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Università Ca'Foscari Venezia
Dipartimento di Scienze Ambientali Informatica e Statistica

Venezia, Università Ca' Foscari

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APDU-Level Attacks in PKCS#11 Devices

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Joint work with
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Talk Outline

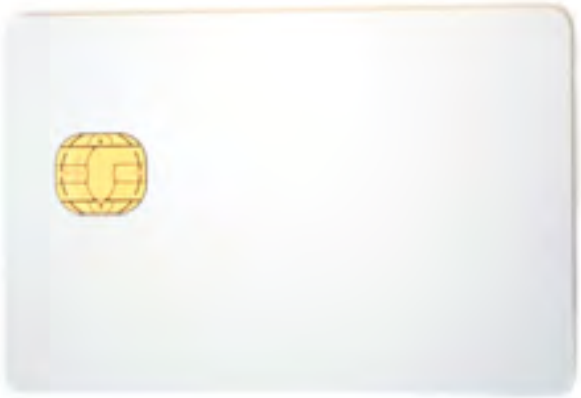
Agenda

1. Background
2. Architecture of PKCS#11 devices
3. Threat model
4. APDU-level attacks on real devices
5. Fixes and mitigations

The problem

Cryptographic hardware

Cyrptographic hardware allows cryptographic operations to be performed inside a protected, tamper-resistant environment



PKCS#11 security properties

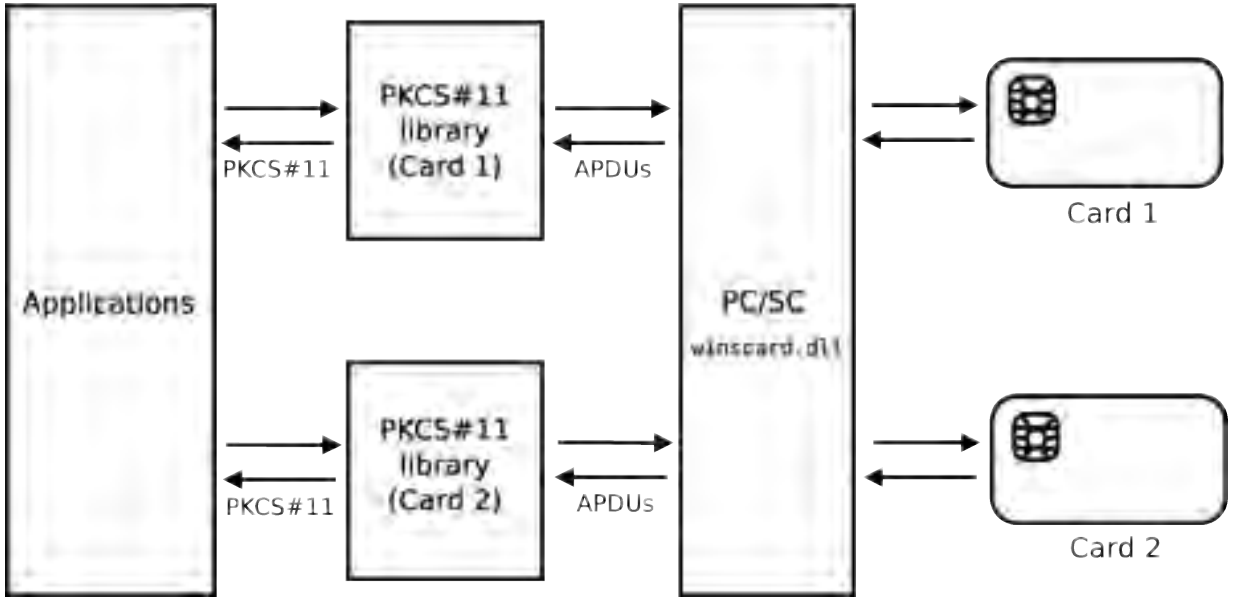
PKCS#11 is a standard API for cryptographic devices:

- Crypto operations should be performed inside the device
- Sensitive keys should never be leaked as plaintexts

Background

PKCS#11 middleware architecture

A software layer (middleware) translates PKCS#11 commands into ISO 7816 Application Protocol Data Units (APDUs) [4].



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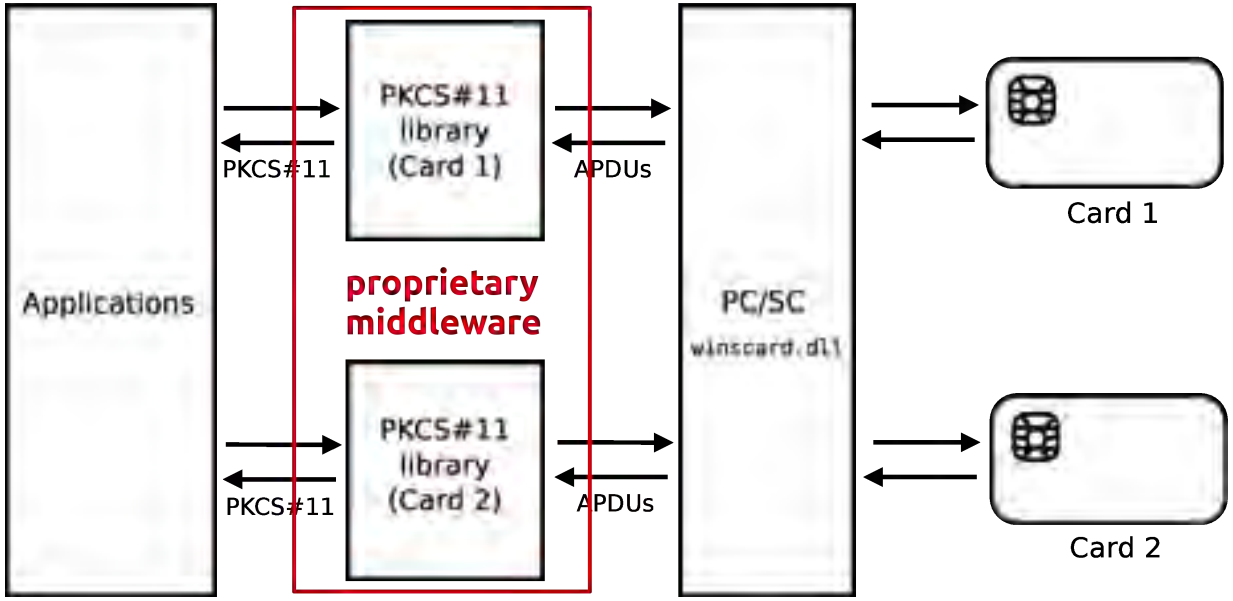

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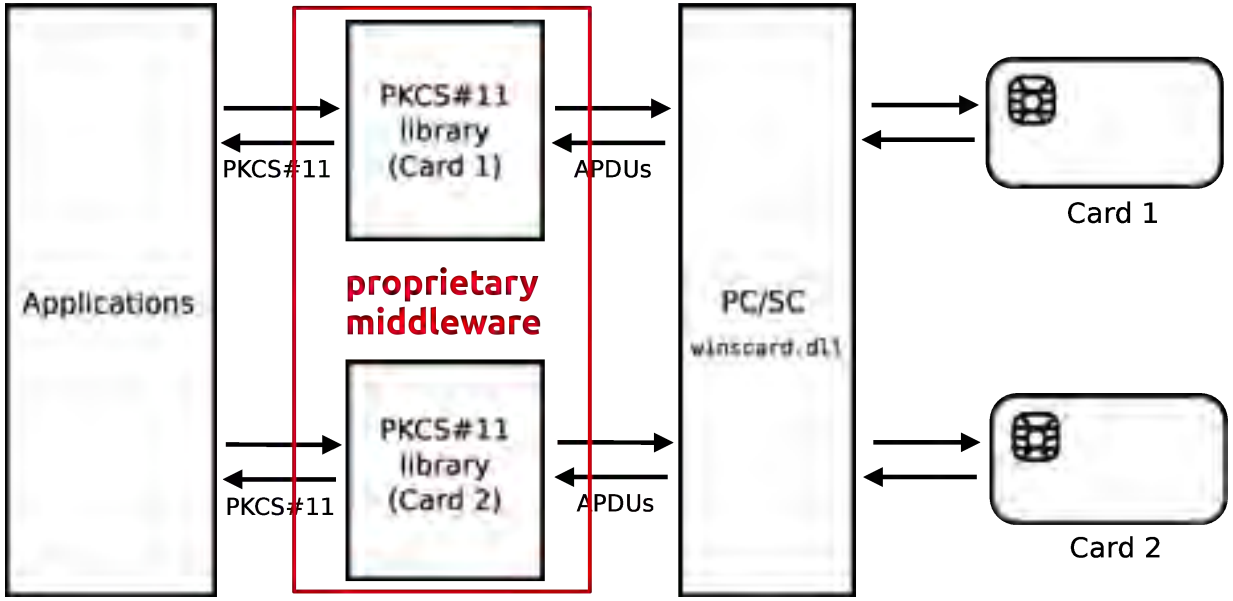


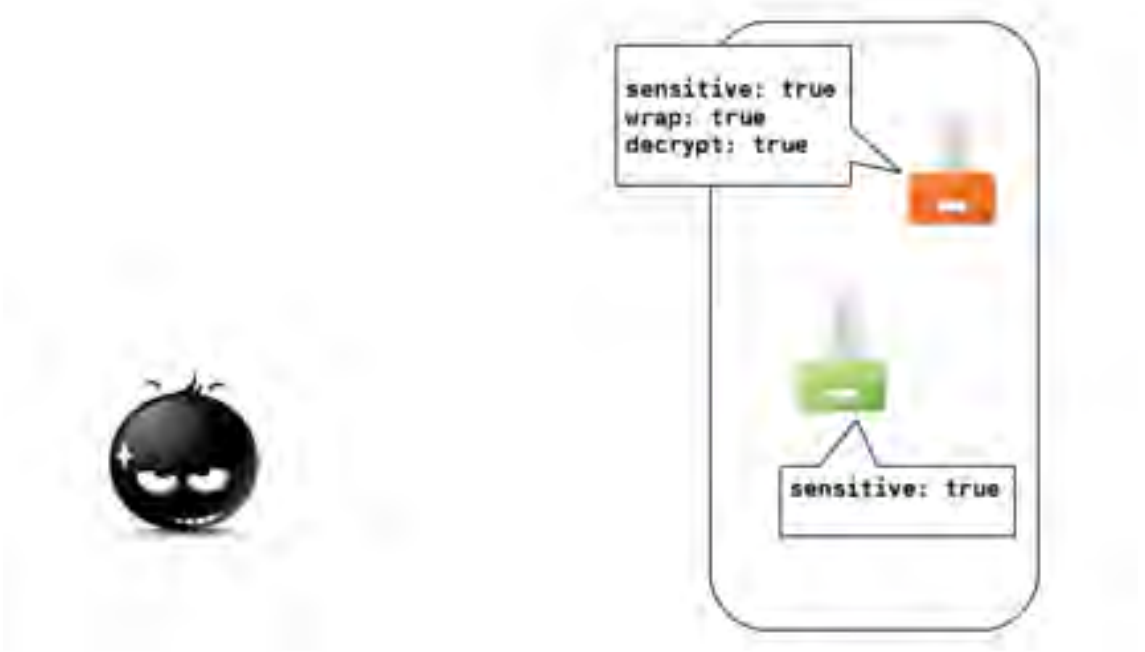
- Known attacks at the PKCS#11-level
- Focus on new attacks at the APDU-level

Background

PKCS#11-level attacks

There exist several well known attacks[1, 2] at the PKCS#11 level. Many of these are key separation attacks, *i.e.* attributes of a key are set so to give a key conflicting roles.

Wrap and decrypt attack:



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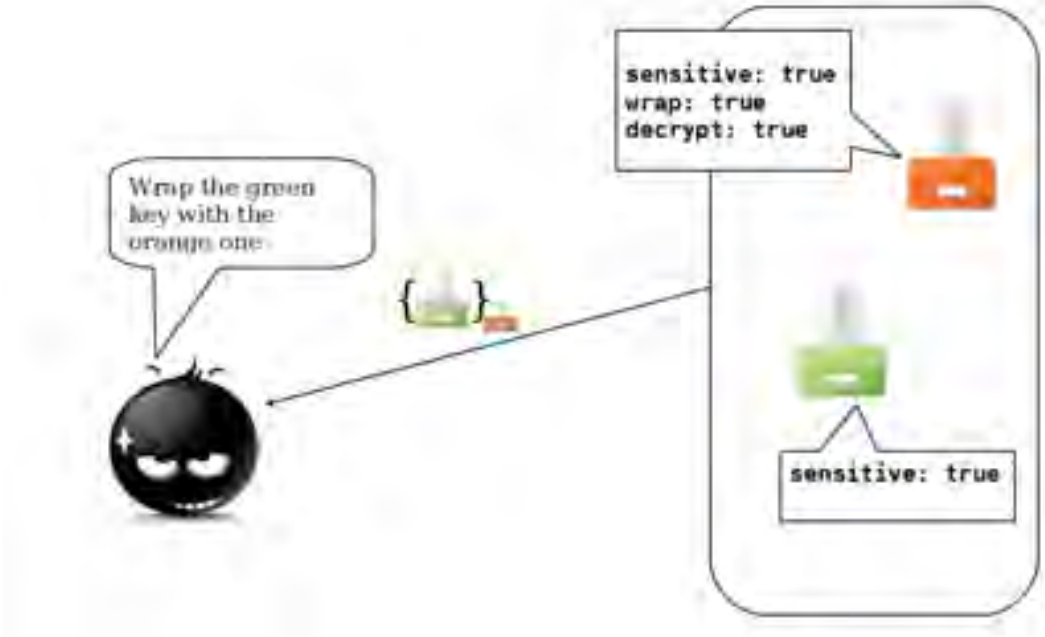

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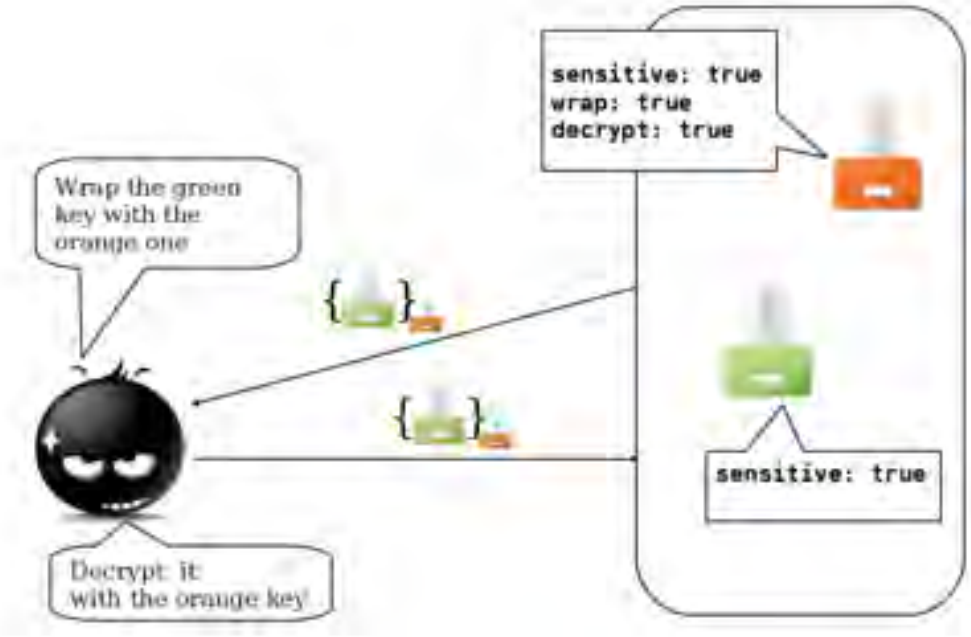

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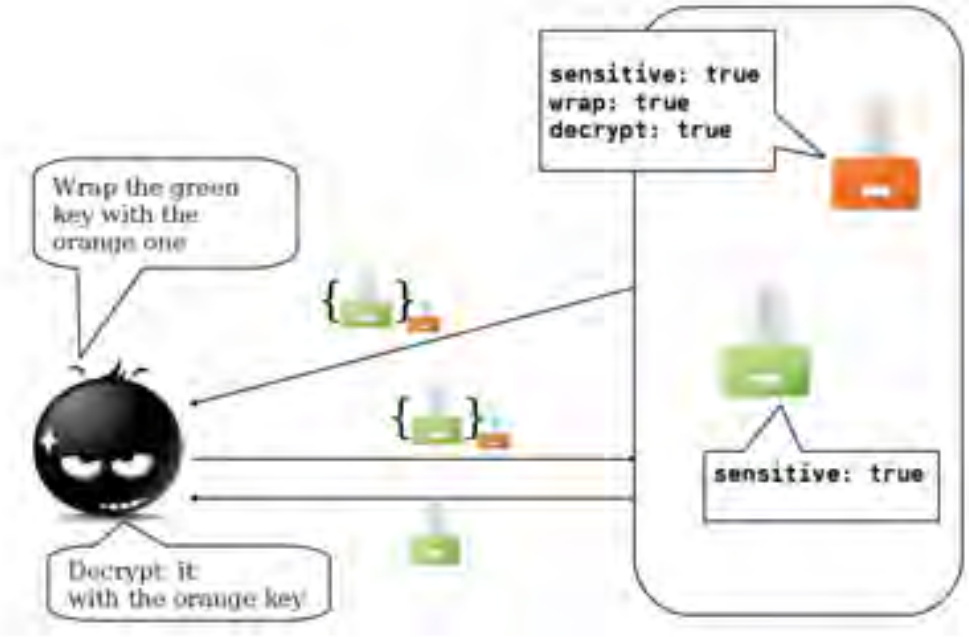


A threat model for PKCS#11 middleware

First threat model for PKCS#11 middleware in literature

Security goals

We focus on these sensitive targets:

- PIN enabling cryptographic operations with the device;
- Cryptographic operations that can be performed independently of the knowledge of the PIN;
- Cryptographic keys leaked in the clear out of the device.

A threat model for PKCS#11 middleware

Typical scenario

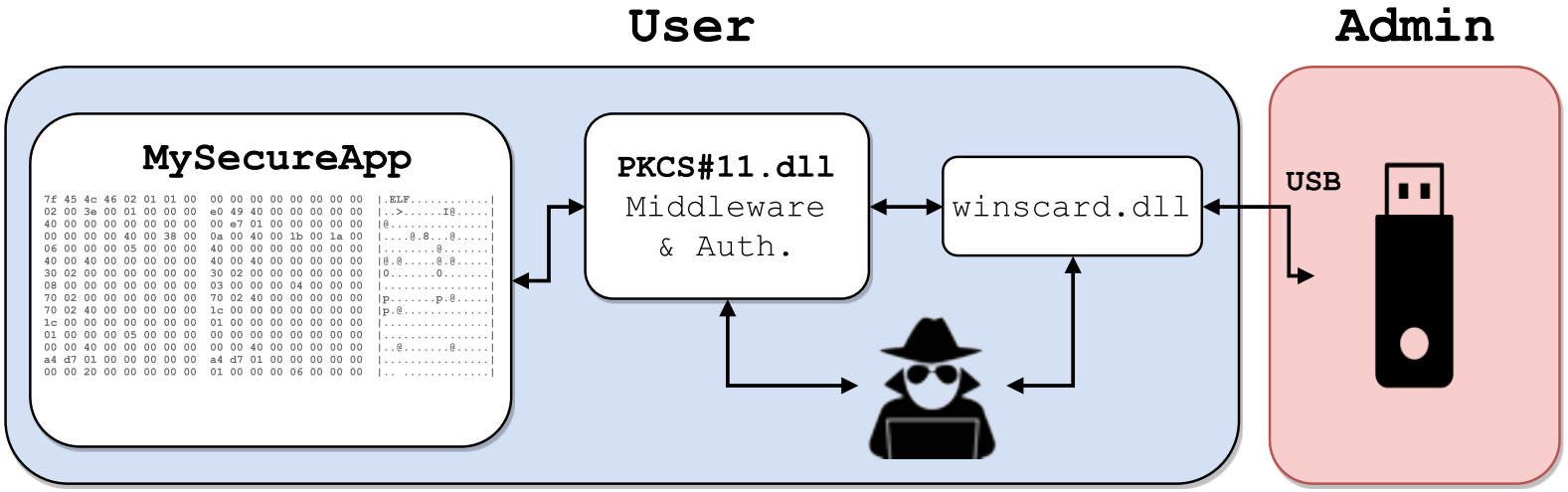
The target token is connected to a desktop/laptop computer in a single-user configuration.

Attacker capabilities

Threat scenarios are classified based on the attacker capabilities:

- Administrator privileges has complete control of the host;
- Physical access can install key-loggers or USB sniffers;
- User privileges has the same privilege level as the regular user.

Threat model: monolithic



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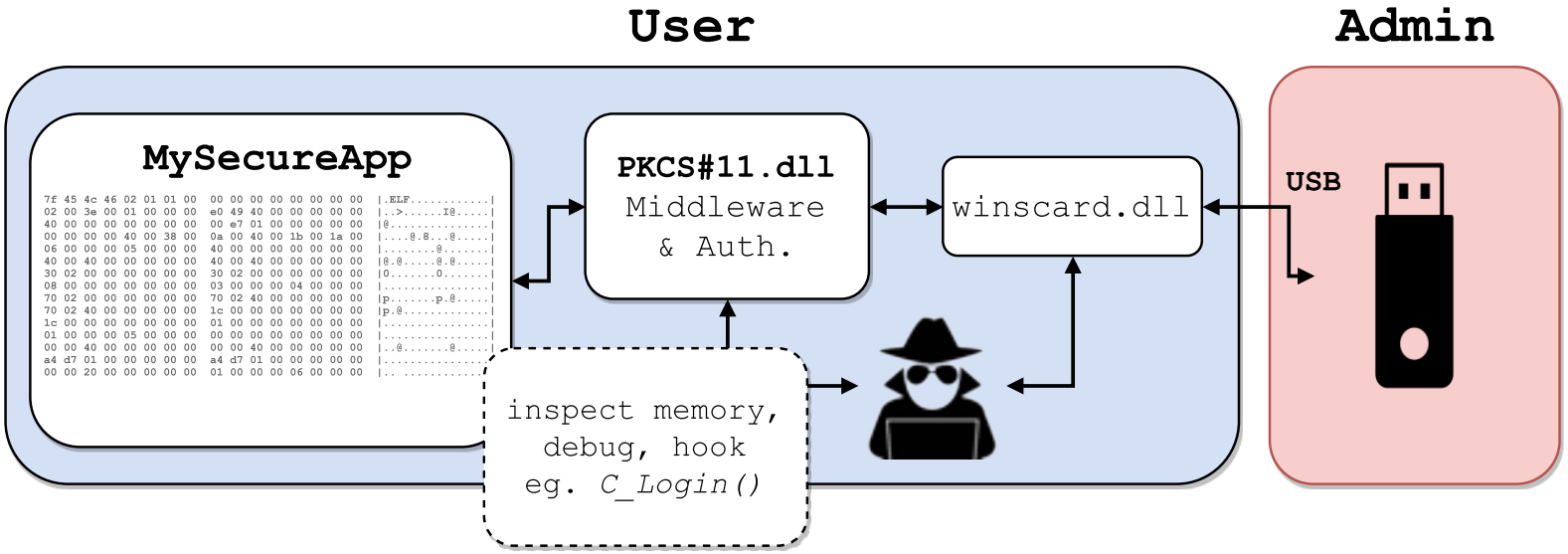

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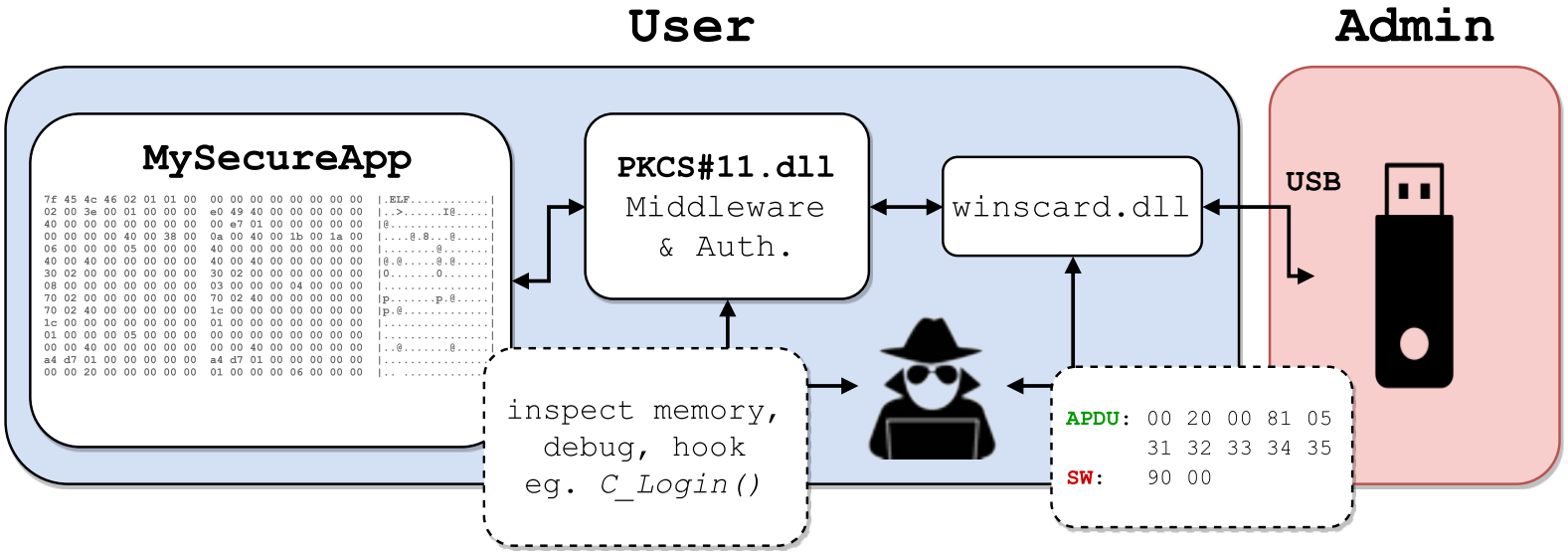
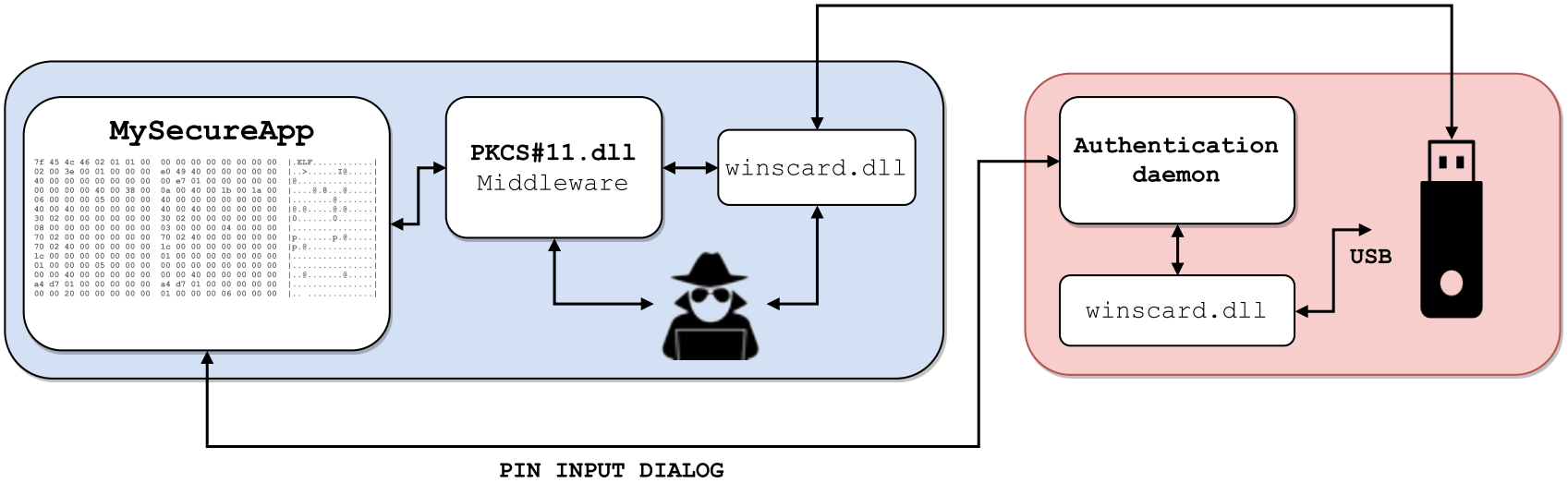
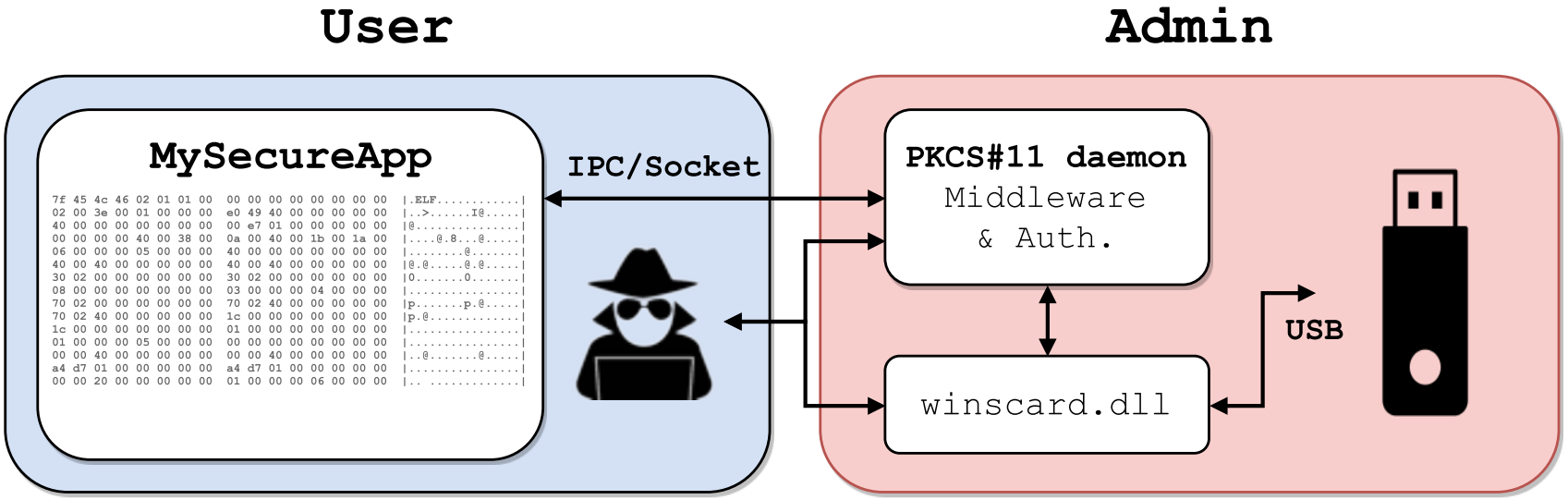


Threat model: separate authentication



Threat model: separate middleware & authentication



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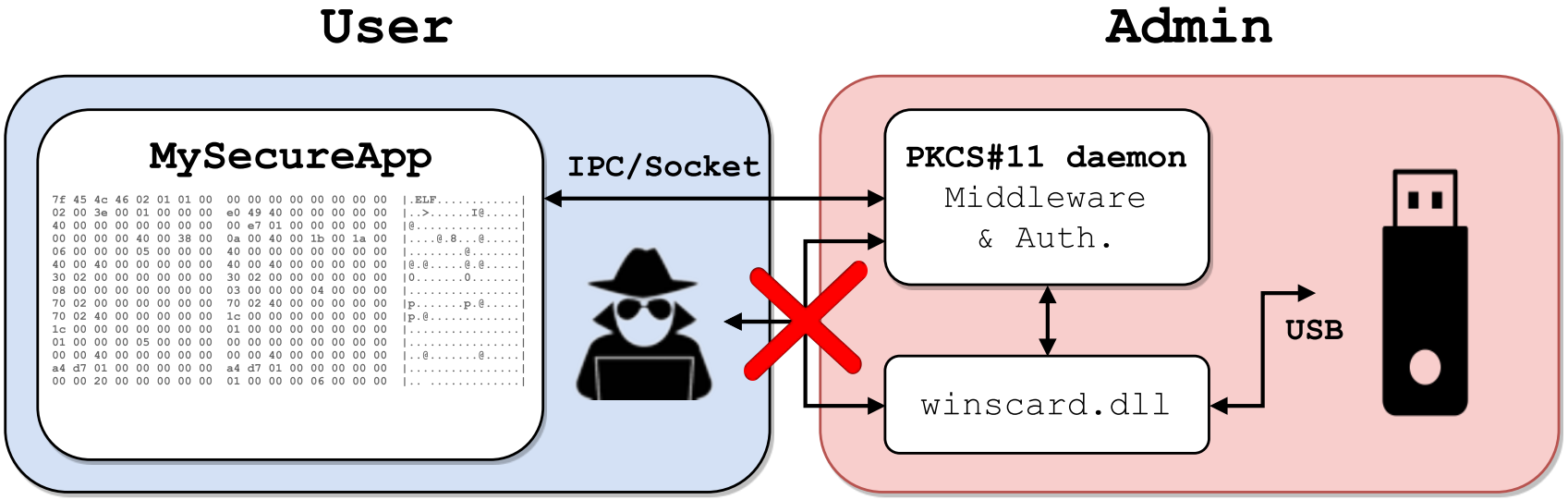

Threat model

How these settings affect the attacker's capabilities?

Attacker	Application	Attacker can access		Attacker can exploit			
		PKCS#11	APDU	PIN	PKCS#11	APDU passive	APDU active
Admin	Any	✓	✓	✓	✓	✓	✓
User	Monolithic	✓	✓	✓	✓	✓	✓
	Sep. Auth.	✓	✓	✗	✓[1]	✓	✓[1]
	Sep. Privileges	✓	✗	✓	✓	✗	✗
	Sep. Auth.&Priv.	✓	✗	✗	✓[1]	✗	✗
Physical	Any	✗	✓	✓[2]	✓[1]	✓[3]	✓[1,3]

[1] Requires MITM.
[2] Through a keylogger or a USB sniffer.
[3] Only APDU payloads, cannot access middleware memory.

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APDU-level attacks on real devices

Tested devices

1. Aladdin eToken PRO
2. Athena ASEKey
3. RSA SecurID 800
4. Safesite Classic TPC IS V1
5. Siemens CardOS V4.3b

Vulnerabilities found

- Authentication
- Symmetric keys
- Key attributes handling
- RSA session keys

1)


2)


3)


4)

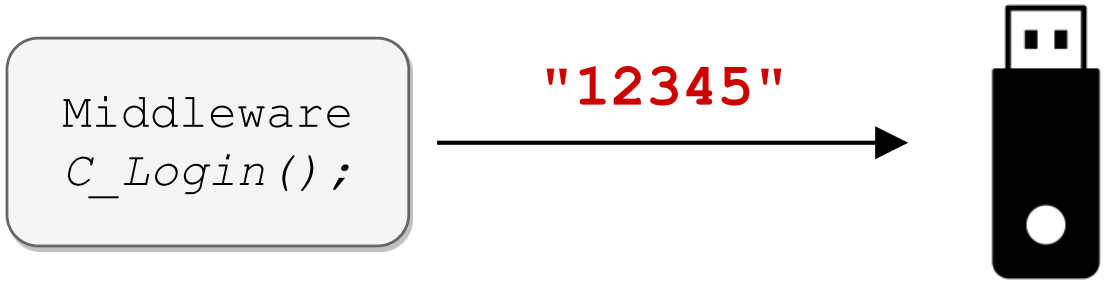

5)


APDU-level attacks: authentication

C_Login() on Siemens CardOS V4.3b:

```
# Standard ISO-7816 Select file:
APDU: 00 a4 04 0c 0c a0 00 00 00 63 50 4b 43 53 2d 31 35
SW:   90 00

# Standard ISO-7816 Verify:
APDU: 00 20 00 81 05 31 32 33 34 35
SW:   90 00
```

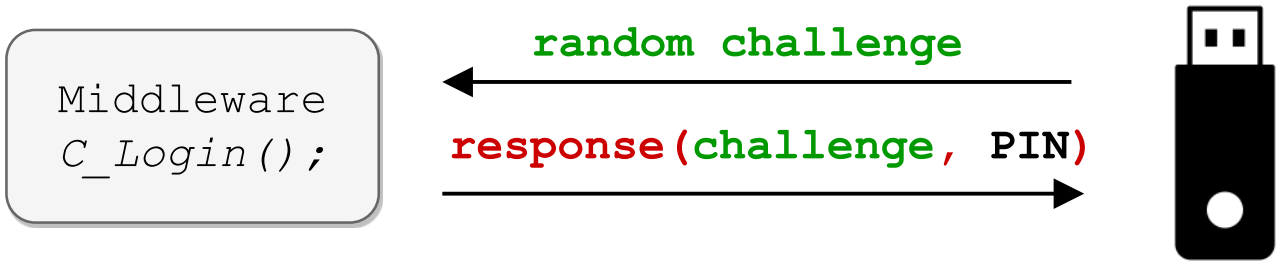


APDU-level attacks: authentication

C_Login() on Aladdin eToken PRO:

```
# Custom Get challenge:
APDU: 80 17 00 00 08
SW:   DF 89 61 34 62 05 13 36  90 00

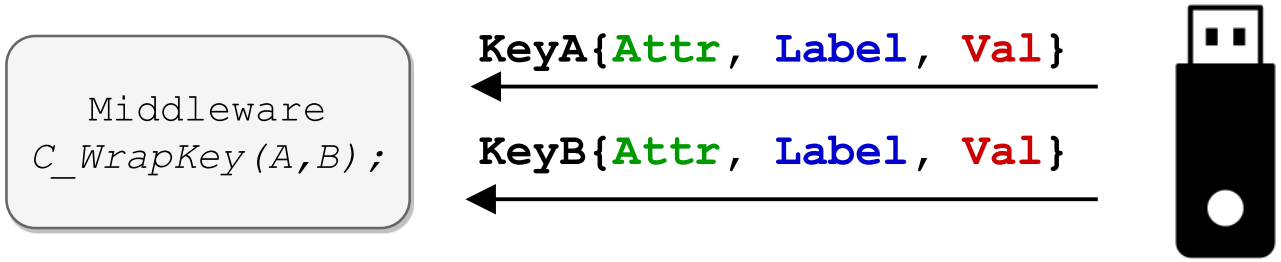
# Custom External authenticate:
APDU: 80 11 00 11 0A 10 08  64 D5 97 15 4A 44 EB 23
SW:   90 00
```



APDU-level attacks: symmetric keys

C_WrapKey() on Aladdin eToken PRO:

```
# Fetch the key
APDU: 80 18 00 00 04 0E 02 00 00 18
SW:   17 3F FF FF FF FF 01 08 3F 44 5F C4 EB 76 F1 86
      06 64 65 73 6B 65 79 00 90 00
```



C_GenerateKey() (DES key) on Athena ASEKey:

```
# Get challenge (Standard ISO-7816):
APDU: 00 84 00 00 00 00 08
SW:   b7 c8 14 4b 4e 5f e6 3e 90 00
# .... (omitted) ....
# Get an RSA modulus
APDU: 80 14 02 91 00 00 00
SW:   79 23 57 33 9a be 2a dd ba ae 2e 09 4c d0 3d 57
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# Send the encrypted key to the token
APDU: 80 24 00 80 00 00 a0 20 5b f1 f9 cd 67 c8 3d e0
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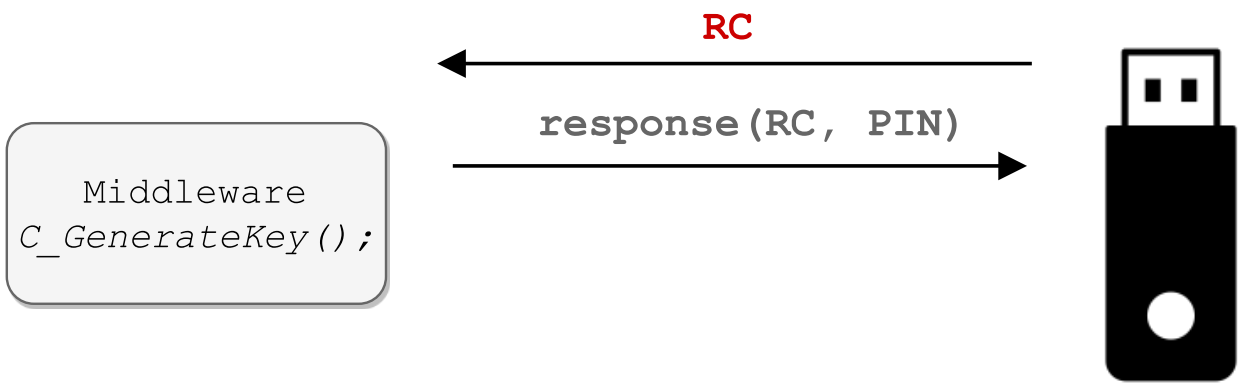

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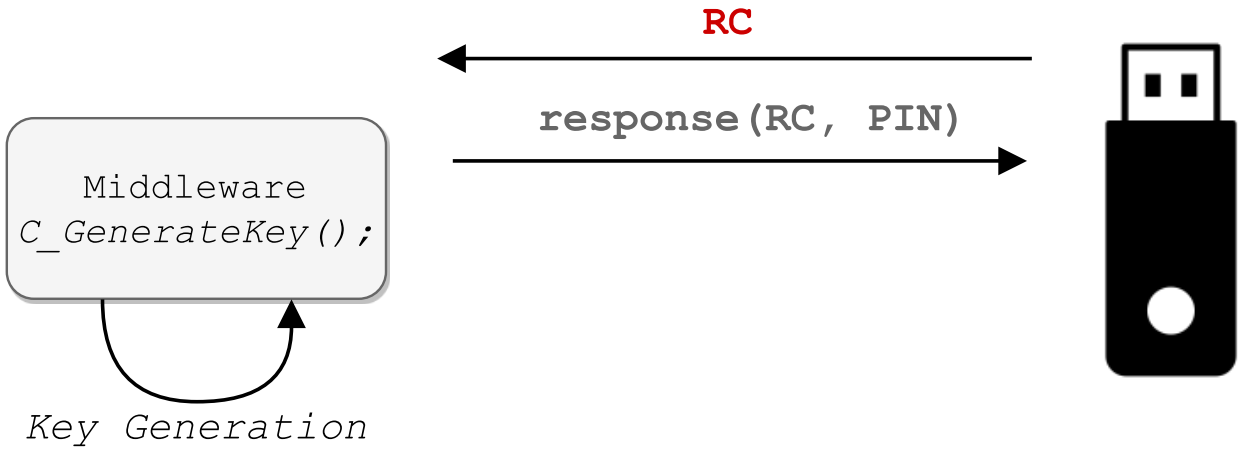

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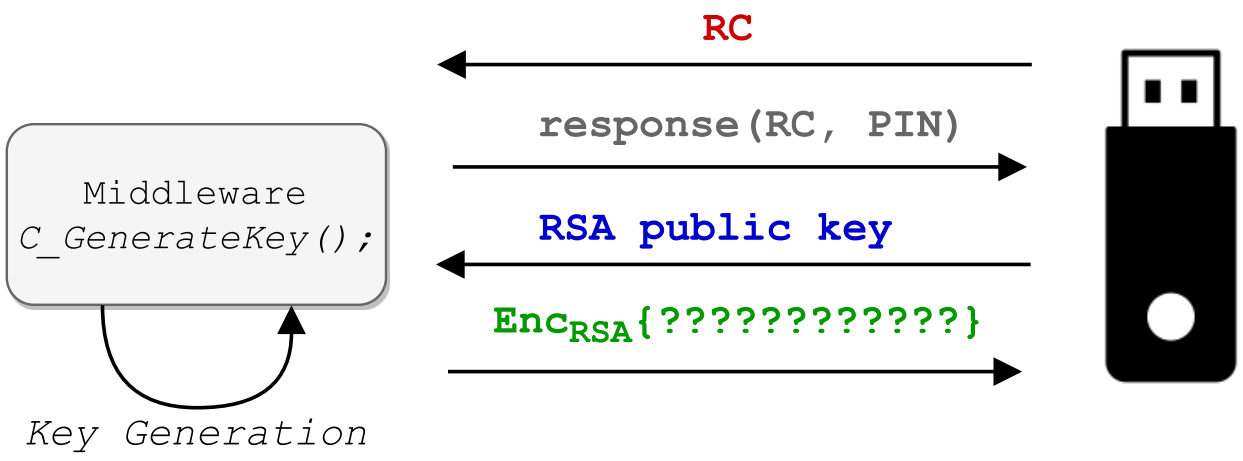

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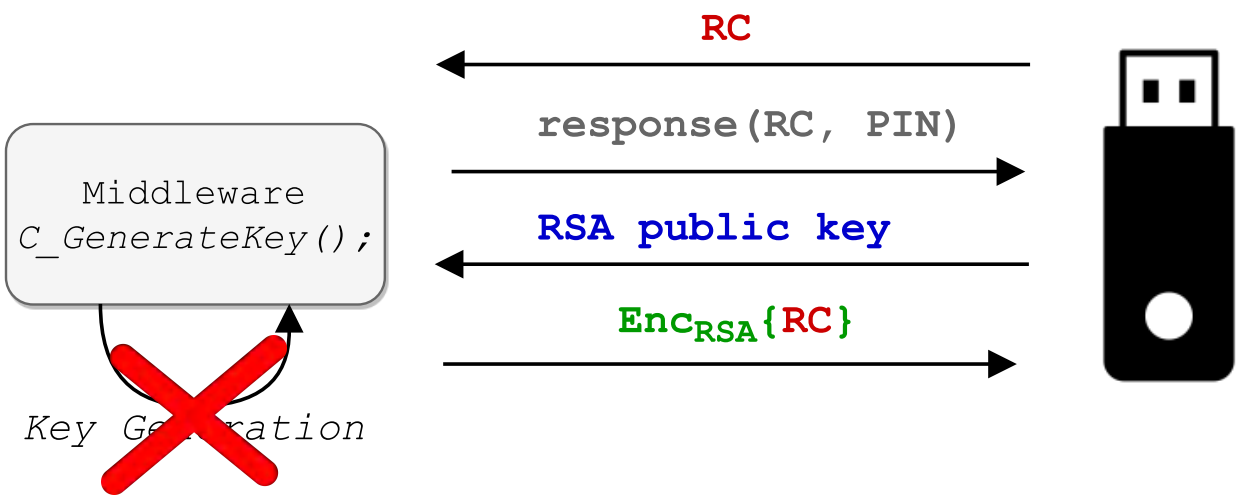

APDU-level attacks: key attributes

A key with **CKA_SIGN** attribute set to `CK_FALSE` cannot perform signature operations.

Bypassing attribute values

1. take a private RSA key with `CKA_SIGN` false;
2. verify that it cannot sign a message via the `PKCS#11` API;
3. perform the sign operation manually, via `APDU`.

APDU-level attacks: summary

Token	Auth.	Sensitive symmetric keys		Bypassing attribute values	RSA session keys	
		PKCS#11[1]	APDU		PKCS#11[1]	APDU
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ASEKey	✓[2]	✗	✓[3]	✓	✗	✗
SecurID	✓[2]	✓[5]	✓	✓	✗	✗
Safesite Classic	✓	✗	✗	✓	✗	✗
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[1] PKCS#11-level attacks discovered in [1], for comparison.
[2] Requires reverse engineering of the authentication algorithm and bruteforcing.
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Fixes and mitigations

Compliant PKCS#11 devices should implement all the cryptographic operations inside the hardware

Fixes

- Hardware/firmware redesign
- Separate authentication
- Higher privileges middleware

Fixes and mitigations

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Mitigation: OTP

$C\_Login(OTP + PIN)$

Conclusion

Contributions

- We introduced a new threat model for PKCS#11 middleware
- We found new, unpublished APDU-level attacks on commercially available tokens and smartcards
- We provided a security analysis of the vulnerabilities with respect to the threat model

Future works

Wish list...

- Test newer devices
- Encrypted `APDU`s
- PIN bruteforcing using card emulation
- Open hardware-firmware-middleware reference implementation

Thank you!

no tokens were harmed during the making of this paper

Want more?

Really?

https://secgroup.dais.unive.it/projects/apduattacks/

- Summary of the paper as a blog post
- Official answers from manufacturers
- Previous / future works [1, 3]

References

- Bortolozzo, M., Centenaro, M., Focardi, R., Steel, G.: Attacking and fixing PKCS#11 security tokens. In: Proceedings of the 17th ACM Conference on Computer and Communications Security (CCS'10). pp. 260–269. ACM (2010)
- Clulow, J.: On the security of PKCS#11. In: 5th International Workshop on Cryptographic Hardware and Embedded Systems (CHES'03). LNCS, vol. 2779, pp. 411–425. Springer (2003)
- Gkaniatsou, A., McNeill, F., Bundy, A., Steel, G., Focardi, R., Bozzato, C.: Getting to know your card: Reverse-engineering the smart-card application protocol data unit. In: Proceedings of the 31st Annual Computer Security Applications Conference, Los Angeles, CA, USA, December 7-11, 2015. pp. 441–450 (2015)
- ISO/IEC 7816-4: Identification cards – Integrated circuit cards – Part 4: Organization, security and commands for interchange (2013)

Backup slides

Related works

PKCS#11

- First attacks on PKCS#11 by Clulow
- General analysis tools for PKCS#11
- Generalization of the model and automatic reverse engineering tool

Low level

- No previous APDU-level attacks and threat models for PKCS#11 devices
- APDU buffer compromised in Java Cards
- MITM attack for payments w/o needing PIN
- Automated method to reverse engineer PKCS#11-APDU mapping