OST
Eastern Switzerland
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Distributed Systems (DSy)

Containers and VMs

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Learning Goals

- Lecture 7 (Containers and VMs)
  - What is the difference of VM / Container?
  - How does docker work (container implementation)?
    - Best practices
  - What is docker-compose, and how to run multiple services
  - How to use it in your challenge task

Virtualization

- “creation of a virtual machine that acts like a real computer with an operating system” [source]
  - Host machine: machine where the virtualization software runs
  - Guest machine: virtual machine
- Hypervisor runs virtual machines
  - Type 1: bare-metal – e.g., Xen
    - “We built Amazon EC2 using a virtual machine monitor by the name of Xen” [source]
  - Type 2: hosted – e.g., VirtualBox
- Run unmodified OS with Intel VT-x and AMD-V, or paravirtualized if not present
  - E.g., VM should not access memory directly

- Needs to be the same architecture
  - Otherwise use emulation, e.g., QEMU
    - Ubuntu on a RISC-V processor
    - Qemu, opensbi, u-boot
  - Gaming console emulators: Snes9x, Mupen64Plus, Switch
- Virtual desktop infrastructure (VDI)
  - Interact with a virtual machine over a network
- Containers
  - Isolated user-space instances
  - OS support: isolations

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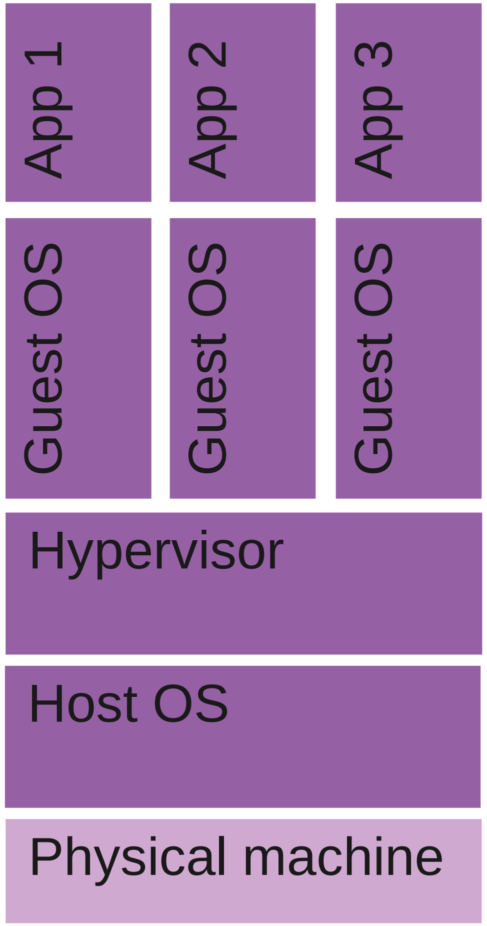
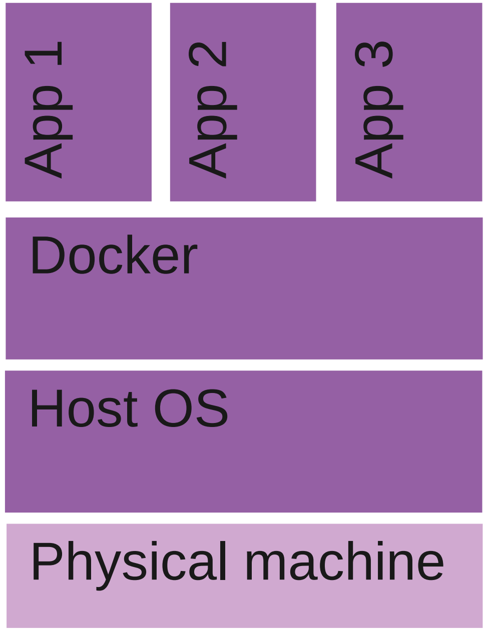
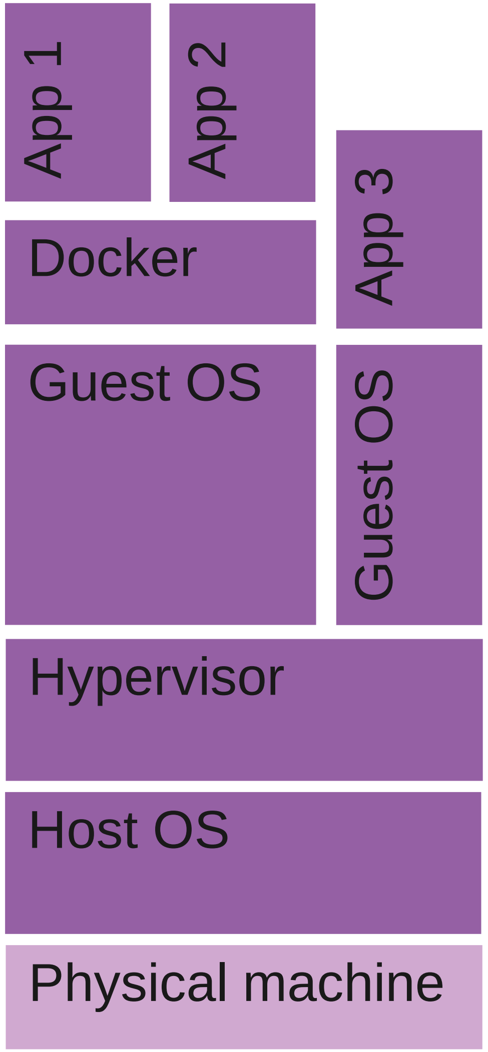
Introduction



- Virtual machines



- Container



- Both

Introduction

- Docker is a containerization platform
- Docker as a software delivery framework
  - Packages software into containers
    - Existing images on Docker Hub
  - Provides OS-level virtualization
  - Containers are isolated from each other
    - Communicate over well-defined channels
  - Docker, Inc is the company behind its tooling
  - Alternatives: Podman
    - Different architecture, docker runs a daemon and you connect via CLI, podman does not [source]
    - Podman supports docker-compose

- OS virtualization (Containers, e.g., Docker) vs virtual machine (VirtualBox) [link]
  - Reduced IT management resources
  - Faster spin ups
  - Smaller size means one physical machine can host many containers
  - Reduced & simplified security updates
  - Less code to transfer, migrate, and upload workloads

Comparison

Container

+ Reduced size of snapshots 2MB vs 45MB

+ Quicker spinning up apps

+ / - Available memory is shared

+ / - Process-based isolation (share same kernel)

Use case: complex application setup, with container less complex configuration

Providers: ECS, Kubernetes Engine, Docker on Azure (or Kubernetes)

Virtual Machine

+ App can access all OS resources

+ Live migrations

+ / - Pre allocates memory

+ / - Full isolation

Use case: better hardware utilization / resource sharing

EC2, Virtual Machines, Compute Engine, Droplets

Market shares

Prices / VM on e.g., AWS

Virtual Machines

- On-Demand
  - Machine
  - Data transfer
  - IP address
- Spot instances (discount when not needed)
- Reserved Instances
- Comparison, comparison, comparison
  - Not easy to compare
  - Optimize for cost → provider changes cost structure, you need to adapt again for optimizing

On-Demand Pricing

Instance Type	AWS	Azure	Google	AWS pricing (per hour)	Azure Pricing (per hour)	Google pricing (per hour)
General purpose	m6g.xlarge	B4MS	e2-standard-4	$0.154	$0.166	$0.134
Compute optimized	c6g.xlarge	F4s v2	c2-standard-4	$0.136	$0.169	$0.208
Memory optimized	r6g.xlarge	E4a v4	m1-ultramem-40	$0.202	$0.252	$6.293
Accelerated computing	p2.xlarge	NC4as T4 v3	a2-highcpu-1g	$0.90	$0.526	$3.678

SIMFORM

https://www.simform.com/blog/compute-pricing-comparison-aws-azure-googlecloud/

	aws	Microsoft Azure	Google Compute Engine
CPUs	1	1	1
RAM	2GB	2GB	3.75GB
Storage	30GB free	16GB	$.02/GB per month
Bandwidth	10GB free	5GB free	$.12/GB per month
Price	$7.00/month	$18.97/month	$15.60/month
	Visit site »	Visit site »	Visit site »

https://www.hostingadvice.com/how-to/aws-azure-google-cloud-alternatives/

Docker Examples

- Install docker [ubuntu, Mac, Windows]
  - `docker run hello-world`
  - Fetches the hello world example from docker hub
  - No version provided – latest
  - Docker Hub: container image repository
    - Community / official
    - Alpine
  - `docker save hello-world -o test.tar`
  - `tar xf test.tar`
  - `tar xf cdccdf50922d90e847e097347de49119be0f17c18b4a2d98da9919fa5884479d/layer.tar`
  - `./hello`

- See your installed images
  - `docker images / docker images -a`
  - `docker rmi hello-world / docker rmi fce289e99eb9`
  - `docker ps -a`
  - `docker rm 913edc5c90c4`
- GUI: e.g., DockStation, other

Details

- Bocker: Docker implemented in around 100 lines of bash
  - Requirements: btrfs-progs, curl, iproute2, iptables, libcgroup-tools, util-linux, coreutils
- FS Virtualization
  - OverlayFS: union filesystem, “combines multiple different underlying mount points into one”
- Dockerfile:
  - docker build . –t test
  - docker run test
  - docker save test:latest > test.tar

```
Dockerfile:

FROM alpine
ADD hello.sh .
CMD ["sh", "hello.sh"]

hello.sh:

#!/bin/sh
echo "Hallo"
```

- 2 Layers
  - Alpine, with BusyBox, 1MB, libc (musl), crypto, ssl, etc.
  - hello.sh
- Add a new layer
  - If input does not change, docker layer is kept - cached

OverlayFS

- Example
  - The lower directory can be read-only or could be an overlay itself
  - The upper directory is normally writable
  - The workdir is used to prepare files as they are switched between the layers.

```
cd /tmp
mkdir lower upper workdir overlay

sudo mount -t overlay -o \
lowerdir=/tmp/lower,\
upperdir=/tmp/upper,\
workdir=/tmp/workdir \
none /tmp/overlay
```

- Read only
- How to remove data in read-only lowerdir
  - Mark as deleted in upperdir

```
cd /tmp
mkdir lower upper workdir overlay

sudo mount -t overlay -o
lowerdir=/tmp/lower1:/tmp/lower2 /tmp/overlay
```

```
cd /tmp
mkdir lower upper workdir overlay

sudo mount -t overlay -o \
lowerdir=/tmp/lower1:/tmp/lower2,\
upperdir=/tmp/upper,\
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none /tmp/overlay
```

Cgroups

- control groups: limits, isolates, prioritization of CPU, memory, disk I/O, network

```
ls /sys/fs/cgroup

sudo apt install cgroup-tools / yay -S libcgroup

cgcreate -g cpu:red
cgcreate -g cpu:blue

echo -n "20" > /sys/fs/cgroup/blue/cpu.weight
echo -n "80" > /sys/fs/cgroup/red/cpu.weight

cgexec -g cpu:blue bash
cgexec -g cpu:red bash

sha256sum /dev/urandom #does not work?
taskset -c 0 sha256sum /dev/urandom
```

- Install tools
- Create two groups
  - Assign 20% of CPU and 80% of CPU
- Execute bash → test CPU
- Resource control with docker

```
docker run \
--name=low_prio \
--cpuset-cpus=0 \
--cpu-shares=20 \
alpine sha256sum /dev/urandom

docker run \
--name=high_prio \
--cpuset-cpus=0 \
--cpu-shares=80 \
alpine sha256sum /dev/urandom
```

Separate Networks

- Linux Network Namespaces
  - provide isolation of the system resources associated with networking [source]

```
ip netns add testnet
ip netns list
```

  - Create virtual ethernet connection

```
ip link add veth0 type veth peer name veth1 netns testnet
ip link list #?
ip netns exec testnet <cmd>
```

  - Configure network

```
ip addr add 10.1.1.1/24 dev veth0
ip netns exec testnet ip addr add 10.1.1.2/24 dev veth1
ip netns exec testnet ip link set dev veth1 up
```

- Run server

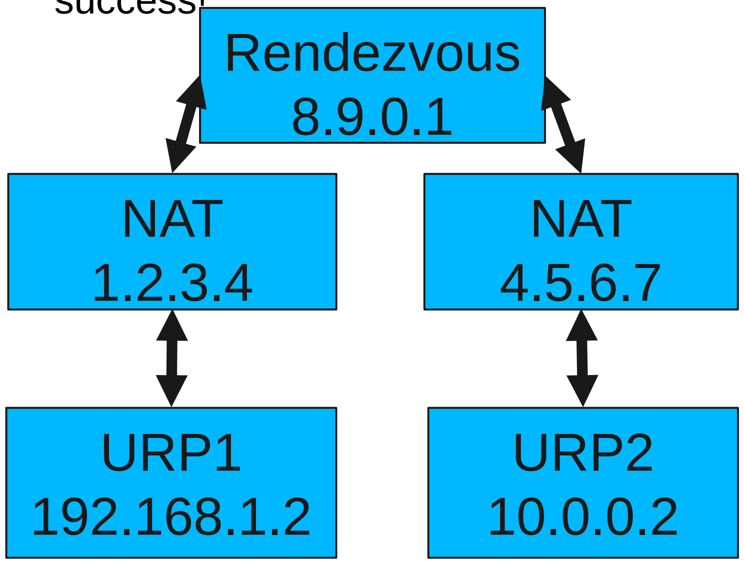
```
ip netns exec blue nc -l 8000
```

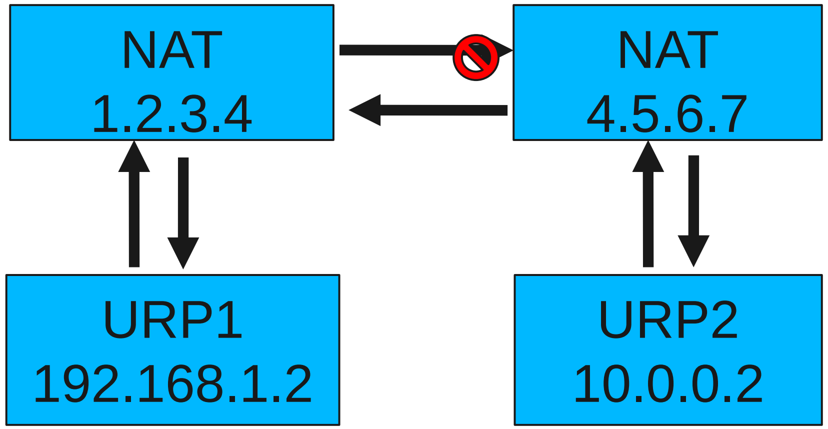
- Server can be contacted
- How to connect to outside?
  - E.g. layer 3

```
iptables -t nat -A POSTROUTING -s 10.1.1.0/24 -o enp9s0 -j MASQUERADE
iptables -A FORWARD -j ACCEPT #open up wide…
```

Connectivity, Security, and Robustness

- Hole punching
  - URP1 got 4.5.6.7:5000, URP2 got 1.2.3.4:4000
  - Unreachable peer 1 request to NAT 4.5.6.7, will fail – no mapping, however, unreachable peer 1 creates mapping with that request
  - Unreachable peer 2 sends request to unreachable peer 1 (1.2.3.4:4000)
    success!





Mapping for NAT 1.2.3.4 (Unreachable peer 1)			
192.168.1.2:4000	4.5.6.7:5000	4.5.6.7:5000	1.2.3.4:4000

Mapping for NAT 4.5.6.7 (Unreachable peer 2)			
10.0.0.2:5000	1.2.3.4:4000	1.2.3.4:4000	4.5.6.7:5000

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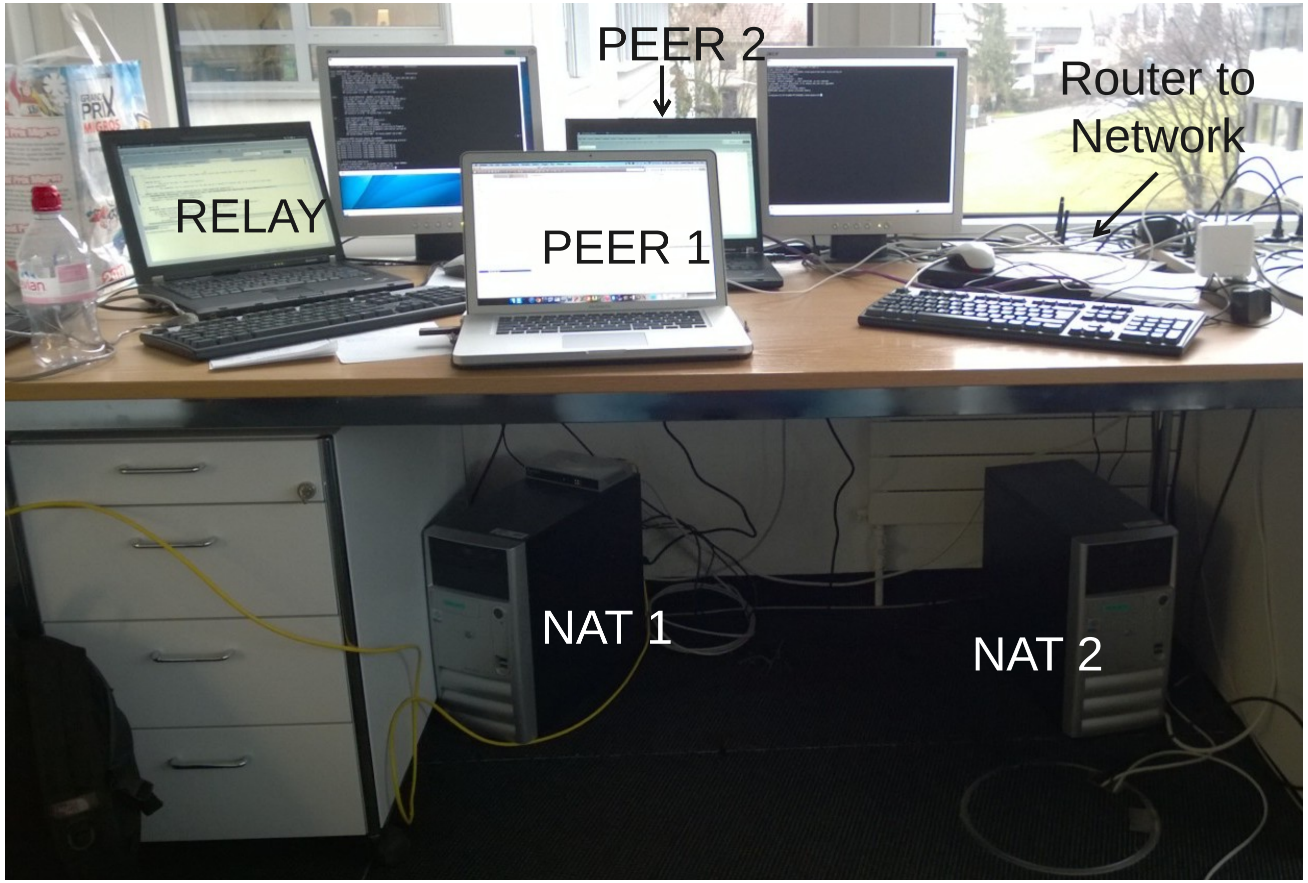
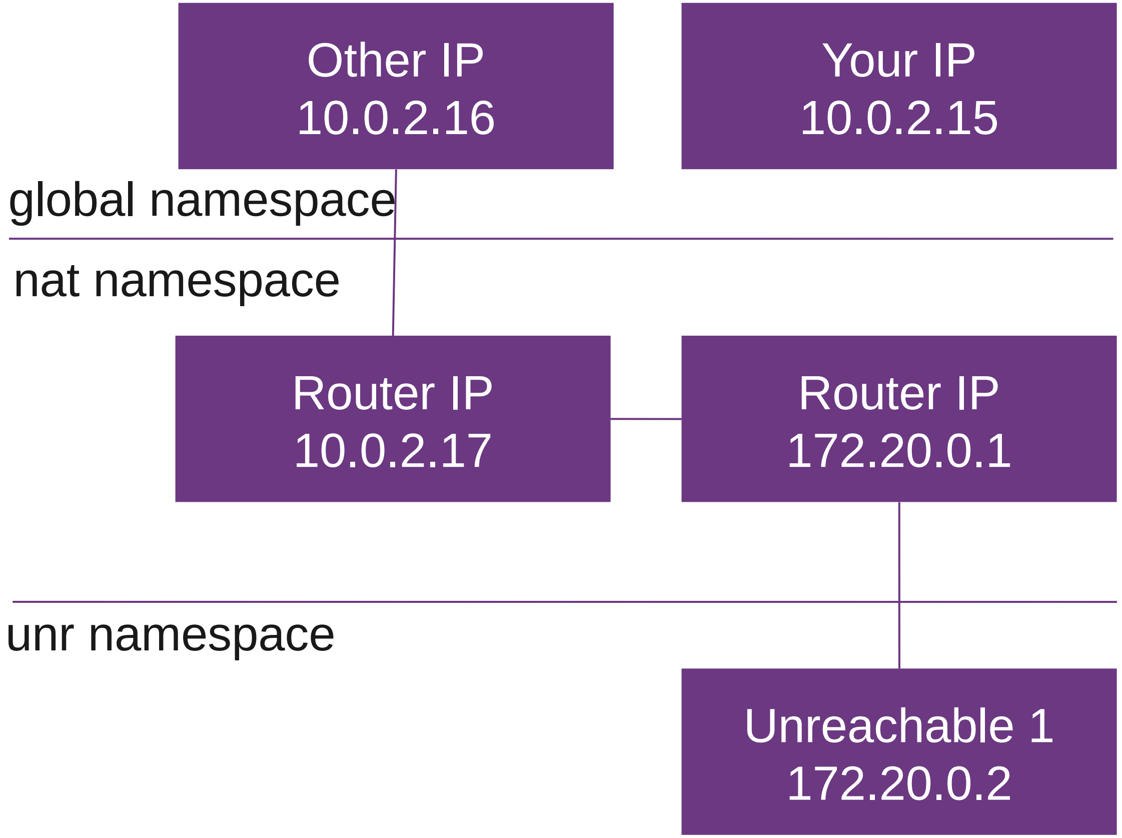
Connectivity, Security, and Robustness

- P2P / Hole Punching Development (in the old days)
- Currently: network namespaces (since Linux 2.6.24)



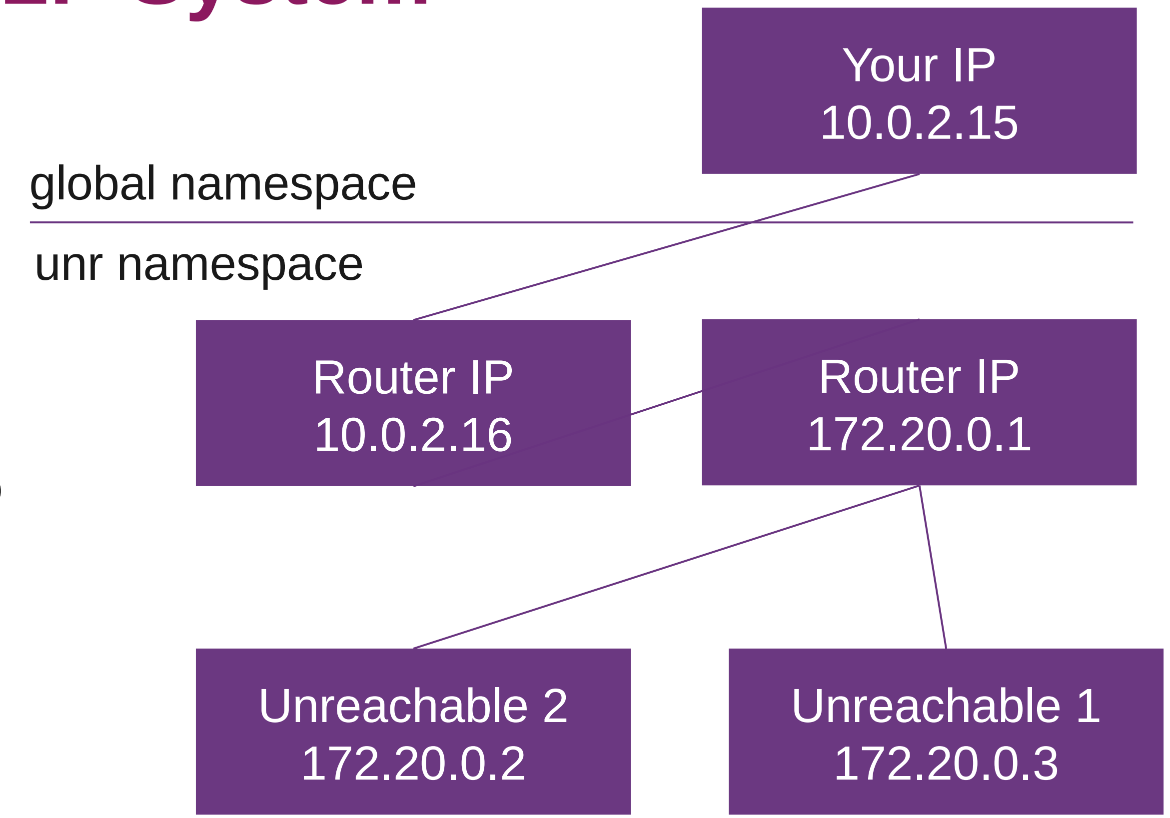
Make your own Testbed for P2P System

- veth - Virtual Ethernet Device
  - Tunnels between network namespaces
  - `ip netns add unr / ip netns list`
  - `ip link add nat_lan type veth peer name nat_wan`
  - `ip link set nat_lan netns unr`
  - `ip address add 10.0.2.16/24 dev nat_wan`
  - `ip link set nat_wan up`
    - ifconfig / ping
  - `ip netns exec unr ip address add 172.20.0.1/24 dev nat_lan`
  - `ip netns exec unr ip link set nat_lan up`



Make your own Testbed for P2P System

- Setup 2 unreachable peers
  - `ip netns exec unr ip link add unr1 type dummy`
  - `ip netns exec unr ip address add 172.20.0.2/24 dev unr1`
  - `ip netns exec unr ip link set unr1 up`
    - `ip netns exec unr ifconfig`
  - `ip netns exec unr ip link set lo up`
  - `ip netns exec unr route add default gw 172.20.0.1`
  - `ip route add 172.20.0.1 dev nat_wan`



Docker Compose

- Docker Compose to deploy multiple containers
  - E.g, load balancer, services, DB
  - Configure your services
  - Lightweight orchestration
    - Start service depending on others (e.g., Postgres)

```
#docker-compose.yml
version: '3'
services:
  server1:
    build: .
  client:
    image: alpine
    command: >
      sh -c "sleep 3 && echo hallo | nc server1 8081"
```

- Dockerfile
  - Build your binary with a Dockerfile - example
  - Create our own image with a Dockerfile
    - keep images small
  - Multi-stage builds, copy required files
  - Remove cache, as docker is caching aggressively

```
#Dockerfile
FROM golang:alpine AS builder
WORKDIR /build
COPY server.go .
RUN go build server.go

FROM alpine
WORKDIR /app
COPY --from=builder /build/server .
CMD ["./server"]
```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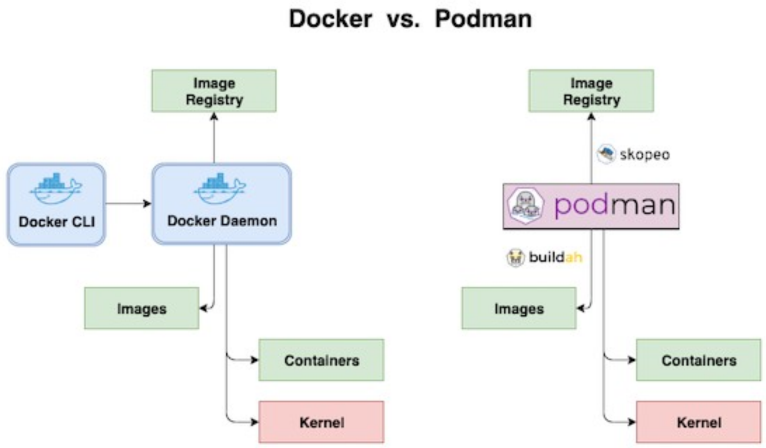
Docker Security

- Best practices [link]
  - Keep images small, up to date / attack surface
  - Use tiny runtimes – alpine / distroless, avoid big images Ubuntu/Arch/Debian/Fedora
    - My preference alpine (switched from distroless to alpine due to convenience)
  - Check your image for vulnerabilities, snyk, clair
  - Do not expose the Docker daemon socket (even to the containers)
    - Well, traefik?
  - Set a user – do not run as root
    - Needs a bit more configuration, but good advice
  - Limit capabilities (Grant only specific capabilities, needed by a container)
    - Seems overkill
  - Disable inter-container communication
    - Ok in prod mode, not in dev mode
  - Limit resources (memory, CPU, file descriptors, processes, restarts)
    - Good for production → docker does not have a hard memory limit. Docker kills process that goes over limit, no pressure for GC if not docker aware
  - Set filesystem and volumes to read-only
    - Very good advice

Docker Security

- Lint the Dockerfile at build time
  - Use an IDE
- Run Docker in root-less mode
  - Architectur better suited for root-less: podman [link] [intro] → no daemon → systemd
- Set the logging level to at least INFO
  - Logging practices



- Think of Your Audience
- Use Logging Libraries
- Use a Suitable Log Level
  - TRACE level: this is a code smell if used in production. This should be used during development to track bugs
  - DEBUG level: log at this level about anything that happens in the program.
  - INFO level: log at this level all actions that are user-driven, or system specific (timers)
  - NOTICE level: this will certainly be the level at which the program will run when in production.

Logging

  - WARN level: log at this level all events that could potentially become an error.
  - ERROR level: log every error condition at this level.
  - FATAL level: too bad, it's doomsday.
- Set the log level per environment. The DEV environment can run in the level DEBUG, the LOCAL environment in the level TRACE, while TEST/STAGE and PROD should run with the level INFO.
- Use Meaningful Messages

- Log in JSON – structured logging
  - Keep the Log Structure Consistent
- Avoid Logging Sensitive Information
  - **Never ever log sensitive data in non local environments. Only do this temporarily in local environments**
- Secret management
  - Use SaaS solutions / e.g., github secrets. Cloud-based: HashiCorp Vault, AWS Secrets Manager or the GCP Secret Manager, or simplified: git secret [link], [link], [link]