Linux on a Confidential VM in a cloud: where's the challenge?

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Confidential VM types on public clouds

- Google Cloud Platform
  - C2D/N2D (AMD SEV), (AMD SEV) option announced in June, 2020.
  - N2D (AMD SEV-SNP), (AMD SEV-SNP) option private preview announced in April, 2023; public preview since January, 2024.
- Microsoft Azure
  - DCasv5/ECasv5 (AMD SEV-SNP), preview announced in November, 2021 GA announced in June, 2022.
  - DCesv5/ECesv5 (Intel TDX), private preview announced in April, 2023 public preview announced in November, 2023.
- Amazon Web Services
  - M6a, C6a, and R6a (AMD SEV-SNP), SEV-SNP feature GA announced in May, 2023.

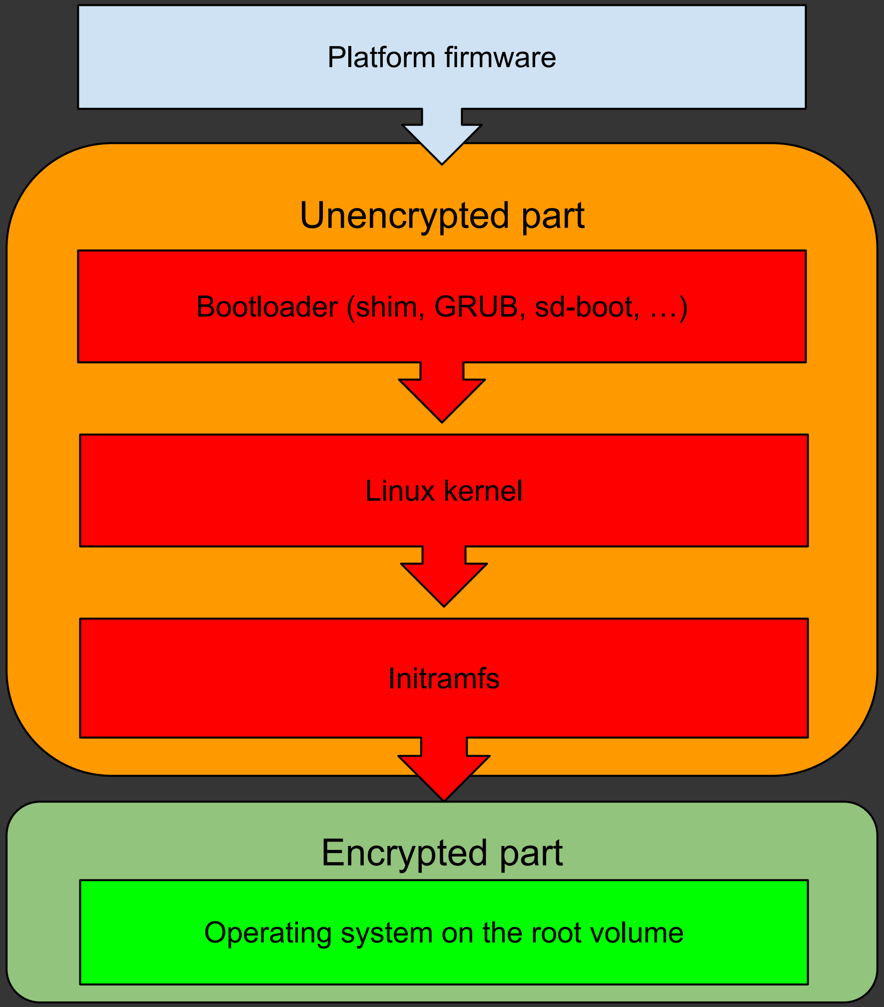
Guarantees

- **Confidentiality guarantees provided by hardware:**
  - VM's memory is encrypted.
    - Encryption is 'transparent' when observed from within the VM.
  - CPU state is encrypted (SEV-ES/SEV-SNP, TDX).
  - Memory integrity guarantees are provided (SEV-SNP, TDX).
- **Confidentiality guarantees NOT provided by hardware:**
  - Protection of data at rest (must be ensured on the guest level!).
  - Protection of data in transit (not specific to CVM).
- **Guarantees which CANNOT be provided with existing hardware:**
  - Non-disruption guarantees.

Protecting data "at rest"

- Must be done at the guest (not host!) level.
- OS data must be protected too:
  - Sensitive OS data (configuration files, private keys, random seed, etc.) must be fully protected (==encrypted)
  - The rest of the operating system (e.g. executable files) requires at least "write protection" from the host (encrypted and/or integrity checked)
- Standard tools (e.g. LUKS for encryption, dm-verity for integrity checking) can be used as the key in memory is protected.
  - … but how does the guest get the right key/hash?

Encryption



Standard Linux boot process

Root volume is encrypted, the key is provided at initramfs time.

Encryption

- Providing a key "manually" (e.g. by entering a password through console) is doomed to be not only inconvenient, but also insecure.
- Keys to sensitive data must be provided to the guest in an automated fashion only after checking that it is in "known good state":
  - The guest is running in a genuine CVM.
  - All the code which was executed on the CPU (loaded from unencrypted part) is "trusted".
  - These properties must be proved to a trusted **third party** holding the key.

vTPM can (sometimes) be used as a trusted “third party”

- Different implementations of vTPM
  - As part of firmware running in a different “trust level”.
  - As a separate “domain”.
  - As a separate “partition”.
  - As an emulated device on the host.
- Different types of vTPM:
  - Stateful
  - Stateless

Stateful vTPM

- Implementation examples:
  - Azure SEV-SNP, Azure TDX
  - AWS SEV-SNP
  - GCP SEV-SNP
- The “state” may be isolated from the host:
  - Azure SEV-SNP/TDX claim to provide the isolation.
  - Isolation claims cannot be proved from within the guest.
- When vTPM’s public key (e.g. SRK) is known, it allows to implement “pre-encryption” of the root volume.
- Self-encryption upon first boot can (in theory) be implemented without the need to know public key in advance.

Stateless (ephemeral) vTPM

- Implementation example: Azure TDX.
- In theory, allows for "zero trust" solutions.
- **Should** be implemented as part of firmware and thus can be measured/attested by the guest:
  - Simpler with SEV-SNP, harder with TDX.
  - In theory, can be brought by cloud user ("bring your own firmware") but no real world implementations yet.
- Could not be used to store/protect secrets, an external attestation server is needed.
  - An intermediary key can be injected after successful attestation thus reproducing "stateful" experience.

Stateful vTPM with no explicit confidentiality guarantees

- Implementation example: AWS SEV-SNP, GCP SEV-SNP
- Can't be used if isolation from the host is a must :-(
- Can simply be "ignored":
  - An external attestation server is needed.
  - A non-vTPM unlocking method for root volume is required, no "standard" for that yet.
  - It's unclear whether PCR measurements can still be used or not (implementation specific).

Verifying unencrypted part

- Traditionally, SecureBoot/Measured boot technologies are used for early boot integrity protection.
    - ***SecureBoot: all artifacts in the boot chain are signed by known keys***
    - ***Measured boot: all important information about boot process is recorded in TPM PCRs***
- To get initramfs under SecureBoot protection and get some 'verifiable' measurements, it must be built and signed by a trusted party (e.g. OS vendor).
- To use existing verification mechanisms, "Unified Kernel Image" concept is introduced:

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UKI implications: static initramfs

- **Initramfs is static** and built at kernel package build time
- The list of drivers and tools is fixed by the OS vendor, the applicable scope must be defined.
  - E.g. Fedora/RHEL ship "kernel-uki-virt" package with drivers needed for popular virt/cloud environments (Virtio, VMBus, Xen, NVMe,...).
- Systemd system extensions mechanism can be used to extend initramfs (with limitations)

UKI implications: static cmdline

- **Kernel command line is static** and built at kernel package build time
- Must be “one size fits all” so e.g. kernel-uki-virt in Fedora/RHEL ship with “console=ttyS0 console=tty0” cmdline.
- Passing “root=UUID” is not possible:
  - root volume must be auto discovered , e.g. with systemd-gpt-auto-generator systemd feature.
- “Signed extensions” mechanism for systemd-stub was recently added upstream.
  - Can be used both by the OS vendor and the instance owner (with limitations).

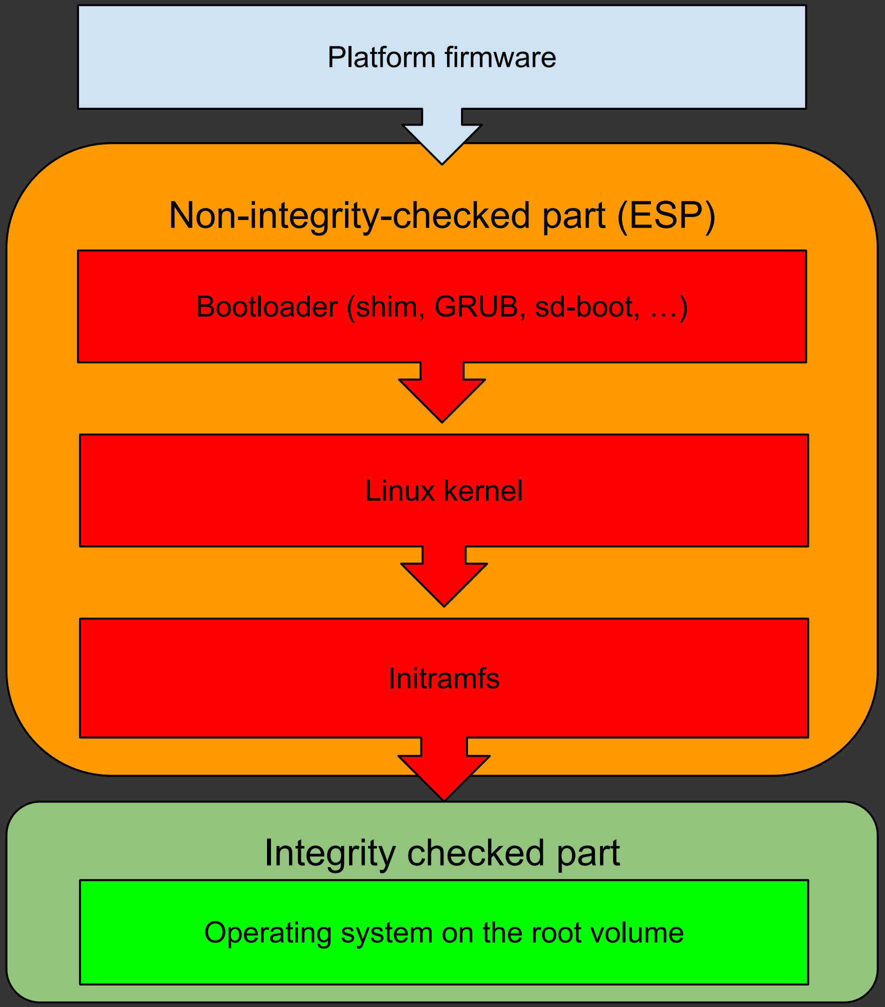
UKI implications: boot flow

- UKI is a UEFI binary and can be loaded:
  - Directly from firmware:
    - Signing key (vendor) must be in SecureBoot DB, revocations must use DBX.
  - By ‘shim’:
    - Signing key can be in SecureBoot DB, shim’s ‘vendor_cert’/’vendor_db’, MOK.
    - SBAT mechanism can additionally be used for revocations.
- No “bootloader UI” experience:
  - Fedora ships kernel-bootcfg (‘uki-direct’ package) for automatic UEFI boot variable management.

Attestation client/server

- Remote attestation **must** be used in all "Stateless vTPM"/"Untrusted vTPM"/"No vTPM" scenarios.
- The presented "evidence" can differ:
    - Different hardware technology (SEV-SNP, TDX).
    - Method to obtain measurements (directly from hardware, through vTPM,...)
    - vTPM/no-vTPM.
- No "standard" implementation for open-source attestation client/server atm
    - KBS project from CoCo looks promising!

Integrity checking



Standard Linux boot process

Root volume is integrity checked, the expected hash is known at initramfs time.

Integrity checking

- Must support runtime checking (e.g. dm-verity)
- Must be accompanied by a trusted kernel/initramfs (UKI)
- OS needs to know the expected root hash:
  - Can be built into UKI (not suitable for general purpose distro UKIs)
  - Can be a signed cmdline extension
  - Can be sourced from a signed file on ESP
- Can be accompanied by writeable overlay
  - All considerations for ‘encryption’ apply

Additional considerations: VM authenticity

- VM user needs a way to verify that they are connecting ('ssh …') to their own CVM and that protection mechanisms (SecureBoot, encryption, integrity checking,…) were actually used.
  - Customized (e.g. customer uploaded pre-encrypted) images can be tailored for the specific deployment and can contain pre-encrypted secrets.
  - Generalized (e.g. Marketplace) images normally support various types of deployment (different instance types, CVM/non-CVM, vTPM/no-vTPM,…) and thus require additional attestation.

Additional considerations: image contents

- Runtime guest agents
  - Cloud-init, WALA,... are **not** isolated from the host as the host provides the (untrusted) data source.
  - Malicious host can try emulating **any** cloud data source.
- Virtual hardware
  - Malicious host can try attacking the guest by presenting **any** device which has corresponding guest driver.
  - Emulated hardware (e.g. serial console) should always be considered ‘insecure’; no sensitive data should appear in the output/input.

Additional considerations: VM storage

- Replay attacks
  - Malicious host can try presenting an older version of guest's storage or some parts of it at any time.
- Source image integrity
  - Even when full disk encryption or integrity checking is in use, it is possible to present an older version of the source image.
  - A guest verifiable data about the source image must be conveyed.
  - No 'standard' way for doing this atm.

Thank you

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