Robot Perception and Control

Tutorial

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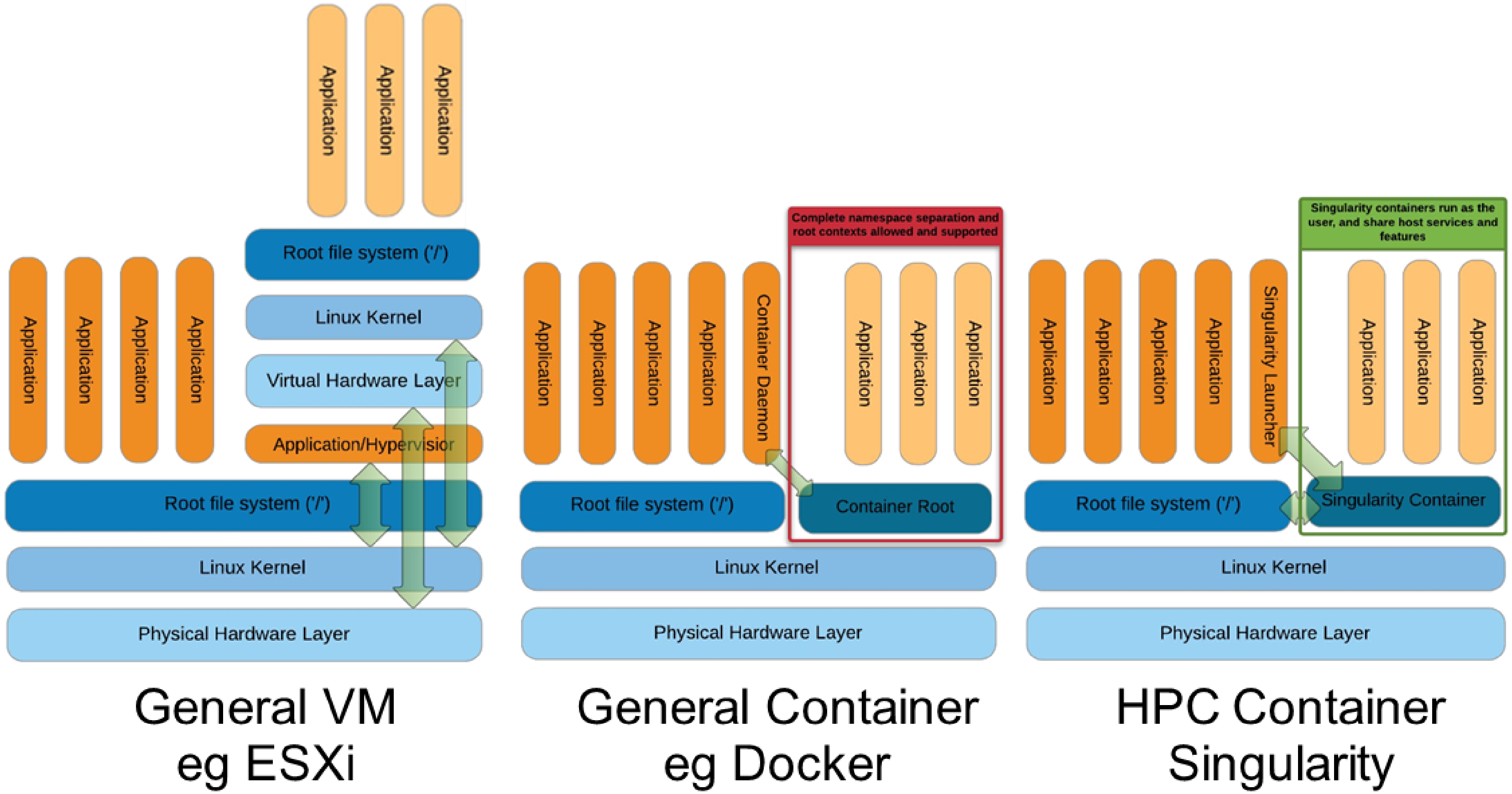
Docker 🐳

Virtual Machine vs Containers

A **Virtual Machine (VM)** virtualizes the underlying hardware by means of a hypervisor, while it provides operating-system-level virtualization. **Containers** are more lightweight than VMs, as they are not emulating hardware.



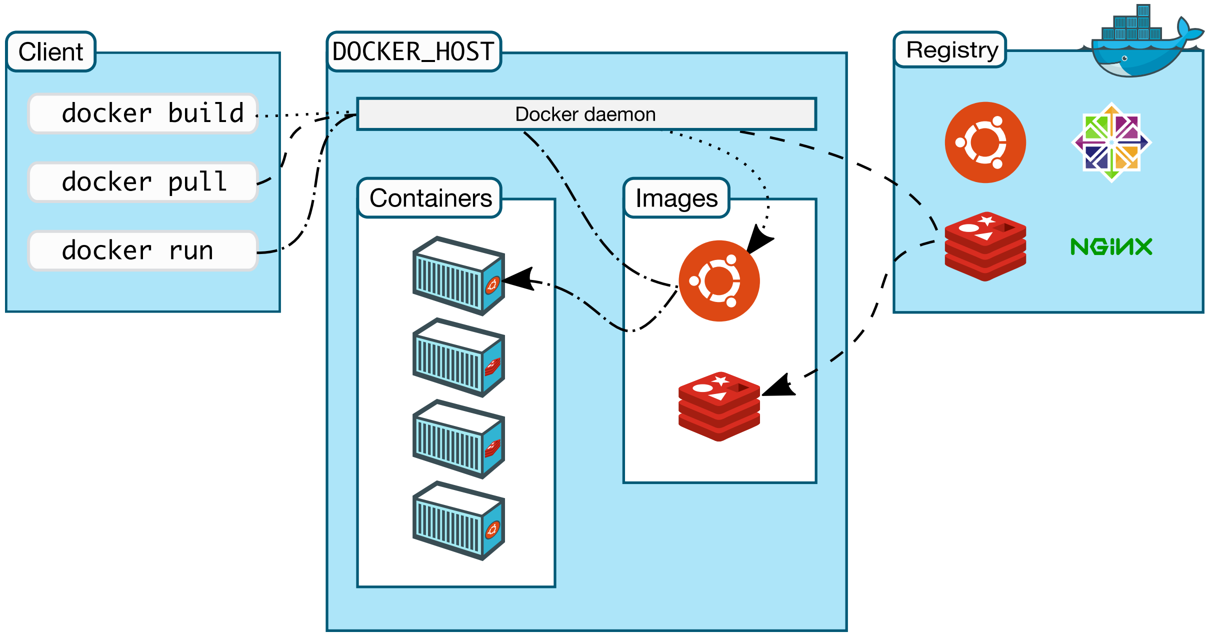
Why Docker?

There are several merits of using Docker.

- We can **share the environment** 😃
  - You can share the Docker Image to help others setup and run your code.
  - **No more repeated setup process on every different machine!**
- We can **improve reproducibility**.
  - The code works even after several years on the Image.
  - No more suffering from messing up your environment after installing some software updates.

> **Note for Mac and Windows**
>
> Docker uses the Linux kernel to manage resources between containers; Docker has to run in a Linux virtual machine for Mac and Windows, which makes some feature fail on Mac and Windows.
> Also the chip architecture needs to be considered (`M1` and `M2`): some has to cross compile `docker buildx build`

Structure of Docker Environment



- **Image**: a template that contains middleware settings or commands needed to launch a container.
- **Container**: a virtual environment created based on a Docker Image where web servers, PyTorch environment, ... run.
- **Registry**: Docker Hub is the place where the Images are published and shared.

Managing Images and Containers

- **List Images:** `docker images`
- **Remove an Image:** `docker rmi <imageID>`
- **Prune an Image:** `docker image prune`
- **Get an Image:** `docker pull`
- **Build an Image:** `docker build -t <imageName> -f Dockerfile .`

- **List Containers:** `docker ps -a`
- **Remove a Container:** `docker rm <containerID>`
- **Start a Container:** `docker run <imageName>`
- **Attach to a running Shell:** `docker exec -it <containerID> bash`

With `docker images` command, you can check `<imageName>` and `<imageID>`.

```
REPOSITORY                   TAG            IMAGE ID        CREATED        SIZE
nvidia/cuda                  8.0-devel      5094464ddfe8    2 weeks ago    1.62 GB
ubuntu                       latest         f49eec89601e    2 weeks ago    129 MB
nvcr.io/nvidia/tensorflow    17.01          4352527009ae    2 weeks ago    2.77 GB
```

Image Name = Repository:Tag

ImageID = Unique Hash

Getting your own Image

You can write a `Dockerfile` to create your own image:

```
# Specify the base image: you can explore docker hub.
FROM pytorch/pytorch:2.0.1-cuda11.7-cudnn8-runtime
# Install dependencies and command-line tools.
RUN apt-get update && apt-get install -y build-essential cmake git wget
# Set the working directory.
WORKDIR /workspace
ENV HOME /workspace
# Pip install python packages.
RUN pip install timm opencv-python
```

Then: `docker build -t <imageName> -f /path/to/Dockerfile .` to build the image.

You can also publish your image on DockerHub by: `docker login && docker push <imageName>`

Running Containers

Docker run Options

- `--rm` remove the container after it exits
- `--gpus` for GPU isolation
- `-i -t` or `-it` interactive, and connect a "tty"
- `-p 5004:8888` map port 8888 on the host to 5004 inside the container
- `-v ~/data:/data` map storage volume from host to container (bind mount) i.e. bind the `~/data` directory in your home directory to `/data` in the container

Starts TensorFlow with ports, volumes, console, and comment (All 1 line):

```
docker run --rm -it --gpus all -p 5004:8888 -v ~/data:/data <imageName>
```

Running GUI Applications with Docker

1. Allow local X11 connections

```
xhost local:root
```

2. Run docker with options

- Intel GPU

```
docker run --device=/dev/dri:/dev/dri -v /tmp/.X11-unix:/tmp/.X11-unix -e DISPLAY
```

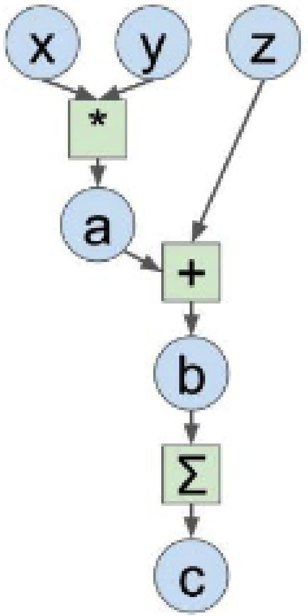
- NVIDIA GPU

```
docker run  --gpus 'all,"capabilities=compute,utility,graphics"' -v /tmp/.X11-unix:/tmp/.X11-unix -e DISPLAY
```

PyTorch 🔥

Computational Graph

Two elements of computational graph: `valuable (blue)` and `operator (green)`.



$$c = \sum_{i}^{B} \sum_{j}^{C} (x_{i,j} \cdot y_{i,j} + z_{i,j})$$

```python
import numpy as np

B, C = 3, 4
x = np.random.randn(B,C)
y = np.random.randn(B,C)
z = np.random.randn(B,C)

# forward pass
a = x * y
b = a + z
c = np.sum(b)

# backward pass (gradient computation)
grad_c = np.ones((1))
grad_b = np.tile(grad_c, b.shape)
grad_a = grad_b.copy()
grad_z = grad_b.copy()
grad_x = grad_a * y
grad_y = grad_a * x
```

```python
import torch

B, C = 3, 4
x = torch.randn(B,C, requires_grad=True)
y = torch.randn(B,C, requires_grad=True)
z = torch.randn(B,C, requires_grad=True)

# forward pass
a = x * y
b = a + z
c = b.sum()

# backward pass (gradient computation)
c.backward()
```

PyTorch implements computational graph with: `tensor` and `function`, which comes with AD for easy gradient computation.

Tensors

Devices

CUDA and CPU

```
device = "cuda" if torch.cuda.is_available() else "cpu"

# move the array to a device
torch_arr = torch_arr.to(device)
print(torch_arr.device)

# move to cuda
torch_arr = torch_arr.to("cuda")
torch_arr = torch_arr.to("cuda:0") # GPU at idx 0
torch_arr = torch_arr.cuda()

# move to cpu
torch_arr = torch_arr.to("cpu")
torch_arr = torch_arr.cpu()
```

NumPy Array to Torch Tensor (CPU)

```
# Numpy to Torch
torch_arr = torch.from_numpy(np_arr) # cpu tensor

# Torch to Numpy
np_arr = torch_arr.cpu().numpy() # first move to cpu
```

Type Checking

```
type(torch_arr.cuda())
# torch.cuda.FloatTensor
type(torch_arr.cpu())
# torch.cpu.FloatTensor
type(np_arr)
# numpy.ndarray
```

Gradients

Optimizers and Loss functions

nn.Module docs ⮭

A neural network model and its components can be represented by a `nn.Module` class.

```
class MLP(nn.Module):
  def __init__(self, ):
    super().__init__() # you have to call this in all child class!
    self.layer1 = nn.Linear(764, 100) # nn.Linear also inherits nn.Module and implements Linear layer (y = w*x + b)
    self.layer2 = nn.Linear(100, 10)

  def forward(self, x): # forward is called in __call__() so that you can run the forward pass just by module(x)
    return self.layer2(F.relu(self.layer(x)))
```

- `__init__`: defines the parts that make up the model (sub-module or parameters)
- `forward`: performs the actual forward computation

PyTorch pre-defines common modules of the modern deep neural networks. See more at basic building blocks ⮭