Lecture 3: Containers I

AI-5

Productionizing AI (MLOps)

Pavlos Protopapas, Shivas Jayaram

Outline

1. Recap & Motivation
2. What is a Container
3. Why use Containers
4. How to use Containers

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1. **Recap & Motivation**
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Recap Virtual Machines: Pros and Cons

Pros

- Full autonomy
- Very secure
- Lower costs
- Cloud Adoption

Cons

- Resource Intensive:
- Portability Issues
- Overhead

Recap Virtual Machines: Pros and Cons

Pros

- **Full autonomy:**
  Complete control over the operating system and applications, similar to a physical server.
- **Very secure:**
  Isolated environment helps in minimizing the risk of system intrusion.
- **Lower costs:**
  Can be more cost-effective for applications that need full OS functionality.
- **Cloud Adoption:**
  Offered by all major cloud providers for on-demand server instances.

Cons

- **Resource Intensive:**
  Consumes hardware resources from the host machine.
- **Portability Issues:**
  VMs are large in size, making them harder to move between systems.
- **Overhead:**
  Requires additional resources to run the hypervisor and manage multiple operating systems.

Recap Virtual Environments: Pros and Cons

Pros

- Reproducible research
- Explicit dependencies
- Improved engineering collaboration

Cons

- Difficulty setting up your environment
- No isolation (from host machine)
- Does not always work across different OS

Recap: Virtual Environments

Pros

- Reproducible Research:
  - Easy to replicate experiments and share research outcomes due to consistent environments.
- Explicit Dependencies:
  - Clear listing of all required packages and versions, reducing ambiguity.
- Improved Engineering Collaboration:
  - Team members can quickly set up the same environment, streamlining development.

Cons

- Difficulty in Setup:
  - Initial setup can be complex, especially for those new to the concept.
- No Isolation from Host:
  - Virtual environments share the host's operating system, leading to potential conflicts.
- OS Limitations:
  - May not be compatible across different operating systems, requiring additional configuration.

Wish List

Automated Setup:

Automatically set up (installs) OS and extra libraries and set up the python environment.

Isolation:

Complete separation from the host machine and other containers, ensuring a consistent run-time environment.

Resource Efficiency:

Minimal use of CPU, Memory, and Disk resources, optimized for performance.

Quick Startups:

Near-instantaneous container initialization, reducing time to deployment.

Containers

Outline

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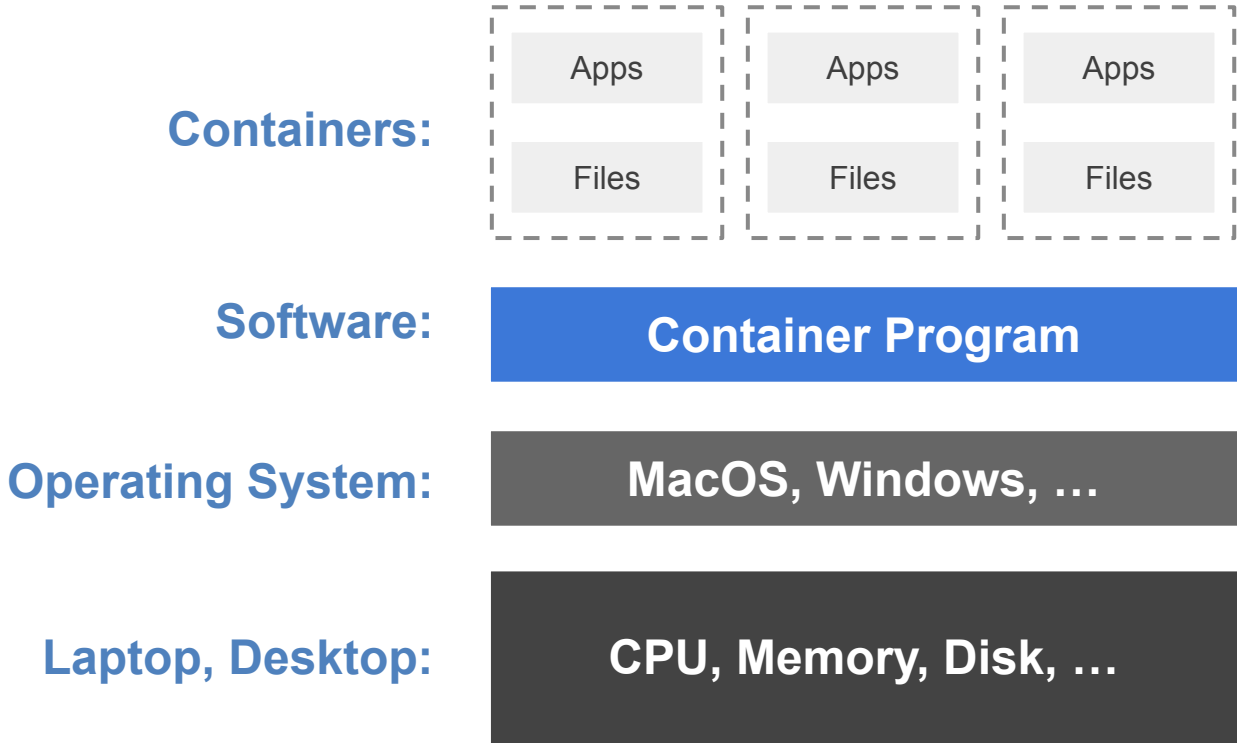
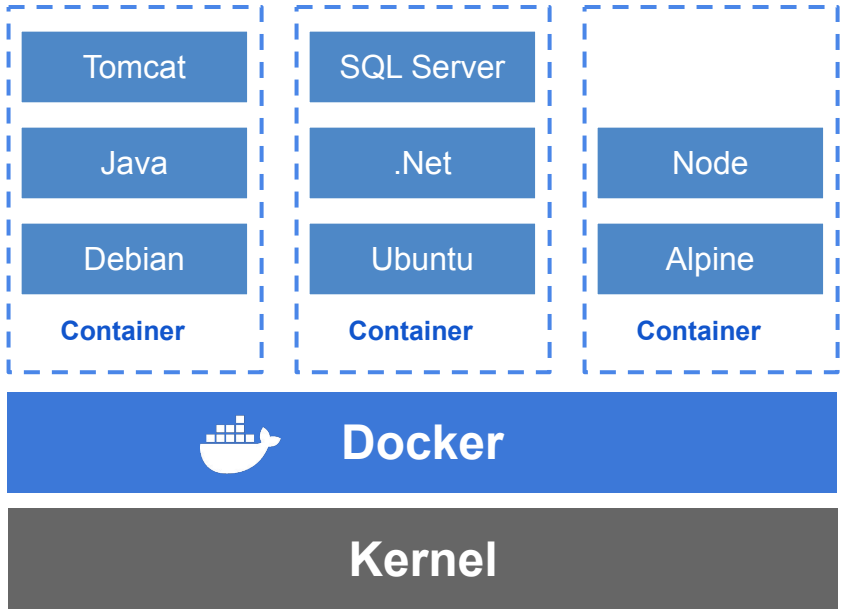
What is a CONTAINER

A container is a program that runs on your machine, essentially acting as a miniature computer within your main computer. It uses resources from the host machine (CPU, Memory, Disk, etc.) but behaves like its own operating system with an isolated file system and network.



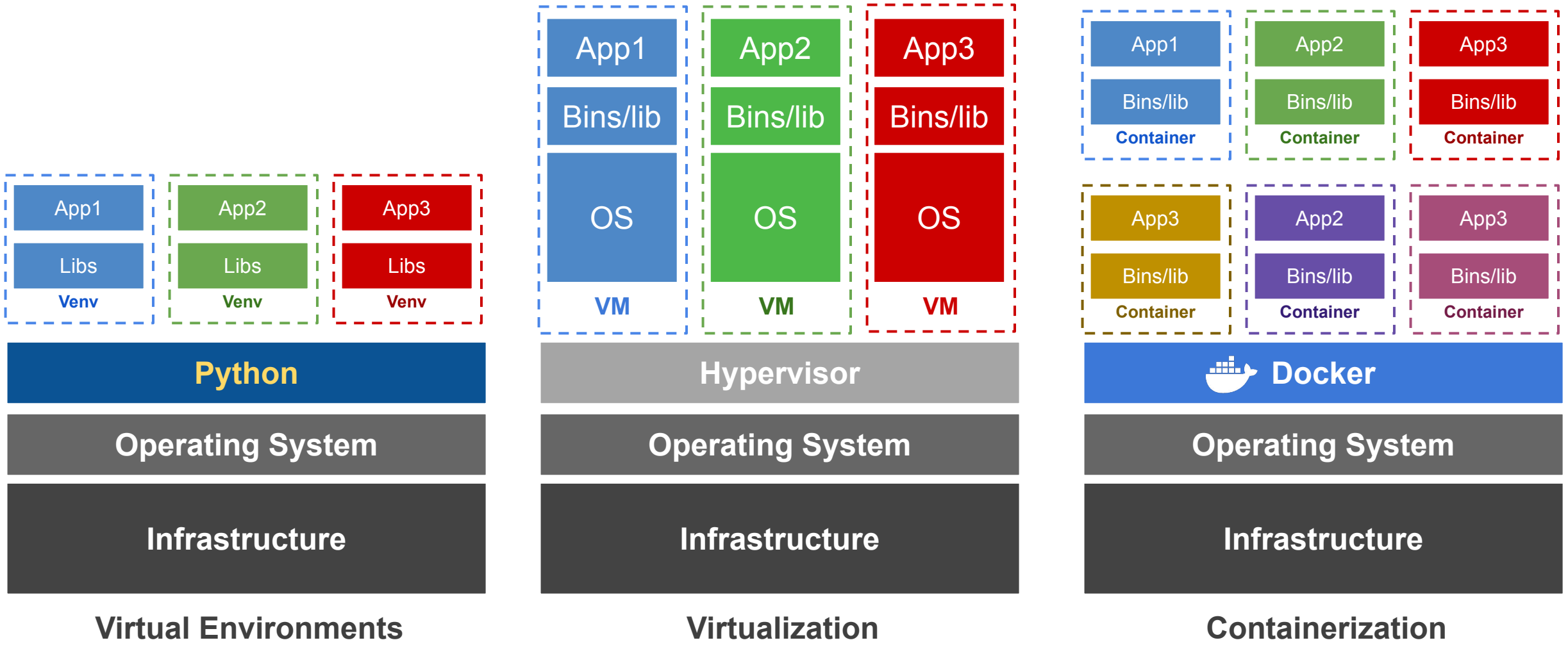
It packages code and all its dependencies to ensure that the application behaves the same way, regardless of where it's run.

What is a Container

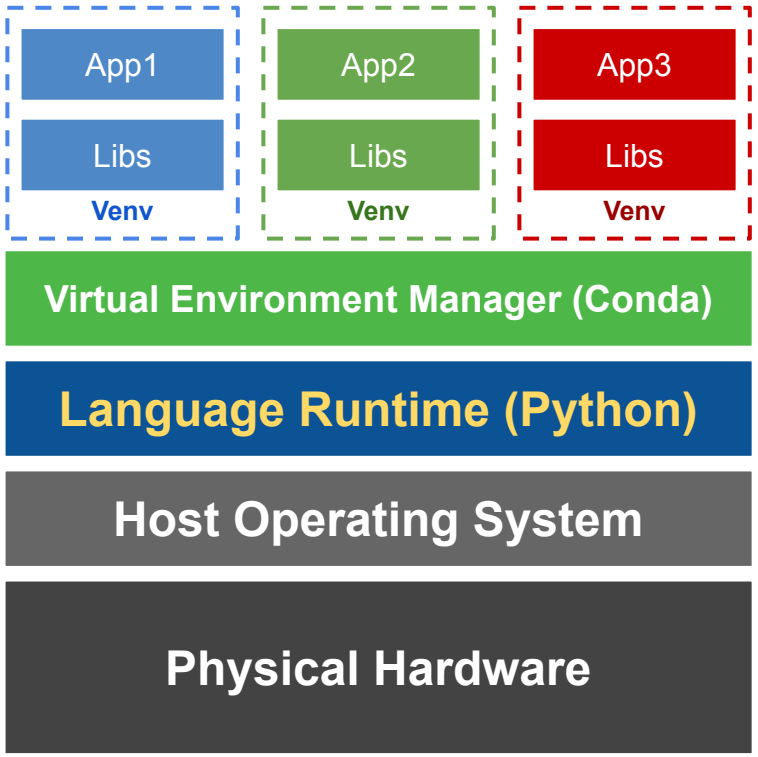


- Standardized packaging for software dependencies
- Isolate apps from each other
- Works for all major Linux distributions, MacOS, Windows

Environments vs Virtualization vs Containerization



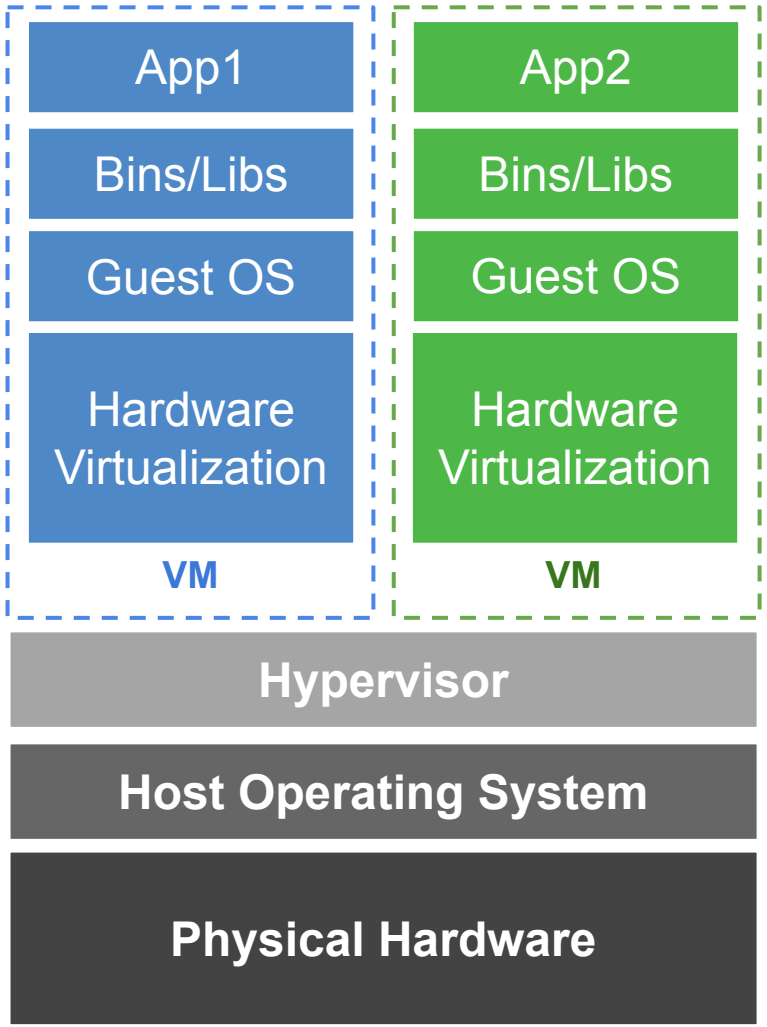
Environments



Virtual Environments

- **Dependency Isolation**: Virtual environments modify the PATH and other environment variables so that the dependencies are loaded from the environment's directory, rather than system-wide directories
- **No Kernel Isolation**: Unlike VMs and containers, virtual environments don't provide any kernel level isolation.
- **Resource Utilization**: Since virtual environments don't have any additional OS or kernel, they are the most efficient in terms of resource utilization among the three.
- **Filesystem Boundaries**: Virtual environments usually don't provide isolation at the filesystem level; files written in one environment are accessible from others.

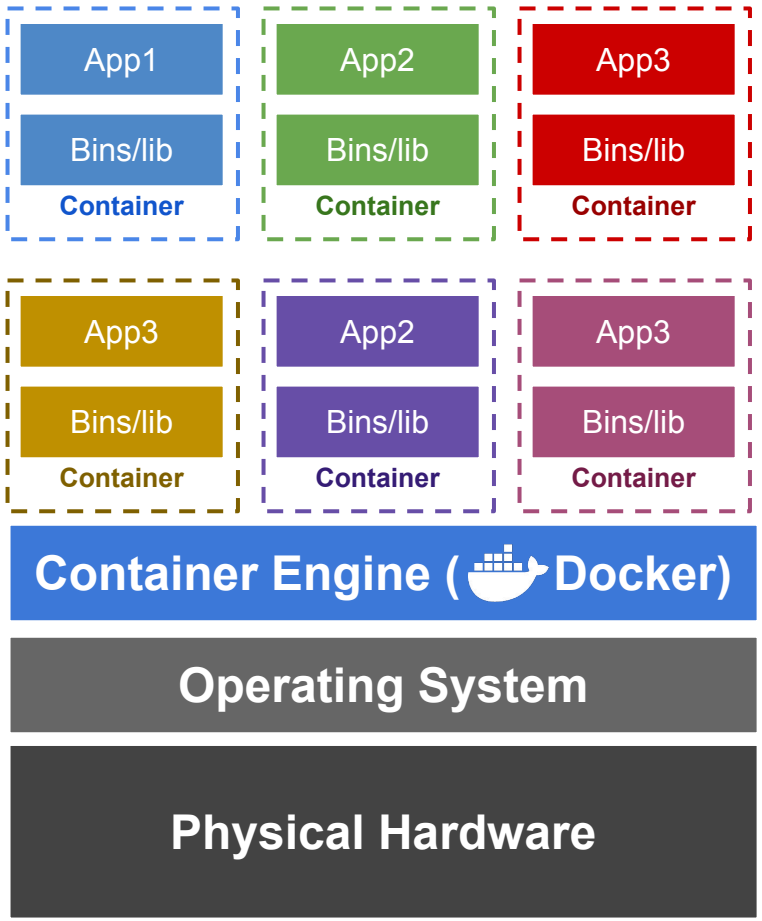
Virtualization (Virtual Machines)



Virtualization

- **CPU Virtualization**: VMs usually have a set number of virtual CPU cores allocated by the hypervisor. These virtual CPUs map to physical CPU cores, but the hypervisor adds a layer of management and overhead, which can lead to inefficiencies.
- **Emulated Devices**: VMs have emulated hardware devices, meaning the VM sees virtual CPUs, virtual network adapters, and virtual disks that the hypervisor translates to real hardware resources.
- **Full OS**: Each VM runs its full guest OS. This means that each VM has its own separate kernel space and user space, making resource management fully independent but less efficient.
- **Resource Allocation:** RAM and CPU are often (not always) allocated in blocks, and disk space is generally pre-allocated, making VMs less flexible in terms of resource utilization.

Containerization



Containerization

- **Namespaces**: Containers use kernel features like namespaces to provide isolation of processes and resources. This allows each container to operate as if it is the only application running on the system. Example namespaces include:
  - PID Namespace: Isolates the process ID number space. In other words, processes in different PID namespaces can have the same PID.
  - Mount Names: Isolates the file system tree so that each namespace can have its own file system layout.
- **Control Groups (cgroups)**: Complementary to namespaces, cgroups limit resource usage, like CPU, memory, and IO, allowing for better resource utilization compared to VMs.
- **Process Virtualization:** Namespaces and cgroups together enable process virtualization by allowing processes to run in isolated environments with controlled access to system resources.
- **Shared Kernel**: Containers share the host's OS kernel but have their own filesystem, libraries, and bins, making them lightweight yet isolated.
- **Direct Access**: Containers can access host resources more directly, avoiding much of the overhead introduced by hypervisors in VMs.

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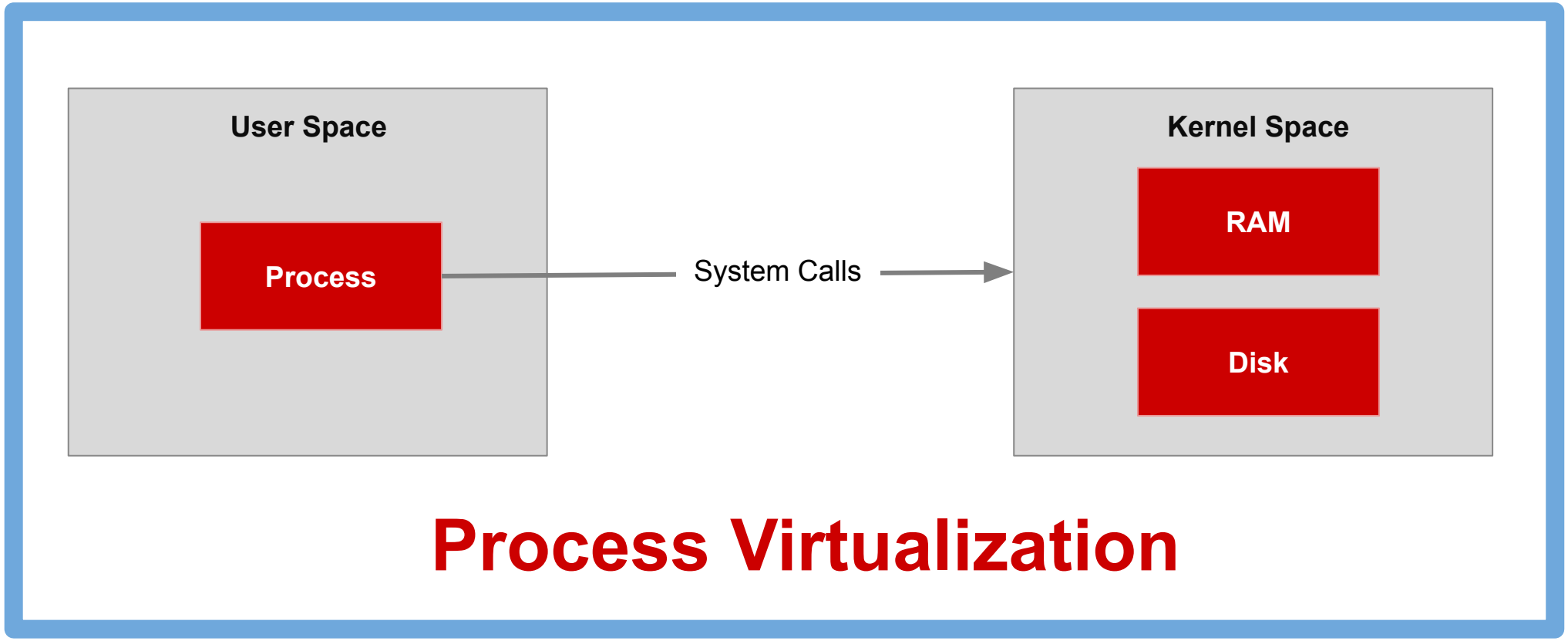
Advantages of a CONTAINER

- **Portability & Lightweight:** Containers encapsulate everything needed to run an application, making them easy to move across different environments.
- **Fully Packaged:** Containers include the software and all its dependencies, ensuring a consistent environment throughout the development lifecycle.
- **Versatile Usage:** Containers can be used across various stages, from development and testing to training and production deployment

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



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What is docker?

Open Source: Community-driven and compatible.

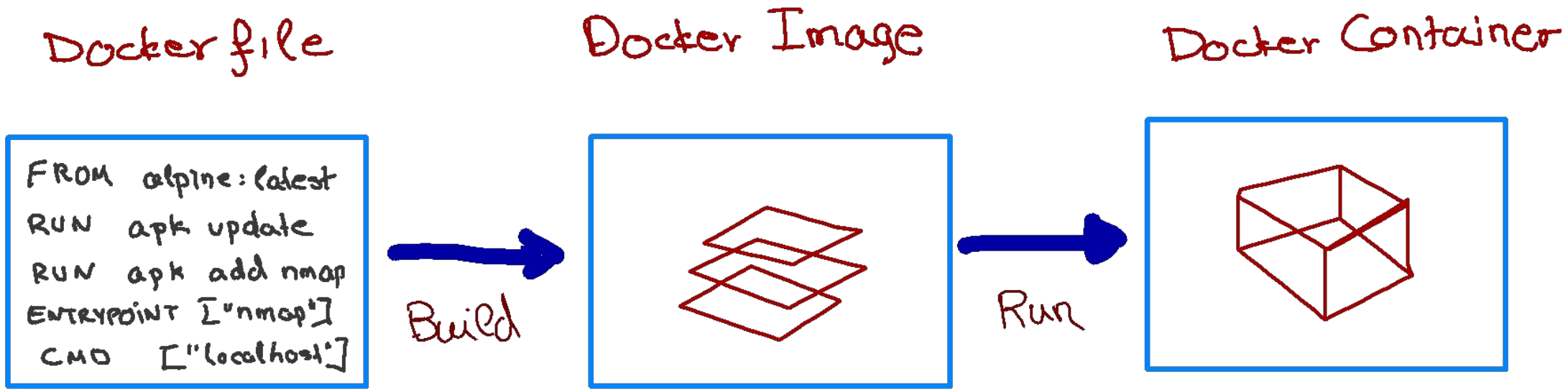
Platform: Develop, ship, and run applications containers.

Portability: Consistent across various environments.

Ecosystem: Docker Hub, Kubernetes, and more

How to run a docker container

- We use a simple text file, the `Dockerfile`, to build the `Docker Image`, which consists of an iso file and other files.
- We run the `Docker Image` to get `Docker Container`.



What is the difference between an image and container

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

`Docker file` is the hand written description of a recipe, `Image` is like the formal recipe and ingredients, `container` is like a dish.

Alternatively, you can think of an `image` as a class and a `container` is an instance of that class.

Anatomy of a Dockerfile


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

FROM: Specifies the base OS image (e.g., alpine, Ubuntu) for building the Docker image.

RUN: Executes commands to build the image. Each RUN creates a new layer.

ENTRYPOINT: Sets the default executable for the container, making it behave like a standalone application.

CMD: Sets default commands or parameters for container startup, but can be overridden by the `docker run` command.

ADD: Similar to **COPY**, but can also handle URLs and auto-extract compressed files.

https://docs.docker.com/engine/reference/builder/

Running Multiple Containers from a Single Image

How can you run multiple containers from the same image?

Yes, you could think of an image as instating a class. You can create multiple instances (containers) from a single image.

Wouldn't all these containers be identical?

Not necessarily. Containers can be instantiated with different parameters using the CMD command, making them unique in behavior.

Dockerfile

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

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

> docker run -it hello_world_cmd
> Hello world
> docker run -it hello_world_cmd 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.

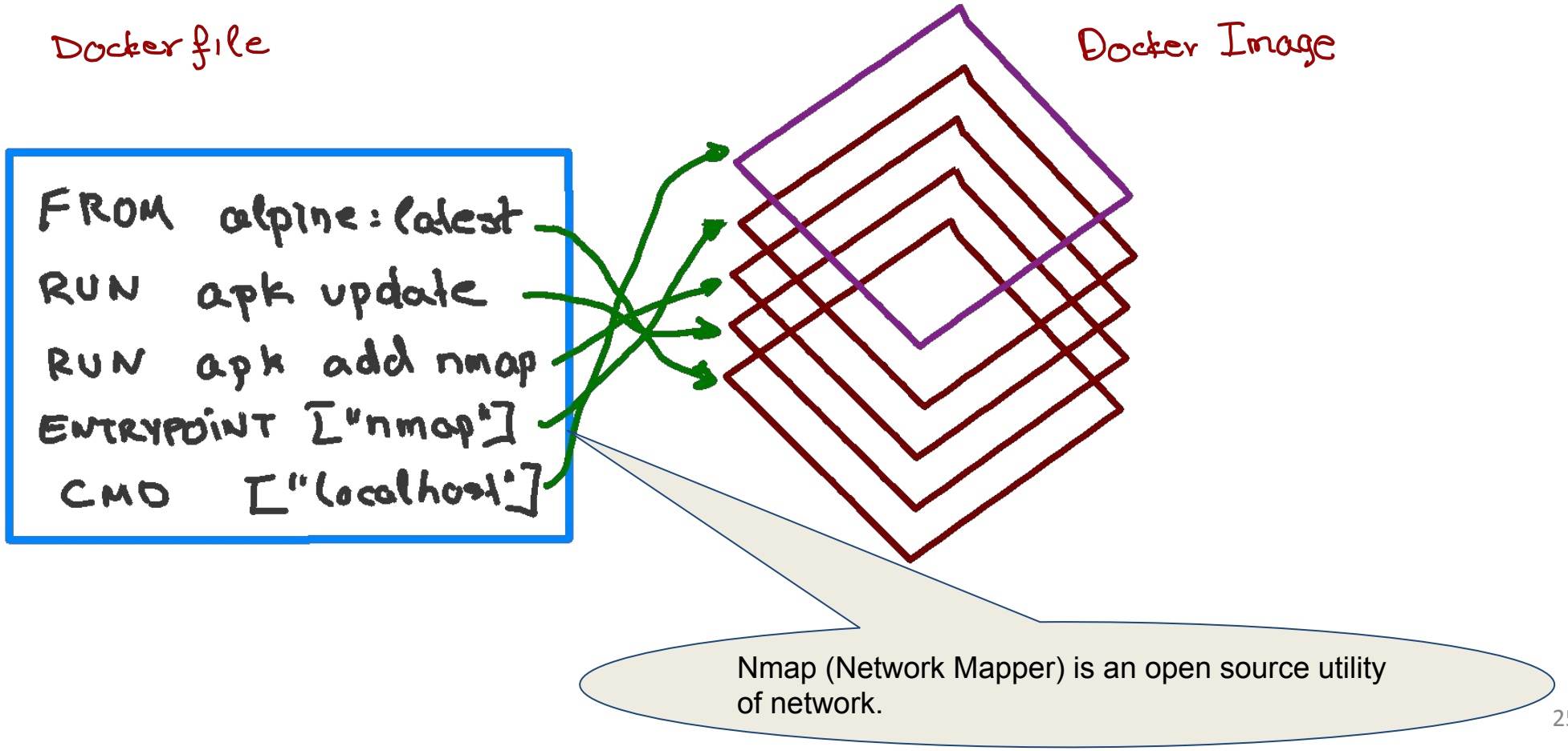
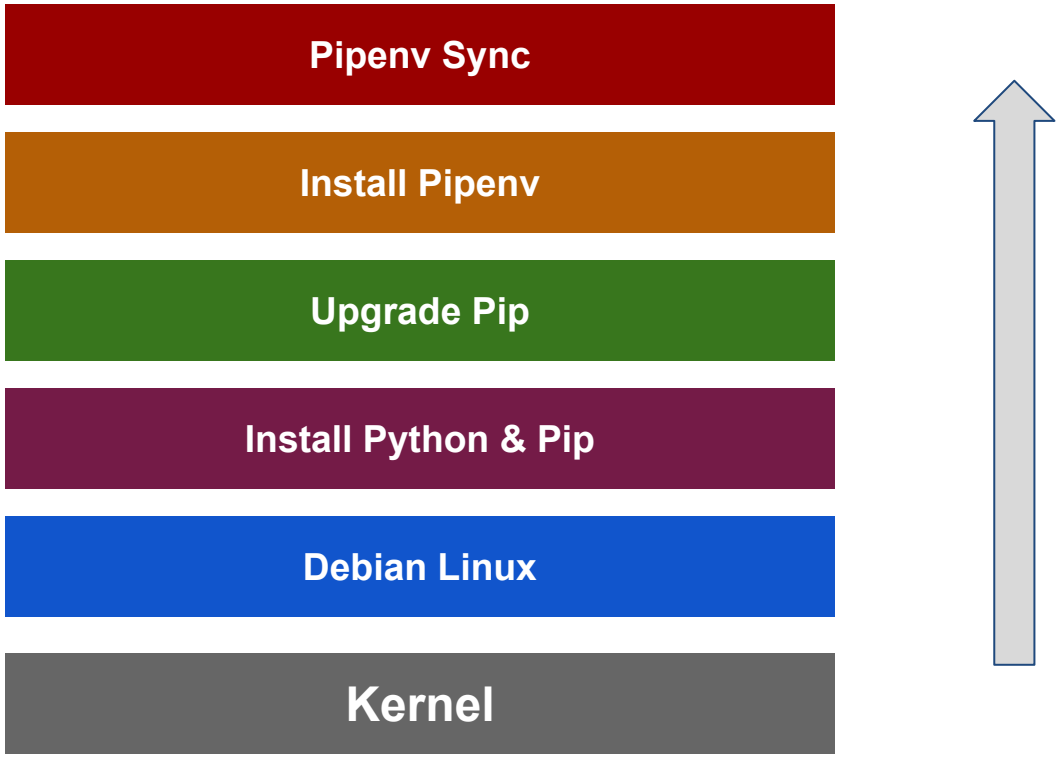


Image Layering - Example

Docker layers for a container running debian and a python environment using Pipenv



Why Layers

Why build an image with multiple layers when we can just build it in a single layer?

Efficiency

Reuse common layers across different images, saving storage and speeding up image creation.

Incremental Updates

Update only the changed layer, reducing the time and bandwidth needed for deployment.

Cache Utilization

Docker caches layers. If no changes are detected, subsequent builds are faster.

Modularity

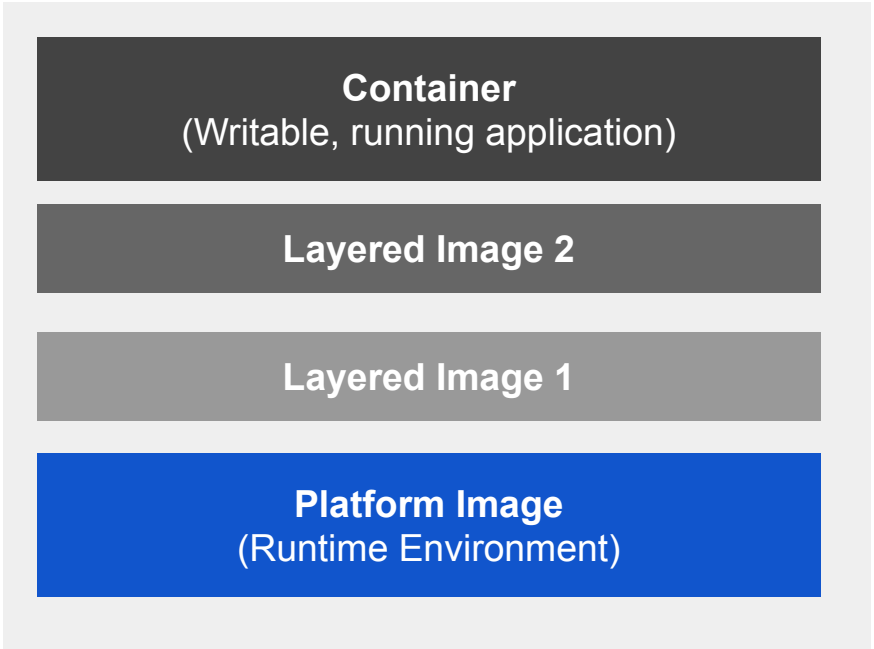
Break down complex setup into manageable pieces, making debugging easier.

Security

Smaller attack surface per layer and easier to scan for vulnerabilities.

WE WILL SEE AN EXAMPLE LATER

Image Layering



A application sandbox
- Each container is based on an image that holds necessary config data
- When you launch a container, a writable layer is added on top of the image

A static snapshot Images are read-only and capture the container's settings.
- Layer images are read-only
- Each image depends on one or more parent images

Platform images define the runtime environment, packages and utilities necessary for containerized application to run. It is an Image that has no parent

Docker Vocabulary

Docker File
A text document with commands on how to create an Image

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

Images
How you **store** your application

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

Containers
How you **run** your application

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

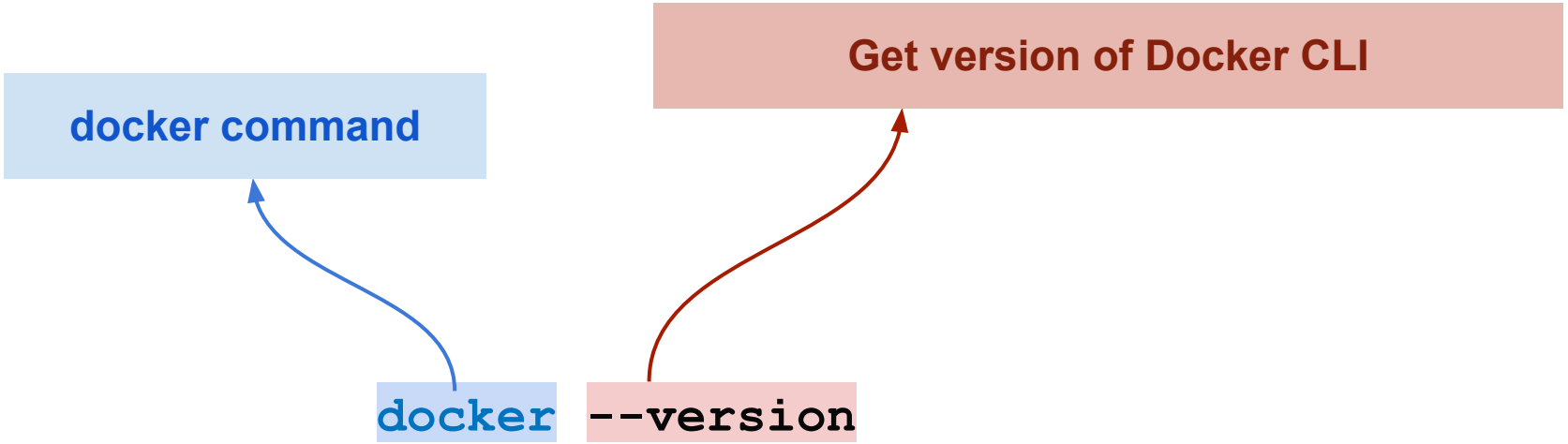
Registry Service (Docker Hub or Docker Trusted Registry)
Cloud or server-based storage and distribution service for your images

Tutorial: Installing Docker Desktop

- Install Docker Desktop. Use one of the links below to download the proper Docker application depending on your operating system.
  - For Mac users, follow this link- https://docs.docker.com/docker-for-mac/install/.
  - For Windows users, follow this link- https://docs.docker.com/docker-for-windows/install/ Note: You will need to install Hyper-V to get Docker to work.
  - For Linux users, follow this link- https://docs.docker.com/install/linux/docker-ce/ubuntu/
- Once installed run the docker desktop.
- Open a Terminal window and type `docker run hello-world` to make sure Docker is installed properly.

Tutorial: Docker commands

Check what version of Docker



Tutorial: Developing App using Containers

- Let us build the simple-translate app using Docker
- For this we will do the following:
  - Clone or download code (https://github.com/dlops-io/simple-translate)

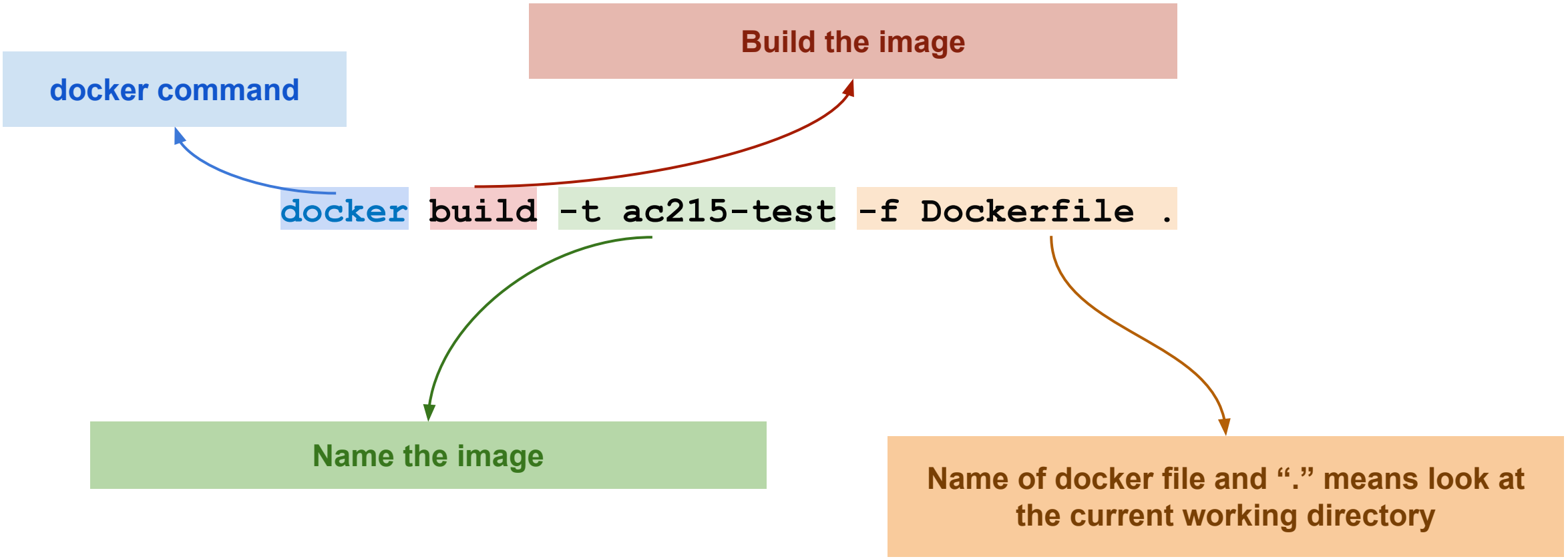
```
git clone https://github.com/dlops-io/simple-translate
```

Tutorial: Developing App using Containers

- Let us build the simple-translate app using Docker
- For this we will do the following:
  - Clone or download code (https://github.com/dlops-io/simple-translate)
  - Build a container

Tutorial: Docker commands

Build an image based on a Dockerfile



Dockerfile

```
# Use the official Debian-hosted Python image
FROM python:3.9-slim-buster

# Tell pipenv where the shell is.
# This allows us to use "pipenv shell" as a container entry point.
ENV PYENV_SHELL=/bin/bash

# Ensure we have an up to date baseline, install dependencies
RUN set -ex; \
   apt-get update && \
   apt-get upgrade -y && \
   apt-get install -y --no-install-recommends build-essential git && \
   pip install --no-cache-dir --upgrade pip && \
   pip install pipenv

# Add Pipfile, Pipfile.lock + python code
ADD . /
RUN pipenv sync

# Entry point
ENTRYPOINT ["/bin/bash"]

# Get into the pipenv shell
CMD ["-c", "pipenv shell"]
```

Docker Image as Layers

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

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: sha256:31dfb10d52ce76c5ca0aa19d10b3e6424b830729e32a89a7c6eee2cda2be67
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

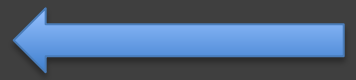
```
FROM ubuntu:latest
RUN apt-get update
ENTRYPOINT ["/bin/echo", "Hello"]
CMD ["world"]
```

Docker Image as Layers

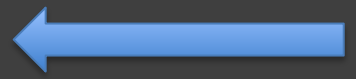
```
FROM ubuntu:latest
RUN apt-get update
ENTRYPOINT ["/bin/echo", "Hello"]
CMD ["world"]
```

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

....
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 Image as Layers

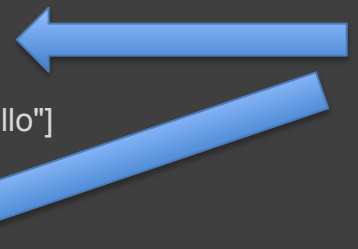
```
> docker images
REPOSITORY          TAG                 IMAGE ID            CREATED             SIZE
hello_world_cmd     latest              a89172ee2876        7 minutes ago       96.7MB
ubuntu              latest              4e2eef94cd6b        3 weeks ago         73.9MB
```

```
> 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", "Hello"]
 ---> Using cache
 ---> 7e4f8b0774de
Step 4/4 : CMD ["world"]
 ---> Using cache
 ---> a89172ee2876
Successfully built a89172ee2876
Successfully tagged hello_world_cmd:latest
```

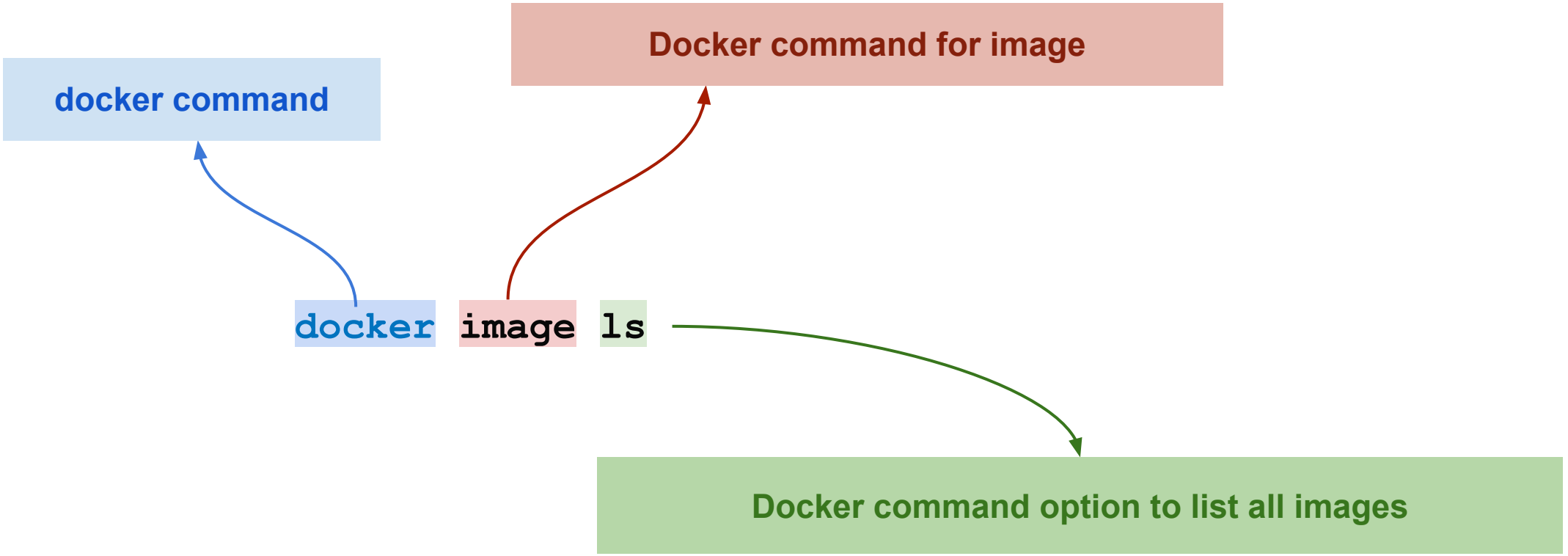


Have seen this before. Use cache

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.

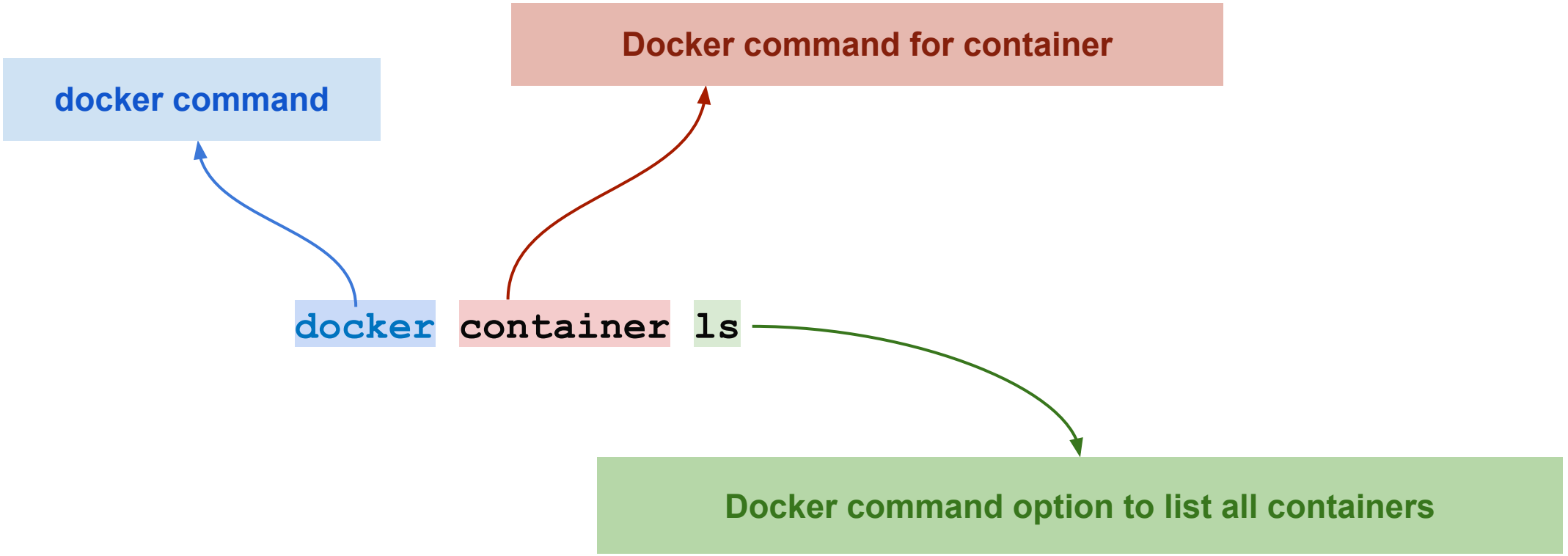
Tutorial: Docker commands

List all docker images



Tutorial: Docker commands

List all running docker containers

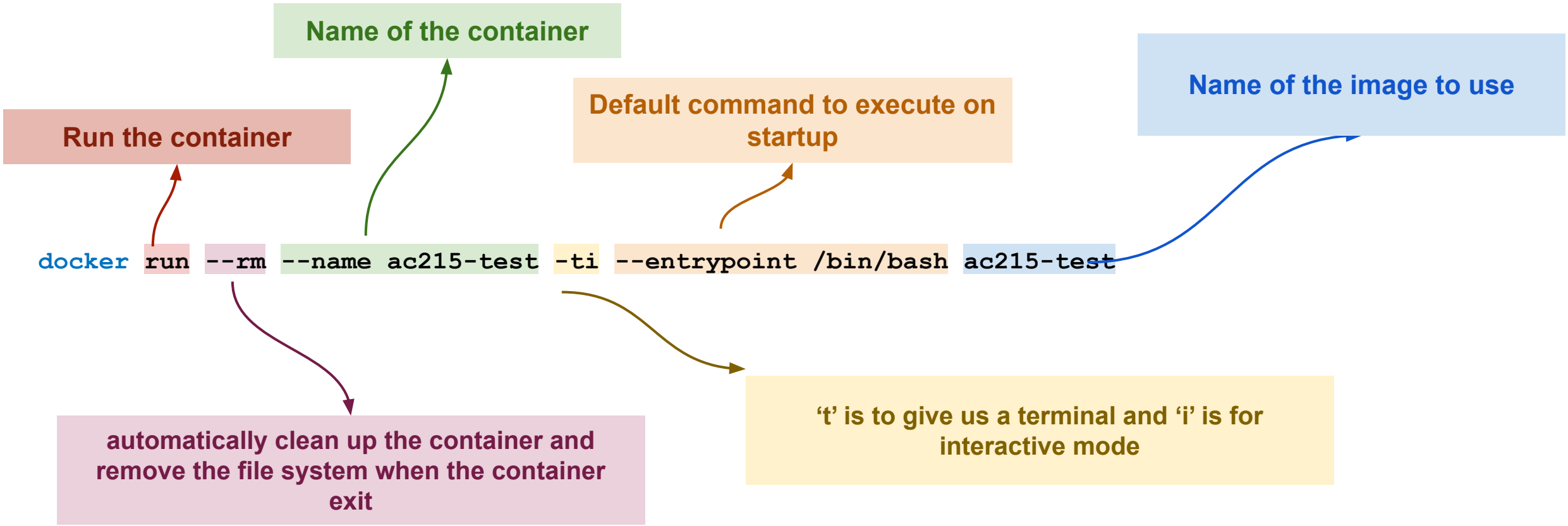


Tutorial: Developing App using Containers

- Let us build the simple-translate app using Docker
- For this we will do the following:
  - Clone or download code (https://github.com/dlops-io/simple-translate)
  - Build a container
  - Run a container

Tutorial: Docker commands

Run a docker container using an image from Docker Hub



Tutorial: Docker commands

Open another command prompt and check how many container and images we have

```
docker container ls
```

```
docker image ls
```

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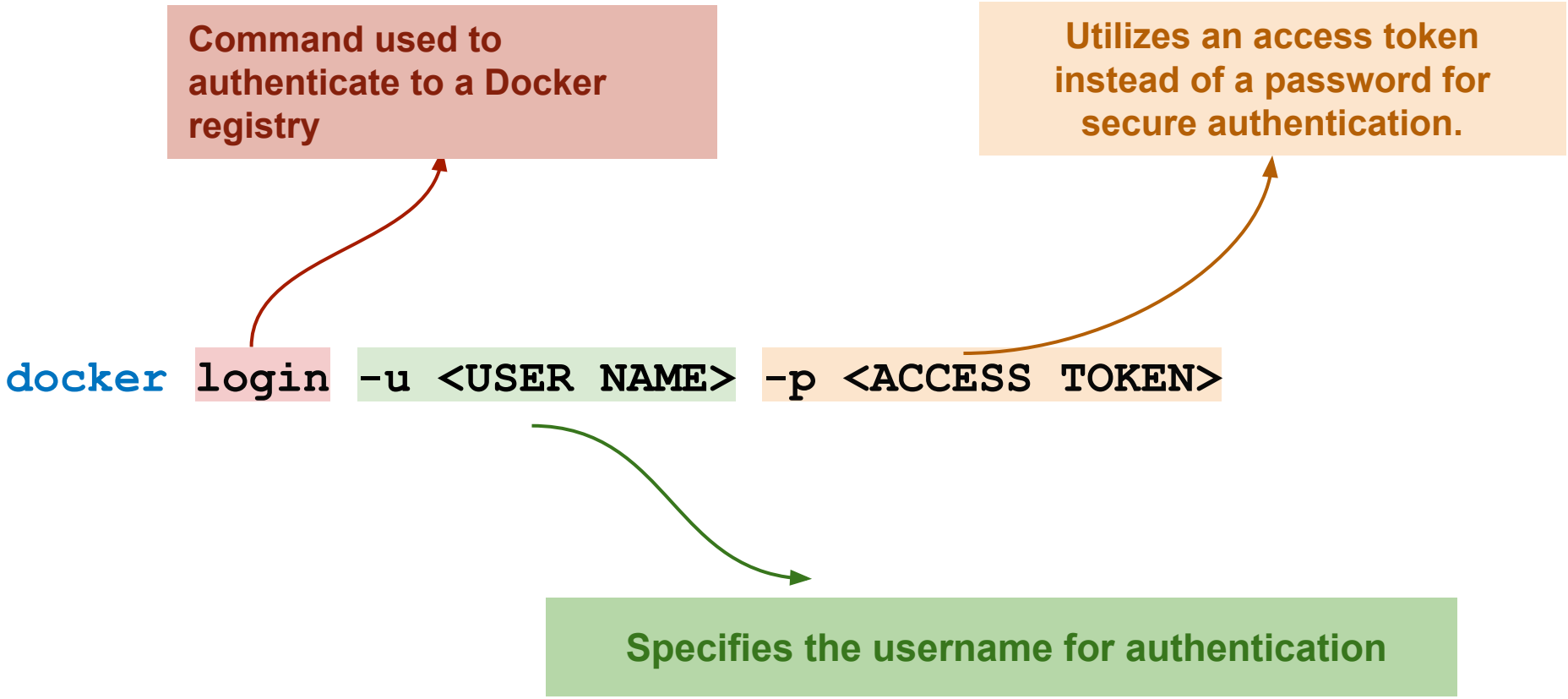
  - Build a container
  - Run a container
  - Push container on Docker Hub

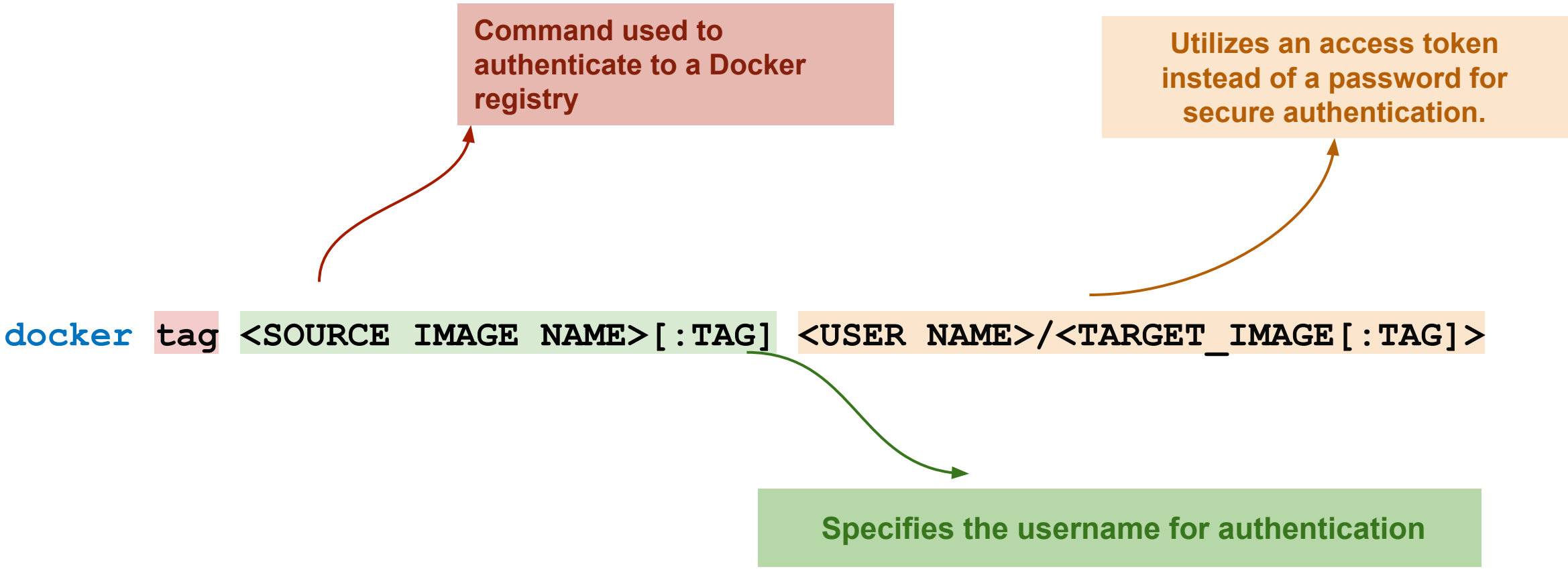
Tutorial: Docker commands

Sign up in Docker Hub and create an Access Token. Use that token to authenticate with the command below



Tutorial: Docker commands

Tag the Docker Image



Tutorial: Docker commands

- Push to Docker Hub

Command used to upload a Docker image from your local machine to a remote registry like Docker Hub

The name of the image you want to push to the registry. User name can be included as part of the name

```
docker push <USER NAME>/<TARGET_IMAGE[:TAG]>
```

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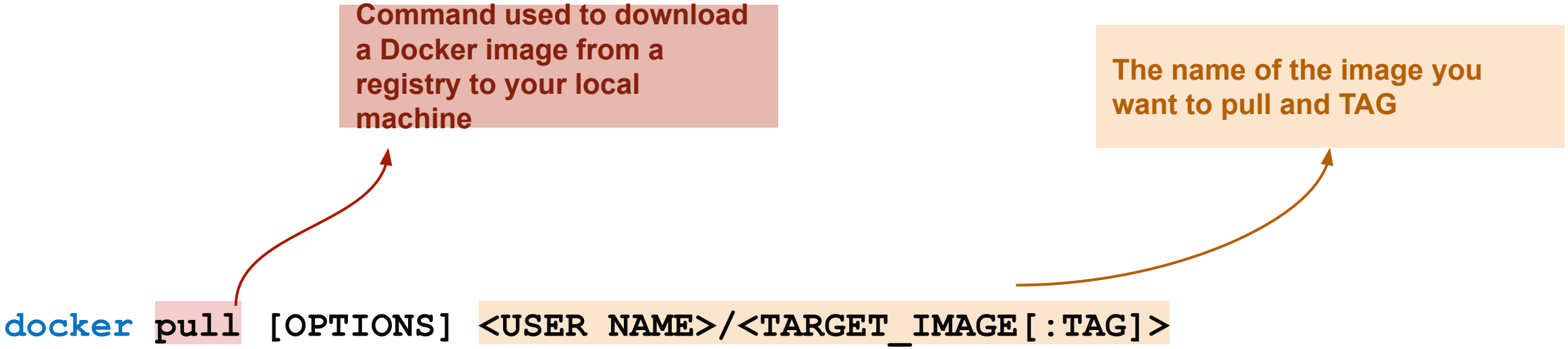
  - Build a container
  - Run a container
  - Push container on Docker Hub
  - Pull the new container and run it

Tutorial: Docker commands

- Pull from Docker Hub



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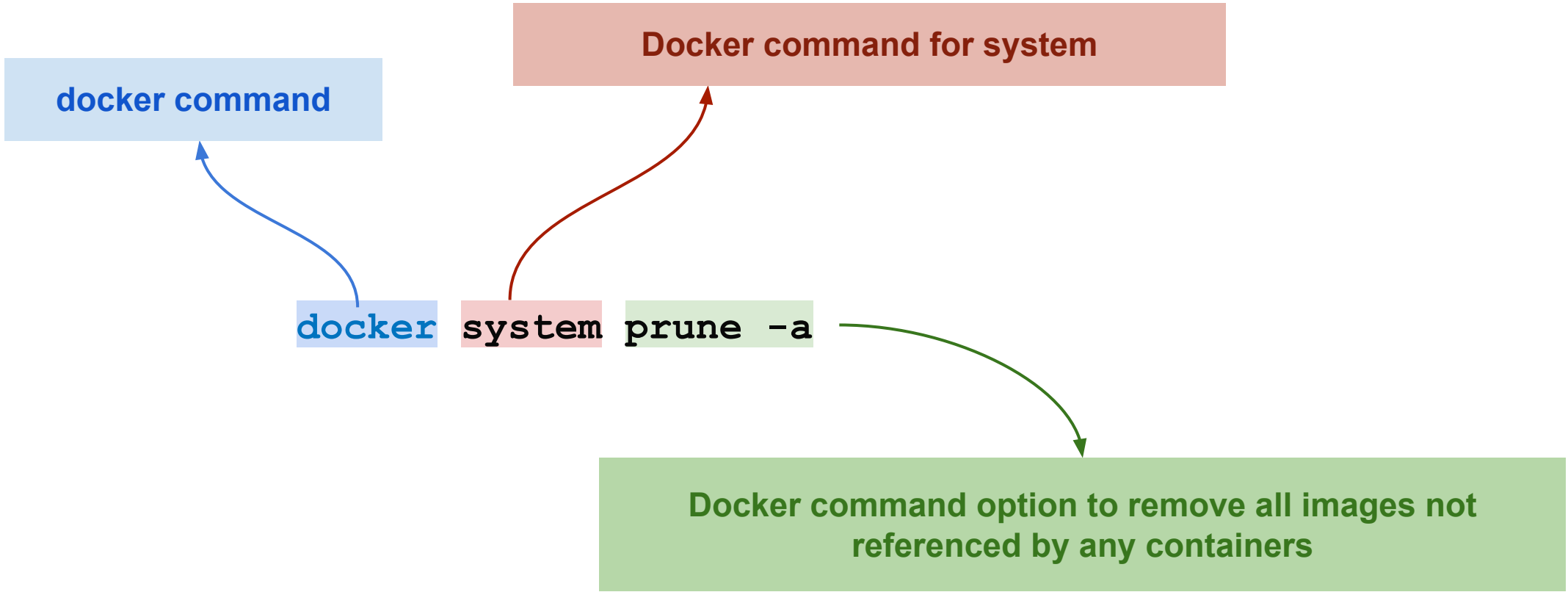
  - Build a container
  - Run a container
  - Push container on Docker Hub
  - Pull the new container and run it
- For detail instruction go here (https://github.com/dlops-io/simple-translate#developing-app-using-containers)

Tutorial: Docker commands

Exit from all containers and let us clear of all images



Tutorial: Docker commands

Check how many containers and images we have currently

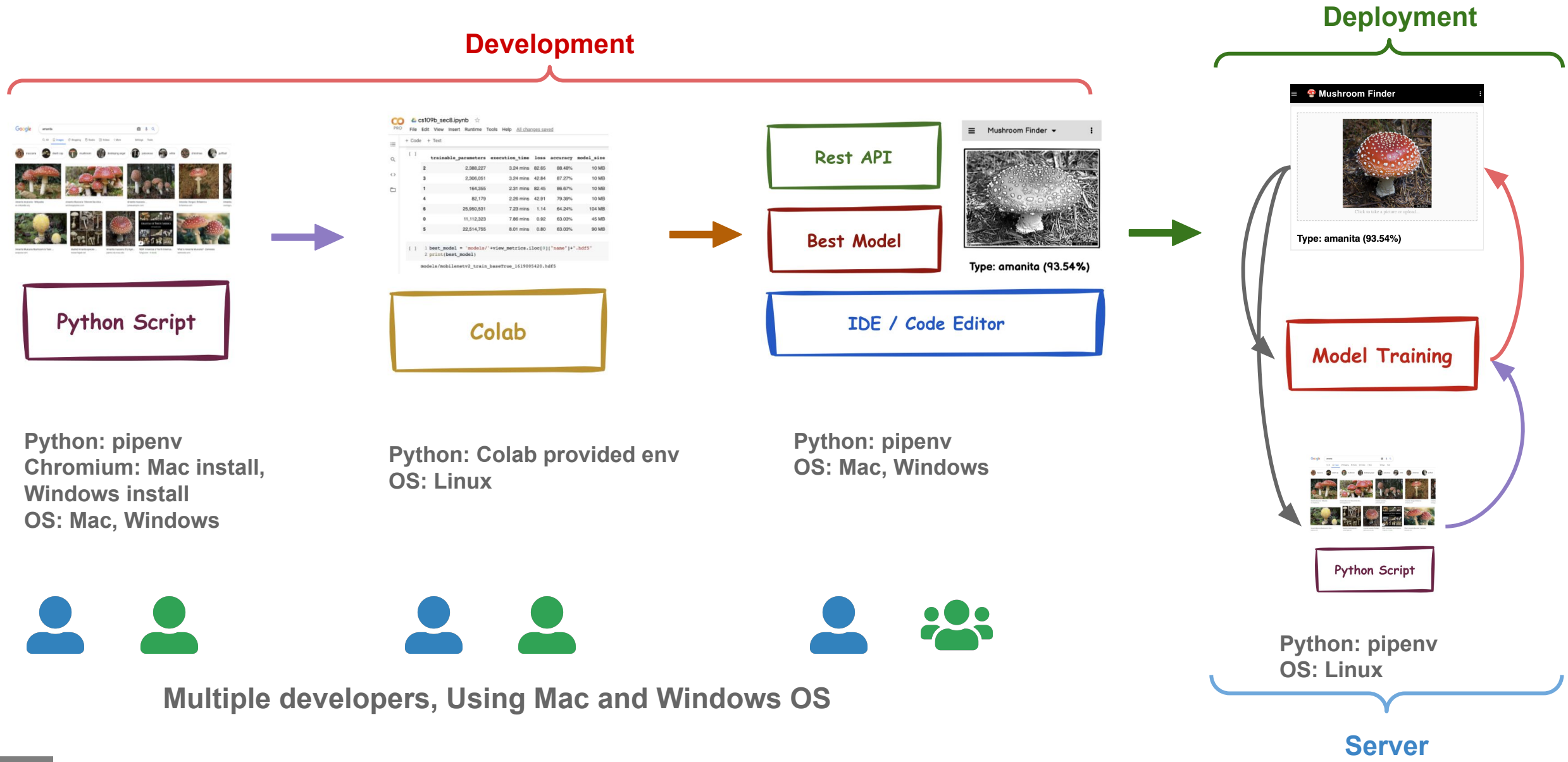
```
docker container ls
```

```
docker image ls
```

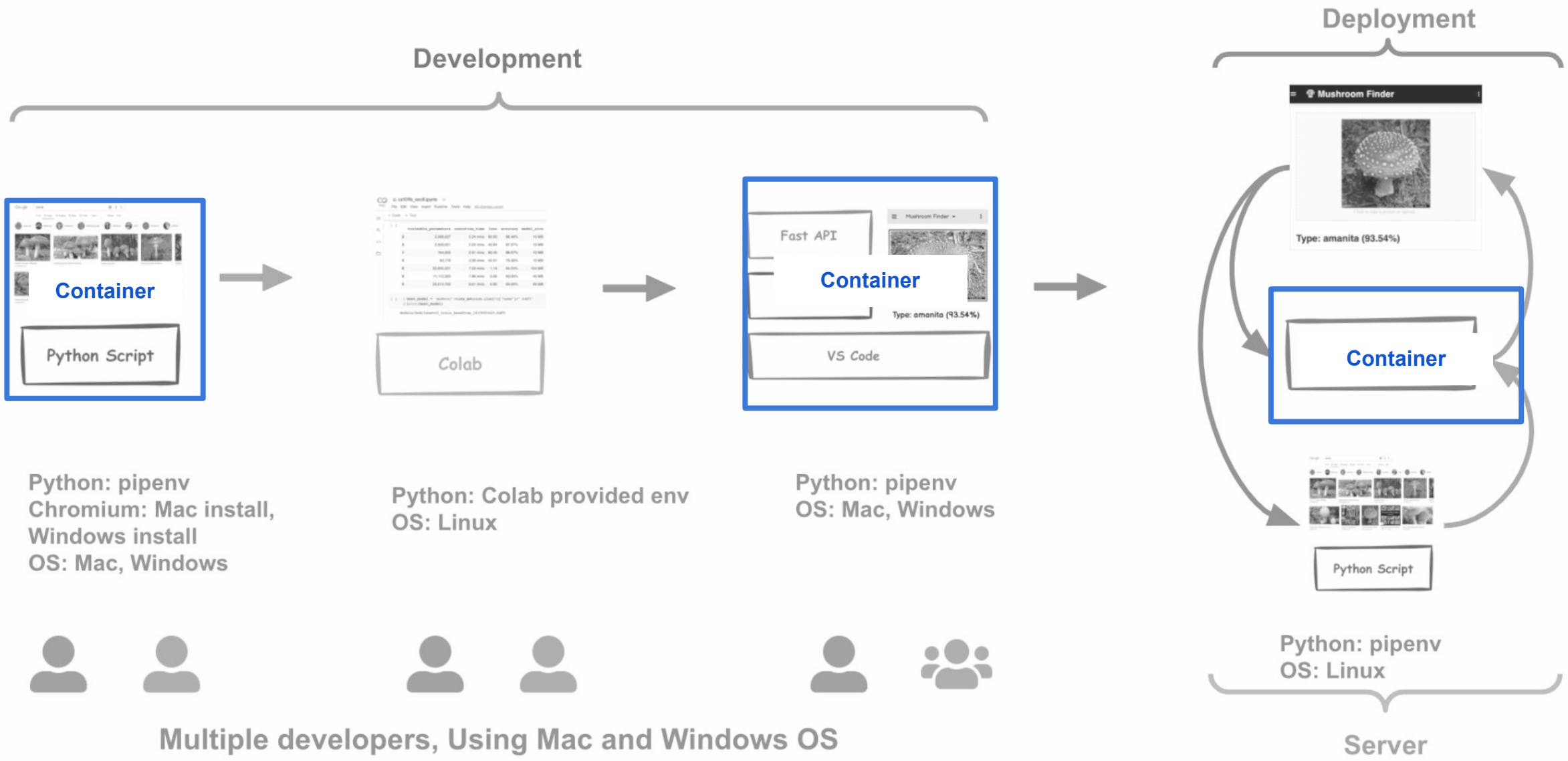
Tutorial: Running App on **VM** using Docker

- Let us run the simple-translate app using Docker
- For this we will do the following:
  - Create a VM Instance
  - SSH into the VM
  - Install Docker inside the VM
  - Run the **containerized simple-translate** app
- Full instructions can be found here (https://github.com/dlops-io/simple-translate#running-app-on-vm-using-docker)

Recap: How do we build an App?



Isolate work into containers



THANK YOU