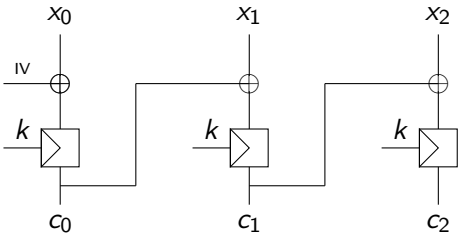
Simulatable Leakage, Revisited

Emilie Deprez, Charles Momin, and François-Xavier Standaert

CASCADE 2026

What is leakage-resilience ?



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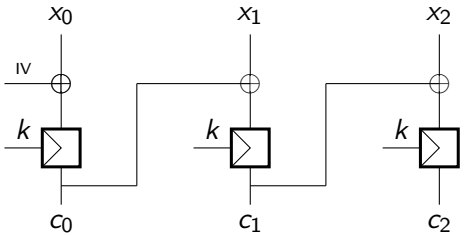

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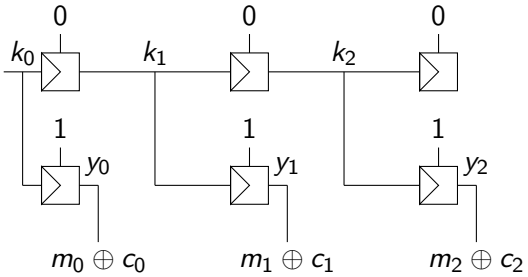

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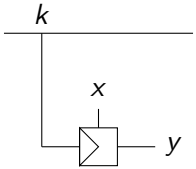

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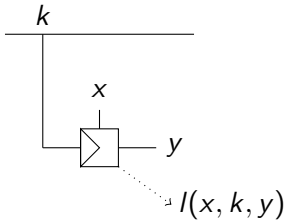

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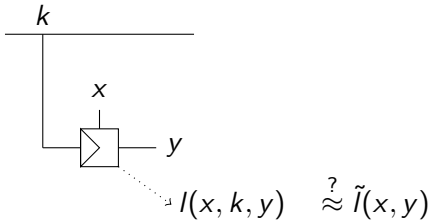

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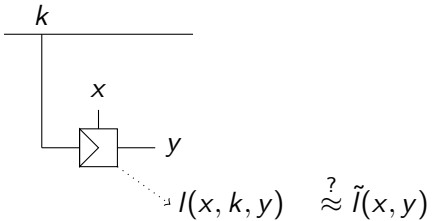

If we can efficiently simulate $l(x, k, y)$ without knowledge of k then the leakage can be viewed as independent of k.

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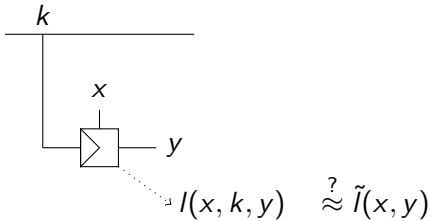

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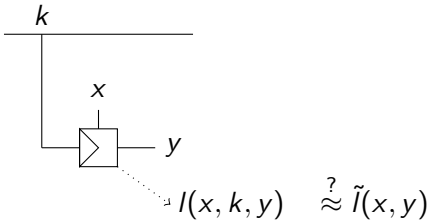

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$\rightarrow$ 1-simulability game

$\rightarrow$ q-simulability game $=$ q block ciphers use k

How to formalize SPA security ?

Question: How to efficiently and concretely simulate an indistinguishable leakage without key knowledge, but with the implementation ?

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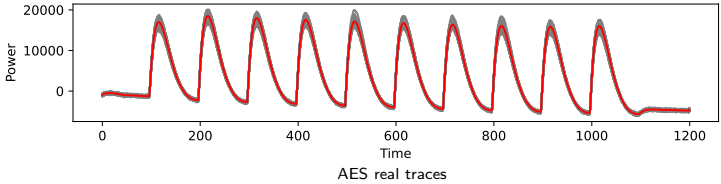
Attempt: the split-and-concatenate simulator

The split-and-concatenate simulator: principle



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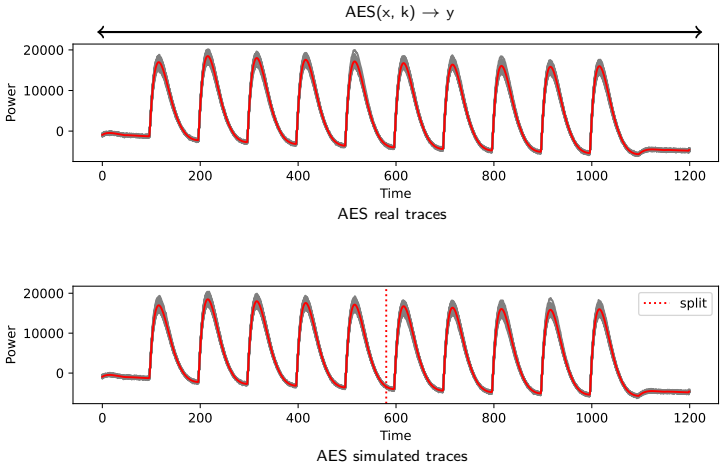

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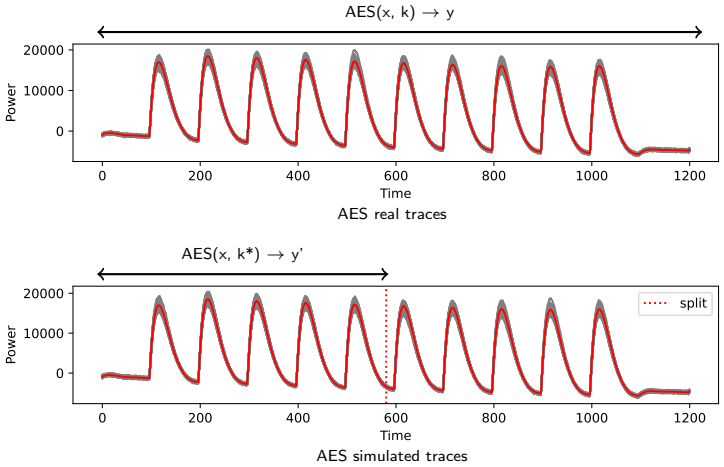

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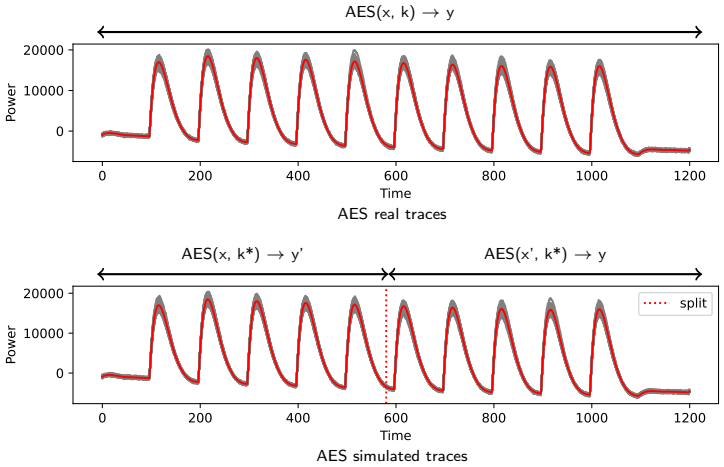

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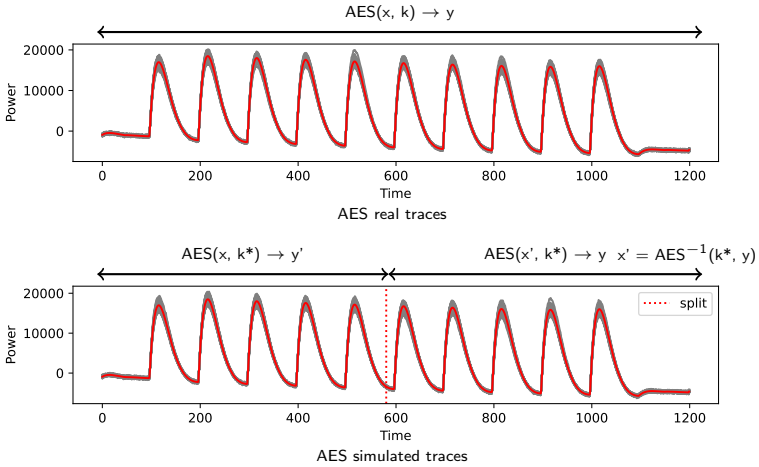

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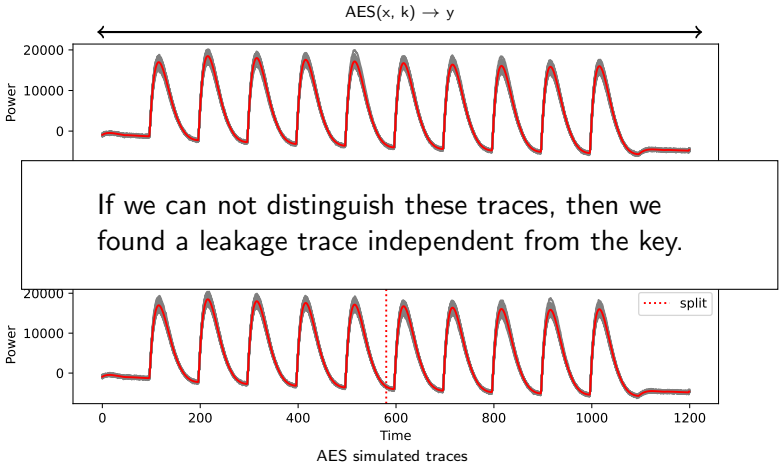

The S&C simulator: the correlation distinguisher

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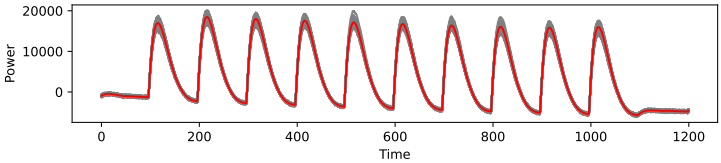

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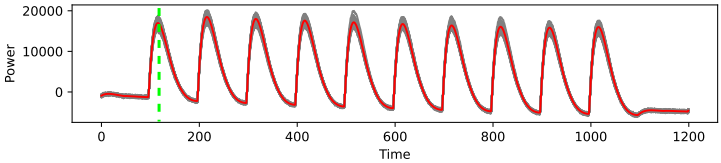

The S&C simulator: the correlation distinguisher

- In 2014 Longo et al. proposed a distinguisher by cross-correlation
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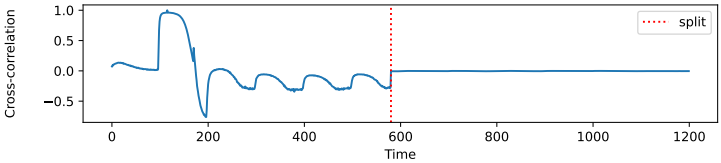
  2. Choose a time index
  3. Perform the correlation with the remaining time indexes



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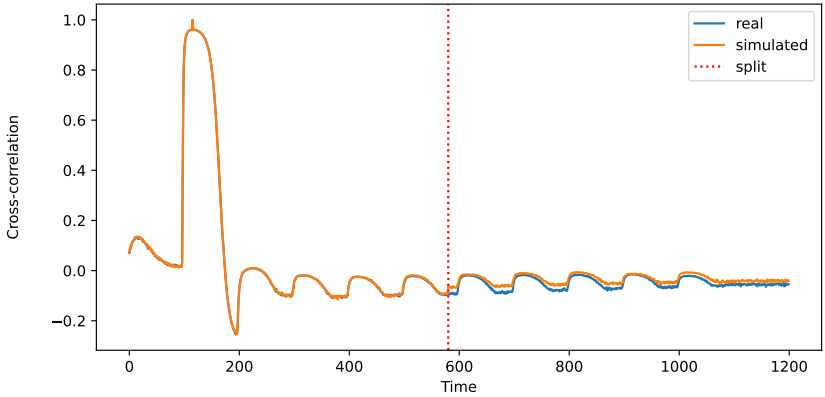

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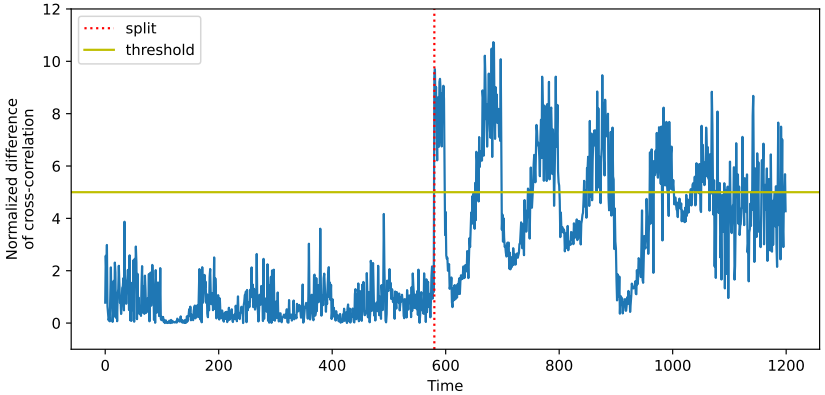

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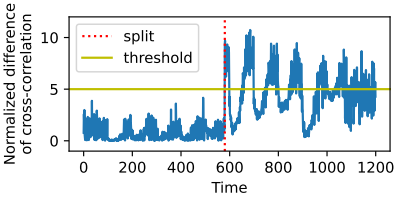

Spartan-6

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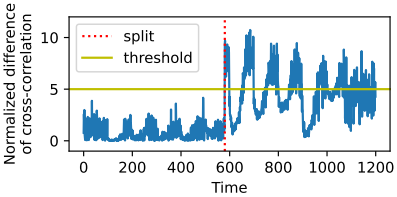

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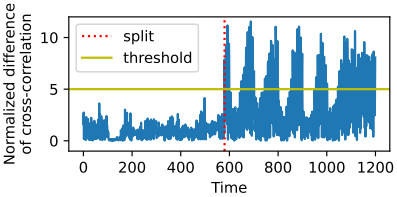

Artix-7

The S&C simulator: discussion

The concrete simulator:

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- based exclusively on manipulating traces

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The S&C simulator: discussion

The concrete simulator:

- based exclusively on manipulating traces
- unlikely to provide confident security guarantees
- a perfect simulation would require an extremely accurate modeling of the leakage function

Theoretical simulator

Theorem[ORR+24,BMO+26]: $L(x) = \delta(x) + n$ can be efficiently simulated from T bits of bounded leakage.

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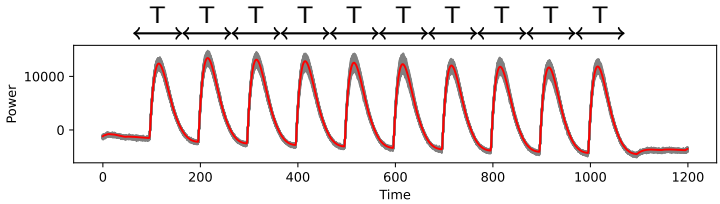
Theoretical simulator

Theorem[ORR+24,BMO+26]: $L(x) = \delta(x) + n$ can be efficiently simulated from T bits of bounded leakage.

- Assume a perfect distribution knowledge
- T depends on the information
- Apply the theorem to each round of AES $\rightarrow$ needs 10x Tbits



Hybrid simulator

Idea: Combine the pros and cons of concrete and theoretical simulator

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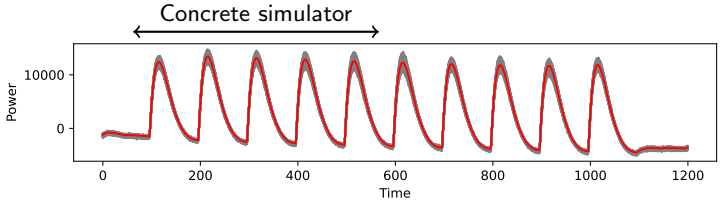

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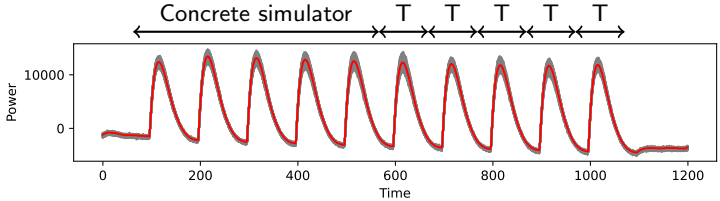

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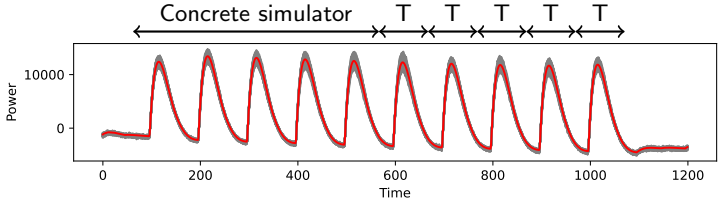

Can we do better ?

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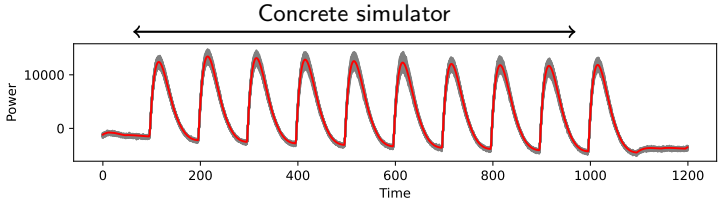

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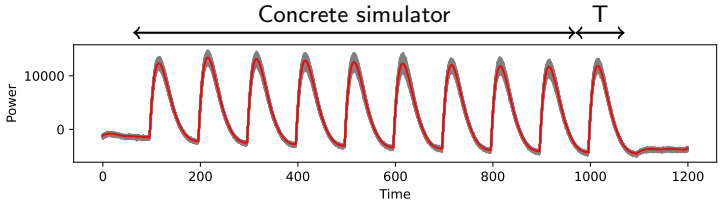

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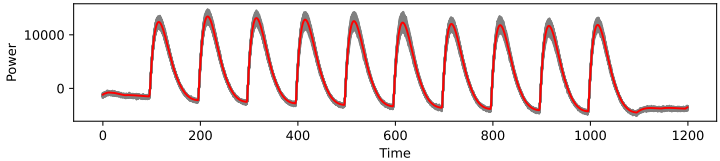

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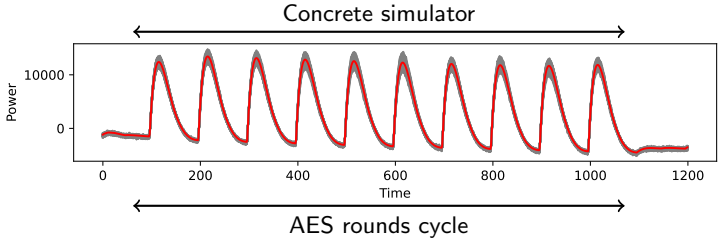

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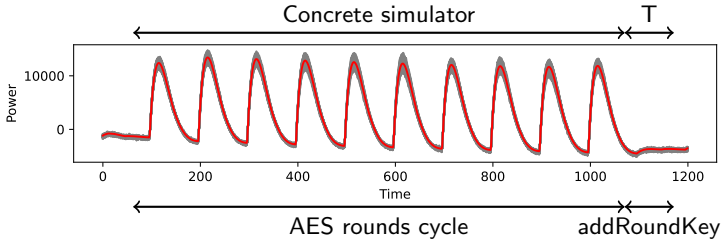

- Last addRoundKey in an extra clock cycle

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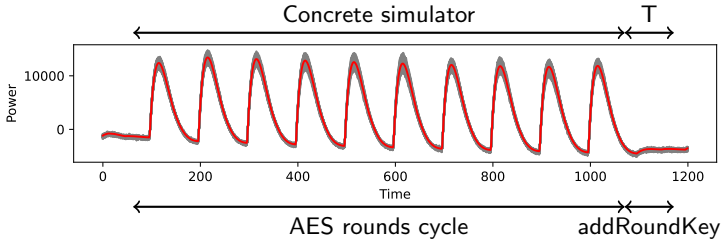

- Last addRoundKey in an extra clock cycle
- T decreases when SNR and/or MI decrease

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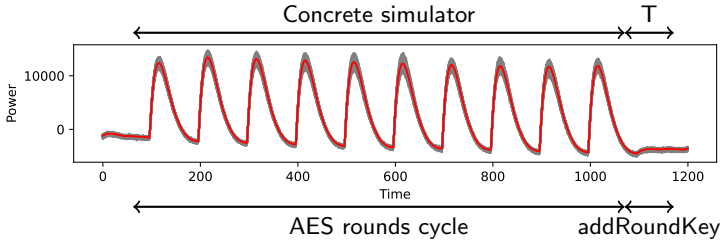

- Last addRoundKey in an extra clock cycle
- T decreases when SNR and/or MI decrease
- Our goal: Reducing key dependency in the last cycle to reduce the need of bounded leakage

The hybrid simulator: theoretical simulation

Simulate the last cycle:

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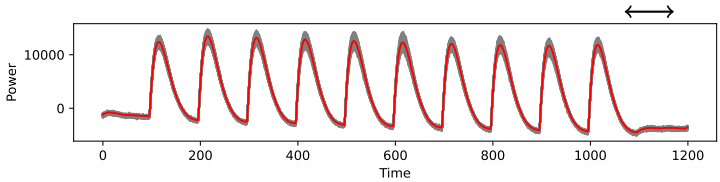
  - $y = y_0 \oplus y_1$

The hybrid simulator: residual leakage analysis

- Power consumption:
  $\rightarrow$ The final cycle consumes significantly less power.



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- SNR of the full AES state:
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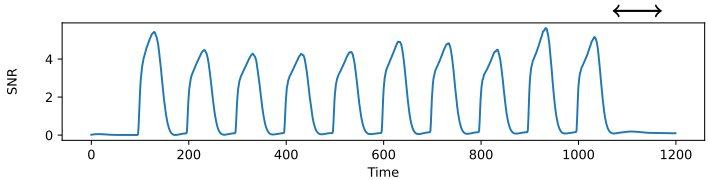
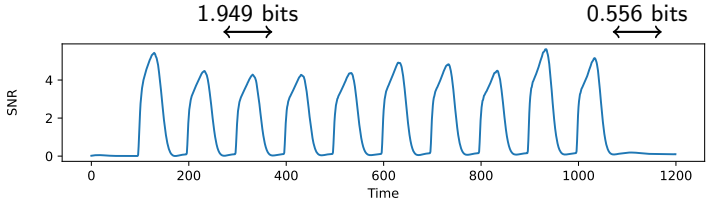


The hybrid simulator: residual leakage analysis

Quantifying residual key dependency

- SNR of the full AES state:
  $\rightarrow$ Drop (but still present) for final cycle.
- Quantifying the information:
  $\rightarrow$ Third cycle $\approx$ 4x more informative than the last cycle.



Conclusion

- **q-sim game** goal: formalize the notion of SPA security
- **Concrete simulator** (split-and-concatenate): hard to achieve in practice
- **Theoretical simulator**: a lot (too much ?) information required
- **Hybrid simulator**: concatenate concrete + theoretical simulator
  - take advantage of both
  - bounded leakage only for the last cycle
  - goal: reducing key dependency in the last cycle
- **Further work**: better formalizing these findings, non-hermetic approaches

Thank you for listening

References

- **[ORR+24]** Obremski, M., Ribeiro, J., Roy, L., Standaert, F. X., & Venturi, D. (2024, August). Improved reductions from noisy to bounded and probing leakages via hockey-stick divergences. In Annual International Cryptology Conference (pp. 461-491). Cham: Springer Nature Switzerland.
- **[BMO+26]** Béguinot, J., Mukherjee, A., Obresmki, M., Ribeiro, J., Roy, L., Standaert, F.X., Venturi, D.: Simulating noisy leakage with bounded leakage: Simpler, better, faster. Cryptology ePrint Archive, Paper 2026/357 (2026), https://eprint.iacr.org/2026/357