Containers, Dockers, and Kubernetes

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These slides and audio/video recordings of this class lecture are at:
http://www.cse.wustl.edu/~jain/cse570-18/

Overview

1. What is a Container and Why?
2. How Docker helps using containers
3. Docker Commands
4. Orchestration: Swarms and Kubernetes
5. Docker Networking and Security

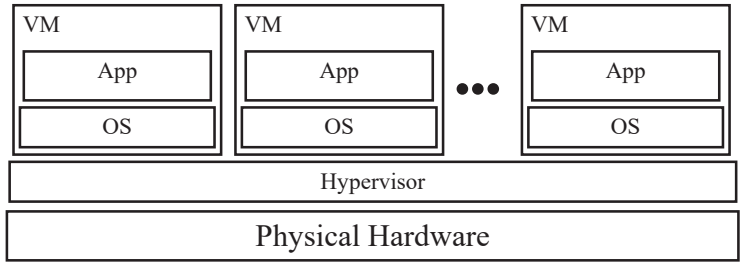
Key Reference: N. Poulton, "Docker Deep Dive," Oct 2017, ISBN: 9781521822807 (Not a Safari Book)

Advantages of Virtualization

- Minimize hardware costs (CapEx)
  Multiple virtual servers on one physical hardware
- Easily move VMs to other data centers
  - Provide disaster recovery. Hardware maintenance.
  - Follow the sun (active users) or follow the moon (cheap power)
- Consolidate idle workloads. Usage is bursty and asynchronous.
  Increase device utilization
- Conserve power
  Free up unused physical resources
- Easier automation (Lower OpEx)
  Simplified provisioning/administration of hardware and software
- Scalability and Flexibility: Multiple operating systems

Ref: http://en.wikipedia.org/wiki/Platform_virtualization
Ref: K. Hess, A. Newman, "Practical Virtualization Solutions: Virtualization from the Trenches," Prentice Hall, 2009, ISBN:0137142978

Problems of Virtualization

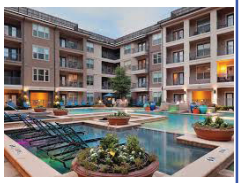


- Each VM requires an operating system (OS)
  - Each OS requires a license ⇒ CapEx
  - Each OS has its own compute and storage overhead
  - Needs maintenance, updates ⇒ OpEx
  - VM Tax = added CapEx + OpEx

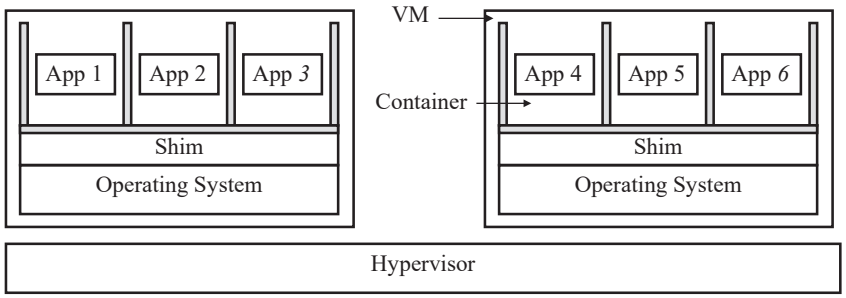
Solution: Containers

- Run many apps in the same virtual machine
  - These apps share the OS and its overhead
  - But these apps can't interfere with each other
  - Can't access each other's resources without explicit permission
  - Like apartments in a complex

  ⇒ Containers



Containers



- Multiple containers run on one operating system on a virtual/physical machine
- All containers share the operating system ⇒ CapEx and OpEx
- Containers are isolated ⇒ cannot interfere with each other
  - Own file system/data, own networking ⇒ Portable

Containers (Cont)

- Containers have all the good properties of VMs
  - Come complete with all files and data that you need to run
  - Multiple copies can be run on the same machine or different machine ⇒ Scalable
  - Same image can run on a personal machine, in a data center or in a cloud
  - Operating system resources can be restricted or unrestricted as designed at container build time
  - Isolation: For example, "Show Process" (ps on Linux) command in a container will show only the processes in the container
  - Can be stopped. Saved and moved to another machine or for later run

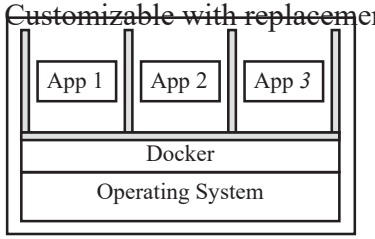
VM vs. Containers

Criteria	VM	Containers
Image Size	3X	X
Boot Time	>10s	~1s
Computer Overhead	>10%	<5%
Disk I/O Overhead	>50%	Negligible
Isolation	Good	Fair
Security	Low-Medium	Medium-High
OS Flexibility	Excellent	Poor
Management	Excellent	Evolving
Impact on Legacy application	Low-Medium	High

Ref: M. K. Weldon "The Future X Network: A Bell Labs Perspective," CRC Press, 2016, 476 pp., ISBN:9781498779142

Docker

- Provides the isolation among containers
- Helps them share the OS
- Docker = Dock worker ⇒ Manage containers
- Developed initially by Docker.com
- Downloadable for Linux, Windows, and Mac from Docker.com
- ~~Customizable with replacement~~ modules from others



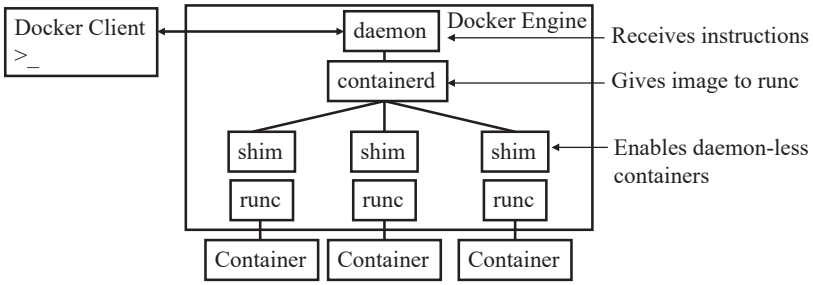
Docker

- Docker Engine: Runtime
- Two Editions:
  - Community Edition (CE): Free for experimentation
  - Enterprise Edition (EE): For deployment with paid support
- Written in "Go" programming language from Google
- Now open source project under mobyproject.org https://github.com/moby/moby
- Download the community edition and explore

Ref: https://golang.org/

Docker Engine Components

- daemon: API and other features
- containderd: Execution logic. Responsible for container lifecycle. Start, stop, pause, unpause, delete containers.
- runc: A lightweight runtime CLI
- shim: runc exists after creating the container. shim keeps the container running. Keep stdin/stdout open.



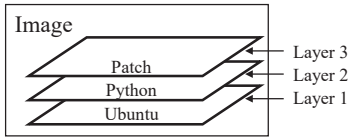
Ref: N. Poulton, "Docker Deep Dive," Oct 2017, ISBN: 9781521822807 (Not a Safari Book)

Image Registries

- Containers are built from images and can be saves as images
- Images are stored in registries
  - Local registry on the same host
  - Docker Hub Registry: Globally shared
  - Private registry on Docker.com
- Any component not found in the local registry is downloaded from specified location
- Official Docker Registry: Images vetted by Docker
- Unofficial Registry: Images not vetted (Use with care)
- Each image has several tags, e.g., v2, latest, …
- Each image is identified by its 256-bit hash

Layers

- Each image has many layers
- Image is built layer by layer
- Layers in an image can be inspected by Docker commands
- Each layer has its own 256-bit hash
- For example:
  - Ubuntu OS is installed, then
  - Python package is installed, then
  - a security patch to the Python is installed
- Layers can be shared among many containers



Building Container Images

- Create a **Dockerfile** that describes the application, its dependencies, and how to run it

```
FROM Alpine                              ← Start with Alpine Linux
LABEL maintainer="xx@gmail.com"          ← Who wrote this container
RUN apk add –update nodejs nodejs –npm   ← Use apk package to install nodejs
COPY . /src                              ← Copy the app files from build context
WORKDIR /src                             ← Set working directory
RUN nmp install                          ← Install application dependencies
EXPOSE 8080                              ← Open TCP Port 8080
ENTRYPOINT ["node", "./app.js"]          ← Main application to run
```

RUN nmp install	← Layer 4
Copy . /src	← Layer 3
RUN apk add …	← Layer 2
FROM Alpine	← Layer 1

Note: WORKDIR, EXPOSE, ENTRYPOINT result in tags. Others in Layers.

Docker Commands

- **docker container run**: Run the specified image
- **docker container ls**: list running containers
- **docker container exec**: run a new process inside a container
- **docker container stop**: Stop a container
- **docker container start**: Start a stopped container
- **docker container rm**: Delete a container
- **docker container inspect**: Show information about a container

Open Container Initiative (OCI)

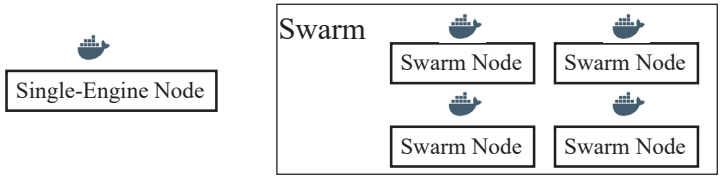
- A company called CoreOS defined alternative image format and container runtime API's
- Led to formation of OCI under Linux Foundation to govern container standards
  - OCI Image spec
  - OCI Runtime spec
- Everyone including Docker is now moving to OCI

OPEN CONTAINER INITIATIVE

Ref: https://www.opencontainers.org/

Swarm

- Orchestrating thousands of containers
- Swarm: A group of nodes collaborating over a network
- Two modes for Docker hosts:
  - Single Engine Mode: Not participating in a swarm
  - Swarm Mode: Participating in a Swarm
- A service may run on a swarm
- Each swarm has a few managers that dispatch tasks to workers. Managers are also workers (i.e., execute tasks)



Swarms (Cont)

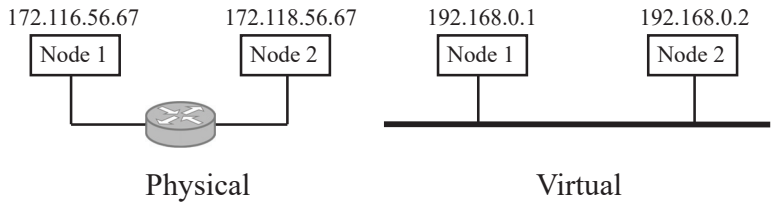
- The managers select a leader, who really keeps track of the swarm
- Assigns tasks, re-assigns failed worker's tasks, …
- Other mangers just monitor passively and re-elect a leader if leader fails
- Services can be scaled up or down as needed
- Several Docker commands:
  - **docker service** : Manage services
  - **docker swarm**: Manage swarms
  - **docker node**: Manage nodes

Docker Swarm Commands

- docker swarm init
- docker swarm join-token
- docker node ls
- docker service create
- docker service ls
- docker service ps
- docker service inspect
- docker service scale
- docker service update
- docker service rm

Docker Overlay Networking

- Nodes in a swarm may not be in the same LAN
- VXLAN is used to provide virtual overlay networking
- VXLAN was discussed in another module of this course



Docker Security

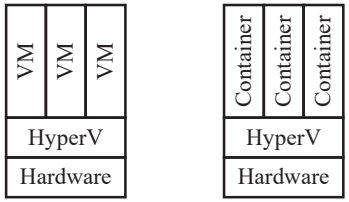
- All built-in security mechanisms in Linux are used and more
- Cryptographic node IDs
- Mutual Authentication
- Automatic Certificate Authority configuration
- Automatic Certificate Renewal on expiration
- Encrypted Cluster Store
- Encrypted Network traffic
- Signed images in Docker Content Trust (DCT)
- Docker Security Scanning detects vulnerabilities
- Docker secrets are stored in encrypted cluster store, encrypted transmission over network, and stored in in-memory file system when in use

Kubernetes

- Open Source Container Orchestration alternative
- Original source released by Google
- Cloud Native Computing Foundation (CNCF) project in Linux Foundation
- Pre-cursor to Swarms
- Facilities similar to Swarms
- A set of related containers is called a "Pod"
  A Pod runs on a single host.
- Swarm is called a "Cluster"

Hyper-V Containers

- Microsoft allows two kinds of containers:
  - Windows Server Containers: Multiple containers on a single VM (like Docker containers)
  - Hyper-V containers: Each container runs on its own VM
    ⇒ No need for a Linux



Ref: https://docs.microsoft.com/en-us/virtualization/windowscontainers/manage-containers/hyperv-container

Intel Clear Containers

- Started 2015 to address security concerns (Dirty COW) in containers
- Idea: Allow lightweight VMs using Intel Virtualization Technology
  - Own lightweight OS and a dedicated kernel
    ⇒ Isolation of network, memory, and I/O
  - Help by hardware enforced isolation
  - No need for full VMs for containers
- Merged with HyperV to form Kata containers on Dec 5, 2017

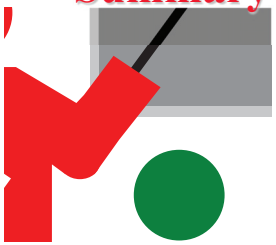
Ref: https://clearlinux.org/containers

Kata Containers

- Lightweight virtual machines
- Dedicated VMs to run one and only one container
- Combines "Intel Clear Containers" and "HyperV runV"
- Open source project under OpenStack Foundation
- Compatible with the OCI specs for Docker containers
- Compatible with CRI for Kubernetes
- Performance like containers, isolation and security like VMs
- Six Components: Agent, Runtime, Proxy, Shim, Kernel and QEMU 2.9
- Kubernetes will be extended to provision VMs (Kata Containers)
- OpenStack's VM orchestration engine (Nova) will be extended to handle containers
- Package once and run anywhere
  - VMware, Google, and Amazon are all moving towards this approach
- No installable distribution of Kata containers yet (April 22, 2018)

Ref: https://katacontainers.io/
https://www.forbes.com/sites/janakirammsv/2017/12/11/why-kata-containers-is-good-for-the-industry-and-customers/2/#3d8cc2e9404f

Summary



- Virtual Machines provide scalability, mobility, and cost reduction but need OS which increase resource requirements
- Containers provide isolation on a single OS and are lightweight
- Docker allows managing containers
- Docker Swarm and Kubernetes allow orchestrating a large number of containers
- Docker provides overlay networking and security

Acronyms

API	Application Programming Interface
CapEx	Capital Expenditure
CE	Community Edition
CLI	Command Line Interface
CNCF	Native Computing Foundation
DCT	Docker Content Trust
EE	Enterprise Edition
ID	Identifier
ISBN	International Standard Book Number
LAN	Local Area Network
OpEx	Operational Expenses
OS	Operating System
TCP	Transmission Control Protocol
VM	Virtual Machine

References

- N. Poulton, "Docker Deep Dive," Oct 2017, ISBN: 9781521822807 (Not a Safari Book) **Highly Recommended.**
- Parminder Singh Kocher, "Microservices and Containers, First edition," Addison-Wesley Professional, April 2018, 304 pp., ISBN:978-0-13-459838-3 (Safari Book).
- Russ McKendrick; Pethuru Raj; Jeeva S. Chelladhurai; Vinod Singh, "Docker Bootcamp," Packt Publishing, April 2017, 196 pp., ISBN:978-1-78728-698-6 (Safari Book).
- Russ McKendrick; Scott Gallagher, "Mastering Docker - Second Edition," Packt Publishing, July 2017, 392 pp., ISBN:978-1-78728-024-3 (Safari Book).
- Jeeva S. Chelladhurai; Vinod Singh; Pethuru Raj, "Learning Docker - Second Edition," Packt Publishing, May 2017, 300 pp., ISBN:978-1-78646-292-3 (Safari Book).

Wikipedia Links

- https://en.wikipedia.org/wiki/Docker_(software)
- https://en.wikipedia.org/wiki/Operating-system-level_virtualization
- https://en.wikipedia.org/wiki/Kubernetes
- https://en.wikipedia.org/wiki/Microservices
- https://en.wikipedia.org/wiki/DevOps
- https://en.wikipedia.org/wiki/OpenShift
- https://en.wikipedia.org/wiki/LXC

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https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Wireless and Mobile Networking (Spring 2016),
https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs_HCd5c4wXF

CSE571S: Network Security (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw