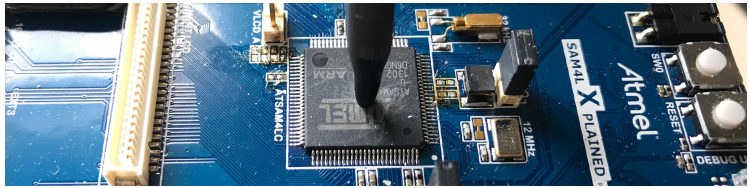

CHES 2023 challenge

SMAesH challenge

Gaëtan Cassiers Charles Momin François-Xavier Standaert

SIMPLE-Crypto

Content

In the CHES2022 Rump session episode

SIMPLE-Crypto Association

Open Source Secure Implementation of Cryptographic Algorithms

Concretely...

Current stage

- Higher-order masked AES in hardware (soon a CTF?)
- SCALib: side-channel evaluation library,

SMAesH challenge

SMAesH you said?

- Masked AES HW IP
- HPC2 (arbitrary order)
- Provably secure
- PRNG included

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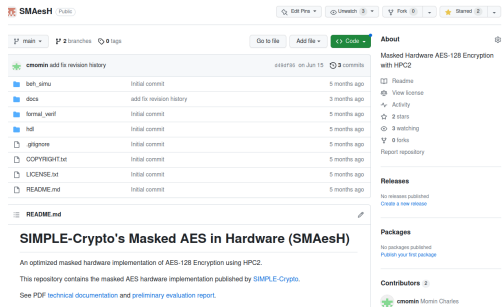

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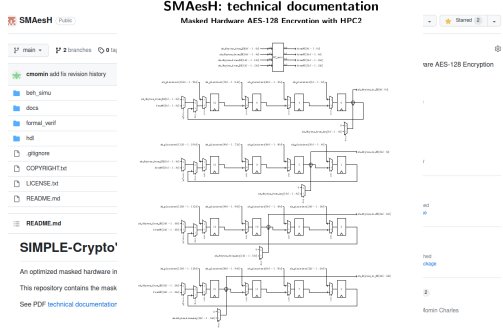

Figure 9: Global architecture of the `MSKaes_32bits_state_datapath`module. The value held by the DFF at index i is depicted by the signal `sh_reg_out[i]` in the HDL.

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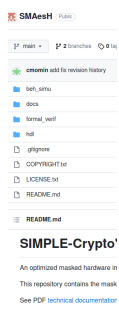

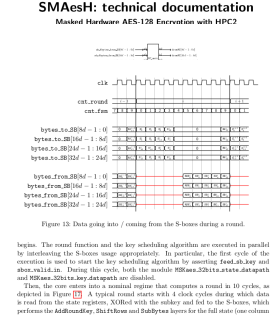

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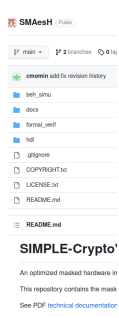

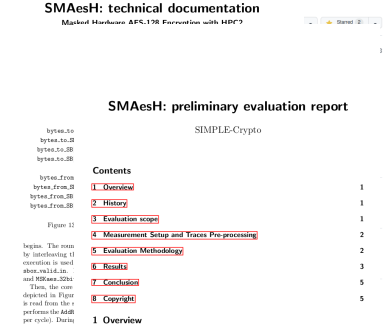

SMAesH you said?

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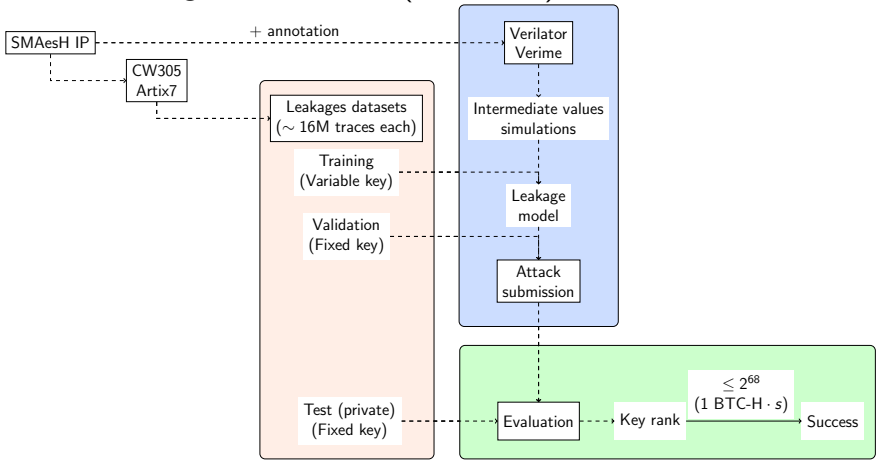
→ See `simple-crypto.org/activities/smaesh/`

Challenge description

Goal: SCA attack against SMAesH (first order)



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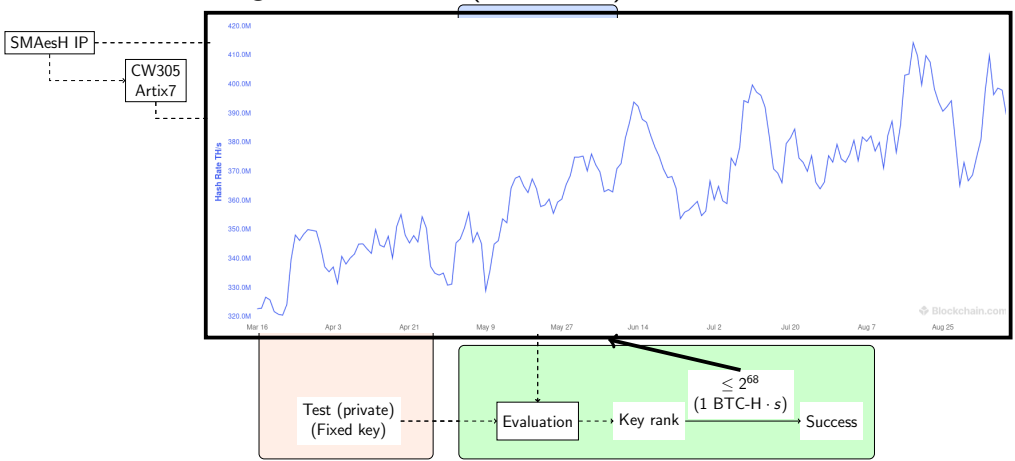

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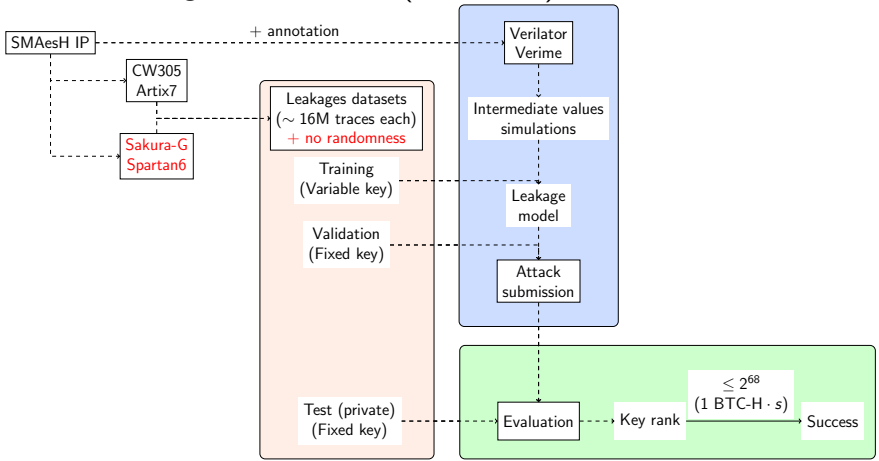

Challenge Stats

- 5 teams: $\infty\times$ '20 CTF :D

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- 112 submissions

Challenge Stats

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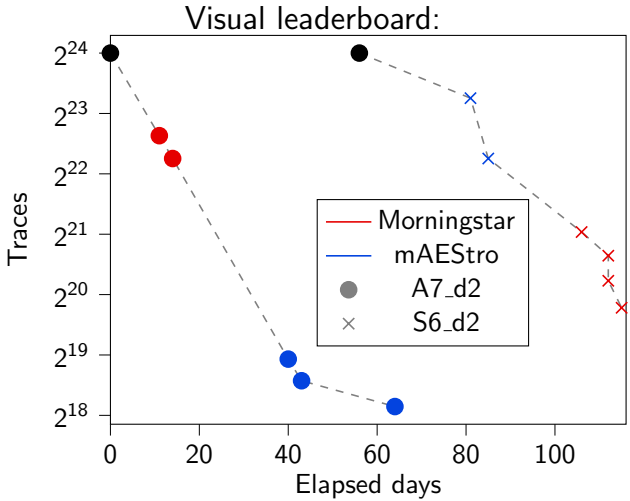
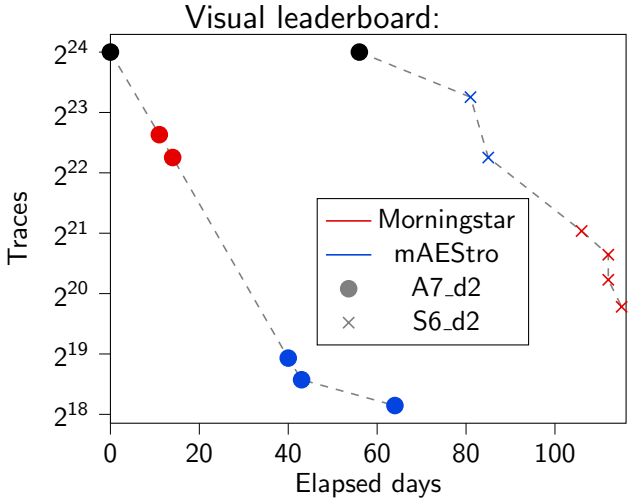
- A7_d2:
  - → 77 submissions
  - → 5 successful attacks
- S6_d2:
  - → 35 submissions
  - → 6 successful attacks

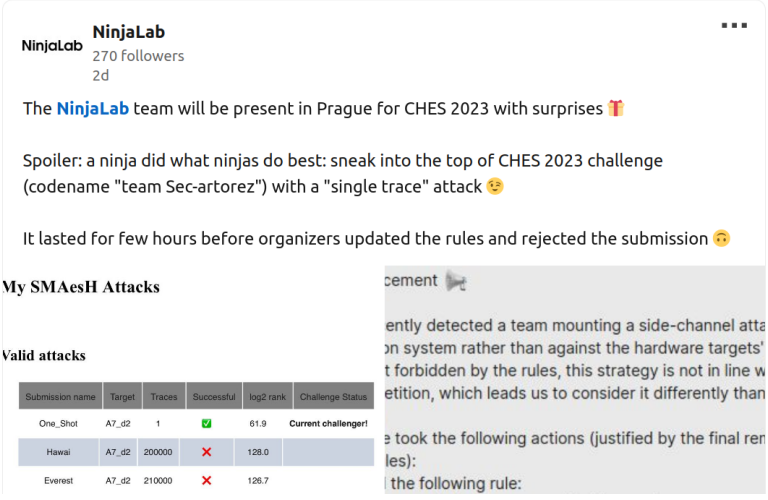


Challenge Stats

- 5 teams: $\infty\times$ '20 CTF :D
- 112 submissions
- A7_d2:
  - → 77 submissions
  - → 5 successful attacks
- S6_d2:
  - → 35 submissions
  - → 6 successful attacks
- Peak rates:
  - 2 submissions/h/team
  - 12 submissions/day



These damn ninjas cutting onions...



Winners

- Prizes[a] for most points and best attack!

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- A7_d2:
  - Most points: Valence Cristiani (team mAEStro)
  - Best attack: Valence Cristiani (team mAEStro)
- S6_d2:
  - Most points: Valence Cristiani (team mAEStro)
  - Best attack: Thomas Marquet (team Morningstar)

[a] Teams cannot win more than one prize...

- Valence Cristiani (NinjaLab) is awarded 1000 USD
- Thomas Marquet (AAU) is awarded 500 USD

Congratulations!

Content

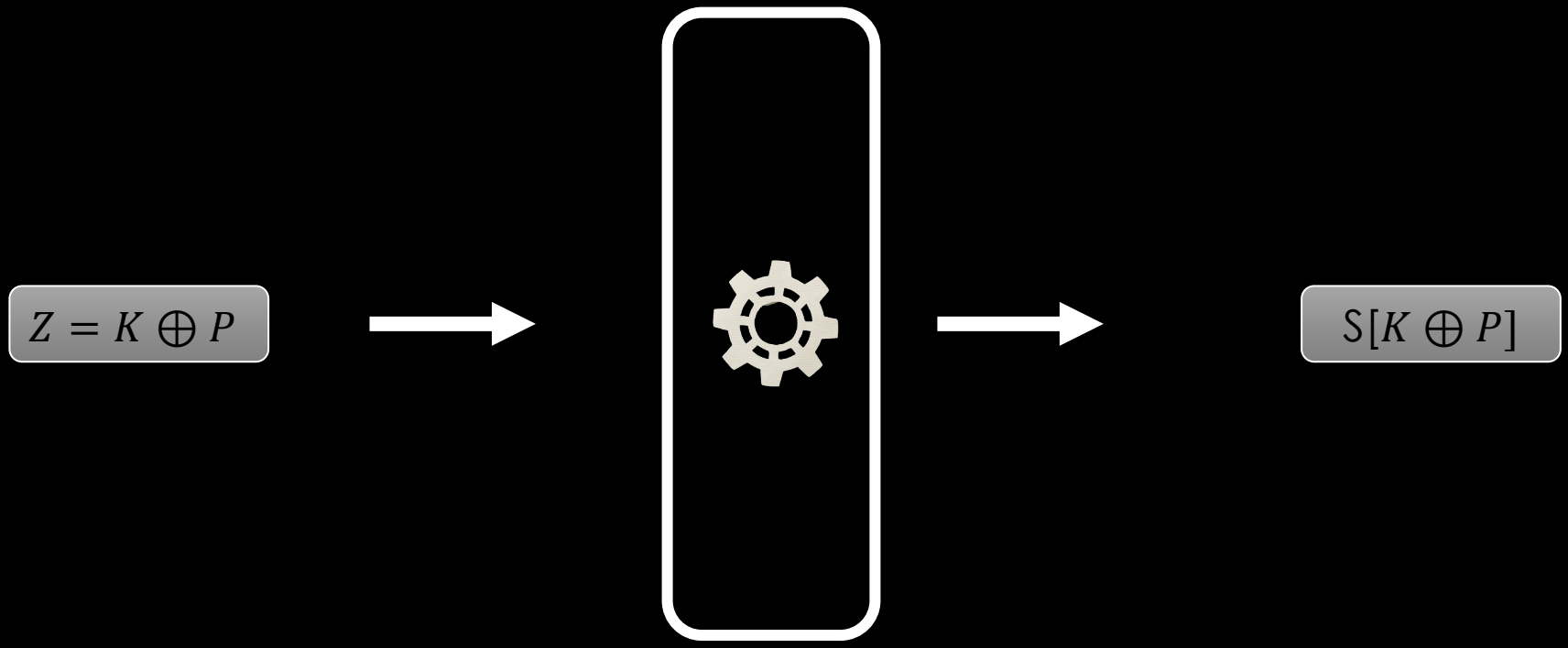
HOW TO SMASH THE SMAESH CHES CHALLENGE ?

BEING HONEST OR EVIL…

Valence Cristiani | Ches 2023

NinjaLab

BEING AN HONEST GUY



BEING AN HONEST GUY

$Z = K \oplus P$

```
T1 = U0 + U3
T2 = U0 + U5
T3 = U0 + U6
T4 = U3 + U5
T5 = U4 + U6
T6 = T1 + T5
T7 = U1 + U2
```

```
T8 = U7 + T6
T9 = U7 + T7
T10 = T6 + T7
T11 = U1 + U5
T12 = U2 + U5
T13 = T3 + T4
T14 = T6 + T11
```

```
T15 = T5 + T11
T16 = T5 + T12
T17 = T9 + T16
T18 = U3 + U7
T19 = T7 + T18
T20 = T1 + T19
T21 = U6 + U7
```

```
T22 = T7 + T21
T23 = T2 + T22
T24 = T2 + T10
T25 = T20 + T17
T26 = T3 + T16
T27 = T1 + T12
```

Figure 5: Top linear transform in forward direction.

```
T23 = U0 + U3
T22 = U1 # U3
T2 = U0 # U1
T1 = U3 + U4
T24 = U4 # U7
R5 = U6 + U7
T8 = U1 # T23
```

```
T19 = T22 + R5
T9 = U7 # T1
T10 = T2 + T24
T13 = T2 + R5
T3 = T1 + R5
T25 = U2 # T1
R13 = U1 + U6
```

```
T17 = U2 # T19
T20 = T24 + R13
T4 = U4 + T8
R17 = U2 # U5
R18 = U5 # U6
R19 = U2 # U4
Y5 = U0 + R17
```

```
T6 = T22 + R17
T16 = R13 + R19
T27 = T1 + R18
T15 = T10 + T27
T14 = T10 + R18
T26 = T3 + T16
```

Figure 6: Top linear transform in reverse direction.

$S[K \oplus P]$

```
M1 = T13 x T6
M2 = T23 x T8
M3 = T14 + M1
M4 = T19 x D
M5 = M4 + M1
M6 = T3 x T16
M7 = T22 x T9
M8 = T26 + M6
M9 = T20 x T17
M10 = M9 + M6
M11 = T1 x T15
M12 = T4 x T27
M13 = M12 + M11
M14 = T2 x T10
M15 = M14 + M11
M16 = M3 + M2
```

```
M17 = M5 + T24
M18 = M8 + M7
M19 = M10 + M15
M20 = M16 + M13
M21 = M17 + M15
M22 = M18 + M13
M23 = M19 + T25
M24 = M22 + M23
M25 = M22 x M20
M26 = M21 + M25
M27 = M20 + M21
M28 = M23 + M25
M29 = M28 x M27
M30 = M26 x M24
M31 = M20 x M23
M32 = M27 x M31
```

```
M33 = M27 + M25
M34 = M21 x M22
M35 = M24 x M34
M36 = M24 + M25
M37 = M21 + M29
M38 = M32 + M33
M39 = M23 + M30
M40 = M35 + M36
M41 = M38 + M40
M42 = M37 + M39
M43 = M37 + M38
M44 = M39 + M40
M45 = M42 + M41
M46 = M44 x T6
M47 = M40 x T8
M48 = M39 x D
```

```
M49 = M43 x T16
M50 = M38 x T9
M51 = M37 x T17
M52 = M42 x T15
M53 = M45 x T27
M54 = M41 x T10
M55 = M44 x T13
M56 = M40 x T23
M57 = M39 x T19
M58 = M43 x T3
M59 = M38 x T22
M60 = M37 x T20
M61 = M42 x T1
M62 = M45 x T4
M63 = M41 x T2
```

Sbox tower fileds implementation

BEING AN HONEST GUY

T1 = U0 + U3	T8 = U7 + T6	T15 = T5 + T11	T22 = T7 + T21
T2 = U0 + U5	T9 = U7 + T7	T16 = T5 + T12	T23 = T2 + T22
T3 = U0 + U6	T10 = T6 + T7	T17 = T9 + T16	T24 = T2 + T10
T4 = U3 + U5	T11 = U1 + U5	T18 = U3 + U7	T25 = T20 + T17
T5 = U4 + U6	T12 = U2 + U5	T19 = T7 + T18	T26 = T3 + T16
T6 = T1 + T5	T13 = T3 + T4	T20 = T1 + T19	T27 = T1 + T12
T7 = U1 + U2	T14 = T6 + T11	T21 = U6 + U7	

Figure 5: Top linear transform in forward direction.

T23 = U0 + U3	T19 = T22 + R5	T17 = U2 # T19	T6 = T22 + R17
T22 = U1 # U3	T9 = U7 # T1	T20 = T24 + R13	T16 = R13 + R19
T2 = U0 # U1	T10 = T2 + T24	T4 = U4 + T8	T27 = T1 + R18
T1 = U3 + U4	T13 = T2 + R5	R17 = U2 # U5	T15 = T10 + T27
T24 = U4 # U7	T3 = T1 + R5	R18 = U5 # U6	T14 = T10 + R18
R5 = U6 + U7	T25 = U2 # T1	R19 = U2 # U4	T26 = T3 + T16
T8 = U1 # T23	R13 = U1 + U6	Y5 = U0 + R17	

Figure 6: Top linear transform in reverse direction.

M1 = T13 x T6	M17 = M5 + T24	M33 = M27 + M25	M49 = M43 x T16
M2 = T23 x T8	M18 = M8 + M7	M34 = M21 x M22	M50 = M38 x T9
M3 = T14 + M1	M19 = M10 + M15	M35 = M24 x M34	M51 = M37 x T17
M4 = T19 x D	M20 = M16 + M13	M36 = M24 + M25	M52 = M42 x T15
M5 = M4 + M1	M21 = M17 + M15	M37 = M21 + M29	M53 = M45 x T27
M6 = T3 x T16	M22 = M18 + M13	M38 = M32 + M33	M54 = M41 x T10
M7 = T22 x T9	M23 = M19 + T25	M39 = M23 + M30	M55 = M44 x T13
M8 = T26 + M6	M24 = M22 + M23	M40 = M35 + M36	M56 = M40 x T23
M9 = T20 x T17	M25 = M22 x M20	M41 = M38 + M40	M57 = M39 x T19
M10 = M9 + M6	M26 = M21 + M25	M42 = M37 + M39	M58 = M43 x T3
M11 = T1 x T15	M27 = M20 + M21	M43 = M37 + M38	M59 = M38 x T22
M12 = T4 x T27	M28 = M23 + M25	M44 = M39 + M40	M60 = M37 x T20
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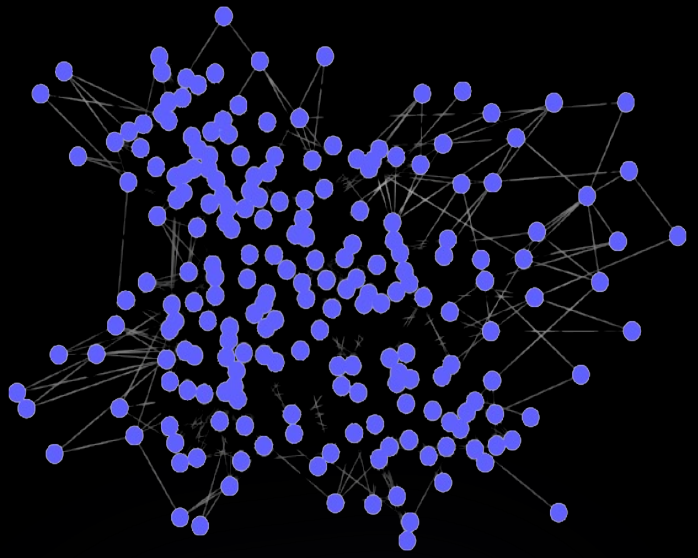
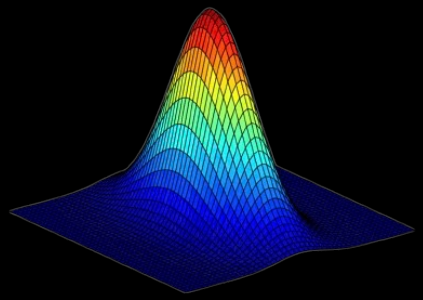


Build the ~~huge and horrible~~ graph from the equations

Make more than 4000 Gaussian templates (2 for each node since it's masked)



Apply belief propagation algorithm (SASCA) and recover the key

BEING AN HONEST GUY

T1 = U0 + U3	T8 = U7 + T6	T15 = T5 + T11	T22 = T7 + T21
T2 = U0 + U5	T9 = U7 + T7	T16 = T5 + T12	T23 = T2 + T22
T3 = U0 + U6	T10 = T6 + T7	T17 = T9 + T16	T24 = T2 + T10
T4 = U3 + U5	T11 = U1 + U5	T18 = U3 + U7	T25 = T20 + T17
T5 = U4 + U6	T12 = U2 + U5	T19 = T7 + T18	T26 = T3 + T16
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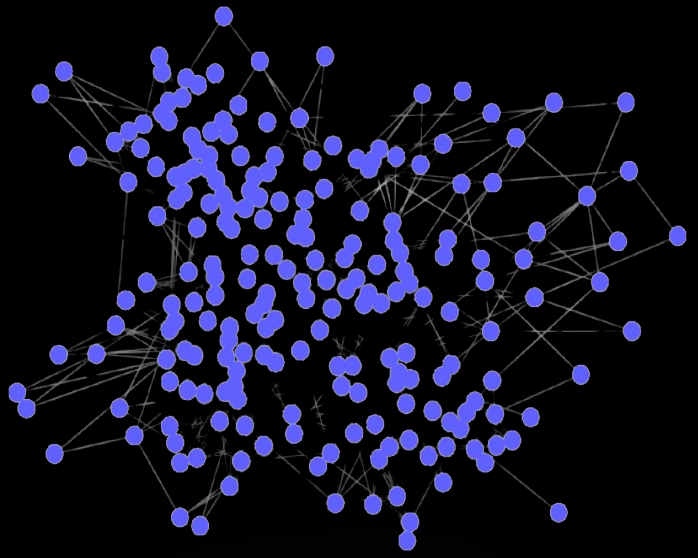

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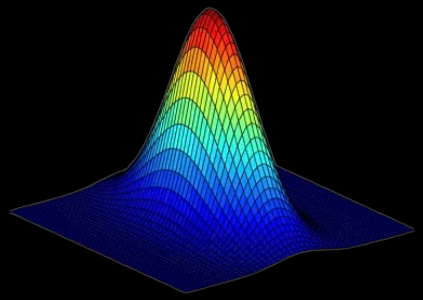


290k traces

Apply belief propagation algorithm (SASCA) and get the key

BEING AN HONEST GUY

But it…

- Requires to understand a lot of theory (graphs, BP algorithm, dealing with the loops etc…)
- Is very long
- Does not even guarantee to win

BEING AN HONEST GUY

But it…

- Requires to understand a lot of theory (graphs, BP algorithm, dealing with the loops etc…)
- Is very long
- Does not even guarantee to win

One need a 0 trace attack !

BEING A BAD GUY

Let's use another side-channel ? Power leakage is so old shcool…

The evaluation framework may leak some information

Inazawa	A7_d2	225000	✗	127.7

Upper bound of $\log_2(KeyRank)$

Aggregating many well-crafted submissions may allow to extract enough information on the key → 60 bits is enough !

BEING AN BAD GUY

How many submissions?

- Uniform probability for all bytes except one
- Return a different score for each of the 256 values with a uniform spacing (ex: 1, 2 … , 256)

Obfuscate this behind a neural network…

- Upload the submission and store the $\log_2(KeyRank)$

↓

Avergage of **4.9** bits of information per submissions

4.9 x 13 = 63.7

Require 13 submissions !

BEING A BAD GUY

Read it backwards…

I created a new account named ***Sec-artorez***

Hawai	A7_d2	200000	✗	128.0
Everest	A7_d2	210000	✗	126.7
Dubai	A7_d2	220000	✗	123.8
Inazawa	A7_d2	225000	✗	127.7
Bahamas	A7_d2	215000	✗	127.8
Zanzibar	A7_d2	200000	✗	127.0
Antarctica	A7_d2	180000	✗	127.3
Capri	A7_d2	205000	✗	128.0
Faliraki	A7_d2	220000	✗	125.2
Gaios	A7_d2	180000	✗	127.9
Jakarta	A7_d2	189000	✗	125.0
Kuala Lumpur	A7_d2	230000	✗	123.3

- First letter is a reminder for the concerned byte
- Space the submission by ~ 2 days…

Local analysis reveals that the we gained 66.1 bits. Means that we should have :

$$\log_2(KeyRank) = 61.9$$

- Aggregate the results and mount the final attack.

And…

BEING A BAD GUY

Number of traces

One_Shot	A7_d2	1	✅	61.9	**Current challenger!**

The SMAesH challenge has been SMASHED

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT

SMAesH Challenge : Or how to enjoy your summer

Thomas Marquet

September 11, 2023

Context

Spartan-6 dataset

- Hardware masked AES with two shares (r and $x \oplus r$)
- No access to r
- Perfectly synchronized traces
- Low SnR
- Problem : How to pick up enough signal ?
- Solution : Praying to the deep learning god

Intermediates under attack

$$\texttt{bytes\_to\_SB}[8d-1:0]$$
$$\texttt{bytes\_to\_SB}[16d-1:8d]$$
$$\texttt{bytes\_to\_SB}[24d-1:16d]$$
$$\texttt{bytes\_to\_SB}[32d-1:24d]$$

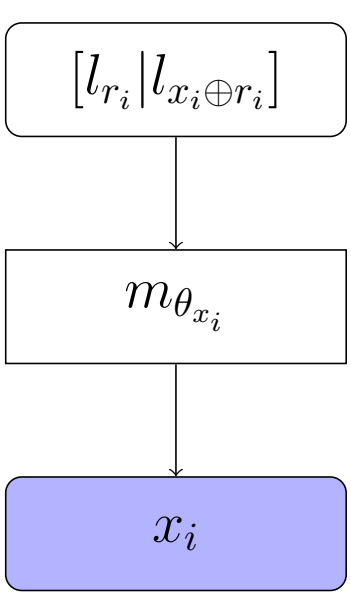
Figure: The victim

Strategy :

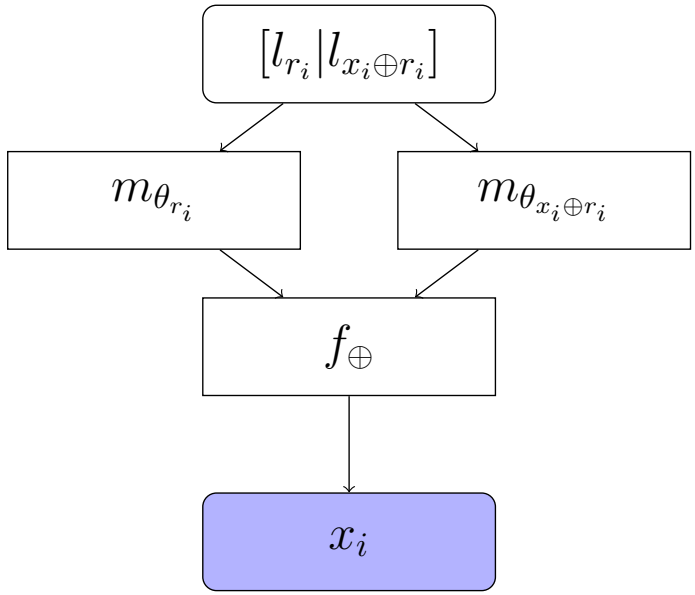
- Recover S_{12}, S_1, S_6, S_{11}
- Recover S_i from $S_i \oplus S_{i+4}$ $(mod\ 16)$

Deep learning when randomness isn't known
Single-task

With $m_{\theta_{x_i}}$ the set of layers expected to fit the intermediate x_i



(a) A model that do not work (most of the time)



(b) A model that do work (sometimes)

Figure: Hard encoding of the masking scheme inside the network

Simply better model
I swear it's not that ugly

l_{c_0} = clk 3 to 11 , l_{c_1} = clk 4 to 12, l_{c_2} = clk 5 to 13

$x_i = S_i \oplus S_{i+4}$ $(mod\ 16)$

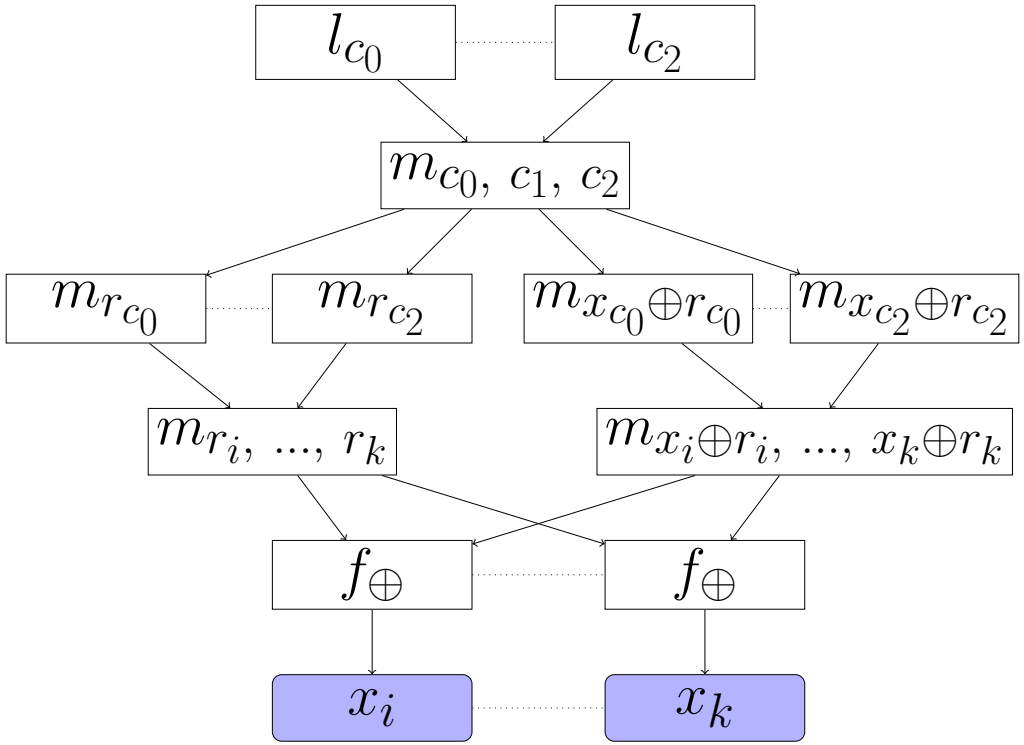


Figure: Multi-task model to recover the transitions x_i

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Conclusion

- It leaks less than ASCAD
- Cross entropy go from 5.5452 to 5.5452
- Sun light is overrated

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What's next?

- Secret fixed key datasets will be published.
- Leaderboard will be updated with SOTA attack.
- SMAesH public evaluation continues...
- ... And more are coming!
  → What are you waiting for?

SIMPLE-crypto

Interested? Want to participate? Question or suggestion?

- SIMPLE-crypto website

  `https://www.simple-crypto.org/`

- SMAesH challenge website

  `https://smaesh-challenge.simple-crypto.org/`

- Contact

  `info@simple-crypto.org`

(or with a beer now ;))

THANKS