ICT academy

Linux Containers

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Linux containers, 19. 12.2023

08:30 – 09:15

- Introduction to Linux Containers

09:15 – 12:00

- LXC

12:00 – 13:00

- Lunch

13:00 – 15:30

- LXD

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AVTORSKE PRAVICE GRADIVA

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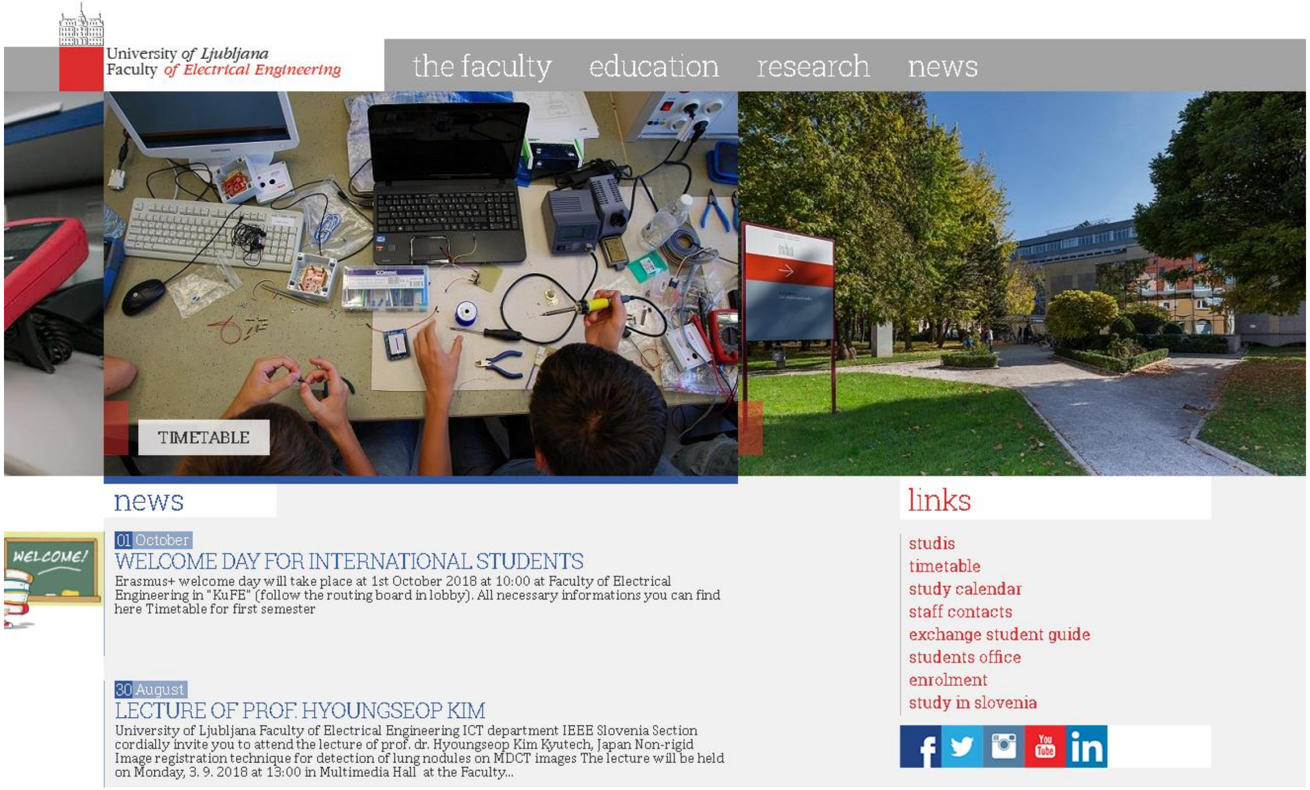

2.200+ študentov

300+ raziskovalcev in akademskega osebja

50 % sredstev pridobljenih na trgu

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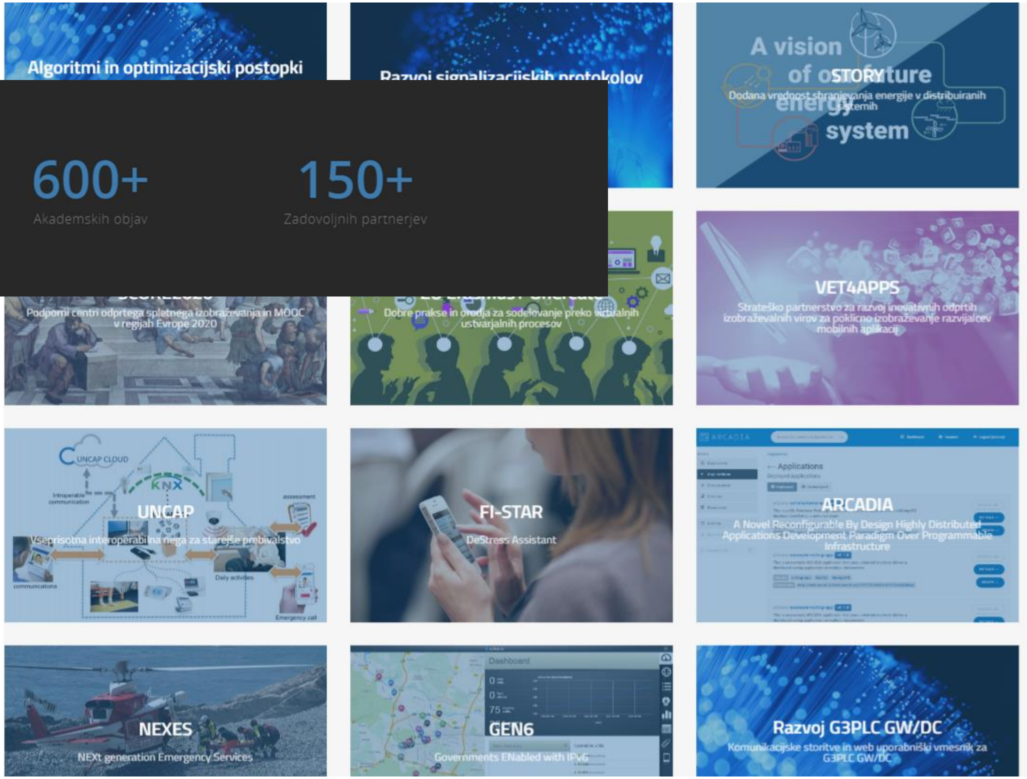

50+	100+	600+	150+
Sodelavcev	Projektov	Akademskih objav	Zadovoljnih partnerjev

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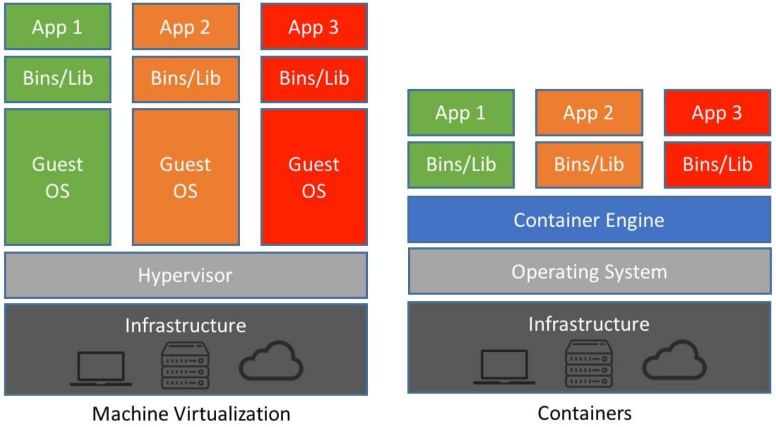
Introduction to Linux Containers

Containerization vs traditional virtualization

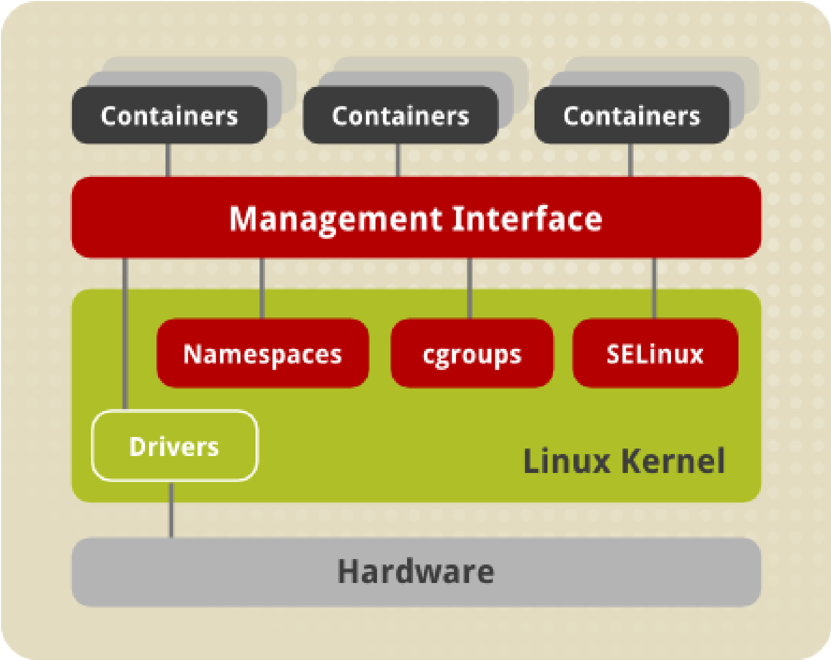
- **Virtualization** uses hypervisors to run multiple virtual machines on a single host, each with its own isolated operating system.
  - Virtual machines are heavy, slow, resource-intensive, and less flexible.
- **Containerization** uses user space and process isolations to run multiple containers on a single host, each with its own application environment.
  - Containers are **lightweight**, fast, resource-efficient, and portable



Source: https://www.netapp.com/blog/containers-vs-vms/

Introduction to Containers

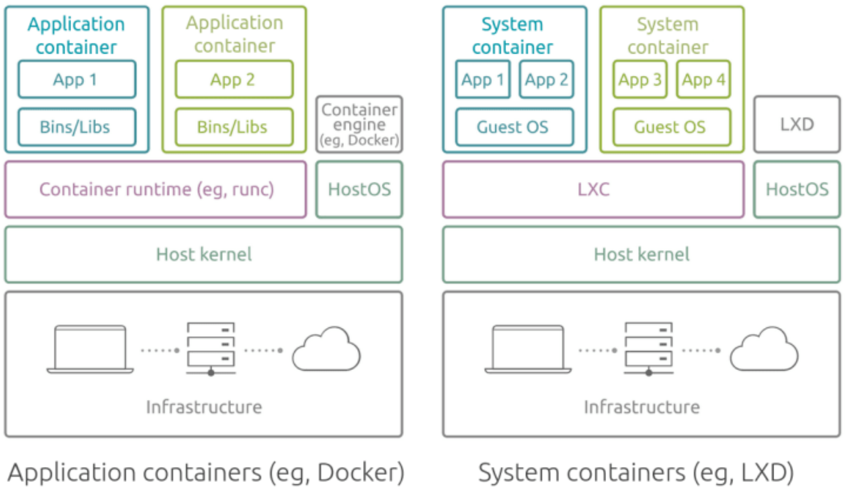
- Containers can **virtualize** both the operating system and the application level
- Containers can **isolate** and package applications with their dependencies
- Containers are **portable** and lightweight, and can run on any host
- Containers can **optimize** resource utilization and scale easily
- Containers can **facilitate** development, test, and production workflows



Source: https://access.redhat.com/documentation/en-us/red_hat_enterprise_linux_atomic_host/7/html/overview_of_containers_in_red_hat_systems/introduction_to_linux_containers

What types of containers are there?

- A **container** is a single operating system image that runs isolated applications and their dependent resources on a host machine.
- There are two types of containers: **operating system level** and **application level**.
- **Operating system level containers** run a full operating system and can host multiple applications. They are long-lasting and similar to virtual machines. An example is LXD.
- **Application level containers run a single process** or service and are stateless and ephemeral. They are lightweight and easy to create and delete. An example is Docker.
- Both types of containers **share the kernel with the host** operating system and create isolated processes.



Source: https://ubuntu.com/blog/lxd-vs-docker

Container History

Container technology has a **long history** in different operating systems, but became popular in Linux with kernel support. **System containers are the oldest type of containers**, and they run a second operating system on the same kernel as the host.

Some of the milestones in container history are:

- 1982: Chroot (Unix-like operating systems)
- 1999: BSD introduced jails, a way of running a second BSD system on the same kernel as the main system.
- 2001: Linux implementation of the concept through Linux vServer.
- 2004: Solaris (Sun Solaris, Open Solaris) grew Zones which was the same concept but a part of Solaris OS.
- 2005: OpenVZ project started to implement multiple VPSs (virtual private servers) on Linux.
- 2008: LXC (Linux)
- 2013: Docker (Linux, FreeBSD, Windows)

LXC and linuxcontainers.org

- LXC is the first system container technology based on mainline Linux features.
- LXC can create both system containers and application containers with a low-level interface.
- LXC containers are similar to chroot, but with more isolation and flexibility.
- LXC containers run a standard Linux installation on the same kernel as the host, with no virtualization overhead.
- linuxcontainers.org is the umbrella project for various Linux container technologies.
- linuxcontainers.org aims to provide a distro and vendor neutral environment for container development.
- linuxcontainers.org offers both containers and virtual machines that run full Linux systems.

When should you use Linux containers?

- Anytime when you're running Linux on Linux, you should be considering using containers instead of virtual machines.
- For almost any use case, you could run the exact same workload in a system container and not get any of the overhead that you usually get when using virtual machines.
- The only exception would be if you needed a specific version of the kernel different from the kernel of the host, for a specific feature of that virtual machine.
- System containers are much easier to manage than virtual machines.

What is LXD?

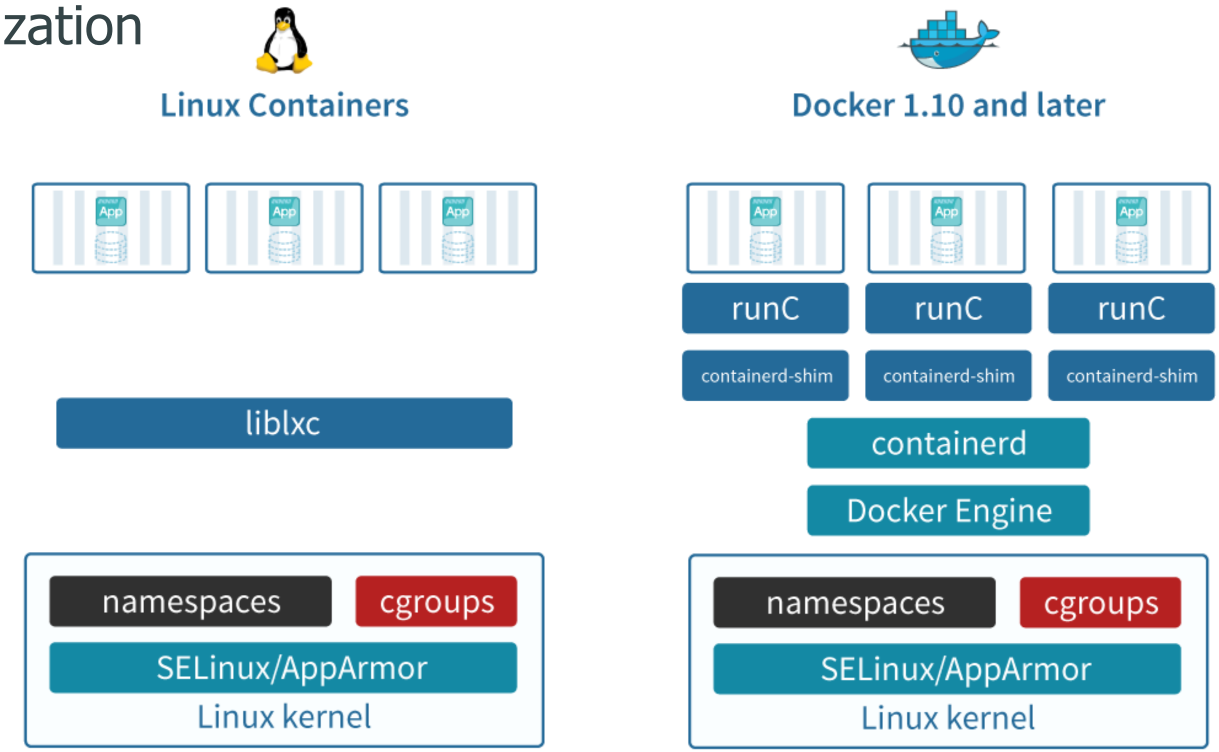
- **LXD is a system container and a virtual machine manager** that runs on top of LXC, enhancing the experience and enabling easier control and maintenance.

- Benefits:
  - System container and virtual machine manager built on top of LXC, enabling easier management, control and integration
  - Supports container and VMs
  - Better user experience through a simple REST API

LXD

Docker vs Linux Containers

- Host-Machine Utilization
- Simplicity
- Tooling
- Use Cases



Source: https://www.techdivision.com/aktuelles/blog/lxc-vs-docker-wir-setzen-bei-techdivision-inzwischen-verstaerkt-auf-lxc

Features to Enable Containers

A look under the hood

Containerization (LXC)

is based on **limiting** and **isolating** processes.

Linux uses two key technologies to achieve this:

- Control groups (cgroups)

- "resource management / limiting"

- Namespaces (ns)

- "process isolation / virtual resources"

Both of these technologies are part of the modern Linux kernel, while their userland tooling is typically installed separately.

Containerization (LXC)

LXC and LXD packages only provide high-level abstraction / tools to efficiently configure and manage containers, ran by OS and enabled by the kernel’s features.

Under the hood, cgroups and namespaces do most of the work in combination with other features enabling modern containers:

- **efficient filesystems with volume managers** (snapshots, cow, …)
- security mechanisms, such as:
    - **seccomp** (limiting system calls)
    - **linux capabilities** (limiting root permissions)

Control groups (cgroups)

Introduced by Google in 2007, enter mainline in 2008 => LXC

Cgroups enable **resource management**:
- allocate, prioritize, deny, manage, and monitor
- CPU time, system memory, network bandwidth, etc.

Core idea: group processes (tasks) and apply group resource limits

Use in LXC / Docker: container resource limits
- prevent monopolizing host system resources
- performance optimization in shared environments

Control groups (cgroups)

Under the hood, cgroups make use of **kernel resource controllers**:

- **io** (set input/output limits/shares on resources)
- **memory** (set memory use limits and reporting)
- **pids** (limit number of processes and their children)
- rdma (set Remote DMA / InfiniBand resource limits)
- **cpu** (adjust scheduler parameters e.g., Completely Fair Scheduler)
- **cpuset** (restrict available cpu and memory nodes)
- perf_event (performance monitoring and reporting)

Under the hood => cpu controller integrates with linux scheduler (cpu time)
memory controller integrates with kernel memory manager

Control groups (cgroups)

We don’t need LXC and LXD to create and manage cgroups:

- interaction via filesystem interface **/sys/fs/cgroup/**
  - in UNIX ”everything is a file”, pseudo-filesystem
- using userland tools e.g. **cgroup-tools, cgutils, libcgroup**

```
ls -lh /sys/fs/cgroup
```

```
-r--r--r--  1 root root 0 Dec 12 16:38 cgroup.controllers
-rw-r--r--  1 root root 0 Dec 12 16:38 cgroup.max.depth
-rw-r--r--  1 root root 0 Dec 12 16:38 cgroup.max.descendants
-rw-r--r--  1 root root 0 Dec 12 16:38 cgroup.pressure
-rw-r--r--  1 root root 0 Dec 12 16:38 cgroup.procs
-r--r--r--  1 root root 0 Dec 12 16:38 cgroup.stat
-rw-r--r--  1 root root 0 Dec 12 16:38 cgroup.subtree_control
-rw-r--r--  1 root root 0 Dec 12 16:38 cgroup.threads
```

Control groups (cgroups)

We don’t need LXC and LXD to create and manage cgroups:

We can now view or modify maximum allowed cgroup memory using standard file operations:

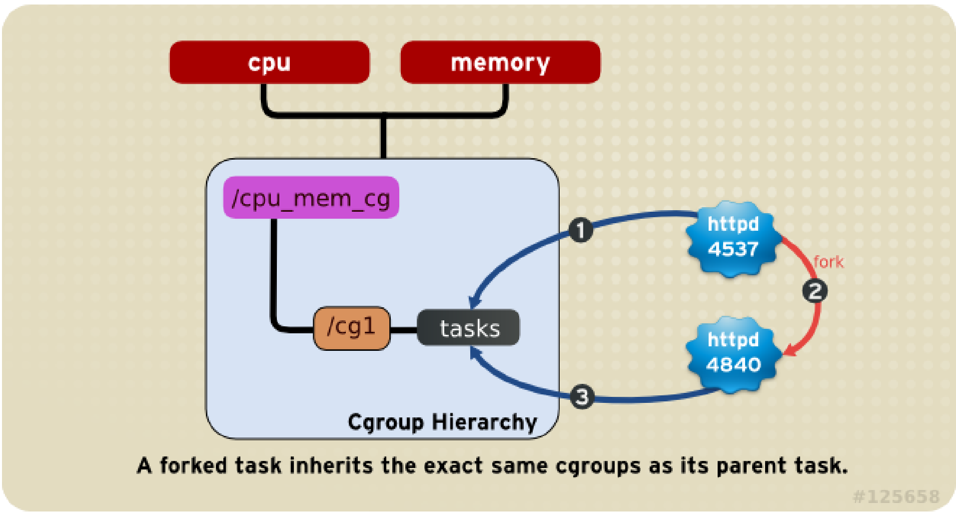
```
# get max memory
cat /sys/fs/cgroup/mygroup/memory.max # result in bytes
# add PID 1234 to group
echo 1234 >> /sys/fs/cgroup/mygroup/cgroup.procs
```

Linux uses inotify to monitor for fs changes and apply resource controller policies in real-time.

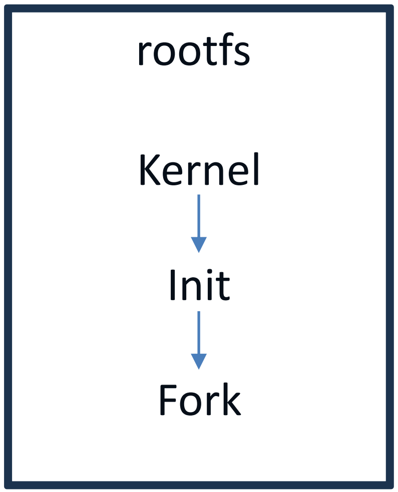
Control groups (cgroups)

Towards containers

cgroups hierarchies follow a set of rules – child task automatically inherits cgroup membership of its parent, but can be moved



Container



Namespaces

enable **resource and process isolation** and allow for the partitioning of various aspects of the operating system, so that each set of processes sees its own isolated instance of the global resource.

Namespaces provide **virtual environments for processes**, isolating them from other processes and resources. Environments / namespace types:

- **Mount**: CLONE_NEWNS - Mount points
- **Network**: CLONE_NEWNET - Network devices, stacks, firewall, routing tables, etc.
- **User**: CLONE_NEWUSER - User and group IDs
- **PID**: CLONE_NEWPID - Process IDs
- **UTS**: CLONE_NEWUTS - Hostname and NIS domain name
- **IPC**: CLONE_NEWIPC - System V IPC, POSIX message queues
- **Cgroup**: CLONE_NEWCGROUP - Cgroup root directory

Namespaces

Towards containers

Mount namespace (chroot / pivot_root)

PID Namespace (remapping process IDs)

parallels@ubuntu: ~

```
root@my-first-debian:/# ps aux | grep nano
root         168  0.0  0.1   7620  4608 pts/5    S+   17:16   0:00 nano matej.txt
root         176  0.0  0.0   6332  2048 pts/6    S+   17:18   0:00 grep nano
root@my-first-debian:/#
```

parallels@ubuntu: ~

```
parallels@ubuntu:~$ ps aux | grep nano
root      142191  0.0  0.1   7620  4608 ?        S+   18:16   0:00 nano matej.txt
paralle+  142338  0.0  0.0   9076  2560 pts/3    S+   18:17   0:00 grep --color=auto nano
parallels@ubuntu:~$
```

Namespaces

Towards containers

Network namespace

```
sudo ip netns add mynetns # add a network namespace
```

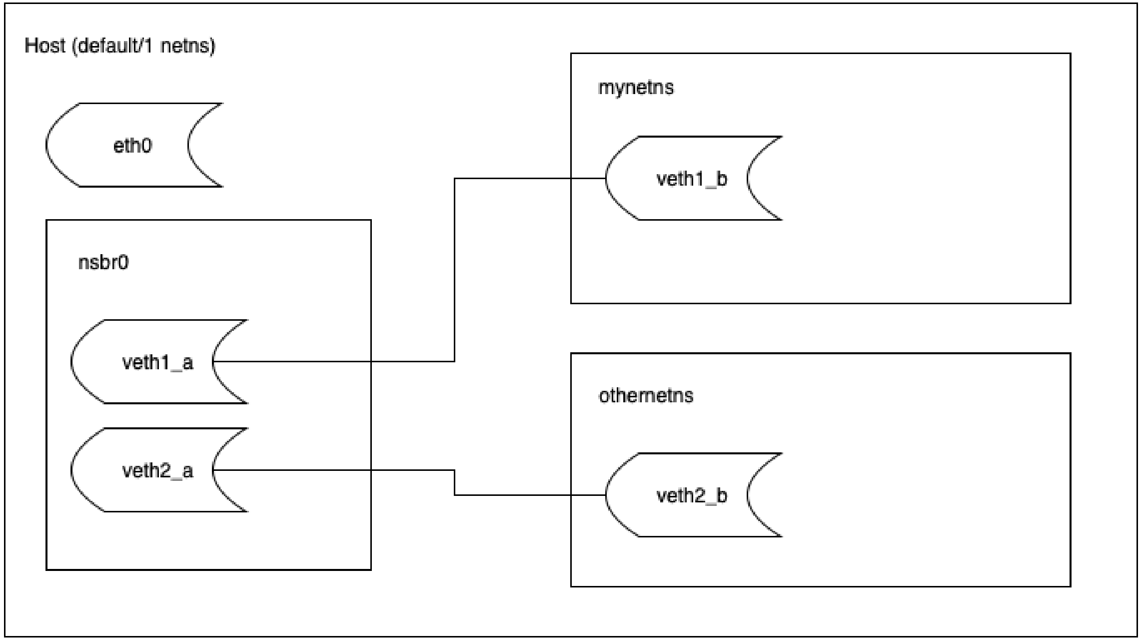
.... configure new IP, routes, etc. inside mynetns ....

```
sudo ip netns exec mynetns bash
ping 1.1.1.1
```

Namespaces

Towards containers

Network namespace



Creating containers

We can now add a **rootfs (root filesystem)** of a desired guest operating system and combine the described mechanisms to start a new container:

1. Creating isolated namespaces.
    - e.g., isolating the filesystem similar to chroot, creating new netns with independent networking stack, etc.
2. Applying resource limits with cgroups.
    - e.g., setting cpu and memmory limits, throttling network interfaces, etc.
3. Implementing security measures with capabilities.
    - e.g., allow creating sockets, define container "privilege" level (more on that later)
4. Starting an init process within the container.
    - init assumes PID 1 inside the container PID ns and starts userspace environment, the init system may differ from the one used by the host (e.g., sysvinit vs systemd)

Securing containers

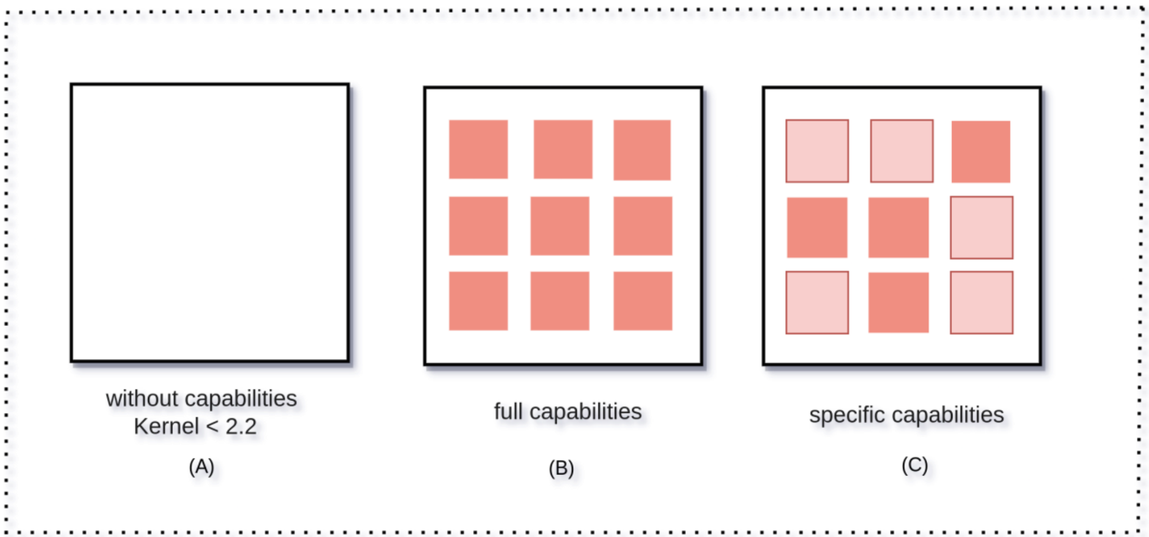
Additionally, we can implement security mechanisms to further limit the contained processes.

Traditional linux security controls are based on filesystem permissions and **users** and **groups** (e.g., root can do everything).

Since we may need to run some containers as root (e.g., to access a host device), we need to limit what other actions this container can do.

We can use **Linux capabilities** mechanism
to further subdivide “unlimited” permission transfer
from root user to root-owned process.

Securing containers



Example:

+ add CAP_SYS_RAWIO to access IO devices

- remove CAP_NET_BIND to prevent network port binding

That’s it!

Thank you!

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