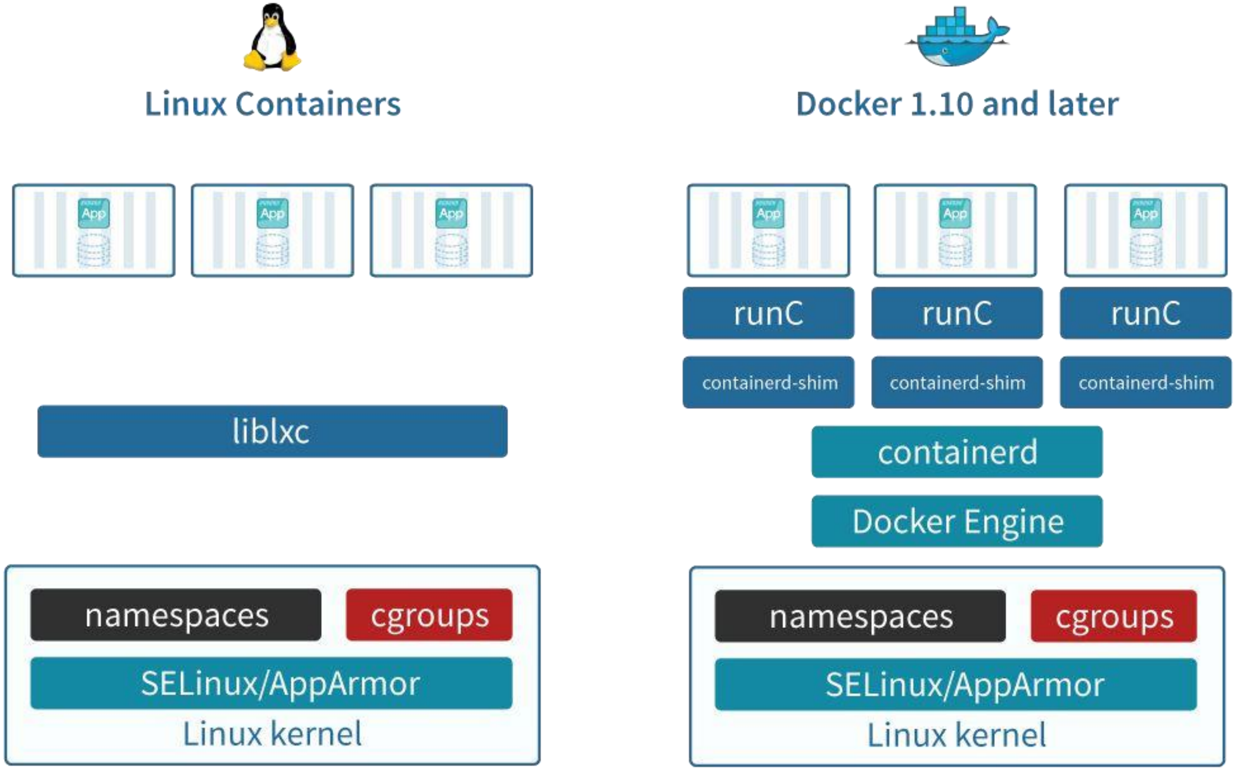
An introduction to Docker

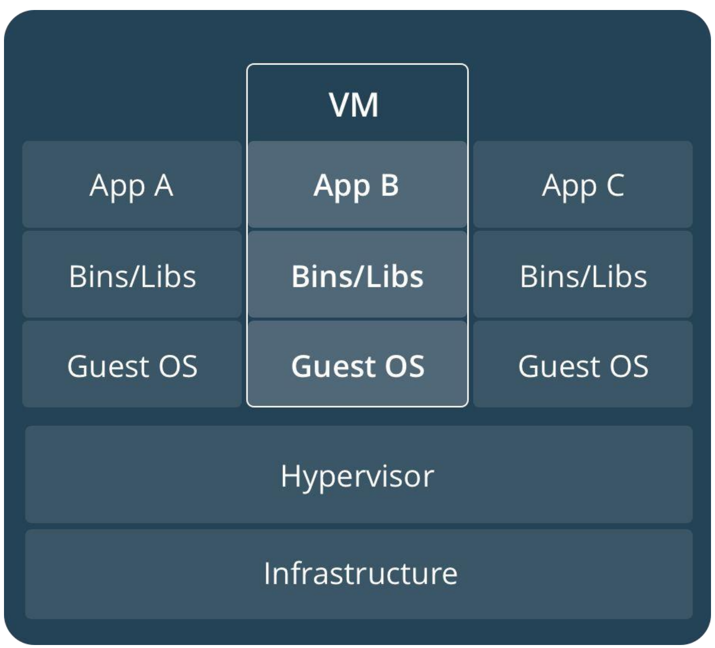
Container technologies on Linux

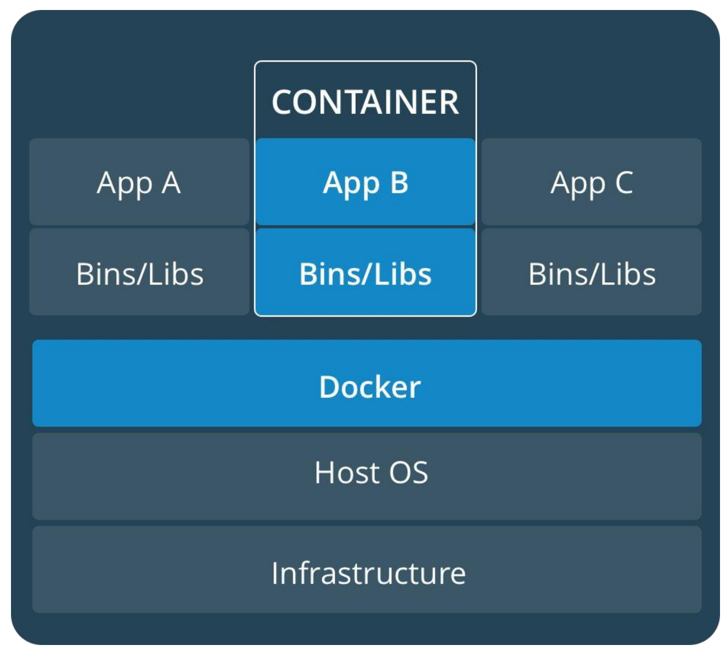
- Several *light virtualization* technologies are available for Linux
  - They build on *cgroups, namespaces* and other containment functionalities
  - LXC (Linux Containers) and Docker are the most popular products



Container vs Virtual Machine

- A VM has emulated hardware and hosts a whole Operating System (*guest*), which is separate from the host O.S.
- A container does not emulate any hardware, and shares the O.S. *kernel* with the host → less isolation, more efficiency





LXC - Linux Containers

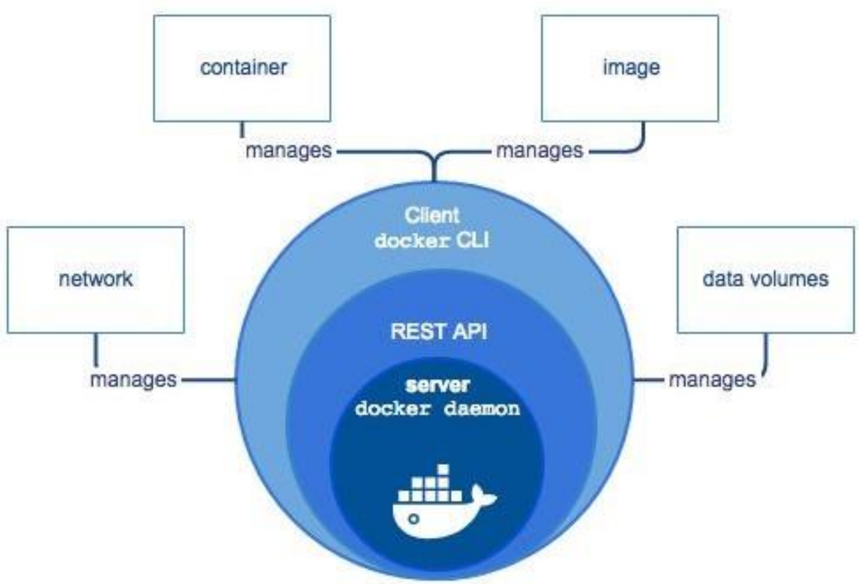
- A set of tools for creating and managing *system containers* (or, to a lesser extent, *application containers*)
  - Supported by virt-manager as a possible hypervisor (even if it's not)
- The goal of LXC is to provide an execution environment as close as possible to a standard GNU/LINUX installation, without the need to have a separate Linux kernel
- Designed for system administrators that are used to work with VMs
  - A LXC (system) container looks like a VM without a *boot loader*
  - The administrator can move its application stack from a VM to a container without the need to modify the applications or their configuration
  - Switching from VMs to LXC gives performance gains
  - Storage technologies for LXC and VMs are similar

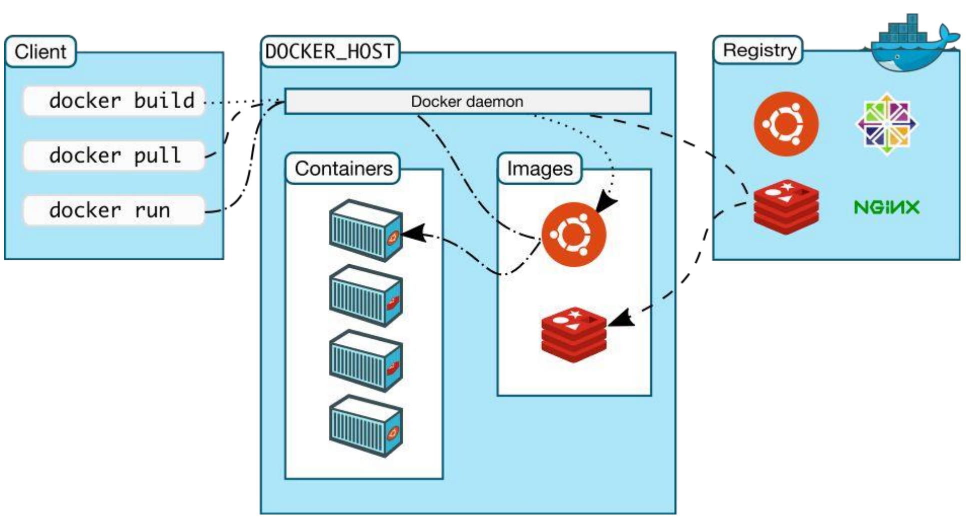
Docker

- Docker is a tool for creating, managing and orchestrating *application containers*
- The goal of Docker is to optimize the process of *development*, *testing*, *delivery* and *deployment* of applications, by means of packaging each application component in a separate *container*
- Designed for software developers:
    - Takes care of all the steps involved in software development
- Switching from VMs to Docker containers is not immediate
    - It may be necessary to modify the application or its configuration
    - The root of the problem is that the execution environment of a Docker container it's not normally a complete UNIX system

Docker architecture

- Client-server architecture to to manage *images*, *containers*, *volumes* and *virtual networks*
  - Client and server may run on different machines
  - Architecture is similar to *libvirt*, but with more functionalities, including the capability to interact with an *image registry* (https://hub.docker.com/)





Docker components (I)

- Image
  - An image is a portable template, accessible in read only mode, that has all the instructions necessary to create a Docker container
  - Contains all the dependencies needed for a software component (code or binary, run-time, libraries, configuration files, environment variables, …)
  - An image can be defined from a file system archive (tarball)
  - Or it can be defined by extending a previous image with a list of instructions specified in a text file (known as *Dockerfile*)
- Docker registry
  - Database to efficiently store images
  - Registries can be public (like DockerHub) or private to an organization

Docker components (II)

- Container
  - A Docker *container* is an executable instance of a Docker image
    - Defined by the image and the configuration specified at creation time
  - A container can be created, started, stopped, migrated, destroyed, connected to one or more virtual networks, associated to one or more data volumes ...
  - The container is the unit of application development, testing, delivery and deployment, assuming that Docker is used as operating support
  - Any modification to the file system visible to a container are not reflected on the image (image is read-only)
  - It's possible to define to what extent a container is isolated from the host
    - Access to the host file system and special devices, limitations on memory allocation and CPU utilization.

Docker components (III)

- Network
  - Virtual networks, implemented by means of *virtual switches* and iptables
  - *Bridge* networks limit connectivity to the containers on a single host
  - *Overlay* networks allow for containers connectivity among different hosts
    - Typically using VXLAN encapsulation
- Volume
  - A volume is a directory that can be associated to one or more containers
  - Its lifespan is independent of the containers that use it
  - Used to share storage across different containers, or anyway storage that can outlive the user container

Docker components (IV)

- Service
  - A Docker *service* is a set of containers that are replicas of the same image, and which together provide a *load balanced* service
  - *Services* are used to deploy containers “in production”
  - A service can be scaled up or down depending on the input load
- Stack
  - A set of interdependent services that interact to implement a complete application:
    - Ex: A web application to share pictures could be made of (i) a service for the storage and search of pictures; (ii) a service for the web interface for the users; and (iii) a service to encode/decode pictures

Single-host mode vs swarm mode

- By default, the containers of a Docker stack are deployed only on the host that runs the `dockerd` daemon
- However, Docker can also be configured in *swarm* mode
  - In this case the containers that make up the stack can be placed on all the nodes of a cluster (a.k.a. *swarm*)
  - A swarm consists of a *swarm manager* node and a set of *swarm worker* nodes

Docker under the hood

- Linux namespaces
  - Normally, each container comes with an instance of each type of namespace (`pid`, `net`, `ipc`, `mnt`, `uts`), to limit the scope of host kernel objects visible to the container
- Linux cgroups
  - Used to limit the amount of resources assigned to the containers
- Union File Systems
  - File systems that are defined by composition, overlapping different *layers*
  - Common layers (e.g. base installation of Ubuntu or Fedora) are reused by many images and containers
    - New containers and new images consume only a small space
    - They can be created very quickly!

Dockerfile

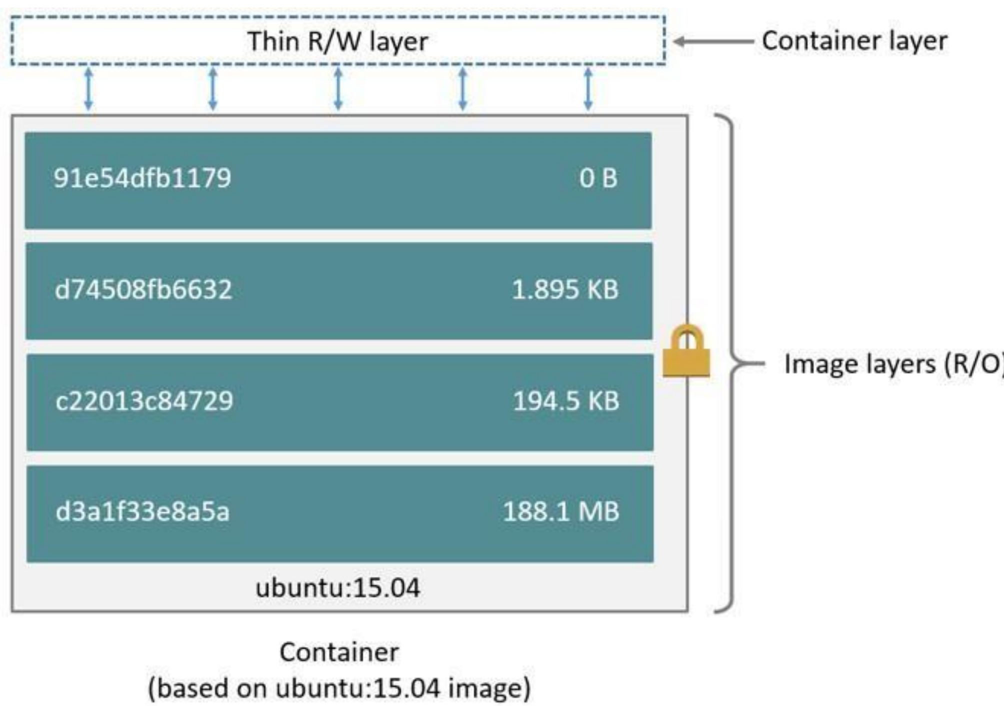
- A text file that contains a recipe to build an image
- An image should be a well-defined component and contain only the software actually needed for a well-defined task

```
# Start from an official image with the Python
runtime FROM python:2.7-slim
# Set the container current working directory (PWD) to “/chess”
WORKDIR /chess
# Copy files from current host directory to the /chess directory in the
container ADD . /chess
# Install some packages
RUN apt-get update && apt-get install -y libcgroup acl
# Flag that the software inside this image listens on port
9000 EXPOSE 9000
# Define an environment variable
ENV PLAYER Ghost
# Specify the command to be run inside the container when it’s
started CMD ["python", "./chess.py"]
```

Structure of a Docker image

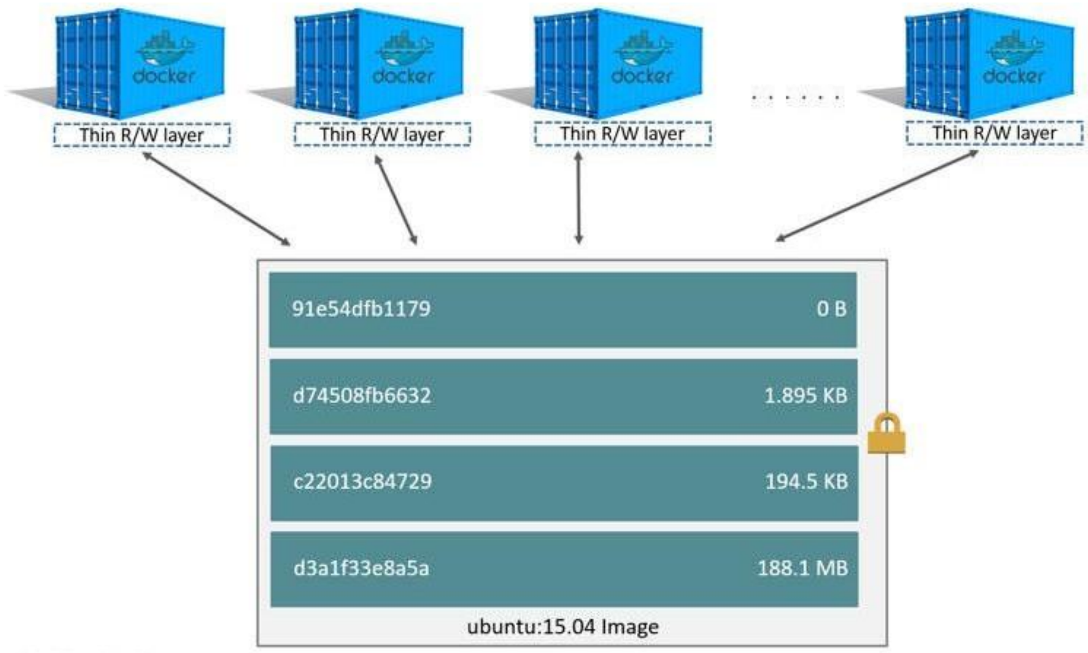
- An image is a *stack* of layers (*onion*-like structure)
- Each instruction in the Dockerfile adds a layer
  - Each layer stores only the difference w.r.t. the previous layers.
- A read/write *container layer* gets created on containers creation

```
# This is a Dockerfile
FROM ubuntu:15.10
COPY . /app
RUN make /app
CMD python /app/app.py
```



Sharing layers

- When a container is running, any modification to its disk are reflected to the *container layer*.
- All the other layers are read-only and can be shared among many container

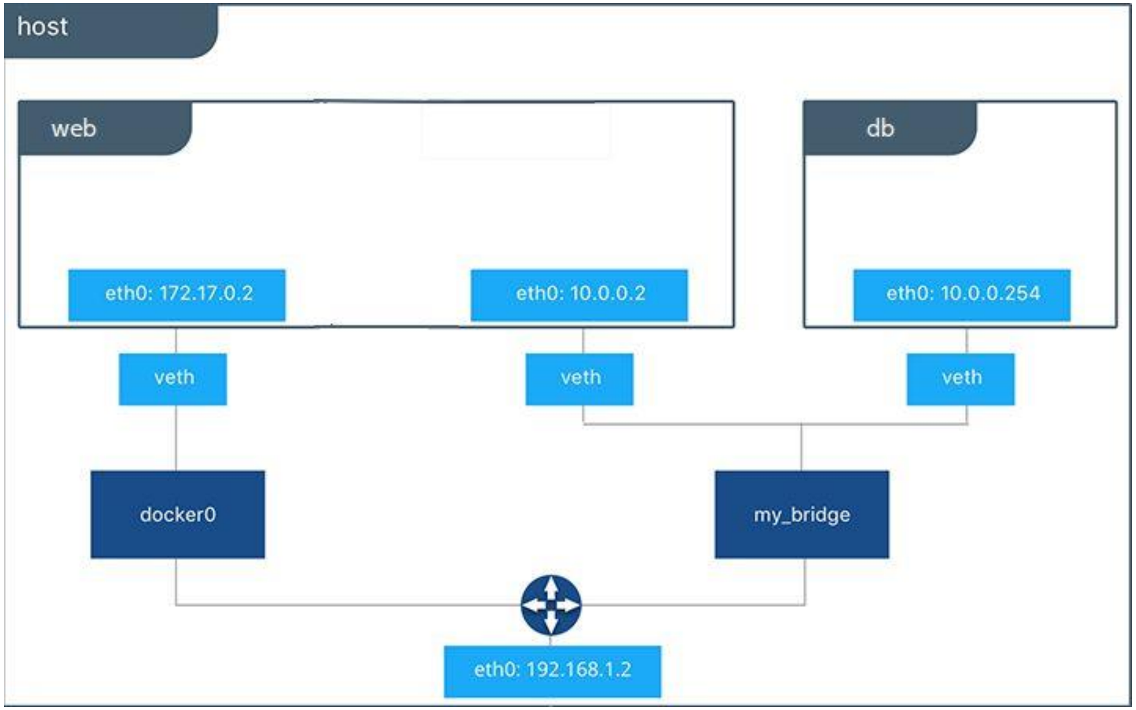


Implications of the onion structure

- A container does not take any disk space until it performs some write operation on the file system
  - In any case it takes only the space needed to store the difference
  - Huge disk space savings compared to VMs and LXC, which both store images with a *monolithic* format (e.g. qcow2)
- Creation of new images and containers is extremely fast compared to VMs and LXC
  - To create a new container it is sufficient to create an empty container layer

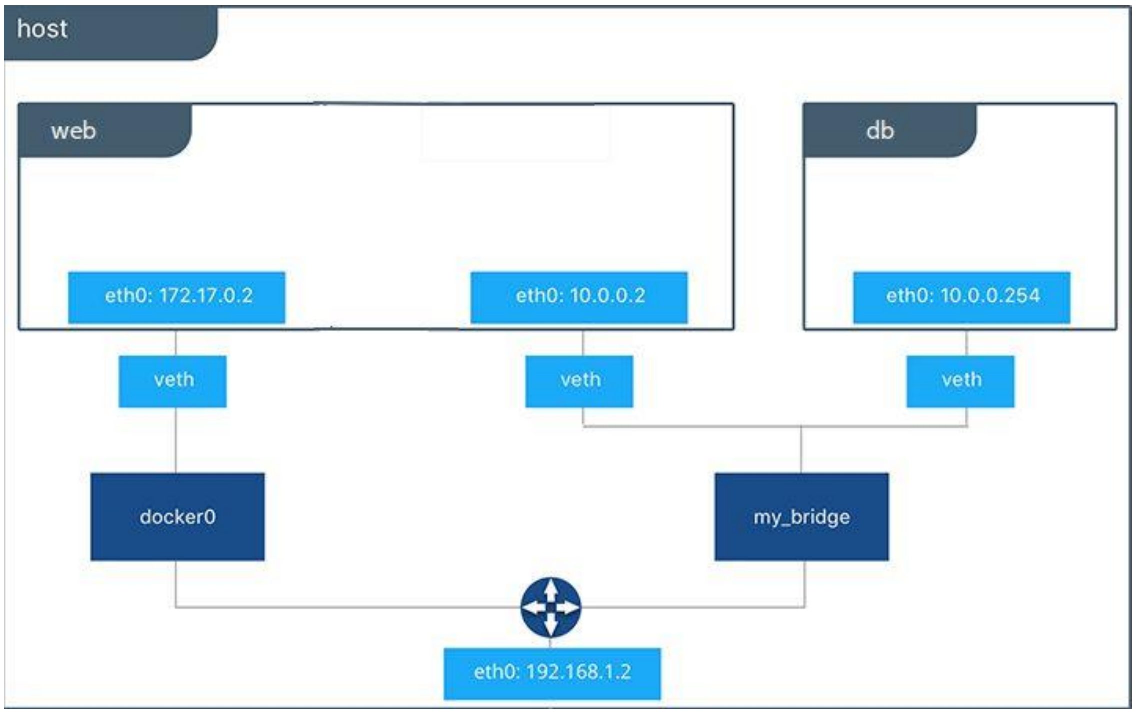
Docker networking (I)

- Standard software bridges are used to connect the containers by means of *virtual interfaces* (*veth* pairs in this case)
- The user can create and manage new networks, connect a container to one or more networks (even while the container is running)



Docker networking (II)

- Each *bridge* network uses a different IP subnet
- The IP subnet is visible to the host
- Networks use the *bridge* driver (host-only + NAT) by default



Main Docker commands

How to install Docker

- Install the latest Docker release on Ubuntu 16.04

```
$ curl -fsSL https://download.docker.com/linux/ubuntu/gpg | sudo apt-key add -
$ sudo add-apt-repository "deb [arch=amd64]
https://download.docker.com/linux/ubuntu $(lsb_release -cs)
stable"
$ sudo apt-get update
$ sudo apt-get install docker-ce
$ sudo usermod -aG docker ${YOUR_USERNAME}
```

- Check that Docker is up and running:

```
$ sudo systemctl status docker
[...]
Active: active (running) since
... [...]
```

Search images in a registry

- Search in a registry (e.g., the default public one)

```
[user@host ~]$ docker search nginx
```

  - The output shows a list of images matching the keyword
  - Images are sorted by decreasing number of *votes* given by Docker users
    - Most popular images first
- *Note: An incomplete command shows and help with all the possible options*

```
[user@host ~]$ docker image
[...]
Commands:
build     Build an image from a Dockerfile
history   Show the history of an image
import    Import the contents from a tarball to create a filesystem
inspect   image Display detailed information on one or more images
[...]
```

Image management

- List the existing images

```
[user@host ~]$ docker image ls
```

- Import an image from a registry

```
[user@host ~]$ docker image pull base/archlinux
```

- Remove an image (locally)

```
[user@host ~]$ docker image rm ubuntu
```

- Show detailed information about an image

```
[user@host ~]$ docker image inspect ubuntu
```

- Remove unused images

```
[user@host ~]$ docker image prune
```

Building an image from a Dockerfile

- Move to the directory containing the Dockerfile

  `[user@host ~]$ cd /path/to/dockerfiledir`

- Build an image from the Dockerfile in the current directory, giving it a name (tag) "`myimg`"

  `[user@host ~]$ docker build -t myimg .`

- The new image will be stored together with the other ones already available on the host
- Each Dockerfile is normally stored in a separate directory
  - The file name must be "`Dockerfile`"

Creating and launching containers

- Create a container and launch it (within the same command)

  `[user@host ~]$ docker run -it --name ubu1 ubuntu /bin/bash`

  - The `ubuntu` argument refers to the name of an available image
  - The `/bin/bash` argument specifies the command to be run by the container
    - If present it overrides the command specified within the image (`CMD`)
  - The `-t` option specifies the allocation of a terminal
  - The `-i` option specifies that the command is interactive (it's a shell)
  - The `-d` option is used to run the container in background
- It is possible to create and launch with separate commands:

  `[user@host ~]$ docker create -it --name ubu1 ubuntu`

  `/bin/bash [user@host ~]$ docker start -i ubu1`

Publication of exposed ports

- An image can expose a `TCP/UDP` port through the `EXPOSE` directive in the Dockerfile
- When a container is launched, it is possible to map each exposed port to an host port, to enable access from the host external network
- This mapping is specified through the `-p` option of the `run` or `create` `commands`
  - Ex: Launch a Web server container exposing port 80, mapping it on the port 8000 of the host

    ```
    [user@host ~]$ docker run -p 8000:80 apache /usr/bin/apacheserv --daemon
    ```

Container management

- Show all the running containers
  `[user@host ~]$ docker ps`
- Show all the containers (in any state)
  `[user@host ~]$ docker ps -a`
  - Includes containers that are not currently running
- Reboot a container (specified by name or ID)
  `[user@host ~]$ docker restart ubu1`
- Stop a container
  `[user@host ~]$ docker stop ubu1`
- Remove a container
  `[user@host ~]$ docker rm ubu1`
- More commands: `kill`, `inspect`, `pause`, `unpause`, ...
- Equivalent commands in *canonical form*:
  `[user@host ~]$ docker container` *`COMMAND`*

Volumes management

- Create a volume called "`myvol`"

```
[user@host ~]$ docker volume create myvol
```

- Remove "`myvol`"

```
[user@host ~]$ docker volume rm myvol
```

- Show the list of volumes available on the host

```
[user@host ~]$ docker volume ls
```

- Run a container, making the content of the "`myvol`" volume available in the `/mntvol` path inside the container

```
[user@host ~]$ docker run -v myvol:/mntvol -it ubuntu /bin/bash
```

- Run a container, making the content of the host directory "`/home/user/tmp`" available in the `/mnt` path inside the container

```
[user@host ~]$ docker run -v /home/user/tmp:/mnt -it ubuntu /bin/bash
```

Data volume containers

- It is possible to create unnamed volumes, implicitly associated to a container (but still independent on the container lifespan)
  - Ex: Create an unnamed volume, making it available in "`/myvol`"

    ```
    [user@host ~]$ docker run -v /myvol --name ubu1 -it ubuntu /bin/bash
    ```
  - Actually, a volume name is assigned automatically
- Unnamed volumes can be attached to other containers
  - Ex: Launch a container importing volumes from another container called `ubu1`

    ```
    [user@host ~]$ docker run --volumes-from ubu1 --name ubu2 -it ubuntu /bin/bash
    ```
  - The imported volumes are mounted in the `ubu2` file system at the same mountpoints used inside `ubu1`
- A container like `ubu1` is called "*Data volume container*"

Management of Docker virtual networks

- Show current networks

  `[user@host ~]$ docker network ls`

- Create an user-defined *bridge* network (“`mynet`”)

  `[user@host ~]$ docker network create --subnet=192.168.13.0/24 mynet`

- Remove a network

  `[user@host ~]$ docker network rm mynet`

- Attach the `ubu2` container to `mynet`

  `[user@host ~]$ docker network connect mynet ubu2`

- Detach the `ubu2` container from `mynet`

  `[user@host ~]$ docker network disconnect mynet ubu2`

- Launch a container attached to `mynet`

  `[user@host ~]$ docker run --network=mynet` *`[options] imagename command`*

- Launch a container attached to `mynet`, specifying a static IP

  `[user@host ~]$ docker run --network=mynet --ip 192.168.13.4` *`[options]`*
  `imagename command`

Other commands

- Show total Docker disk usage

```
[user@host ~]$ docker system df
```

- System clean up: remove stopped containers, and unused volumes, networks and images

```
[user@host ~]$ docker system prune
```

- Remove all the images and all containers (including the ones in use)

```
[user@host ~]$ docker rm $(docker ps -a -q)
[user@host ~]$ docker image remove $(docker images -q)
```

- Show per-container real-time statistics, including utilization of CPU, memory, network and disk

```
[user@host ~]$ docker stats
```