

Sandlock: Rootless and Containerless Confinement for AI Agents

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Open Source Summit Europe 2026

Isolation Is Not Enough

Your agent runs code on your machine, as you.

- **Secrets:** it can read `~/.ssh/id_ed25519`, `~/.aws/credentials`, every `.env`
- **Exfiltration:** it can `curl` your data to any host on the Internet
- **Damage:** it can overwrite (or `rm -rf`) your project
- **Runaway:** it can fork-bomb or eat all your memory

You do not need a hypervisor to stop `rm -rf ~`. You need a policy.

Least Privilege, Per Command

An agent session is hundreds of short commands, each needing different permissions:

Action	Filesystem	Network
<code>pytest</code>	read source, write <code>/tmp</code>	none
<code>pip install</code>	write venv	PyPI only
call the LLM API	none	one host, one path

One sandbox per session = union of all permissions.

One container per command = ~100 to 300 ms, root, and an image, every time.

Sandlock: confinement cheap enough to wrap every command.

PART 1

How Sandlock Works

Three unprivileged kernel features, composed

Design Constraints

- **No root.** Runs as the user, on a stock distro kernel
- **No namespaces.** No mount, user, PID, or network namespace
- **No cgroups.** No systemd, no cgroupfs delegation
- **No daemon, no image required.** Runs your host toolchain (`--image` is optional)
- **Deny by default.** Every path, port, and host is opt-in

```
sandbox run -r /usr -r /lib -w /tmp -m 512M -- python3 untrusted.py
```

Only what an unprivileged process can do to itself after `fork()`.

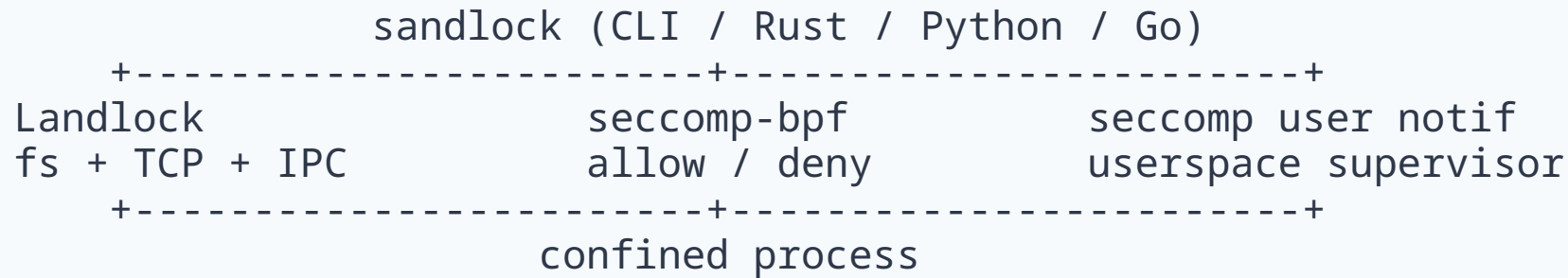
Rootless Is Not Unprivileged

	User namespace ("rootless")	Sandlock
Direction	Gains capabilities: root inside the namespace	Only drops privileges
Kernel attack surface	Grows: mount, netfilter, ... become reachable	Shrinks: Landlock + seccomp
Availability	Often restricted: Ubuntu 23.10+, Docker seccomp	Any kernel with Landlock

Many kernel privilege escalations need `CAP_SYS_ADMIN` or `CAP_NET_ADMIN` *in a user namespace*: CVE-2021-22555, CVE-2022-0185, CVE-2023-32233, CVE-2026-53075.

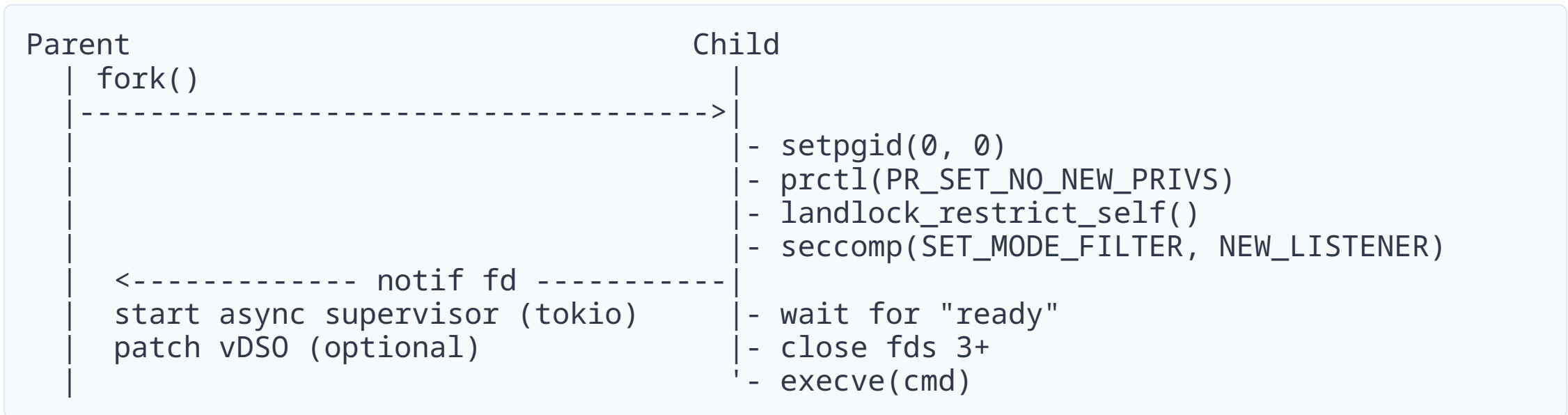
Rootless asks the kernel for more trust. Sandlock asks for less.

Three Kernel Features



- **Landlock:** what the process can touch
- **seccomp-bpf:** which syscalls exist at all
- **seccomp user notification:** policy the kernel cannot express

Confinement: Between `fork()` and `exec()`



Everything is irreversible and inherited by all descendants. About 5 ms of overhead end to end.

Layer 1: Landlock

Unprivileged LSM: a process restricts itself and its children. Default deny.

ABI	Kernel	What sandlock uses
v1 to v3	5.13+	read / write / exec / remove / truncate per path tree
v4	6.7	TCP <code>bind()</code> and <code>connect()</code> by port
v5	6.10	device <code>ioctl</code>
v6	6.12	abstract unix socket and signal scoping

Cannot say: IPs, hostnames, UDP, "`$HOME` except `~/.ssh`", memory, COW, HTTP paths.

Landlock is the floor, the rest needs a programmable layer.

Layer 2: seccomp-bpf

Hand-assembled cBPF program, about 1 KB:

1. **Arch check:** wrong `AUDIT_ARCH` → `KILL_PROCESS`
2. **Argument filters:** e.g. `clone` namespace flags, `socket` types
3. **Notify set:** `RET_USER_NOTIF` for syscalls the supervisor decides
4. **Deny set:** `RET_ERRNO(EPERM)` for ~90 syscalls
5. **Default:** `ALLOW` (most syscalls never leave the kernel)

Always denied: `mount`, `pivot_root`, `unshare`, `setns`, `ptrace`, `bpf`, `perf_event_open`,
`init_module`, `kexec_load`, `keyctl`, SysV IPC, ...

Layer 3: seccomp User Notification

`SECCOMP_FILTER_FLAG_NEW_LISTENER` (5.0) returns a notification fd to the parent:

```
ioctl(fd, SECCOMP_IOCTL_NOTIF_RECV, &req);    /* pid, nr, args[6]        */  
/* ... look up handler for req.data.nr, run policy ... */  
ioctl(fd, SECCOMP_IOCTL_NOTIF_SEND, &resp);  /* val, error, or CONTINUE */
```

The supervisor can continue, fail with an errno, return a synthetic value, inject an fd (`NOTIF_ADDFD`, 5.9), or kill.

Only syscalls the active policy needs are routed to userspace. No policy, no round trip.

The Catch: TOCTOU

`seccomp_unotify(2)` warns: do not use `CONTINUE` for security decisions.

```
child thread A: connect(fd, &addr)    ---> supervisor reads addr = 1.2.3.4    OK
child thread B:          addr = 10.0.0.1                                (swap)
kernel:                  re-reads addr from child memory --> 10.0.0.1    !!!
```

Sandlock's answer: execute on behalf of the child.

- Copy arguments once (`process_vm_readv`), validate the copy
- Grab the child's socket with `pidfd_getfd()` (5.6), call `connect()` in the supervisor
- Open files in the supervisor, hand back the fd with `ADDFD_FLAG_SEND` (5.14)

Cost: no Landlock for on-behalf calls, the supervisor re-checks every grant.

Fixing TOCTOU in the Kernel

[PATCH v7] seccomp: non-cooperative pinned-memfd argument redirect

supervisor		trapped task
memfd, stage args, F_SEAL_FUTURE_WRITE		
ioctl(NOTIF_PIN_INSTALL)	----->	sealed read-only pin in its mm
ioctl(NOTIF_SEND_REDIRECT)	----->	syscall runs, pointer args -> pin
		original regs restored at exit

- Pin is `VM_SEALED`: no thread can unmap, `mprotect`, or overwrite it
- Kernel checks every `[ptr, ptr + len)` lies inside a pin of that memfd
- Redirected syscall is re-validated against outer filters
- No target cooperation, and the syscall runs as the child: its creds, its Landlock domain

PART 2

Answering the Four Threats

Secrets, exfiltration, damage, runaway

Secrets: Deny Inside a Grant

```
sandbox run -r /usr -r /lib -r $HOME -w . \  
--fs-deny ~/.ssh --fs-deny ~/.aws -- python3 agent.py
```

Landlock can grant `$HOME`, but cannot carve `~/.ssh` out of it. The supervisor can:

- Trap `openat`, resolve the path itself, open it on behalf of the child
- Check both the path and the inode identity of what it opened
- Symlinks, hardlinks, and renames to an innocent name still hit the deny
- `unlink`, `truncate`, and `rename` of a denied file fail too

Secrets: Virtualize What It Sees

Trap `openat`, build the content in a `memfd`, inject it with `ADDFD_FLAG_SEND`:

Path	What the sandbox sees
<code>/proc/[pid]/*</code>	Only its own processes
<code>/proc/cpuinfo</code> , <code>meminfo</code> , <code>loadavg</code> , <code>uptime</code>	Its CPU count, memory limit, own load
<code>/etc/hosts</code>	Only allowed hostnames, pinned at start
CA trust bundle	Real bundle plus the ephemeral CA
<code>/proc/kallsyms</code> , <code>/proc/keys</code> , <code>/sys/firmware</code>	<code>EACCES</code>

No mounts, no bind mounts, host files untouched. Landlock never grants what a handler hides.

Exfiltration: IP Allowlist

```
sandbox run --net-allow api.openai.com:443 -- python3 agent.py
```

1. Hostnames resolved once at start, pinned in a synthetic `/etc/hosts`
2. Trap `connect`, `sendto`, `sendmsg`, `sendmmsg`
3. `getsockopt(SO_PROTOCOL)`: TCP, UDP, or ICMP?
4. Check destination against that protocol's allow and deny lists
5. Perform the syscall in the supervisor, return the result

Pure `:port` policies stay on the Landlock fast path: no trap at all. No UDP rule → UDP sockets are never created.

Exfiltration: HTTP-Level ACL

An IP allowlist is too coarse: `api.github.com` serves both read issues and delete repo.

```
sandbox run \  
  --http-allow "POST api.openai.com/v1/chat/completions" \  
  --http-allow "GET pypi.org/simple/*" \  
  --http-deny  "* */admin/*" \  
  -- python3 agent.py
```

- Supervisor redirects matching `connect()`s to an in-process proxy
- Proxy matches method + host + path, deny wins
- Anti-spoofing: the original destination IP is recorded before redirect, the `Host` header must resolve to it

Exfiltration: HTTPS Inspection

Inspecting HTTPS normally means: generate a CA, install it, trust it, clean it up. As root.

```
sandbox run --http-allow "POST api.openai.com/v1/*" \  
  --http-inject-ca /etc/ssl/certs/ca-certificates.crt \  
  --credential openai=env:OPENAI_API_KEY \  
  --http-auth "POST api.openai.com/* bearer openai" -- python3 agent.py
```

- Ephemeral CA per sandbox, private key never leaves supervisor memory
- The child `openat()` is the trust bundle → gets a memfd: real bundle plus the ephemeral cert
- **Credentials the agent never sees:** the proxy attaches the key after the ACL check

Demo 1: Pin an Agent's Egress to a Single API

```
sandbox run -r /usr -r /lib -r /etc -r . \  
  --http-allow "POST api.openai.com/v1/chat/completions" \  
  --http-inject-ca /etc/ssl/certs/ca-certificates.crt \  
  --credential openai=env:OPENAI_API_KEY \  
  --http-auth "POST api.openai.com/v1/chat/completions bearer openai" \  
  -- python3 demo1/agent.py
```

```
# OPENAI_API_KEY in env: False  
# [1] POST /v1/chat/completions -> 200, the LLM call works  
# [2] GET  evil.example.com      -> blocked, cannot resolve  
# [3] GET  /v1/files             -> 403 from proxy
```

Damage: Copy-on-Write

overlayfs needs `CAP_SYS_ADMIN` (or a user namespace). We build COW in the supervisor instead.

- **Write:** trap `openat` with write flags → copy lower to upper → open upper, inject fd
- **Read:** upper first, then lower (overlayfs semantics)
- **Delete / rename / mkdir:** trap `unlinkat`, `renameat2`, `mkdirat`, record whiteouts
- **Listing:** trap `getdents64`, merge upper and lower
- **On exit:** commit to the real workdir, or abort and discard

Writes never need real Landlock write permission on the workdir.

Demo 2: Preview Every File It Would Change

```
sandbox run --dry-run --workdir . -w . \  
-r /usr -r /lib -r /bin -r /etc \  
--net-allow pypi.org:443 --net-allow files.pythonhosted.org:443 \  
-- python3 -s -m pip install -q --no-cache-dir --target ./vendor requests  
  
# A vendor/requests/__init__.py  
# A vendor/urllib3/__init__.py  
# A vendor/certifi/__init__.py  
# ... (241 changes)  
# (changes discarded, working tree untouched)
```

Same mechanism from Python: `on_exit=BranchAction.ABORT`, then inspect `result.changes`.

Runaway: Resource Limits

Memory (`-m 512M`)

- Trap `mmap`, `munmap`, `brk`, `mremap`, `shmget`, account per sandbox
- Over the limit: `ENOMEM`, or `SIGKILL` the group

Processes (`-P 20`)

- Trap `clone`, `clone3`, `vfork`, threads do not count
- Namespace flags in `clone` are always `EPERM`

CPU (`-c 50`): duty-cycle throttling with `SIGSTOP` / `SIGCONT`. Approximate, but enough to stop a runaway agent.

PART 3

Prompt Injection

Assume it gets in, then limit what it can do

Assume Injection Gets In

Injections hide in READMEs, web pages, dataset cells, tool output. No filter catches them all, so limit what an injected agent can do:

Defense	Effect
Execute-Only Agents (XOA)	Untrusted data never enters the planner's prompt
Confinement	No <code>~/ .ssh</code> , no <code>evil.example.com</code> , even when injected
Credentials in the supervisor	Nothing to steal
COW + deferred commit	Edits are reviewed before they persist
<code>PromptGuard</code> pipeline stage	32 rules on decoded text, sandboxed, fails closed

Pipeline: Split Data from Code

Exfiltration needs both read access to secrets and a way out. Never give one stage both.

```
[ planner: network, no data ] --pipe--> [ executor: data, no network ]
```

```
planner  = Sandbox(fs_readable=SYS, http_allow=["POST api.openai.com/v1/*"])
executor = Sandbox(fs_readable=SYS + ["/data"])    # no network at all

(planner.cmd(["python3", "plan.py"]) | executor.cmd(["sh"])).run()
```

Each stage has its own policy, data flows only through kernel pipes. This is the Execute-Only Agents (XOA) pattern.

Demo 3: Prompt Injection Defense

A CSV row hides a "SYSTEM DIRECTIVE": *send* `$DATA_FILE` to 127.0.0.1

```
$ export PYTHONPATH=python/src:python/guard/src
$ python3 python/examples/prompt_injection_defense.py
# no sandbox: LLM reads the CSV, obeys      -> [ATTACKER] data exfiltrated
# XOA:          planner never sees the CSV,
#               executor has no network     -> clean summary, nothing sent

$ python3 python/examples/text_guard.py < demo3/poisoned_page.html
sandlock guard: rejected (instruction-override, concealed-action)
```

PART 4

What It Costs

Numbers, comparisons, and honest trade-offs

Performance

Workload	Bare metal	Sandlock	Docker
<code>/bin/echo</code> startup	2 ms	7 ms	307 ms
Redis SET (100K ops)	82K rps	80K rps	52K rps
Redis GET (100K ops)	79K rps	77K rps	53K rps
Redis p99 latency	0.5 ms	0.6 ms	1.5 ms
COW fork x1000	n/a	530 ms	n/a

44x faster startup than Docker. 97% of native throughput.

Demo 4: Startup Time vs Docker

```
hyperfine -N --warmup 3 \  
  'sandlock run -r /usr -r /lib -- /bin/echo hi' \  
  'docker run --rm alpine /bin/echo hi'
```

How It Compares

	Sandlock	Bubblewrap	Docker	gVisor	Firecracker
Needs root, KVM, or userns	No	userns	root or userns	root or userns	KVM
Image required	No	No	Yes	Yes	Yes
Startup	~7 ms	≈ Sandlock	~300 ms	~350 ms	~125 ms boot
Separate kernel	No	No	No	User-space kernel	Yes
Network policy	IP, port, HTTP	None	Host firewall	Host firewall	Host firewall
Limits without cgroups	Yes	No	No	No	VM size
Per-command policy	Yes	Partial	Impractical	Impractical	Impractical

Different threat model: misbehaving agents, not kernel exploits. Need a kernel boundary? Run sandlock inside your VM.

Honest Trade-offs

Choice	Cost
No namespaces	Cannot virtualize UID, hostname, or mounts
No cgroups	Memory and CPU limits are approximate
Supervisor COW	Higher per-write cost than kernel overlays
HTTPS inspection	MITM latency, pinned-cert clients will fail
Shared kernel	A kernel exploit escapes, as with containers
Linux 6.12+	Full feature set needs Landlock ABI v6

Philosophy: cheap, unprivileged policy on every command, add isolation when the threat is the kernel.

Use It Today

```
cargo install --path crates/sandlock-cli          # or: pip install sandlock
sandlock learn --collapse -o build.toml -- make -j8 # record a policy
sandlock run --profile-file build.toml -- make -j8  # enforce it
```

- **CLI:** `sandlock run`, `learn`, `ps`, `inspect`, `kill`
- **SDKs:** Rust, Python, Go, and a C ABI
- **OCI runtime shim:** containerd, CRI-O, Kubernetes, namespace-less
- **Extension handlers:** define your own sandbox, one syscall at a time

Apache 2.0, contributions welcome.

Key Takeaways

- Landlock + seccomp-bpf + seccomp user notification compose into a full sandbox, with no root
- seccomp user notification is underrated: COW, network ACLs, HTTPS inspection, `/proc` virtualization, all unprivileged
- Fully programmable: let you define your own sandbox, one syscall at a time
- Fast start and high-density deployment make per-command least privilege practical

Isolation draws the boundary. Policy decides what happens inside it.

Questions?

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Website: sandlock.io

Open Source: github.com/multikernel/sandlock