Containerization and Container Orchestration

CS 40 | January 29, 2024

Assignment 2 Out (Due 2/13)

AWS Credits Released (see Ed)

History of Web Hosting
(and enterprise compute)

Early 1990s: Physical Hosting

- Each individual physical server hosted one website on port 80
- **Scale challenge**: Adding capacity to accommodate traffic influx is subject to hardware lead time
- **Provisioning challenge**: Even if hardware available, still need to reinstall server software manually!

Late 1990s – Mid 2010s: Virtual Hosting

- Key innovation (1999): *virtual machine hypervisors* allow running of multiple guest OSes on a single physical host
    - Emulate the *entire* guest OS, both kernel and userspace
- Addresses many inefficiencies with physical hosting:
    - Can buy fewer, high-capacity servers, dividing capacity across VMs for different websites
    - Provisioning is faster: just create new VMs from stored images (or script provisioning)
- Enables cloud IaaS: *someone else* buys the physical servers and rents you the VM abstraction

Challenges of Physical Hosting

- Continued **scale challenges**:
  - VM provisioning can be multiple minutes → **under capacity** while dealing with traffic influxes
  - VM images can be several GB → **storage cost**

- **Management overhead**: still responsible for patching OS and software
  - Need for DevOps/Infrastructure Engineers to handle this responsibility

Guiding principle: Make running web (or other) applications as independent as possible from the underlying infrastructure.

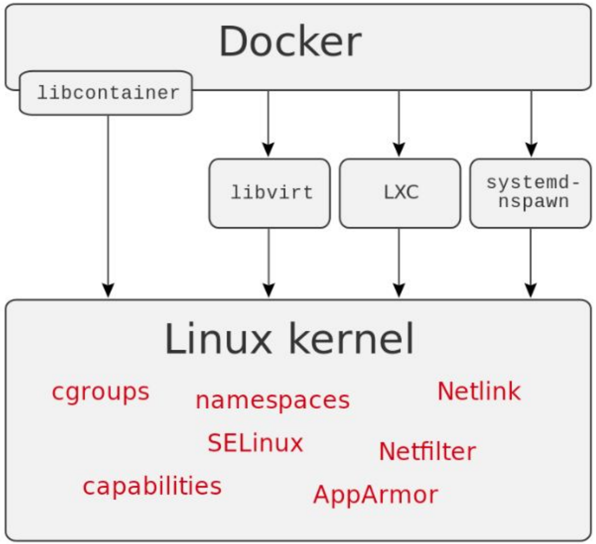
Containers

Containers

- **Definition**: a *container* is a portable software package containing all resources needed to run it, providing:
    - **Isolation**: processes of container A don't interfere with those of container B
    - **Replicability**: same process from same container image should execute the same on any host machine/OS/configuration
- Introduced in its current form in 2013 by Docker
    - Alternatives include Podman and LXD, but Docker is by far the most commonly used platform

More about containers

- A container behaves somewhat like its own isolated OS, **but shares its kernel with the host OS**
    - **Key distinction compared to virtual machines**
- Usually run on Linux hosts, deeply reliant on Linux kernel features
    - **Cgroups** (for process isolation and resource limiting)
    - **iptables** (for networking)
    - **OverlayFS** (layered, contained filesystems)



Building a Docker Container

```
Dockerfile
----------

# Inherit from parent container definition
FROM python:3.12-slim
# Run all future commands in /app directory
WORKDIR /app
RUN echo “Hello World!” > index.html
# Make port 8080 accessible from host
EXPOSE 8080
# Run a simple HTTP server
# Use ENTRYPOINT to avoid overwriting parent setup steps
CMD [“python3”, “-u”, “-m”, “http.server”, “8080”]
```

Demo: Interacting with a Web Container

Container Networking

- By default: Docker containers are given own **isolated network interface**

- NAT behind host machine allows **outbound network access**, but need to **explicitly expose ports** for inbound

- Containers cannot talk to each other unless they are attached to the same software-defined network
  - Alternatively: use **host networking mode** to remove NAT abstraction (i.e., process that listens on a container port is accessible at the host scope too)

Container Storage

- Anything saved within the filesystem of a running container is *ephemeral*
  - Destroyed after the invocation ends

- Storage persistence through *volumes*: directories on the host system mapped to directories within the container

```
docker run --rm -v ~/postgres:/var/lib/postgresql/data -p 5432:5432 postgres:latest
```

- Volumes are also how we can share host data with the container!

```
docker run --rm -v ~/.aws:/root/.aws:ro my-aws-dependent-service:latest
```

Container Storage on the Cloud

- In practice: we want to **separate compute and storage concerns**
  - *Treat your compute like cattle, not pets*

- Generally, store long-term persistent data elsewhere
  - Databases
  - Object storage (e.g., S3)

Container Registries

- Use pre-made container definitions as is, or extend them
    - Analogy: **package management for containers**
    - Inheriting from a parent container in a Dockerfile appends your Dockerfile to the parent's

- Public registries: DockerHub, Quay.io
    - Freely download and host public images, many base images e.g. Go, Python, Nginx, Postgres

- Private registries: AWS Elastic Container Registry, Google Artifact Registry
    - Often used for organization-internal images, since download requires authentication

- Pulling containers: through Fully-Qualified Image Identification (FQID)
    - Format components include: `registry_name`, `username`, `image_name:tag`
    - e.g. `docker pull` **`docker.io/library/ubuntu:22.04`**
    - e.g. `FROM` **`123456789012.dkr.ecr.us-west-2.amazonaws.com/mywebapp:latest`**

How to Containerize a Web Application

1. Pick a base image that simplifies some work for you
   - e.g. something with a language package manager/common dependencies installed
2. Copy app files
3. Install dependencies
4. Expose inbound port
5. Run application

*Note: **multistage builds** can reduce final container size when working with compiled languages (e.g. Go, Rust)*

Demo: Multistage Go Webapp Container Build

Container Orchestration

Motivation

- Containers, on their own, help us deal with *software challenges* of running web apps: dependencies and isolation

- But *infrastructure challenges* still persist: scale, provisioning, storage, ...

- **Container Orchestration**: tooling that automates provisioning, scheduling, scaling, resource allocation, monitoring, and networking configuration across container task lifecycles.

Basic container orchestration: `docker-compose`

- Container orchestration for development environments
  - Run an application and all its dependencies together in an isolated networked environment

- **Limitation**: can only run containers on a single host
  - Hampers scaling and redundancy

Demo: `docker-compose`

Kubernetes

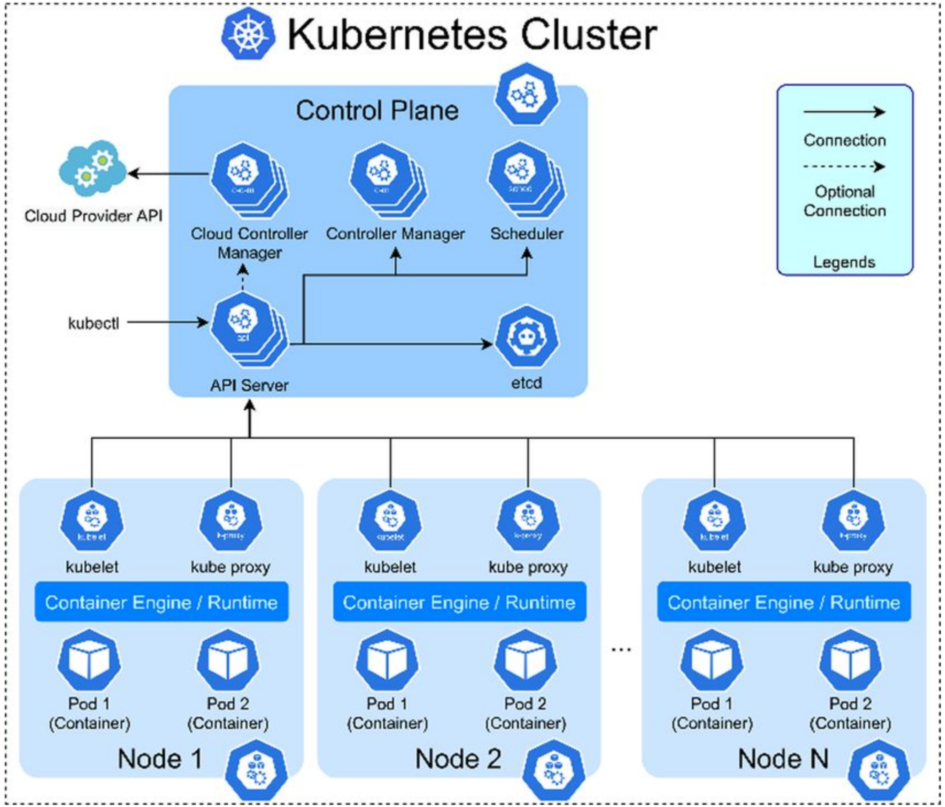
- Conceptually: Kubernetes is an **operating system for distributed container clusters**
  - Each process is a container
  - Kubernetes takes care of scheduling the container and managing its lifecycle given some configuration parameters

- Kubernetes features are oriented towards building scalably deployable and portable application patterns
  - Container scheduling, autoscaling, versioning, health checks
  - Networking, DNS service discovery, load balancing, ACLs, MTLS
  - Secrets and config management, observability
  - Further extensible using third party plugins!

Kubernetes Terminology

- **Cluster**: a set of *nodes* (hosts) that run containers
  - Made up of a single *control plane* and multiple *worker nodes*
- **Namespace**: an isolated group of resources within a cluster
- **Pod**: a group of one or more containers used for a single purpose
  - Share a *network namespace,* just like docker-compose
- **Deployment**: a way of maintaining a set of pods for scaling and redundancy
  - Ensures that the right number of pods are always running regardless of failures
- **Service**: a way to expose pods/deployments for external network access
  - Assigns a pod/deployment a virtual IP and/or DNS address

Example Architecture with Kubernetes



Demo: Kubernetes

Q: *Kubernetes has a lot of features! Why don’t we just use the open-source framework instead of closed-source cloud provider-managed solutions?*

A: *Management overhead.*

AWS Elastic Container Service (ECS)

- Fully-featured container orchestration service
  - Proprietary AWS platform
  - Just like Kubernetes: can handle container management **across multiple nodes**
  - Some different terminology: *tasks* vs *pods*

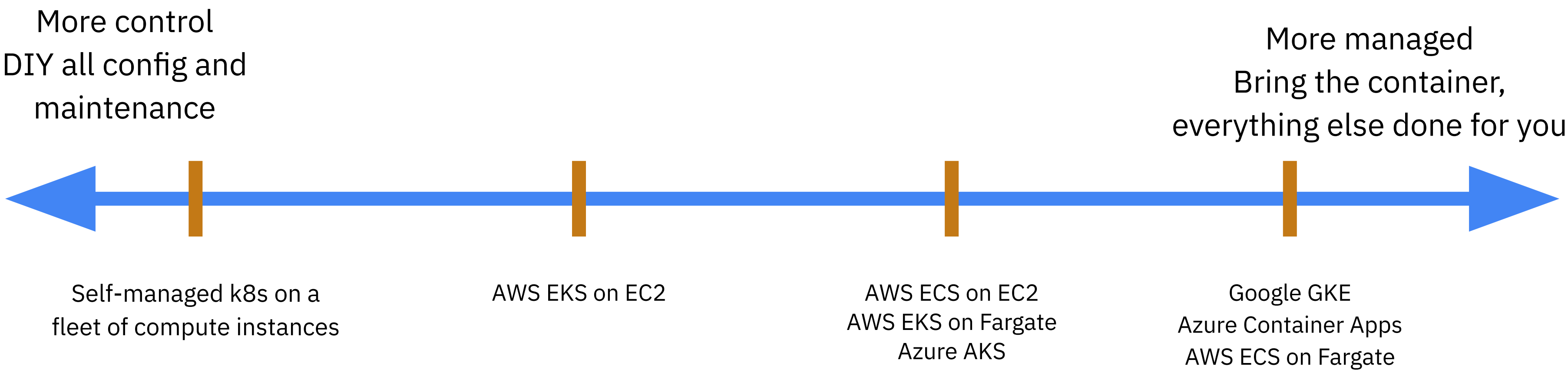
- A lot simpler to manage than Kubernetes (and EKS)
  - Can simply bring the container(s) and tell AWS how to run it
  - Set and forget

- Some limitations, such as persistent storage and task count

Takeaway: ECS is a great way to start doing simple container deployments (e.g. Assignment 2) without dealing with the complexity of Kubernetes

Zooming out: Cloud-Managed Container Orchestration

How much control do you want to retain vs
how much the cloud provider manages for you?



Next Lecture: Infrastructure-as-Code (1/31)