Cloud Computing Systems

Lecture 9-10

Nuno Preguiça

(nuno.preguica_at_fct.unl.pt)

OUTLINE

Containers

- Introduction
- Under the hood
  - Kernel namespaces
  - Cgroups
  - Copy-on-write File system
- Docker
- Docker compose
- Docker swarm
- Kuebernetes

Virtual machines: Pros

Efficiency. A virtual machine allows to efficiently use resource and provides isolation.

Flexibility. Resources can be allocated as needed.

Backup and recovery. Virtual machines can be stored as a single file that can be easily backed up on another source.

OS freedom. Different guest OSs can exist on the same hypervisor.

Performance and moving. Hypervisors support moving a virtual machine from one host to another in case of performance degradation on the host machine.

VIRTUAL MACHINES: CONS

Performance overhead. A VM stack includes the guest OS, the hypervisor and potentially the host OS (for type 2 hypervisors).

Efficient resource utilization. Using multiple OSs in the same hypervisor duplicates the used resources.

WHY NOT USING SIMPLE PROCESSES INSTEAD OF VMS?

Isolation. We want that an application does not affect other applications in any way.

- E.g.: be sure that a malicious user in a web application cannot gain access to the entire server.

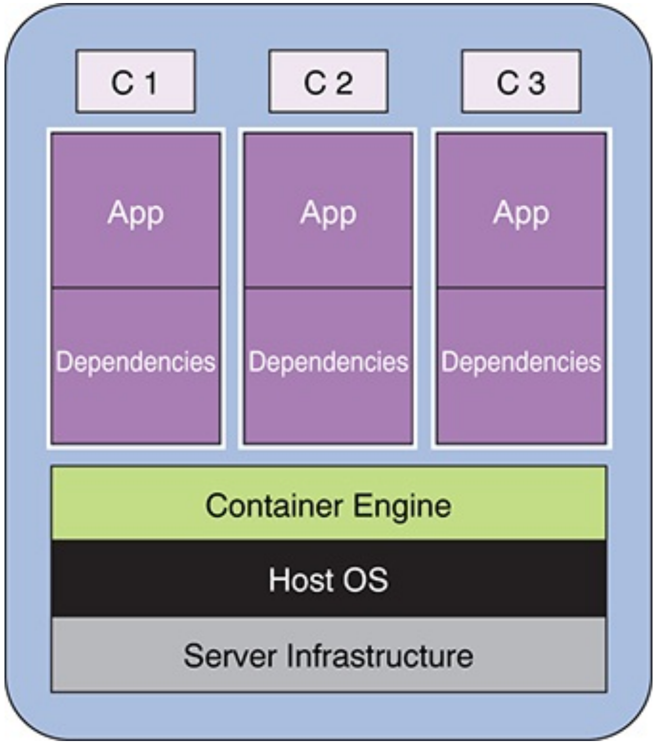
Manage application dependencies. Different applications have different dependencies – libraries, library versions, etc. Sometimes it is complex to install all dependencies of an application or keep the dependencies of all application in the same system.

What are containers?

Containers provide OS-level virtualization.

Provides private namespace, network interface and IP address, file systems, etc.

Unlike VMs, containers share the host system's kernel with other containers.



CONTAINERS PROMISES

Build once, run anywhere

- Faster deployment
- Portability across machines
- Version control
- Simplified dependency management

Before containers

Isolating applications is problem that exists for years.

chroot – Allows to specify a directory as the root directory for an application. This makes it impossible for an application to access other application files (and other resources, depending on the systems).

Chroot isolation not perfect. The process can still access the underlying IO devices, it can execute a second chroot if it has enough privileges.

All application dependencies need to be copied into the chroot directory.

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DOCKER

Docker is the most popular container technology.

It builds on the following technologies:

- Kernel namespaces
- Cgroups
- Copy-on-write File system

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KERNEL NAMESPACES

Kernel namespaces split kernel resources (processes, users, network stacks, etc.) into one instance per namespace.

A process only views the resources in its namespace.

There are currently 6 namespaces:

- mnt (mount points, filesystems)
- pid (processes)
- net (network stack)
- ipc (System V IPC)
- uts (hostname)
- user (UIDs)

KERNEL NAMESPACES: IMPLEMENTATION

Support for kernel namespaces added to the kernel.

New system calls:

- clone() - creates a new process and a new namespace;
  - The process is associated to the new namespace.
- unshare() - creates a new namespace and attaches the current process to it.
- setns() - allows for joining an existing namespace.

USE OF KERNEL NAMESPACES

Kernel namespaces are used to create isolated containers that have no visibility to objects outside the container.

The processes running inside a container share the underlying kernel with other containers.

SOME MORE INFO

UTS Namespace:

- Provides namespace-specific hostname and domain name.

Network Namespace:

- A network namespace is logically a copy of the network stack, with its own routes, firewall rules, and network devices.
- Each network namespace has its own IP addresses.
- A network device belongs to exactly one network namespace. A socket belongs to exactly one network namespace.
- Communicating between two network namespaces:
  - Veth (virtual ethernet) is used like a pipe between two namespaces
  - Sockets also work

Some more info (2)

Mount Namespace:

- On creation, the file system tree is copied to new space, with all previous mounts visible.
- Future mounts/unmounts invisible to the rest of the system.

PID Namespace:

- Processes in different PID namespaces can have the same process ID.

User Namespace:

- A process will have distinct set of UIDs, GIDs and capabilities.

IPC Namespace:

- Each namespace gets its own IPC objects and POSIX message queues.

DOCKER

Docker is the most popular container technology.

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- Kernel namespaces
- **Cgroups**
- Copy-on-write File system

CONTROL GROUPS (CGROUPS)

Cgroups are a mechanism for applying hardware resource limits and access controls to a process or collection of processes.

The cgroup mechanism and the related subsystems provide a tree-based hierarchical, inheritable and optionally nested mechanism of resource control.

CGROUPS UNDER THE HOOD

The implementation of cgroups requires a few, simple hooks into the rest of the kernel: in boot phase, process creation and destroy.

All operations on cgroups are executed using operations on a VFS (virtual file system).

There are 11 cgroup subsystems: cpuset, freezer, mem, blkio, net_cls, net_prio, devices, perf, hugetlb, cpu_cgroup, cpuacct.

CGROUPS UNDER THE HOOD (2)

cpu, cpuacct, cpuset – allows to control the minimum and maximum CPU time of the processes in a cgroup, and to assign processes to a cgroup.

memory – allows to limit the memory used by a cgroup.

devices – allows to control which processes may create devices and open them for eeading and writing.

freezer – allows to suspend and restore all processes in a cgroup.

net_cls, net_prio – allows to give priorities, per network interface, and to place a classid on packets created in a cgroup; this classid can be used in firewall rules, shape traffic, etc. (does not apply to incoming traffic)

CGROUPS UNDER THE HOOD (2)

blkio – controls and limits access to specified block devices.

perf_event – allows perf monitoring of the set of processes in a cgroup.

hugetlb - supports limiting the use of huge pages by cgroups.

pids – allows limiting the number of process that may be created in a cgroup (and its descendants).

rdma - permits limiting the use of RDMA/IB-specific resources per cgroup.

USE OF CGROUPS

Cgroups are used to limit the memory and CPU consumption of containers. A container can be resized by simply changing the limits of its corresponding cgroup.

DOCKER

Docker is the most popular container technology.

It builds on the following technologies:

- Kernel namespaces
- Cgroups
- **Copy-on-write File system**

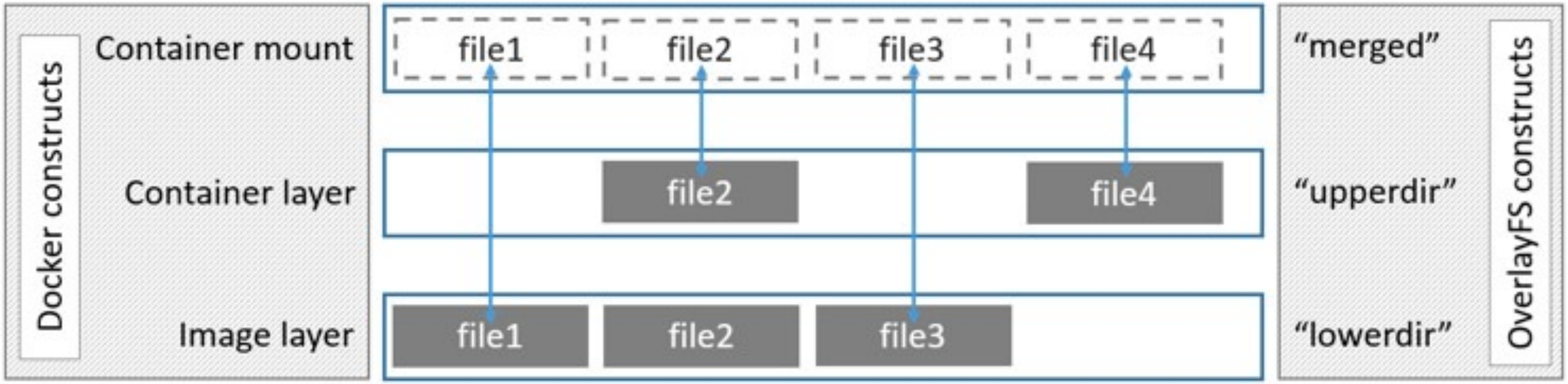
UnionFS

UnionFS is a copy-on-write file system that is the union of existing file systems.

Gives a unified view of the file system, that combines all stacked file systems.

On write to the UnionFS, the overwritten data is saved to a new path, specific to that container.

- Thus, writes of one container do not affect reads of another container



USE OF UNIONFS

UnionFS allows several containers to share common data. Each layer is only stored once.

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Docker

Built on top of kernel namespaces, cgroups, unionFS, and capabilities.

Each container gets its own set of namespaces and cgroups.

Namespaces isolate containers from each other: one container cannot even see the list of processes in another container.

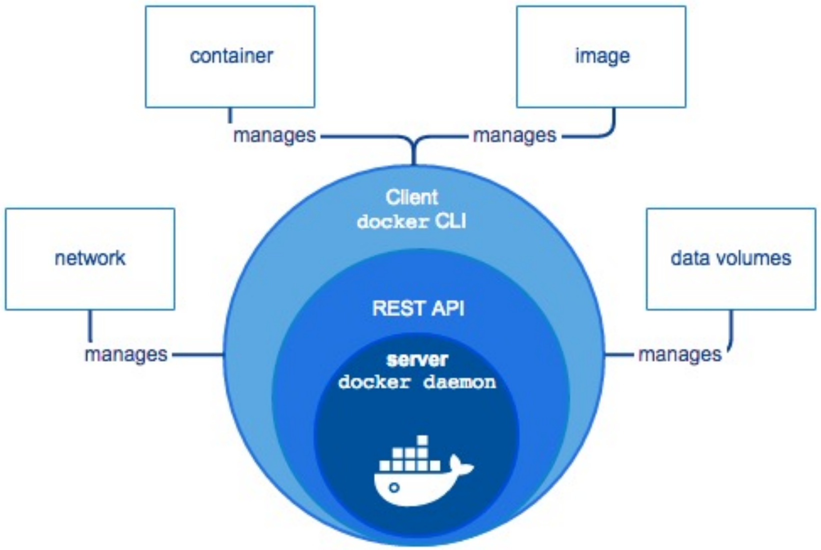
Cgroups allow the admin to isolate the resources used by each container and its children.

Running the docker daemon requires root privileges.

Docker provides a whitelist of capabilities to root users inside a container.

DOCKER ENGINE

- Docker daemon (dockerd) manages Docker objects such as images, containers, networks, and volumes.
- The docker client sends requests to docker daemon.

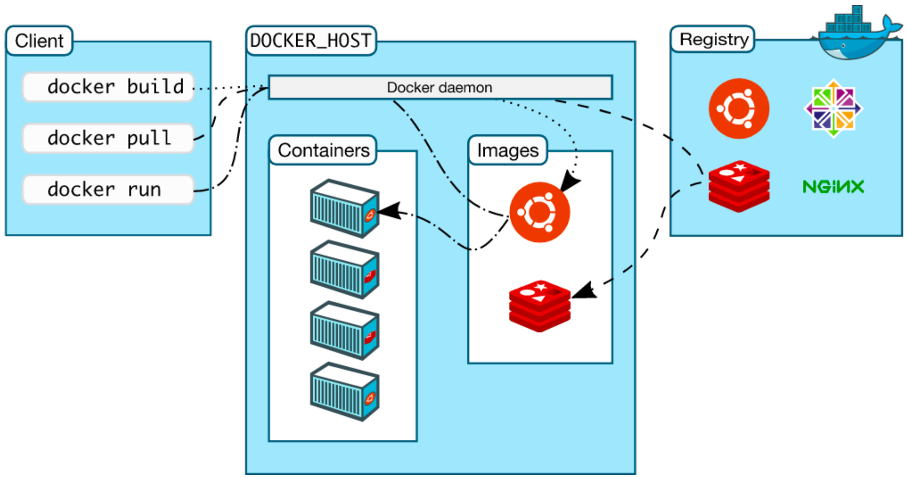


Docker engine (2)

A Docker *registry* stores Docker images. Docker is configured to search in Docker Hub by default.

An *image* is a read-only template with instructions for creating a Docker container. Often, an image is *based on* another image, with some additional customization.

A Docker image can be created from the specification in a Dockerfile.



CREATING DOCKER IMAGE

FROM <image>[:<tag>] [AS <name>]

Initializes a new build stage and sets the Base Image.

ADD <src>... <dest>

COPY <src>... <dest>

Copies new files, directories from <src> and adds them to the filesystem of the image at the path <dest>.

ADD allows to use URL as src and unpacks (tar, bzip) archives.

This creates a new layer.

```
FROM jboss/wildfly:14.0.1.Final

COPY *.war
/opt/jboss/wildfly/standalone/deploymen
ts/

RUN /opt/jboss/wildfly/bin/add-user.sh
admin Admin#70365 --silent

EXPOSE 9990

CMD
["/opt/jboss/wildfly/bin/standalone.sh"
, "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
```

Creating docker image (2)

RUN <command>

RUN ["exec","param1","param2"]

Execute a commands in a new layer on top of the current image and commit the results.

As a RUN creates a new layer, cleanup should be made in the same command.

```
RUN apt-get update && \
  apt-get install -y \
  --no-install-recommends \
  g++ \
  gcc \
  libc6-dev \
  make \
  && rm -rf /var/lib/apt/lists/*
```

```
FROM jboss/wildfly:14.0.1.Final

COPY *.war
/opt/jboss/wildfly/standalone/deploymen
ts/

RUN /opt/jboss/wildfly/bin/add-user.sh
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EXPOSE 9990

CMD
["/opt/jboss/wildfly/bin/standalone.sh"
, "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
```

Creating docker image (3)

`EXPOSE <port> [<port>/<protocol>...]`

Informs Docker that the container listens on the specified network ports at runtime. By default, protocol is assumed to be TCP.

```
FROM jboss/wildfly:14.0.1.Final

COPY *.war
/opt/jboss/wildfly/standalone/deploymen
ts/

RUN /opt/jboss/wildfly/bin/add-user.sh
admin Admin#70365 --silent

EXPOSE 9990

CMD
["/opt/jboss/wildfly/bin/standalone.sh"
, "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
```

Creating docker image (4)

`CMD command param1 param2`

`CMD ["exec","param1","param2"]`

Sets the command to be executed when running the image.

Only one command per image is allowed. If more than one command is specified, only the last one is executed. When running the docker, the command can be overridden.

```
FROM jboss/wildfly:14.0.1.Final

COPY *.war
/opt/jboss/wildfly/standalone/deploymen
ts/

RUN /opt/jboss/wildfly/bin/add-user.sh
admin Admin#70365 --silent

EXPOSE 9990

CMD
["/opt/jboss/wildfly/bin/standalone.sh"
, "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
```

CREATING DOCKER IMAGE (5)

`ENTRYPOINT command param1 param2`

`ENTRYPOINT ["exec","param1","param2"]`

Sets the command to be executed when running the image. This cannot be overridden when starting the image.

Parameters specified when starting the image will be passed as parameters.

```
FROM jboss/wildfly:14.0.1.Final

COPY *.war
/opt/jboss/wildfly/standalone/deploymen
ts/

RUN /opt/jboss/wildfly/bin/add-user.sh
admin Admin#70365 --silent

EXPOSE 9990

CMD
["/opt/jboss/wildfly/bin/standalone.sh"
, "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
```

CREATING DOCKER IMAGE (6)

`WORKDIR /path/to/workdir`

Sets the environment variable <key> to the value <value>, for both the build process and when the container runs.

```
FROM jboss/wildfly:14.0.1.Final

WORKDIR /opt/jboss/wildfly

ADD scc-backend-aula4-0.1.war
standalone/deployments/

RUN bin/add-user.sh admin Admin#70365 -
-silent

EXPOSE 9990

CMD ["bin/standalone.sh", "-b",
"0.0.0.0", "-bmanagement", "0.0.0.0"]
```

CREATING DOCKER IMAGE (7)

ENV <key> <value>

ENV <key>=<value> ...

Sets the environment variable <key> to the value <value>, for both the build process and when the container runs.

USER <user>

Sets the user name (or UID) and optionally the user group (or GID) to use when running the image and for any RUN, CMD and ENTRYPOINT instructions that follow it in the Dockerfile.

```
FROM jboss/wildfly:14.0.1.Final

COPY *.war
/opt/jboss/wildfly/standalone/deploymen
ts/

RUN /opt/jboss/wildfly/bin/add-user.sh
admin Admin#70365 --silent

EXPOSE 9990

CMD
["/opt/jboss/wildfly/bin/standalone.sh"
, "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
```

CREATING DOCKER IMAGE (8)

VOLUME ["/data"]

Creates a mount point with the specified name and marks it as holding externally mounted volumes from native host or other containers.

```
FROM jboss/wildfly:14.0.1.Final

COPY *.war
/opt/jboss/wildfly/standalone/deploymen
ts/

RUN /opt/jboss/wildfly/bin/add-user.sh
admin Admin#70365 --silent

EXPOSE 9990

CMD
["/opt/jboss/wildfly/bin/standalone.sh"
, "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
```

BUILD DOCKER IMAGE

```
docker build [OPTIONS] PATH
```

Builds a docker image. PATH should specify a directory containing a Dockerfile and all resources to be copied.

Some options:

-t tag: specifies the tag for the built image.

BUILD DOCKER IMAGE (9)

```
nmp$ docker build -t nunopreguica/ccs1920-app container
Sending build context to Docker daemon  20.94MB
Step 1/6 : FROM jboss/wildfly:14.0.1.Final
 ---> 8c9bcba630f0
Step 2/6 : WORKDIR /opt/jboss/wildfly
 ---> Using cache
 ---> d6992eeae570
Step 3/6 : ADD scc-backend-aula4-0.1.war  standalone/deployments/
 ---> Using cache
 ---> 46f3931aff1a
Step 4/6 : RUN bin/add-user.sh admin Admin#70365 --silent
 ---> Using cache
 ---> 24fd2f62ab29
Step 5/6 : EXPOSE 9990
 ---> Using cache
 ---> 025cf1e0321b
Step 6/6 : CMD ["bin/standalone.sh", "-b", "0.0.0.0", "-bmanagement",
"0.0.0.0"]
 ---> Using cache
 ---> 4a7f4c112ff0
Successfully built 4a7f4c112ff0
Successfully tagged nunopreguica/ccs1920-app:latest
```

DOCKER RUN

```
docker run [OPTIONS] IMAGE[:TAG|@DIGEST] [COMMAND] [ARG...]
```

Runs an image, downloading it if necessary.

Some options:

-P : Publish all exposed ports to the host interfaces

-p=[] : Publish a container's port or a range of ports to the host

```
$ docker run -p 9990:9990 -p 8080:8080
nunopreguica/ccs1920-app
```

-it : Runs the image in interactive mode.

```
$ docker run -it ubuntu:14.04 /bin/bash
```

DOCKER RUN (2)

```
docker run [OPTIONS] IMAGE[:TAG|@DIGEST] [COMMAND] [ARG...]
```

Runs an image, downloading it if necessary.

Some options:

-v, --volume=[host-src:]container-dest[:<options>]: Bind mount a volume.

```
$ docker run -v $(pwd):/config -t nunopreguica/ccs1920-test artillery run create-posts.yml
```

DOCKER RUN (3)

-c, --cpu-shares=0	CPU shares (relative weight)
--cpus=0.000	Number of CPUs. Number is a fractional number. 0.000 means no limit.
--cpu-period=0	Limit the CPU CFS (Completely Fair Scheduler) period
--cpuset-cpus=""	CPUs in which to allow execution (0-3, 0,1)
--cpuset-mems=""	Memory nodes (MEMs) in which to allow execution (0-3, 0,1). Only effective on NUMA systems.
--cpu-quota=0	Limit the CPU CFS (Completely Fair Scheduler) quota
--cpu-rt-period=0	Limit the CPU real-time period. In microseconds. Requires parent cgroups be set and cannot be higher than parent. Also check rtprio ulimits.
--cpu-rt-runtime=0	Limit the CPU real-time runtime. In microseconds. Requires parent cgroups be set and cannot be higher than parent. Also check rtprio ulimits.

DOCKER RUN (4)

-m, --memory=""	Memory limit (format: <number>[<unit>]). Number is a positive integer. Unit can be one of b, k, m, or g. Minimum is 4M.
--memory-swap=""	Total memory limit (memory + swap, format: <number>[<unit>]). Number is a positive integer. Unit can be one of b, k, m, or g.
--memory-reservation=""	Memory soft limit (format: <number>[<unit>]). Number is a positive integer. Unit can be one of b, k, m, or g.
--kernel-memory=""	Kernel memory limit (format: <number>[<unit>]). Number is a positive integer. Unit can be one of b, k, m, or g. Minimum is 4M.

Other docker commands

`docker ps [OPTIONS]`

Lists containers.

`docker kill [OPTIONS] CONTAINER [CONTAINER...]`

Kills one or more containers.

OTHER DOCKER COMMANDS (2)

```
docker images [OPTIONS] [REPOSITORY[:TAG]]
```

Lists images.

```
docker pull [OPTIONS] NAME[:TAG|@DIGEST]
```

Pulls an image from a registry.

```
docker push [OPTIONS] NAME[:TAG]
```

Push an image or a repository to a registry.

DOCKER NETWORKING

There are several options of networking.

Bridge networking allows to connect several dockers containers running in the same docker host.

A network can be created using docker network create.

```
$ docker network create my-net
```

When running a docker, you can specify it will be in the network. The following example would allow to run the server and artillery client in the same network.

```
$ docker run --network=my-net --name=server
nunopreguica/ccs1920-app

$ docker run --network=my-net  -v $(pwd):/config -t
nunopreguica/ccs1920-test artillery run create-posts.yml
```

DOCKER NETWORKING

The **overlay** network driver creates a distributed network among multiple Docker daemon hosts.

DOCKER STORAGE

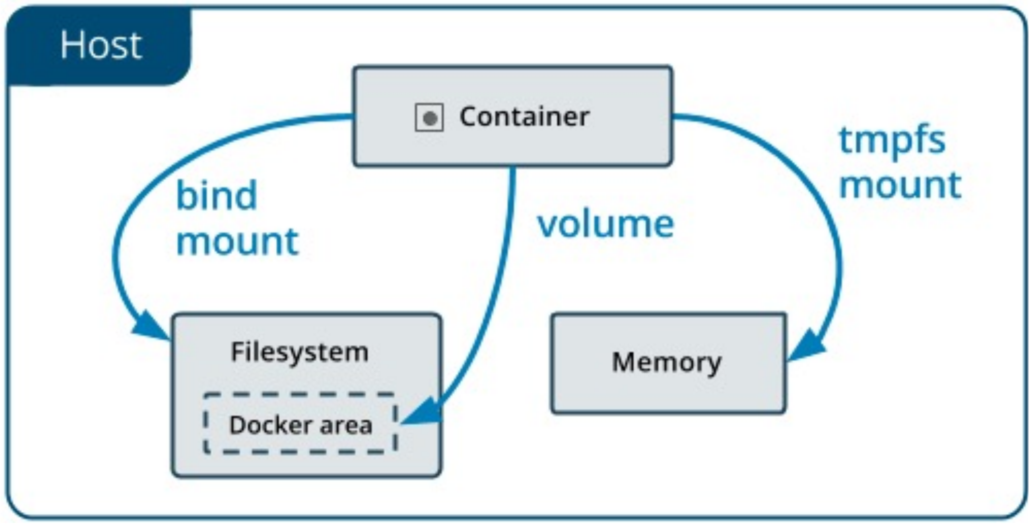
By default all files created inside a container are stored on a writable container layer that is not persisted.

Docker has two options for containers to store files in the host machine, so that the files are persisted even after the container stops: *volumes*, and *bind mounts*.

DOCKER STORAGE: VOLUMES

Volumes are stored in a part of the host filesystem which is *managed by Docker*.

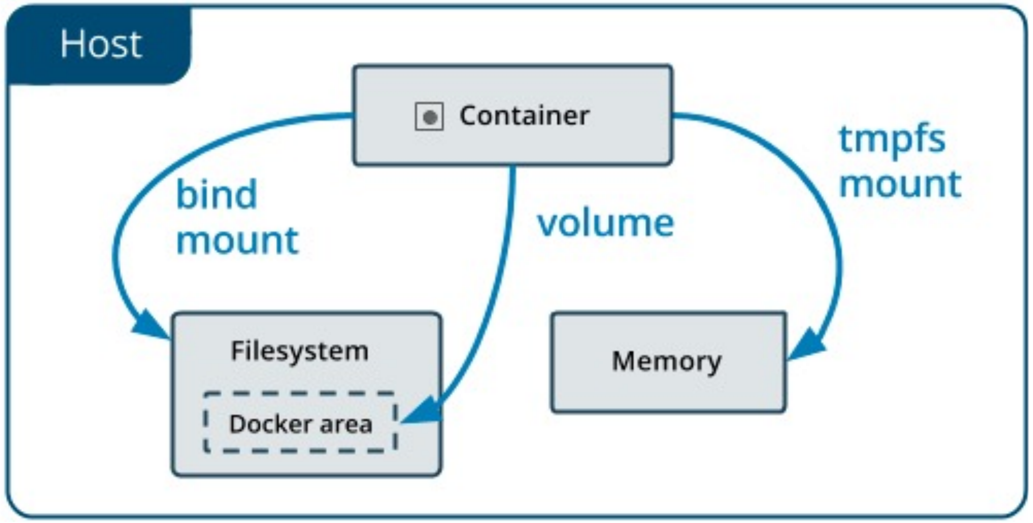
Non-Docker processes should not modify this part of the filesystem. Volumes are the best way to persist data in Docker.



DOCKER STORAGE: BIND VOLUMES

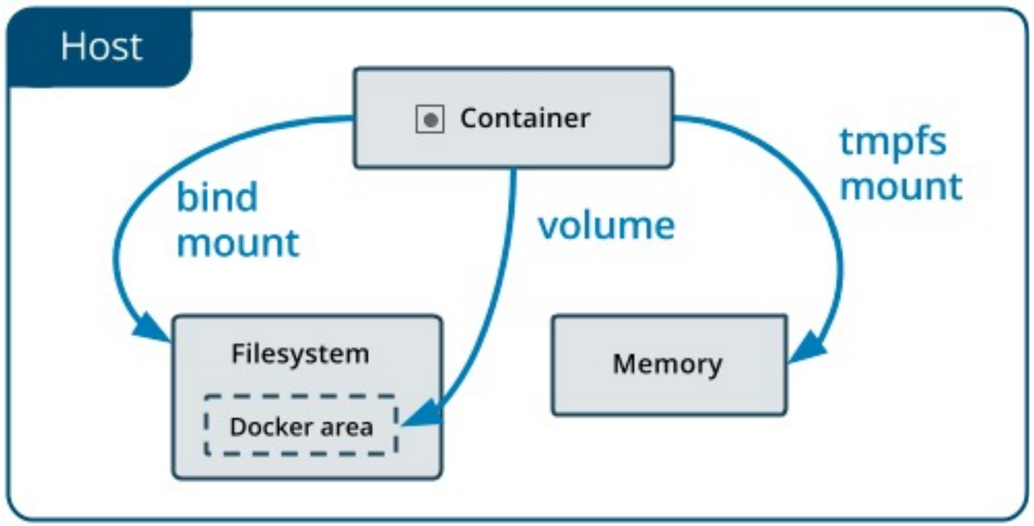
Bind mounts may be stored *anywhere* on the host system. They may even be important system files or directories.

Non-Docker processes on the Docker host or a Docker container can modify them at any time.



DOCKER STORAGE: TMPFS

tmpfs mounts are stored in the host system's memory only, and are never written to the host system's filesystem.



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DOCKER COMPOSE

Docker compose allows to define and run multi-container Docker applications.

The specification should be defined in a docker-compose.yml file.

Multi-container application started using:

```
$ docker-compose up -d
```

DOCKER COMPOSE: EXAMPLE

```
version: "3”
services:
  web:
    image: webserver
    depends_on:
      - ”db”
    ports:
      - "8000:8000”
  db:
    image: postgres

networks:
  default:
    external:
      name: my-pre-existing-network
```

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