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Trusted Computing

→ Trusted Platform Module (TPM)

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if(is) internet security.

Content

- Aim and outcomes of this lecture
- Overview of the idea of TPM
- Terminology and Assumption
- Identities
- TPM Keys and Keys´ Properties
- TPM Key Types
- Some More TPM Details
- Summary

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Trusted Platform Module (TPM)
→ Aims and outcomes of this lecture

Aims

- To introduce the idea of the Trusted Platform Module (TPM)
- To explore the architecture and the functions of Trusted Platform Module (TPM)
- To analyze the functions and protocols of the Trusted Platform Module (TPM)
- To assess needs of the Trusted Platform Module (TPM)

At the end of this lecture you will be able to:

- Understand what is meant by the Trusted Platform Module (TPM).
- Know some of the functions of the Trusted Platform Module (TPM).
- Know what the protocols of the Trusted Platform Module (TPM) look like.
- Understand the capabilities and limitations of the Trusted Platform Module (TPM).

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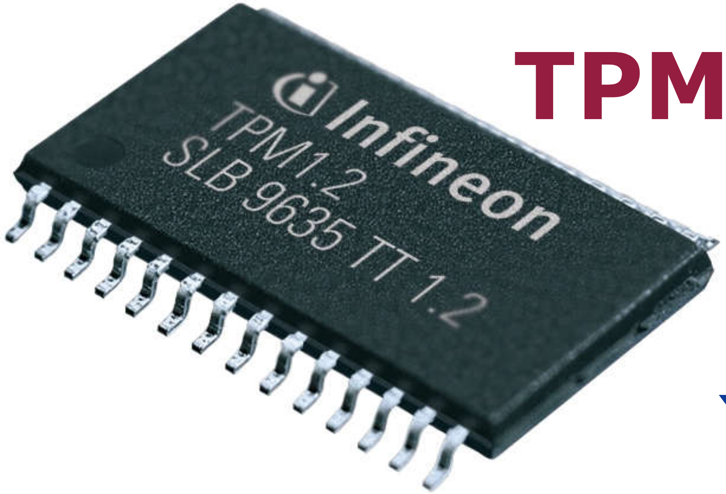
Trusted Platform Module (TPM)
→ Overview (1/4)



TPM

The Safe

on our Motherboard!

Trusted Platform Module (TPM)

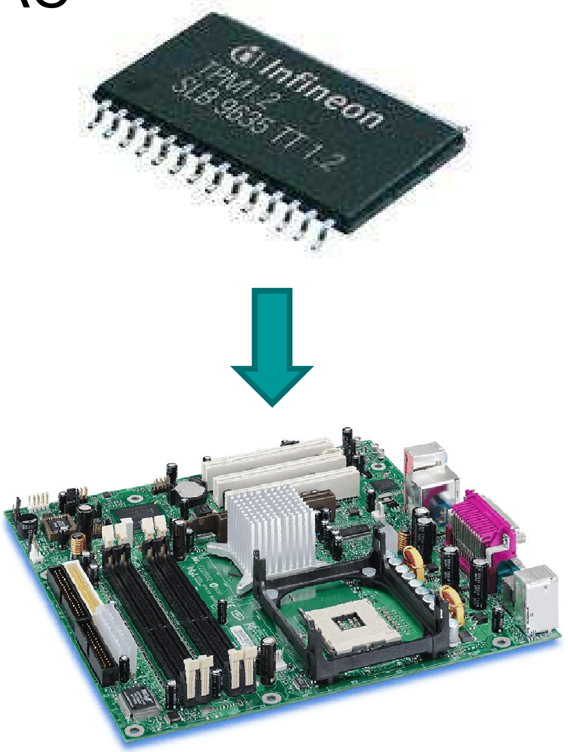
→ Overview (2/4)

The Trusted Platform Module (TPM) is ...

- a **passive** security controller
- **bound to the mainboard** of a computing platform
  (e.g. PC, notebook, PDA, mobile phone, ...)
- but **physically separated** from the **main processor**
- capable to **withstand logical and physical attacks** to protect it’s credentials
- proven and **certified by a third-party** Common Criteria evaluation
- **integrated in the booting process** as well as in the operating system

Trusted Platform Module (TPM)
→ Overview (3/4)

- Current implementation is a **security controller**
  - Hardware-based random number generation
  - Small set of cryptographic functions
    - Key generation, signing, encryption, hashing, MAC
- Offers **additional functionalities**
  - Secure storage (ideally tamper-resistant)
  - Platform integrity measurement and reporting
- **Embedded** into the platform’s motherboard
- Acts as a **“Root of Trust”**
  - TPM must be trusted by all parties
- Two versions of specification **available**
- Many vendors already ship their platforms with a TPM [TPMMatrix2006]



Trusted Platform Module (TPM)
→ Overview (4/4)

Common misconceptions

- The TPM does not measure, monitor or control anything
  - Software measurements are made by the “PC” and sent to the TPM
  - The TPM has no way of knowing what was measured
  - The TPM is unable to reset the PC or prevent access to memory

- The platform owner controls the TPM
  - The owner must opt-in using initialization and management functions
  - The owner can turn the TPM on and off
  - The owner and users control use of all keys

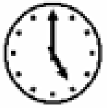
Security features of Infineon TPM
→ Overview (Example of one TPM)

Electro Magnetic Analysis (EMA)

Differential Fault Attack (DFA)

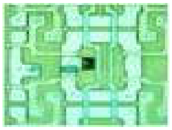
Alpha Particle Penetration

Timing Analysis



Global and Local Optical Attacks

Contrast Etching / Decoration



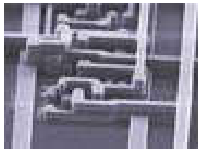
Countermeasures:

- ☺ Active Shields
- ☺ Security Memory Cells
- ☺ Hardware Encryption
- ☺ Hidden Layout Techniques
- ☺ Memory Scrambling
- ☺ Proprietary CPU Kernel
- ☺ Randomizing Features
- ☺ Test mode Locking Mechanism
- ☺ Sensors and Filters

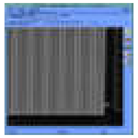
… more than 50 security features

Probing / Forcing

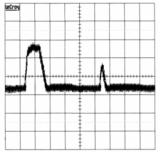
Reverse Engineering / Delayering



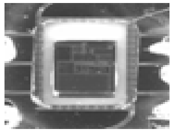
Electron Microscopy



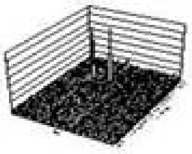
Spike / Glitch Penetration



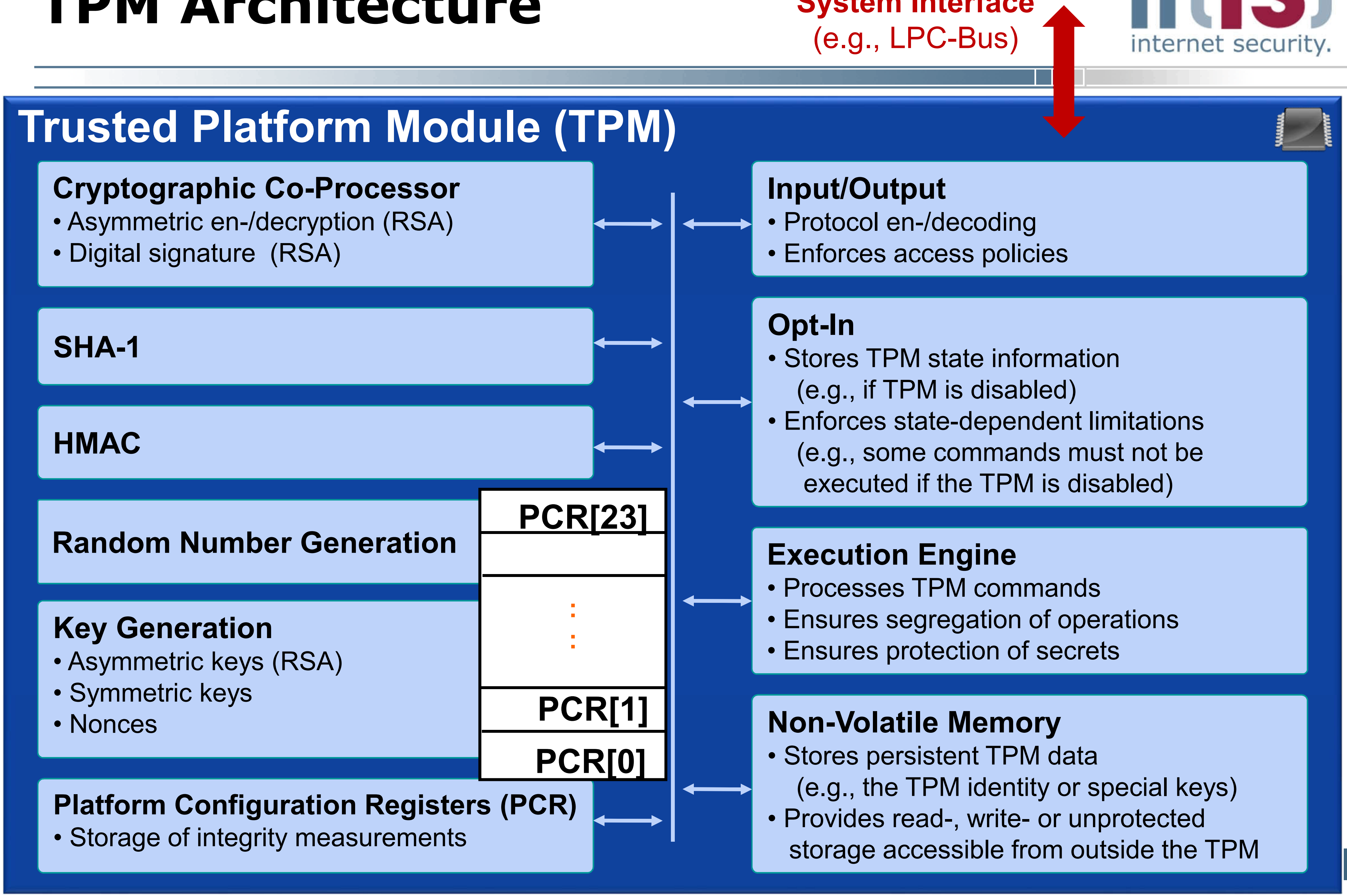
Atomic Force Microscopy (AFM)



Differential Power Analysis (DPA)



TPM Architecture



System Interface
(e.g., LPC-Bus)

Trusted Platform Module (TPM)

Cryptographic Co-Processor
- Asymmetric en-/decryption (RSA)
- Digital signature (RSA)

SHA-1

HMAC

Random Number Generation

Key Generation
- Asymmetric keys (RSA)
- Symmetric keys
- Nonces

Platform Configuration Registers (PCR)
- Storage of integrity measurements

Input/Output
- Protocol en-/decoding
- Enforces access policies

Opt-In
- Stores TPM state information (e.g., if TPM is disabled)
- Enforces state-dependent limitations (e.g., some commands must not be executed if the TPM is disabled)

Execution Engine
- Processes TPM commands
- Ensures segregation of operations
- Ensures protection of secrets

Non-Volatile Memory
- Stores persistent TPM data (e.g., the TPM identity or special keys)
- Provides read-, write- or unprotected storage accessible from outside the TPM

TPM Internal Functions
→ Features I

- **SHA-1 engine**
  - Computes the SHA-1 digest (digest) of arbitrary data (data)

    digest ← SHA-1(data)

- **HMAC engine**
  - Computes the HMAC digest authDigest resulting from a secret secret and arbitrary data (data)

    authDigest ← HMAC(secret , data)

  - Mainly used in TPM's authentication protocols
    - See OSAP/OIAP protocols (TPM authorization protocols)

- **Platform Configuration Registers (PCR)**
  - Copies the current values stored in the TPM's PCRs to state

    state ← getCurrentPCRs()

  - e.g., used in the context of sealing to derive platform's current configuration

TPM Internal Functions
→ Features II

- **Random Number Generator**
  - Returns n random bytes

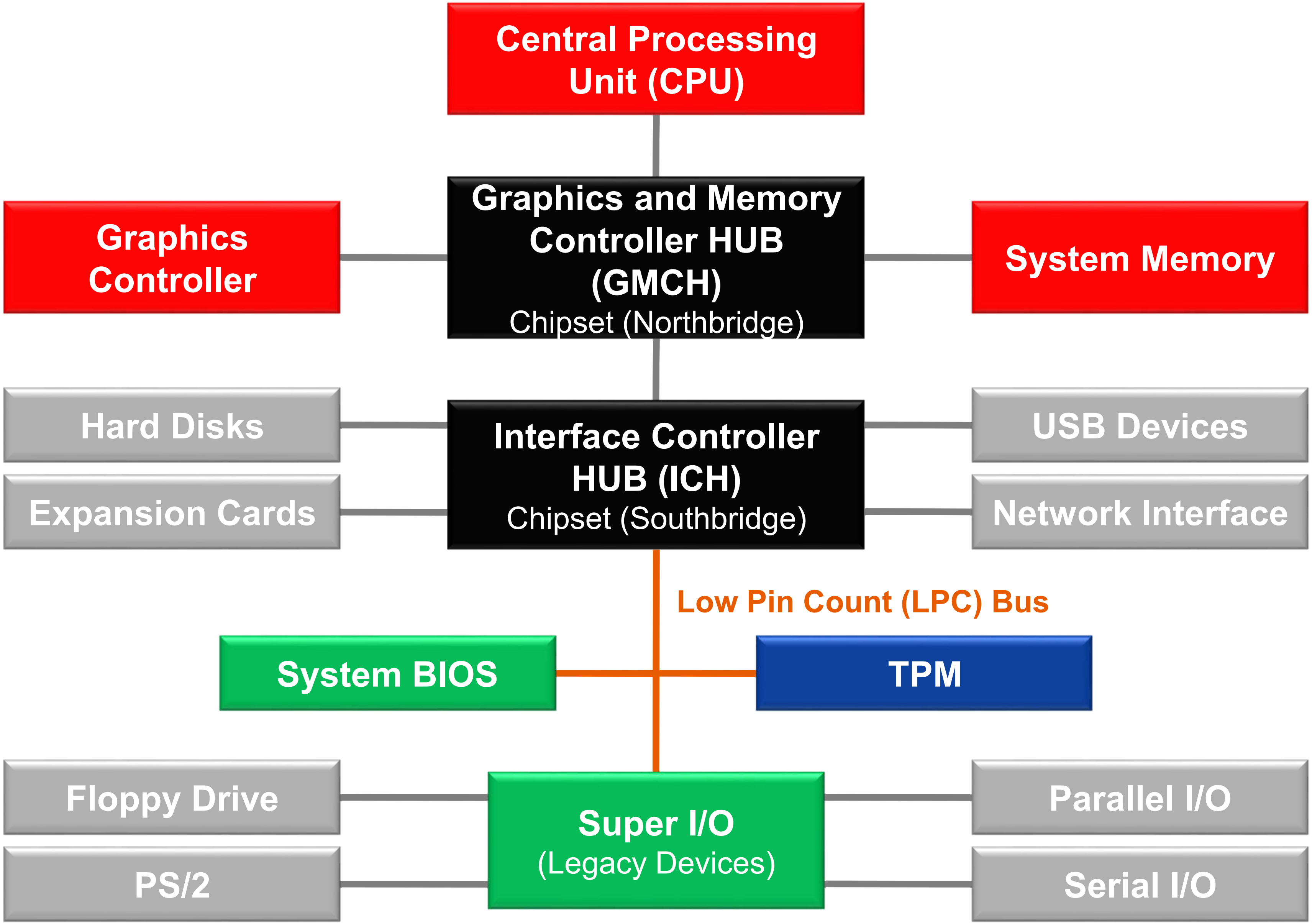
$$\text{rand} \leftarrow \text{RNG}(\ n\ )$$

  - Mainly used to derive 20 random bytes
    - e.g., to be used as nonce (anti-replay value)

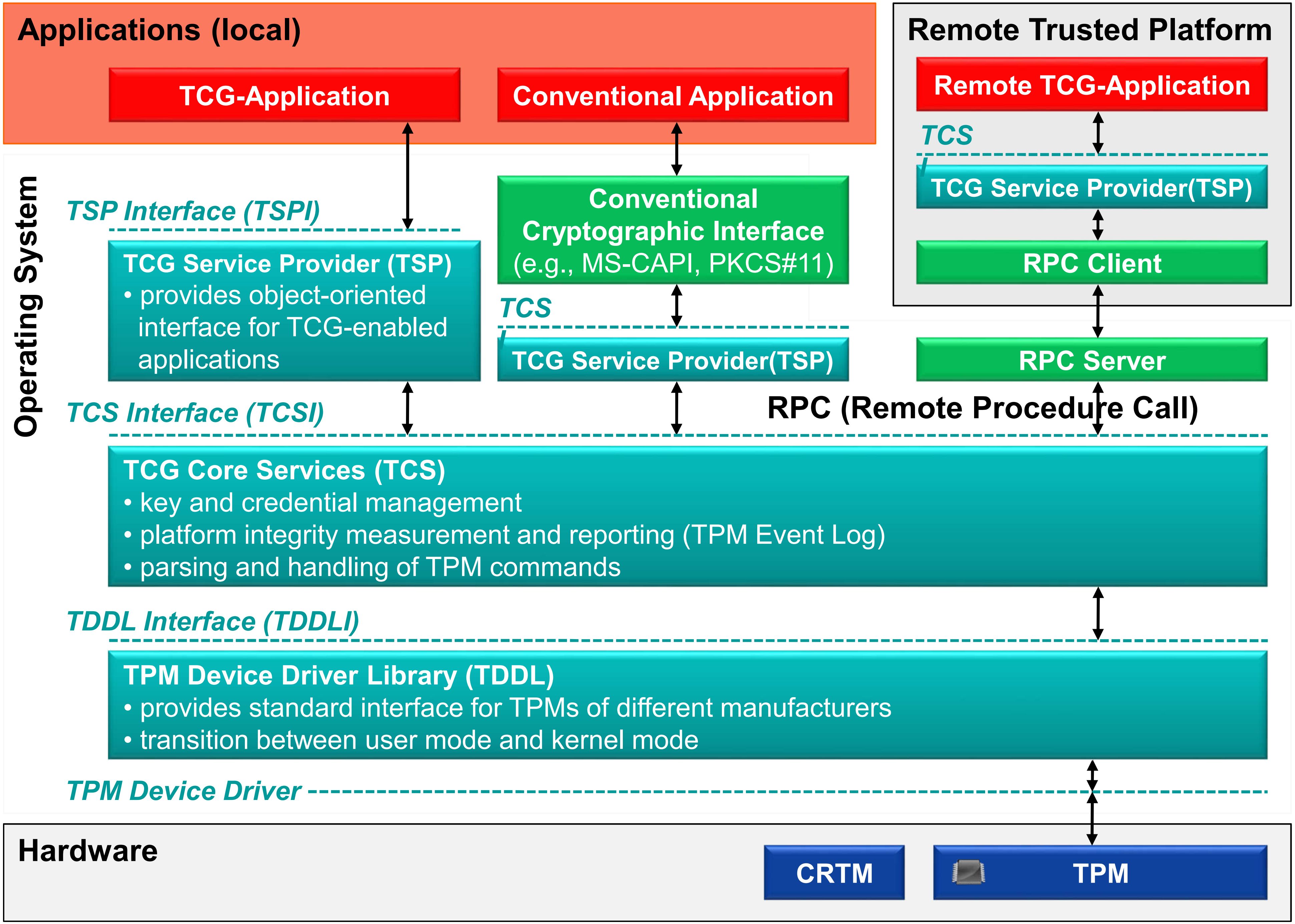
- **Key Generation Engine**
  - Generates a key pair (pk, sk) according to the parameters given in par (e.g., key size, key type, etc.)

$$(\ pk\ ,\ sk\ ) \leftarrow \text{GenKey}(\ par\ )$$

Trusted Platform Module (TPM)
→ TPM Integration into PC-Hardware



TPM Software Integration



Applications (local)

TCG-Application

Conventional Application

Remote Trusted Platform

Remote TCG-Application

TCS

TCG Service Provider(TSP)

RPC Client

Operating System

TSP Interface (TSPI)

TCG Service Provider (TSP)
- provides object-oriented interface for TCG-enabled applications

Conventional Cryptographic Interface
(e.g., MS-CAPI, PKCS#11)

TCS

TCG Service Provider(TSP)

RPC Server

RPC (Remote Procedure Call)

TCS Interface (TCSI)

TCG Core Services (TCS)
- key and credential management
- platform integrity measurement and reporting (TPM Event Log)
- parsing and handling of TPM commands

TDDL Interface (TDDLI)

TPM Device Driver Library (TDDL)
- provides standard interface for TPMs of different manufacturers
- transition between user mode and kernel mode

TPM Device Driver

Hardware

CRTM

TPM

🟦 Trusted Software Stack (TSS) 🟩 System Services

Trusted Platform Module (TPM)

→ TPM Startup in a PC

Power-Off State

TPM_Init()

Limited Self-Test Mode
- *TPM performs a minimal self-test*
- *Only `TPM_Startup()` can be executed*

TPM_Startup(clear)

Limited Operational Mode

Can only execute commands related to
- *hashing*
- *integrity measurement and*
- *obtaining self-test results*

TPM_ContinueSelfTest()

Fully Operational Mode

For all TPM functions to be available
- *a TPM Owner must be installed*
- *TPM must be enabled*

🟦 TPM state

1. **User powers on / resets platform**

   `TPM_Init()`
   - No software-executable command
   - Informs TPM about system-wide reset
   - Platform design must ensure that TPM receives `TPM_Init()` only if platform performs a complete reset

2. **BIOS starts TPM**

   `TPM_Startup(state)`
   - Executed by the system BIOS
   - state ϵ { clear , save , deactivated }

   clear volatile memory initialized with default values

   save volatile memory initialized with values previously saved to TPM's non-volatile memory

   deactivated deactivates the TPM

3. **BIOS instructs TPM to perform a full self-test**

   `TPM_ContinueSelfTest()`
   - Executed by the system BIOS
   - Instructs TPM to perform a full self-test

4. **TPM is ready to be used**

Trusted Platform Module (TPM)
→ Core Root of Trust for Measurement

- **Immutable portion** of the host platform’s initialization code that executes upon a host platform reset
- **Trust** in all measurements is based on the **integrity of the “Core Root of Trust for Measurement” (CRTM)**
- Ideally the CRTM is **contained in the TPM**
- Implementation decisions may require it to be located in other firmware (e.g., BIOS boot block)

Two Possible CRTM Implementations

1. **CRTM is the BIOS Boot Block**
   - BIOS is composed of a BIOS Boot Block and a POST BIOS
   - Each of these are independent components
     - Each can be updated independent of the other
   - BIOS Boot Block is the CRTM while the POST BIOS is not, but is a measured component of the Chain of Trust

2. **CRTM is the entire BIOS**
   - BIOS is composed of a single atomic entity
   - Entire BIOS is updated, modified, or maintained as a single component

CRTM: Core Root of Trust for Measurement

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Trusted Computing Group (TCG)
→ Terminology I

- **Shielded Location**
  - ***Place*** where ***sensitive data can* safely *be stored or operated***
    - e.g., memory locations **inside the TPM** or data objects **encrypted by the TPM** and stored on external storage (e.g., hard disk)
- **Protected Capabilities (Protected Functions)**
  - Set of commands with **exclusive permission** to access shielded locations
    - e.g., commands for cryptographic key management, sealing of data to a system state, etc.
- **Protected Entity**
  - Refers to a protected capability or sensitive data object stored in a shielded location

Trusted Computing Group (TCG)
→ Terminology II

- **Integrity Measurement**
  - Process of obtaining metrics of platform characteristics that affect the integrity (trustworthiness) of a platform and storing digests of those metrics to the TPM's **PCRs (Platform Configuration Registers)**
    - Platform characteristic = **digest of the software to be executed**
- **Platform Configuration Registers (PCR)**
  - **Shielded location** to **store integrity measurement values**
  - Can only be extended: $PCR_{i+1} \leftarrow$ SHA-1(PCR_i , value)
  - PCRs are reset only when the platform is rebooted
- **Integrity Logging**
  - Storing integrity metrics in a log for later use
  - e.g., storing additional information about what has been measured like software manufacturer name, software name, version, etc.

Trusted Computing Group (TCG)
→ Assumption and Trust Model I

- **Unforgeability of measurements**
  - Platform configuration **cannot be forged after measurements**
  - *However, today's OS can be modified*

- **Digest values express trustworthiness**
  - Verifier can determine initial configuration from **digests**
  - *However, TCBs of today's platforms are too complex*

- **Secure channels can be established**
  - Between HW components (TPM and CPU) since they might have certified authentication keys provided by a PKI
  - Between machines running on a platform (e.g., attestor and host), provided by operating system mechanisms (secure OS)

Trusted Computing Group (TCG)
→ Assumption and Trust Model II

- **Protection against software attacks only**
  - Unprotected communication link between TPM and CPU
  - See, e.g., [KuScPr2005]

- **Security issues of certain TPM aspects**
  - See, e.g., [GuRuScAtPl2007] for an automated verification

- **Integration of TPM functionality in chipset may potentially be problematic**
  - Engineering trade off between security and technical evaluation
  - TPM Construction Kit
  - Towards more security against hardware attacks

- **Currently**
  - TPMs have rudimentary protection mechanisms (TPM stems from smartcards)
  - Some manufacturers started third party certification
  - CRTM is not tamper-resistant

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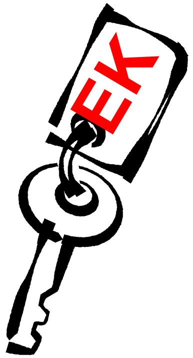
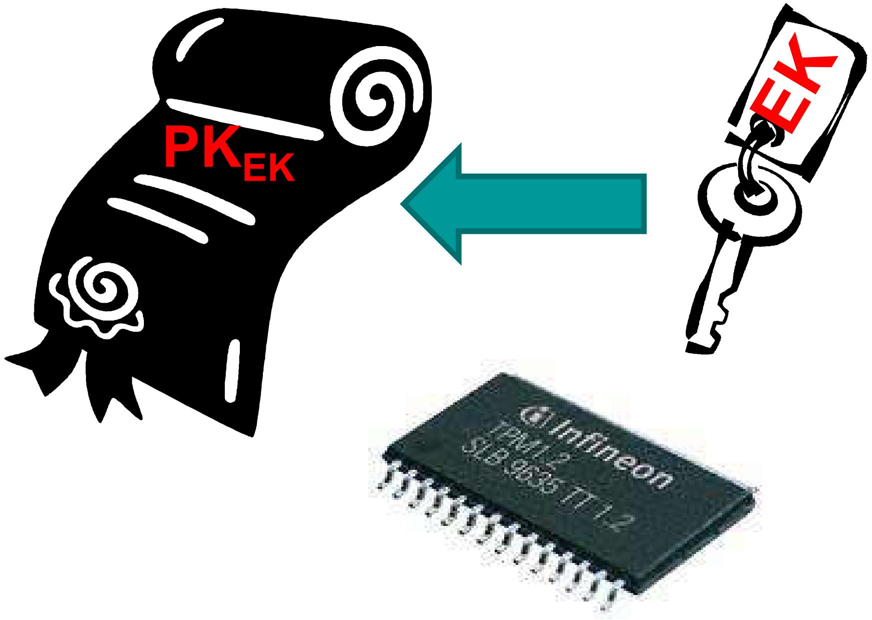
Identities
→ TPM Identity (Endorsement Key)

- **TPM identity represented as Endorsement Key (EK)**
- **Unique en-/decryption key pair**
  - Private key does not leave TPM
  - Public key is privacy-sensitive (since it identifies a TPM/platform)
- **Generated during manufacturing process of TPM**
  - Either **in TPM** or **externally** and then embedded into the TPM
- **Must be certified by EK-generating entity**
  - e.g., by the TPM manufacturer
- **Can be deleted (revoked) and re-generated by a TPM user**
  - Revocation must be enabled during creation of the EK
  - Deletion must be authorized by a secret defined during EK creation
  - EK-recreation invalidates Endorsement Credential (EC)
- **Readable from TPM via**
  - `TPM_ReadPubek` (command disabled after taking ownership)
  - `TPM_OwnerReadInternalPub` (requires owner authorization)



Identities
→ Endorsement Credential

- **Digital certificate stating that**
  - EK has been properly created and embedded into a TPM
- **Issued by the entity who generated the EK**
  - e.g., the TPM manufacturer
- **Includes**
  - TPM manufacturer name
  - TPM model number
  - TPM version
  - Public EK (privacy sensitive)



Identities

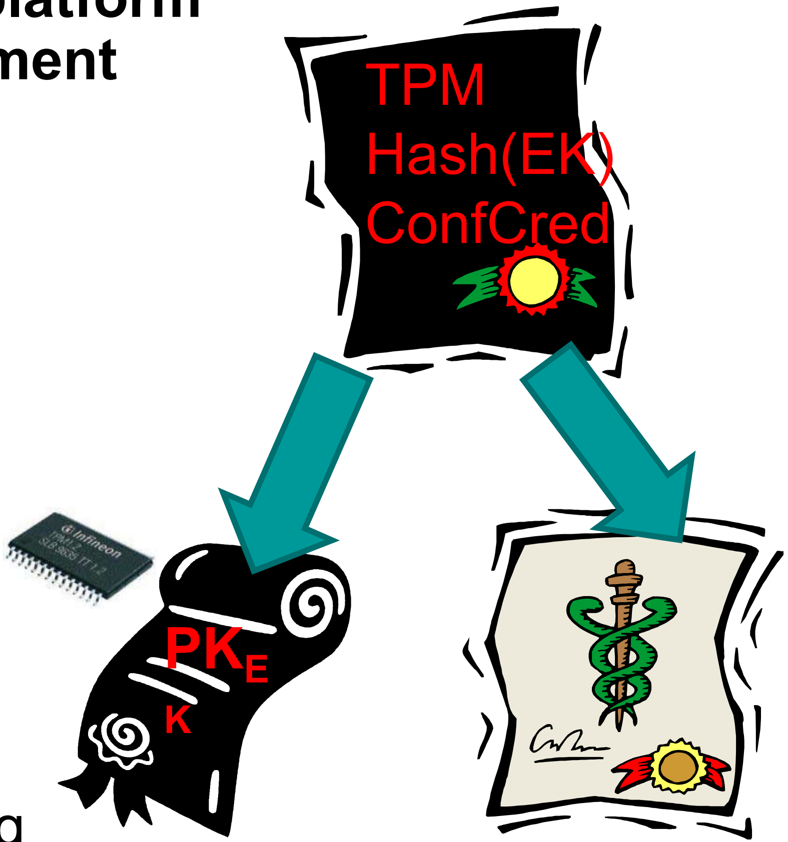
→ Platform Identity

- **Platform identity is equivalent to TPM identity (EK)**
  - EK is unique identifier for a TPM
  - A TPM must be bound to only one platform
    - Either physical binding (e.g., soldered to the platform’s motherboard) or logical binding (e.g., by using cryptography)
    - Common implementation: TPM soldered to the platform’s motherboard
  - Therefore an EK uniquely identifies a platform

- **Platform Credential asserts that a TPM has been correctly integrated into a platform**

Identities
→ Platform Credential

- **Digital certificate stating that an individual platform contains the TPM described in the Endorsement Credential (EC)**
- **Issued by the platform manufacturer**
  - e.g., system or motherboard manufacturer
- **Includes**
  - Platform manufacturer name
  - Platform model and version number
  - References to (digests of) the corresponding Endorsement and Conformance Credential
    - Conformance Credential asserts that a platform type fulfills the evaluation guidelines defined by the TCG



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TPM Keys and Keys´ Properties
→ Migratable and Non-Migratable Keys

- **Migratable keys**
  - Can be migrated to other TPMs/platforms
  - Third parties have no assurance that such keys have been generated by a TPM
    - Third parties may not trust migratable keys

- **Non-migratable keys**
  - Cannot be migrated to other TPMs/platforms
  - Guaranteed to only reside in TPM-protected locations
  - TPM can generate certificate stating that a key is non-migratable

TPM Keys and Keys´ Properties
→ Certified Migratable Keys (CMK)

- **Introduced with TPM Specification 1.2**

- **Migration delegated to**
  - Migration-Selection Authority (MSA)
    - Controls migration of keys
  - Migration Authority (MA)
    - Performs the migration of keys

- **Migration of CMK to another TPM requires certificate of MA stating that the key is allowed to be transferred**
  - See Migration of TPM Keys

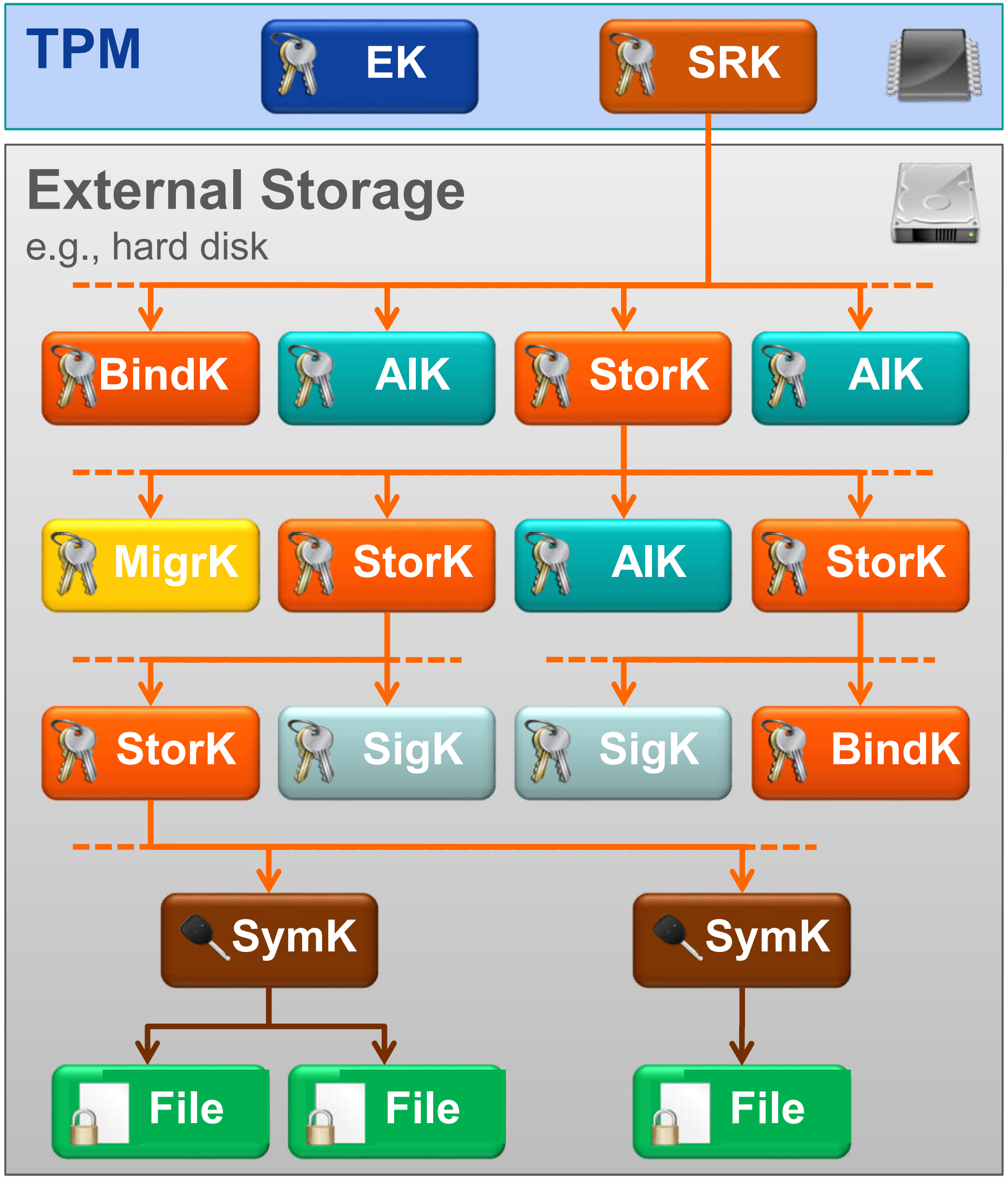
TPM Keys and Keys´ Properties
→ Secure Root Key (SRK)

- **TPM contains Root of Trust for Storage (RTS)**
  - Secure data storage implemented as a **hierarchy of keys**
  - Storage Root Key (SRK) is root of this key hierarchy

- **Storage Root Key (SRK) represents RTS**
  - RSA en-/decryption key pair
    - Must at least have 2048-bit key length
    - **Private SRK must not leave TPM**
  - Generated by TPM during process of installing TPM Owner
  - Deleted when the TPM Owner is deleted
    - This makes key hierarchy inaccessible and thus **destroys all data encrypted** with keys in that hierarchy!!!

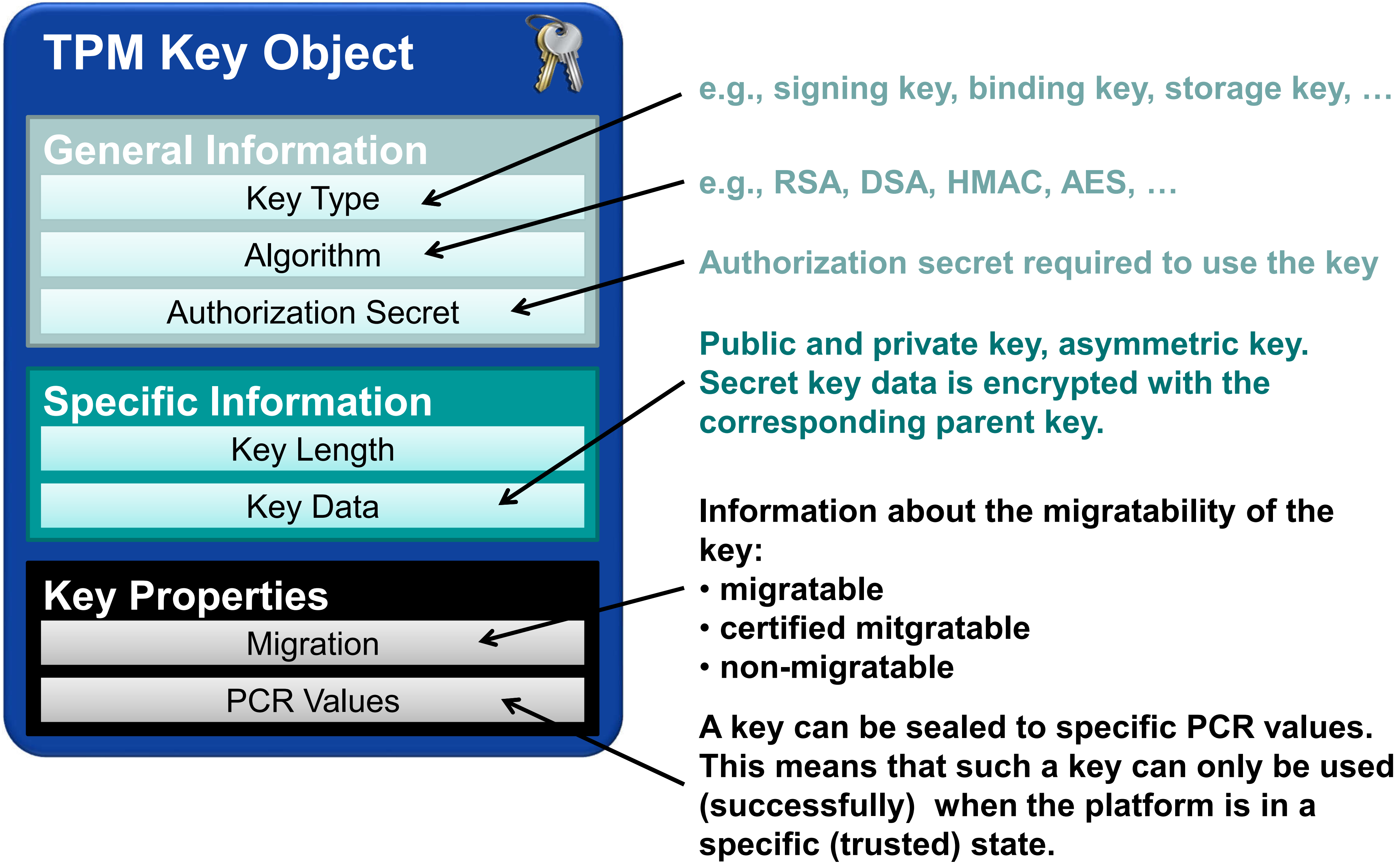
A → B means A encrypts B
A is called **parent key** of B

TPM Key Hierarchy



- Depth of hierarchy and number of TPM-protected keys only limited by size of external storage
- **Storage keys (StoreK)** protect all other key types
  - **Attestation ID keys (AIK)**
  - **Signing keys (SigK)**
  - **Binding keys (BindK)**
  - **Migration Keys (MigrK)**
  - **Symmetric keys (SymK)**
- Transitive protection
  - SRK indirectly protects arbitrary data (e.g., **files)**

TPM Keys and Keys´ Properties
→ TPM Key Object – Important Fields



TPM Key Object

General Information
- Key Type
- Algorithm
- Authorization Secret

Specific Information
- Key Length
- Key Data

Key Properties
- Migration
- PCR Values

e.g., signing key, binding key, storage key, …

e.g., RSA, DSA, HMAC, AES, …

Authorization secret required to use the key

Public and private key, asymmetric key. Secret key data is encrypted with the corresponding parent key.

Information about the migratability of the key:
- **migratable**
- **certified mitgratable**
- **non-migratable**

A key can be sealed to specific PCR values. This means that such a key can only be used (successfully) when the platform is in a specific (trusted) state.

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TPM Key Types
→ Overview

- **TPM provides 9 different types of keys**
  - 3 special TPM key types
    - Endorsement Key, Storage Root Key, Attestation Identity Keys
  - 6 general key types
    - Storage, signing, binding, migration, legacy and “authchange” keys
  - Most important key types explained in following slides …

- **Each key may have additional properties, the most important ones are**
  - Migratable, non-migratable, certified migratable
    - e.g., whether the key is allowed to be migrated to another TPM
  - Whether the key is allowed only to be used when the platform is in a specific (potentially secure) configuration

Legacy Keys (not recommended)

TPM Key Types
→ Attestation Identity Keys (AIK)

- **Purpose**
  - Used to attest to current platform configuration
    - e.g., authentically report the current hard- and software environment to a remote party (see attestation)
  - **Alias for TPM/platform identity (Endorsement Key)**
  - Use of AIKs should prevent tracking of TPMs/platforms
    - e.g., the transactions of a platform can be traced if the EK is used in various protocol runs with different colluding service providers

- **Properties**
  - AIKs are non-migratable signing keys (e.g., 2048-bit RSA)
  - **Generated by the TPM Owner**
  - TPM/platform may have multiple AIKs
    - e.g., one for online-banking, one for e-mail, etc.

TPM Key Types
→ Certification of AIKs

- **AIK requires certification by Trusted Third Party (Privacy CA in TCG Terminology) certifying that an AIK comes from a TPM**

- **Unlinkability achieved by DAA (Direct Anonymous Attestation) protocols**
    - No Privacy CA needed
    - Zero-knowledge proof of knowledge of possession of a valid certificate

TPM Key Types
→ Storage Keys

- **Purpose: Protection of keys outside the TPM**
  - e.g., a storage key can be used to encrypt other keys, which can be stored on a hard disk
  - **Storage Root Key (SRK) is a special storage key**
  - Strong protection of arbitrary TPM-external data (sealing)
    - e.g., encryption of secrets, which can only be recovered if the platform has a defined hard-/software environment (see **sealing**)

- **Properties**
  - Typically 2048-bit RSA en-/decryption key pair
  - Generally allowed to be migrated to other TPMs
    - Are not allowed to be non-migratable if one of their parent keys is migratable
    - **Must be non-migratable if used for sealing**

TPM Key Types
→ Binding Keys

- **Purpose**
  - Protection of arbitrary data outside the TPM
    - Binding is equivalent to traditional asymmetric encryption

- **Description**
  - Asymmetric en-/decryption key pair
    - Typically RSA 2048-bit
    - Other asymmetric encryption schemes may be supported by the TPM
  - Migratable to other TPMs/platforms
    - Are not allowed to be non-migratable if one of their parent keys is migratable

- **Can only be used with binding-commands**

TPM Key Types
→ Signing Keys

- **Purpose**
  - Message authentication of arbitrary TPM-external data
    - e.g., to ensure integrity of arbitrary files stored on the platform or protocol messages sent by the platform and their origin
  - Authentic report of TPM-internal information
    - e.g., for auditing TPM commands or reporting TPM capabilities

- **Description**
  - Typically 2048-bit RSA signing/verification key pair
    - Other signing algorithms may be supported by the TPM
  - Signing keys may be migrated to other TPMs/platforms
    - Are not allowed to be non-migratable if one of their parent keys is migratable

TPM Key Types
→ Migration Keys

- **Purpose**
  - Enable TPM to act as migration authority
  - Used to encrypt migratable keys for secure transport from one TPM to another
- **Description**
  - 2048-bit RSA en-/decryption key pair
  - Are allowed to be migrated to another TPM

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- Identities
- TPM Keys and Keys´ Properties
- TPM Key Types

- **Some More TPM Details**
  - **Creating TPM Identity**

- Summary

Creating TPM Identity
→ Creating a Non-Revocable EK

$(pk_{EK} , digest_{EK}) \leftarrow$ TPM_CreateEndorsementKeyPair(Nonce , par_{EK})

```
if EK exists or then
   return error;
else
   if $par_{EK}$ describes a storage key providing security at least
   equivalent to RSA-2048 then
      $( sk_{EK} , pk_{EK} ) \leftarrow$ GenKey( $par_{EK}$ );
      $digest_{EK} \leftarrow$ SHA-1( $pk_{EK}$ , Nonce );
      return ( $pk_{EK}$ , $digest_{EK}$ );
   else
      return error;
   end if;
end if;
```

Input

- Nonce is an anti-replay value chosen by the caller of the command (e.g., a software for creating the EK)
- par_{EK} are parameters for the key generation algorithm (e.g., key size, key type, etc.) chosen by the caller of the command

Note

- EK typically is a RSA key

Creating TPM Identity
→ Creating a Revocable EK

$(pk_{EK}, digest_{EK}, A_{Rev}) \leftarrow$ TPM CreateRevocableEK(Nonce, par_{EK}, $par_{A_{Rev}}$, A'_{Rev})

```
if EK exists then
  return error;
else
  if $par_{EK}$ provides security at least equivalent to RSA-2048 then;
    ( $sk_{EK}$ , $pk_{EK}$ ) $\leftarrow$ GenKey( $par_{EK}$ );
    if $par_{A_{Rev}}$ = TRUE then
      $A_{Rev} \leftarrow$ RNG( 20 );
    else
      $A_{Rev} \leftarrow A'_{Rev}$;
    end if;
    $digest_{EK} \leftarrow$ SHA-1( $pk_{EK}$ , Nonce );
    return ( $pk_{EK}$ , $digest_{EK}$ , $A_{Rev}$ );
  else
    return error;
  end if;
end if;
```

Perquisites

- Command is executed in a secure environment (e.g., during manufacturing)

Input

- A'_{Rev} is authorization secret chosen by the caller of the command that must be presented to TPM in order to revoke the EK later

Note

- This is an optional command

Creating TPM Identity
→ Revoking a revocable EK

$( ) \leftarrow$ TPM_RevokeTrust(A_{Rev})

```
if EK is non-revocable then
  return error;
else
  if $A'_{Rev} = A_{Rev}$ and physical presence is asserted then
    TPM_OwnerClear(...);
    invalidate all TPM-internal EK-related data;
    invalidate the EK;
  else
    return error;
  end if;
end if;
```

Perquisites

- Existing EK is revocable
- Authorization data required to revoke EK is A_{rev} , which has been defined during creation of the EK

Note

- The TPM recognizes physical presence, e.g., via a pin at the TPM wired to a button at the platform
- This is an optional command
- `TPM_OwnerClear()` resets all owner-specific data to default values (see TPM Owner)

Content

- Aim and outcomes of this lecture
- Overview of the idea of TPM
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- **Some More TPM Details**
  - **TPM Owner**
- Summary

TPM Owner
→ Overview

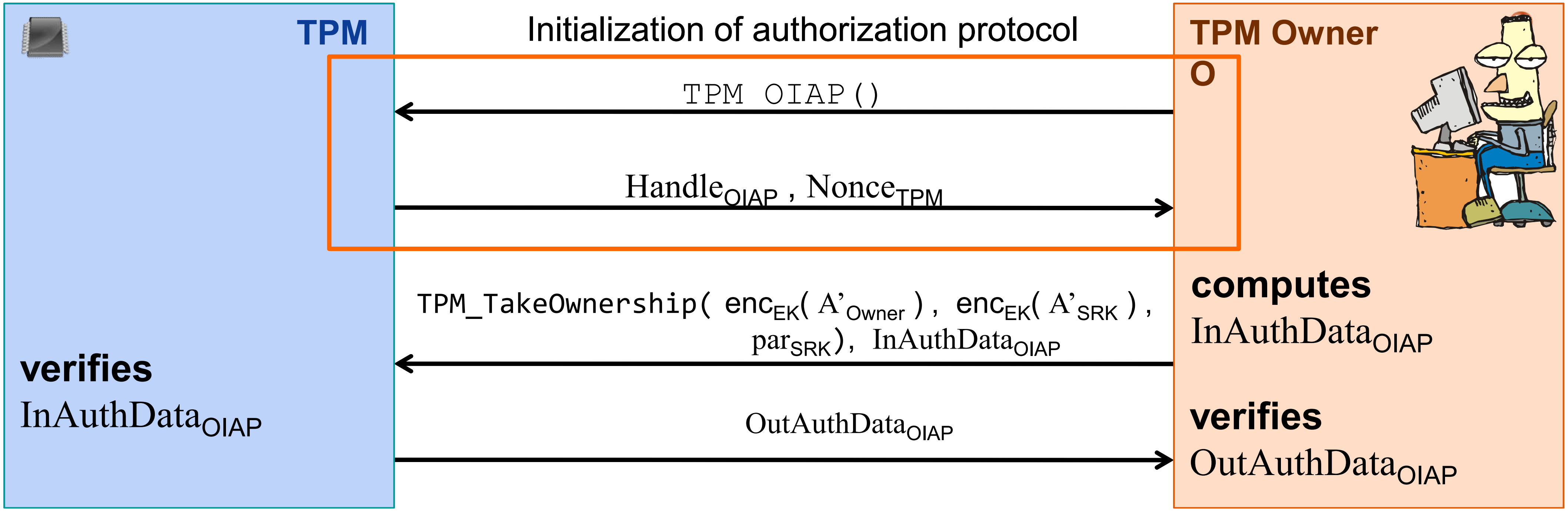
- **Entity owning a TPM-enabled platform**
  - e.g., platform owning person or IT-department
- **TPM Owner must initialize TPM to use its full functionality (“take ownership” of the TPM)**
  - Owner sets owner authorization secret
  - Owner creates the **Storage Root Key (SRK)** (see TPM keys)
- **Owner authorization**
  - Proof of knowledge of the owner credentials to the TPM
    - e.g., via a challenge and response protocol or physical presence
  - Permits the TPM to use several protected capabilities
    - e.g., migration of cryptographic keys or deletion of TPM Owner

TPM Owner
→ Methods of Proving Ownership to a TPM

- **User proves knowledge of TPM owner authorization secret to the TPM**
  - e.g., OIAP or OSAP (see TPM authorization protocols)

- **Assertion of physical presence**
  - Proof of physical access to the TPM/platform
    - e.g., by using a hardware switch or changing a BIOS setting
  - Interface for asserting physical presence specified by the PC Client Specification
  - Only a few commands can be authorized via physical presence
    - e.g., deletion of TPM Owner, activation/deactivation of the TPM, enabling/disabling the TPM

TPM Owner
→ Protocol for Creating a TPM Owner



TPM

TPM Owner
O

Initialization of authorization protocol

`TPM OIAP()`

$\mathrm{Handle}_{\mathrm{OIAP}}$, $\mathrm{Nonce}_{\mathrm{TPM}}$

computes $\mathrm{InAuthData}_{\mathrm{OIAP}}$

`TPM_TakeOwnership(` $\mathrm{enc}_{\mathrm{EK}}(\mathrm{A'}_{\mathrm{Owner}})$, $\mathrm{enc}_{\mathrm{EK}}(\mathrm{A'}_{\mathrm{SRK}})$, $\mathrm{par}_{\mathrm{SRK}}$), $\mathrm{InAuthData}_{\mathrm{OIAP}}$

verifies $\mathrm{InAuthData}_{\mathrm{OIAP}}$

$\mathrm{OutAuthData}_{\mathrm{OIAP}}$

verifies $\mathrm{OutAuthData}_{\mathrm{OIAP}}$

Here, OIAP is only used to authenticate the TPM’s response to the TPM Owner

- e.g., on successful verification of $\mathrm{OutAuthData}_{\mathrm{OIAP}}$ the TPM Owner can be assured that the TPM has created a TPM Owner and set the correct authorization secrets $\mathrm{A'}_{\mathrm{Owner}}$ and $\mathrm{A'}_{\mathrm{SRK}}$
- See OIAP protocol (OIAP = Object Independent Authorization Protocol)

TPM Owner
→ TPM Interface for Taking Ownership

$(\mathrm{pk}_{SRK} , \mathrm{OutAuthData}_{OIAP}) \leftarrow$ `TPM_TakeOwnership(` $\mathrm{enc}_{EK}(A'_{Owner}), \mathrm{enc}_{EK}(A'_{SRK}), \mathrm{par}_{SRK}),$
$\mathrm{InAuthData}_{OIAP}$

```
if owner exists or EK is invalid
or $\mathrm{InAuthData}_{OIAP}$ does not refer to an active OIAP session then
  return error;
else
  if $\mathrm{par}_{SRK}$ describes 2048-bit non-migratable RSA encryption key then
    $A_{Owner} \leftarrow \mathrm{dec}_{EK}( \mathrm{enc}_{EK}( A'_{Owner} ) );$
    store $A_{Owner}$ as owner authorization data in non-volatile memory;
    $A_{SRK} \leftarrow \mathrm{dec}_{EK}( \mathrm{enc}_{EK}( A'_{SRK} ) );$
    $( \mathrm{sk}_{SRK} , \mathrm{pk}_{SRK} ) \leftarrow \mathrm{GenKey}( \mathrm{par}_{SRK} );$
    $SRK \leftarrow ( ( \mathrm{sk}_{SRK} , \mathrm{pk}_{SRK} ) , A_{SRK} );$
    store  SRK in non-volatile memory;
    initialize all owner-related TPM-internal variables;
    compute $\mathrm{OutAuthData}_{OIAP}$;
    return $( \mathrm{pk}_{SRK} , \mathrm{OutAuthData}_{OIAP} );$
  else
    return error;
  end if;
end if;
```

- SRK is used to protect shielded locations moved off the TPM to, e.g., a hard disk (see TPM keys)

Perquisites

- TPM Owner obtained authentic pk_{EK}, e.g., from Endorsement Credential

Input

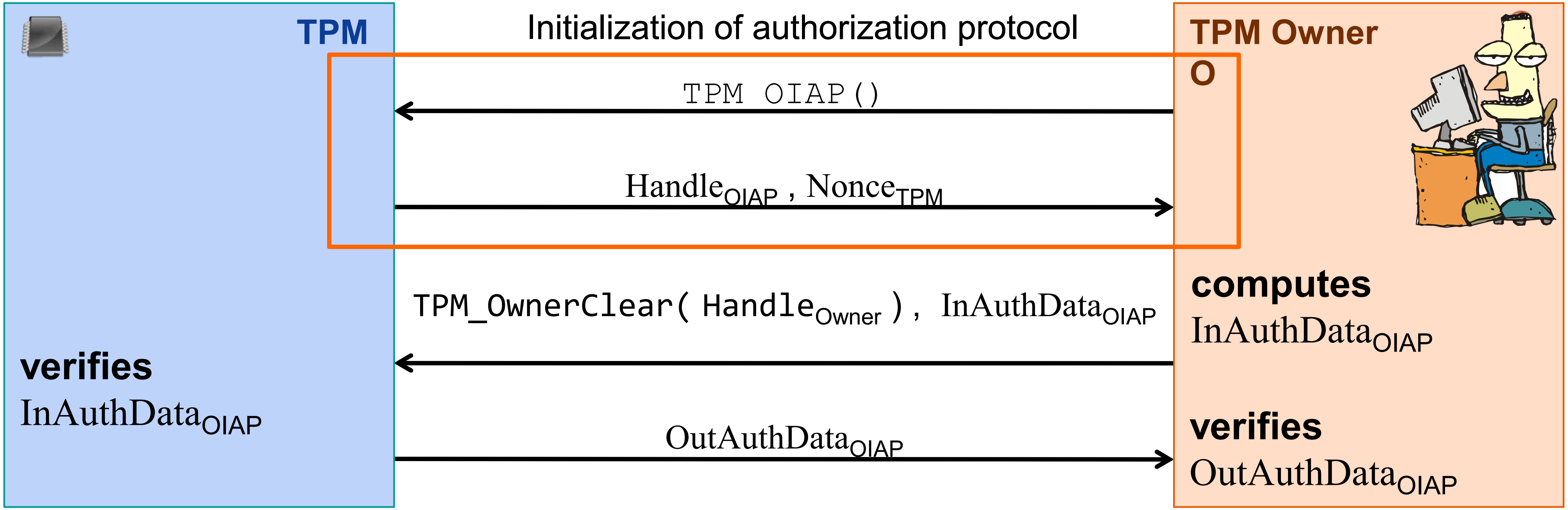
- A'_{Owner} and A'_{SRK} are authorization secrets (e.g., digests of passphrases) chosen by the TPM Owner

Notes

- $\mathrm{InAuthData}_{OIAP}$ is used to prove knowledge of the owner authorization secret to the TPM
- $\mathrm{OutAuthData}_{OIAP}$ provides authenticity of the TPM's output to TPM Owner
- See OIAP protocol

TPM Owner

→ Protocol for Deleting a TPM Owner



TPM

Initialization of authorization protocol

TPM Owner O

`TPM OIAP()`

$\text{Handle}_{\text{OIAP}}$, $\text{Nonce}_{\text{TPM}}$

computes $\text{InAuthData}_{\text{OIAP}}$

`TPM_OwnerClear( Handle`$_{\text{Owner}}$`),` $\text{InAuthData}_{\text{OIAP}}$

verifies $\text{InAuthData}_{\text{OIAP}}$

$\text{OutAuthData}_{\text{OIAP}}$

verifies $\text{OutAuthData}_{\text{OIAP}}$

OIAP session is used to authenticate

- **the TPM Owner to the TPM**

  e.g., on successful verification of $\text{InAuthData}_{\text{OIAP}}$ the TPM can be assured that the command has been called by the TPM Owner

- **the TPM’s response to the TPM Owner**

  e.g., on successful verification of $\text{OutAuthData}_{\text{OIAP}}$ the TPM user can be assured that the TPM has actually deleted the TPM Owner and all associated data

TPM Owner
→ TPM Interface for Deleting Owner

$\text{OutAuthData}_{\text{OIAP}} \leftarrow \text{TPM\_OwnerClear}(\text{Handle}_{\text{Owner}})\ ,\ \text{InAuthData}_{\text{OIAP}}$

```
if OIAPVerify( $\text{Handle}_{\text{Owner}}$ , $\text{InAuthData}_{\text{OIAP}}$ ) $\neq$ ok
or deletion of owner has been disabled then
    return error;
else
    compute $\text{OutAuthData}_{\text{OIAP}}$;
    unload all currently loaded keys;
    delete $A_{\text{Owner}}$;
    delete SRK;
    set all owner-related internal variables to their defaults;
    terminate all currently open sessions;
    return $\text{OutAuthData}_{\text{OIAP}}$;
end if;
```

Notes

- $\text{Handle}_{\text{Owner}}$ informs the TPM that the TPM Owner should be authorized
- InAuthDataOIAP refers to parameters of a previously opened OIAP authorization session used to prove knowledge of the owner authorization secret to the TPM
- $\text{OutAuthData}_{\text{OIAP}}$ refers to the parameters of a previously opened OIAP session providing authenticity of the TPM's output (e.g., proof that the TPM actually deleted the TPM Owner)
- OIAP_Verify() verifies if user knows owner authorization secret
- See OIAP authorization protocol

TPM Owner
→ Deleting Owner via Physical Presence

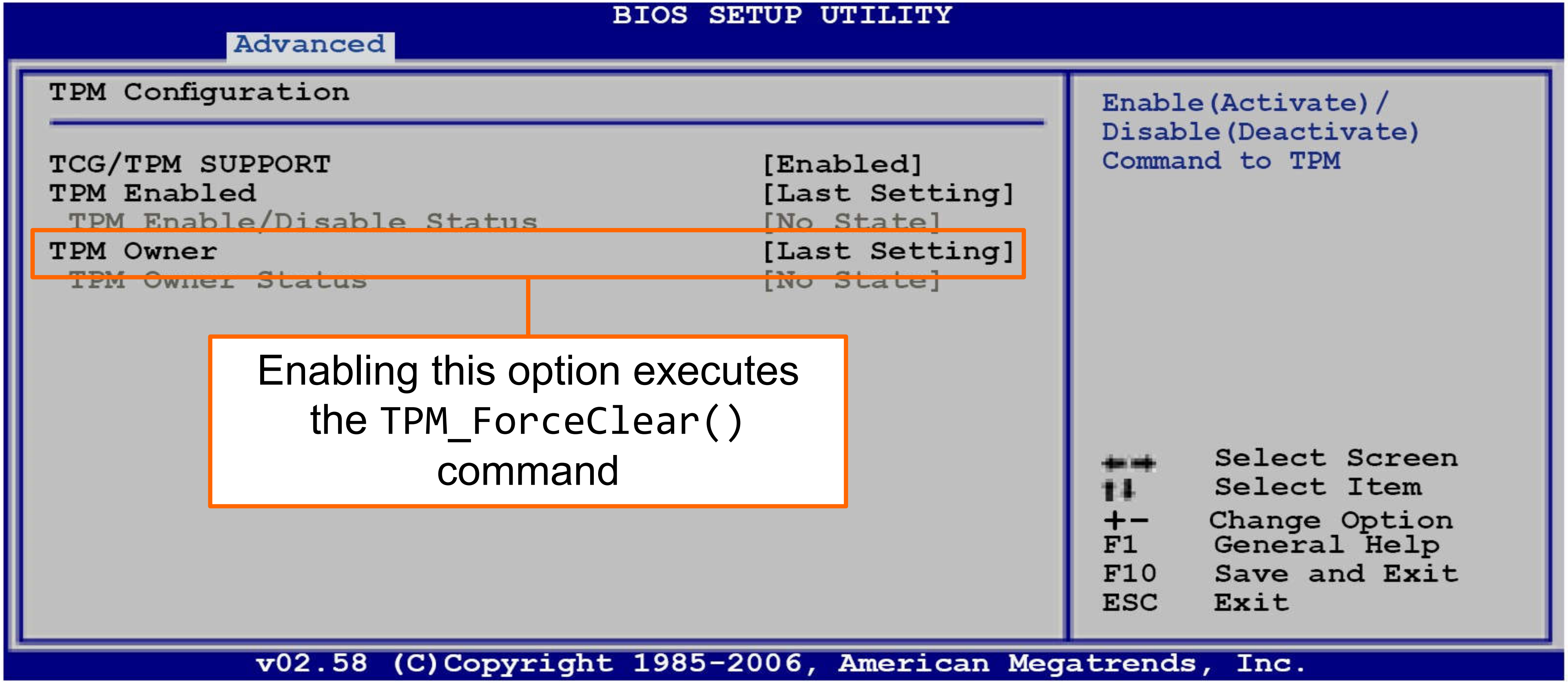
( ) ← TPM_ForceClear()

```
if physical presence is not asserted
   return error;
else
   unload all currently loaded keys;
   delete $A_{Owner}$;
   delete SRK;
   set all owner-related internal variables to their defaults;
   terminate all currently open sessions;
end if;
```

Note

- This command is authorized by asserting physical presence (e.g., via a pin at the TPM wired to a button at the platform)

TPM Owner
→ Asserting Physical Presence via BIOS



```
                         BIOS SETUP UTILITY
        Advanced
  TPM Configuration                                 Enable(Activate)/
                                                    Disable(Deactivate)
  TCG/TPM SUPPORT                [Enabled]          Command to TPM
  TPM Enabled                    [Last Setting]
   TPM Enable/Disable Status     [No State]
  TPM Owner                      [Last Setting]
   TPM Owner Status              [No State]



                                                    ←→     Select Screen
                                                    ↑↓     Select Item
                                                    +-     Change Option
                                                    F1     General Help
                                                    F10    Save and Exit
                                                    ESC    Exit
          v02.58 (C)Copyright 1985-2006, American Megatrends, Inc.
```

Enabling this option executes the `TPM_ForceClear()` command

A remote adversary cannot access the BIOS.
A local adversary with access to the BIOS is able to disable the TPM and even to delete the TPM Owner without the need to know any secret!

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- Summary

Authentication to the TPM
→ Accessing Protected Entities

- **Typically requires authorization**
  - User must prove knowledge of an authorization secret
    - e.g., authorization secret = digest of a passphrase

- **Authorization secrets are set by TPM users and stored inside shielded locations**
  - e.g., during the process of creating a key, a user sets a passphrase required for authorizing later use of the key.
  - TPM stores the passphrase together with the key in a shielded location.

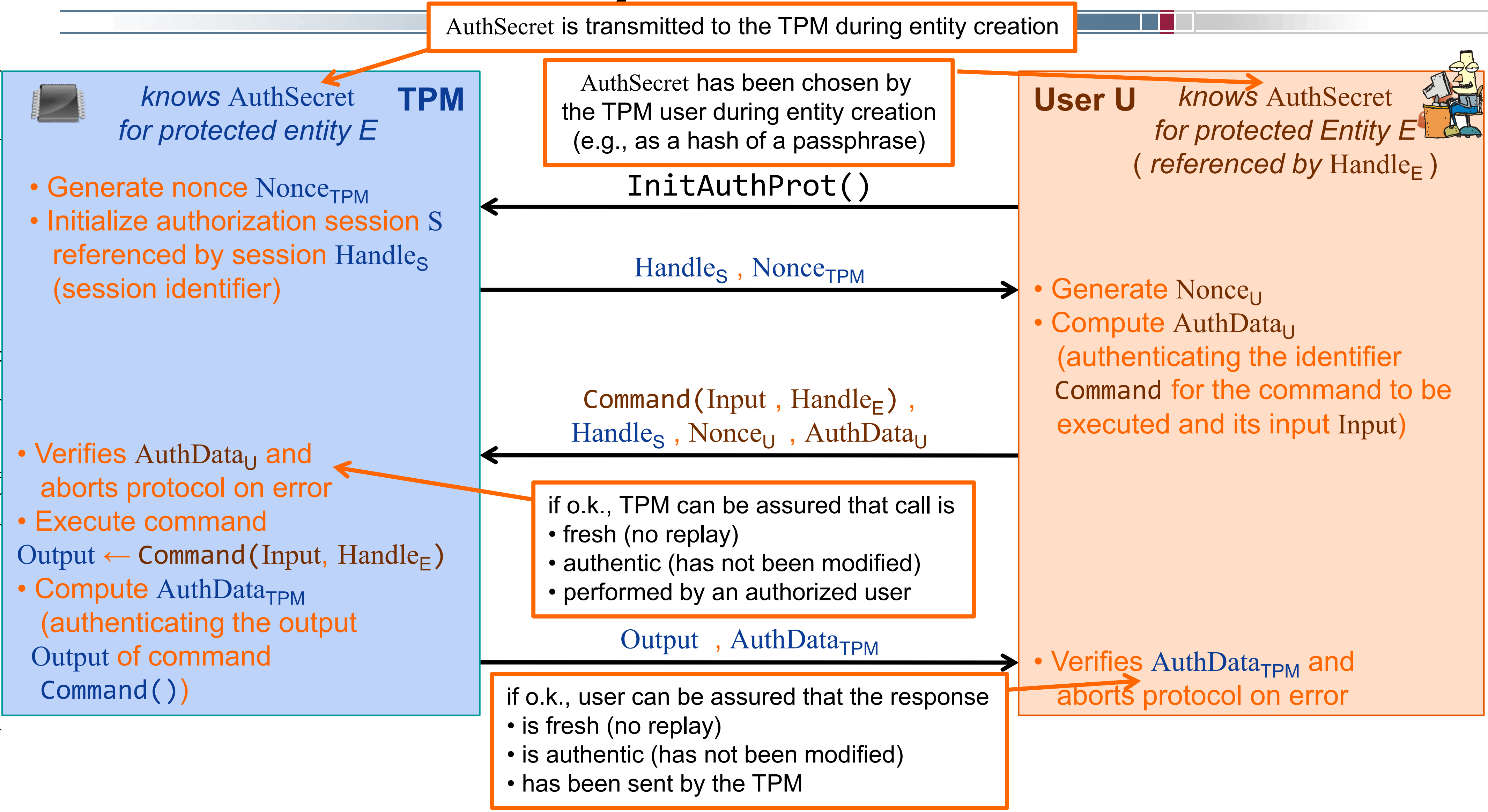
Authentication to the TPM
→ TPM Authorization Protocols (AP)

- **Authentication of commands and their parameters**
  - Provide assurance that the command, its parameters and the corresponding response of the TPM have not been modified during their transmission to or from the TPM

- **TPM basically supports two authorization protocols**
  - OSAP (Object Specific Authorization Protocol)
  - OIAP (Object Independent Authorization Protocol)

- **TPM must support at least two parallel authorization sessions**
  - Some TPM commands require two authorizations
    - e.g., command for unsealing data (see sealing)

Authentication to the TPM
→ Basic Functionality of TPM's APs



AuthSecret is transmitted to the TPM during entity creation

TPM

knows AuthSecret *for protected entity E*

- Generate nonce $\text{Nonce}_{\text{TPM}}$
- Initialize authorization session S referenced by session Handle_{S} (session identifier)

AuthSecret has been chosen by the TPM user during entity creation (e.g., as a hash of a passphrase)

User U

knows AuthSecret *for protected Entity E* (*referenced by* Handle_{E})

`InitAuthProt()`

Handle_{S} , $\text{Nonce}_{\text{TPM}}$

- Generate Nonce_{U}
- Compute $\text{AuthData}_{\text{U}}$ (authenticating the identifier `Command` for the command to be executed and its input Input)

`Command`(Input , Handle_{E}) , Handle_{S} , Nonce_{U} , $\text{AuthData}_{\text{U}}$

- Verifies $\text{AuthData}_{\text{U}}$ and aborts protocol on error
- Execute command

Output ← `Command`(Input, Handle_{E})

- Compute $\text{AuthData}_{\text{TPM}}$ (authenticating the output Output of command `Command()`)

if o.k., TPM can be assured that call is
- fresh (no replay)
- authentic (has not been modified)
- performed by an authorized user

Output , $\text{AuthData}_{\text{TPM}}$

- Verifies $\text{AuthData}_{\text{TPM}}$ and aborts protocol on error

if o.k., user can be assured that the response
- is fresh (no replay)
- is authentic (has not been modified)
- has been sent by the TPM

$\text{AuthData}_{\text{U}}$ ← HMAC(AuthSecret , SHA-1(`Command` , Input) , $\text{Nonce}_{\text{TPM}}$, Nonce_{U})

$\text{AuthData}_{\text{TPM}}$ ← HMAC(AuthSecret , SH-A-1(`Command` , Output) , Nonce_{U} , …)

Authentication to the TPM
→ OIAP vs. OSAP

OIAP

Object Independent Authorization Protocol

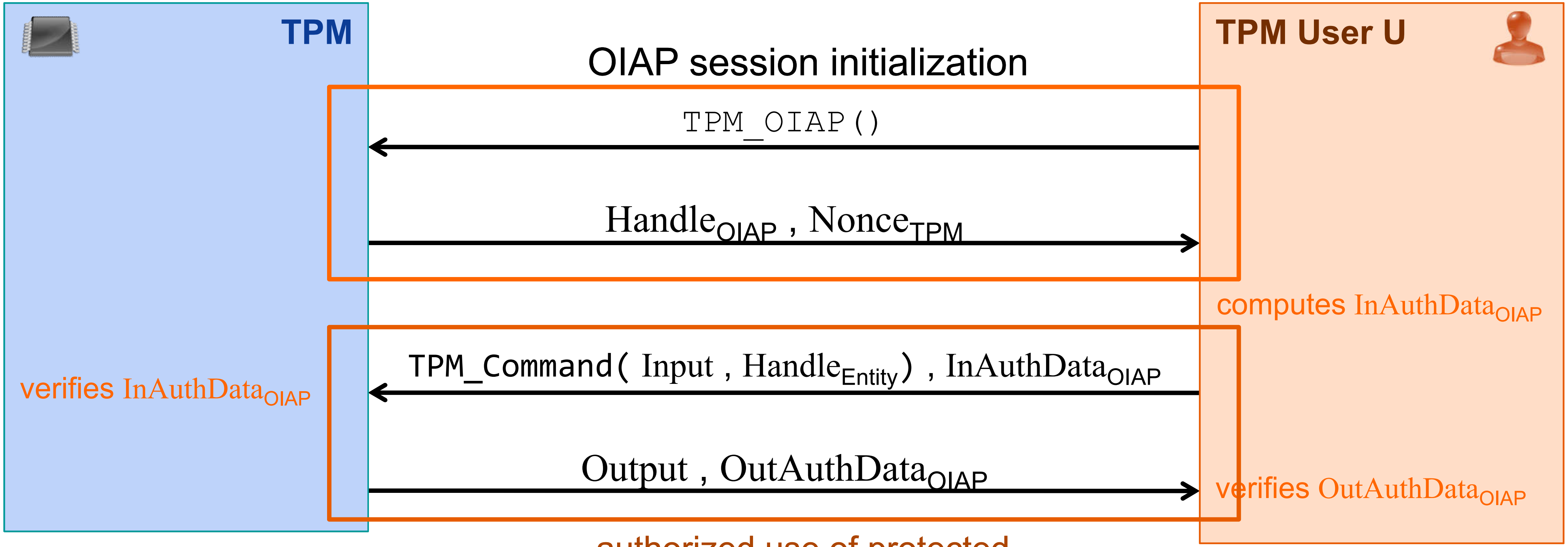
- **Properties**
  - Can authorize use of multiple different protected entities with multiple commands
  - Only one setup necessary for many different entities to be authorized
  - **No session key establishment**
- **Mainly used for**
  - Authorization of using protected entities without the need for a shared session secret/key

OSAP

Object Specific Authorization Protocol

- **Properties**
  - Can authorize use of a single protected entity with multiple commands
  - One setup required for each entity to be authorized
  - Establishes an ephemeral shared session secret, which can be used as a cryptographic key
- **Mainly used for**
  - Setting or changing authorization data for protected entities

Authentication to the TPM
→ OIAP Protocol Session



TPM

TPM User U

OIAP session initialization

`TPM_OIAP()`

$\text{Handle}_{\text{OIAP}}$, $\text{Nonce}_{\text{TPM}}$

computes $\text{InAuthData}_{\text{OIAP}}$

`TPM_Command`(Input , $\text{Handle}_{\text{Entity}}$) , $\text{InAuthData}_{\text{OIAP}}$

verifies $\text{InAuthData}_{\text{OIAP}}$

Output , $\text{OutAuthData}_{\text{OIAP}}$

verifies $\text{OutAuthData}_{\text{OIAP}}$

authorized use of protected entity $\text{Handle}_{\text{Entity}}$ (e.g., a key)

Nonce is chosen by user U

$$\text{InAuthDigest}_{\text{OIAP}} = \text{HMAC}(\ \text{AuthSecret}_{\text{Entity}}\ ,\ \text{SHA-1}(\ \texttt{TPM\_Command}\ ,\ \text{Input}\ )\ ,\ \text{Nonce}_{\text{TPM}}\ ,\ \text{Nonce}\ )$$

$$\text{InAuthData}_{\text{OIAP}} = (\ \text{Handle}_{\text{OIAP}}\ ,\ \text{Nonce}\ ,\ \text{InAuthDigest}_{\text{OIAP}}\ )$$

$$\text{OutAuthDigest}_{\text{OIAP}} \leftarrow \text{HMAC}(\ \text{AuthSecret}_{\text{Entity}}\ ,\ \text{SHA-1}(\ \texttt{TPM\_Command}\ ,\ \text{Ouput}\ )\ ,\ \text{Nonce}_{\text{TPM,2}}\ ,\ \text{Nonce}\ )$$

$$\text{OutAuthData}_{\text{OIAP}} \leftarrow (\ \text{Nonce}_{\text{TPM,2}}\ ,\ \text{OutAuthDigest}_{\text{OIAP}}\ )$$

Authentication to the TPM
→ Initialization of OIAP Session

$(\text{Handle}_{\text{OIAP}} , \text{Nonce}_{\text{TPM}}) \leftarrow \text{TPM\_OIAP}()$

```
if maximum number of authorization sessions has been reached then
   return error;
else
   create $\text{Handle}_{\text{OIAP}}$;
   $\text{Nonce}_{\text{TPM}} \leftarrow \text{RNG}( 20 )$;
   store ( $\text{Handle}_{\text{OIAP}}$ , $\text{Nonce}_{\text{TPM}}$ ) in volatile memory;
   return ( $\text{Handle}_{\text{OIAP}}$ , $\text{Nonce}_{\text{TPM}}$ );
end if;
```

Notes

- $\text{Handle}_{\text{OIAP}}$ is an identifier for the new OIAP session
- TPM must ensure that no other active auth. session is referenced by $\text{Handle}_{\text{OIAP}}$
- S_{OIAP} represents the data associated with an OIAP session

Verification of an OIAP Session

$$\text{InAuthDigest}_{\text{OIAP}} = \text{HMAC}(\ \text{AuthSecret}_{\text{Entity}}\ ,\ \text{SHA-1}(\ \texttt{TPM\_Command}\ ,\ \text{Input}\ )\ ,\ \text{Nonce}_{\text{TPM}}\ ,\ \text{Nonce}\ )$$

$$\text{InAuthData}_{\text{OIAP}} = (\ \text{Handle}_{\text{OIAP}}\ ,\ \text{Nonce}\ ,\ \text{InAuthDigest}_{\text{OIAP}}\ )$$

$$(\ \text{Output}\ ,\ \text{OutAuthData}_{\text{OIAP}}\ ) \leftarrow \text{TPM\_Command}(\ \text{Input}\ ,\ \text{Handle}_{\text{Entity}})\ ,\ \text{InAuthData}_{\text{OIAP}}$$

```
if OIAPVerify( $\text{InAuthData}_{\text{OIAP}}$ , $\text{Handle}_{\text{Entity}}$ ) ≠ ok then
   return error;
else
   Output ← TPM_Command(Input , $\text{Handle}_{\text{Entity}}$);
   $\text{Nonce}_{\text{TPM,2}}$ ← RNG( 20 );
   $\text{OutAuthDigest}_{\text{OIAP}}$ ← HMAC( $\text{AuthSecret}_{\text{Entity}}$ ,
         SHA-1( TPM_Command , Ouput ) , $\text{Nonce}_{\text{TPM,2}}$ , Nonce );
   $\text{OutAuthData}_{\text{OIAP}}$ ← ( $\text{Nonce}_{\text{TPM,2}}$ , $\text{OutAuthDigest}_{\text{OIAP}}$ );
   return ( Output , $\text{OutAuthData}_{\text{OIAP}}$ ) ;
end if;
```

$$\text{ind} \leftarrow \text{OIAPVerify}(\ \text{InAuthData}_{\text{OIAP}}\ ,\ \text{Handle}_{\text{Entity}}\ )$$

```
if $\text{Handle}_{\text{OIAP}}$ does not refer to an open OIAP session then
   return error;
else
   obtain $\text{AuthSecret}_{\text{Entity}}$ from entity referred to by $\text{Handle}_{\text{Entity}}$;
   return Verify( $\text{InAuthDigest}_{\text{OIAP}}$ , $\text{AuthSecret}_{\text{Entity}}$ );
end if;
```

Perquisites

- `TPM_OIAP()` must have been executed before
- The protected entity (e.g., key) to be authorized must have been previously loaded into the TPM. The command that loaded the entity returns an identifier $\text{Handle}_{\text{Entity}}$ for that entity

Notes

- `TPM_Command()` may be any command that requires authorization via OIAP
- Verify() re-computes $\text{InAuthDigest}_{\text{OIAP}}$ using $\text{AuthSecret}_{\text{Entity}}$ stored with the entity to be authorized and compares it to $\text{InAuthDigest}_{\text{OIAP}}$

Authentication to the TPM
→ Verification of an OIAP Session

$(\text{Output} , \text{OutAuthData}_{\text{OIAP}}) \leftarrow \texttt{TPM\_Command}(\text{Input} , \text{Handle}_{\text{Entity}}) , \text{InAuthData}_{\text{OIAP}}$

```
if OIAPVerify( $\text{InAuthData}_{\text{OIAP}}$ , $\text{Handle}_{\text{Entity}}$ ) ≠ ok then
   return error;
else
   Output ← TPM_Command(Input , $\text{Handle}_{\text{Entity}}$);
   $\text{Nonce}_{\text{TPM,2}}$ ← RNG( 20 );
   $\text{OutAuthDigest}_{\text{OIAP}}$ ← HMAC( $\text{AuthSecret}_{\text{Entity}}$ ,
         SHA-1( TPM_Command , Ouput ) , $\text{Nonce}_{\text{TPM,2}}$ , Nonce );
   $\text{OutAuthData}_{\text{OIAP}}$ ← ( $\text{Nonce}_{\text{TPM,2}}$ , $\text{OutAuthDigest}_{\text{OIAP}}$ );
   return ( Output , $\text{OutAuthData}_{\text{OIAP}}$ ) ;
end if;
```

authorized use of Entity

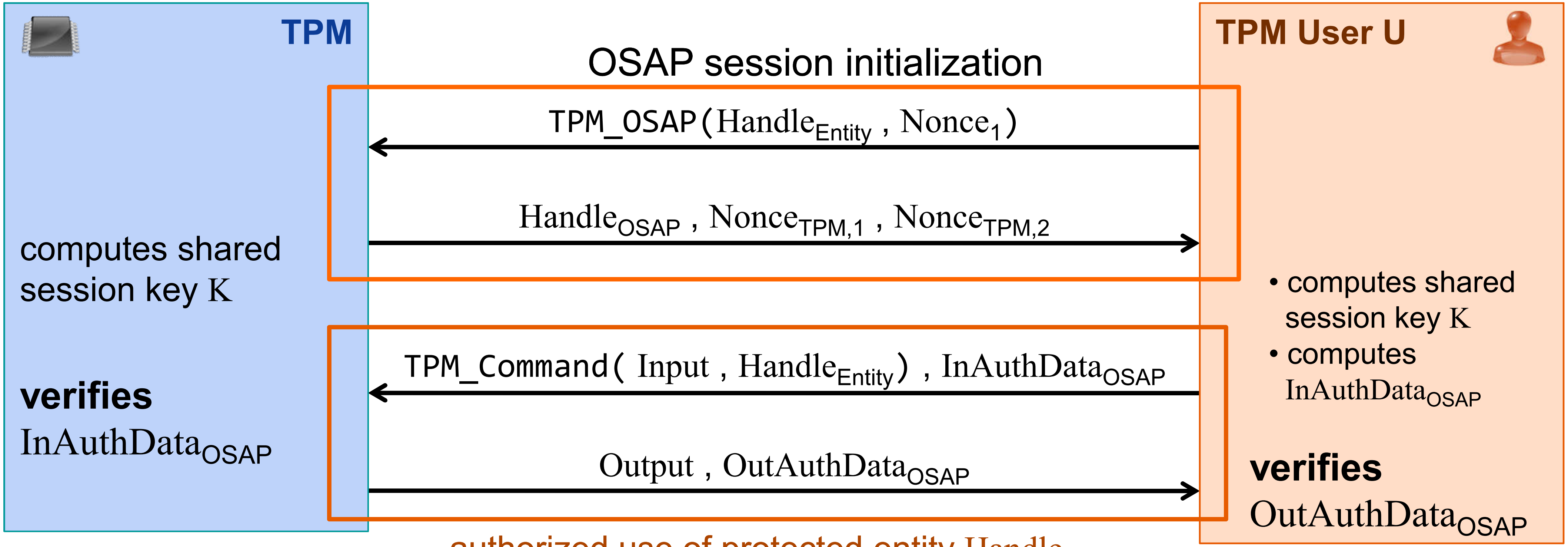
authenticator for TPM’s response

verification of authorization

$\text{ind} \leftarrow \text{OIAPVerify}(\text{InAuthData}_{\text{OIAP}} , \text{Handle}_{\text{Entity}})$

```
if $\text{Handle}_{\text{OIAP}}$ does not refer to an open OIAP session then
   return error;
else
   obtain $\text{AuthSecret}_{\text{Entity}}$ from entity referred to by $\text{Handle}_{\text{Entity}}$;
   return Verify( $\text{InAuthDigest}_{\text{OIAP}}$ , $\text{AuthSecret}_{\text{Entity}}$ );
end if;
```

Authentication to the TPM
→ OASP Protocol Session



TPM

TPM User U

OSAP session initialization

$\texttt{TPM\_OSAP}(\mathrm{Handle}_{\mathrm{Entity}}\ ,\ \mathrm{Nonce}_1)$ ←

→ $\mathrm{Handle}_{\mathrm{OSAP}}\ ,\ \mathrm{Nonce}_{\mathrm{TPM,1}}\ ,\ \mathrm{Nonce}_{\mathrm{TPM,2}}$

computes shared session key K

- computes shared session key K
- computes $\mathrm{InAuthData}_{\mathrm{OSAP}}$

$\texttt{TPM\_Command}(\ \mathrm{Input}\ ,\ \mathrm{Handle}_{\mathrm{Entity}})\ ,\ \mathrm{InAuthData}_{\mathrm{OSAP}}$ ←

verifies $\mathrm{InAuthData}_{\mathrm{OSAP}}$

→ $\mathrm{Output}\ ,\ \mathrm{OutAuthData}_{\mathrm{OSAP}}$

verifies $\mathrm{OutAuthData}_{\mathrm{OSAP}}$

authorized use of protected entity $\mathrm{Handle}_{\mathrm{Entity}}$ (e.g., key) and shared session secret K

Nonce is chosen by user U

$$K \leftarrow \text{HMAC}(\ \mathrm{AuthSecret}_{\mathrm{Entity}}\ ,\ \mathrm{Nonce}_{\mathrm{TPM,2}}\ ,\ \mathrm{Nonce}_1\ )$$

$$\mathrm{InAuthDigest}_{\mathrm{OSAP}} = \text{HMAC}(\ K\ ,\ \text{SHA-1}(\ \texttt{TPM\_Command}\ ,\ \mathrm{Input}\ )\ ,\ \mathrm{Nonce}_{\mathrm{TPM,1}}\ ,\ \mathrm{Nonce}_2\ )$$

$$\mathrm{InAuthData}_{\mathrm{OSAP}} = (\ \mathrm{Handle}_{\mathrm{OSAP}}\ ,\ \mathrm{Nonce}_2\ ,\ \mathrm{InAuthDigest}_{\mathrm{OSAP}}\ )$$

$$\mathrm{OutAuthDigest}_{\mathrm{OSAP}} \leftarrow \text{HMAC}(\ K\ ,\ \text{SHA-1}(\ \texttt{TPM\_Command}\ ,\ \mathrm{Ouput}\ )\ ,\ \mathrm{Nonce}_{\mathrm{TPM,3}}\ ,\ \mathrm{Nonce}_2\ )$$

$$\mathrm{OutAuthData}_{\mathrm{OSAP}} \leftarrow (\ \mathrm{Nonce}_{\mathrm{TPM,3}}\ ,\ \mathrm{OutAuthDigest}_{\mathrm{OSAP}}\ )$$

Authentication to the TPM
→ Initialization of OSAP Session

$$(\ \mathrm{Handle}_{OSAP}\ ,\ \mathrm{Nonce}_{TPM,1}\ ,\ \mathrm{Nonce}_{TPM,2}\ ) \leftarrow \mathrm{TPM\_OSAP}(\mathrm{Handle}_{Entity}\ ,\ \mathrm{Nonce}_1)$$

```
if maximum number of authorization sessions has been reached then
    return error;
else
    create $Handle_{OSAP}$;
    $Nonce_{TPM,1} \leftarrow$ RNG();
    $Nonce_{TPM,2} \leftarrow$ RNG();
    $K \leftarrow$ HMAC( $AuthSecret_{Entity}$ , $Nonce_{TPM,2}$ , $Nonce_1$ );
    store ( $Handle_{OSAP}$ , $Handle_{Entity}$ , $K$ , $Nonce_{TPM,1}$ , $Nonce_{TPM,2}$ ) in
        volatile memory;
    return ( $Handle_{OSAP}$ , $Nonce_{TPM,1}$ , $Nonce_{TPM,2}$ );
end if;
```

Prequisites

- The protected entity (e.g., key) to be authorized must have been previously loaded into the TPM. The command that loaded the entity returns an identifier Handle_{Entity} for that entity

Notes

- Handle_{OSAP} is identifier for the new OSAP session
- TPM must ensure that no other active auth. session is referenced by Handle_{OSAP}

Authentication to the TPM
→ Initialization of OSAP Session

$$(\text{Handle}_{\text{OSAP}}\ ,\ \text{Nonce}_{\text{TPM,1}}\ ,\ \text{Nonce}_{\text{TPM,2}}) \leftarrow \texttt{TPM\_OSAP}(\text{Handle}_{\text{Entity}}\ ,\ \text{Nonce}_1)$$

```
if maximum number of authorization sessions has been reached then
   return error;
else
   create $\text{Handle}_{\text{OSAP}}$;
   $\text{Nonce}_{\text{TPM,1}} \leftarrow$ RNG();
   $\text{Nonce}_{\text{TPM,2}} \leftarrow$ RNG();
   $\boxed{K \leftarrow \text{HMAC}(\ \text{AuthSecret}_{\text{Entity}}\ ,\ \text{Nonce}_{\text{TPM,2}}\ ,\ \text{Nonce}_1\ );}$
   store ( $\text{Handle}_{\text{OSAP}}$ , $\text{Handle}_{\text{Entity}}$ , $K$ , $\text{Nonce}_{\text{TPM,1}}$ , $\text{Nonce}_{\text{TPM,2}}$ ) in
      volatile memory;
   return ( $\text{Handle}_{\text{OSAP}}$ , $\text{Nonce}_{\text{TPM,1}}$ , $\text{Nonce}_{\text{TPM,2}}$ );
end if;
```

creation of shared session secret

Notes

- $\text{Handle}_{\text{OSAP}}$ is identifier for the new OSAP session
- TPM must ensure that no other active auth. session is referenced by $\text{Handle}_{\text{OSAP}}$

Verification of an OSAP Session

$$K \leftarrow \mathrm{HMAC}(\ AuthSecret_{\mathrm{Entity}}\ ,\ Nonce_{\mathrm{TPM,2}}\ ,\ Nonce_1\ )$$

$$InAuthData_{\mathrm{OSAP}} = (\ Handle_{\mathrm{OSAP}}\ ,\ Nonce_2\ ,\ InAuthDigest_{\mathrm{OSAP}}\ )$$

$$InAuthDigest_{\mathrm{OSAP}} = \mathrm{HMAC}(\ K\ ,\ \text{SHA-1}(\ \texttt{TPM\_Command}\ ,\ Input\ )\ ,\ Nonce_{\mathrm{TPM,1}}\ ,\ Nonce_2\ )$$

$$(\ \mathrm{Output}\ ,\ \mathrm{OutAuthData}_{\mathrm{OSAP}}\ ) \leftarrow \mathrm{TPM\_Command}(\ \mathrm{Input}\ ,\ \mathrm{Handle}_{\mathrm{Entity}})\ ,\ \mathrm{InAuthData}_{\mathrm{OSAP}}$$

```
if OSAPVerify( $InAuthData_{OSAP}$ , $Handle_{Entity}$ ) $\neq$ ok then
  return error;
else
  $Output \leftarrow$ TPM_Command($Input$ , $Handle_{Entity}$ , $K$);
  $Nonce_{TPM,3} \leftarrow$ RNG( 20 );
  $OutAuthDigest_{OSAP} \leftarrow$ HMAC( $K$ ,
        SHA-1( TPM_Command , $Ouput$ ) , $Nonce_{TPM,3}$ , $Nonce_2$ );
  $OutAuthData_{OSAP} \leftarrow$ ( $Nonce_{TPM,3}$ , $OutAuthDigest_{OSAP}$ );
  return ( $Output$ , $OutAuthData_{OSAP}$ ) ;
end if;
```

$$\mathrm{ind} \leftarrow \mathrm{OSAPVerify}(\ \mathrm{InAuthData}_{\mathrm{OSAP}}\ ,\ \mathrm{Handle}_{\mathrm{Entity}}\ )$$

```
if $Handle_{OSAP}$ does not refer to an open OSAP session then
  return error;
else
  obtain $AuthSecret_{Entity}$ from entity referred to by $Handle_{Entity}$;
  return Verify( $InAuthDigest_{OSAP}$ , $AuthSecret_{Entity}$ );
end if;
```

Perquisites

- `TPM_OSAP()` must have been executed before
- Protected entity (e.g., key) to be authorized must have been previously loaded into the TPM
- $Handle_{\mathrm{Entity}}$ refers to entity to be authorized

Notes

- `TPM_Command()` may be any command supporting authorization via OSAP
- Verify() re-computes $InAuthDigest_{\mathrm{OSAP}}$ using $AuthSecret_{\mathrm{Entity}}$ stored with the entity to be authorized and compares it to $InAuthDigest_{\mathrm{OSAP}}$

Authentication to the TPM
→ Verification of an OSAP Session

$(\text{Output}, \text{OutAuthData}_{\text{OSAP}}) \leftarrow$ `TPM_Command`$(\text{Input}, \text{Handle}_{\text{Entity}}), \text{InAuthData}_{\text{OSAP}}$

```
if OSAPVerify( $\text{InAuthData}_{\text{OSAP}}$ , $\text{Handle}_{\text{Entity}}$ ) ≠ ok then
    return error;
else
    Output ← TPM_Command(Input , $\text{Handle}_{\text{Entity}}$ , K);
    $\text{Nonce}_{\text{TPM,3}}$ ← RNG( 20 );
    $\text{OutAuthDigest}_{\text{OSAP}}$ ← HMAC( K ,
        SHA-1( TPM_Command , Ouput ) , $\text{Nonce}_{\text{TPM,3}}$ , $\text{Nonce}_2$ );
    $\text{OutAuthData}_{\text{OSAP}}$ ← ( $\text{Nonce}_{\text{TPM,3}}$ , $\text{OutAuthDigest}_{\text{OSAP}}$ );
    return ( Output , $\text{OutAuthData}_{\text{OSAP}}$ ) ;
end if;
```

authorized use of Entity and session secret K

authenticator for TPM's response

verification of authorization

$\text{ind} \leftarrow \text{OSAPVerify}(\text{InAuthData}_{\text{OSAP}}, \text{Handle}_{\text{Entity}})$

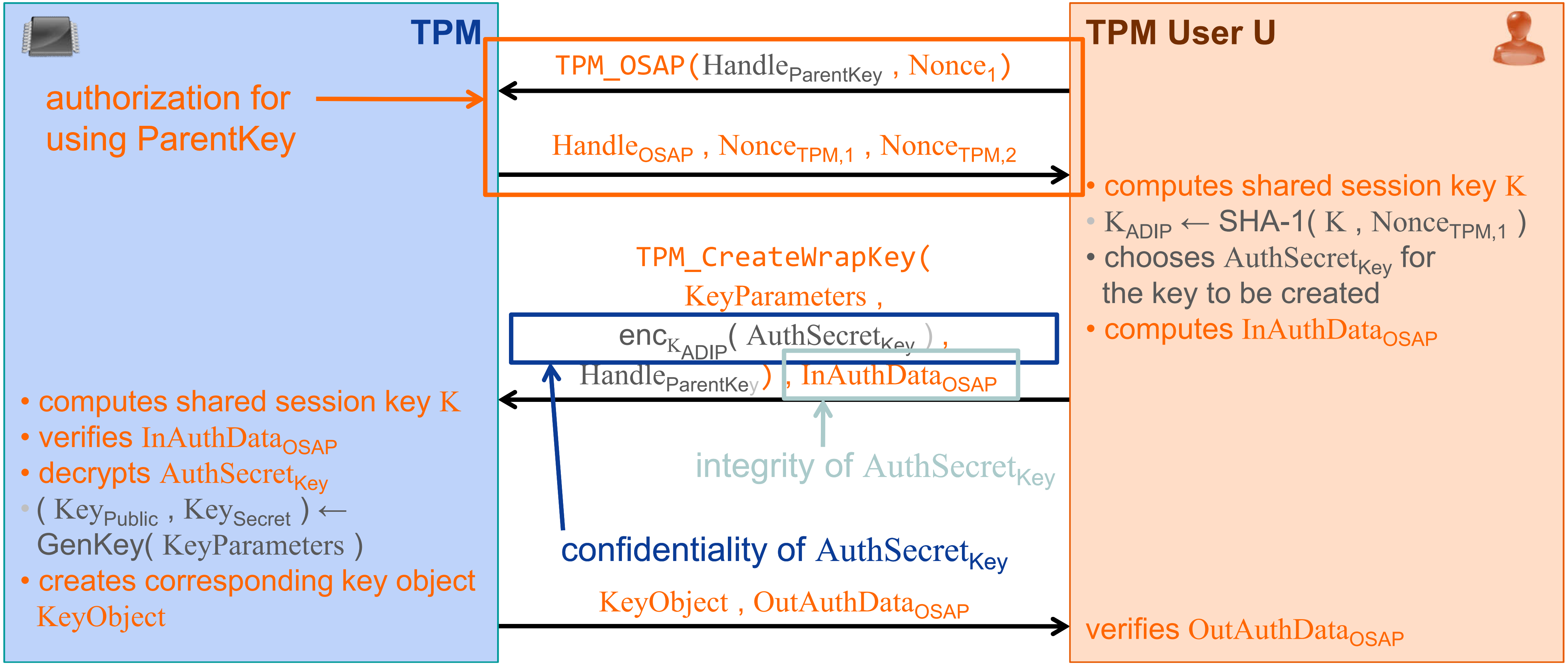
```
if $\text{Handle}_{\text{OSAP}}$ does not refer to an open OSAP session then
    return error;
else
    obtain $\text{AuthSecret}_{\text{Entity}}$ from entity referred to by $\text{Handle}_{\text{Entity}}$;
    return Verify( $\text{InAuthDigest}_{\text{OSAP}}$ , $\text{AuthSecret}_{\text{Entity}}$ );
end if;
```

Authentication to the TPM
→ Insertion and Change of Auth Secrets

- **Authorization Data Insertion Protocol (ADIP)**
  - Used to set authorization secret for protected entities
  - Extension of OSAP to protect the authorization secret
    - Confidentiality: Encryption with key derived from OSAP session
    - Integrity: HMAC of OSAP session ($\mathrm{InAuthData}_{\mathrm{OSAP}}$)
    - Authorization for using the corresponding parent key: OSAP

- **Authorization Data Change Protocol (ADCP)**
  - Used to change authorization secrets for protected entities
  - Defines how to use ADIP and OIAP/OSAP to protect new authorization secret and to authorize change
    - Confidentiality & integrity: ADIP
    - Authorization for access to the new protected entity: OSAP
    - Authorization for changing authorization secret: OIAP or OSAP

Authentication to the TPM
→ ADIP Example: Creation of a new Key



TPM

authorization for using ParentKey

- computes shared session key K
- verifies InAuthData$_{OSAP}$
- decrypts AuthSecret$_{Key}$
- (Key$_{Public}$, Key$_{Secret}$) ← GenKey(KeyParameters)
- creates corresponding key object KeyObject

`TPM_OSAP(`Handle$_{ParentKey}$, Nonce$_1$`)`

Handle$_{OSAP}$, Nonce$_{TPM,1}$, Nonce$_{TPM,2}$

`TPM_CreateWrapKey(`
KeyParameters ,
enc$_{K_{ADIP}}$(AuthSecret$_{Key}$) ,
Handle$_{ParentKey}$) , InAuthData$_{OSAP}$

integrity of AuthSecret$_{Key}$

confidentiality of AuthSecret$_{Key}$

KeyObject , OutAuthData$_{OSAP}$

TPM User U

- computes shared session key K
- K_{ADIP} ← SHA-1(K , Nonce$_{TPM,1}$)
- chooses AuthSecret$_{Key}$ for the key to be created
- computes InAuthData$_{OSAP}$

verifies OutAuthData$_{OSAP}$

KeyObject = (KeyParameters , Key$_{Public}$, enc$_{ParentKey}$(AuthSecret$_{Key}$, Key$_{Secret}$))

ADIP extensions

Content

- Aim and outcomes of this lecture
- Overview of the idea of TPM
- Terminology and Assumption
- Identities
- TPM Keys and Keys´ Properties
- TPM Key Types
- **Some More TPM Details**
  - **Migration of TPM Keys**
- Summary

Migration of TPM Keys
→ Overview of Maintenance

- **Transfers all TPM-protected data to another TPM**
  - Necessary when exchanging a (defective) subsystem that contains a TPM without loosing non-migratable data
- **Different from backup/migration**
  - Maintenance can also migrate data that cannot be migrated using the TPM’s migration functionality
  - **Requires intervention of the subsystem’s manufacturer**
- **Vendor-specific feature**
  - Maintenance commands are not exactly specified by TCG
- **Optional feature, but if implemented**
  - All specified maintenance capabilities are mandatory
  - No other maintenance capabilities must be implemented

Migration of TPM Keys
→ Specified Security Requirements

- **Confidentiality and cloning: Data to be migrated must not be**
  - accessible by more than one TPM at a time nor
  - exposed to third parties including the manufacturer
- **Policy conformance: Maintenance must require**
  - Source and target platforms are from the same manufacturer and model
  - Active participation of the TPM Owner
- **Migration of non-migratable data requires cooperation of**
  - owner of the non-migratable data
    - e.g., to authorize moving his sensitive data to another platform
  - manufacturer of the subsystem
    - e.g., must revoke old Endorsement Credential and guarantee destruction of old TPM (which still contains the migrated data)

Migration of TPM Keys
→ Interface to Perform Maintenance I

- **TPM_CreateMaintenanceArchive**
  - Creates maintenance archive encrypted with
    - Symmetric key derived from TPM Owner’s authorization secret or the TPM’s random number generator (TPM Owner decides)
    - Subsystem manufacturer’s public maintenance key
  - Requires authorization by the TPM Owner

- **TPM_LoadMaintenanceArchive**
  - Loads and restores a maintenance archive
    - All current TPM-protected data will be overwritten with the data from the maintenance archive
  - Must be authorized by the TPM Owner

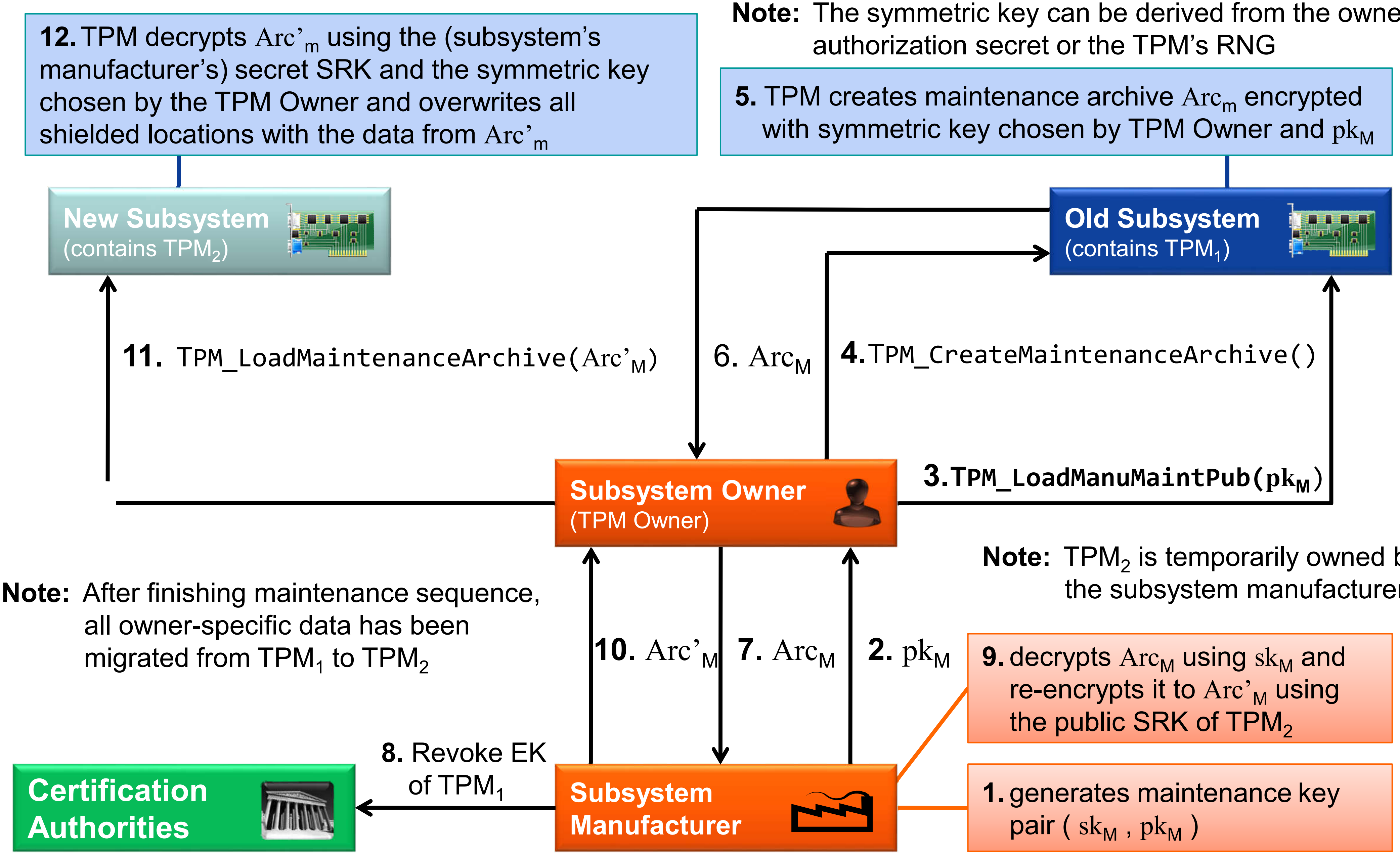
Migration of TPM Keys
→ Interface to Configure Maintenance II

- **TPM_KillMaintenanceFeature**
  - Disables all maintenance commands until a new TPM Owner is set
  - Must be authorized by the current TPM Owner

- **TPM_LoadManuMaintPub**
  - Installs a manufacturer’s public maintenance key into TPM
  - Usually done by the subsystem manufacturer before delivery

- **TPM_ReadManuMaintPub**
  - Reads manufacturer’s public maintenance key from TPM

Typical Maintenance Sequence



12. TPM decrypts Arc'_m using the (subsystem's manufacturer's) secret SRK and the symmetric key chosen by the TPM Owner and overwrites all shielded locations with the data from Arc'_m

Note: The symmetric key can be derived from the owner authorization secret or the TPM's RNG

5. TPM creates maintenance archive Arc_m encrypted with symmetric key chosen by TPM Owner and pk_M

New Subsystem
(contains TPM$_2$)

Old Subsystem
(contains TPM$_1$)

11. `TPM_LoadMaintenanceArchive(`Arc'_M`)`

6. Arc_M

4. `TPM_CreateMaintenanceArchive()`

3. **`TPM_LoadManuMaintPub(`pk_M`)`**

Subsystem Owner
(TPM Owner)

Note: TPM$_2$ is temporarily owned by the subsystem manufacturer

Note: After finishing maintenance sequence, all owner-specific data has been migrated from TPM$_1$ to TPM$_2$

10. Arc'_M

7. Arc_M

2. pk_M

9. decrypts Arc_M using sk_M and re-encrypts it to Arc'_M using the public SRK of TPM$_2$

8. Revoke EK of TPM$_1$

Certification Authorities

Subsystem Manufacturer

1. generates maintenance key pair (sk_M , pk_M)

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Trusted Platform Module (TPM)
→ Summary

- The TPM is the **anchor** for Trusted Computing

- The TPM is a **passive security controller** with
  - cryptographic functions
  - a secure storage and
  - with **Platform Configuration Registers (PCR)**
  - …

- Has a **complex key hierarchy** and different types of keys with additional properties

- Offers a lot of intelligent functions (protocols) with help together with additional components (e.g. TCB) to **measure and prove the integrity** of IT systems

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Trusted Computing
→ Trusted Platform Module (TPM)

Thank you for your attention!
Questions?

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Trusted Platform Module (TPM)

→ Literature

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Links:

Institute for Internet Security:
http://www.internet-sicherheit.de/forschung/aktuelle-projekte/trusted-computing/