hardware resources (such as processors, memory, storage, and networking) using a software layer, allowing a single physical server to run multiple independent, isolated virtual environments (Virtual Machines or VMs) simultaneously.

Benefits of Virtualization

- **Hardware Consolidation:** Allows organizations to run multiple workloads on a single physical machine, increasing server utilization from typical averages of 10% to upwards of 80%, reducing capital expenses.
- **Isolation & Security:** If one virtual machine crashes or is infected with malware, it does not impact other VMs sharing the same physical hardware.
- **Disaster Recovery:** Virtual machines are stored as simple files (disk images). They can be easily backed up, snapshotted, cloned, and migrated to another physical host in real-time (Live Migration) without downtime.

Understanding Hypervisors

The software layer that creates, manages, and executes virtual machines is called a Hypervisor or Virtual Machine Monitor (VMM). The hypervisor abstracts physical hardware and presents a virtualized hardware interface to the guest operating systems. Hypervisors are classified into two main types:

- **Type-1 (Bare-Metal) Hypervisor:** Runs directly on the physical hardware of the host machine, beneath the operating systems. Guest operating systems run as processes on top of it. It offers high performance, efficiency, and scalability, making it the standard choice for enterprise data centers and public cloud infrastructures. (Examples: VMware ESXi, Microsoft Hyper-V, KVM, Xen).
- **Type-2 (Hosted) Hypervisor:** Runs as a software application on top of an existing host operating system (such as Windows, macOS, or Linux). It has higher latency because physical hardware access must pass through the host OS. Ideal for personal testing and development. (Examples: Oracle VirtualBox, VMware Workstation).

2.2 Types & Architectures of Virtualization

Virtualization can be applied to different levels of the computing stack:

Core Virtualization Categories

- **Processor (CPU) Virtualization:** Abstracts the physical CPU execution cycles. Guest operating systems believe they have exclusive access to a CPU. Since guest operating systems execute sensitive instructions, the hypervisor must intercept and translate these instructions. This is done via Binary Translation (software translation of CPU calls) or Hardware-Assisted Virtualization (Intel VT-x or AMD-V technology allowing direct safe execution of guest rings).
- **Memory Virtualization:** Abstracts physical RAM. The hypervisor maps the guest operating system's Virtual Memory addresses to the host's actual Physical RAM addresses, creating a translation layer using Shadow Page Tables or Nested Page Tables (NPT/EPT).
- **Device & I/O Virtualization:** Abstracts physical peripheral hardware (such as network cards, graphic cards, and USB controllers) so multiple VMs can share access.

Full Virtualization vs. Para-Virtualization

- **Full Virtualization:** The guest operating system is completely unaware that it is running in a virtualized environment. The hypervisor emulates all hardware devices. Guest operating systems require no modifications to run, but emulation introduces performance overhead.
- **Para-Virtualization:** The guest operating system is modified to be aware that it is running on a hypervisor. The guest OS bypasses hardware emulation by making direct API calls (hypercalls) to the hypervisor. This significantly reduces virtualization overhead and improves speed, but requires access to modified guest OS source code.

2.3 Containers, Clusters, & Network Virtualization

Modern cloud architectures combine hypervisor virtualization with containerization, virtual clusters, and software-defined networking.

Containerization vs. Virtualization

While virtual machines virtualize the underlying physical *hardware* (each VM contains its own full guest operating system), Containerization virtualizes the *operating system kernel* itself. Multiple containers run on top of a single host operating system, sharing the same OS kernel. Containers are lightweight (megabytes instead of gigabytes), start in seconds, and have minimal overhead. (Example: Docker). Orchestration engines (like Kubernetes) coordinate container deployment, scaling, and networking across clusters.

Network and Storage Virtualization

- **Network Virtualization:** Abstracts physical network hardware (switches, routers) using software. Software-Defined Networking (SDN) separates the control plane (routing intelligence) from the data plane (hardware forwarding), allowing administrators to dynamically configure virtual subnets, firewalls, and load balancers via code.
- **Storage Virtualization:** Combines multiple physical storage devices into a single, logical storage pool managed by software. This abstracts physical disk boundaries, allowing dynamically scalable logical volumes.

> **NOTE**
> Issues with Virtualization include Performance Overhead (the translation layer consumes CPU cycles), Security Risks (Hypervisor Escape, where an attacker breaks out of a VM to compromise the host OS), and Resource Contention (Noisy Neighbor effect, where one VM consumes excessive CPU/disk bandwidth, slowing down other VMs).

Unit Summary

This unit explored virtualization technologies in cloud computing.

- Virtualization abstracts physical hardware, enabling multiple VMs to run on a single host.
- Hypervisors are Type-1 (Bare-Metal, running directly on hardware) or Type-2 (Hosted, running on an OS).
- CPU and Memory virtualization map guest resource calls to physical resources safely.
- Full virtualization requires no guest OS changes, while Para-virtualization uses hypercalls to improve speed.
- Containers share the host kernel, offering lighter packaging than hardware VMs.
- Network (SDN) and Storage virtualization abstract network structures and disk boundaries via software.