Trust

What it is and how to get it

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Defining Trust

Trust

"An entity can be trusted if it always behaves in the expected manner for the intended purpose [1]"

Properties

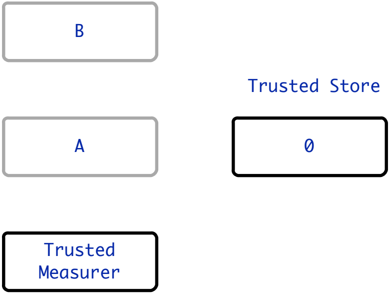
- Unambiguous identification
- Unimpeded operation
- First-hand observation of good behavior *or* indirect experience of good behavior by a trusted third party

Necessary Capabilities for Trust

- *Strong Identification* — An unambiguous, immutable identifier associated with the platform. The identifier is a protected encryption key in the TXT implementation.
- *Reporting Configuration* — An unambiguous identification mechanism for software and hardware running on the platform. The mechanism is hashing in the TXT implementation

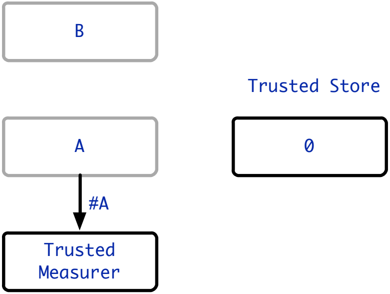
Chaining Measurements

- Start with a measurer and store that is trusted



Chaining Measurements

- Start with a measurer and store that is trusted
- Measure software to be launched



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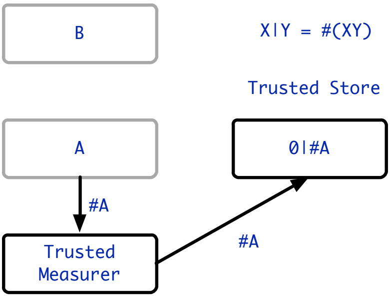
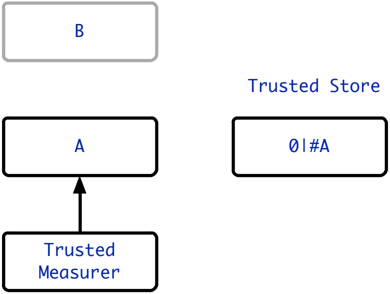


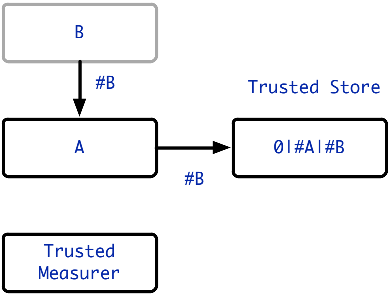
Chaining Measurements

- Start with a measurer and store that is trusted
- Measure software to be launched
- Store the measurement
- Launch the new software



Chaining Measurements

- Start with a measurer and store that is trusted
- Measure software to be launched
- Store the measurement
- Launch the new software
- Repeat until system boot



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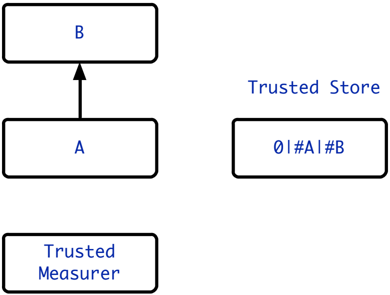

What Do We Know?

Assume we know $0|\#A|\#B$ is correct

- $\#A$ and $\#B$ must be correct
  - A and B are the correct binaries
  - A and B include hash and launch functions
- Measurement occurred in the right order
  - $\#(XY) \neq \#(YX)$
  - Trusted store started with 0

But Why Trust B?

A chain exists from Trusted Measurer and Trusted Store to B

- Trusted Measurer and Trusted Store are trusted *a priori*
- A is trusted to be A because its measurement is:
  - Correct
  - Taken by a trusted party (Trusted Measurer)
  - Stored by a trusted party (Trusted Store)
- B is trusted to be B because its measurement is:
  - Correct
  - Taken by a trusted party (A)
  - Stored by a trusted party (Trusted Store)
  - If A's ability to measure B were compromised, $\#A$ would be wrong
- and so on and so on...

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Trust is a Preorder

$T^{\mathsf{x}}[\mathsf{y}]$ is an homogeneous relation over actors that is true when *x trusts y*. $T^{\mathsf{x}}[\mathsf{y}]$ is a preorer:

- Reflexive - $\forall x \cdot T^{\mathsf{x}}[\mathsf{x}]$
- Transitive - $\forall x, y, z \cdot T^{\mathsf{x}}[\mathsf{y}] \wedge T^{\mathsf{y}}[\mathsf{z}] \Rightarrow T^{\mathsf{z}}[\mathsf{x}]$

Trusted Boot builds evidence supporting these chains

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Trusted Platform Module

The *Trusted Platform Module (TPM)* is a cryptographic coprocessor for trust.

- Endorsement Key (EK) — factory generated asymmetric key that uniquely identifies the TPM
- Attestation Instance Key (AIK) — `TPM_CreateIdentity` generated asymmetric key alias for the EK
- Storage Root Key (SRK) — `TPM_TakeOwnership` generated asymmetric key that encrypts data associated with the TPM
- Platform Configuration Registers (PCRs) — protected registers for storing and extending hashes
- NVRAM — Non-volatile storage associated with the TPM

Endorsement Key

- Asymmetric key generated at TPM fabrication
- EK^{-1} is protected by the TPM
- *EK* by convention is managed by a Certificate Authority
  - Binds *EK* with a platform
  - Classic trusted third party
- Only used for encryption
- Attestation Instance Keys (AIK) are aliases for the EK
  - Used for signing
  - Authorized by the EK

Storage Root Key

- Asymmetric key generated by `TPM_TakeOwnership`
- SRK^{-1} is protected by the TPM
- *SRK* is available for encryption
- Used as the root for chaining keys by *wrapping*
  - A wrapped key is an asymmetric key pair with it's private key sealed
  - Safe to share the entire key
  - Only usable in the presence of the wrapping key with expected PCRs

Platform Configuration Registers

- Operations on PCRs
  - Extension — Hash a new value juxtaposed with the existing PCR value
  - Reset — Set to 0
  - Set — Set to a known value
- Operations using PCRs
  - Sealing data — PCR state dependent encryption
  - Wrapping keys — PCR state dependent encryption of a private key
  - Quote — Reporting PCR values to a third party
- Properties
  - Locality — Access control
  - Resettable — Can a PCR be reset
  - Many others that we don't need yet

Roots of Trust

A *root of trust* provides a basis for transitively building trust. Roots of trust are trusted implicitly.

There are three important Roots of Trust:

- Root of Trust for Measurement (RTM)
- Root of Trust for Reporting (RTR)
- Root of Trust for Storage (RTS)

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Root of Trust for Measurement

A *Root of Trust for Measurement* is trusted to take the base system measurement.

- A hash function called on an initial code base from a protected execution environment
- Starts the measurement process during boot
- In the Intel TXT process the RTM is `SENTER` implemented on the processor

Root of Trust for Reporting

A *Root of Trust for Reporting* is trusted to guarantee the integrity of the base system report or quote

- A protected key used for authenticating reports
- In the Intel TXT processes this is the TPM's Endorsement Key (EK)
- Created and bound to its platform by the TPM foundry
- EK^{-1} is stored in the TPM and cannot be accessed by any entity other than the TPM
- EK is available for encrypting data for the TPM
- EK^{-1} is used for decrypting data inside the TPM
- Linking EK to its platform is done by a trusted Certificate Authority (CA)

Root of Trust for Storage

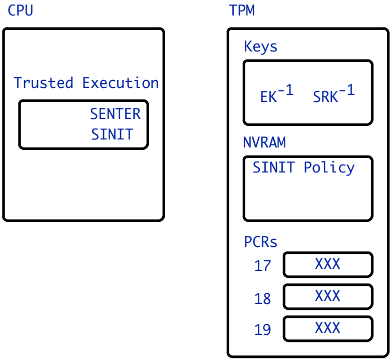
A *Root of Trust for Storage* is trusted to protect stored data

- A key stored in a protected location
- In the Intel TXT boot process this is the TPM's Storage Root Key (SRK)
- Created by `TPM_TakeOwnership`
- SRK^{-1} is stored in the TPM and cannot be accessed by any entity other than the TPM
- SRK is available for encrypting data for the TPM
- SRK is used for protecting other keys

One Step from Roots of Trust

Roots of trust are used to build a trusted system from boot.

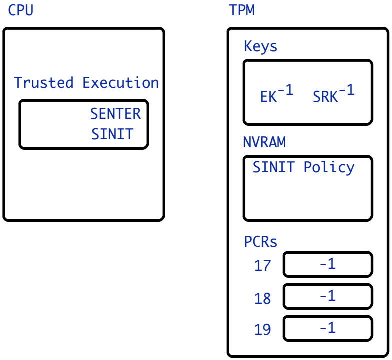
- Power-on reset



One Step from Roots of Trust

Roots of trust are used to build a trusted system from boot.

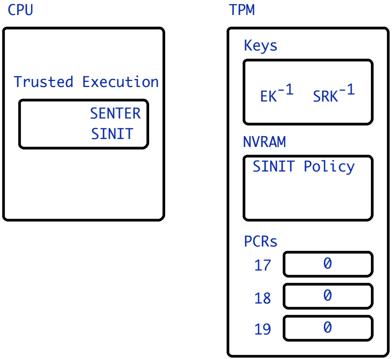
- Power-on reset
- Resettable PCRs set to -1



One Step from Roots of Trust

Roots of trust are used to build a trusted system from boot.

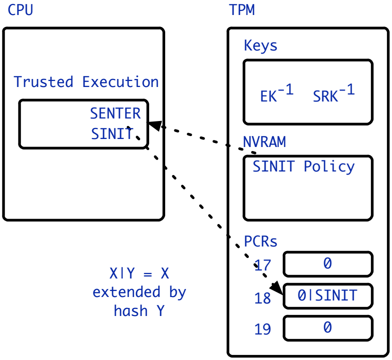
- Power-on reset
- Resettable PCRs set to -1
- SENTER called, resets resettable PCRs to 0



One Step from Roots of Trust

Roots of trust are used to build a trusted system from boot.

- Power-on reset
- Resettable PCRs set to -1
- `SENTER` called, resets resettable PCRs to 0
- `SENTER` measures `SINIT` policy into PCR 18



What We Know From Good PCR 18

A good value in PCR 18 tells us:

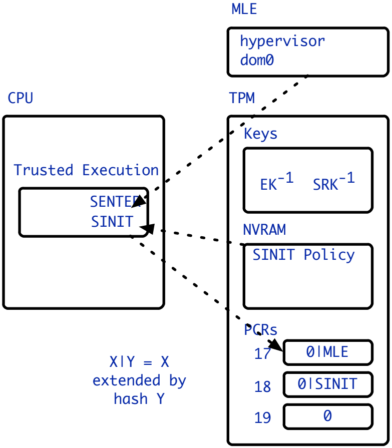
- `SENTER` was called — Resetting PCR 18 starts measurements at 0 rather than -1
- `SINIT` was measured by `SENTER` — Only `SENTER` can extend PCR 18
- `SINIT` uses the correct policy — PCR 18 is extended with `SINIT` measurement policy
- `SENTER` ran before `SINIT` was measured — $A \mid B \neq B \mid A$

Measurement $\neq$ Trust

Measurements must be appraised to determine trust.

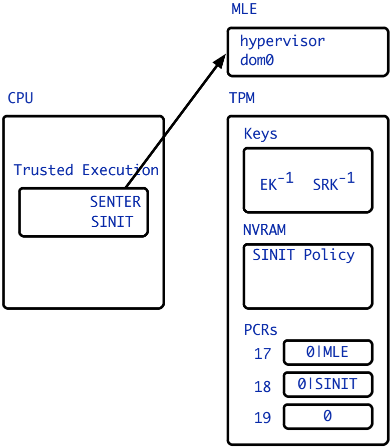
Two Steps from Roots of Trust

- `SINIT` measures the Measured Launch Environment (MLE) using measured policy
- `SINIT` returns control to `SENTER`



Two Steps from Roots of Trust

- SINIT measures the Measured Launch Environment (MLE) using measured policy
- SINIT returns control to SENTER
- SENTER invokes the MLE

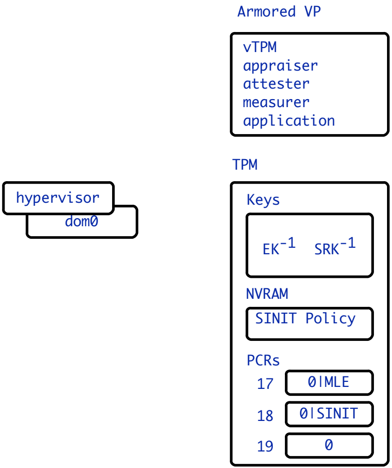


What We Know From Good PCRs

- `SENTER` was called — Resetting PCR 18 starts measurement sequence at 0 rather than -1
- `SINIT` policy was measured by `SENTER` — Only `SENTER` can extend PCR 18
- `SINIT` uses the correct policy — PCR 18 is extended with `SINIT` measurement policy
- `SENTER` ran before `SINIT` — $0 \mid SINIT \neq -1 \mid SINIT$
- `SLE` is good — Measured by good `SINIT` into PCR
- Initial OS is good — Measured by good `SLE` into PCR

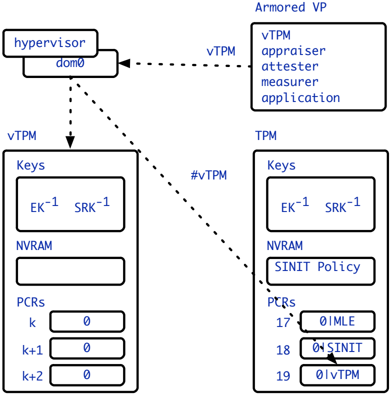
Boot the MLE

- SENTER starts the MLE
  - SENTER starts the hypervisor
  - SENTER passes dom0 to hypervisor
  - hypervisor starts dom0



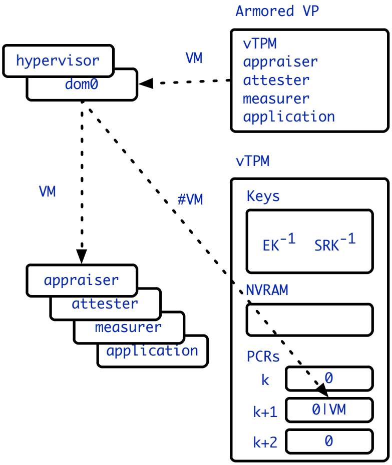
Boot the MLE

- SENTER starts the MLE
  - SENTER starts the hypervisor
  - SENTER passes dom0 to hypervisor
  - hypervisor starts dom0
- dom0 constructs the Armored VP
  - Measures the vTPM into the TPM
  - Starts the vTPM



Boot the MLE

- SENTER starts the MLE
  - SENTER starts the hypervisor
  - SENTER passes dom0 to hypervisor
  - hypervisor starts dom0
- dom0 constructs the Armored VP
  - Measures the vTPM into the TPM
  - Starts the vTPM
  - Measures remaining Armored VMs into the vTPM
  - Starts remaining Armored VMs
  - Measures Armored application into the vTPM
  - Starts the Armored application



Boot the MLE

- SENTER starts the MLE
  - SENTER starts the hypervisor
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  - hypervisor starts dom0
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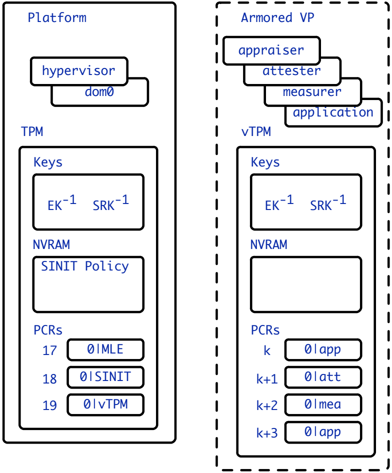
  - Measures remaining Armored VMs into the vTPM
  - Starts remaining Armored VMs
  - Measures Armored application into the vTPM
  - Starts the Armored application



Chaining Trust (Reprise)

- Trust is transitive
  - $T^x[y] \wedge T^y[z] \Rightarrow T^x[z]$
  - Construct evidence trust chains
  - Remember "directly observed or indirectly observed by a trusted third party"
- Roots of Trust define the "root" for trust
  - Use Roots of Trust to establish base for chain
  - RTM is the Trusted Measurer
  - RTS is the Trusted Store
  - RTR is the Trusted Reporter (coming soon...)
- Extend chains of trust by measuring before executing

[1] A. Martin et al. The ten page introduction to trusted computing. Technical Report CS-RR-08-11, Oxford University Computing Labratory, Oxford, UK, 2008.

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