CLIP OS: Building a defense-in-depth OS with the Linux kernel and open source software

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About the ANSSI

- *Agence nationale de la sécurité des systèmes d’information*
- French authority in the area of cyberdefence, network and information security
- Provides its expertise and technical assistance to government departments and businesses and plays an enhanced role in supporting operators of vital importance.
CLIP OS?

- Linux distribution developed by the ANSSI
- Initially only available internally
- Now open source, mostly under the LGPL v2.1+
- Code and issue tracker hosted on GitHub\(^1\):
  - Version 4: available as reference and for upstream patch contribution
  - Version 5: currently developed version, alpha status, beta coming soon

\(^1\)https://github.com/CLIPOS
\(^2\)https://github.com/CLIPOS-Archive
CLIP OS?

Not yet another Linux distribution
- Not a generic/multi-purpose distribution

Targets three main use cases
- Mobile office workstation
- Remote administration workstation
- IPsec gateway
Hardened OS

- Based on Gentoo Hardened
- Hardened Linux kernel and confined services
- No interactive root account available:
  \[ \Rightarrow \) "Unprivileged" admin, audit and update roles
- Automatic updates using A/B partition model (similar to Android 7+)
- Multilevel security:
  - Provide two isolated user environments
  - Controlled interactions between isolated environments
Multilevel from the end user point of view (v4)
Admin panel: devices assignment per level (v4)
Differences with Qubes OS

CLIP OS development began 5 years earlier than Qubes OS

Main goals
- We target non-expert users
- Multilevel security model with two levels
- We favor a defense-in-depth approach

Technical point of view
- Hypervisor (Qubes OS) vs. supervisor isolation (CLIP OS)
- CLIP OS: Limited access rights and capabilities, even for administrators
Security features

Goals
- High resistance to remote or local exploits
- Defense in depth: limit impact of successful exploits
- Limited options for attacker persistence

Challenges
- Mobility / road warrior / remote worker use case
- Multi-level isolation and hardware sharing
General architecture overview

- Cage 1 (Debian)
- Cage 2 (Gentoo)
- Cage 3 (…)

Core (Gentoo Hardened)

Linux kernel

Hardware

--- Enforced isolation --- Controlled interaction
Defense in depth

Concepts
- Minimal attack surface
- Isolation based on containers

Implementation
- All services confined in Linux "containers"

v4
- Additional isolation using Linux-VServer
- Specific Linux Security Module (CLIP-LSM) & capability split

v5
- Linux-VServer like LSM (early development stage)
- Landlock\(^3\)(planned)

\(^3\)See landlock.io
Network level isolation

Low level
- App
- App
- Virtual interface

High level
- App
- App
- Virtual interface

Core
- routing

Physical interface

"Cleartext" traffic
- Encrypted traffic
## Application hardening and exploit mitigation

### Memory-unsafe programming languages (C, C++, etc.)

Root cause of most major vulnerabilities in the last 10+ years\(^4\)

### Mitigation

- Built from source with compile-time hardening (Gentoo Hardened)
- v4: PaX (part of grsecurity): strict $W \oplus X$ for memory allocations

### Long term solution

- Use only memory safe languages (Rust, OCaml, etc.)
- v4 & planned for v5: PKCS#11 proxy written in OCaml (Caml Crush\(^5\))
- v5: Updater written in Rust (in progress)

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Linux kernel and system hardening

Goals
- Protect the kernel from itself and from userspace
- Provide good defaults for userspace applications

Implementation
- Strict kernel build time configuration
- Per hardware curated profiles (modules, firmwares, etc.)
- Paranoid command line (IOMMU, PTI, etc.)
- Strict sysctl defaults (kptr_restrict, ptrace_scope, etc.)

Additional changes
- v4: grsecurity
- v5: STACKLEAK (now upstream), linux-hardened, Lockdown
No arbitrary code execution: $W \oplus X$

**Goal**
Defense in depth and difficulty for an attacker to persist post compromission

**Implementation**

- User partitions always mounted as RW and `noexec`
- Multiple partitions to allow RO + `exec` and RW + `noexec` mounts

**v4**
- System partitions mounted as RW + `exec` to apply updates during boot
- Then remounted as RO + `exec` once boot is completed

**v5**
- Stricter split between system and configuration partitions
- RO and `exec`: system executables, configuration and data
- RW and `noexec`: runtime configuration, logs, user and application data
O_MAYEXEC

Read-write filesystem (e.g. /home/user)

- prog.py

Read-only filesystem (e.g. /usr/bin)

- Python interpreter
- prog.py

Linux kernel

-EACCES

open(prog.py, O_MAYEXEC)

v4 & planned for v5

Kernel support currently in progress upstream \(^6\)

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Updates

Goals

◮ Unattended, automatic and in the background updates
◮ User-controlled rollback at boot time

Implementation

◮ Signed packages (v4) & images (v5) transmitted over HTTPS over IPsec
◮ v4: Installed at boot time for the core / runtime for GUI environments
◮ v5: Installed in background and effective on reboot
**Full boot chain integrity guarantee (v5)**

**Goal**

Guarantee full system integrity even in the event of a system compromise

- Will only boot if the system’s integrity can be cryptographically verified
- Based on UEFI Secure Boot feature:
  - Signed bootloader, initramfs, Linux kernel and its command line
  - Read-only system partition (Squashfs) protected by DM-Verity (with forward error correction)
  - Custom keys (i.e. not signed by Microsoft, requires enrollment in hardware)

Diagram:

1. UEFI Firmware
2. Bootloader
3. EFI Binary (Linux kernel + initramfs + kernel command line)
4. Read-only rootfs (DM-Verity)
Password-less encrypted partitions (v5)

Implementation

- Automatic secret sealing & unsealing with a TPM 2.0
- Based on boot chain integrity measurements

Diagram:

1. Firmware configuration
2. Secure Boot configuration
3. UEFI Firmware
4. Bootloader
5. TPM (PCR)
6. EFI Binary (Linux kernel + initramfs + kernel command line)
7. Sealed LUKS key
8. Cleartext LUKS key
9. Read-write state partition (DM-Integrity + DM-Crypt)
Project status (v5)

- First alpha release in September 2018
- Now close to beta release
- Current use-case: server & virtualization (no graphical user interface)

```bash
This is clipos-qemu.unknown_domain (Linux x86_64 5.0.14-clipos) 14:07:12
Hint: Num Lock on

clipos-qemu login: root
clipos-qemu ~ # lsblk
NAME   MAJ:MIN   RM SIZE RO TYPE MOUNTPOINT
vda    254:0     0   20G 0 disk
l-vda1  254:1     0  512M 0 part /mnt/efiboot
`-vda2  254:2     0  19.5G 0 part
 |  `-mainvg-core_5.0.0--alpha.1 253:0     0   4G 0  lum
 |  `-verity_core_5.0.0--alpha.1 253:3     0  177M 1  crypt /
 |  `-mainvg-core_state 253:1     0  512M 0  lum
 |  `-core_state_dif 253:4     0  474M 0  crypt
 |  `-core_state 253:5     0  474M 0  crypt /mnt/state
 |  `-mainvg-core_swap 253:2     0   1G 0  lum
 |  `-swap 253:6     0   1G 0  crypt [SWAP]
clipos-qemu ~ # uname -sr
Linux 5.0.14-clipos
clipos-qemu ~ #
```
Roadmap: 5.0 Beta

Completed
- "Unprivileged" admin, audit and update roles
- SSH server (for audit, admin and debug)

In progress
- Client for automatic updates
- Confined IPsec client
- Basic network (DHCP, static IP) and firewall (static rules) support
Roadmap: 5.0 stable

**Planned**

- Confined user environments (GUI)
- Multilevel support (Linux-VServer like LSM)
- Automated installation using PXE
- etc.
Remaining challenges

Hardware sharing

- Workarounds available for audio, video, smartcards
- Partial solution for USB devices
- Safe access to filesystems on USB devices?
- Safe USB devices? (see WooKey project\(^7\))

Application confinement

- Flatpak (planned for v5)

\(^7\)https://github.com/wookey-project
**Conclusion**

**Pragmatic approach**
- Defense in depth instead of single strong barrier
- Properly configured system: safe by default

**Built to be reusable for multiple use cases**
- May need some adaptation work for integration into an IT infrastructure

**Open source project**
- Sources: [https://github.com/CLIPOS](https://github.com/CLIPOS)
- Bugs: [https://github.com/CLIPOS/bugs](https://github.com/CLIPOS/bugs)
- Documentation: [https://docs.clip-os.org](https://docs.clip-os.org)
- Code review: [https://review.clip-os.org](https://review.clip-os.org)
Thanks!

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