Attacking and Fixing PKCS#11 Security Tokens

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Describes ‘cryptoki’: cryptographic token interface

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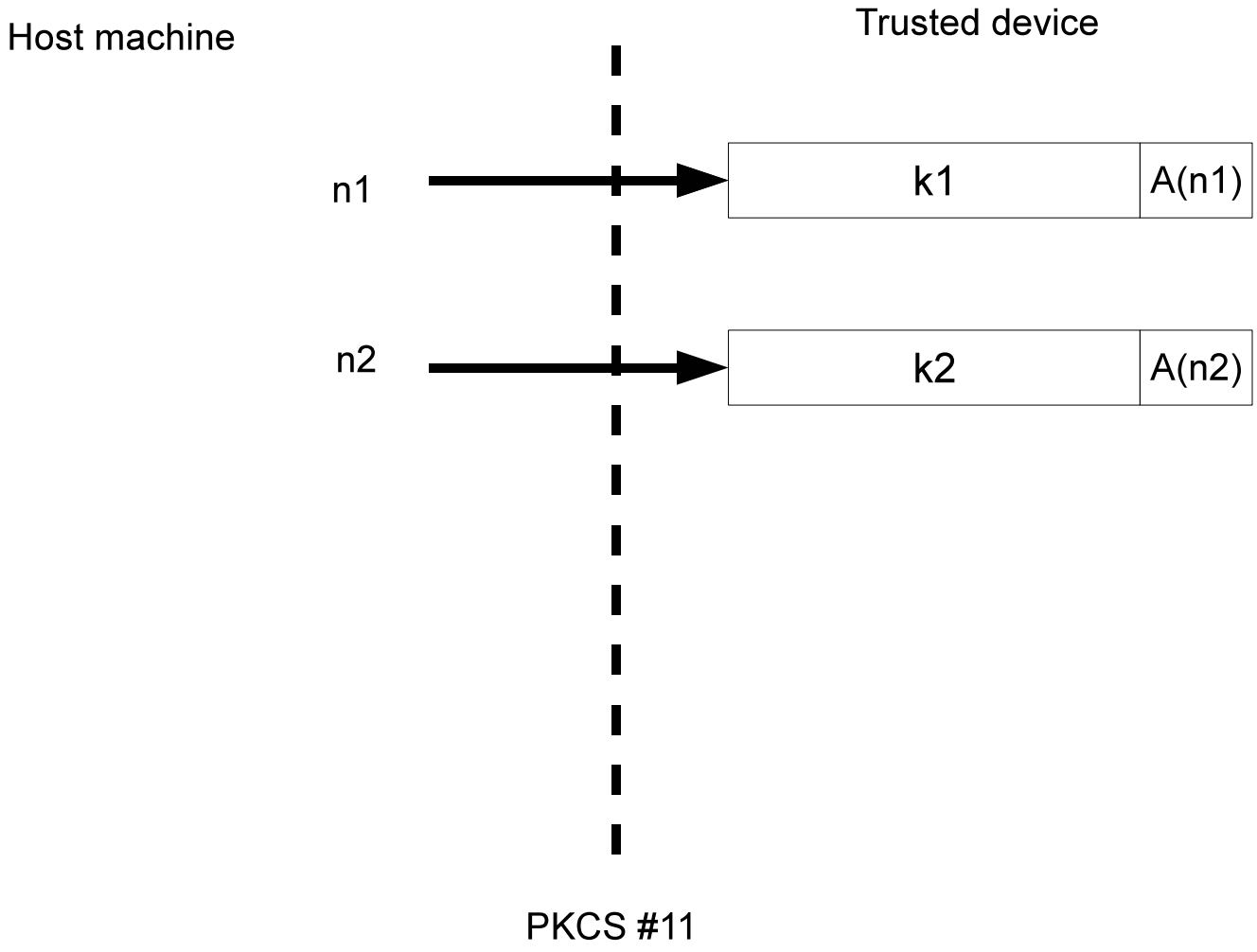
Cryptoki provides a logical view of objects on the token

Keys (etc.) stored on the device and accessed by *handles*

Attributes stored with keys to control usage


Host machine
Trusted device
n1
k1
A(n1)
n2
k2
A(n2)
PKCS #11

PKCS#11 Security

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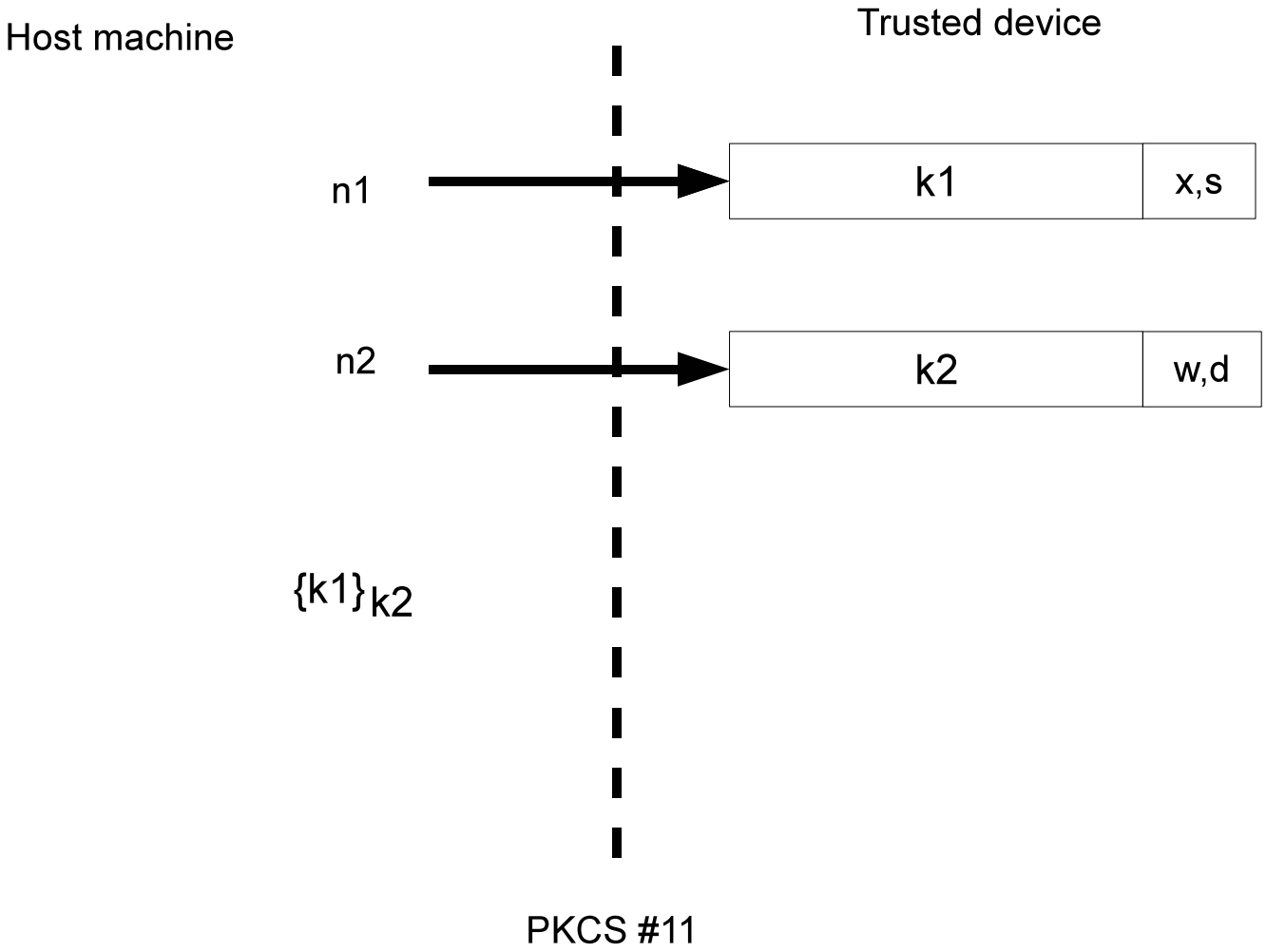
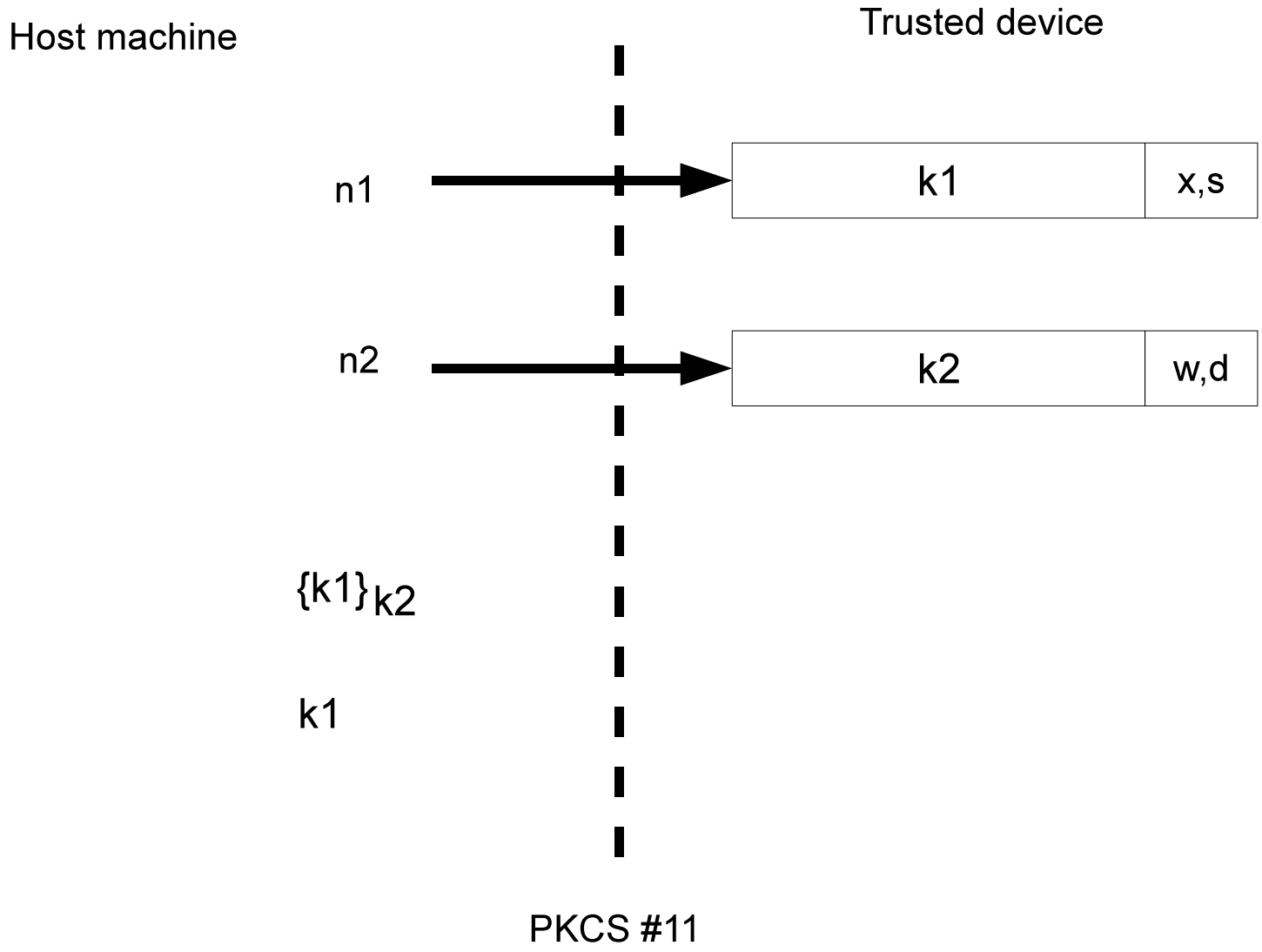
“Rogue applications and devices may also change the commands sent to the cryptographic device to obtain services other than what the application requested [but cannot] compromise keys marked “sensitive,” since a key that is sensitive will always remain sensitive. Similarly, a key that is unextractable cannot be modified to be extractable.”


Host machine
Trusted device
n1
k1
x,s
n2
k2
w,d
{k1}k2
PKCS #11

Clulow, CHES 2003



Formal Model (Delaune, Kremer, S., CSF 2008)

Abstract 'Dolev-Yao' style

$\mathsf{h}(\mathsf{n1}, \mathsf{k1})$ - a handle $\mathsf{n1}$ for key $\mathsf{k1}$ (h is a *private symbol*)

$\mathsf{a1}(\mathsf{n1})$ - setting of attribute $\mathsf{a1}$ for handle $\mathsf{n1}$

Command :

$$\mathsf{input}; \mathsf{state} \xrightarrow{\mathsf{new}} \mathsf{output}; \mathsf{state}'$$

Key Management - 1

$$\text{KeyGenerate} : \xrightarrow{\text{new n,k}} \quad h(n,k);L$$

Where $L = \text{extract}(n), \neg\text{wrap}(n), \neg\text{unwrap}(n),$
$\neg\text{encrypt}(n), \neg\text{decrypt}(n), \neg\text{sensitive}(n)$

Key Management - 2

$$
\begin{array}{lrcl}
\mathsf{Set\_Wrap}: & \mathsf{h}(x_1, y_1);\ \neg\mathsf{wrap}(x_1) & \rightarrow & ;\mathsf{wrap}(x_1) \\
\mathsf{Set\_Encrypt}: & \mathsf{h}(x_1, y_1);\ \neg\mathsf{encrypt}(x_1) & \rightarrow & ;\mathsf{encrypt}(x_1) \\
\vdots & & \vdots & \\
\mathsf{UnSet\_Wrap}: & \mathsf{h}(x_1, y_1);\ \mathsf{wrap}(x_1) & \rightarrow & ;\neg\mathsf{wrap}(x_1) \\
\mathsf{UnSet\_Encrypt}: & \mathsf{h}(x_1, y_1);\ \mathsf{encrypt}(x_1) & \rightarrow & ;\neg\mathsf{encrypt}(x_1) \\
\vdots & & \vdots &
\end{array}
$$

Some restrictions, e.g. can't unset sensitive, can't set extract

Key Management - 3

Wrap :

$$h(x_1, y_1), h(x_2, y_2);\ \mathsf{wrap}(x_1), \mathsf{extract}(x_2) \longrightarrow \{y_2\}_{y_1}$$

Unwrap :

$$h(x_2, y_2), \{y_1\}_{y_2};\ \mathsf{unwrap}(x_2) \xrightarrow{\text{new } n_1} h(n_1, y_1);\ L$$

Where $L = \mathsf{extract}(n), \neg\mathsf{wrap}(n), \neg\mathsf{unwrap}(n), \neg\mathsf{encrypt}(n), \neg\mathsf{decrypt}(n), \neg\mathsf{sensitive}(n)$

Key Usage

Encrypt :

$$h(x_1, y_1), y_2;\ \mathsf{encrypt}(x_1) \quad \rightarrow \quad \{y_2\}_{y_1}$$

Decrypt :

$$h(x_1, y_1), \{y_2\}_{y_1};\ \mathsf{decrypt}(x_1) \quad \rightarrow \quad y_2$$

Fix decrypt/wrap, (and encrypt/unwrap):

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Intruder knows: $h(n_1, k_1)$, $h(n_2, k_2)$, k_3

State: $\mathsf{sensitive}(n_1), \mathsf{extract}(n_1)$, $\mathsf{extract}(n_2)$

Set_wrap:	$h(n_2, k_2)$	$\longrightarrow$	$;\mathsf{wrap}(n_2)$
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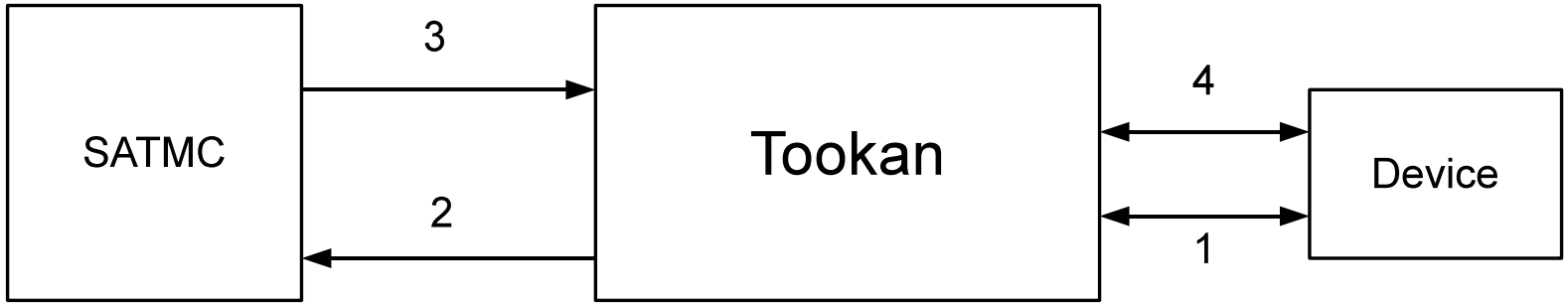
Wrap:	$h(n_1, k_1), h(n_2, k_2)$	$\longrightarrow$	$\{k_2\}_{k_1}$
Set_unwrap:	$h(n_1, k_1)$	$\longrightarrow$	$;\mathsf{unwrap}(n_1)$
Unwrap:	$h(n_1, k_1), \{k_2\}_{k_1}$	$\xrightarrow{\mathsf{new}\, n_3}$	$h(n_3, k_2)$
Wrap:	$h(n_2, k_2), h(n_1, k_1)$	$\longrightarrow$	$\{k_1\}_{k_2}$
Set_decrypt:	$h(n_3, k_2)$	$\longrightarrow$	$;\mathsf{decrypt}(n_3)$
Decrypt:	$h(n_3, k_2), \{k_1\}_{k_2}$	$\longrightarrow$	k_1

TOOKAN

‘Tool for cryptoKi Analysis’



Templates

$$\text{KeyGenerate}: \quad \xrightarrow{\text{new n,k}} \quad \mathsf{h}(\mathsf{n},\mathsf{k}); \mathcal{A}(\mathsf{n},\mathsf{B}) \qquad (\text{with } \mathsf{B} \in \mathcal{G})$$

$$\text{KeyPairGenerate}: \quad \xrightarrow{\text{new n,s}} \quad \mathsf{h}(\mathsf{n},\mathsf{s}), \mathsf{pub}(\mathsf{s}); \mathcal{A}(\mathsf{n},\mathsf{B}) \quad (\text{with } \mathsf{B} \in \mathcal{G})$$

$$\text{Unwrap}\,(\text{sym}/\text{sym}):$$

$$\mathsf{h}(\mathsf{x},\mathsf{y}_2), \{\!|\mathsf{y}_1|\!\}_{\mathsf{y}_2}; \mathsf{unwrap}(\mathsf{x},\top) \quad \xrightarrow{\text{new n}_1} \quad \mathsf{h}(\mathsf{n}_1,\mathsf{y}_1); \mathcal{A}(\mathsf{n}_1,\mathsf{B}) \quad (\text{with } \mathsf{B} \in \mathcal{U})$$

$$\text{CreateObject}: \quad \mathsf{x}; \quad \xrightarrow{\text{new n}} \quad \mathsf{h}(\mathsf{n},\mathsf{x}); \mathcal{A}(\mathsf{n},\mathsf{B}) \quad (\text{with } \mathsf{B} \in \mathcal{C})$$

Configuration Language

Functions

Attributes

Always on/off

Conflicts

Tied

Templates

Flags

(see http://secgroup.ext.dsi.unive.it/tookan for full description)

Abstractions for Proof (based on Fröschle & Steel WITS '09)

$$\mathsf{KeyGenerate}: \quad \rightarrow \quad \mathsf{h}(\mathsf{n_i}, \mathsf{k_i}); \mathcal{A}(\mathsf{n_i}, \mathsf{B_i}) \qquad (\text{with } \mathsf{B_i} \in \mathcal{G})$$

$$\mathsf{KeyPairGenerate}: \quad \rightarrow \quad \mathsf{h}(\mathsf{n_j}, \mathsf{s_j}), \mathsf{pub}(\mathsf{s_j}); \mathcal{A}(\mathsf{n_j}, \mathsf{B_j}) \quad (\text{with } \mathsf{B_j} \in \mathcal{G})$$

$\mathsf{Unwrap}\,(\mathsf{sym}/\mathsf{sym})$:

$$\mathsf{h}(\mathsf{x}, \mathsf{y_2}), \{\!|\mathsf{y_1}|\!\}_{\mathsf{y_2}}; \mathsf{unwrap}(\mathsf{x}, \top) \quad \rightarrow \quad \mathsf{h}(\mathsf{n_k}, \mathsf{y_1}); \mathcal{A}(\mathsf{n_k}, \mathsf{B_k}) \quad (\text{with } \mathsf{B_k} \in \mathcal{U})$$

$$\mathsf{CreateObject}: \quad \mathsf{x}; \quad \rightarrow \quad \mathsf{h}(\mathsf{n_l}, \mathsf{x}); \mathcal{A}(\mathsf{n_l}, \mathsf{B_l}) \quad (\text{with } \mathsf{B_l} \in \mathcal{C})$$


TOOKAN

Device		Supported Functionality						Attacks found				
Brand	Model	s	as	cobj	chan	w	ws	wd	rs	ru	su	Tookan
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

Manufacturer Reaction

All 7 received notification at least 5 months before publication.

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Gemalto responded to Cyberflex vulnerability, but not to SafeSite, and not to request to publish their reponse.

Minimal response from anyone else (e.g. requests to know who else is vulnerable)

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Available to download from

http://secgroup.ext.dsi.unive.it/cryptokix

Conclusions

Tookan: our tool for formal analysis of PKCS#11 configurations

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