Containerization (with Docker)

Professorship of Open Source Software

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ADAP B01

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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

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Modern Tech Stacks

- Modern Applications use many different tech … ented 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…

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??!?

	Service A (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…		…10.16.3 …TS	Postgres 10.10	MongoDB 4.0

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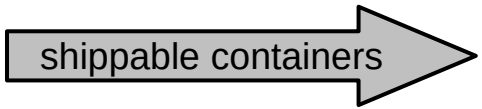
The Transportation Problem

How to transport things of different sizes effectively?



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

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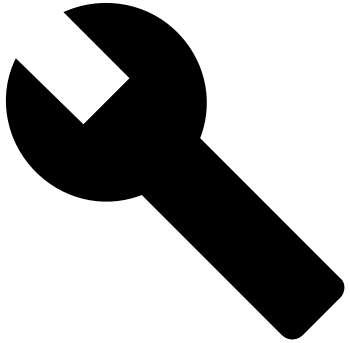
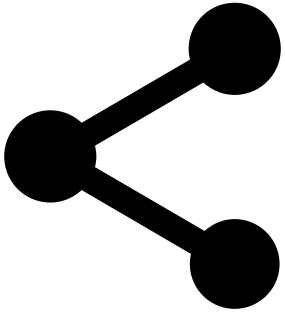
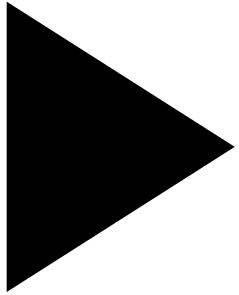
How Docker Summerize Itself in three Words



Build



Share



Run

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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

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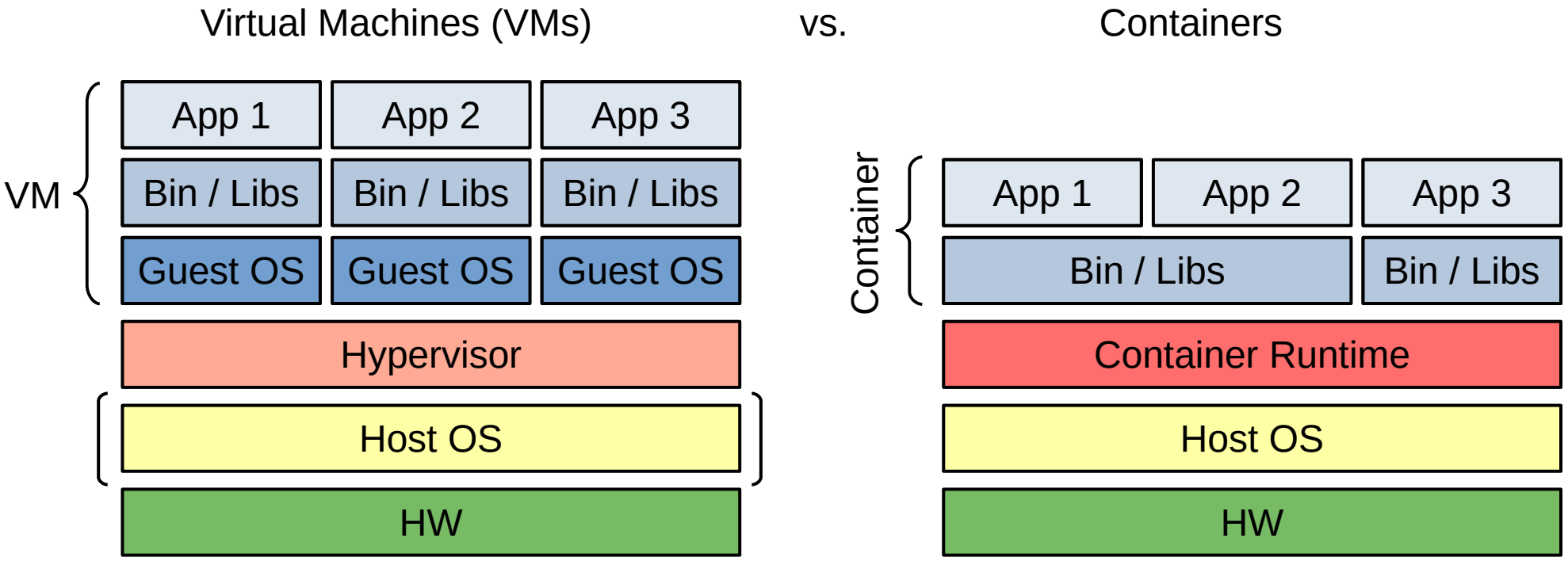
Virtual Machines vs Containers



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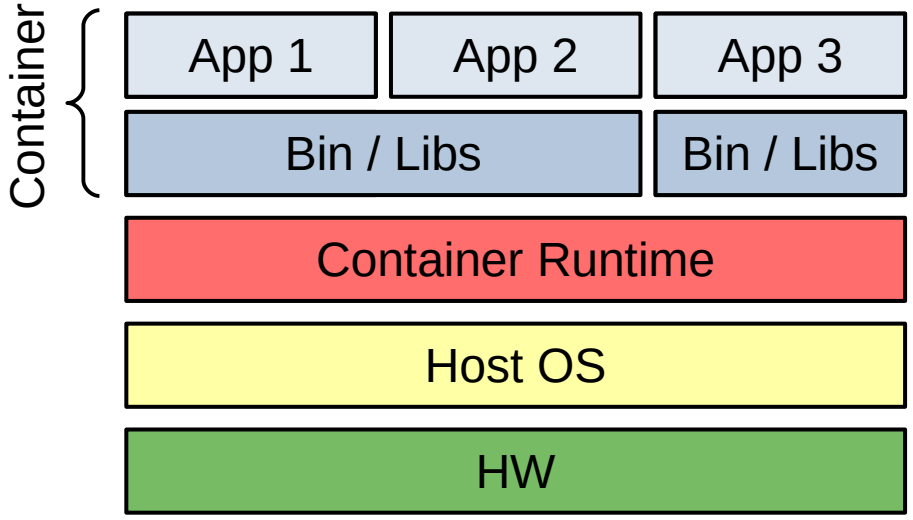
Virtual Machines vs Containers

- 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



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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

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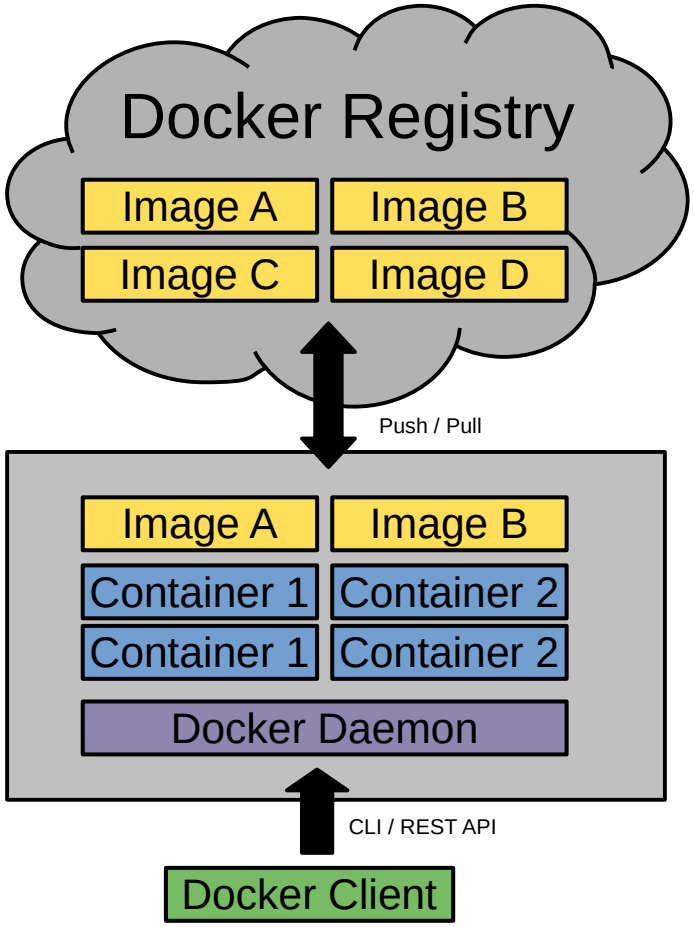
Docker Concepts

- 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



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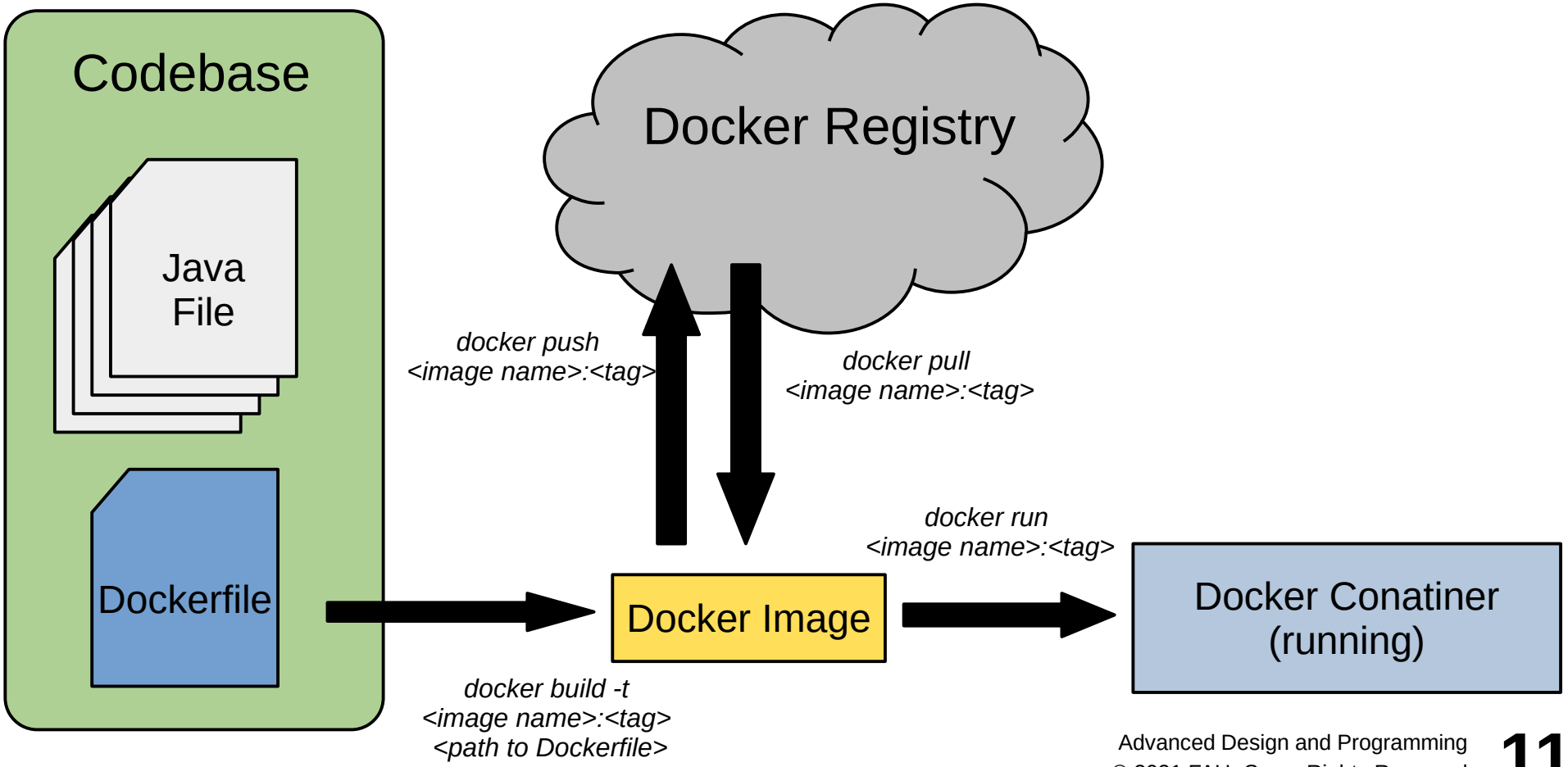
Docker Workflow



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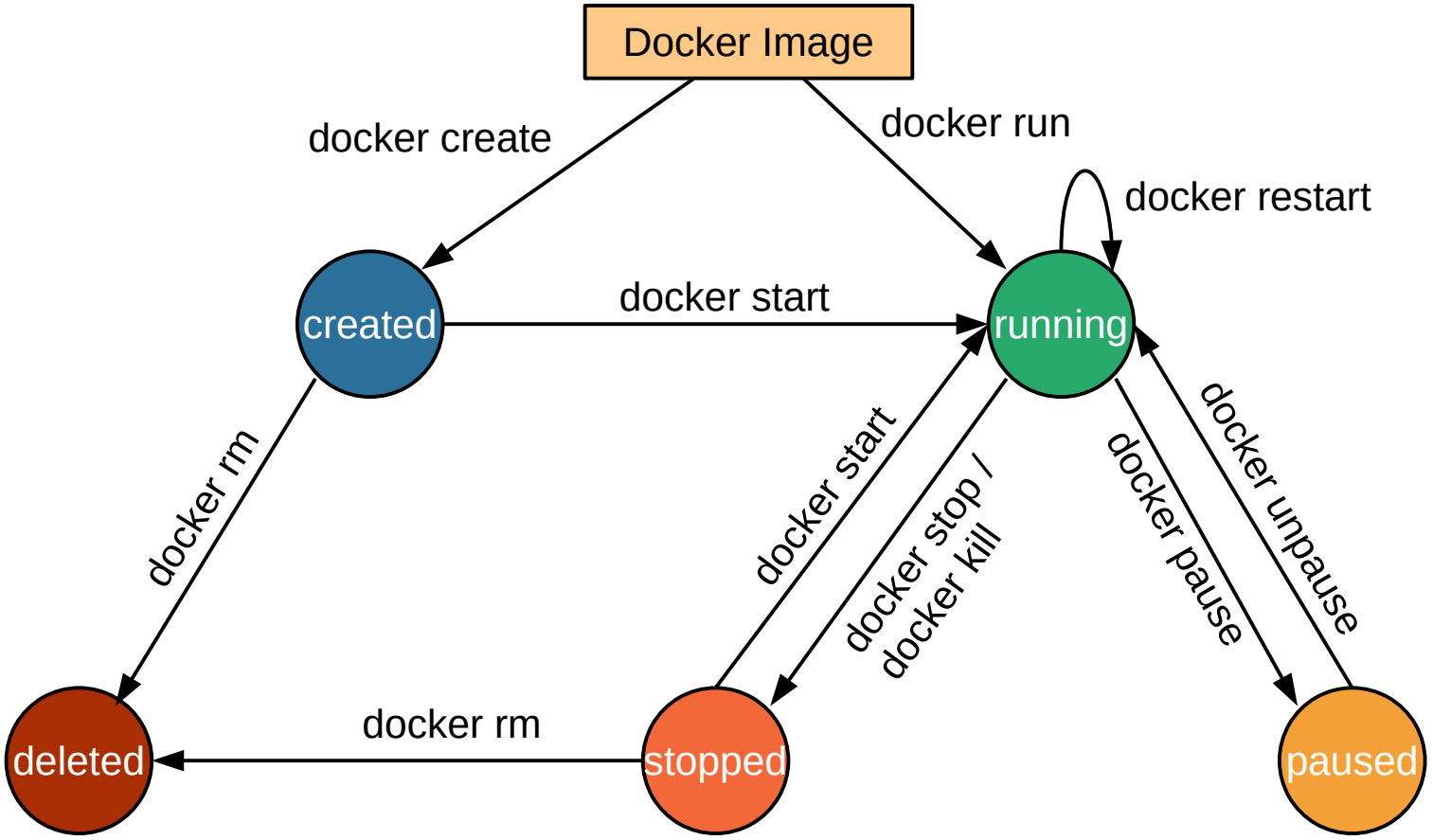
Docker Container Lifecycle



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Docker File

- 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

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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

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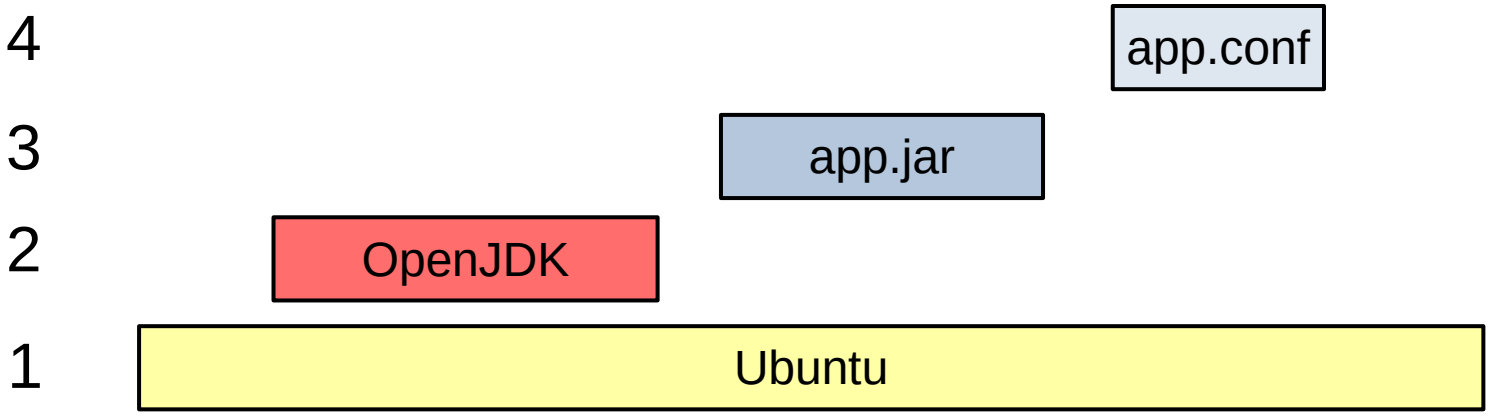
Docker Image Layers

Image Layer



Finale File System

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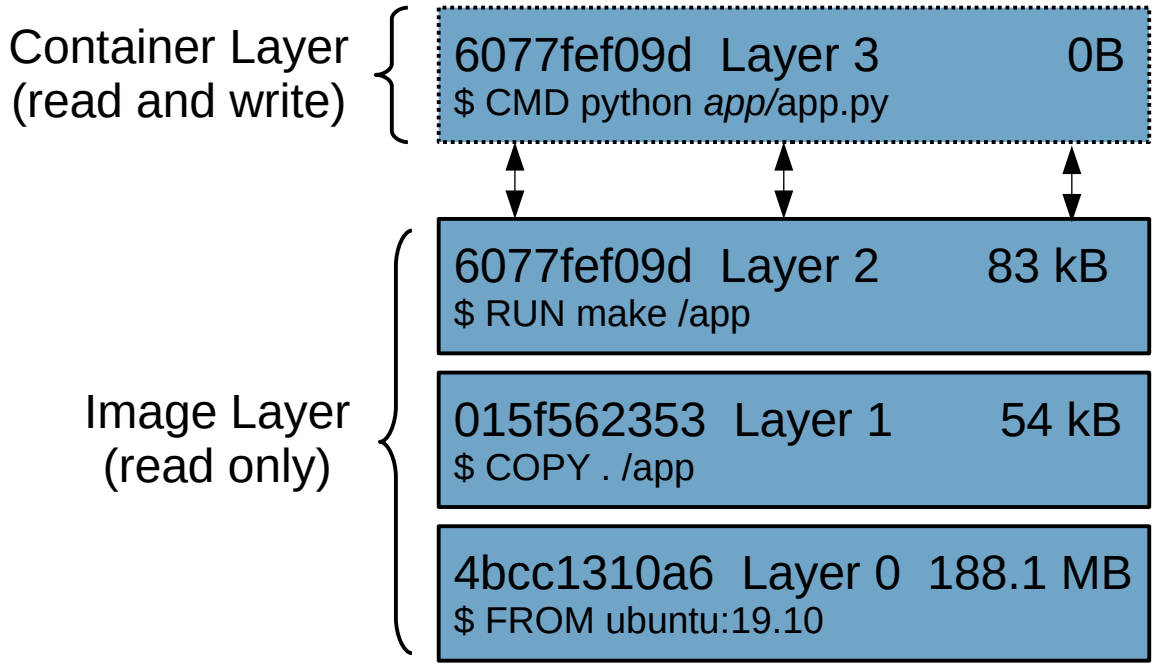
Docker Image Layers



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Docker Images

- What is the difference regarding the resulting Docker image?

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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

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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

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Docker Build Example

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

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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

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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

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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

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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

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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

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Share Images with the World or a Team

Docker Hub

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

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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

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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

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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/

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Thank you! Questions?

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