IronMask

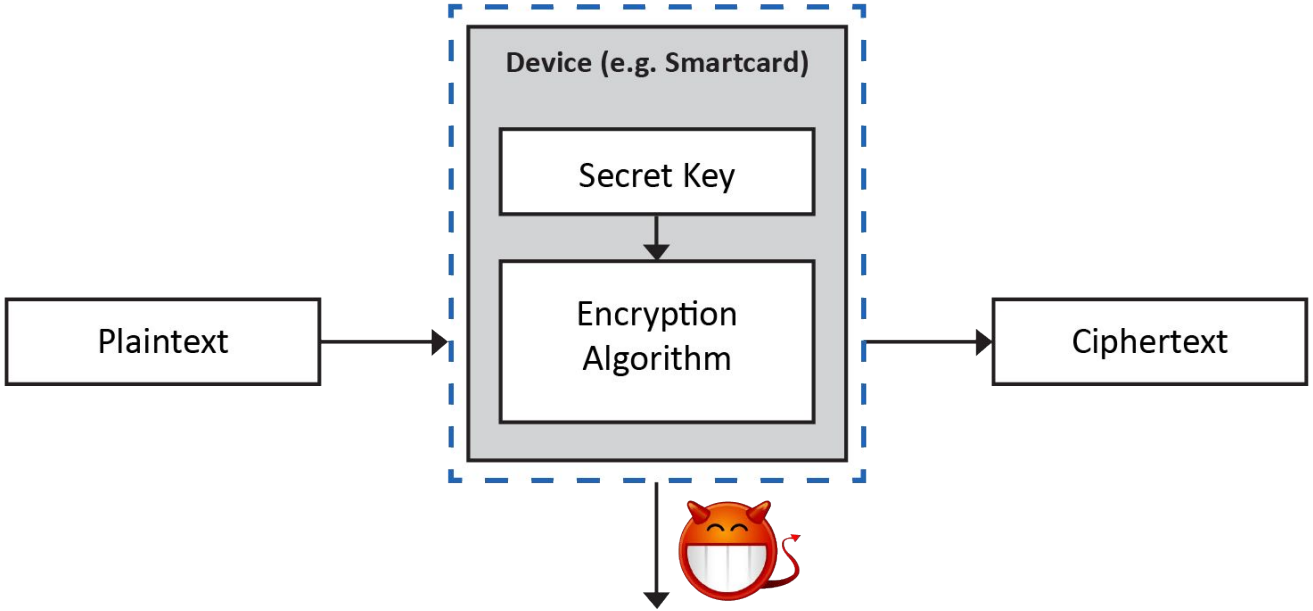
Versatile Verification of Masking Security

Sonia Belaïd Darius Mercadier
Matthieu Rivain Abdel Taleb

CryptoExperts, France

LIP6 Seminar - ALMASTY
February 10, 2022

Introduction - Side-Channel Attacks



Introduction - Masking

Sensitive variable x

$$x = x_0 \oplus \ldots \oplus x_{n-1}$$

All *n* shares are needed to recover the value of x

Leakage Models

- *t*-Probing model

  t variables leak during an execution

- Random probing model

  each variable leaks with fixed probability *p*

- Noisy leakage model

  each variable leaks a noisy function of its value

Automatic Verification Tools

- Check security/composition properties for relatively small circuits/gadgets

- Determine which variable reveals information about the secret shares

- Conclude depending on the constraints of the properties (probing-like, random probing-like, …)

Contributions

- Formalisation of all of the probing and random probing properties from a single common building block.

- Exact verification method for almost all circuits/gadgets in the state-of-the-art, using an extension of the algebraic characterization introduced in [EC:BBPPTV16,C:BBPPTV17] of gadgets with linear randomness (all random values are additive) to more general gadgets with non-linear randomness (e.g multiplication gadgets with input refreshing) like [CHES:BCPZ16,EC:BelRivTal21].

- IronMask: an **exact** verification tool for **all** probing and random probing properties

Building Block for Security Properties

Simulation based definitions of all (random) probing properties

Given a set of probes P + a set of output shares O, determine the set of input shares I necessary for a perfect simulation

Example: set of variables $\{a_0 + r_0, a_1 + r_1, a_2\}$, uniform random values r_0, r_1

Input share a_2 is necessary for a perfect distribution simulation

Building Block for Security Properties

Simulation based definitions of all (random) probing properties

Given a set of probes P + a set of output shares O, determine the set of input shares I necessary for a perfect simulation

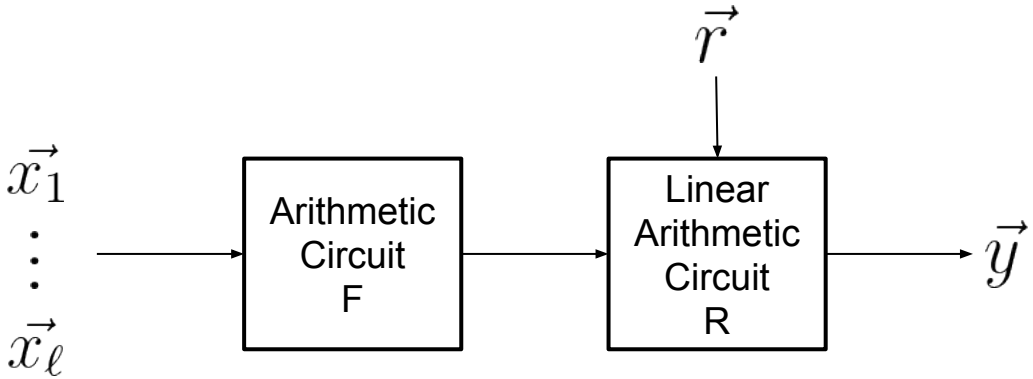
SIS: a function which outputs the smallest of the sets I

For a n-share ℓ -input 1-output gadget G

$$SIS_G(P, O) = (I_1, \ldots, I_\ell)$$

Algebraic Characterization of Gadgets

Gadgets with linear randomness



Probe *p* on such gadgets

$$p = f_p(\vec{x}_1, \ldots, \vec{x}_\ell) + \vec{r}^T \cdot \vec{s}_p$$

Algebraic Characterization of Gadgets

Gadgets with linear randomness: exact verification $p = f_p(\vec{x}_1, \ldots, \vec{x}_\ell) + \vec{r}^T \cdot \vec{s}_p$

Set of probes $\vec{P} = (p_1, \ldots, p_d)$

$$S = \begin{pmatrix} \vec{s}_{p_1} \\ \vdots \\ \vec{s}_{p_d} \end{pmatrix} \xrightarrow{\text{row reduction}} S' = N \cdot S = \begin{pmatrix} 0_{m,d-m} & 0_{m,R-d+m} \\ I_{d-m} & S'' \end{pmatrix}$$

$$\vec{P}' = N \cdot \vec{P} = (p'_1, \ldots, p'_m, p'_{m+1}, \ldots, p'_d)$$

Algebraic Characterization of Gadgets

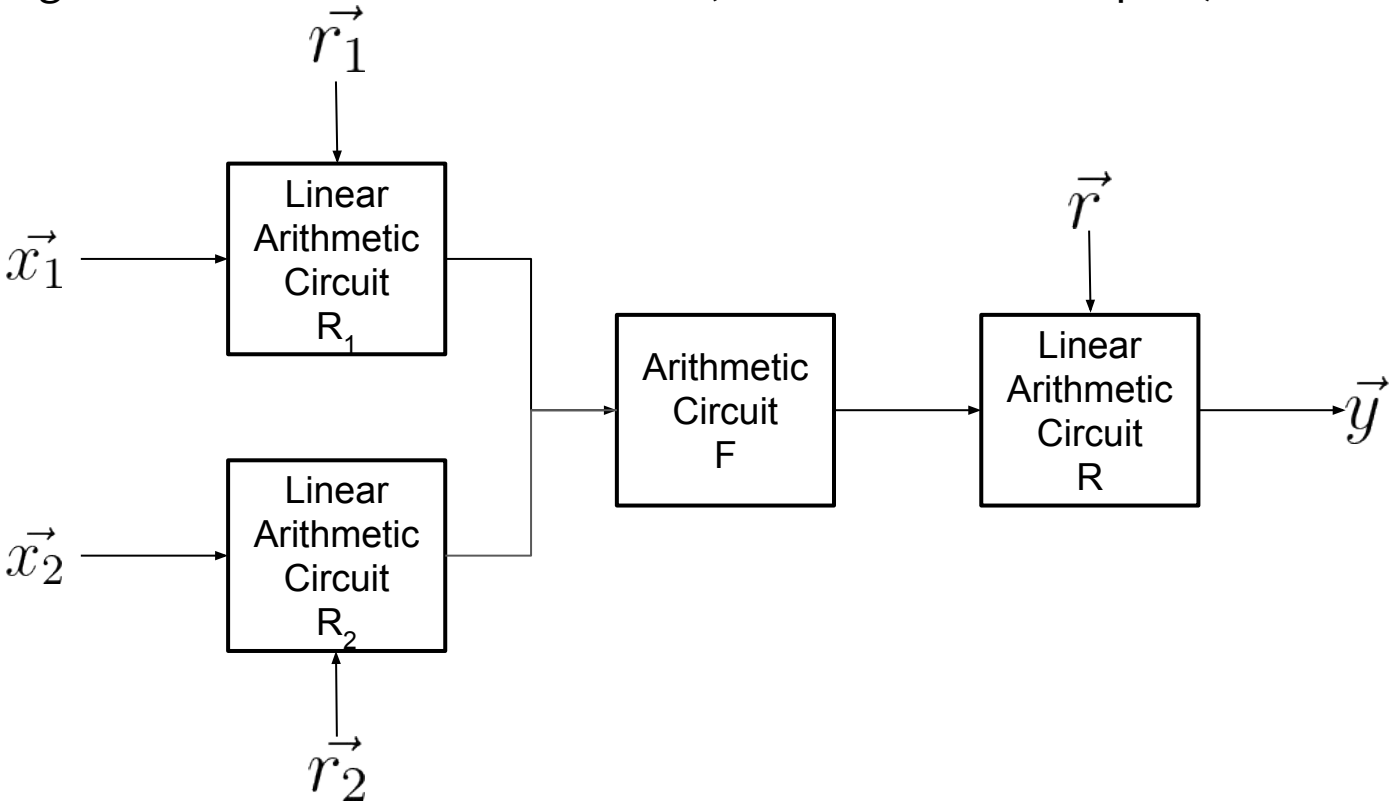
$$\vec{P'} = N \cdot \vec{P} = (p'_1, \ldots, p'_m, p'_{m+1}, \ldots, p'_d)$$

$(p'_{m+1}, \ldots, p'_d)$ can be simulated from uniform random values

Input shares necessary to simulate $\vec{P}$ are the same to simulate $(p'_1, \ldots, p'_m)$

Algebraic Characterization of Gadgets

Gadgets with non-linear randomness (illustration with 2 inputs)



Algebraic Characterization of Gadgets

Gadgets with non-linear randomness

Probe *p* on such gadgets

$$p = f_p(R_1(\vec{x_1}, \vec{r_1}), R_2(\vec{x_2}, \vec{r_2})) + \vec{r}^T \cdot \vec{s}_p$$

Perform three Gaussian Eliminations

- First with respect to $\vec{r}$
- Then with respect to $\vec{r_1}$ and $\vec{r_2}$

Proven Result: the strategy is an exact verification method for such gadgets

IronMask

- C Implementation of the new exact verification technique
- Implements state-of-the-art verification optimizations
- Represents variable dependence as integer arrays to accelerate operations

IronMask - overview

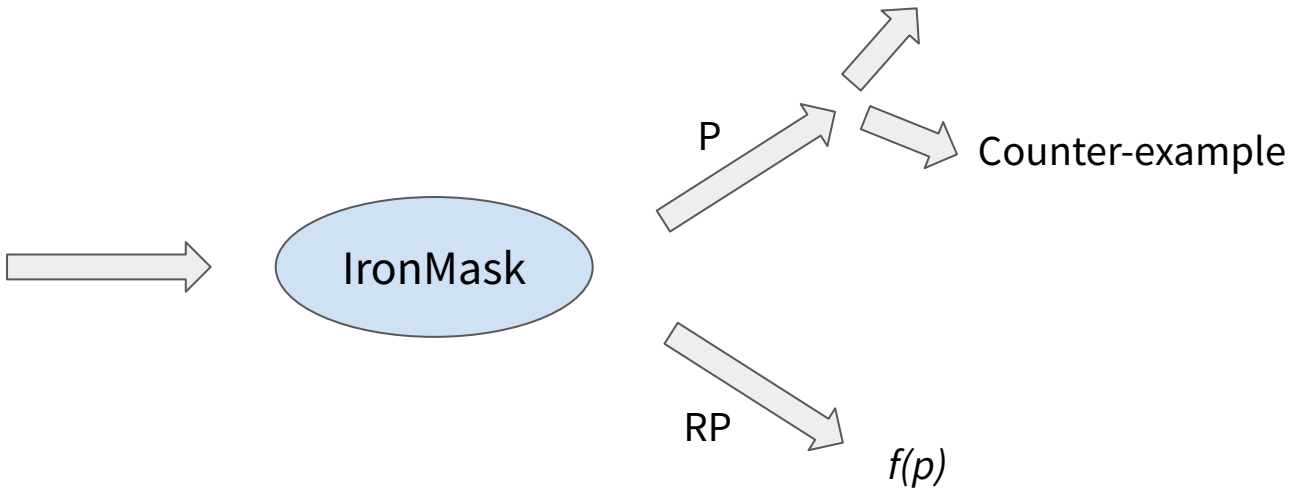
```
$ ./ironmask isw-2-shares.sage SNI -t 1
```

```
#shares 2
#in a b
#randoms r0
#out c

m0 = a0 * b1
t0 = r0 + m0
m1 = a1 * b0
t1 = t0 + m1

m2 = a0 * b0
c0 = m2 + r0

m3 = a1 * b1
c1 = m3 + t1
```



Evaluation - Scope

✔ handled
✔ handled but inexact
✘ not handled
P: Probing
RP: Random Probing

Tool	Properties	Supported gadgets			Fast verification
		Linear randomness	Non-linear randomness with 2 inputs	Non-linear randomness with > 2 inputs	
SILVER	P	✔	✔	✔	✘
Maskverif	P	✔	✔	✔	✔
Matverif	P	✔	✘	✘	✔
VRAPS	RP	✔	✔	✔	✘
IronMask	P, RP	✔	✔	✘	✔

Performance - Probing

Competitive with the fastest verification tools for probing-like properties

Performance - Random Probing

Gadget	Verification time	
	IronMask	VRAPS
ISW mult 5 shares	3sec	1h 15min
ISW mult 6 shares	17sec	24h
ISW mult 7 shares	24sec	24h

Conclusion

- Formalization of all (random) probing properties in the state-of-the-art
- Algebraic Characterization of gadgets with (non-)linear randomness
- Exact proven verification methods
- IronMask
    - Exact for linear and non-linear randomness with 2 inputs
    - Probing: similar performance as other fast verification tools
    - Random probing: much faster than VRAPS