Symmetric Techniques for Advanced Protocols: What *are* They?

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Inria, Paris

14th of March 2025

Trendy topics

MPC-friendly?

Arithmetization-Oriented?

Verification efficiency?

Algebraic attacks?

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Symmetric crypto **for the blockchain...**

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Symmetric crypto **for the blockchain...**

... for neural networks???

The conclusion of today: **symmetric cryptography** has always had to deal with specific **implementation criteria**, but the new ones are indeed a bit **stranger than before**.

Outline

Plan of this Section

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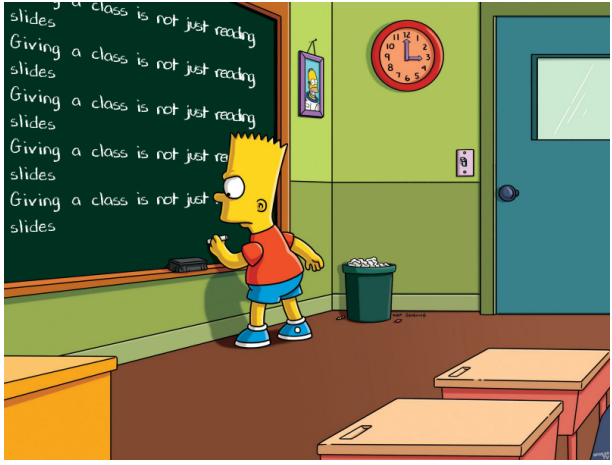
Let's talk!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Unstable Definitions

What is "efficient" varies

- What are the operations that we **can** use?
- What are the associated **costs**?

How to get the best security for a given price?

What is "secure" varies

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- Do we care about nonce-misuse?

How do we define the **security** that the primitive must provide?

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What is "secure" varies

- Should the primitive work in many context? — Modularity vs. Single use
- Do we care about nonce-misuse? — Robustness vs. "not our problem"

How do we define the **security** that the primitive must provide?

Plan of this Section

Web Encryption

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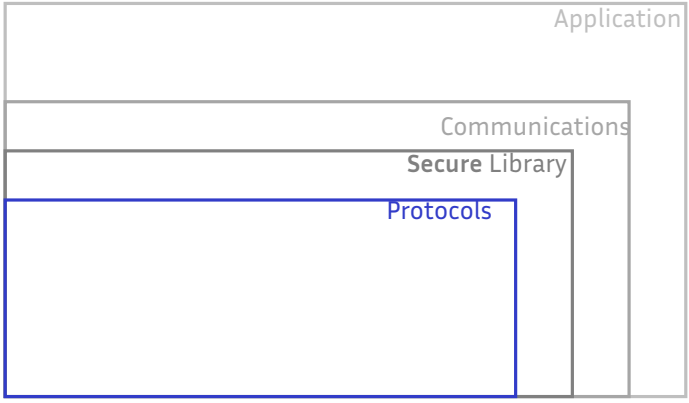

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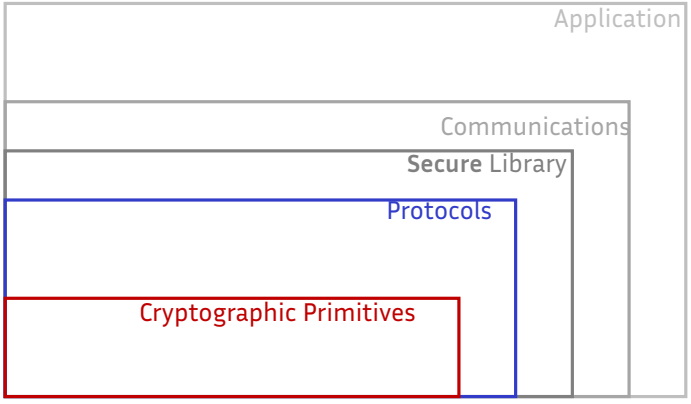

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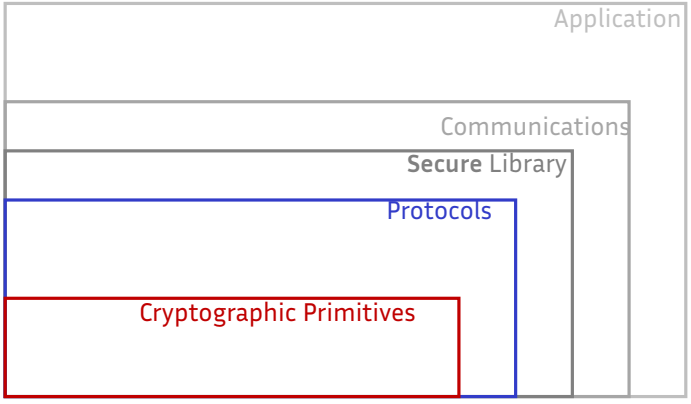

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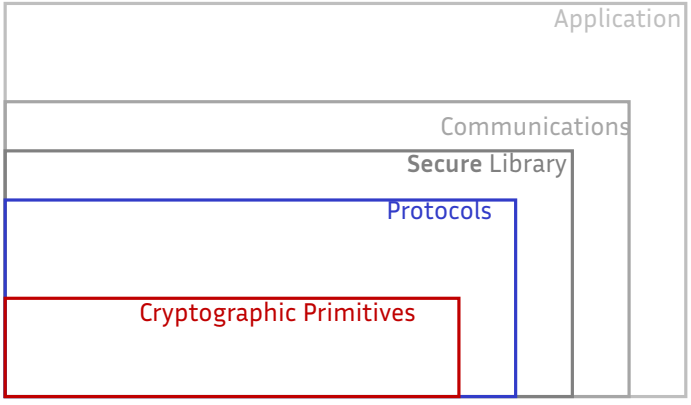

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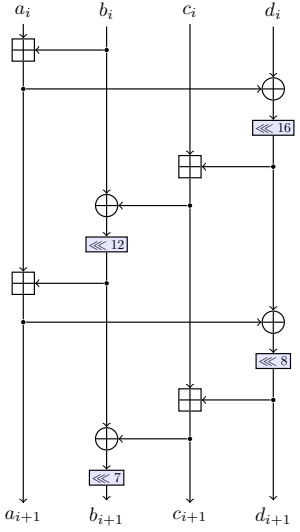
- AES-GCM; Chacha-poly1305.

What Chacha looks like



- Addition / Rotation / XOR
- 256-bit key
- 512-bit state
- Defined over 32-bit words

RAM Encryption

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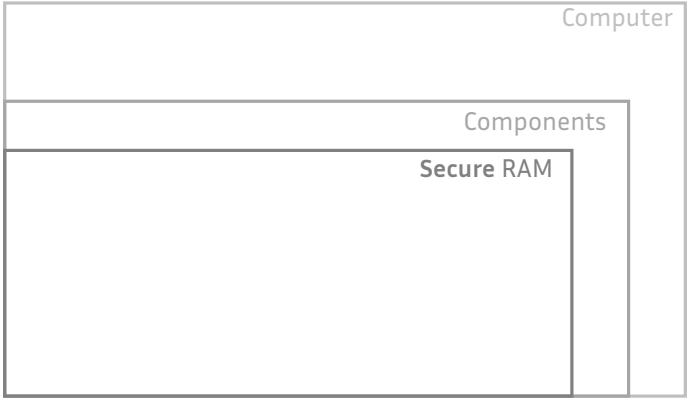

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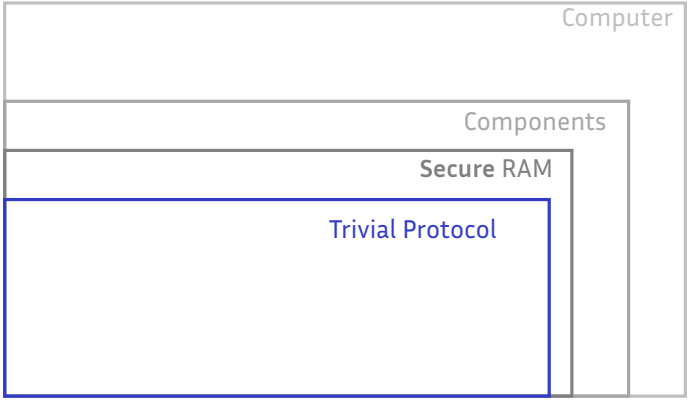

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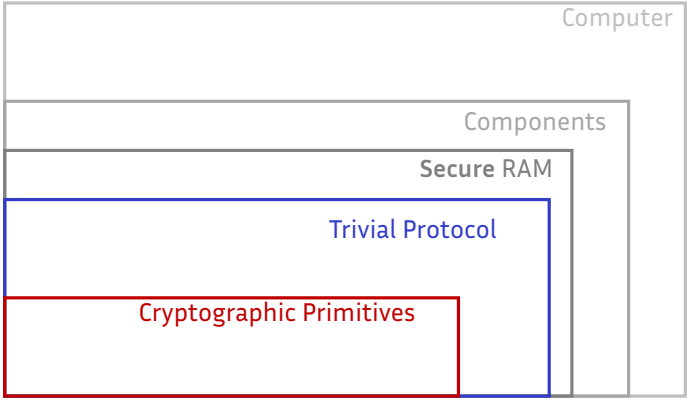

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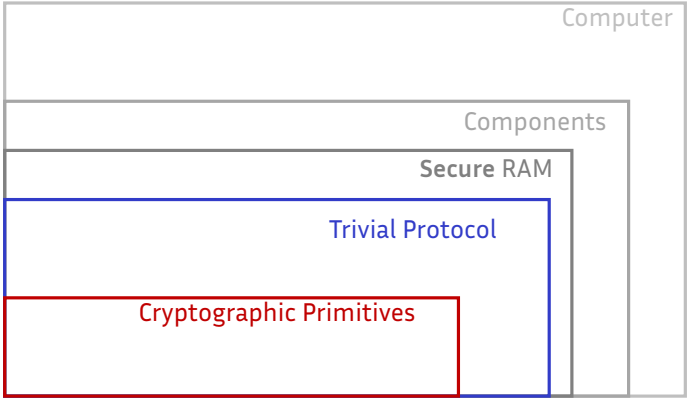

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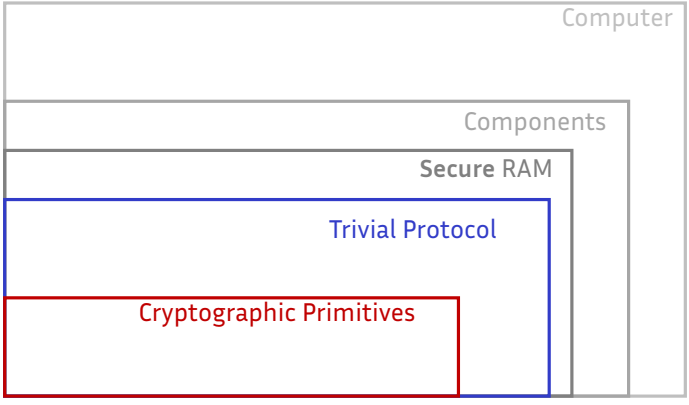

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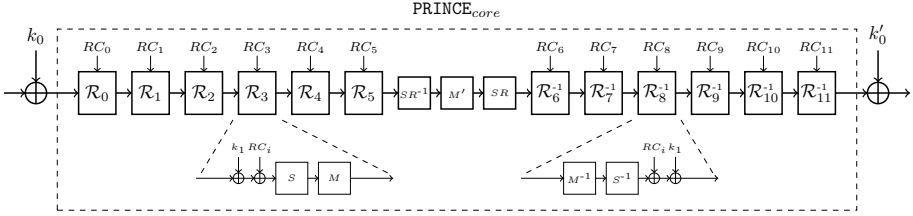
- PRINCE? QARMA? not so clear at this stage.

What PRINCE looks like



- 4-bit S-box optimized for hardware
- 2 different matrices
- FX construction
- "α-reflexion"
- inverse rounds used in the second half

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- A symmetric primitive is a very small (but crucial) cog in a very big machine,
- there are many different "big machines", and
- this has a huge influence on what the primitive looks like.

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Usually, we secure data (at rest or in transit).

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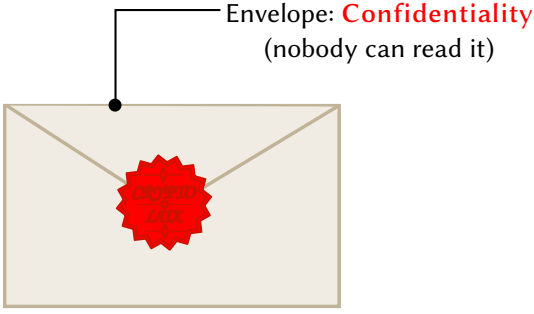

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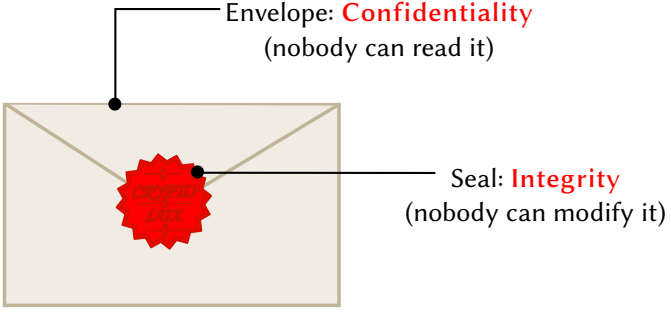

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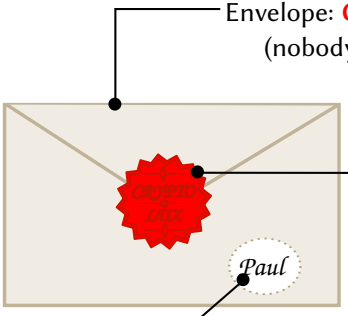

Securing Computation

More and more protocols intend to secure whole computations.

FHE Fully Homomorphic Encryption

MPC Multi Party Computations

ZK-* Zero Knowledge- [proof, argument...]

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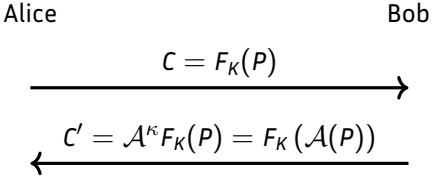

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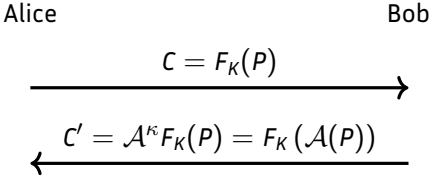

Trivial example

XOR-ing a constant to a ciphertext obtained using a stream cipher XORs the same constant in the plaintext.

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Applications

- Masking (the side-channel attack counter-measure)
- MPC-in-the-head (e.g. for signatures)
- ...

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- BLOCKCHAIN!!1!

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Verifying if $y = c(ax + b)^{10} + x$ in R1CS

1. $t_0 = ax$
2. $t_1 = t_0 + b$
3. $t_2 = t_1 \times t_1$
4. $t_3 = t_2 \times t_2$
5. $t_4 = t_3 \times t_3$
6. $t_5 = t_2 \times t_4$
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This verification costs R1CS 4 constaints

A not basic at all example of arithmetization

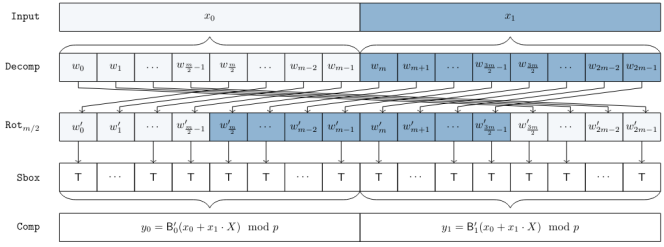
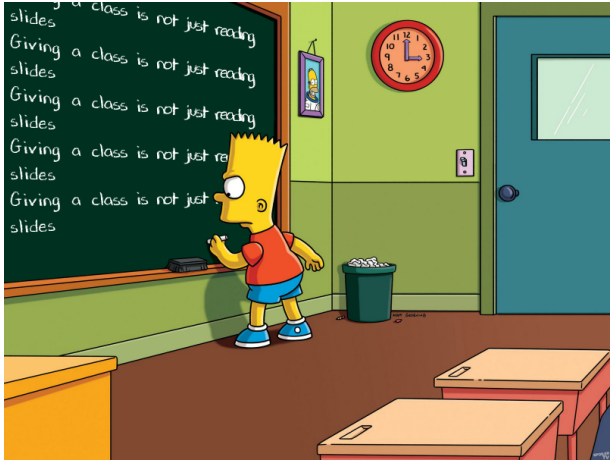


Figure 3: The Bar layer $\mathsf{B}' : \mathbb{F}_{p^n} \to \mathbb{F}_{p^n}$ for $n = 2$ in detail, including the decomposition, the rotation, the S-box, and the composition.

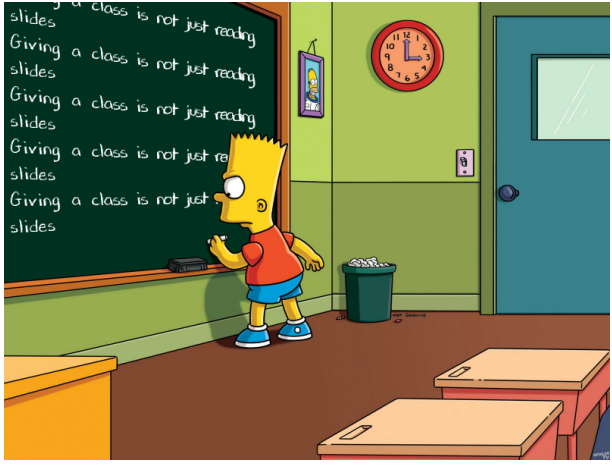
source: *Skyscraper: Fast Hashing on Big Primes*,
`https://eprint.iacr.org/2025/058.pdf`

Arithmetization: General Principle



"Arithmetization-Oriented"?

(the term was coined in [AAB+20])



Symmetric Techniques for Advanced Protocols

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Masking	BGV	R1CS
MPC-in-the-head (signatures...)	FV	AIR
PCF	TFHE	Plonk
VDF		

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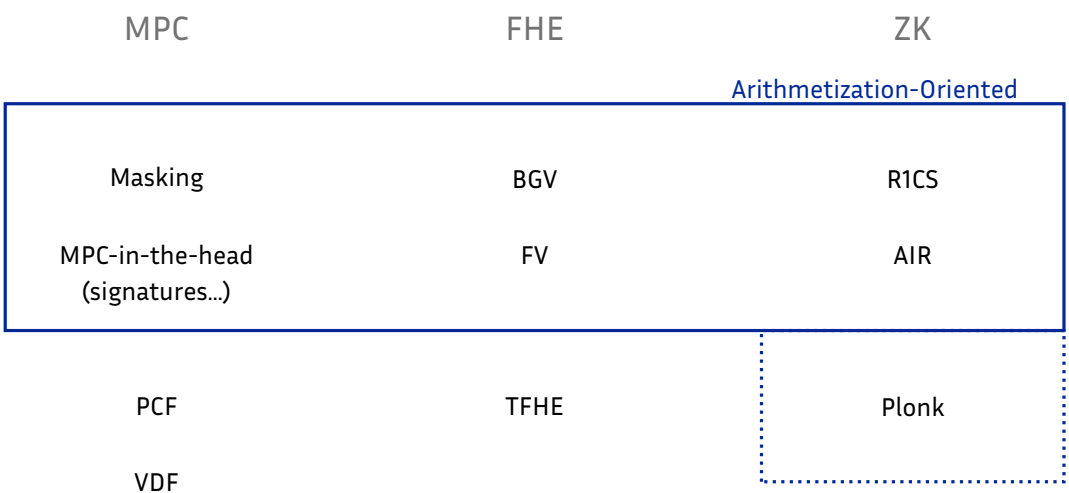

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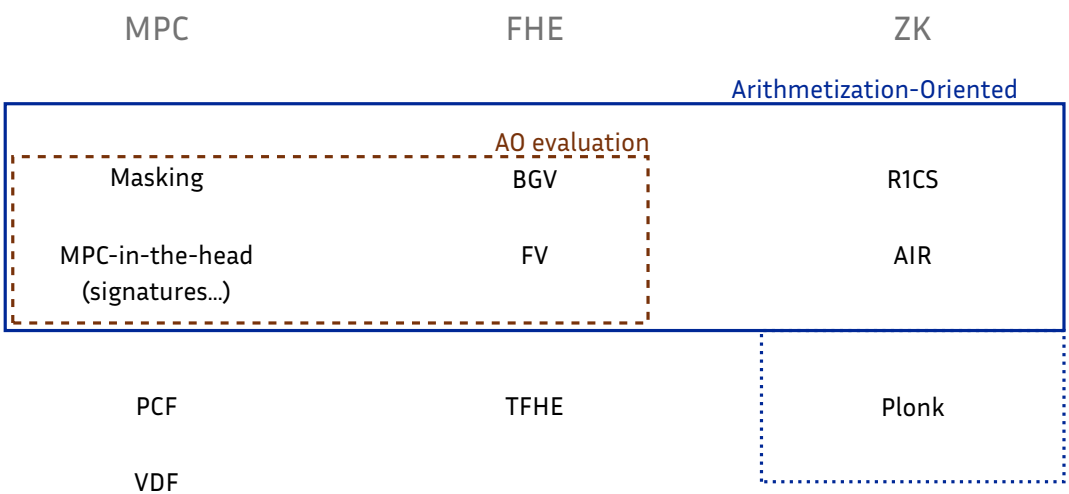

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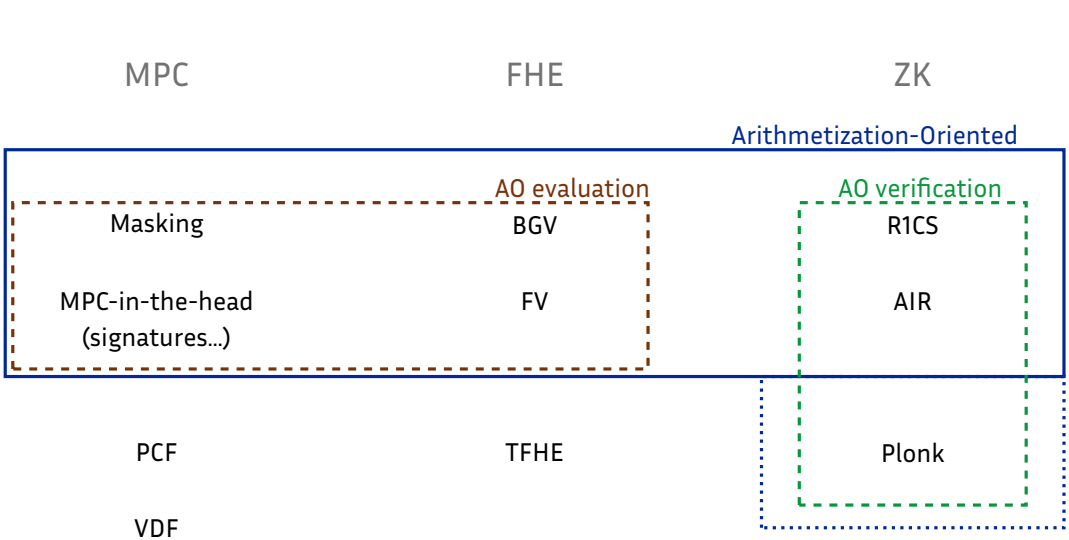

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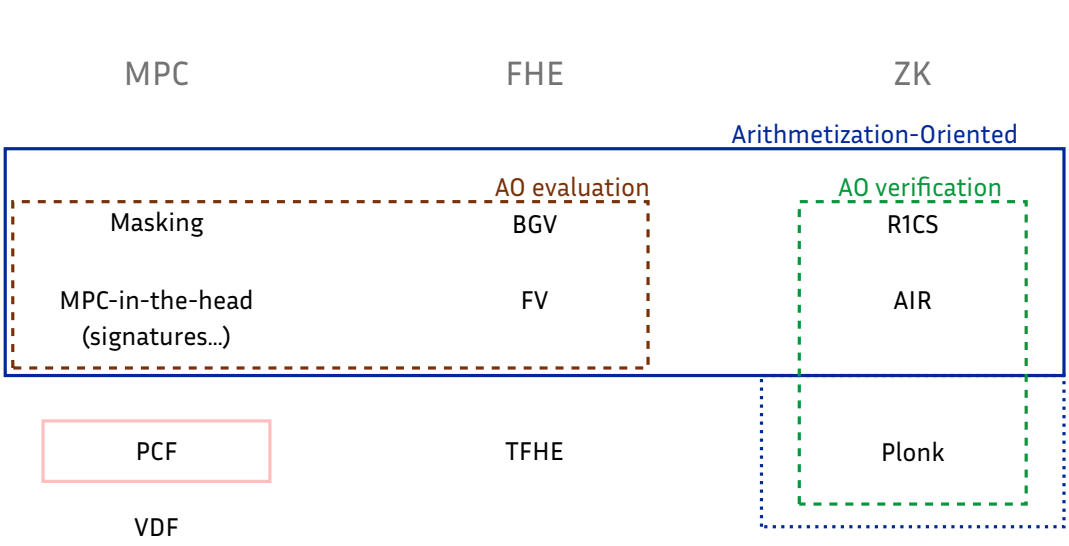

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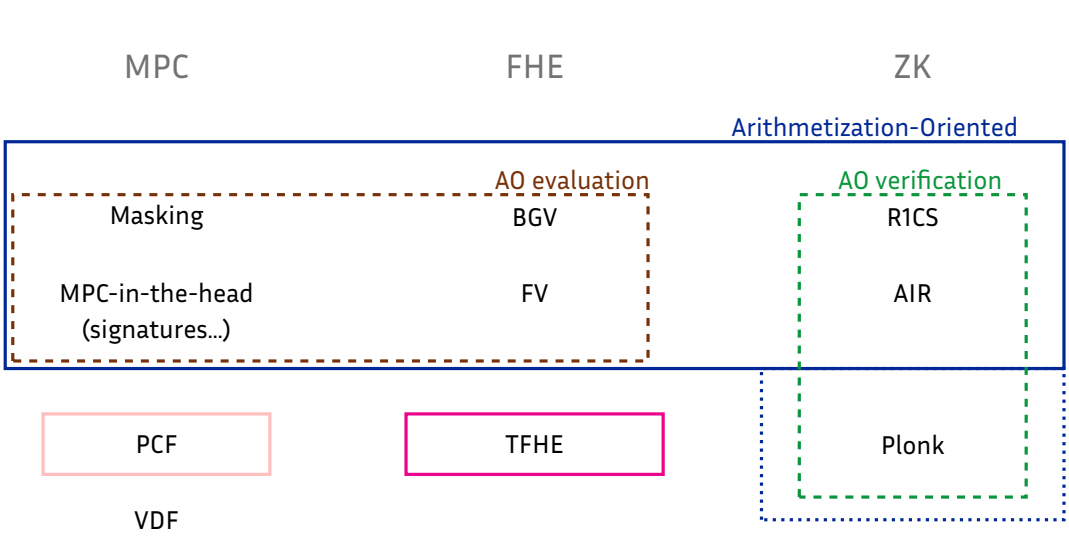

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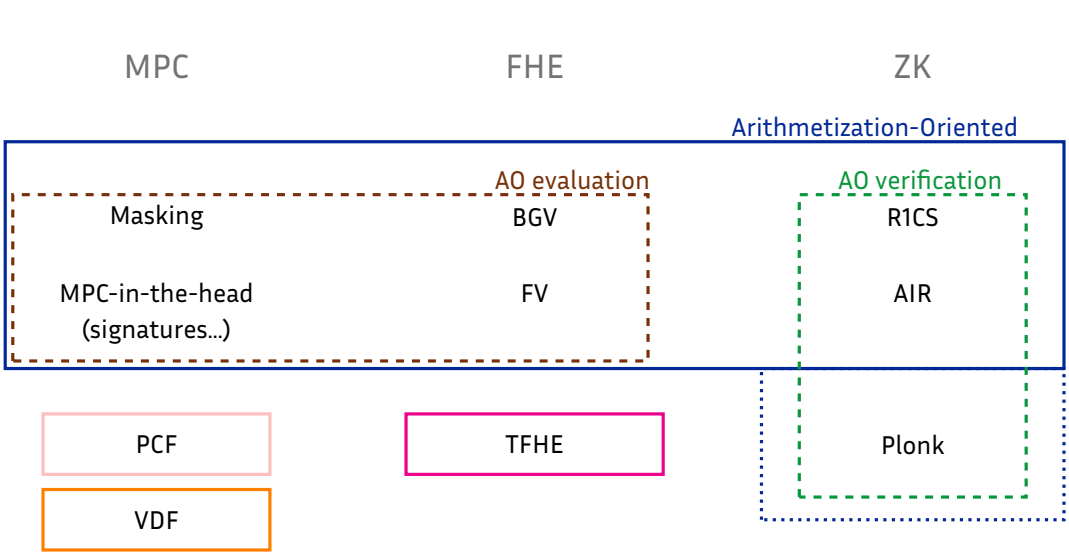

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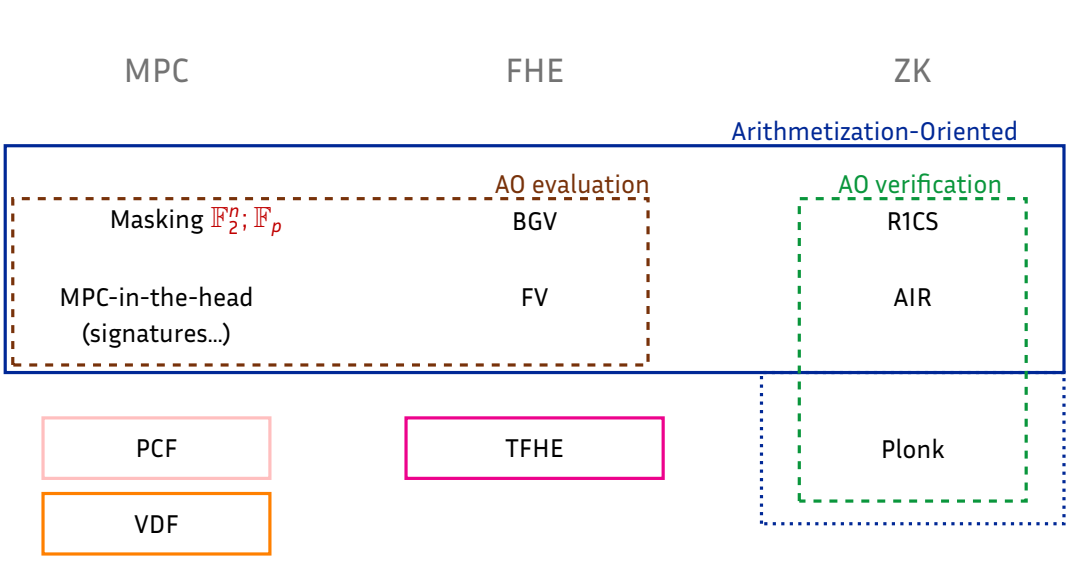

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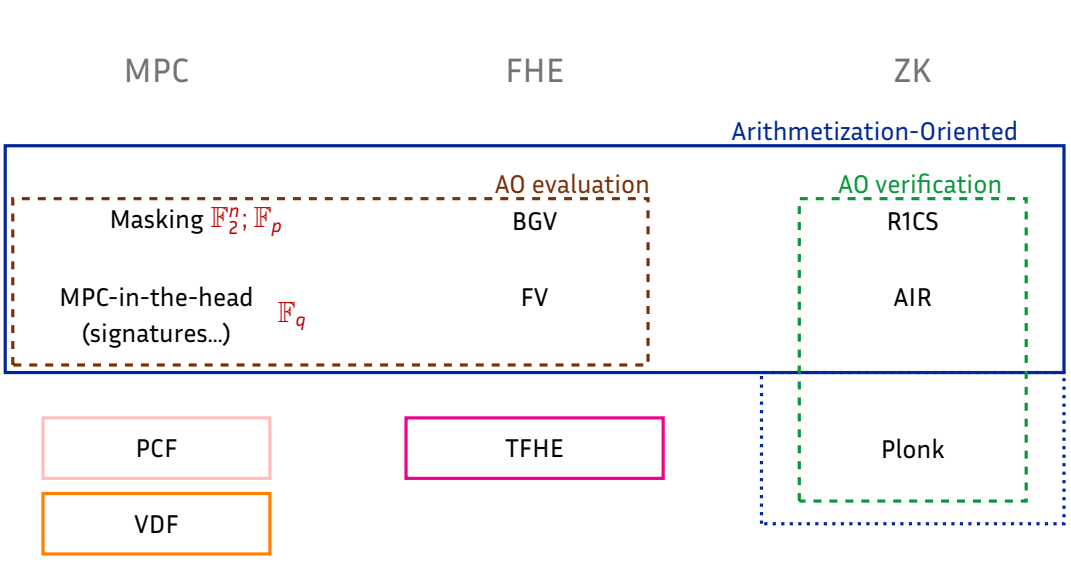

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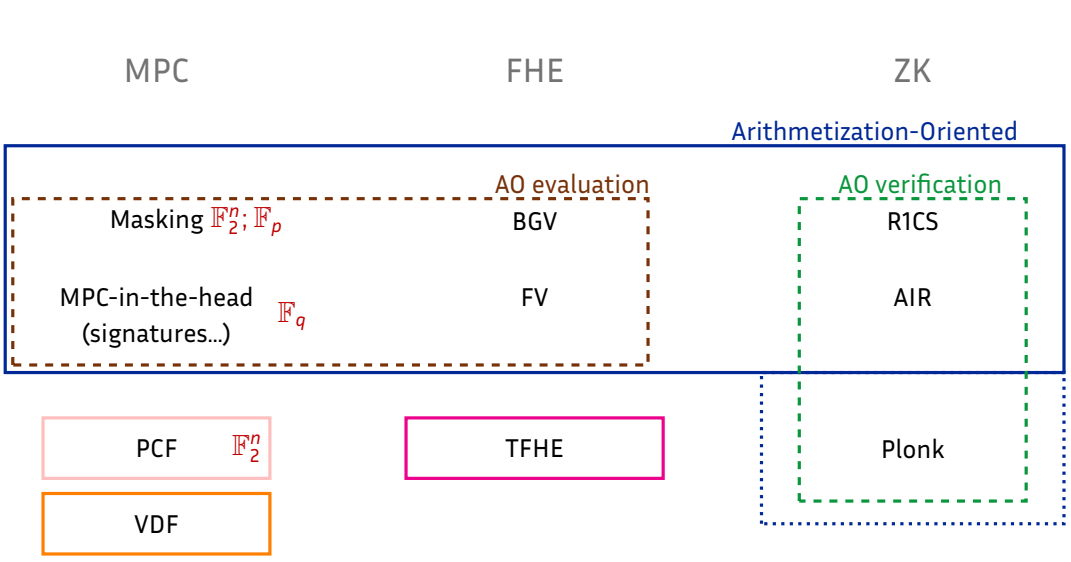

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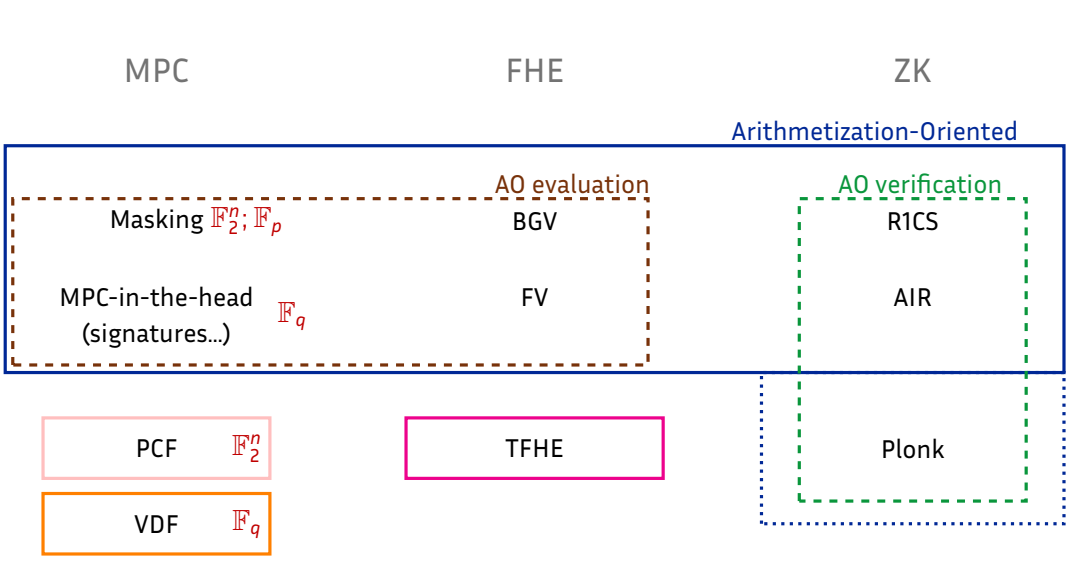

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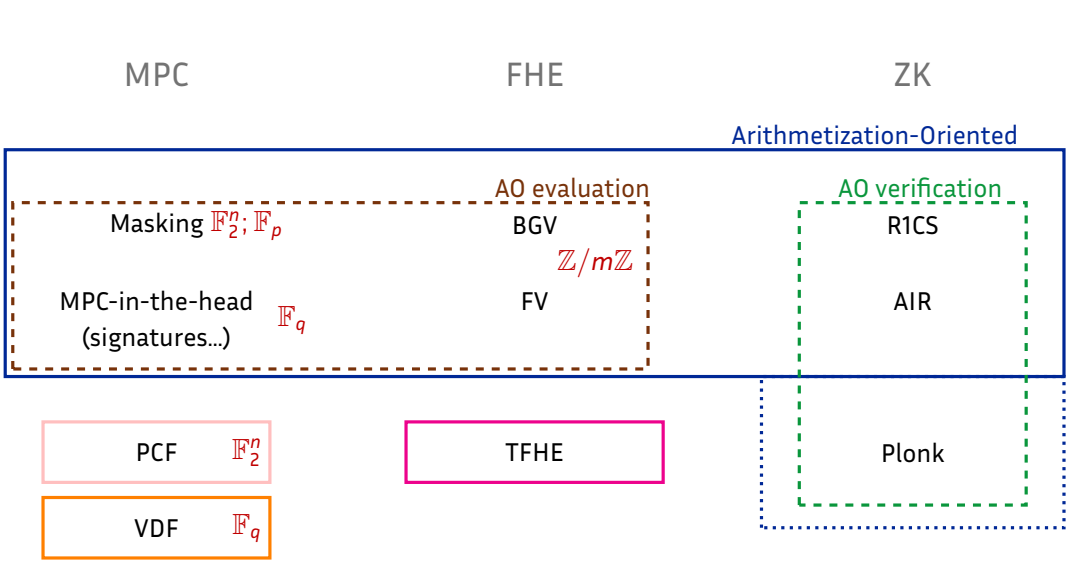

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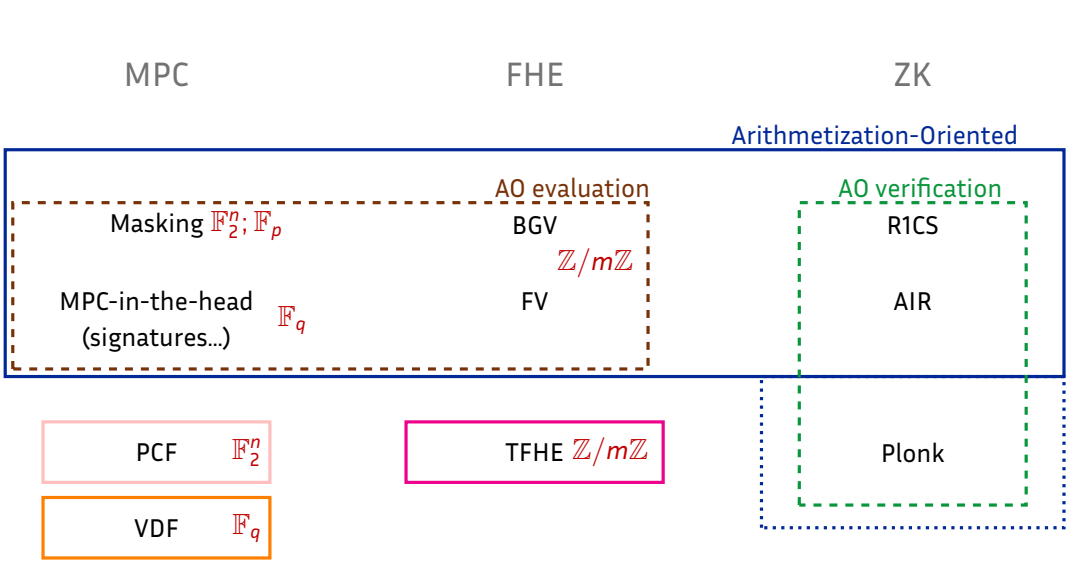

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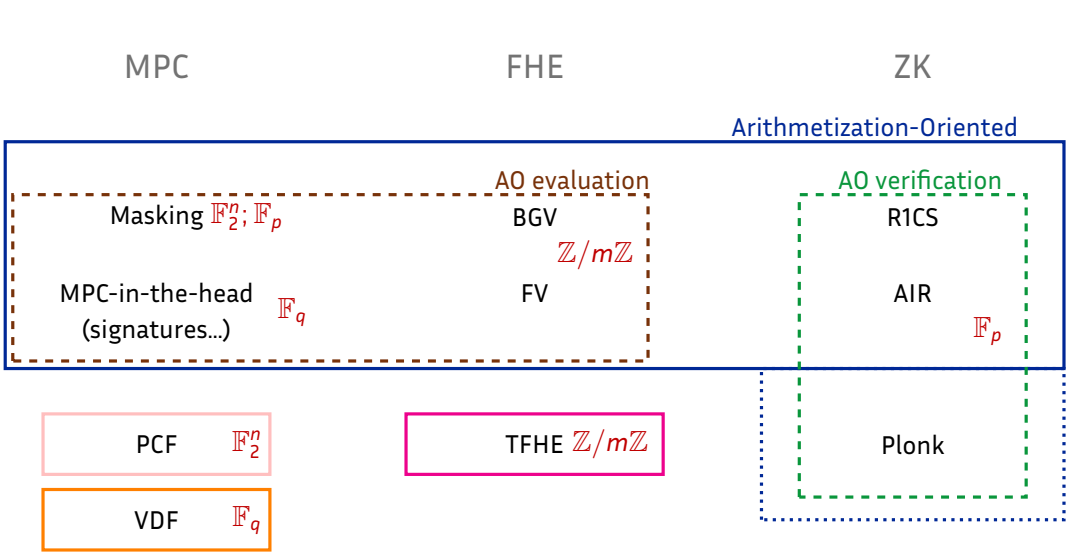

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$\mathbb{F}_q$ and $\mathbb{F}_2^n$ are not the same!

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My Personal Opinion

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- Low degree arithmetization implies low degree algebraic modeling
  beware of algebraic attacks!
- **However** good design approaches are good design approaches, regardless of the underlying structure.

FHE: Stream ciphers for transciphering
MPC: low multiplicative depth, and PCF
ZK: Hash function with AO verification

Plan of this Section

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The case of TFHE

Operates on $\mathbb{Z}/q\mathbb{Z}$, where q can be anything, though: more efficient if q is smaller.

Operations allowed

Linear Combinations $\sum_i \alpha_i x_i$, where the α_i are constant while x_i is input/key dependent.

- Costs almost nothing in terms of time/communication complexity...
- But noise increases

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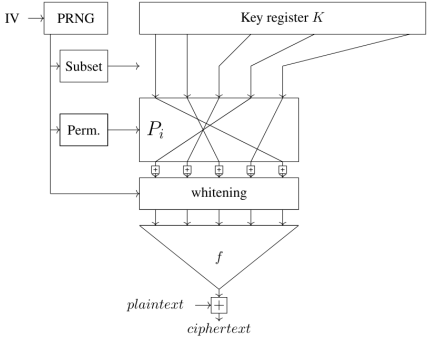
- Very time consuming...
- But resets the noise to a base level
- Can be composed with arbitrary table lookups! *∗ S-box sounds ∗*
- If the ring size is even, it is better if it is nega-cyclic ($S(x + 2^{n-1}) = -S(x)$)

TFHE: corresponding stream ciphers

Elisabeth-4 [CHMS22] ; $q = 2^4$

Uses a constant key register on which index-dependent non-linear functions are applied.

Can be linearized [GBJR23]



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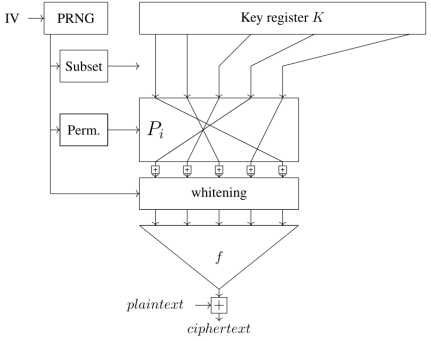

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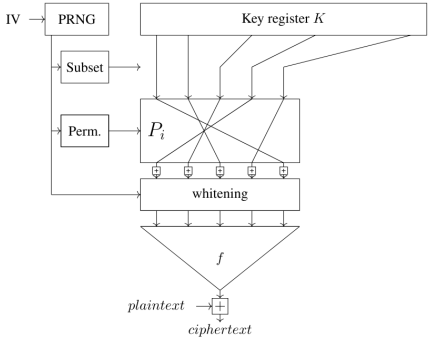

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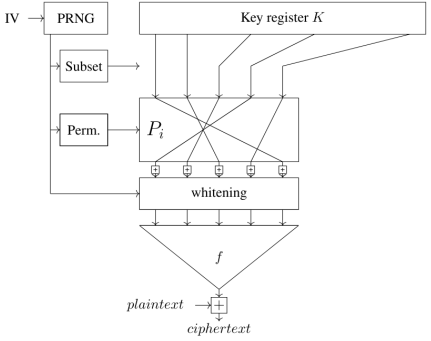
Transistor [BBB$^+$25] ; $q = 2^4 + 1$
SNOW-like round structure
See you at Anne's invited talk :D



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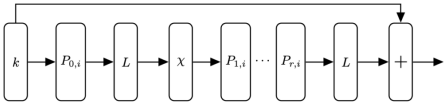
  Rely on large, randomly generated, nonce-dependent matrices.



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Dasta – Alternative Linear Layer for Rasta

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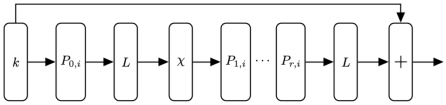

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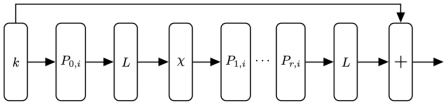

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Plan of this Section

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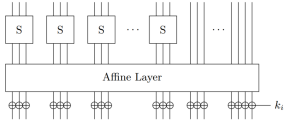
Only one encryption/key; broken anyway



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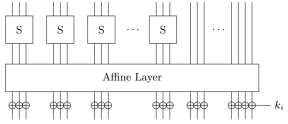

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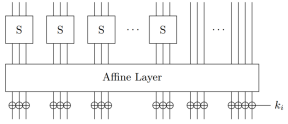
small-pSquare [?] $q = 127$
Generalized Feistel network with low degree round function.
Optimized specifically for hardware masking.



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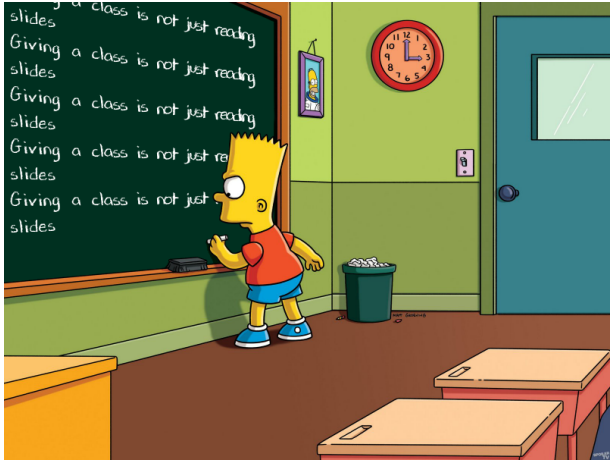
VDLPN [BCG+20]

$$f_k(x) = \bigoplus_{i=1}^{D} \bigoplus_{j=1}^{w} \bigwedge_{\ell=1}^{i} (x_{i,j,\ell} \oplus k_{i,j,\ell}),$$

Plan of this Section

Arithmetization-Oriented Verification: CCZ-equivalence?



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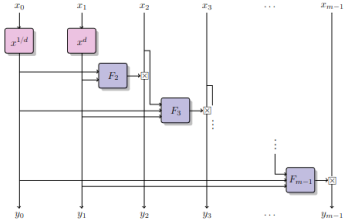

source: *"The Algebraic Freelunch: Efficient Gröbner Basis Attacks Against Arithmetization-Oriented Primitives"*

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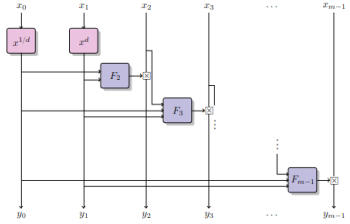

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Thank you!


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