

# Middleware Architectures 1

## Lecture 4: Containers

**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>

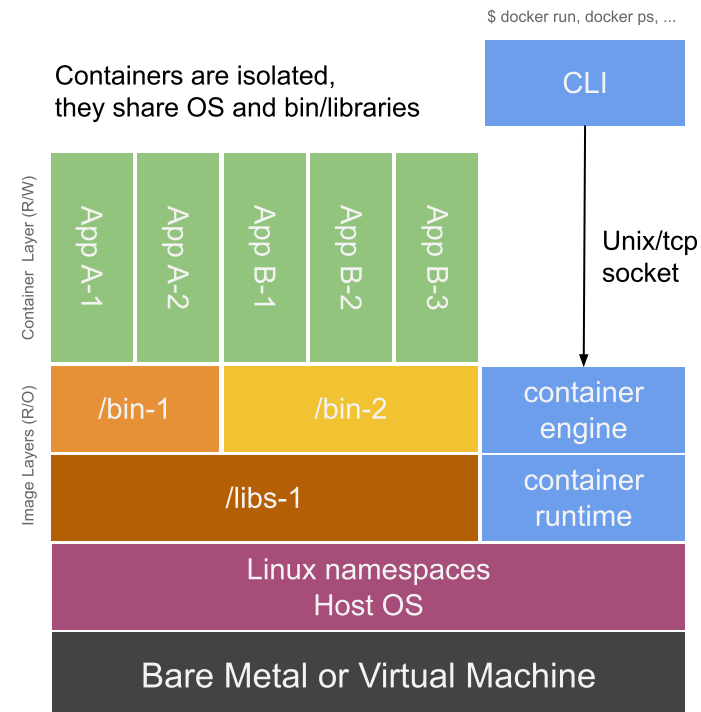
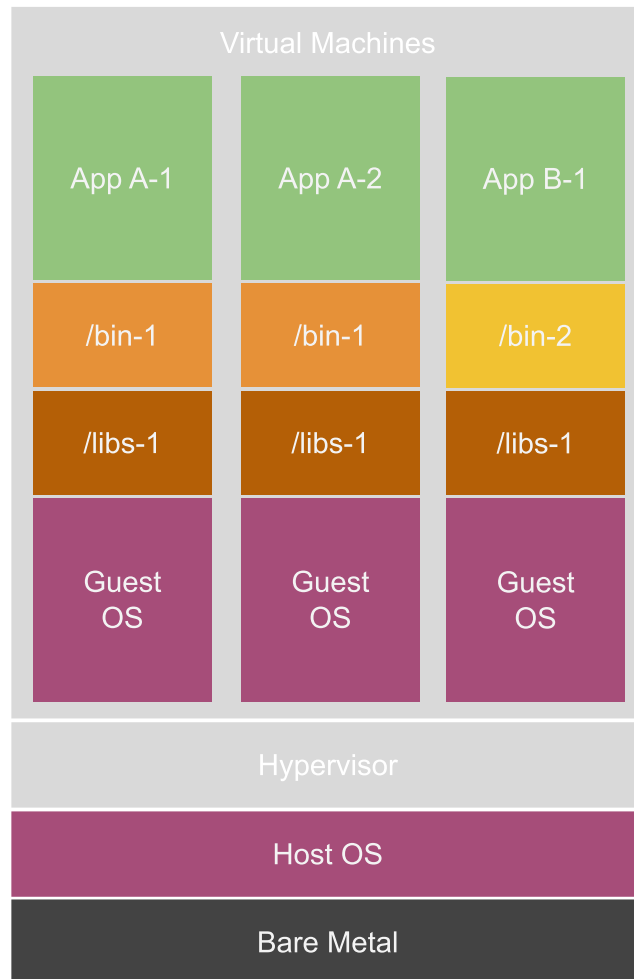


Modified: Mon Oct 27 2025, 06:42:02  
Humla v1.0

# Overview

- Overview
- Linux Namespaces
- Container Image

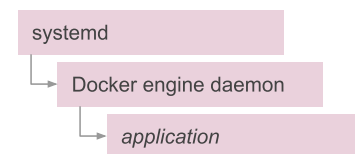
# Virtual Machines vs. Containers



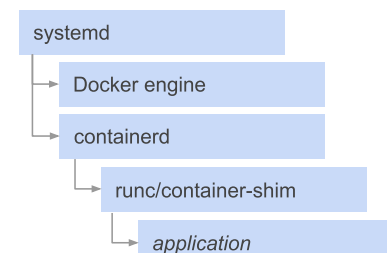
# Overview

- 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

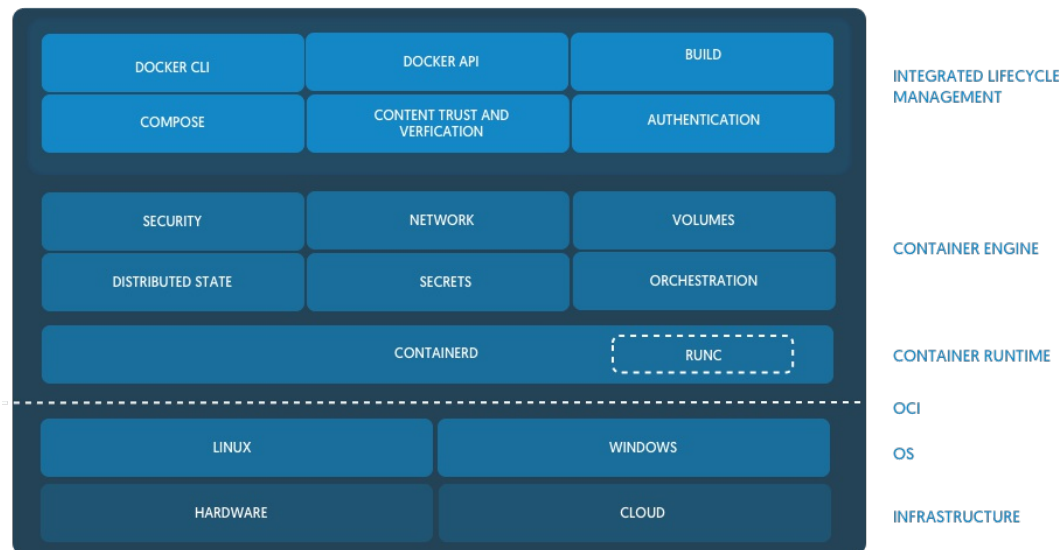
**Docker version <1.11.0**



**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

- Overview
- **Linux Namespaces**
- Container Image

# 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*

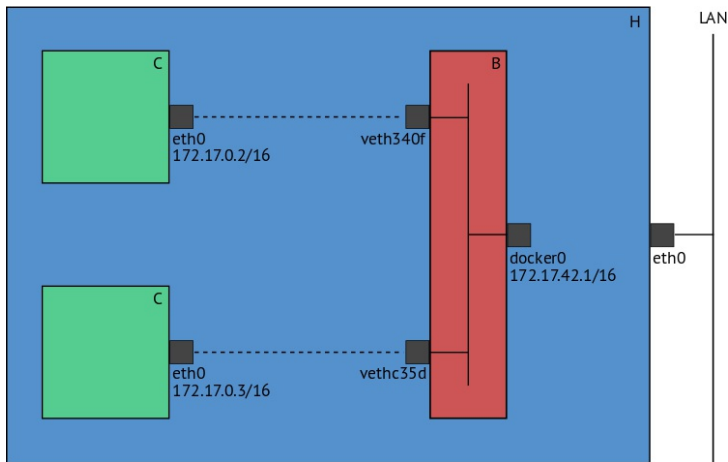


# Types: mnt, uts, ipc and pid

- **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

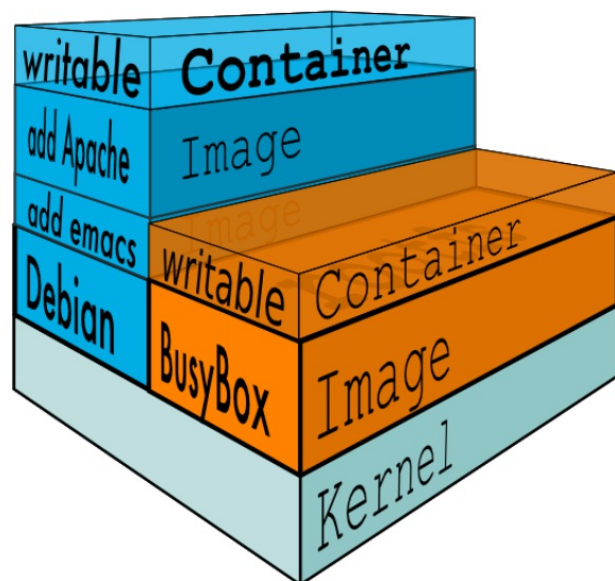
# Types: User & Cgroup

- **user** namespace
  - Isolates user and group IDs (UIDs/GIDs) between processes
  - Allows a process to have different privileges inside and outside the namespace
  - Enables **rootless containers** (process is non-root on host, but appears as root inside)
  - Example
    - A process runs as UID 0 (root) inside the container, but maps to a regular UID on the host
- **cgroup** namespace
  - **cgroups** (control groups)
    - Kernel feature to limit and measure process resource usage (CPU, memory, I/O)
  - cgroup namespace
    - Isolates the view of the cgroup hierarchy for each process
    - Prevents a container from seeing/modifying cgroups of the host/other containers
    - Improves security by restricting what resource controls a container can observe
    - **Example:** A container only sees its own CPU/memory usage limits, not the host's full cgroup tree

# Overview

- Overview
- Linux Namespaces
- Container Image

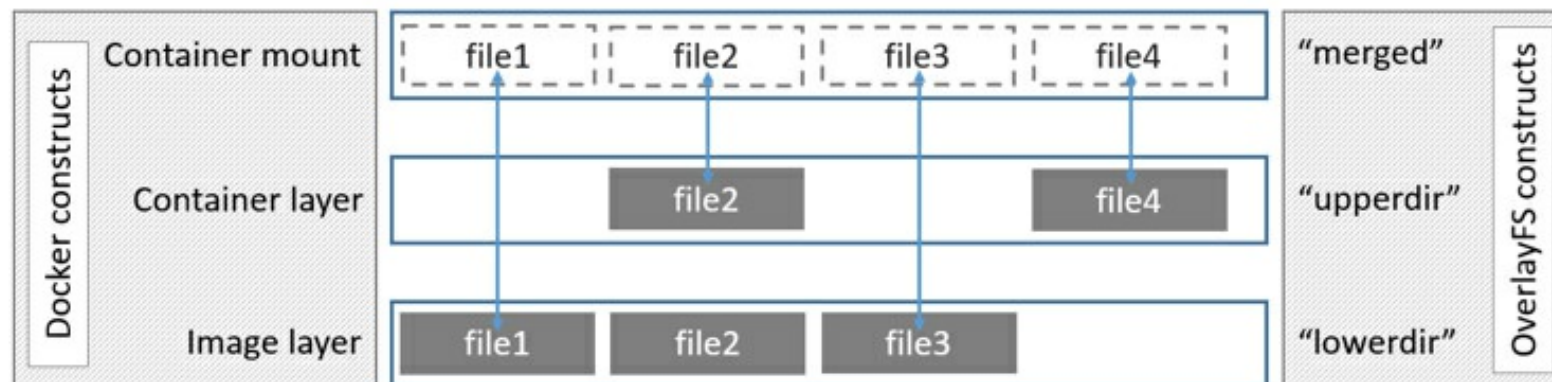
# Container Images



- 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
```

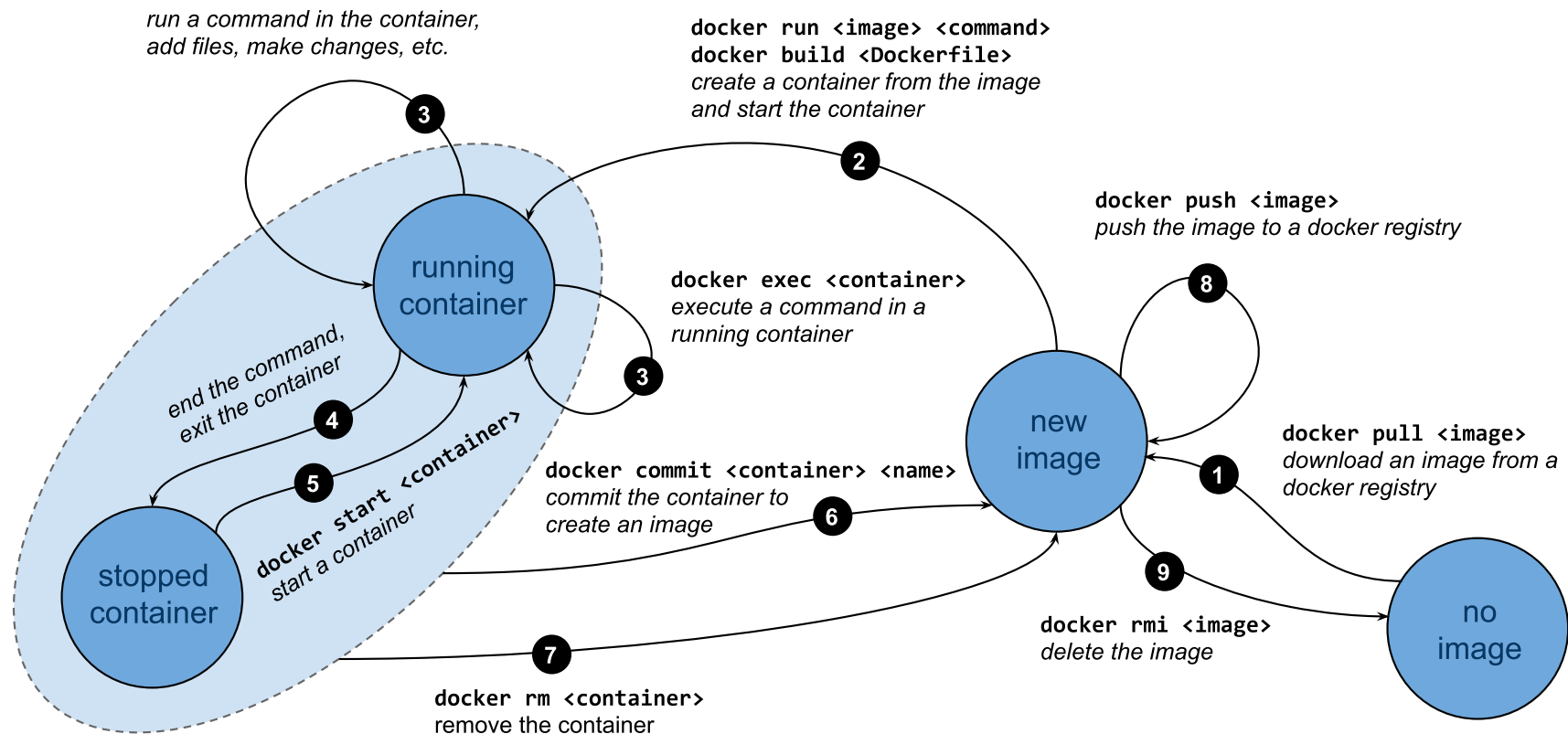
- A line in the Dockerfile will create an intermediary layer

```
$ 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.*



# 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.