UMD DATA605 - Big Data Systems

DevOps with Docker

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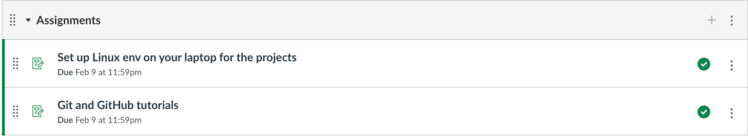
v1.1

Class Announcements

- Install Docker
  - Assignments on ELMS



Assignments

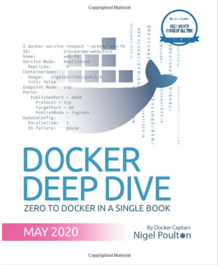
Set up Linux env on your laptop for the projects
Due Feb 9 at 11:59pm

Git and GitHub tutorials
Due Feb 9 at 11:59pm

- 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



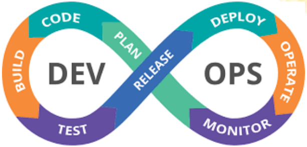
```
$ docker service inspect --pretty web-fe
ID:             z7ovearqmruwk0u2vc5
Name:           web-fe
Service Mode:   Replicated
  Replicas:      5
ContainerSpec:
  Image:   nigelpoulton/gsd:1.0
  init: false
Endpoint Mode:  vip
Ports:
   PublishedPort = 8080
     Protocol = tcp
     TargetPort = 80
     PublishMode = ingress
UpdateConfig:
  Parallelism:   1
  On failure:    pause
```

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

Run on bare metal

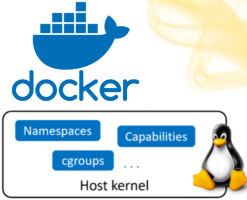
- $<$ 2000s
  - Running one or few applications on each server (without virtualization)
- Pros
  - No virtualization overhead
- Cons
  - Not safe / not secure since no separation between applications
  - Expensive
- Expensive / low efficiency
  - IT would buy a new server for each application
  - Difficult to spec out the machine → 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.)



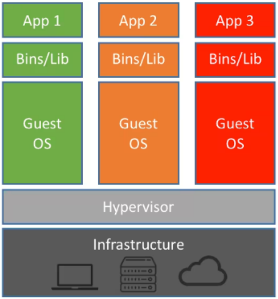
Serverless Computing

- 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

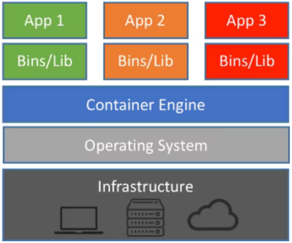
HW vs OS Virtualization

- **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



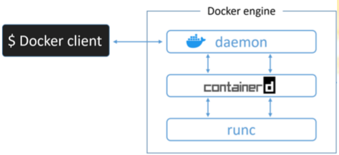
Machine Virtualization

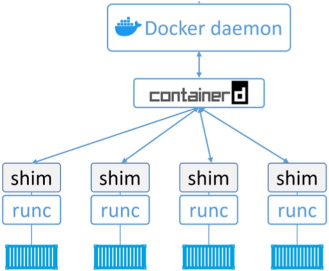


Containers

Docker: Client-Server

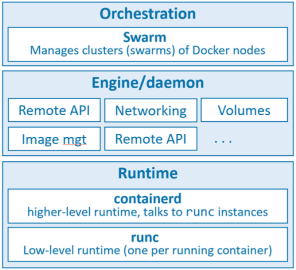
- Client-Server architecture
- **Docker client**
  - Command line interface
  - Communicate with the server through IPC socket
    - E.g., **/var/run/docker.sock** or IP port
- **Docker engine**
  - Run and manage containers
  - Modular and built from several OCI-compliant sub-systems
    - E.g., Docker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


Orchestration
Swarm
Manages clusters (swarms) of Docker nodes
Engine/daemon
Remote API
Networking
Volumes
Image mgt
Remote API
. . .
Runtime
containerd
higher-level runtime, talks to runc instances
runc
Low-level runtime (one per running container)

Docker Container

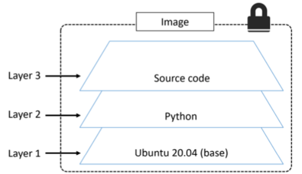
- **Docker Container**
    - Unit of computation
    - Lightweight, stand-alone, executable software package
    - Include everything needed to run
        - E.g., code, runtime / system libraries, settings
    - It is a run-time object
        - vs Docker images are built-time objects
        - Like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

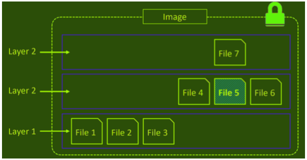
Docker Image

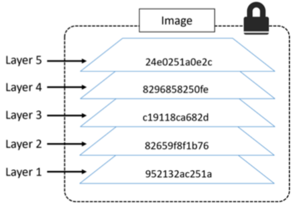
- Docker Image
  - Unit of deployment
  - Contain everything needed by an app to run
    - Application code
    - Application dependencies
    - Minimal OS support
    - File system
  - Users can
    - Build images from Dockerfiles
    - Pull pre-built images from a registry
  - Multiple layers stacked 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





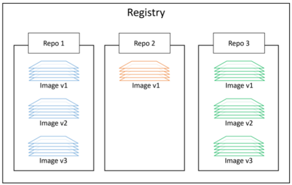


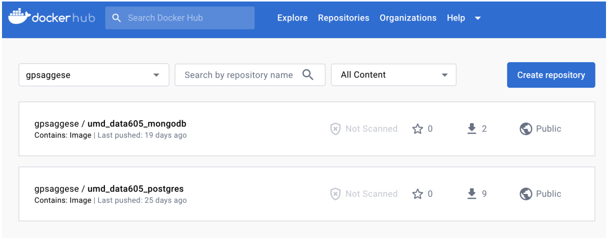
Docker: Container Data

- 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
    - <registry>/<repo>:<tag>
    - bash docker.io/alpine:latest
    - E.g., DockerHub, AWS ECR
  - Some repos are vetted by Docker
  - Unofficial repos shouldn't be trusted
  - E.g., https://hub.docker.com/





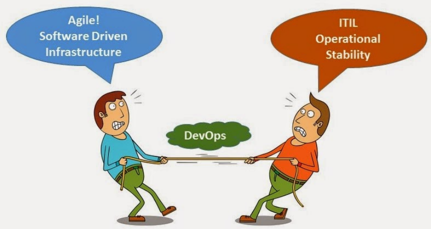
gpsaggese

All Content

gpsaggese / umd_data605_mongodb
Contains: Image | Last pushed: 19 days ago
Not Scanned 0 2 Public

gpsaggese / umd_data605_postgres
Contains: Image | Last pushed: 25 days ago
Not Scanned 0 9 Public

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 ls

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 minutes  0.0.0.0:5001->5000/tcp  counter_app-web-fe-
c1889540cfd2  redis:alpine        "docker-entrypoint.sh"  7 minutes ago  Up 7 minutes  6379/tcp                counter_app-redis-1
```

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
0.0.0.0:5001->5000/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

```
> 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
    ports:
      - target: 5000
        published: 5001
    networks:
      - counter-net
    volumes:
      - type: volume
        source: counter-vol
        target: /code
  redis:
    image: "redis:alpine"
    networks:
      counter-net:
networks:
  counter-net:
volumes:
  counter-vol:
```

Docker Compose: Commands

```
> docker compose --help
Usage:  docker compose [OPTIONS] COMMAND
Options:
      --env-file string            Specify an alternate environment file.
  -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 format
  cp          Copy files/folders between a service container and the local filesystem
  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
  port        Print the public port for a port binding.
  ps          List containers
  pull        Pull service images
  push        Push service images
  restart     Restart containers
  rm          Removes stopped service containers
  run         Run a one-off command on a service.
  start       Start services
  stop        Stop services
  top         Display the running processes
  unpause     Unpause services
  up          Create and start containers
  version     Show the Docker Compose version information
```

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 *:6379

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/bin/python /code/app.py
```

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*