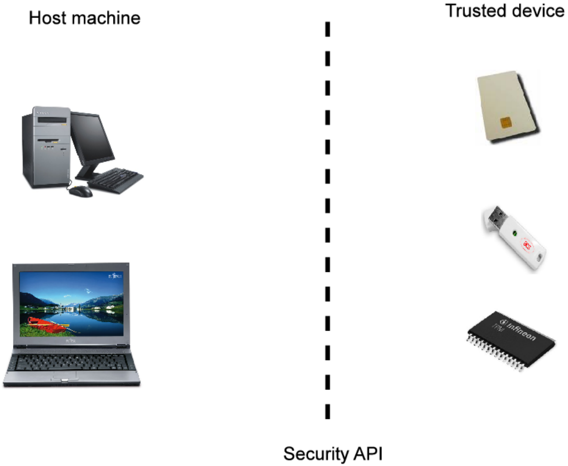
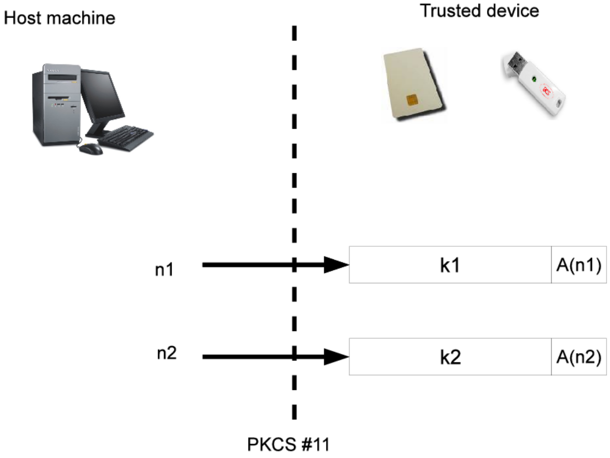
Attacking and fixing PKCS#11

Security Course, Ca' Foscari, 2016

Security APIs



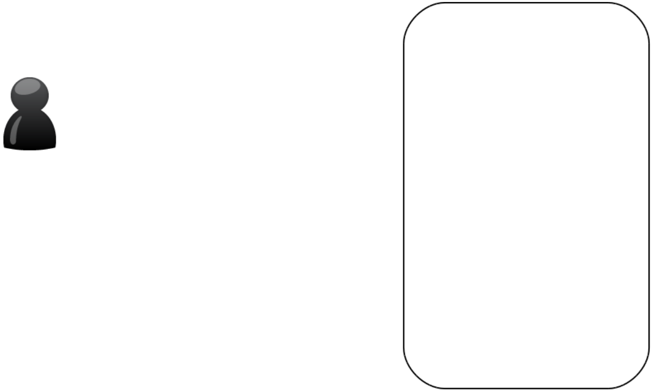
PKCS#11 API for trusted devices



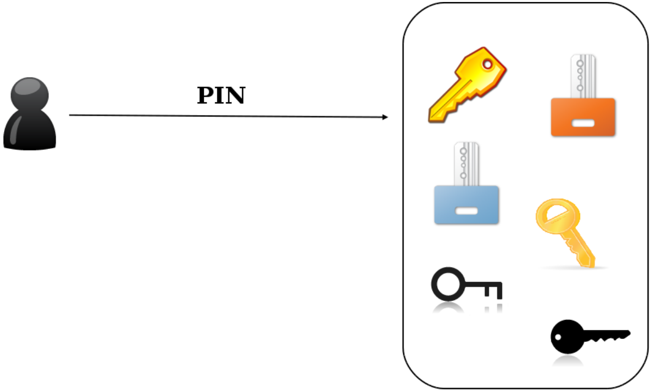
Outline

- API Overview
- PKCS#11 key management attacks
- API configuration problems
- How to make PKCS#11 secure?

PKCS#11, an overview



PKCS#11, an overview



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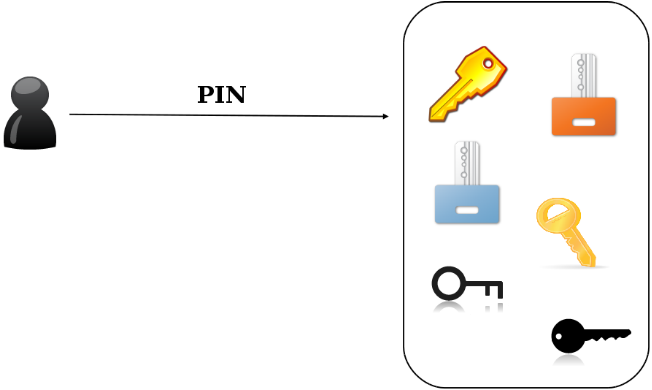
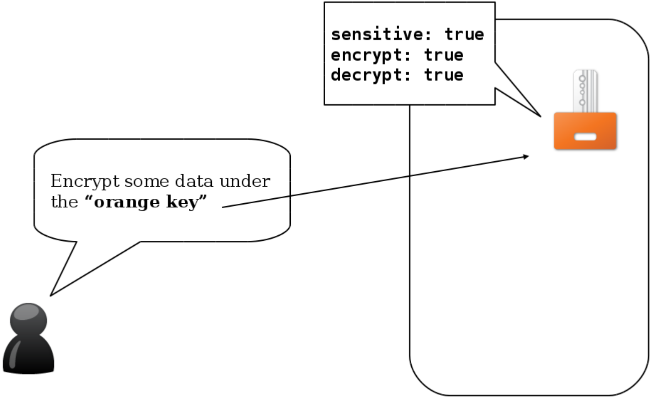


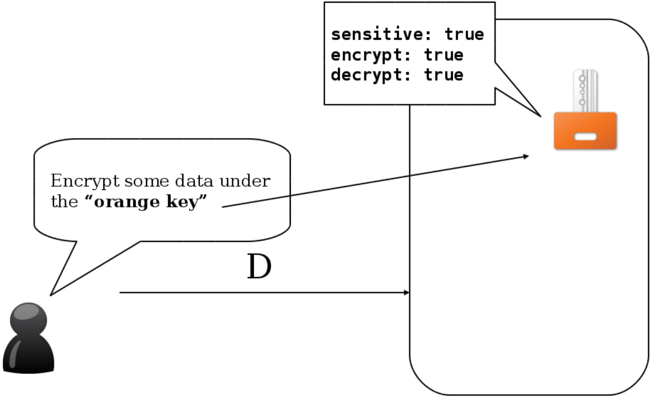
- the PIN is a ‘second-layer’ protection to unlock the token
  ⇒ it should never give access to `sensitive` key values

PKCS#11 keys and cryptographic operations



- Keys have *attributes* and are referenced via *handles*
- APIs for *cryptographic operations*

PKCS#11 keys and cryptographic operations



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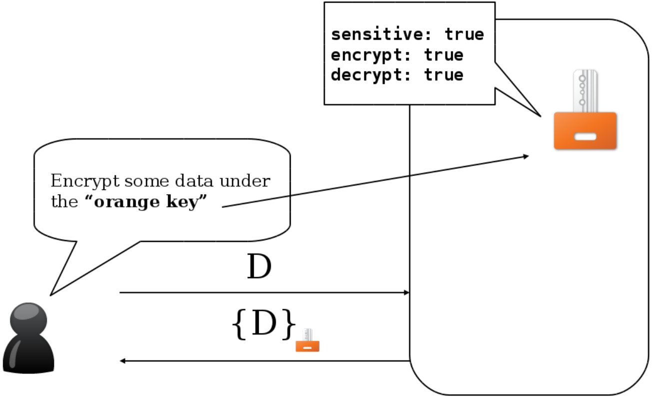

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- APIs for *cryptographic operations*

Security of keys

Confidentiality of sensitive keys

- `sensitive` keys never accessible as plaintext outside the device
  ... even if we know the PIN

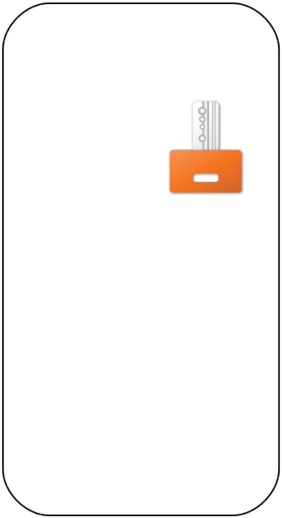
Attack scenario

1. token used on compromised host
2. attacker sniffs PIN and extracts `sensitive` keys
3. attacker clones the token

"... the PIN may be passed through the operating system. This can make it easy for a rogue application on the operating system to obtain the PIN ... " [RSA Security]

PKCS#11 key management

Create a new key inside the token



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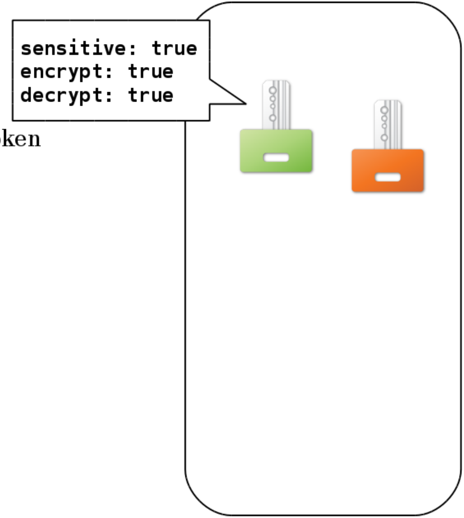

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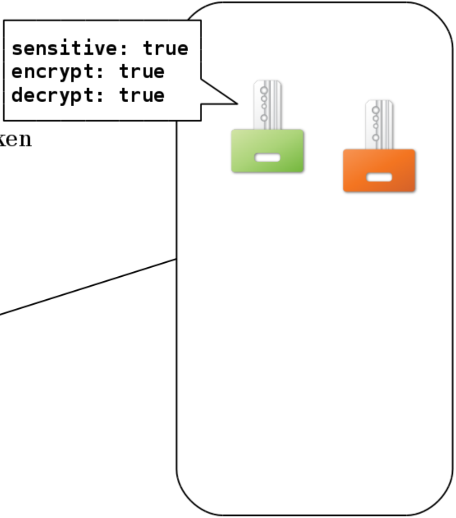

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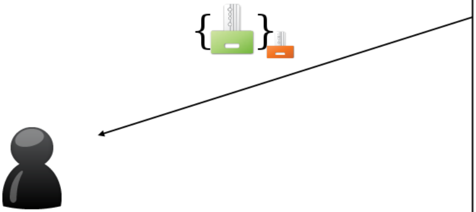
Export a key encrypted under another key (***WrapKey***)



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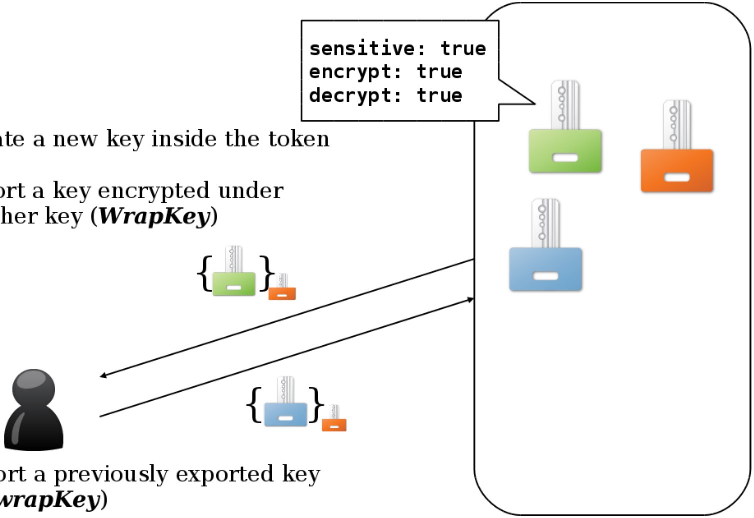

Import a previously exported key (***UnwrapKey***)

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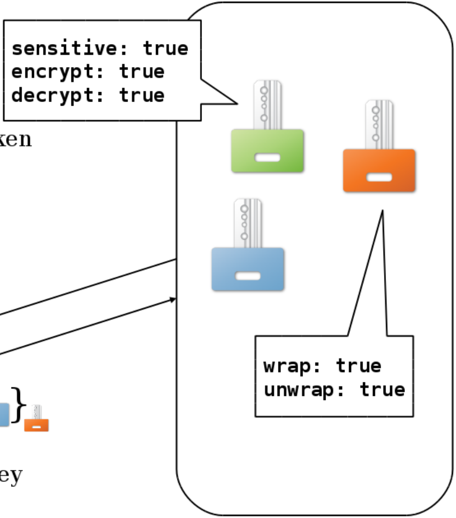

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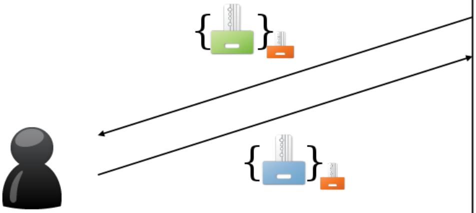

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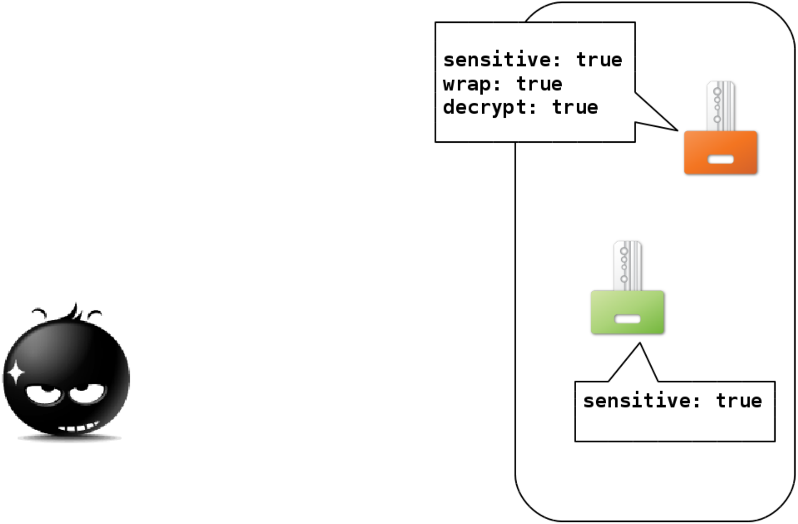
A simple API-level attack [Clulow CHES'03]



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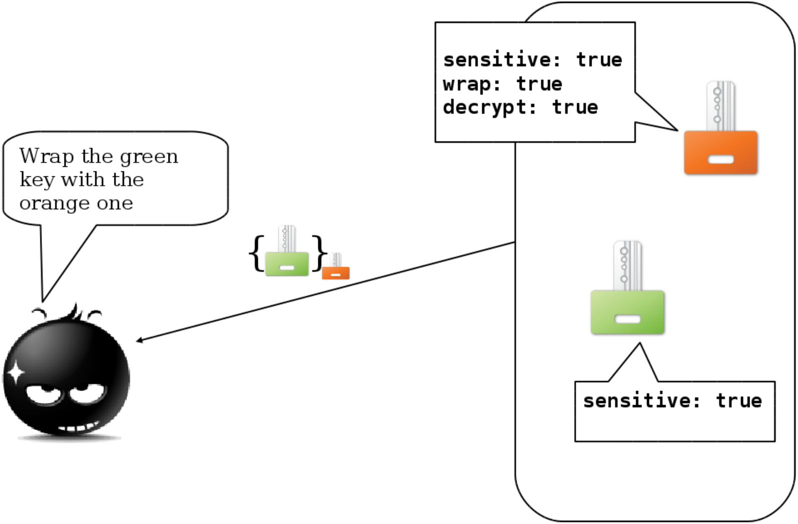

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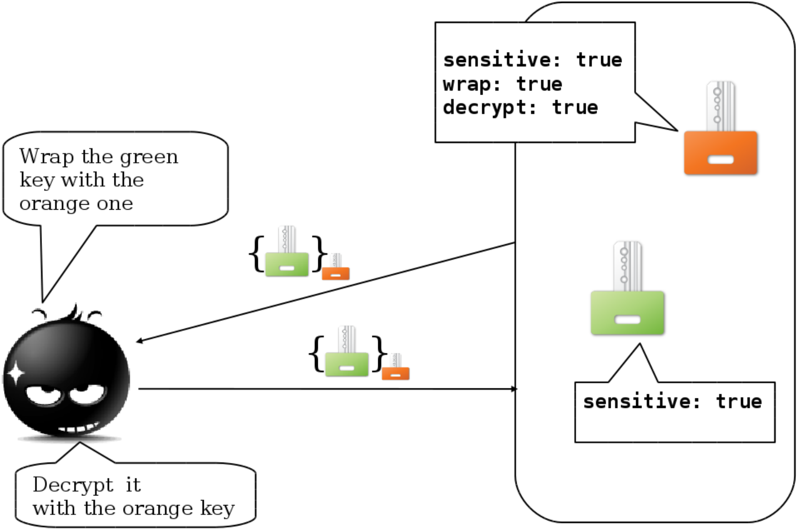

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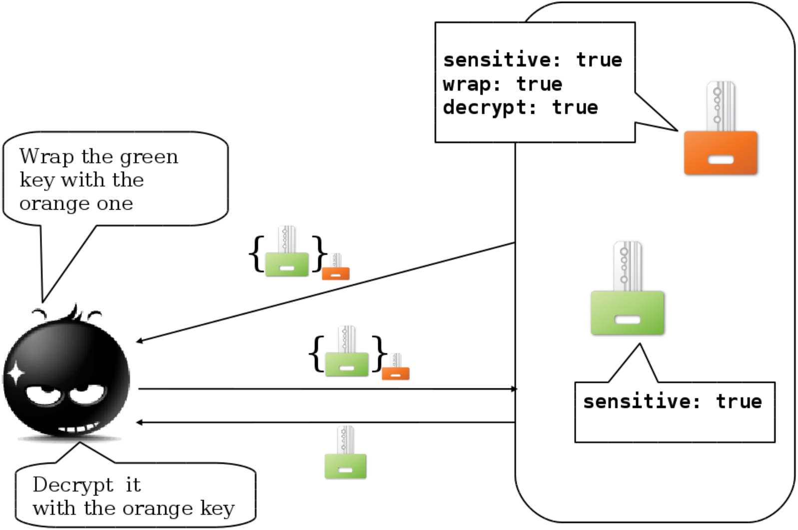
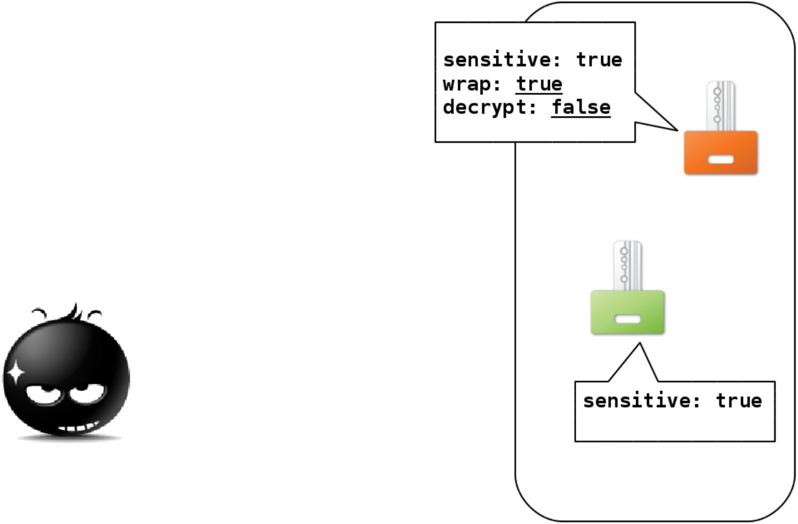


Key separation: forbid wrap and decrypt together



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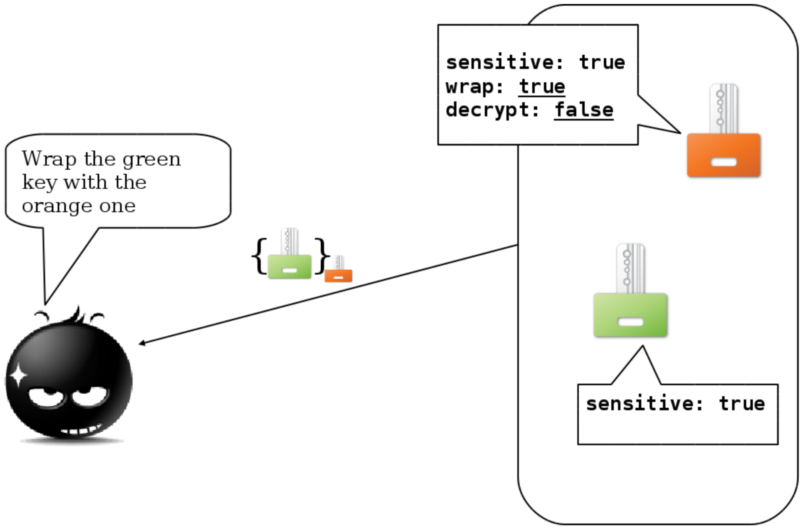

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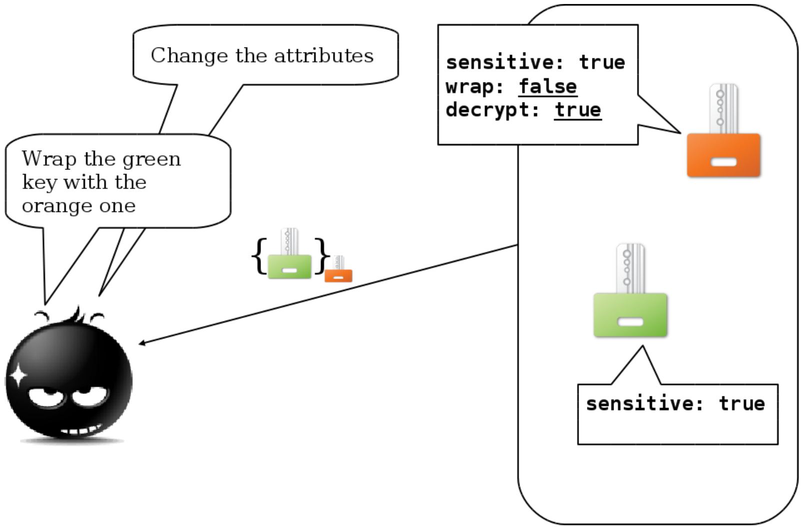

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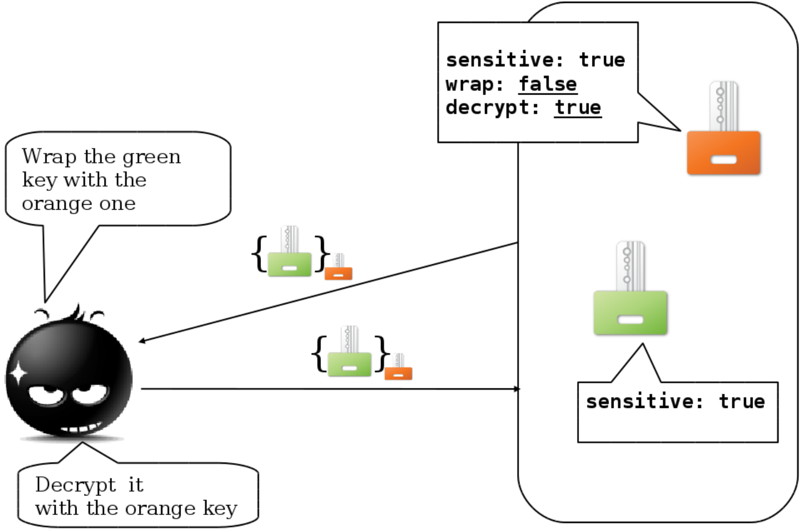

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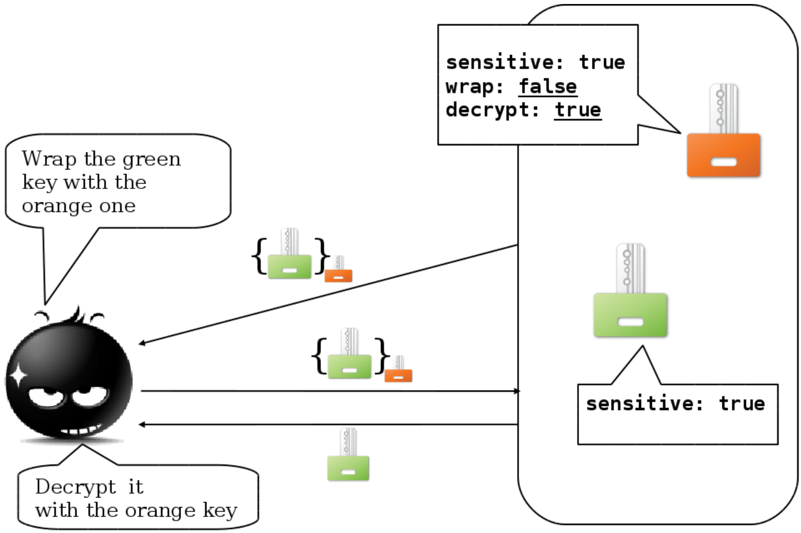
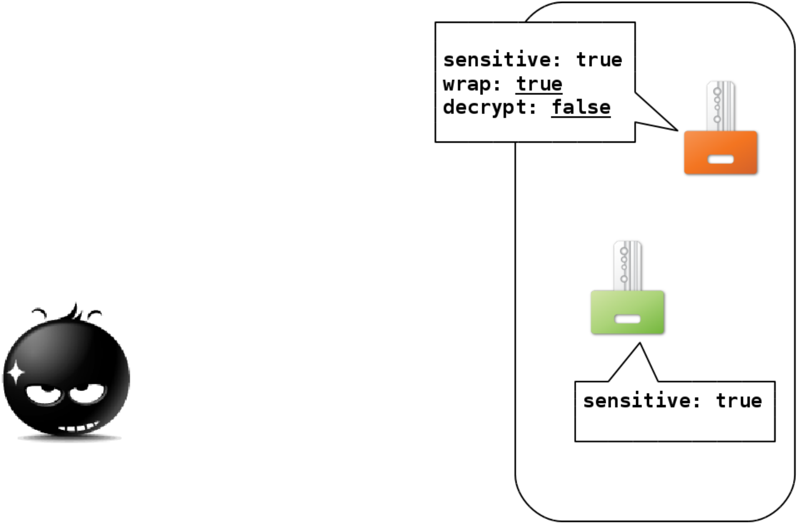


Well ... make attributes 'sticky on'



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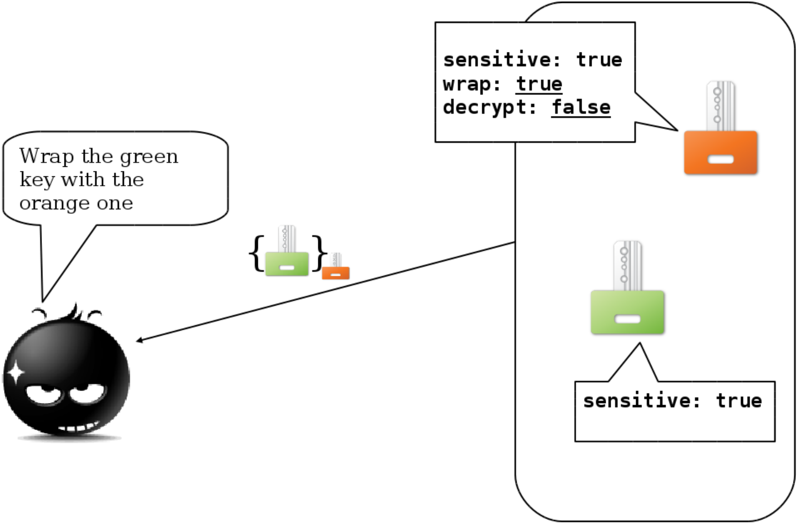

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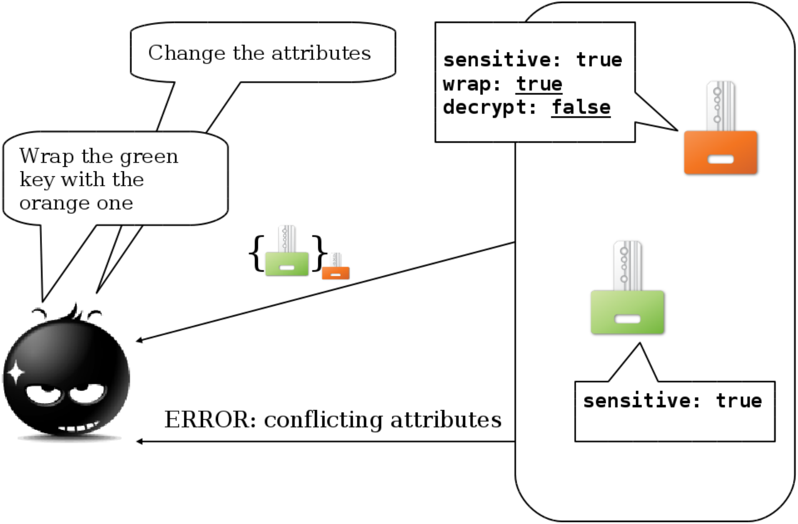

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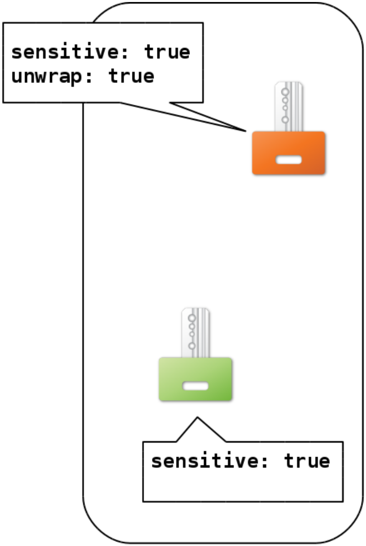

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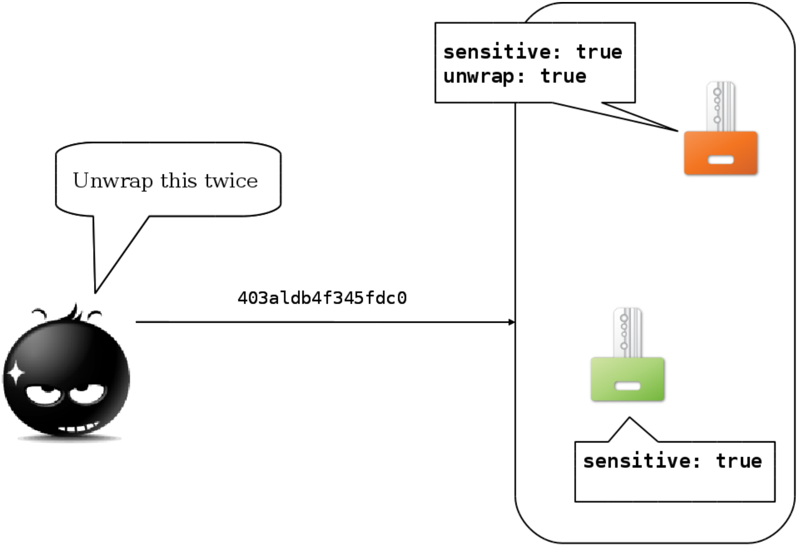
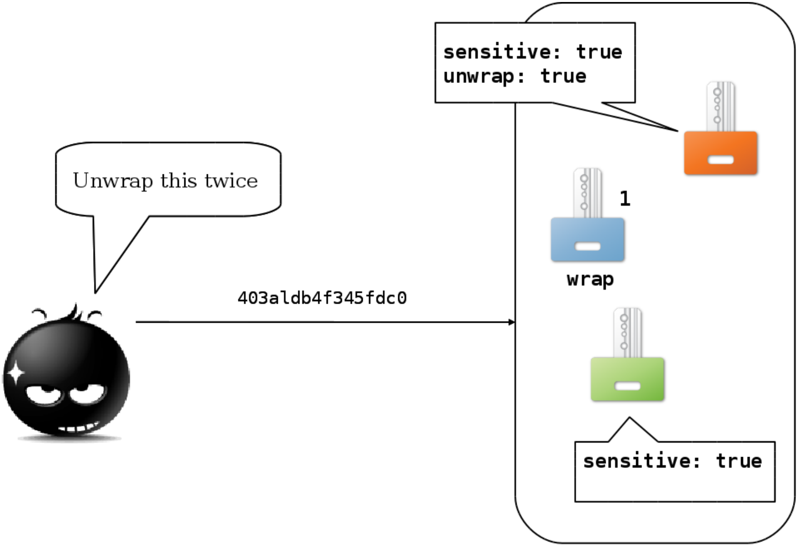
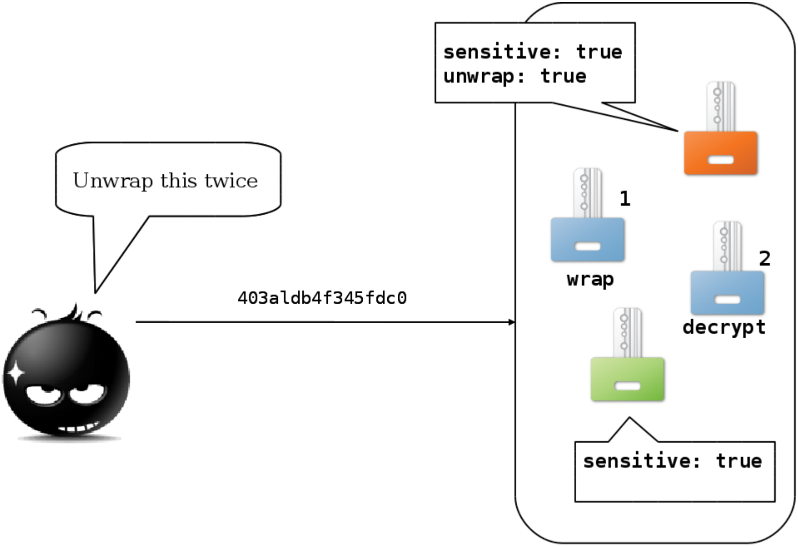

sensitive: true
unwrap: true
Unwrap this twice
403a1db4f345fdc0
sensitive: true

But still ...


Unwrap this twice
403a1db4f345fdc0
sensitive: true
unwrap: true
1
wrap
sensitive: true

But still ...


Unwrap this twice
403a1db4f345fdc0
sensitive: true
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1
wrap
2
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sensitive: true

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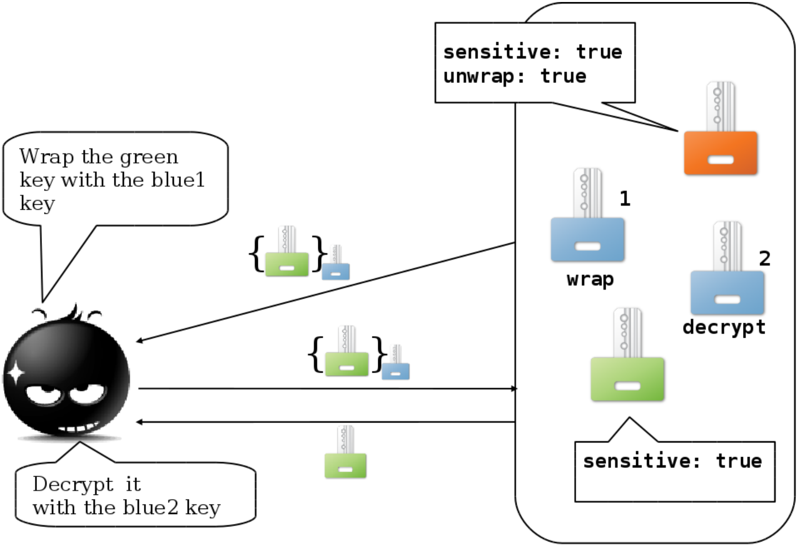
sensitive: true
unwrap: true
Wrap the green
key with the blue1
key
1
wrap
2
decrypt
sensitive: true
Decrypt it
with the blue2 key

Now what?

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- check if two instances of the same key have different attributes
  - is this of any help?

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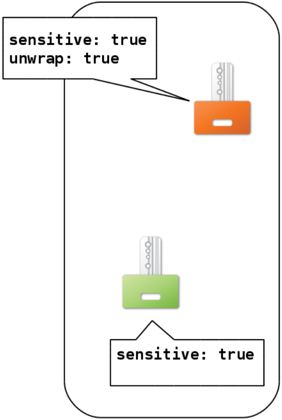

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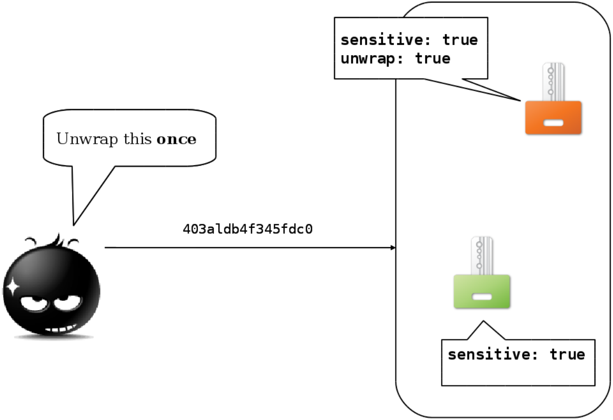

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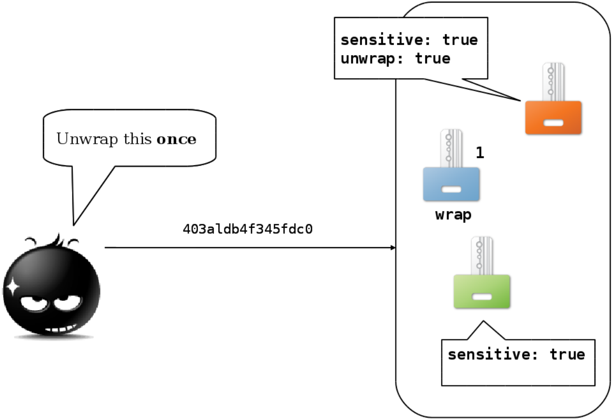

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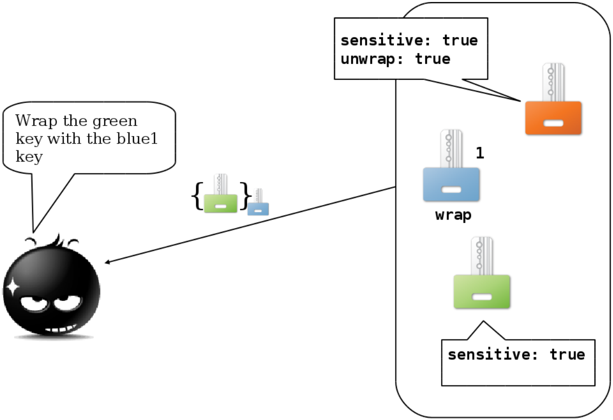

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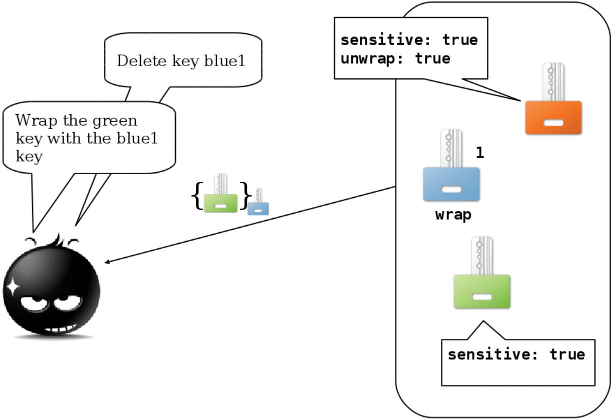

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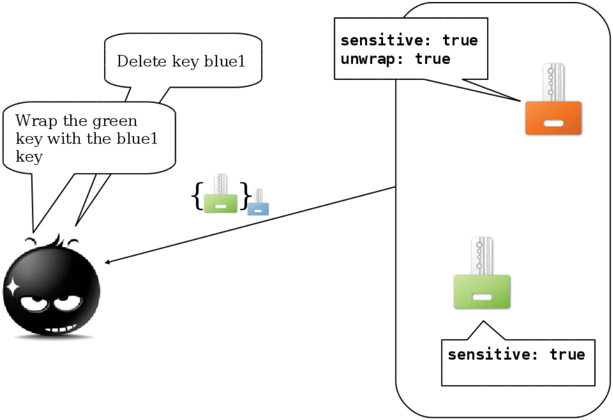

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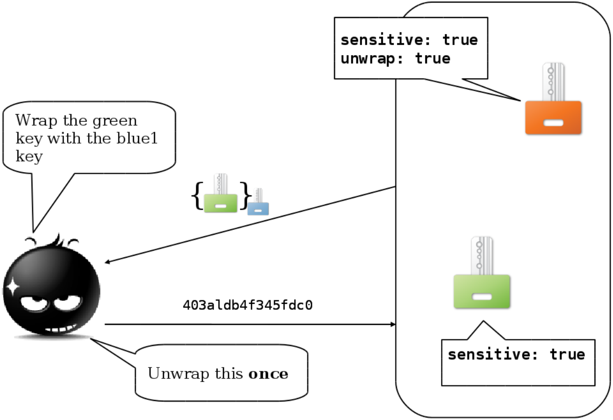

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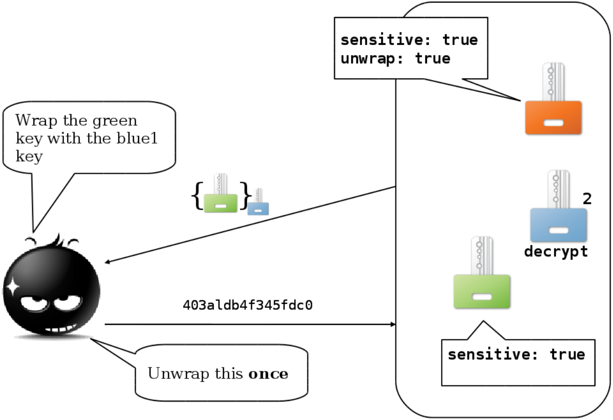

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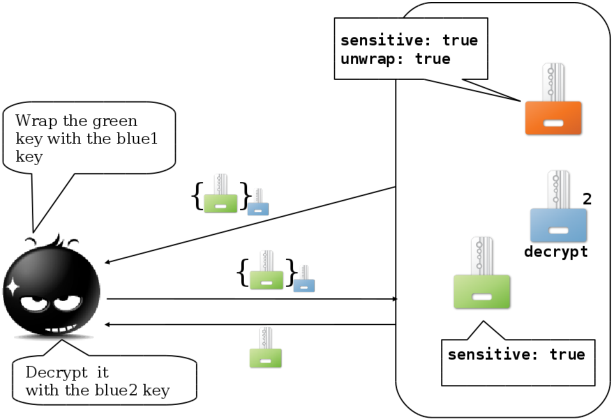

Wrapping format

- keep track of key template when wrapping it
- check that it corresponds when unwrapping

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💡 Compute a CBC-MAC of the wrapped key together with its relevant attributes

$$\mathrm{MAC}_{k_m}(\{k_1\}_{k_2}, \text{sensitive}, \text{wrap}, \text{unwrap}, \ldots)$$

and give it as output together with $\{k_1\}_{k_2}$

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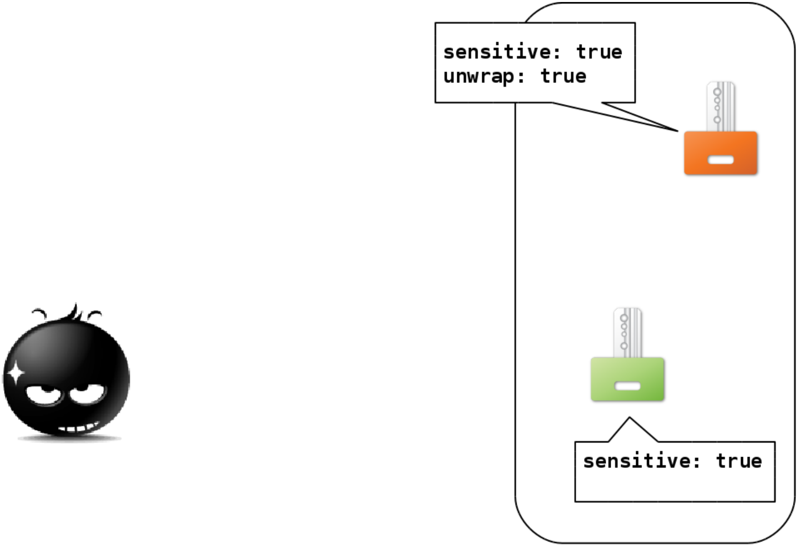
Note: k_m can be derived from k_2, e.g., by encrypting some constant

Unwrap of arbitrary data is prevented



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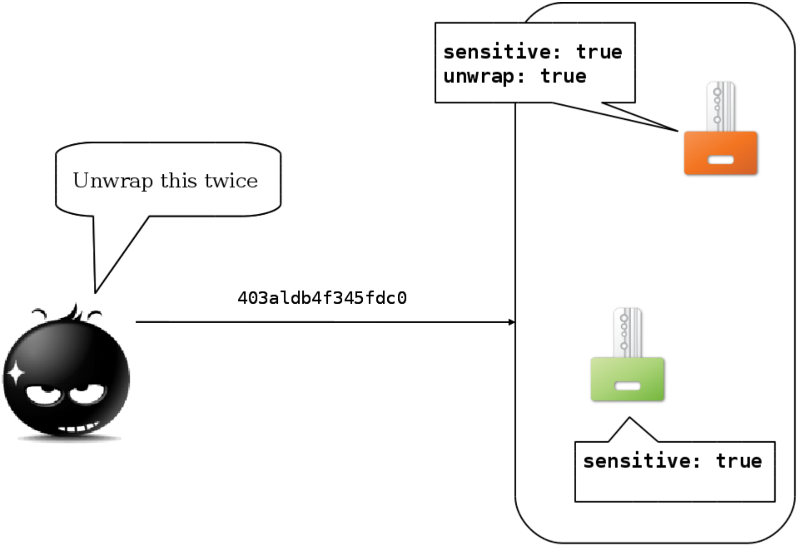

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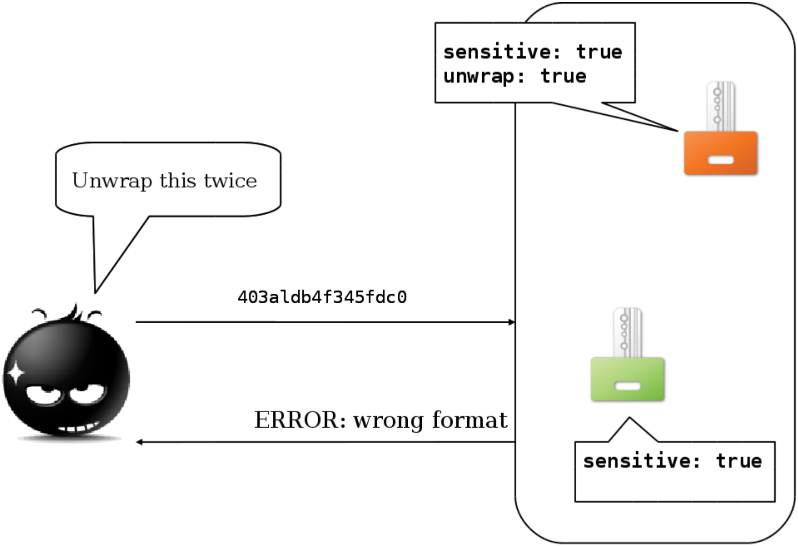

Summary: Attribute policies and wrapping formats

Sticky

Once an attribute is set (unset), it may not be unset (set).
Read-only attributes can be thought as both sticky on and off.

Conflicting

Pairs of attributes that cannot be simultaneously set.
(not in the PKCS#11 documentation)

Wrapping format

Keep track of relevant attributes when wrapping, and check they are the same when unwrapping

What's the problem?

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buffalo buffalo buffalo buffalo buffalo buffalo buffalo buffalo

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buffalo buffalo buffalo buffalo buffalo buffalo buffalo buffalo

Buffalo buffalo Buffalo buffalo buffalo buffalo Buffalo buffalo

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buffalo buffalo buffalo buffalo buffalo buffalo buffalo buffalo

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Buffalo buffalo, Buffalo buffalo buffalo, buffalo Buffalo buffalo

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buffalo buffalo buffalo buffalo buffalo buffalo buffalo buffalo

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Buffalo buffalo, Buffalo buffalo buffalo, buffalo Buffalo buffalo

buffalo FROM Buffalo WHO buffalo (intimidate) buffalo FROM Buffalo, buffalo (intimidate) buffalo FROM Buffalo

Formal analysis of PKCS#11 (2 slides!)

- Terms representing keys, ciphertexts, handles

$$k, senc\,(d, k)\,, h(n, k)$$

- Rules $T; L \xrightarrow{\text{new } \tilde{n}} T'; L'$ representing API calls

$$h\,(x_1, y_1)\,, y_2;\ \texttt{encrypt}\,(x_1)\ \rightarrow\ senc\,(y_2, y_1)$$

- Transitions $(S, V) \rightsquigarrow (S', V')$ representing API invocation

$$\langle\ \{h(n, k), d\}; \texttt{encrypt}(n)\ \rangle \rightsquigarrow \langle\ \{h(n, k), d, senc(d, k)\}; \texttt{encrypt}(n)\ \rangle$$

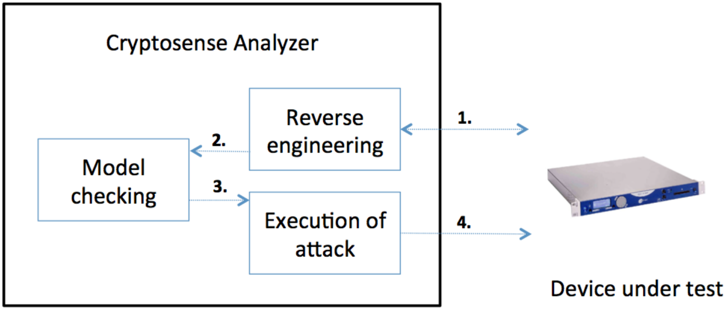
Wrap-Decrypt attack, formally

- Rules for key generation, wrap, decrypt:

$$\begin{array}{rcl} & \xrightarrow{\text{new } n,k} & h(n,k)\,;\mathcal{A} \\ h(x_1,y_1)\,,h(x_2,y_2)\,;\mathtt{wrap}(x_1)\,,\mathtt{extract}(x_2) & \longrightarrow & senc(y_2,y_1) \\ h(x_1,y_1)\,,senc(y_2,y_1)\,;\mathtt{decrypt}(x_1) & \longrightarrow & y_2 \end{array}$$

- We start from state $\langle\ \{h(n_1,k_1)\}, \mathtt{sensitive}(n_1), \mathtt{extract}(n_1)\ \rangle$
  - $\leadsto \langle\ \{h(n_1,k_1), h(n_2,k_2)\},$ $\mathtt{sensitive}(n_1), \mathtt{extract}(n_1), \mathtt{wrap}(n_2), \mathtt{decrypt}(n_2)\ \rangle$
  - $\leadsto \langle\ \{h(n_1,k_1), h(n_2,k_2), senc(k_1,k_2)\},$ $\mathtt{sensitive}(n_1), \mathtt{extract}(n_1), \mathtt{wrap}(n_2), \mathtt{decrypt}(n_2)\ \rangle$
  - $\leadsto \langle\ \{h(n_1,k_1), h(n_2,k_2), senc(k_1,k_2), k_1\},$ $\mathtt{sensitive}(n_1), \mathtt{extract}(n_1), \mathtt{wrap}(n_2), \mathtt{decrypt}(n_2)\ \rangle$

Crytpsense Analyzer



Results of testing of Tokens/Smarcards

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

Towards a secure PKCS#11

Fixing this kind of attacks is far from being trivial

- most real tokens are either vulnerable or cut-down so to avoid wrap/unwrap [Bortolozzo et al. CCS'10].
- secure configuration + wrapping format [Delaune et al. JCS'09] (e.g., Eracom mechanism `Wrapkey_DES3_CBC`, out of the standard)
- more on wrapping formats [Fröschle, Steel ARSPA-WITS'09]
- configuration with mixed roles [Bortolozzo et al. CCS'10]
- configuration with trusted keys [Fröschle, Sommer FAST'11]
- key diversification [Centenaro et al. POST'12]

Summary

- Crypto APIs are irritatingly liberal
- Attacks to compromise a sensitive key and fixes
- The APIs are hard, sometimes impossible, to configure securely
- Formal methods are effective
  - Find (new) attacks
  - Provide a high level of certification

References

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