Introduction to Side Channel Attacks

Ileana Buhan, March 2024
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Radboud University

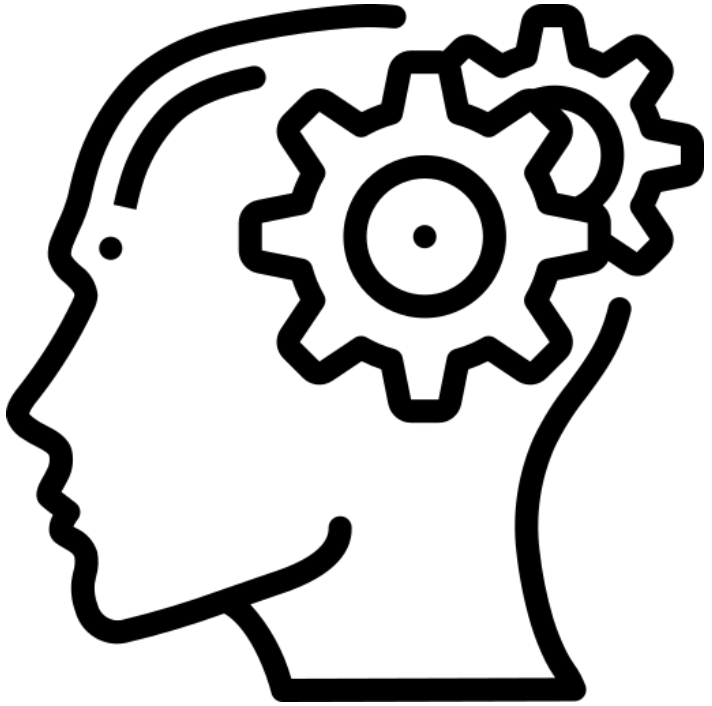
This lecture

1. What is leakage?
2. Simple Power Analysis
3. Differential Power Analysis
4. Countermeasures

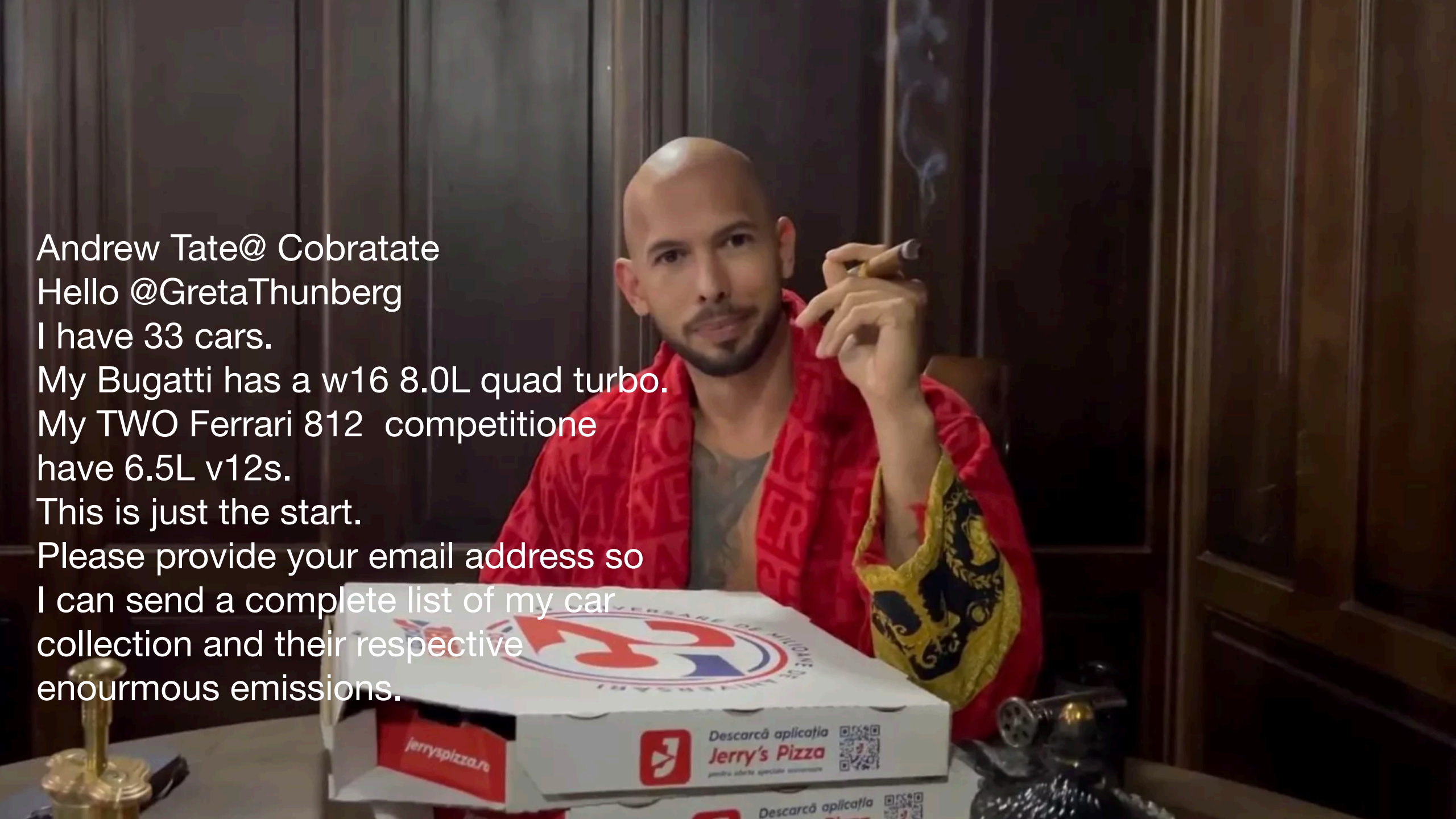
What is leakage?

Take a few minutes

What is leakage?




jerryspizza.ro
Descarcă aplicația
Jerry's Pizza


Andrew Tate@ Cobratate
Hello @GretaThunberg
I have 33 cars.
My Bugatti has a w16 8.0L quad turbo.
My TWO Ferrari 812 competitione
have 6.5L v12s.
This is just the start.
Please provide your email address so
I can send a complete list of my car
collection and their respective
enourmous emissions.
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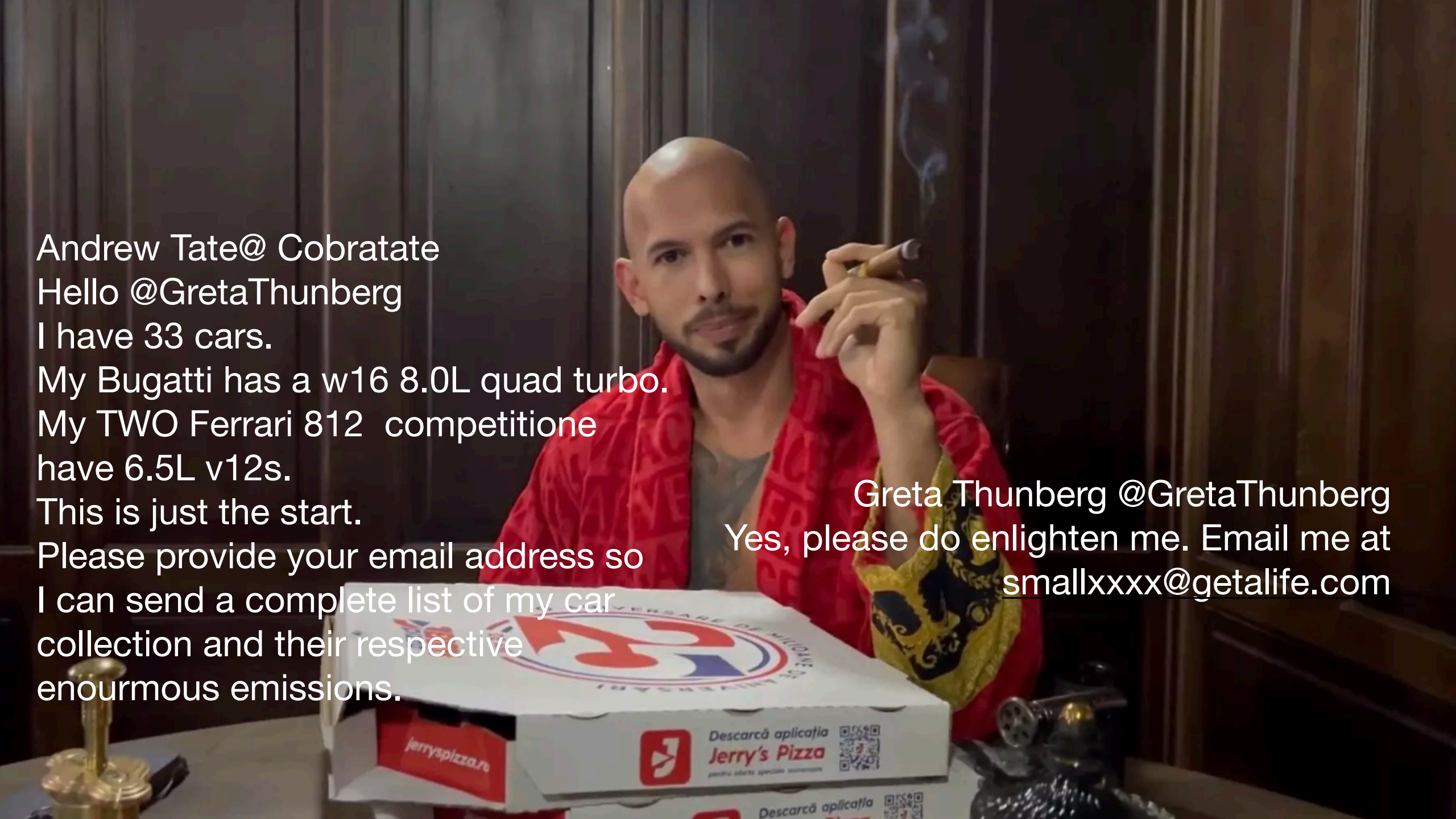

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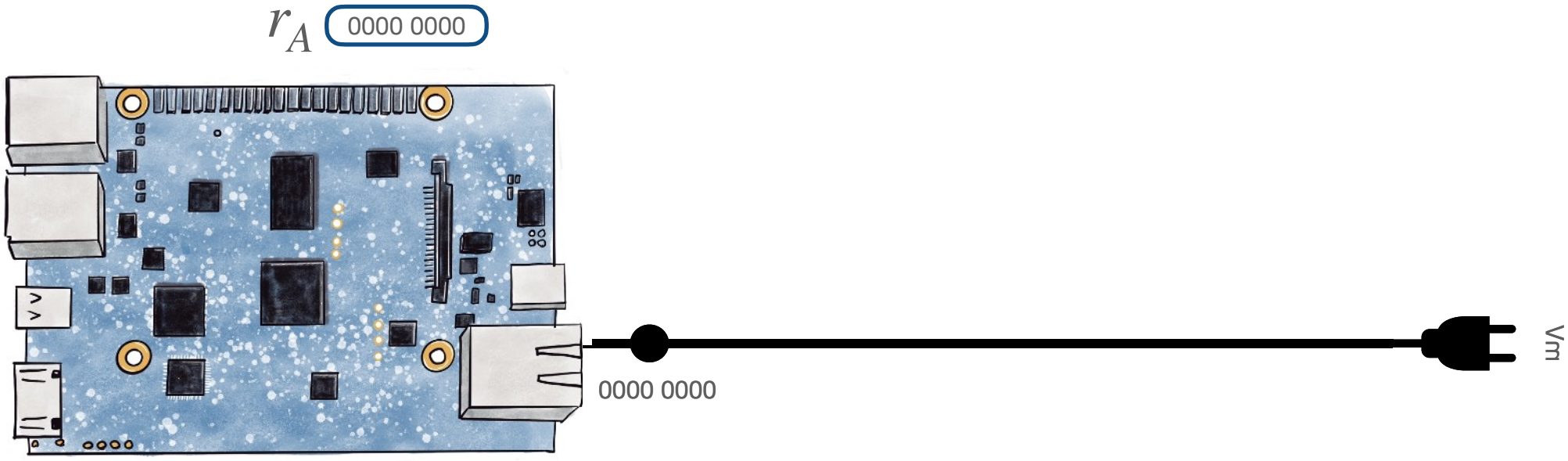
enourmous emissions.

Greta Thunberg @GretaThunberg
Yes, please do enlighten me. Email me at
smallxxxx@getalife.com

Greta Thunberg @GretaThunberg
This is what happens when you dont recycle your pizza boxes

What is leakage for electronic devices?



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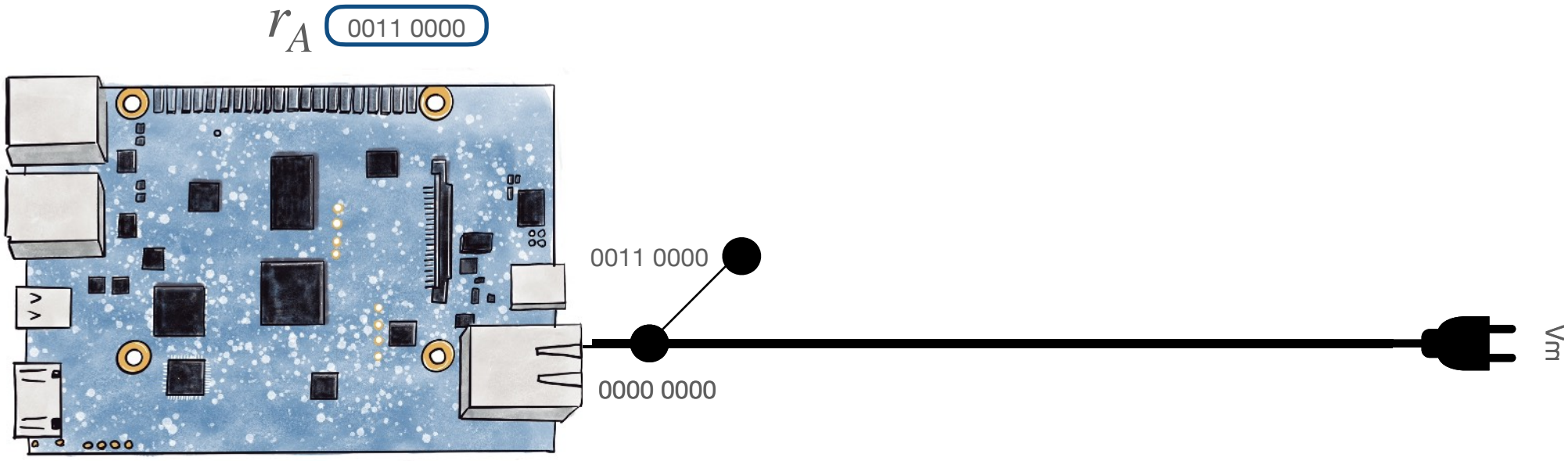

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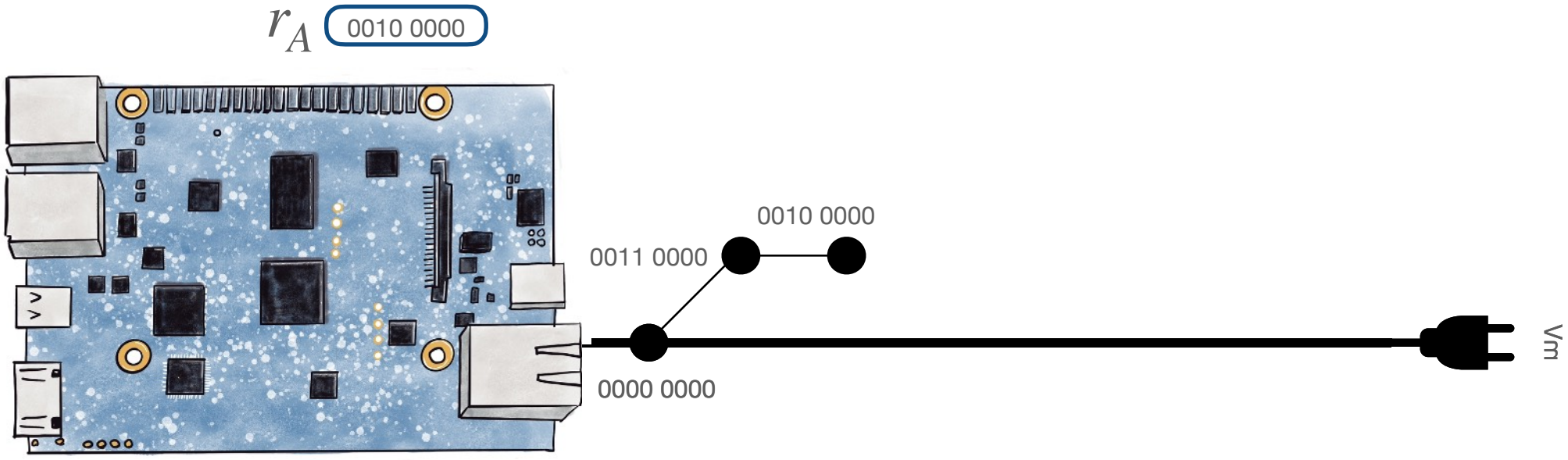

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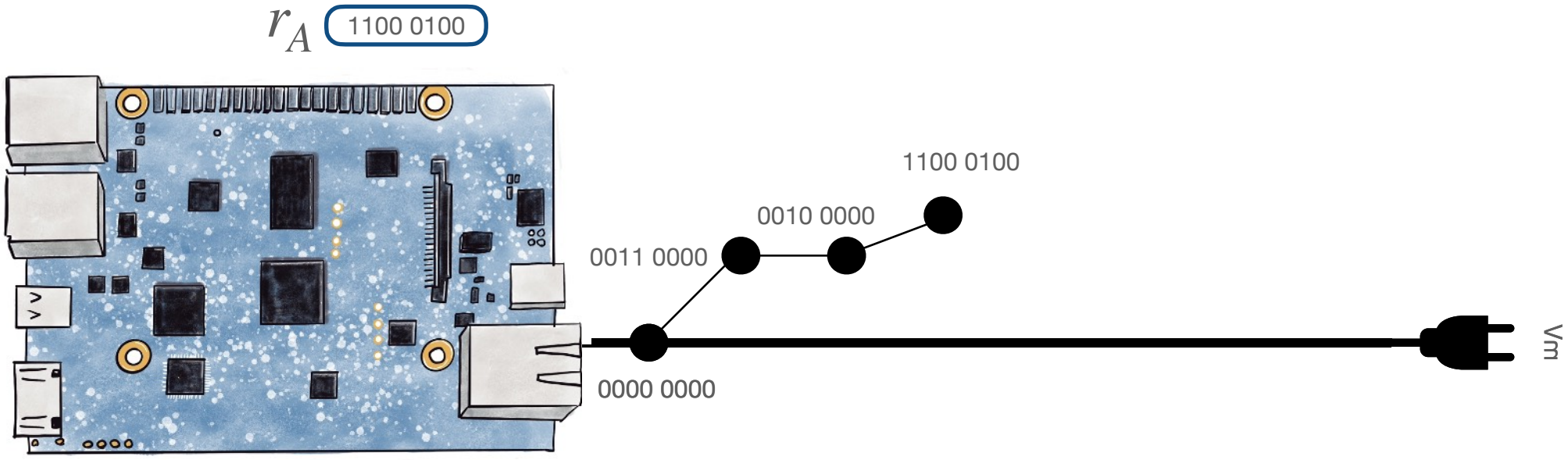

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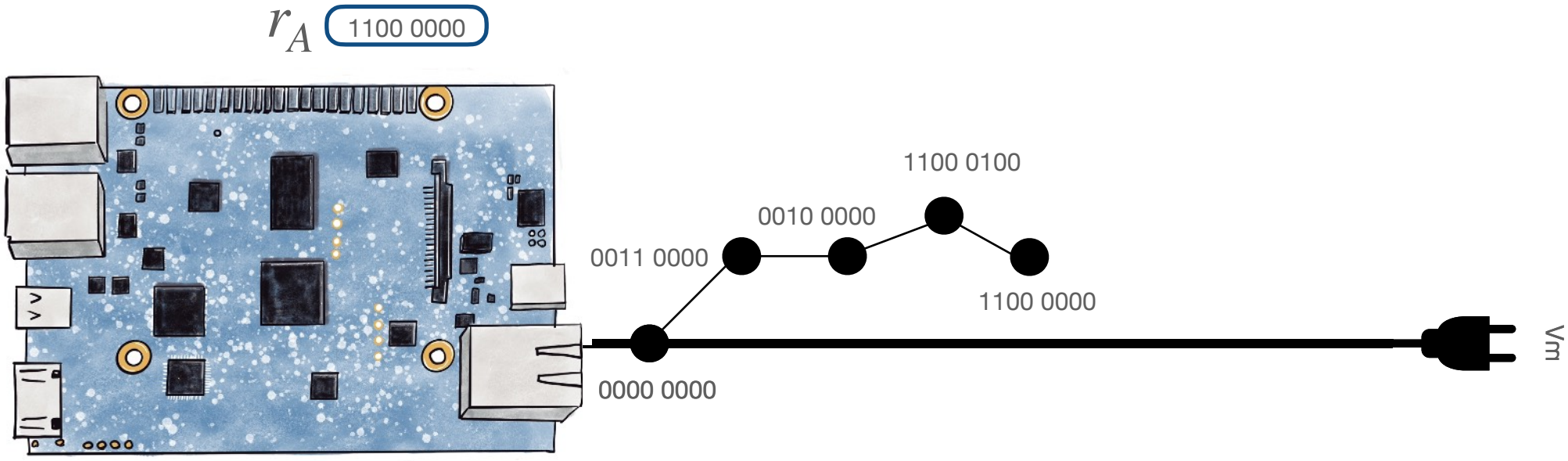

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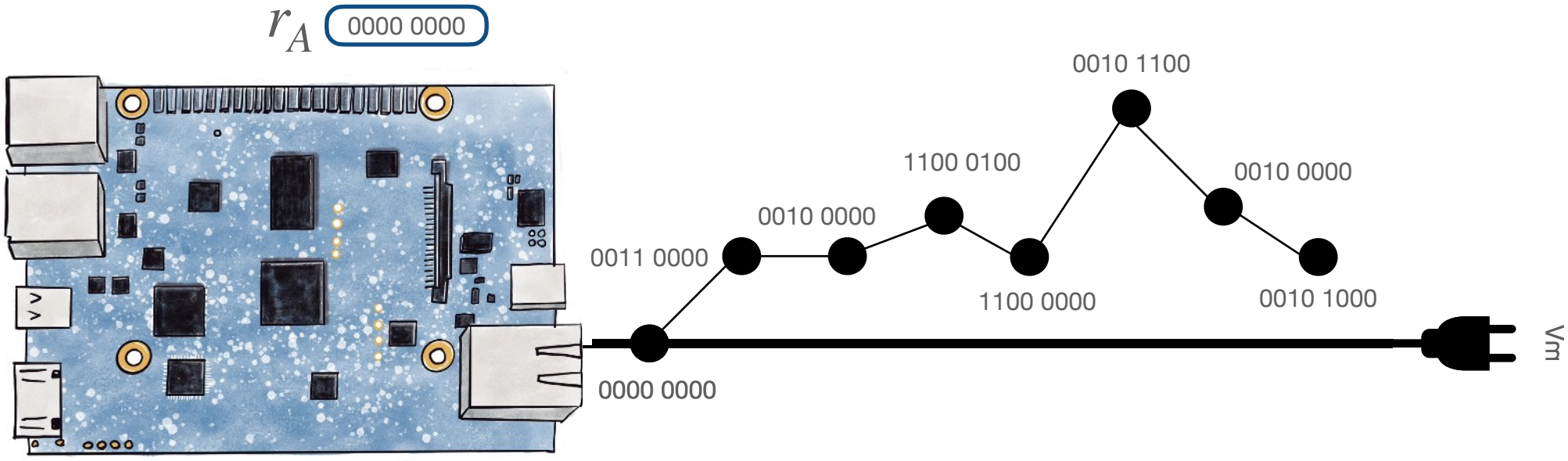

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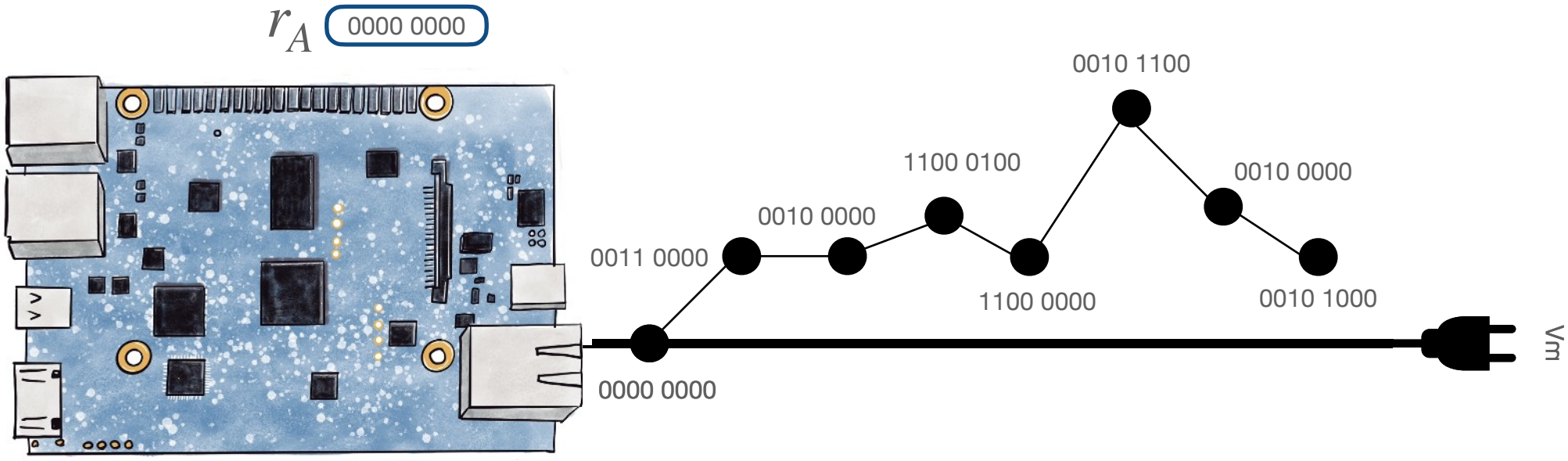


Any observable relation between the value manipulated by the device and a side channel controled by an adversary

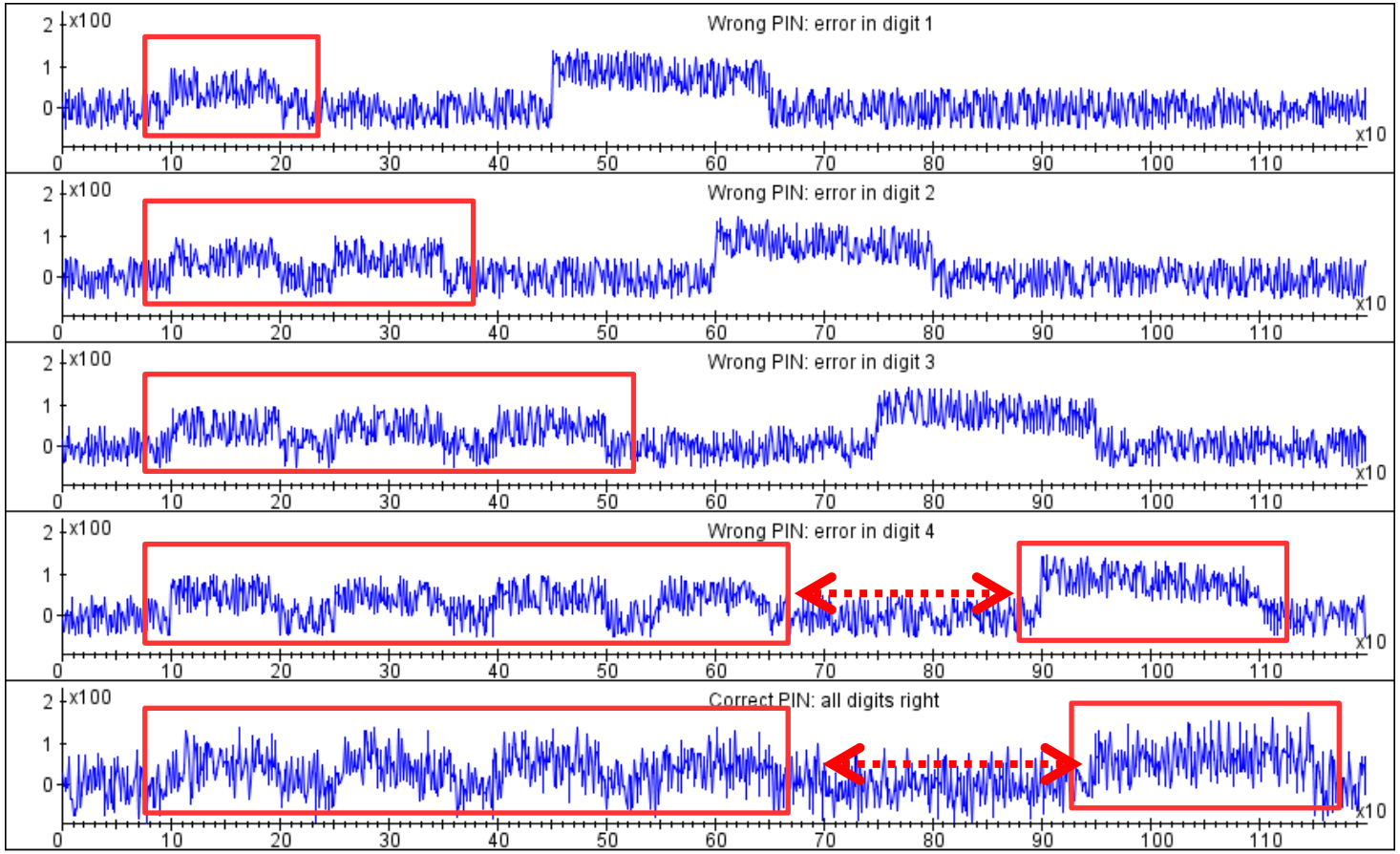
Simple Power Attacks (SPA)

SPA attacks

- Based on one or few measurements

- Used for discovery of data or instruction dependent operations:
  - Symmetric:
    - Number of rounds -> which gives us the key length
    - Memory accesses
  - Asymmetric :
    - The key (ECC/RSA)
    - Implementation details (vannila RSA/RSA-CRT)
    - Key length

PIN verification attempt



????

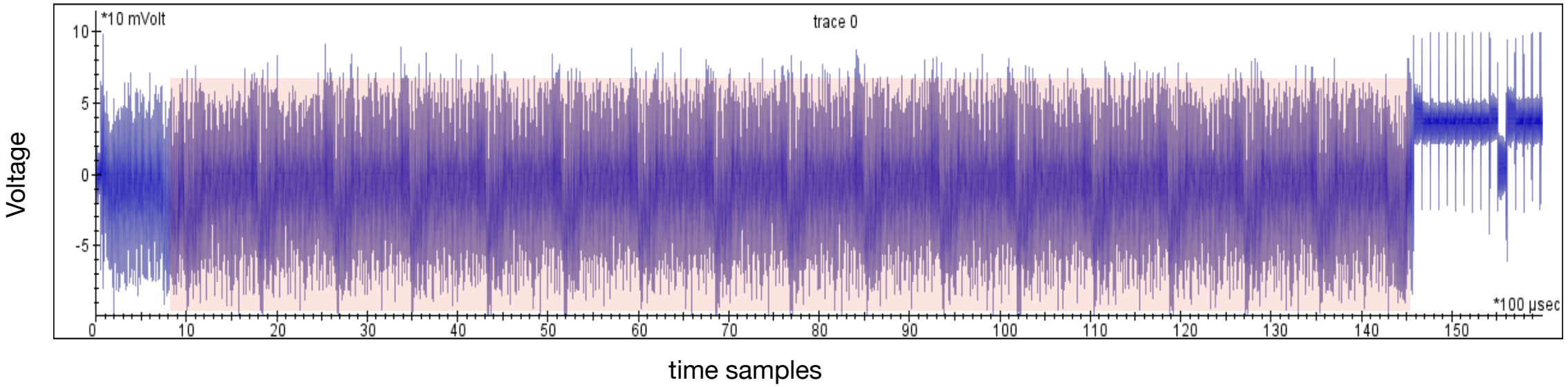
4???

47??

471?

4710

Which algorithm is this?



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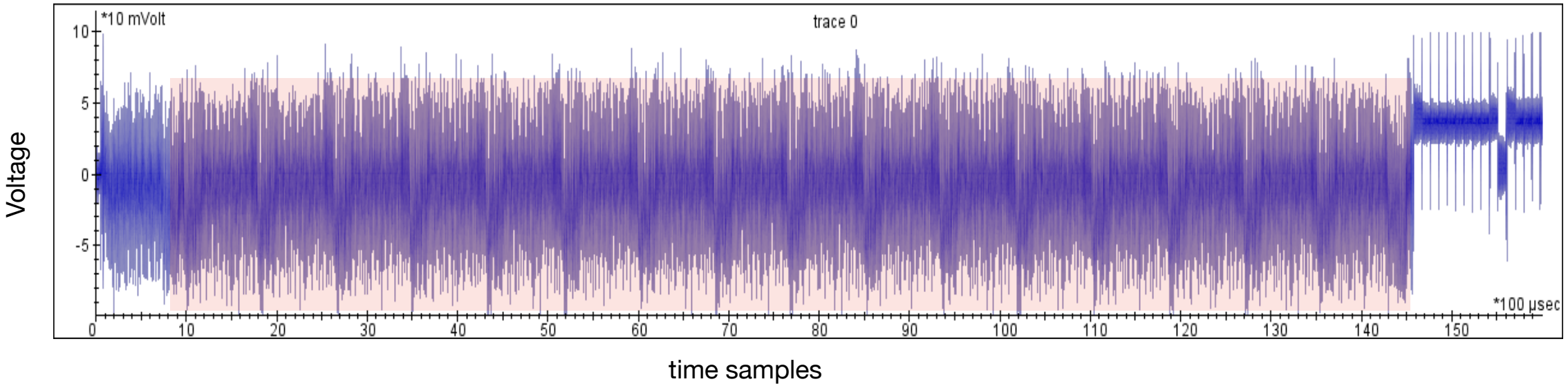
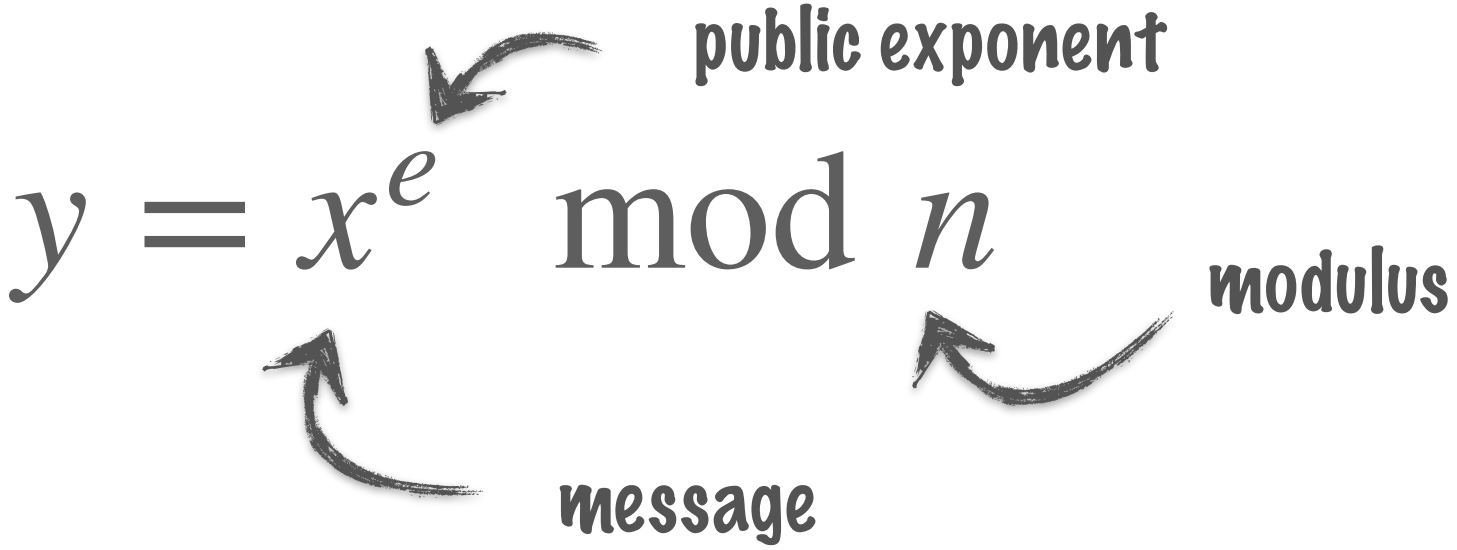


Answer: DES

RSA exponentiation operation



Implementation of exponentiation operation

Compute $y = x^e \mod n$

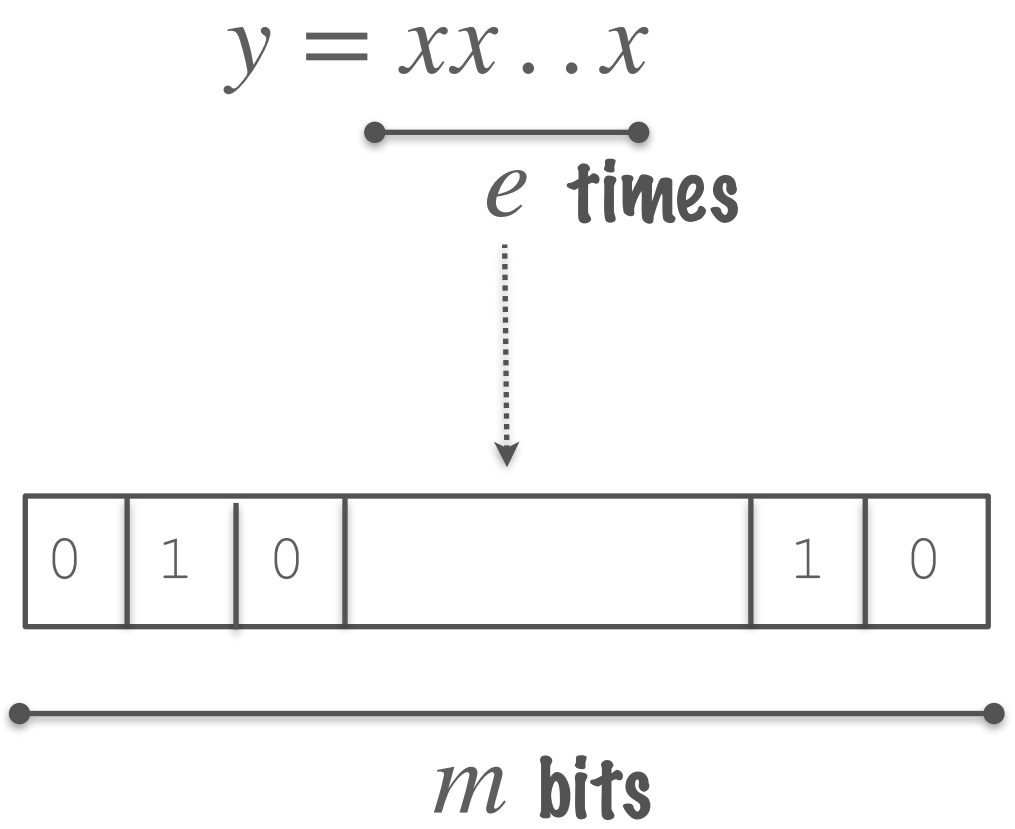
$$y = \underbrace{xx\ldots x}_{e \text{ times}}$$

```
expNaive (x, e, n):
   y=x
   for i=1 to e-1:
      y=yx mod n
return y
```

Implementation of exponentiation operation

Compute $y = x^e \mod n$

```
expFast (x, e, n):
   y=x
   for i=m-1 to 0:
      y=y*y mod n
      if e_i==1:
         y=y*x mod n
return y
```



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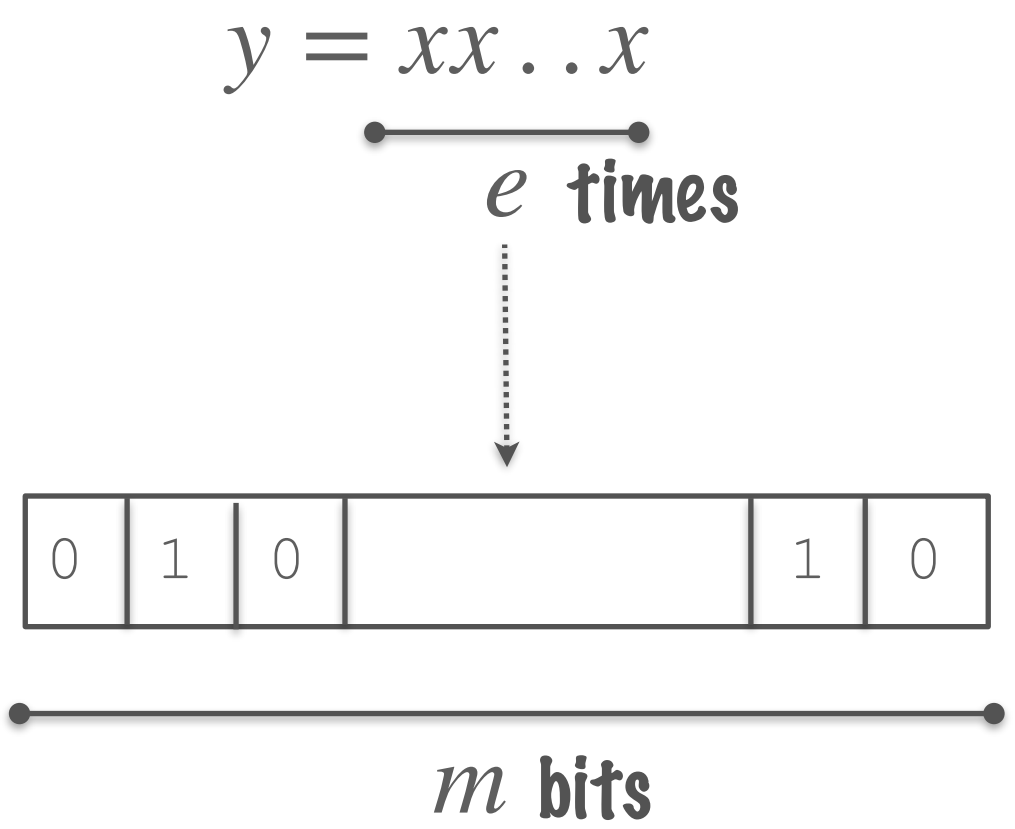
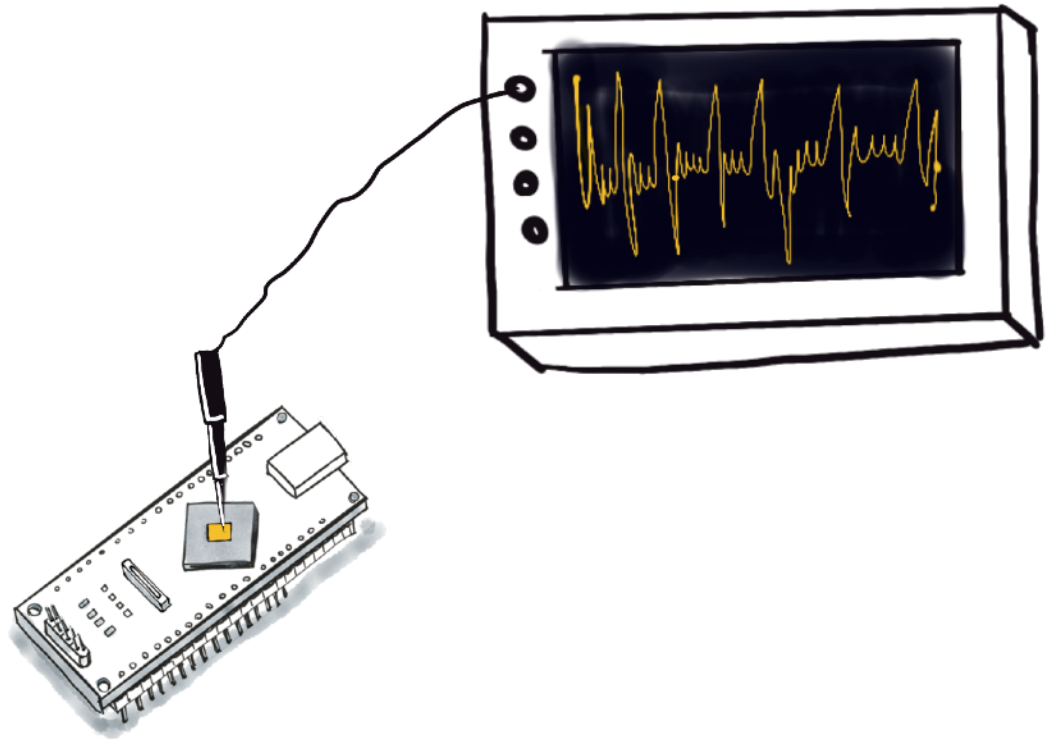


Can you see a potential side-channel?

Implementation of exponentiation operation

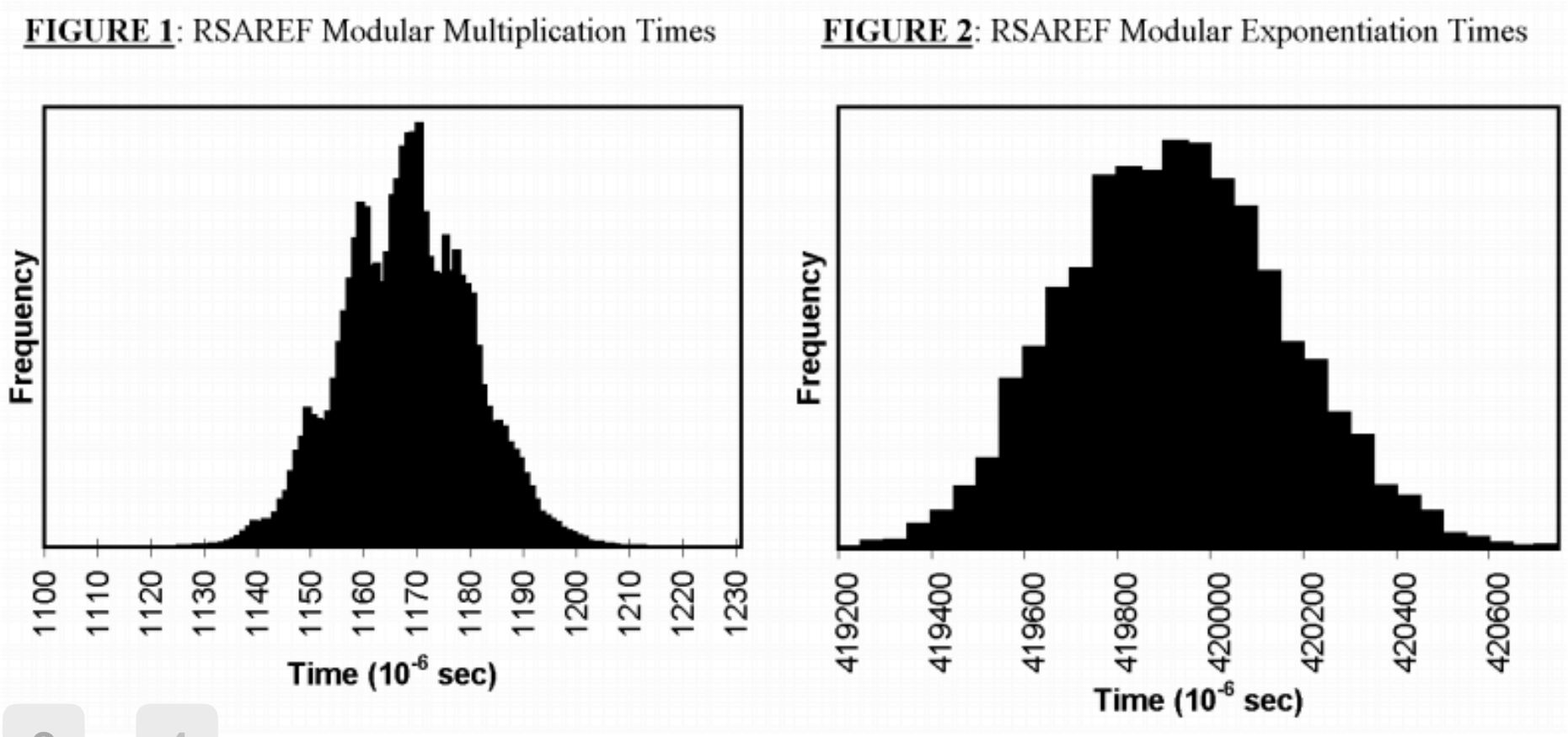
Compute $y = x^d \mod n$

```
expFast (x, d, n):
   y=x
   for i=m-1 to 0:
      y=y*y mod n
      if d_i==1:
         y=y*x mod n
return y
```



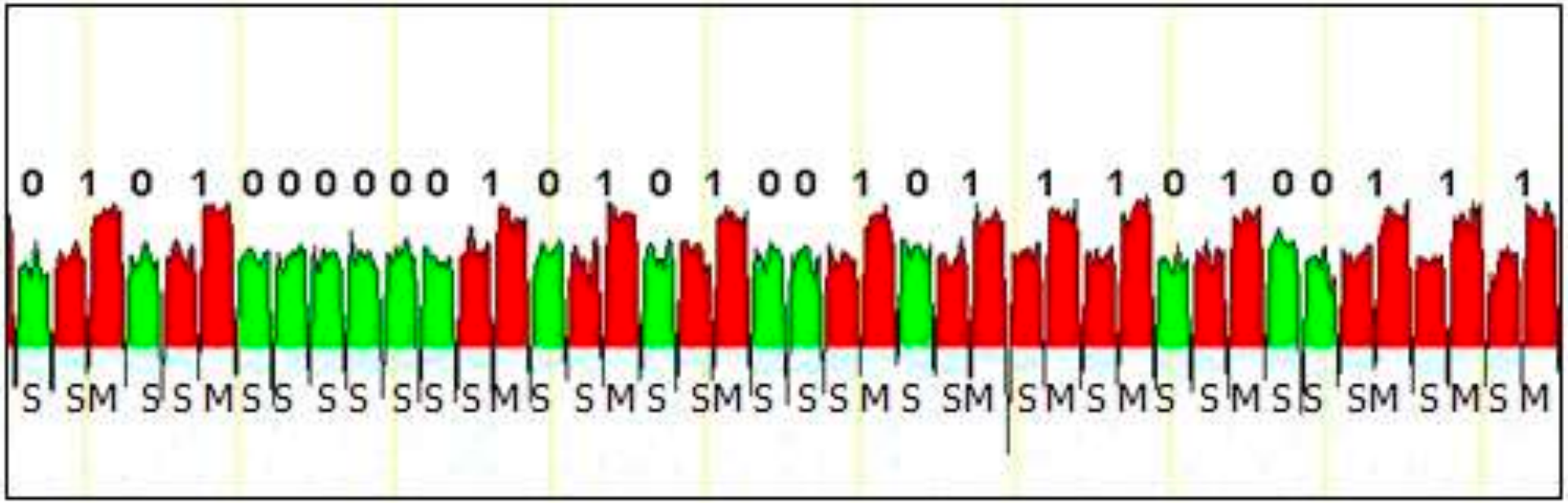
Can you see a potential side-channel?

Is there anything wrong in this picture?



Timing Attacks on Implementations of Die-Hellman, RSA, DSS, and Other Systems, Paul Kocher,1996

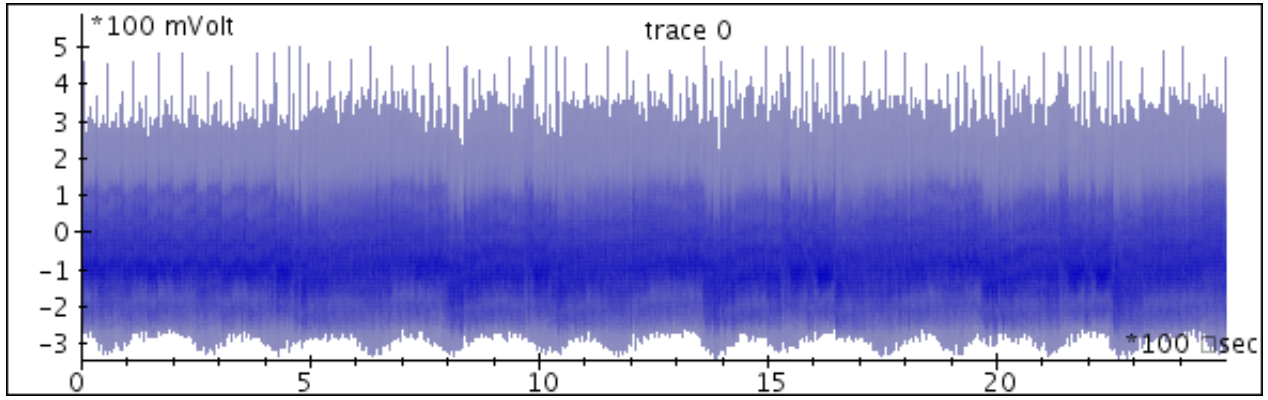
SPA attack of RSA



Source: https://www.eetimes.com/protecting-fpgas-from-power-analysis/#

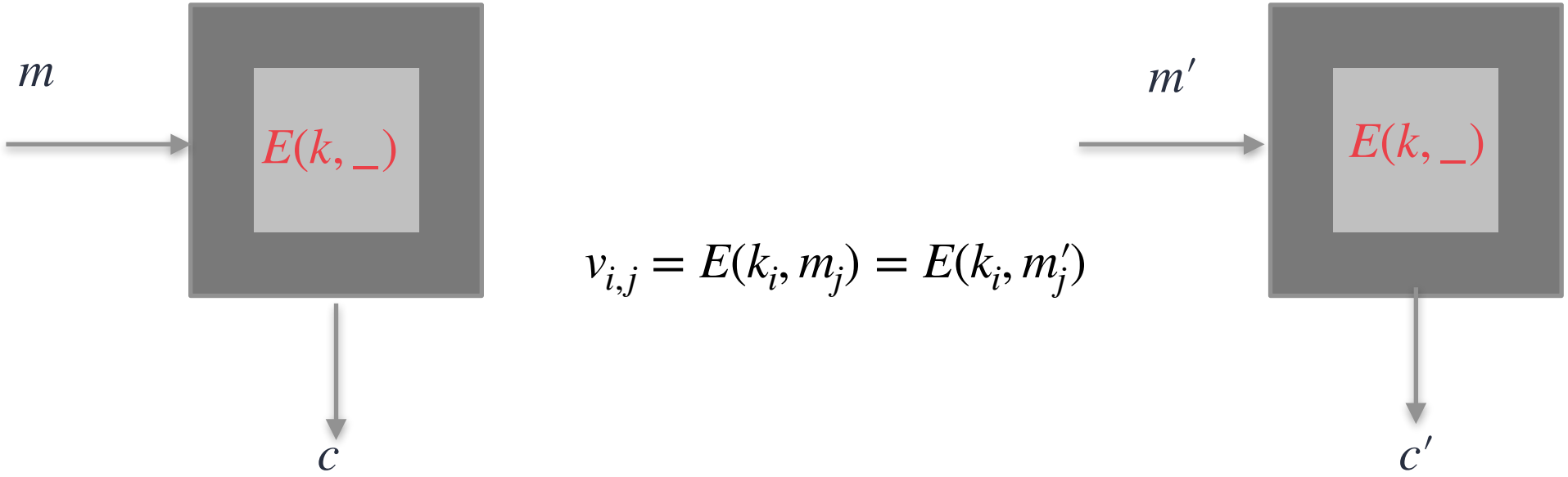
SPA attacks summary

- SPA attacks are not so simple, require detailed knowledge about the implementation



- An advanced option is called collision attacks
- Protecting against RSA means sticking to regularity in computation
- The advanced form of SPA attacks today is called horizontal attacks
- SPA attacks are used to enable more comples physical attacks

Collision attacks



$$v_{i,j} = E(k_i, m_j) = E(k_i, m'_j)$$

Colliding values, reduce the values for the possible keys

DPA attacks

Differential Power/Electromagnetic Analysis

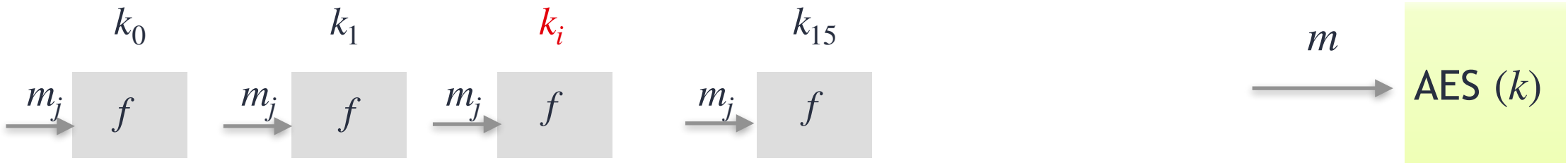
DPA attacks exploit the data dependecy of the power consumption of cryptographic devices. They use a large number of traces to analyze the power consumption at a fixed moment in time as a function of the processed data.

Main steps:

1. Choose the target intermediate value
2. Measure traces, known plaintext/ciphertext
3. Calculate (hypothetical) intermediate values
4. Choose leakage model
5. Recover key using a side channel distinguisher

Power Analysis Attacks, Revealing the Secrets of Smart Cards, Stefan Mangard, Elisabeth Oswald, Thomas Popp, 2007

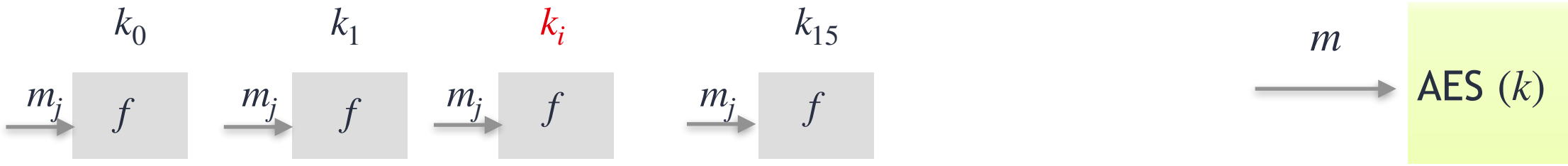
1. Choose the target intermediate value



Intermediate value

$$v_{i,j} = f(k_i, m_j)$$

1. Choose the target intermediate value

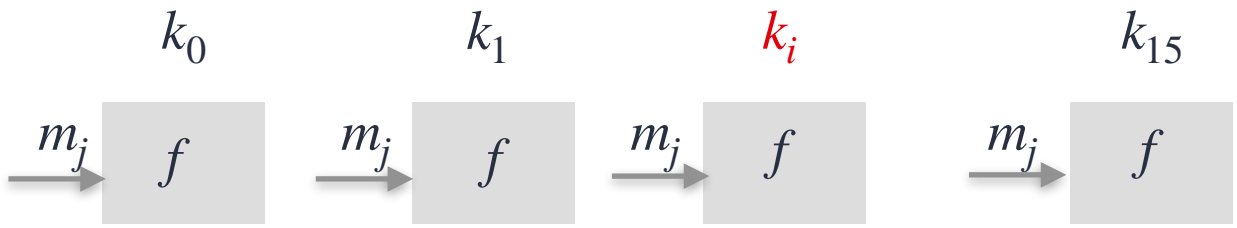


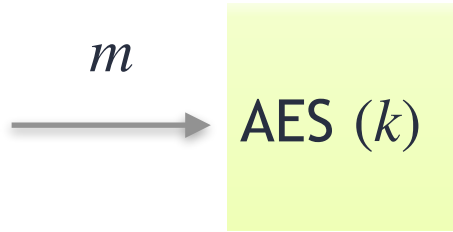
Intermediate value

$$v_{i,j} = f(k_i, m_j)$$

How to choose the target intermediate value?

1. Choose the target intermediate value





Intermediate value

$$v_{i,j} = f(k_i, m_j)$$

How to choose the target intermediate value?

Function of the secret

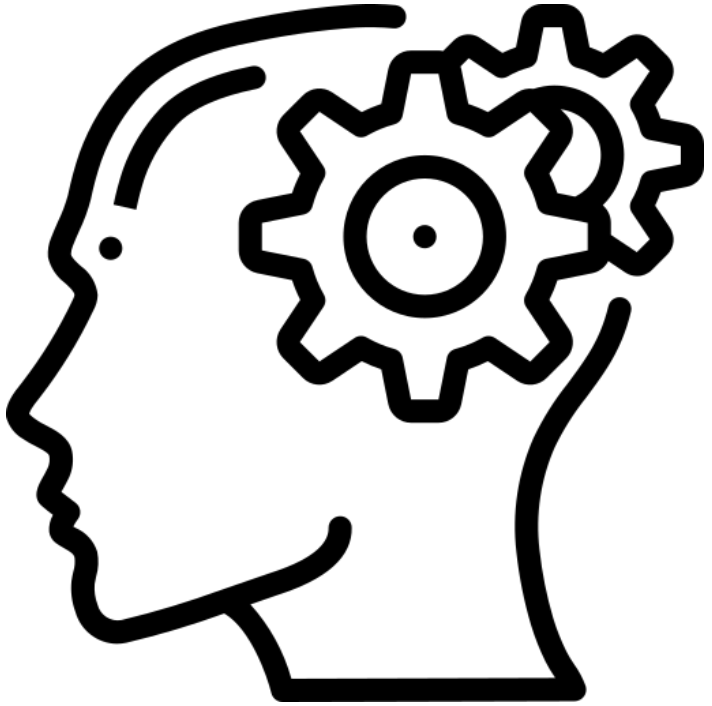
Function of controllable inputs

Function with confusion property

Function with divide and conquer property

Take a few minutes

What would make a good intermediate value for block ciphers? e.g. AES, DES



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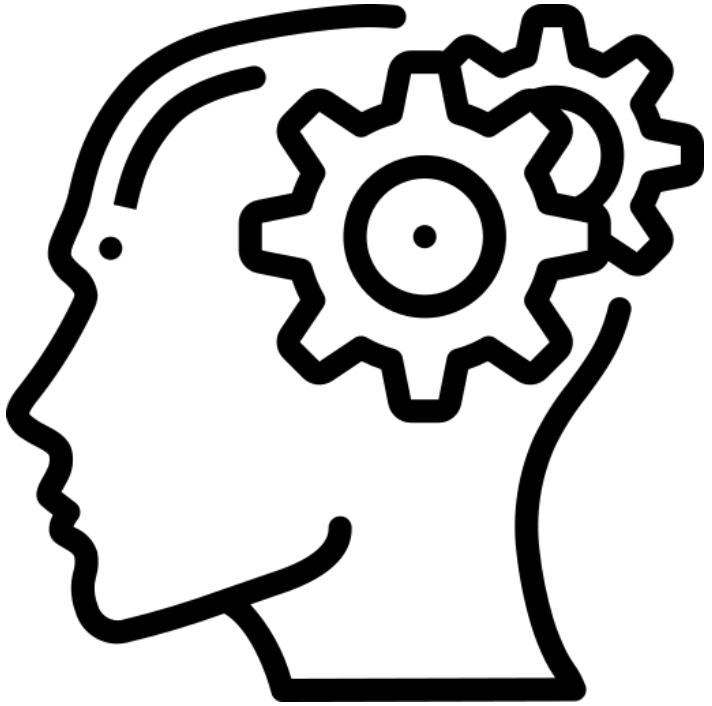
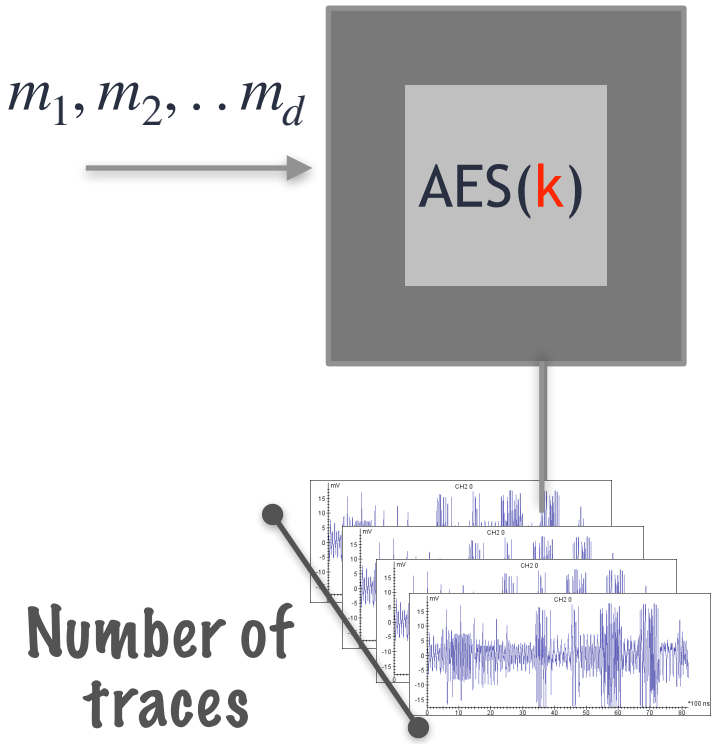
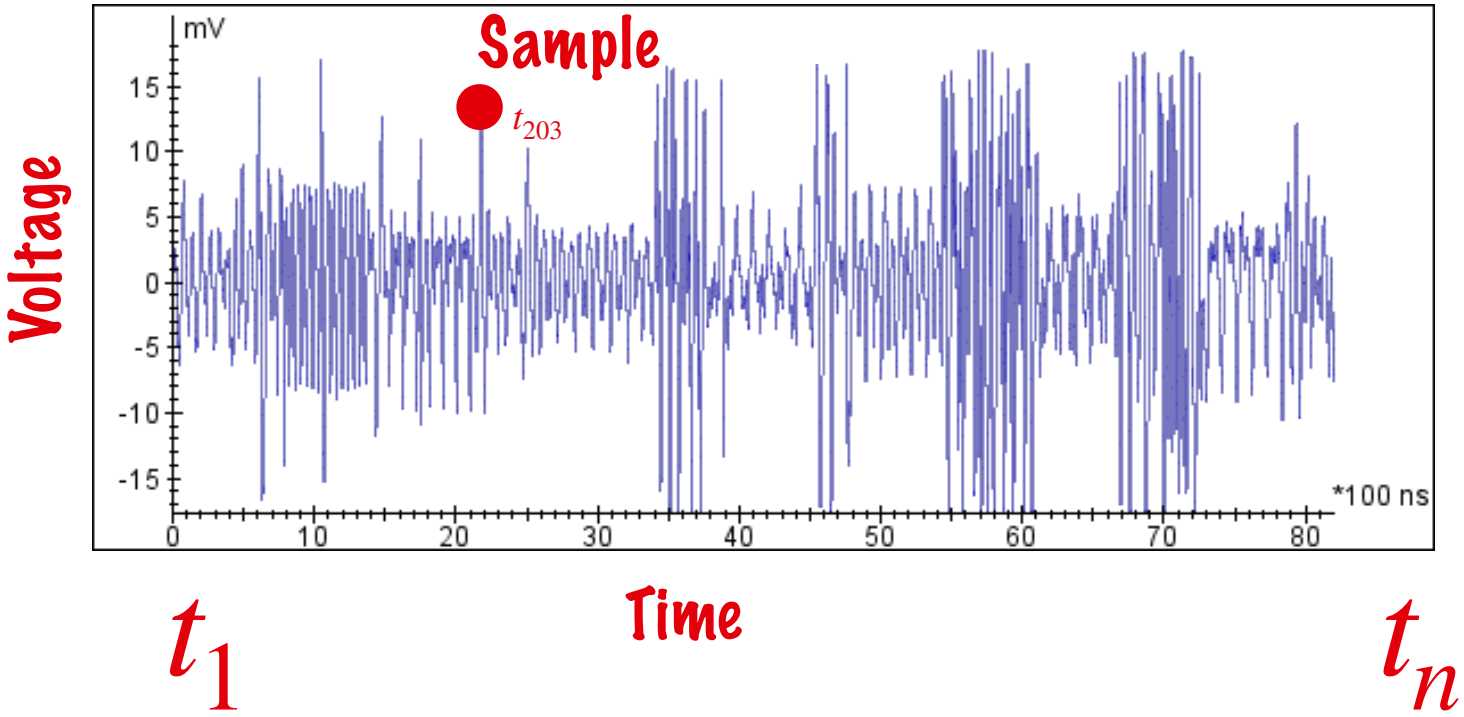


Answer: S-box out, Round-out

2. Measure (power) traces



Anatomy of a power trace



It is important that the traces are aligned.

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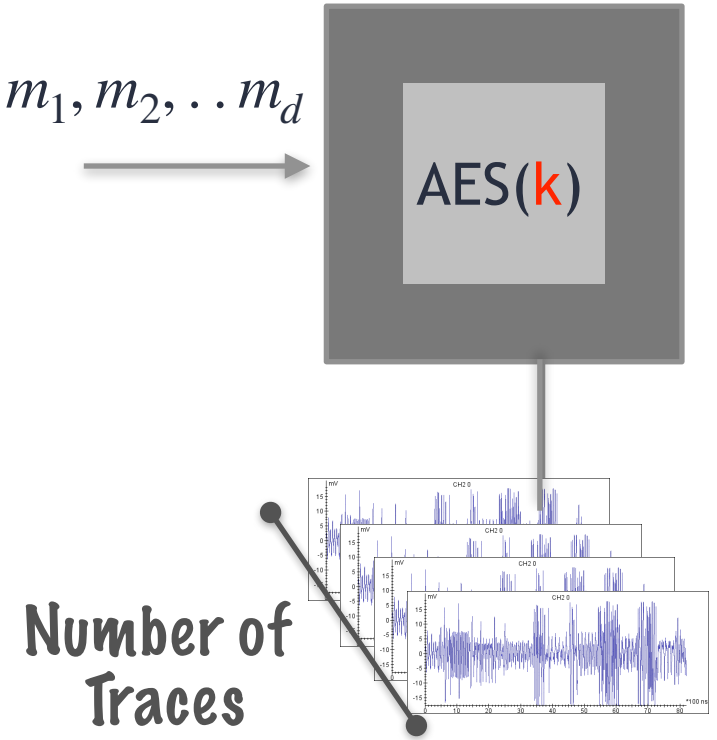
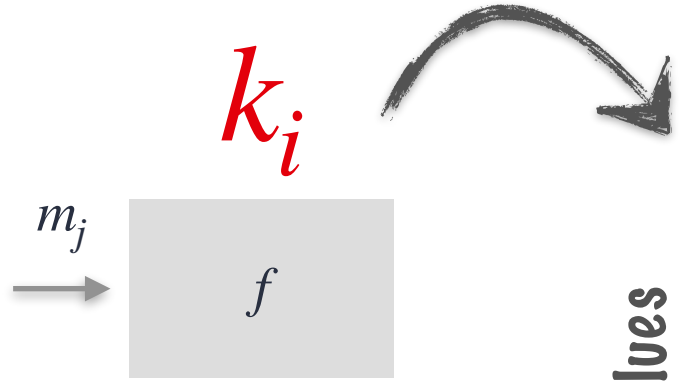


m_1	t_1^1	t_2^1		t_n^1	c_1
m_2	t_1^2	t_2^2		t_n^2	c_2
m_d	t_1^d	t_2^d		t_n^d	c_d

It is important that the traces are aligned.

3. Calculate Hypothetical Intermediate Values



$$v_{i,j} = f(k_i, m_j)$$

Possible values

0000 0000
0000 0001
0000 0010

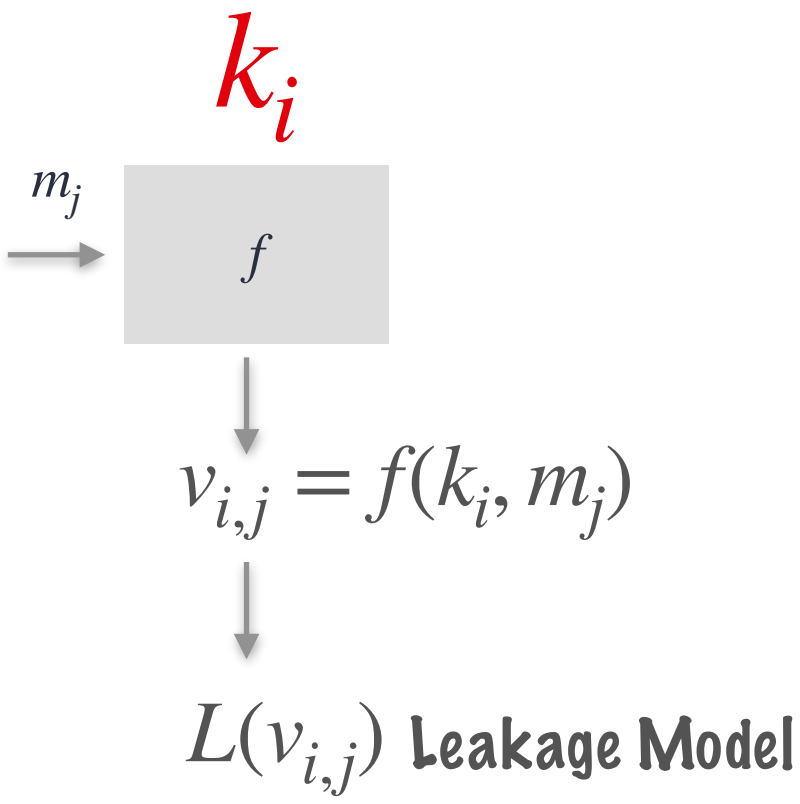
1111 1110
1111 1111

$v_{0,\_} = f(0000\ 0000, m_j)$
$v_{1,\_} = f(0000\ 0001, m_j)$
$v_{2,\_} = f(0000\ 0010, m_j)$

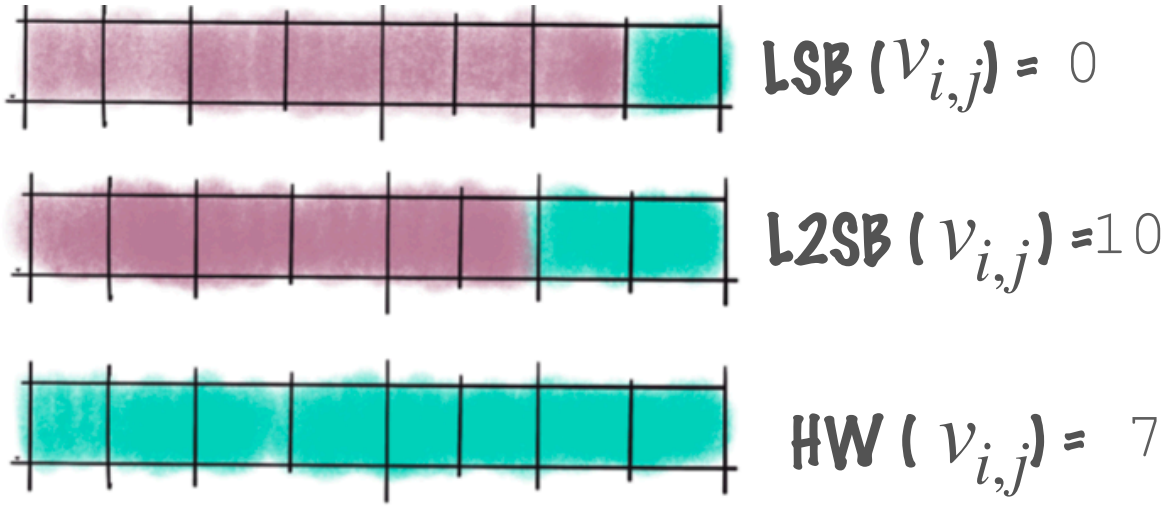
$v_{254,\_} = f(1111\ 1110, m_j)$
$v_{255,\_} = f(1111\ 1111, m_j)$

List of Hypothetical Intermediate Values

4. Map Intermediate Values -> Power Values



$v_{i,j} =$ 1111 1110

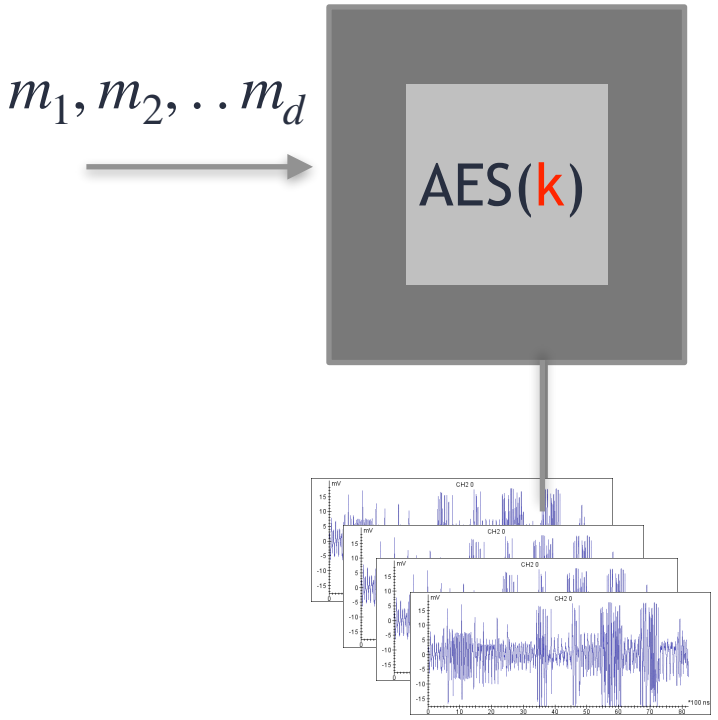


4. Map Intermediate Values -> Power Values

Construct prediction matrix

	k_0	k_1		k_{255}
m_1	$L(v_{0,m_j^1})$	$L(v_{1,m_j^1})$		$L(v_{255,m_j^1})$
m_2	$L(v_{0,m_j^2})$	$L(v_{1,m_j^2})$		$L(v_{255,m_j^2})$
m_d	$L(v_{0,m_j^d})$	$L(v_{1,m_j^d})$		$L(v_{255,m_j^d})$

5. Compare Intermediate Values <-> Power Traces



	k_0	k_1		k_{255}
m_1	$L(v_{0,m_j^1})$	$L(v_{1,m_j^1})$		$L(v_{255,m_j^1})$
m_2	$L(v_{0,m_j^2})$	$L(v_{1,m_j^2})$		$L(v_{255,m_j^2})$
m_d	$L(v_{0,m_j^d})$	$L(v_{1,m_j^d})$		$L(v_{255,m_j^d})$

5. Compare Intermediate Values <-> Power Traces

Traces

m_1	t_1^1	t_2^1		t_n^1	c_1
m_2	t_1^2	t_2^2		t_n^2	c_2
m_d	t_1^d	t_2^d		t_n^d	c_d

	k_0	k_1		k_{255}
m_1	$L(v_{0,m_j^1})$	$L(v_{1,m_j^1})$		$L(v_{255,m_j^1})$
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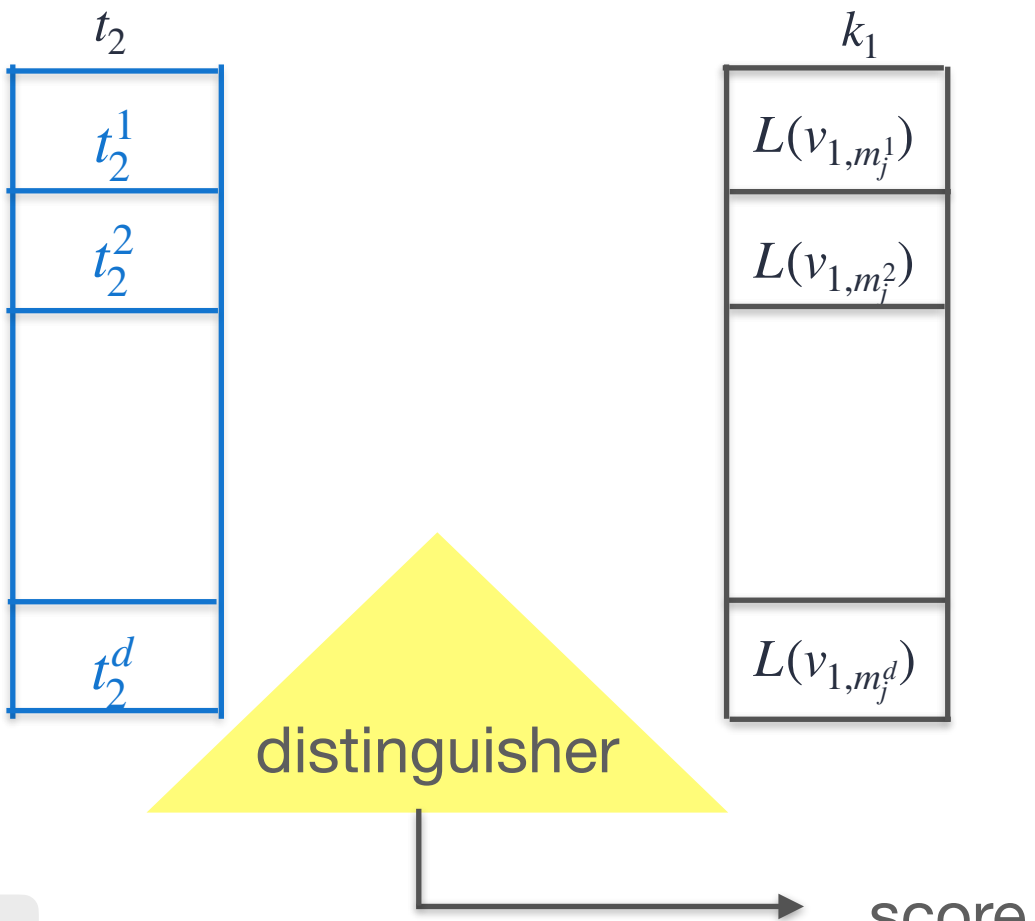
m_d	$L(v_{0,m_j^d})$	$L(v_{1,m_j^d})$		$L(v_{255,m_j^d})$

distinguisher

5. Compare Intermediate Values <-> Power Traces



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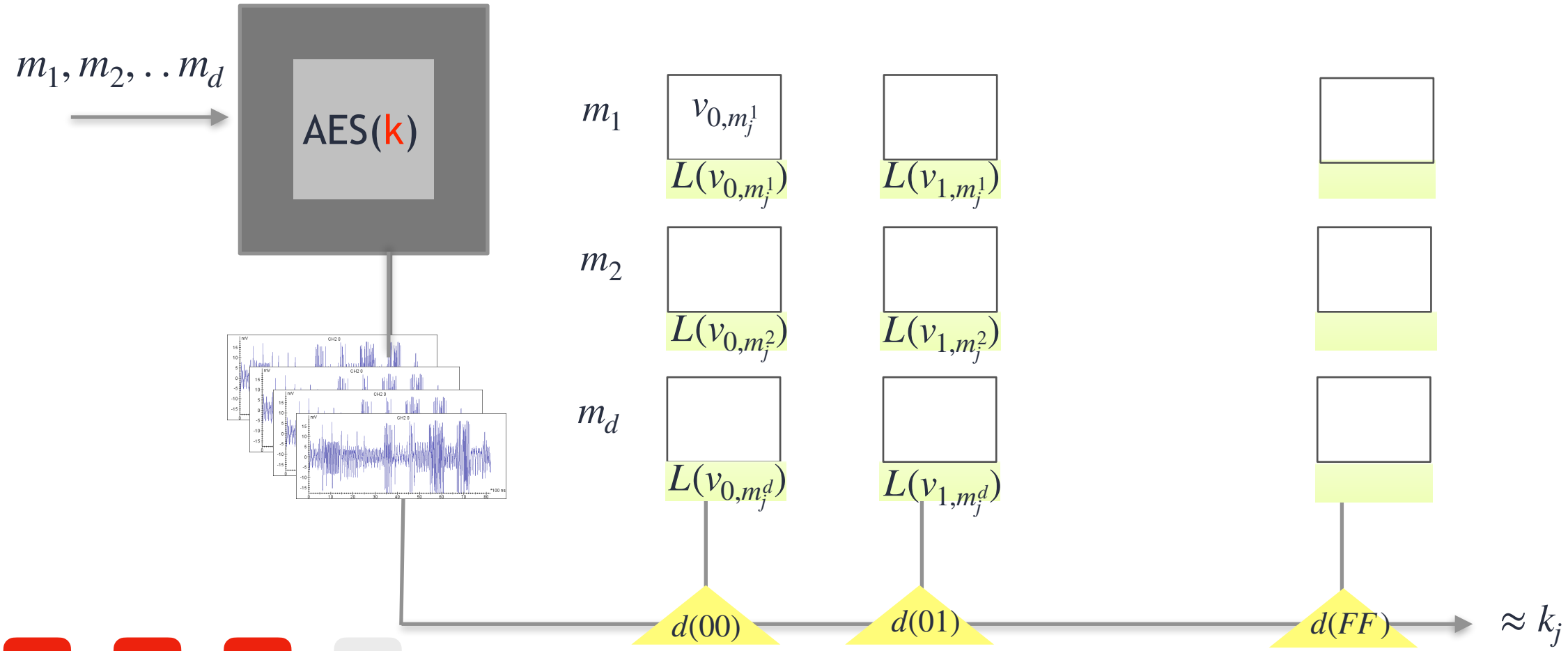

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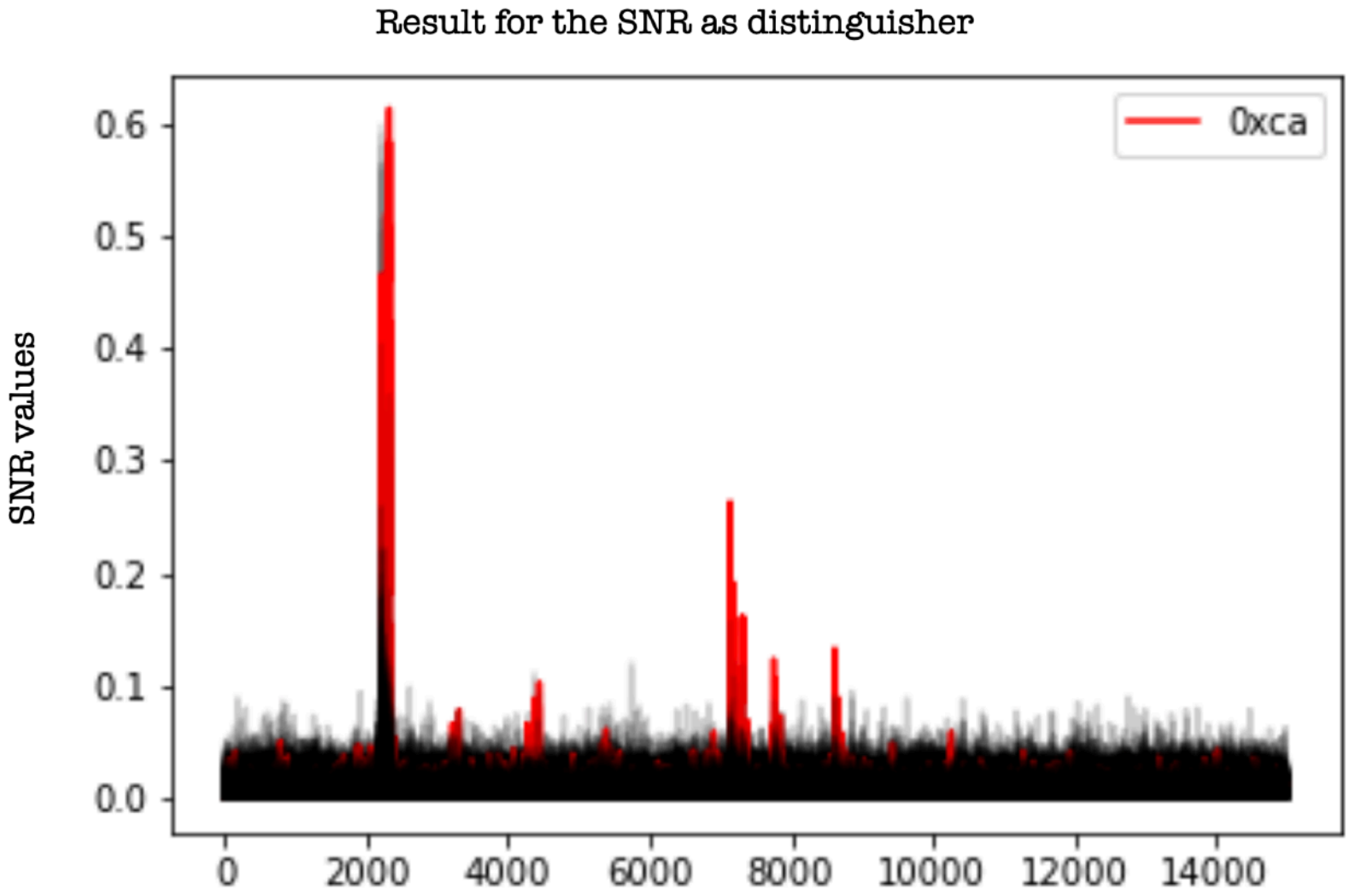
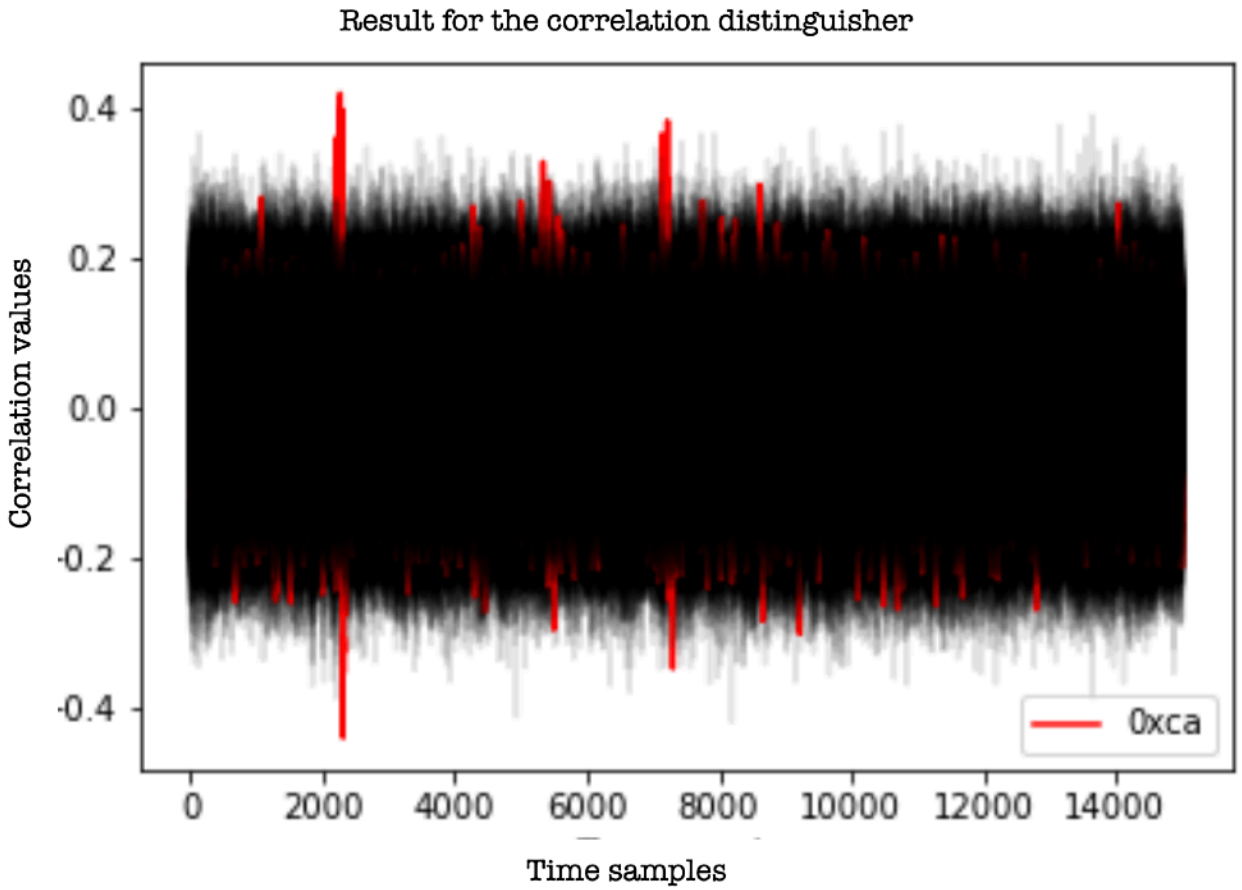


5. Compare Intermediate Values <-> Power Traces



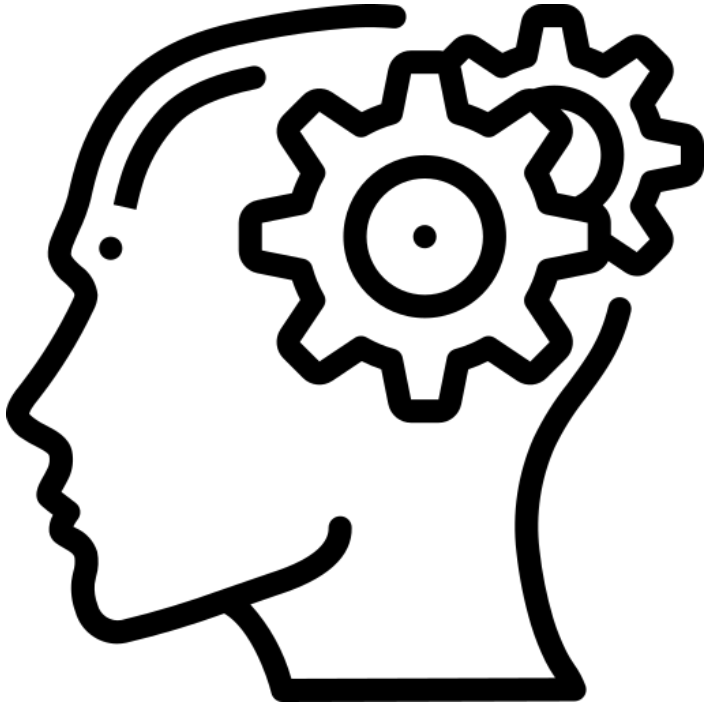
DPA attacks summary

- Choice of leakage model is key to a successfull attack
- Choice of distinguisher:
  - the most powerful is the Correlation Coefficient
  - the most intuitive one is the Difference of Means (DoM)
- DPA vs CPA
- Security order - unprotected implementation - univariate

Countermeasures

Take a few minutes

What would make a good intermediate value for block ciphers? e.g. AES, DES



Answer: S-box out, Round-out

Protection at different levels

Break the link between (actual) intermediate computation values and power consumption

- ➡Transistor-level: special logic styles e.g. WDDL, SABL
- ➡Platform-level: redundancy, adding jitter, noise, . . .
- ➡Program-level: dummy instructions, randomized order, . . .
- ➡Algorithmic level: depends on algebraic operations
- ➡Protocol level: key usage limits, session keys, . . .

The main idea

Masking:

- A random mask is concealing every intermediate value
- The power consumption depends on the masked values and not on the actual values.
- Masking is in principle done on the algorithmic level

Hiding:

- Making power consumption independent of the intermediate values and ofthe operations, uniform or randomized
- Examples: special logic styles, randomization in time domain, lowering SNR

THANK YOU