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Rootless containers with Podman and fuse-overlayfs

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Introduction

Rootless Containers

- *"Rootless containers refers to the ability for an unprivileged user* (i.e. non-root user) *to create, run and otherwise manage containers."* (https://rootlesscontaine.rs/)

- Not just about running the container payload as an unprivileged user

- Container runtime runs also as an unprivileged user

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Don’t confuse with...

- `sudo podman run --user foo`
  - Executes the process in the container as non-root
  - Podman and the OCI runtime still running as root

- `USER` instruction in Dockerfile
  - same as above
  - Notably you can’t `RUN dnf install ...`

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Don't confuse with...

- `podman run --uidmap`
  - Execute containers as a non-root user, using user namespaces
  - Most similar to rootless containers, but still requires podman and runc to run as root

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Motivation of Rootless Containers

- To mitigate potential vulnerability of container runtimes

- To allow users of shared machines (e.g. HPC) to run containers without the risk of breaking other users environments

- To isolate nested containers

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Caveat: Not a panacea

- Although rootless containers could mitigate these vulnerabilities, it is not a panacea , especially it is powerless against kernel (and hardware) vulnerabilities
  - CVE 2013-1858, CVE-2015-1328, CVE-2018-18955 😥

- Castle approach 🏰 : it should be used in conjunction with other security layers such as seccomp and SELinux

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Podman

Rootless Podman

Podman is a daemon-less alternative to Docker

- $ alias docker=podman
- Better integration with systemd

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Rootless Podman

	Root	**Rootless**
Storage	*/var/lib/containers*	*$HOME/.local/share/containers*
Runtime data	*/run/libpod*	*$XDG_RUNTIME_DIR/libpod (/run/user/1000/libpod)*
Configuration	*/etc/containers*	*$HOME/.config/containers*

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Rootless Podman

$ podman run --name nginx -d -p 8080:80 -v ~/public_html:/usr/share/nginx/html:ro nginx

Podman process (euid=$UID)

Join existing user+mount namespace, or create one

Podman process (euid=0)

Setup the network namespace with slirp4netns

Setup the storage and the fuse-overlayfs mount

conmon

OCI runtime

container process

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Implementation details

User Namespaces

- The key component of rootless containers.
  - Map UIDs/GIDs in the guest to different UIDs/GIDs on the host.
  - Unprivileged users can have (limited) root inside a user namespace!

- Root in a user namespace has UID 0 and full capabilities, but obvious restrictions apply.
  - Inaccessible files, inserting kernel modules, rebooting, ...

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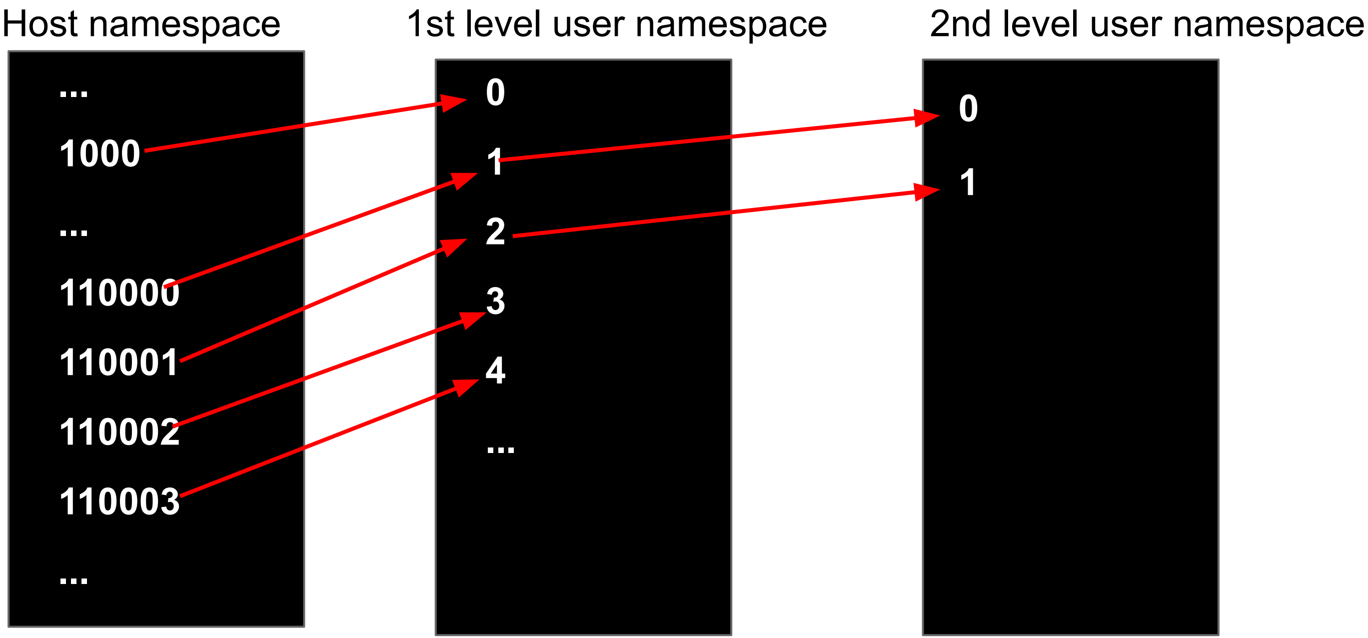
User Namespaces



User Namespaces

- To allow multi-user mappings, shadow-utils provides **`newuidmap`** and **`newgidmap`** (packaged by most distributions).
  - SETUID binaries writing mappings configured in `/etc/sub[ug]id`

```
/etc/subuid:
 1000:420000:65536
```

Provided by the admin (real root)

```
/proc/42/uid_map:
   0    1000       1
   1  420000   65536
```

User can configure map UIDs after unsharing a user namespace

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User Namespaces

Problems:

- SETUID binary can be dangerous ⚠️
  - `newuidmap` & `newgidmap` had two CVEs so far:
    - CVE-2016-6252 (CVSS v3: 7.8): integer overflow issue
    - CVE-2018-7169 (CVSS v3: 5.3): supplementary GID issue
- Hard to maintain `subuid` & `subgid`
  - Having 65536 sub-IDs should be ok for most cases, but to allow nesting user namespaces, an enormous number of sub-IDs would be needed
    - Potential sub-ID starvation

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User Namespaces

Alternative way: Single-mapping mode

- Single-mapping mode does not require `newuidmap/newgidmap`
- There is only one UID/GID available in the container

Limit the privileges of `newuidmap/newgidmap`

- Install them using file capabilities rather than **SETUID** bit
  - Only **CAP_SETUID** and **CAP_SETGID** are needed

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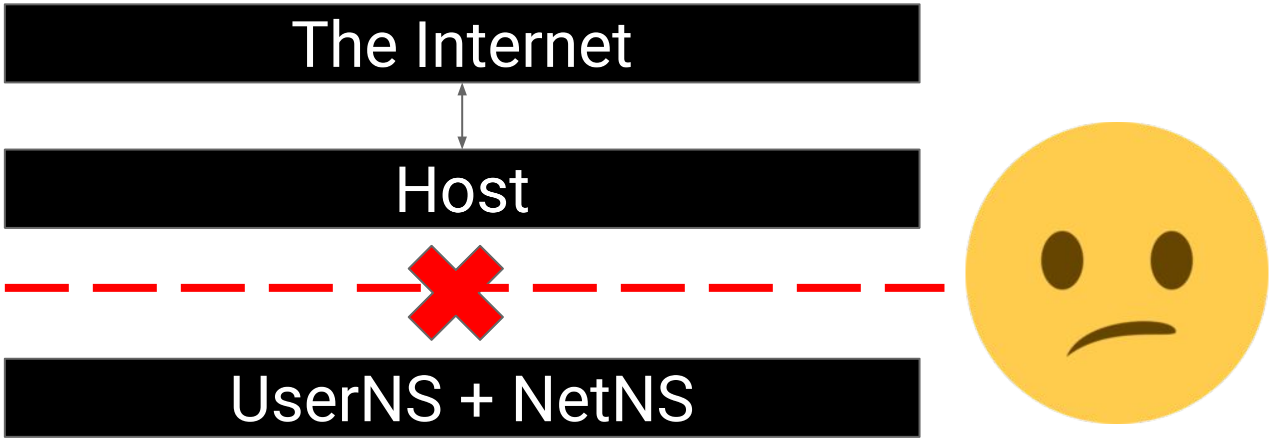
Network Namespaces

- An unprivileged user can create network namespaces along with user namespaces

- With network namespaces, the user can
  - create iptables rules
  - isolate abstract (pathless) UNIX sockets
  - set up overlay networking with VXLAN
  - run tcpdump
  - ...

Network Namespaces

- But an unprivileged user cannot set up `veth` pairs across the host and namespaces, i.e. No internet connection



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Network Namespaces

Prior work: LXC uses SETUID binary (`lxc-user-nic`) for setting up the `veth` pair across the the host and containers

Problem: SETUID binary can be dangerous! ⚠️

- CVE-2017-5985 (CVSS v3: 3.3): netns privilege escalation
- CVE-2018-6556 (CVSS v3: 3.3): arbitrary file `open(2)`

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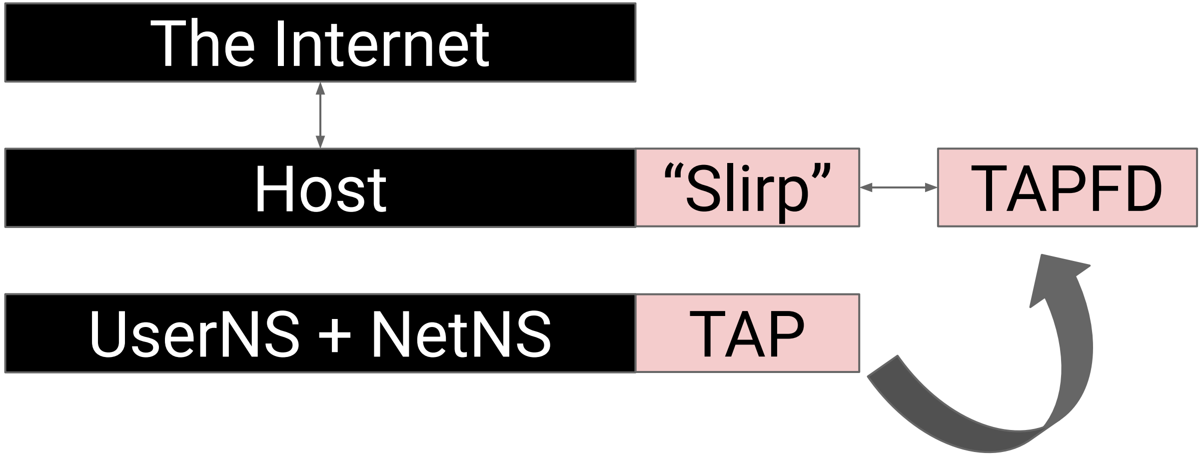
Network Namespaces

we use a completely unprivileged usermode network (“slirp”) with a TAP device



send fd as `SCM_RIGHTS` cmsg via an UNIX socket

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Network Namespaces

Benchmark of several “Slirp” implementations:

	MTU=1500	MTU=4000	MTU=16384	MTU=65520
vde_plug	763 Mbps	Unsupported	Unsupported	Unsupported
VPNKit	514 Mbps	526 Mbps	540 Mbps	Unsupported
slirp4netns	1.07 Gbps	2.78 Gbps	4.55 Gbps	9.21 Gbps
cf. rootful veth	52.1 Gbps	45.4 Gbps	43.6 Gbps	51.5 Gbps

- slirp4netns (based on QEMU Slirp) is the fastest because it avoids copying packets across the namespaces

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Multi-node networking

- Flannel VXLAN is known to work
  - Encapsulates Ethernet packets in UDP packets
  - Provides L2 connectivity across rootless containers on different nodes

- Other protocols should work as well, except ones that require access to raw Ethernet

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cgroups

/sys/fs/cgroup is a roadblock to many features we want in rootless containers (accounting, pause and resume, even getting a list of PIDs!).

- By default completely owned by root (and managed by systemd).

Some workarounds:

- LXC's pam_cgfs requires installation of a PAM module (and only works for logged-in users). It needs to be used carefully as it gives cgroupv1 write access to unprivileged users.
- cgroup namespaces (with nsdelegate) only work in cgroupv2.

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cgroups v2

- Safe to use for unprivileged user
- An entire subtree is delegated to the user
- The file path is not the only difference ⚠️

```
/sys/fs/cgroup/memory/foo/bar/memory.limit_in_bytes

/sys/fs/cgroup/cpu/foo/bar/cpu.shares

...
```

```
/sys/fs/cgroup/foo/bar/memory.max

/sys/fs/cgroup/foo/bar/cpu.max

...
```

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cgroups v2

- OCI runtime specs are designed around cgroup v1
- supporting cgroup v2 will require changes in the OCI specs
- **crun** attempts to convert from cgroup v1 to cgroup v2 (https://github.com/giuseppe/crun/). Alternative OCI runtime, drop-in replacement for runc.

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Storage

Root Filesystems

The container root filesystem has to live *somewhere*. Many filesystem features used by “rootful” container runtimes aren’t available.

- Ubuntu allows overlayfs in a user namespace, but this isn't supported upstream (due to security concerns).
- BTRFS allows unprivileged subvolume management, but requires privileges to set it up beforehand.
- Devicemapper is completely locked away from us.

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Root Filesystems

A “simple” work-around is to just extract images to a directory!

- It works … but people want storage deduplication.

Alternatives:

- Reflinks to a "known good" extracted image (inode exhaustion).
  - (Can use on XFS, btrfs, ... but not ext4.)
- Unprivileged userspace overlayfs using FUSE (Kernel 4.18+).

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fuse-overlayfs

- Overlayfs implementation using FUSE ➕
- Layers deduplication as for root containers ➕
- Fast setup for a new container ➕
- Built-in support for shifting UIDs/GIDs ➕

- Adds complexity ➖

fuse-overlayfs UIDs/GIDs shifting

- When creating a user namespace, we must ensure proper ownership of the files in the RO layers.
- the file system “lies” about the owner, so that it has the correct UID/GID in the user namespace and the same layer on disk can be used by different user namespaces.
- Less expensive alternative to `cp -r` and `chown`’ing the entire image and layers.

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fuse-overlayfs UIDs/GIDs shifting

Namespace configuration	From the host	From the container
1000 -> 0 110000:4096 -> 1..4096	/usr/bin/ls 1000:1000 /usr/bin/write 1000:110004	/usr/bin/ls 0:0 /usr/bin/write 0:5
1000 -> 0 118000:4096 -> 1..4096	/usr/bin/ls 1000:1000 /usr/bin/write 1000:118004	/usr/bin/ls 0:0 /usr/bin/write 0:5

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Questions?

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