UMD DATA605 - Big Data Systems

DevOps with Docker

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v1.1

SCIENCE ACADEMY

Class Announcements

- **Install Docker**
- Assignments on ELMS
- **Do the Git and GitHub tutorial**
- **Quiz about Git next week**
- **Class project**
- Study and experiment with different big data technology
- We will give you different examples
  - Individual project
  - Different complexity

Docker - Resources

- We will use Docker during the class project and most tutorials
- Concepts in the slides
- Class tutorials:
  - tutorial_docker
  - tutorial_docker_compose
- Web resources:
  - Docker Tutorial for beginners
  - https://labs.play-with-docker.com/
  - https://training.play-with-docker.com
  - A Beginner-Friendly Introduction to Containers, VMs and Docker
  - Official Docker Getting Started Tutorial
- Mastery:
  - Poulton, Docker Deep Dive: Zero to Docker in a single book, 2020

Application Deployment

- **For (almost all) Internet companies, the application is the business**
  - If the application breaks, the business stops working
  - E.g., Amazon, Google, Facebook, on-line banks, travel sites (e.g., Expedia), . . . , OpenAI
- **Problem**
  - How to release / deploy / manage / monitor applications?
- **Solutions**
  - Before 2000s: "bare-metal era"
  - 2000s-2010s: "virtual machine era"
  - *~2013: "container era"*

DevOps

- **DevOps** = set of practices that combines:
  - Software development (*dev*)
  - IT operations (*ops*)
- **Containers revolutionized DevOps**
  - Enable true independence between application development and IT ops
    - One team creates an application
    - Another team deploys and manages the applications
  - Create a model for better collaboration (fewer conflicts) and innovation
    - IT: "It doesn't work!"
    - Devs: "What? It works for me"

- Plan
- Code
- Build
- Test
- Release
- Deploy
- Operate
- Monitor

SCIENCE ACADEMY

Run on bare metal

- $<$ 2000s
  - Running one or few applications on each server (without virtualization)
- **Pros**
  - No virtualization overhead
- **Cons**
  - Not safe / not secure since no separation between applications
  - Expensive
- **Expensive / low efficiency**
  - IT would buy a new server for each application
  - Difficult to spec out the machine $\rightarrow$ buy "big and fast servers"
    - Overpowered servers operating at 5-10% of capacity
    - Tons of money in the 2000 DotCom boom was spent on machines and networks
- It kind of came back in 2020 but with different use cases in Cloud Computing
- **Winners**: Cisco, Sun, Microsoft

Virtual Machine Era

- **Circa 2000-2010: Virtual Machine**
  - Virtual machine technology = run multiple copies of OSes on the same hardware
- **Pros**
  - VM runs safely and securely multiple applications on a single server
  - IT could run apps on existing servers with spare capacity
- **Cons**
  - Every VM requires an OS (waste of CPU, RAM, and disk)
  - Buy an OS license
  - Monitor and patch each OS
  - VMs are slow to boot
- **Winners**: VMWare, RedHat, Citrix

Containers Era

- **Circa 2013: Docker becomes ubiquitous**
- **Docker**
  - Didn't invent containers
  - Made containers simple and mainstream
- Linux supported containers for some time
  - Kernel namespaces
  - Control groups
  - Union filesystems
- **Pros**
  - Containers are fast and portable
  - Containers don't require full-blown OS
  - All containers run on a single host
  - Reduce OS licencing cost
  - Reduce overhead of OS patching and maintenance
- **Cons**
  - CPU overhead
  - Toolchain to learn / use
- **Winners**: AWS, Microsoft Azure, Google (not Docker Inc.)

Serverless Computing

- **Containers run in an OS, OS runs on a host**
  - **Where is the host running?**
    - Local (your laptop)
    - On premise (your own computer in a rack)
    - Cloud instance (e.g., AWS EC2 instance)
  - **How is the host running?**
    - On bare-metal server
    - On a virtual machine
    - On a virtual machine running a virtual machine
- **Serverless computing**
  - As long your application runs somewhere, you don't care "how" or "where"
  - E.g., AWS Lambda

HW vs OS Virtualization

- **Hypervisor performs HW virtualization**
  - Carves out physical hardware resources into VMs
  - Resources (CPUs, RAM, storage) are allocated to a VM
  - It's like having multiple computers
- "Virtual machine tax"
  - To run 3 apps, you need 3 VMs
    - Each VM requires time to start
    - Consumes CPU, RAM, storage
    - VM needs a OS license
    - VM / OS need admins, patching
  - You just want to run 3 apps!
- **Containers perform OS virtualization**
  - It's like having multiple OSes

Docker: Client-Server

- Client-Server architecture
- **Docker client**
  - Command line interface
  - Communicate with the server through IPC socket
    - E.g., **/var/run/docker.sock** or IP port
- **Docker engine**
  - Run and manage containers
  - Modular and built from several OCI-compliant sub-systems
    - E.g., Docker daemon, **containerd**, **runc**, plug-ins for networking and storage

Docker Architecture

- **Docker run-time**
  - **runc**: start and stop containers
  - **containerd**
    - Pull images
    - Create containers, volumes, network interfaces
- **Docker engine**
  - **dockerd**
    - Expose remote API
    - Manage images, volumes, networks
- **Docker orchestration**
  - **docker swarm**
  - Manage clusters of nodes
  - Replaced by Kubernetes
- **Open Container Initiative (OCI)**
  - Standardize low-level components of container infrastructure
  - E.g., image format, run-time API
  - "Death" of Docker

Docker Container

- **Docker Container**
  - Unit of computation
  - Lightweight, stand-alone, executable software package
  - Include everything needed to run
    - E.g., code, runtime / system libraries, settings
  - It is a run-time object
    - vs Docker images are built-time objects
    - Like program running (container) vs program code (image)

Docker Image

- **Docker Image**
  - Unit of deployment
  - Contain everything needed by an app to run
    - Application code
    - Application dependencies
    - Minimal OS support
    - File system
  - Users can
    - Build images from Dockerfiles
    - Pull pre-built images from a registry
  - Multiple layers stacked on top of each other
    - Typically few 100s MBs

Docker Image Layers

- **Docker image** is a configuration file that lists the layers and some metadata
  - It is composed of read-only layers
  - Each layer is independent from each other
  - Each layer comprises of many files
- **Docker driver**
  - Stacks these layers as a unified filesystem
  - Implements a copy-on-write behavior
  - Files from the top layers can obscure the files from the bottom layers
- **Layer hash**
  - Each layer has an hash based on its content
  - Layers are pulled and pushed compressed
- **Image hash**
  - Each image has an hash
  - The hash is function of the config file and of the layers
  - When an image changes, a new hash is generated

Docker: Container Data

- A container has access to different data
- **Container storage**
  - It is a copy-on-write layer in the image
  - It is ephemeral (only temporary data)
  - Data inside of containers is persisted as long as the container is not killed
    - If you stop or pause a container data is not lost
  - Containers are designed to be immutable
    - It's not good practice to write "persistent" data into containers
- **Bind-mount a local dir**
  - = a local dir is mounted to a dir inside a container
- **Docker volumes**
  - Docker provides volumes that exist separately from the container
    - E.g., to store the content of a Postgres DB
  - State is permanent across container invocations
  - Can be shared across containers

Docker Repos

- **Docker Repo (Registry)**
  - Store Docker images #### Devops = Devs + Ops
- **Devs**
- Implement the app
  - E.g., Python, virtual env
- Containerize the app
  - Create Dockerfile
  - Contain the instruction on how to build an image
- Build image
- Run the app as a container
- Test "locally"

- **Ops**
- Download container images
  - Contain filesystem, application, app dependencies
- Start / destroy containers
- In case of issues, it's easy to repro the problem
  - "Here is the log"
  - Run command line
  - Deploy on a test system and debug

Containerizing an App

- = create a container with your app inside
- Develop your application code using the needed dependencies
  - E.g., install dependencies
    - Directly inside a container
    - Inside a virtual env
- Create a Dockerfile describing:
  - your app
  - its dependencies
  - how to run it
- Build image with **docker image build**
- (Optional) Push image to a Docker image registry
- Run / test container from image
- Distribute your app as a container (no installation)

Building a Container

- **Dockerfile**
  - Describe how to create a container
- **Build context**
  - > **docker build -t web:latest .**
  - . is the build context
  - Directory containing the application and what's needed to build it
  - Sent to Docker engine to build the application
  - Typically the Dockerfile is in the root directory of the build context

Dockerfile Example

```
FROM python:3.8-slim-buster LABEL
maintainer="gsaggese@umd.edu" WORKDIR /app COPY
requirements.txt requirements.txt RUN pip3 install -r requirements.txt
COPY . . CMD ["python3", "-m", "flask", "run", "–host=0.0.0.0"]
```

Docker: Commands

Show all the available images

```
**\> docker images**
REPOSITORY TAG IMAGE ID CREATED SIZE
counter_app-web-fe latest 4bf6439418a1 17 minutes ago 54.7MB
**...**
Show a particular image
**\> docker images counter_app_web-fe**
counter_app-web-fe latest 4bf6439418a1 17 minutes ago 54.7MB
...
Note that docker images ls is incorrect since it shows the image l
Delete an image
**\> docker rmi ...**
Show the running containers
**\> docker container ls**
CONTAINER ID IMAGE COMMAND CREATED STATUS PORTS NAMES
505541bcfe8b counter_app-web-fe "python app.py" 7 minutes ago Up 7
c1889540cfd2 redis:alpine "docker-entrypoint.s..." 7 minutes ago U
```

Docker: Commands

Show running containers

docker container ls CONTAINER ID IMAGE COMMAND CREATED STATUS PORTS NAMES 281d654f6b8d counter_app_web-fe “python app.py” 5 minutes ago Up 5 minutes 0.0.0.0:5000->5001/tcp counter_app-web-fe-1 de55ae4104da redis:alpine “docker-entrypoint.s...” 5 minutes ago Up 5 minutes 6379/tcp counter_app-redis-1 Show volumes and networks docker volume ls DRIVER VOLUME NAME local counter_app_counter-vol docker network ls NETWORK ID NAME DRIVER SCOPE b4c1976d7c27 bridge bridge local 33ff702253b3 counter-app_counter-net bridge local

Docker: Delete state

Commands: `-> docker container ls -> docker container rm $(docker container ls -q) -> docker images -> docker rmi $(docker images -q) -> docker volume ls -> docker volume rm $(docker volume ls -q) -> docker network ls -> docker network rm $(docker network ls -q)`

Docker Tutorial

- tutorial_docker.md

Docker Compose

- **Manage multi-container apps running on a single node**
  - Describe app in a single *declarative* configuration YAML file
    - Instead of scripts with long Docker commands
  - Compose talks to Docker API to achieve what you requested
  - E.g., you need a client app and Postgres DB
  - E.g., microservices
    - Web front-end
    - Ordering
    - Back-end DB
- In 2020 Docker Compose has become an open standard for "code-to-cloud" process
- **Manage multi-container apps running on multiple hosts**
  - Docker Stacks / Swarm
  - Kubernetes

Docker Compose: Tutorial Example

- The default name for a Compose file is `docker-compose.yml`
  - You can specify `-f` for custom filenames
- **Top-level keys** are:
  - `version`:
    - Mandatory first line to specify API version
    - Ideally always use the latest version
    - Typically 3 or higher
  - `services`:
    - Define the different microservices
  - `networks`:
    - Creates new networks
    - By default it creates a `bridge` network to connect multiple containers on the same Docker host
  - `volumes`:
    - Creates new volumes
- **Key in services** describe a different "service" in terms of container
  - **Inner keys** specify the params of Docker run command

```
version: "3.8"
services:
  web-fe:
    build: .
    command: python app.py
```

Docker Compose: Commands

docker compose –help

```
Usage:  docker compose [OPTIONS] COMMAND
Options:
      --env-file string              Specify an alternate environmen
  -f, --file stringArray             Compose configuration files
  -p, --project-name string          Project name

Commands:
  build       Build or rebuild services
  convert     Converts the compose file to platform's canonical fo
  cp          Copy files/folders between a service container and t
  create      Creates containers for a service.
  down        Stop and remove containers, networks
  events      Receive real time events from containers.
  exec        Execute a command in a running container.
  images      List images used by the created containers
  kill        Force stop service containers.
  logs        View output from containers
  ls          List running compose projects
  pause       Pause services
```

Docker Compose: Commands

Build the containers for the services > docker compose build Pull the needed images for the services > docker compose pull Show the running services > docker compose ps Show the status of the service > docker compose ls Bring up the entire service > docker compose up Rebuild after trying out some changes in dockerfile/compose file > docker-compose up –build –force-recreate Show the processes inside each container > docker compose top

```
counter_app-redis-1
UID    PID      PPID     C     STIME    TTY    TIME         CMD
999    49590    49549    0     10:40    ?      00:00:02     redis-server *
counter_app-web-fe-1
UID     PID      PPID     C     STIME    TTY    TIME         CMD
root    49614    49574    0     10:40    ?      00:00:00     python app.py
root    49734    49614    1     10:40    ?      00:00:08     /usr/local/bi
```

Docker Compose: Commands

Build the containers for the services

docker compose down [+] Running 3/2 Container counter_app-redis-1 Removed

Container counter_app-web-fe-1 Removed Network counter_app_counter-net Removed Shutdown service removing the volume (i.e., resetting state) `docker-compose down -v` *Shutdown service removing images and volume* `docker-compose down $\downarrow$ --rmi all`

Docker Compose: Tutorial

- Example taken from https://github.com/nigelpoulton/counter-app
- tutorial_docker_compose
- `> cd tutorials/tutorial_docker_compose`
- `> vi tutorial_docker_compose.md`

Class Announcements

-**1 Project teams** - Posted UMD DATA605 - Class Project Teams - Spring 2023 - If your name is not on any of the teams, please send me an email - No midterm or final exam, complete class project to get a grade -**2 Team composition** - Teams based on your self-assessed skills - In each group there should be someone with experience with Git, Docker, Python, and so on - Teams are not perfect, but none of your team at your future jobs will be - Working in a team is a skill that takes a long time to hone: let's start practicing it -**3 Class project complexity** - Projects have about the same complexity - If not, we will try to account for this when grading - Projects were assigned randomly to the teams

Class Announcements

-**4 Add personal info** - Fill the spreadsheet UMD DATA605 - Class Project Teams - Spring 2023 with your information - Email - GitHub username (free account at https://github.com) - Telegram Handle for IM (free account at https://telegram.org) -**5 Next steps** - Read carefully UMD DATA605 - Class Project - If things are not clear send us an email or add a comment to the Google Doc - Read the Google doc corresponding to your assigned project from UMD DATA605 - Class Project Teams - Spring 2023 - Read the first Deliverable 1 from UMD DATA605 - Class Project -**6 Golden rule** - *Treat others how you want to be treated* - Everybody comes from a different place and different skill level, somebody has a job, somebody has a full-time work - *If you want to go fast, go alone; if you want to go far, go together*