On the Design Criteria for Symmetric Primitives

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Journées C2

European Research Council
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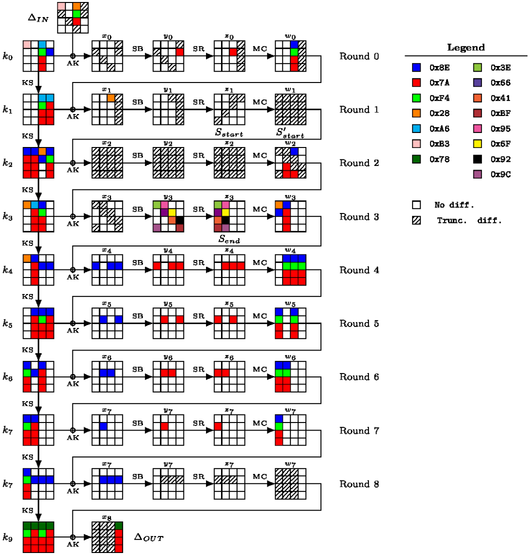
Classical vs. new Symmetric Cryptography



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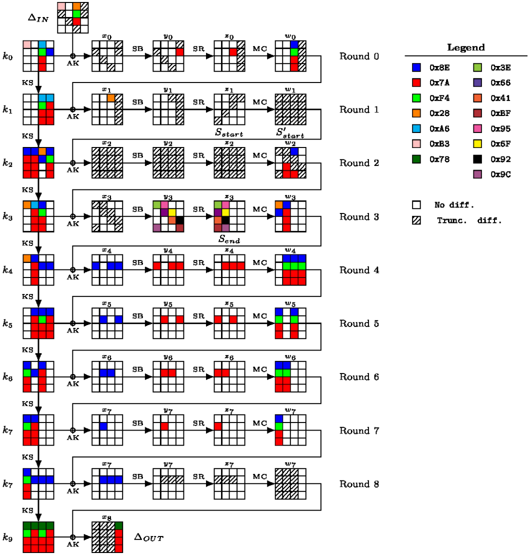

$i = \alpha_0 - 2, \ldots, 0$. This does not change the value of the determinant, and after these row operations, the resulting determinant to compute is:

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In this block matrix representation, the determinant of the full matrix is the determinant of the top right matrix, up to the sign $(-1)^{\alpha_0+1}$. □

Complexity Analysis. We call `polyDet` the procedure returning the polynomial $\det(x_0\boldsymbol{I}_{D_I} - T_0)$ using Lemma 2. This step has a complexity $\tilde{\mathcal{O}}(D_I D_H^{\omega-1}) = \tilde{\mathcal{O}}(\alpha_0 D_H^{\omega})$ with the algorithm of [40]. Note that this is precisely the complexity that was obtained with the algorithm of [12] for systems satisfying the *stability* and *shape position* properties. In order to estimate the logarithmic factors in the complexity formula, we bound the complexity with [34, Theorem 4.4], using a polynomial matrix multiplication algorithm of complexity $\mathcal{O}(D_H^{\omega}\log(\alpha_0) + D_H^2\log(\alpha_0)\log(\log(\alpha_0)))$ [20]. This way, we bound the number of operations of `polyDet` with (when D_H is large):

$$\mathcal{O}\left(\alpha_0\log(\alpha_0)^2 D_H^{\omega} + \alpha_0\log(\alpha_0)^2\log(\log(\alpha_0))D_H^2\right) \approx \mathcal{O}(\alpha_0\log(\alpha_0)^2 D_H^{\omega}). \quad (2)$$

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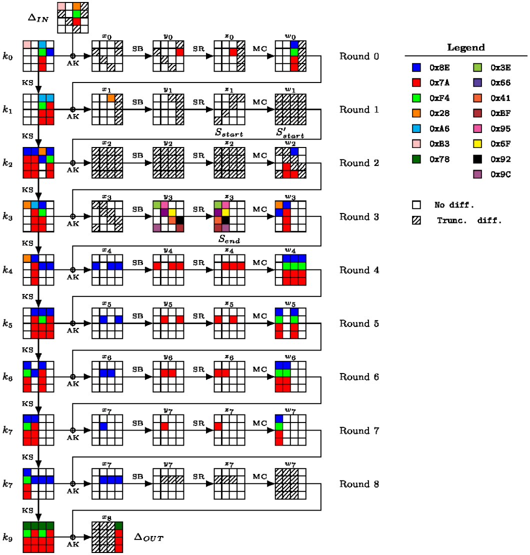

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Arithmetization-oriented ZK-friendly hash function for the BLOCKCHAIN

??

In this talk

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Part 1.1 (symmetric cryptography)

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Part 1.2 (Design criteria)

Part 1

1. How do we build symmetric primitives?
2. On their design constraints

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Part 1.2 Part 2

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1. Securing computations vs. data
2. Arithmetization-Orientation?

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Conclusion

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Outline

Plan of this Section

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Definition (Primitive)

A primitive is a very low level algorithm, a *basic brick* used to build larger things.

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Efficiency **Security**

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Let $\mathbb{F}_q$ be a finite field.

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Message Authentication Code (MAC) Family of functions $M_K : (\mathbb{F}_q)^* \to {\mathbb{F}_q}^n$ mapping arbitrarily sized inputs to fixed-size outputs. Poly-1305,GHASH...

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The Big Trade Secret of Symmetric Cryptographers©

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plaintext

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plaintext $\longrightarrow x_i$

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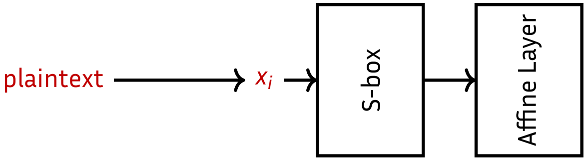

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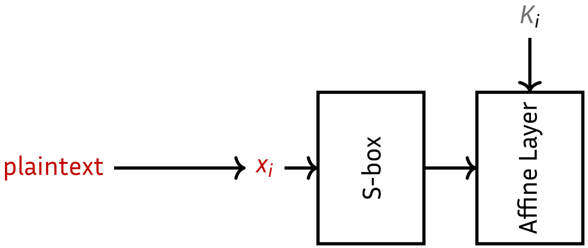

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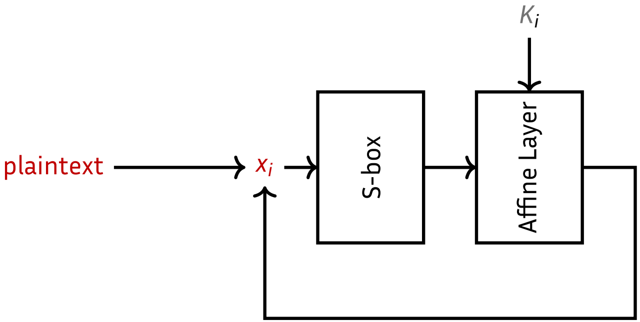

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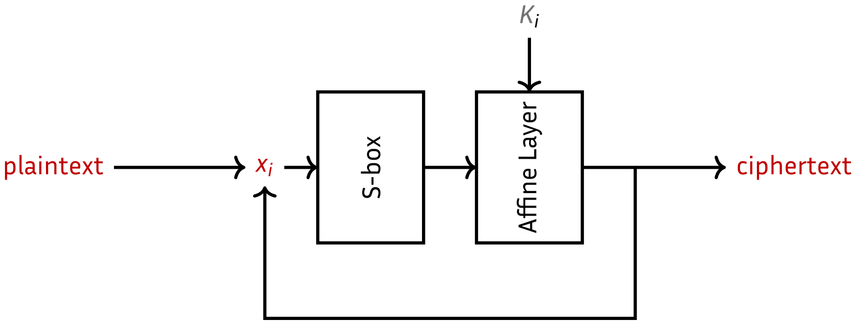

To Build a Cipher

I will make an **efficient** and **secure** primitive!

your idea

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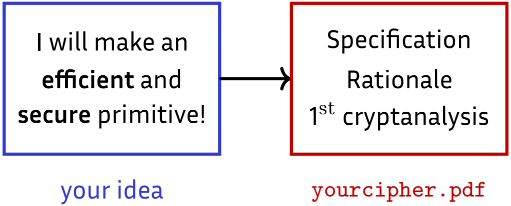

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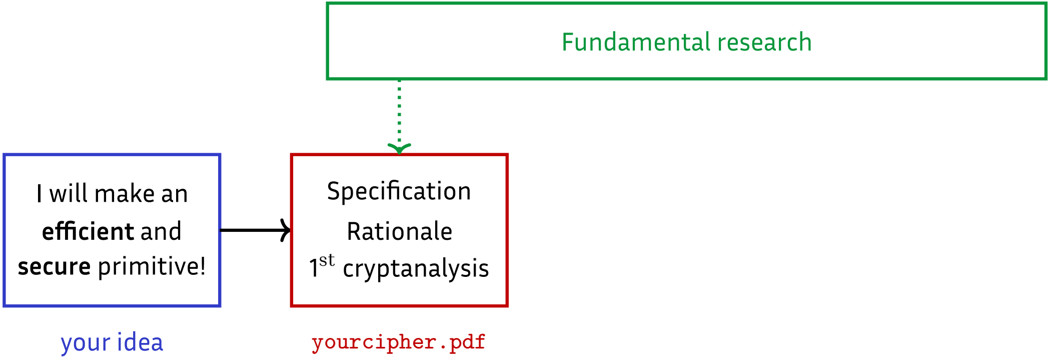

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Rationale
1st cryptanalysis

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Standardisation

Usage

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What are the relevant forms of cryptanalysis?

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What is the intended execution context?

Plan of this Section

Web Encryption

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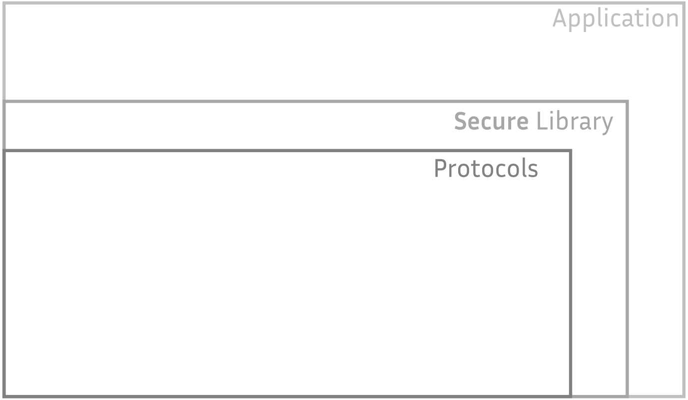

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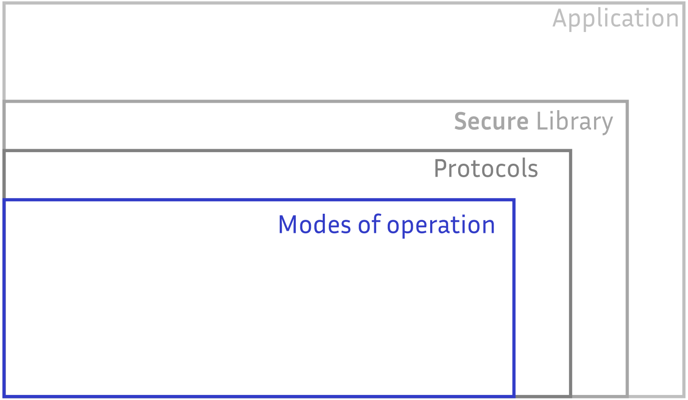

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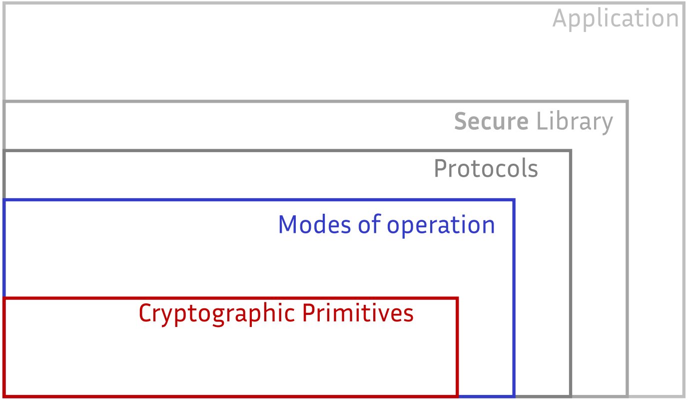

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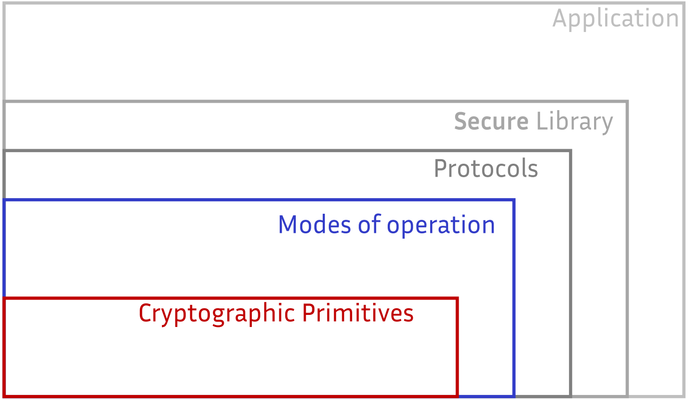

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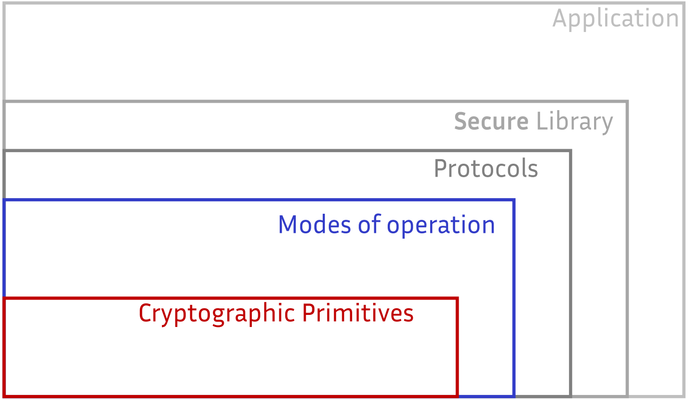

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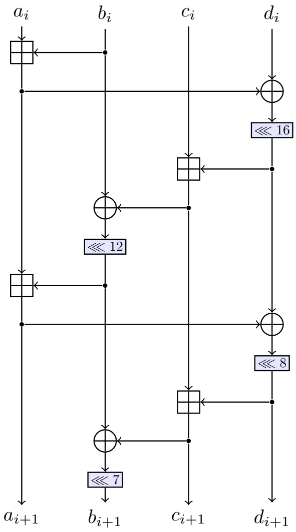
- AES-GCM; Chacha-poly1305.

What Chacha looks like



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

RAM Encryption

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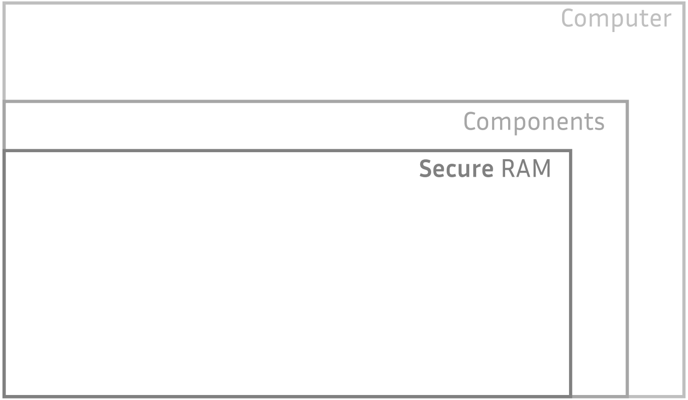

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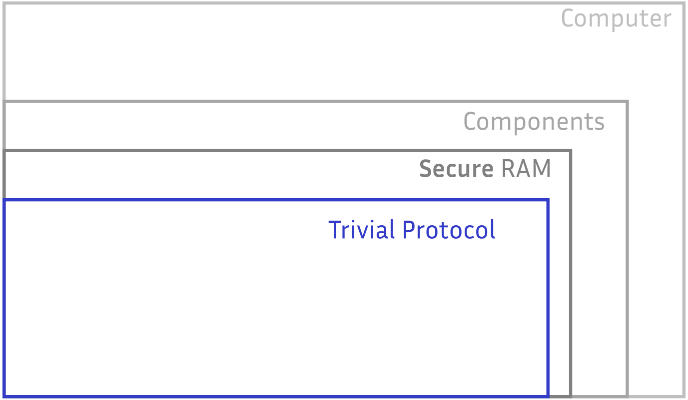

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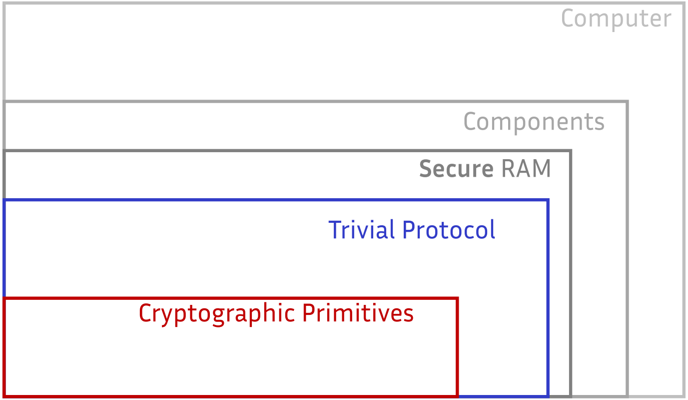

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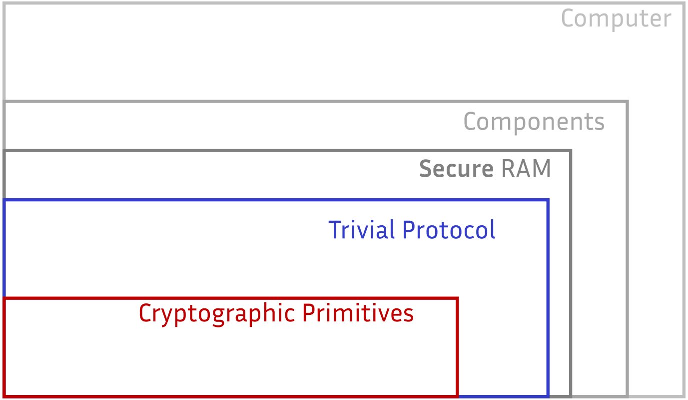

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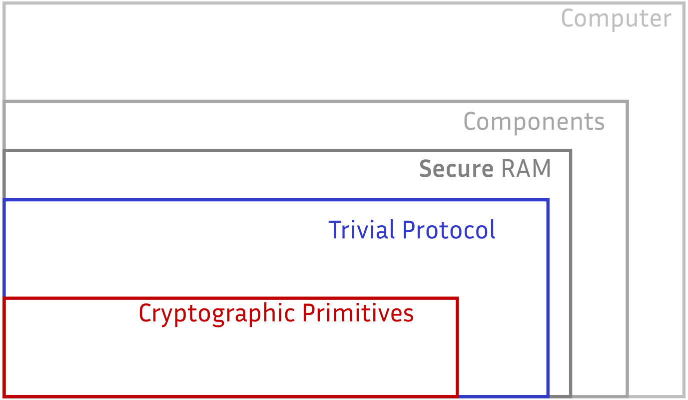

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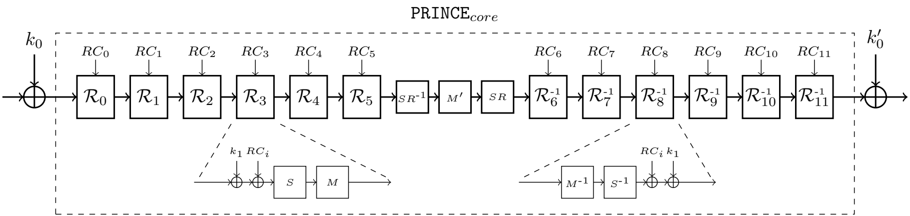
- PRINCE? QARMA? not so clear at this stage.

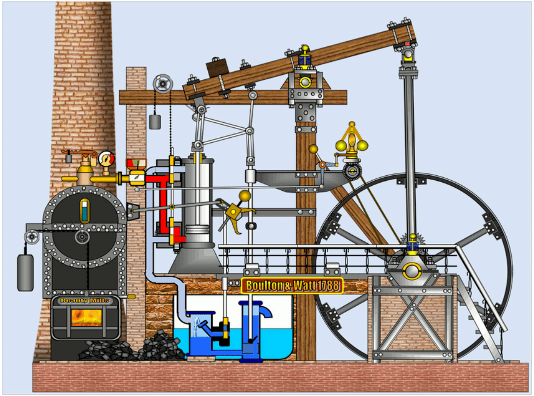
What PRINCE looks like



- 64-bit block size; 128-bit key size ($\approx$)
- 4-bit S-box optimized for hardware
- 2 different 16×16 matrices of $\mathbb{F}_2$, also optimized for hardware
- FX construction
- "α-reflexion": inverse rounds used in the second half

Some Constants

There are many different "big machines", and



source: https://www.researchgate.net/figure/The-Steam-Engine-of-James-Watt-and-Mathew-Bolton-15_fig2_347657192

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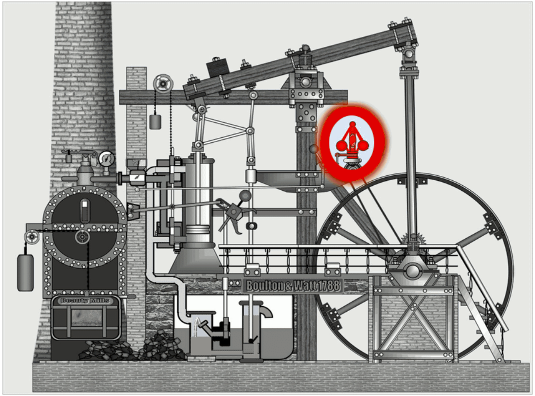

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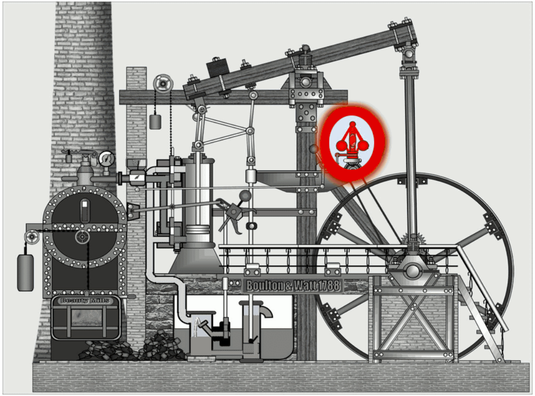
this has a huge influence on what the primitive looks like.



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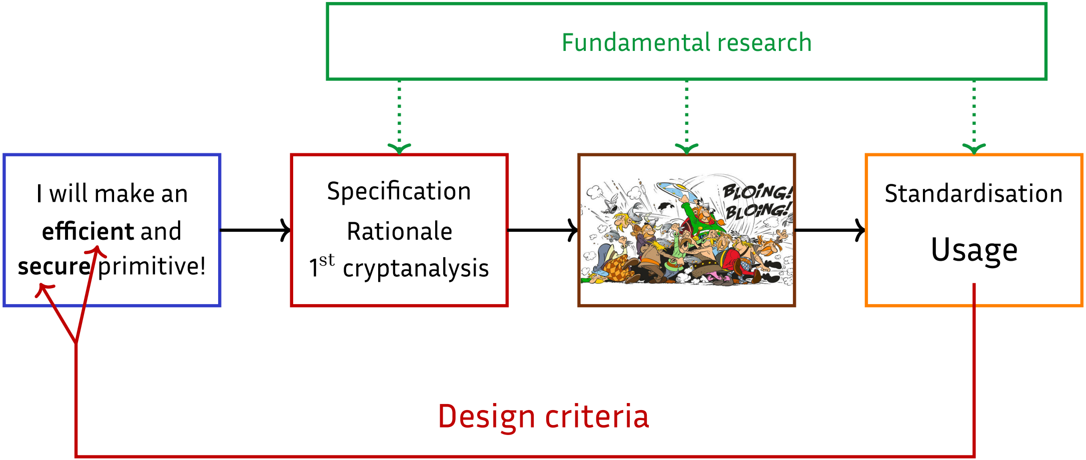

Plan of this Section

Securing Data

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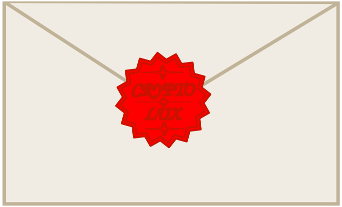

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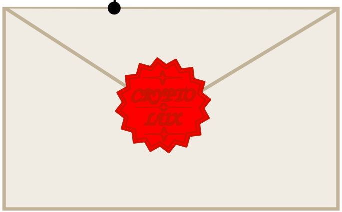

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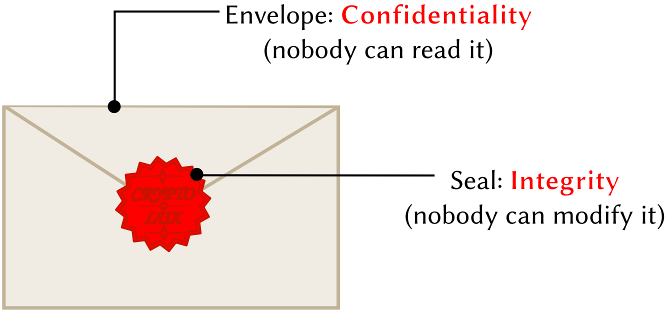

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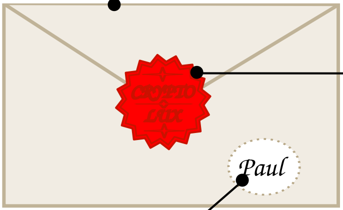

Seal: Integrity
(nobody can modify it)

Signature: Authentication
(it was written by the right person)

Securing Computation

More and more protocols intend to secure computations.

- **FHE** Fully Homomorphic Encryption
- **MPC** Multi Party Computations
- **ZK-*** Zero Knowledge- [proof, argument...]

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An example of (not F)HE

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

$$C \oplus t = (P \oplus K) \oplus t = (P \oplus t) \oplus K$$

The Symmetric Crypto They Need: Transciphering

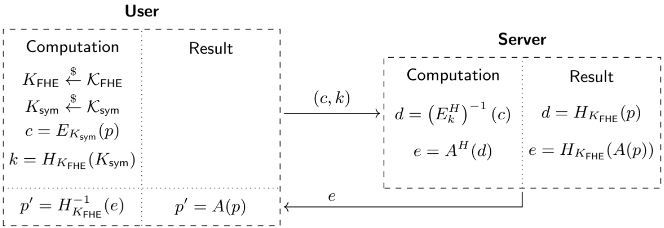
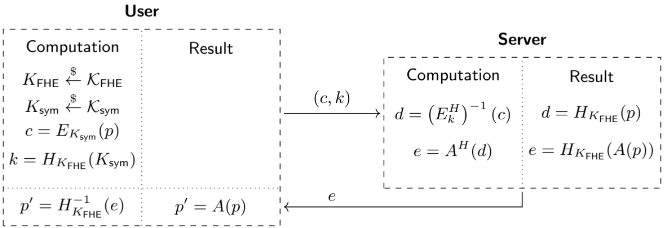


Fig. 1: The principle of transciphering, where E is a symmetric cipher (with secret key K_{sym} sampled from the space $\mathcal{K}_{\mathsf{sym}}$), H is a fully homomorphic cipher (with private key K_{FHE} sampled from the space $\mathcal{K}_{\mathsf{FHE}}$), E^H is a homomorphic evaluation of E, A corresponds to some arbitrary operations, and A^H to their homomorphic evaluation.

source: *Transistor: a TFHE-friendly Stream Cipher*

https://eprint.iacr.org/2025/282

The Symmetric Crypto They Need: Transciphering



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A symmetric encryption algorithm with a **high throughput** when evaluated homomorphically

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

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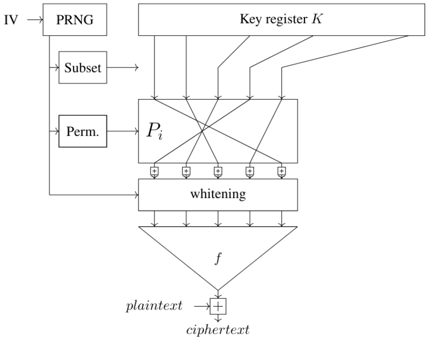
(not T)FHE operates differently, but **noise** is still present

Examples of stream ciphers for transciphering

Elisabeth-4 [CHMS22]

$q = 2^4$ Can be linearized [GBJR23]



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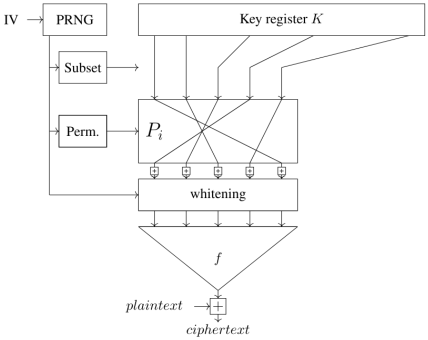

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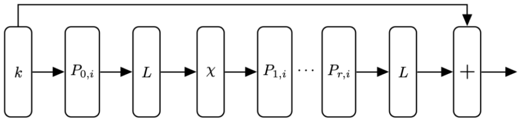

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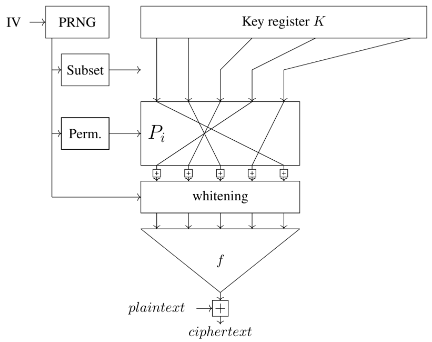

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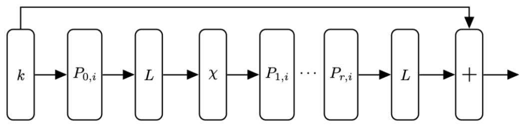

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Shameless plug

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Plan of this Section

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Goal

Allow multiple parties to evaluate a function together even if some parties are not trustworthy.

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Applications

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

The SymCry They Need: a Lot of Different Things

Masking-friendly (Tweakable) BCs. Low number of multiplications in the underlying field.

Examples: `small-pSquare` [GMM+24b], `Fantomas` [GLSV15],...

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Pseudo-random Correlated Functions Very low degree evaluation; no chosen plaintext attack allowed; only low data complexity.
Examples: `Crypto DarkMatter` [BIP+18], `VDLPN` [BCG+20]

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I want to convince you I know a secret without revealing it

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Generalization it is sufficient that F is CCZ-equivalent to a low degree function.

Plan of this Section

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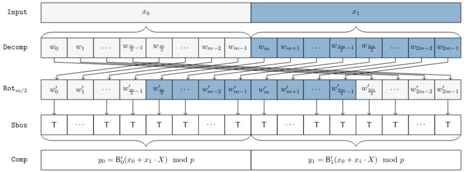

Figure 3: The Bar layer $\mathsf{B}' : \mathbb{F}_{p^n} \to \mathbb{F}_{p^n}$ for $n = 2$ in detail, including the decomposition, the rotation, the S-box, and the composition.

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

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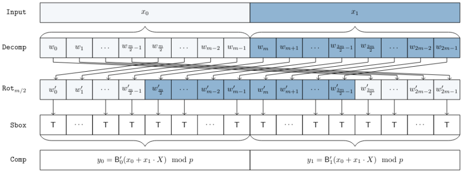

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Shameless plug

Be sure to check the talks of Antoine Bak and **Guilhem Jazeron** tomorrow morning!

Symmetric Techniques for Advanced Protocols

MPC FHE ZK

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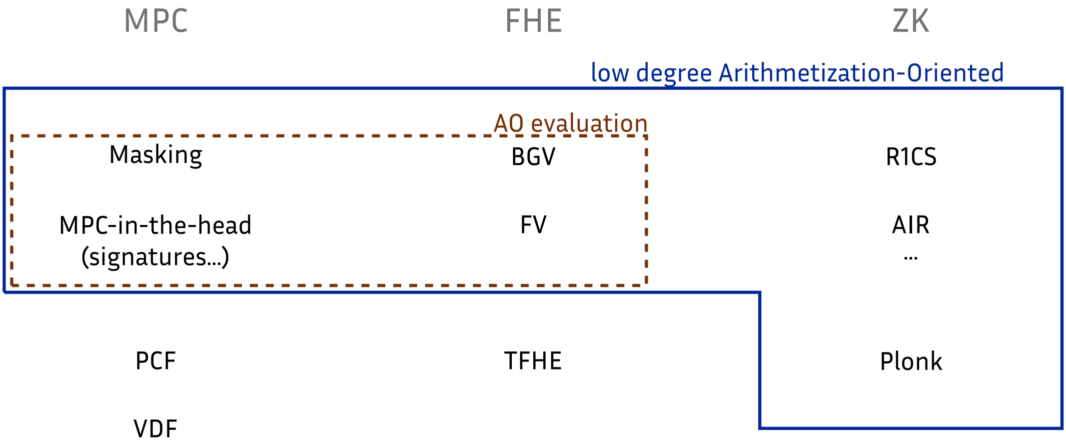

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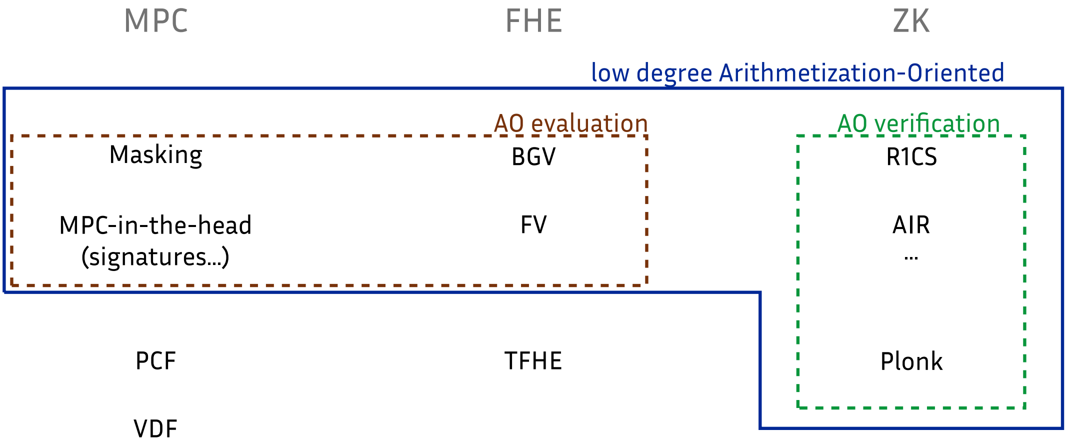

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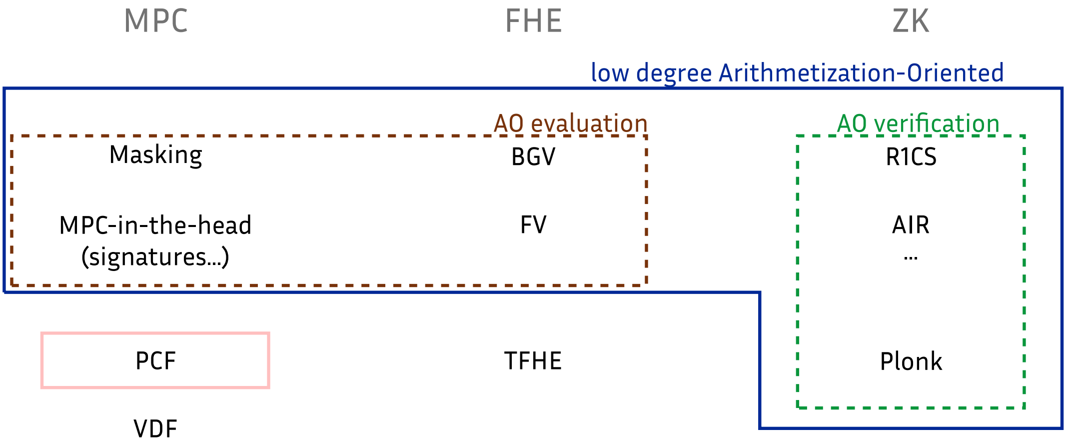

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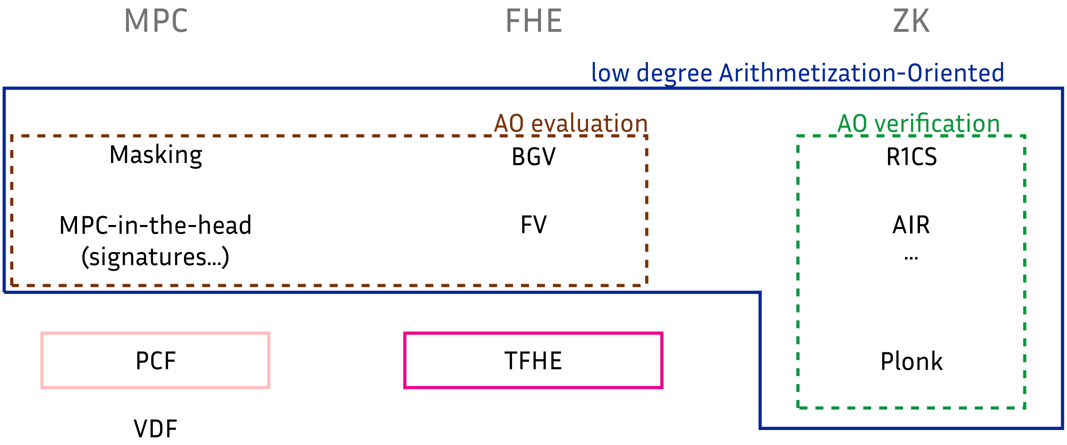

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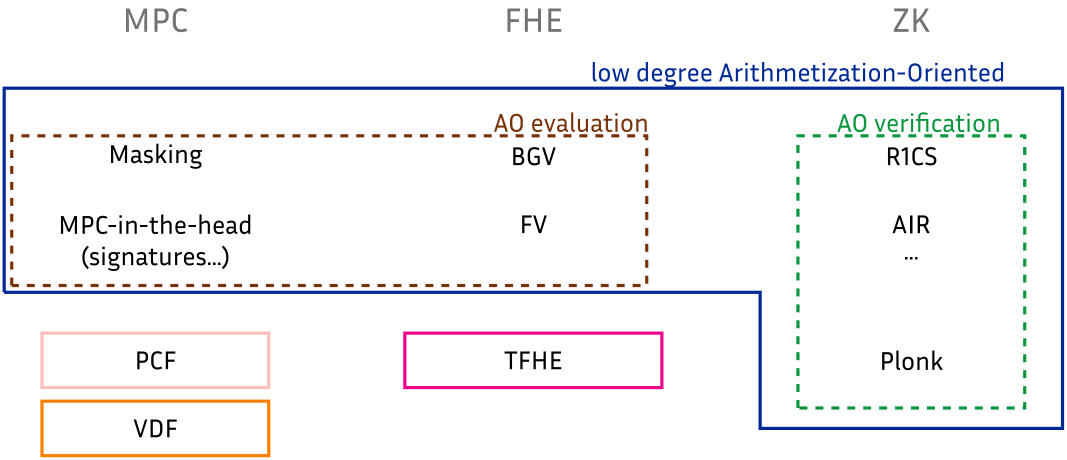

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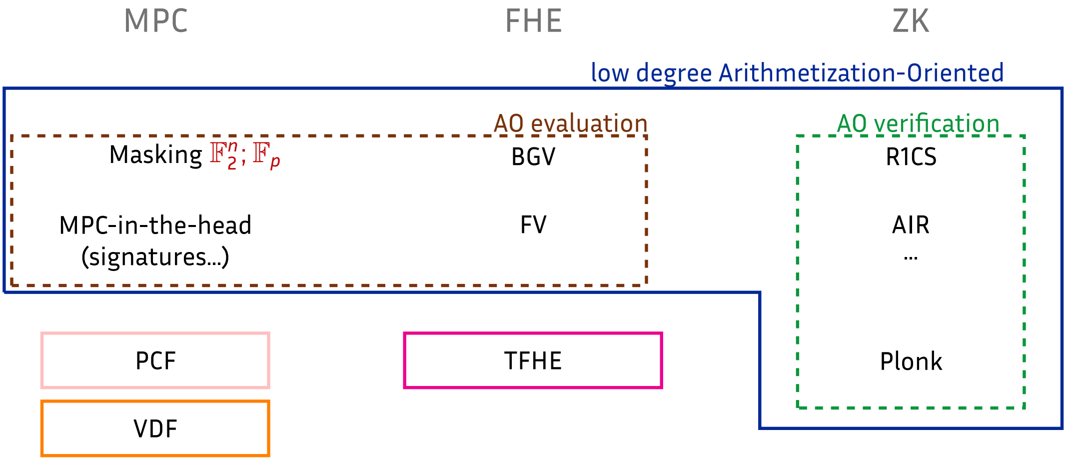

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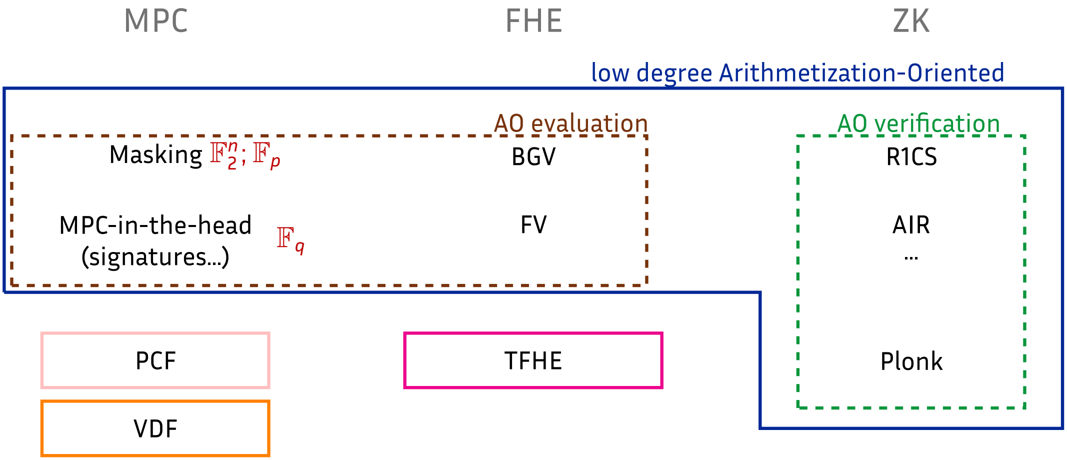

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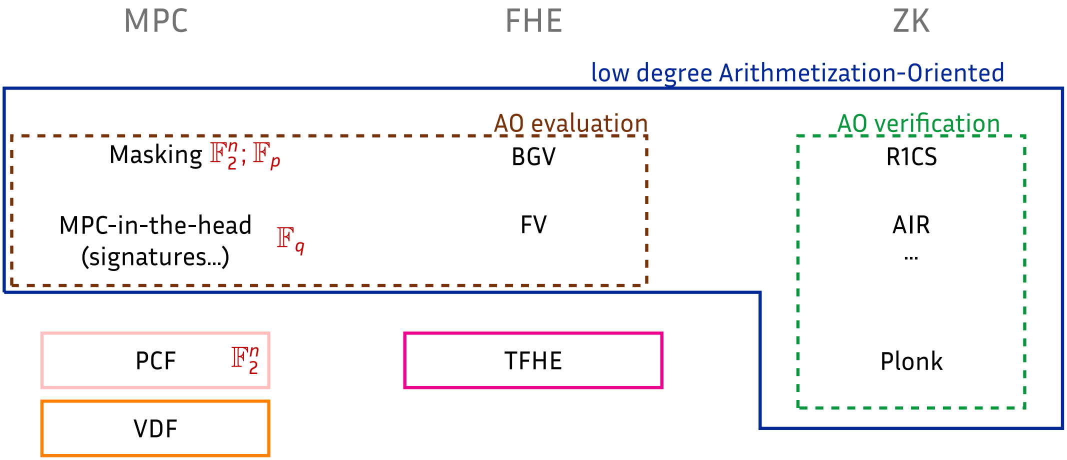

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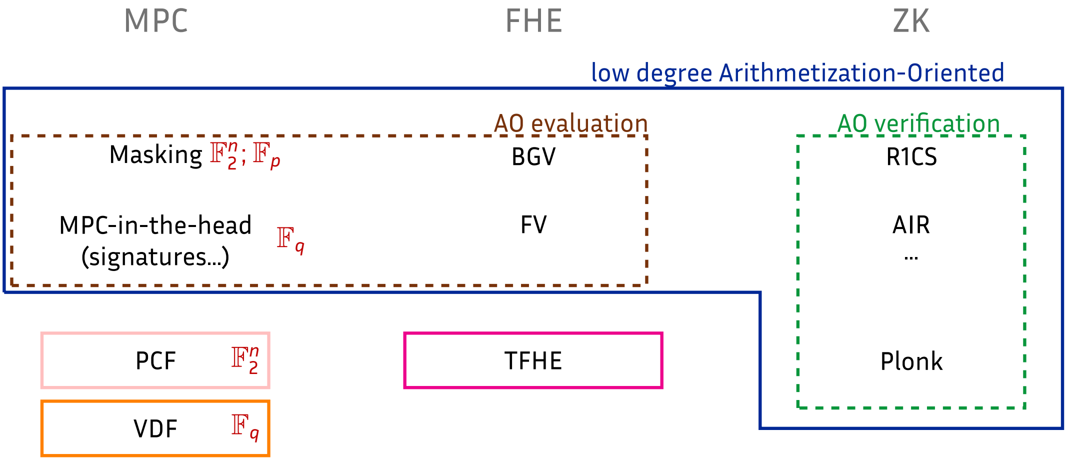

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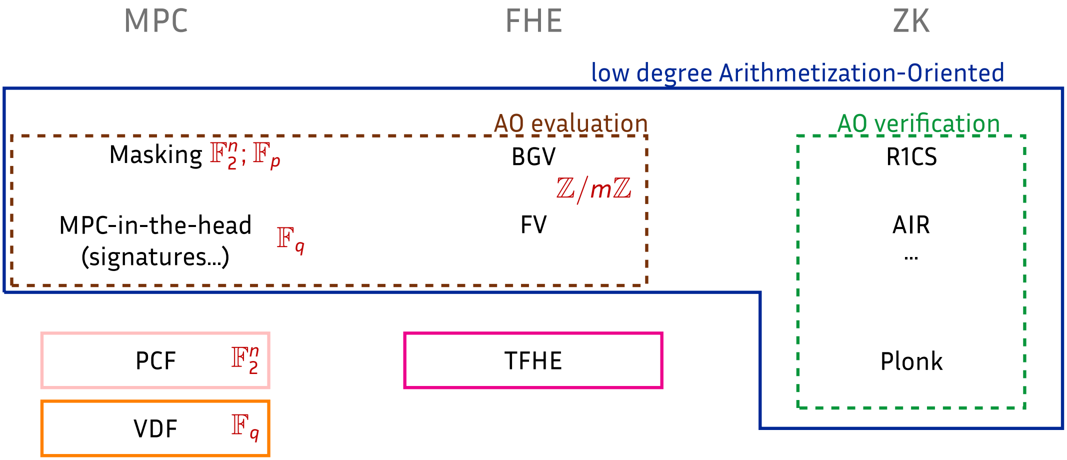

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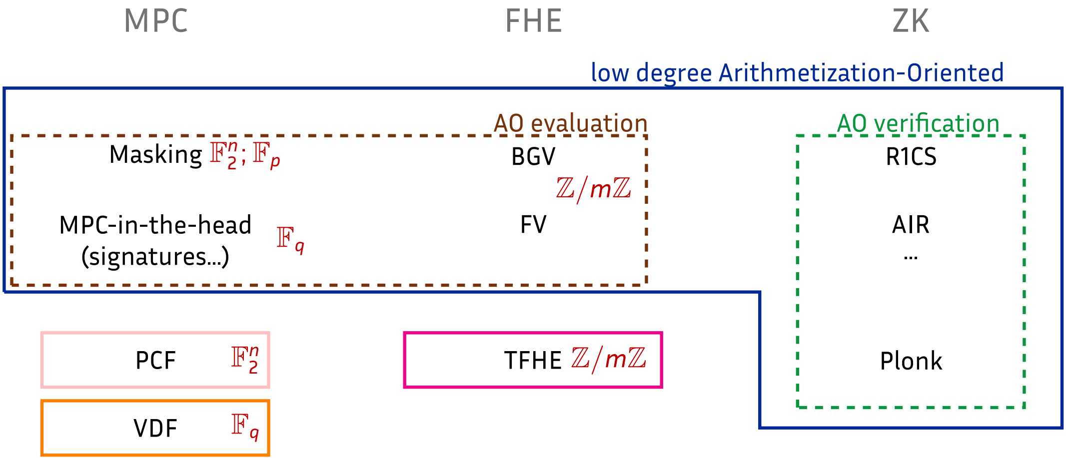

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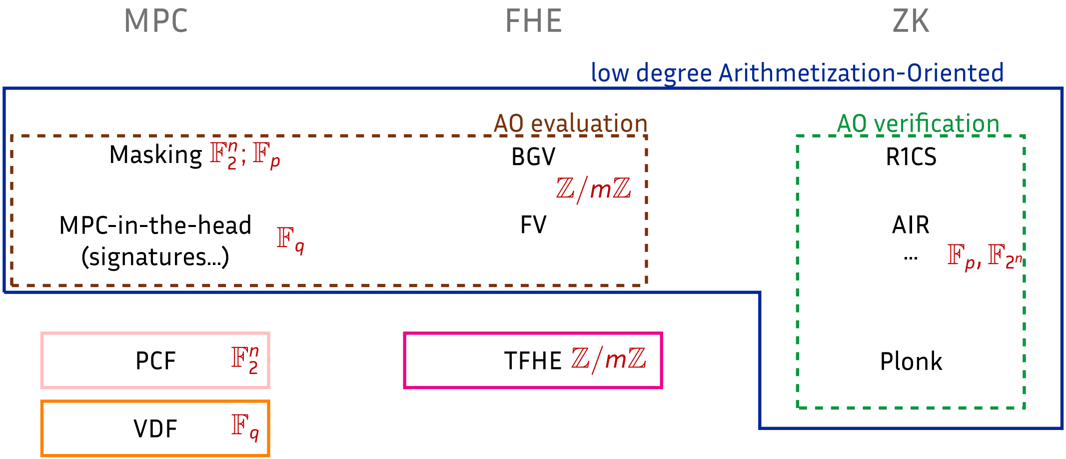
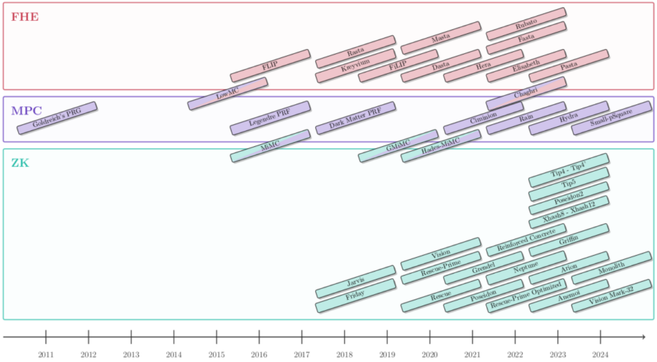


A Cambrian Explosion

credit: Clémence Bouvier [Bou23]



https://stap-zoo.com/

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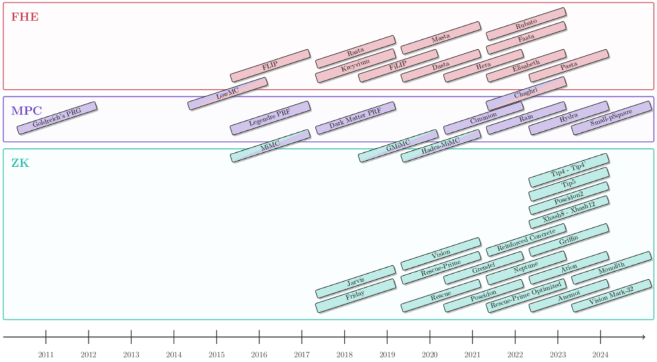

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An **increased diversity of design criteria** leads to a Cambrian explosion of new symmetric primitives!

Plan of this Section

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all of them!

Opinion 1

STAPs are nothing special: we (symmetric people) need to do what we always did.

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Opinion 2

Working over $\mathbb{F}_q$ (especially if low degree arithmetizations are needed) and the need for primitive generators introduce **new cryptanalysis vectors**

Underlying Alphabet

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

- Indeed. In particular, q prime means no Frobenius automorphisms, meaning linear operations are only constant multiplications.
- Protocol flexibility means STAPs are often in fact primitives generators, i.e., algorithms **generating** primitives.
- Low degree arithmetization implies low degree algebraic modeling

beware of algebraic attacks!

(there already was a mass extinction event, the **Freelunch attack**

(shameless plug: check out Aurélien's talk later this morning)

Opinion 2

Working over $\mathbb{F}_q$ (especially if low degree arithmetizations are needed) and the need for primitive generators introduce **new cryptanalysis vectors**, but design approaches will rely on tried and true methods.

Primitive Overdose

credit: Diego Delso, CC BY-SA 4.0,

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Cryptanalysis has not followed the design explosion

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Potential Explanations

- Not all primitives are designed to **ease analysis**
- So many (too many) minor variants...

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Opinion 3

1. We need more cryptanalysis!
2. We must become better at handling primitive generators.

Plan of this Section

What Have We Learnt?

- The shape of symmetric primitives has always been dictated by external constraints

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Thank you!

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Plan of this Section

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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]

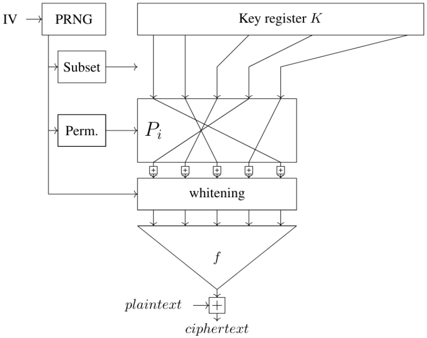

Fig. 1: The group filter permutator design

source: *Towards Case-Optimized Hybrid Homomorphic Encryption Featuring the Elisabeth Stream Cipher*

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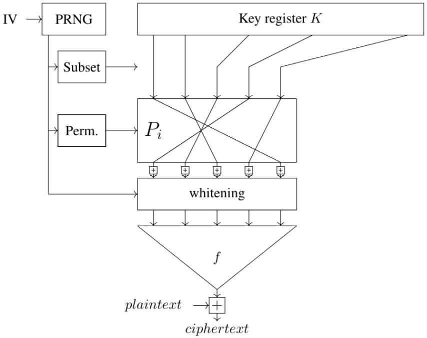

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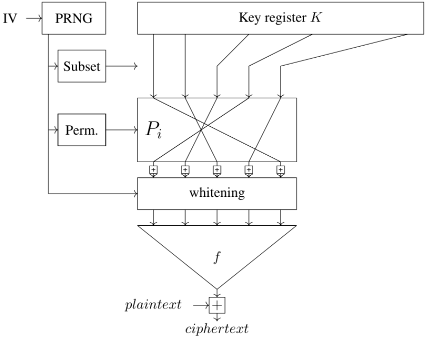
See you at the rump session :D



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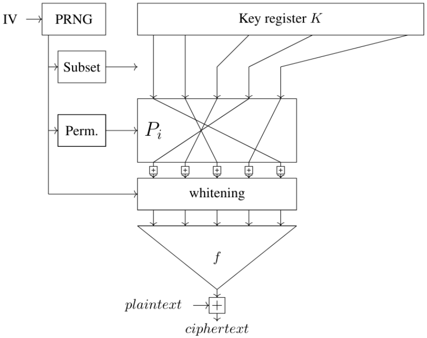
Transistor [BBB+25] ; $q = 2^4 + 1$
SNOW-like round structure
See you at Anne's invited talk :D



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BGV/FV: corresponding stream ciphers

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

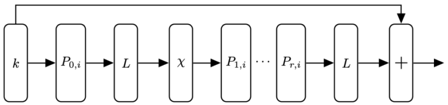

Figure 2: Generation of i-th block of DASTA.

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Dasta – Alternative Linear Layer for Rasta

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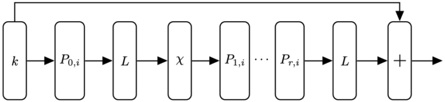

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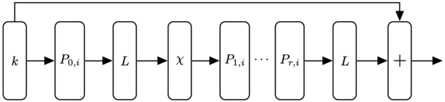

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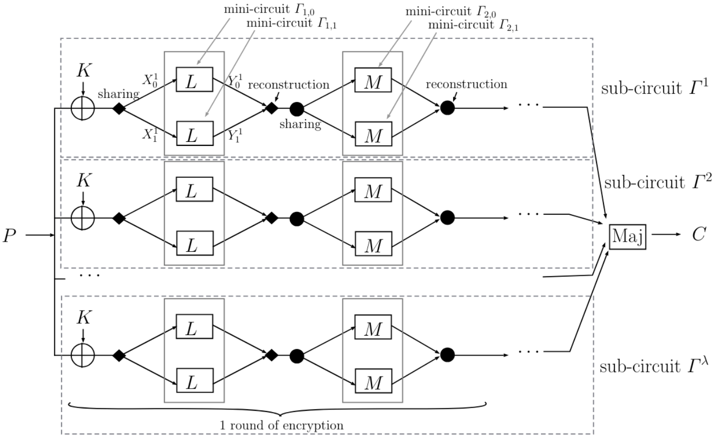
Plan of this Section

Trojan Resilience



source: *MOE: Multiplication Operated Encryption with Trojan Resilience*

https://tosc.iacr.org/index.php/ToSC/article/view/8834

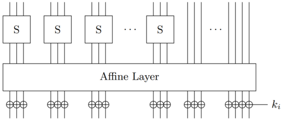
MPC-Friendly Encryption

LowMC [ARS+15] $q = 2$

SPN with partial layer of quadratic S-boxes.

Rely on large, randomly generated matrices.

Only one encryption/key; broken anyway



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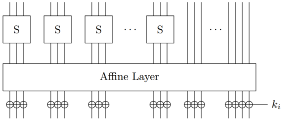

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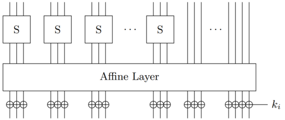

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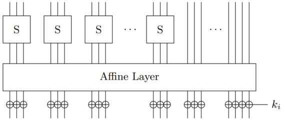
MOE [BFL+21] $q = 2^{128}$, $m = 2^{128}$
Dedicated structure with linear operations in $\mathbb{F}_q$ and $\mathbb{Z}/q\mathbb{Z}$. Intended for hardware trojan resilience.



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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

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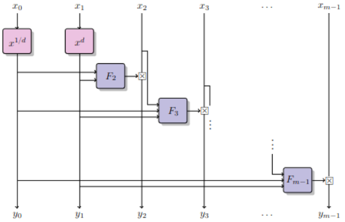

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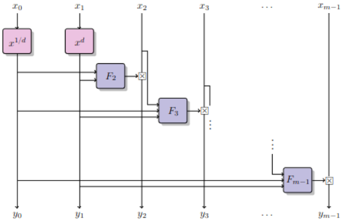
Anemoi [BBC+23] $q = 2^n$ or large prime
Uses the “Flystel”, a high degree S-box
CCZ-equivalent to a function of low degree.



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