Algebraic Side-Channel Attacks on the AES: Why Time also Matters in DPA

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Algebraic Side-Channel Attack

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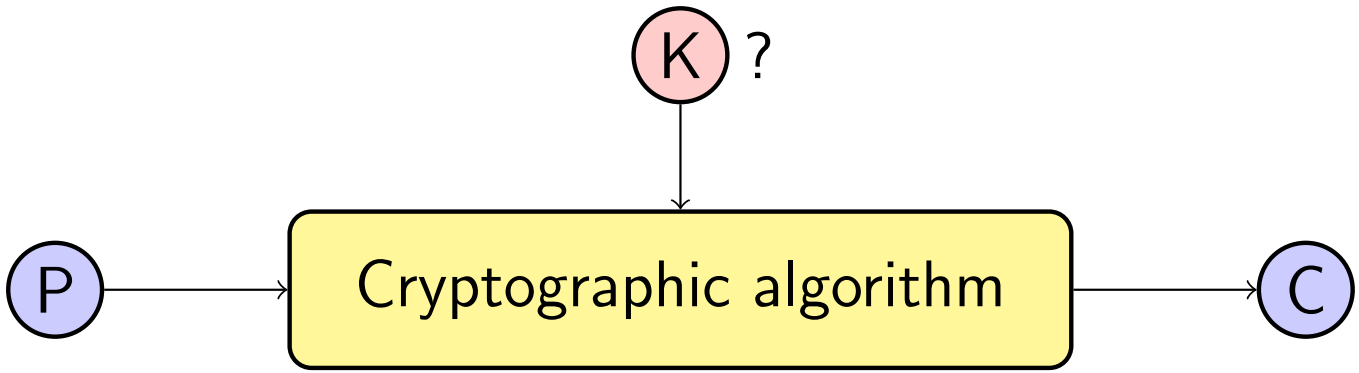
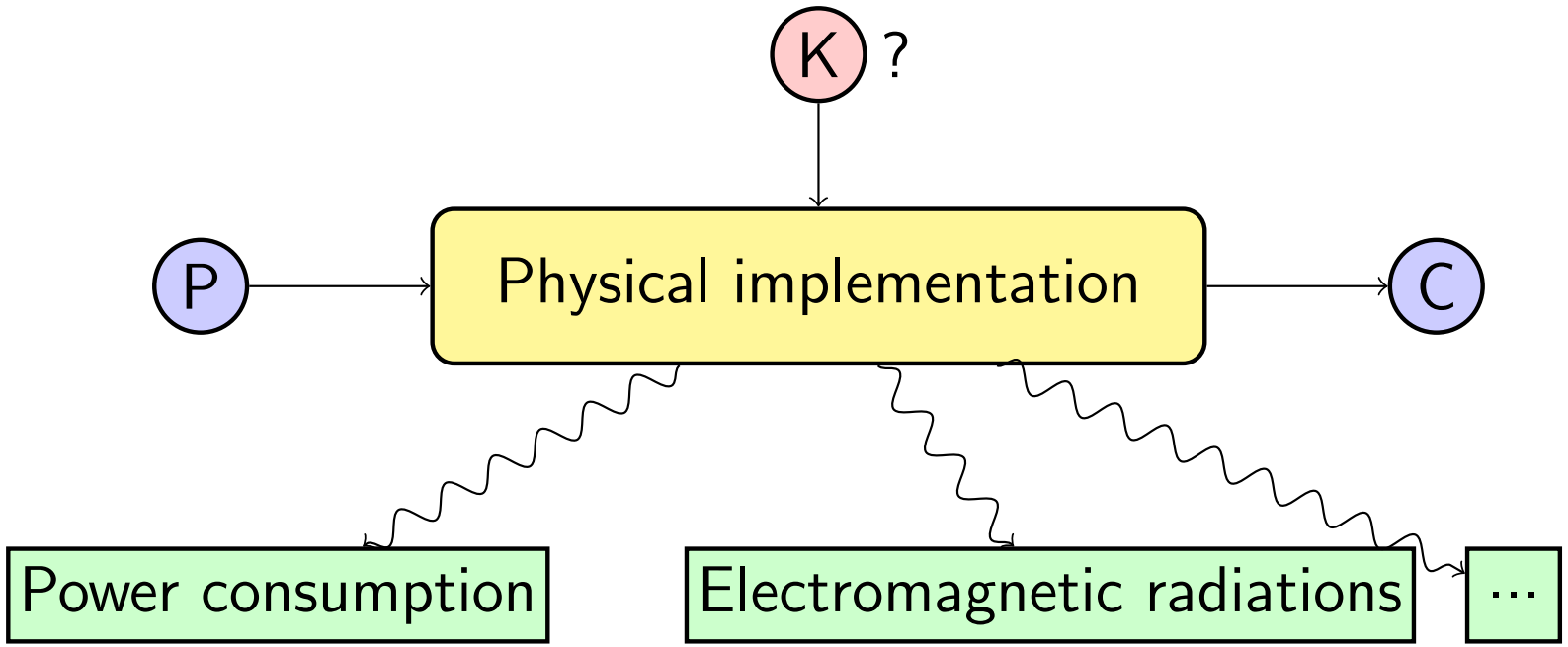
Classical cryptanalysis



Introduction

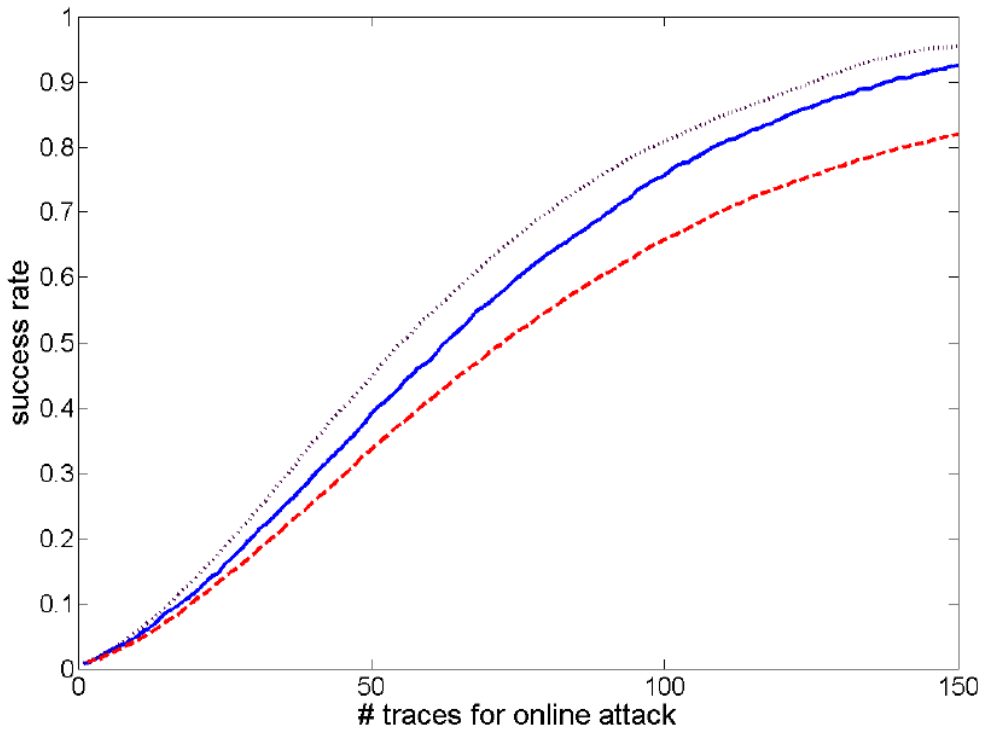
Side-Channel cryptanalysis



Introduction

Open questions

What is the smallest possible data complexity?



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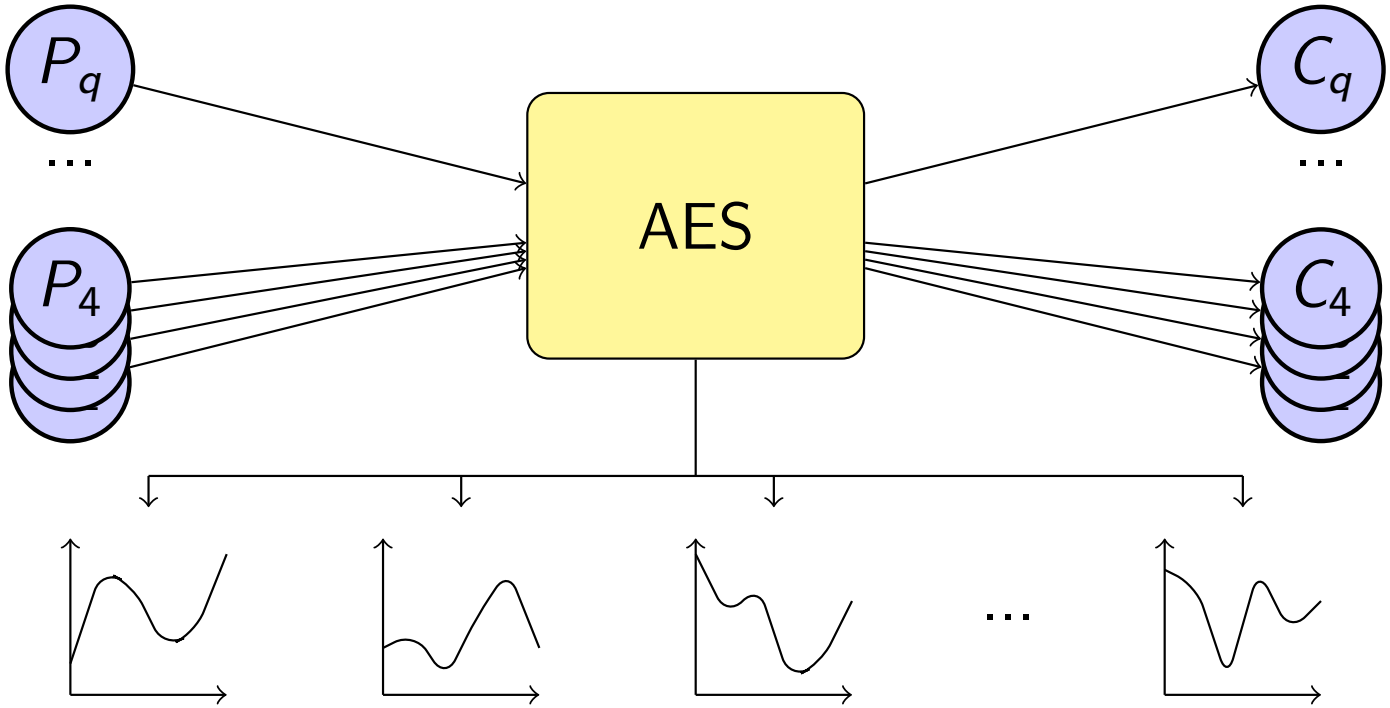
Data complexity q



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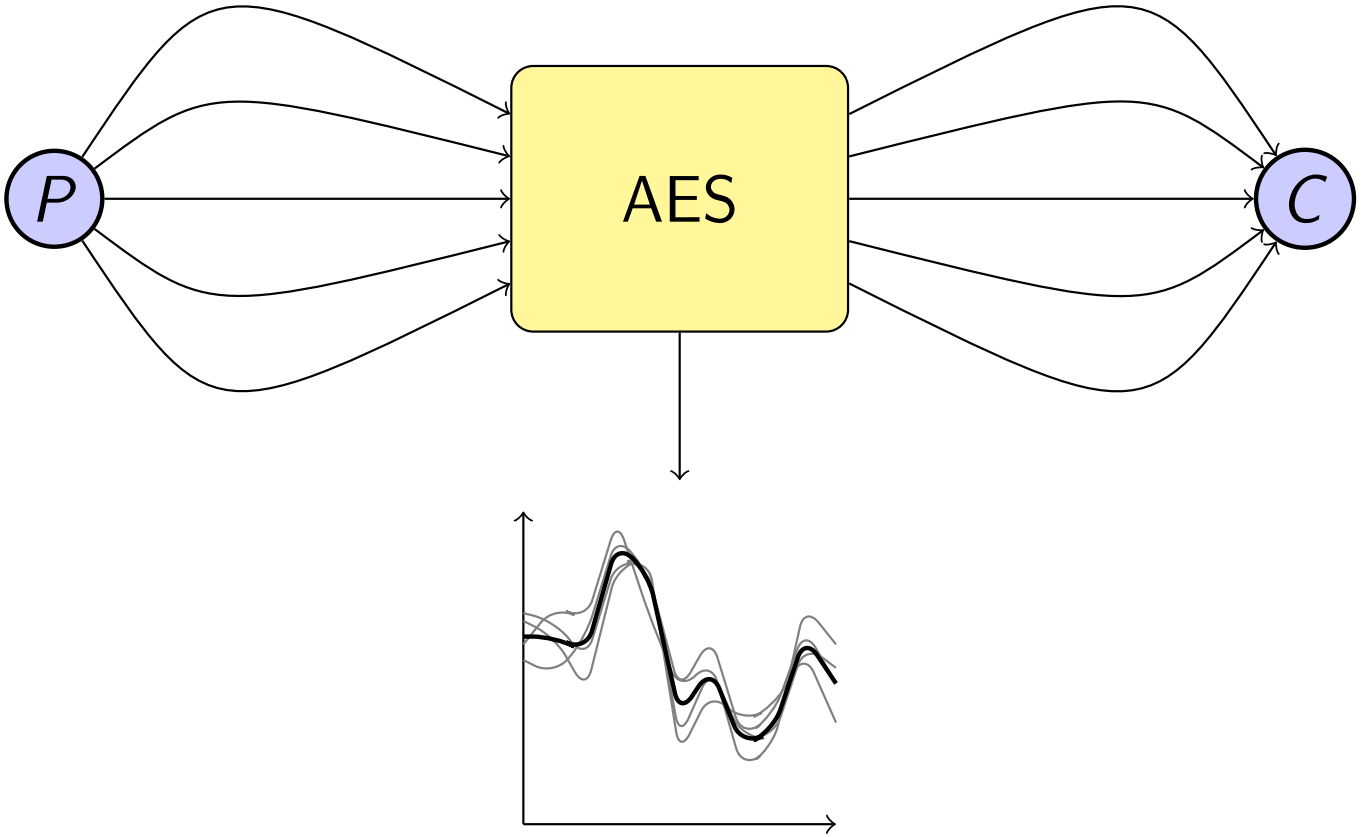
Repetition number n_r



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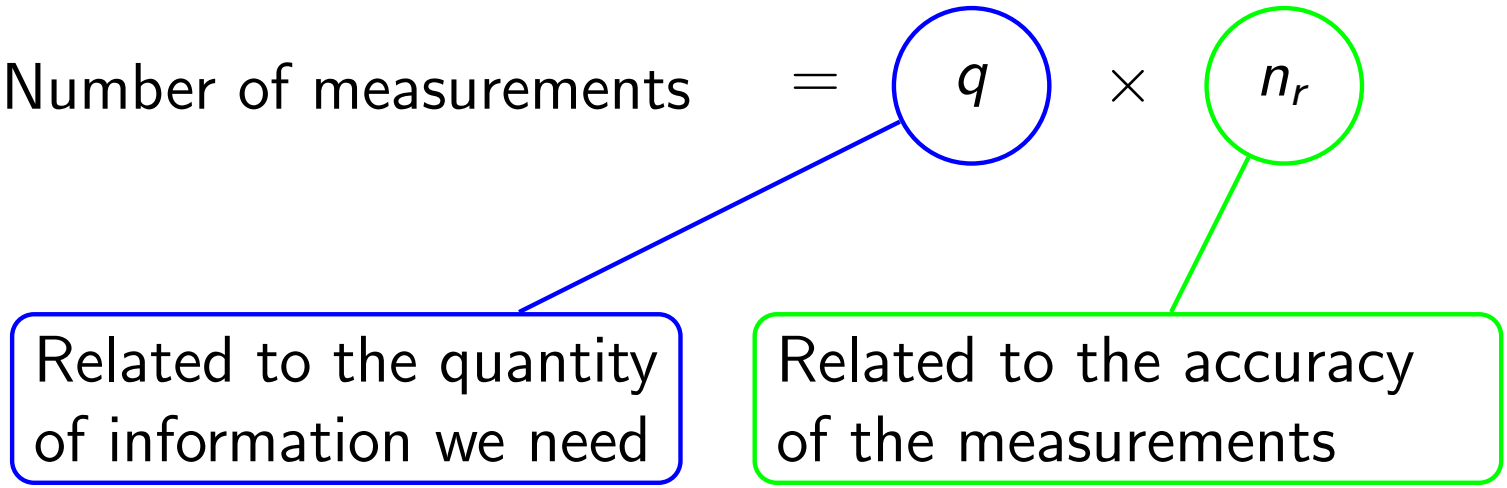

What is the minimum value for q?

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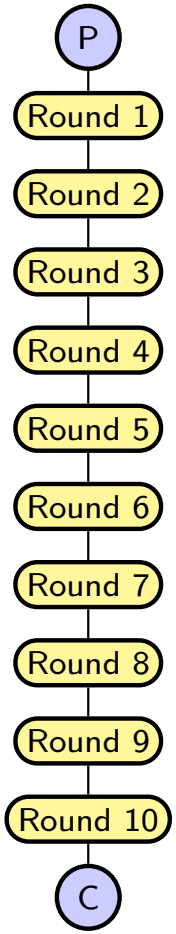

Which information can be used?

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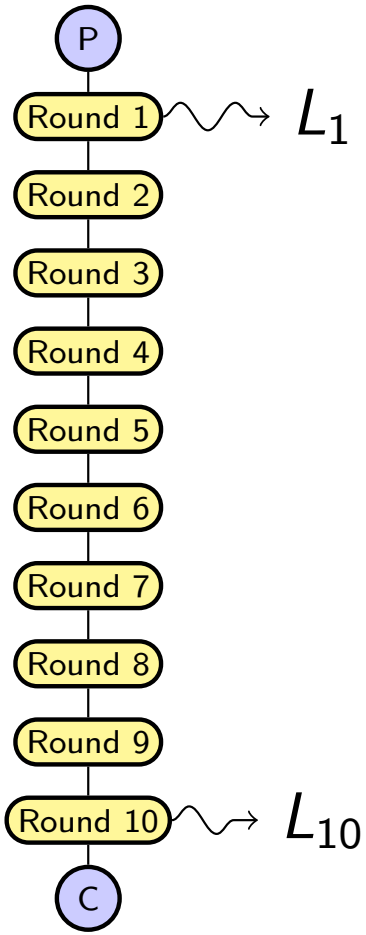

DPA uses information from the first or last round (low diffusion)

Which information can be used?

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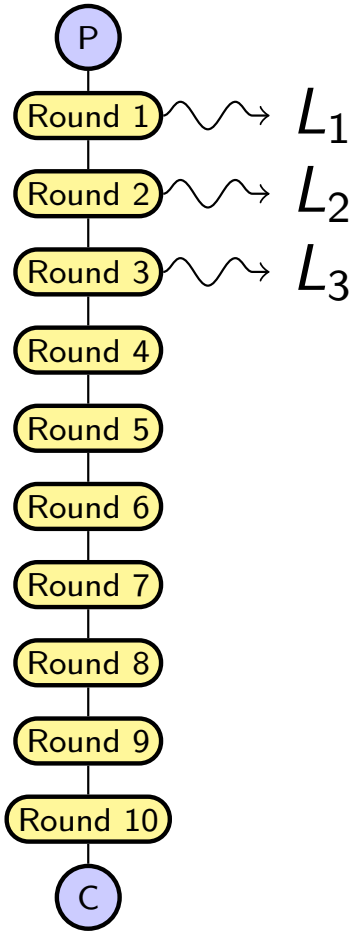

Collision attacks can use leakages up to the third round

Which information can be used?

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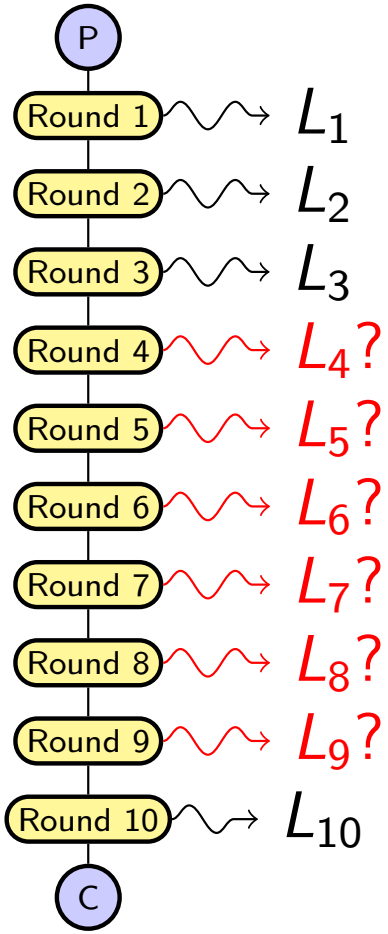

What about the middle rounds?

Which information can be used?

Introduction

Most of the side-channel attacks aim to directly recover the key bits

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Is it possible to use side-channel to recover less informative (easier) targets ...

... and combine this with a classic cryptanalysis phase to recover the key?

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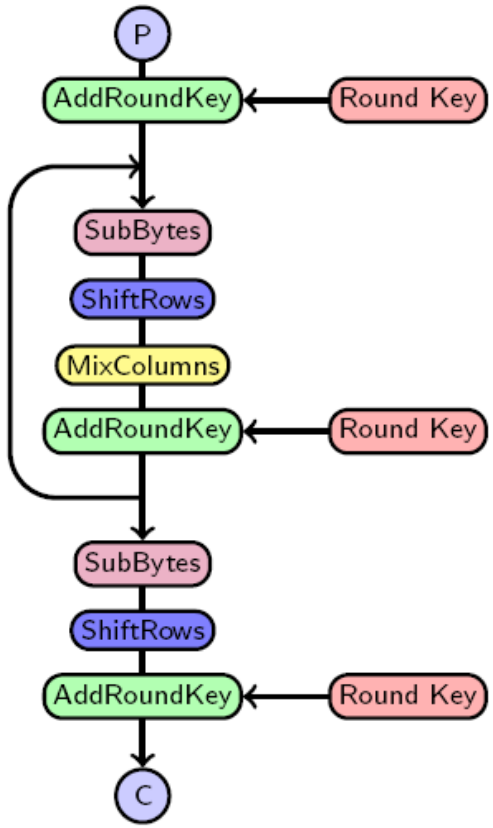
Is it possible to use side-channel to recover less informative (easier) targets ...

... and combine this with a classic cryptanalysis phase to recover the key?

We decided to use *algebraic cryptanalysis*.

Introduction

A block cipher ...

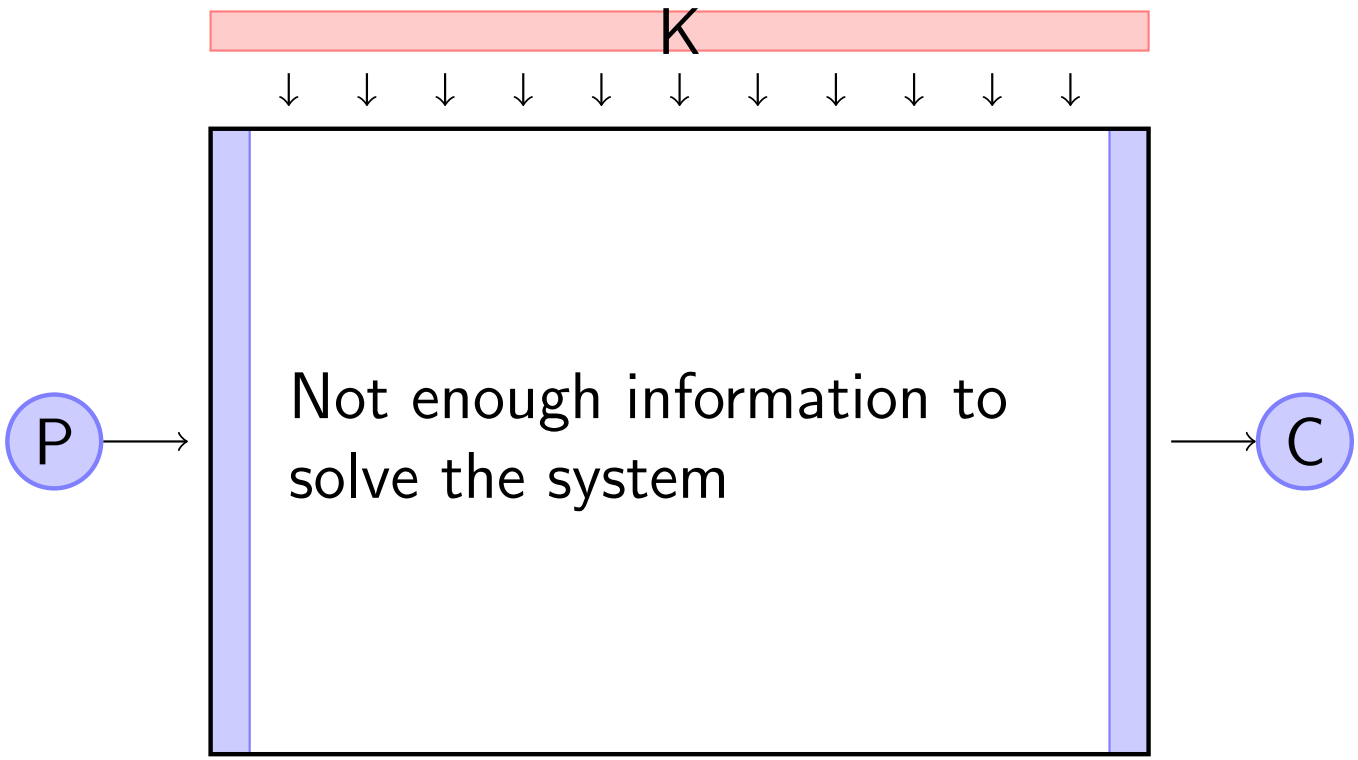


becomes a big set of low degree boolean equations

$$
\begin{aligned}
0 &= x_2 + x_{11} + x_{14} + x_2x_5 + x_4x_{10} \\
0 &= x_5 + x_9 + x_1x_6 + x_3x_{10}x_{13} + x_5x_7x_{16} \\
1 &= x_7 + x_{15} + x_{16} + x_3x_7 + x_9x_{11} \\
0 &= x_7 + x_1x_5 + x_6x_{11} + x_4x_5x_{12} \\
1 &= x_8 + x_{10} + x_{11} + x_{15} + x_2x_6 + x_6x_{10} \\
0 &= x_{10} + x_{15} + x_{16} + x_6x_{12} + x_9x_{16} + x_2x_9x_{14} \\
0 &= x_{13} + x_{14} + x_5x_{13} + x_8x_{12} + x_4x_7x_{12} + x_8x_9x_{11} \\
&\dots
\end{aligned}
$$

Introduction

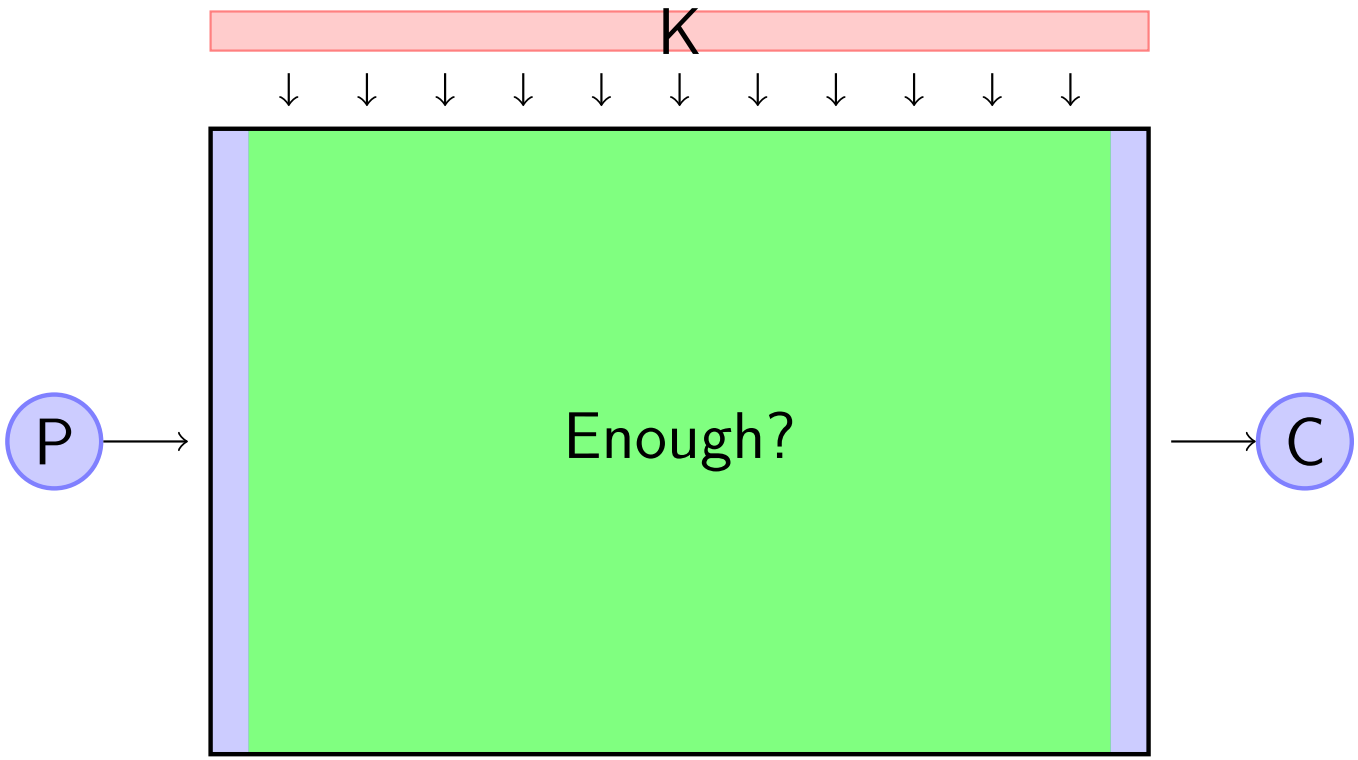
Classic algebraic attack



256 known bits

Introduction

Algebraic attack + side-channel information



256 known bits + side-channel information

Related work

Square attacks + side-channel

- V. Carlier, H. Chabanne, E. Dottax, H. Pelletier, 2005.

Differential cryptanalysis + side-channel

- H. Handschuh, B. Preneel, 2006.

Collision attacks

- A. Biryukov, D. Khovratovich, 2007.
- A. Bogdanov, 2007.
- A. Bogdanov, I. Kizhvatov, A. Pyshkin, 2008.

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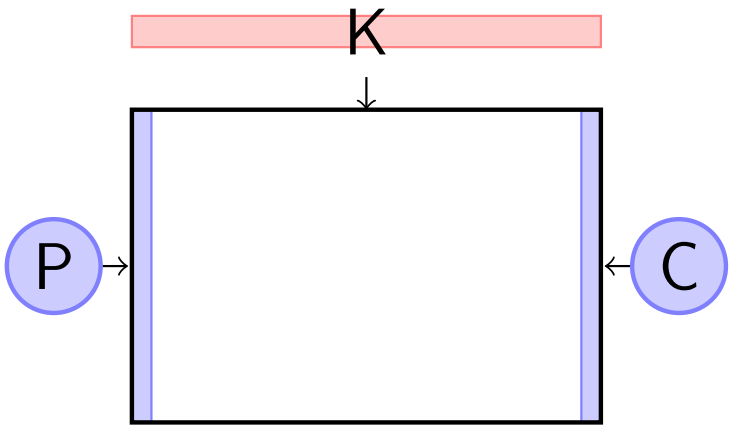
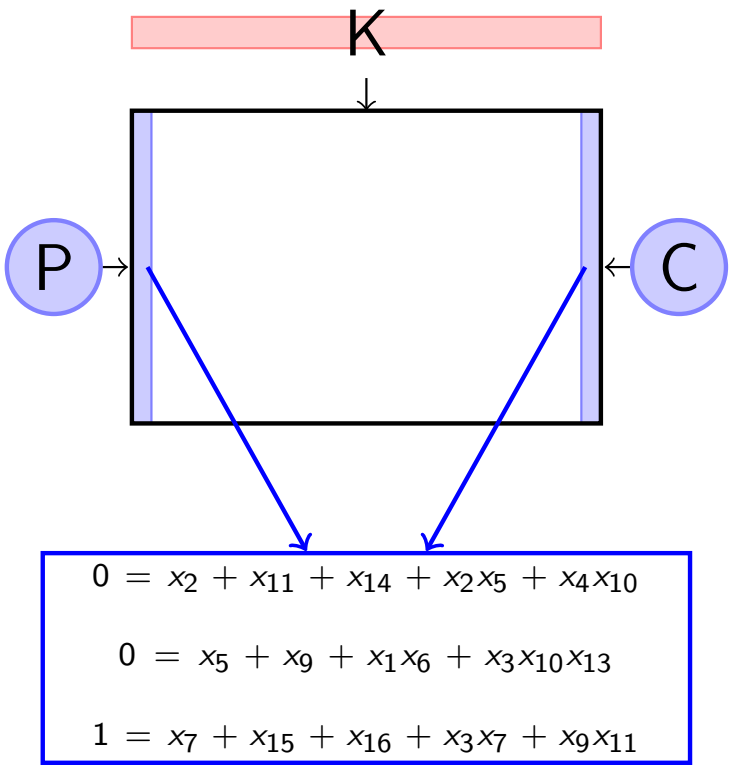


Algebraic Side-Channel Attack



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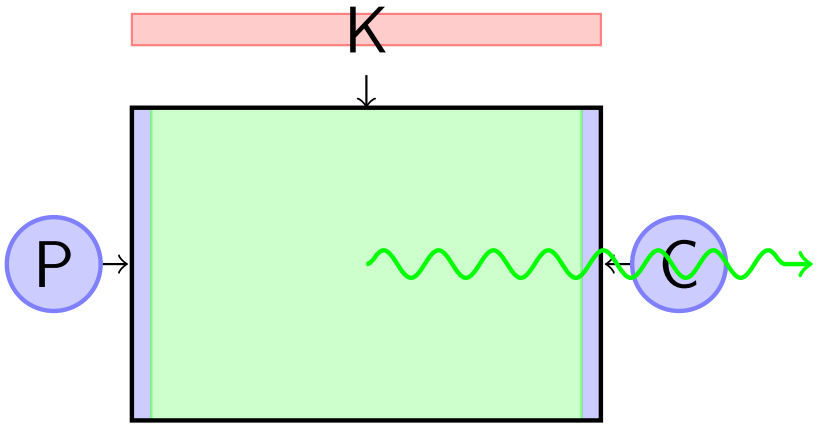

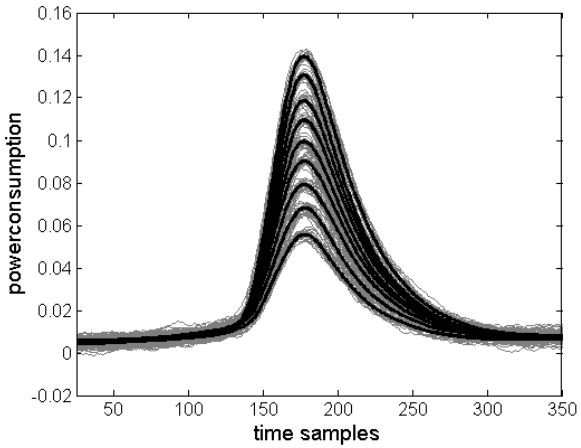

$$0 = x_2 + x_{11} + x_{14} + x_2x_5 + x_4x_{10}$$

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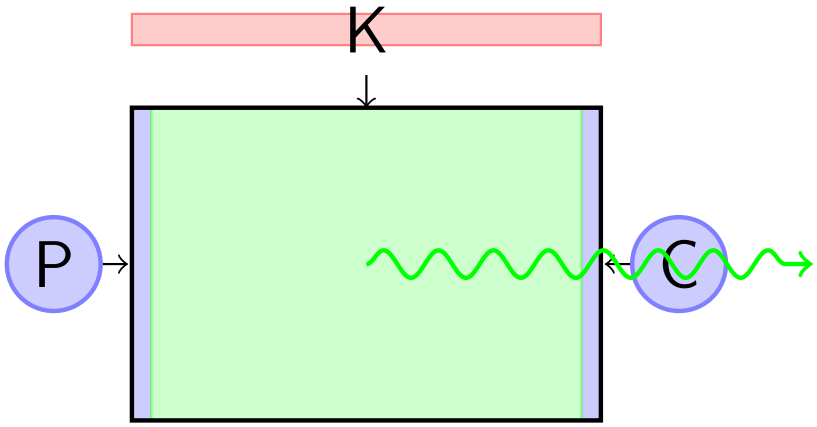

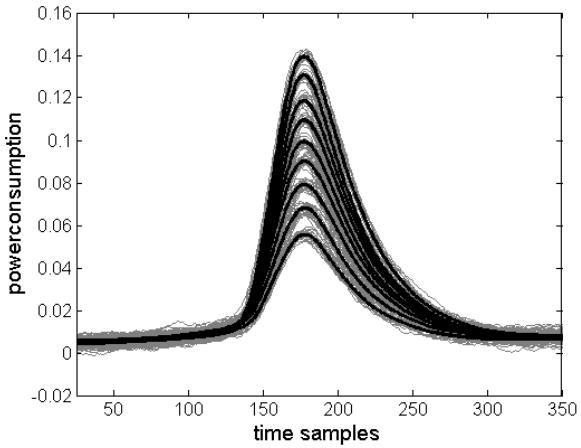

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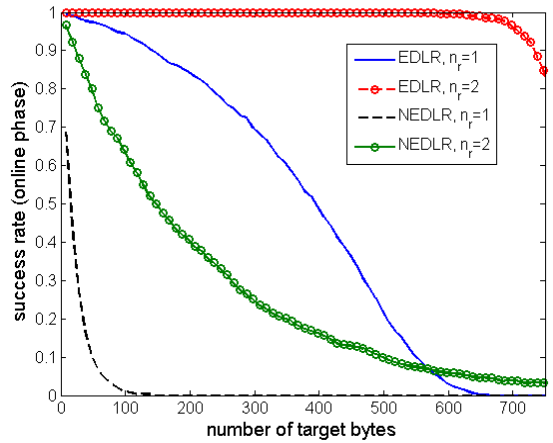

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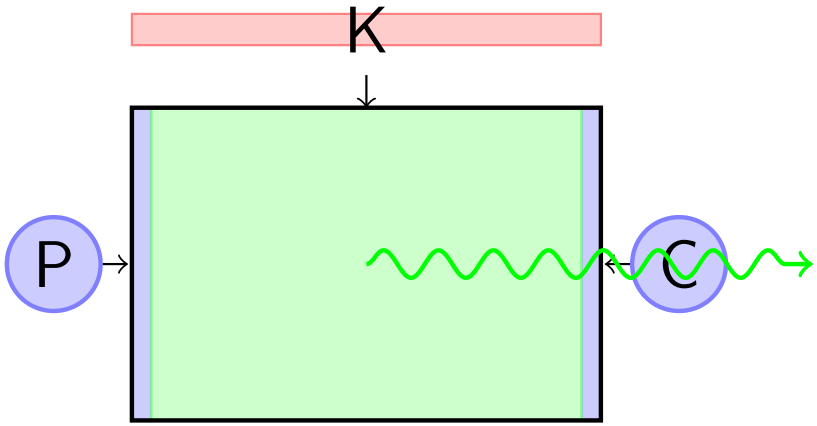

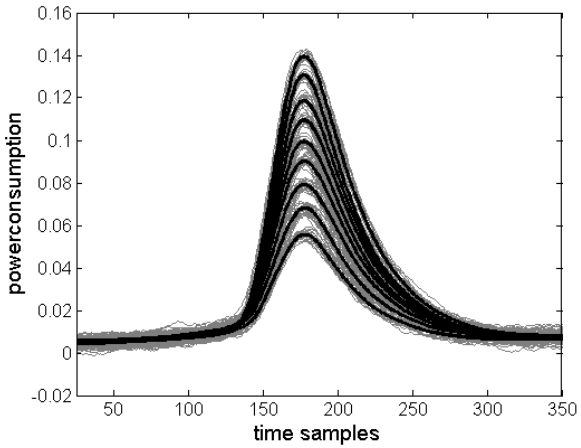

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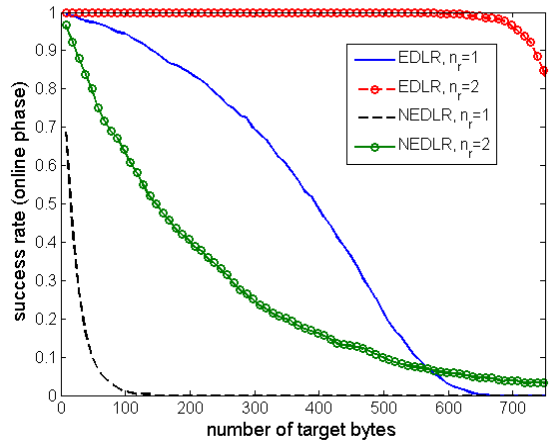

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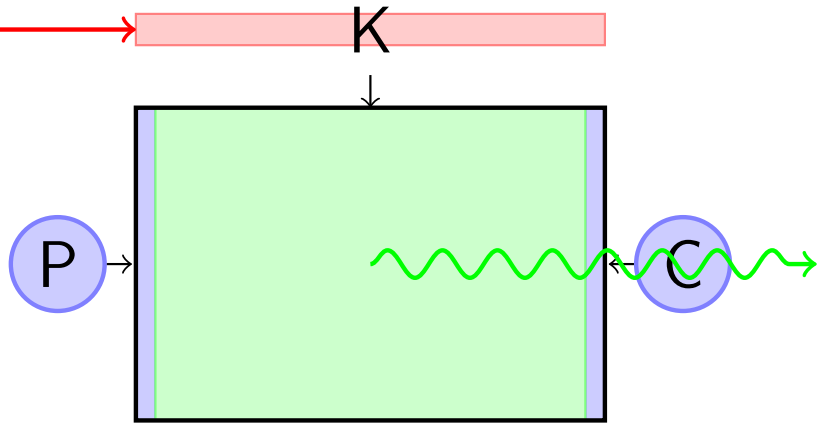

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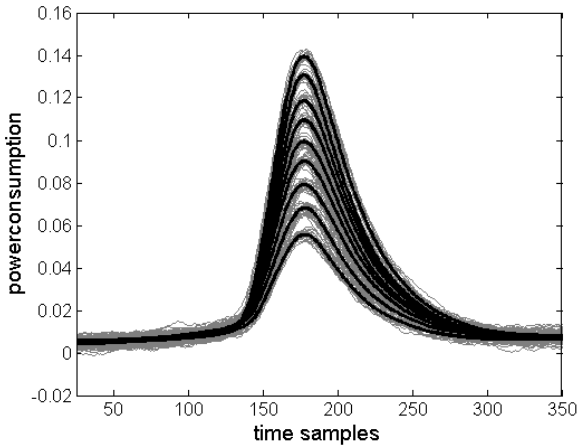

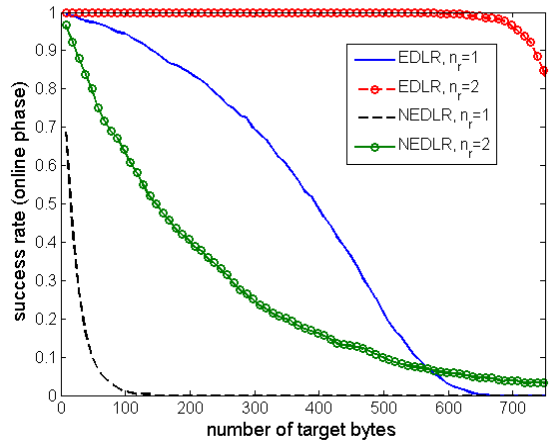

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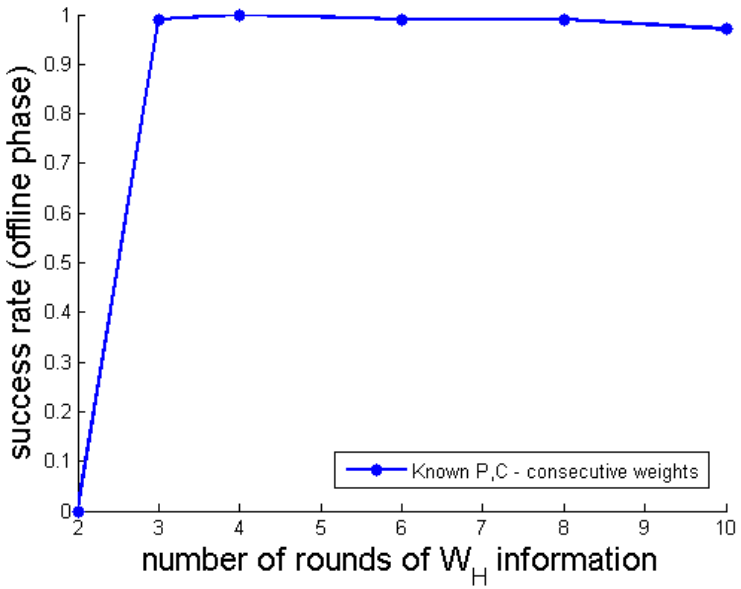
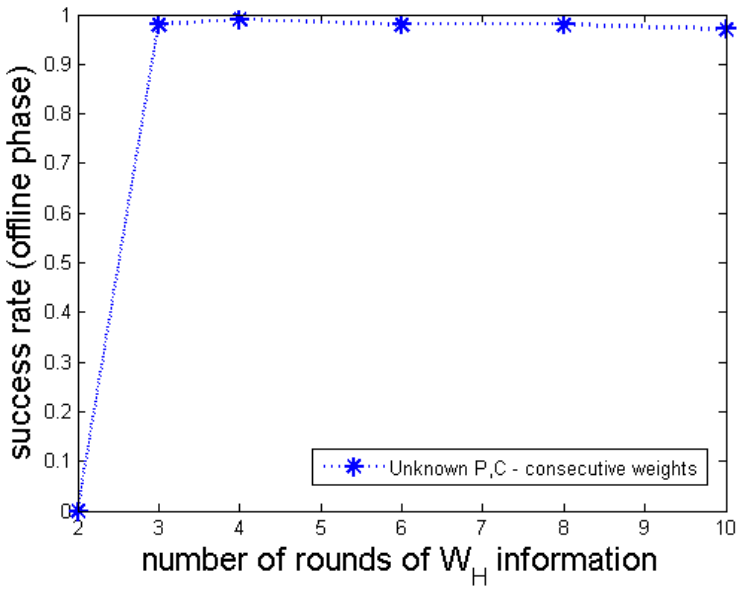
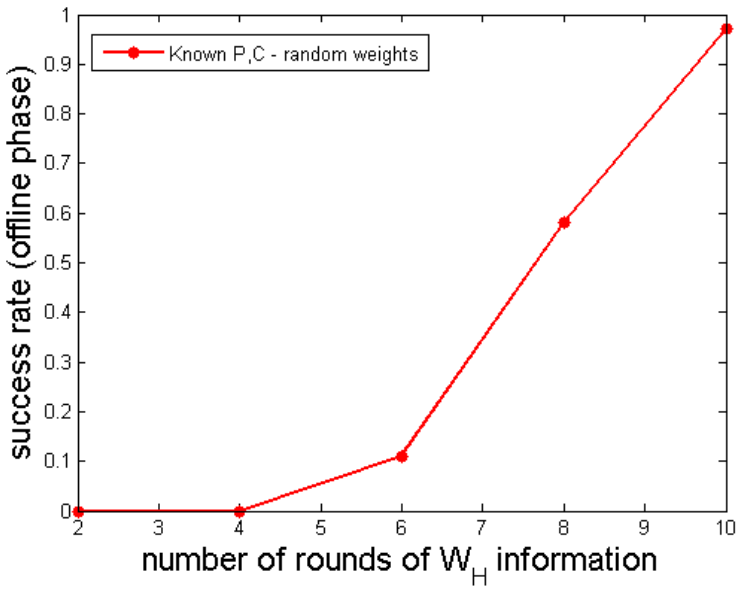


Known P, C, consecutive weights

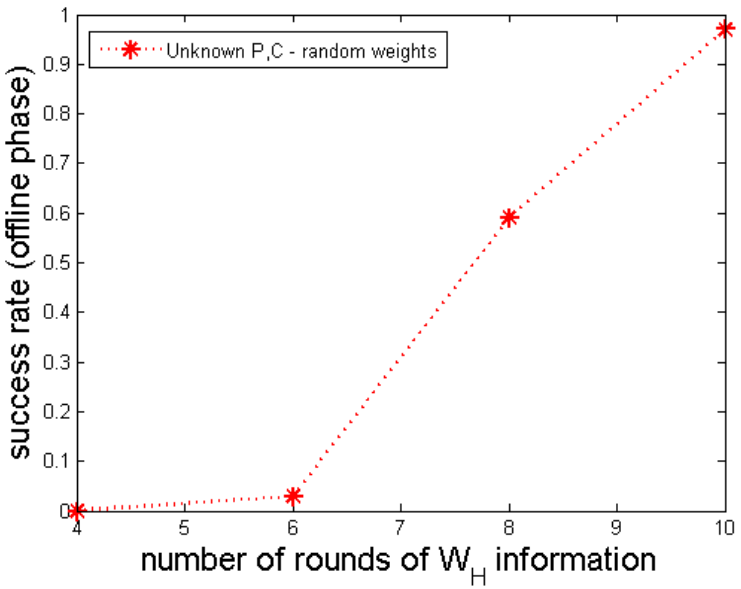


Unknown P, C, consecutive weights

Algebraic Side-Channel Attacks



Known P, C, random weights



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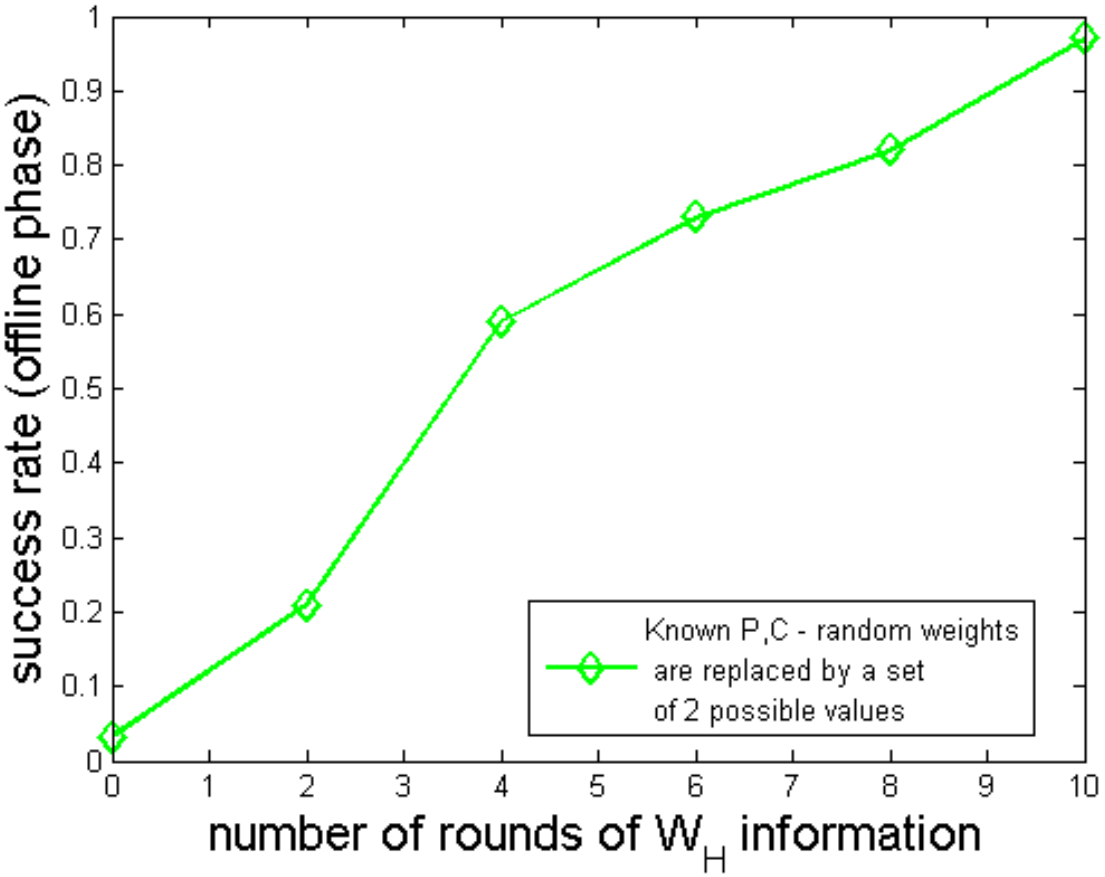
Algebraic Side-Channel Attacks



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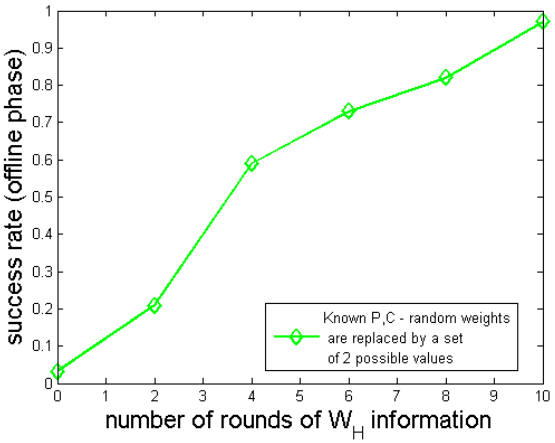

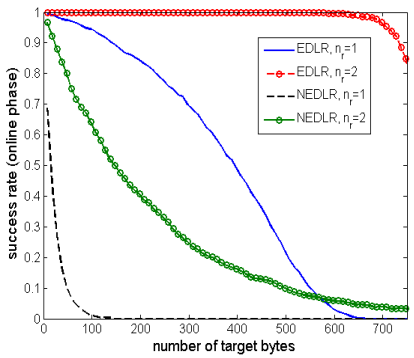

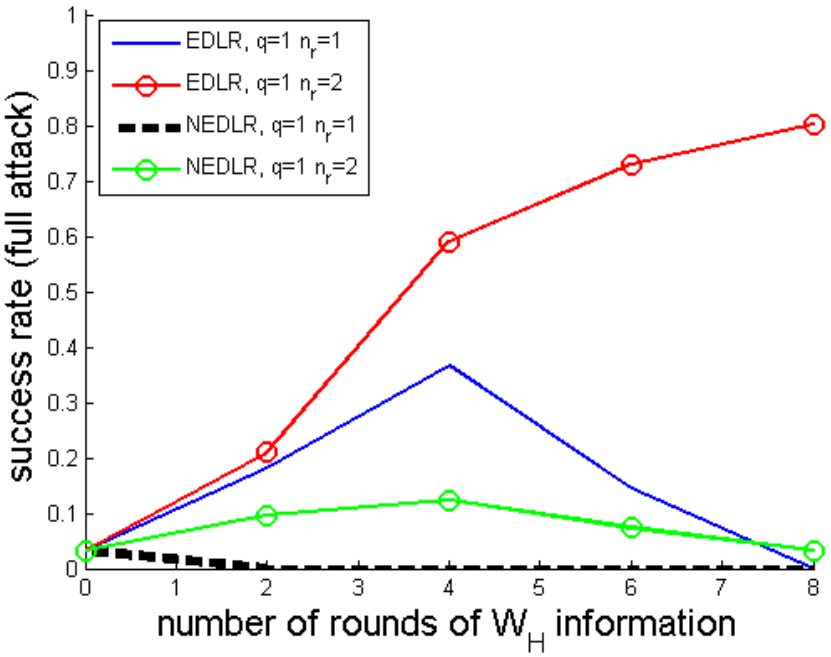

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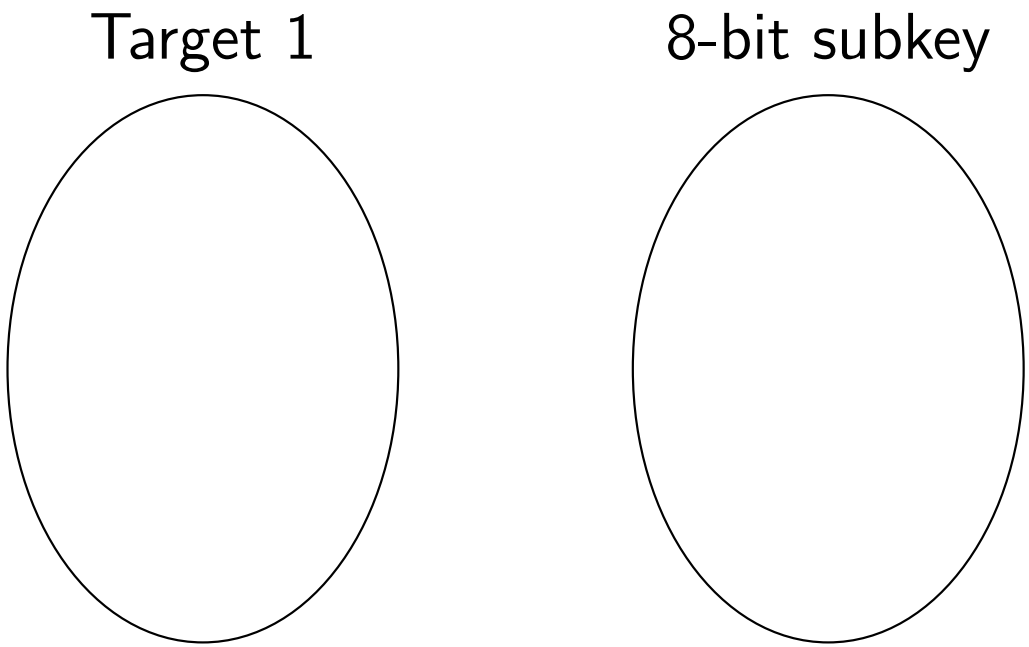
Classical power analysis attack (DPA)



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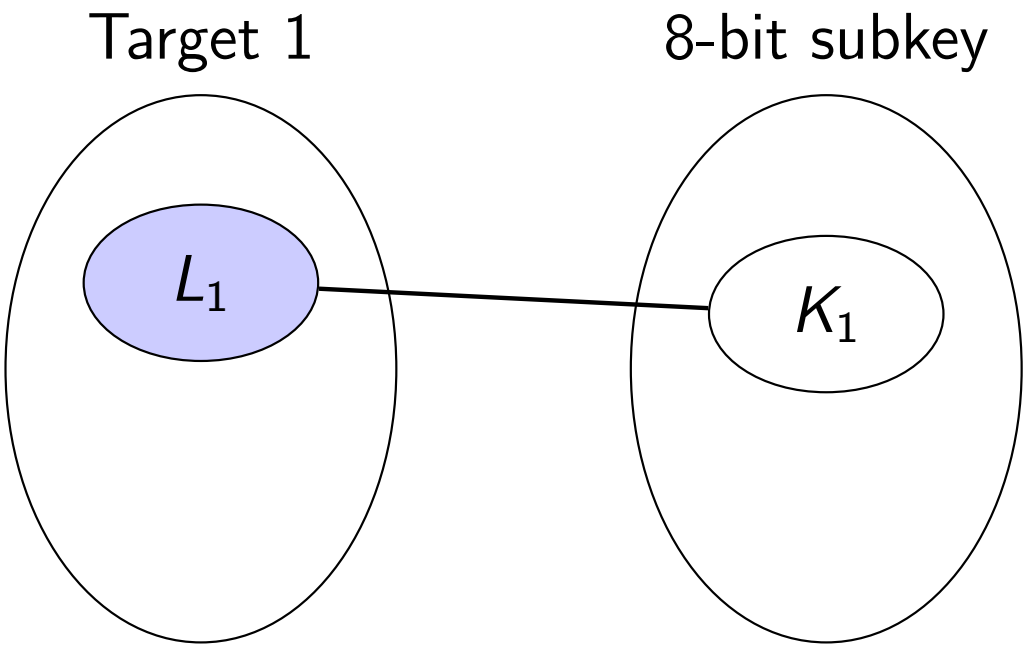

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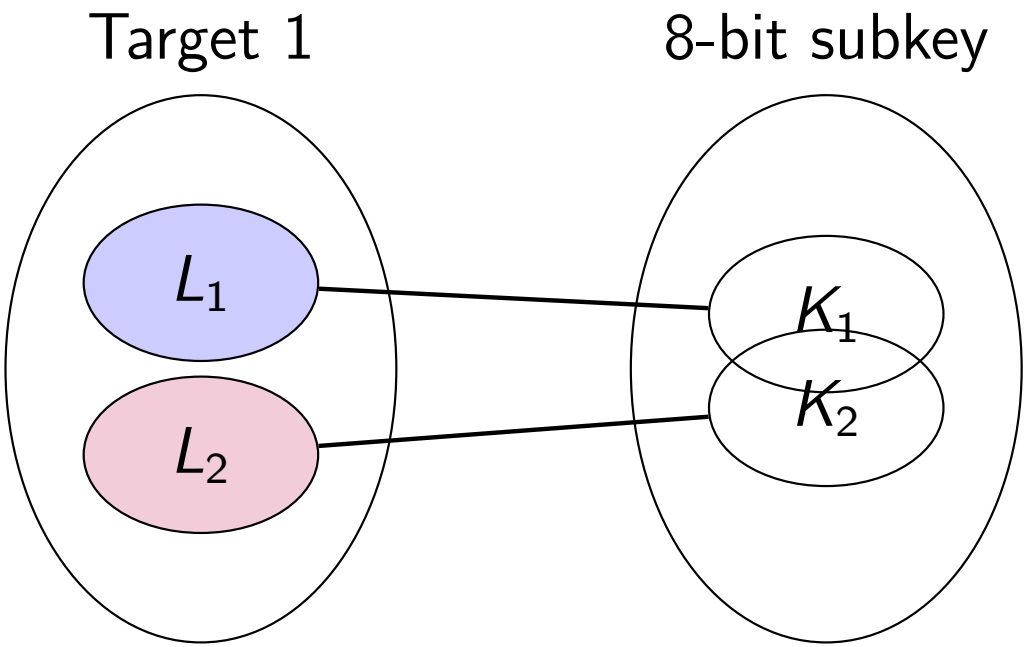

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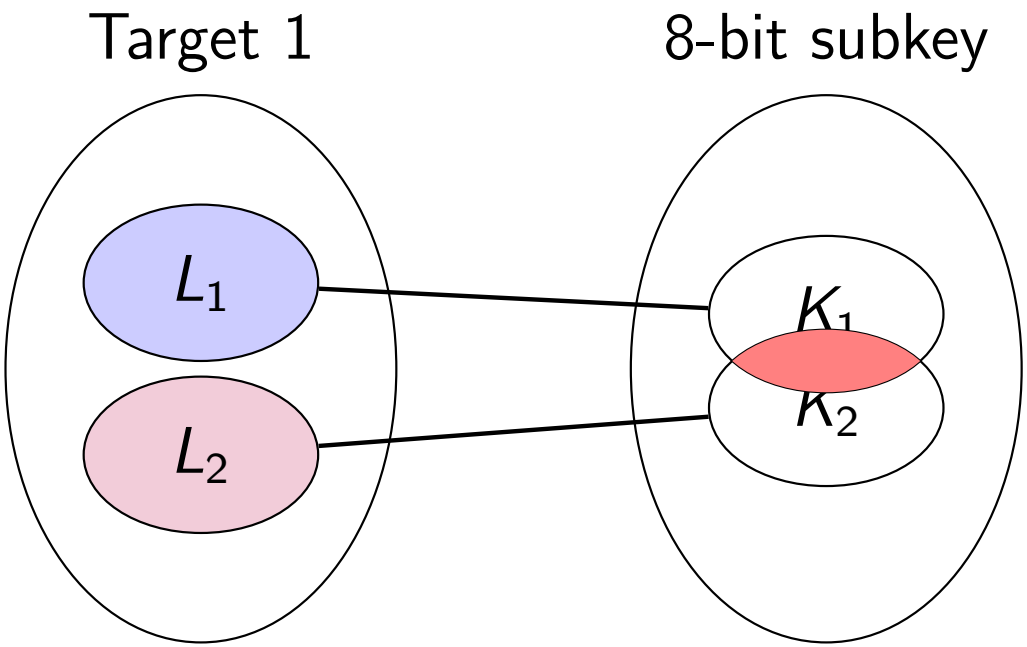

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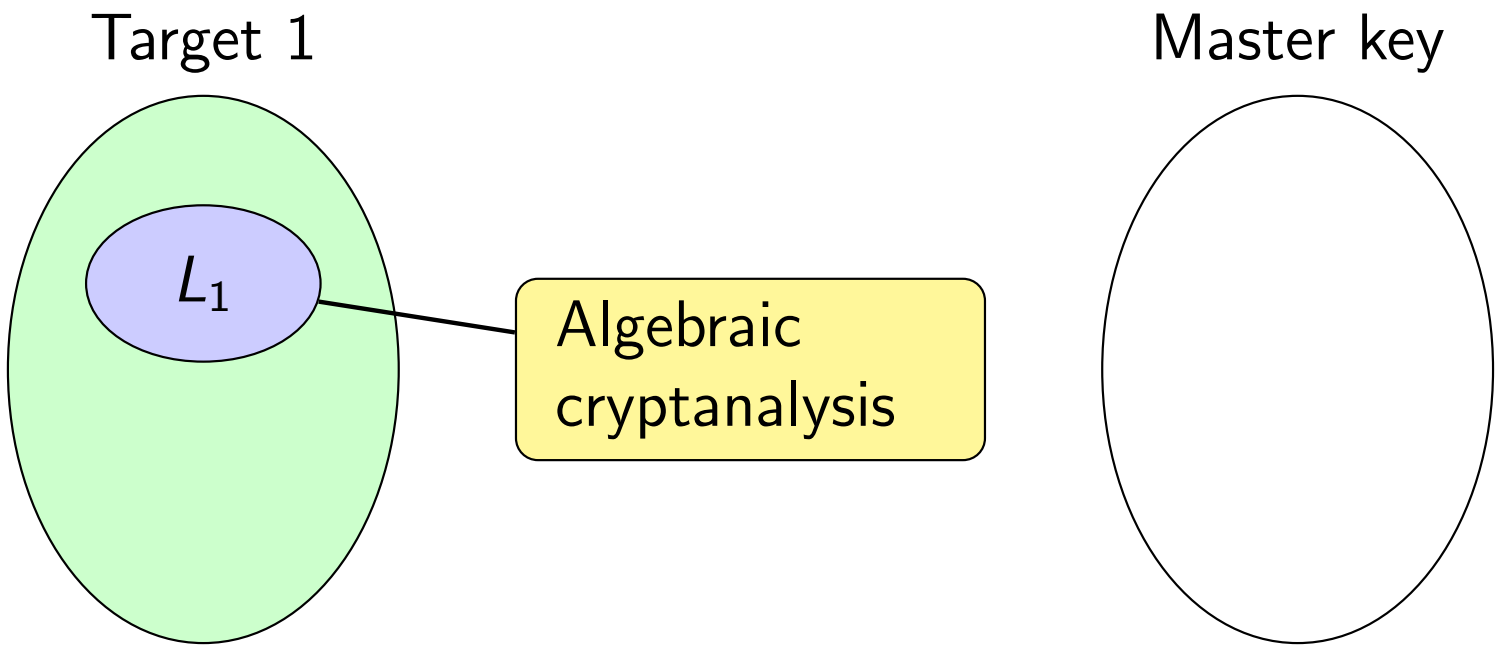

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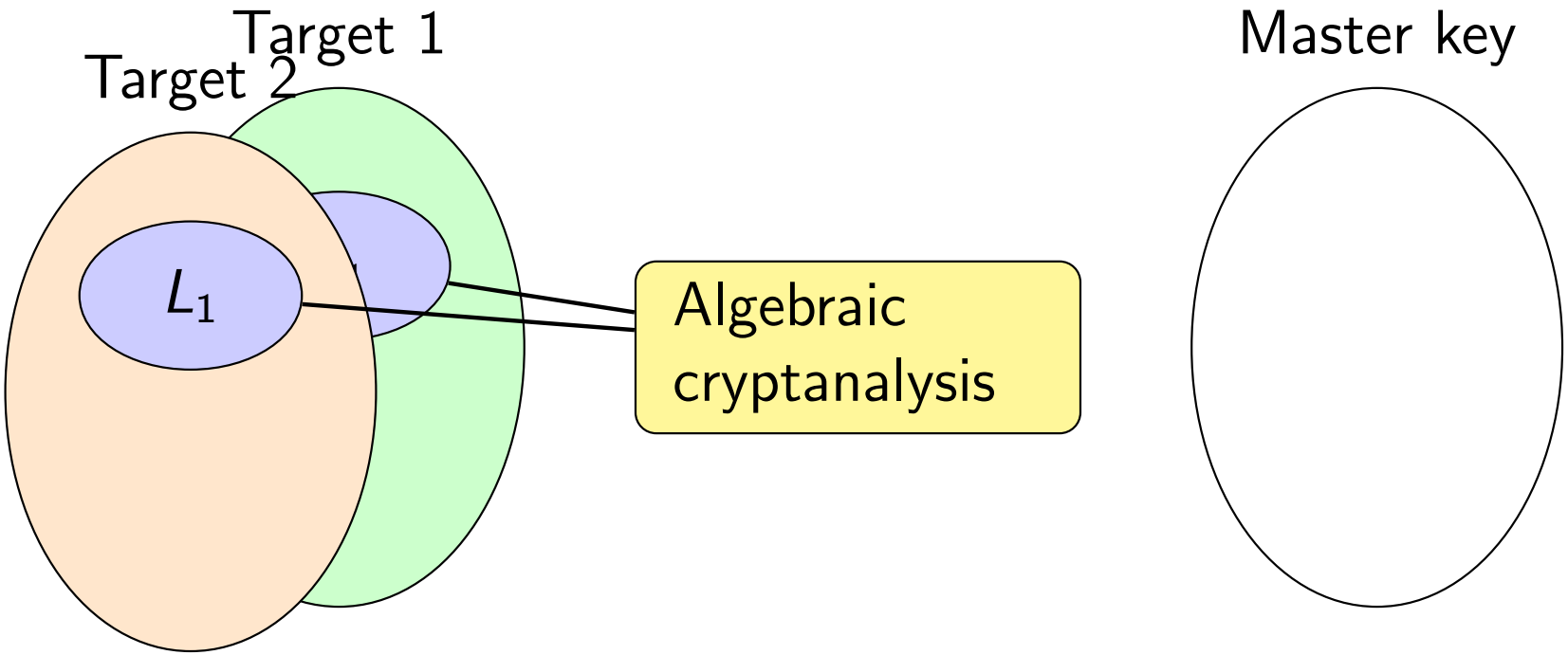

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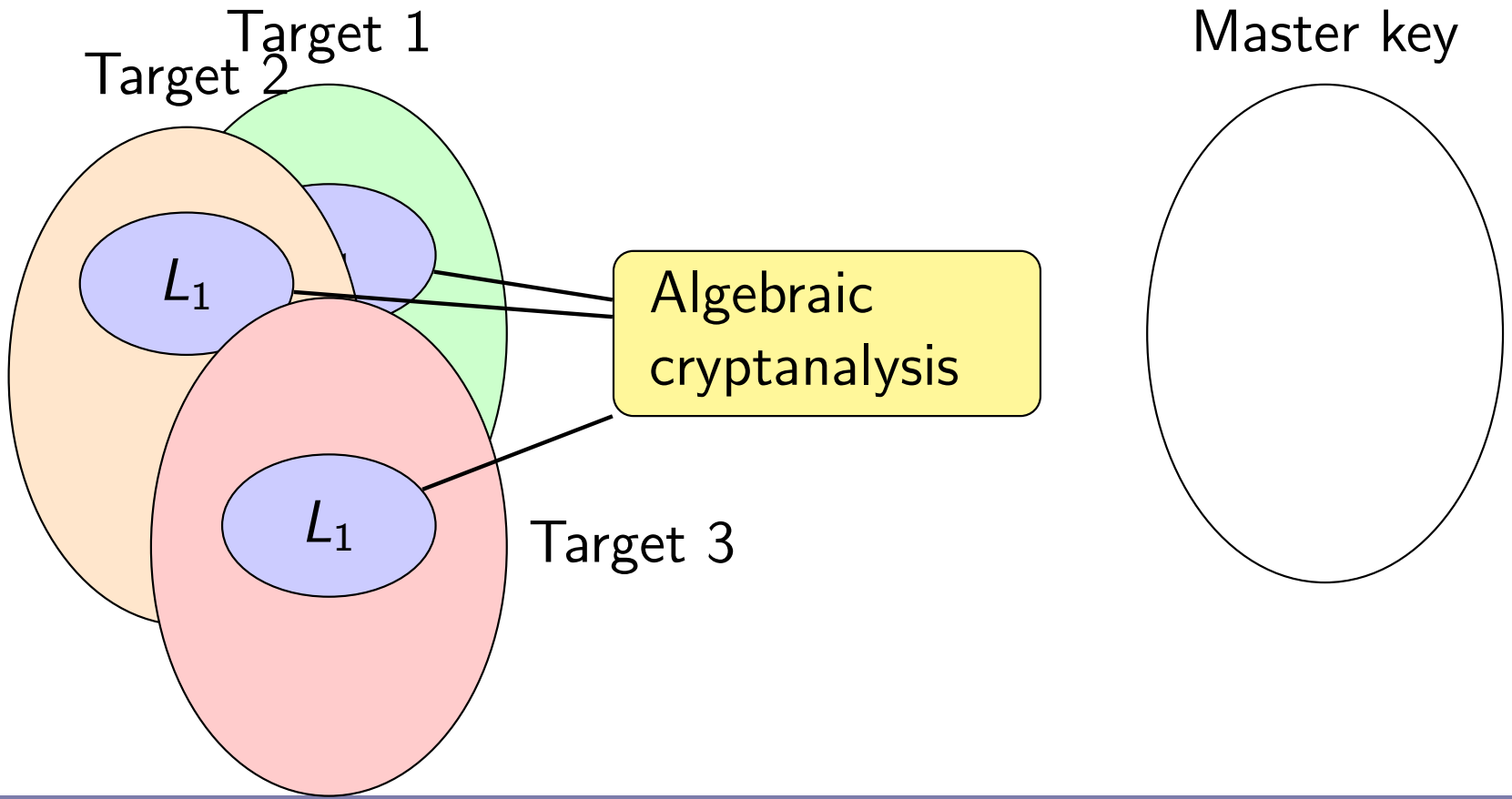

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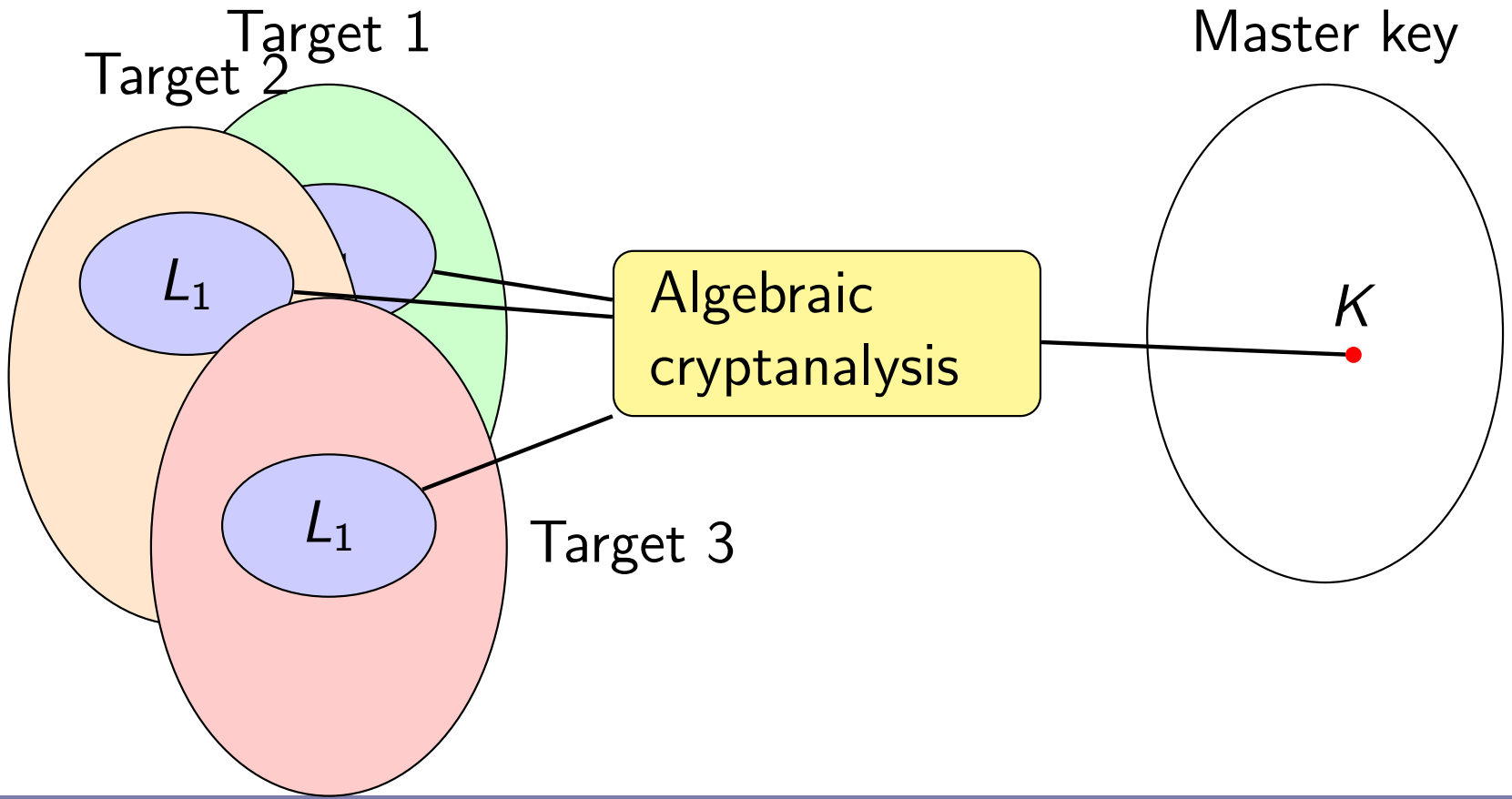

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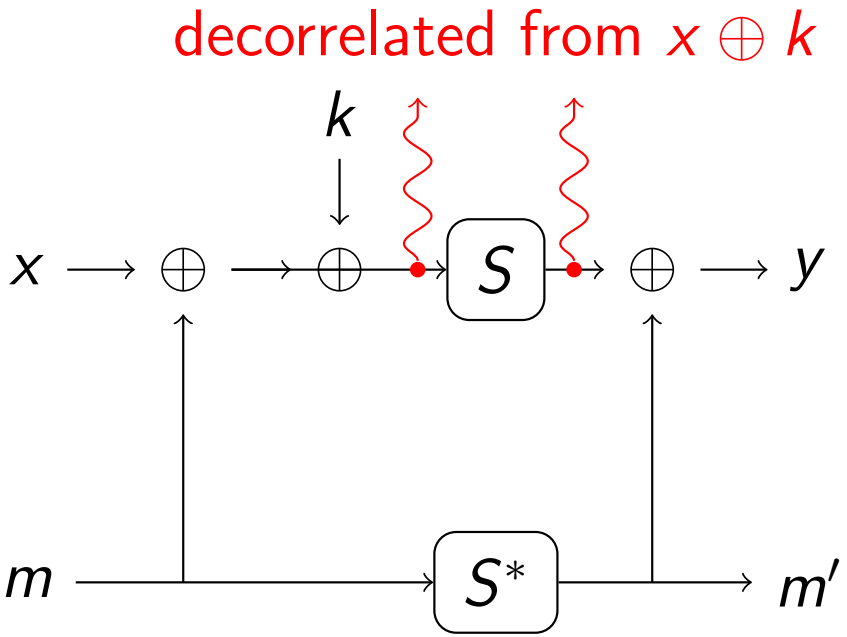
Masked implementation

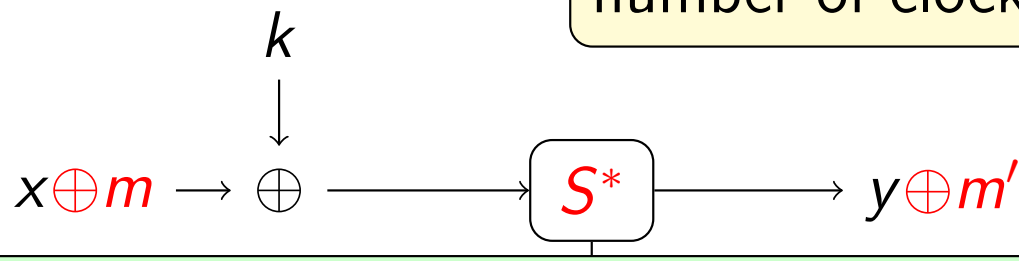


Advanced scenarios

Masking with S-box pre-computation (Herbst et al., 2006).

Mask size = 48 bits

Little impact on the number of clock cycles



New table look-up S^*; S^* is pre-computed on the fly for m and m'.

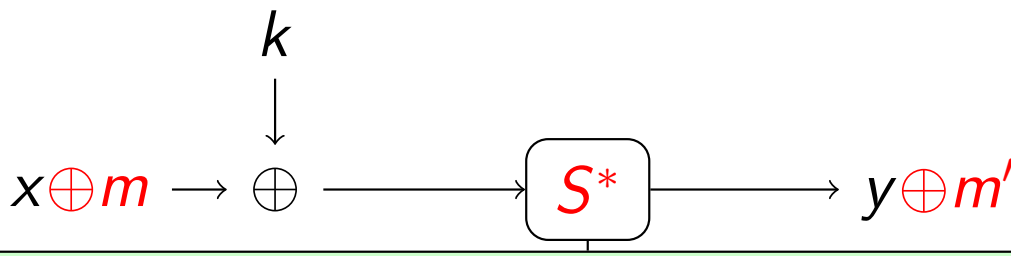
Some additional targets, but increased algebraic complexity $\Rightarrow$ **harder** to attack.

Advanced scenarios

Masking in $GF(2^4)^2$ (Oswald and Schramm, 2005).

Each S-box can have a different mask

Bigger impact on the number of clock cycles

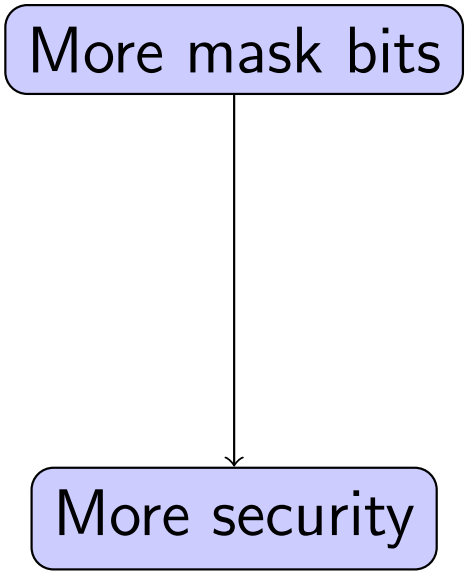


Masked inversion in $GF(2^4)^2$ via 14 table look-ups and 15 XOR operations.

A lot more targets $\Rightarrow$ **easier** to attack.

Advanced scenarios

Classical assumption



Advanced scenarios

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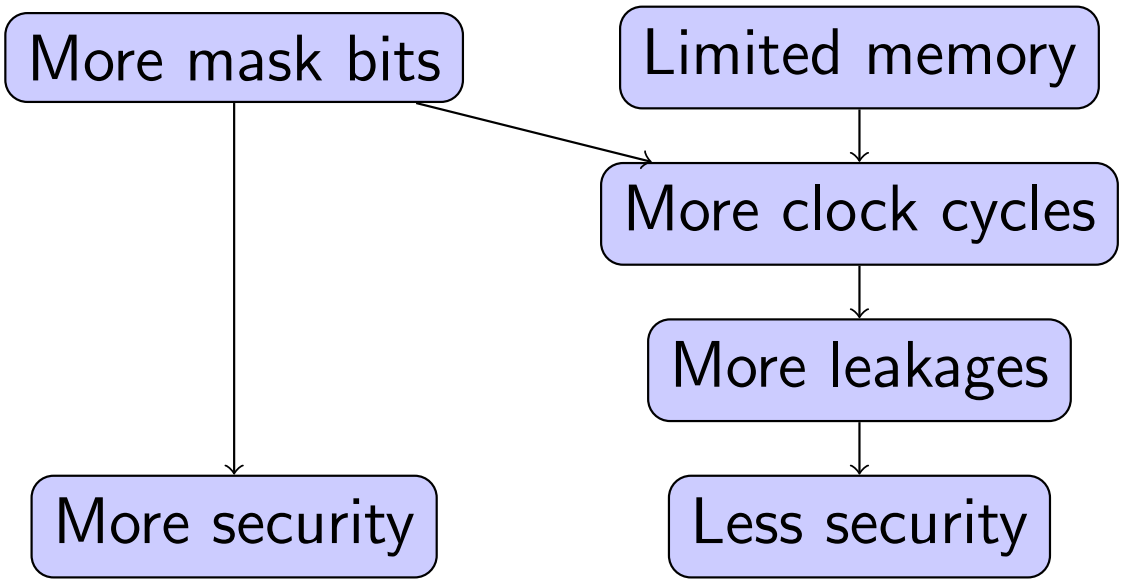

Time also matters.

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Advantages

- data complexity $q = 1$
- side-channel information from everywhere in the cryptosystem
- efficient in an unknown plaintext/ciphertext context
- efficient against some masked implementations

Disadvantages

- require a strong profiling phase
- not error-tolerant

Conclusion

Between theoretical and practical

require a strong profiling phase

data complexity = 1

What about the rekeying strategies?

Thank you for your attention.