Authenticated Booting, Remote Attestation, Sealed Memory aka “Trusted Computing”

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Goals

Understand principles of:

- authenticated booting
- the difference to (closed) secure booting
- remote attestation
- sealed memory

Non-Goal:

lots of TPM, TCG-Spec details
→ read the documents once needed

Some terms

Secure Booting

Authenticated Booting

(Remote) Attestation

Sealed Memory

Late launch / dynamic root of trust

Trusted Computing

Trusted Computing Base

Attention:

terminology has changed ...

Trusted Computing (Base)

Trusted Computing Base (TCB)

The set of all components, hardware, software, procedures, that must be relied upon to enforce a security policy

Trusted Computing (TC)

A particular technology comprised of authenticated booting, remote attestation and sealed memory

TC key problems

- Can running certain SW be prevented ?
- Which computer system do I communicate with ?
- Which stack of Software is running ?
  - in front of me ?
  - on my server somewhere ?
- Can I restrict access to certain secrets (keys) to certain programs ?

Trusted Computing Terminology

Measuring

- "process of obtaining metrics of platform characteristics"
- Example for metric: Hash- Codes of SW

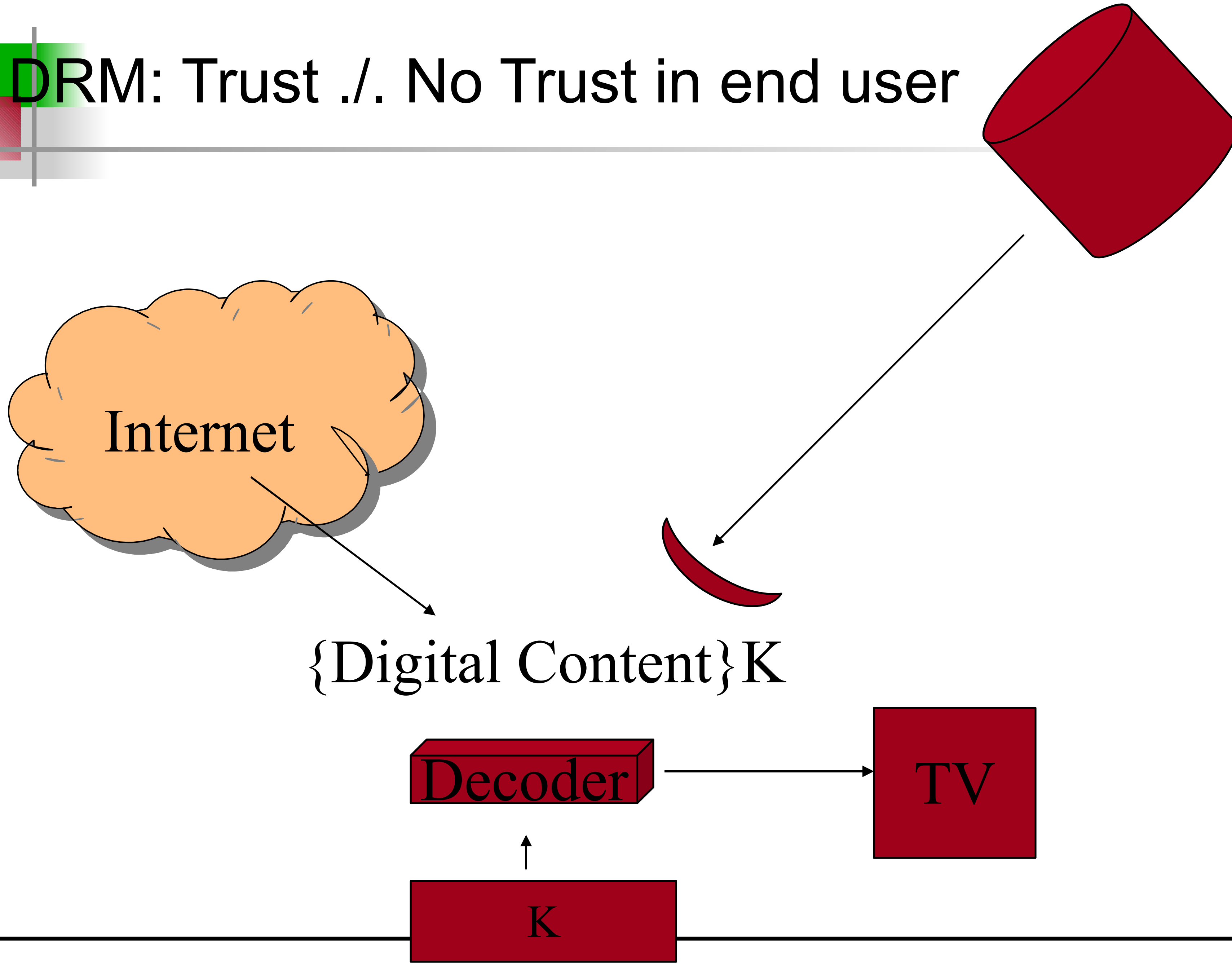
Attestation

- "vouching for accuracy of information"

Sealed Memory

- binding information to a configuration

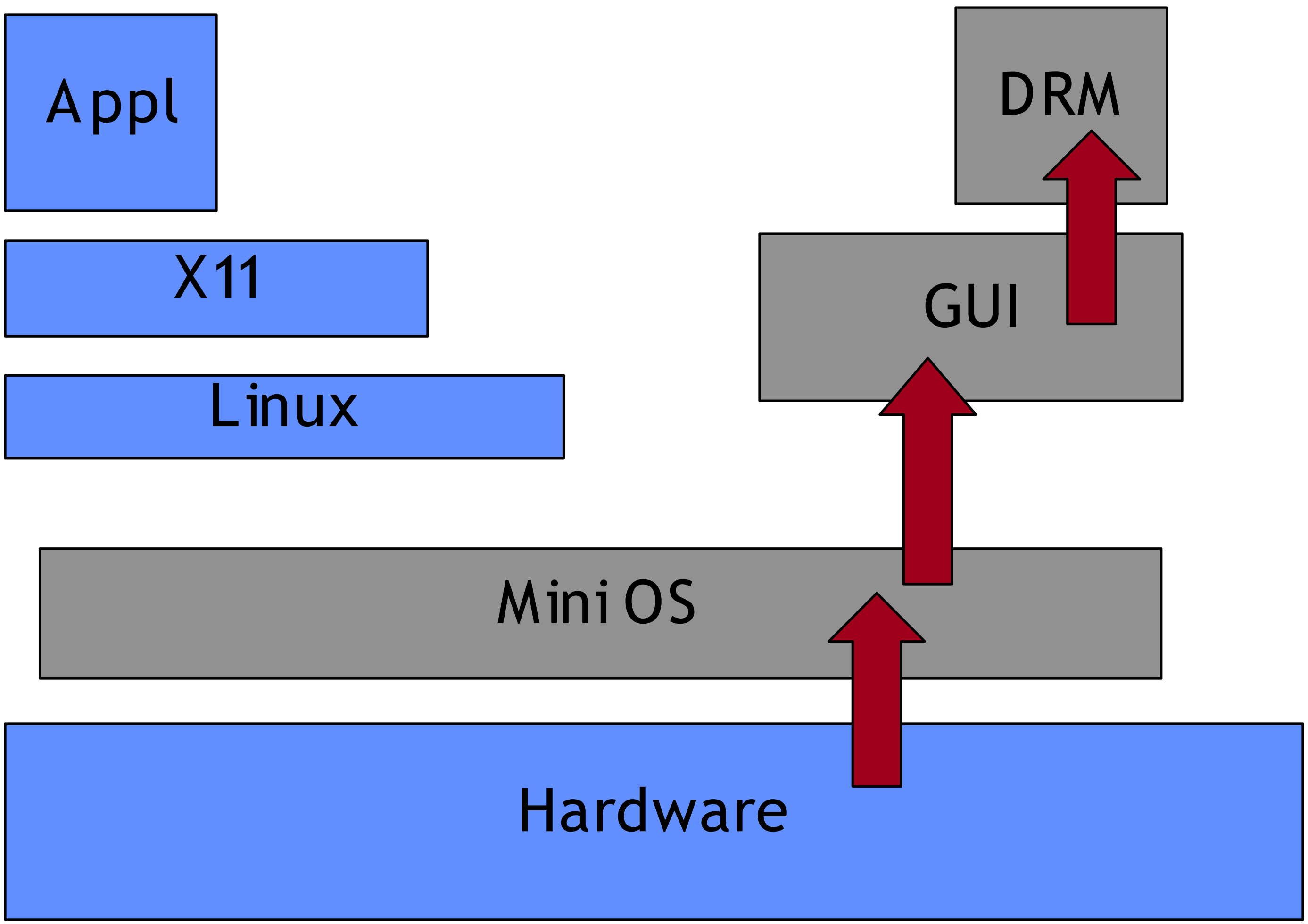
DRM: Trust ./. No Trust in end user



An Example Application: DRM

- „Digital Content“ is encrypted using symmetric key
- Smart- Card
  - contains key
  - authenticates device
  - delivers key only after successful authentication
- Assumptions
  - Smart Card can protect the key
  - „allowed“ OS can protect the key
  - OS cannot be exchanged

Secure Booting / Authenticated Booting



Notation

SK^{priv} Sk^{pub} Asymmetric key pair of some entity S

- { M }Sk^{priv} Digital Signature for message M using the private key of signer S

  { M }Sk^{pub} Message encrypted using public concellation key of S

- H(M) Collision-Resistant Hash Function

- Certificate by authority Ca:

  { ID, SK^{pub} , other properties } CaK^{priv}

Notation

Note:

- "{ M }Sk^{priv} Digital Signature" is short for:

  encrypt(H(M),Sk^{priv})

- "{ M }Sk^{pub} Message concealed ..."

  does not necessarily imply public key encryption for all of M (rather a combination of symmetric and asymmetric methods

Identification of Software

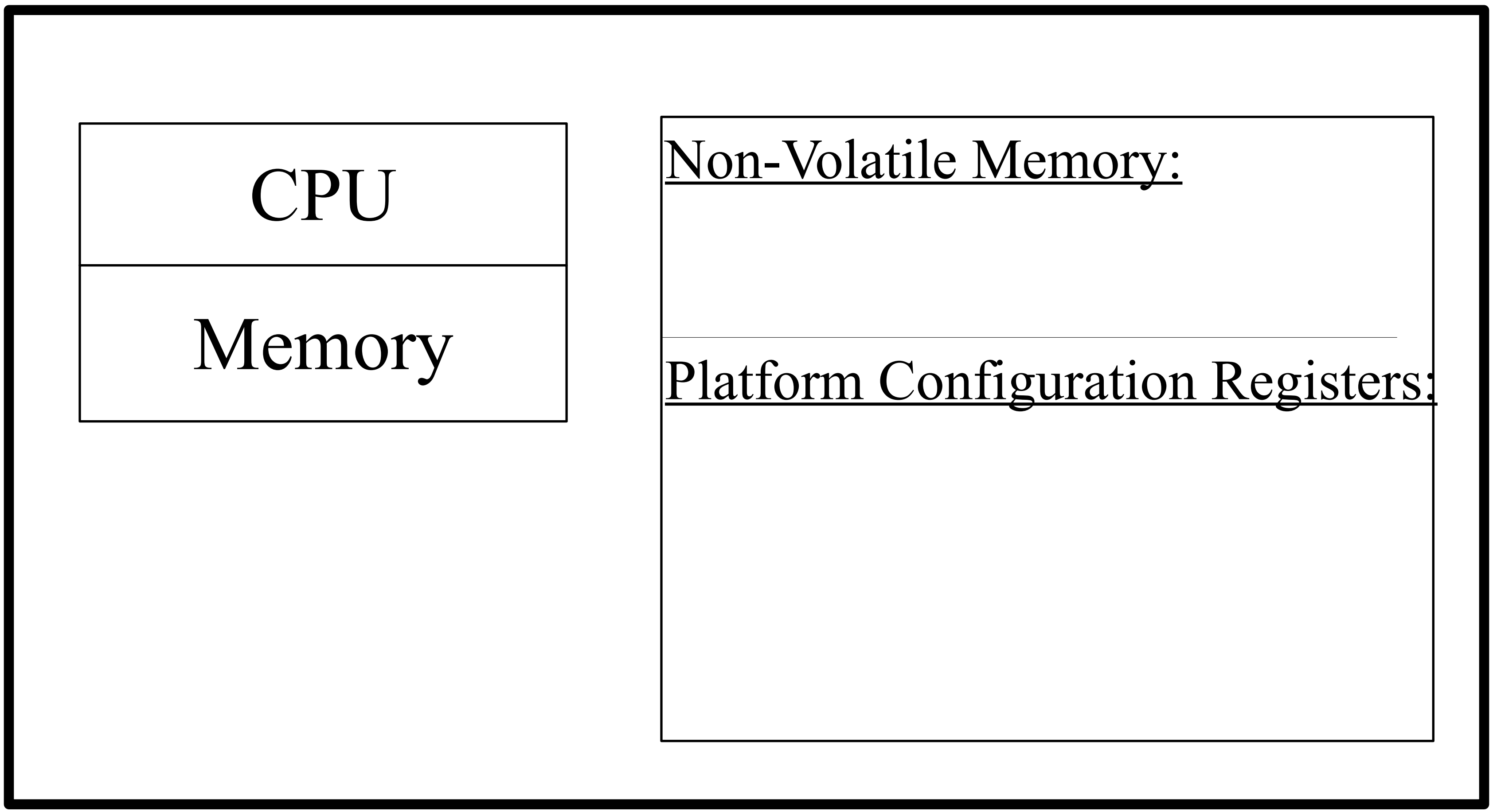
Program vendor: Foosoft FS

Two ways to identify Software:

- H(Program)
- {Program, ID- Program}FSK^{priv}
  use FSK^{pub} to check
  the signature must be made available, e.g. shipped with the Program

The „ID” of SW must be made available somehow.

Tamperresistant black box (TRB)



Ways to “burn in” the OS or secure booting

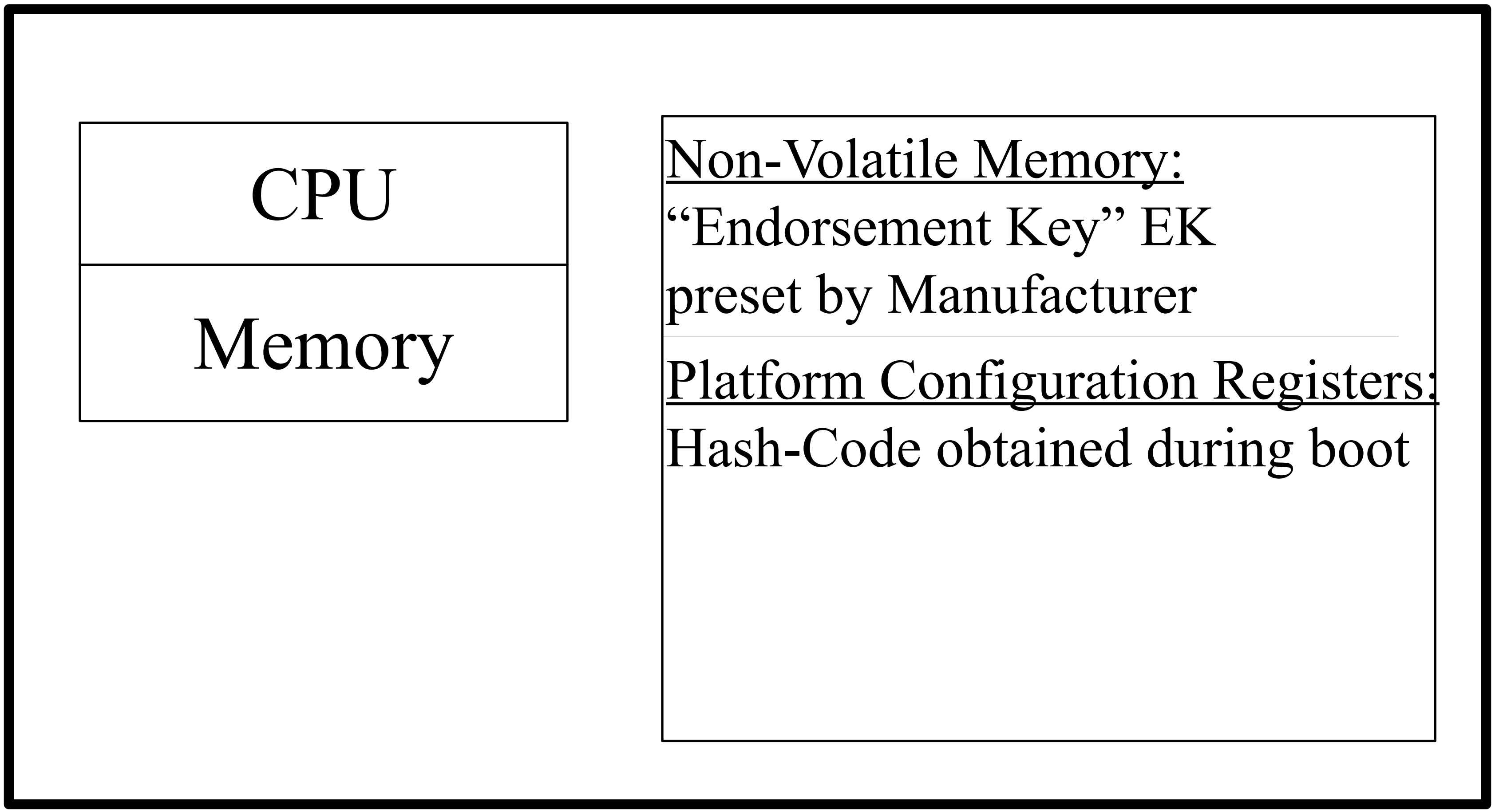
- Read- Only Memory
- Allowed H(OS) in NV memory preset by manufacturer
  - load OS- Code
  - compare H(loaded OS code) to preset H(OS)
  - abort if different
- Preset FSK^{pub} in NV memory preset by manufacturer
  - load OS- Code
  - check signature of loaded OS-Code using FSK^{pub}
  - abort if check fails

Authenticated Booting (AB)

Phases:

- Preparation by Manufacturers (TRB and OS)
- Booting & “Measuring”
- Remote attestation

Authenticated Booting (AB)



Vendors of TRB and OS

TRB_generates key pair: „Endorsement Key“ (EK)

stores in TRB NV Memory: EK^{priv}

emits: EK^{pub}

TRB vendor certifies: {“a valid EK”, EK^{pub}}TVK^{priv}

OS-Vendor certifies:{„a valid OS“, H(OS)}$OSVK^{priv}$

serve as identifiers: EK^{pub} and H(OS)

Booting & Attestation

Booting:

TRB “measures” OS- Code (computes H(OS-Code))

stores in PCR

no other way to write PCR

Attestation:

Challenge: nonce

TRB generates Response:

$\{PCR, nonce'\}EK^{priv}$

Remaining problems

Now we know identities: H(loaded-OS) and EK^{pub}

Problems to solve:

- OS versioning
- Remote attestation on each message (what about reboot ?)
- not only “OS” on platform (SW stacks or trees)
- Privacy: remote attestation always reveals EK^{pub}
- Black box to big
- Sealed memory

AB (Variant 2, allow OS versions)

CPU

Memory

Non-Volatile Memory:

"Endorsement Key" EK preset by Manufacturer

Platform Configuration Registers:

OSK^{pub} used to check OS

Vendors of TRB and OS

TRB_generates key pair:

stores in TRB NV Memory: EK^{priv}

emits: EK^{pub}

TRB vendor certifies: {“a valid EK”, EK^{pub}}TVK^{priv}

OS-Vendor certifies:{„a valid OS“, OSK^{pub}}$OSVK^{priv}$

and signs OS-Code: {OS-Code}OSK^{priv}

serve as identifiers: EK^{pub} and OSK^{pub}

Booting & Attestation (Variant 2)

Booting:

TRB checks OS- Code using some OSK^{pub}

stores OSK^{pub} in PCR

no other way to write PCR

Attestation:

Challenge: nonce

TRB generates Response:

{PCR, nonce' }EK^{priv}

AB (Variant 3, check for reboot)

attestation required at each request:

$\{PCR, nonce'\}EK^{priv}$

PCR: H(OS) bzw. OSK^{pub}

always requires access to and usage of EK

race condition!

Instead:

create new keypair on every reboot:

$OSrunningAuthK^{priv}$ $OSrunningAuthK^{pub}$

Booting (Variant 3)

Booting:

TRB checks OS- Code using some OSK^{pub}

stores OSK^{pub} in PCR

creates OSrunningAuthK keypair

certifies: $\{ OSrunningAuthK^{pub}, H(OS)\}EK^{priv}$

Attestation (Variant 3)

Attestation:

Challenge: nonce

OS generates response:

{ OSrunningAuthK^{pub}, H(OS)}EK^{priv}

{nonce} OsrunningAuthK^{priv}

Establish Secure Channel to OSRunning

Booting:

TRB checks OS- Code using some OSK^{pub}

stores OSK^{pub} in PCR

creates OSrunningAuthK keypair

creates OSrunningConsK keypair

certifies: { $OSrunningAuthK^{pub}$, OSrunningConsKpub, H(OS)}EK^{priv}

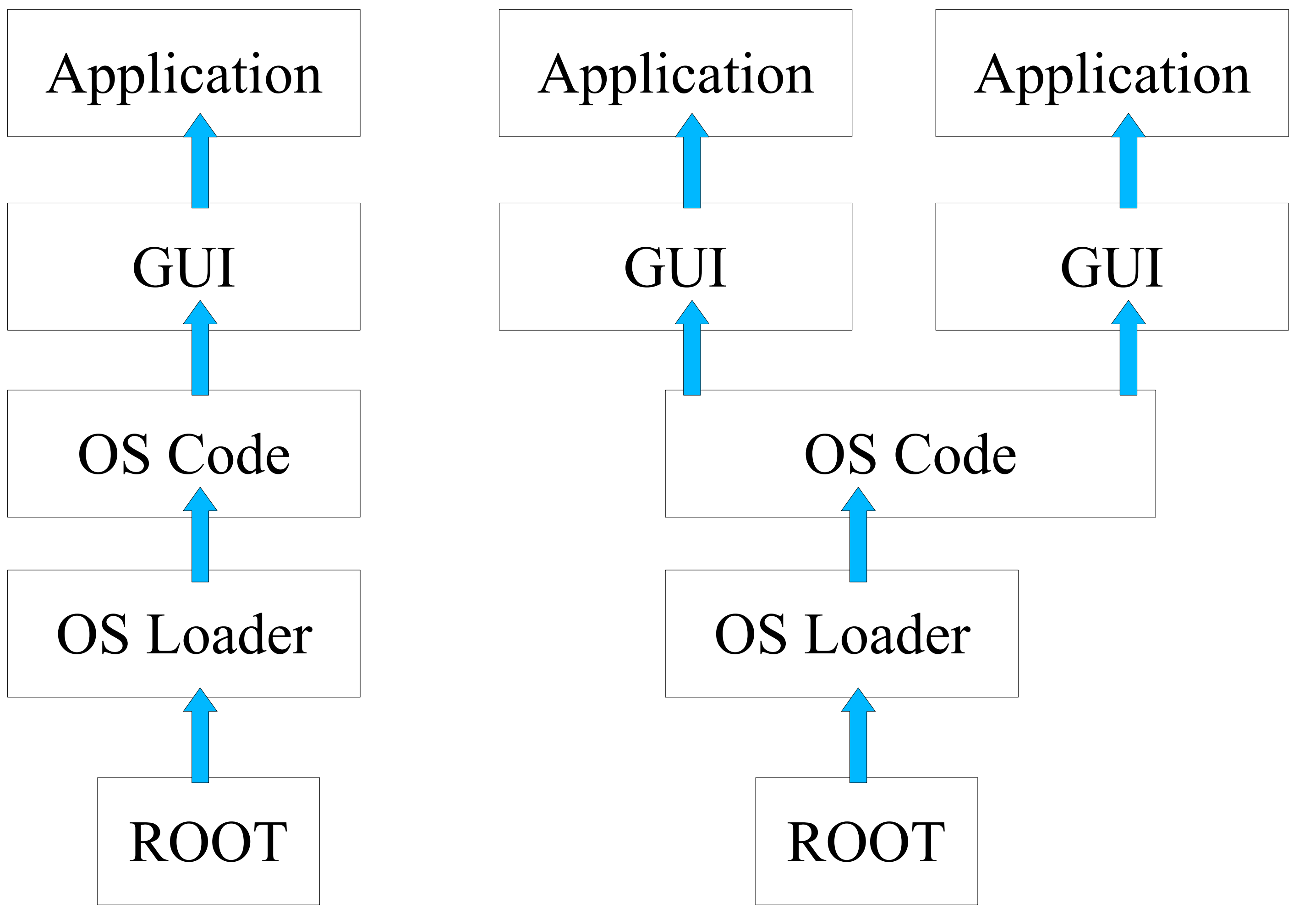
Secure Channel:

{ message } $OSrunningConsK^{pub}$

Assumptions

- TRB can protect: EK, PCR
-
- OS can protect: $OSrunningK^{priv}$
-
- Rebooting destroys content of
  - PCR and Memory Holding $OSrunningK^{priv}$

Software stacks and trees



Software stacks and trees

- “Extend” Operation
  - stack: $PCR_n = H(PCR_{n-1} \,||\, \text{next-component})$
  - tree: difficult (unpublished ?)

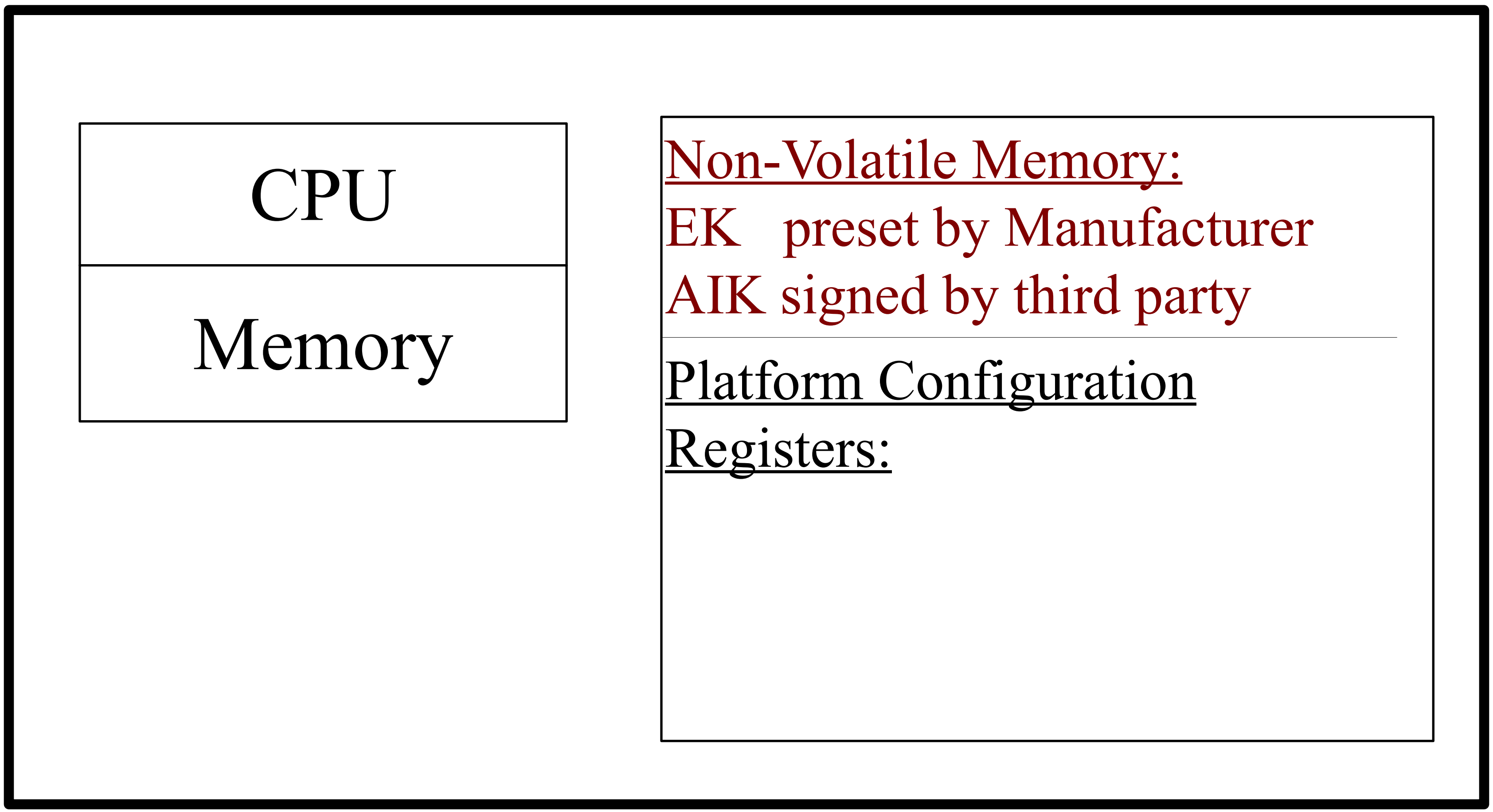
- Key pairs:
  - OS controls applications -> generate key pair per application
  - OS certifies
    { Application 1, $App1K^{pub}$ } $OSrunningK^{priv}$
    { Application 2, $App2K^{pub}$ } $OSrunningK^{priv}$

Remote Attestation and Privacy

- Remote attestation reveals platform identity: EK^{pub}

- add intermediate step:
  - Attestation Identity Key (AIK)
  - Trusted third party as anonymizer (TTP)

Remote Attestation and Privacy



Remote Attestation and Privacy

- Generate AIK in TRB

- send { AIK } EK^{priv} to trusted third party
- third party certifies: {AIK, “good ID” } $TTPK^{priv}$

- AIK used instead of EK during remote attestation, response:

  {AIK, “good ID” } $TTPK^{priv}$

  { $OSrunningK^{pub}$, H(OS)}AIK^{priv}

  {nonce} $OSrunningK^{priv}$

Late Launch

- Use arbitrary SW to start system and load all SW

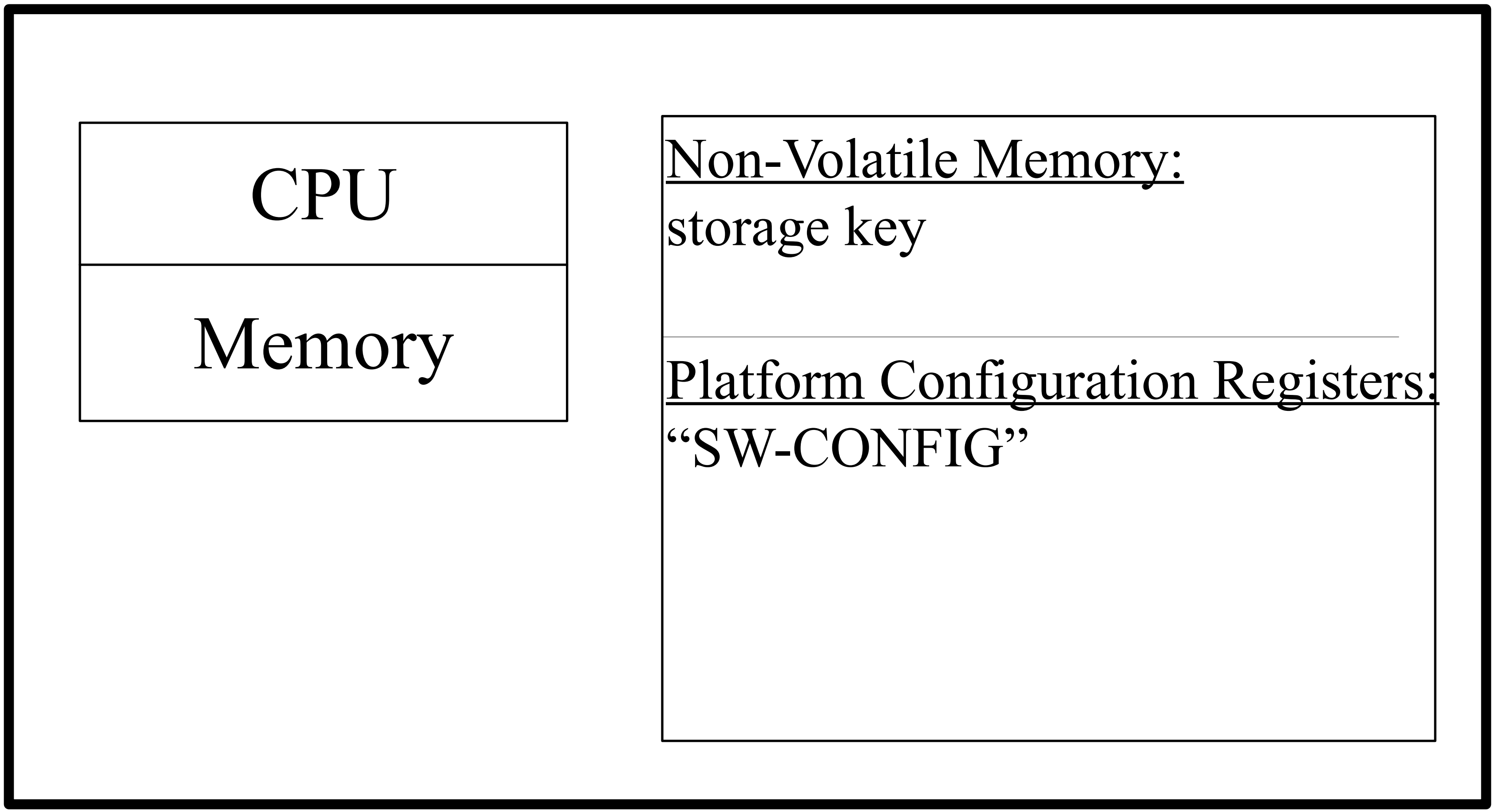
- provide specific instruction to enter “secure mode”
- - set HW in specific state (stop all processors, IO, ...)
- - Measure “root of trust” SW
- - store measurement in PCR

- AMD: “skinit” (Hash) arbitrary root of trust
- Intel: “senter” (must be signed by chip set manufacturer)

Sealed Memory

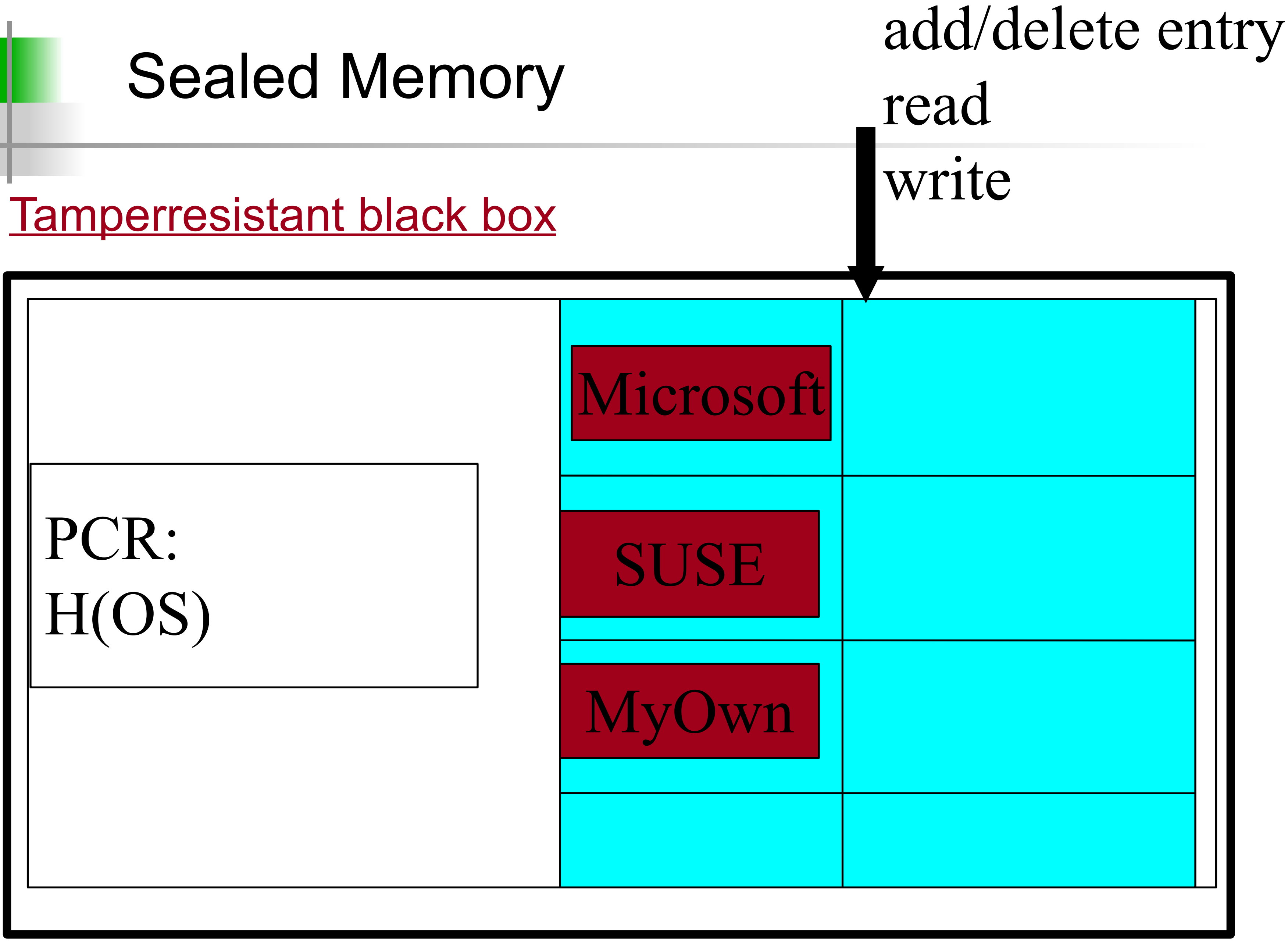
- Bind sensitive information to specific configuration (for example: keys to specific machine, specific OS)
- Provide information using secure channels
- How to store information in the absence of communication channels?

Tamperresistant black box (TRB)



Sealed Memory

Tamperresistant black box



Sealed Memory

- Seal(PCR, message):
  - encrypt(“PCR, message”, Storage-Key)
- Seal(SW config, message):
  - encrypt(“SW config, message”, Storage-Key)
- Unseal(sealed message):
  - decrypt(“sealed message”, Storage-Key) -> “SW config, message”
  - If SW config == PCR then emit message else abort

Migration ?

- How to transfer information form one TRB to another
- for example: key for decryption of videos

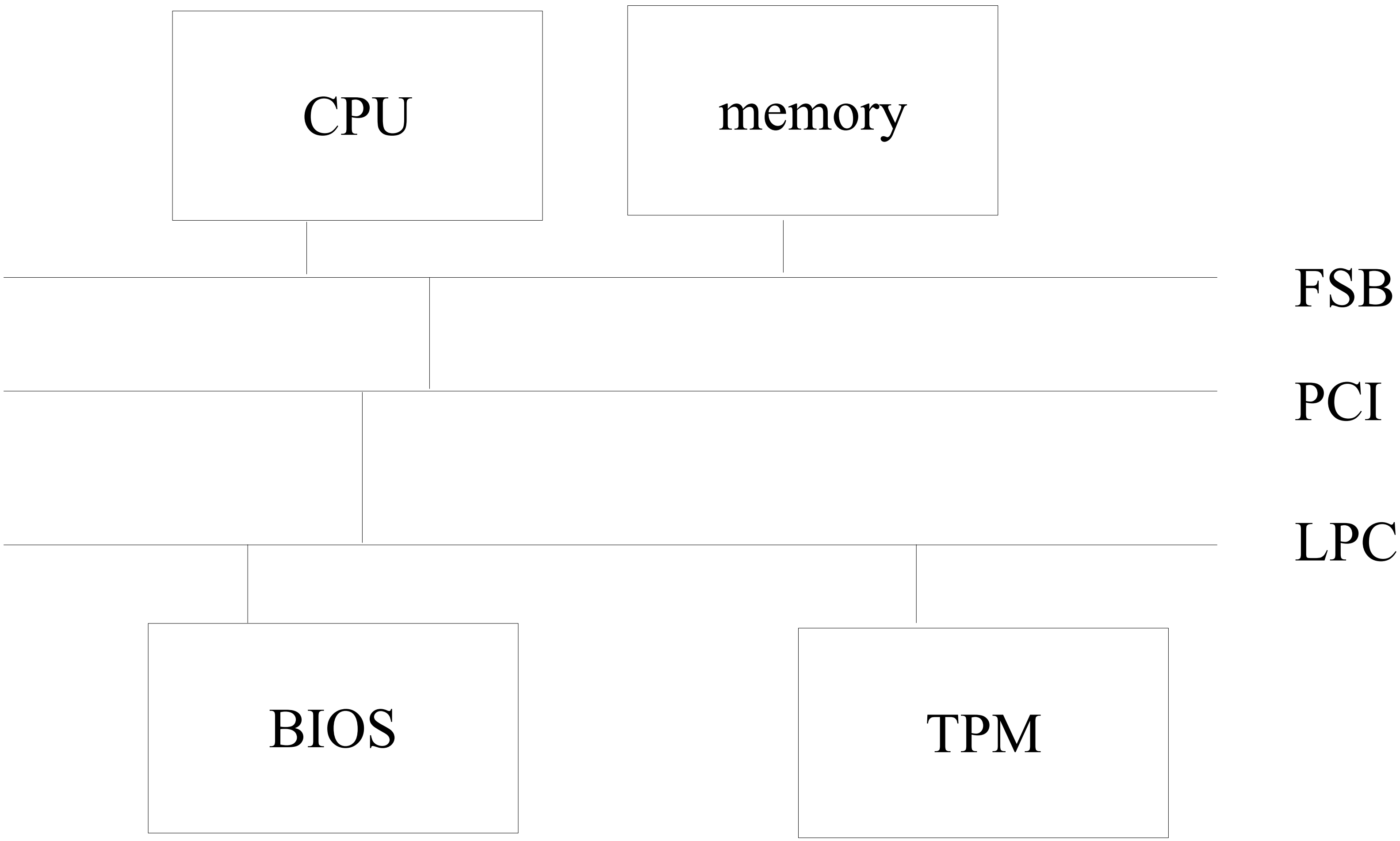
- Send information to third party
- Destroy information locally and prove to third party
- Thirds party provides information to another entity

Tamper Resistant Box ?

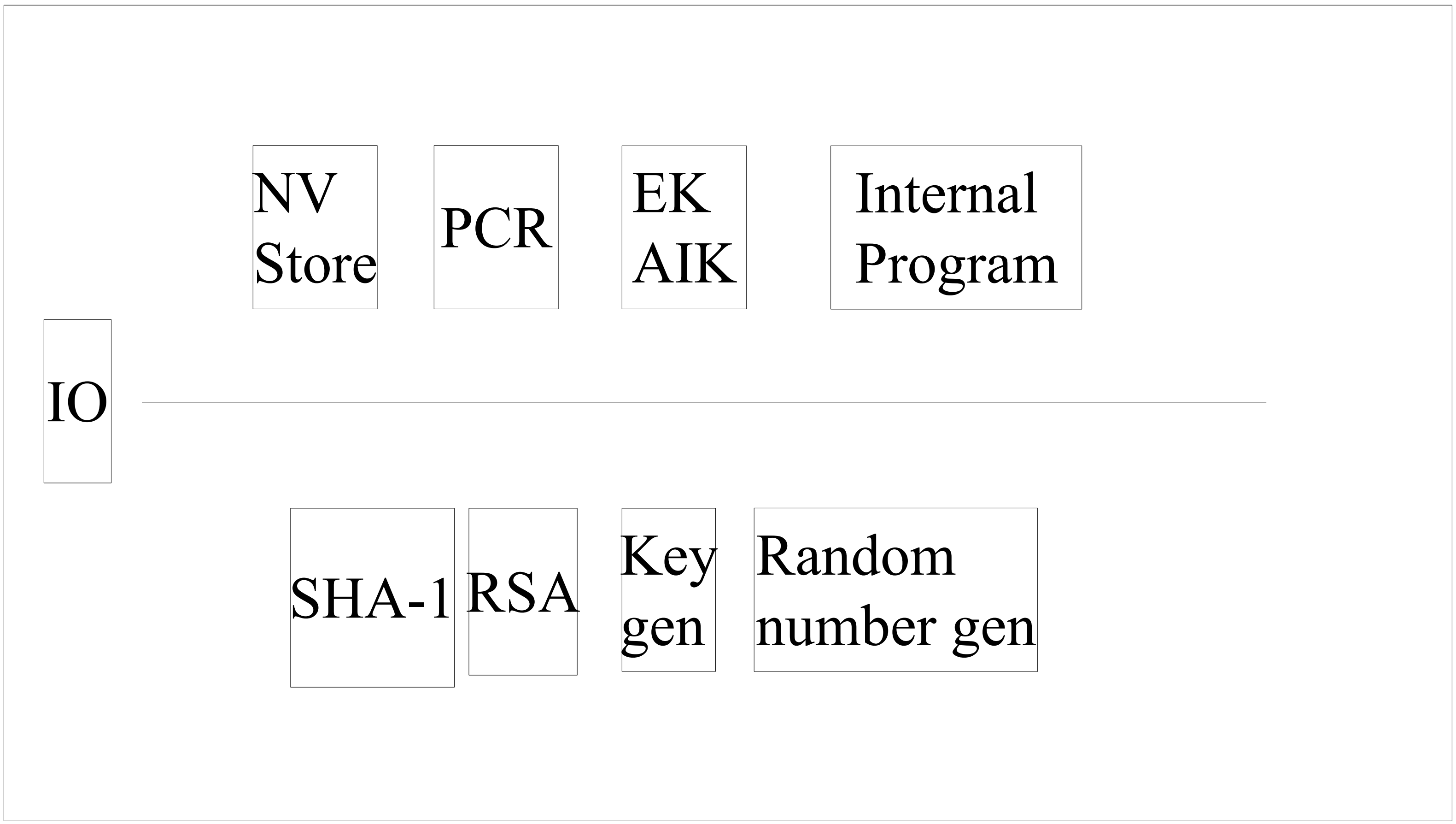
Ideally, includes CPU, Memory, …

- In practise: very rarely, for example IBM 4758 ...
- In practise:
  separate “Trusted Platform Modules”
  replacing BIOS breaks TRB

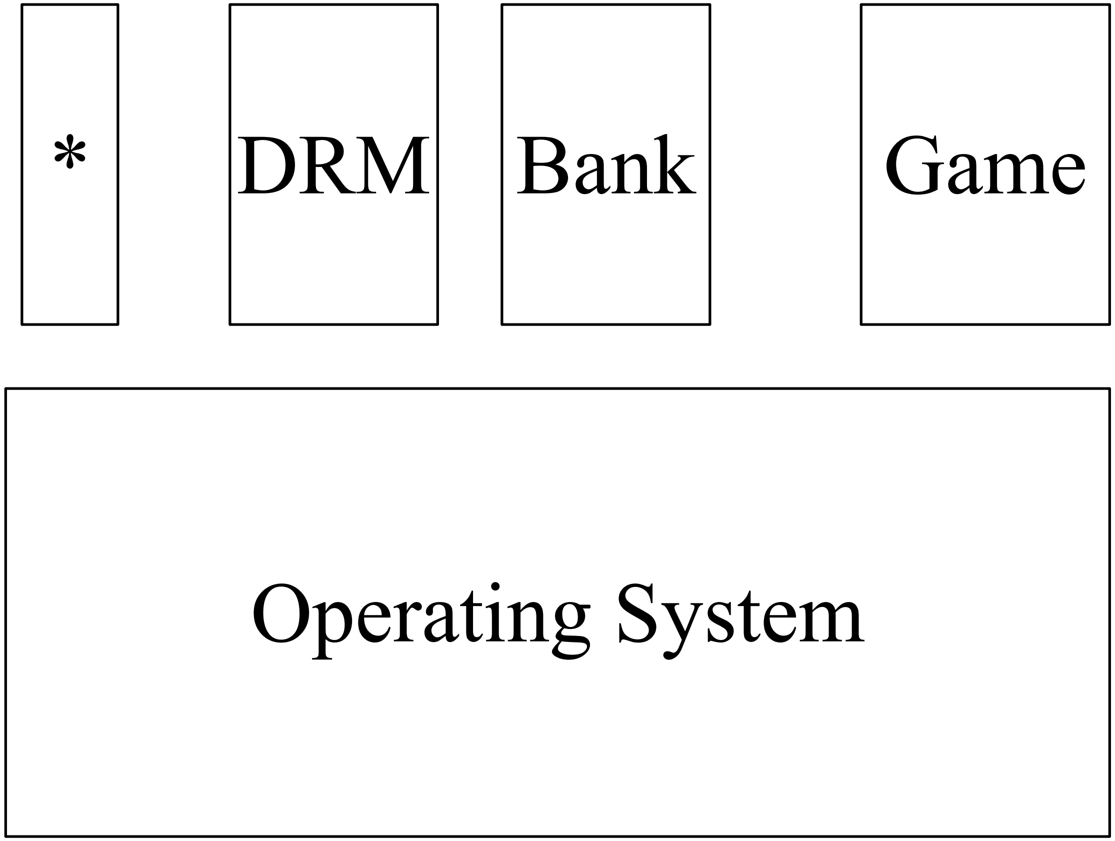
TCG PC Platforms



TPM


NV Store
PCR
EK AIK
Internal Program
IO
SHA-1
RSA
Key gen
Random number gen

Usage Scenarios and Technical Risks



Technical Risks

Hardware:

- Authenticity, Integrity, Tamper-Resistance
- Protection of CPU-priv
  Integrity of RKey-OS-pub

Operating System

- Protection of keys (OSRunning, ...), Content, ...
- Isolation Applications
- Assurance

Side Channels !

References

- Specifications:
- https://www.trustedcomputinggroup.org/groups/TCG_1_3_Architecture_Overview.pdf
-
- Important Foundational Paper:
- Authentication in distributed systems: theory and practice
- Butler Lampson, Martin Abadi, Michael Burrows, Edward Wobber
- ACM Transactions on Computer Systems (TOCS)