# Middleware Architectures 2

## Lecture 6: 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

Evropský sociální fond
Praha & EU: Investujeme do vaší budoucnosti

Modified: Sun Mar 10 2024, 20:40:09
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 mashes, 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)*

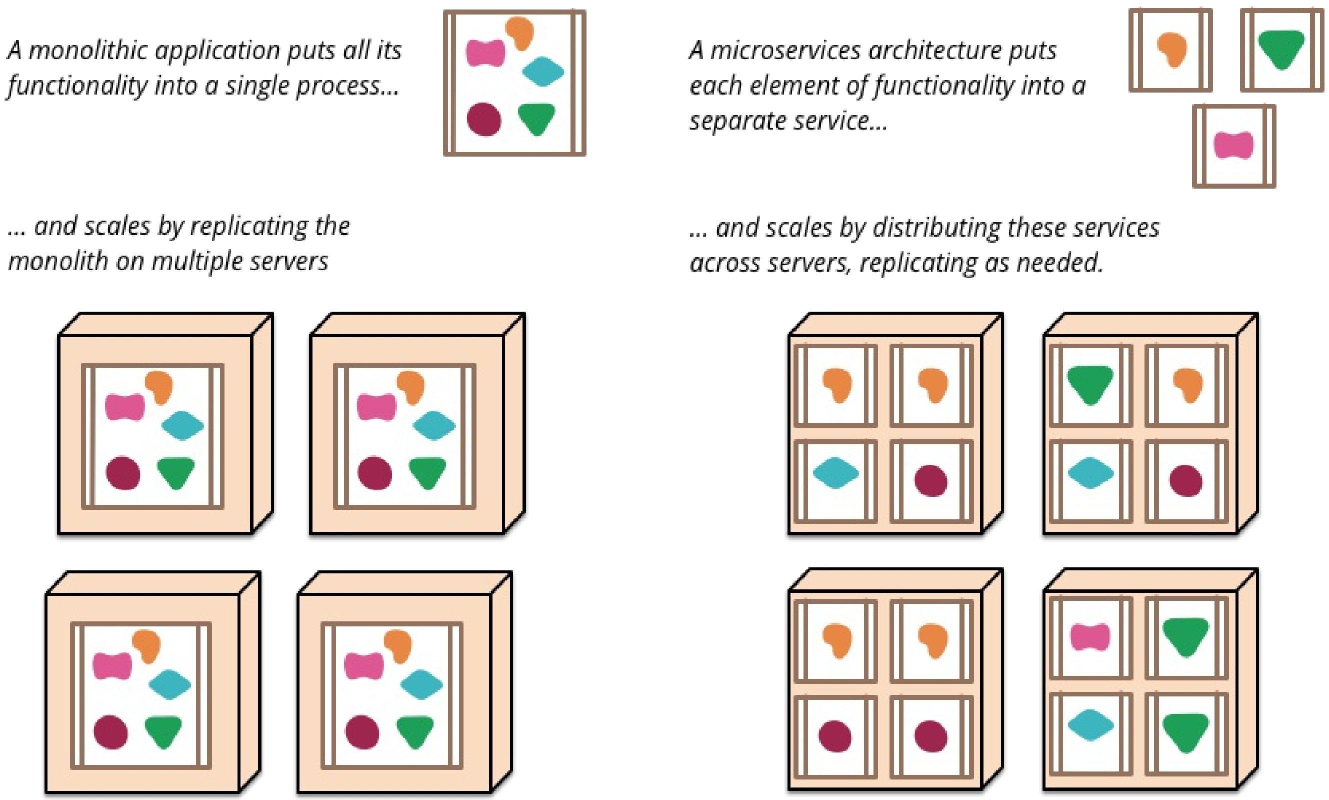
# CNFS Trail Map

# Overview

- Cloud Native
- Microservices
- Containers
- Kubernetes

# Overview

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



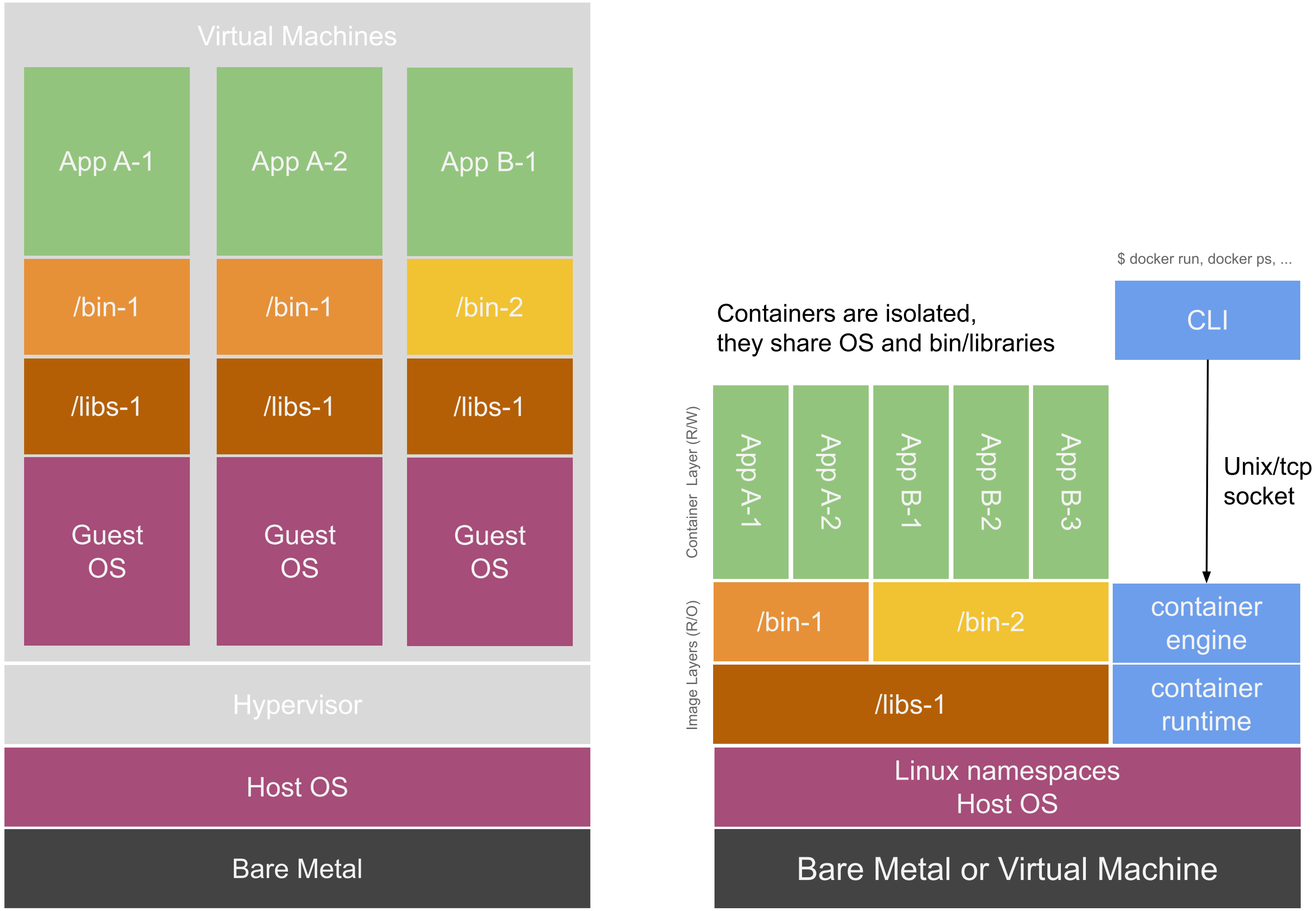
# Major Characteristics

- 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.*
- Impplemented using different technologies
  - *polyglot – programming languages, databases*

# Overview

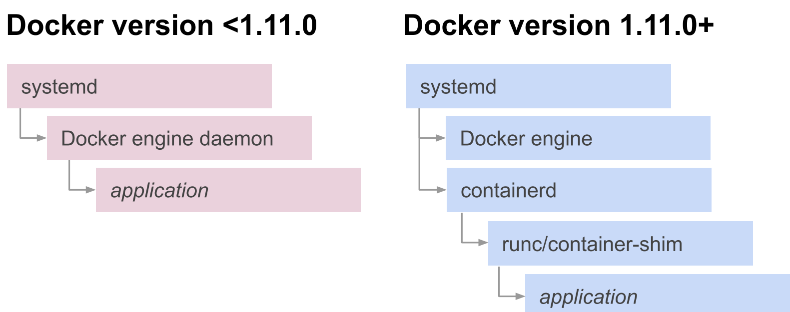
- Cloud Native
- Microservices
- Containers
  - *Overview*
  - *Linux Namespaces*
  - *Images*
  - *Working with Docker*
- Kubernetes

# Virtual Machines vs. Containers

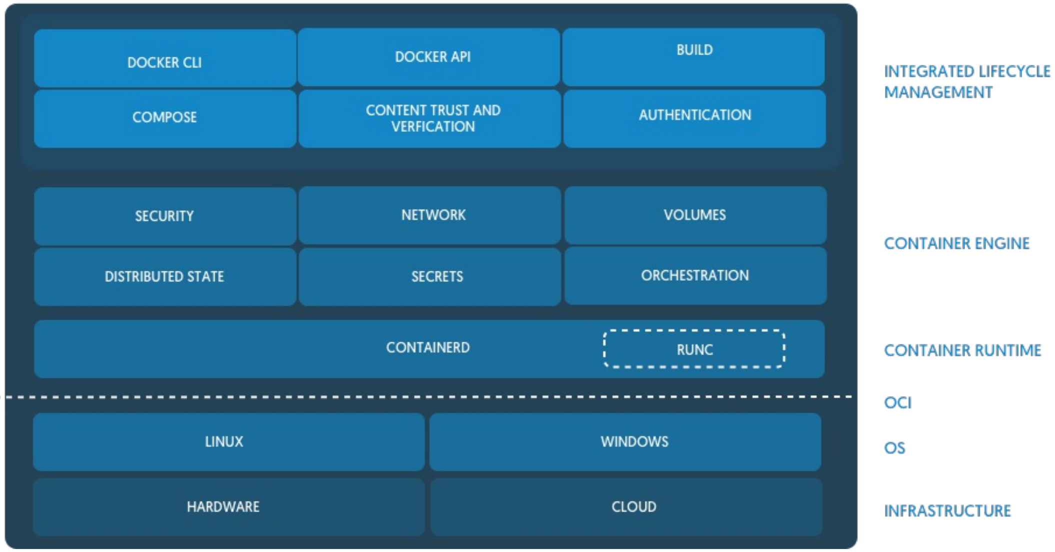


# Overview

- 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*



# 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.sh
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.sh
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
...
```

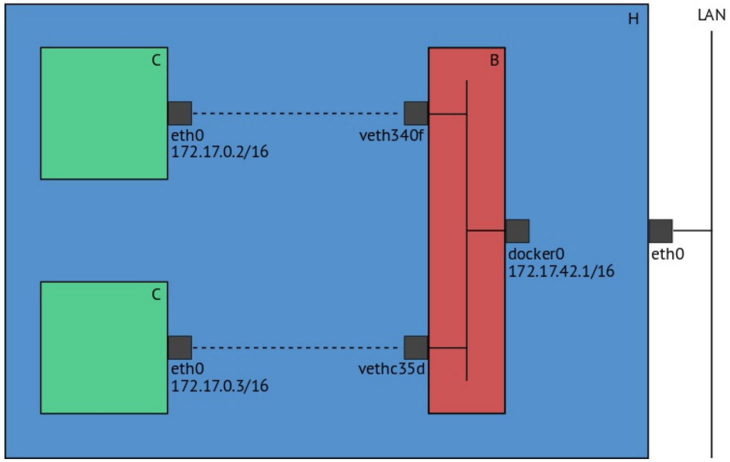
- Flexible configuration, for example:
  - *You can run two apps that only share the network namespace, e.g.* `4026531956`
  - *The apps can talk to each other*
  - *Any other app (not in this namespace) won't be able to talk to the apps*

# 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 prefered 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*

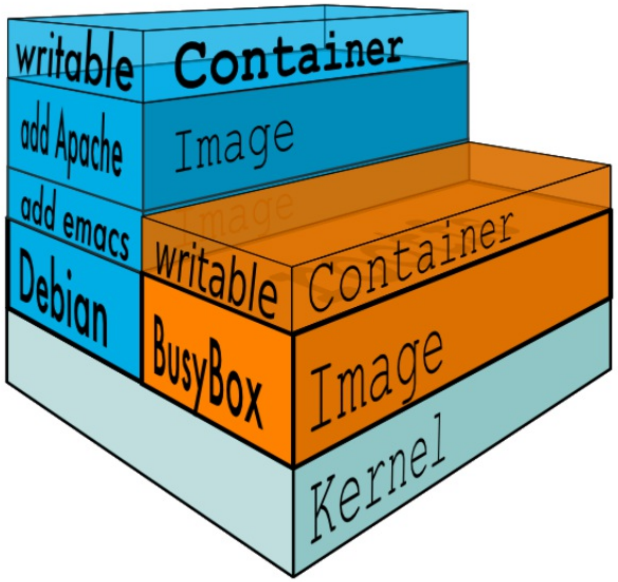
# Types: user

- `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

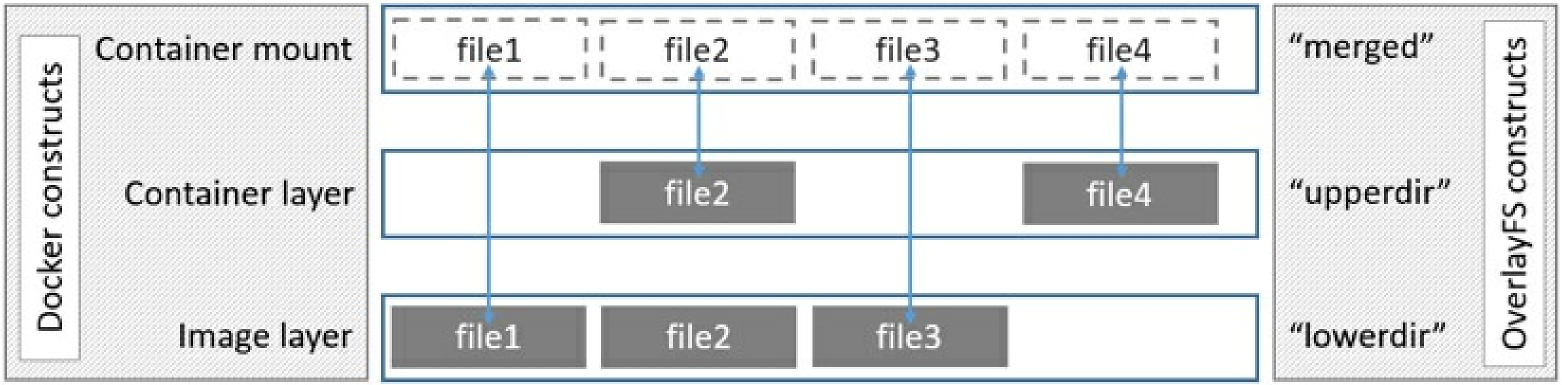
# Container Images




– *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
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 38f3ed2eac129654acef11c32670b534670c3a06e483fce313d72e3e0a15baa
drwx------ 3 root root 4096 Jun 20 16:11 55f1e14c361b90570df46371b20ce6d480c434981cbda5fd68c6ff61aa0a535
drwx------ 3 root root 4096 Jun 20 16:11 824c8a961a4f5e8fe4f4243dab57c5be798e7fd195f6d88ab06aea92ba93165
drwx------ 3 root root 4096 Jun 20 16:11 ad0fe55125ebf599da124da175174a4b8c1878afe6907bf7c78570341f30846
drwx------ 3 root root 4096 Jun 20 16:11 edab9b5e5bf73f2997524eebeac1de4cf9c8b904fa8ad3ec43b3504196aa380
```

  – *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

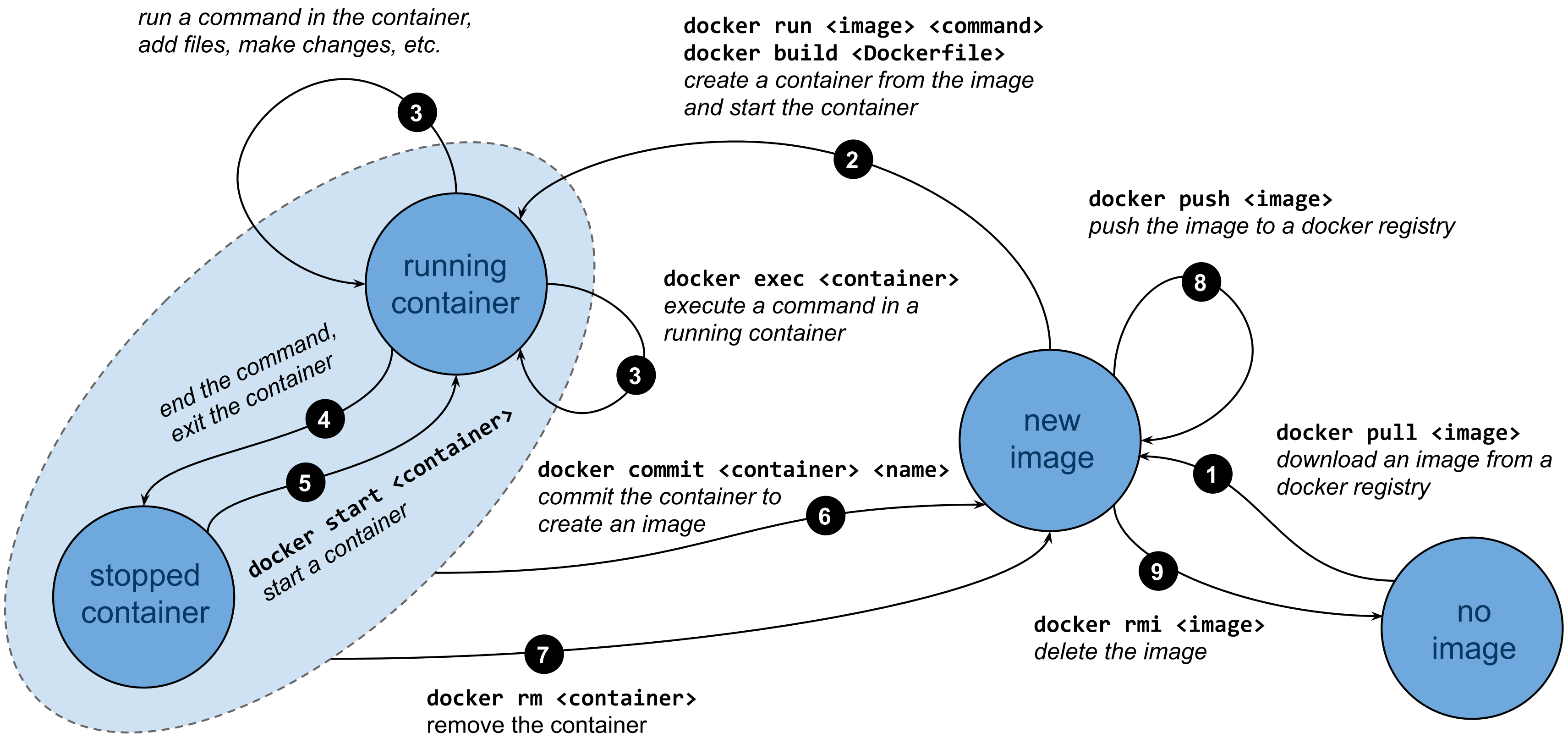
```
$ docker build -t tomvit/httpd:v1 .
Sending build context to Docker daemon 2.048 kB
Step 1 : FROM oraclelinux:7
 ---> 4c357c6e421e
Step 2 : MAINTAINER Tomas Vitvar <tomas@vitvar.com>
 ---> Running in 35feebb2ffab
 ---> 95b35d5d793e
Removing intermediate container 35feebb2ffab
Step 3 : RUN yum install -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 a remote registry.
**2:** You run a new container on top 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 sotrage volume as a data value 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 value 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*

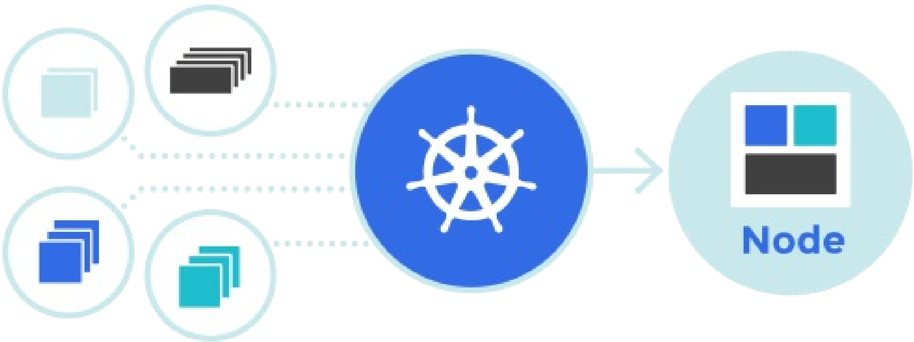
  ```
  docker create -v /dbdata --name dbstore training/postgres /bin/true
  docker run -d --volumes-from dbstore --name db1 training/postgres
  docker run -d --volumes-from dbstore --name db2 training/postgres
  ```

# Overview

- Cloud Native
- Microservices
- Containers
- Kubernetes

# Overview

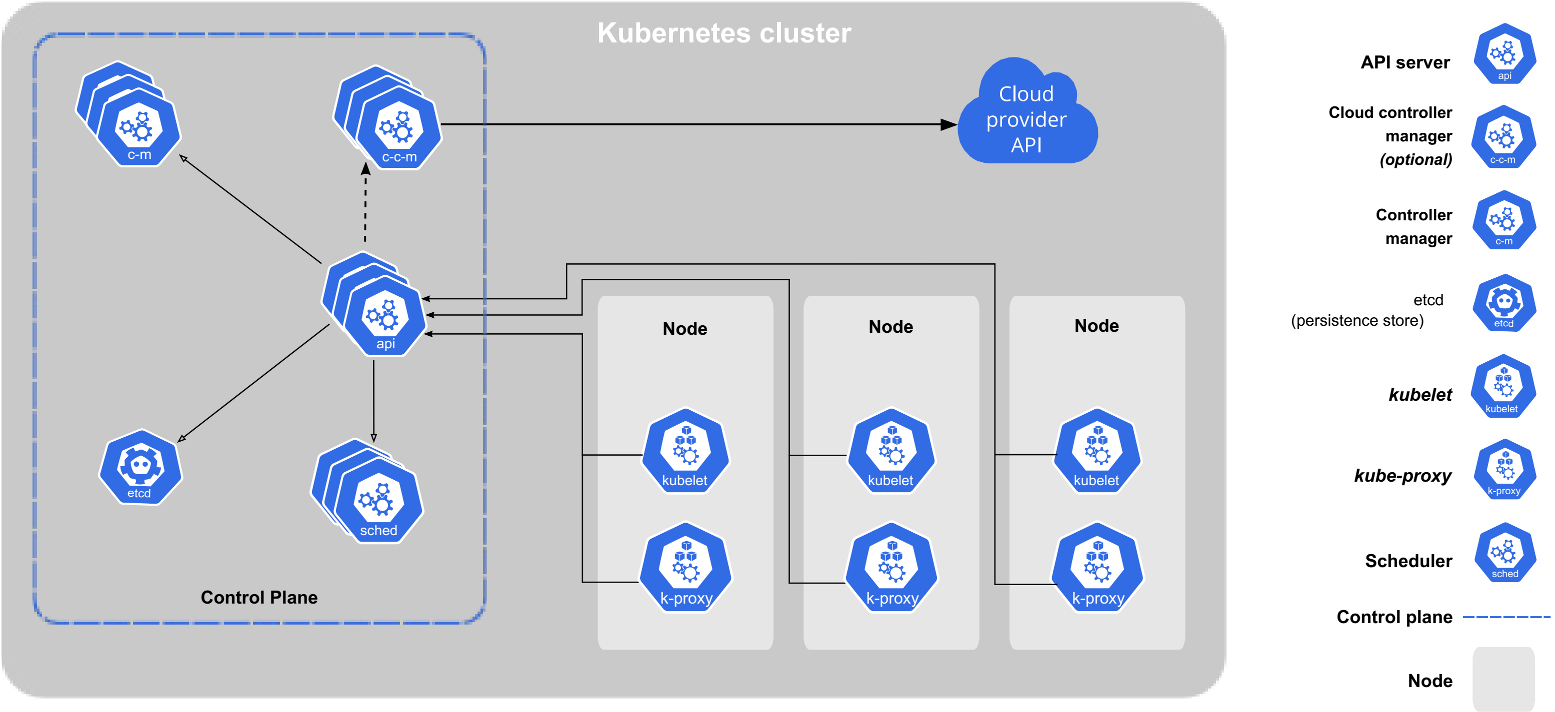
- In your architecture...
  - *Containers are atomic pieces of application architecture*
  - *Containers can be linked (e.g. web server, DB)*
  - *Containers access shared resources (e.g. disk volumes)*
- Kubernetes
  - *Automation of deployments, scaling, management of containerized applications across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



# 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
  - *Schedulling*
  - *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*

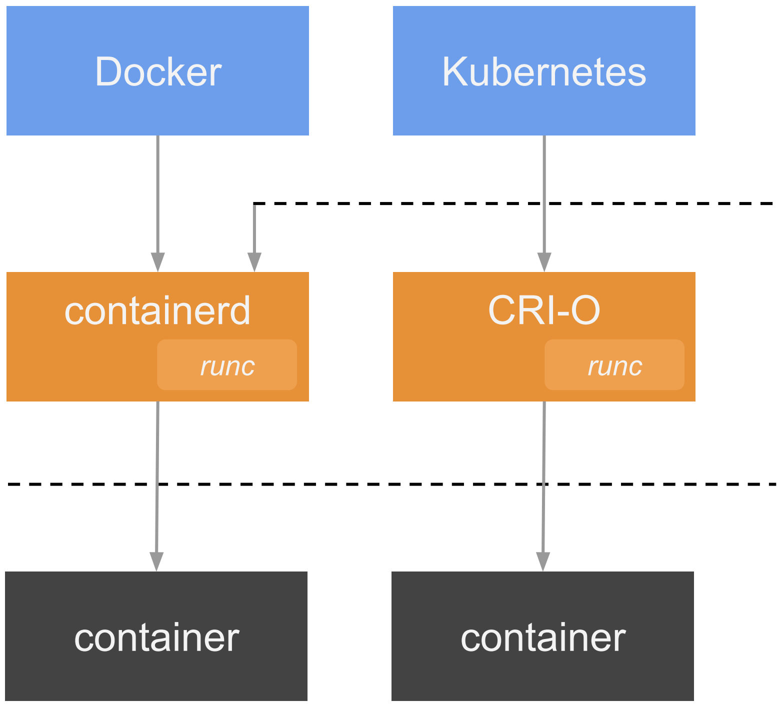
# Control Plane Components

- 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***

# 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*

# Container Stack




Tools to manager containers in both dev and prod environments.

**Container Runtime Interface (CRI)**
Kubernetes API defines how Kubernetes interact with container runtime.

Container runtimes that implement CRI spec. The containerd is a Docker component, it's CRI-compliant via *cri* plugin. CRI-O is a CRI implementation developed by RedHat/IBM.

**Open Container Initiative (OCI)**
A specification for container images and running containers.

Running containerized processes.

# 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 lifecylce 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

```yaml
apiVersion: apps/v1
kind: Deployment
metadata:
  name: nginx-deployment
spec:
  selector:
    matchLabels:
      app: nginx
  replicas: 3 # tells deployment to run 3 pods matching the template
  template:
    metadata:
      labels:
        app: nginx
    spec:
      containers:
      - name: nginx
        image: nginx:1.14.2
        ports:
        - 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`

```yaml
apiVersion: v1
kind: Service
metadata:
  name: my-service
spec:
  selector:
    app: nginx
  ports:
    - protocol: TCP
      port: 80
      targetPort: 9376
```

  - *This specification creates a new Service object named* `my-service`
  - *The servive 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`.