

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: Mon Apr 14 2025, 05:10:47
Humla v1.0

Overview

- Cloud Native
- Microservices
- Containers
- Kubernetes

Overview

- The Cloud Native Computing Foundation (CNCF)
 - *Motto: Building sustainable ecosystems for cloud native software*
 - *CNCF 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)*

CNCF Trail Map

Overview

- Cloud Native
- Microservices
- Containers
- Kubernetes

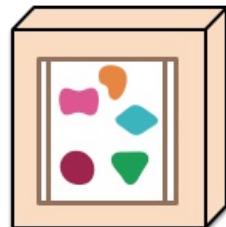
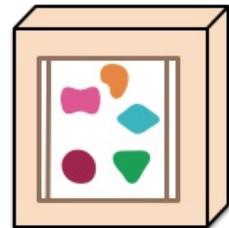
Overview

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

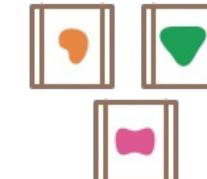
A monolithic application puts all its functionality into a single process...



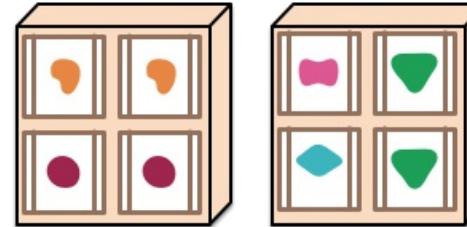
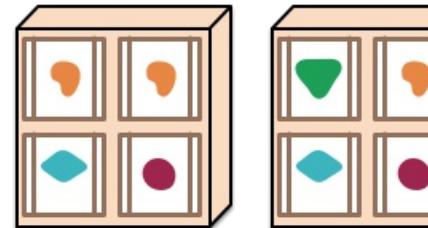
... and scales by replicating the monolith on multiple servers



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



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



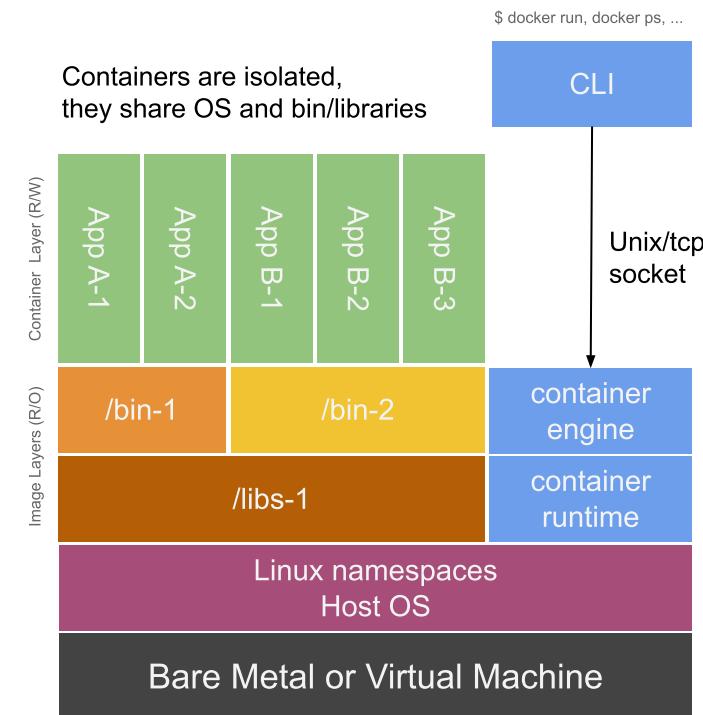
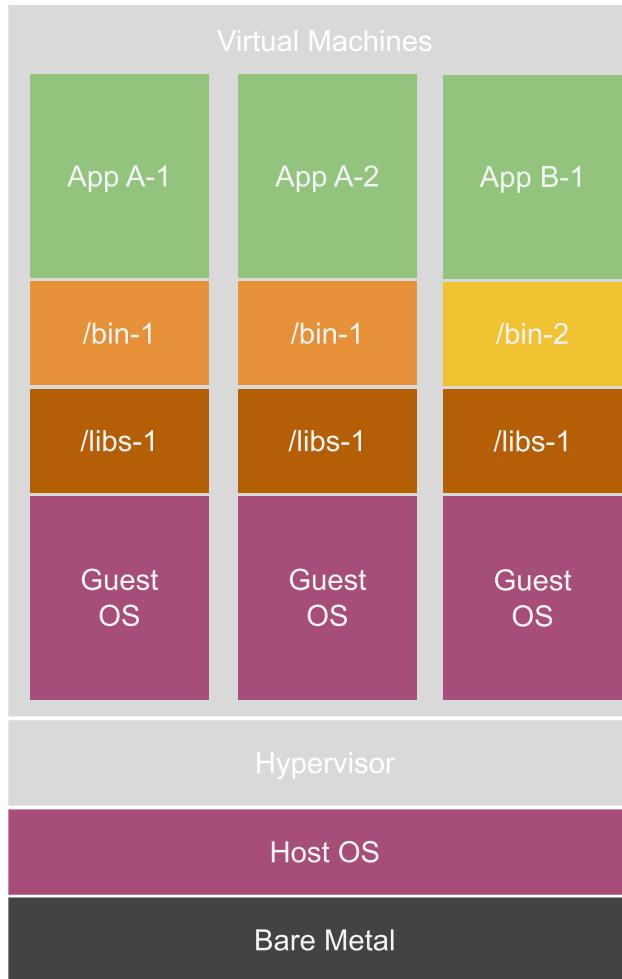
Major Characteristics

- 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

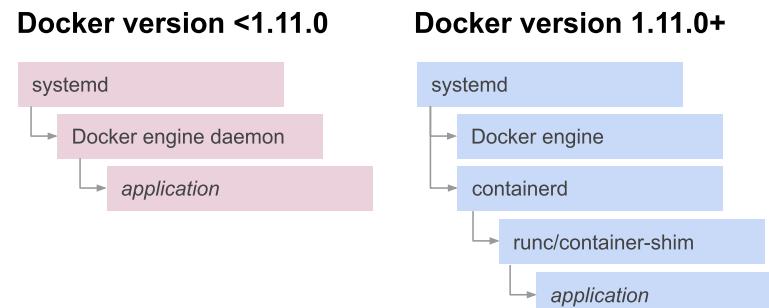
- Cloud Native
- Microservices
- Containers
 - *Overview*
 - *Linux Namespaces*
 - *Images*
 - *Working with Docker*
- Kubernetes

Virtual Machines vs. Containers

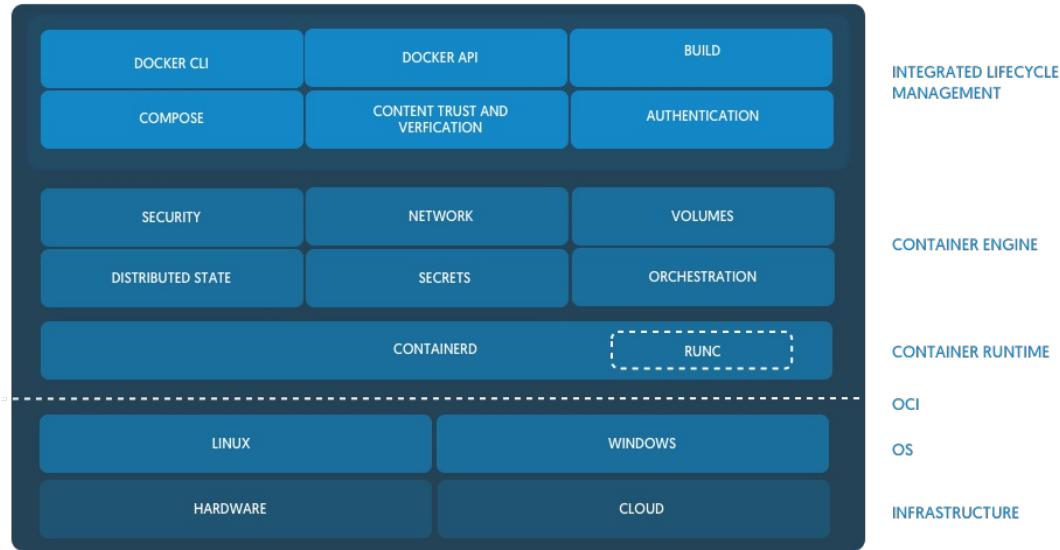


Overview

- 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*



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
...
```

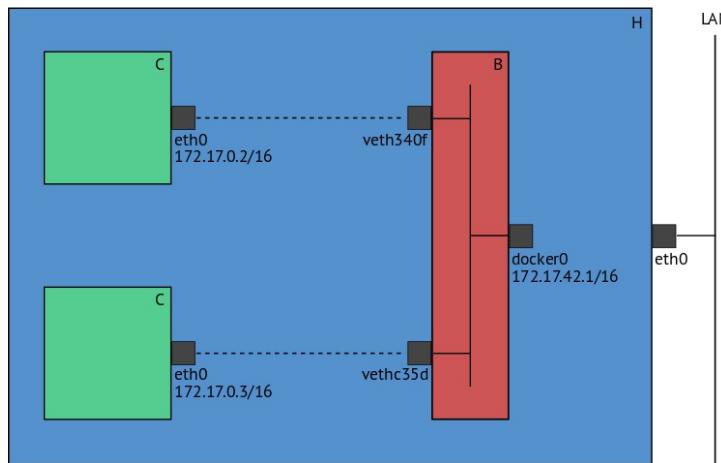
- Flexible configuration, for example:
 - *You can run two apps that only share the network namespace, e.g. 4026531956*
 - *The apps can talk to each other*
 - *Any other app (not in this namespace) won't be able to talk to the apps*

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 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

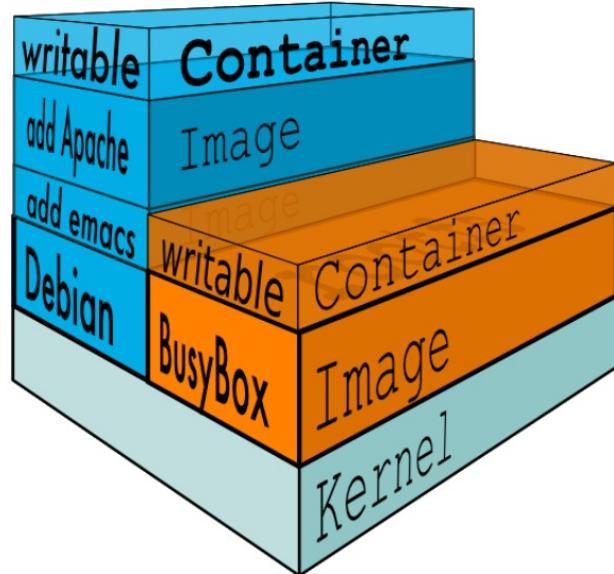
Types: user

- **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.

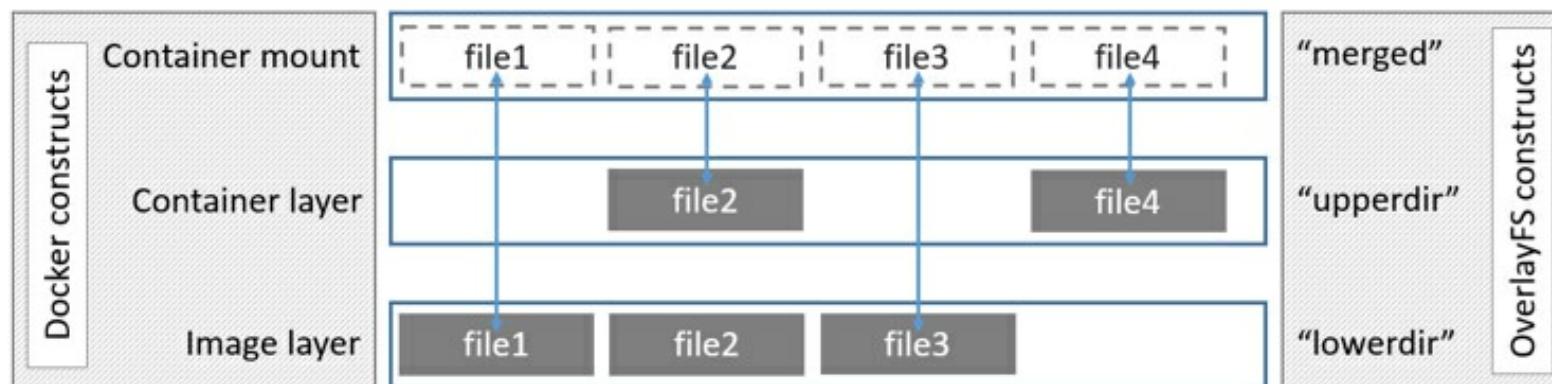


Image Layers Example

- 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
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

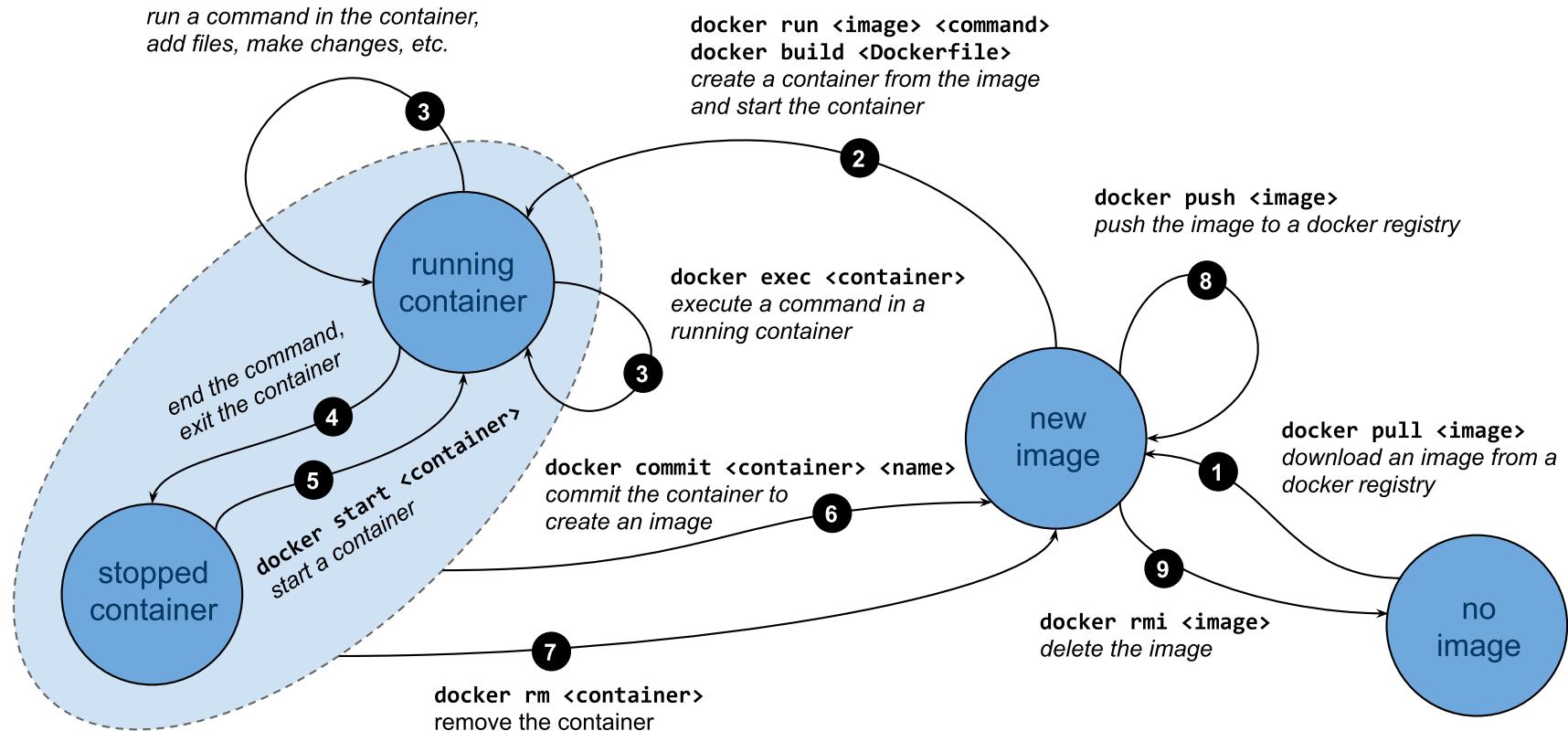
```
$ docker build -t tomvit/httpd:v1 .
Sending build context to Docker daemon 2.048 kB
Step 1 : FROM oraclelinux:7
--> 4c357c6e421e
Step 2 : MAINTAINER Tomas Vitvar <tomas@vitvar.com>
--> Running in 35feebb2ffab
--> 95b35d5d793e
Removing intermediate container 35feebb2ffab
Step 3 : RUN yum install -q -y httpd
--> Running in 3b9aeee3c3ef1
--> 888c49141af9
Removing intermediate container 3b9aeee3c3ef1
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

- 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
```

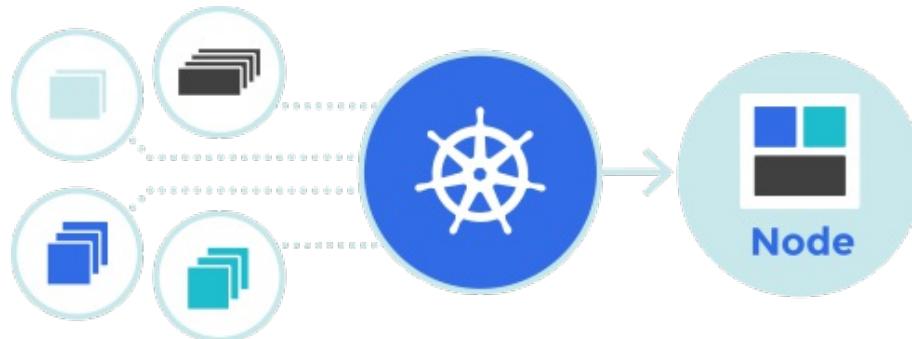
```
docker run -d --volumes-from dbstore --name db2 training/postgres
```

Overview

- Cloud Native
- Microservices
- Containers
- Kubernetes

Overview

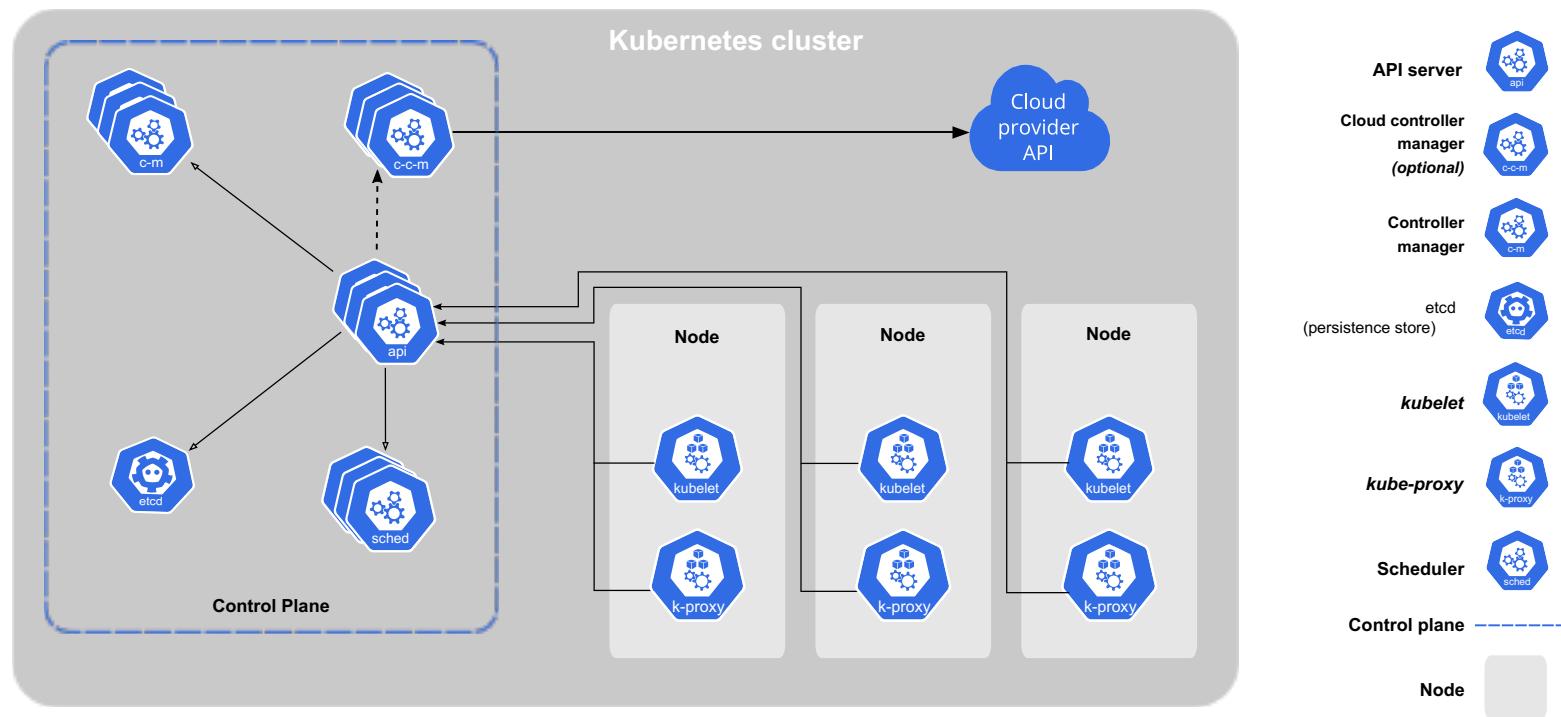
- In your architecture...
 - *Containers are atomic pieces of application architecture*
 - *Containers can be linked (e.g. web server, DB)*
 - *Containers access shared resources (e.g. disk volumes)*
- Kubernetes
 - *Automation of deployments, scaling, management of containerized applications across 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*

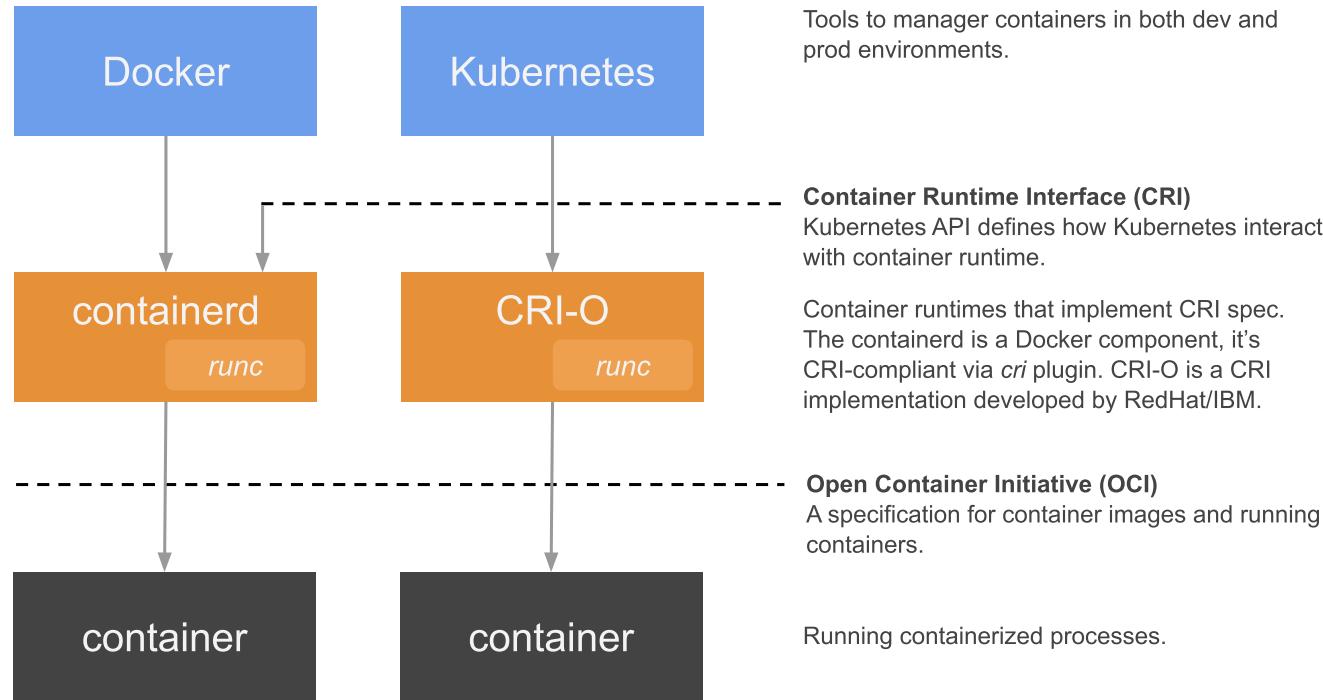
Control Plane Components

- 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**

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`.*