Practical course: Advanced System Programming

# Containers

https://dse.in.tum.de/

Jörg Thalheim

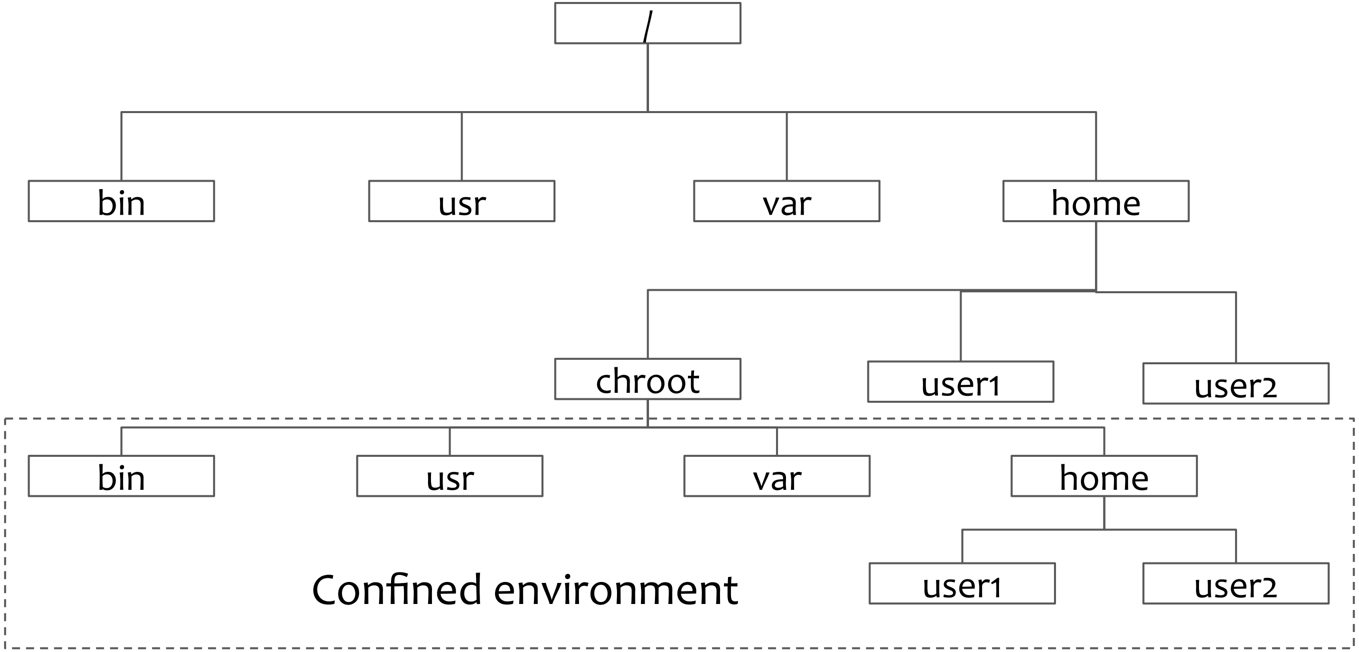
# OS-Virtualisation

- Resource isolation only enforced in software - the operating system
    - Granularity:  Process level
    - Only one OS unlike hardware virtualisation
    - Flexible resource sharing between processes
- Present in all general purpose operating system:

| |
|---|
| *Unix*<br>“chroot” |

# Chroot: Origins of Containers

- **Ch**ange **R**oot -> makes a subdirectory the new root of a process
- syscall: chroot()
- Useful to contain unprivileged processes (i.e. postfix mail demon, sshd)
- Root users can easily undo this



# OS-Virtualisation

- Resource isolation only enforced in software - the operating system
  - Granularity: Process level
  - Only one OS unlike hardware virtualisation
  - Flexible resource sharing between processes

Our focus

- Present in all general purpose operating system:

*Unix*
"chroot"

macOS
"Sandbox Apps"

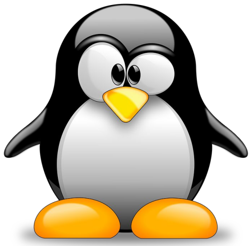
Solaris
"Zones"

Linux
"Containers"

Windows:
"Process
Isolation"

FreeBSD
"Jails"

# OS-Virtualisation on Linux: Container

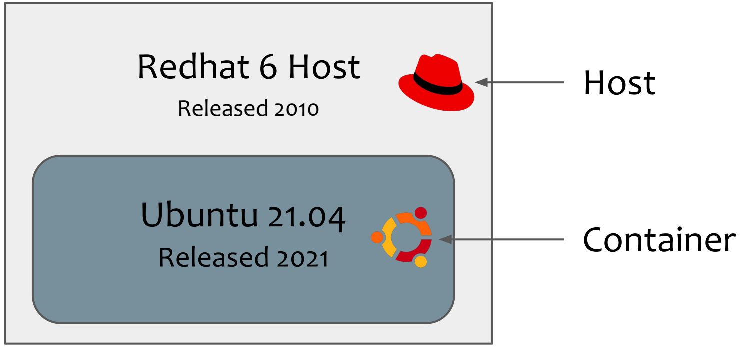


Why did it became so popular on Linux?

- (Very) stable syscall interface
  - Kernel devs: “Don't Break Userspace”

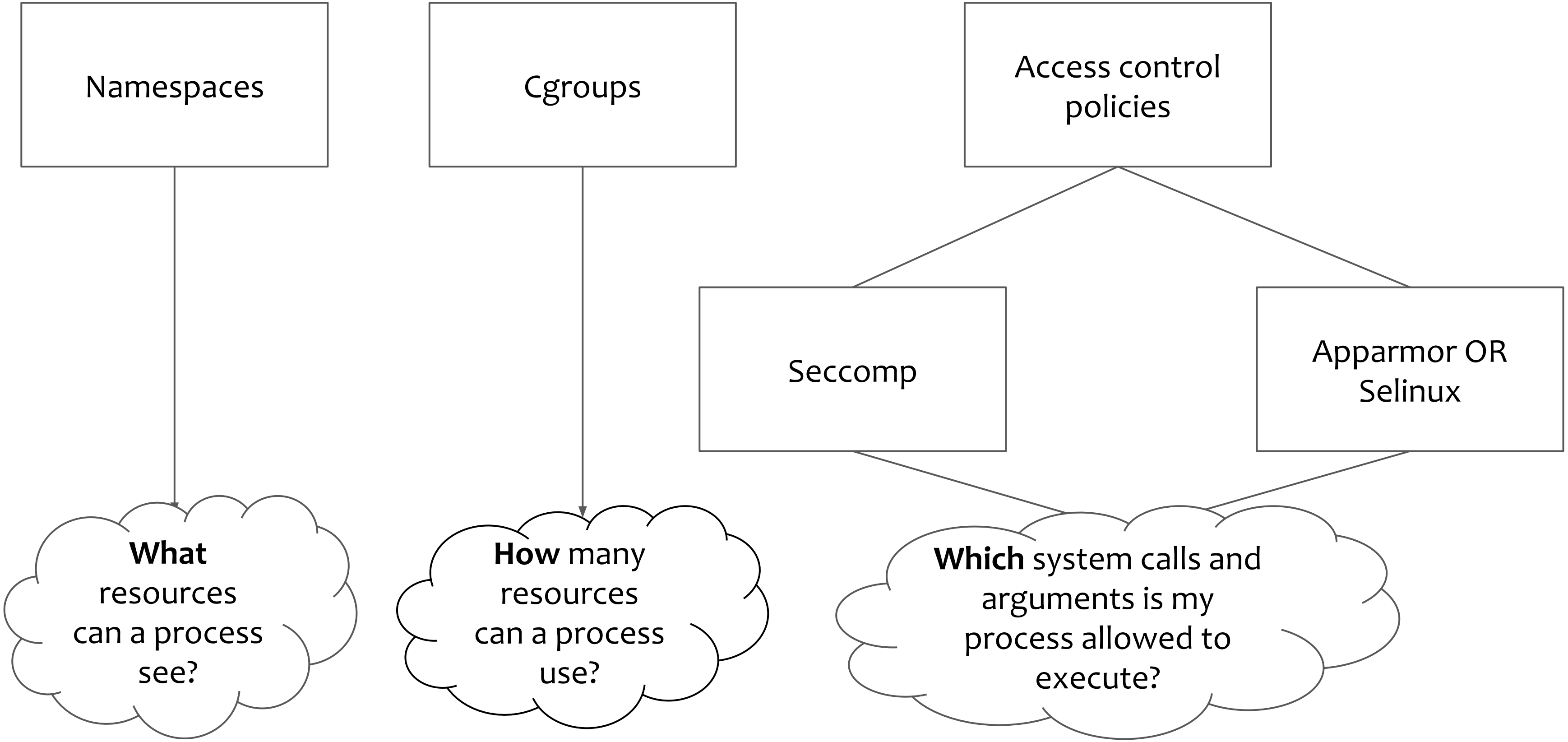
  -> libc can be replaced & distributed independently (unlike i.e. FreeBSD jails)

- Convenient application packaging & distribution: Docker -> Kubernetes:
  - Less dependency hell & rollbacks



# Linux APIs

# Linux APIs



Namespaces
Cgroups
Access control policies
Seccomp
Apparmor OR Selinux
What resources can a process see?
How many resources can a process use?
Which system calls and arguments is my process allowed to execute?

# Namespaces

- Control visibility of kernel resources (mounts, network interfaces, time etc)
- System calls and kernel subsystems needs to be aware of namespaces:
  - Stored in process context: task_struct->nsproxy
- Pid 1 (init process) starts with initial namespace
- Children inherit namespace from their parents

| **Create namespace** | **Switch namespace** | **Inspect namespace** |
| --- | --- | --- |
| System call: *unshare()* or *clone()*<br>Example: $ docker run | System call: *setns()*<br>Example: $ docker exec | Interface: /proc/self/ns<br>Example: $ ls -la /proc/self/ns |

See “man namespaces” for further information (well written)

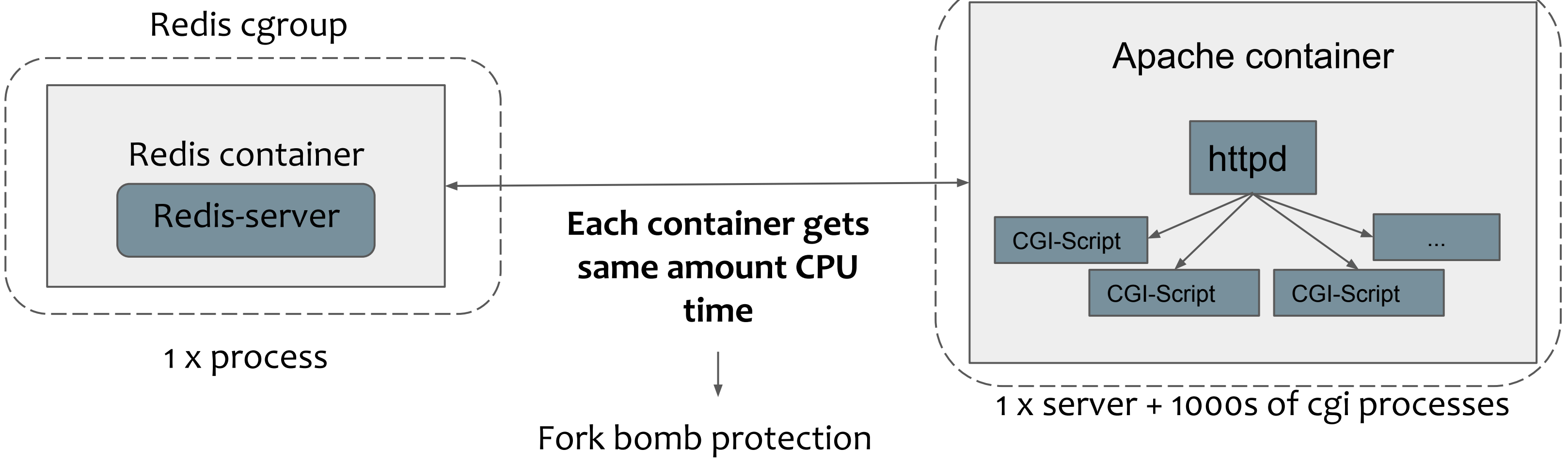
# Namespaces types

- 8 namespaces so far, but list is growing:
  - Cgroup, IPC, Network, Mount, PID, Time, User, UTS

| Mount namespace | PID | Network namespaces | User namespaces |
|---|---|---|---|
| • Isolates mountpoints seen in a namespace<br>• Useful in combination with chroot | • Isolates what processes are visible<br>• Allows containers to have their own Init process (Pid1) | • Own routing table and set of network interfaces and firewall<br>• Often combined with veth-interfaces to provide virtual ethernet interfaces | • Allows to remap a user / group ids to different ranges<br>• Important for unprivileged containers (rootless), i.e.<br>  ○ Uid 1000 on the host becomes uid 0 (root uid) in the namespace |

# Cgroup

- Hierarchical resource groups:
  - Child inherits cgroup from parent
  - 9 different subsystems for different purposes
- Limits how much resources processes
  - Cpu schedule slices
  - Memory limits
  - Block I/O weight
  - Freeze processes (freezer)



# Cgroup

- Also reliable process tracking:
  - SystemD/Docker puts each service/container in a cgroup
  - Member's of cgroup == all childs belonging to service/container

- Major API change: Cgroup v1 -> Cgroup V2
  - unified cgroup instead of separated by subsystem

- Interface through a filesystem: /sys/fs/cgroup/ (in this example cgroup v2)

| **Create cgroup** | **Join a cgroup** | **See current cgroup membership** |
| --- | --- | --- |
| $ mkdir /sys/fs/cgroup/foo | $ echo $PID > /sys/fs/cgroup/foo/cgroup.procs | $ cat /proc/self/cgroup |

# Seccomp/Capabilities/MAC

- **Goal:** restrict (root) user further by restricting system calls it can execute
- Capabilities
  - More granular permissions instead of privileged  vs unprivileged processes
  - Examples:
    - CAP_CHOWN: change uid/gid of arbitrary files
    - CAP_NET_ADMIN: network configuration
- Seccomp/seccomp-ebpf
  - Filter programs that prevent system calls based on arguments
  - Example: disallow chown() with setuid bit set.
- MAC:
  - Application firewall: More complex policies/profiles to allow/disallow what files/resources
  - Two major implementations: apparmor or selinux

# Implementations

# Overview over implementations (1/2 )

- “System” container engines (runs multiple services like a VM)
  - Systemd-nspawn, lxc/lxd, Openvz, …

LXD

OpenVZ

systemd

- Application sandboxes, special purpose container engines
  - Bubblewrap, snap, chromium sandbox
  - Singularity (High performance Computing)

snapcraft

# Overview over implementations (2/2)

- "Application" container engines (one container per service)
  - **O**pen **C**ontainer **I**nitiative: Mostly standardized images/runtime
  - Docker, Podman, Containerd, …
- Cluster manager:
  - Schedule container over multiple hosts
  - make use of the underlying container engine

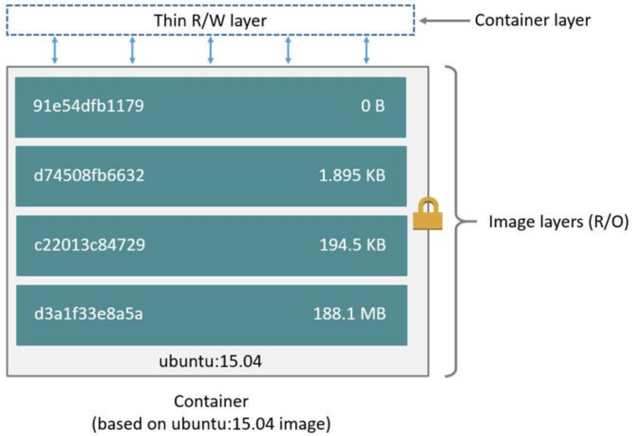
Used to run your tests!

# OCI image & runtime

- **Docker:** Most popular container runtime
- **Dockerfile:** build description to build container images
- Makes heavy of overlay/snapshot filesystems to save space

**# Dockerfile***
FROM ubuntu:18.04
COPY . /app
RUN make /app
CMD python /app/app.py

$ docker build




- Standardized by OCI:
  - both runtime (i.e VMs instead of container) and build tools (buildah instead of Dockerfile) can be exchanged

* Dockerfile used in our course https://gist.github.com/Mic92/7ae91f5f0239acb56c67535c683f1bc1

Demo time!