Image-based Linux with systemd

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What have systemd developers been up to?

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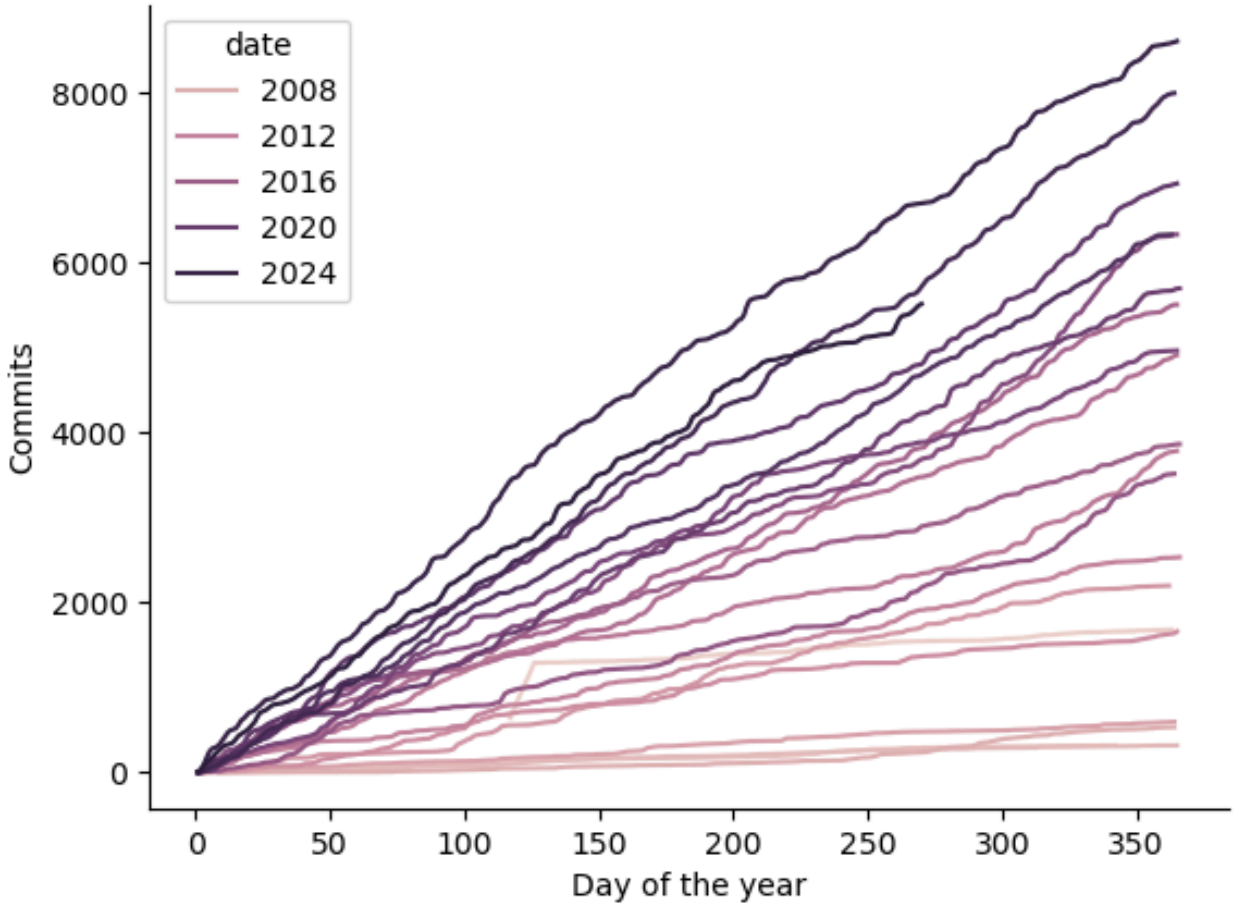

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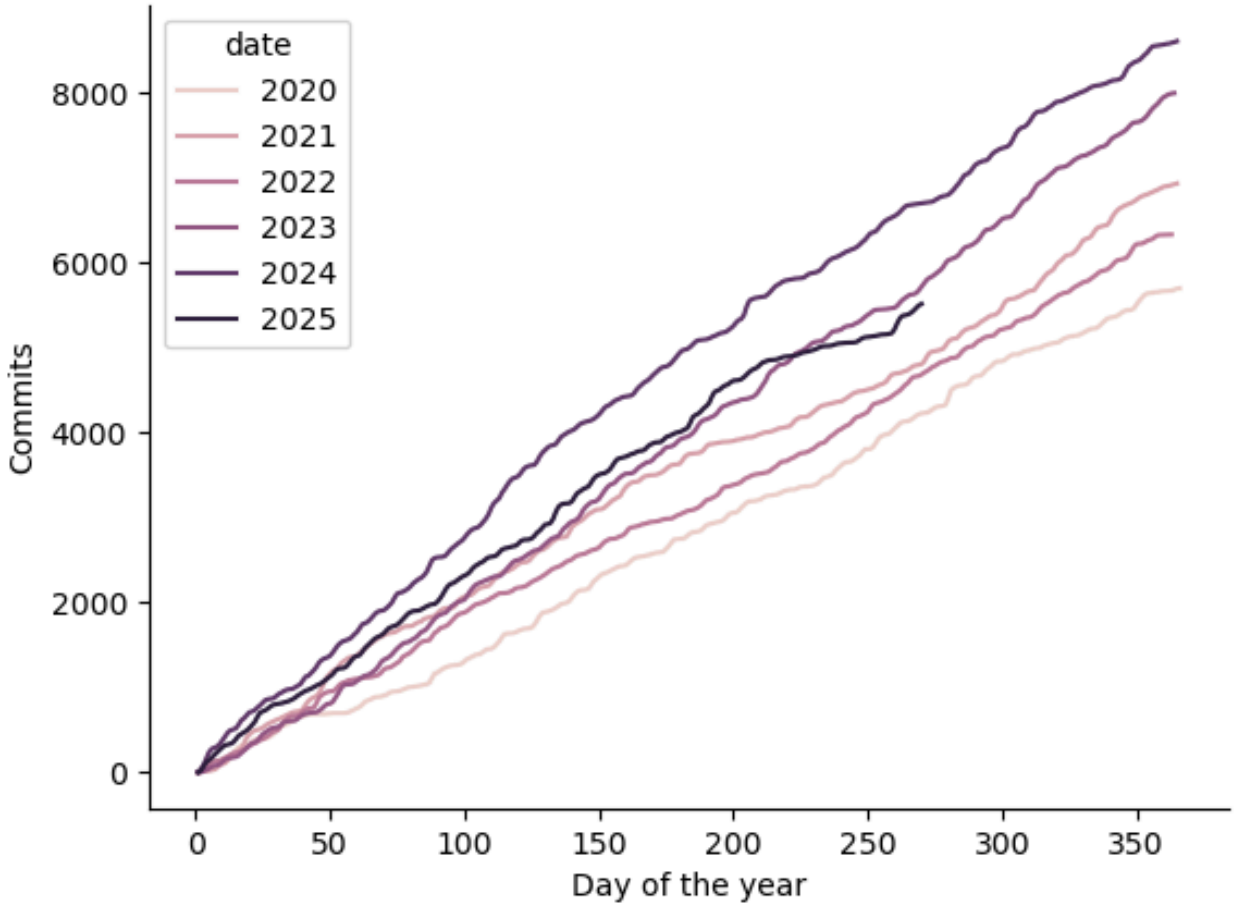

What have systemd developers been up to?

- few new features directed at “traditional system adminstration”
- a lot of new code for “image-based systems”

Linux systems in 2025

always connected ,
untrusted physical environment *and* untrusted payloads
=> always exposed

traditional installations: mutable package-based system

- each system is a snowflake
- changes are non-atomic
- modifications are persistent

Why image-based systems?

want to verify authenticity *at runtime*

=> signed

=> immutable

=> image-based

What have systemd developers been up to?

New(-ish) components

`systemd-pcrextend`, `systemd-creds`, `systemd-homed`, `systemd-cryptenroll`, `systemd-cryptsetup`, `systemd-repart`, `systemd-measure`, `systemd-pcrlock`, `systemd-dissect`, `systemd-tpm2-setup`, `systemd-tpm2-clear`, `systemd-veritysetup`, `systemd-gpt-auto-generator`, `systemd-boot`, `systemd-stub`, `systemd-sysupdate`, `ukify`, `mkosi`

What needs to be done?

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Building images: mkosi

“make operating system image”

see mkosi: Building Bespoke Operating System Images @ ASG 2023
systemd-repart: Building Discoverable Disk Images @ ASG 2023

Building images: why mkosi?

- builds images from packages
- developed in tandem with systemd
- lightweight: heavy lifting is delegated to `systemd-repart`, `dnf`/`apt`/`pacman`/`apk`, `mkfs.btrfs`/`mkfs.ext4`/`mkfs.xfs`, `systemd-firstboot` and other tools
- systemd-style configuration (ini files, drop-ins, match sections)
- fully offline (no VMs, no loopback devices, plain file IO)
- Fedora/Debian/Kali/Ubuntu/PostmarketOS/ArchLinux/OpenSUSE/Mageia/CentOS/RHEL/RHEL-UBI/OpenMandriva/Rocky/Alma/AzureLinux

Why mkosi?, part II

mkosi-initrd: “build initrds from distro packages”

We reuse the same code for the initrd, the OS, the exitrd.

DEMO!

mkosi + OBS

(Open Build Service @ SUSE)

mkosi is “local first”

goal: IBaaS (image builds as a service)

- customization via declarative config
- multiple distros
- multiple architectures
- automated rebuilds
- secure signing

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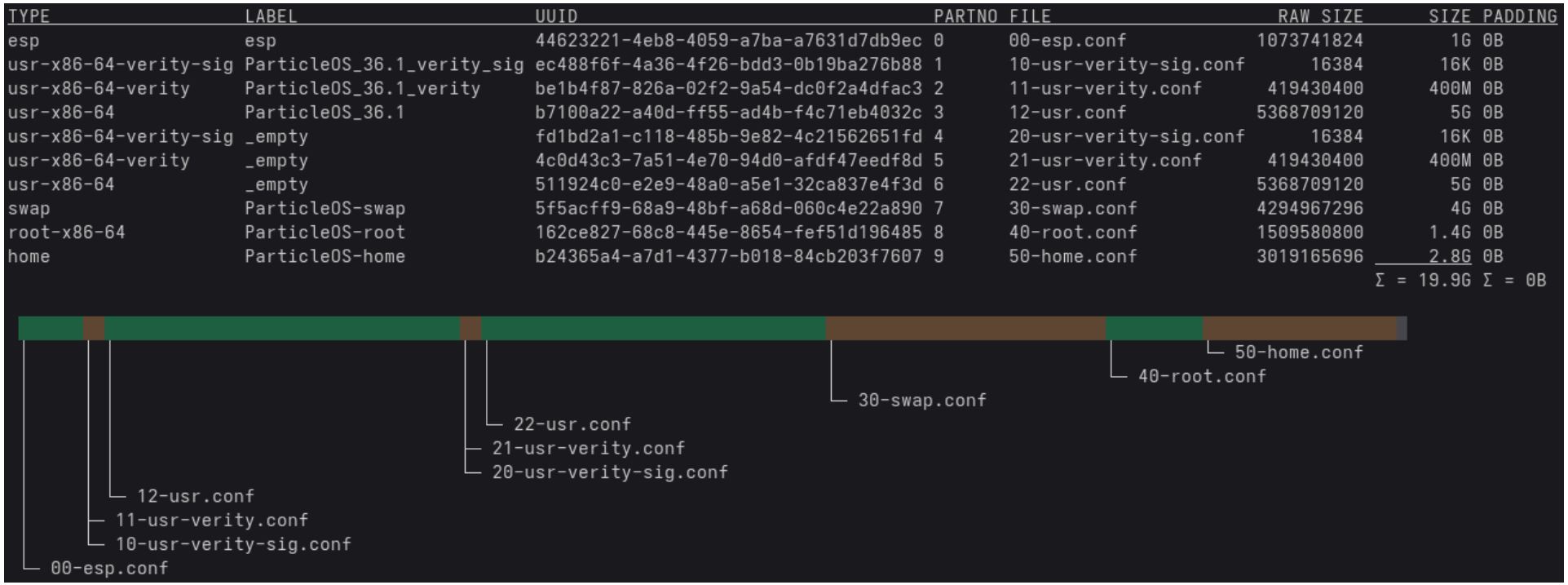
How to install?

- the system is “immutable”
- … but `dd` is not enough!
  (GPT sector size, sector alignment, partition UUIDs)

`systemd-repart`

“online and offline partitioning based on declarative data”



How to install?

Our answer: copy partition *contents*, initialize the rest on the fly

- `systemd-repart` with `CopyBlocks=auto`: copy read-only partitions, dm-verity and signatures
  initialize partition structure for system A/B updates, encrypted storage
- `systemd-cryptsetup`: lock the encrypted storage to TPM

How to install?

Installers used to be very complex => better to do configuration in the live system

Features/InitialExperience (Fedora 19)
Changes/ReduceInitialSetupRedundancy (Fedora 28)
Changes/Unified_KDE_OOBE (Fedora 44)

`systemd-firstboot`

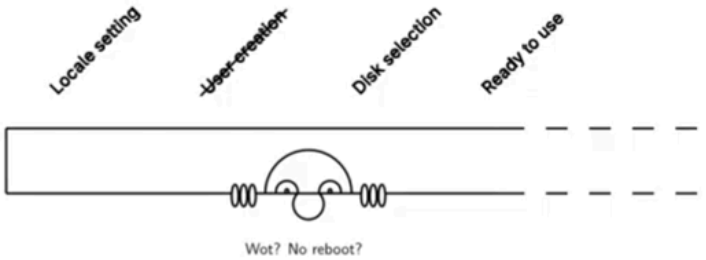
DEMO!

How to install?

Do we **need** to reboot?

GNOME OS' prêt-à-booter image @ ASG2025

Installation: GNOME OS way



(youtube)

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Verify before running

Traditional SecureBoot with shim which checks `vmlinuz` but not the initrd or the kernel command line is security theater.

UKI — Unified Kernel Image
`=>` a single file with the kernel, initrd, command line, device tree, microcode
signed as a whole

`ukify` builds UKI images — `objcopy` on steroids

SecureBoot and measured boot are available to anyone

- real deployements would use a “proper” key
- for development, we make our own

`systemd-boot` supports autoenrollment

- put files in `/loader/keys/auto/` (`KEK.auth`, `PK.auth`, `db.auth`, `dbx.auth`)
- put machine in SB setup mode
- set `secure-boot-enroll if-safe`
- set `secure-boot-enroll-action reboot`

SecureBoot vs. measured boot

SecureBoot: hardware manufacturers embed their own key
-> those keys sign the main Microsoft key
-> that signs … many shims for Linux
-> that trusts distro artifacts

- a **very** wide tent

measured boot: TOFU, unlock secrets if state is good, establish trust

tl;dr: generate own key, use `ukify` to build signed UKIs, enroll key on first boot

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Measure what is run

UEFI measures shim,
shim measures the boot loader,
the boot loader measures the UKI

```
systemd-pcrextend --machine-id/--file-system=/$phase
```

systemd devides runtime into phases:
“enter-initrd”, “leave-initrd”, “sysinit”, “ready”

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Binding secrets to TPM PCR state

TPM PCRs reflect system state: firmware hash, SecureBoot database hash, boot loader hash, UKI hash…

`systemd-pcrextend` records more state

two major approaches:

1. bind secrets to a TPM PCR digest
2. bind secrets to a public certificate hash signing a TPM PCR digest

Binding secrets to TPM PCR state

`systemd-measure` — precalculate PCR measurements for UKI & phase, sign a policy digest with a private key

`ukify` — gather those signed digests and embed them in the UKI

`systemd-cryptenroll` & `systemd-cryptsetup` — enroll and decrypt a disk via via public key infra

`systemd-creds` — the same for credentials

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Downloading images

(`mkosi` to build the new image)

`systemd-sysupdate` implements a downloader that does A/B updates

`systemd-sysupdated` + `updatectl` a daemon+client service for updates

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Protect user data

`systemd-homed` manages home directories with per-user encryption

`homectl`, `pam_systemd_home.so`

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How to make changes to the shiny new *immutable* system?

First answer: don't

flatpaks for apps

custom images

Second answer: verified extension mechanisms

- initrd variants — multi-profile UKIs
- "addons" → checked via SecureBoot db / shim
- systemd-sysexts
- systemd-confexts → checked via kernel keyring
- credentials → encrypted via TPM|local key

Credentials

- `systemd.hostname` — set basic host information
- `firstboot.locale|keymap|timezone` — set basic host information
- `passwd.hashed-password.$user` / `passwd.shell.$user` — like `usermod`
- `fsck.mode` — new `/forcefsck` and `/fastboot`
- `quotacheck.mode` — new `/forcequotacheck`
- `home.add-signing-key.*` — provision homed user record signing keys
- `home.register.*` — create user automatically at boot
- `systemd.unit-dropin.*` — tweak various units
- `vmm.notify_socket` — establish notification channel to the host
- `ssh.listen` — establish ssh access
- `ssh.authorized_keys.root` — backdoor sshd
- `ssh.ephemeral-authorized_keys-all` — backdoor sshd harder

https://systemd.io/CREDENTIALS/

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Factory reset

“all state, user data, and configuration is wiped”

- “the system” is in `/usr` — everything else can go
- `systemd-factory-reset`
- `systemd-repart --factory-reset`
- `systemd-tpm2-clear`

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questions?