

Vulnerability Analysis on Smart Cards using Fault Tree

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INOSSEM

Outline

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 - Java Card Technology
 - Attacks on Java Card
- 2 Fault Tree Analysis
 - Definition
 - FTA for Smart Card
 - Code Integrity
- 3 An API to Mitigate the Undesirable Events
 - Principle
 - The INOSSEM API
- 4 Conclusion

The Smart Card



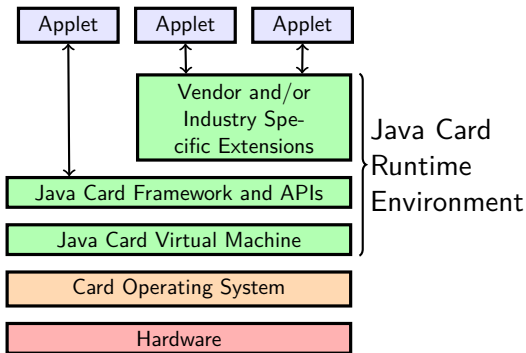
Widely used device

- ▶ Credit Card;
- ▶ (U)SIM Card;
- ▶ Health Card (french Vitale card);
- ▶ Pay TV;
- ▶ ...

This device contains sensitive data

Java Card based Smart Card

- ▶ Created by Schlumberger in 1996.
- ▶ **Specified** by Oracle
- ▶ Provide a **friendly** environment to develop **secure** Java-applications.

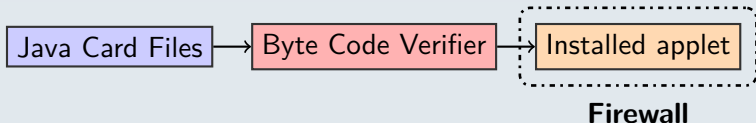


Java Card Security Model

Off-card Security



On-card Security



Java Card Attacks

Logical attacks

- ▶ Execution of malicious Java Card byte codes

Physical attacks

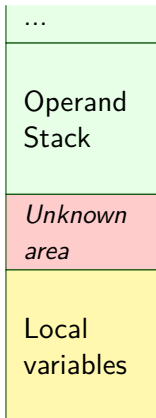
- ▶ Side Channel attacks (timing attacks, power analysis attack, ...);
- ▶ Fault attacks (electromagnetic injection, laser beam injection, ...)



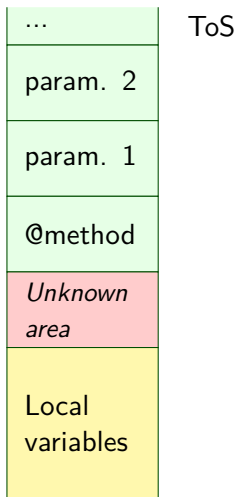
Combined attacks

Mix of physical and logical attacks.

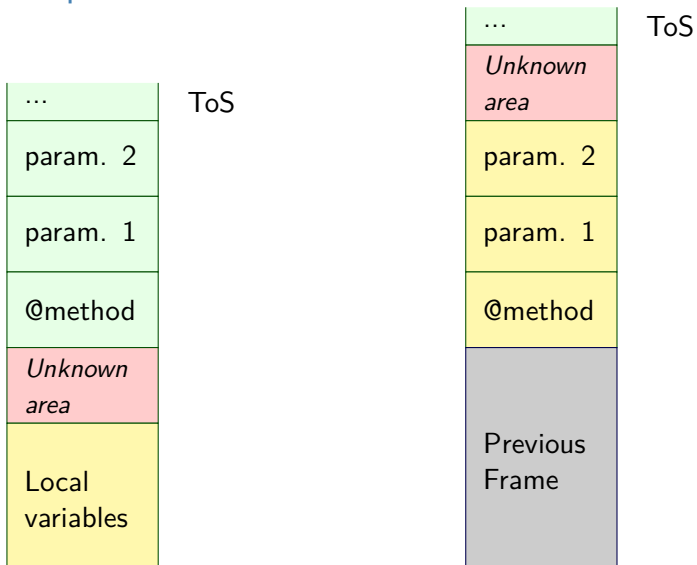
Example: EMAN 2 attack



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Example: EMAN 2 attack

```
public void ModifyStack
    (byte [] apduBuffer,
     APDU apdu,
     short a) {
    short i=(short)0xCAFE;
    short j=(short)
        maliciousFunction();
    i = j ;
}
```

Example: EMAN 2 attack

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public void ModifyStack
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invokevirtual @ModifyStack

ModifyStack Method

Any unchecked byte code

Example: EMAN 2 attack

```

public void ModifyStack
  (byte[] apduBuffer,
   APDU apdu, short a)
{ 02 // flags:0 max_stack:2
 42 // nargs:4 max_locals:2
 11 CAFE sspush      0xCAFE
 29 04   sstore      4
 18     aload_0
 7B 00   getstatic_a  0
 8B 01   invokevirtual 1
 29 05   sstore      5
 16 05   sload       5
 29 04   sstore      4
 7A     return
}

```

invokevirtual @ModifyStack

ModifyStack Method

Any unchecked byte code

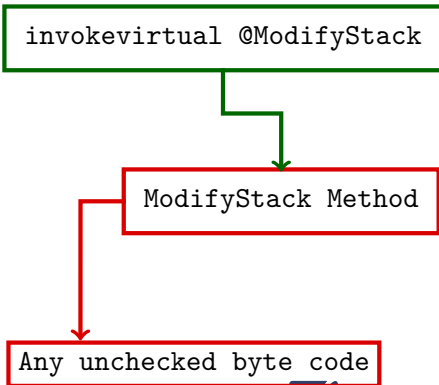
Example: EMAN 2 attack

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 29 04   sstore      4
 18     aload_0
 7B 00   getstatic_a  0
 8B 01   invokevirtual 1
 29 05   sstore      5
 16 05   load         5
 29 07   sstore      7
 7A     return
}

```

The Return Address of the current function is changed!



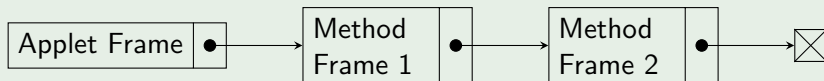
Example: EMAN 2 attack – Countermeasure

Security Requirements

- ▶ Embed a **Byte Code Verifier (BCV)**;
- ▶ Check the number of locals;
- ▶ Check the frame integrity;

Proposed Countermeasure: the *linked-frame*

- ▶ The memory area is non-contiguous
- ▶ The top of stack should be copied



Problematic

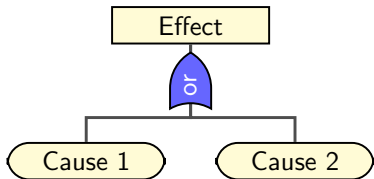
Inductive Approach

- ▶ 1 attack = 1 countermeasure
- ▶ bottom-up solution

Our Requirements

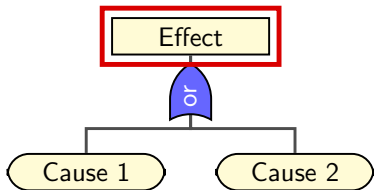
- ▶ A top-down analytic solution;
- ▶ Definition of each undesirable events;

The Fault Tree Analysis (FTA)



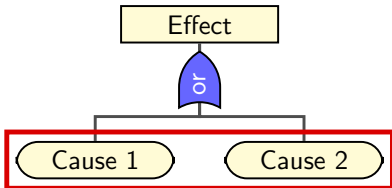
- ▶ Undesirable event;
- ▶ Initial causes;
- ▶ Gate Connector.

The Fault Tree Analysis (FTA)



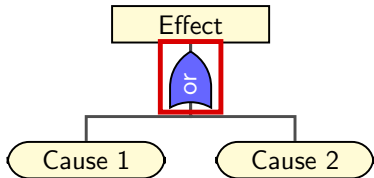
- ▶ **Undesirable event;**
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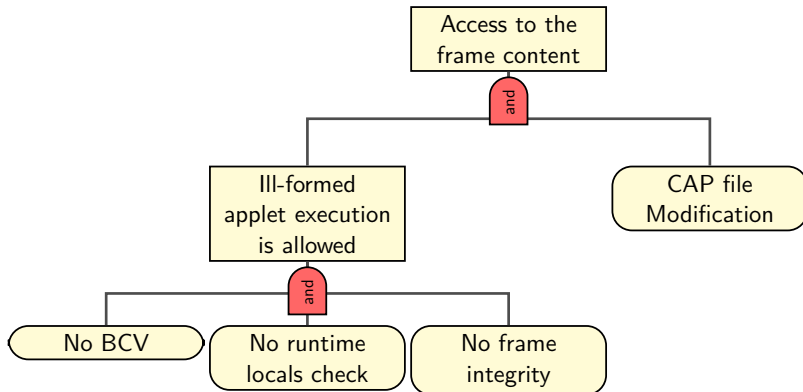
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The Fault Tree Analysis (FTA)



- ▶ Undesirable event;
- ▶ Initial causes;
- ▶ **Gate Connector.**

FTA for EMAN 2 attack



Smart Card's Assets

Undesirable events can affect:

- ▶ Code integrity;
- ▶ Data integrity;
- ▶ Code confidentiality;
- ▶ Data confidentiality;

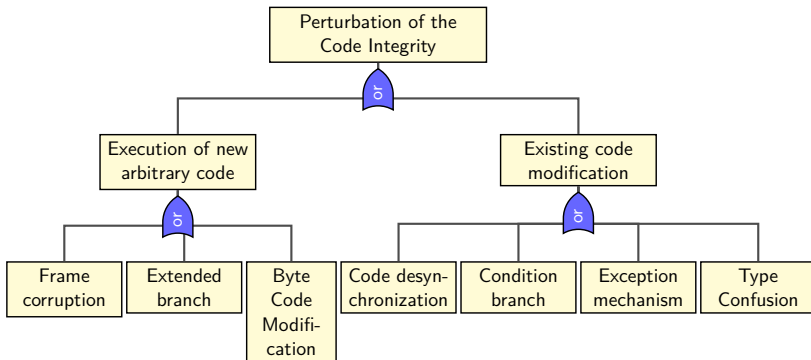
Smart Card's Assets

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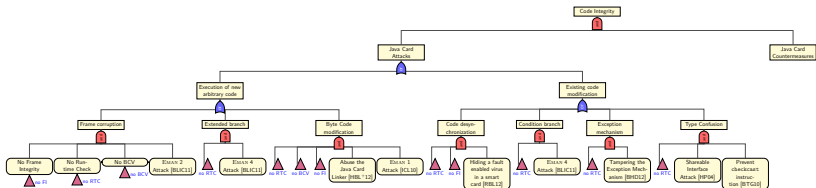
- ▶ **Code integrity;**
- ▶ Data integrity;
- ▶ Code confidentiality;
- ▶ Data confidentiality;

An attack offers the execution of a malicious byte code.

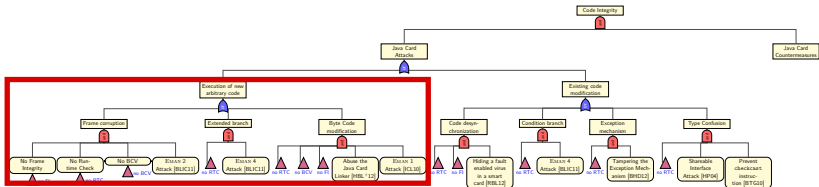
How to break the Java Card Code Integrity?



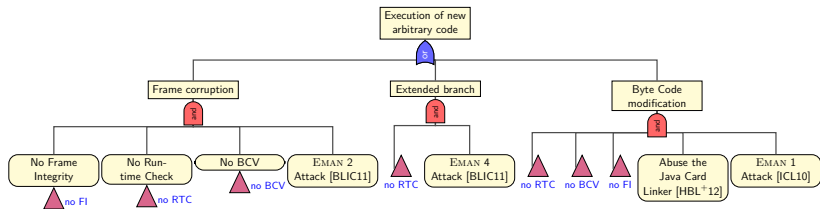
Code Integrity Tree



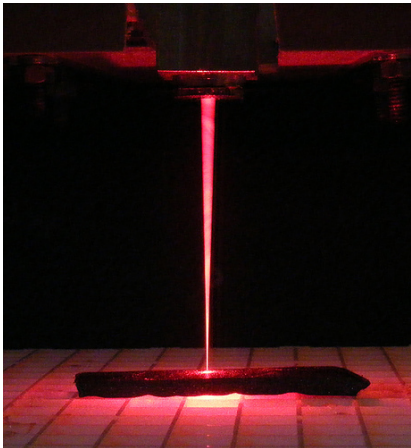
Code Integrity Tree



Code Integrity Tree



New Undesirable Events detected



Laser beam injection effects

- ▶ Precise byte errors into the memory;
- ▶ Perturb the runtime execution.

Laser beam injection issues

- ▶ Modification of the returned value;
- ▶ Bypass a method calls;
- ▶ Modify the data's address.

Principle

Countermeasures should be implemented in the:

- ▶ application level;
- ▶ Java Card Virtual Machine level.

Principle

Countermeasures should be implemented in the:

- ▶ **application level;**
- ▶ Java Card Virtual Machine level.

Advantages

- ▶ Implementation of several checks;
- ▶ The developer knows the assets to protect.

Drawbacks

- ▶ Code redundancy;
- ▶ Increase the program's size.

Principle

Countermeasures should be implemented in the:

- ▶ application level;
- ▶ **Java Card Virtual Machine level.**

Advantages

- ▶ Low level system countermeasures;
- ▶ Stored in ROM module.

INOSSEM API

“The aim [of the INOSSEM project] is to provide security interoperability between smart card manufacturers.”

INOSSEM

The INOSSEM API defines functions to protect:

- ▶ Code Integrity;
- ▶ Frame Integrity;
- ▶ Data Integrity.

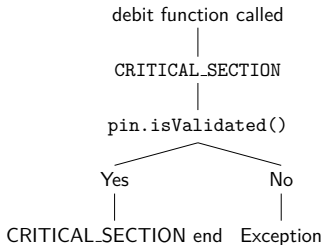
Frame Integrity Protection

```
// initialize the signature object with the first  
parameter  
paramChkInstance.init(firstParam);  
// update signature buffer  
paramChkInstance.update(secondParam);  
// sign parameters  
short paramChk = paramChkInstance.doFinal(userPIN);  
// invoke the sensitive method  
sensitiveMeth(firstParam, secondParam,  
              userPIN,      paramChk);
```


JPC Protection

The **J**ava **P**rogram **C**ounter (JPC) can be **corrupted** by a **laser beam injection**.

```
private void debit(APDU apdu) {  
    // transition to a new state  
    this.setState(CRITICAL_SECTION);  
    if (!pin.isValidated()) {  
        this.endStateMachine  
            (PIN_VERIFICATION_REQUIRED_STATE);  
        ISOException.throwIt  
            (SW_PIN_VERIFICATION_REQUIRED);  
    }  
}
```



Conclusion



- ▶ FTA can be used for safety and smart card vulnerabilities analysis;
- ▶ New undesirable events were found;
- ▶ Detected undesirable events are prevented by the INOSSEM API;
- ▶ Next step: quantify the attacker's power

Thank you for your attention!
Do you have any questions?





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References I

-  Guillaume Barbu, Philippe Hoogvorst, and Guillaume Duc.
Tampering with Java Card Exceptions - The Exception Proves the Rule.
In Pierangela Samarati, Wenjing Lou, and Jianying Zhou, editors, *SECURITY*, pages 55–63. SciTePress, 2012.
-  Guillaume Bouffard, Jean-Louis Lanet, and Julien Iguchy-Cartigny.
Combined Software and Hardware Attacks on the Java Card Control Flow.
In *Smart Card Research and Advanced Applications*, volume 7079 of *Lecture Notes in Computer Science*, pages 283–296, Berlin / Heidelberg, 2011. Springer.

References II

-  Guillaume Barbu, Hugues Thiebeauld, and Vincent Guerin. Attacks on Java Card 3.0 Combining Fault and Logical Attacks.
In Dieter Gollmann, Jean-Louis Lanet, and Julien Iguchi-Cartigny, editors, *CARDIS*, volume 6035 of *Lecture Notes in Computer Science*, pages 148–163. Springer, 2010.
-  Samiya Hamadouche, Guillaume Bouffard, Jean-Louis Lanet, Bruno Dorsemaine, Bastien Nouhant, Alexandre Magloire, and Arnaud Reygnaud.
Subverting Byte Code Linker service to characterize Java Card API.
In *Seventh Conference on Network and Information Systems Security (SAR-SSI)*, pages 75–81, May 22rd to 25th 2012.

References III



Engelbert Hubbers and Erik Poll.

Transactions and non-atomic API methods in Java Card: specification ambiguity and strange implementation behaviours.

Technical Report NIII-R0438, Radboud University Nijmegen, 2004.



Julien Iguchi-Cartigny and Jean-Louis Lanet.

Developing a trojan applets in a smart card.

Journal in Computer Virology, 6(4):343–351, 2010.

References IV



Tiana Razafindralambo, Guillaume Bouffard, and Jean-Louis Lanet.

A Friendly Framework for Hidding fault enabled virus for Java Based Smartcard.

In Nora Cuppens-Boulahia, Frédéric Cuppens, and Joaquín García-Alfaro, editors, *DBSec*, volume 7371 of *Lecture Notes in Computer Science*, pages 122–128. Springer, 2012.