A High-Order Infective Countermeasure Framework

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Context

Faults are a serious threat in cryptographic implementations.

Attacker's goal: getting an erroneous output that leaks the secret key.

Dealing with **block ciphers**, two strategies in state of the art to avoid it:

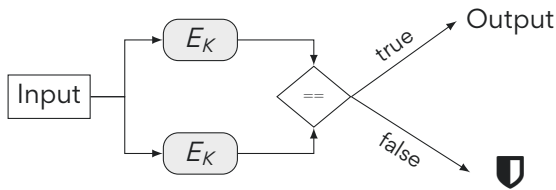
- Detection
- Infection

Detection

Principle

The algorithm is run twice and the outputs are compared.

If different, an appropriate measure is taken (for instance, no output).



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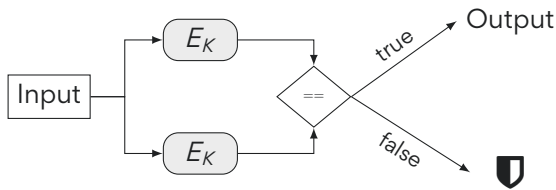


But...

Comparison can be corrupted by an extra fault.

Infection

Principle

The algorithm's output is corrupted by an amplified error.

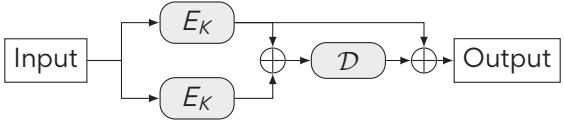
No need for comparison and non-informative output.

But...

How to amplify the error in practice?

Infection today

- External infection



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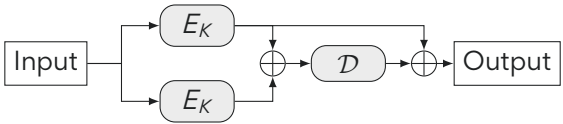

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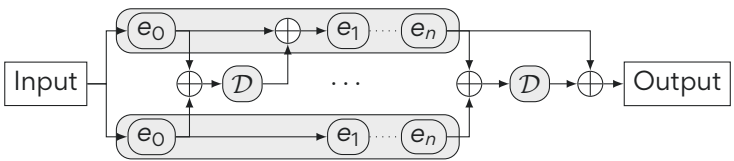

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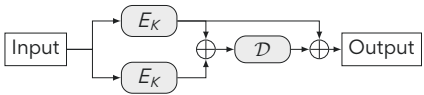

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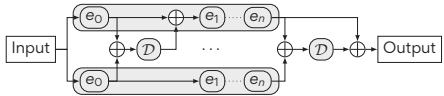

Almost all propositions up to now are broken.

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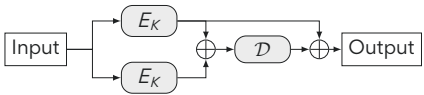

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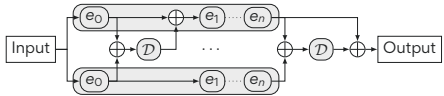

Almost all propositions up to now are broken.

Either because of:

- A deterministic $\mathcal{D}$,
- Or an invertible $\mathcal{D}$,
- Or a low-diffusion $\mathcal{D}$.

Infection today

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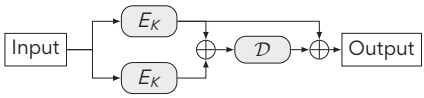

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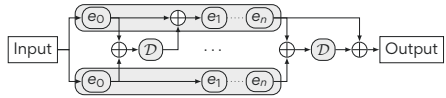

In a secure scheme, $\mathcal{D}$ should be:

- ✓ *Non-deterministic*
- ✓ And *non-invertible*
- ✓ And with *high-diffusion* capacity

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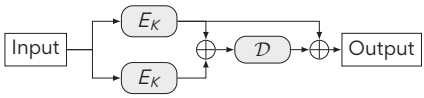

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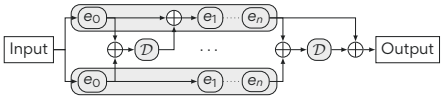

In a secure scheme, $\mathcal{D}$ should be:

- ✓ *Non-deterministic*
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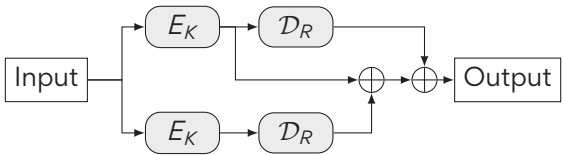
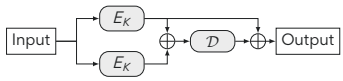
Hard to find such $\mathcal{D}$ with the constraint $\mathcal{D}(0) = 0$

Principle of our framework

External infection but the infective value is $\Delta\mathcal{D}(E_K)$ instead of $\mathcal{D}(\Delta E_K)$



Our proposal



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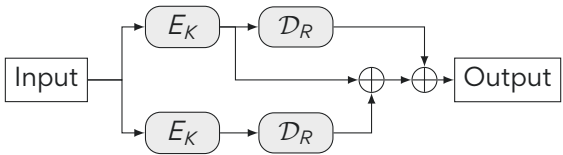

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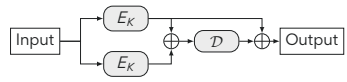

SoA external infection

- Constraint $\mathcal{D}(0) = 0$ removed
  $\Longrightarrow$ $\mathcal{D}$ can be a hash function: *non-invertibility* and *high diffusion* achieved

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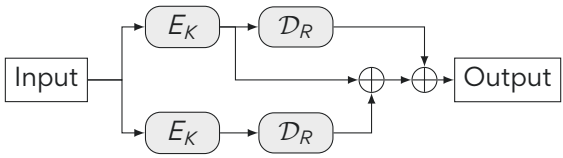

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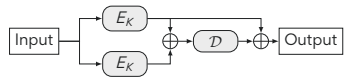
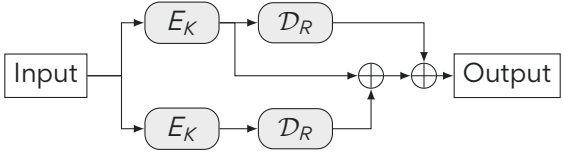


SoA external infection

- Constraint $\mathcal{D}(0) = 0$ removed
  $\Longrightarrow$ $\mathcal{D}$ can be a hash function: *non-invertibility* and *high diffusion* achieved
- R: random value seeding $\mathcal{D}$: *non-determinism* constraint fulfilled

Principle of our framework

Secure only against one fault!



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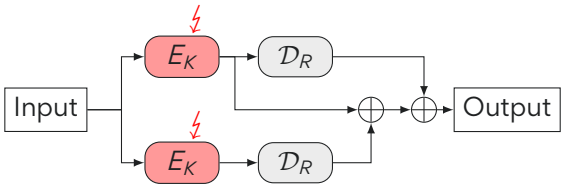

$$\begin{aligned}\text{Output} &= E_K^{\ell} \oplus \mathcal{D}(E_K^{\ell}) \oplus \mathcal{D}(E_K^{\ell}) \\ &= E_K^{\ell}\end{aligned}$$

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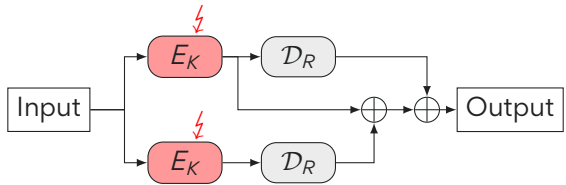
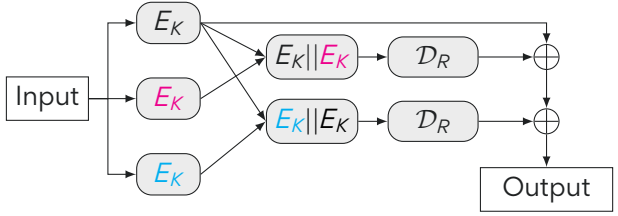


$$\begin{aligned}\text{Output} &= E_K^i \oplus \mathcal{D}(E_K^i) \oplus \mathcal{D}(E_K^i) \\ &= E_K^i\end{aligned}$$

How to get secure against several faults?

Improved construction

Construction to defend oneself against **two** faults:



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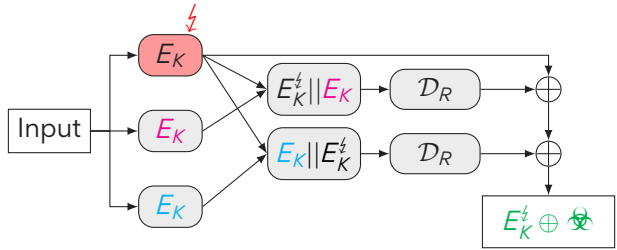

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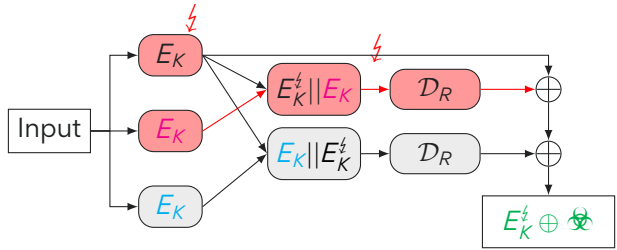

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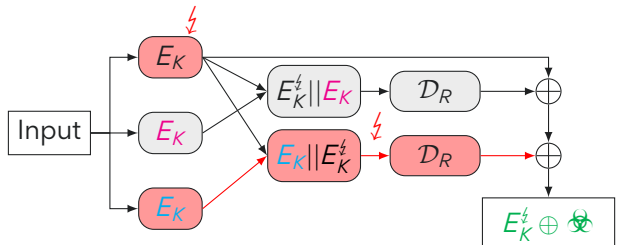
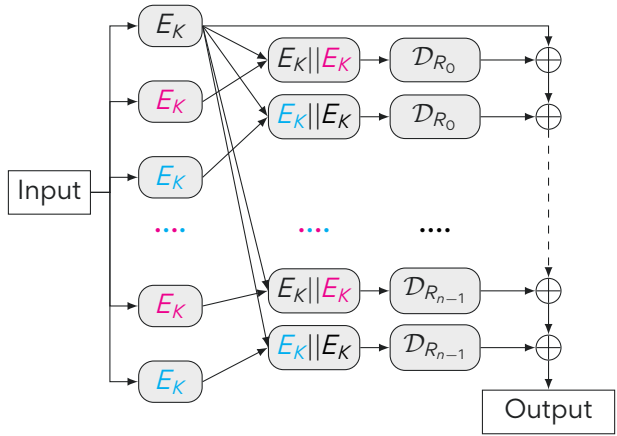


Extension against $2n$ faults



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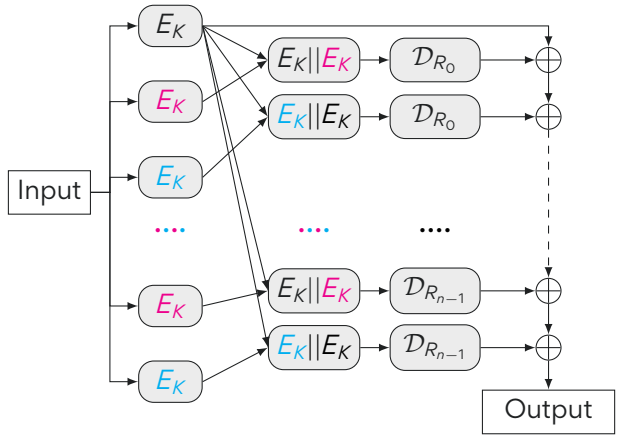
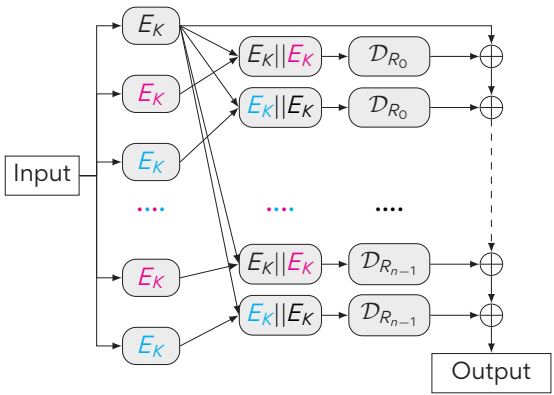


- R is changed from a couple of $\mathcal{D}$'s to another

Extension against $2n$ faults



Scheme is **proven secure** in the paper

Attacker model

Per fault, the attacker:

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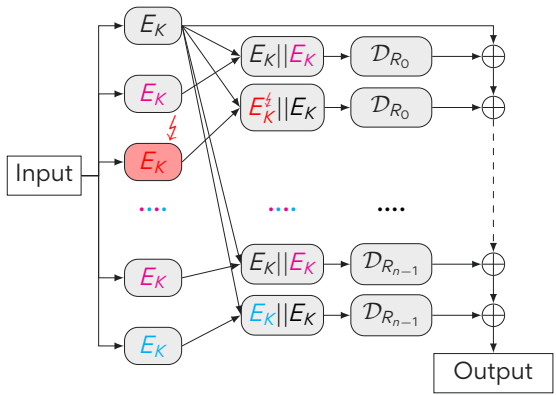

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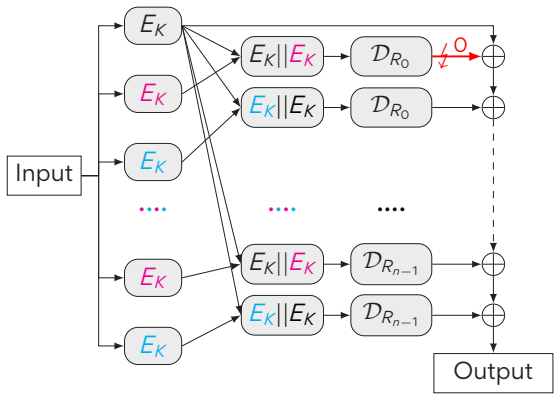

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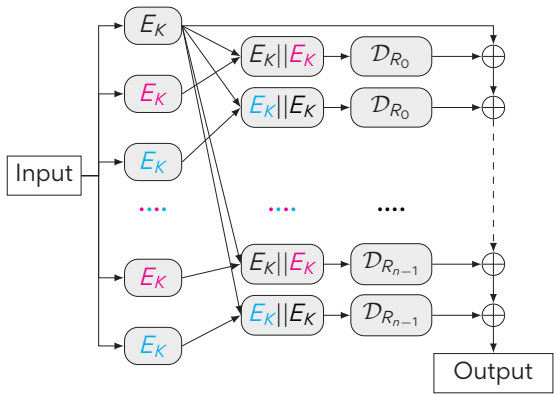

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And $\mathcal{D}$ is supposed:

- ✓ *Non-invertible*,
- ✓ To have a *high-diffusion* capacity.

Conclusion

- Identification of some common flaws in the propositions of the state of the art
- Proposal of a **new solution** taking into account our observations
- **First proposal** of an infective scheme allowing one to **resist several-fault attacks**
- **Security proof** of our solutions provided in the paper
- Open question: find the best suited $\mathcal{D}$ that meets the scheme's constraints