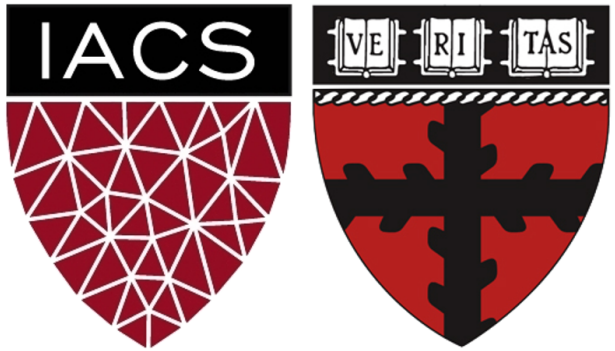
Lecture 2: Containers

AC295

Advanced Practical Data Science

Pavlos Protopapas



Outline

1: Class organization

2: Recap

3: Software Development

4: Containers

5: Hands On

Class organization

Group formation

Presentation schedule

Review class flow

Outline

1: Class organization

2: Recap

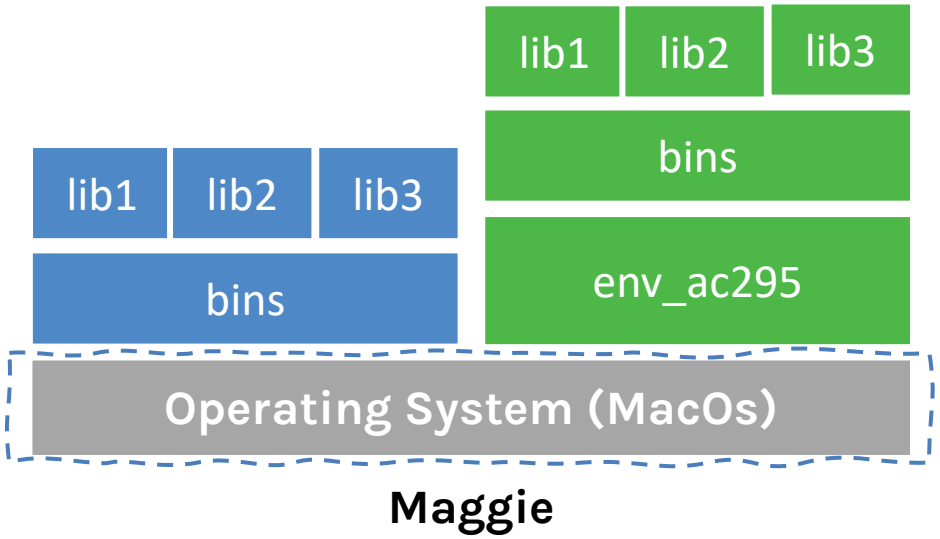
3: Software Development

4: Containers

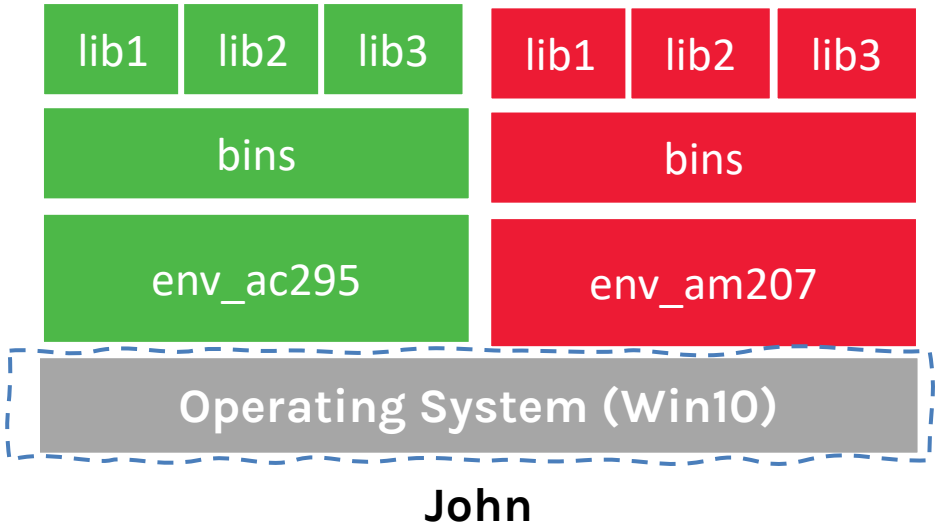
5: Hands On

Why should we use virtual environment?

- What could go wrong? Unfortunately, Maggie and John reproduce different results and they think the issue relates to their operating systems. Indeed while Maggie has a MacOS, John uses a Win10.



Maggie



John

Virtual environments

Pros

- Reproducible research
- Explicit dependencies
- Improved engineering collaboration
- Broader skill set

Cons

- Difficulty setting up your environment
- Not isolation
- Does not work across different OS

Virtual Machines Limitations

- Uses hardware in your local machine (cannot run more than two on an average laptop)
- There is overhead associated with virtual machines
    1. guest is not as fast as the host system
    2. Takes long time to start up
    3. may not have the same graphics capabilities

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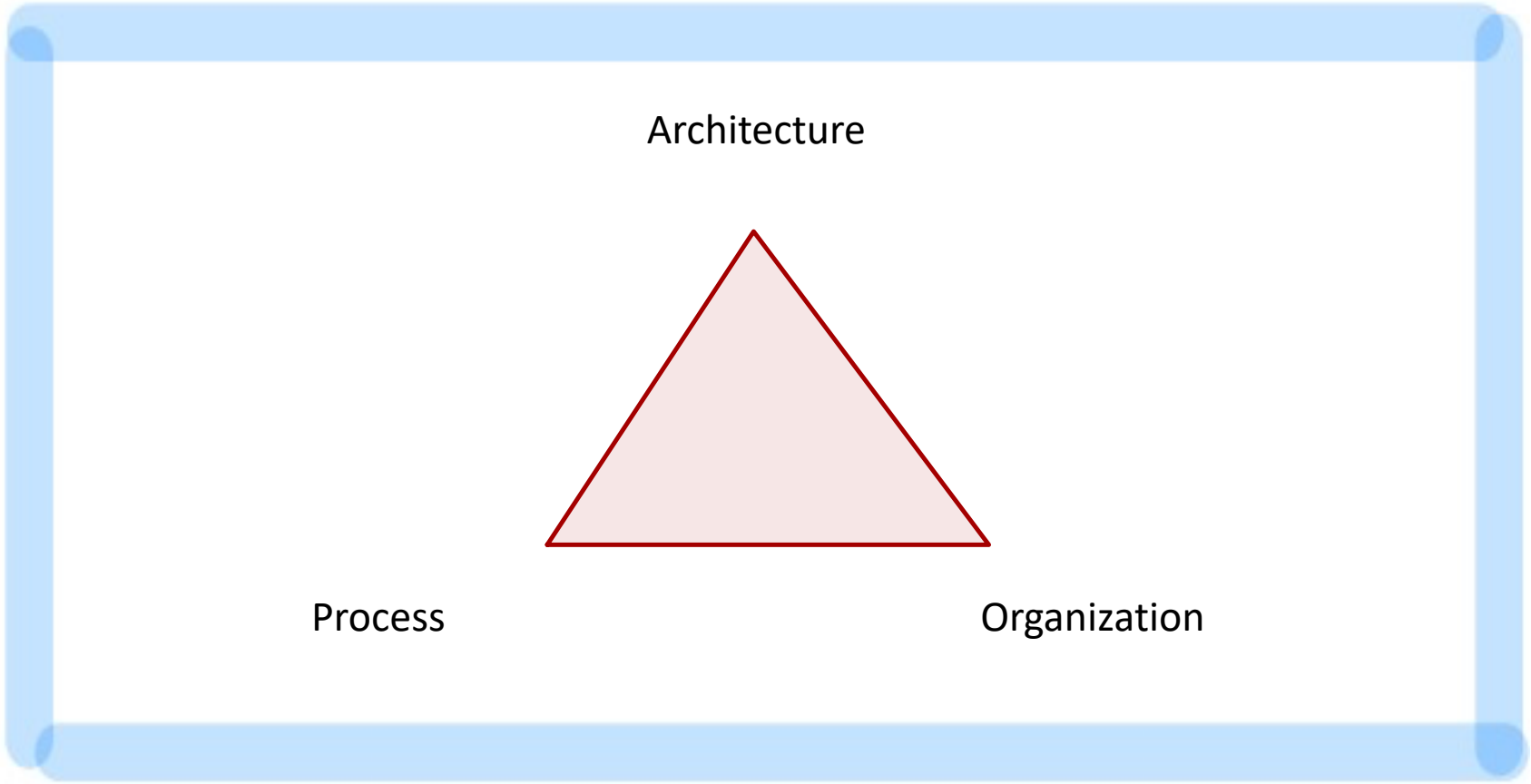
Successful Software Application

- Imagine you are building a large complex application (e.g. Online Store)



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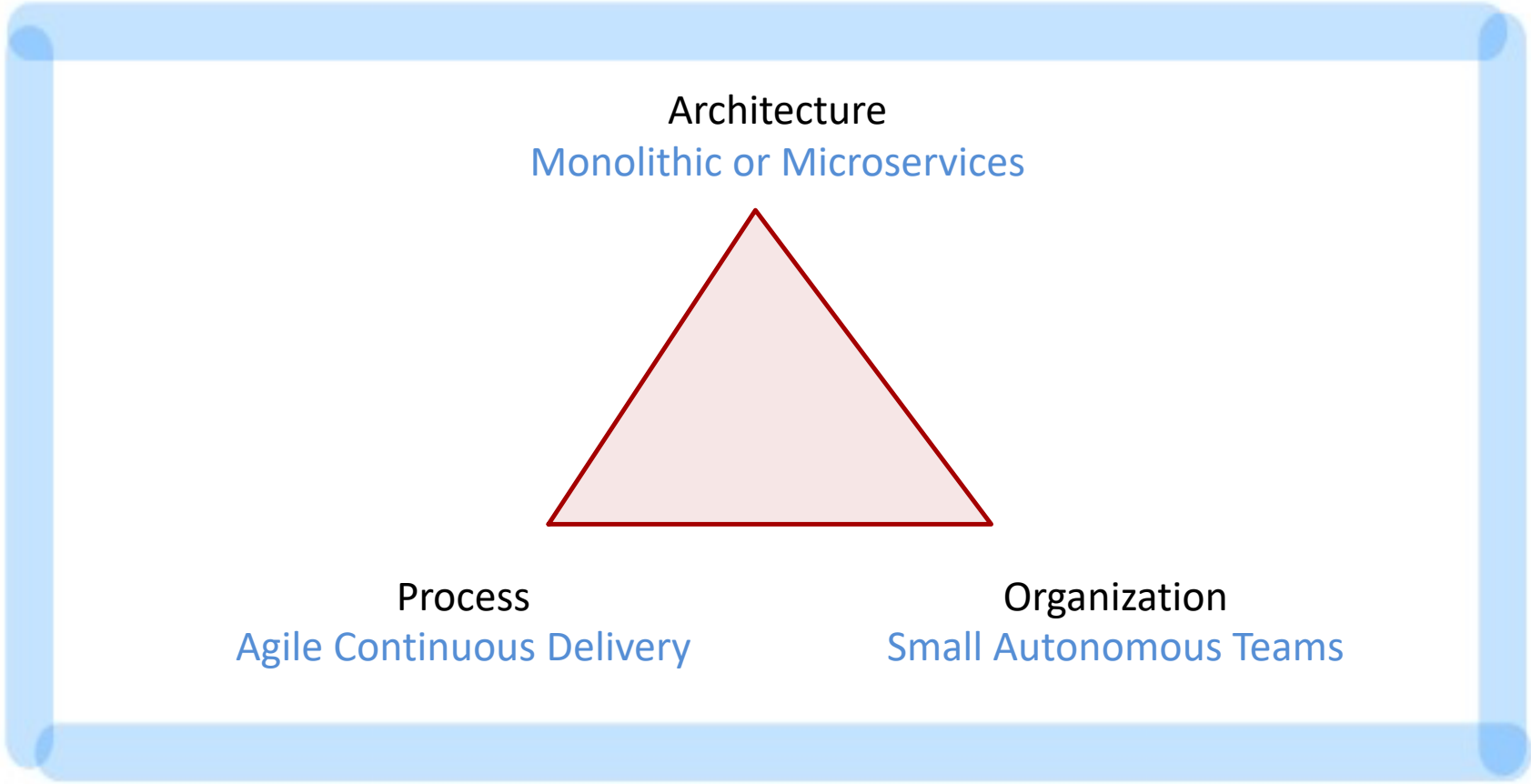
Successful Software Application

- Imagine you are building a large complex application (e.g. Online Store)



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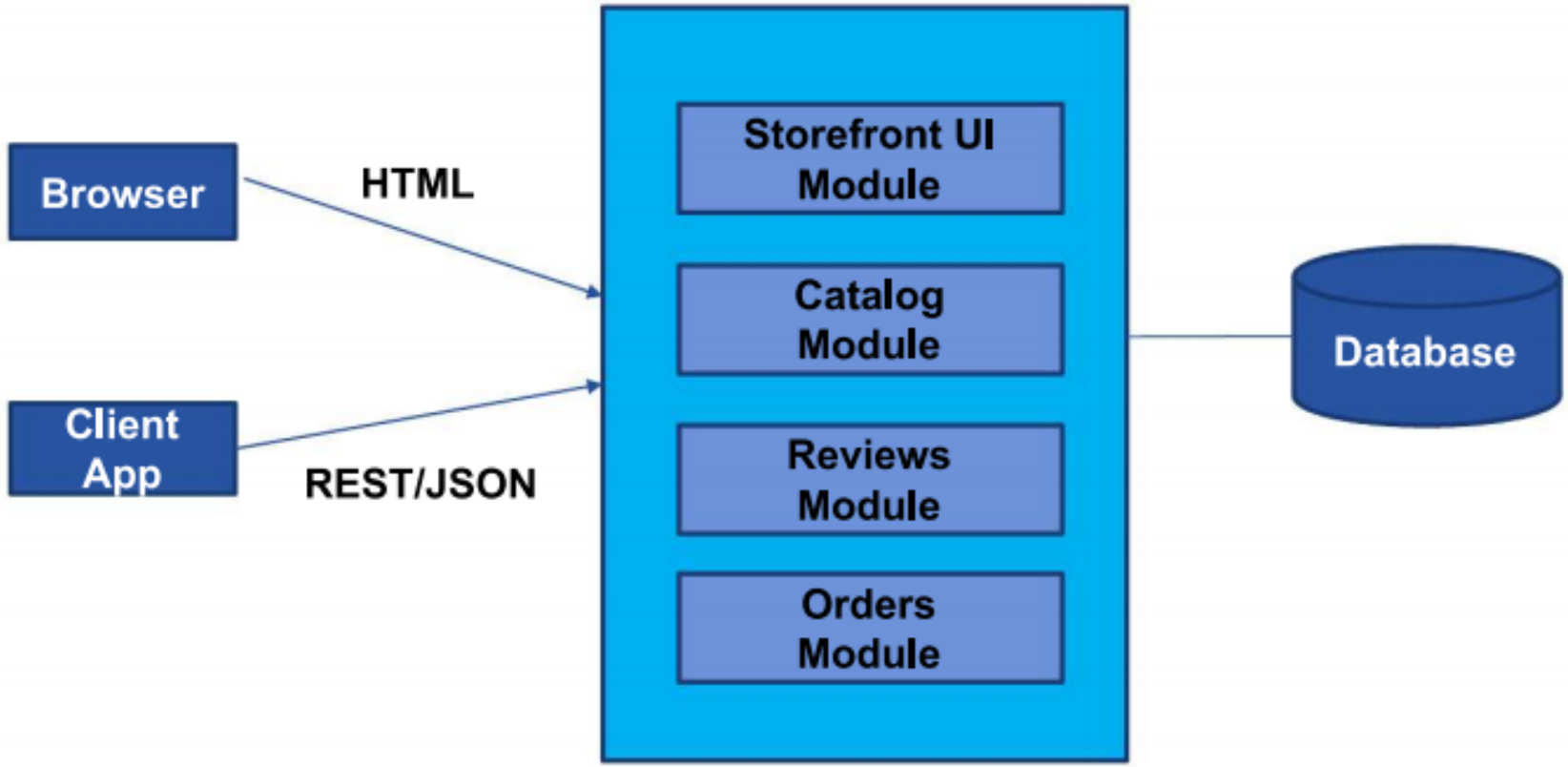
Monolithic Architecture



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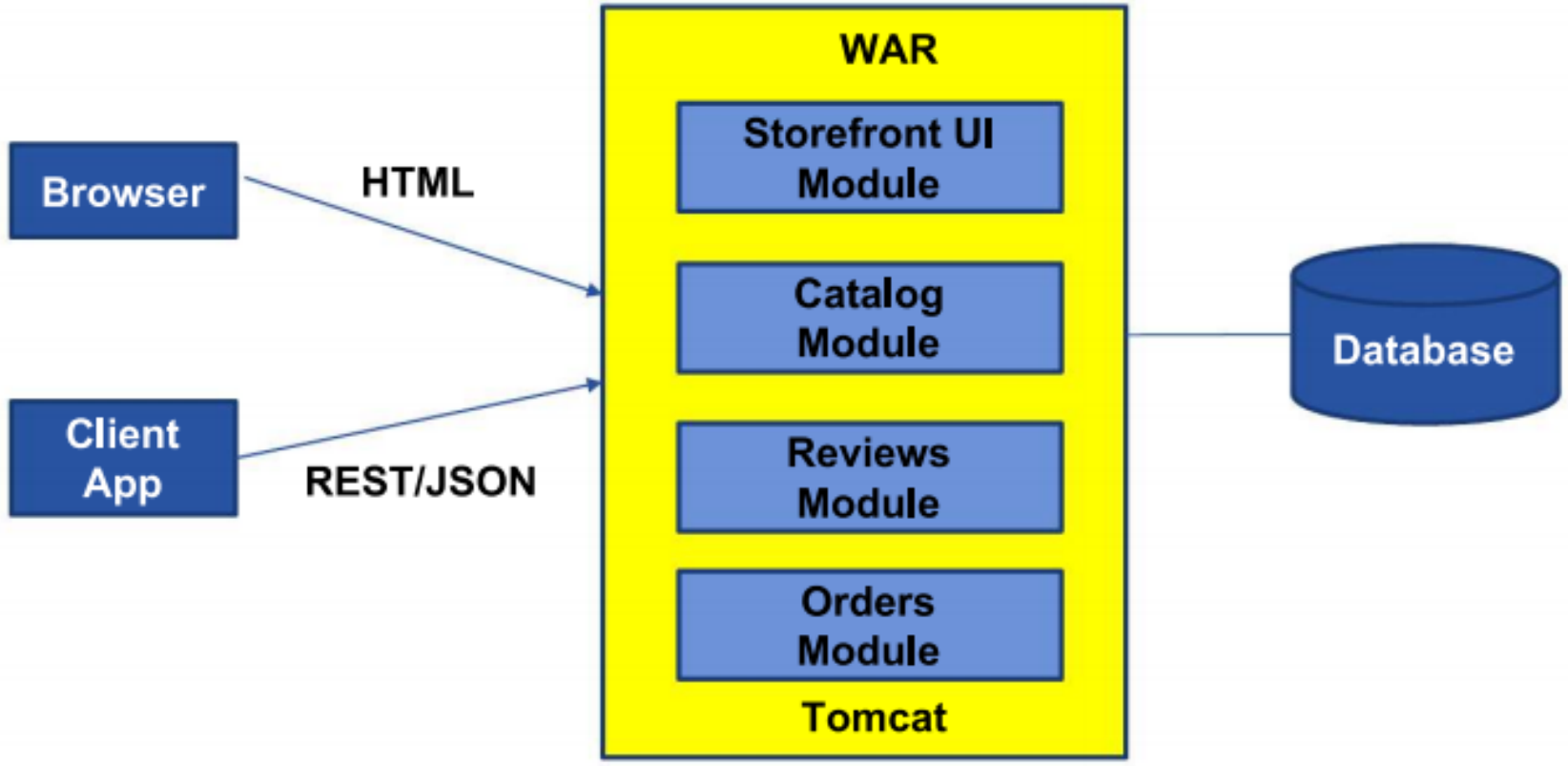
Monolithic Architecture



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I finally remember what Zoom meetings remind me of.

Benefits of Monolith

Simple to **Develop**, **Test**, **Deploy** and **Scale**:

1. Simple to develop because all the tools and IDEs support the applications by default
2. Easy to deploy because all components are packed into one bundle
3. Easy to scale the whole application

Disadvantages of Monolith

1. Very difficult to maintain
2. One component failure will cause the whole system to fail
3. Very difficult to create the patches for monolithic architecture
4. Adapting to new technologies is challenging
5. Take a long time to startup because all the components needs to get started

Applications have changed drammatically

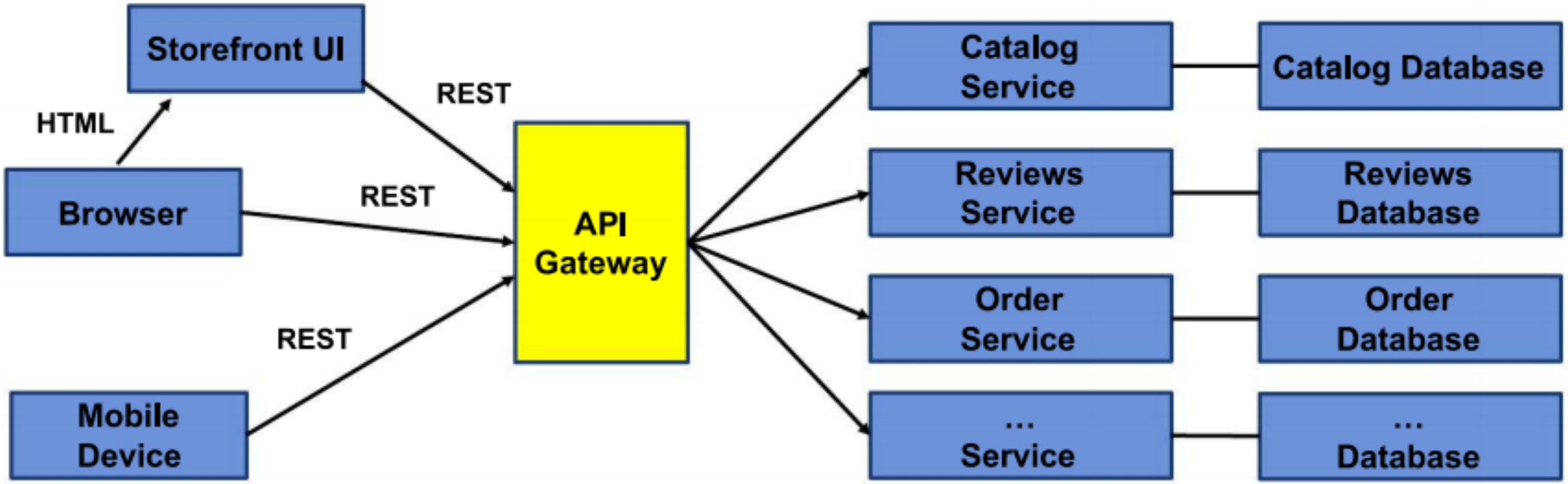
A decade ago

Apps were monolithic
Built on a single stack (e.e. .NET or Java)
Long lived
Deployed to a single server

Today

Apps are constantly being developed
Build from loosely coupled components
Newer version are deployed often
Deployed to a multitude of servers

Microservice Architecture



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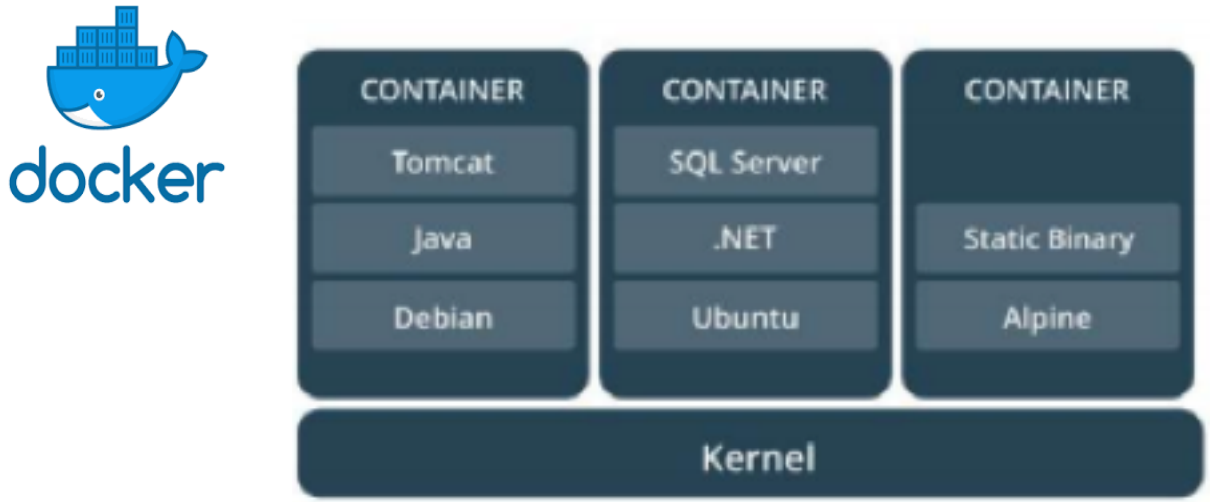
What is container



- Standardized packaging for software dependencies
- Isolate apps from each other
- Works for all major Linux distributions, MacOS, Windows

What is the difference between an image and container

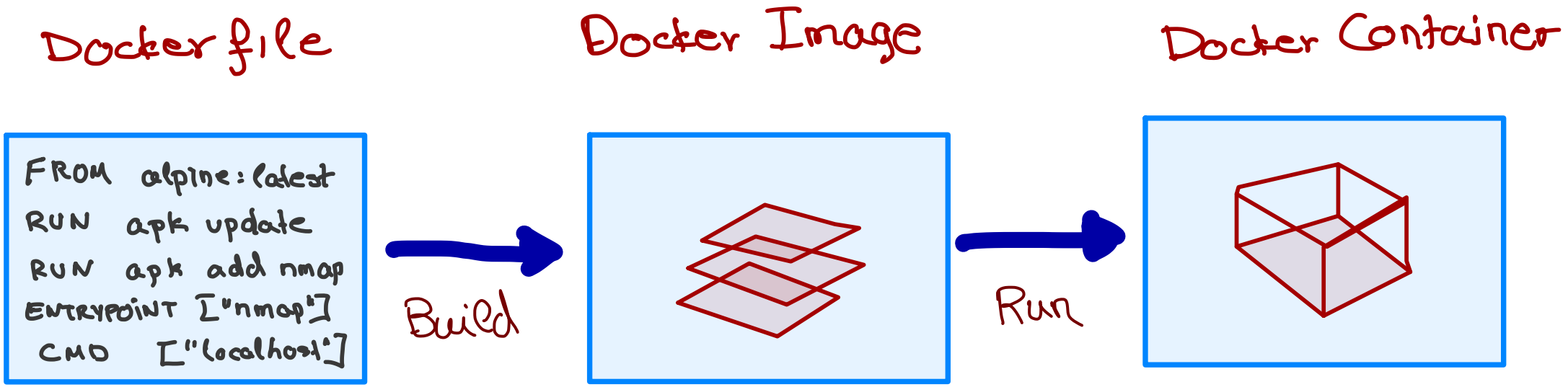
Docker Image is a template aka blueprint to create a running Docker container. Docker uses the information available in the Image to create (run) a container.

Image is like a recipe, container is like a dish

You can think of an image as a class and a container is an instance of that class.

How to build an image

We use the Dockerfile, a simple text editor, to build the Docker Image which are iso files and other files. We run the Docker Image to get Docker Container.



Inside the Dockerfile

Dockerfile

```
FROM alpine:latest
RUN apk update
RUN apk add nmap
ENTRYPOINT ["nmap"]
CMD ["localhost"]
```

FROM: This instruction in the Dockerfile tells the daemon, which base image to use while creating our new Docker image. In the example here, we are using a very minimal OS image called alpine (just 5 MB of size). You can also replace it with Ubuntu, Fedora, Debian or any other OS image.

RUN: This command instructs the Docker daemon to run the given commands as it is while creating the image. A Dockerfile can have multiple RUN commands, each of these RUN commands create a new **layer** in the image.

ENTRYPOINT: The ENTRYPOINT instruction is used when you would like your container to run the same executable every time. Usually, ENTRYPOINT is used to specify the binary and CMD to provide parameters.

CMD: The CMD sets default command and/or parameters when a docker container runs. **CMD can be overwritten** from the command line via the docker run command.

Multiple containers from same image

How can you run multiple containers from the same image? Wouldn't they all be identical?

Yes, you could think of an image as instating a class. You could instate it with different parameters using the CMD and therefore different containers will be different.

Dockerfile

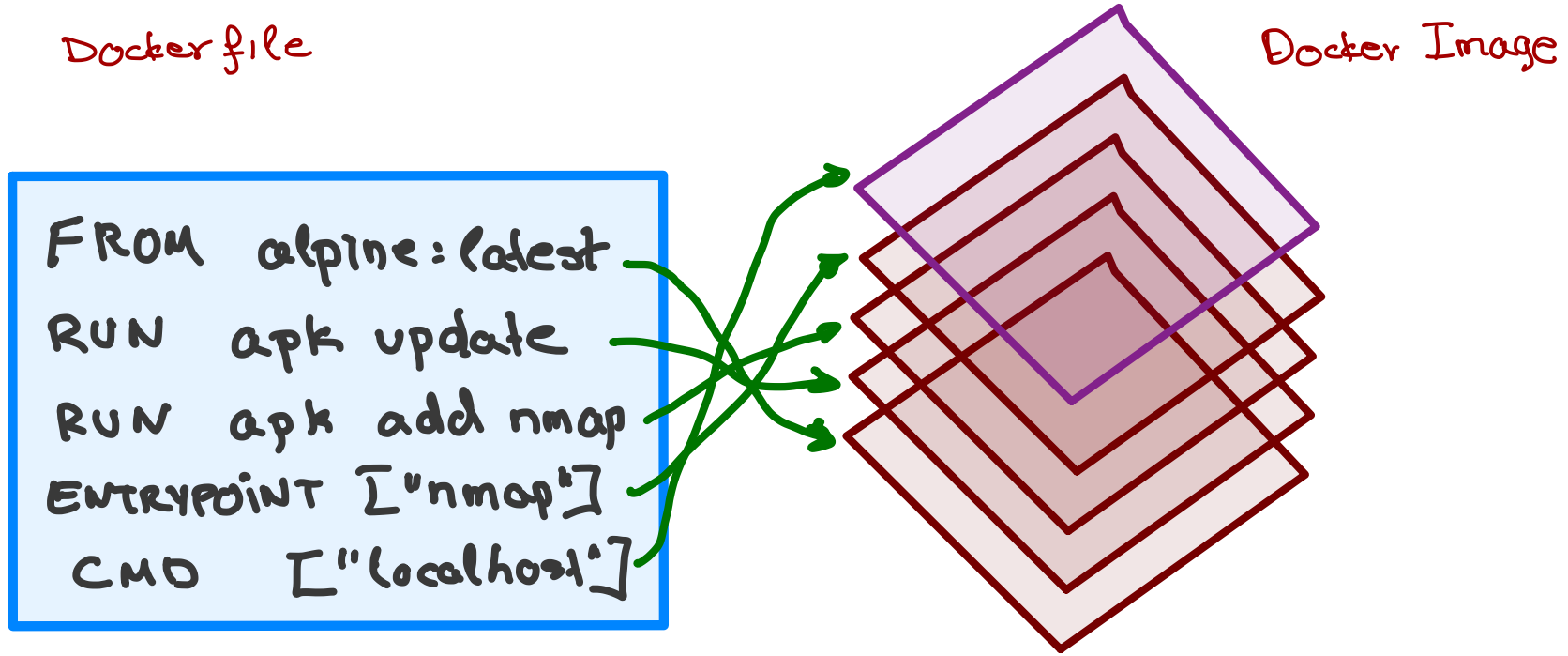
```
FROM ubuntu:latest
RUN apt-get update
ENTRYPOINT ["/bin/echo", "Hello"]
CMD ["world"]
```

```
> docker build -t hello_world_cmd:first -f
Dockerfile_cmd .

> docker run -it hello_world_cmd:first
> Hello world
> docker run -it hello_world_cmd:first Pavlos
> Hello Pavlos
```

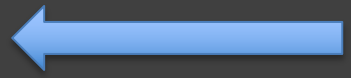
Docker Image as Layers

When we execute the build command, the daemon reads the Dockerfile and creates a layer for every command.

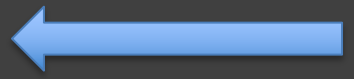


```
>docker build -t hello_world_cmd -f Dockerfile_cmd .

Sending build context to Docker daemon   34.3kB
Step 1/4 : FROM ubuntu:latest
latest: Pulling from library/ubuntu
54ee1f796a1e: Already exists
f7bfea53ad12: Already exists
46d371e02073: Already exists
b66c17bbf772: Already exists
Digest: sha256:31dfb10d52ce76c5ca0aa19d10b3e6424b830729e32a89a7c6eee2cda2be67a5
Status: Downloaded newer image for ubuntu:latest
 ---> 4e2eef94cd6b
Step 2/4 : RUN apt-get update
 ---> Running in e3e1a87e8d6e
Get:1 http://archive.ubuntu.com/ubuntu focal InRelease [265 kB]
Get:2 http://security.ubuntu.com/ubuntu focal-security InRelease [107 kB]
Get:3 http://security.ubuntu.com/ubuntu focal-security/universe amd64 Packages [67.5
kB]
Get:4 http://archive.ubuntu.com/ubuntu focal-updates InRelease [111 kB]
Get:5 http://archive.ubuntu.com/ubuntu focal-backports InRelease [98.3 kB]
Get:6 http://security.ubuntu.com/ubuntu focal-security/main amd64 Packages [231 kB]
Get:7 http://archive.ubuntu.com/ubuntu focal/restricted amd64 Packages [33.4 kB]
Get:8 http://archive.ubuntu.com/ubuntu focal/main amd64 Packages [1275 kB]
Get:9 http://security.ubuntu.com/ubuntu focal-security/multiverse amd64 Packages [1078
B]
…
```



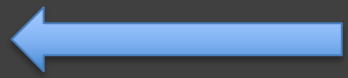
Step1: Instruction 1



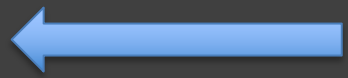
Step2: Instruction 2

```
>docker build -t hello_world_cmd -f Dockerfile_cmd .

….
Step 3/4 : ENTRYPOINT ["/bin/echo", "Hello"]
 ---> Running in 52c7a98397ad
Removing intermediate container 52c7a98397ad
 ---> 7e4f8b0774de
Step 4/4 : CMD ["world"]
 ---> Running in 353adb968c2b
Removing intermediate container 353adb968c2b
 ---> a89172ee2876
Successfully built a89172ee2876
Successfully tagged hello_world_cmd:latest
```



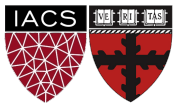
Step3: Instruction 3



Step4: Instruction 4

```
> docker images
REPOSITORY          TAG                 IMAGE ID            CREATED             SIZE
hello_world_cmd     latest              a89172ee2876        7 minutes ago       96.7MB
ubuntu              latest              4e2eef94cd6b        3 weeks ago         73.9MB
```

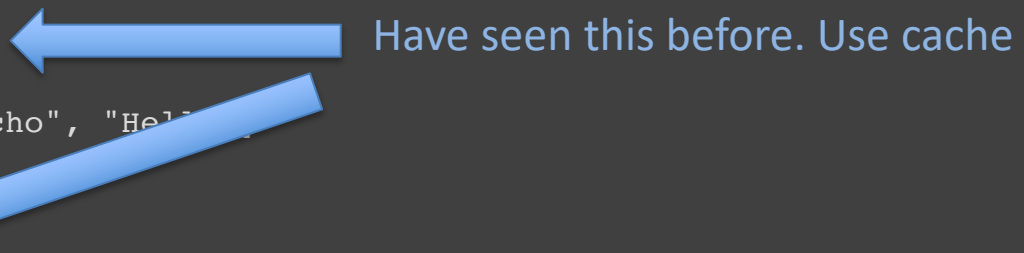
```
> docker image history hello_world_cmd
IMAGE               CREATED             CREATED
BY                                      SIZE                COMMENT
a89172ee2876        8 minutes ago       /bin/sh -c #(nop)  CMD ["world"]                0B
7e4f8b0774de        8 minutes ago       /bin/sh -c #(nop)  ENTRYPOINT ["/bin/echo" "…   0B
cfc0c414a914        8 minutes ago       /bin/sh -c apt-get update                       22.8MB
4e2eef94cd6b        3 weeks ago         /bin/sh -c #(nop)  CMD ["/bin/bash"]            0B
<missing>           3 weeks ago         /bin/sh -c mkdir -p /run/systemd && echo 'do…   7B
<missing>           3 weeks ago         /bin/sh -c set -xe   && echo '#!/bin/sh' > /…   811B
<missing>           3 weeks ago         /bin/sh -c [ -z "$(apt-get indextargets)" ]     1.01MB
<missing>           3 weeks ago         /bin/sh -c #(nop) ADD file:9f937f4889e7bf646…   72.9MB
```



Why Layers

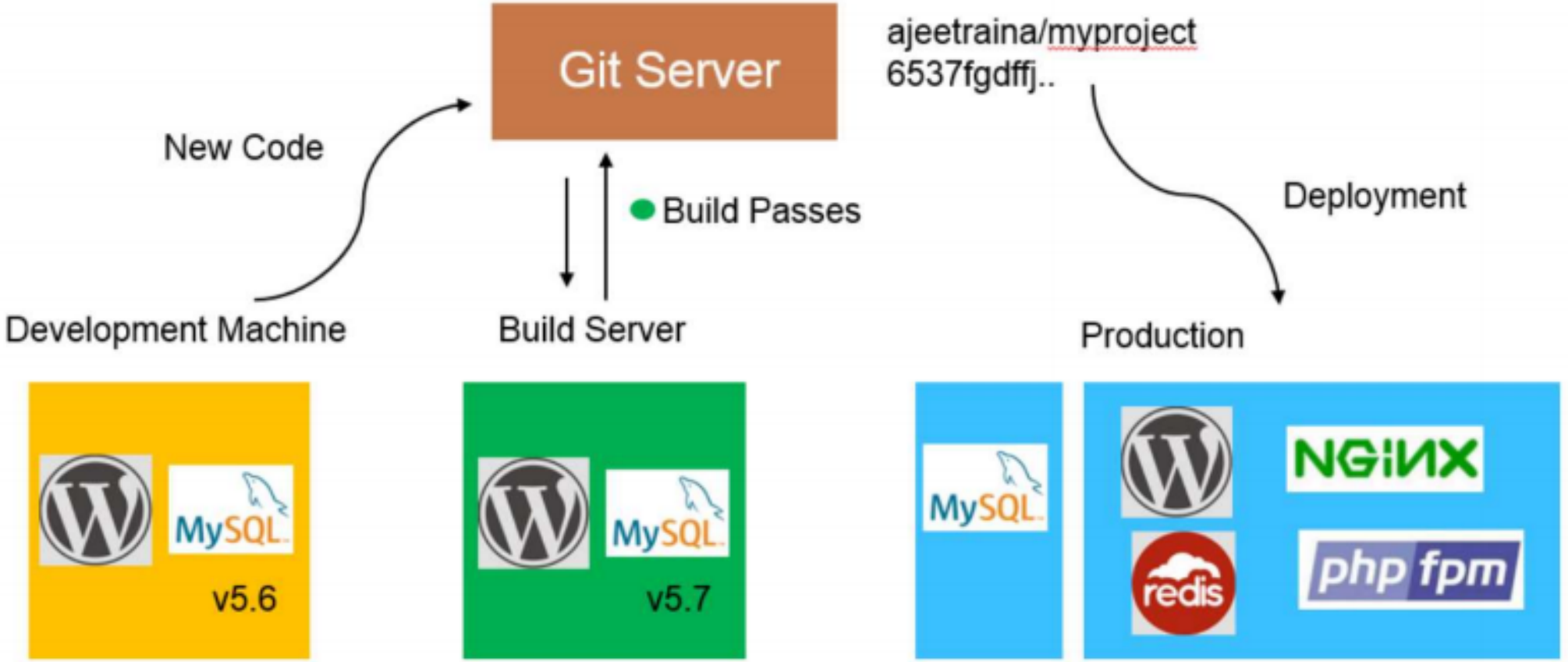
Why build an image with multiple layers when we can just build it in a single layer?
Let's take an example to explain this concept better, let us try to change the Dockerfile_cmd we created and rebuild a new Docker image.

```
> docker build -t hello_world_cmd -f Dockerfile_cmd .
Sending build context to Docker daemon   34.3kB
Step 1/4 : FROM ubuntu:latest
 ---> 4e2eef94cd6b
Step 2/4 : RUN apt-get update
 ---> Using cache
 ---> cfc0c414a914
Step 3/4 : ENTRYPOINT ["/bin/echo", "Hel
 ---> Using cache
 ---> 7e4f8b0774de
Step 4/4 : CMD ["world"]
 ---> Using cache
 ---> a89172ee2876
Successfully built a89172ee2876
Successfully tagged hello_world_cmd:latest
```



As you can see that the image was built using the existing layers from our previous docker image builds. If some of these layers are being used in other containers, they can just use the existing layer instead of recreating it from scratch.

Traditional Software Development Workflow
(without Docker)



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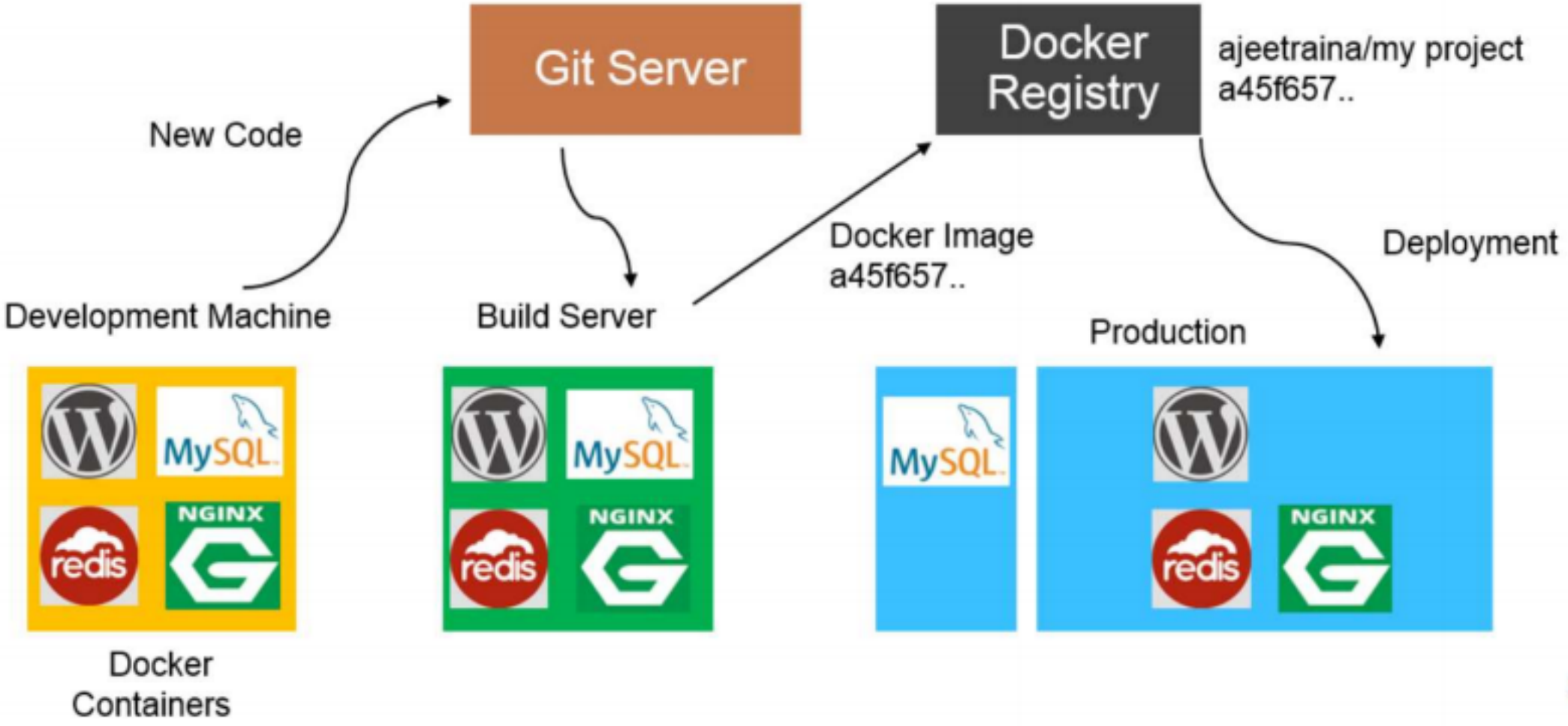
Traditional Software Development Workflow
(with Docker)



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Docker Registry Services

DOCKER REGISTRY SERVICES

DOCKER HUB

Docker hub is the official image repository of the docker.Its helps to store , share and distribute the docker image

QUAY

It is the docker registry owned by Red hat. Its helps to create on premises and cloud repository

GOOGLE CONTAINER REGISTRY

It is the docker registry created by the google.Its used to setup the private registeries

AMAZON

Docker Containers are not Virtual Machines

Virtual Machines

Containers

Docker Container vs Virtual Machines (VM)

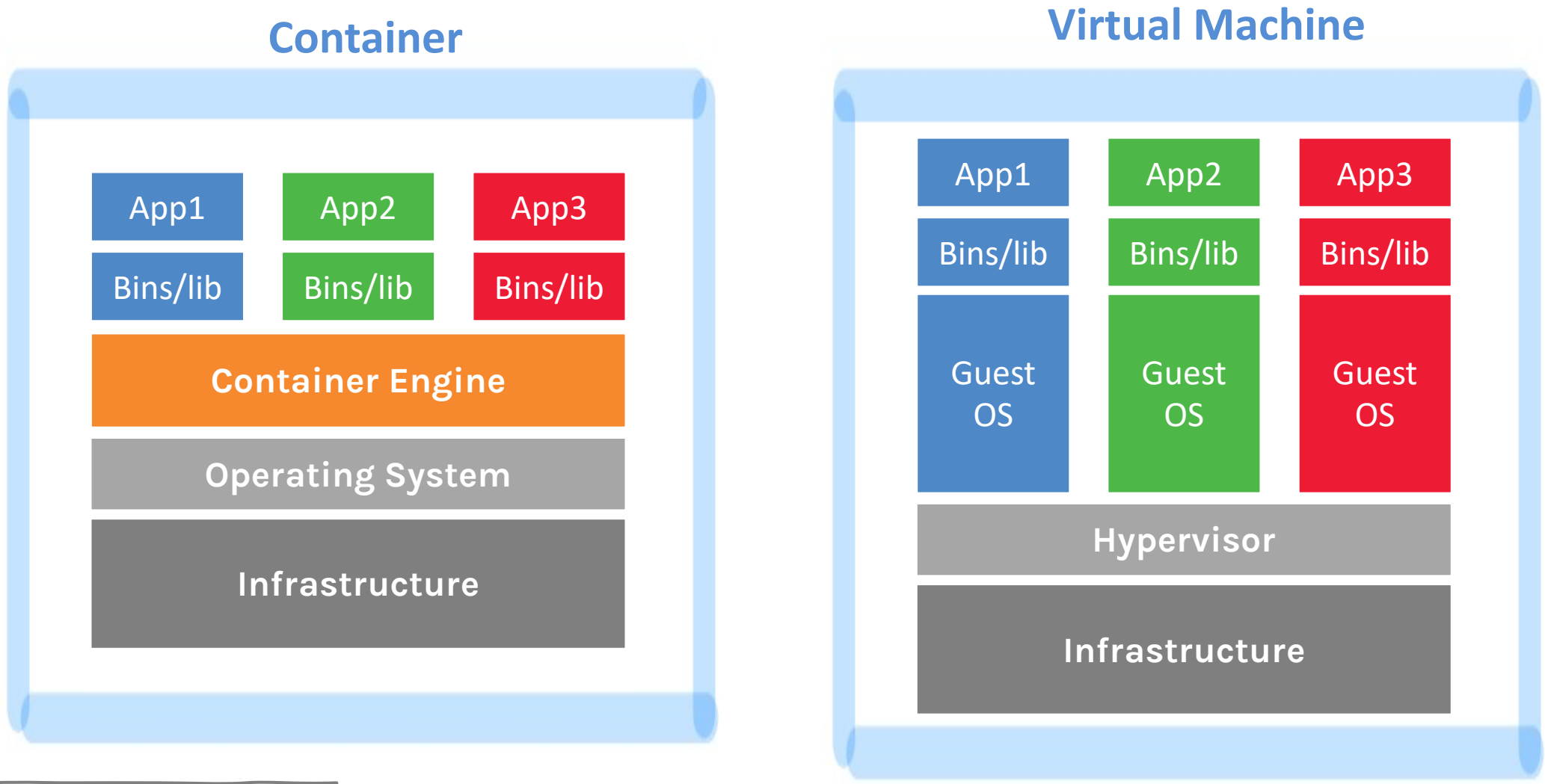
VMs

- Each VM runs its own OS
- Boot up time is in minutes
- Not version controlled
- Cannot run more than couple of VMs on an average laptop
- Only one VM can be started from one set of VMX and VMDK files

Docker

- Container is just a user space of OS
- Containers instantiate in seconds
- Images are built incrementally on top of another like layers. Lots of images/snapshots
- Images can be diffed and can be version controlled. Docker hub is like Github
- Can run many Dockers in a laptop
- Multiple docker containers can be started from one Docker image

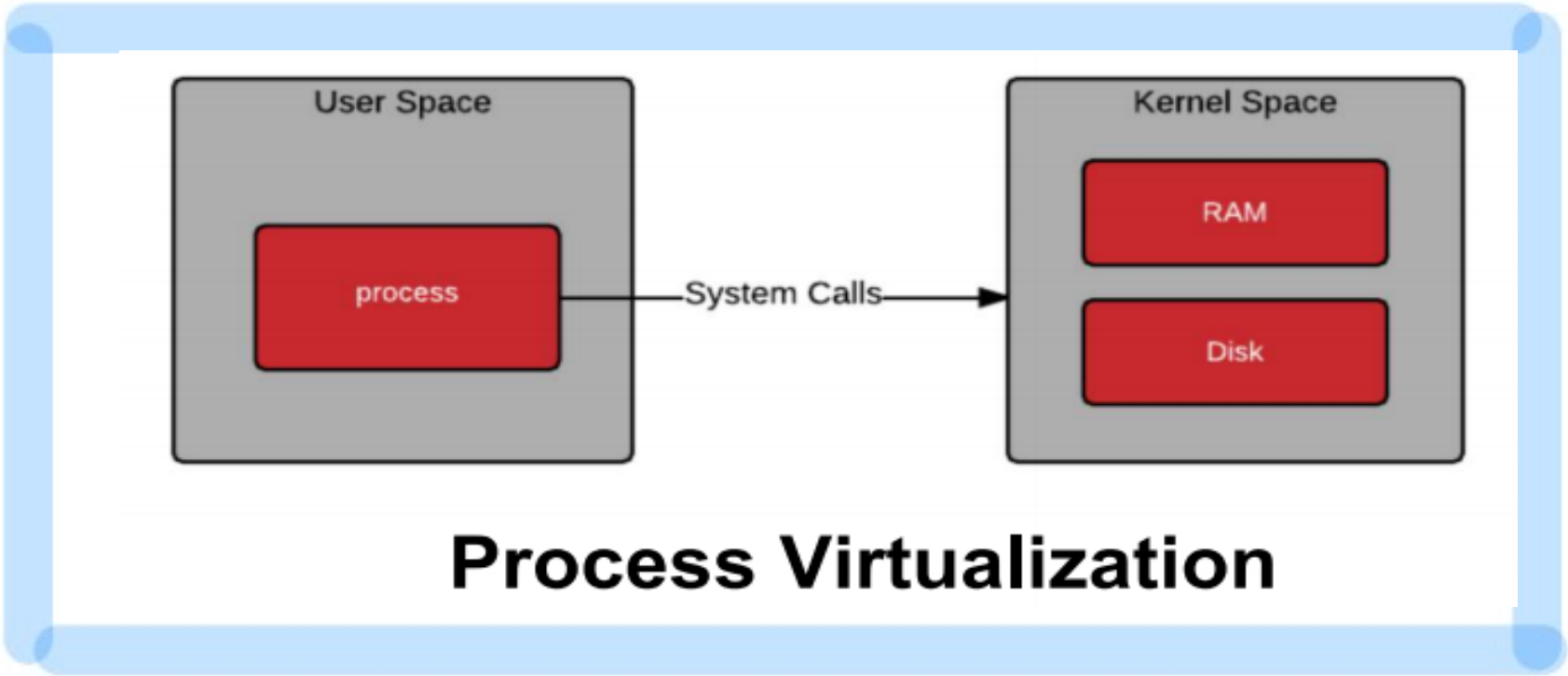
Docker Container vs Virtual Machines



What Makes Containers so Small?

Container = User Space of OS

- User space refers to all of the code in an operating system that lives outside of the kernel

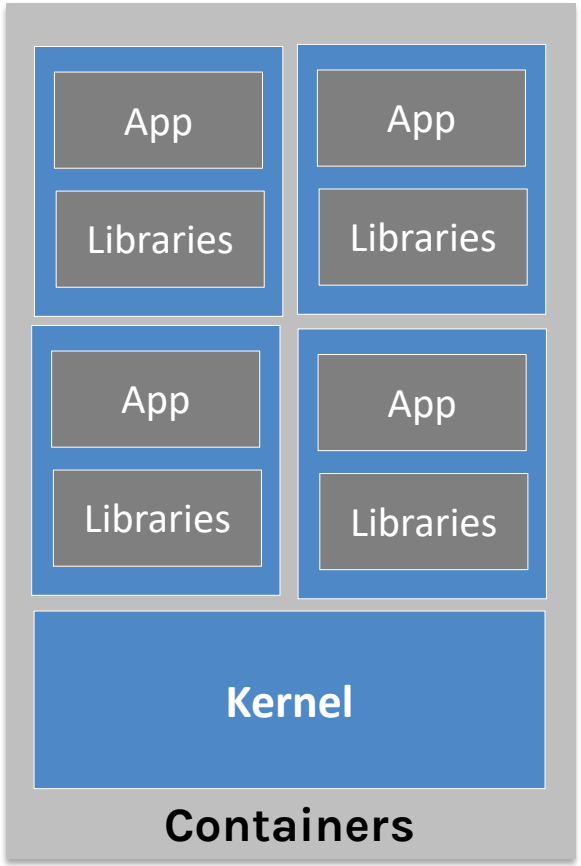


Why should we use containers?

- It has the best of the two worlds because it allows:
  1. to create isolate environment using the preferred operating system
  2. to run different operating system without sharing hardware

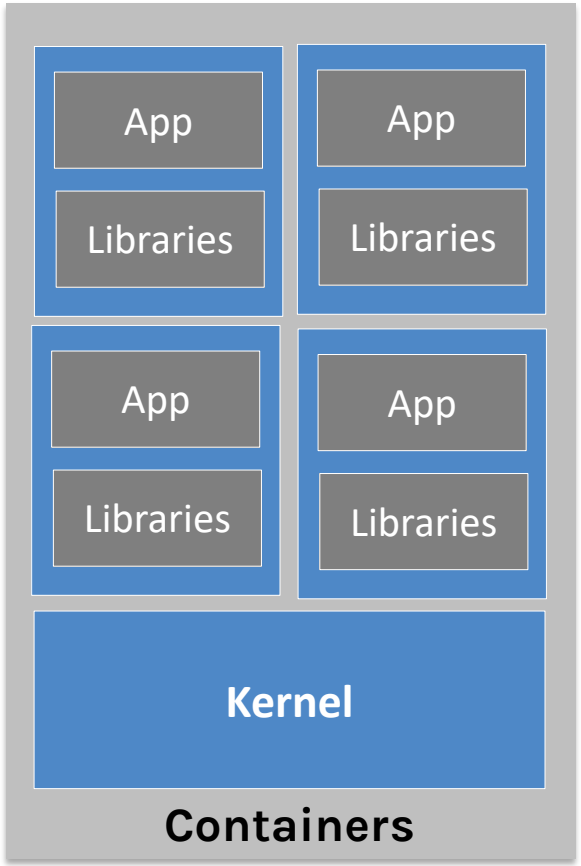
- The advantage of using containers is that they only virtualize the operating system and do not require dedicated piece of hardware because they share the same kernel of the hosting system.

- Containers give the impression of a separate operating system however, since they're sharing the kernel, they are much cheaper than a virtual machine.



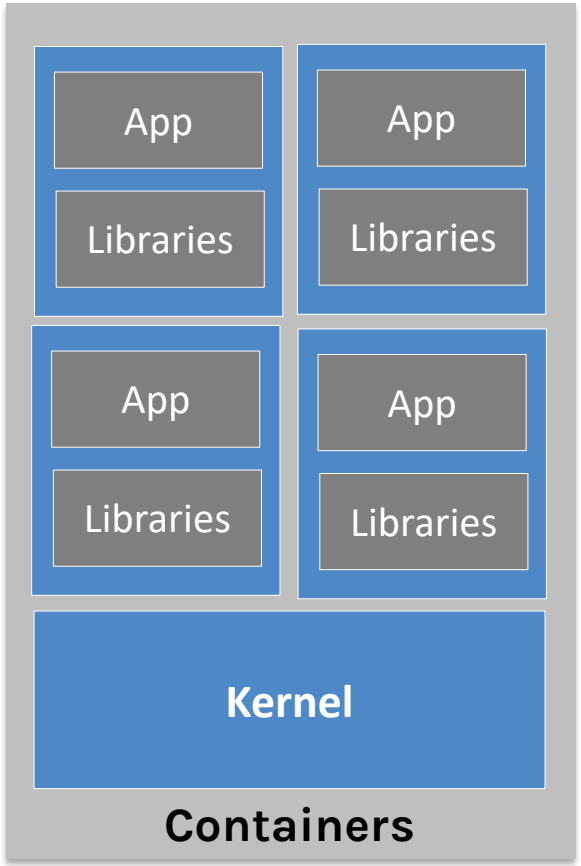
Why should we use containers? (cont)

- With container images, we confine the application code, its runtime, and all its dependencies in a pre-defined format.
- With the same image, you can reproduce as many containers as you wish. Think about the image as the recipe, and the container as the cake ;-) you can make as many cakes as you'd like with a given recipe.
- A container orchestrator (see next lecture) is a single controller/management unit that connects multiple nodes together.
- You can create a container on a Window but install an image of a Linux OS inside that container. The container still works on the Window



Why should we use containers? (cont)

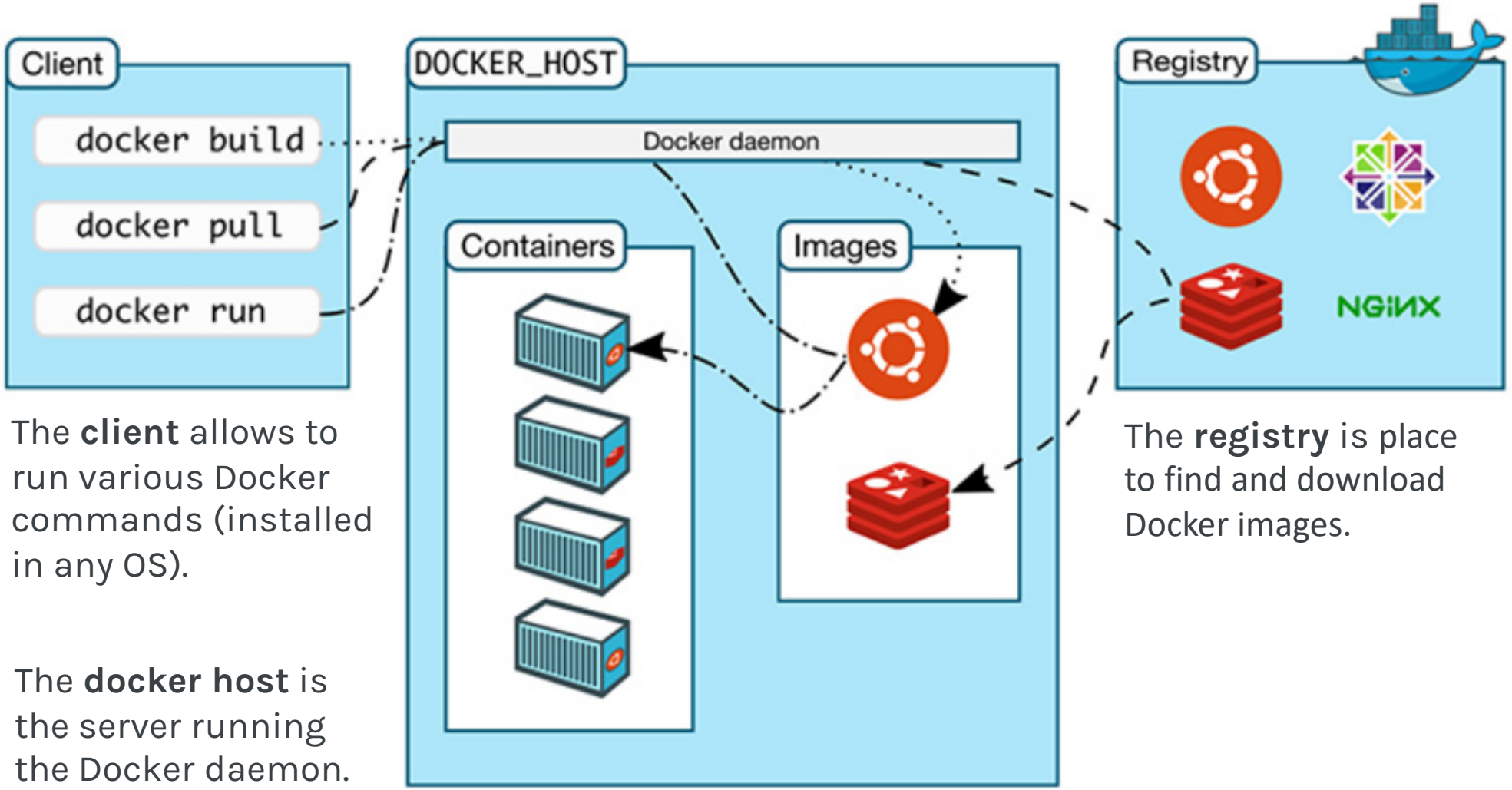
- Containers are application-centric methods to deliver high-performing, scalable applications on any infrastructure of your choice.
- Containers are best suited to deliver **microservices** by providing portable, isolated virtual environments for applications to run without interference from other running applications.
- Containers run container images, it bundles the application along with its runtime and dependencies.
- Because they're so lightweight, you can have many containers running at once on your system.



Why containers recap?

- Their startup time is on the order of seconds (vs. minutes for Virtual Machines).
- They provide pseudo-isolation. This means they're still pretty secure, but not as secure at a Virtual Machines.
- A container is deployed from the container image offering an isolated executable environment for the application.
- Containers can be deployed from a specific image on many platforms, such as workstations, Virtual Machines, public cloud, etc.
- Containers are extremely popular, and their popularity is growing.
- One of the first widely used containers was provided by Docker.
- Docker containers can be used to run websites and web applications.
- Multiple containers can be managed by a service called Kubernetes (see next lecture)

The Docker Engine Architecture



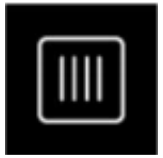
The **client** allows to run various Docker commands (installed in any OS).

The **docker host** is the server running the Docker daemon.

The **registry** is place to find and download Docker images.

https://nickjanetakis.com/blog/understanding-how-the-docker-daemon-and-docker-cli-work-together

Some Docker Vocabulary



Docker Image
The basis of a Docker container. Represent a full application

Docker Container
The standard unit in which the application service resides and executes

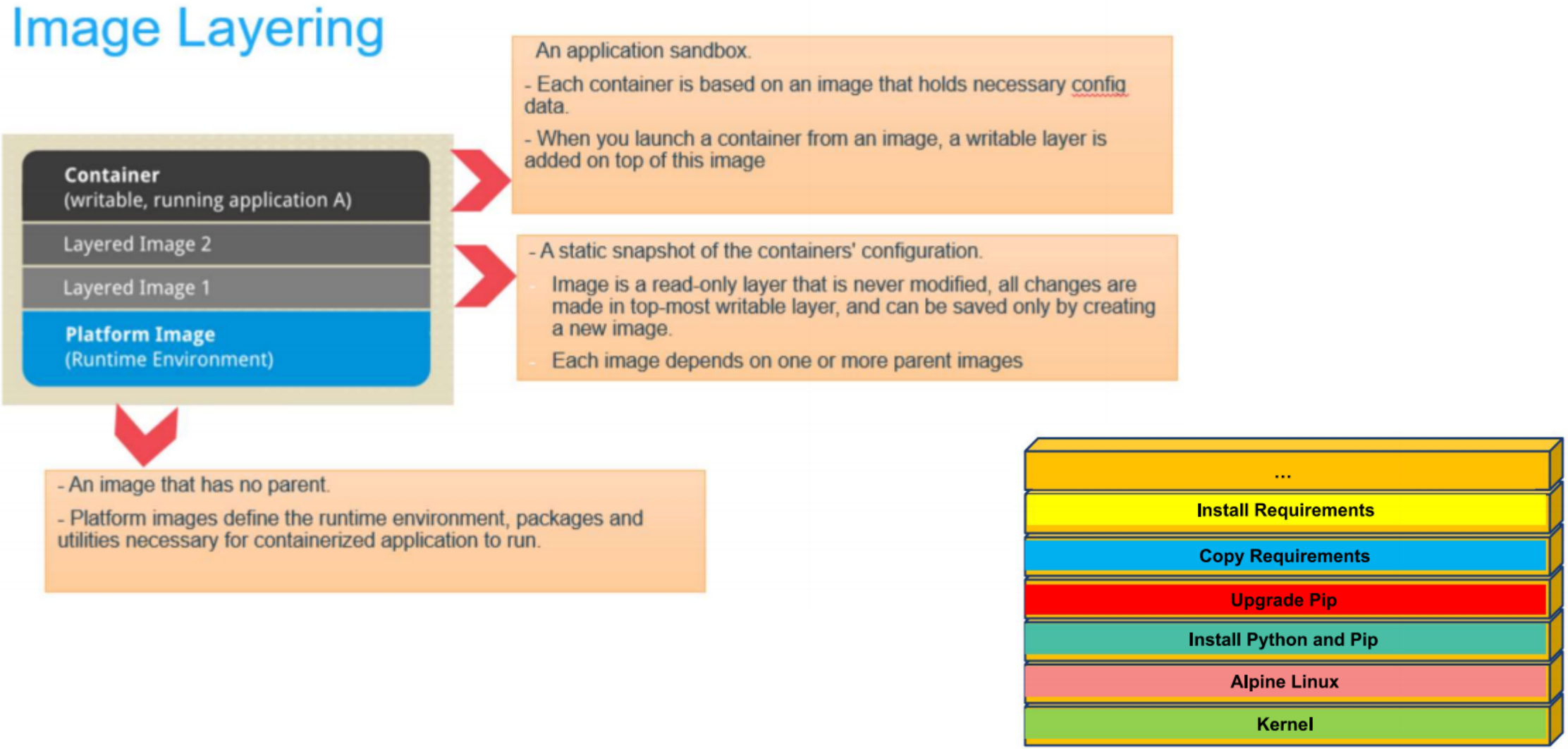
Docker Engine
Creates, ships and runs Docker containers deployable on a physical or virtual, host locally, in a datacenter or cloud service provider

Registry Service (Docker Hub or Docker Trusted Registry)
Cloud or server-based storage and distribution service for your images

Images
How you **store** your application

Containers
How you **run** your application

Image Layering



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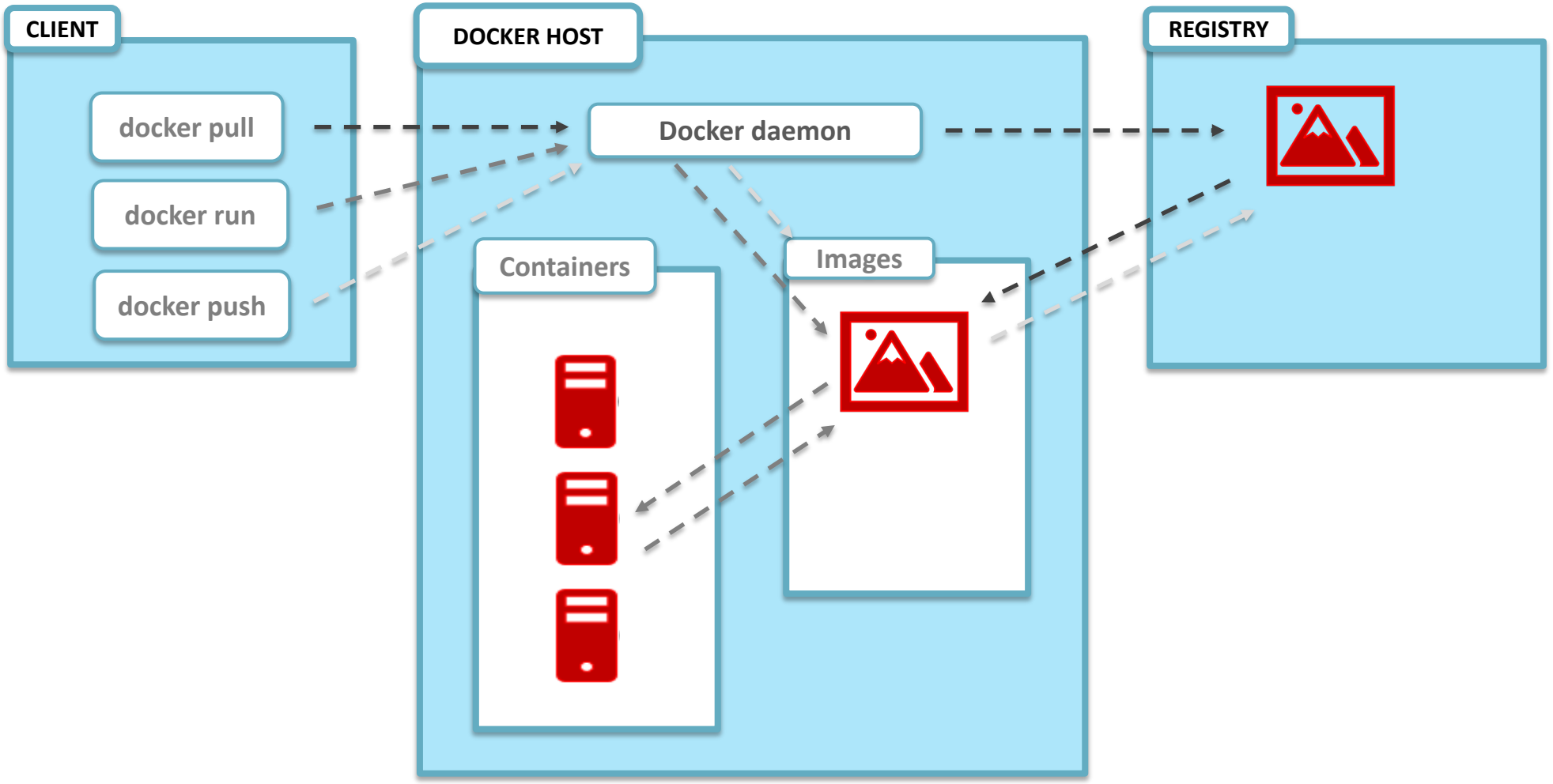
Hands on Containers

Exercise 3; For you to play

Exercise 1: Pull, modify, and push a Docker image from DockerHub

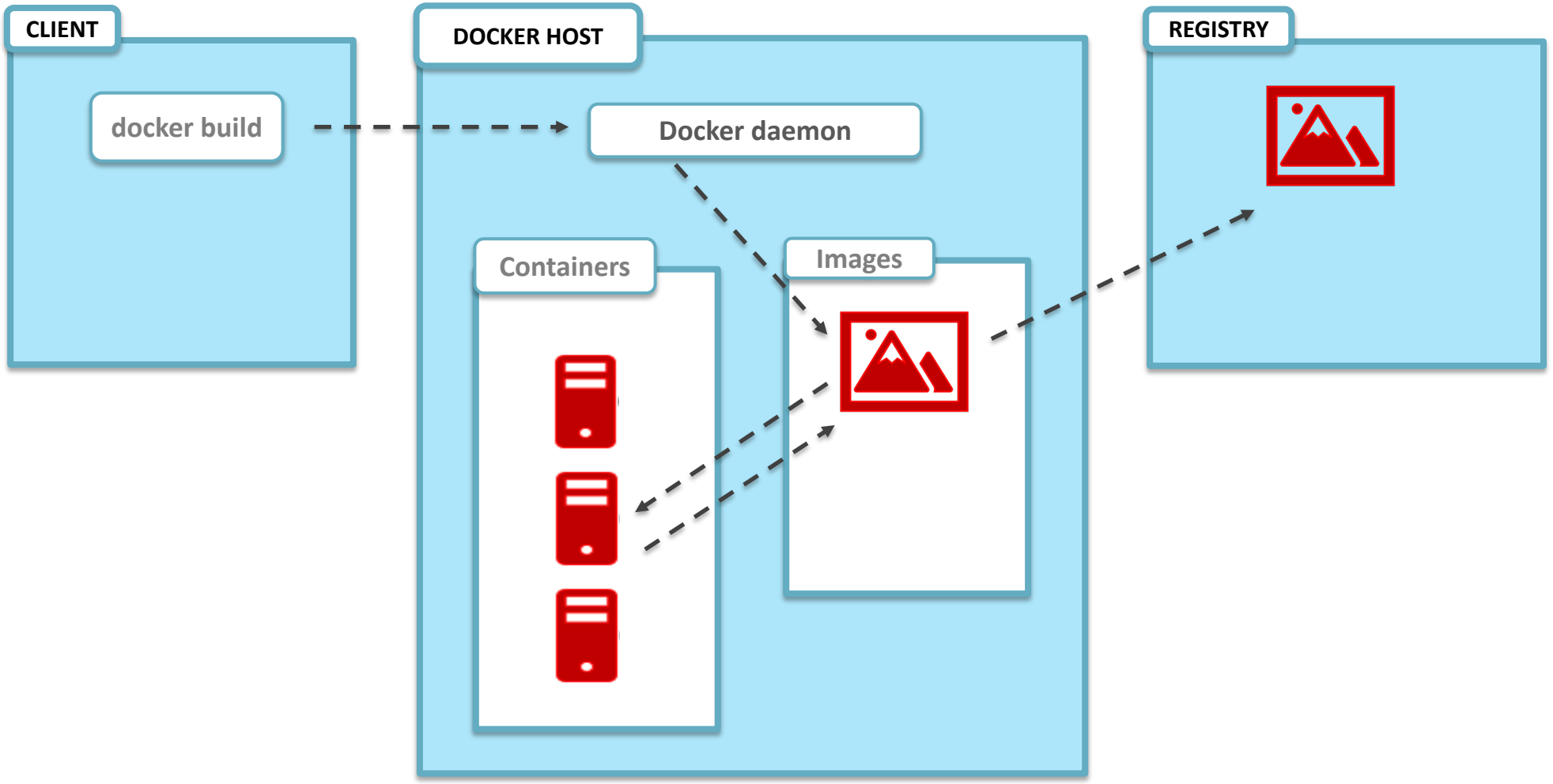
Exercise 2: Build a Docker Image and push it to DockerHub

Exercise 1: pull, modify, and push an image



https://nickjanetakis.com/blog/understanding-how-the-docker-daemon-and-docker-cli-work-together

Exercise 2: build a Docker Image



https://nickjanetakis.com/blog/understanding-how-the-docker-daemon-and-docker-cli-work-together

Hands on Containers | Instructions

Exercise set up

- install docker (https://hub.docker.com/)
- have docker up and running
- create a class repository in docker hub (`yourhubusername/ac295_playground`)

Exercise 1: modify images from Docker Hub

- Step 1 | pull image `pavlosprotopapas/ac295_l2:latest`
- Step 2 | run container in interactive mode (`-it`)
- Step 3 | open Readme.txt file and follow instructions to modify image
- Step 4 | push modified image (`pavlosprotopapas/ac295_l2`)

Exercise 2: Docker Do It Yourself

- Step 1 | pull course repository and cd to `lecture2/exercises/exercise1`
- Step 2 | build an image using Dockerfile (for MacOs)
- Step 3 | push image to docker hub (`yourhubusername/ac295_playground`)

THANK YOU

AC295 Advanced Practical Data Science

Pavlos Protopapas