

Web 2.0

Lecture 2: Cloud Architectures

doc. Ing. Tomáš Vitvar, Ph.D.

tomas@vitvar.com • @TomasVitvar • <http://vitvar.com>



Czech Technical University in Prague

Faculty of Information Technologies • Software and Web Engineering • <http://vitvar.com/courses/w20>



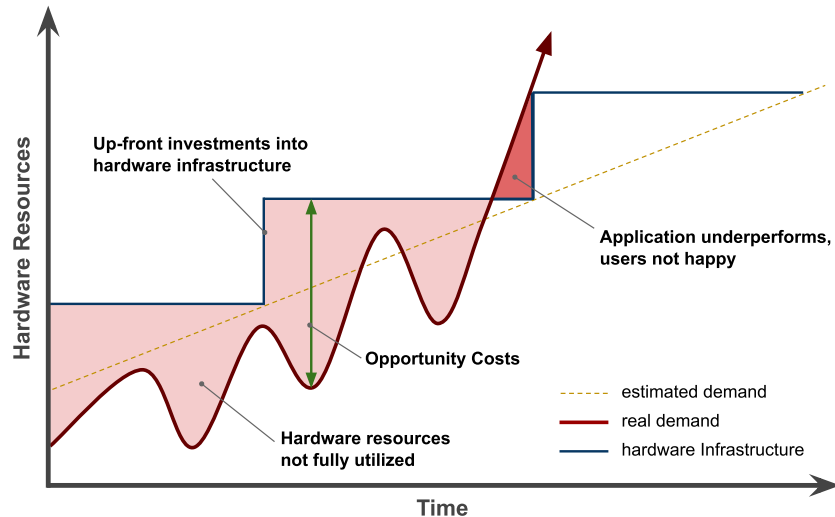
Modified: Sun Mar 10 2019, 22:00:05
Humla v0.3

Overview

- **Introduction**
- Infrastructure as a Service
- Multitenancy
- Microservices Architecture
- Docker
- Kubernetes

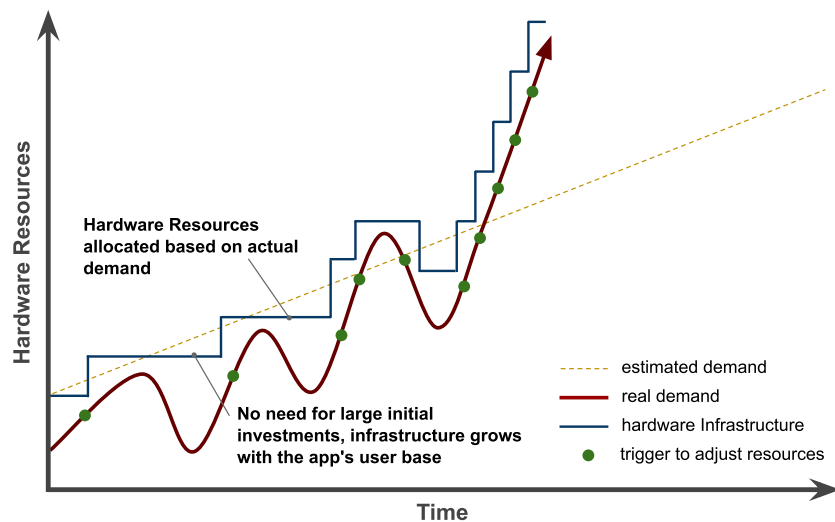
Traditional Solution to Infrastructure

- Traditional hardware model
 - *Up-front hardware investments*
 - *Hardware not optimally utilized*



Good Performance – Cloud Solution

- Cloud Computing model
 - *No up-front hardware investments*
 - *Hardware optimally utilized*



Cloud Computing Concepts

- **Resource Pooling**
 - *Resources reused by multiple tenants (multitenancy)*
 - *Resources: CPU, memory, storage, network*
- **On-demand and Self-service**
 - *Resources are provisioned as they are requested and when they are required*
 - *No human interaction, automatic*
- **Scalability and Elasticity**
 - *Infrastructure may grow and shrink according to needs*
 - *Automatic or manual*
- **Pay-per-use**
 - *Consumers only pay for resources when they use them*

Cloud Service Concepts

- **Service Models (aka Cloud Layers)**
 - *IaaS – Infrastructure as a Service*
 - *PaaS – Platform as a Service*
 - *MWaaS, DBaaS, ...*
 - *SaaS – Software as a Service*
- **Deployment Models**
 - *Public Cloud*
 - *Private Cloud*
 - *Hybrid Cloud*
- **Usage**
 - *Cloud native applications*
 - *Moving existing applications from on-premise to cloud*

Overview

- Introduction
- **Infrastructure as a Service**
 - *Infrastructure as Code*
- Multitenancy
- Microservices Architecture
- Docker
- Kubernetes

Terminology (1)

- Region
 - *A localized geographical area*
 - *A cloud provider usually has multiple regions around the world.*
- Availability Domain
 - *A datacenter in a region; there can be more AD in a region*
- Tenancy
 - *Isolated partition where a customer creates and organizes cloud resources.*
- Instance
 - *Compute host running in the cloud*
- Bare Metal
 - *Physical host that run directly on bare metal servers without hypervisor*
- Shape/Class
 - *Amount of computing resources allocated to the instance*
 - *CPUs, Memory, Local Disk, Network Bandwidth, Number of VNICs*
- Image
 - *A template of a virtual hard drive that defines operating system and other software for an instance.*

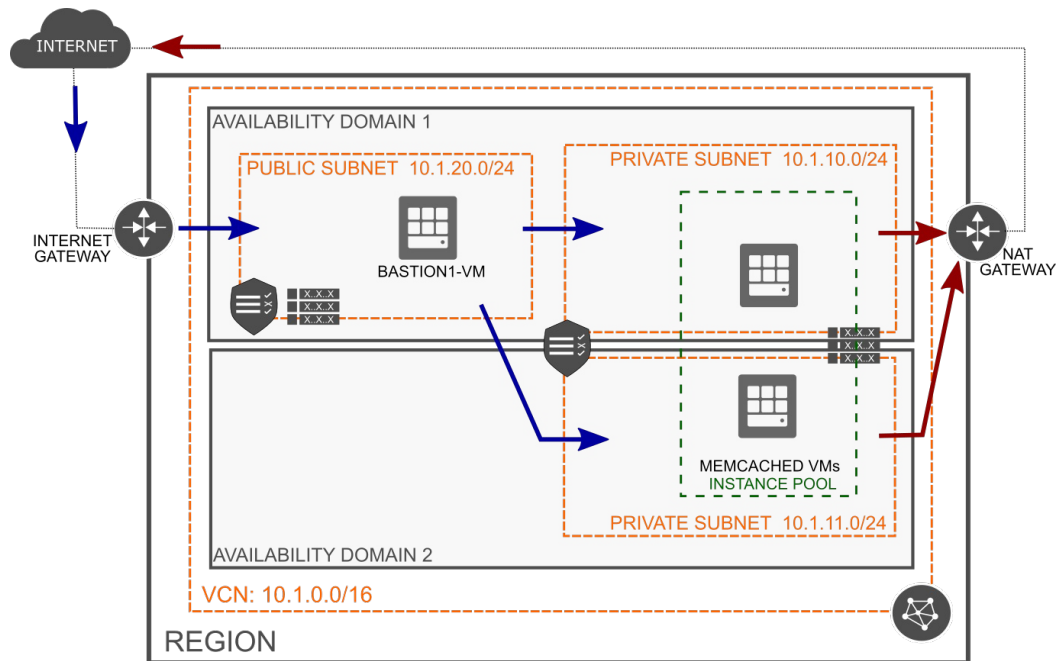
Terminology (2)

- Instance Pool
 - *A group of instances*
- Virtual Cloud Network (VCN)
 - *A virtual network in which instances run*
 - *It includes: **subnets**, **route tables**, **firewall rules**, **gateways***
- Block Volume
 - *A virtual disk providing persistent storage*
 - *It can be used as a volume attached to the instance*
- Object Storage
 - *Allows to store and manage data as objects in logical containers (**buckets**)*
 - *The data can be of any type and are usually of large size*
 - *The data does not change frequently*
 - *Examples: data backup, storing unstructured data, sensor-generated data*

Access and Usage

- Layers
 - *Cloud Infrastructure → REST API → CLI, Web Console, other tools*
- Key pair
 - *Authentication mechanism using **public** and **private** key*
 - *public key is uploaded to an instance, a client uses the private key to authenticate*
 - *Example: ssh using key authentication to access ssh daemon running in Linux*

IaaS Example



Overview

- Introduction
- Infrastructure as a Service
 - *Infrastructure as Code*
- Multitenancy
- Microservices Architecture
- Docker
- Kubernetes

Overview

- Definition
 - *Application envs (in a cloud) managed via definition files*
 - *Version control, team development, scripting, etc.*
- Major Technologies
 - **Configuration Management Tools**
 - *install and manage software on machines that already exist*
 - *Examples: Ansible, Chef, Puppet*
 - **Abstraction of cloud infrastructure**
 - *Terraform*

Terraform

- Higher-level abstraction of the datacenter and associated services
- Supports many service providers
 - *Google, Microsoft, Oracle, AWS*
- Steps
 1. *Description of resources in Hashicorp Configuration Language (HCL)*
 - *instances, networks, firewall rules, routing tables, etc.*
 2. *Terraform generates execution plan to reach the desired state*
 3. *Terraform executes the plan to reach the desired state; can generate incremental execution plan*

Overview

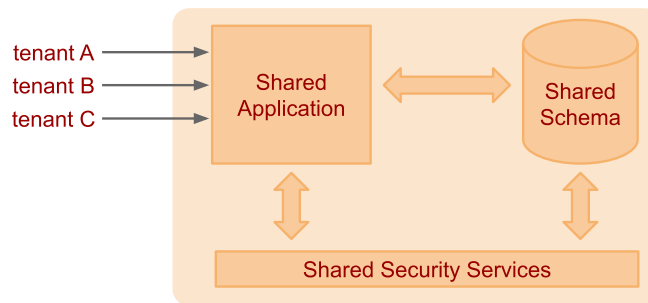
- Introduction
- Infrastructure as a Service
- **Multitenancy**
- Microservices Architecture
- Docker
- Kubernetes

Multitenancy

- Architectural approach where resources are shared between multiple tenants or consumers
- Implications
 - *Centralization of infrastructure in locations with lower costs*
 - *Peak-load capacity increases*
 - *Utilisation and efficiency improvements for systems that are not well utilised*
- Sharing options
 - *Shared Everything*
 - *Shared Infrastructure*
 - *Virtual Machines*
 - *O/S virtualization*

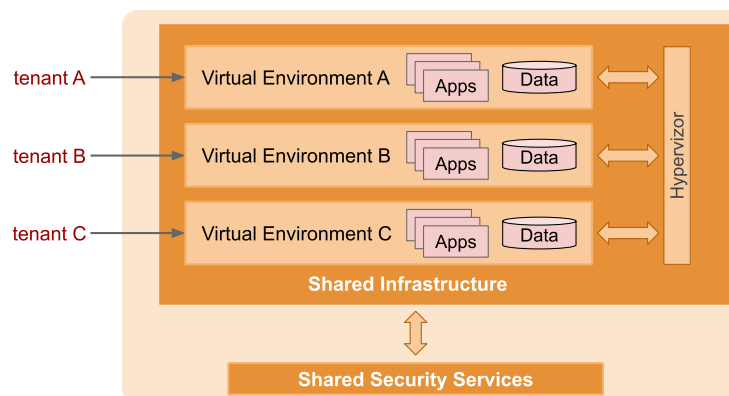
Shared Everything

- Resources are shared between all tenants or consumers
 - *tenant: a service consumer*
- Common for the SaaS model
- The application should provide tenant isolation
- Data for multiple tenants is stored in the same database tables



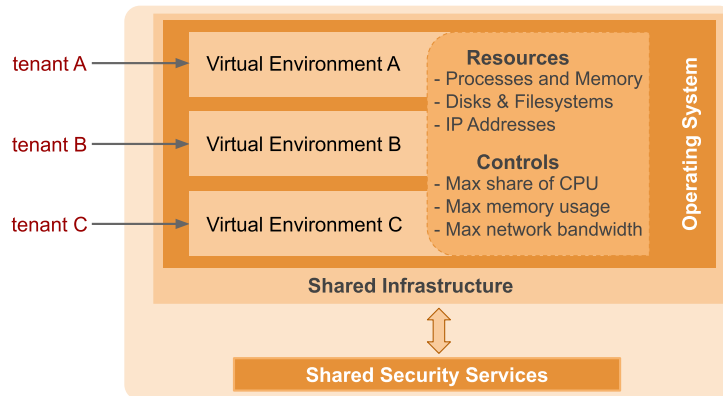
Shared Infrastructure: Virtual Machines

- Infrastructure shared via virtual machines
 - *each tenant has its own virtual environment*
 - *Isolation provided by hypervisor*
 - *hypervisor: virtual machine manager, runs virtual machines*
 - *Resource contention depends on VM capability and configuration*
 - *Adds an additional layer and processes to run and manage*



Shared Infrastructure: OS Virtualization

- Infrastructure shared via OS Virtualization
 - Each tenant has its own processing zone
 - Isolation provided by the operating system
 - Resource contention depends on zone configuration
 - No VMs to run and manage, no abstraction layer between app & OS



Overview

- Introduction
- Infrastructure as a Service
- Multitenancy
- **Microservices Architecture**
- Docker
- Kubernetes

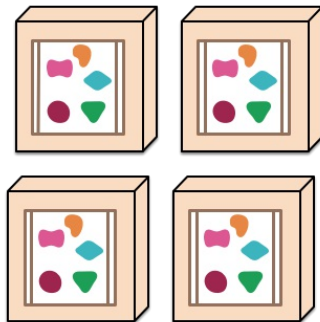
Overview

- Emerging software architecture
 - *monolithic vs. decoupled applications*
 - *applications as independently deployable services*

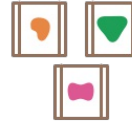
A monolithic application puts all its functionality into a single process...



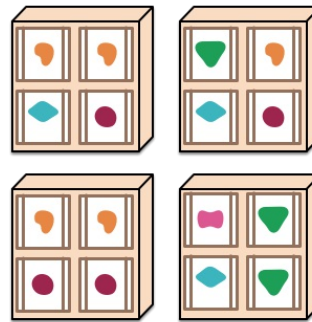
... and scales by replicating the monolith on multiple servers



A microservices architecture puts each element of functionality into a separate service...



... and scales by distributing these services across servers, replicating as needed.



Major Characteristics

- Loosely coupled
 - *Integrated using well-defined interfaces*
- Technology-agnostic protocols
 - *HTTP, they use REST architecture*
- Independently deployable and easy to replace
 - *A change in small part requires to redeploy only that part*
- Organized around capabilities
 - *such as accounting, billing, recommendation, etc.*
- Implemented using different technologies
 - *polyglot – programming languages, databases*

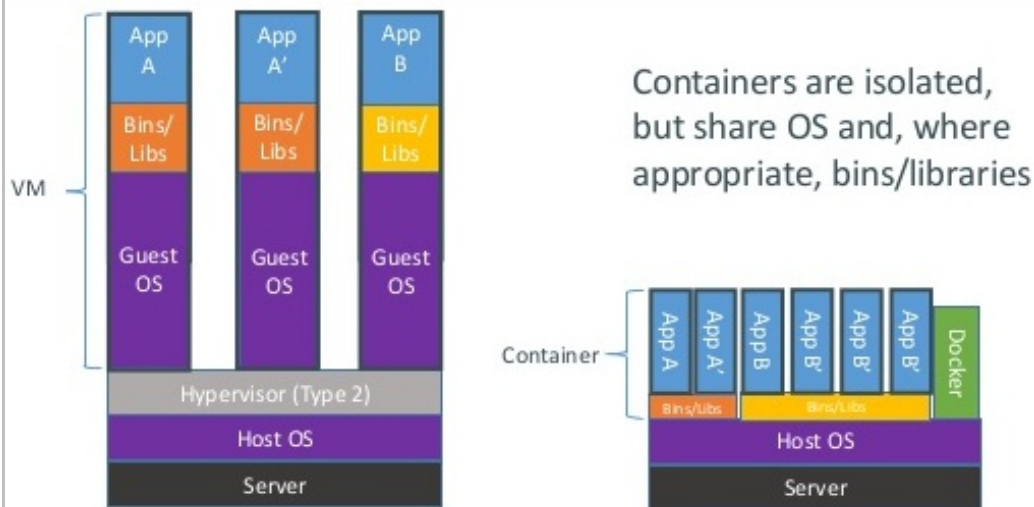
Overview

- Introduction
- Infrastructure as a Service
- Multitenancy
- Microservices Architecture
- Docker
 - *Overview*
 - *Image Layering*
 - *Working with Docker*
 - *Swarm*
- Kubernetes

Overview

- Linux Containers
 - *Introduced in 2008*
 - *Allow to run a process tree in a isolated system-level "virtualization"*
 - *Use much less resources and disk space than traditional virtualization*
- Implementations
 - *LXC – default implementation in Linux*
 - **Docker Containers**
 - *Builds on new Kernel features: control groups (cgroups), kernel namespaces, union-capable file system (OverlayFS, AUFS, etc.)*
 - *A way to build, commit and share images*
 - *Build images using a description file called Dockerfile*
 - *Large number of available base and re-usable images*

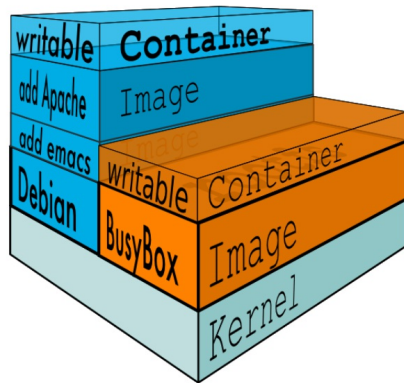
VM vs. Docker Containers



Docker Basic Terms

- **Image**
 - Basis for containers.
 - An image contains a union of layered filesystems stacked on top of each other.
 - An image does not have state and it never changes.
- **Container**
 - A runtime instance of a Docker image, a standard to "ship software".
- **Docker Engine**
 - The core process providing the Docker capabilities on a host.
- **Docker Client**
 - Interface that integrates with docker engine.
- **Registry**
 - A hosted service containing repository of images.
 - A registry provides a registry API to search, pull and push images.
 - Docker Hub is the default Docker registry.
- **Swarm**
 - A cluster of one or more docker engines.

Docker Images



- Containers are made up of R/O layers via a storage driver (OverlayFS, AUFS, etc.)
- Containers are designed to support a single application
- Instances are ephemeral, persistent data is stored in bind mounts or data volume containers.

Overview

- Introduction
- Infrastructure as a Service
- Multitenancy
- Microservices Architecture
- Docker
 - Overview
 - *Image Layering*
 - *Working with Docker*
 - *Swarm*
- Kubernetes

Image Layering with OverlayFS

- OverlayFS
 - A filesystem service implementing a **union mount** for other file systems.
 - Docker uses **overlay** and **overlay2** storage drivers to build and manage on-disk structures of images and containers.
- Image Layering
 - OverlayFS takes two directories on a single Linux host, layers one on top of the other, and provides a single unified view.
 - Only works for two layers, in multi-layered images hard links are used to reference data shared with lower layers.

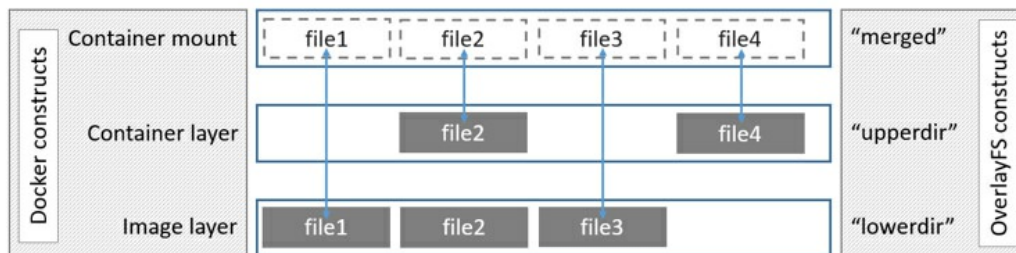


Image Layers Example

- Pulling out the image from the registry

```
$ sudo docker pull ubuntu
Using default tag: latest
latest: Pulling from library/ubuntu
5ba4f30e5bea: Pull complete
9d7d19c9dc56: Pull complete
ac6ad7efd0f9: Pull complete
e7491a747824: Pull complete
a3ed95caeb02: Pull complete
Digest: sha256:46fb5d001b88ad904c5c732b086b596b92cfb4a4840a3abd0e35dbb6870585e4
Status: Downloaded newer image for ubuntu:latest
```

- Each image layer has its own directory under **/var/lib/docker/overlay/**.
- This is where the contents of each image layer are stored.

- Directories on the file system

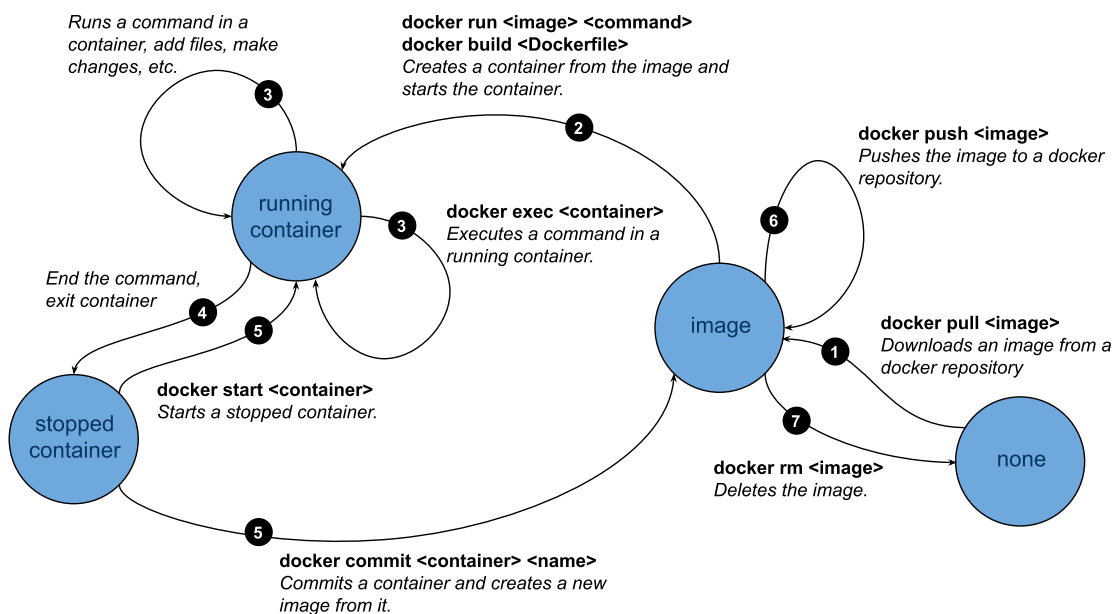
```
$ ls -l /var/lib/docker/overlay/
total 20
drwx----- 3 root root 4096 Jun 20 16:11 38f3ed2eac129654acef11c32670b534670c3a06e483fce313d72e3e
drwx----- 3 root root 4096 Jun 20 16:11 55f1e14c361b90570df46371b20ce6d480c434981cbda5fd68c6ff61
drwx----- 3 root root 4096 Jun 20 16:11 824c8a961a4f5e8fe4f4243dab57c5be798e7fd195f6d88ab06aea92
drwx----- 3 root root 4096 Jun 20 16:11 ad0fe55125ebf599da124da175174a4b8c1878afe6907bf7c7857034
drwx----- 3 root root 4096 Jun 20 16:11 edab9b5e5bf73f2997524eebeac1de4cf9c8b904fa8ad3ec43b35041
```

- The organization of files allows for efficient use of disk space.
- There are **files unique to every layer** and **hard links to files** shared with lower layers

Overview

- Introduction
- Infrastructure as a Service
- Multitenancy
- Microservices Architecture
- Docker
 - Overview
 - Image Layering
 - *Working with Docker*
 - Swarm
- Kubernetes

Docker Container Lifecycle State Diagram



Commands (1)

docker version

list current version of docker engine and client

docker search <image>

search for an image in the registry

docker pull <image[:version]>

download an image of a specific version from the registry

if the version is not provided, the latest version will be downloaded

docker images

list all local images

docker run -it <image[:version]> <command>

start the image and run the command inside the image

if the image is not found locally, it will be downloaded from the registry

option -i starts the container in interactive mode

option -t allocates a pseudo TTY

docker ps [-as]

list all running containers

option -a will list all containers including the stopped ones.

option -s will list the container's size.

Commands (2)

docker rm <container>

remove the container

docker rmi <image>

remove the image

docker commit <container> <name[:version]>

create an image from the container with the name and the version

docker history <image>

display the image history

Networking and Linking

- There are 3 docker networks by default
 - **bridge** – container can access host's network (default)
 - Docker creates subnet **172.17.0.0/16** and gateway to the network
 - When a container is started, it is automatically added to this network
 - All containers in this network can communicate with each other
 - **host** – all host's network interfaces will be available in the container.
 - **none** – container will be placed on its own network and no network interfaces will be configured.
- Custom Network configuration
 - You can create a new network and add containers to it
 - Containers in the new network can communicate with each other but the network will be isolated from the host network
- Linking containers (legacy)

```
$ docker run -d --name redmine-db postgres
$ docker run -it --link redmine-db:db postgres /bin/bash
root@c4b12143ebe8:/# psql -h db -U postgres
psql (9.6.1)
Type "help" for help.
postgres=# SELECT inet_server_addr();
postgres=# SELECT * FROM pg_stat_activity \x\g\x
```

Networking Commands

docker network ls

lists all available networks

docker network inspect <network-id>

Returns the details of specific network

docker network create --driver bridge isolated_nw

creates a new isolated network

docker run -it --network=isolated_nw ubuntu bin/bash

starts the container ubuntu and attaches it to the isolated network

Data Volumes

- Data Volume
 - A directory that bypass the union file system
 - Data volumes can be shared and reused among containers
 - Data volume persists even if the container is deleted
 - It is possible to mount a shared storage volume as a data volume by using a volume plugin to mount e.g. NFS
- Adding a data volume

```
docker run -d -v /webapp training/webapp python app.py
```

will create a new volume with name `webapp`,
the location of the volume can be determined by using `docker inspect`.
- Mount a host directory as a data volume

```
docker run -d -v /src/webapp:/webapp training/webapp python app.py
```

if the path exists in the container, it will be overlayed (not removed),
if the host directory does not exist, the docker engine creates it.
- Data volume container
 - Persistent data to be shared among two or more containers

```
docker create -v /dbdata --name dbstore training/postgres /bin/true
docker run -d --volumes-from dbstore --name db1 training/postgres
docker run -d --volumes-from dbstore --name db2 training/postgres
```

Dockerfile

- Dockerfile is a script that creates a new image

```
# This is a comment
FROM oraclelinux:7
MAINTAINER Tomas Vitvar <tomas@vitvar.com>
RUN yum install -q -y httpd
EXPOSE 80
CMD httpd -X
```

- A line in the Dockerfile will create an intermediary layer

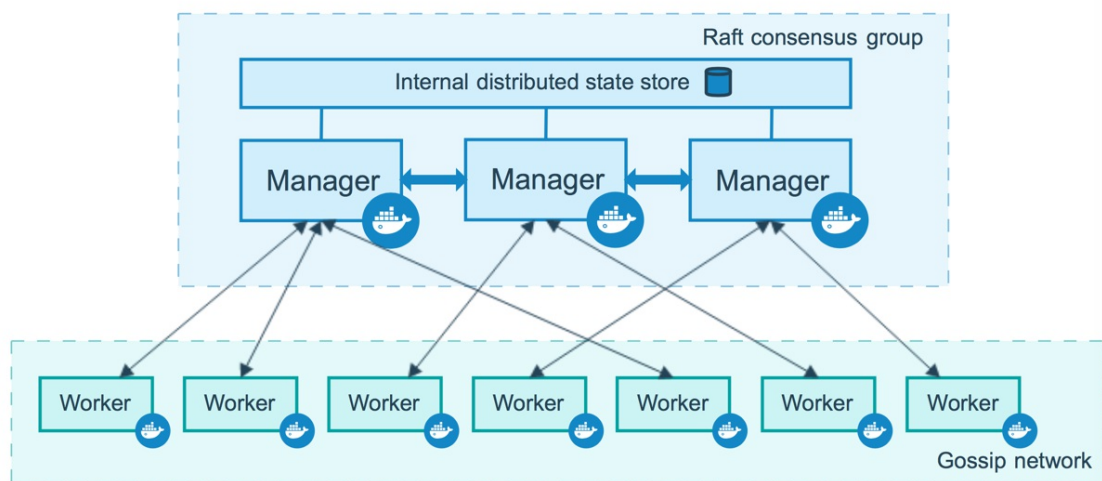
```
$ docker build -t tomvit/httpd:v1 .
Sending build context to Docker daemon 2.048 kB
Step 1 : FROM oraclelinux:7
----> 4c357c6e421e
Step 2 : MAINTAINER Tomas Vitvar <tomas@vitvar.com>
----> Running in 35feebb2ffab
----> 95b35d5d793e
Removing intermediate container 35feebb2ffab
Step 3 : RUN yum install -q -y httpd
----> Running in 3b9aee3c3ef1
----> 888c49141af9
Removing intermediate container 3b9aee3c3ef1
Step 4 : EXPOSE 80
----> Running in 03e1ef9bf875
----> c28545e3580c
Removing intermediate container 03e1ef9bf875
Step 5 : CMD httpd -X
----> Running in 3c1c0273a1ef
```

If processing fails at some step, all preceding steps will be loaded from the cache on the next run.

Overview

- Introduction
- Infrastructure as a Service
- Multitenancy
- Microservices Architecture
- Docker
 - *Overview*
 - *Image Layering*
 - *Working with Docker*
 - *Swarm*
- Kubernetes

Swarm

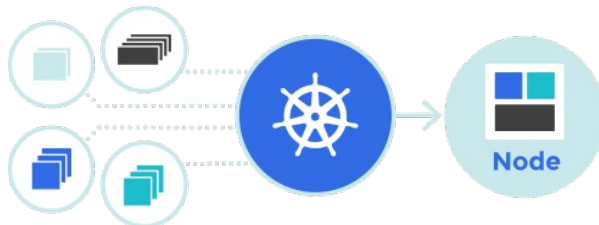


Overview

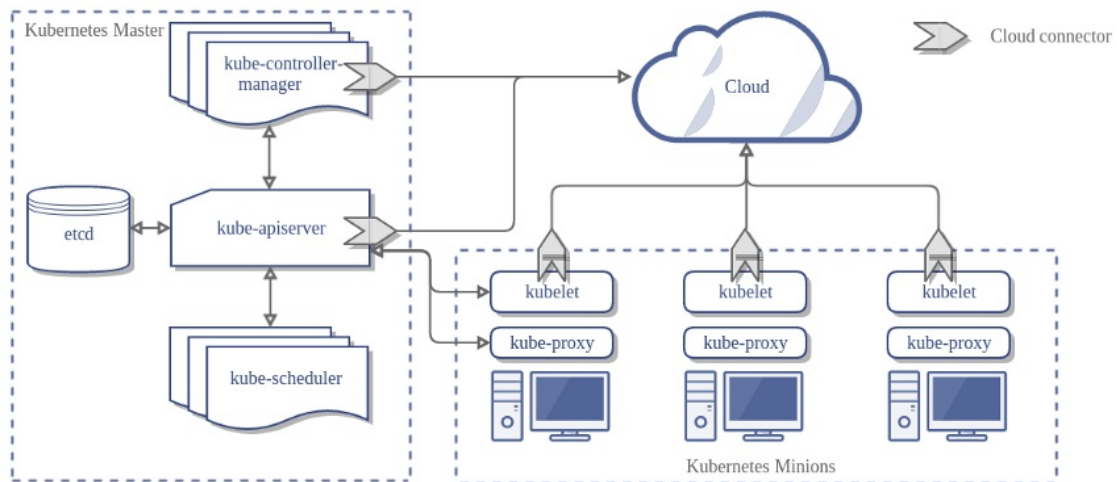
- Introduction
- Infrastructure as a Service
- Multitenancy
- Microservices Architecture
- Docker
- **Kubernetes**

Overview

- In your architecture...
 - Containers are atomic pieces of application architecture
 - Containers can be linked (e.g. web server, DB)
 - Containers access shared resources (e.g. disk volumes)
- Kubernetes
 - Automation of deployments, scaling, management of containerized applications across number of nodes
 - Based on Borg, a parent project from Google



System Architecture



Major Terms

- **Node**
 - a worker machine in Kubernetes, previously known as a minion (a VM or physical machine). It uses **kubelet** and **kube-proxy** to communicate with the master and other nodes/services.
- **Master**
 - A node that manages the cluster of nodes.
- **Pod**
 - The basic building block of Kubernetes, one or more dependant containers.
- **Service**
 - A set of pods with rules allowing pods to talk to each other, such as:
 - **NodePort** exposes the pod under a cluster IP.
 - **LoadBalancer** exposes the pod for load balancing by external load balancer
- **Controllers**
 - Worker units to ensure a desired state, such as:
 - **ReplicaSet** ensures that a specified number of pod replicas are running.
 - **Deployment** manages ReplicaSets, provides declarative updates to pods.
 - **StatefulSet** manages deployment and scaling of a set of Pods.

Features

- Automatic binpacking
 - Automatically places containers onto nodes based on their resource requirements and other constraints.
- Horizontal scaling
 - Scales your application up and down with a simple command, with a UI, or automatically based on CPU usage.
- Automated rollouts and rollbacks
 - Progressive rollout out of changes to application/configuration, monitoring application health and rollback when something goes wrong.
- Storage orchestration
 - Automatically mounts the storage system (local or in the cloud)
- Self-healing
 - Restarts containers that fail, replaces and reschedules containers when nodes die, kills containers that don't respond to user-defined health checks.
- Service discovery and load balancing
 - Gives containers their own IP addresses and a single DNS name for a set of containers, and can load-balance across them.

Demo

- Environment Setup
 - `minikube` – a local virtual machine (running a master and a single node)
 - `kubectl` – CLI to access Kubernetes cluster
- Steps
 1. create `hello-node` app in `node.js` and test it [see `server.js`]
`node server.js`
 2. create docker image for the app [see `Dockerfile`]
`docker build -t hello-node:v1 .`
 3. deploy the app to Kubernetes by using `kubectl`
`kubectl run hello-node --image=hello-node:v1 --port=8080`
 4. Expose the app as a load balancer service.
`kubectl expose deployment hello-node --type=LoadBalancer`
 5. Explore the app in minikube dashboard.
`minikube dashboard`
 6. Fire requests at the service and count them [see `test.sh`]
`./test.sh.`
 7. Change the number of replicas by using the dashboard or `kubectl`.