How to safely restrict access to files in a programmatic way with Landlock?

Mickaël Salaün

ANSSI

August 27, 2018

Part 1: Why Landlock, what is it and how does it work? (quick recap)

Designed to create tailored security sandboxes

Threat

bug exploitation or backdoor in an application (client or server side)

Designed to create tailored security sandboxes

Threat
bug exploitation or backdoor in an application (client or server side)

Goal
protect user of the application against unintended accesses

Features and use cases

Tailored security policy, by the developer

- e.g. able to choose the security model that fit best
- e.g. embedded in an application and evolve with it
- e.g. use application's configuration

Features and use cases

Tailored security policy, by the developer

- e.g. able to choose the security model that fit best
- e.g. embedded in an application and evolve with it
- e.g. use application's configuration

Compose access controls from multiple tenants

- e.g. sysadmin, end user and developers
- e.g. multiple cloud clients

Features and use cases

Tailored security policy, by the developer

- e.g. able to choose the security model that fit best
- e.g. embedded in an application and evolve with it
- e.g. use application's configuration

Compose access controls from multiple tenants

- e.g. sysadmin, end user and developers
- e.g. multiple cloud clients

Able to update access control on the fly

- e.g. native powerbox support (file picker, portal...)
- e.g. dynamic policy update according to external factors

Demonstration #1

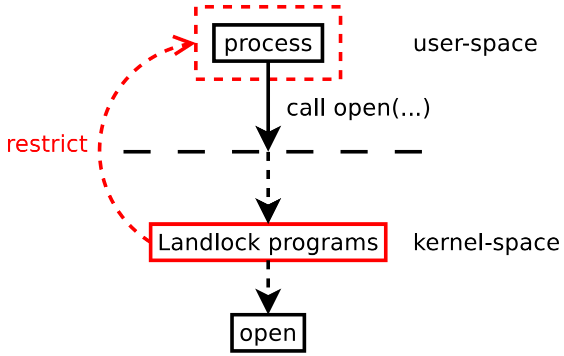
Read-only accesses...

- `/public`
- `/etc`
- `/usr`
- `...`

...and read-write accesses

- `/tmp`
- `...`

Landlock overview



Gears of Landlock

Linux Security Modules (LSM)

- allow or deny user-space actions on kernel objects
- 200+ hooks: `inode_permission`, `inode_unlink`, `file_ioctl`...

Gears of Landlock

Linux Security Modules (LSM)

- allow or deny user-space actions on kernel objects
- 200+ hooks: `inode_permission`, `inode_unlink`, `file_ioctl`...

extended Berkeley Packet Filter (eBPF)

- safely interpret bytecode in the kernel at run time
- can call dedicated functions
- can exchange data through maps between eBPF programs and user-space

Gears of Landlock

Linux Security Modules (LSM)

- allow or deny user-space actions on kernel objects
- 200+ hooks: `inode_permission`, `inode_unlink`, `file_ioctl`...

extended Berkeley Packet Filter (eBPF)

- safely interpret bytecode in the kernel at run time
- can call dedicated functions
- can exchange data through maps between eBPF programs and user-space

Landlock

- hook: set of actions on a specific kernel object
- program: access control checks stacked on a hook
- triggers: actions mask for which a program is run

Unprivileged access control

Protect access to process ressources

- the process requesting to apply a new access control must be allowed to `ptrace` the sandboxed process

Unprivileged access control

Protect access to process ressources

- the process requesting to apply a new access control must be allowed to `ptrace` the sandboxed process

Protect access to kernel ressources

- prevent information leak: an eBPF program shall not have access to informations not otherwise granted to the process requesting the sandboxing
- avoid side-channels: only interpreted on viewable objects and after other access controls
- account kernel resources used by the access controls

Part 2: Why and how the filesystem access control is different between Landlock and other LSMs?

Inode's extended attributes (xattr)

Pros

- native and efficient for the kernel to identify a file access

Inode's extended attributes (xattr)

Pros

- native and efficient for the kernel to identify a file access

Cons (for Landlock)

- no composability: only one label/view per inode (hard link, bind mounts, namespaces. . .)
- not unprivileged:
  - no (efficient) accounting per access control
  - need a filesystem which support xattr
  - need write access to label a file
- not dynamic: impose a persistent labelling

File path

Pros

- point of view of the user

File path

Pros

- point of view of the user

Cons (for Landlock)

- composability: need to remember how a file was (relatively) accessed
- unprivileged:
  - dealing with underlying inode can be tricky: partial path, anonymous inodes, chroot, namespaces. . .
  - risk of leaking path informations

eBPF inode map

A new eBPF map type to identify an inode

- filled with a reference to the inode pointed by a file descriptor
- efficient inode matching
- updatable from user-space
- unprivileged use

eBPF inode map

A new eBPF map type to identify an inode

- filled with a reference to the inode pointed by a file descriptor
- efficient inode matching
- updatable from user-space
- unprivileged use

Properties

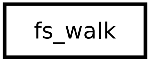
- inode identification not stored on the filesystem but (accounted) in the map
- use inode as key and associate it with a 64-bits arbitrary value

Demonstration #2

Update access rights on the fly

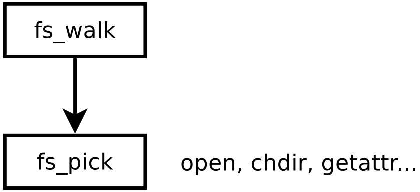
Chained programs and session

Landlock programs and their triggers (example)



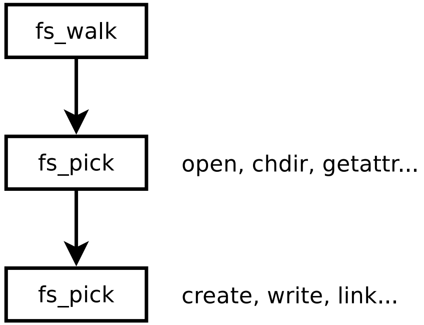
Chained programs and session

Landlock programs and their triggers (example)



Chained programs and session

Landlock programs and their triggers (example)



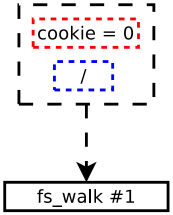
Walking through a file path

Example: `open /public/web/index.html`

key	value
/etc	1
/public	1
/tmp	1

Walking through a file path

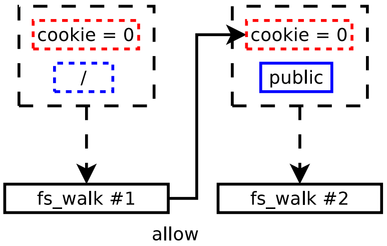
Example: `open /public/web/index.html`



key	value
/etc	1
/public	1
/tmp	1

Walking through a file path

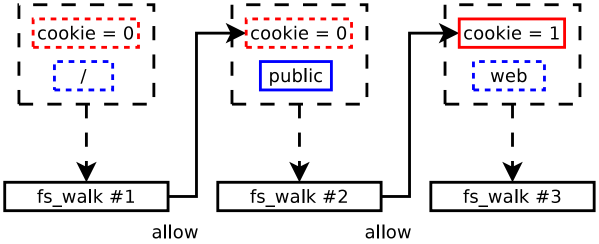
Example: `open /public/web/index.html`



key	value
/etc	1
/public	1
/tmp	1

Walking through a file path

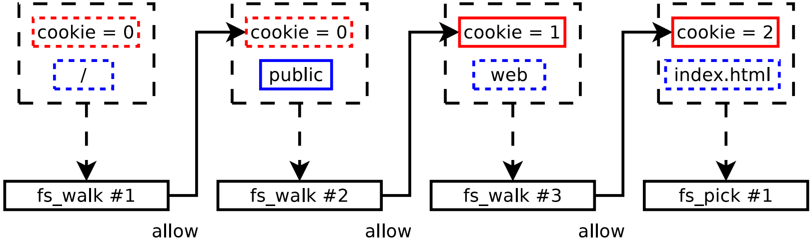
Example: `open /public/web/index.html`



key	value
/etc	1
/public	1
/tmp	1

Walking through a file path

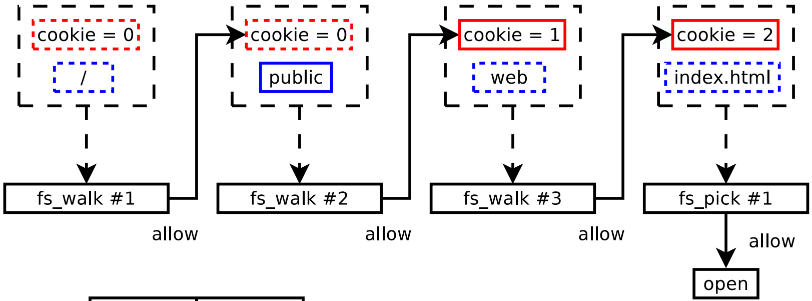
Example: `open /public/web/index.html`



key	value
/etc	1
/public	1
/tmp	1

Walking through a file path

Example: `open /public/web/index.html`



key	value
/etc	1
/public	1
/tmp	1

Identifying access to a subset of the filesystem, the Landlock way

Pros

- agnostic to chroot and namespaces
- no need for extra informations (not already available to the requester process)
- accountable security policy
- updatable on the fly
- do not rely on string matching
- can still rely on file hierarchy... this way or another
- easy to implement tests

Identifying access to a subset of the filesystem, the Landlock way

Pros

- agnostic to chroot and namespaces
- no need for extra informations (not already available to the requester process)
- accountable security policy
- updatable on the fly
- do not rely on string matching
- can still rely on file hierarchy… this way or another
- easy to implement tests

Cons

- rely on the way the kernel does (relative) pathname lookup (e.g. symlinks, *dot*, *dotdot*)
- add a security blob to `nameidata`

Identifying access to a subset of the filesystem, the Landlock way

Concern from the filesystem kernel developers

might rely too much on the current pathname lookup implementation, which changed multiple times until 2000 (cf. header comments in `fs/namei.c`)

Identifying access to a subset of the filesystem, the Landlock way

Concern from the filesystem kernel developers

might rely too much on the current pathname lookup implementation, which changed multiple times until 2000 (cf. header comments in `fs/namei.c`)

However...

- this logic is already visible and used by DAC and MAC systems
- ...and user-defined policies

Landlock: wrap-up

User-space hardening

- programmatic and embeddable access control
- designed for unprivileged use

Landlock: wrap-up

User-space hardening

- programmatic and embeddable access control
- designed for unprivileged use

Current status

- `security/landlock/*`: ~2000 SLOC
- ongoing patch series: LKML, `@l0kod`
- figuring out about the pathname lookup concerns
- full security module stacking is coming!

Landlock: wrap-up

User-space hardening

- programmatic and embeddable access control
- designed for unprivileged use

Current status

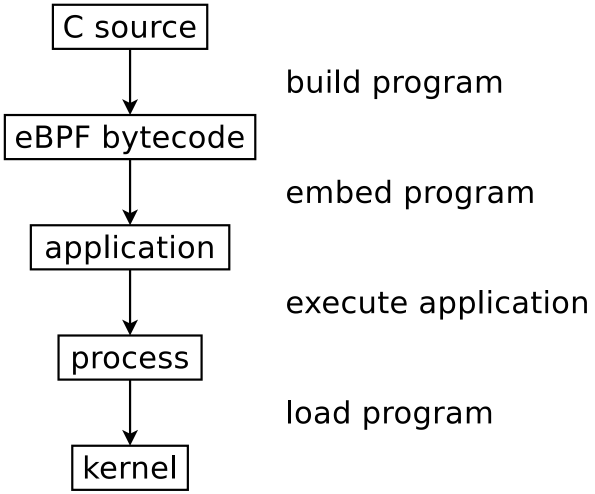
- `security/landlock/*`: ∼2000 SLOC
- ongoing patch series: LKML, `@l0kod`
- figuring out about the pathname lookup concerns
- full security module stacking is coming!

Further along the way

- audit support
- extend access control: network, IPC…
- (real) (programmable) capabilities
- library and tools

https://landlock.io

Life cycle of a Landlock program



Landlock program's metadata

```c
static union bpf_prog_subtype metadata = {
        .landlock_hook = {
                .type = LANDLOCK_HOOK_FS_PICK,
                .options = LANDLOCK_OPTION_PREVIOUS,
                .previous = 2, /* landlock2 */
                .triggers = LANDLOCK_TRIGGER_FS_PICK_APPEND | \
                            LANDLOCK_TRIGGER_FS_PICK_CREATE | \
                            // [...]
                            LANDLOCK_TRIGGER_FS_PICK_WRITE,
        }
};
```

Landlock program's metadata

```c
static union bpf_prog_subtype metadata = {
        .landlock_hook = {
                .type = LANDLOCK_HOOK_FS_PICK,
                .options = LANDLOCK_OPTION_PREVIOUS,
                .previous = 2, /* landlock2 */
                .triggers = LANDLOCK_TRIGGER_FS_PICK_APPEND | \
                            LANDLOCK_TRIGGER_FS_PICK_CREATE | \
                            // [...]
                            LANDLOCK_TRIGGER_FS_PICK_WRITE,
        }
};
```

Landlock program's metadata

```
static union bpf_prog_subtype metadata = {
        .landlock_hook = {
                .type = LANDLOCK_HOOK_FS_PICK,
                .options = LANDLOCK_OPTION_PREVIOUS,
                .previous = 2, /* landlock2 */
                .triggers = LANDLOCK_TRIGGER_FS_PICK_APPEND | \
                            LANDLOCK_TRIGGER_FS_PICK_CREATE | \
                            // [...]
                            LANDLOCK_TRIGGER_FS_PICK_WRITE,
        }
};
```

Landlock program's metadata

```c
static union bpf_prog_subtype metadata = {
        .landlock_hook = {
                .type = LANDLOCK_HOOK_FS_PICK,
                .options = LANDLOCK_OPTION_PREVIOUS,
                .previous = 2, /* landlock2 */
                .triggers = LANDLOCK_TRIGGER_FS_PICK_APPEND | \
                            LANDLOCK_TRIGGER_FS_PICK_CREATE | \
                            // [...]
                            LANDLOCK_TRIGGER_FS_PICK_WRITE,
        }
};
```

Landlock program's metadata

```
static union bpf_prog_subtype metadata = {
        .landlock_hook = {
                .type = LANDLOCK_HOOK_FS_PICK,
                .options = LANDLOCK_OPTION_PREVIOUS,
                .previous = 2, /* landlock2 */
                .triggers = LANDLOCK_TRIGGER_FS_PICK_APPEND | \
                            LANDLOCK_TRIGGER_FS_PICK_CREATE | \
                            // [...]
                            LANDLOCK_TRIGGER_FS_PICK_WRITE,
        }
};
```

Landlock program’s metadata

```
static union bpf_prog_subtype metadata = {
        .landlock_hook = {
                .type = LANDLOCK_HOOK_FS_PICK,
                .options = LANDLOCK_OPTION_PREVIOUS,
                .previous = 2, /* landlock2 */
                .triggers = LANDLOCK_TRIGGER_FS_PICK_APPEND | \
                            LANDLOCK_TRIGGER_FS_PICK_CREATE | \
                            // [...]
                            LANDLOCK_TRIGGER_FS_PICK_WRITE,
        }
};
```

Landlock program code

```c
int fs_pick_write(struct landlock_ctx_fs_pick *ctx) {
        __u64 cookie = ctx->cookie;

        cookie = update_cookie(cookie, ctx->inode_lookup,
                                (void *)ctx->inode);
        if (cookie & MAP_MARK_WRITE)
                return LANDLOCK_RET_ALLOW;
        return LANDLOCK_RET_DENY;
}
```

Landlock program code

```
int fs_pick_write(struct landlock_ctx_fs_pick *ctx) {
        __u64 cookie = ctx->cookie;

        cookie = update_cookie(cookie, ctx->inode_lookup,
                                (void *)ctx->inode);
        if (cookie & MAP_MARK_WRITE)
                return LANDLOCK_RET_ALLOW;
        return LANDLOCK_RET_DENY;
}
```

Landlock program code

```
int fs_pick_write(struct landlock_ctx_fs_pick *ctx) {
        __u64 cookie = ctx->cookie;

        cookie = update_cookie(cookie, ctx->inode_lookup,
                                (void *)ctx->inode);
        if (cookie & MAP_MARK_WRITE)
                return LANDLOCK_RET_ALLOW;
        return LANDLOCK_RET_DENY;
}
```

Landlock program code

```
int fs_pick_write(struct landlock_ctx_fs_pick *ctx) {
        __u64 cookie = ctx->cookie;

        cookie = update_cookie(cookie, ctx->inode_lookup,
                                (void *)ctx->inode);
        if (cookie & MAP_MARK_WRITE)
                return LANDLOCK_RET_ALLOW;
        return LANDLOCK_RET_DENY;
}
```

Landlock program code

```
int fs_pick_write(struct landlock_ctx_fs_pick *ctx) {
        __u64 cookie = ctx->cookie;

        cookie = update_cookie(cookie, ctx->inode_lookup,
                                (void *)ctx->inode);
        if (cookie & MAP_MARK_WRITE)
                return LANDLOCK_RET_ALLOW;
        return LANDLOCK_RET_DENY;
}
```

Landlock program code

```
int fs_pick_write(struct landlock_ctx_fs_pick *ctx) {
        __u64 cookie = ctx->cookie;

        cookie = update_cookie(cookie, ctx->inode_lookup,
                                (void *)ctx->inode);
        if (cookie & MAP_MARK_WRITE)
                return LANDLOCK_RET_ALLOW;
        return LANDLOCK_RET_DENY;
}
```

Loading a rule in the kernel

```c
union bpf_attr attr = {
        .insns = bytecode_array,
        .prog_type = BPF_PROG_TYPE_LANDLOCK_HOOK,
        .prog_subtype = &metadata,
        // [...]
};
int prog_fd = bpf(BPF_PROG_LOAD, &attr, sizeof(attr));
```

Loading a rule in the kernel

```c
union bpf_attr attr = {
        .insns = bytecode_array,
        .prog_type = BPF_PROG_TYPE_LANDLOCK_HOOK,
        .prog_subtype = &metadata,
        // [...]
};
int prog_fd = bpf(BPF_PROG_LOAD, &attr, sizeof(attr));
```

Loading a rule in the kernel

```
union bpf_attr attr = {
        .insns = bytecode_array,
        .prog_type = BPF_PROG_TYPE_LANDLOCK_HOOK,
        .prog_subtype = &metadata,
        // [...]
};
int prog_fd = bpf(BPF_PROG_LOAD, &attr, sizeof(attr));
```

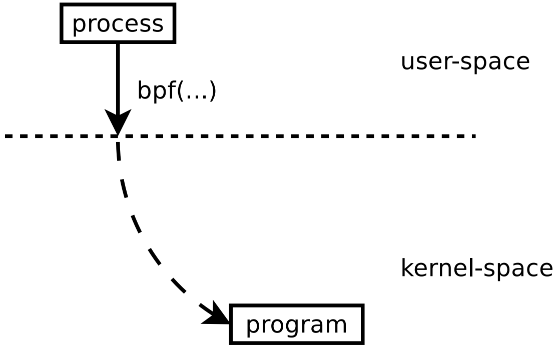
Loading a rule in the kernel

```
union bpf_attr attr = {
        .insns = bytecode_array,
        .prog_type = BPF_PROG_TYPE_LANDLOCK_HOOK,
        .prog_subtype = &metadata,
        // [...]
};
int prog_fd = bpf(BPF_PROG_LOAD, &attr, sizeof(attr));
```

Loading a rule in the kernel

```c
union bpf_attr attr = {
        .insns = bytecode_array,
        .prog_type = BPF_PROG_TYPE_LANDLOCK_HOOK,
        .prog_subtype = &metadata,
        // [...]
};
int prog_fd = bpf(BPF_PROG_LOAD, &attr, sizeof(attr));
```

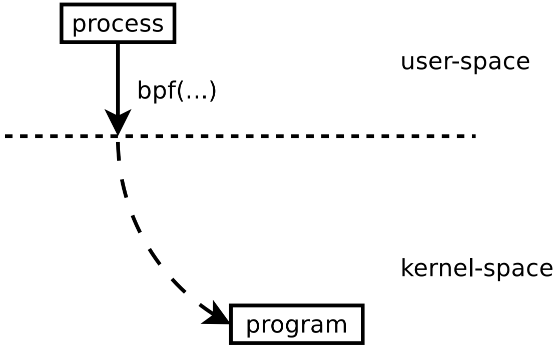
Loading a rule in the kernel



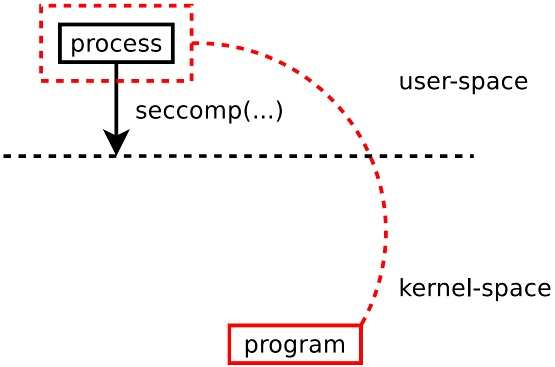
Applying a Landlock program to a process

```
seccomp(SECCOMP_PREPEND_LANDLOCK_PROG, 0, &prog_fd);
```

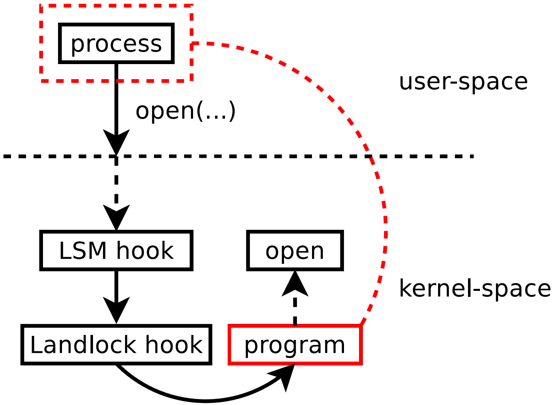
Applying a Landlock program to a process



Applying a Landlock program to a process



Applying a Landlock program to a process

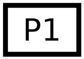


Kernel execution flow

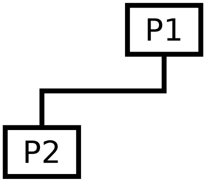
Example: the `inode_create` hook

1. check if `landlocked(current)`
2. call `decide_fs_pick(LANDLOCK_TRIGGER_FS_PICK_CREATE, dir)`
3. for all *fs_pick* programs enforced on the current process
   3.1 update the program's context
   3.2 interpret the program
   3.3 continue until one denies the access

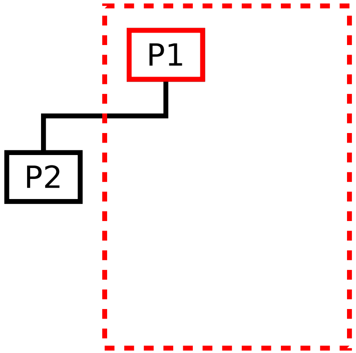
Rule enforcement on process hierarchy



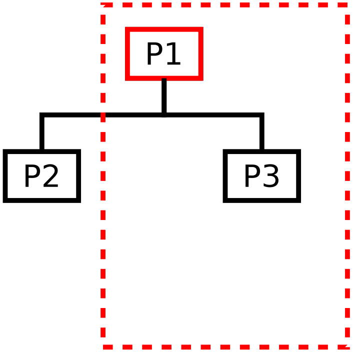
Rule enforcement on process hierarchy



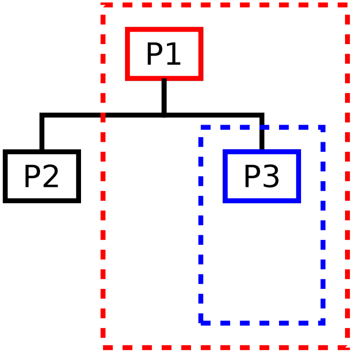
Rule enforcement on process hierarchy



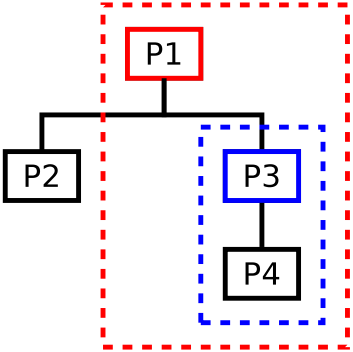
Rule enforcement on process hierarchy



Rule enforcement on process hierarchy



Rule enforcement on process hierarchy



Enforcement through cgroups

Why?

user/admin security policy (e.g. container): manage groups of processes

Enforcement through cgroups

Why?

user/admin security policy (e.g. container): manage groups of processes

Challenges

- complementary to the process hierarchy rules (via *seccomp(2)*)
- processes moving in or out of a cgroup
- unprivileged use with cgroups delegation (e.g. user session)

Future Landlock program types

fs_get

tag inodes: needed for relative path checks (e.g. *openat(2)*)

Future Landlock program types

fs_get

tag inodes: needed for relative path checks (e.g. *openat(2)*)

fs_ioctl

check IOCTL commands

Future Landlock program types

fs_get
tag inodes: needed for relative path checks (e.g. *openat(2)*)

fs_ioctl
check IOCTL commands

net_*
check IPs, ports, protocol...