FTF 2016
TECHNOLOGY FORUM

# SMARTCARD SECURITY: COUNTERING SIDE CHANNEL & FAULT ATTACKS

## FTF-DES-N1892

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PUBLIC USE

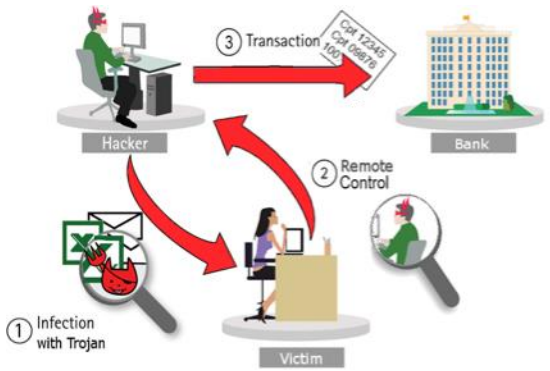
# AGENDA

- Physical Attacks
- Security Evaluation & Certification
- JHAS Attack Rating
- Summary

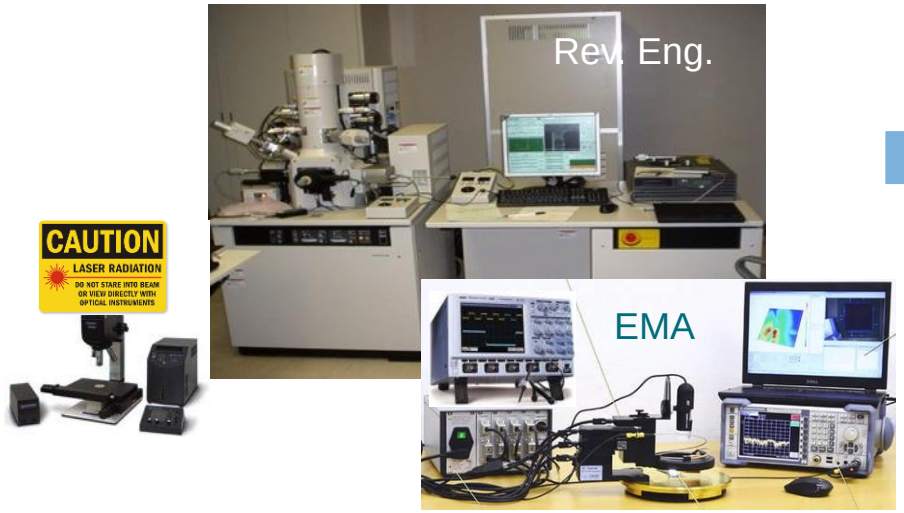
# PHYSICAL ATTACKS

# Functional vs. Physical Security

## Remote / Online / Logical Attacks




## Local / Offline / Physical Attacks




Fault Injection

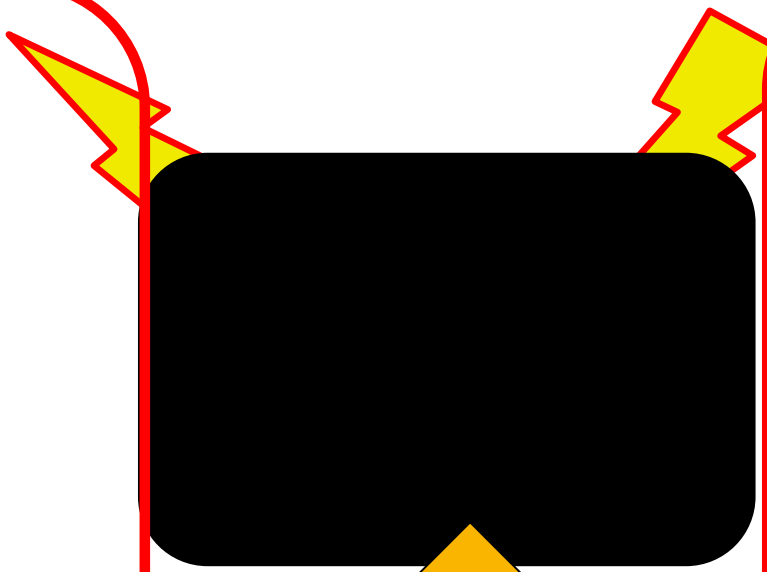
## Functional Security

- Standard crypto toolbox
- SW-only is good enough
- SW firewall
- Virtualization techniques
- Maybe HW accelerators, e.g. crypto copros, TZ,…

## Physical Security

- Functional Security
- Implementation Security
  - Side-channel (e.g., EMA), Fault Injection, Reverse Engineering
- Secure Element
- HW firewall, HW trust anchor
- HW-SW co-design

# Attacks on Smart Cards and Similar Devices



**Side-Channels**
Power Consumption
Electromagnetic Emanation
Timing
Communication (Errors)
Heat Emanation

**SCA-Attacks**
Simple Power Analysis (SPA)
Differential Power Analysis (DPA)
Template Attacks
Timing Analysis

**Non Invasive Attacks**

What is implemented?
**Reverse Engineering**

**Fault Injection**
Laser Beam
Power- Clock Glitches
Probes
EM Pulses
Focused Ion Beam
Environmental Stress

**Fault Attacks**
Attacks on Algorithm
Attacks on Programm Flow
Single Bit vs. Multiple Bit
Differential Fault Attacks

**Semi- / Invasive Attacks**

# SIDE-CHANNEL ANALYSIS ATTACKS

# Pentagon Pizza Attack

## Washington Domino Pizza Index (early ’90)

**Pentagon, at any normal evening about 12 - 15 pizzas…**

**But every once in a while 36 - 45 pizzas…**

**Panama, Gulf War, …**

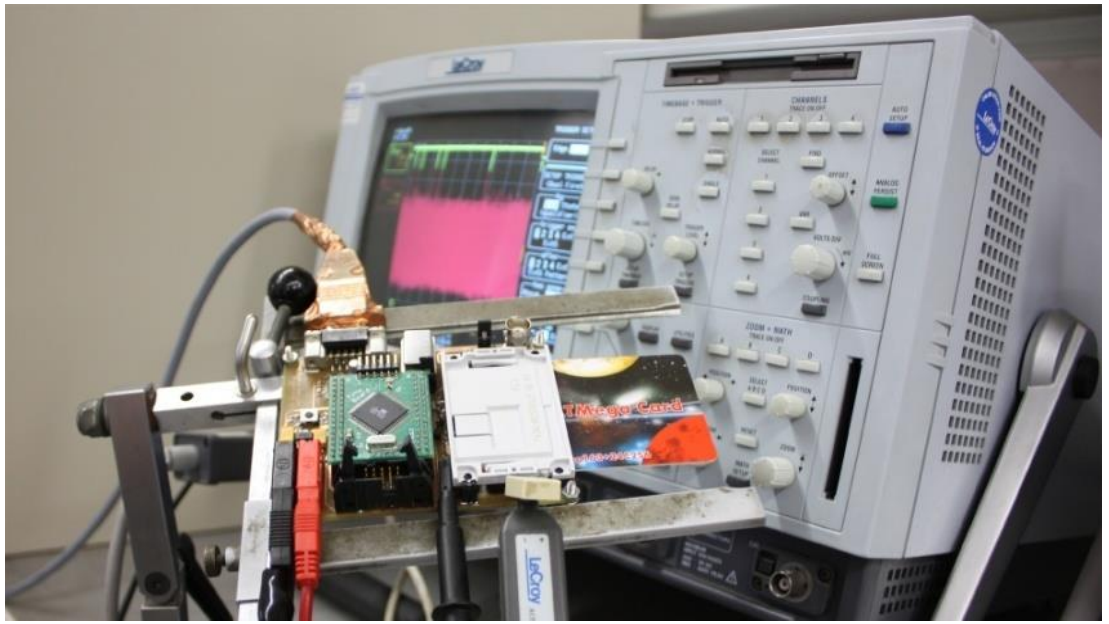
**Information leakage without any official press announcement!**

**Power**
**SPA: Simple Pizza Analysis**

**Power**
**DPA: Differential Pizza Analysis**

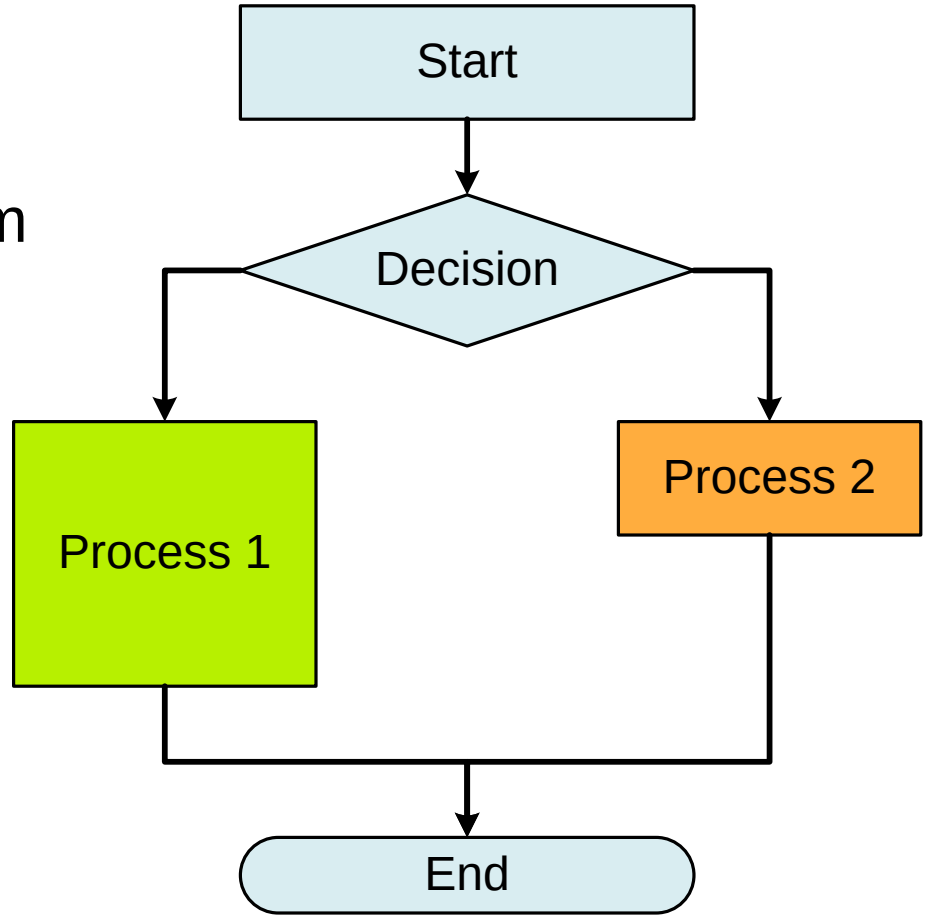
# Side-Channel Analysis Attacks

- Timing Attacks
  - Measure time for calculation → statistically extract secret
- Power Measurement Attacks
  - Measure power consumption during calculation → extract secret
- Electromagnetic Emanation Attacks
  - Same principal as power attacks
  - Very local measurements possible
- Communication
  - Analyze the response to commands
- Heat measurements
  - Can be used to localize crypto units on a chip



# Timing Attacks

- Processing Time depends on Secret Data
- Get Secret by measuring runtime of program



# PIN Code Verification

- 8 Digit PIN code used to grant data access
- Entering one PIN takes minute (card restricts higher frequency)
- Brute Force Attack:

$$\frac{10^8}{60 \cdot 24 \cdot 365} \approx 190 \; years$$

# PIN Code Verification

- Straightforward Implementation of PIN verification:

```
for i=0 to 7
{
  if PIN[i] != userInput[i]
    return error;
}
return ok;
```

- Possible Attack:
  - Try all 10 possible values for 1st digit and measure execution time
  - Execution with correct value will take longer
  - Take correct 1st digit and continue with 2nd one

$$8 \cdot 10 = 80 \text{ min}$$

# PIN Code Verification

- Countermeasure: Add random delay at end of comparison

```
retVal = ok;
for i=0 to 7{
  if PIN[i] != userInput[i]{
    retVal = error;
    break;
  }
}
wait random time;
return retVal;
```

# PIN Code Verification

- Attack still possible:
  - Try all 10 possible values for 1st digit and measure execution time many times
  - Take mean execution time for each value
  - For the correct digit the mean execution time will be longer
- Number of measurements per digit depends on length of break

$$\frac{32 \cdot 8 \cdot 10}{60} \approx 43\,hrs$$

# PIN Code Verification

- Best countermeasure is timing invariant code
- Code should have no conditional branch
- If conditional branch cannot be avoided:
  - Execution time of both branches equal
  - Be aware the execution time of a branch command can depend on the fact that a branch is taken or not

# PIN Code Verification

- Code resistant against timing attacks:

```
check = 0;
for i=0 to 7
{
  check |= PIN[i] ^ userInput[i];
}
if (check == 0){
  return ok;
} else {
  return error;
}
```

# Timing / SPA Attack: Example RSA

See also Livedemo at Booth 331 from Axel Poschmann

- Modular exponentiation: $x = m^k \bmod N$

$x = m$

for $i = n-2$ down to $0$

execution time depends on value of secret bit $k_i$!

$x = x^2$

if $(k_i == 1)$ then

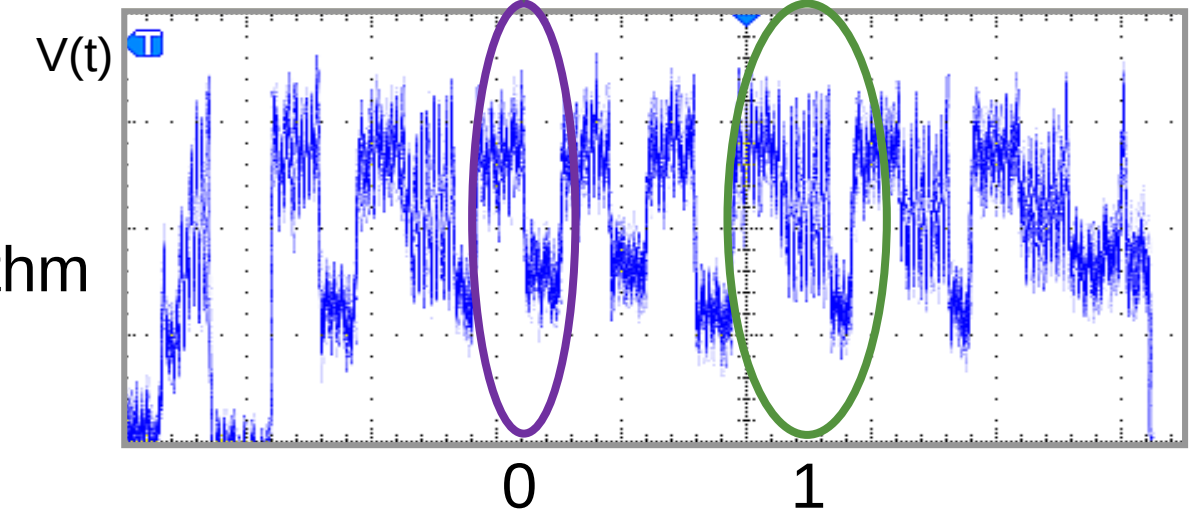
$x = x \cdot m$

endfor

return $x$

n … number of exponent bits

square & multiply algorithm



# Good Practice to Avoid Information Leakage

- Unpredictable timing
- Unpredictable program execution order
- Where possible clear the local stack before returning from a function
- Add randomization where possible
- Avoid any branches on secret data
- Clear local variables directly when no longer needed

# FAULT ATTACKS

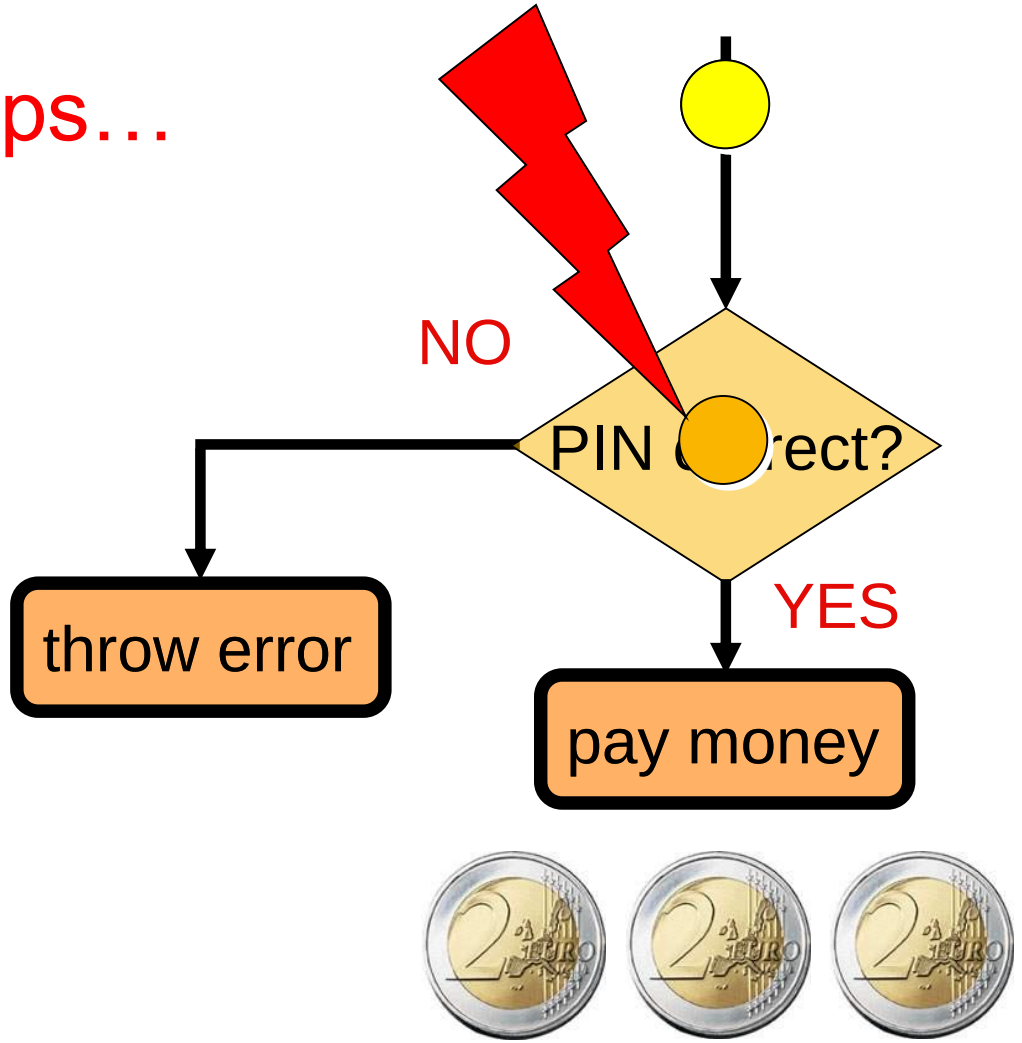
# Fault Attacks

- Introduce a fault in the computation
  - Laser beam
  - Flash light
  - Voltage burst
  - Clock jitter
  - Permanent fault (Focused Ion Beam)
- Use the faulty output as additional information
  - AES skip last key add
- Manipulate branch
  - IO loops, conditional branches
- Change security setting

Riscure laser system (diode laser)

# Simple Fault Attacks: Code Execution

attack critical jumps…



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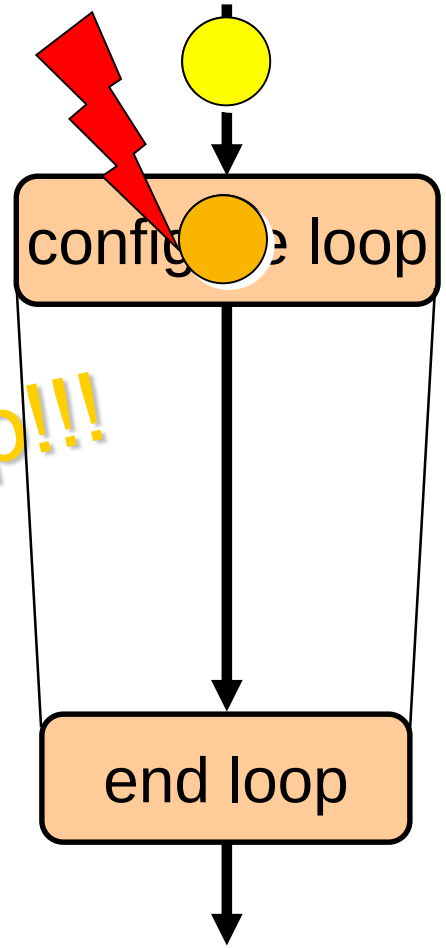
# Simple Fault Attacks: Code Execution

attack I/O loop…
(copy from buffer)




There is always an I/O loop!!!

Hello world!

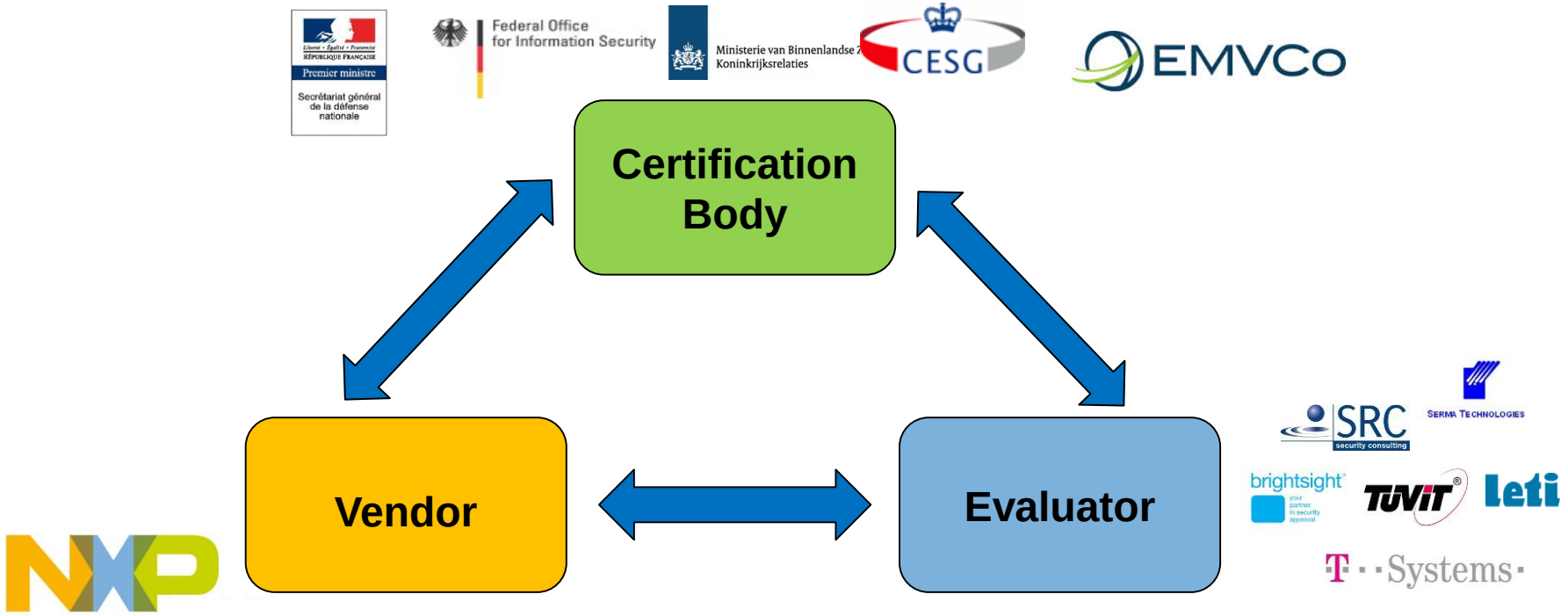
Memory dump: FB AE 04 23 82 F3 D1 …

# Good Practice to Protect Flow Control / Data Integrity

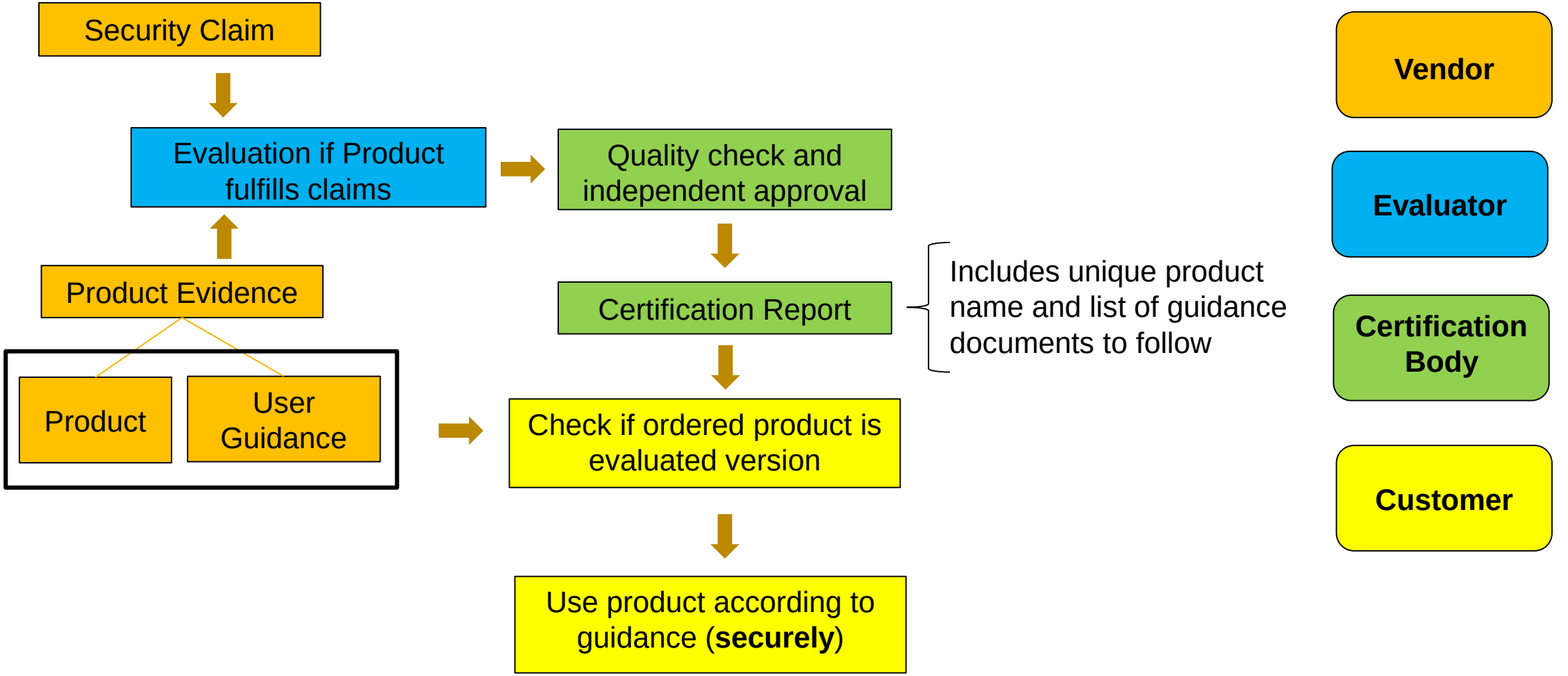
- Program flow verification
- Dummy operations, beware to choose these wisely!
- Avoid FF and 00 as security values, use values with inverse, e.g. A5 and 5A.
- Use complex patterns for decision information (not only a single bit)
- Checks at the beginning of each function (in function)
- Checks before function return (in function) and after function return (in caller)
- Check and double check
- Double executions, where the second is the inverse of the first evaluation
- Write secure code preferably in assembly (compile may remove redundancy)
- Check data (integrity) before use, NOT after!
- Make sure that checks are always performed
- Check after write

# SECURITY EVALUATION & CERTIFICATION

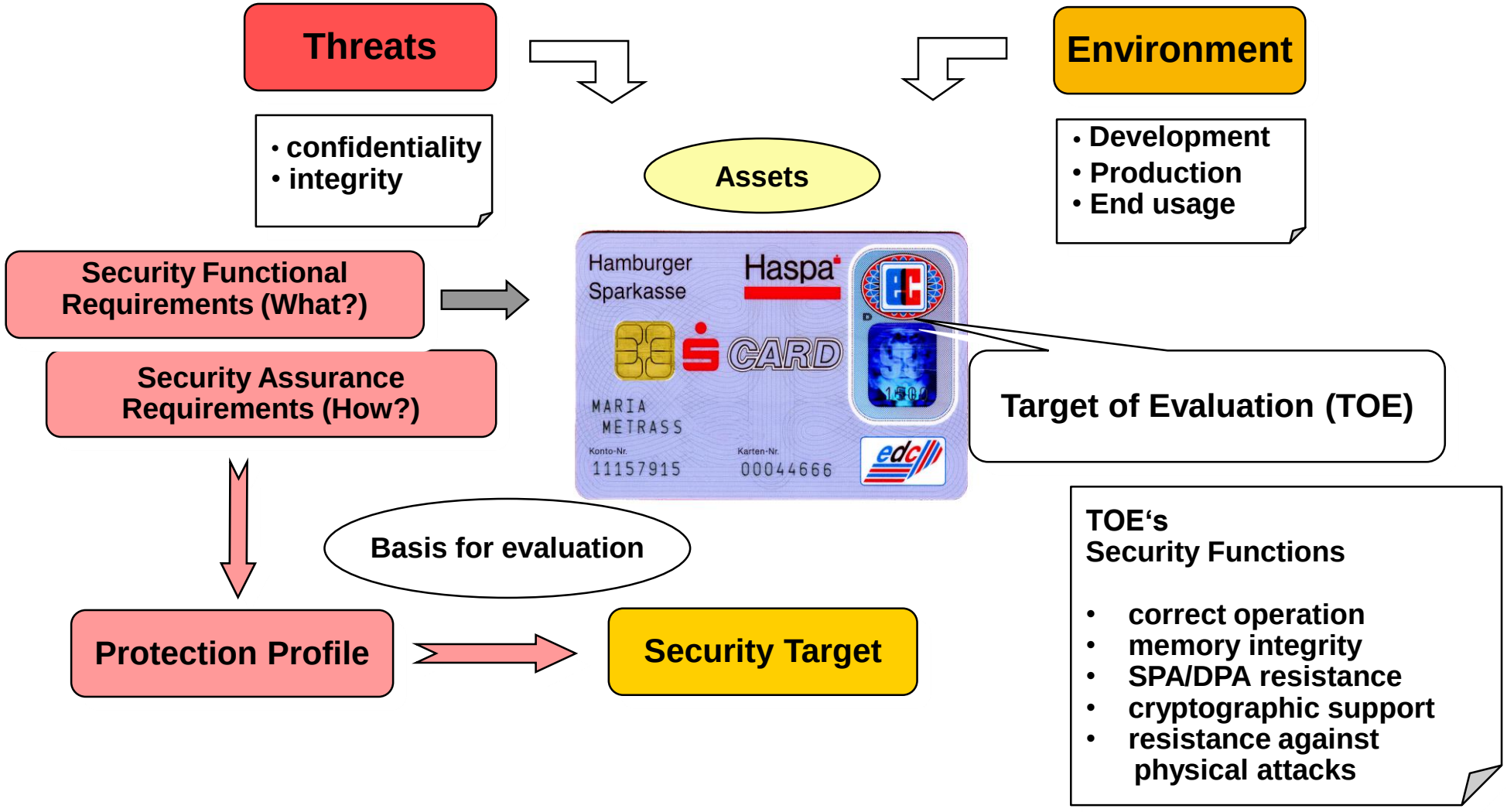
# Security Evaluation & Certification



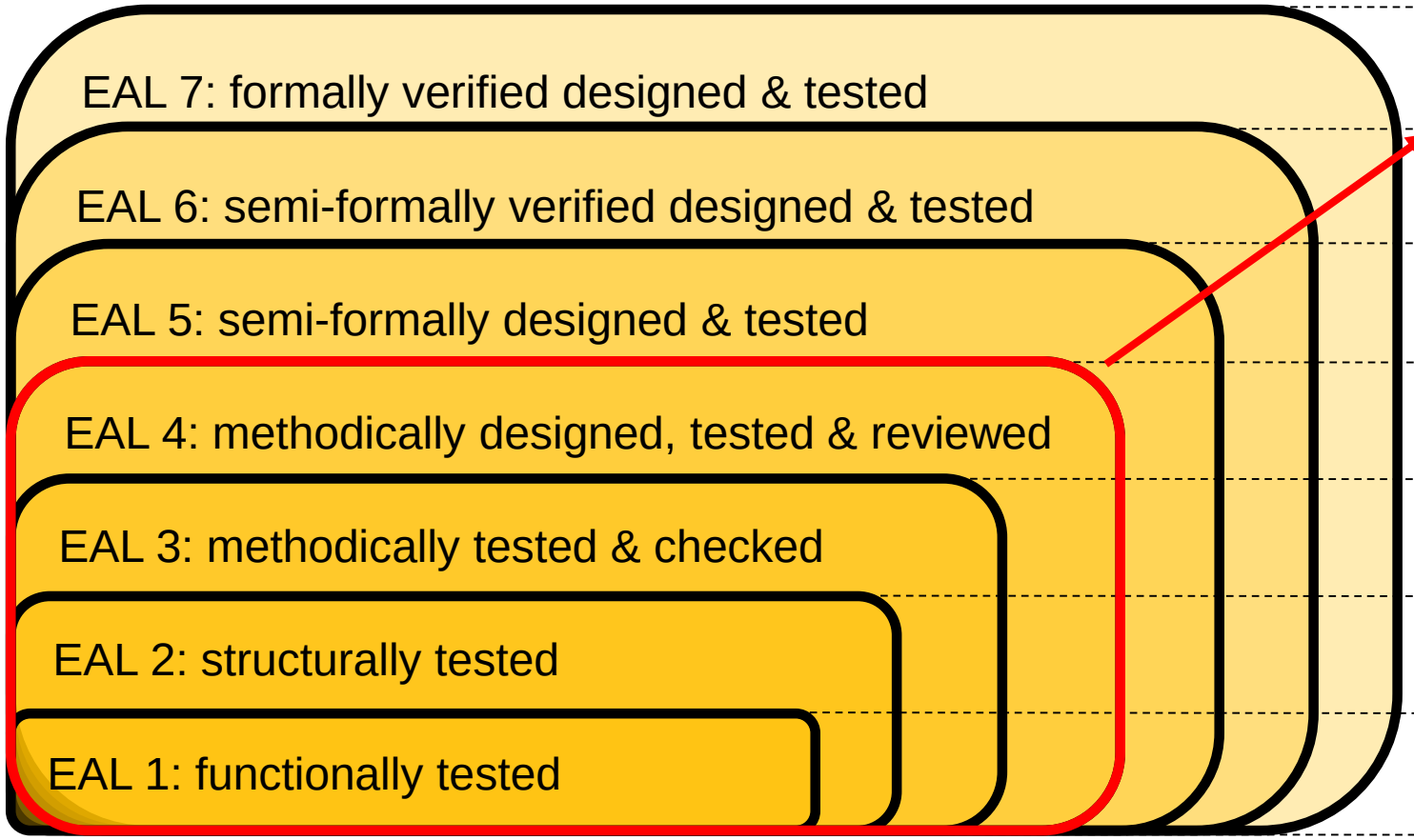
# General Workflow



# Security Evaluation acc. to Common Criteria (CC) – Smart Cards



# Evaluation Assurance Levels (EALs)



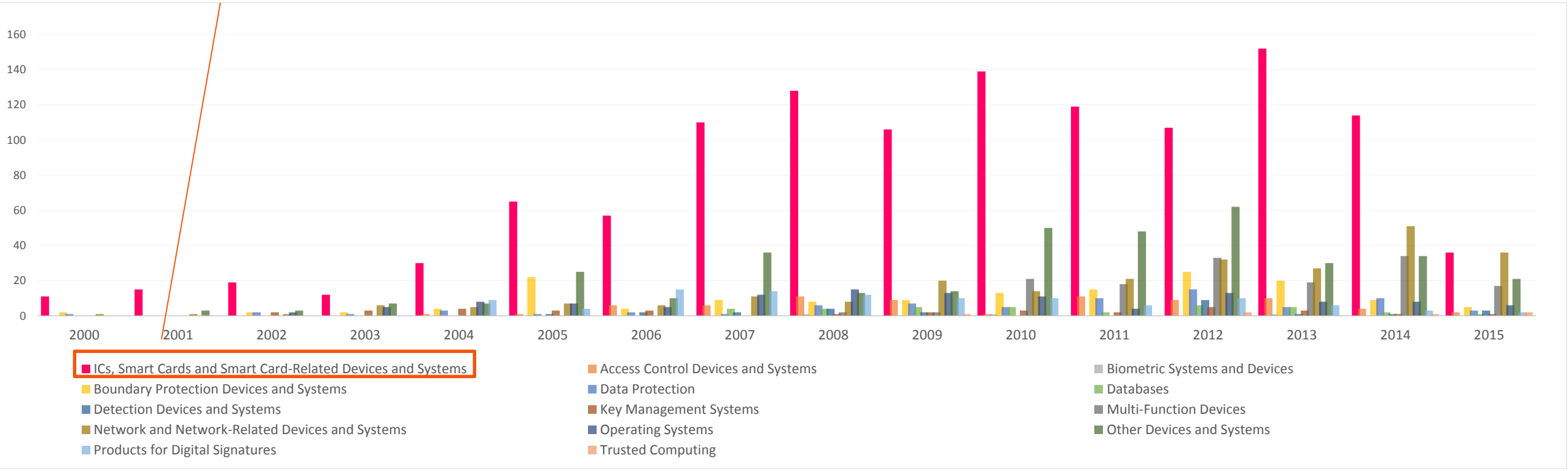

| Vulnerability Assessment Level | |
|---|---|
| AVA_VAN.5 | High |
| AVA_VAN.5 | High |
| AVA_VAN.4 | Moderate |
| AVA_VAN.3 | Enhanced-Basic |
| AVA_VAN.2 | Basic |
| AVA_VAN.2 | Basic |
| AVA_VAN.1 | No |

Augmentation (noted as “+” e.g. EAL5+): at least one component from a higher level has been taken

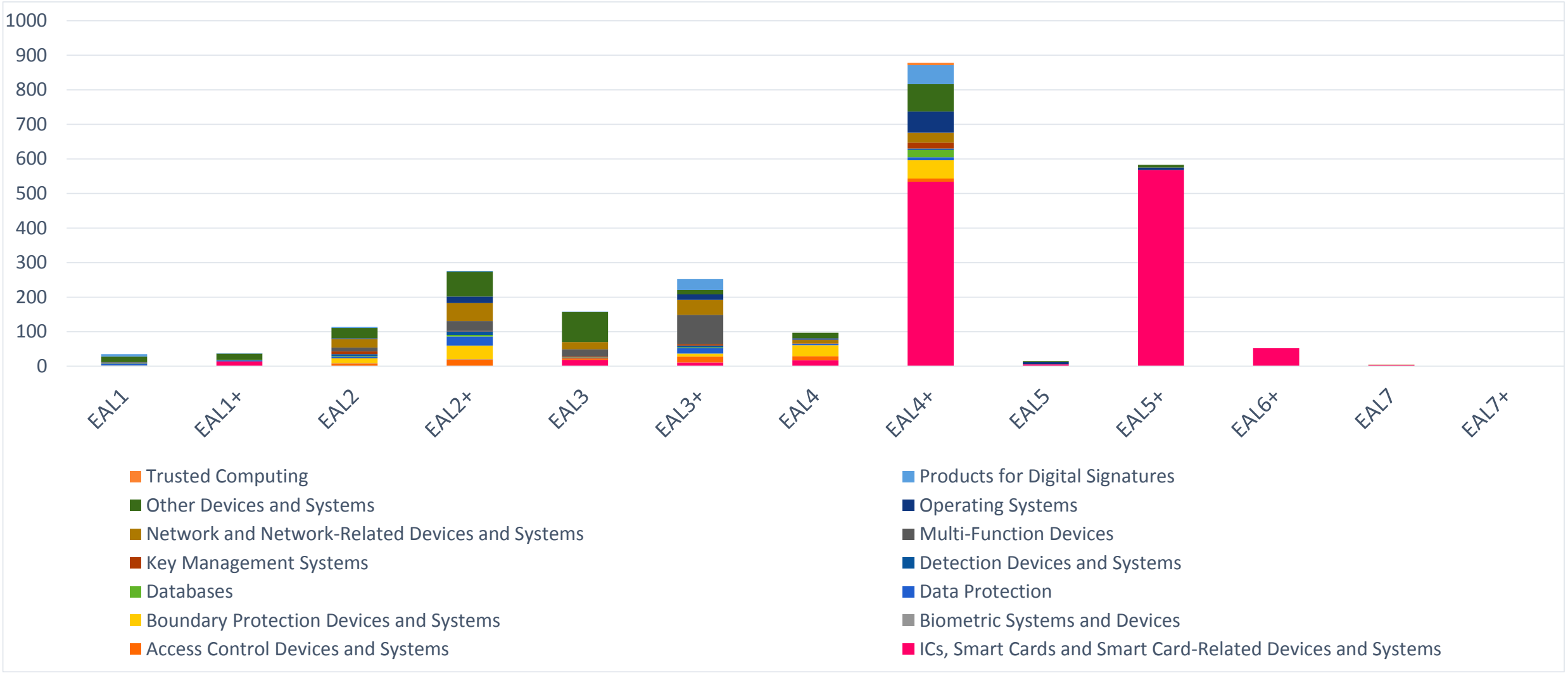
For Smart Cards according to protection profile PP0084 the assurance level MUST BE at least EAL4+, where + is always AVA_VAN.5

# Number of CC Certificates in the Different Domains

ICs, Smart Cards and Smart Card-Related Devices and Systems



# Number of Certificates per Domain and EAL



# NXP (Composite) Certifications: Payment vs. eID

Payment

eID

**VISA / MasterCard / AMEX**

**EMVCo Platform Approval**

**EMVCo HW Approval**

| | |
|---|---|
| Paym. Applet | ID Applet |
| Java Card OS | |
| Cryptographic Library | |
| SmartMX2 HW | |

**PassPort App CC Certification EAL5+**

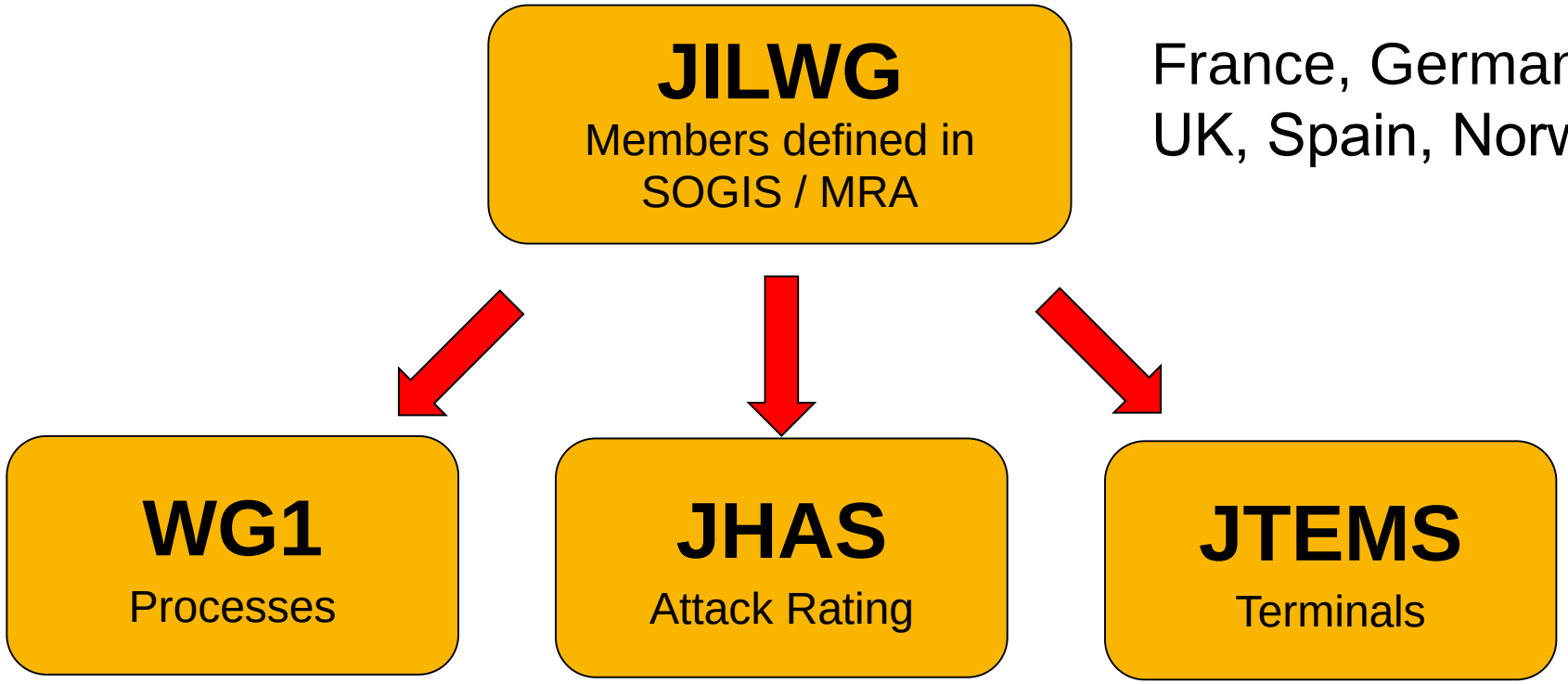
**JCOP CC Certification EAL6+**

**CryptoLib CC Certification EAL6+**

**HW CC EAL6+**

# JHAS ATTACK RATING

# Working Groups in the Smart Card Domain




France, Germany, Netherlands, UK, Spain, Norway,…

# Major Attack Classes

- Physical Attacks (e.g. Reverse Engineering)
- Overcoming Sensors and Filters (e.g. Disconnection)
- Perturbation Attacks (e.g. Skipping instruction)
- Side-channel Attacks (e.g. extract key bits from power profile)
- ...
- Exploitation of Test Features (e.g. set TOE back to test mode)
- Attacks on RNG (e.g. influence quality)
- Software Attacks (e.g. replay attacks)

# Attack Phases

- **Identification Phase**:
  Perform the attack once to demonstrate its feasibility and / or achieve a one-time benefit (learning phase)

- **Exploitation Phase**:
  Perform the attack multiple times for commercial exploitation

- **Information Flow between these Phases**:
  One of the outcomes of the Identification Phase is a virtual script that tells the attacker of the Exploitation Phase how to perform the attack

# Rating Tables for Smart Cards

| Range of values CC 3.1 | TOE resistant to attackers with attack potential of: |
|---|---|
| 0-15 | No rating |
| 16-20 | Basic |
| 21-24 | Enhanced-Basic |
| 25-30 | Moderate |
| 31 and above | High |

- For Smart Cards we need to achieve 31 points for
  - CC AVA_VAN.5 (part of EAL 4+, 5, 5+, 6, 6+, 7)
  - EMVCo
  - MasterCard
  - VISA
  - AMEX, …
- for each and every attack path!

| Factors | Identification | Exploitation |
|---|---|---|
| **Elapsed time** | | |
| < one hour | 0 | 0 |
| < one day | 1 | 3 |
| < one week | 2 | 4 |
| < one month | 3 | 6 |
| > one month | 5 | 8 |
| Not practical | * | * |
| **Expertise** | | |
| Layman | 0 | 0 |
| Proficient | 2 | 2 |
| Expert | 5 | 4 |
| Multiple Expert | 7 | 6 |
| **Knowledge of the TOE** | | |
| Public | 0 | 0 |
| Restricted | 2 | 2 |
| Sensitive | 4 | 3 |
| Critical | 6 | 5 |
| Very critical hardware design | 9 | NA |
| **Access to TOE** | | |
| < 10 samples | 0 | 0 |
| < 100 samples | 2 | 4 |
| > 100 samples | 3 | 6 |
| Not practical | * | * |
| **Equipment** | | |
| None | 0 | 0 |
| Standard | 1 | 2 |
| Specialized | 3 | 4 |
| Bespoke | 5 | 6 |
| Multiple Bespoke | 7 | 8 |
| **Open samples** | | |
| Public | 0 | NA |
| Restricted | 2 | NA |
| Sensitive | 4 | NA |
| Critical | 6 | NA |

# SUMMARY

# Summary

- A lot of **solutions exist to build secure systems** – at least on paper

- **Implementing them securely** – especially on embedded systems – is extremely **challenging (facing physical attacks)**

- To **convince customers** that a system is secure and implemented securely requires **security evaluation & certification**

- The **level of** implementation **security** needs to be finally **rated** (e.g. JHAS attack rating) which expresses the **costs of attacks to break the product**

SECURE CONNECTIONS
FOR A SMARTER WORLD

# ATTRIBUTION STATEMENT

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