Security APIs

System Security (CM0625, CM0631) 2024-25
Università Ca’ Foscari Venezia

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Security APIs

Host machine

Trusted device

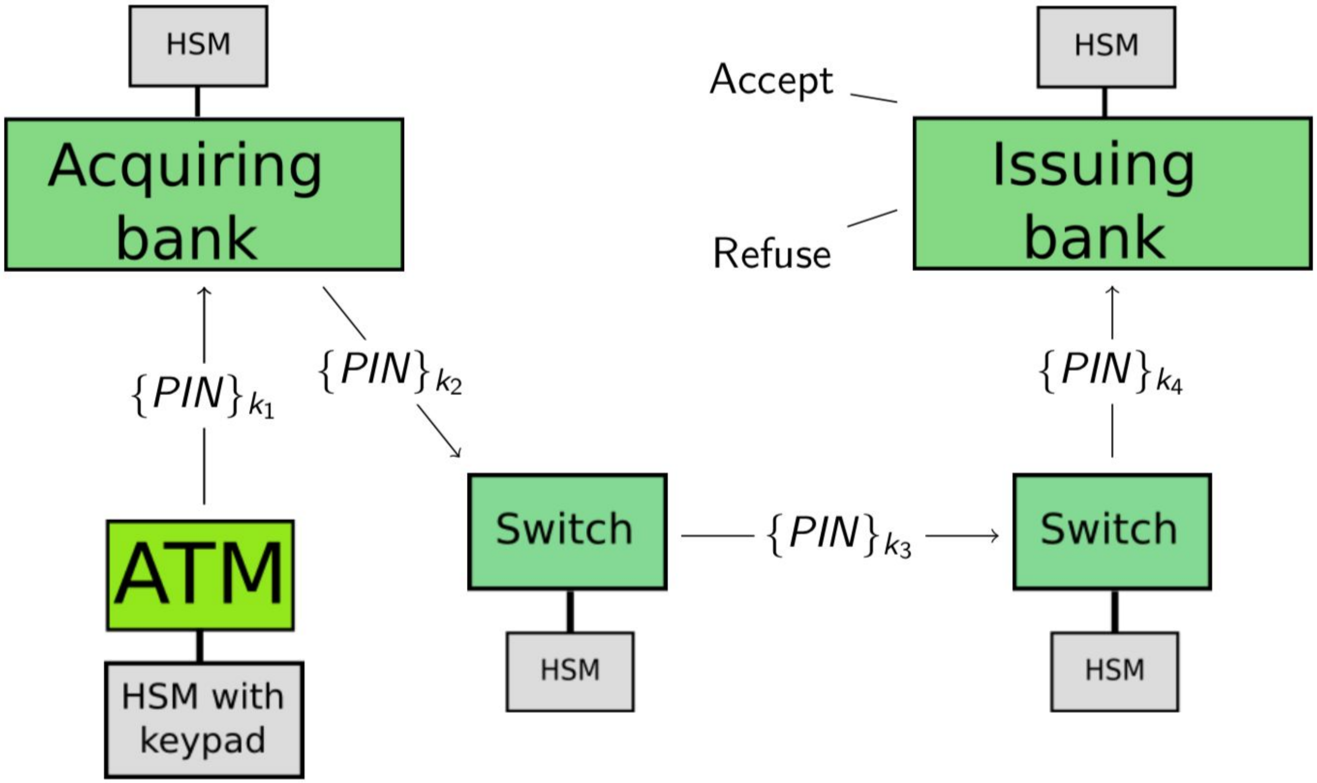
Security API

Case study 1: PIN verification

Hardware Security Modules (HSM)

- Used in the ATM Bank network
- Tamper resistant
- Offer APIs for:
  - Managing cryptographic keys
  - Decrypting/re-encrypting the PIN
  - Checking the validity of the PIN

PIN verification infrastructure (old protocol)



PIN verification

Encrypted PIN Block : contains the PIN at the ATM

PIN_V(EPB , vdata,len,dectab,offset)

Data for computing the user PIN

Example: PIN_V($\{4104,r\}_k$, vdata, 4, 0123456789012345, 4732)

1. $dec_k(\{4104,r\}_k)$ = 4104,r
   4104
2. $enc_{pdk}(vdata)$ = A47295FDE32A48B1
   $0472 \oplus 4732 \bmod 10 = 4104$
3. The two values coincide: PIN_V returns 'true'

PIN verification pseudo-code

```
PIN V(EPB, vdata, len, dectab, offset) {
    x1 := dec(k,EPB);  // decrypt the typed PIN
    t_pin:=fcheck(x1); // check format, remove random
    if (t_pin =⊥) then return(''format wrong'');

    x2 :=encpdk(vdata); // encrypt vdata
    x3 :=left(len,x2);  // take left 4-5 hex digits
    x4 :=decimalize(dectab,x3);     // decimalize digits
    u_pin := sum_mod10(x4, offset); // sum offset

    if (t_pin == u_pin) then return(''PIN is correct'');
}
```

Decimalization attack [Bond, Zielinski '03]

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1. We “compensate” on the offset to find the position

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⇒ If so we discover value and position!

Decimalization attack [Bond, Zielinski ’03]

This attack has been shown on real devices

- An insider sniffs ATM card data, launches the attack and <u>infers the PIN</u>
- **How many invocations** on average?
  - Four digit PINs: 14.47
  - Five digit PINs: 19.3
  - Strategies found automatically in [Focardi, Luccio ’10]
- Once the PIN is found (old) cards can be cloned

⇒ Thousand of PINs leaked in a lunch break!

NOTE: in countries where the chip cards are not yet widely used the attack would still work

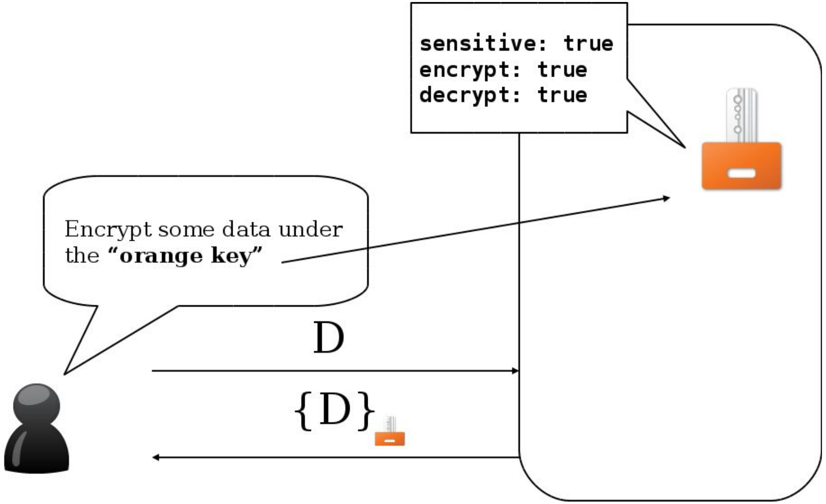
Case study 2: PKCS#11

PKCS#11 cryptographic operations

PKCS#11 is a standard API to cryptographic devices

Keys have **attributes** and are referenced via **handles** (that we represent with colors)

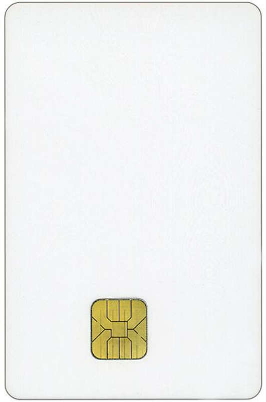
Example: orange key is sensitive and can be used to encrypt/decrypt data



Security of keys

Confidentiality of sensitive keys

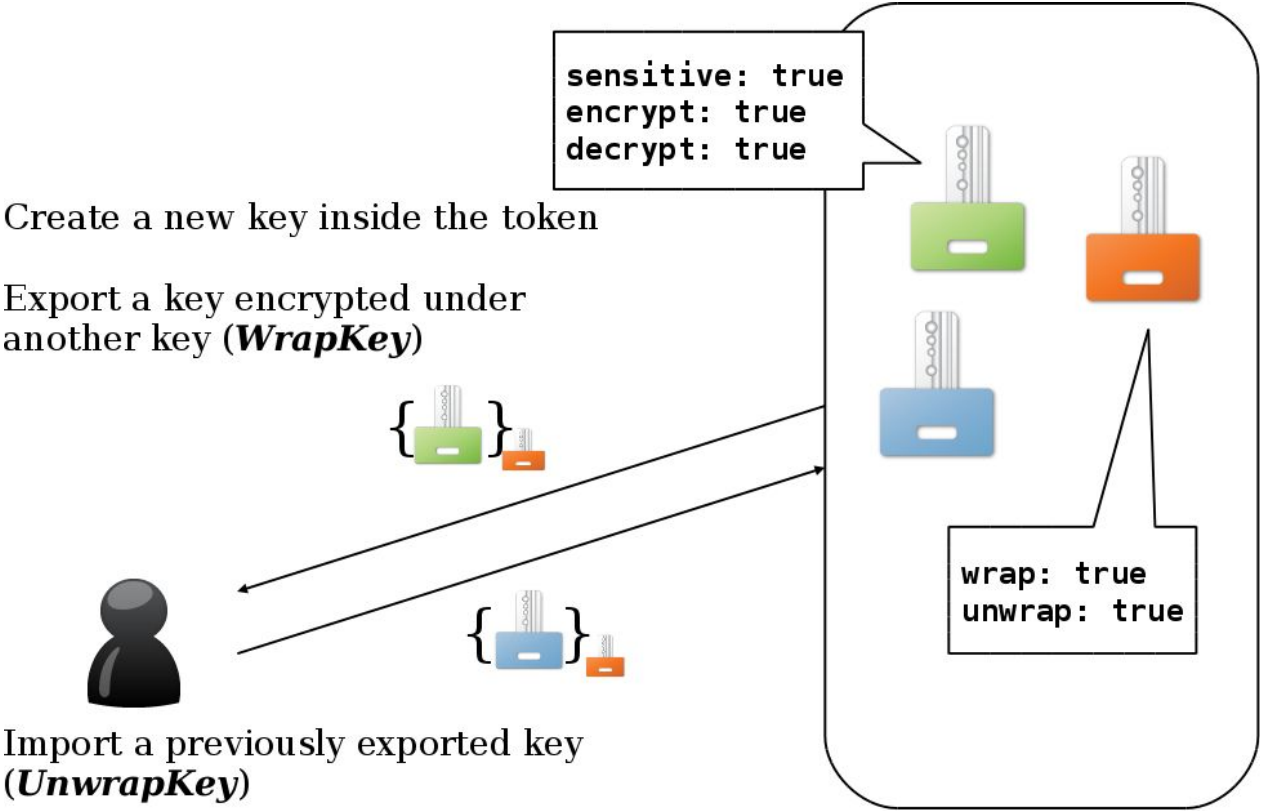
- `sensitive` keys should never be **accessible as plaintext** outside the device
- all crypto operations happen inside the device



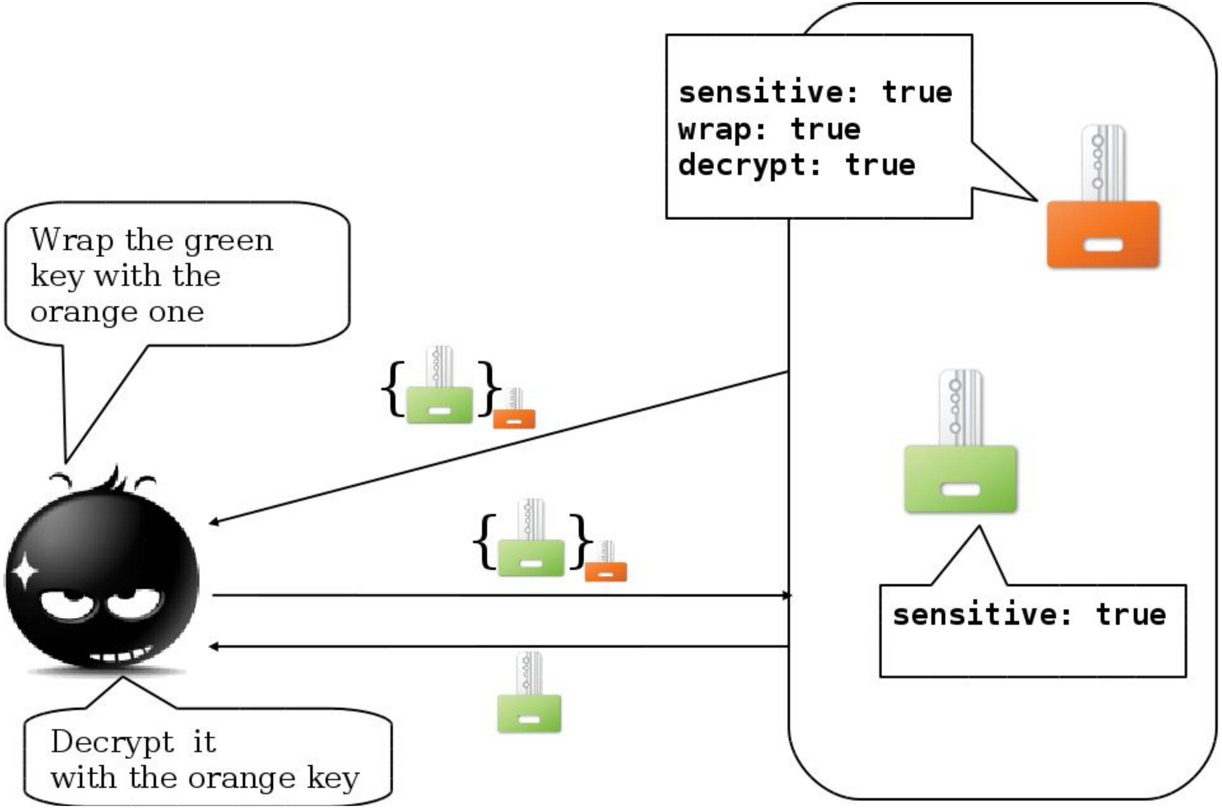
Attack scenario

1. the device is used on compromised host
2. the attacker extracts `sensitive` keys
3. the attacker **clones the device**

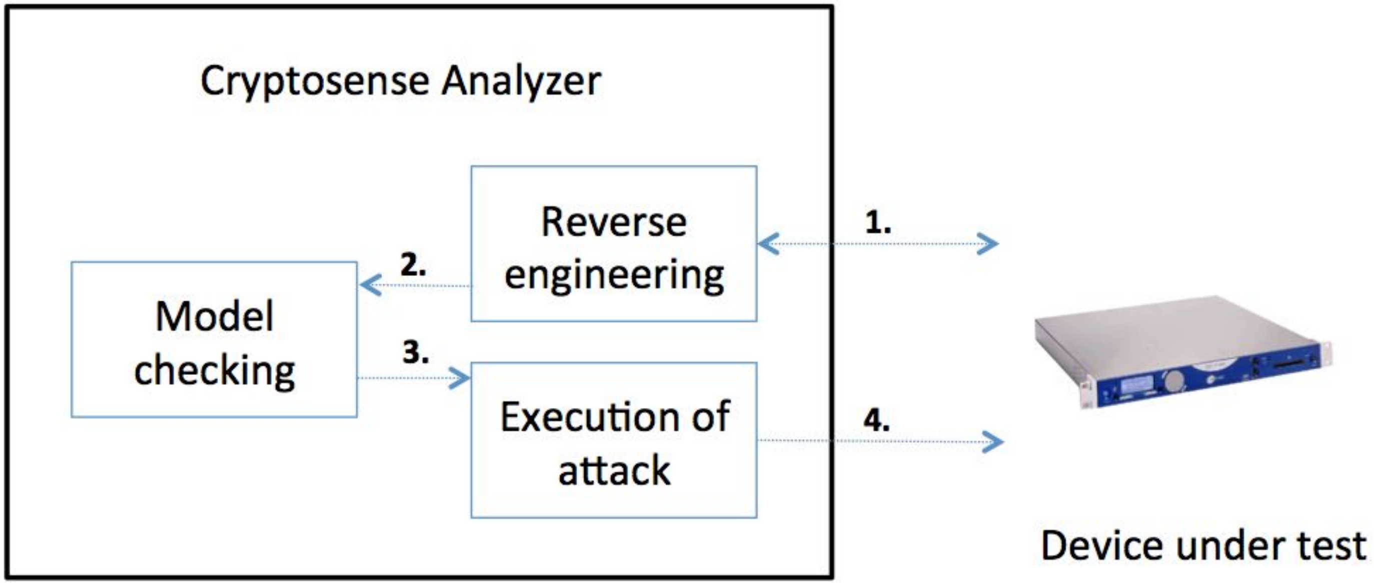
Key management example



The *wrap-and-decrypt* attack [CHES'03]



Formal verification



Real attacks [ACM CCS’10]

Device		Supported Functionality						Attacks found				
Brand	Model	s	as	cobj	chan	w	ws	wd	rs	ru	su	Tk
Aladdin	eToken PRO	✓	✓	✓	✓	✓	✓	✓				wd
Athena	ASEKey	✓	✓	✓								
Bull	Trustway RCI	✓	✓	✓	✓	✓	✓	✓				wd
Eutron	Crypto Id. ITSEC		✓	✓								
Feitian	StorePass2000	✓	✓	✓	✓	✓	✓	✓	✓	✓		rs
Feitian	ePass2000	✓	✓	✓	✓	✓	✓	✓	✓	✓		rs
Feitian	ePass3003Auto	✓	✓	✓	✓	✓	✓	✓	✓	✓		rs
Gemalto	SEG		✓		✓							
MXI	Stealth MXP Bio	✓	✓		✓							
RSA	SecurID 800	✓	✓	✓	✓				✓	✓	✓	rs
SafeNet	iKey 2032	✓	✓	✓		✓						
Sata	DKey	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	rs
ACS	ACOS5	✓	✓	✓	✓							
Athena	ASE Smartcard	✓	✓	✓								
Gemalto	Cyberflex V2	✓	✓	✓		✓	✓	✓				wd
Gemalto	SafeSite V1		✓		✓							
Gemalto	SafeSite V2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	rs
Siemens	CardOS V4.3 B	✓	✓	✓		✓				✓		ru

The code for devices like RSA Security's SecurID 800 constantly changes, but computer scientists have found weaknesses.

Scientists Make Short Work Of Breaking Security Keys

By SOMINI SENGUPTA

For years private companies and government agencies have given their employees a card or token that produces a constantly changing set of numbers. Those devices became the preferred method of securing confidential communications online. No one could have access to the data without a secret key generated by the device.

Computer scientists say they have now figured out how to extract that key from a widely used RSA electronic token in as little as 13 minutes.

The scientists, who call them-

encryption tools were antiquated and susceptible to attack.

“It would be nice if manufacturers paid more heed to what they might see only as theoretical attacks and were more cautious,” said Chris Peikert, a theoretical cryptographer who teaches computer science at the Georgia Institute of Technology. “In an ideal world this problematic standard would have been transitioned away from years ago.”

One of the reasons this standard has persisted, Mr. Peikert said, is that until now, researchers and manufacturers reckoned that it would take a long time to

PKCS#11 is still flawed after 20+ years !?!

Fixes?

Fixes: Various proposals in the literature to modify the API, but never included in PKCS#11

⇒ Proprietary fixes exist but break compliance

Example: offline key management and **no key wrapping** in production

Mitigations: monitor/filter API calls **locally**

`wrap_with_trusted` *attribute* requires that keys are only wrapped under **`trusted`** keys (flagged by the Security Officer)

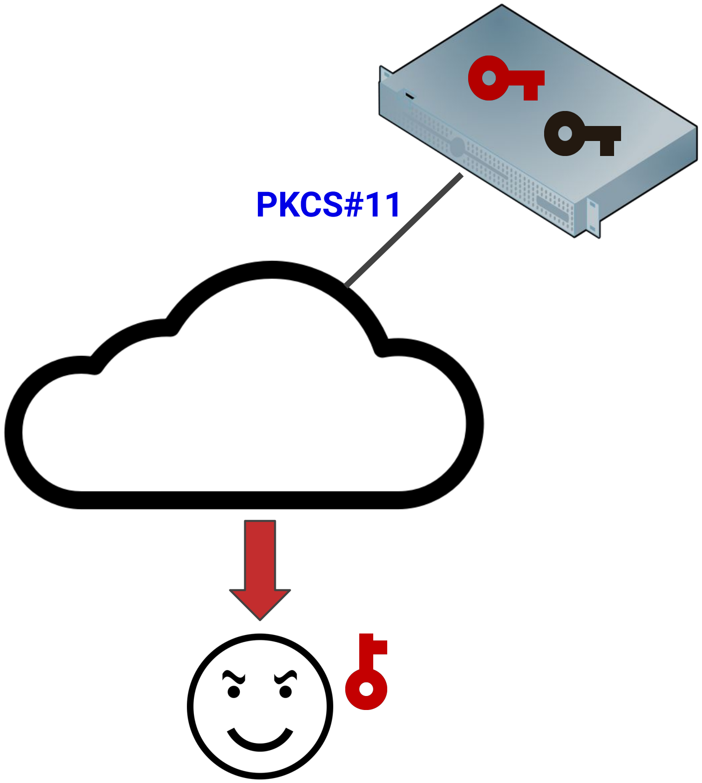
👍 Secure key wrapping, *in principle*
⚠️ No guidance in the docs
⚠️ How should **`trusted`** keys be generated/managed?
⚠️ What if a **`trusted`** key is flagged **`wrap+decrypt`**?

A new scenario: cloud HSMs

HSM hardware accessible as a service in the cloud

- Compliance to standard APIs: no proprietary fixes
- No offline, secure key management procedures
- No API-level monitors/filters

New attacker model: a vulnerability in one application would expose the full (flawed!) PKCS#11 API



A formally verified configuration

Focardi & Luccio
ACM CCS’21

- User **roles** to secure PKCS#11
- First secure PKCS#11 configuration that does not break the API **compliance**
- Implementation in a **real Cloud HSM solution**
- Formal model and automated **proof of security**

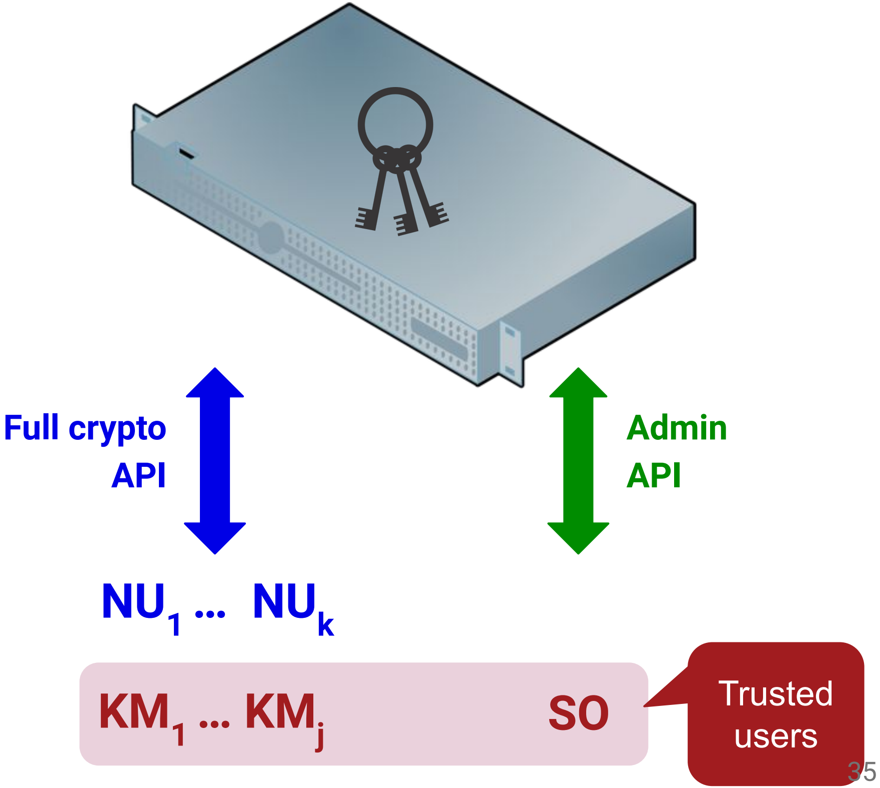
User roles

Normal Users (NU): used in production applications, full API but no attack should be possible

Key Managers (KM): create and manage candidate `trusted` keys

Security Officer (SO): admin, cannot do crypto but marks `trusted` keys

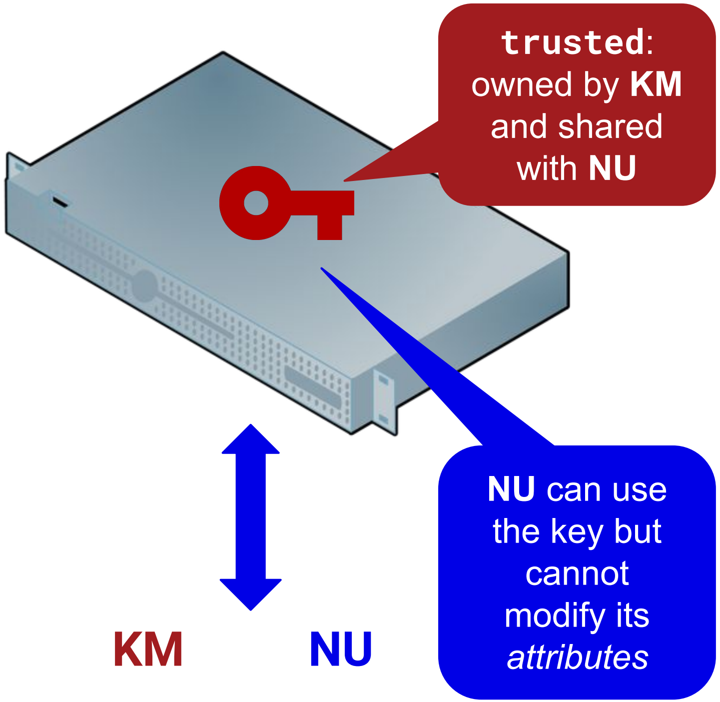
- KMs and SO only accessed by management apps or humans



Key sharing

1. **KMs** generate (candidate) **`trusted`** wrapping keys
2. **KMs share** these keys with **NUs**
3. **NUs** can use wrapping keys but **cannot** modify their *attributes*, e.g., cannot mark them as **`decrypt`** keys

- ***Key sharing*** is not in PKCS#11 but can be added on top, at the cloud/admin layer



Secure configuration

Rule 1 (Sensitive keys). Sensitive keys should be generated with **`wrap_with_trusted`** set or **`extractable`** unset (i.e. will never be wrapped).

Rule 2 (Trusted keys). The SO sets the **`trusted`** attribute only on candidate keys generated by one of the KMs.

Rule 3 (Roles of candidate keys). Candidate keys managed by the KMs should only admit **`wrap`** and **`unwrap`** operations, during their lifetime.

Rule 4 (Management of candidate keys). Candidate keys managed by the KMs should be generated with **`extractable`** unset (i.e. will never be wrapped)

Rule 5 (Freshness of candidate keys). Candidate keys managed by the KMs should be freshly generated in the device.

Implementation in real cloud HSMs

AWS CloudHSM implements the required **key sharing** capability:
*"Users who share the key can use the key in cryptographic operations, but they **cannot change its attributes**"*

- The secure configuration can be implemented straightforwardly

Note: we assume a worst-case scenario in which <u>all keys are shared</u>

Other cloud solutions:

- do not have publicly available documentation
  (e.g. Utimaco, Microsoft)
- do not implement PKCS#11, yet?
  (e.g. Google)
- do not seem to implement key sharing in the form we need
  (e.g. IBM)

Formal analysis

We formalize a significant subset of PKCS#11 in the Tamarin prover:

- Symmetric crypto and wrap
- **`wrap_with_trusted`** and **`trusted`** attributes
- User roles + key sharing

We automatically prove security for an **unbounded** number of users, keys and sessions

```
rule Wrap:

  [ !NU(U),
    !Key(U1,ha1,k1),
    !Key(U2,ha2,k2) ]

--[
    Wrap(U,ha1,ha2),
    IsSet(ha1,'wrap_with_trusted'),
    IsSet(ha1,'extractable'),
    IsSet(ha2,'trusted'),
    IsSet(ha2,'wrap')
  ]->

  [ Out(senc(k1,k2)) ]
```

Normal User U

Keys k1, k2 owned by U1, U2 (ha1, ha2 are *handles*)

U wraps ha1 with ha2, i.e., k1 with k2

Appropriate attributes

ciphertext is sent out (**simplified**, see the paper for detail!)

Automated proof

Keys which, at some point, are marked as **`trusted`** are never leaked

```
lemma SecrecyTrusted:
"
All W ha k #i #j #w.
  IsHandle(ha,k)@i &
  SetAttr(W,ha,'trusted')@j &
  KU(k)@w
==> F
"
```

ha is a handle for key k at time i

and ha has **`trusted`** set at time j

and the attacker knows k at time w

implies `false`, i.e., it cannot occur

Similar lemmas for sensitive keys generated with **`wrap_with_trusted`** set or **`extractable`** unset (*cf*. Rule 1)

Complete model with additional helper and sanity lemmas available at github.com/secgroup/CloudHSM-model

The complete model can be proved automatically in about **1m30s** on a MacBook Pro 2018