Università degli Studi di Roma “Tor Vergata”

Dipartimento di Ingegneria Civile e Ingegneria Informatica

Container-based virtualization: Docker

Corso di Sistemi Distribuiti e Cloud Computing

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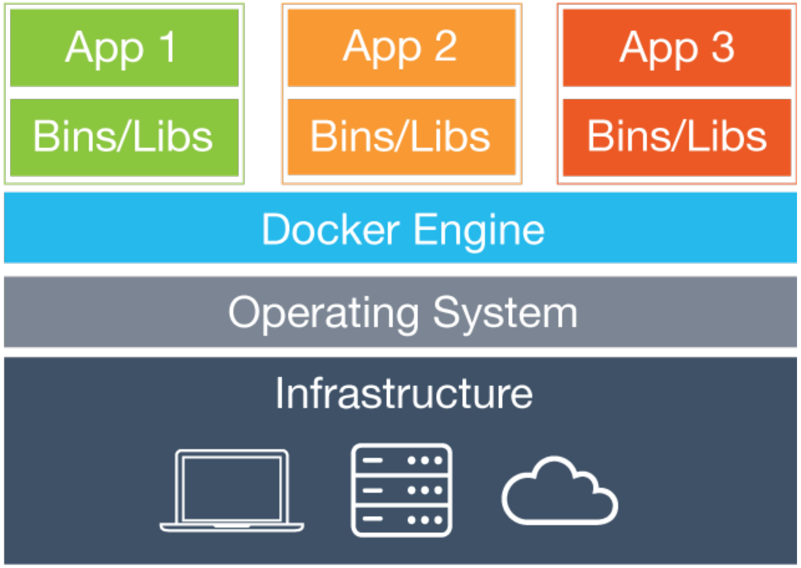
Valeria Cardellini

Matteo Nardelli

Case study: Docker

- Lightweight, open and secure container-based virtualization
  - Containers include the application and all of its dependencies, but share the kernel with other containers
  - Containers run as an isolated process in userspace on the host operating system
  - Containers are also not tied to any specific infrastructure



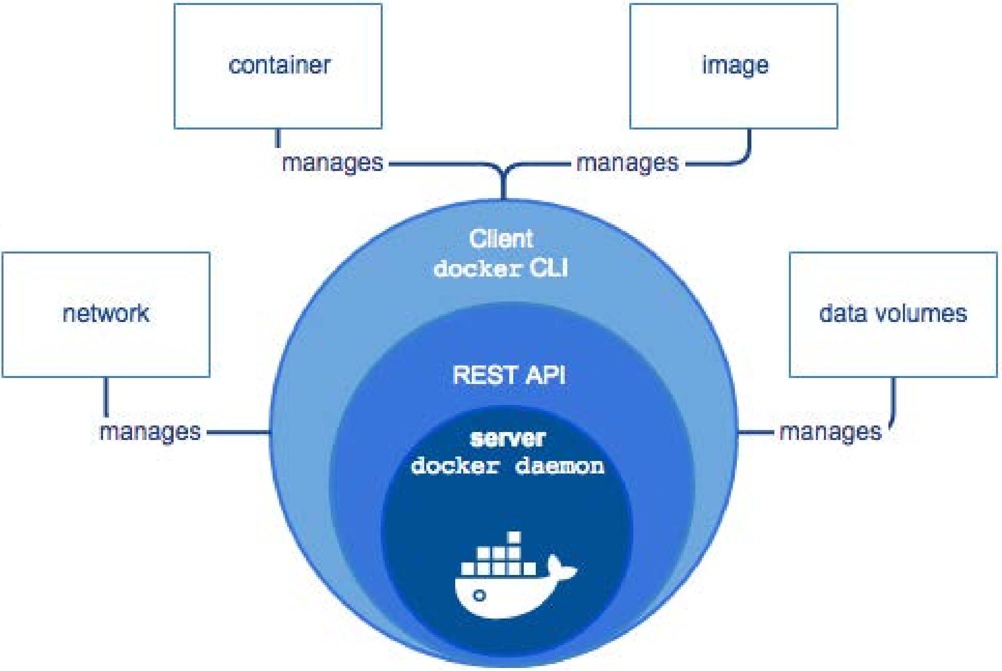
App 1
Bins/Libs
App 2
Bins/Libs
App 3
Bins/Libs
Docker Engine
Operating System
Infrastructure

Docker internals

- Docker is written in Go language
- With respect to other OS-level virtualization solutions, Docker is a higher-level platform that exploits Linux kernel mechanisms such as cgroups and namespaces
  - First versions based on LXC
  - Now based on its own *libcontainer* runtime that uses Linux kernel namespaces and cgroups directly
  - *libcontainer* (now included in *runc*): cross-system abstraction layer aimed to support a wide range of isolation technologies
- Dockers adds to LXC
  - Portable deployment across machines
  - Versioning, i.e., git-like capabilities
  - Component reuse
  - Shared libraries, see Docker Hub hub.docker.com

Docker engine

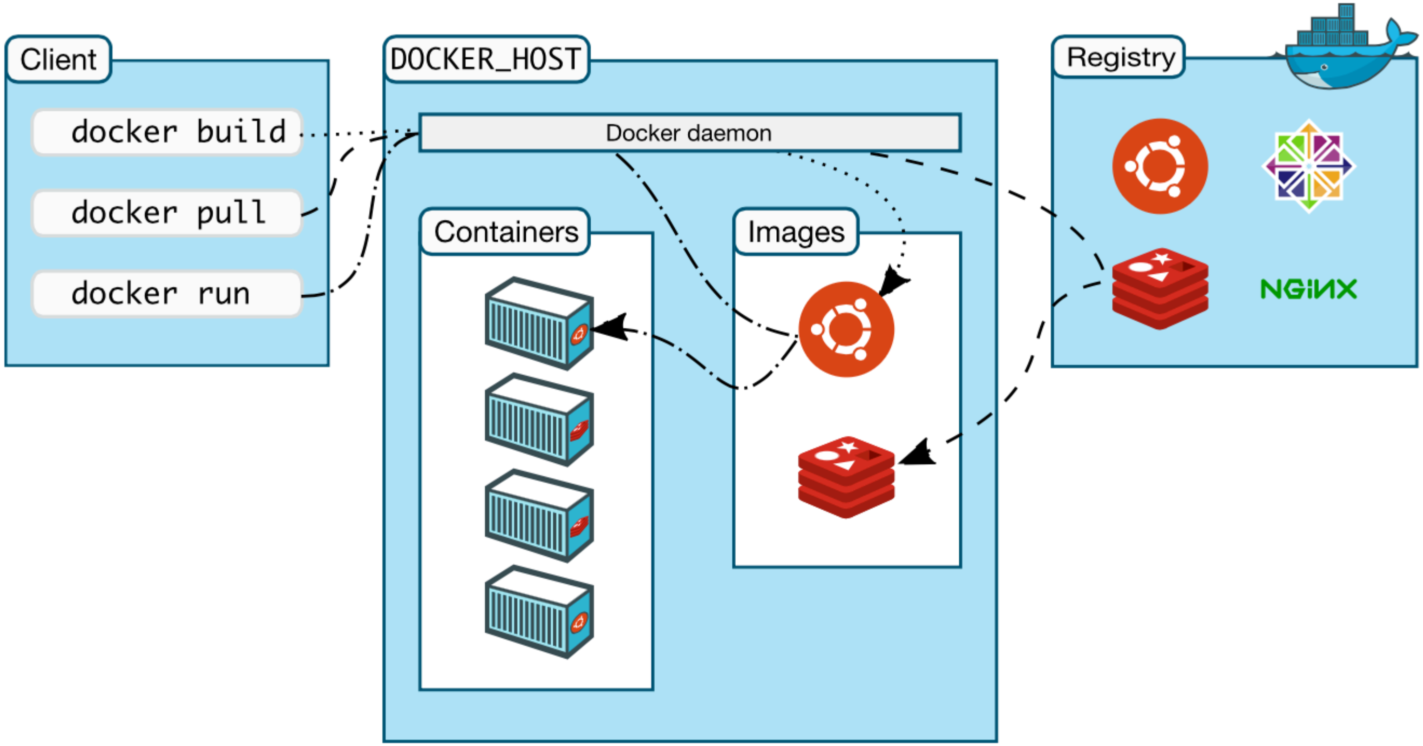
- *Docker Engine:* client-server application composed by:
  - A server, called daemon process
  - A REST API which specifies interfaces that programs can use to control and interact with the daemon
  - A command line interface (CLI) client



See docs.docker.com/engine/understanding-docker/

Docker architecture

- Docker uses a client-server architecture
  - The Docker *client* talks to the Docker *daemon*, which builds, runs, and distributes Docker containers
  - Client and daemon communicate via sockets or REST API



Docker image

- Read-only template with instructions for creating a Docker container
  - Described in text file called *Dockerfile*, with simple, well-defined syntax
  - The ***Build*** component of Docker
  - Enables the distribution of applications with their runtime environment: a Docker image incorporates all the dependencies and configuration necessary for it to run, eliminating the need to install packages and troubleshoot
  - Target machine must be Docker-enabled
- A Docker Image
  - A template for containers
  - Can be pulled and pushed towards a registry
  - Image names have the form [registry/][user/]name[:tag]
  - The default for the tag is *latest*

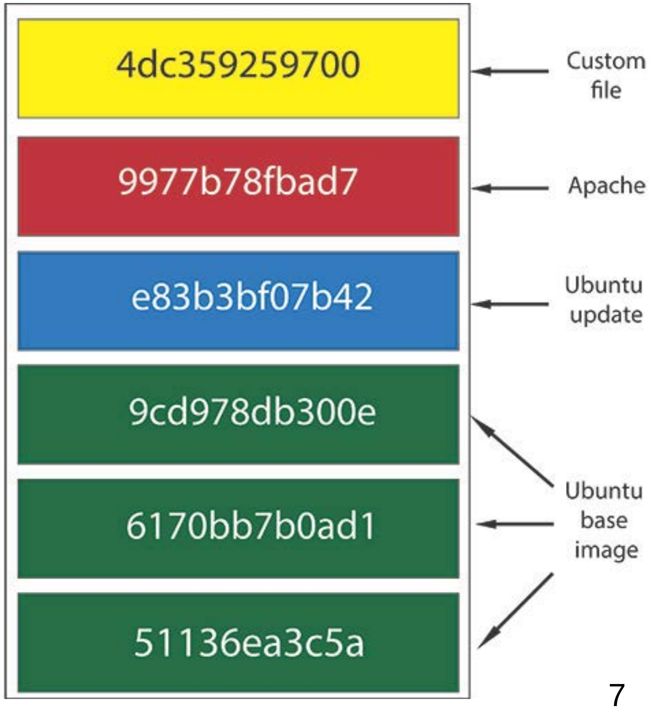
Docker image

- Images can be created from a Dockerfile and a context:
  - Dockerfile: instructions to assemble the image
  - Context: set of files (e.g., application, libraries)
  - Often, an image is based on another image (e.g., ubuntu)
- Example of a Dockerfile

```
# Use an official Python runtime as a parent image
FROM python:2.7-slim
# Set the working directory to /app
WORKDIR /app
# Copy the current directory contents into the container at /app
ADD . /app
# Install any needed packages specified in requirements.txt
RUN pip install -r requirements.txt
# Make port 80 available to the world outside this container
EXPOSE 80
# Define environment variable
ENV NAME World
# Run app.py when the container launches
CMD ["python", "app.py"]
```

Docker image (2)

- Layered image
  - Each image consists of a *series of layers*
  - Docker uses *union file systems* to combine these layers into a single unified view
    - Layers are stacked on top of each other to form a base for a container's root file system
    - Based on the *copy-on-write* (COW) principle
- Layering pros
  - Enable layer reuse, installing common layers only once and saving bandwidth and storage space
  - Manage dependencies and separate concerns
  - Facilitate software specializations



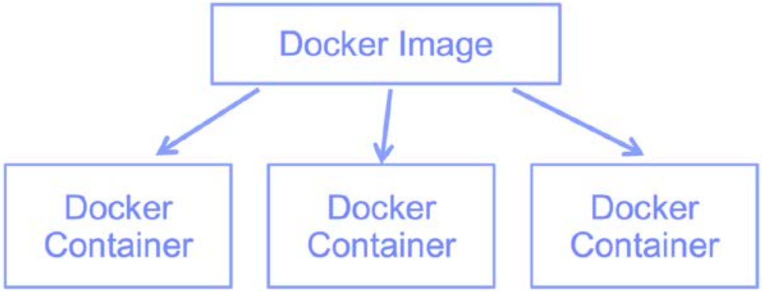
Docker image (3)

- Containers should be stateless. Ideally:
  - Very little data is written to a container's writable layer
  - Data should be written on Docker volumes
  - Nevertheless: some workloads require to write data to the container's writable layer

- The storage driver controls how *images* and *containers* are stored and managed on the Docker host.
- Docker supports multiple choices for the storage driver
  - Including AuFS, Device Mapper, Btrfs and OverlayFS
  - Storage driver's choice can affect the performance of the containerized applications
  - See Select a storage driver - Docker

Docker container and registry

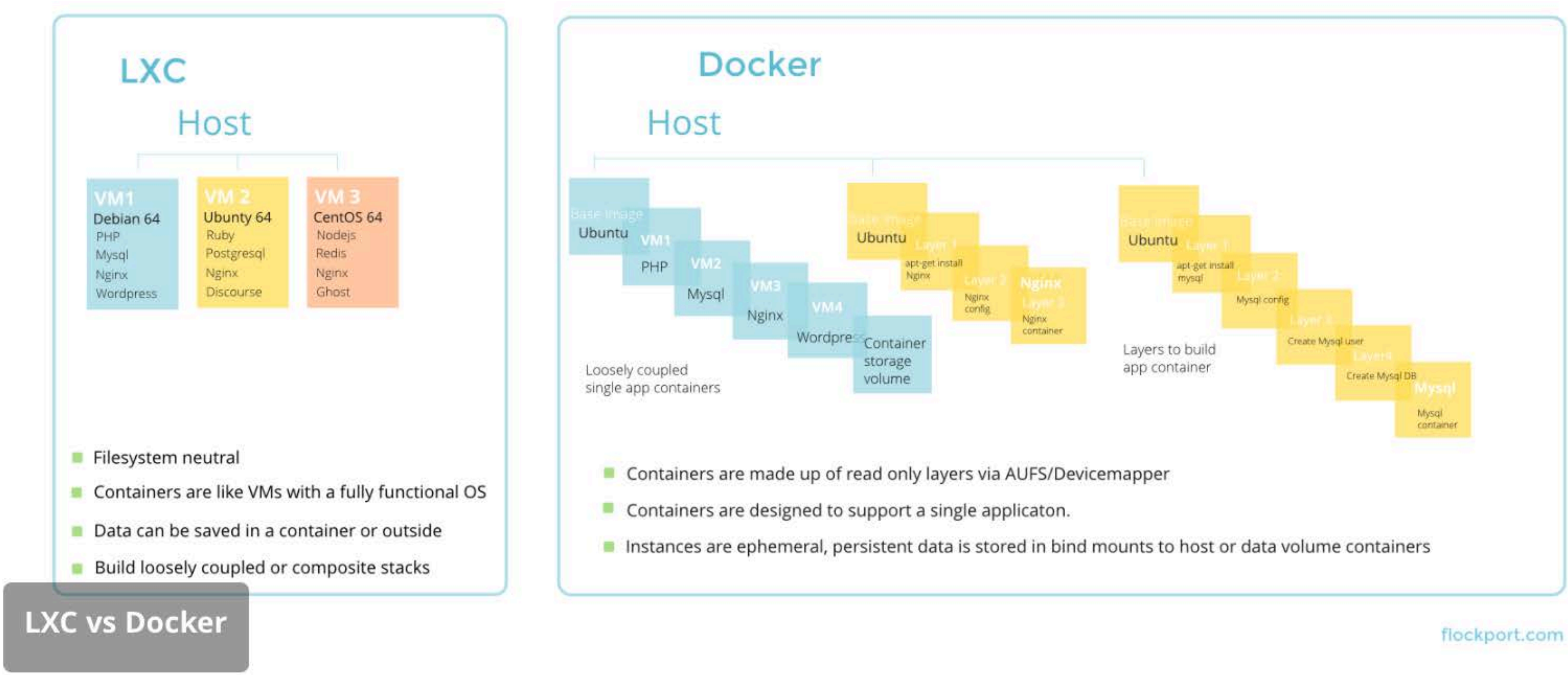
- Docker **container**: runnable instance of a Docker image
  - Run, start, stop, move, or delete a container using Docker API or CLI commands
  - The ***Run*** component of Docker
  - Docker containers are stateless: when a container is deleted, any data written that is not stored in a *data volume* is deleted along with the container



- Docker **registry**: stateless server side application that stores and lets you distribute Docker images
  - Provides an open library of images
  - The ***Distribute*** component of Docker
  - Docker-hosted registries: Docker Hub, Docker Store (open source and enterprise verified images)

Docker vs LXC

- Non overlapping solutions
- Main differences in the figure



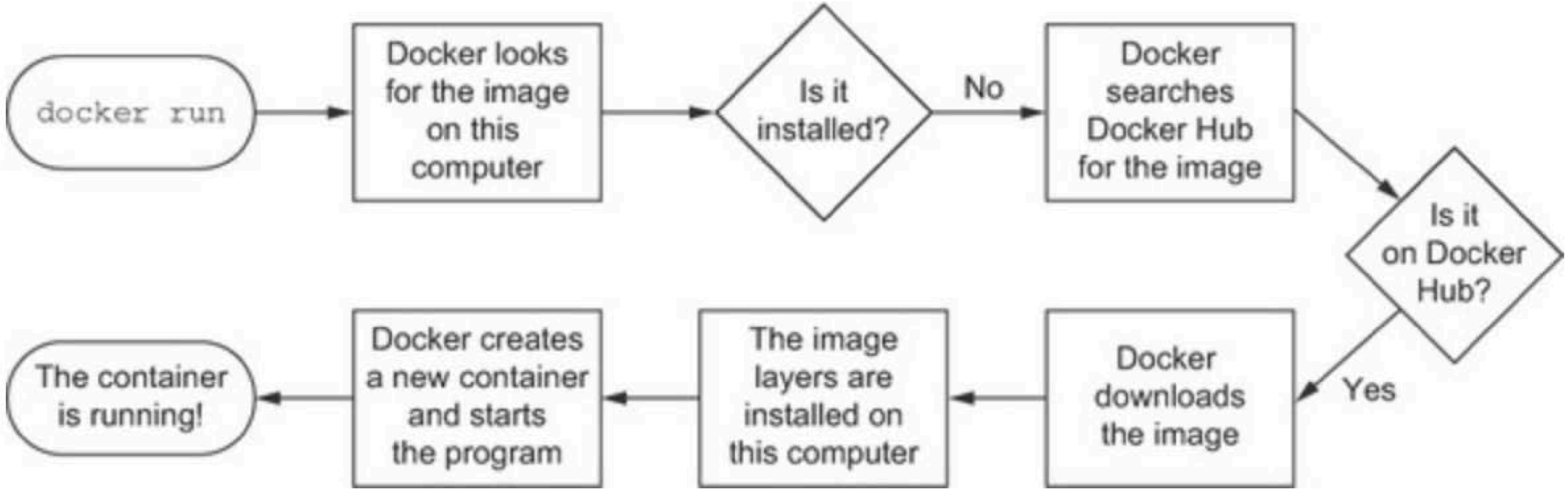
- Filesystem neutral
- Containers are like VMs with a fully functional OS
- Data can be saved in a container or outside
- Build loosely coupled or composite stacks

- Containers are made up of read only layers via AUFS/Devicemapper
- Containers are designed to support a single applicaton.
- Instances are ephemeral, persistent data is stored in bind mounts to host or data volume containers

See [Flockport - LXC vs Docker]

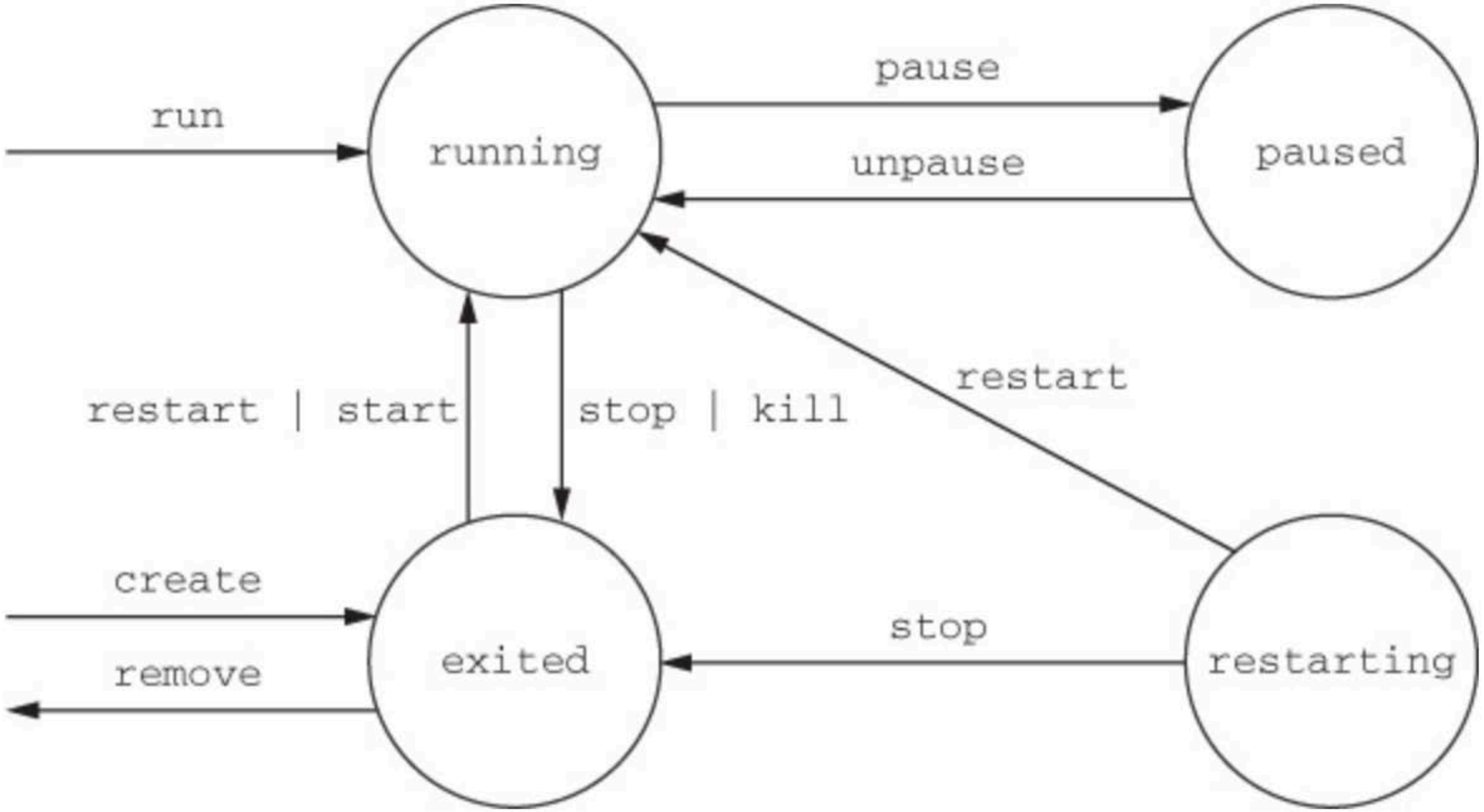
Docker: run command

- When you run a container whose image is not yet installed but is available on Docker Hub


docker run
Docker looks for the image on this computer
Is it installed?
No
Docker searches Docker Hub for the image
Is it on Docker Hub?
Yes
Docker downloads the image
The image layers are installed on this computer
Docker creates a new container and starts the program
The container is running!

Courtesy of “Docker in Action” by J. Nickoloff

State transitions of Docker containers



Courtesy of “Docker in Action” by J. Nickoloff

Commands: Info and image handling

- Obtain detailed info on your Docker installation

  ```
  $ docker info
  ```

  E.g., to know the used storage driver (e.g., AuFS)

- Download/update an image from the registry

  ```
  $ docker pull image-id
  ```

- Upload an image to the registry

  ```
  $ docker push image-id
  ```

- List images

  ```
  $ docker images
  ```

- Inspect an image

  ```
  $ docker inspect image-id
  ```

- Remove an image

  ```
  $ docker rmi image-id
  ```

Command: Run

```
$ docker run [OPTIONS] IMAGE [COMMAND] [ARGS]
```

- Most common options

  `--name` assign a name to the container

  `–d` detached mode (in background)

  `–it` foreground with attached pseudo-tty and STDIN (interactive)

  `–expose=[]` expose a range of ports inside the container

  `–p=[]` publish a container's port or a range of ports to the host

  `–v` bind and mount a volume

  `–e` set environment variables

  `–link=[]` link to other containers

- The “Hello World” container

```
$ docker run ubuntu /bin/echo 'Hello world'
```

  – See Hello world in a container

Command: Management

- List containers
  - Only running containers: `$ docker ps`
  - All containers (including exited ones): `$ docker ps -a`
- Container lifecycle
  - Stop container

    ```
    $ docker stop containerid
    ```

  - Start stopped container

    ```
    $ docker start containerid
    ```

  - Kill running container

    ```
    $ docker kill containerid
    ```

  - Remove container

    ```
    $ docker rm containerid
    ```

- Copy files from and to docker container

  ```
  $ docker cp containerid:path localpath
  $ docker cp localpath containerid:path
  ```

Some examples of using Docker (2)

- Running a web application in Docker
  - Also bind the container to a specific port

```
$ docker run -d -p 80:5000 training/webapp python app.py
```

  - See [Run a simple application]

- Stopping and removing a container

```
$ docker ps
```

```
CONTAINER ID  IMAGE             COMMAND          CREATED
26ea7a6908bd  training/webapp   "python app.py"  4 seconds ago        ...
-------------------------------------------------------------------------------
          STATUS             PORTS                          NAMES
  ...     Up 3 seconds       0.0.0.0:32768->5000/tcp        angry_chandrasekhar
```

```
$ docker stop 26ea7a6908bd
$ docker rm 26ea7a6908bd
```

Some examples of using Docker (3)

- Running a Web server inside a container and sending an HTTP request through an interactive container

```
$ docker run -d --name web nginx:latest

$ docker run -i -t --link web:web
          --name web_test busybox:latest
          /bin/sh wget -O - http://web:80/ exit
```

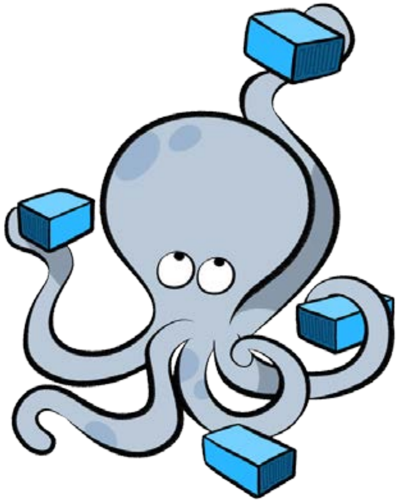
- Checking the logs of a container

```
$ docker logs web
```

Docker Compose

To easily coordinate the execution of multiple services, we can use **Docker Compose**

- Read more at https://docs.docker.com/compose/



Docker Compose:

- is not bundled within the installation of Docker (on Linux)
- it can be installed following the official Docker documentation
  - https://docs.docker.com/compose/install/
- Allows to easily express the container to be instantiated at once, and the relations among them
- By itself, Docker compose runs the composition on a single machine; however, in combination with Docker Swarm, containers can be deployed on multiple nodes

Docker Compose

- We specify how to compose containers in a easy-to-read file, by default named `docker-compose.yml`

- To start the Docker composition (in background with -d):

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

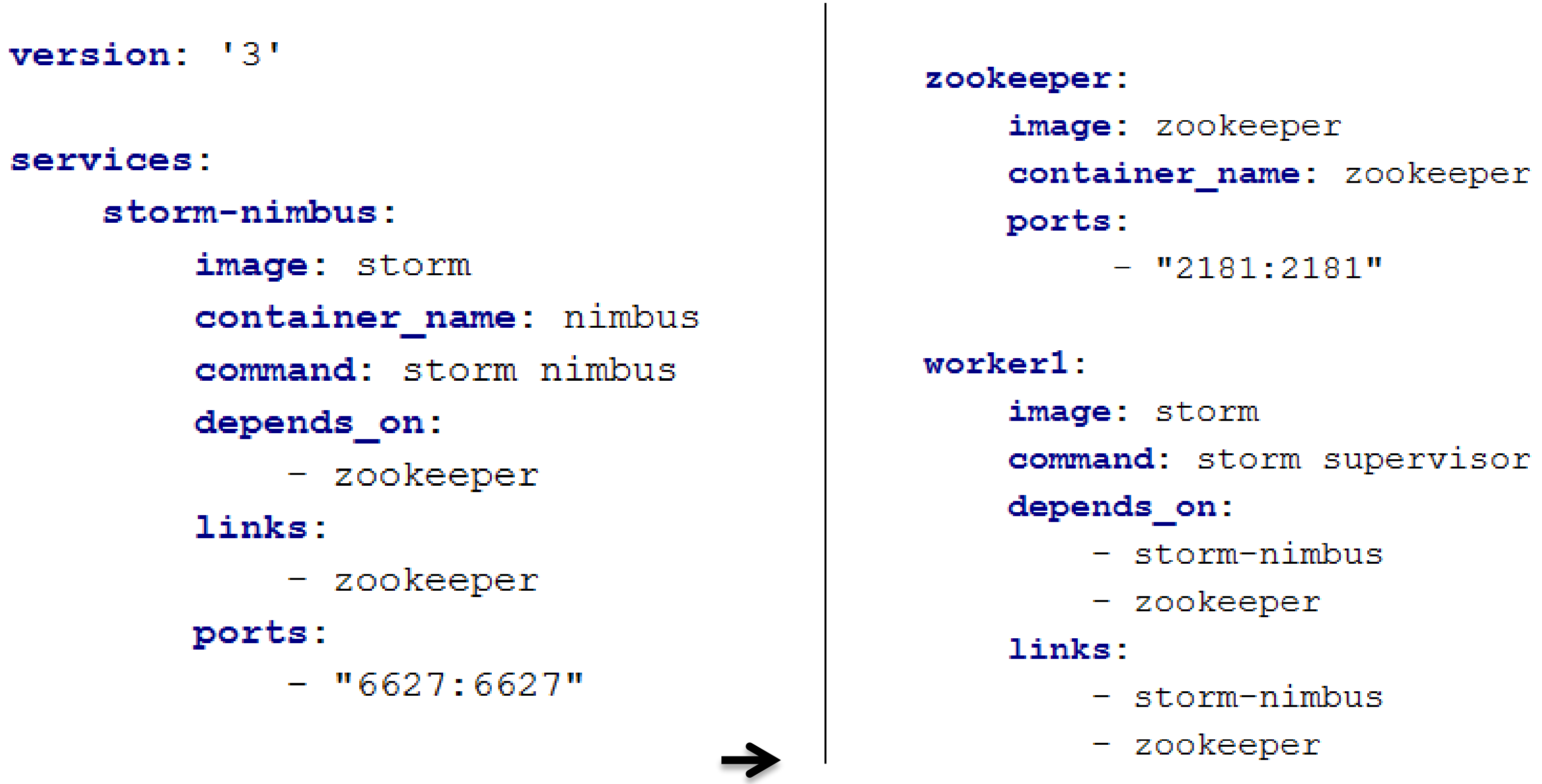
- To stop the Docker composition:

```
$ docker-compose down
```

- By default, Docker-compose looks for the `docker-compose.yml` file in the current working directory; we can change the file with the configuration using the `-f` flag

Docker Compose

- There are different versions of the Docker compose file format
- Latest: version 3 is supported from Docker Compose 1.13



```
version: '3'

services:
    storm-nimbus:
        image: storm
        container_name: nimbus
        command: storm nimbus
        depends_on:
            - zookeeper
        links:
            - zookeeper
        ports:
            - "6627:6627"
```

→

```
zookeeper:
    image: zookeeper
    container_name: zookeeper
    ports:
         - "2181:2181"

worker1:
    image: storm
    command: storm supervisor
    depends_on:
        - storm-nimbus
        - zookeeper
    links:
        - storm-nimbus
        - zookeeper
```

On the Docker compose file format: https://docs.docker.com/compose/compose-file/

Docker: Swarm mode

Docker includes the **swarm mode** for natively managing a cluster of Docker Engines, which is called *swarm*

- Read more at https://docs.docker.com/engine/swarm/

A *task* is a running container which is part of a swarm service

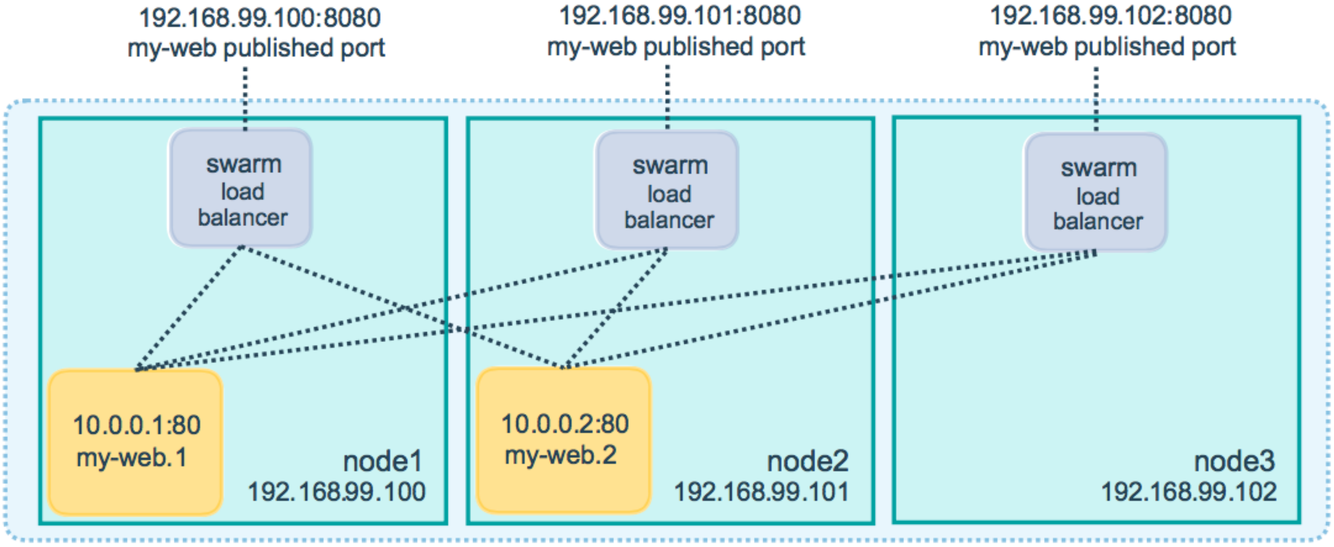
Basic features of the swarm mode:

- **Scaling:** it allows to declare the number of tasks for each service
- **State reconciliation:** swarm monitors the cluster state and reconciles any differences w.r.t. the expressed desired state
- **Multi-host networking:** it allows to specify an overlay network among services
- **Load balancing:** it allows to expose the ports for services to an external load balancer. Internally, the swarm lets you specify how to distribute service containers between nodes

Docker: Swarm mode

A swarm consists of multiple Docker hosts which run in swarm mode

- Node: an instance of the Docker engine
  - **Manager node** dispatches tasks to worker nodes
  - **Worker nodes** receive and execute tasks
- Load balancing
  - The swarm manager can automatically assign the service a (configurable) PublishedPort
  - External components can access the service on the PublishedPort. All nodes in the swarm route ingress connections to a running task



Commands: Swarm cluster

- Create a swarm: Manager node

```
$ docker swarm init --advertise-addr <MANAGER-IP>
Swarm initialized: current node (<nodeid>) is now a manager.
To add a worker to this swarm, run the following command:

    docker swarm join --token <token> <manager-ip>:port
```

Create a swarm: Worker node

```
$ docker swarm join --token <token> <manager-ip>:port
```

- Inspect status

```
$ docker info
```

```
$ docker node ls

ID              HOSTNAME       STATUS        AVAILABILITY    MANAGER STATUS
<nodeid> *      controller     Ready         Active          Leader
<nodeid>        storage        Ready         Active
```

Commands: Swarm cluster

- Leave the swarm

```
$ docker swarm leave
```

If the node is a manager node, you will receive a warning about maintaining the quorum. To override the warning, pass the `--force` *flag*

- After a node leaves the swarm, you can run the `docker node rm` command on a manager node to remove the node from the node list

```
$ docker node rm node-id
```

Commands: Manage Services

- Deploy a service to the swarm (from the manager node)

```
$ docker service create -d --replicas 1 \
     --name helloworld alpine ping docker.com
```

- List running services

```
$ docker service ls
```

```
ID            NAME             MODE          REPLICAS  IMAGE            PORTS
<serviceid>   helloworld       replicated    1/1       alpine:latest
```

Commands: Manage Services

- Inspect the service

```
$ docker service inspect --pretty <SERVICE-ID>
$ docker service ps <SERVICE-ID>
```

```
ID          NAME          IMAGE          NODE        DESIRED ST CURRENT ST   ERROR   PORTS
<cont.id1> helloworld.1  alpine:latest  controller  Running    Running …
<cont.id2> helloworld.2  alpine:latest  storage     Running    Running …
```

- Inspect the container

```
$ docker ps <cont.id1>
```

```
# Manager node
CONTAINER ID  IMAGE          COMMAND            CREATED    STATUS    ... NAMES
<cont.id1>    alpine:latest  "ping docker.com"  2 min ago  Up 2 min helloworld.1.iuk1sj…

# Worker node
CONTAINER ID  IMAGE          COMMAND            CREATED    STATUS    ... NAMES
<cont.id2>    alpine:latest  "ping docker.com"  2 min ago  Up 2 min helloworld.2.skfos4…
```

Commands: Manage Services

- Scale the service

```
$ docker service scale <SERVICE-ID>=<NUMBER-OF-TASKS>
```

The swarm manager will automatically enact the updates

- Apply rolling updates to a service

```
$ docker service update --image redis:3.0.7 redis
$ docker service update --replicas 2 helloworld
```

- Roll back an update

```
$ docker service rollback [OPTIONS] <SERVICE-ID>
```

- Remove a service

```
$ docker service rm <SERVICE-ID>
```