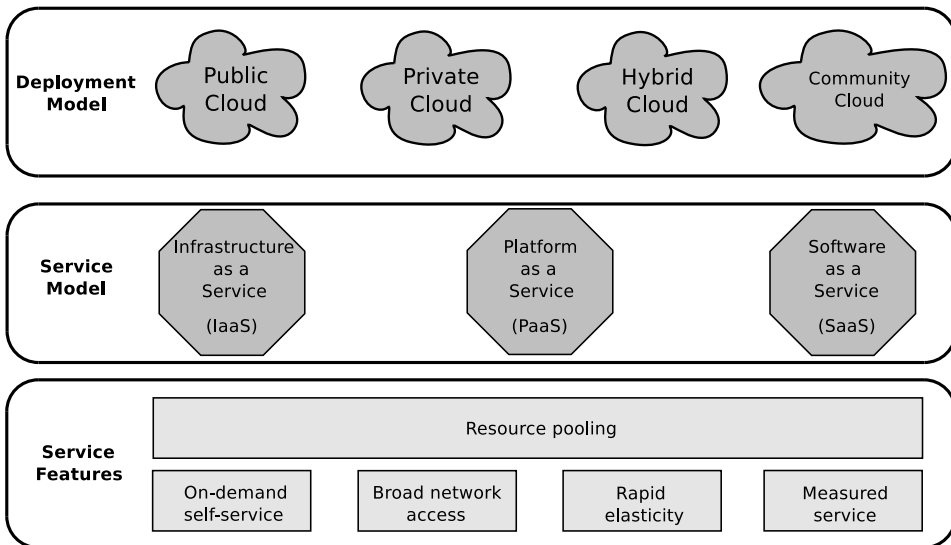


NIST definition of Cloud Computing



Legacy IT

- Data center technology for the operation of applications and storage of data
- Servers for the operation of applications for a business
- Networking technologies for the physical connection of the servers
- Storage capabilities for the storage of large amounts of data

Not part of legacy IT! But helpful for the operation of workloads! (More in slide 32 to 40)

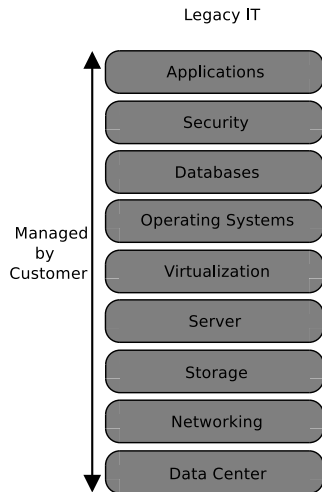


Figure: Layers of operation in legacy IT

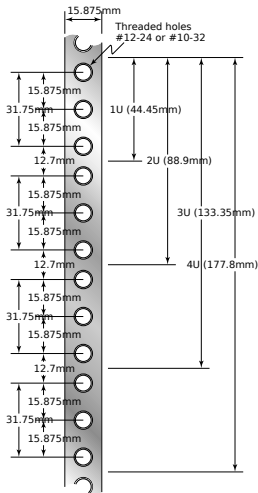
Source: Adobe Stock



- Enclosure in cabinets (server racks).
- Air conditioning and centralized cooling.
- Electrical power with uninterruptible power supply (UPS).
- Fire protection with sprinklers or gas (Halon gas).
- Security though personal, access control and other features.

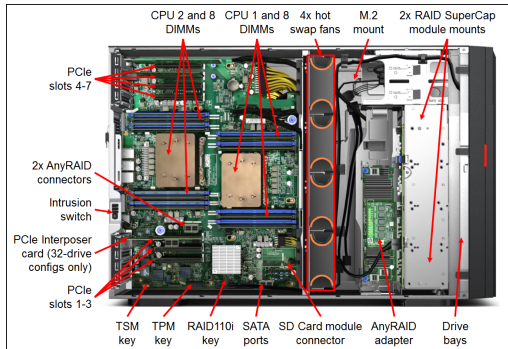
Data centers are designed to meet high standards on the availability of the services!

Source: Wikipedia



- Servers are mounted on rails for easy access.
- A rack consists of networking devices (switches, routers), servers and storage (SAN).
- All components are setup together for simpler operation and maintenance.
- The unit of measurements for components is 1 Unit (44,45mm)
- A standard cabinet has 42 Units for the installation of components

Source: Lenovo Press



Server grade hardware

- Server grade hardware is designed for 24/7 operation.
- Mainboards usually contain > 2 CPUs per board and have larger caches.
- RAM sizes are usually very large in size (> 1 TB).
- Network interface cards (NIC) are usually equipped with multiple ports, different port specifications and have high bandwidths (> 10 GBit/s!).
- Storage capabilities are usually designed for fault tolerance and performance (e.g. RAID 6).
- Power supplies and generally the hardware designed redundantly (e.g. Battery backed units).

Bare metal servers

Bare metal server

- One standalone physical server
- One dedicated OS installed on the server
- Exclusive access to all hardware resources (CPU, RAM, storage)
- Suitable for high performance, because of direct access to hardware capabilities

Drawbacks

- Management and maintenance is complex
- Management and maintenance is very expensive
- High cost for operation of servers
- Dedicated usage of server leads to many idle times

Solution!

Operation of applications/services in virtual machines (VM)!

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Networking in data centers – very brief overview ;-)

- **Addressing**

- MAC-addresses for physical addressing of devices and appliances
- 48 bit for the addressing of devices (e.g. 38:f3:ab:d2:34:67)
- IP-addresses for logical addressing servers and appliances
- With IPv4 a maximum of 4.294.967.295 devices can be addressed
- With IPv6 a maximum of 3.4×10^{38} devices can be addressed

- **Private LAN**

- Private network area for local machines (e.g. data center)
- Switched networks separate collision domains
- Messages internally are not routed (Broadcast Domain)

- **IP Networks and their limitations**

- Physical networks cannot be subdivided properly and therefore extend the broadcast domain!
- IP-addresses are limited and routing is not necessary in LAN!
- Administration of physical and logical networks is very complex and rigid!
- Shared transmission medium for different traffic is not ideal!

Collision and Broadcast domain

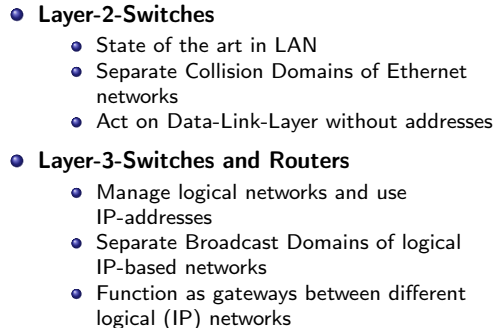
Collision domain:

A collision domain is an area of a network in which collisions between data packets can occur. In Ethernet networks based on CSMA/CD (Carrier Sense Multiple Access with Collision Detection), collisions can occur when two devices attempt to send data via the same transmission medium at the same time.

Broadcast domain:

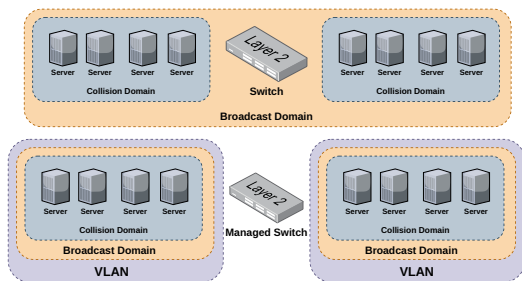
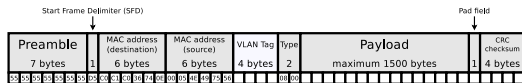
A broadcast domain is an area of a network in which a broadcast packet is sent and received by all devices in that area. Broadcast packets are messages that are sent to all devices in the network without having a specific destination address.

Collision and Broadcast Domains



The subdivision in this form is very inflexible! Since servers inside a data center are inside of (very large) LANs we need a method to subdivide the LAN (and broadcast domain) on the physical Data-Link-Layer without the use of IP-addresses!

VLAN Benefits



- **Segmentation:** VLANs allow a physical network to be divided into multiple logical networks.
- **Security:** By splitting traffic across different VLANs, administrators can increase security by restricting access to sensitive data or resources.
- **Security:** By splitting traffic across different VLANs, administrators can increase security by restricting access to sensitive data or resources.
- **Reduce broadcast domains:** In a flat network, broadcast messages sent from one device can reach all devices on the network and put a strain on network resources. By segmenting the network into VLANs, broadcast domains can be reduced, resulting in more efficient use of network bandwidth.
- **Flexibility:** VLANs allow administrators to create logical groups of devices that can communicate with each other regardless of their physical location on the network.
- **Performance optimization:** By segmenting the network into VLANs, administrators can optimize network performance by better controlling and prioritizing traffic within the network.

Limitations

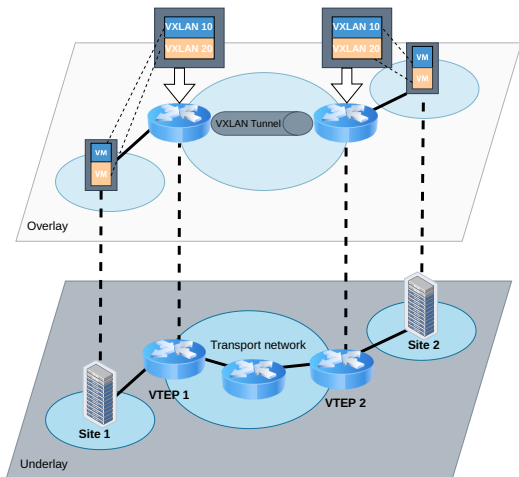
VLAN can only address 4094 distinct physical networks. This may be enough for hardware servers but not enough for VMs!

Overlay networks

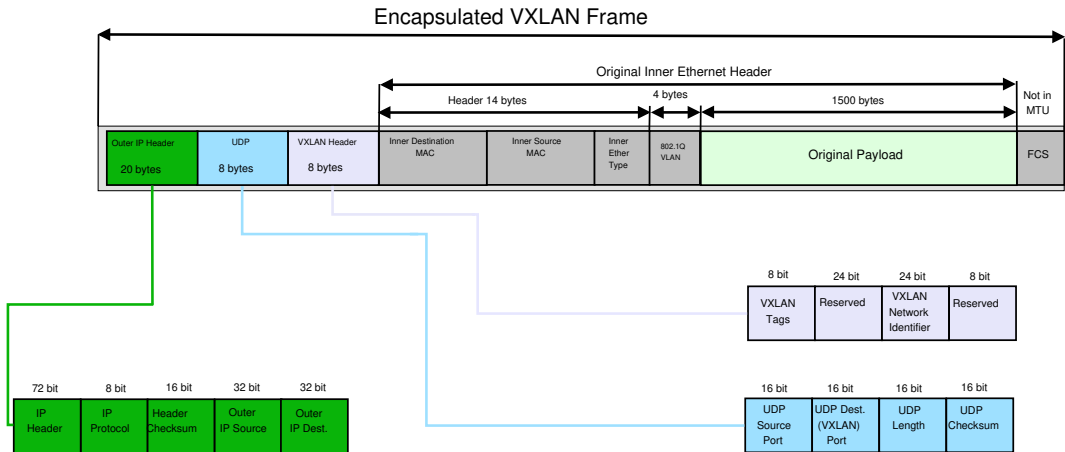
- Separation of physical network (so called underlay network) from logical networks (so called overlay networks).
- Network traffic can be transmitted via a physical transport network and routed through different intermediate stations.
- The logical traffic (e.g. from VMs) is tunneled and therefore the transport is transparent to the endpoints
- Geographically distributed sites can be connected via a tunnel and form large logical LAN

- Protocol for the overlay connection of physical LAN over UDP.
- VXLANs can be addressed using 24 bit VXLAN Network Identifier (VNI).
- The VNI can be used to establish a VXLAN Tunnel Endpoint (VTEP) for the connection of different physical sites.
- VXLAN uses UDP as a transport protocol and tunnels ethernet frames in UDP segments (see slide 23).

VXLAN is an extension of VLAN. In contrast to VLAN VXLAN can address up to 16 million distinct isolated VXLAN. This is enough for VMs!



VXLAN Header



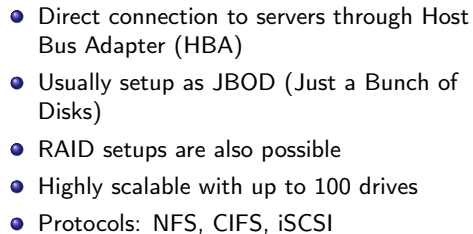
Benefits of VXLAN compared to VLAN

- **Scalability:** VLANs have a limited number of IDs (4096), which can quickly be exhausted in large data centers with many virtual machines (VMs) or containers. VXLAN uses a 24-bit VXLAN segment ID, theoretically allowing for over 16 million isolated networks. This makes VXLAN better suited to meet the demands of large and constantly changing data center environments.
- **Multi-Tenancy Support:** VXLAN provides better support for multi-tenancy scenarios where different customers or applications require isolated networks. With VXLAN, multiple virtual networks can run over the same physical network segment, improving resource utilization and enhancing security and isolation.
- **Flexibility and Mobility:** VXLAN enables the virtualization of Layer-2 networks across Layer-3 networks. This allows VMs or containers to be moved between different physical locations without needing to change their IP addresses. This enables applications and workloads to scale or move flexibly and without interruption.
- **Integration with SDN and Cloud Technologies:** VXLAN is often tightly integrated with Software-Defined Networking (SDN) and cloud technologies, facilitating the automation, orchestration, and management of networks in dynamic and virtualized environments.

VXLAN in data centers

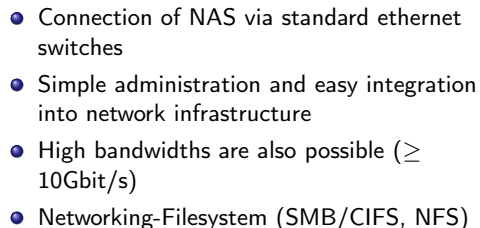
VXLAN (Virtual Extensible LAN) offers several advantages over traditional VLANs (Virtual Local Area Networks), especially in data center environments. Overall, VXLAN provides a powerful solution for scaling, isolating, and providing flexibility to networks in modern data center environments compared to traditional VLANs.

Direct Attached Storage



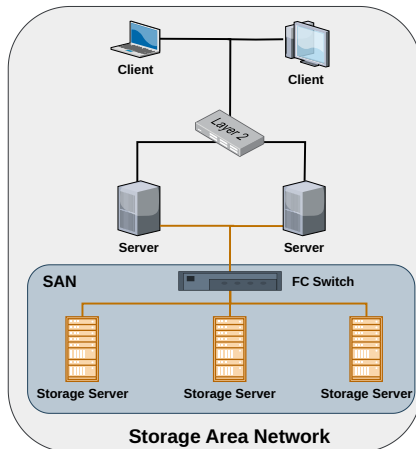
- + Low hardware costs
- + Low costs
- + No additional protocol stack
- + Conceptually very performant
- Exclusive to one host
- Limited scalability in capacity
- Limited distance from host to storage

Network Attached Storage



- + Simple connection to existing network
- + With dedicated 10 Gbit/s LAN in real operation true alternative to FC-SAN
- + Easy concurrent access for multiple clients thanks to networking file system
- Underlying TCP/IP protocol not optimized for storage traffic
- Additional high load on the existing LAN

Storage Area Networks

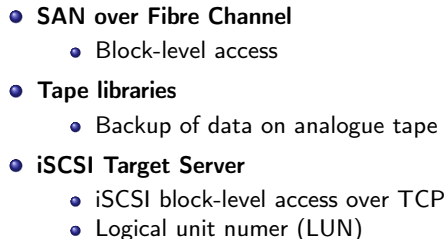


- Attached via Fibre-Channel-HBA and FC-Switch
- Setup of storage in own network infrastructure
- Very high bandwidths over Fibre-Channel
- Centralized administration for storage network
- Highly scalable with up to 100 drives

Strengths and weaknesses

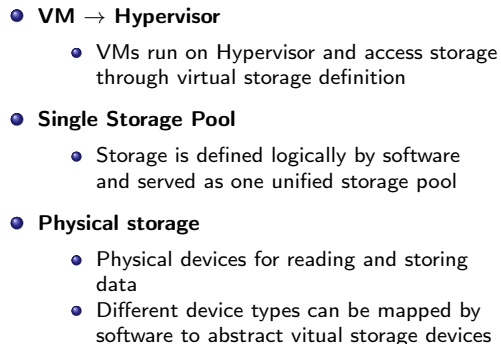
- + Direct accessibility of all components to each other
- + High transfer rates
- + Cost savings through storage consolidation
- + Easier administration through centralization
- Additional dedicated infrastructure level for storage
- Problems with interoperability
- Expensive hardware components
- Complicated configuration

Storage Area Networks



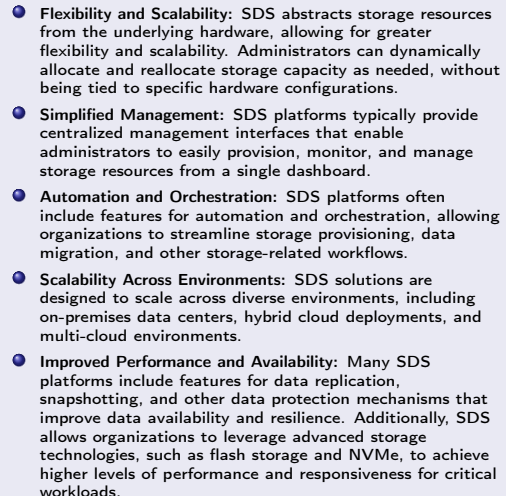
The most significant advantage of a storage area network is the direct accessibility of all components integrated into the SAN to each other. Cluster applications are easy to implement in the storage area network; every server can access every block device (LUN), and concurrent write access is even possible with the right software.

Software defined Storage



The most significant advantage of a software defined storage is the abstraction of physical storage by the abstraction layer. This improves the management and flexible attachment of physical storage to virtual machines!

Benefits



Virtualization – Fundamentals and general idea

- By using virtualization, the resources of a computer system can be split and used by multiple independent operating system instances
- Several fundamentally different approaches and technologies exist to implement virtualization
- Each virtual machine (VM). . .
 - behaves like any other computer, with own components
 - runs inside an isolated environment on a physical machine
- Inside a VM, an operating system with applications can be installed, exactly like on a physical computer
- The applications do not notice that they are located inside a VM
- Requests from the operating system instances are transparently intercepted by the virtualization software and converted for the existing physical or emulated hardware
- The VM itself does not become aware of the virtualization layer between itself and the physical hardware

Virtualization concepts

History of Virtualization

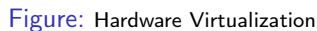
- 1970/71: IBM introduced the Virtual Machine Facility/370 (VM/370)
- On this platform, multi-user operation is implemented by using multiple single-user mode instances, which are executed in virtual machines
- Each VM is a complete duplicate of the underlying physical hardware

Creasy RJ. The origin of the VM/370 time-sharing system. IBM Journal of Research and Development (1981), No. 5, P.483–490,

Different virtualization concepts exist:

- Partitioning
- Hardware emulation
- Application virtualization
- **Full virtualization (Virtual Machine Monitor = Type-2 Hypervisor)**
- **Paravirtualization (Type-1 Hypervisor)**
- Hardware virtualization
- **Operating system-level virtualization / Container / Jails**
- Storage virtualization (SAN/SDS)
- Network virtualization (VLAN/VXLAN)

Hardware Virtualization



- Hardware resources (CPU, RAM, Networking, etc.) are shared between different OS instances
- The Virtual Machine Monitor translates the requests between the Hardware and the OS
- The OS instances are isolated from each other
- The OS is running on virtualized hardware resources which are mapped to physical resources
- Different types of virtualization exist depending on the level of abstraction

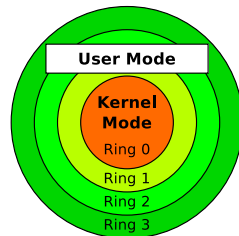
- x86-compatible CPUs implement 4 privilege levels
 - Objective: Improve stability and security
 - Each process is assigned to a ring permanently

- Implementation: The register CPL (Current Privilege Level) stores the current privilege level
- Source: <http://css.csail.mit.edu/6.858/2012/readings/i386.pdf>

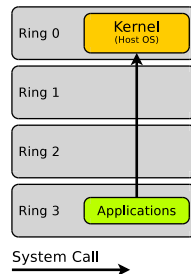
- In ring 0 (= **kernel mode**) runs the kernel
 - Processes here have full hardware access
- In ring 3 (= **user mode**) run the applications
 - Processes are in Protected Mode

Unmodified modern operating systems only use 2 privilege levels (rings) \Rightarrow Rings 0 and 3

- If a user-mode process must carry out a higher privileged task (e.g. access hardware), it can tell this the kernel via a **system call**
 - The user-mode process generates an exception, which is intercepted in ring 0 and handled there

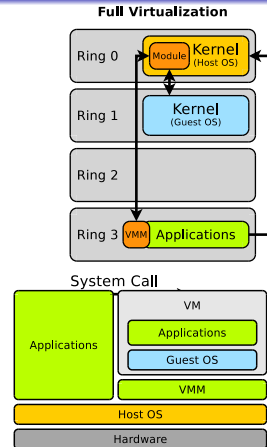
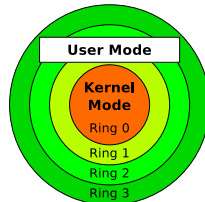


Without Virtualization



Full Virtualization (2/3)

- Full virtualization makes use of the fact, that x86 systems typically use only 2 privilege levels
 - The VMM runs together with the applications in ring 3
 - VMs are in the less privileged ring 1
- The VMM contains for every exception a treatment, which catches, interprets and executes privileged operations of guest operating systems
- VMs can only access the hardware via the VMM
 - This ensures controlled access to shared system resources



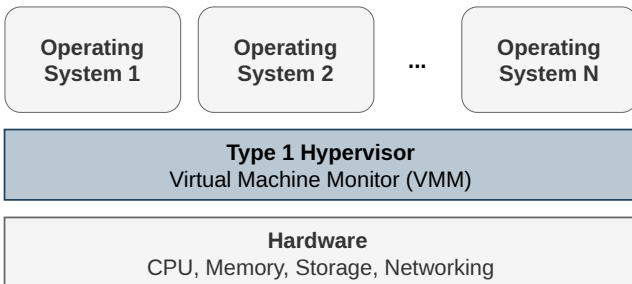
Full Virtualization (3/3)

- Advantages:
 - Few modifications in the host and guest operating systems are required
 - Access to the main resources is just forwarded (passed through)
⇒ guest operating systems run almost with native performance
 - Each guest operating system has its own kernel
⇒ high degree of flexibility
- Drawbacks:
 - Switching from one ring to another one requires a process/context switch
⇒ each process/context switch consumes CPU time
 - If an application in the guest operating system requests the execution of a privileged instruction, the VMM provides a replacement function, which commands the execution via the kernel API of the host operating system
⇒ speed losses

Full Virtualization Examples: Some virtualization solutions, which implement the VMM concept

- VirtualBox
- VMware Server, VMware Workstation and VMware Fusion
- Parallels Desktop and Parallels Workstation

Type-1 Virtualization – Hypervisor



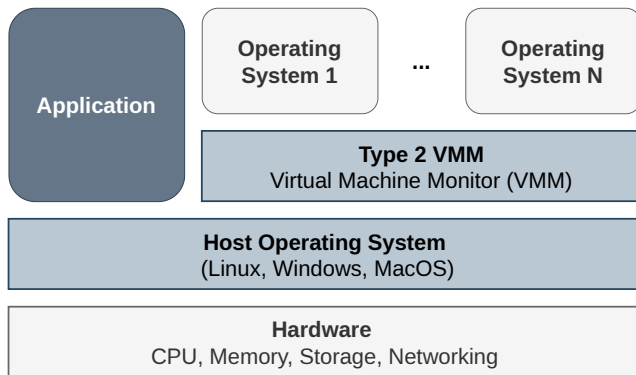
Type 1 Virtualization

- The Hypervisor runs between the hardware and the operating system(s)
- The Hypervisor acts as a (specialized form of) operating system
- The VMs run as processes on the Hypervisor
- The VMs are unaware of this fact
- The VM need drivers for the interaction with the Hypervisor
- Also called bare-metal Hypervisor

Examples

VMWare vSphere, Microsoft Hyper-V, Kernelbased Virtual Machine (KVM)

Type-2 Virtualization – Virtual Machine Monitor



Type 2 Virtualization

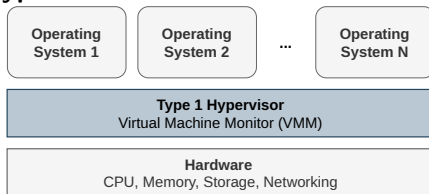
- The VMM runs on an operating system
- The VMM is another process inside of the operating system and runs among other applications
- The VMM has lower privilege than the host operating system

Examples

Oracle Virtualbox, VMWare WorkStation, MacOS Parallels

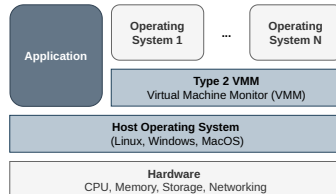
Comparison of Virtualization types

Type-1 Virtualization



- Approx. 5% performance overhead compared to physical (bare metal) operation
- Resources are managed directly by Hypervisor
- More complex administration skills necessary
- More isolation of virtual environments

Type-2 Virtualization



- Approx. 10% performance overhead compared to physical (bare metal) operation
- Runs inside of host OS and therefore just indirect management of resources
- Easier to administer inside of host OS
- Less isolation than virtual environments

Cloud providers

Because of the performance benefits CSP use Type-1 Hypervisors!

Operating System Virtualization

Operating System Virtualization

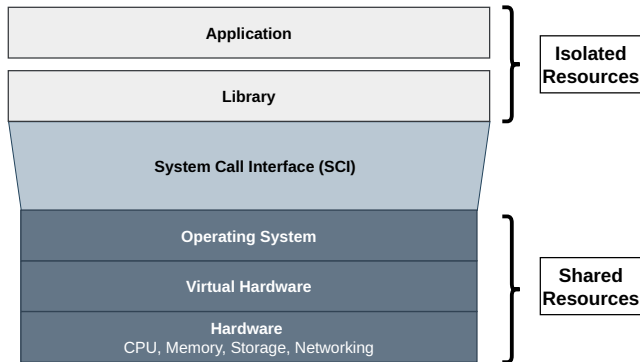
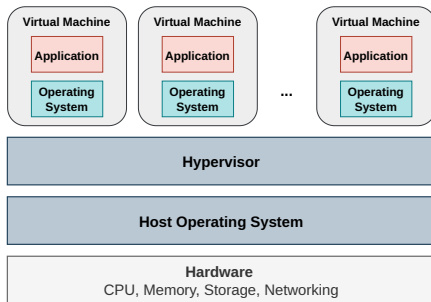


Figure: OS Virtualization

Operating System Virtualization

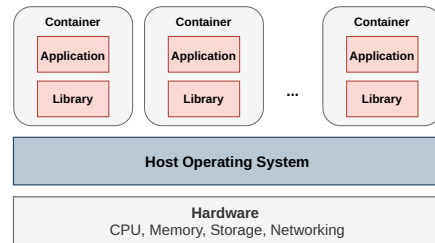
- Operating System virtualization does not use a Hypervisor between the hardware and the virtual environment
- The virtual environments run on a host OS and share the OS resources and underlying hardware resources
- The System Call Interface is managing the requests of the virtual environments and handles the hardware resources
- The virtual environments are called containers

Hardware vs Operating System Virtualization



HW virtualization

- Operation of full OS inside of VM → **heavyweight**
- More isolation of applications through Hypervisor → **more secure**
- Longer statup times of VMs → **slower**



OS virtualization

- Container only packages libraries and applications → **lightweight**
- Less isolation of applications because of missing Hypervisor → **less secure**
- Lower statup times of VMs → **faster**

Docker

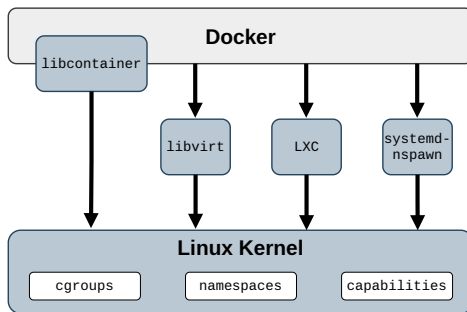


Docker is a popular platform used for containerization, allowing developers to package applications and their dependencies into isolated containers.

Characteristics

- **Containerization:** Docker enables the creation and management of containers, which are lightweight, portable, and self-sufficient environments that encapsulate an application and its dependencies.
- **Portability:** Docker containers can run on any machine that supports Docker, regardless of the underlying operating system or infrastructure. This makes it easier to develop, deploy, and scale applications consistently across different environments.
- **Isolation:** Containers provide process and resource isolation, ensuring that applications running within them do not interfere with each other.
- **Versioning and image-based deployment:** Docker uses a layered filesystem and Docker images to capture the application's environment and dependencies.

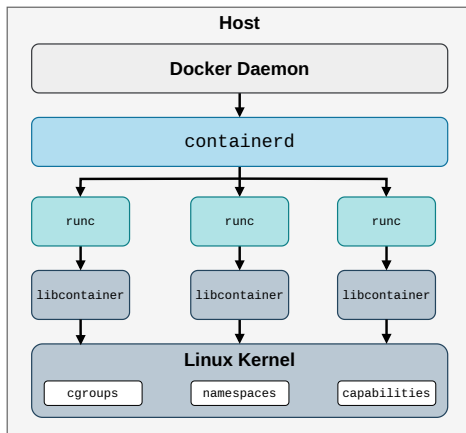
Docker Architecture till version 0.9



Docker Architecture v.0.9

- **libcontainer** as a native Go abstraction layer implementation for creating containers
- **libvirt** as an API for the management of containers (also used by other Hypervisors e.g. KVM)
- **LXC** (Linux Containers) as a native Container execution platform
- **systemd-nspawn** to run a command in a light-weight namespace container with virtual file system and IPC
- **Linux Kernel functionalities:**
 - **cgroups**
 - **namespaces**
 - **capabilities**
 - other libraries for networking, etc.

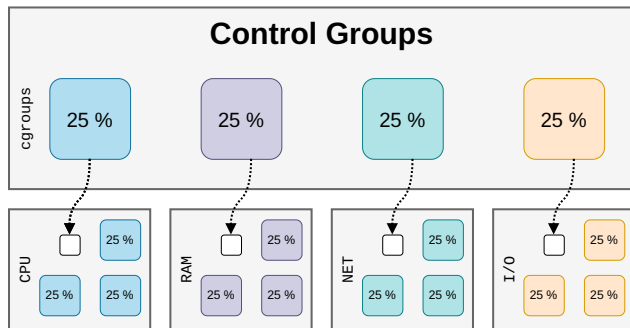
Docker Architecture



Docker Architecture now

- Replaced LXC with a new high-level container interface called **containerd**
- **containerd** pulls images, manages networks and storage and uses **runc** to execute containers
- Replaced **libvirt** with a new unified low-level runtime called **runC**
- **runC** uses **libcontainer** for the interaction with Linux Kernel components **runC** offers...
 - native support for Linux Kernel security features
 - full support for the complete Linux Kernel namespace

Control Groups



Limits and isolates the resource usage (CPU, memory, disk I/O, etc.) of processes.

Control Groups

- **Resource Limiting:** Sets quota limits for resources like CPU, RAM size, I/O bandwidth limits.
- **Prioritization:** Management of allocation and assignment of resources to processes.
- **Accounting:** Measurement of a group's resource usage and logging of metrics.
- **Control:** Controlling groups and checkpointing and restarting the processes.
- Kernel provides access to multiple controllers for accessing the control groups

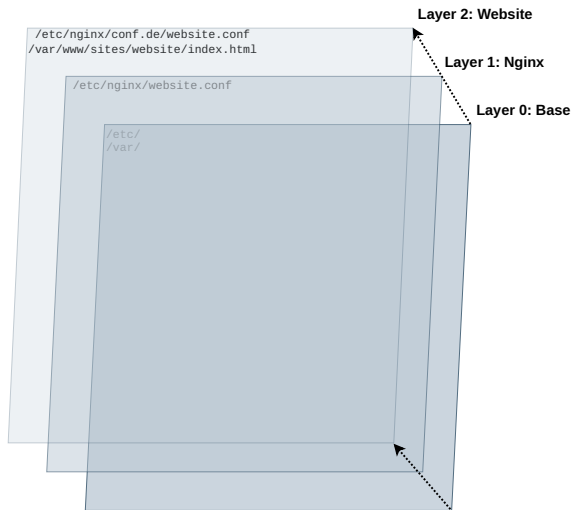
Namespaces

- Linux Namespaces partition the Kernel resources for processes and limits the visibility to processes.
- Namespaces refer to distinct resources and processes can be assigned to one or multiple namespaces
- Examples for namespaces are:
 - **Process ID** (pid) – provides processes with an independent set of pids
 - pids are nested inside namespaces for processes
 - Terminating the first process in a tree will terminate all subsequent processes
 - **Network** (net) – virtualizes the network stack and upon creation only the loopback interface is present
 - Each namespace has a private set of IP addresses, own routing table, socket listing and other network-related resources.
 - **Interprocess communication** (ipc) – isolates the processes' ipc namespaces
 - Produces distinct regions for ipc functions and two processes can use the same identifier across different namespaces

Capabilities

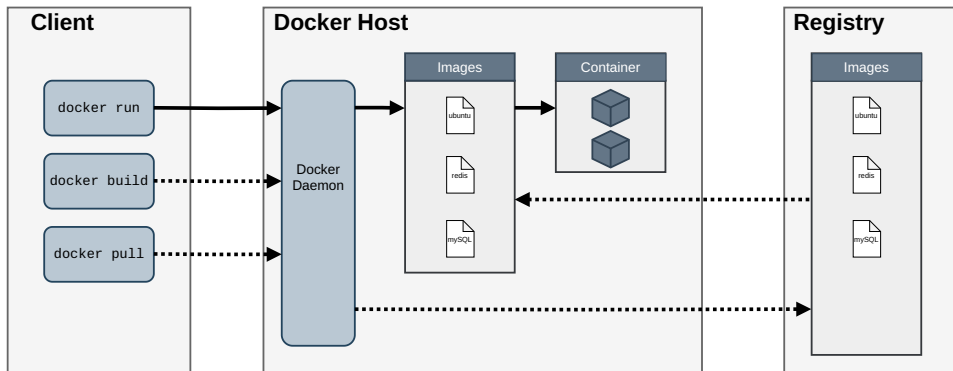
- Linux has two basic controls for privileges:
 - **Superuser** (root) – User ID (uid) of 0
 - **Normal-user** – non 0 uid signals non-root user
- Linux capabilities are used to assign privileges to processes and threads
- Capabilities make it possible to restrict privileges without having full access to the system
- Containers start with a set of capabilities and the Linux Kernel can restrict the access

Union Filesystem



- UnionFS is a layered file system and allows for „branching“
- Branches can be transparently overlaid on top of read-only branches
- This way a coherent file system can be presented and used
- Branches are prioritized on mounting and name conflicts can be resolved
- This mechanism is also used in Live CDs

Docker Image Registry

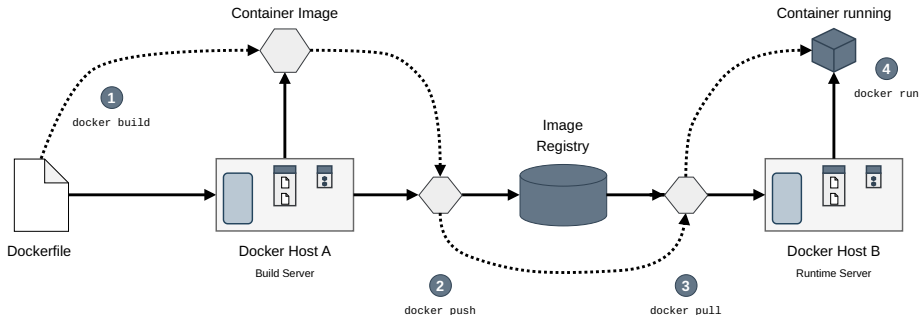


- Open source implementation of a repository for storing and distributing container images and other content
- Two types of registries exist:
 - **Private:** Managed by an institution
 - **Public:** Accessible by public for up- and download
- Natively integrated into the Docker platform

Docker commands

- `docker run` – run containers
- `docker build` – build image and make runnable container
- `docker pull` – pull an image from the registry

Docker Image Workflow



1 Building Docker image from Dockerfile on Host A (Build Server)

2 Pushing image to registry after successful build

3 Docker Host B (Runtime Server) pulls image from registry

4 Docker Host B runs container

This demonstrates the workflow of a container platform. This workflow automates the build process of container images and sets the basis for DevOps Software engineering processes.

Kubernetes



kubernetes

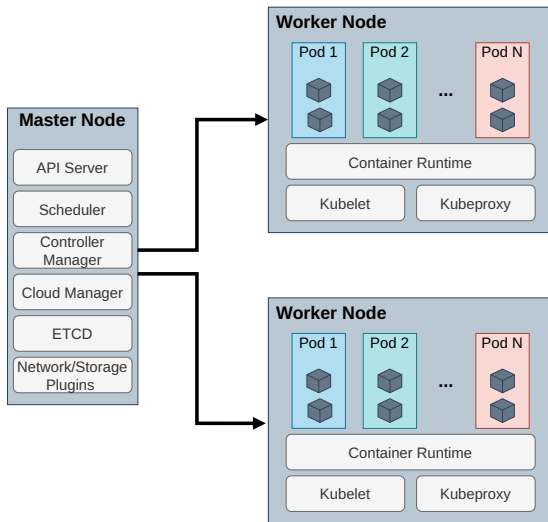
Kubernetes (also called K8S) is an open-source container orchestration platform designed to automate the deployment, scaling, and management of containerized applications. It provides a highly flexible and resilient infrastructure for deploying and managing distributed systems across clusters of machines.

Characteristics

- **Container Orchestration:** automates the deployment, scaling, and management of containerized applications, handling tasks like scheduling, load balancing, and resource allocation across clusters of machines.
- **Scalability and Flexibility:** allows for horizontal scaling of applications, dynamically allocating resources based on demand, and supporting both stateless and stateful workloads.
- **Self-Healing:** continuously monitors the health of applications and automatically restarts or reschedules containers that fail, ensuring high availability and reliability.
- **Service Discovery and Load Balancing:** It provides built-in mechanisms for service discovery and load balancing, allowing containers to communicate with each other and distributing traffic across multiple instances of an application.
- **Declarative Configuration:** Kubernetes uses a declarative approach to configuration, allowing users to specify the desired state of their applications and infrastructure using YAML or JSON files, which Kubernetes then reconciles with the actual state.
- **Portability and Vendor-agnosticism:** is platform-agnostic and can run on any infrastructure, including on-premises data centers, public clouds, and hybrid environments.

Kubernetes Architecture

(1/3)

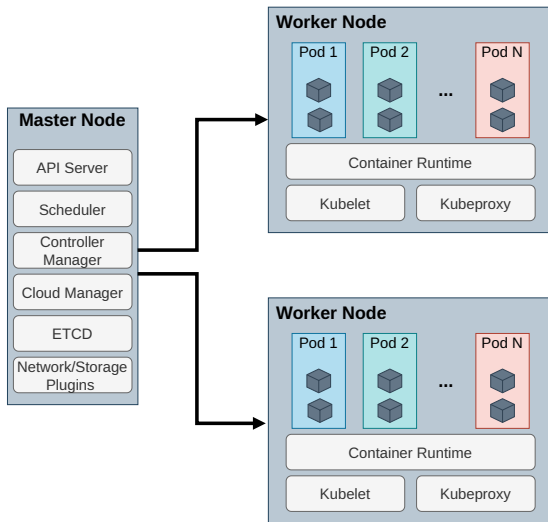


Master Node

- **API Server:** The Kubernetes API server is the central management component that exposes the Kubernetes API, which clients use to interact with the cluster. It serves as the front-end for the Kubernetes control plane.
- **Scheduler:** The Kubernetes scheduler is responsible for placing newly created pods (groups of containers) onto nodes in the cluster.
- **(Kube) Controller Manager:** The controller manager is a collection of controller processes responsible for managing various aspects of the cluster's state. These controllers include the node controller, replication controller, endpoint controller, and service account controller, among others.

Kubernetes Architecture

(2/3)

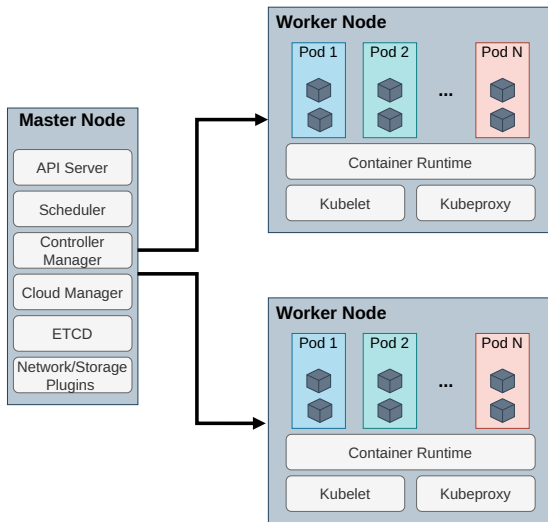


Master Node

- **Cloud Manager (optional):** This component interacts with the underlying cloud infrastructure provider to manage resources such as virtual machines, load balancers, and storage volumes.
- **ETCD:** etcd is a distributed key-value store used by Kubernetes to store cluster configuration and state information. It acts as the cluster's database, storing information such as configuration settings, metadata, and the current state of the cluster.
- **Network/Storage Plugins:** Plugins for the use of network and storage functionalities inside of pods.

Kubernetes Architecture

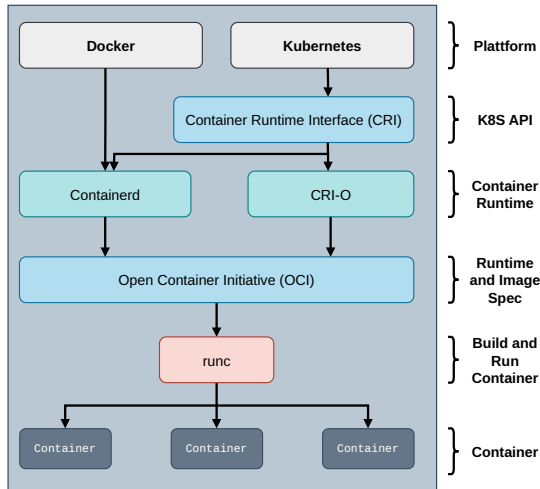
(3/3)



Worker Node

- **Kubelet:** Primary Node agent for the registration with the API Server.
- **Kubeproxy:** proxy is responsible for network communication within the cluster. It maintains network rules and routes traffic to the appropriate containers or services based on IP address and port number.
- **Pod:** Collection of one or more Containers.

Container Runtime Interface and Open Container Initiative



CRI – High-Level Interface

API between Kubernetes and the container runtime

- **Containerd**

- container runtime
- containerd has a CRI plugin by default (from version 1.1). It allows to run Kubernetes with containerd as container runtime

- **CRI-O**

- open source alternative to containerd

OCI – Low-Level Interface

Defines a standard for images and container

- **runC**

- Low-level container runtime

Measuring service offerings

For the optimal operation of servers and applications measuring these instances is important! Monitoring tools are used to observe, track, and manage the performance, health, and availability of IT infrastructure components, applications, and services.

Characteristics

- **Performance Optimization:** provide insights into the performance of IT infrastructure components, applications, and services.
- **Capacity Planning:** help organizations forecast future resource requirements and plan for capacity expansion.
- **Fault Detection and Troubleshooting:** enable organizations to quickly detect and diagnose issues within their IT infrastructure, applications, and services.
- **Compliance and Reporting:** help organizations ensure compliance with regulatory requirements and industry standards by monitoring and reporting on key performance metrics.
- **Service Level Agreement (SLA) Management:** allow organizations to monitor and enforce service level agreements (SLAs) by tracking key performance indicators, uptime guarantees, and response times.

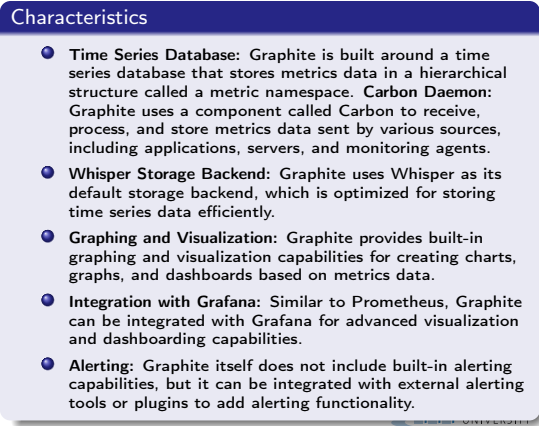
We will look at three monitoring solution that are widely used in the industry.

Source: <https://prometheus.io/docs/>

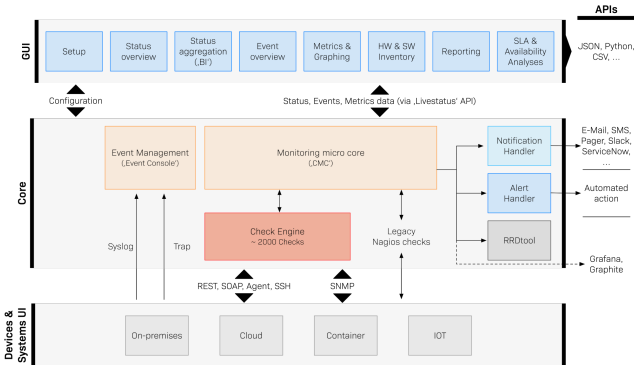


- **Pull-based Metrics Collection:** Prometheus follows a pull-based model where it periodically scrapes metrics data from instrumented targets.
- **Multi-dimensional Data Model:** Prometheus uses a flexible data model with key-value pairs called labels, allowing for multidimensional data collection and querying.
- **Powerful Query Language (PromQL):** Prometheus provides a powerful query language called PromQL for querying and aggregating metrics data, enabling advanced analysis and visualization.
- **Alerting:** Prometheus includes built-in support for alerting based on predefined rules and thresholds, allowing administrators to receive notifications when certain conditions are met.
- **Time Series Database:** Prometheus stores metrics data in a time series database, enabling efficient storage, retrieval, and querying of historical data.
- **Integration with Grafana:** Prometheus integrates seamlessly with Grafana, a popular visualization tool, allowing users to create rich dashboards and graphs based on Prometheus metrics.

Source: <https://graphiteapp.org/>



Source: <https://docs.checkmk.com/latest/en/cmc.html>



Characteristics

- **Agent-based and Agentless Monitoring:** Checkmk supports both agent-based and agentless monitoring methods, allowing administrators to monitor a wide range of devices and platforms.
- **Service Discovery:** Checkmk includes automatic service discovery capabilities, which can dynamically detect and monitor new services or devices added to the network.
- **Rich Set of Plugins:** Checkmk offers a large number of built-in monitoring plugins for monitoring various technologies and applications, as well as the ability to create custom plugins.
- **Event Console:** Checkmk includes an event console for managing and correlating monitoring alerts, events, and notifications in real-time.
- **Role-based Access Control (RBAC):** Checkmk provides RBAC capabilities for managing user access and permissions, allowing administrators to control who can access monitoring data and perform specific actions.
- **Integration with Grafana:** Checkmk can be integrated with Grafana for advanced visualization and dashboarding capabilities, allowing users to create custom dashboards based on monitoring data.

Mutable



Characteristics

Managing Infrastructures – Infrastructure as Code (IaC)

Infrastructure as Code (IaC) is a method in system administration where infrastructure configurations and provisioning are managed and automated through code rather than manual processes. With IaC, infrastructure components such as servers, networking, and storage resources are defined, configured, and managed using code-based configuration files, scripts, or templates.

Benefis

- **Consistency:** IaC ensures that infrastructure configurations are consistent across environments, such as development, testing, staging, and production.
- **Automation:** IaC enables automation of infrastructure provisioning and management tasks, reducing the need for manual intervention and human error.
- **Scalability:** With IaC, organizations can easily scale their infrastructure up or down in response to changing demand.
- **Version Control and Auditability:** Infrastructure code is treated like application code and stored in version control systems such as Git.
- **Reusability and Modularity:** IaC promotes reusability and modularity by allowing common configurations to be abstracted into reusable components or modules.

Source of examples

The examples were taken from the book of Daniel Stender „*Cloud-Infrastrukturen: Das Handbuch für DevOps-Teams und Administratoren*“, Rheinwerk Computing (2020), ISBN 978-3-8362-6949-0.



HashiCorp

Vagrant

Vagrant is an open-source¹ tool for building and managing portable development environments. It allows developers to create reproducible, shareable, and lightweight virtualized environments that closely resemble production setups.

¹From August 10, 2023 on the licensing has changed to Business Source License (BUSL)!

Characteristics

- **Portable Development Environments:** allows developers to create and manage reproducible development environments that are easily portable across different machines and platforms.
- **Configuration Management:** simplifies configuration management by allowing developers to define environment settings, provisioning scripts, and dependencies using simple configuration files.
- **Integration with Virtualization Providers:** supports various virtualization providers, including VirtualBox, VMware, and Docker, allowing developers to choose the most suitable environment for their projects.

(2/2)

- The example Vagrantfile presents the installation of a Ubuntu instance.
- The script also configures the network and installs an Apache webserver.
- The example could be enhanced with more complex provision scenarios and combined with other tools e.g. Ansible.

Only the following commands are necessary:

- vagrant up
- vagrant ssh
- vagrant destroy

Terraform

$$(1/2)$$


Terraform is an open-source¹ infrastructure as code tool used for building, changing, and versioning infrastructure safely and efficiently. It allows users to define infrastructure configurations using declarative code in a simple, human-readable language.

There is the alternative **OpenTofu**, which is a fork of Terraform that is open-source, and managed by the Linux Foundation!!! Link:<https://opentofu.org/>

Characteristics

- **Multi-Cloud Support:** supports multiple cloud providers (such as AWS, Azure, Google Cloud Platform) and infrastructure services, as well as on-premises environments.
- **State Management:** maintains a state file that tracks the current state of the infrastructure managed by Terraform. This state file helps Terraform understand the relationships between resources and enables it to plan and execute changes to the infrastructure in a safe and predictable manner.
- **Modularity and Reusability:** allows users to define infrastructure configurations using modular and reusable components called modules.

¹From August 10, 2023 on the licensing has changed to Business Source License (BSL)!

(2/2)

- The provider is used to create and manage resources (here aws).
- Multiple provider blocks can be used to manage resources from different providers.
- The resource blocks define components of the infrastructure (e.g. physical or virtual component, here an EC2 instance).

- terraform init
- terraform apply
- terraform show
- terraform apply -destroy

(3/3)

Packer



Packer is an open-source¹ tool for automating the creation of machine images for multiple platforms, such as AWS, Azure, VMware, and Docker. It allows users to define machine configurations using declarative JSON templates, enabling consistent and reproducible image builds across different environments.

¹From August 10, 2023 on the licensing has changed to Business Source License (BUSL)

Characteristics

- **Multi-Platform Support:** Packer supports multiple platforms and providers, including AWS, Azure, Google Cloud Platform, VMware, VirtualBox, and Docker.
- **Provisioning:** Packer supports various provisioning methods, including shell scripts, Ansible playbooks, Chef recipes, and Puppet manifests. This allows users to automate the installation and configuration of software packages, dependencies, and applications within the machine image.
- **Parallel Builds:** Packer can perform parallel builds to speed up the image creation process, especially when building images for multiple platforms or configurations simultaneously.
- **Idempotent Operations:** ensures idempotent operations.

Case Study for example calculation (1/3)

Case Study

As an example we can consider a small to medium enterprise (SME), going into business. We will make assumptions on the demands of that company in order to have a common ground for the calculation of the expected costs for the operation of the service offering.

Source of example calculation

K. Konstantinos, M. Persefoni, F. Evangelia, M. Christos, and N. Mara, 'Cloud computing and economic growth', in Proceedings of the 19th Panhellenic Conference on Informatics, Athens, Greece, 2015, pp. 209–214.

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CapEx

- IT infrastructure (servers, networking, software, etc.)
- IT equipment
- Data center housing
- Infrastructure maintenance

OpEx

- Business-related operating costs (on-demand rent, utilities, salaries, etc.)
- Cloud-based software or service subscription fees (SaaS, PaaS, IaaS, etc.)
- Software and service support
- Data center or off-premises cloud costs

Traditional IT-Infrastructures - OpEx (3/3)

OpEx (3 years)		Price	Annual Cost	Three Year Cost
Actual Operating Power ²	308 Watts per server	0,22€/kwh	2.962 €	8.885 €
Actual Cooling Power ³	385 Watts per server	0,22€/kwh	3.702 €	11.106 €
Real Estate Rent	5 sq.m	5€/sq.m	300 €	900 €
Operating Expenditures			6.964 €	20.891 €

Total cost of ownership (TCO)

This calculation demonstrates a total cost of ownership (TCO) of **89.715 €** over three years!

²With current prices (approx. 0,38€/kwh) 5126 € resp. 15.379 €!

³With current prices (approx. 0,38€/kwh) 6407 € resp. 19223 €!

