

# Middleware Architectures 2

## Lecture 3: Cloud Native and Microservices

**doc. Ing. Tomáš Vitvar, Ph.D.**

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



Czech Technical University in Prague

Faculty of Information Technologies • Software and Web Engineering • <https://vitvar.com/lectures>



Modified: Mon Mar 07 2022, 14:16:19  
Humla v1.0

## Overview

- **Cloud Native**
- Microservices
- Containers
- Kubernetes

# Overview

- The Cloud Native Computing Foundation (CNFS) [↗](#)
  - *Motto: Building sustainable ecosystems for cloud native software*
  - *CNFS is part of the nonprofit Linux Foundation*
- Cloud Native = scalable apps running in modern cloud environments
  - *containers, service meshes, microservices*
  - *Apps must be usually re-built from scratch or refactored*
  - *Benefits:*
    - *loosely coupled systems that are resilient, manageable, and observable*
    - *automation allowing for predictable and frequent changes with minimal effort*
  - *Trail Map*
    - *provides an overview for enterprises starting their cloud native journey* [↗](#)
- Lift and Shift
  - *Cloud transition program in organizations*
  - *Move app from on-premise to the cloud*
  - *Benefits*
    - *Infrastructure cost cutting (OPEX vs. CAPEX)*
    - *Improved operations (scaling up/down if possible can be faster)*

## CNFS Trail Map



## Overview

- Cloud Native
- **Microservices**
- Containers
- Kubernetes

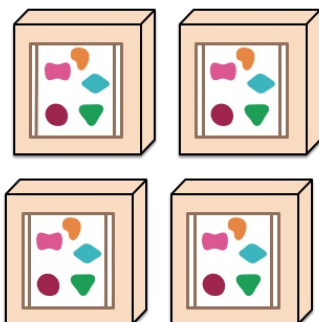
## Overview

- 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

- Cloud Native
- Microservices
- Containers
  - *Overview*
  - *Linux Namespaces*
  - *Images*
  - *Working with Docker*
- Kubernetes

# Virtual Machines vs. Containers



## 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 Linux namespaces and union file system (OverlayFS)
    - 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
- **Monolithic design originally**
  - Now several layers
  - container runtime
  - container engine

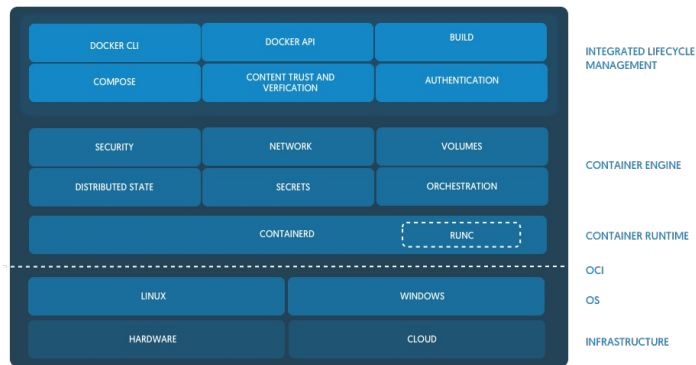
Docker version <1.11.0



Docker version 1.11.0+



# Containerd



- Container engine
  - Accepts user inputs (via CLI or API), pulling images from registry, preparing metadata to be passed to container runtime
- Container runtime
  - Abstraction from syscalls or OS specific functionality to run containers on linux, windows, solaris, etc.
  - Uses **runc** and **container-shim**
  - Communicates with kernel to start containerized processes

## Terminology

- Image
  - An image contains a union of layered filesystems stacked on top of each other
  - Immutable, it does not have state and it never changes
- Container
  - One or more processes running in one or more isolated namespaces in a filesystem provided by the image
- Container Engine/Runtime
  - The core processes providing container capabilities on a host
- Client
  - An app (e.g. CLI, custom app), communicates with a container engine by its API
- 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

## Overview

- Cloud Native
- Microservices
- Containers
  - Overview
  - *Linux Namespaces*
  - Images
  - Working with Docker
- Kubernetes

## Linux Namespaces

- Isolation of Linux processes, there are **7 namespaces**
  - Mount, UTS, IPC, PID, Network, User, Cgroup
  - By default, every process is a member of a default namespace of each type
  - In case no additional namespace configuration is in place, processes and all their direct children will reside in this exact namespace
  - Run **lsns** to check namespaces the process is in

```
$ lsns
NS                TYPE  NPROCS  PID USER  COMMAND
4026531836 pid    2 30873 oracle -bash
4026531837 user   108 1636 oracle /bin/bash /u01/oracle/scripts/startWebLogicContainer.sl
4026531838 uts     2 30873 oracle -bash
4026531839 ipc     2 30873 oracle -bash
4026531840 mnt     2 30873 oracle -bash
4026531956 net    108 1636 oracle /bin/bash /u01/oracle/scripts/startWebLogicContainer.sl
4026532185 mnt     13 13542 oracle /bin/bash /u01/oracle/scripts/startNM_ohs.sh
4026532192 pid     13 2798 oracle /bin/bash /u01/oracle/scripts/startNM_ohs.sh
...
```

- Flexible configuration, for example:
  - You can run two apps that only share the network namespace, e.g. **4026531956**
  - The apps can talk to each other
  - Any other app (not in this namespace) won't be able to talk to the apps

## Types: mnt, uts, ipc and pid

- **mnt** namespace
  - Isolates filesystem mount points
  - Restricts the view of the global file hierarchy
  - Each namespace has its own set of mount points
- **uts** namespace
  - The value of the hostname is isolated between different UTS namespaces
- **ipc** namespace
  - Isolates interprocess communication resources
  - message queues, semaphore, and shared memory
- **pid** namespace
  - Isolates PID number space
  - A process ID number space gets isolated
    - Processes can have PIDs starting from the value 1
    - Real PIDs outside of the namespace of the same process is a different number
  - Containers have their own init processes with a PID value of 1

## Types: net

- **net** namespace
  - Processes have their own private network stack (interfaces, routing tables, sockets)
  - Communication with external network stack is done by a virtual ethernet bridge



- On the host there is a **userland proxy** or **NAT**
  - NAT is a preferred solution over userland proxy (`/usr/bin/docker-proxy`)
  - Lack of NAT hairpinning may prevent to use NAT
- Use case
  - Multiple services binding to the same port on a single machine, e.g. **tcp/80**
  - A port in the host is mapped to the port exposed by a process in the NS



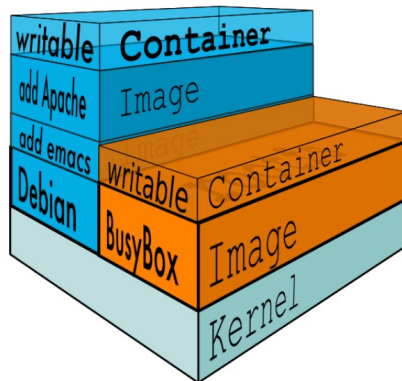
## Types: user

- **user** namespace
  - *Isolates UID/GID number spaces*
- **cgroup** namespace
  - *Isolate cgroup root directory*

## Overview

- Cloud Native
- Microservices
- Containers
  - *Overview*
  - *Linux Namespaces*
  - *Images*
  - *Working with Docker*
- Kubernetes

# Container 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.

## 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

```
$ docker pull ubuntu

Using default tag: latest
latest: Pulling from library/ubuntu

5ba4f30e5bea: Pull complete
9d7d19c9dc56: Pull complete
ac6ad7efd0f9: Pull complete
e7491a747824: Pull complete
a3ed95cae02: Pull complete
Digest: sha256:46fb5d001b88ad904c5c732b086b596b92cfb4a4840a3abd0e35d5bb6870585e4
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**

# 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 preceeding steps will be loaded from the cache on the next run.*

## Overview

- Cloud Native
- Microservices
- Containers
  - Overview
  - Linux Namespaces
  - Images
  - *Working with Docker*
- Kubernetes

## Docker Container State Diagram



- 1: There is no image in the local store; you pull an image from a remote registry.
- 2: You run a new container on top of a specified image.
- 3: You modify the container by adding a library/content in it; you can also run a command in the container from the host.
- 4: You stop a running container.

- 5: You start a stopped container.
- 6: You commit the container and create a new image from it.
- 7: You remove the container.
- 8: You push the image to the remote registry.
- 9: You can remove the image from the local store.

## 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
```

## Overview

- Cloud Native
- Microservices
- Containers
- **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



## 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.



# Architecture



## Control Plane Components

- Global decisions about the cluster
  - *Scheduling*
  - *Detecting and responding to cluster events, starting up new pods*
- kube-apiserver
  - *exposes the Kubernetes API*
  - *The API server is the front end for the Kubernetes control plane.*
- etcd
  - *highly-available key value store used to store all cluster data*
- kube-scheduler
  - *watches for newly created Pods with no assigned node*
  - *selects a node for Pods to run on.*
  - *Decision factors: resource requirements, hardware/software/policy constraints, affinity and anti-affinity specifications*

## Control Plane Components

- **kube-controller-manager**
  - *runs controller to ensure the desired state of cluster objects*
  - **Node controller**
    - *noticing and responding when nodes go down*
  - **Job controller**
    - *creates Pods to run one-off tasks to completion.*
  - **Endpoints controller**
    - *Populates the Endpoints object (that is, joins Services & Pods).*
- **cloud-controller-manager**
  - *Integration with cloud services (when the cluster is running in a cloud)*
  - **Node controller**
    - *checks if a node has been deleted in the cloud after it stops responding*
  - **Route controller**
    - *For setting up routes in the underlying cloud infrastructure*
  - **Service controller**
    - *For creating, updating and deleting cloud provider load balancers*

## Node

- **Kubernetes runtime environment**
  - *Run on every node*
  - *Maintaining running pods*
- **kubelet**
  - *An agent that runs on each node in the cluster*
  - *It makes sure that containers are running in a Pod.*
- **kube-proxy**
  - *maintains network rules on nodes*
  - *network rules allow network communication to Pods from inside or outside of the cluster*
  - *uses the operating system packet filtering layer or forwards the traffic itself.*
- **Container runtime**
  - *Responsible for running containers*
  - *Kubernetes supports several container runtimes (containerd, CRI-O)*
  - *Any implementation of the Kubernetes CRI (Container Runtime Interface)*

# Container Stack



## Pod

- **Pod**
  - A group of one or more tightly-coupled containers.
  - Containers share storage and network resources.
  - A Pod runs a single instance of a given application
  - Pod's containers are always co-located and co-scheduled
  - Pod's containers run in a shared context, i.e. in a set of Linux namespaces
- Pods are created using workload resources
  - You do not create them directly
- Pods in a Kubernetes cluster are used in two main ways
  - Run a single container; the most common Kubernetes use case
  - Run multiple containers that need to work together

## Workloads

- An application running on Kubernetes
- Workloads run in a set of Pods
- Pre-defined workload resources to manage lifecycle of Pods
  - **Deployment** and **ReplicaSet**
    - managing a stateless application workload
    - any Pod in the Deployment is interchangeable and can be replaced if needed
  - **StatefulSet**
    - one or more related Pods that track state
    - For example, if a workload records data persistently, run a StatefulSet that matches each Pod with a persistent volume.
  - **DaemonSet**
    - Ensures that all (or some) Nodes run a copy of a Pod
    - Such as a cluster storage daemon, logs collection, node monitoring running on every node
  - **Job** and **CronJob**
    - Define tasks that run to completion and then stop.
    - Jobs represent one-off tasks, whereas CronJobs recur according to a schedule.

## Deployment Spec Example

- Deployment spec

```
1  apiVersion: apps/v1
2  kind: Deployment
3  metadata:
4    name: nginx-deployment
5  spec:
6    selector:
7      matchLabels:
8        app: nginx
9    replicas: 3 # tells deployment to run 3 pods matching the template
10   template:
11     metadata:
12       labels:
13         app: nginx
14     spec:
15       containers:
16         - name: nginx
17           image: nginx:1.14.2
18           ports:
19             - containerPort: 80
```

- A desired state of an application running in the cluster
- Kubernetes reads the Deployment spec and starts three app instances
- If an instance fails, Kubernetes starts a replacement app instance

# Service

- Networking
  - Containers within a Pod use networking to communicate via loopback
  - Cluster networking provides communication between different Pods.
- Service resource
  - An abstract way to expose an application running on a set of Pods
  - Example: a set of Pods with a label **app=nginx**, each listens on **tcp/9376**

```
1  apiVersion: v1
2  kind: Service
3  metadata:
4    name: my-service
5  spec:
6    selector:
7      app: nginx
8    ports:
9      - protocol: TCP
10      port: 80
11      targetPort: 9376
```

- This specification creates a new Service object named **my-service**
- The service targets **tcp/9376** on any Pod with the **app=nginx** label.
- Kubernetes assigns this Service a cluster IP address, which is used by the Service proxies.

# 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**.