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][2]:
  - 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

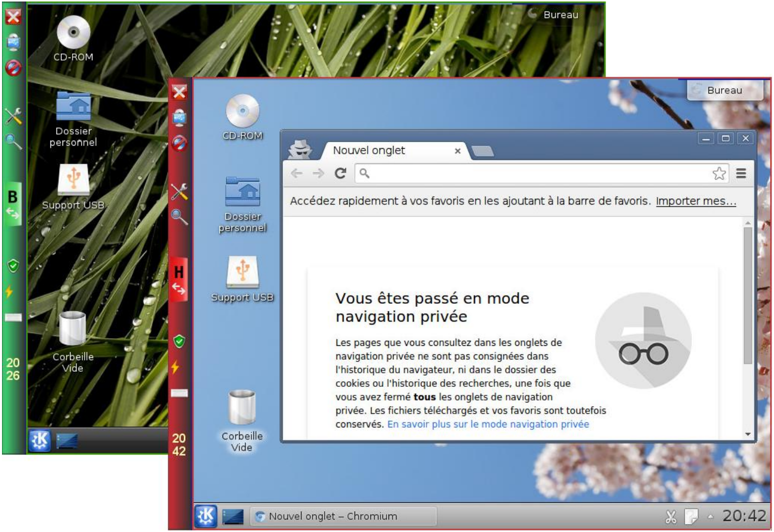
Targets three main use cases

- Mobile office workstation
- Remote administration workstation
- IPsec gateway

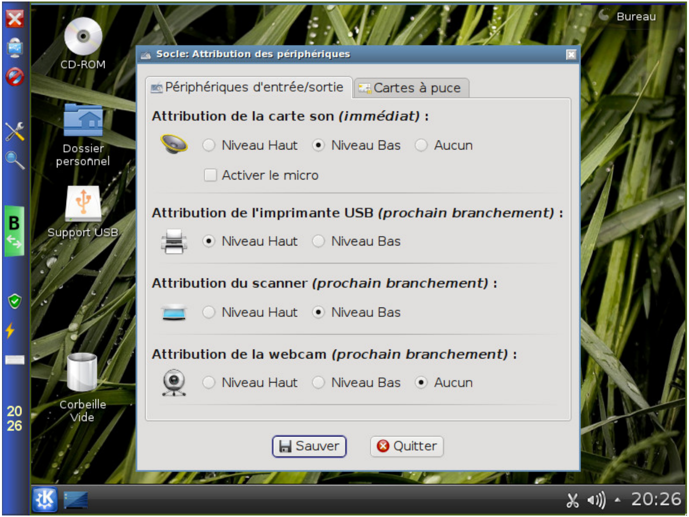
Hardened OS

- 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

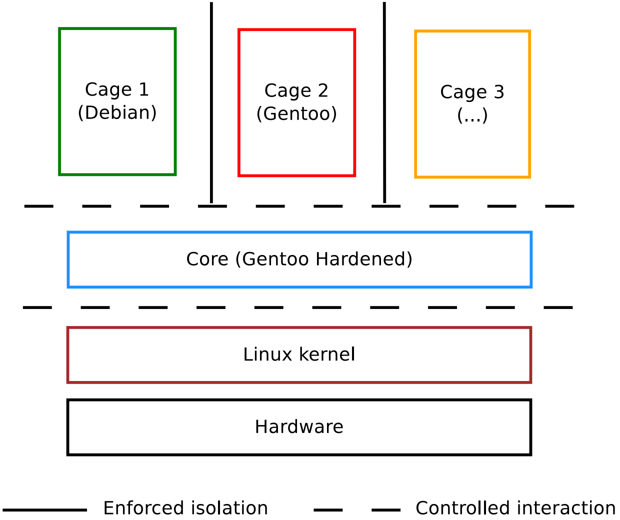
Goals

- 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



Defense in depth

Concepts

- Minimal attack surface
- Isolation based on containers

Implementation

- All services confined in Linux "containers"

v4

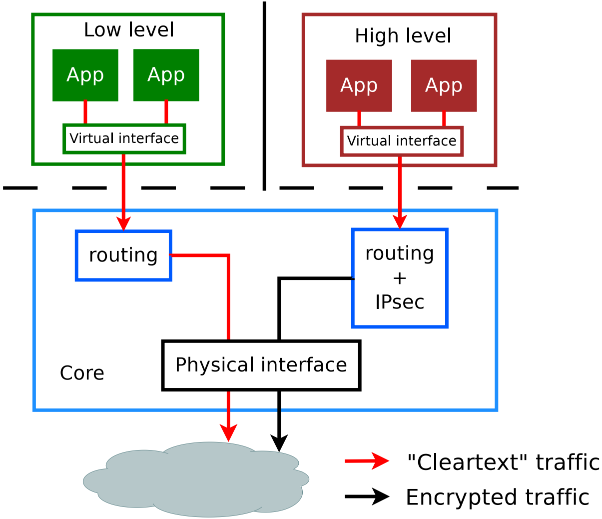
- Additional isolation using Linux-VServer
- Specific Linux Security Module (CLIP-LSM) & capability split

v5

- Linux-VServer like LSM (early development stage)
- Landlock[3](planned)

[3] See landlock.io

Network level isolation



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)

[4] https://www.zdnet.com/.../microsoft-70-percent-of-all-security-bugs-are-memory-safety-issues/
[5] https://github.com/caml-pkcs11/caml-crush

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.)

Additionnal 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

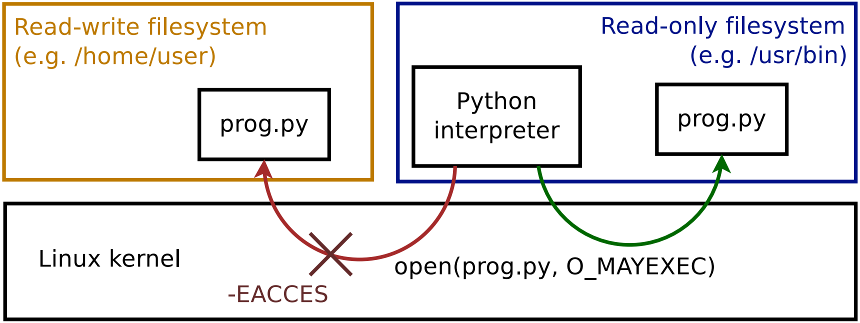
v4

- 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



v4 & planned for v5

- Kernel support currently in progress upstream[6]

[6] See the talk at Kernel Recipes 2018, Paris (https://clip-os.org/en/talks)

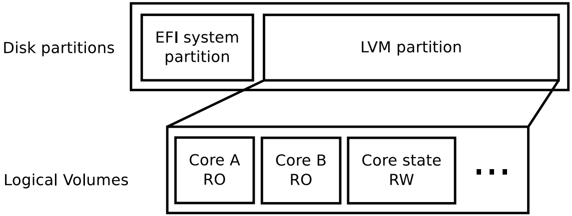
Updates

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

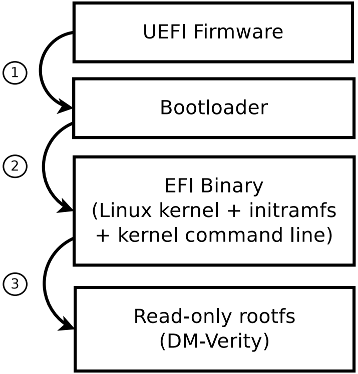


Full boot chain integrity guarantee (v5)

Goal

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

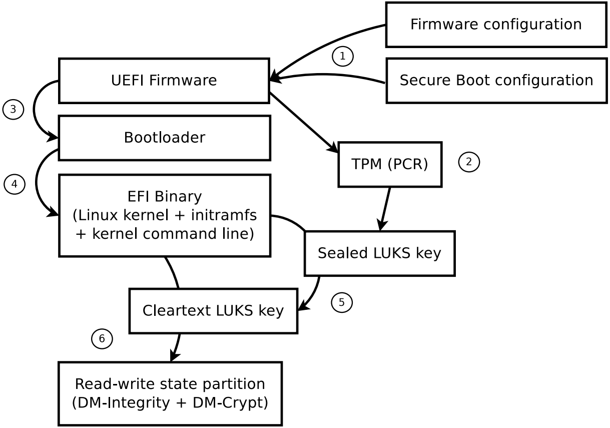
- Will only boot if the system's integrity can be cryptographically verified
- Based on UEFI Secure Boot feature:
  - Signed bootloader, initramfs, Linux kernel and its command line
  - Read-only system partition (Squashfs) protected by DM-Verity (with forward error correction)
  - Custom keys (i.e.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



Password-less encrypted partitions (v5)

Implementation

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



Project status (v5)

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

```
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
|-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 lvm
  | `-verity_core_5.0.0-alpha.1 253:3    0  177M  1 crypt /
  |-mainvg-core_state           253:1    0  512M  0 lvm
  | `-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 lvm
    `-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
- Bugs: https://github.com/CLIPOS/bugs
- Documentation: https://docs.clip-os.org
- Code review: https://review.clip-os.org

Thanks!

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- Website: clip-os.org
- Docs: docs.clip-os.org
- Sources: github.com/CLIPOS
- Bugs: github.com/CLIPOS/bugs