TU Graz

SCIENCE
PASSION
TECHNOLOGY

First Order Masking for Hybrid Homomorphic Encryption Schemes

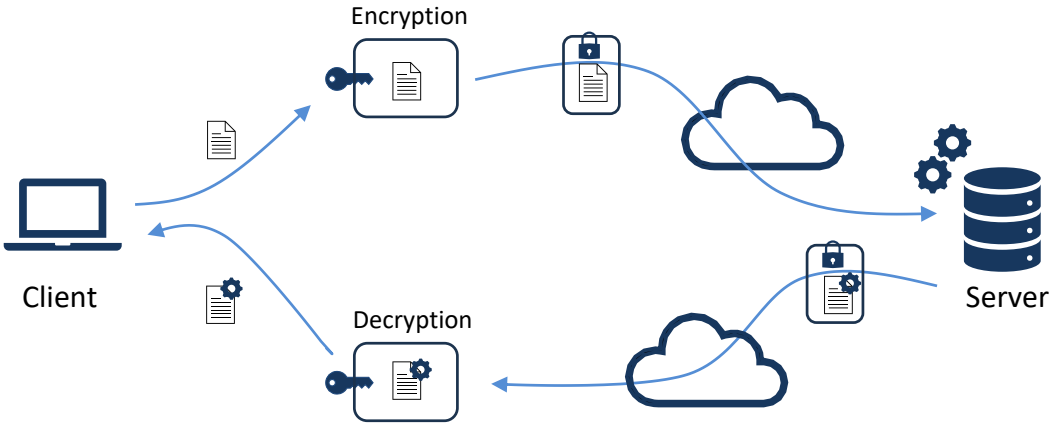
Nedžma Mušović

Master Project Presentation

Outline

- Introduction
- **HERA** - First Order Masking
- Application to **PASTA**
- Higher Order Masking and Conclusion

Homomorphic Encryption



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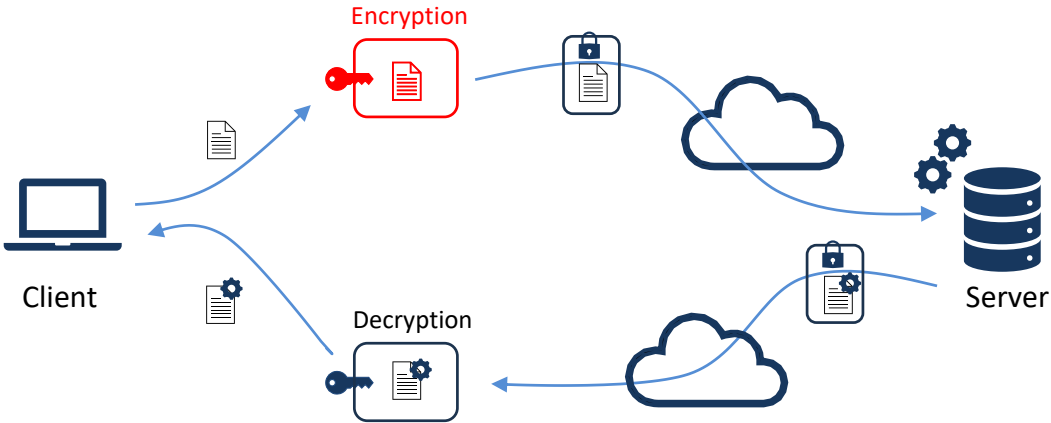

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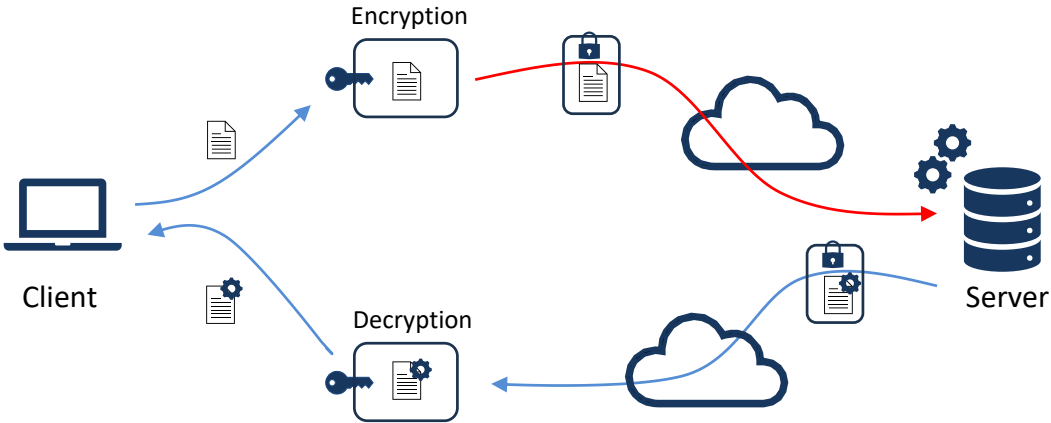

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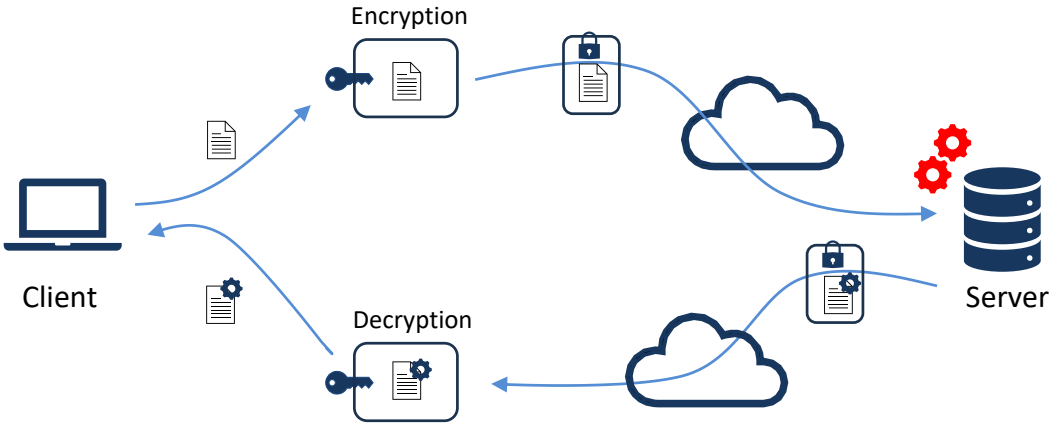

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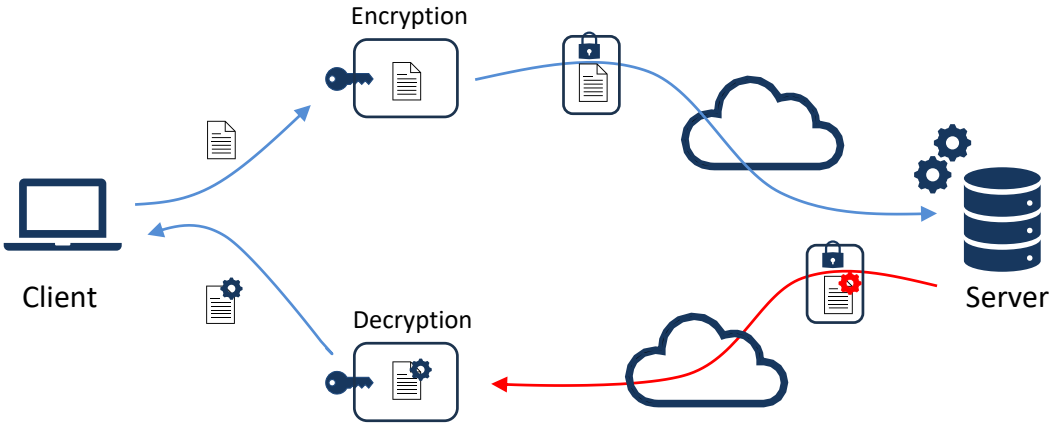

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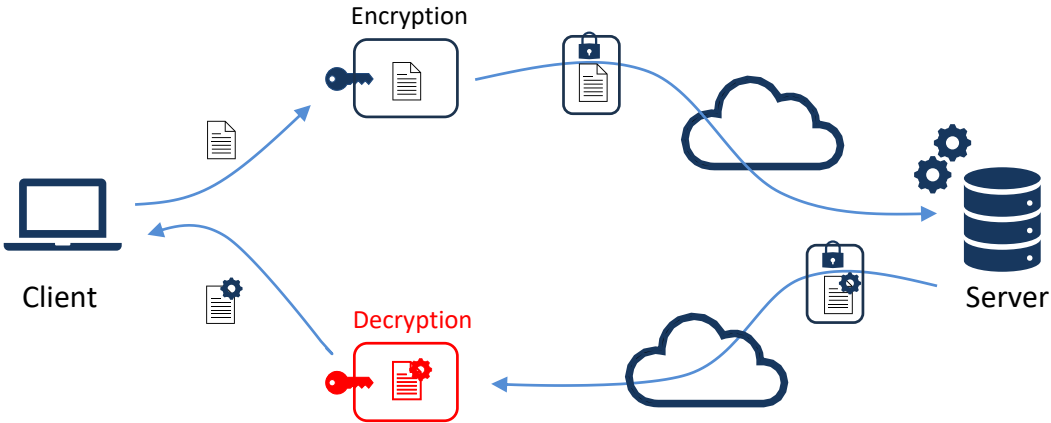
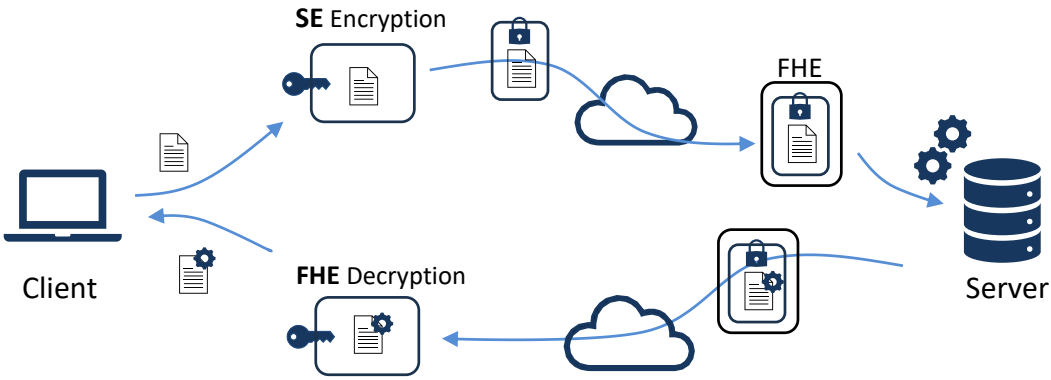


Hybrid Homomorphic Encryption



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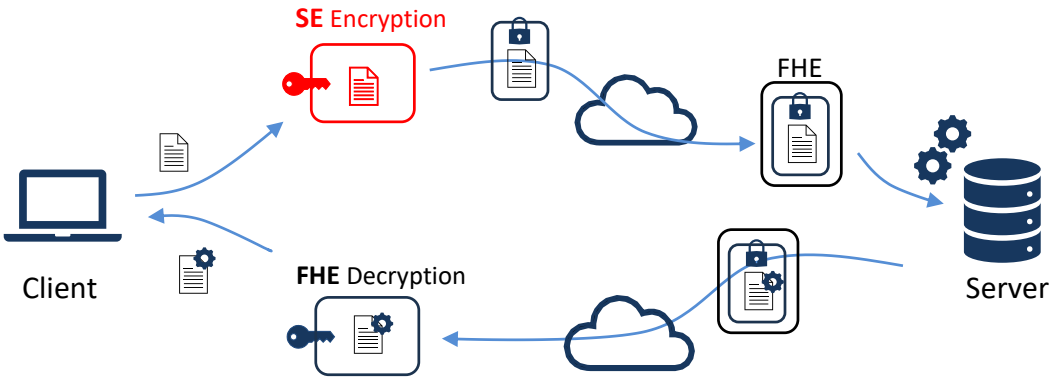

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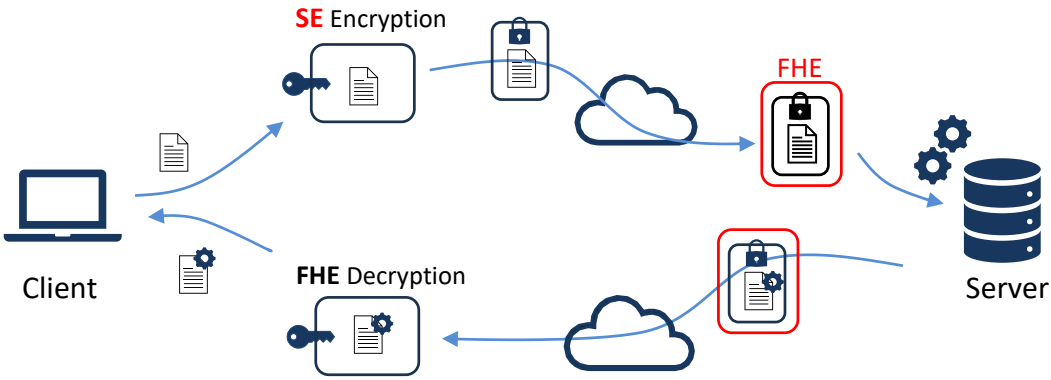

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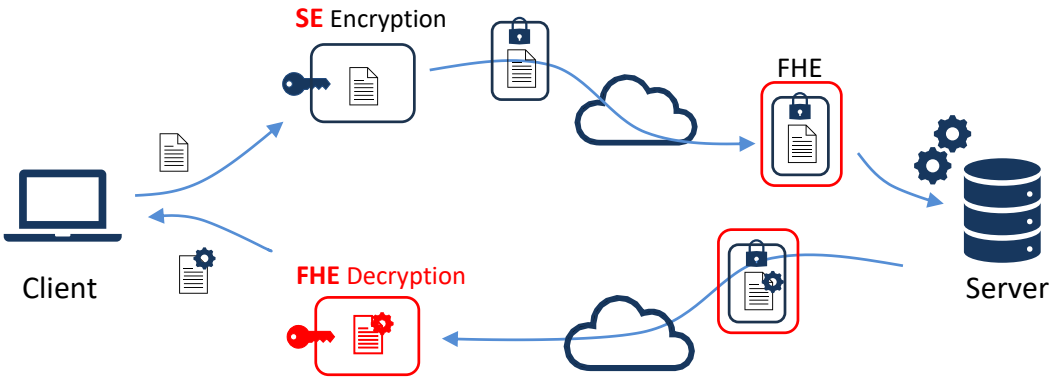

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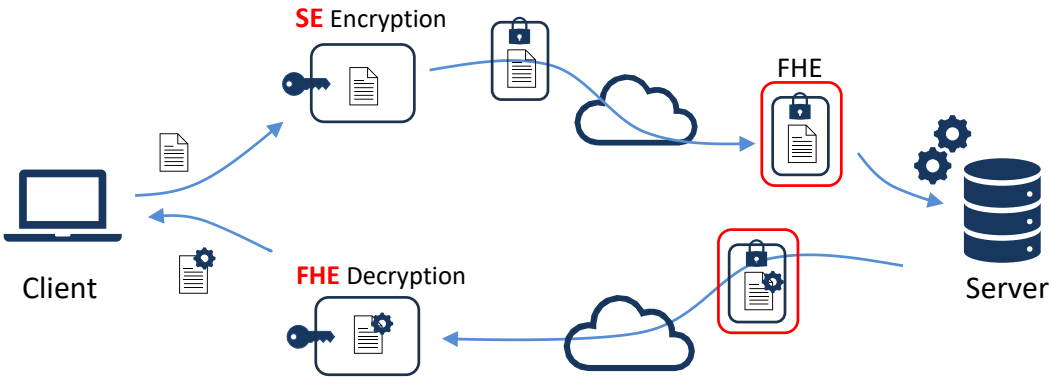

HERA Encryption

- Prime-field arithmetic; 16 to 60 bits prime number p.
- Generates a keystream from the input key *K* and adds it to the plaintext.
- Typical **HERA** permutation consists out of 5 rounds.
- State size: $n = 16$; hence state $X \in \mathbb{Z}_p^n$.

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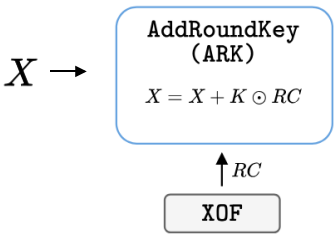

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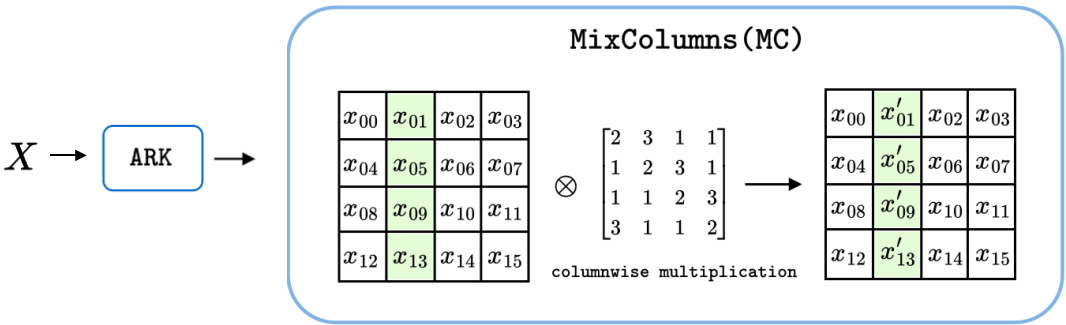

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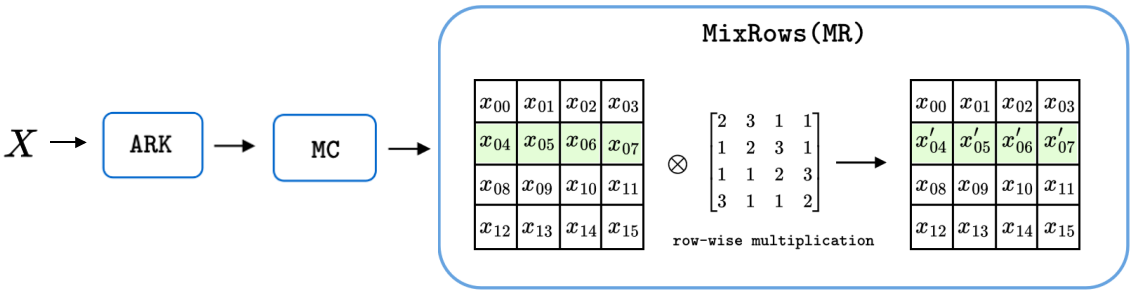

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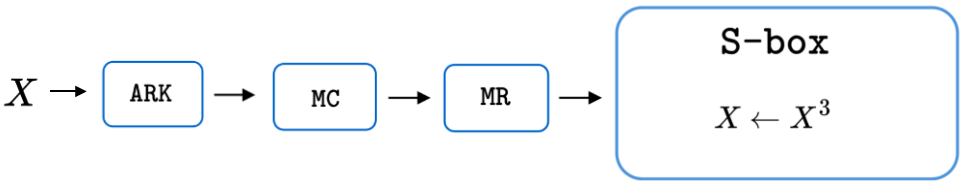

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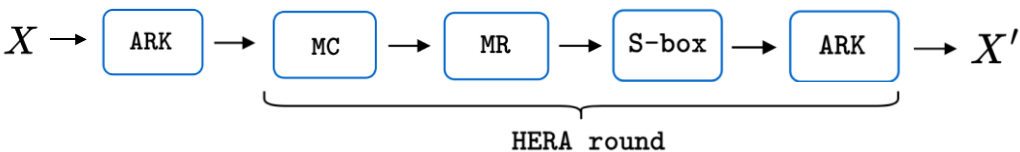

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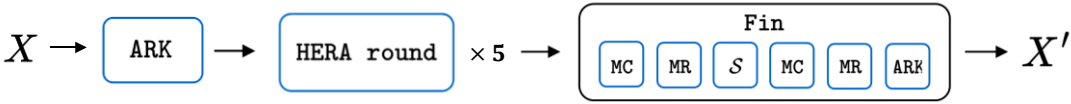
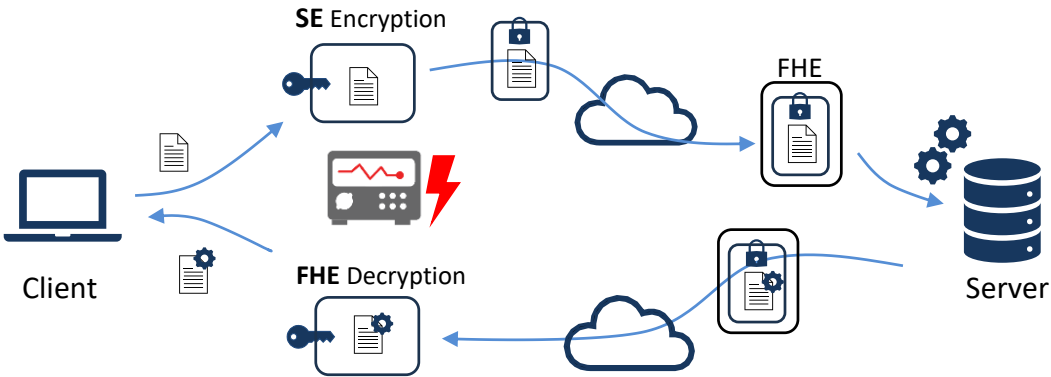


HERA Side-Channels Potential



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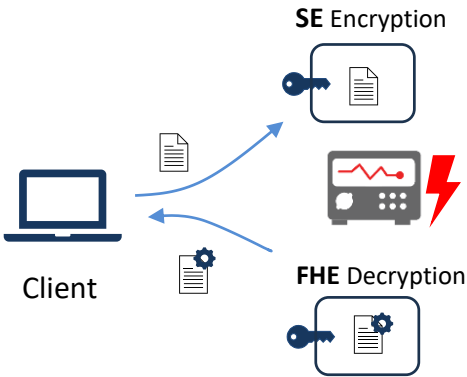
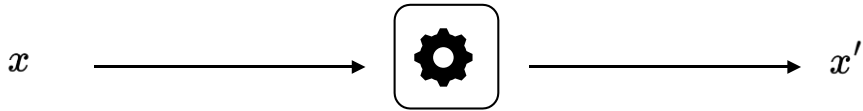


- Exploit relation between power consumption and processed data.
- Statistical methods to guess secret key bits - **DPA/CPA** possible.
- Modular arithmetics spreads side-channel leakage.

First Order Masking



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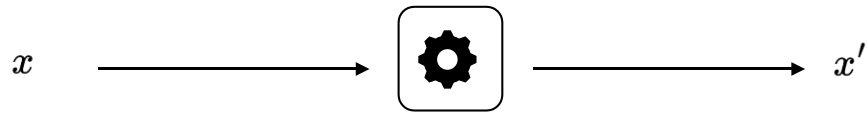

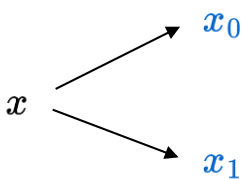

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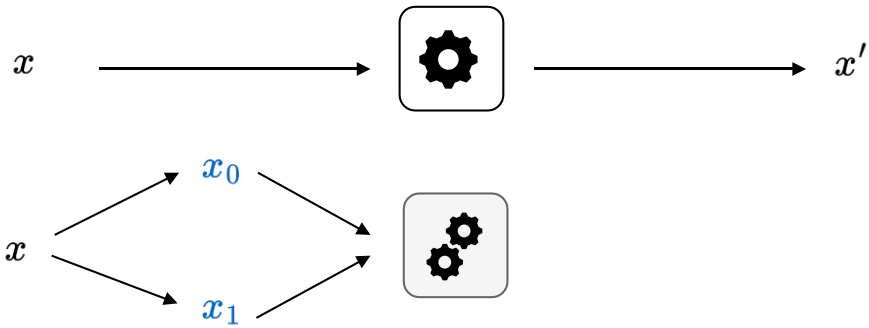

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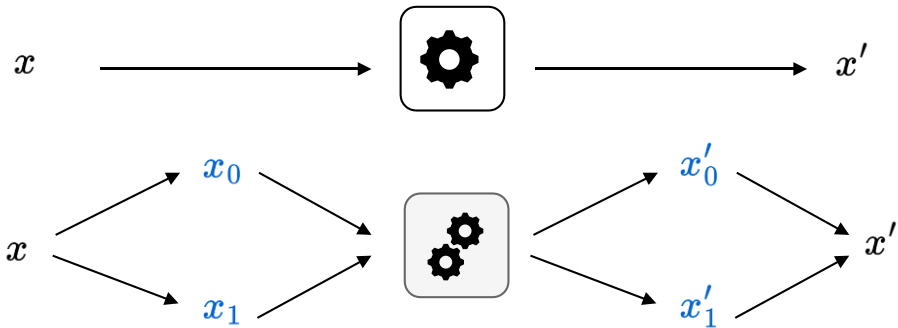

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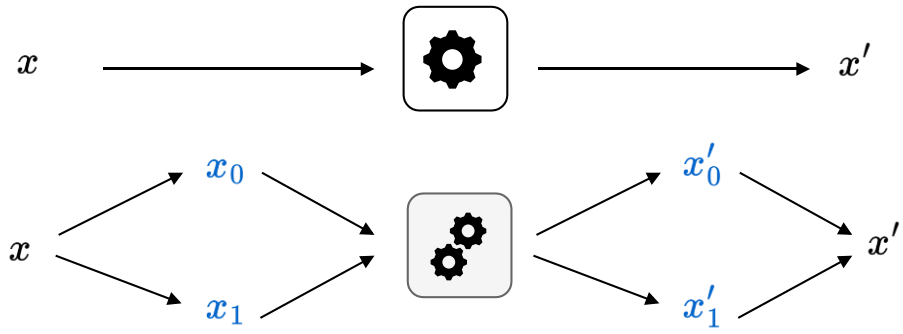
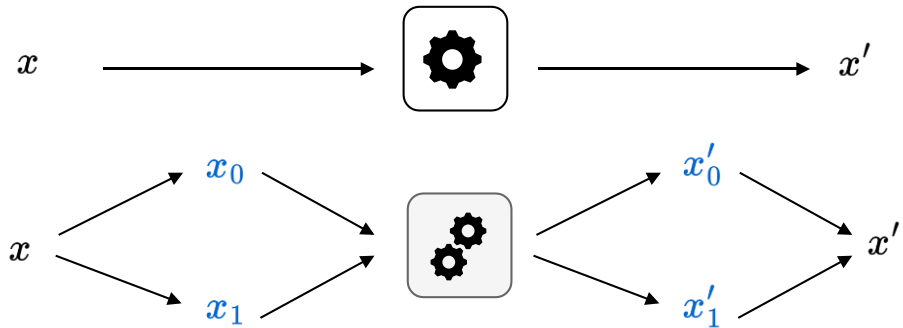


Boolean sharing

First Order Masking



Arithmetic sharing

$$x = x_0 + x_1 \qquad x' = x'_0 + x'_1$$

Test Vector Leakage Assessment (TVLA)

- Standard statistical method to detect **side-channel leakage**.
- Compares device traces for **fixed vs random inputs**.
- Applies **Welch's t-test** at each time point.
- Evidence of leakage: $|t| > 4.5$.

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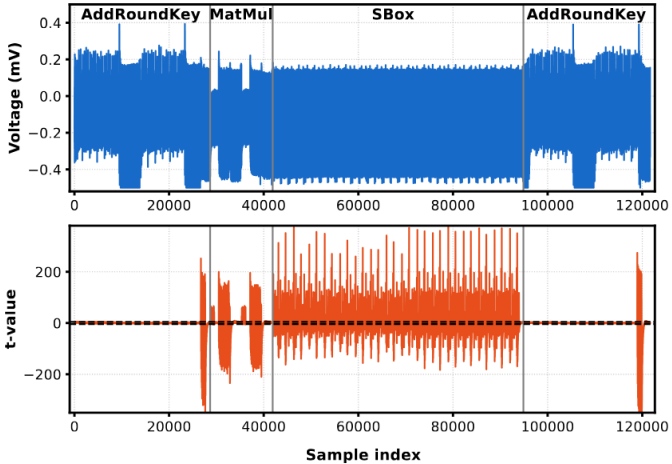

Masking a HERA round

$$X = X_0 + X_1 \pmod{p}$$

$X_0 \longrightarrow$

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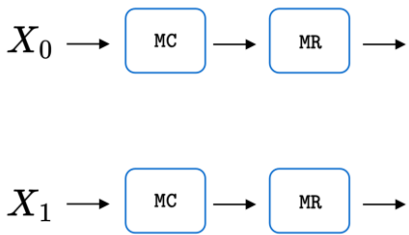

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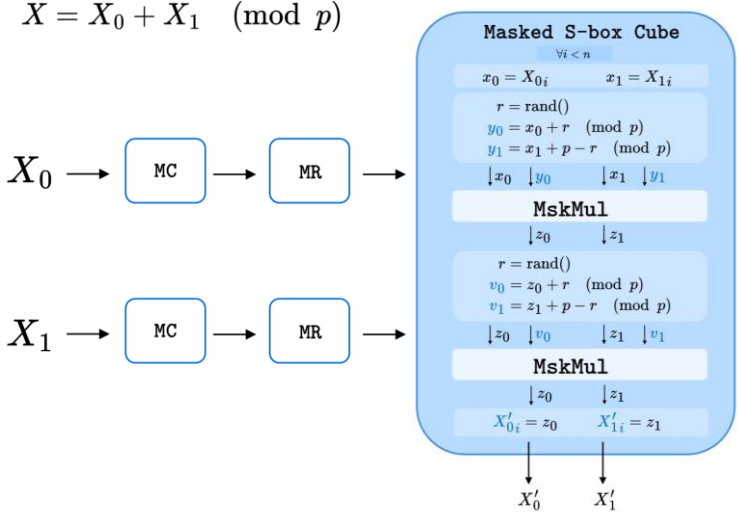

Masking a HERA round

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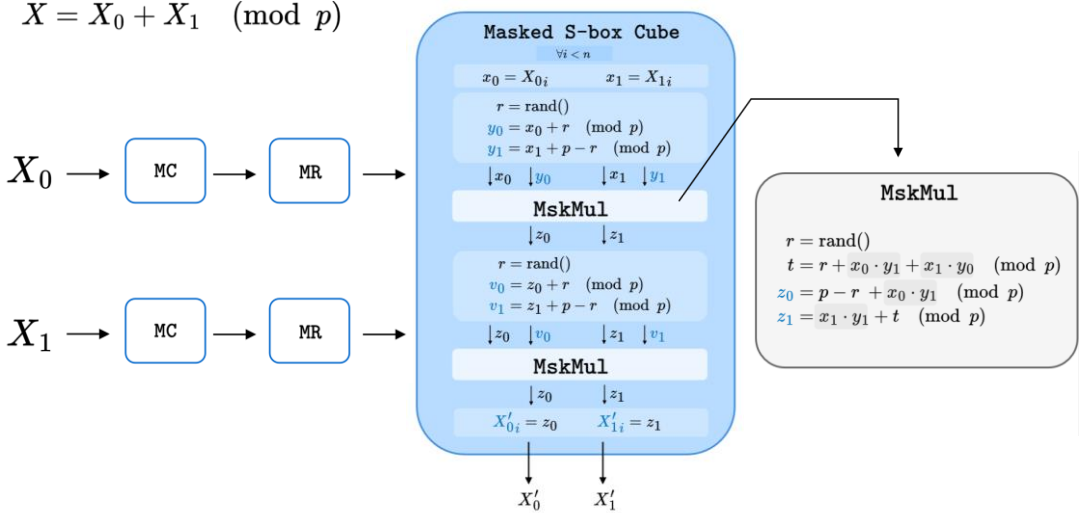

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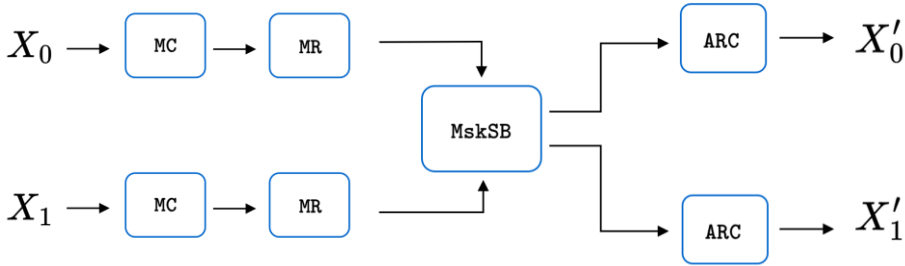
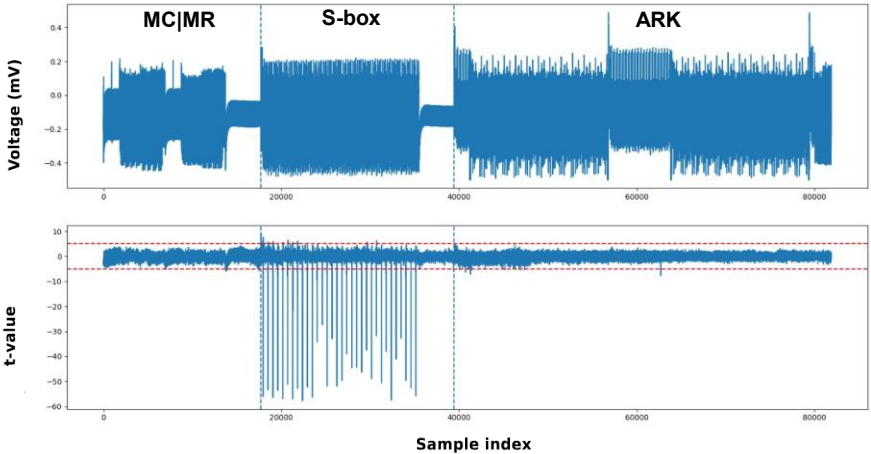
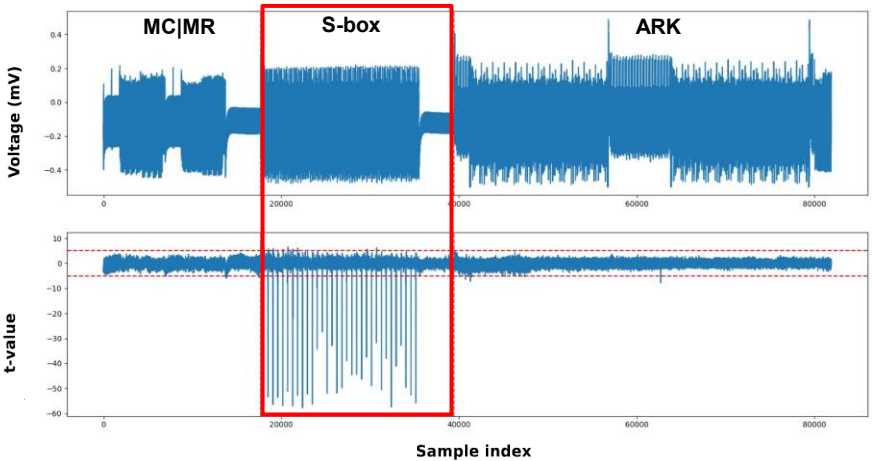


TVLA Results



Preliminary Results

TVLA Results



Implementation Heuristic

- Ensure the random source is random indeed.
- Separate shares usage within the C code.
- Employ assembly code for full register control.
- Address critical points which could lead to the statistical leakage despite the masked model.

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$r_4 \leftarrow x_0$

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$$\mathtt{HD}(x_0, x_1) = \mathtt{HW}(x_0 \oplus x_1) = \mathtt{HW}(x)$$

leakage through Hamming distance

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leakage through Hamming distance

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$$r_4 \leftarrow x_1$$

Implementation Heuristic

$r_3 \leftarrow x_0$

Implementation Heuristic

unknown $r_3 = ?$

$r_3 \leftarrow x_0$

$$\mathtt{HD}(x_0, x_1) = \mathtt{HW}(x_0 \oplus x_1) = \mathtt{HW}(x)$$

potential leakage through Hamming distance

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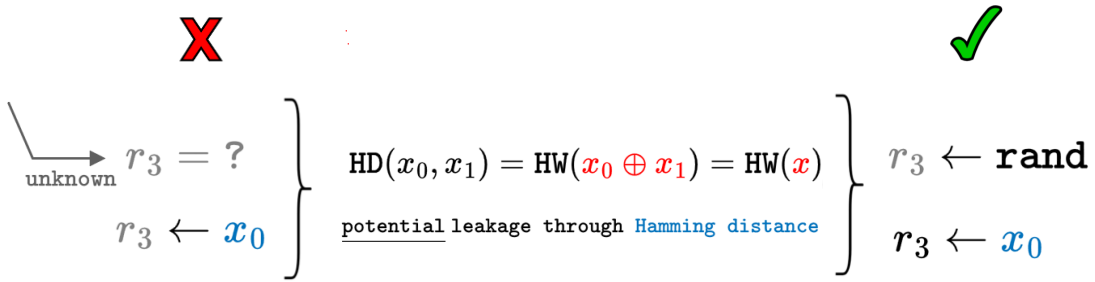

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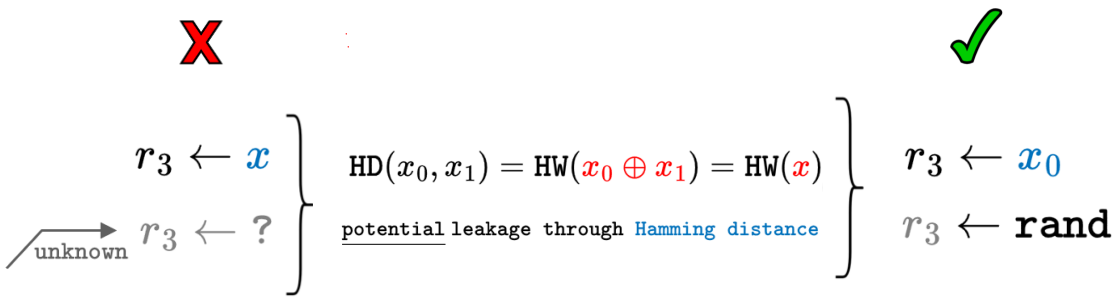

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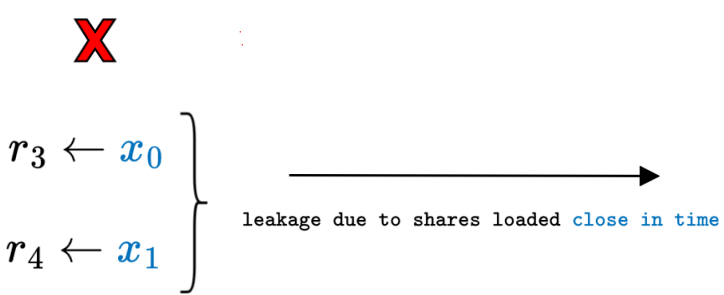
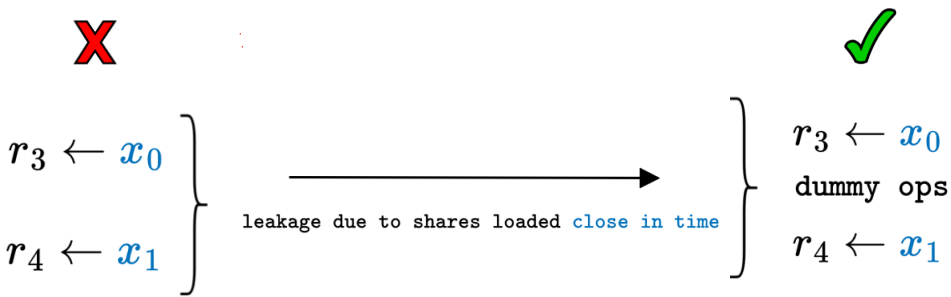


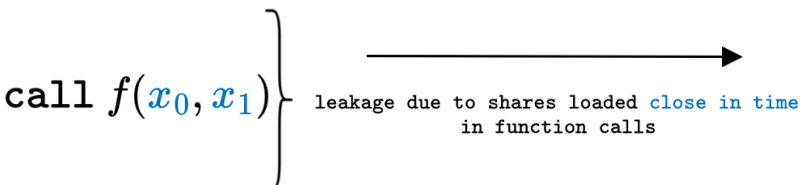
Implementation Heuristic



Implementation Heuristic

`call` $f(x_0, x_1)$

Implementation Heuristic



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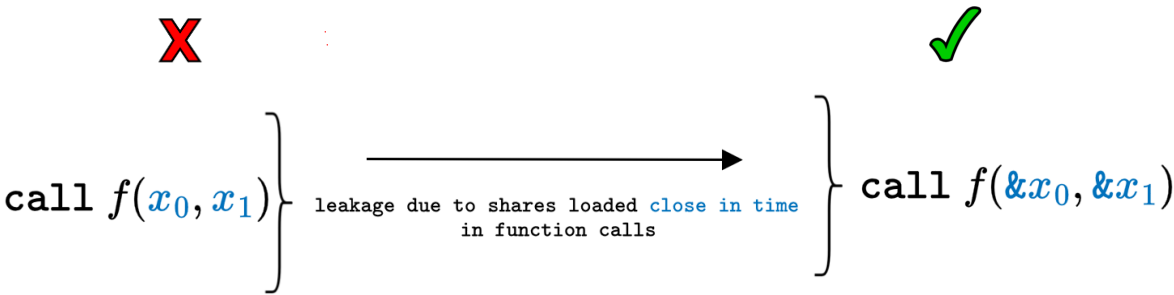
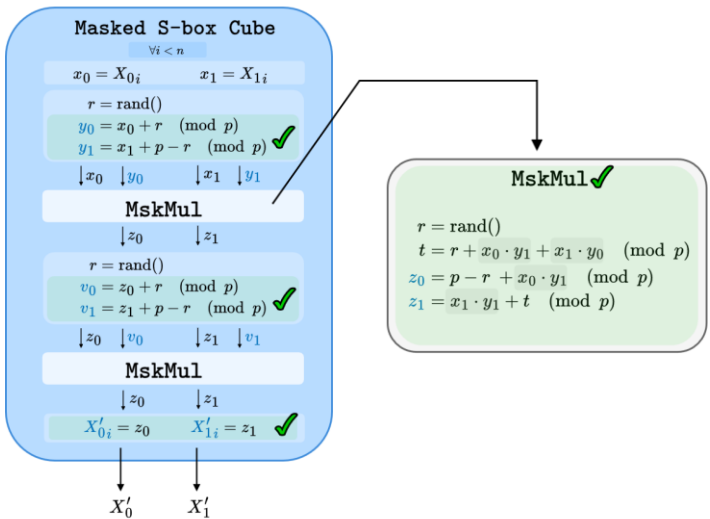
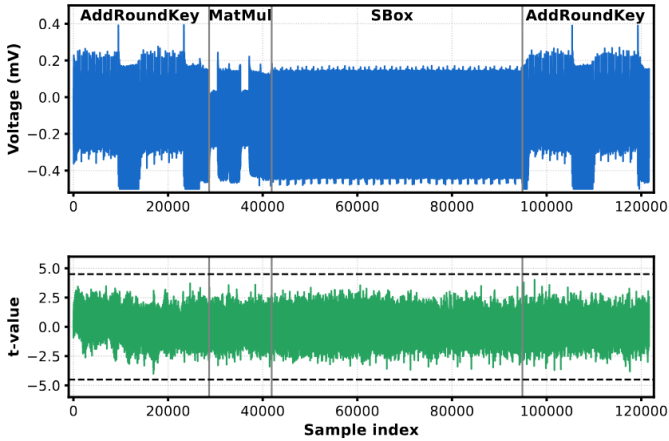


Application to HERA S-box



TVLA Results



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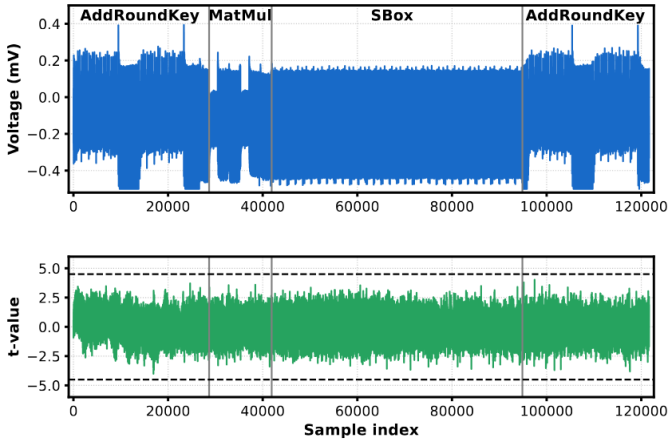
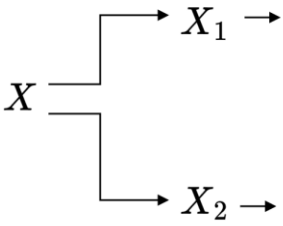
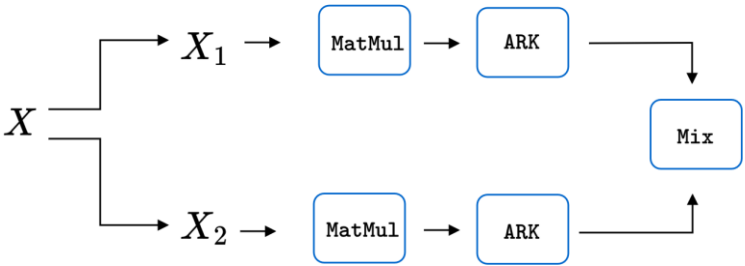


PASTA Encryption

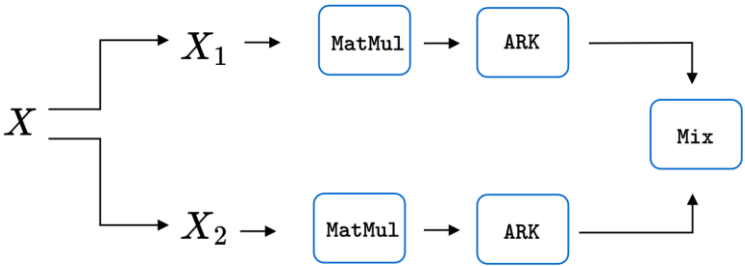


PASTA Encryption



Application to Similar Encryption Schemes

PASTA Encryption

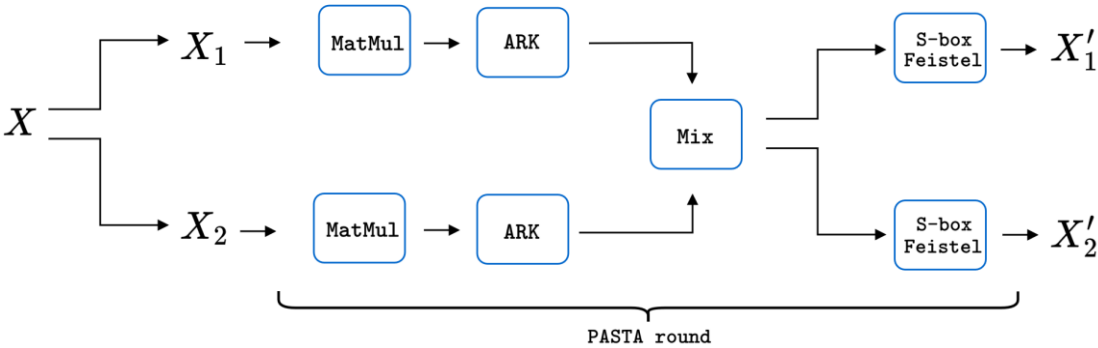


S-box Feistel

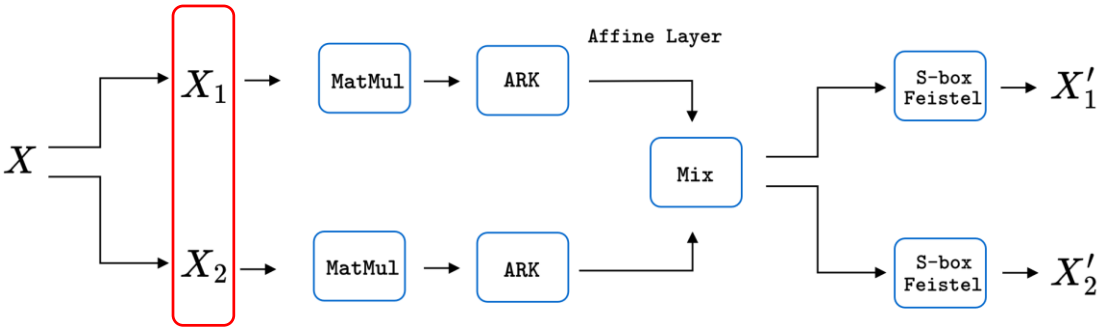
$$\forall i < n$$

$$= \begin{cases} x_i & \text{if } i = 0, \\ x_i + (x_{i-1})^2 & \text{otherwise.} \end{cases}$$

PASTA Encryption

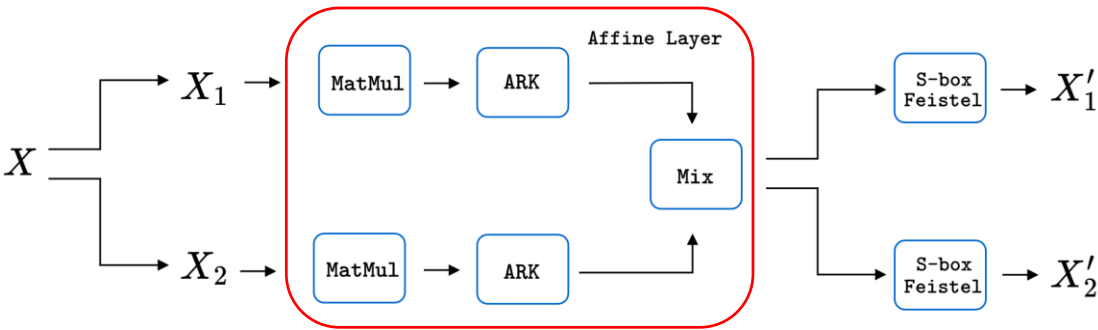


Masking PASTA Round



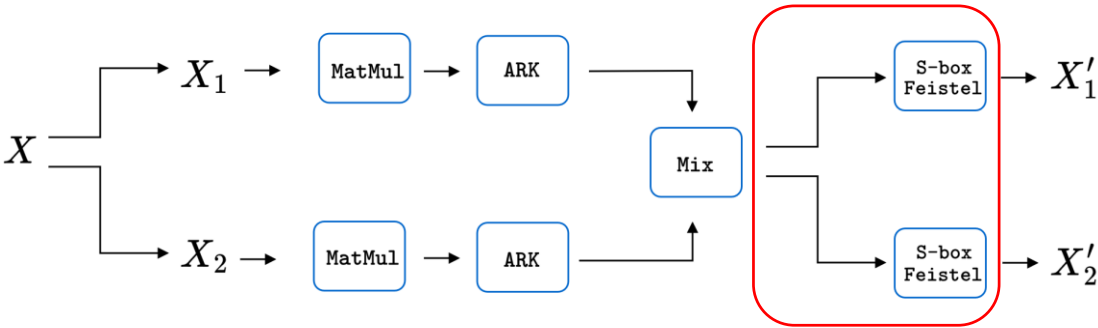
- ✓ mask both parts

Masking PASTA Round



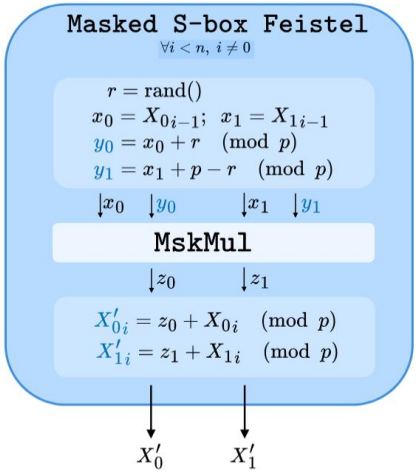
✓ apply linear layers on each share

Masking PASTA Round

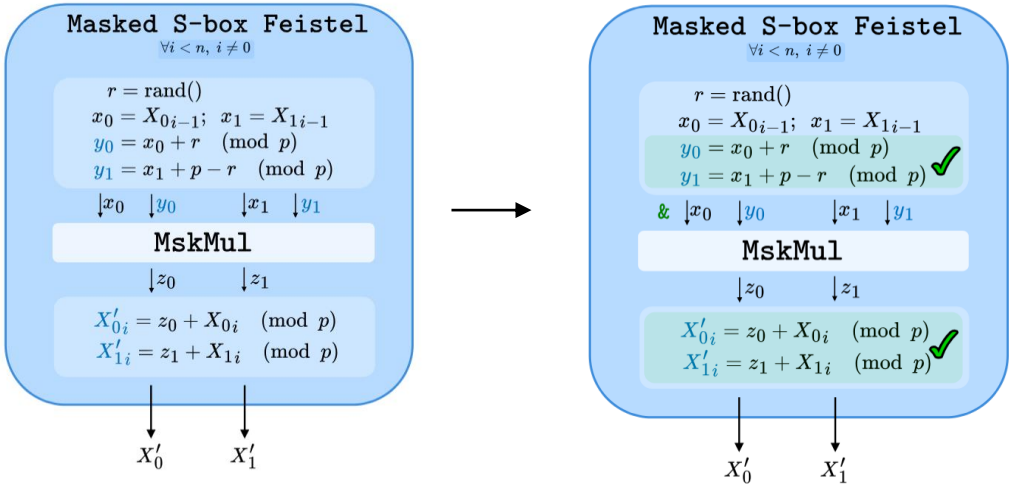


✓ Use secure multiplication

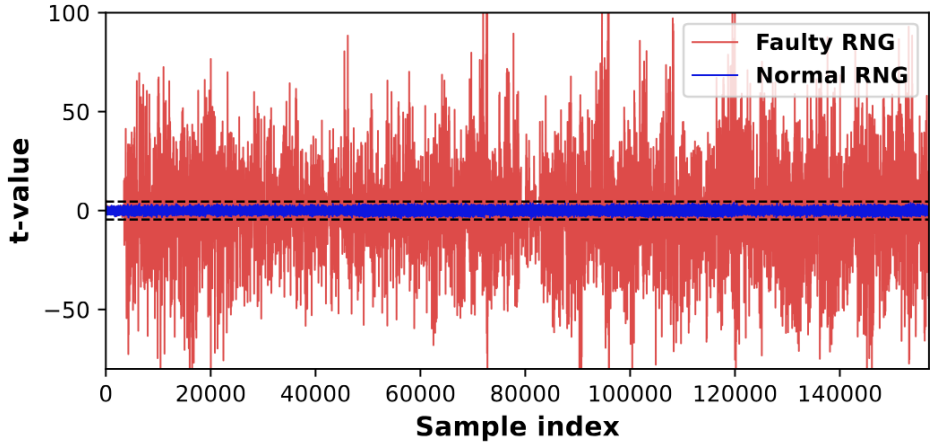
Masking PASTA Round



Masking PASTA Round



TVLA Results



Higher Order Masking

- First order masking protects only against single-probe attacks.
- Extend with **higher order masking** for more security, by expanding the MskMul accordingly.

Conclusion

- HERA vulnerable to side-channel attacks.
- Correct masking model can leak due to implementation specifities.
- The proposed approach application concretely verified on PASTA.
- First order masking protects only against single-probe attacks.