# Enabling Hardware Security Modules for Confidential Computing

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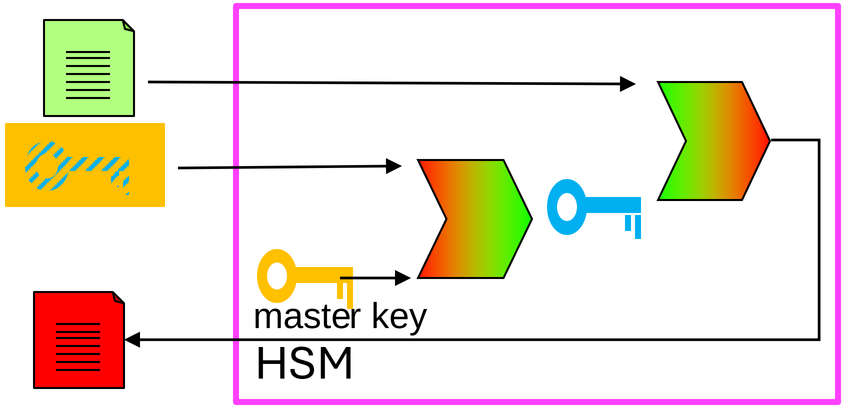
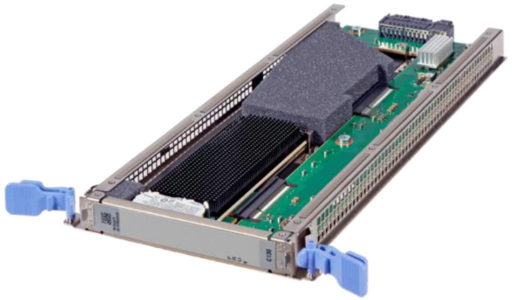
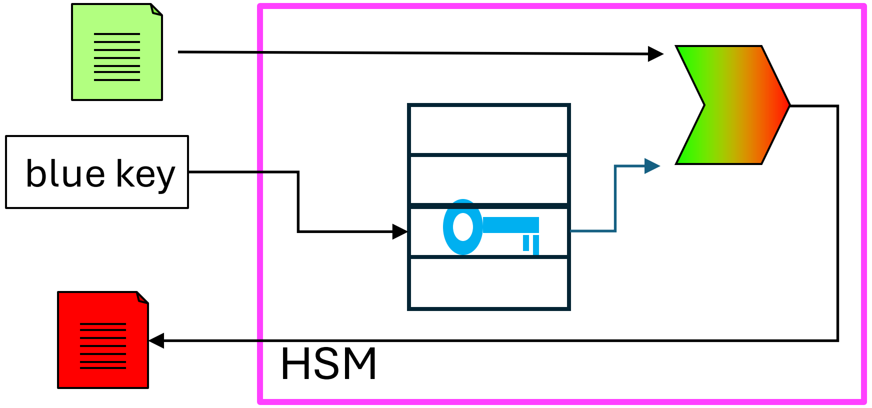
# What are Hardware Security Modules (HSMs)?

- Hardware device
- Protects keys objects:
  - HSM protected keys can only be used inside HSM
  - Plaintext values of HSM protected keys are not observable outside of HSM
- Good HSMs are tamper-respondent
  - Protect key material against physical attacks
  - Typically certified for FIPS 140-2/3 level ≥2
- Implements crypto operations
  - To generate HSM protected keys
  - Operating on HSM protected keys
- HSM protected keys are useless w/o access to HSM
  - an HSM is something you own



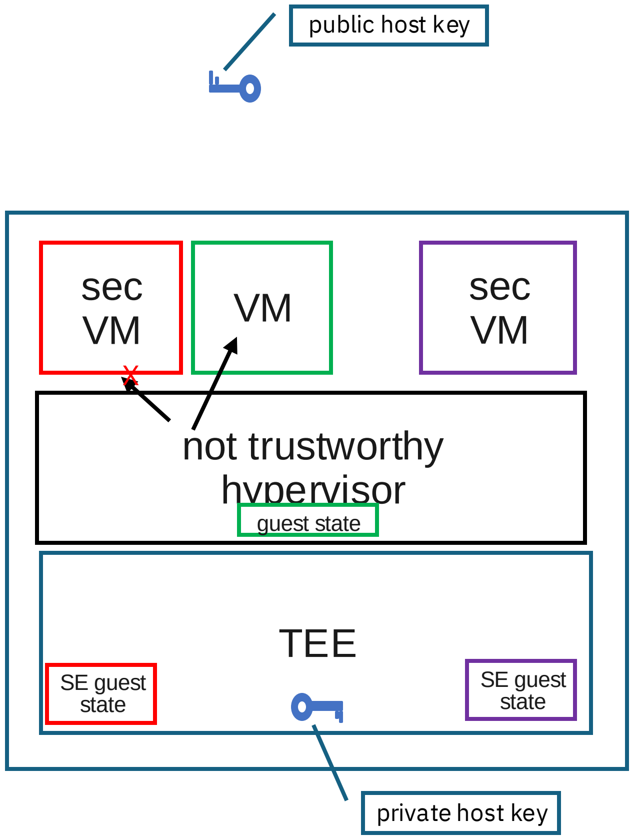







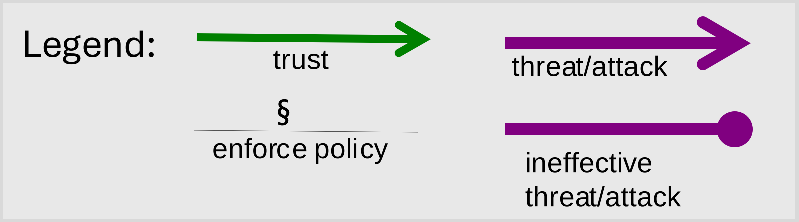
# Confidential Computing

- provides a trusted execution environment TEE for enclaves (mostly virtual machines*)
- such that the SW hosting the enclaves (e.g., hypervisor) and the administration of enclaves need not be trusted
  - hosting SW has no access to memory or registers of enclaves
  - TEE maintains sensitive state of enclave
- Examples: Intel SGX, IBM Secure Execution (SEL), AMD SEV, Intel TDX, ARM Realms




*) virtual machine (VM) aka guest

# Computation in the Cloud is a Matter of Trust

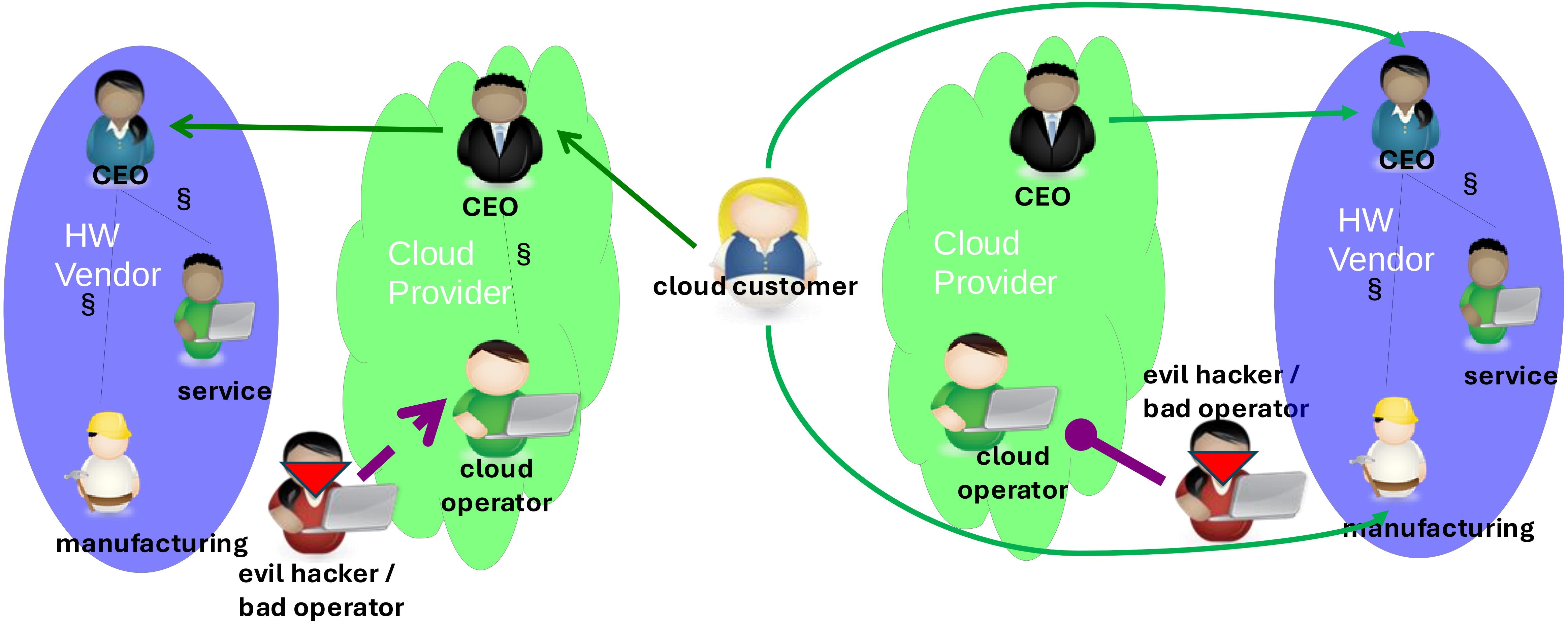



**“Traditional cloud trust model”**

- customer trusts good CEO
- good CEO enforces good policies on employees

**“Confidential Computing trust model”**

- customer trusts HW vendor



# Why do we use HSMs? What is the essence of an HSM?

(Other than checking a checkbox to satisfy a regulation)

An HSM is a means to protect cryptographic keys from being used *outside of* your system (which has access to the HSM).

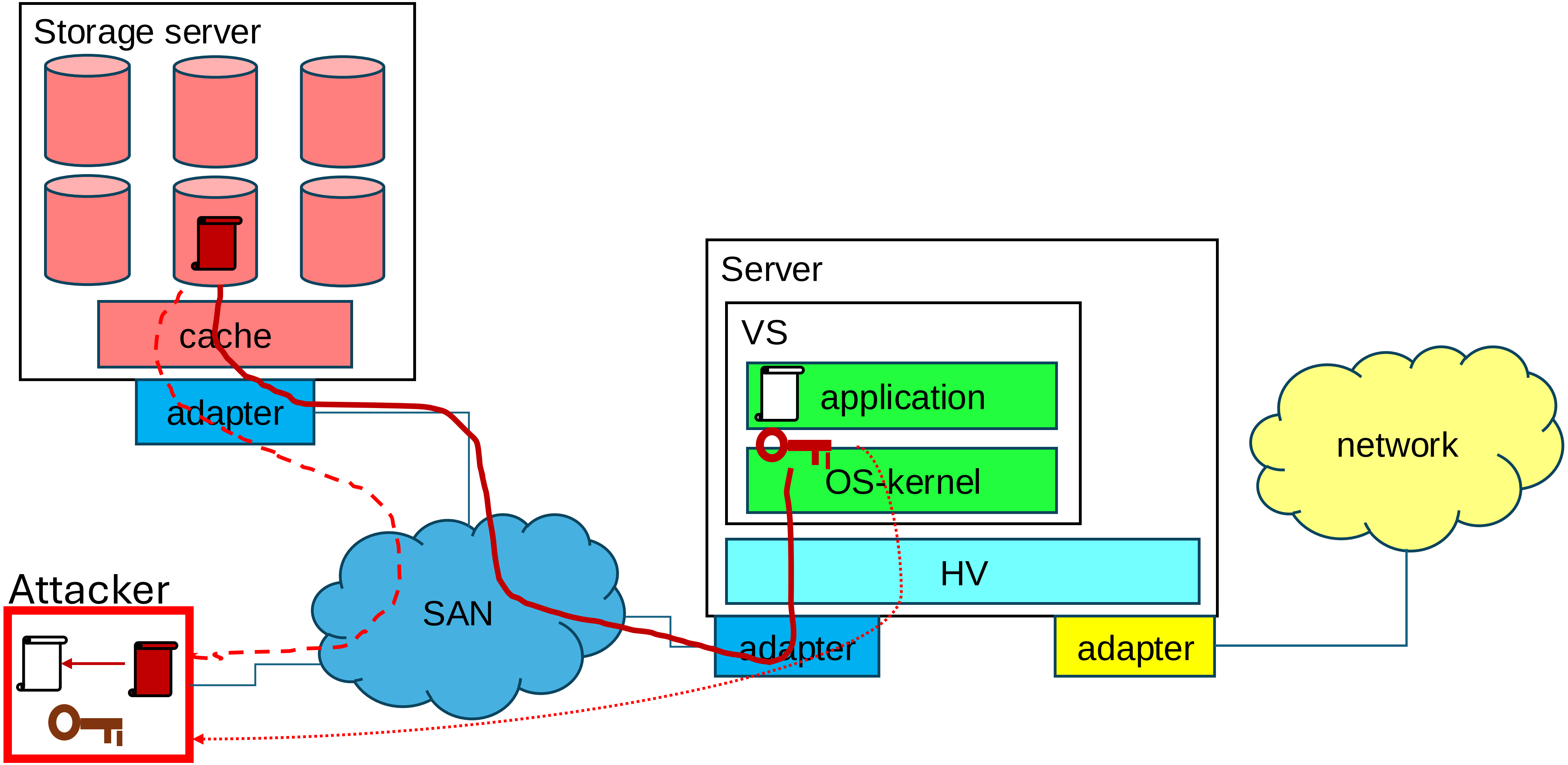
- Note, an HSM does *not* protect against an intruder in your system with root access who uses your system to observe or manipulate data.
- I.e., it protects against an **off-line attack** with your operational keys object stolen from
    - a running system (e.g., via a vulnerability like Heartbleed) or
    - a storage medium

Therefore, an HSM must be

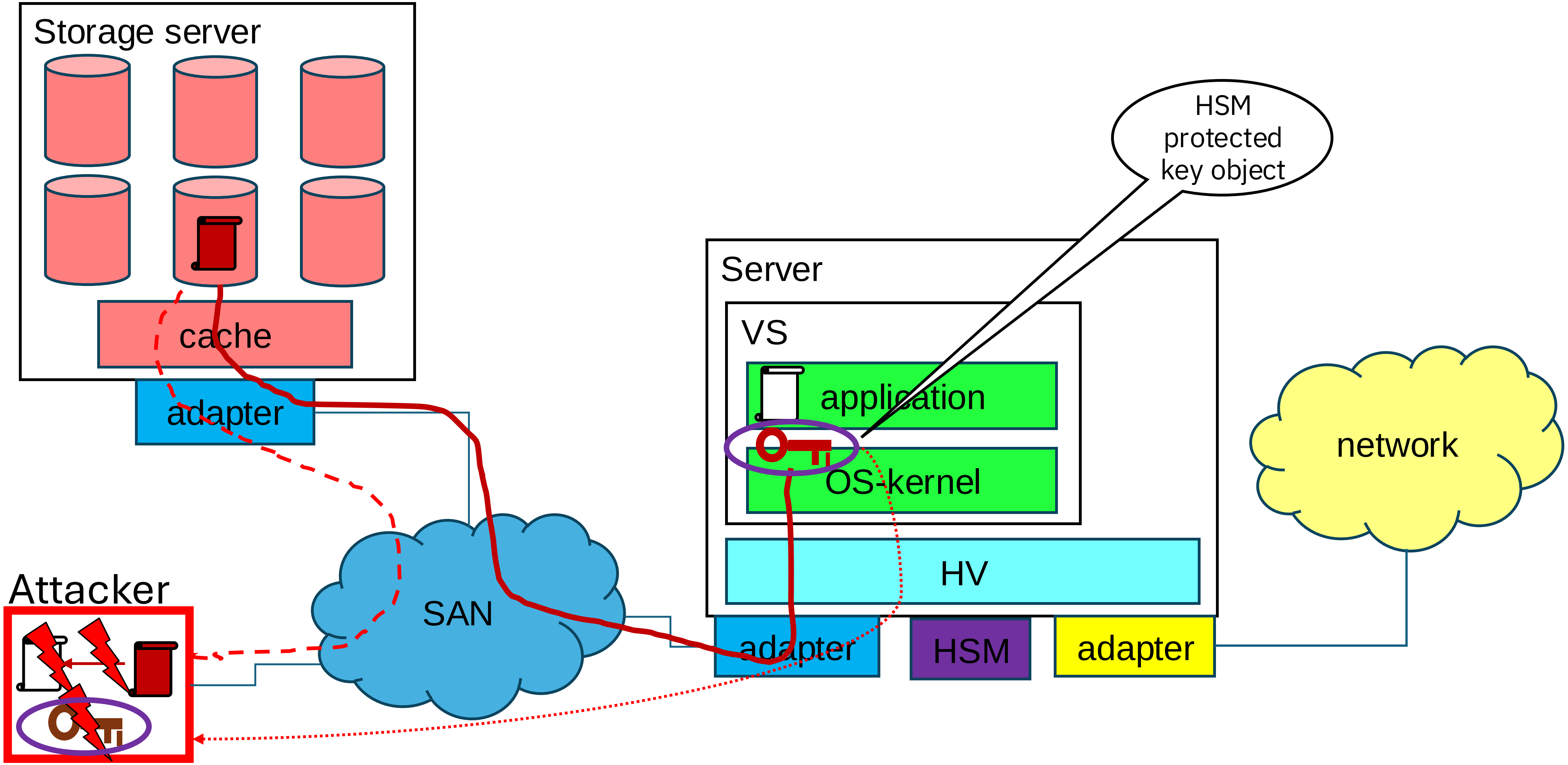
- something you own
- something that only you can use
    - remember the PIN of your credit card that protects it against lost/theft

Conclusion: **an HSM is a device that renders stolen keys useless**

# Example E2E Data Encryption: w/o HSM protection



# Example E2E Data Encryption: preventing off-line attacks with keys that cannot be stolen



# So, what is wrong with using an HSM in a non-trusted cloud?

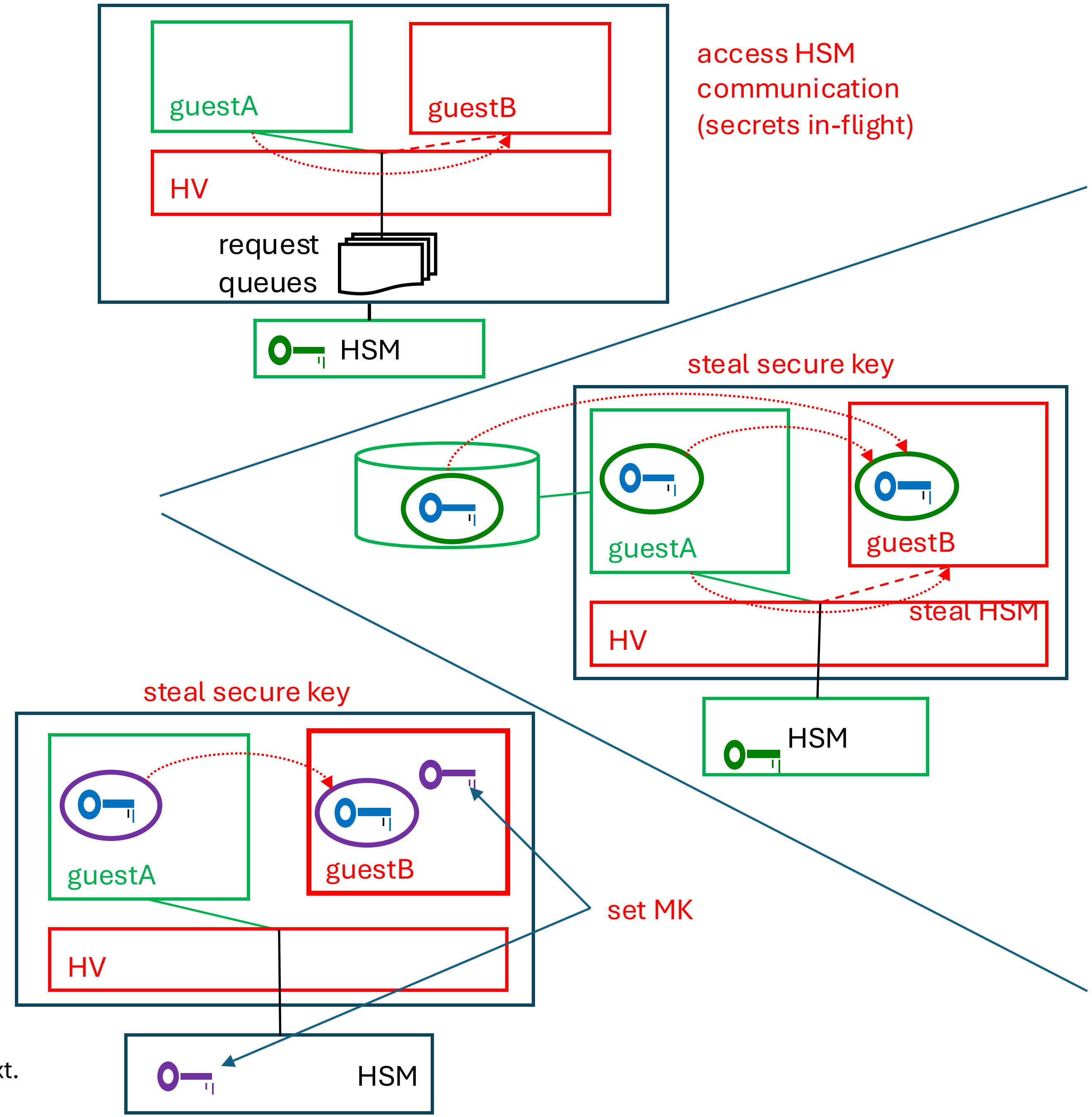
- Stealing an HSM is easy for the cloud admin: just a matter of device assignment to another system.
  - Steal both an HSM protected key and the HSM (by assigning it to the thief‘s guest) then you can use the stolen HSM protected key offline.
- So why not use a PIN?
  - Interactive entry of PINs is not reasonable on a server.
  - So, you must store the PINs somewhere, but then stealing that PIN is as easy as stealing the HSM protected key ☹
- What about network HSMs?
  - You need secrets to authenticate against the network HSM.
  - On a server you must store those secrets somewhere, but then stealing that secret is as easy as stealing the HSM protected key ☹

# Attacks on HSM usage by a guest in a virtualized environment

1. The attacker accesses HSM used by guest and reads crypto request or response
   - SIE* design allows to configure AP queue of a running guest to another component (hypervisor/HV or guest) such that a new owner can read responses of requests submitted by guest

2. The attacker both steals a secure key from guest and “steals” (i.e., configures) access to HSM to component owned by attacker
   - in a virtualized environment, an HSM is no longer something you own

3. The attacker presents an HSM to guest that is configured by attacker
   - secure keys generated on HSM are no longer secret as attacker may know HSM master key




*) SE = start interpretive execution, is the s390x instruction to enter a VM context.

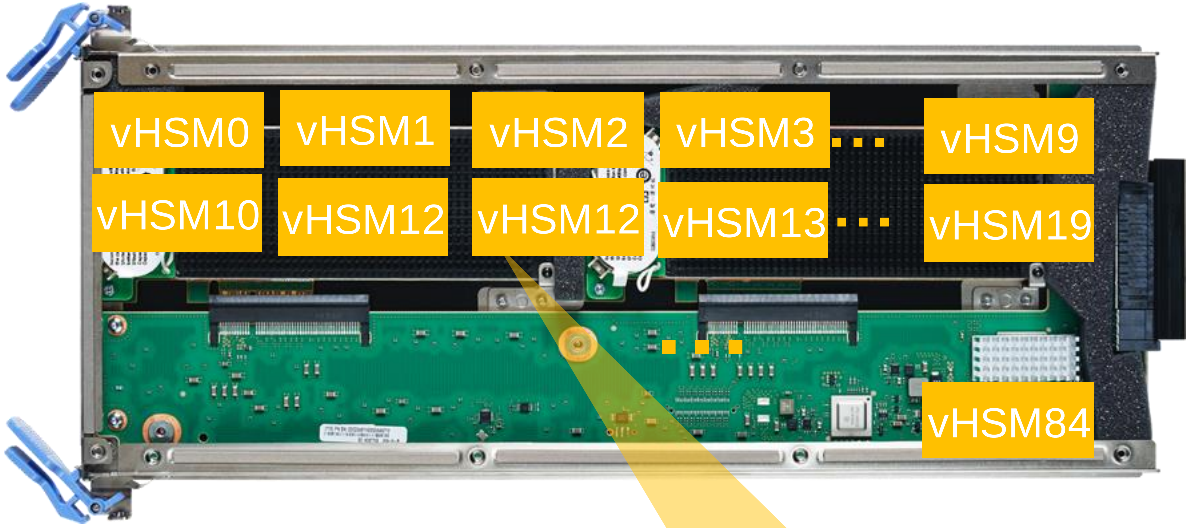
# Crypto Express Adapters

**Three different firmware loads**

– Accelerator mode

– Hardware Security Modules (HSMs):

- CCA mode
- EP11 mode




crypto adapter domain or AP queue with a master key of its own
=>
virtual HSM

**Mostly stateless HSM**

- **HSM protected keys (secure keys) are keys wrapped by a HSM master key**
- **the HSM master key cannot be extracted from the HSM**

**Adapter virtualization**

– Adapter can be partitioned into different domains of the same mode (separate master keys per domain)

– Crypto Express 8 (CEX8S) up to 85 domains

– KVM guests have passthrough access to AP queue

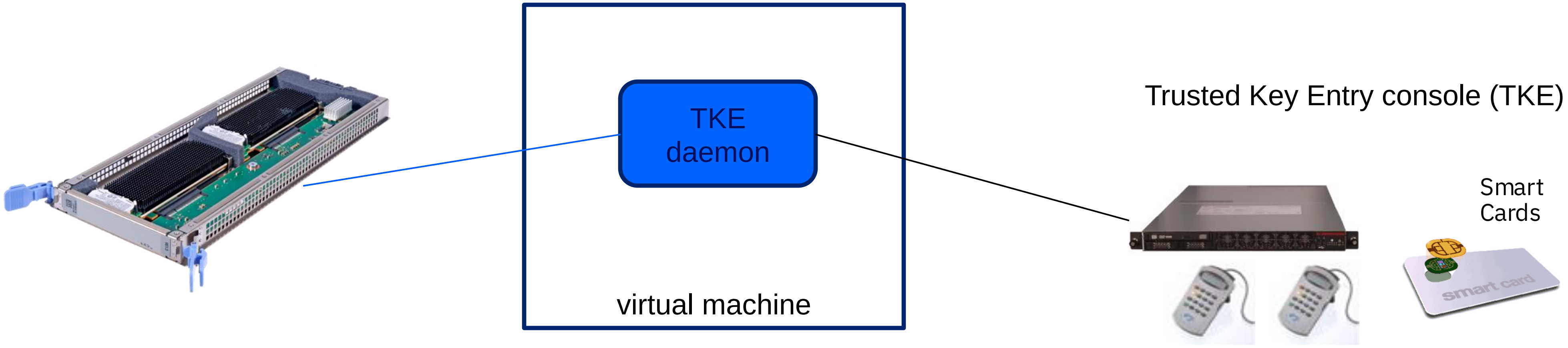
CCA mode certified as PCI HSM

FIPS 140-2 Level 4 certified

# CEX domain / master key configuration

The Trusted Key Entry console (TKE) is the management interface to configure domains in  Crypto Express adapters

– allows to take ownership of an adapter domain
  - enforces dual control
    – n out of m signatures for configuration requests
  - set master keys in Crypto Express domains
    – manages key (parts) with a build-in HSM and smart cards



# IBM Secure Execution for Linux (SEL)

**IBM z15 and IBM® LinuxONE III**

Neither HW management console nor Linux/KVM host can access

- CPU state of SEL guest*
- memory of SEL guest

A special trusted firmware component called ultravisor (UV)

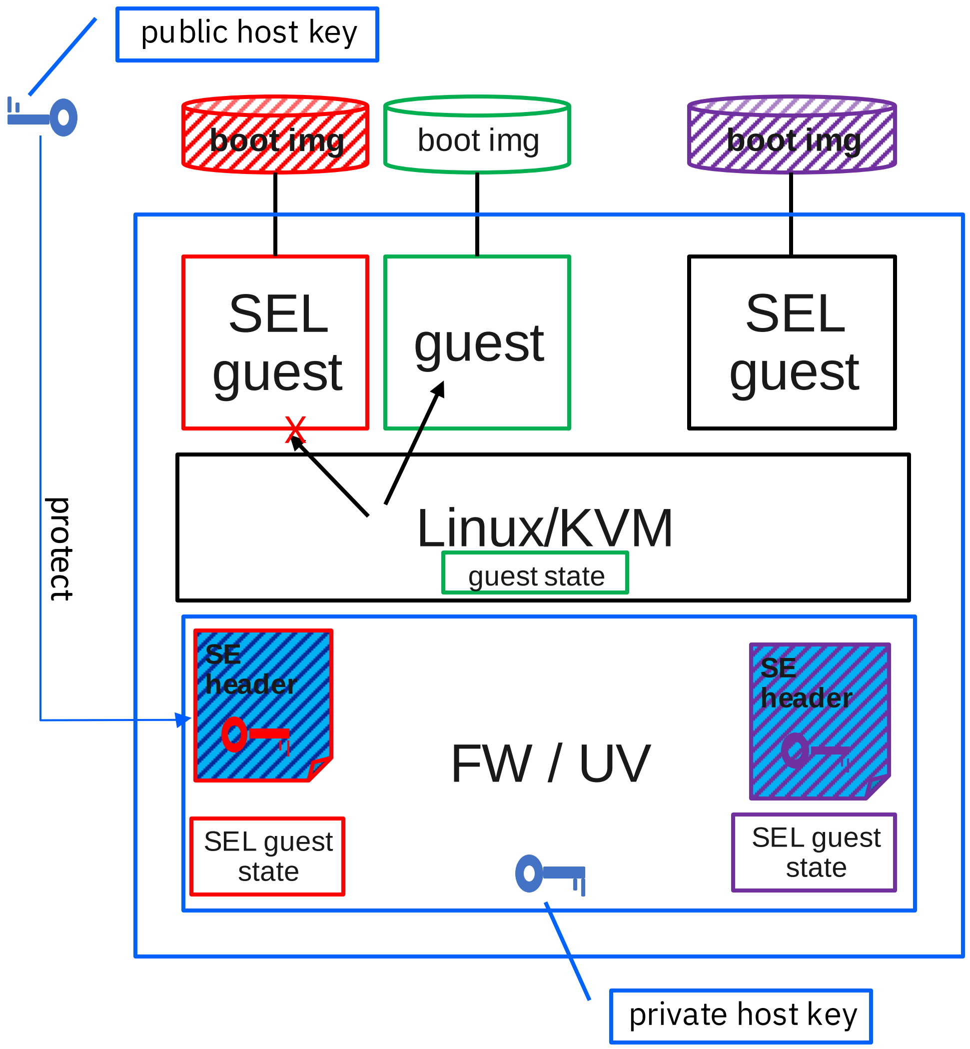
- maintains & protects the SEL guest state
- has access to the root of trust: the private host key

Image of SEL guest is integrity protected & typically encrypted

- image encryption key is passed to UV in SE-header protected using host key

**New with IBM z16 and IBM® LinuxONE 4**:

- IBM no longer keeps a copy of the private host keys.
- Support for remote attestation
  - to get trustworthy confirmation that a guest is an SE guest
  - to get a unique id of an SEL guest instance
- 04/2024: FW update to support Crypto Express accelerators and EP11 HSMs




*) guest = virtual machine

# Why is there no Crypto Express support for Secure Execution today?

The Secure Execution promise:

- the owner of a secure guest need not trust the HW admin nor the hypervisor nor the hypervisor admin

So far, a secure guest could **not** control

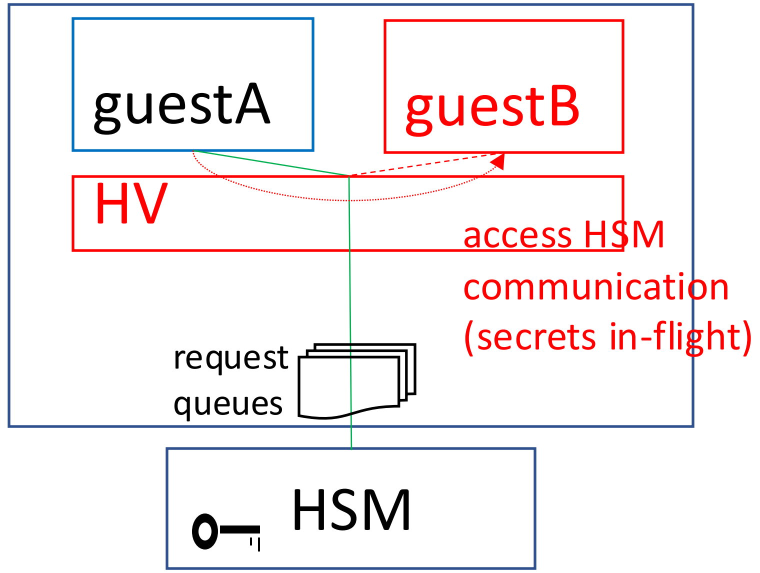
- that data exchanged with the Crypto Express domain cannot be observed by a non-trusted component
- which Crypto Express domain it is connected to
- that its Crypto Express domain is never assigned to a different guest or LPAR
- secure keys generated by a secure guest cannot be used by another guest or hypervisor

Therefore, the usage of Crypto Express adapters was disabled.

# Protection against Attack 1

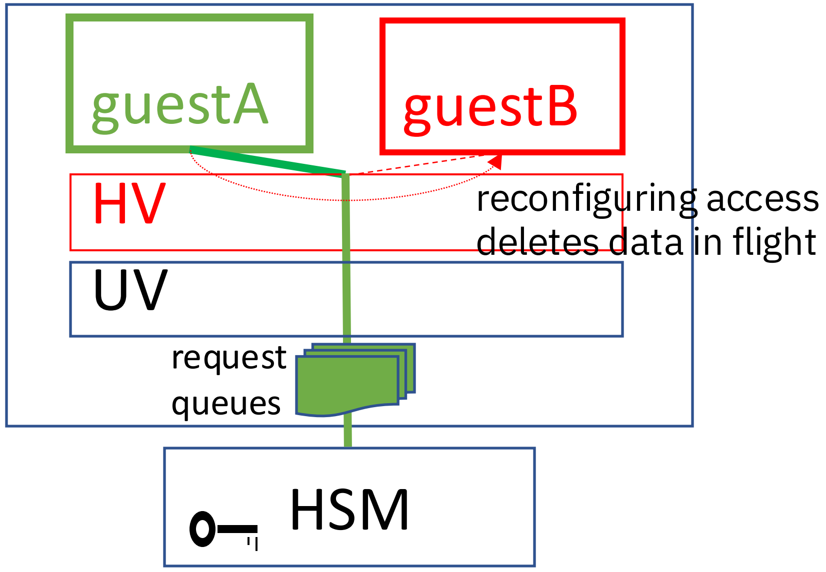
Attacker accesses HSM used by guest and reads crypto request or response

- SIE design allows to configure AP queue of a running guest to another component (HV or guest) such that new owner can read responses of requests submitted by guest




Protection: AP queue can be bound to a *running* SEL guest:

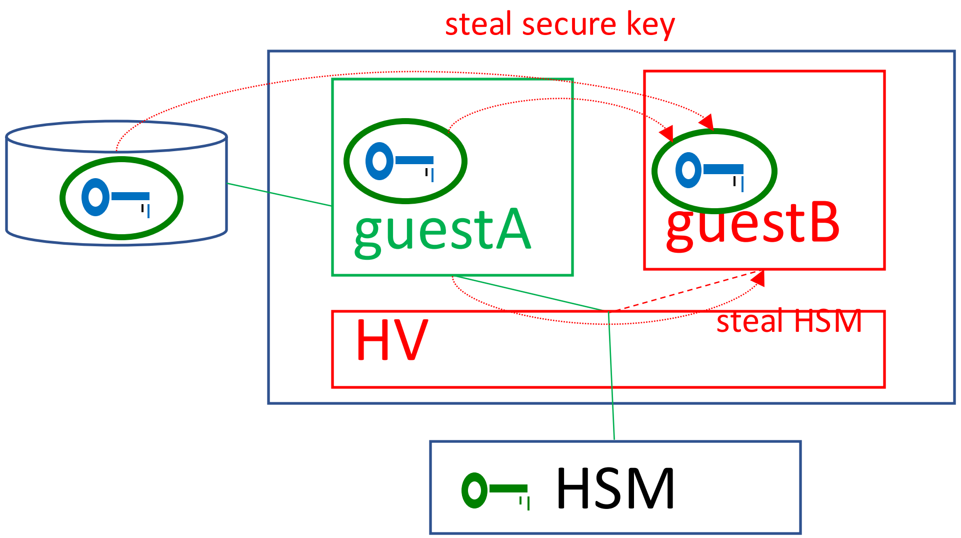
- AP queue can only be accessed by **bound** SEL-guest
- UV disables any communication between an SEL guest and AP queues not bound to the SEL guest
- other components (HW management consoles, HV, other guests):
  - cannot access AP queues bound to an(other) SEL-guest
  - resetting an AP queues undoes binding (implicit if the AP queue is (forcefully) configured to another component)
  - HW (re)plug triggers reset & unbinding
- Note, HSM can still be configured to another component
- Sufficient protection for accelerator



# Protection against Attack 2

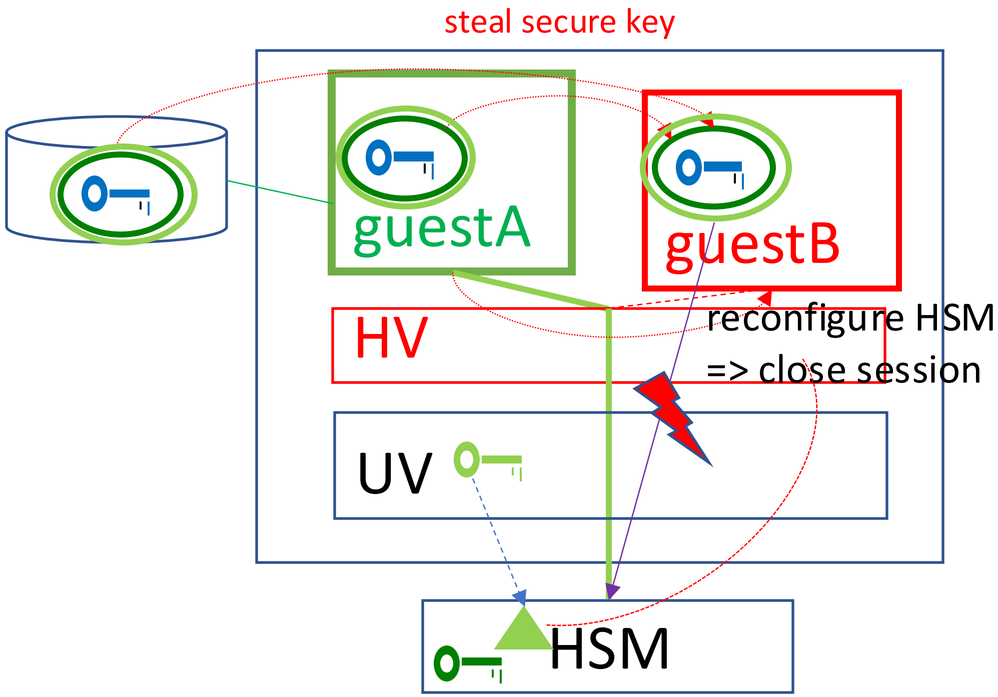
Attacker steals a secure key from guest and “steals” (i.e., configures access to)  HSM to component owned by attacker

- in a virtualized environment, an HSM is no longer something you own




Protection: UV uses association secret from SEL guest meta data and associates it with AP queue / HSM

- open a session based on association secret in HSM
- block crypto requests containing secure keys unless AP queue is associated
- all EP11 sessions opened by the SEL guest become child sessions of the session bound to the association secret
- all keys generated by an associated HSM are bound to the (child) session based on the association secret
- An AP queue will be deassociated (sessions will be closed) when the AP queue is unbound or its HSM is plugged
- Note, HSM management requests (including MKVP queries) work w/o association



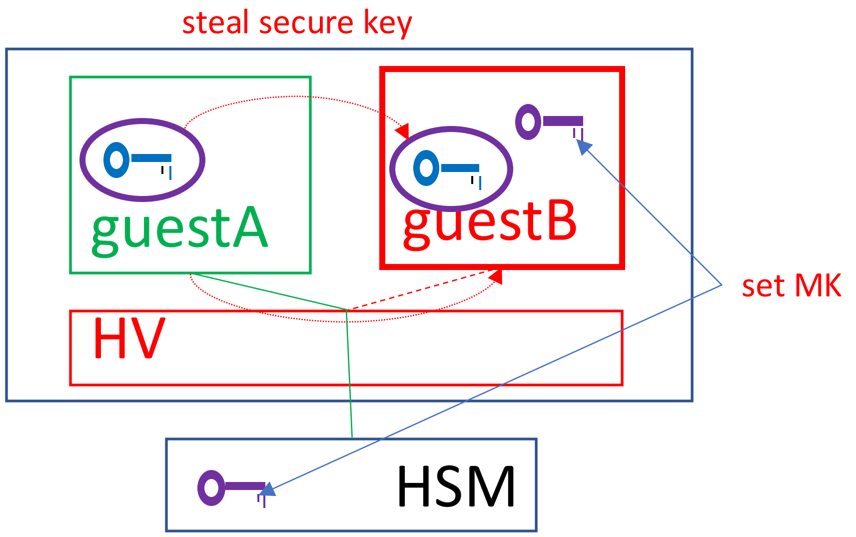
# Protection against Attack 3

## Attacker presents an HSM to guest that is configured by attacker

- secure keys generated on HSM are no longer secret as attacker may know HSM master key
- Note, if EP11 domain admins are trusted this attack is only possible while the domain is in the zeroized state

## Protection

- SEL guest can control association:
  - before associating an AP queue, the MKVP* (SN, certificate) of an HSM must be verified
    - e.g., see `sys/bus/ap/devices/<XY>.<DDDD>/mkvps`
  - association (& binding) gets lost with every HSM HW configuration event
- SEL guest program must check MKVP of each newly generated secure key
  - with openCryptoki v3.19 and later, ep11 tokens can be configured with an expected MKVP, failing all creations (generate, unwrap derive) of secure keys including an unexpected MKVP
  - zkey validate shows the MKVP of a key

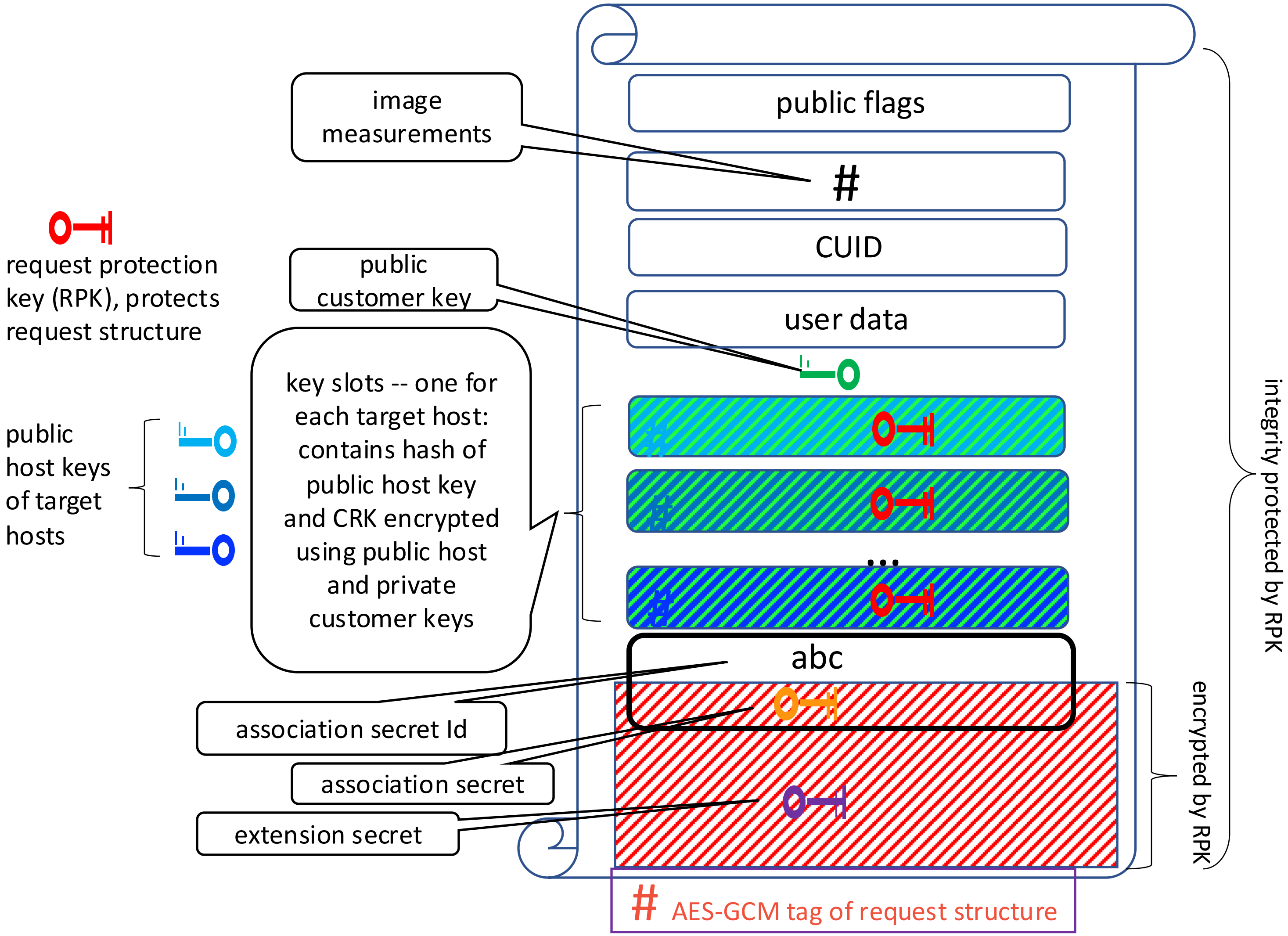



*) HSM master key verification pattern

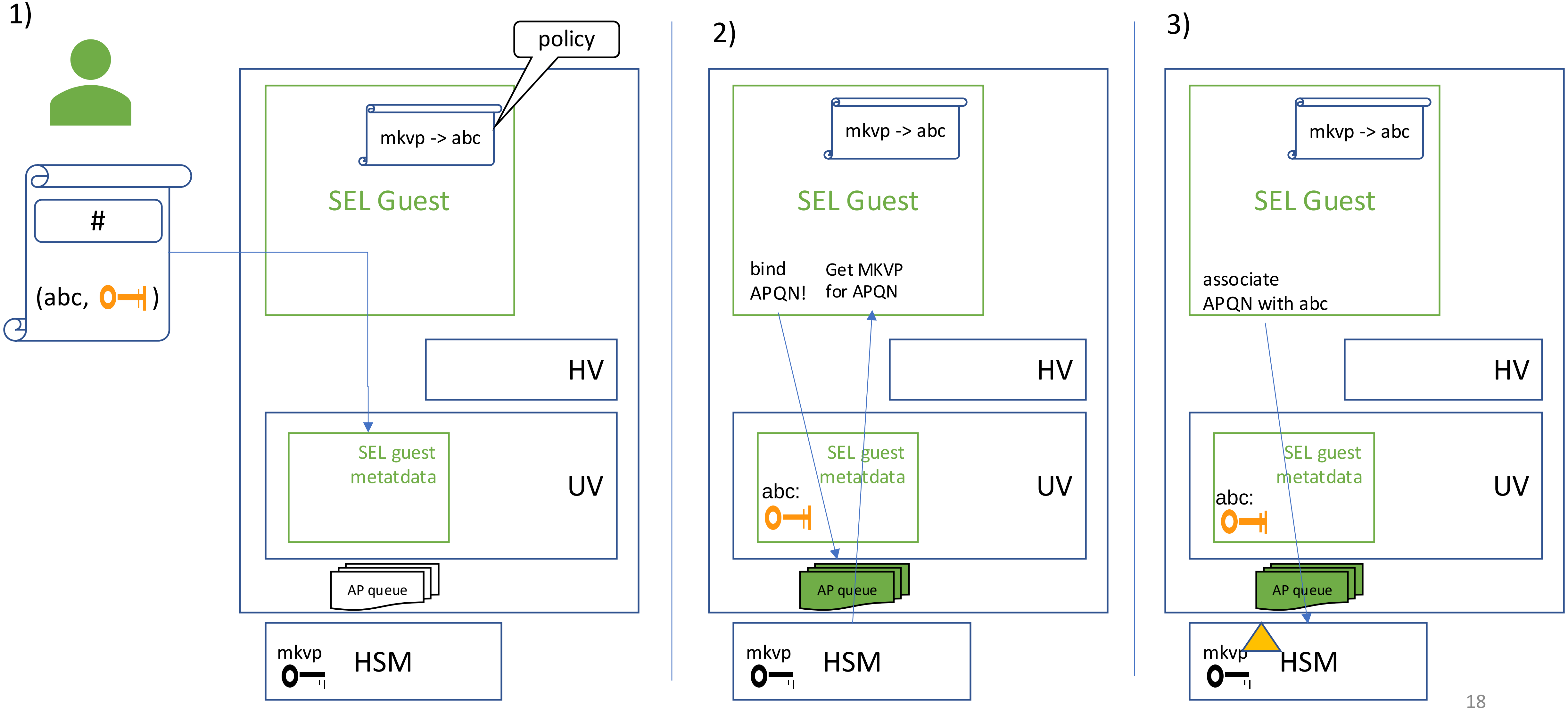
# Adding association secrets to UV protected meta data of a running guest?  -- Part 1

- A secret used to associate an AP queue is called association secret
- **It must never be in plaintext inside the memory of a secure guest**
- It can be submitted to the UV via an interface callable by a secure guest using an add-secret request structure that must be prepared by the owner of the guest
- There are safeguards to avoid misusing an add-secret request structure.
    - CUID
    - extension secret
        - to be shared by all add-secret requests of an SEL-guest
    - user data

## Add-secret request structure

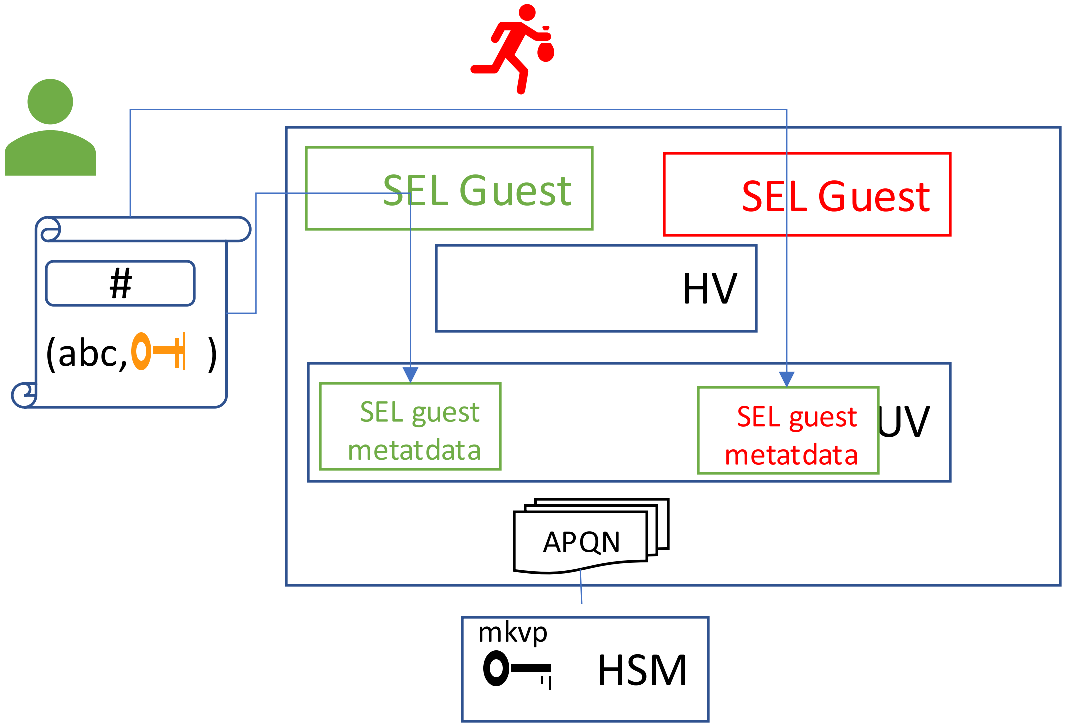


# Adding association secrets to UV-protected meta data of a running guest -- Part 2

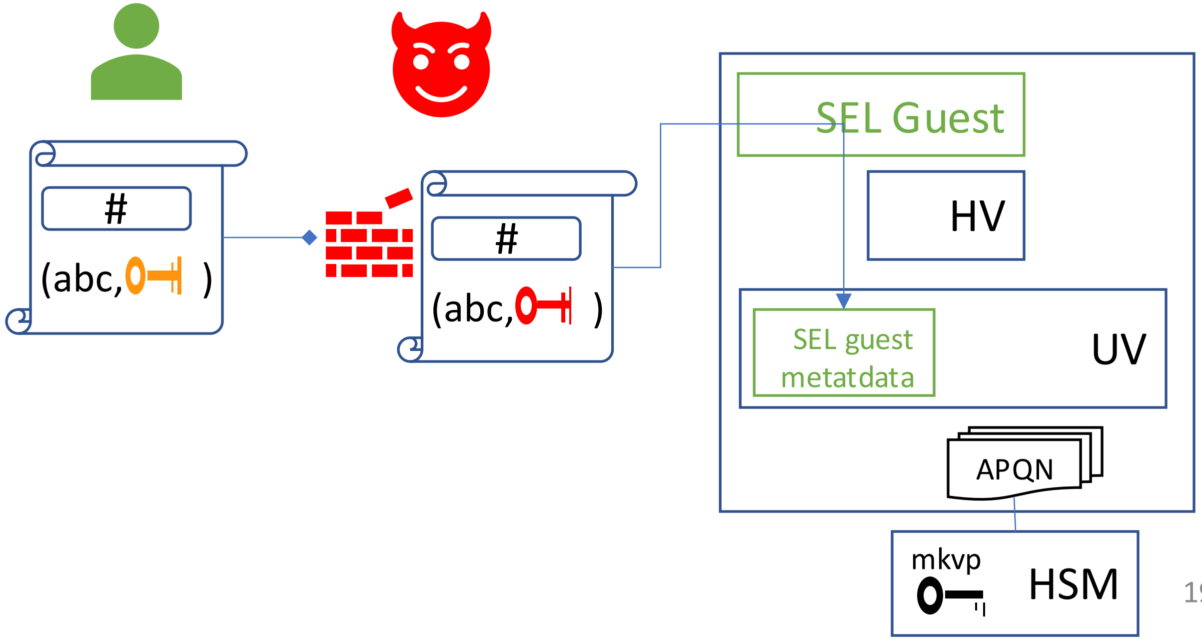


# Possible misuses of add-secret requests

- an attacker may steal an add-secret request and try to use it in an attacker's secure guest




- an attacker may trick a secure guest (owner) to use the attacker's add-secret request instead of the secure guest owner's add-secret request.



# Safeguards against misuses of add-secret requests

**Use cases**

- SEL image specific to to tenant,
  - contains tenant secrets such that only tenant has privileged access to SEL guest
  - add-secret request may or may not be generated before the SEL guest is started
- SEL image is a generic image that gets personalized after a remote attestation
  - it is OK to generate add secret requests after the guest was started and attested
- SEL image is a generic image that gets personalized with contract data including the tenant's certificate and association secrets
  - the add-secret request must be available before the SEL guest is started

Personalization of a generic confidential VM:

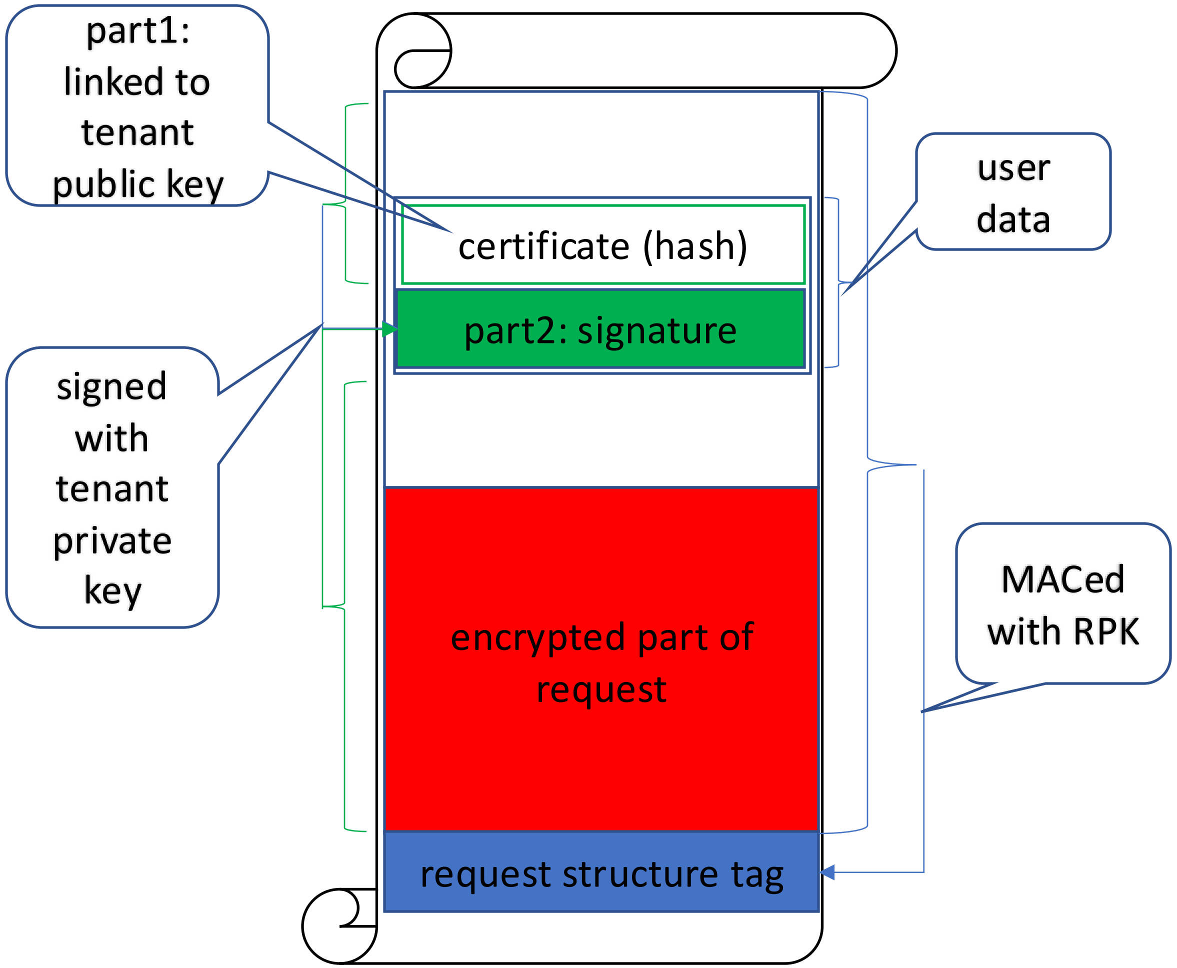
- the image of confidential VM does not contain tenant secrets
- the image may contain image vendor secrets
- the image may support remote attestation
- tenant can securely install root secrets (dm-crypt keys and/or ssh keys) to enforce exclusive (privileged) access to the confidential VM

**Safeguards**

- image and SEL header digests (ALD, PLD, TLD, SEHT):
  - Add-secret request must only be used with secure guest booted from a specific SEL image.
  - a specific behavior of the SEL guest is guaranteed during an initial phase
- extension secret
  - All add-secret requests used by a secure guest must share the extension secret.
- extension secret with CCK option
  - Owner of SEL guest image / SEL-header and add-secret request creator must share a secret.
  - genprotimg option `--enable-cck-extension-secret`
  - Not useful for generic SE guests.
- CUID
  - Add-secret request can only be used with specific guest instance.
  - the CUID can be queried with an attestation request
  - Guest must be running before the add secret request can be created.
- user data
  - Allow guest code to determine eligible add-secret requests.
  - useful for generic guest images (e.g., with personalization based on attestation or contract)
  - See next slide.
- lock secrets
  - UV call to disable guest to submit further add-secret requests to UV.
  - may be called before guest transitions from a restricted stage to a more open stage

# Binding an add-secret request to tenant certificate

- use user data in add secret request as follows:
  - part 1: optional data, e.g. digest of tenant certificate
  - part 2: signature of add-secret request with the exception of the bytes to store this signature and the MAC tag of the add-secret request using the tenant private key
- program to submit request structure to UV
  - verifies part 1 of user data to be a digest of the tenant certificate from the contract
  - verifies part 2 of user data to be a valid signature
  - only if both verifications succeed submit request to UV
- see `--user-data` and `--user-sign-key` options and `verify` sub-command options of the pvsecret tool.
- before general I/O is opened to SE guest call lock secret store UVcall



# Linux tools for HSM support for SEL

https://github.com/ibm-s390-linux/s390-tools

- kernel
  - uv DD
    - misc device node extended to submit add-secret requests to UV
  - ap/zcrypt DD
    - sys fs extensions for binding and association
    - unchanged: device node to submit crypto requests
- zcrypt tools
  - s390-tools/zconf/zcrypt
    - lszcrypt
      - show AP queue status
    - chzcrypt
      - bind & associate AP queues

- SEL image generation
  - s390-tools/genprotimg
    - genprotimg
- add-secret request handling
  - s390-tools/rust
    - pvsecret create|add|verify|lock
      - create: create request
      - add: submit request to UV
      - verify: verify user data
      - lock: prevent further secret submission
    - pvapconfig
      - apply a policy describing with association secret belongs to which MKVP

# pvapconfig – AP passthrough policies

pvapconfig associates association secrets installed in the UV with APQNs based on

- AP type (accelerator or EP11)
- master key verification patterns (EP11 only)
- association secret ID or name (SHA256 hash of name = ID)

```
# my AP config for my very secure SE guest

# we'd like to have one accelerator
- name: my Accelerator
  mode: Accel
  mingen: CEX8

# a pair of EP11 AP queues with same master key and same secret id
# but on different crypto cards as backup pair for my application
- name: my EP11 APQN 1
  mode: EP11
  mkvp: 0xdb3c3b3c3f097dd55ec7eb0e7fdbcb93
  serialnr: 93AADFK719460083

- name: my EP11 APQN 2
  mode: EP11
  mkvp: 0xdb3c3b3c3f097dd55ec7eb0e7fdbcb93
  serialnr: 93AADHZU42082261
  secretid: 0x546869732069732061207665727920736563726574207365637265742069642e
```

# Conclusion

- HSMs must not be used in environments provided by a provider that is not fully trusted, unless …
- The new Crypto Express support for Secure Execution will allow a Secure Execution guest to securely use a Crypto Express 8 adapter in accelerator or EP11 mode.

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TAPADH LEIBH

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БАЯРЛАЛАА

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TEŞEKKÜR EDERIM

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KÖSZÖNÖM

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DANKON

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HVALA

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ESKERRIK ASKO

GO RAIBH MAITH AGAT

MAHADSANID

HVALA

БЛАГОДАРЯ

GRACIAS

THANK YOU

TEŞEKKÜR EDERIM

ТИ БЛАГОДАРАМ

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TAKK SKAL DU HA

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FALEMINDERIT

ありがとうございました

DI OU MÈSI

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