Securing Container Runtimes

(How Hard Could It Be?)

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PLEASE USE USER NAMESPACES

(Folks who did were *not vulnerable to most of these bugs*...)

container_runtime.pdf

- Download and extract image archive into rootfs [see my OCIv2 talk].
- Fork (and re-exec) to create proto-pid1.
  - Child will exec() pid1's code at end.
  - Parent assists during setup.

container_runtime (2).pdf

- Parent's job:
  - Move child process into correct cgroup.
  - Set up and container's veth or other network devices (if configured).
  - Signal child to start.

container_runtime (3).pdf

- Child's job:
  - Create or join namespaces (mount, pid, net, ipc, …, and *hopefully* user).
  - Configure mountpoints for container process, pivot_root(new root).
  - Configure seccomp filters, LSM labels, no_new_privs, process credentials, …
  - Wait for parent signal, then execve(user's code).

container_runtime (4).pdf

- Other jobs:
  - Spawn a new process inside the container **while it's running**.
    - Rather that creating and configuring namespaces, join existing ones.
  - Modify existing container state (cgroup limits, network devices, …).
  - Many more uninteresting things.

CVE-2014-????

- `docker cp` didn't do *any* path sanitisation.
  - Oops.
  - `docker cp container:<symlink to /etc/shadow> w00t_w00t`
- Lesson learned:
  - Maybe we should sanitise paths.

CVE-2015-{3627,3629,3630,3631}

- Mostly related to bad configuration or permitting bad configurations.
  - Oops.
- Lessons learned:
  - Don't make those kinds of mistakes(?).
  - `VOLUME` was probably a mistake.
  - Containers are hard.

CVE-2016-9962

- We kept open a file descriptor to the root filesystem while joining the container.
  - Oops.
  - Container could access host through `/proc/$pid/fd/$n`.
- Lessons learned:
  - `procfs` is terrifying.
  - Make ourselves “non-dumpable” to block container process trickery.
    - Turns out there were some kernel bugs here too…

CVE-2018-15664

- Path sanitisation isn't enough if the attacker can change the paths underneath you.
  - Oops.
  - `RENAME_EXCHANGE` can be used to swap ("symlink-exchange") a component.
- Lessons learned:
  - Plain path sanitisation (as used to fix the 2014 bugs) is insufficient.
  - Solving this properly is non-trivial (see how LXD has done it).

CVE-2019-5736

- We could be tricked into re-executing ourselves, pinning `/proc/self/exe`.
  - Oops.
  - This clears the “non-dumpable” bit, but maintains `/proc/self/exe`.
  - `open(“/proc/self/exe”, O_RDONLY)` then re-open it after the process dies.
- Lessons learned:
  - `procfs` is *really* terrifying.
  - Make a copy of the runc binary each time, so overwriting does nothing.
  - Maybe we should do some kernel work to block re-opens like this…

CVE-2019-19921

- With custom images, you can use the symlink-exchange trick to mess with `/proc`.
  - Oops.
  - This means the container runtime can be tricked into not setting security labels.
  - `/proc/self/sched` can be used as a no-op writeable `procfs` target.
    - Ditto for `/proc/self/environ`.
- Lessons learned:
  - `procfs` is *absolutely horrifying*.
  - `VOLUME` (as well as several of my life decisions) were a mistake.

What is the common theme?

- Filesystem operations are really easy to screw up.
- `p r o c f s`

Let’s make filesystem operations safe!

The Problem

`/foo/bar/baz`

- `baz` might be a symlink. *(Just use **`O_NOFOLLOW`**!)*
- `bar` might be a symlink. *(Uhhh… sanitise it in userspace?)*
- `foo` might be attacker-controlled and thus `bar` can become a symlink. *(Dammit.)*
- This *is* a solveable problem in userspace, but almost nobody does it correctly.

openat2

```
int openat2(int dfd, const char *path,
            struct open_how *how, size_t size);


struct open_how {
  u64 flags;            // openat(2) flags
  u64 mode;             // openat(2) mode
  u64 resolve;          // RESOLVE_* flags
  // future fields go here
};
```

openat2

```
#define RESOLVE_NO_SYMLINKS   … /* Don’t traverse symlinks. */
#define RESOLVE_NO_MAGICLINKS … /* Don’t traverse magiclinks. */
#define RESOLVE_NO_XDEV       … /* Don’t cross mounts. */
#define RESOLVE_IN_ROOT       … /* Resolve within a root. */
```

libpathrs

Why Yet Another Library?

- Even with `openat2`:
  - Programs on old kernels still need to be hardened.
  - Users need to be **exceptionally** careful when doing other VFS operations.

Introducing libpathrs!

- Rust library (with C bindings, usable from almost any language).
- Emulates `openat2`'s `RESOLVE_IN_ROOT` on older kernels.
- Implements helpers that match most VFS syscalls (which are correctly written).
- Includes some additional hardening (related to procfs).

Usage

```rust
// Get a root handle for resolution.
let root = Root::open("/path/to/root")?;
// Resolve the path.
let handle = root.resolve("/etc/passwd")?;
// Upgrade the handle to a full std::fs::File.
let file = handle.reopen(libc::O_RDONLY)?;

// Or, in one line:
let file = root.resolve("/etc/passwd")?
               .reopen(libc::O_RDONLY)?;
```

docs.rs/pathrs

Usage

```
    root = pathrs_open("/path/to/root");
    error = pathrs_error(PATHRS_ROOT, root);
    if (error)
        goto err;

    handle = pathrs_resolve(root, "/etc/passwd");
    error = pathrs_error(PATHRS_ROOT, root);
    if (error) /* or (!handle) */
        goto err;

    fd = pathrs_reopen(handle, O_RDONLY);
    error = pathrs_error(PATHRS_HANDLE, handle);
    if (error) /* or (fd < 0) */
        goto err;

err:
    if (error)
        fprintf(stderr, "Uh-oh: %s (errno=%d)\n", error->description, error->saved_errno);
    pathrs_free(PATHRS_ROOT, root);
    pathrs_free(PATHRS_HANDLE, handle);
    pathrs_free(PATHRS_ERROR, error);
```

docs.rs/pathrs

Great! We're all done, right?


let's have a chat about procfs

The Problem

`/proc/self/attr/exec`

- How do I make sure that I'm writing to the real `procfs` file?
  - You can grab a `/proc` handle which is definitely real (the inode is 1).
  - You can check if the target is a procfs file (but you aren't sure it's the right one).
  - You can disable all symlink crossings a-la `openat2` (or emulate it).
    - Wait … how on earth do you check for bind-mounts?

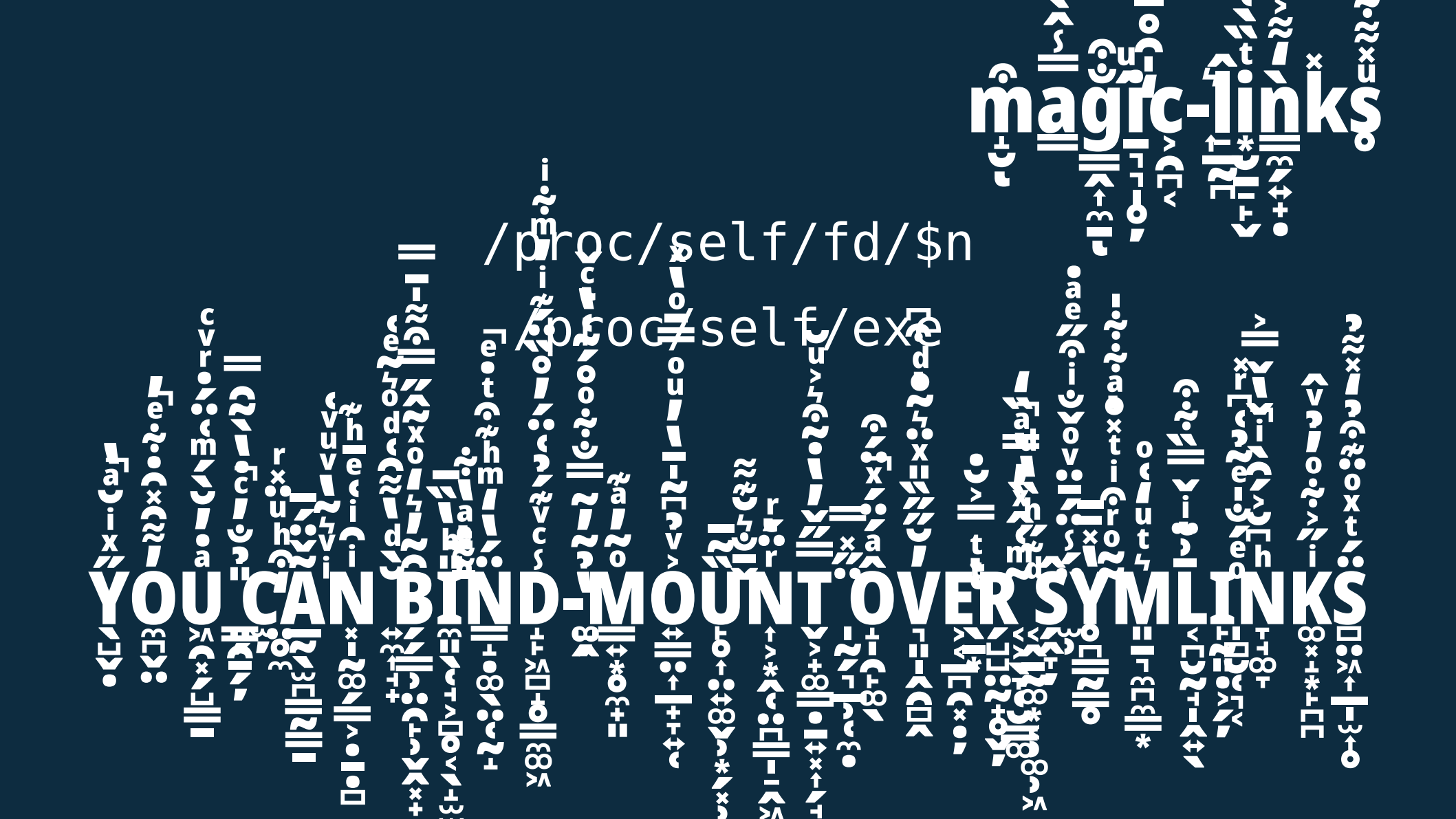
yeah, what about bind-mounts?

There is no way on Linux to be verify if you've crossed a bind-mount (until openat2).

and then there's magic-links

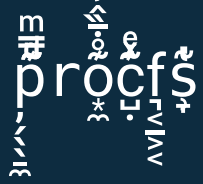
/proc/self/fd/$n

/proc/self/exe


magic-links
/proc/self/fd/$n
/proc/self/exe
YOU CAN BIND-MOUNT OVER SYMLINKS

incomprehensible rambling

Next Steps?

- Stabilise the base libpathrs C API.
- Start porting programs to libpathrs.
  - Needs Go bindings to port umoci.
- Continue kernel hardening work (which libpathrs can support opportunisically).
  - Lots of work needed to make  safe to use.

Links

- openat2
  - lwn.net/Articles/767547
  - lwn.net/Articles/796868
- libpathrs
  - github.com/openSUSE/libpathrs
  - docs.rs/pathrs
- github.com/cyphar/talks

Questions?

Magic-link Restriction

- Don't allow a read-only magic-link to be re-opened as read-write.
  - Requires lots of fun semantics with `O_PATH`.
  - Doesn't break userspace (based on my testing).
  - Needs to cover up a **lot** of different holes.

O_EMPTYPATH?

```
openat(fd, “”, O_EMPTYPATH | O_RDWR);
```

Built-in procfs handle?

```
openat(AT_PROCFD, “self/fd/$n”, O_RDWR);


setupfd = fsopen(“procfs”, FSOPEN_CLOEXEC);
procfd = fsmount(setupfd, FSMOUNT_CLOEXEC, 0);
openat(procfd, “self/fd/$n”, O_RDWR);
```

Pidfd-based /proc/self ??

```
selffd = pidfd_open(getpid(), 0);

pidfd_get_resource(selffd, PIDFD_EXE,
                   O_RDONLY);          // ???

openat(selffd, “exe”, O_RDONLY);       // ???
```