Containerization (with Docker)

Prof. Dr. Dirk Riehle

Friedrich-Alexander University Erlangen-Nürnberg

ADAP Z01

Modern Tech Stacks

- Modern Applications use many different technologies, esp. service-oriented architectures
- Managing a complex tech stack on one machine is hard
- Managing a complex tech stack on different machines and environments is even harder
  - Especially if setting up the environment is done manually

	Service A (Java)	Service B (Java)	Service C (NodeJS)	Frontend (VueJS)	Database A (PostGreSQL)	Database B (MongoDB)
Laptop Dev A	Java 11	Java 11	Node 12.10.0 Current	Node 12.10.0 Current	-	MongoDB 4.2
Laptop Dev B	Java 13	Java 13	Node 12.10.0 Current	Node 12.10.0 Current	Postgres 11.5	-
QA Servers	Java 11	Java 11	Node 10.16.3 LTS	Node 10.16.3 LTS	Postgres 10.10	MongoDB 4.0
Prod Servers	Java 8	Java 8	Node 10.16.3 LTS	Node 10.16.3 LTS	Postgres 10.10	MongoDB 4.0

Modern Tech Stacks

- Modern Applications use many different tech iented architectures
- Managing a complex tech stack on one mac
- Managing a complex tech stack on different nts is even harder
  - E up the environment is done man

	(Java)	Service B (Java)	Service C (NodeJS)	Frontend (VueJS)	Database A (PostGreSQL)	Database B (MongoDB)
Laptop Dev A	Jav	11	Node 12.10.0 Current	No		MongoDB 4.2
Laptop Dev B		13	Node 12.10.0 Current	Current		-
QA Servers	Java 11	Java 11	Node 10.16.3 LTS	Node 10.16.3 LTS	Postgres 10.10	MongoDB 4.0
Prod Servers	Java 8	Ja		0.16.3 S	Postgres 10.10	MongoDB 4.0

Service C crashed the whole machine, so Service A and the Frontend is down, too!

Everything finally works!

Not on my machine...

Which new dependency do I have to install again?

Somehow broke the production! Hm, on my local machine it worked??!?

The Transportation Problem

How to transport things of different sizes effectively?

shippable containers

Images from https://www.pexels.com/

How Docker Summerize Itself in three Words

Build

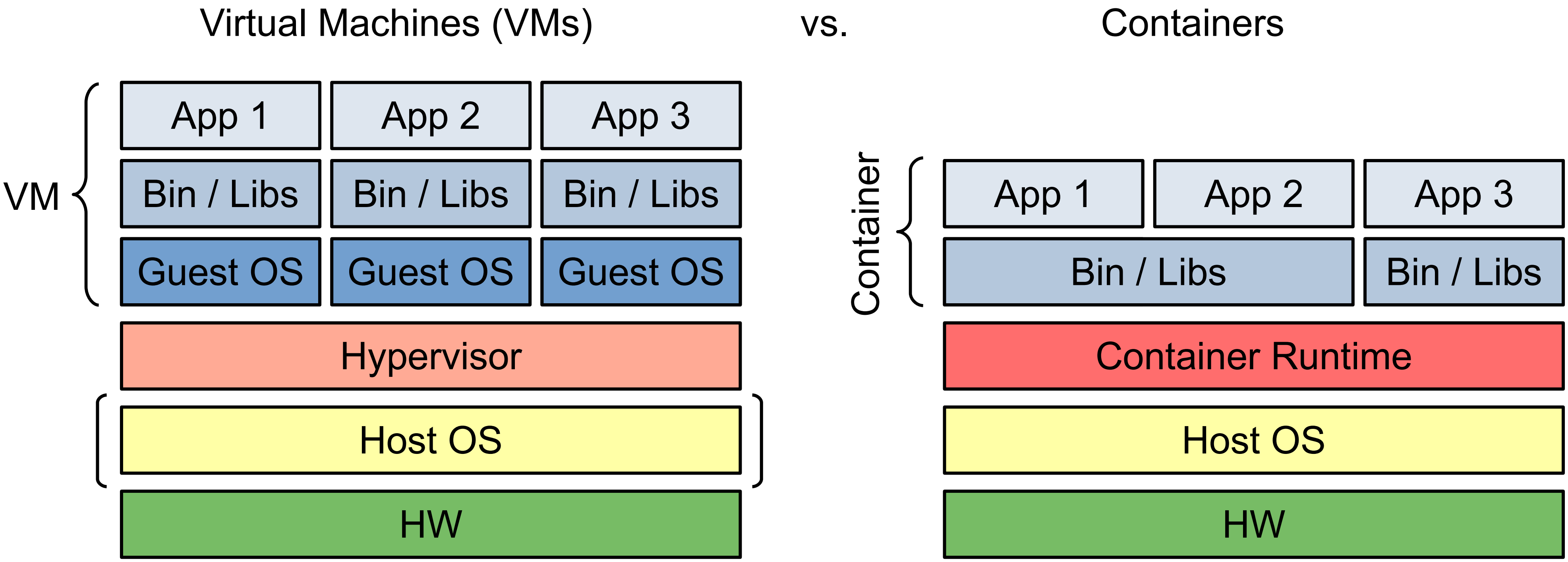
Share

Run

Advantages of Containerization

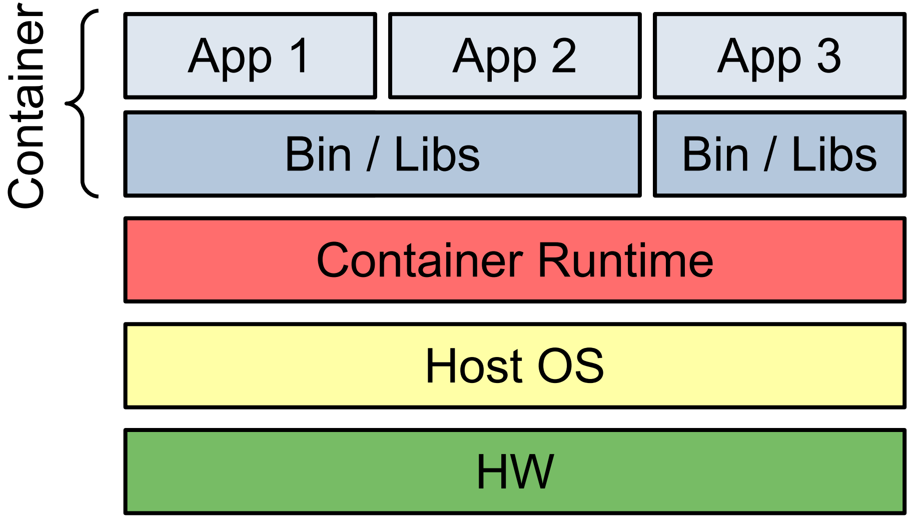
- Standardized packaging for software and its dependencies
- Consistent environment
  - Correct libraries and runtimes
  - Same environment for dev, QA and production
- Isolation / Sandboxing
  - No impact on other applications
  - Additional security layer (if configured correctly)
- Build once, run anywhere
  - Developer machine vs. on-premise vs. cloud
  - Linux vs. Windows vs. Mac
- Infrastructure as Code
  - Flexibility
  - Code = documentation

Virtual Machines vs Containers



Virtual Machines vs Containers

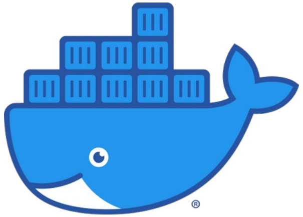
- Benefits of lightweight containers compared to VMs
  - Share host's OS with container results in
    - improved deployment speed
    - faster reboots
    - less resource overhead
      - memory and storage



Container Standards

- Standardization: Open Container Initiative (OCI)
  - Open governance structure to create open industry standards for containers
  - Runtime Specification
  - Image Specification
- Linux Containers (LXC)
  - OS-level virtualization technology
    - Use Linux kernel features
    - Like namespaces and control groups
  - Uses virtual environments (VE) to run isolate applications or an entire OS
- Docker is an extension of LXC with improved capabilities
  - Provides a high-level API
  - Versioning of containers
  - Container reuse (base images)
  - A public registry to share containers
  - Available as Community Edition (CE) or Enterprise Edition (EE)

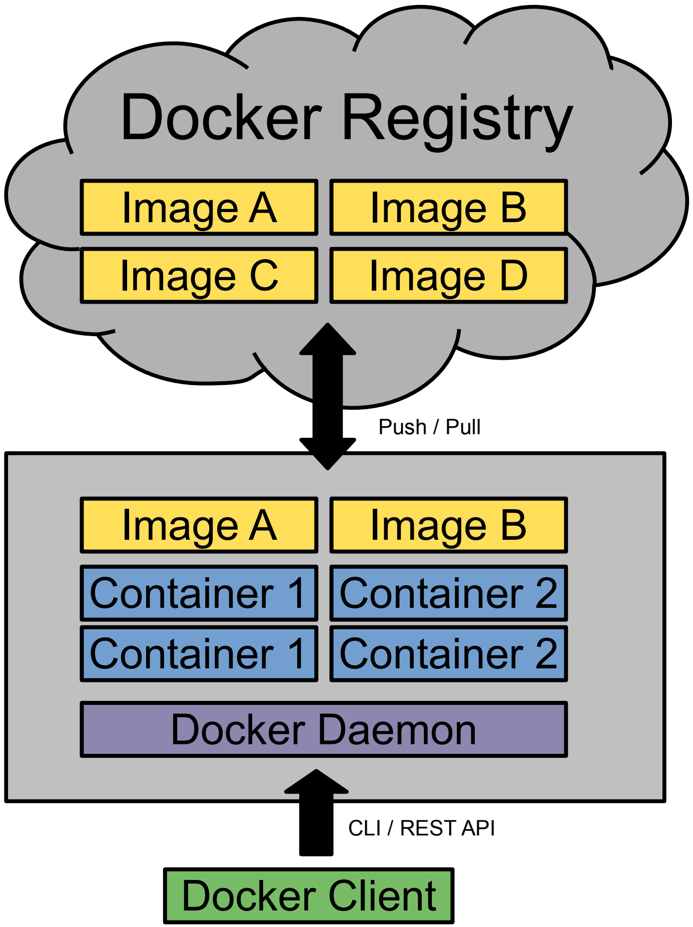
https://discuss.linuxcontainers.org/uploads/default/original/1X/9a2865f528f7b846cda54335dec298dda6109bb3.png



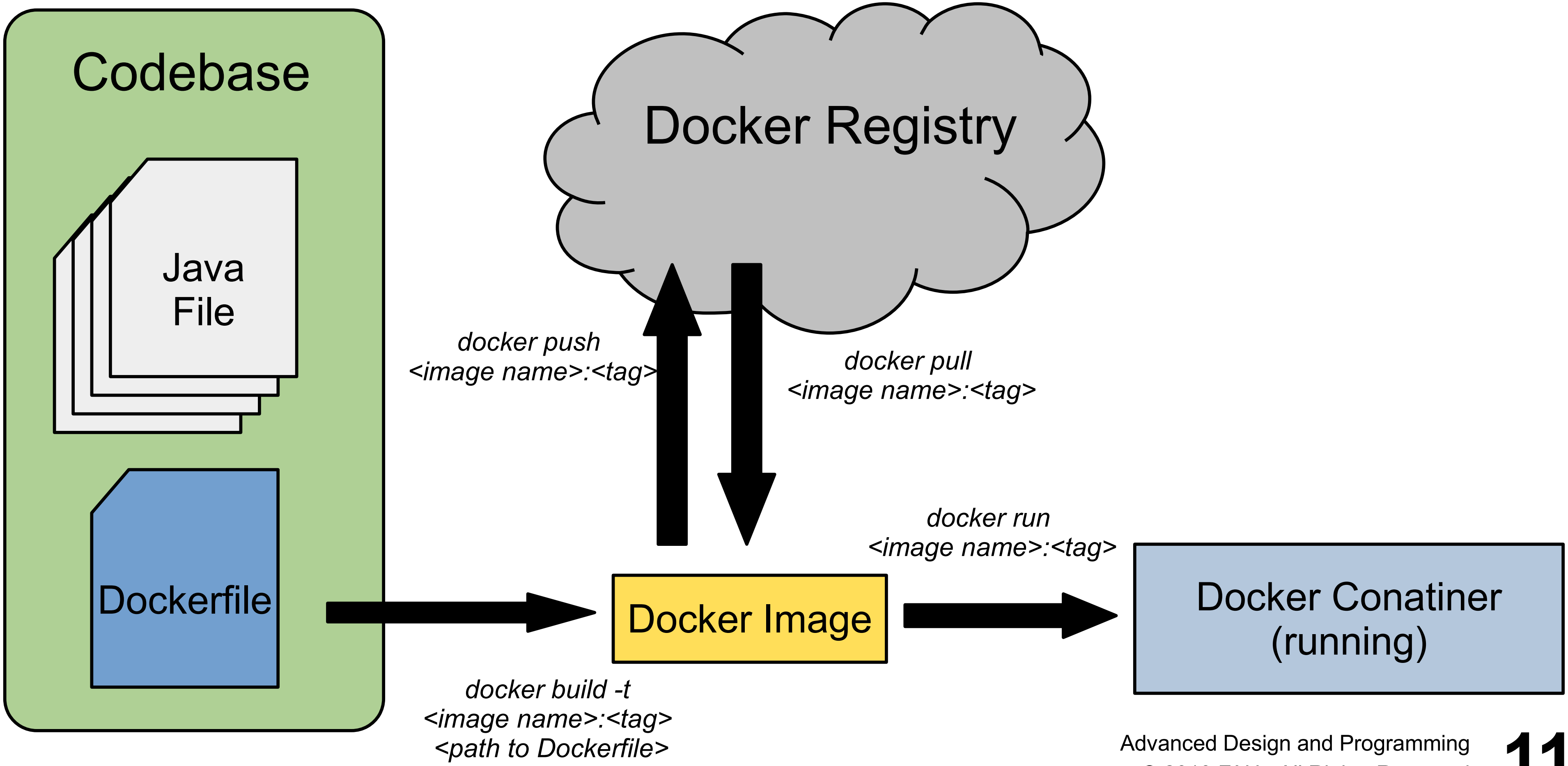
https://www.docker.com/sites/default/files/d8/2019-07/Moby-logo.png

Docker Concepts

- Docker Client and Daemon
  - Docker Daemon is responsible for all actions that are related to containers
  - Receives commands from Docker Client by CLI or REST API
  - Docker Client and Daemon can be on same machine, but don't have to (client-server architecture)
- Docker Images
  - Executable package to run an application
  - Includes the code, a runtime, libraries, environment variables, and configuration files
- Docker Containers
  - Execution environment for Docker
  - Instance of an Docker Image (created from it)
- Docker Registry
  - Share Docker Images
  - Public vs. private

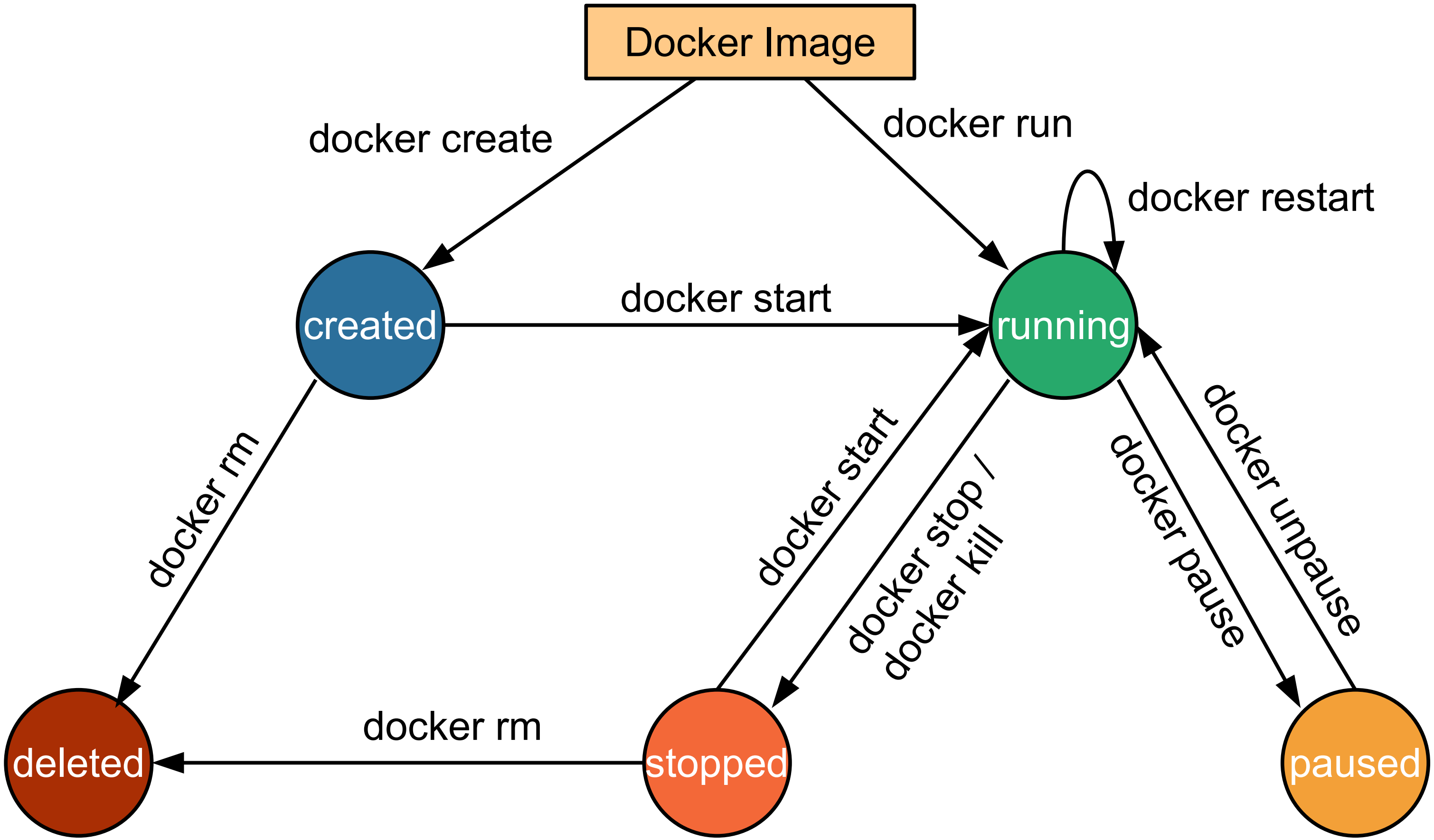


Docker Workflow

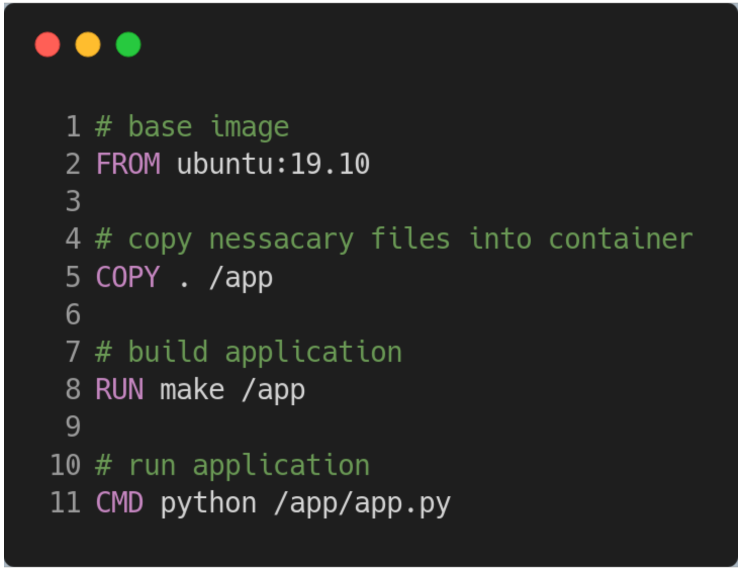


Codebase
Java File
Dockerfile
Docker Registry
docker push <image name>:<tag>
docker pull <image name>:<tag>
Docker Image
docker run <image name>:<tag>
Docker Conatiner (running)
docker build -t <image name>:<tag> <path to Dockerfile>

Docker Container Lifecycle



Docker File



```
# base image
FROM ubuntu:19.10

# copy nessacary files into container
COPY . /app

# build application
RUN make /app

# run application
CMD python /app/app.py
```

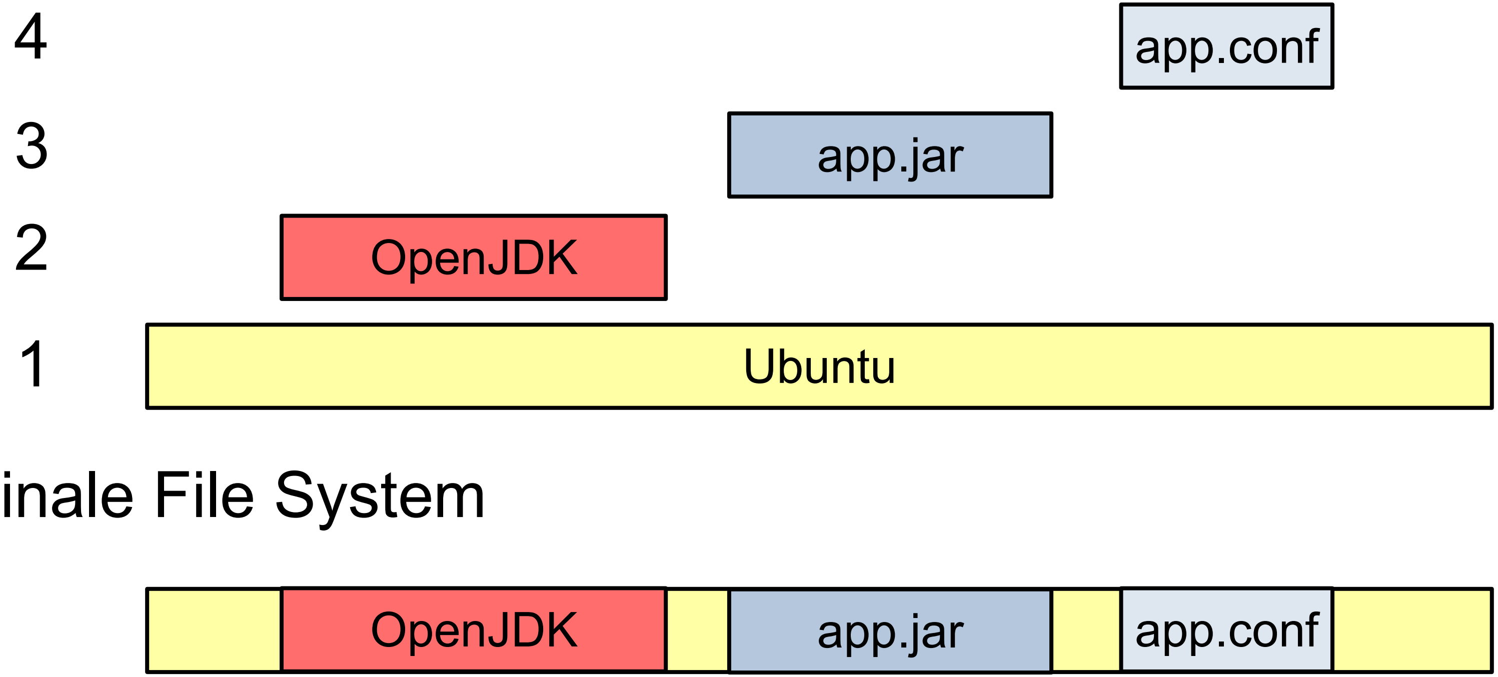
- A Dockerfile is a text document which describes how a Docker image is assembled
- A Dockerfile starts with the definition of the base image
- Each instruction creates a new layer on top of the previous image layer
- **CMD** and **ENTRYPOINT** define the command to be executed when running the image

Docker Images

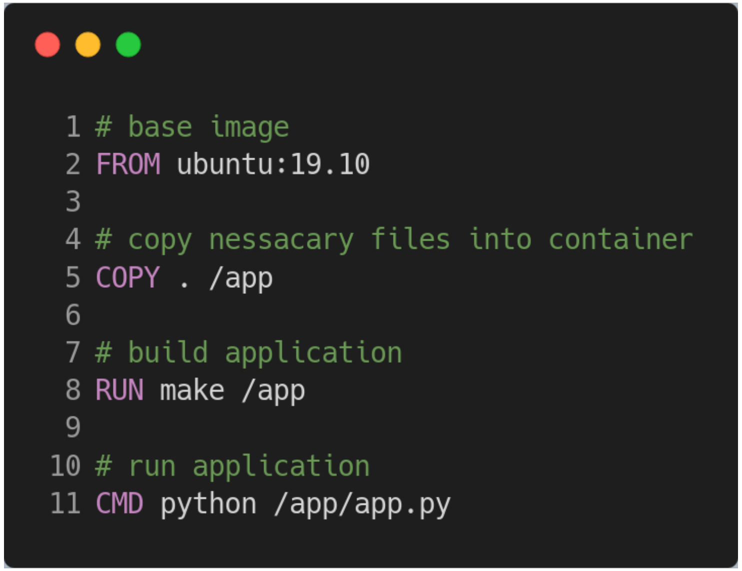
- OOP analogy: Image is like a class and a container is like an instance of a class
- Images are designed to be composed of other images
- Union File System (UFS) is the key technology used for Docker images
  - UFS allows to overlay different file systems and provide a view as a single file system on it
  - Docker allows different implementations of the UFS, e.g. AUFS, Overlay, or BTRFS
- Image layers
  - Are committed by Copy on Write (CoW)
  - Are read only
  - Can be reused to network traffic and storage consumption
  - Reuse of image layers increasing the build speed of new images
- Developers try to avoid unnecessary image layers
  - AUFS limits the amount of image layers to 127

Docker Image Layers

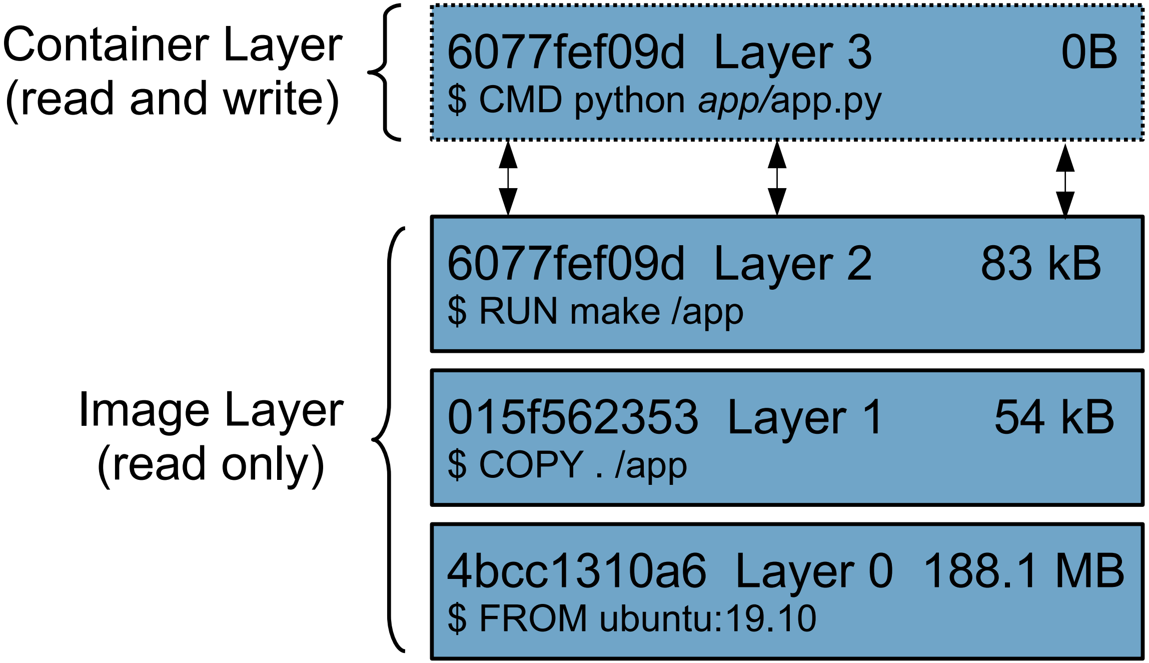
Image Layer



Docker Image Layers



```
# base image
FROM ubuntu:19.10

# copy nessacary files into container
COPY . /app

# build application
RUN make /app

# run application
CMD python /app/app.py
```



Container Layer
(read and write)

6077fef09d Layer 3 0B
$ CMD python *app/*app.py

Image Layer
(read only)

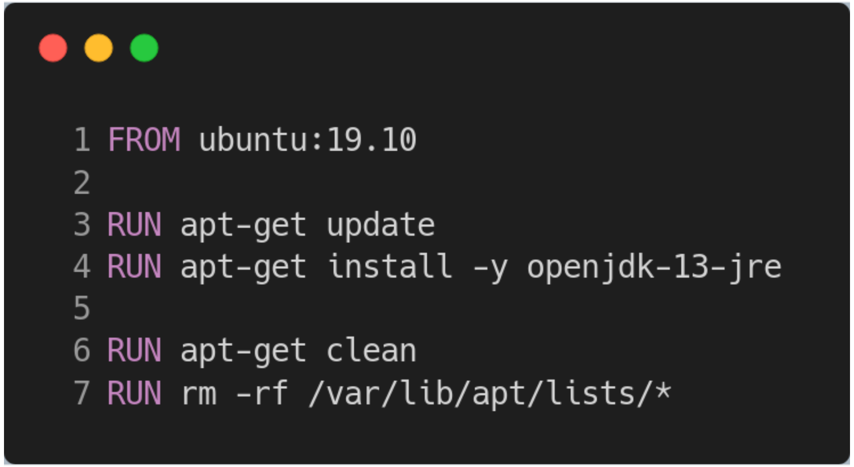
6077fef09d Layer 2 83 kB
$ RUN make /app

015f562353 Layer 1 54 kB
$ COPY . /app

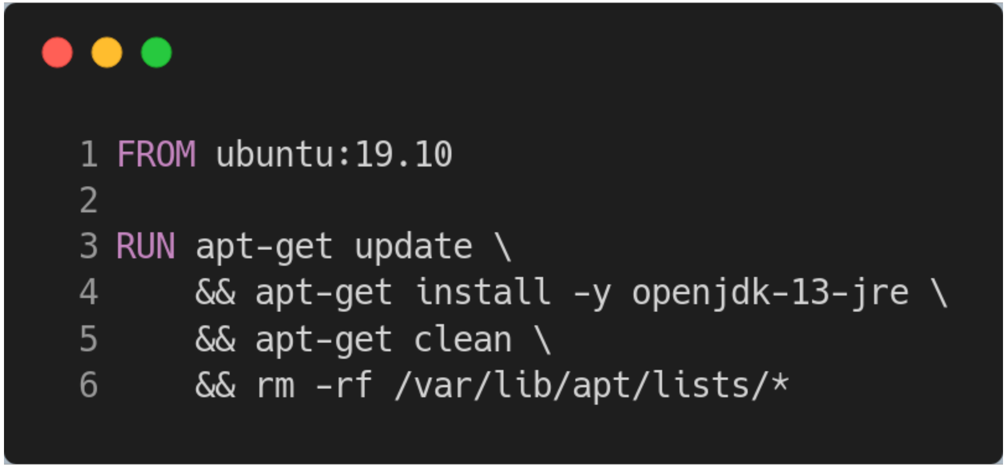
4bcc1310a6 Layer 0 188.1 MB
$ FROM ubuntu:19.10

Docker Images

- What is the difference regarding the resulting Docker image?



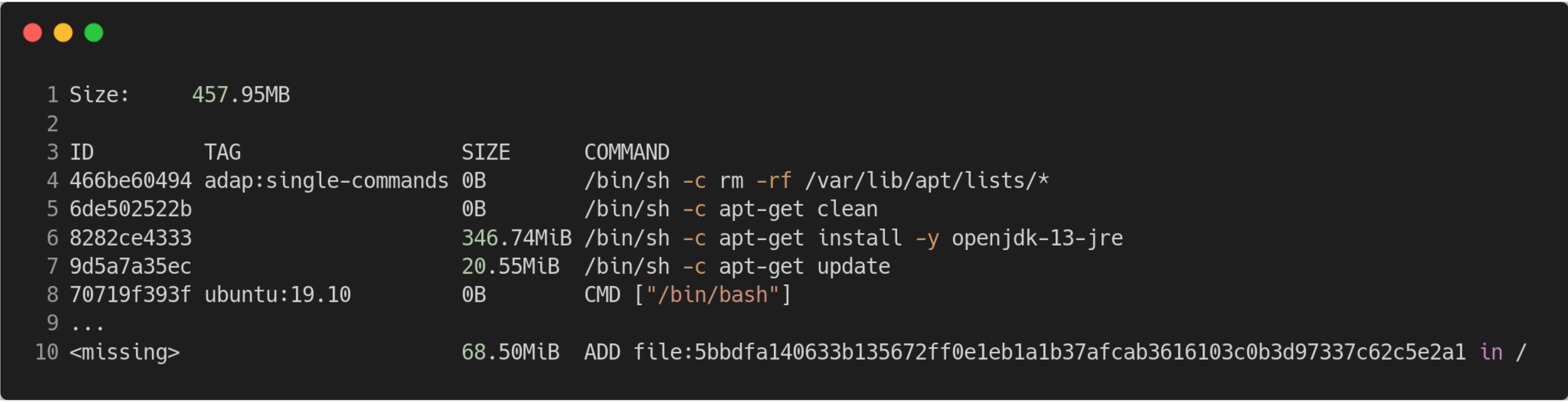
```
FROM ubuntu:19.10

RUN apt-get update
RUN apt-get install -y openjdk-13-jre

RUN apt-get clean
RUN rm -rf /var/lib/apt/lists/*
```



```
FROM ubuntu:19.10

RUN apt-get update \
    && apt-get install -y openjdk-13-jre \
    && apt-get clean \
    && rm -rf /var/lib/apt/lists/*
```

Docker Image Layers: Example multiple commands

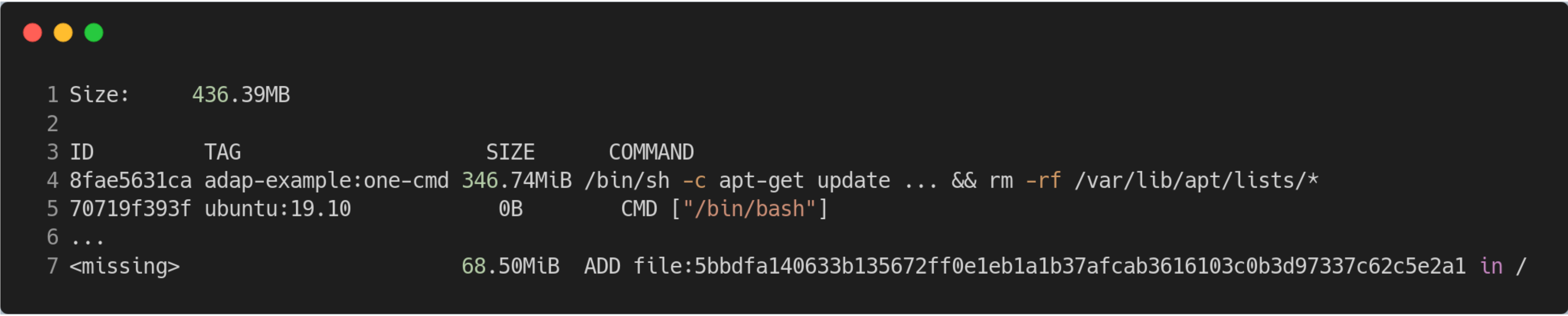
- Cleaning up with an extra RUN command doesn’t reduce the size of the image, it creates just a new layer with the information that the files does not exist anymore



```
Size:     457.95MB

ID         TAG                  SIZE      COMMAND
466be60494 adap:single-commands 0B        /bin/sh -c rm -rf /var/lib/apt/lists/*
6de502522b                      0B        /bin/sh -c apt-get clean
8282ce4333                      346.74MiB /bin/sh -c apt-get install -y openjdk-13-jre
9d5a7a35ec                      20.55MiB  /bin/sh -c apt-get update
70719f393f ubuntu:19.10         0B        CMD ["/bin/bash"]
...
<missing>                       68.50MiB  ADD file:5bbdfa140633b135672ff0e1eb1a1b37afcab3616103c0b3d97337c62c5e2a1 in /
```

Docker Image Layers: Example only one command

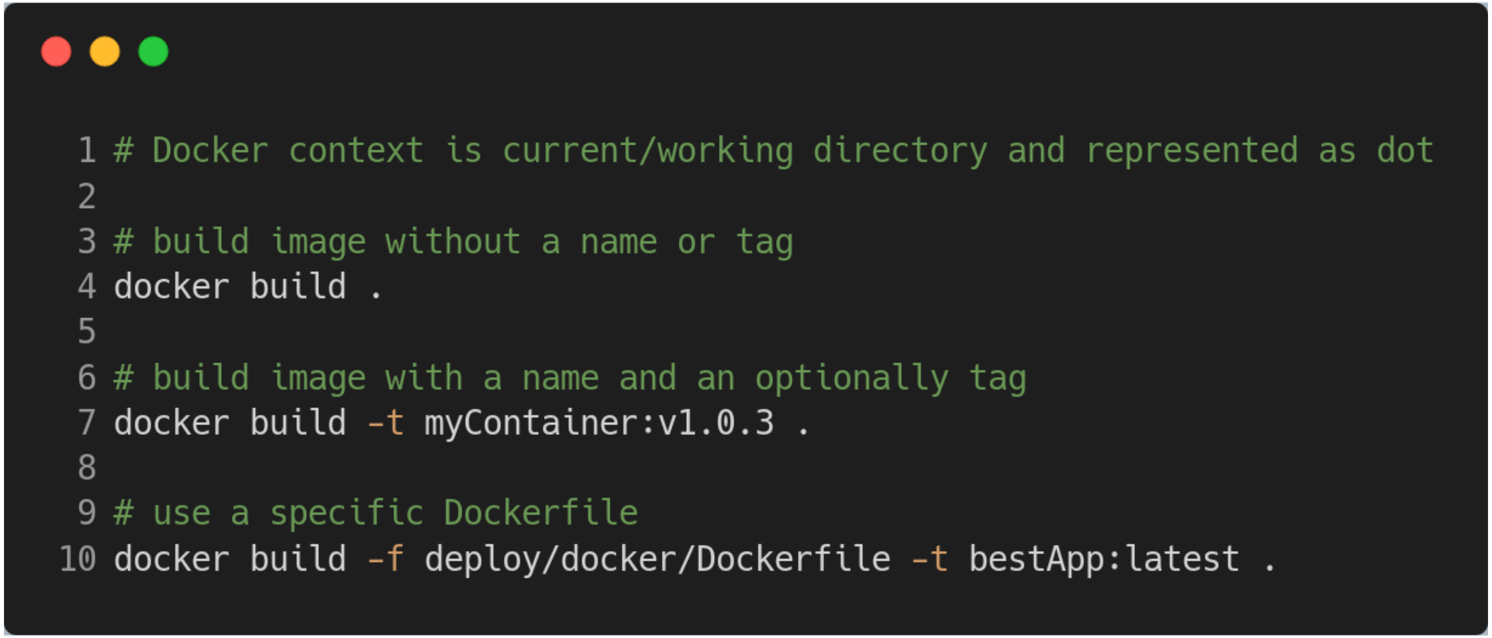
- Cleaning up within the same RUN command ensures that unnecessary files are not part of the resulting image



```
Size:     436.39MB

ID         TAG                    SIZE      COMMAND
8fae5631ca adap-example:one-cmd 346.74MiB /bin/sh -c apt-get update ... && rm -rf /var/lib/apt/lists/*
70719f393f ubuntu:19.10            0B        CMD ["/bin/bash"]
...
<missing>                       68.50MiB  ADD file:5bbdfa140633b135672ff0e1eb1a1b37afcab3616103c0b3d97337c62c5e2a1 in /
```

Docker Build Example

- The **docker build** command builds an image from a Dockerfile and a context



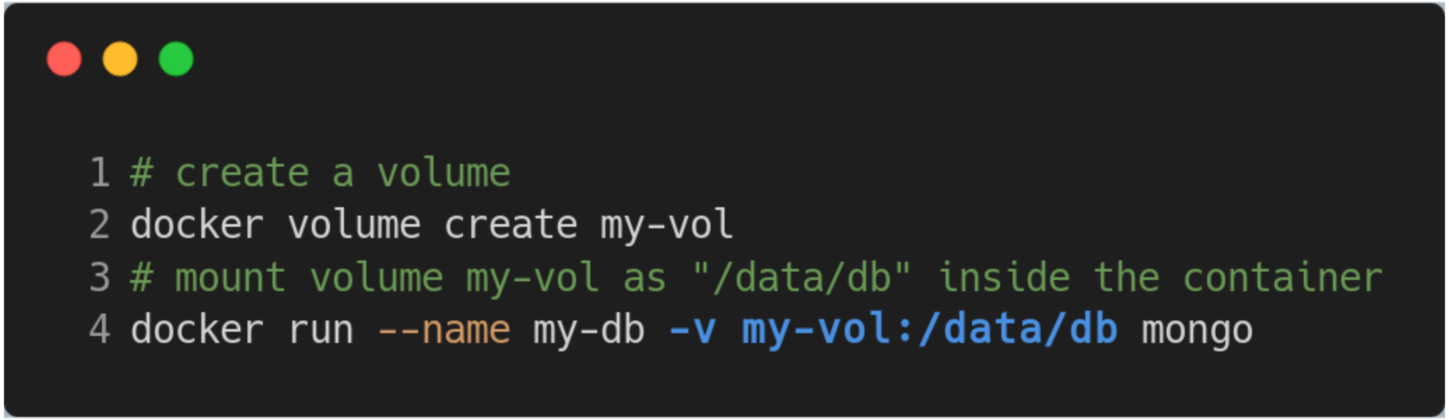
```
# Docker context is current/working directory and represented as dot

# build image without a name or tag
docker build .

# build image with a name and an optionally tag
docker build -t myContainer:v1.0.3 .

# use a specific Dockerfile
docker build -f deploy/docker/Dockerfile -t bestApp:latest .
```

Persistence in Docker

- By default all file changes inside a container are stored on the writable container layer
  - If the container is deleted, all file changes are also gone
  - Writable container layer is tightly coupled to the host machine and can’t be moved easily
  - Data depend on the lifecycle of the container
- Docker provides the following options to store data on the host system
  - Volumes (preferred option)
    - A volume is stored within a directory on the host and is managed by Docker
  - Bind mounts
    - Mounting files or directories from the host system
- Non-persistent mount with tmpfs (Linux only)
  - Store data temporary in the host memory
  - Often used to store secrets temporarily

Persistence in Docker: Volumes

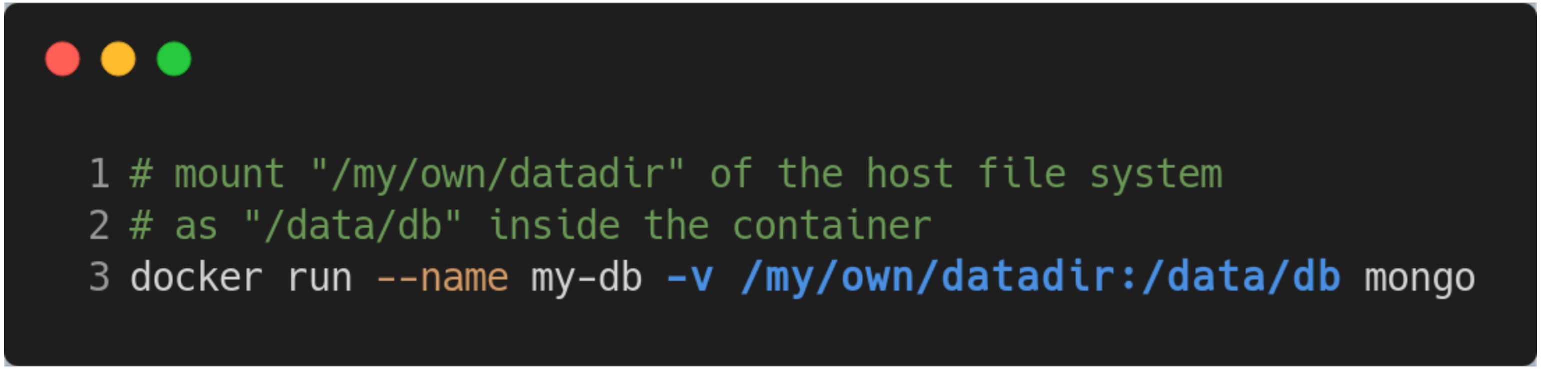
- Volumes (preferred option)
  - Created and managed by Docker
  - A volume is stored within a directory on the host
  - Easy to backup and snapshot
  - Volumes can be shared among multiple containers
  - Manage volumes using Docker CLI or API
  - Volume drivers allows to store volume on a remote host (e.g. a cloud provider)
- Example
  - Store date of MongoDB outside the container in a volume



```
# create a volume
docker volume create my-vol
# mount volume my-vol as "/data/db" inside the container
docker run --name my-db -v my-vol:/data/db mongo
```

Persistence in Docker: Bind Mounts

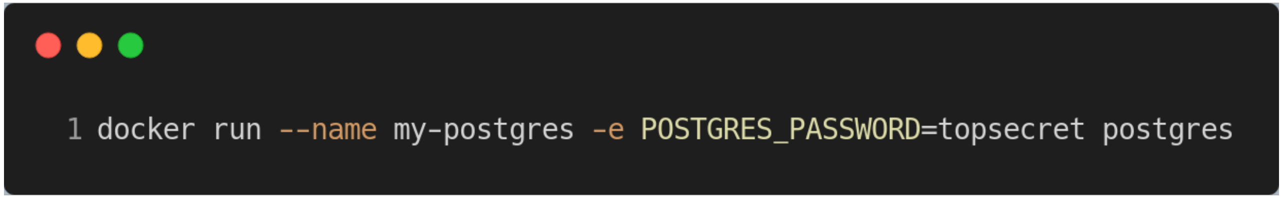
- Bind mounts
  - Mount files or directories from the host system into a container
  - Limited functionality compared to volumes
  - File or directory will be created if does not exist already
  - Allows easy sharing of config files or development artifacts to container
- Example
  - Store date of MongoDB outside the container



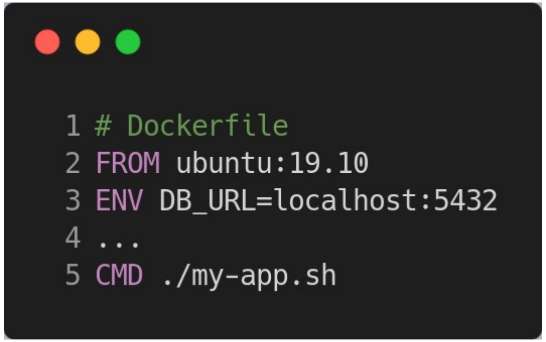
```
# mount "/my/own/datadir" of the host file system
# as "/data/db" inside the container
docker run --name my-db -v /my/own/datadir:/data/db mongo
```

Docker Environment Variables

- Environment variables allows us to configure a containerized application
  - With the **-e** parameter you can pass environment variables from the host to the container
  - With **ENV** you can define environment variables in the Dockerfile to provide default values
  - To use environment variables during image build-time you need first to introduce the variable with the **ENV** instruction
  - **ARG**s (build-time variables) can be used to pass variables during build-time
    - Running container can’t access **ARG** values



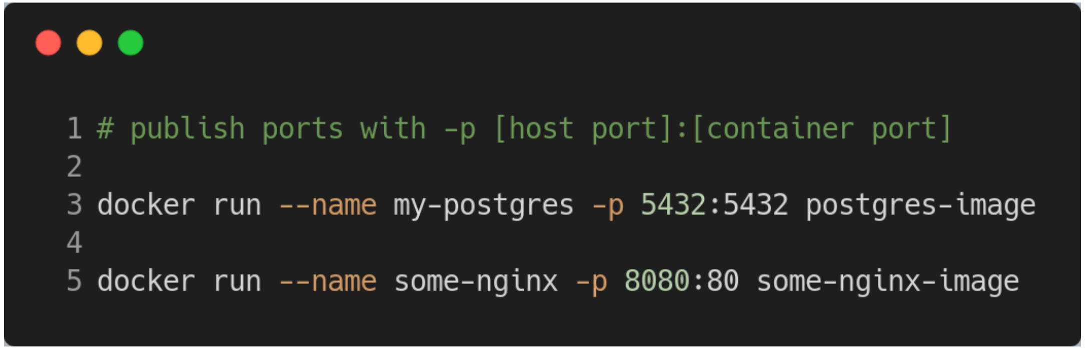
```
docker run --name my-postgres -e POSTGRES_PASSWORD=topsecret postgres
```



```
# Dockerfile
FROM ubuntu:19.10
ENV DB_URL=localhost:5432
...
CMD ./my-app.sh
```

Publish a Container’s Port(s) to the Host

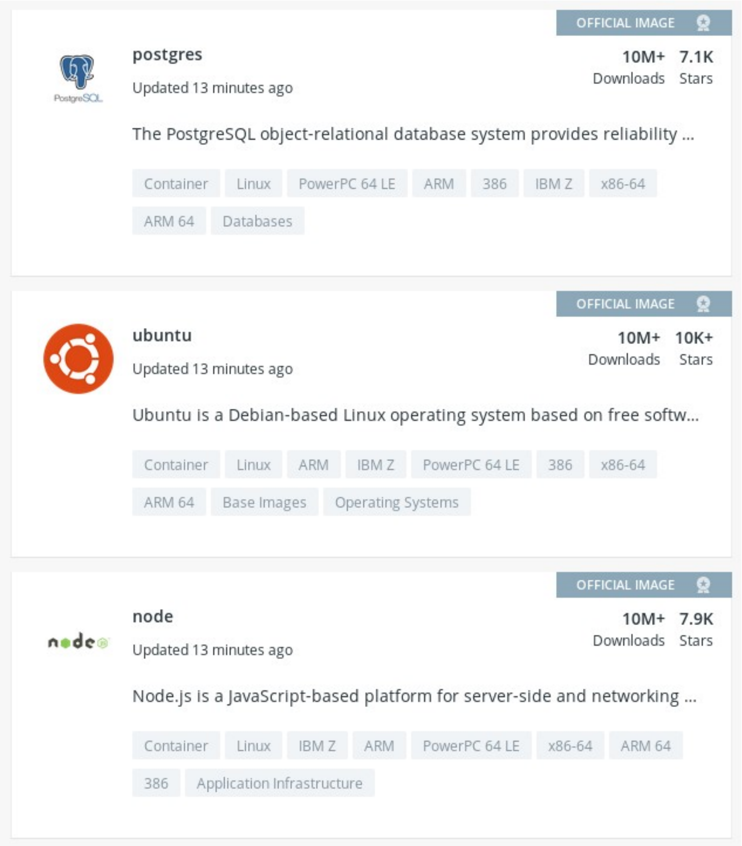
- Default behavior: Host can’t access ports of processes inside a container
- **EXPOSE** instruction inside Dockerfile declare ports used inside a container
  - A way of documentation
- Running container with option for port mapping is required
  - Option **-P** publish all exposed ports to the host
  - Option **-p** publish one or a range of ports to the host



```
# publish ports with -p [host port]:[container port]

docker run --name my-postgres -p 5432:5432 postgres-image

docker run --name some-nginx -p 8080:80 some-nginx-image
```

Share Images with the World or a Team

Docker Hub



OFFICIAL IMAGE

postgres

Updated 13 minutes ago

10M+ Downloads 7.1K Stars

The PostgreSQL object-relational database system provides reliability ...

Container Linux PowerPC 64 LE ARM 386 IBM Z x86-64 ARM 64 Databases

OFFICIAL IMAGE

ubuntu

Updated 13 minutes ago

10M+ Downloads 10K+ Stars

Ubuntu is a Debian-based Linux operating system based on free softw...

Container Linux ARM IBM Z PowerPC 64 LE 386 x86-64 ARM 64 Base Images Operating Systems

OFFICIAL IMAGE

node

Updated 13 minutes ago

10M+ Downloads 7.9K Stars

Node.js is a JavaScript-based platform for server-side and networking ...

Container Linux IBM Z ARM PowerPC 64 LE x86-64 ARM 64 386 Application Infrastructure

- Public and private image repositories allow to easy share and manage images
- Docker Hub is the default repository for Docker

Docker Environment on different OS

- Linux
  - Containers are part of the Linux ecosystem
  - Native isolated processes
  - Direct access to the host Linux kernel
  - Best performance
- Mac (Docker for Mac)
  - Lightweight virtual machine (LinuxKit) running on macOS Hypervisor
  - No direct access to the network stack and native file mounts
  - Uses Unix sockets to bridge host and Docker VM
- Windows
  - Runs LinuxKit VM with the virtualization tool Hyper-V
  - Similar to Docker for Mac
- Docker Toolbox (legacy solution for Mac and Windows)
  - Runs a Linux VM using Virtual Box
  - Bridges host and Docker VM via TCP connection
  - Lower performance

Why Container Orchestration

- Modern applications consist of smaller (micro)services that work together
- This way a containerized application consists of multiple container that communicate over network to provide a service
- Managing containers becomes a complex task
  - E.g. deploying the whole application requires custom scripts
- The process of organizing multiple container is called **container orchestration** [1]
- Container orchestration solutions
  - **Docker Swarm** by Docker Inc
  - **Kubernetes** based on Google's work (the gold standard)
  - **Mesos** by Apache

[1] https://www.hpe.com/de/de/what-is/container-orchestration.html

Container Orchestration

- *“Kubernetes (K8s) is an open-source system for automating deployment, scaling, and management of containerized applications.”* [2]
- Horizontal scaling (for medium to large clusters)
  - Spawn new instances of services either by hand, or
  - Automatically based on metrics like CPU usage
  - Optimized usage of a cluster’s resources
- Service discovery and load-balancing
- Self-healing features
  - like restart on failure with health monitoring
- Manage deployments
  - Define deployment units
  - Automated rollouts and rollbacks

Image: https://github.com/kubernetes/kubernetes/tree/master/logo
[2] https://kubernetes.io/

Thank you! Questions?

dirk.riehle@fau.de – http://osr.cs.fau.de

dirk@riehle.org – http://dirkriehle.com – @dirkriehle

Credits and License

- Original version
  - © Friedrich-Alexander University Erlangen-Nürnberg, all rights reserved
- Contributions
  - Andreas Bauer (2019)
  - Georg Schwarz (2019)