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L'insoutenable légèreté du chiffrement

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L'insoutenable légèreté du chiffrement

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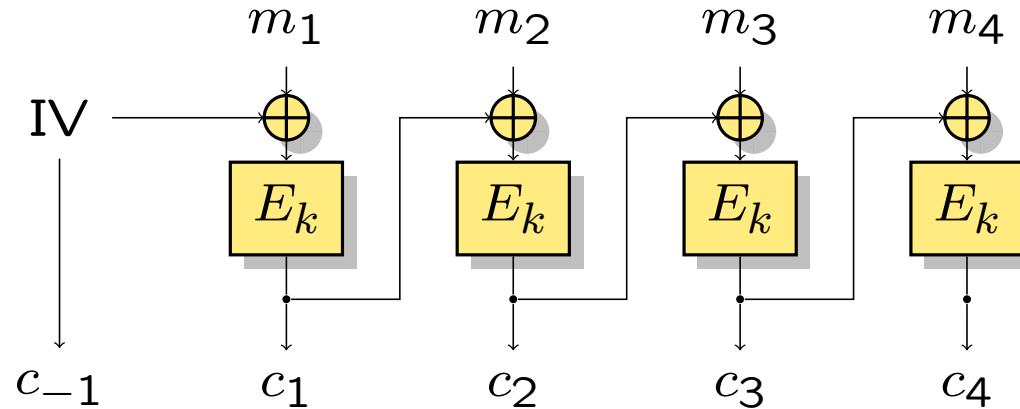
(travaux communs avec C. Beierle, G. Leander et Y. Rotella)

Journées Scientifiques 2018, Bordeaux

Symmetric Encryption Schemes

For encrypting messages of an arbitrary length:

- use a transformation operating on n -bit blocks (**block cipher**)
- chain the blocks with a mode of operation (CBC, CTR...)



Typical block size:

$$n \in \{128, 64\}$$

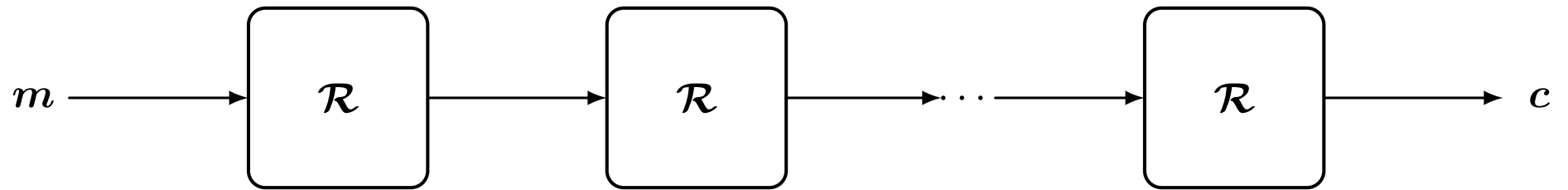
What is a block cipher?

$$E_k : \{0, 1\}^n \longrightarrow \{0, 1\}^n, \quad n \in \{64, 128\}$$

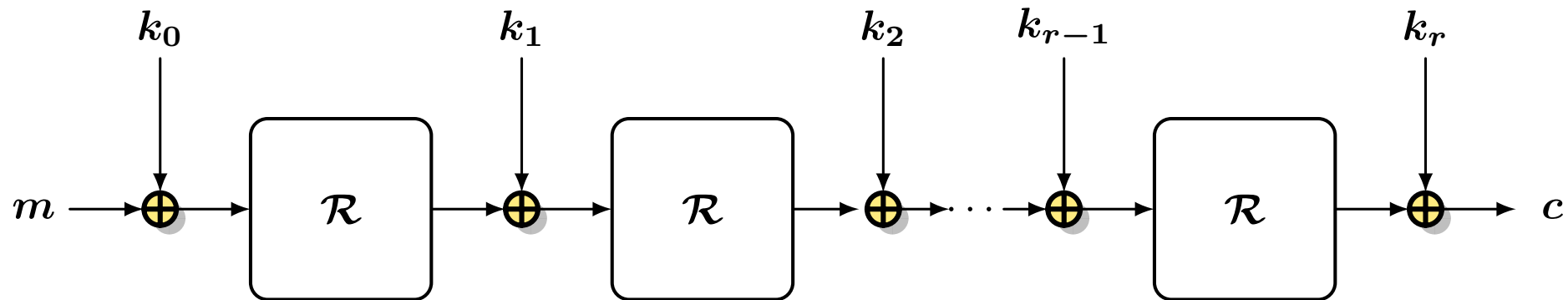
- indistinguishable from a set of randomly chosen permutations of $\{0, 1\}^n$
- implementable

→ Contradiction!

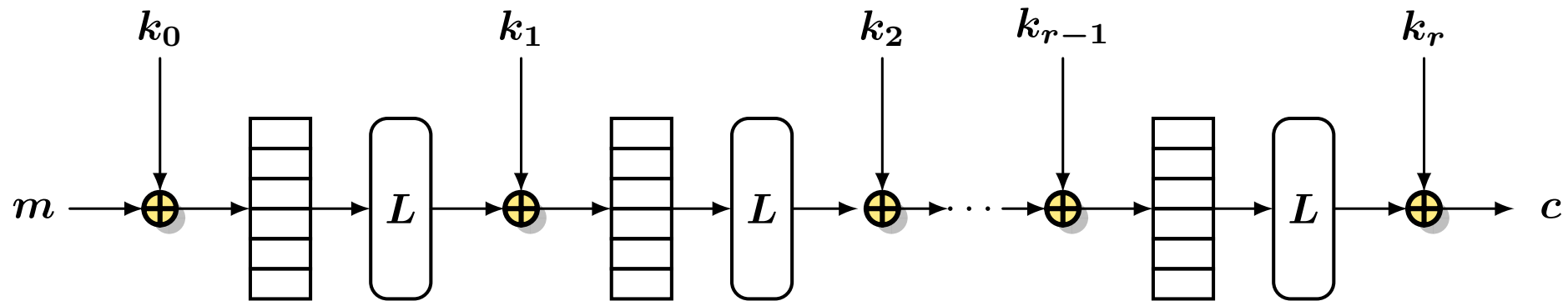
Iterated block ciphers



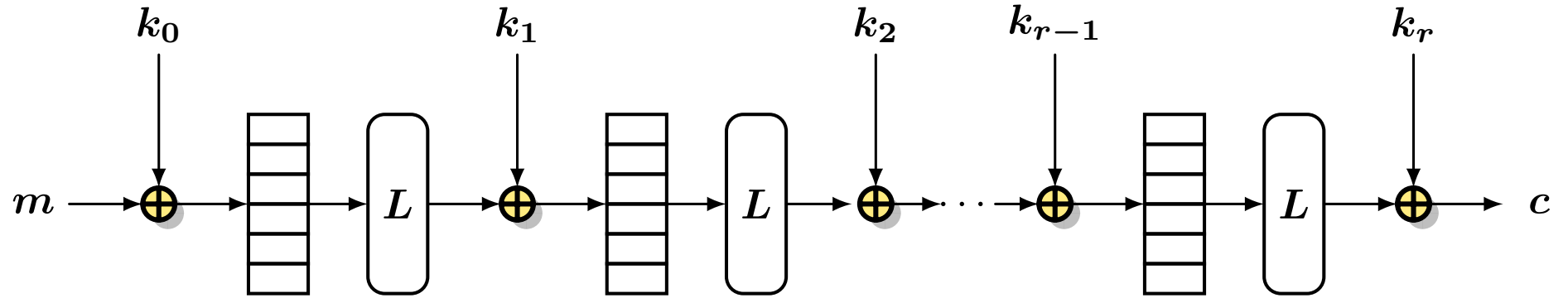
Iterated block ciphers



Iterated block ciphers

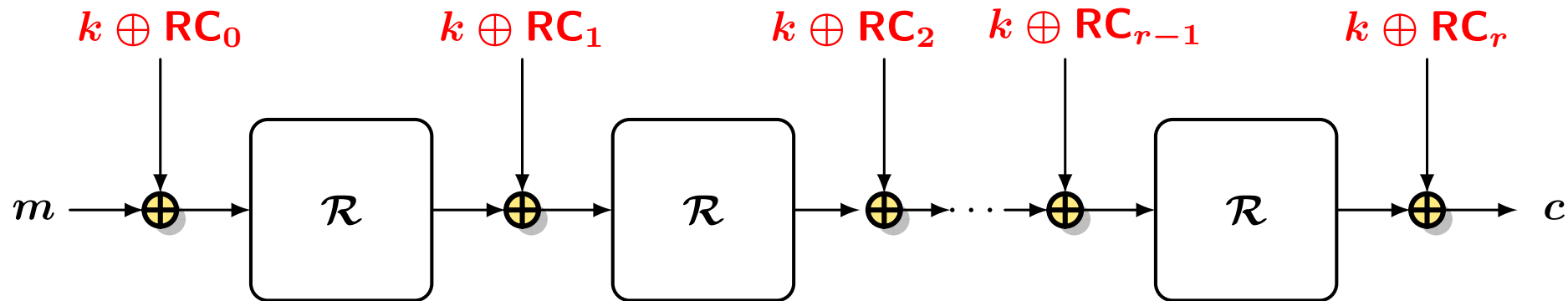


Lightweight block ciphers



- lighter nonlinear functions
- lighter diffusion layers
- simpler key schedules

Lightweight key schedules



where $\text{RC}_0, \text{RC}_1, \dots, \text{RC}_r$ are fixed round-constants.

Examples:

- PrintCipher [Knudsen et al. 10]
- LED [Guo et al. 11]
- Prince [Borghoff et al. 12]
- Scream and iScream [Grosso et al. 14]
- Midori [Banik et al. 15]
- Skinny and Mantis [Beierle et al. 16]...

Invariant attacks [Todo-Leander-Sasaki 16]

Principle:

Exhibit a set \mathcal{X} of inputs **invariant under E_k** for many weak keys.

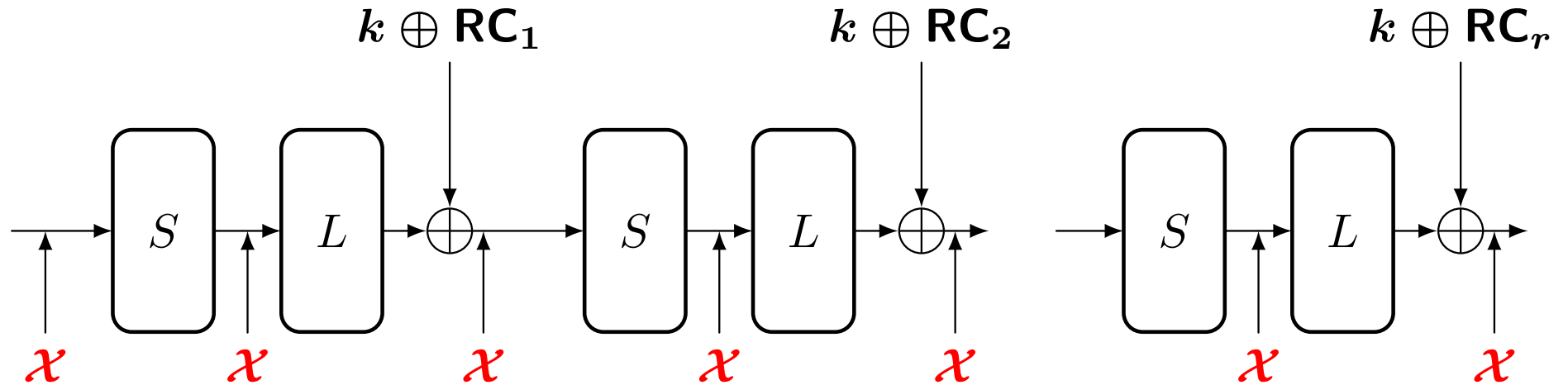
Ex: Invariant subspace for Midori-64 [Guo et al. 16]

$\mathcal{X} = \{8, 9\}^{16}$ is invariant under E_k , for any 128-bit key $k \in \{0, 1\}^{32}$.

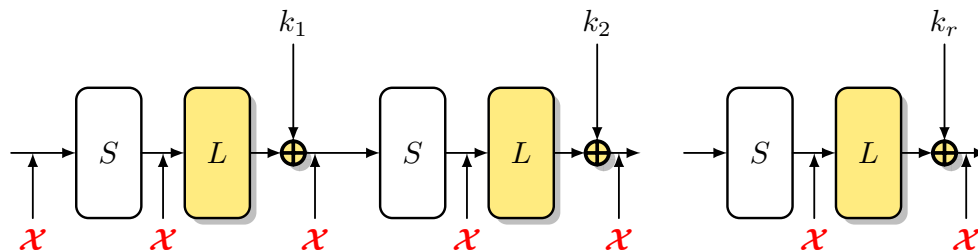
For $k = (1100110011001100, 0011001100110011)$,

$m = 9999999999999999$ leads to the ciphertext $c = 89999999988988989$

Using the same invariant for all layers in an iterated cipher



Finding an \mathcal{X} invariant under all linear layers



$$L(\mathcal{X}) \oplus k_i = \mathcal{X} \text{ and } L(\mathcal{X}) \oplus k_j = \mathcal{X} \Rightarrow \mathcal{X} \oplus k_i = \mathcal{X} \oplus k_j$$

\mathcal{X} is invariant under addition of any $(\mathbf{RC}_i \oplus \mathbf{RC}_j)$

Proposition.

$$\mathbf{LS}(\mathcal{X}) = \{a \in \{0, 1\}^n : (a \oplus \mathcal{X}) = \mathcal{X}\}$$

- $\mathbf{LS}(\mathcal{X})$ is a linear space
- $\mathbf{LS}(\mathcal{X})$ is invariant under L
- $\mathbf{LS}(\mathcal{X})$ contains all $(\mathbf{RC}_i \oplus \mathbf{RC}_j)$

Condition on the existence of invariant sets

$$D := \{(\mathbf{RC}_i \oplus \mathbf{RC}_j), \quad 0 \leq i < j \leq r\}$$

$W_L(D) :=$ smallest subspace invariant under L which contains D .

Problem.

Is there a set $\mathcal{X} \subset \{0, 1\}^n$ such that $S(\mathcal{X}) = \mathcal{X}$ and \mathcal{X} is invariant under addition of any element in $W_L(D)$?

Condition on the existence of invariant sets

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No if $W_L(D) = \{0, 1\}^n$

Some lightweight ciphers with $n = 64$

Skinny-64-64.

$$D = \{\text{RC}_1 \oplus \text{RC}_{17}, \text{RC}_2 \oplus \text{RC}_{18}, \text{RC}_3 \oplus \text{RC}_{19}, \text{RC}_4 \oplus \text{RC}_{20}, \text{RC}_5 \oplus \text{RC}_{21}\}$$

$$\dim W_L(D) = 64$$

The round-constants and L guarantee that the attack does not apply.

Prince.

$$D = \{\text{RC}_1 \oplus \text{RC}_2, \text{RC}_1 \oplus \text{RC}_3, \text{RC}_1 \oplus \text{RC}_4, \text{RC}_1 \oplus \text{RC}_5, \alpha\}.$$

$$\dim W_L(D) = 56$$

Midori-64.

$$\dim W_L(D) = 16$$

Maximizing the dimension of $W_L(d)$

$$W_L(d) = \langle L^t(d), t \in \mathbb{N} \rangle .$$

Theorem. There exists d such that $\dim W_L(d) = k$ if and only if k is the degree of a divisor of the minimal polynomial of L .

$$\Rightarrow \max_{d \in \mathbb{F}_2^n} \dim W_L(d) = \deg \text{Min}_L$$

For some lightweight ciphers

LED.

$$\text{Min}_L(X) = (X^8 + X^7 + X^5 + X^3 + 1)^4 (X^8 + X^7 + X^6 + X^5 + X^2 + X + 1)^4$$

There exist some d such that $\dim W_L(d) = 64$

Prince.

$$\text{Min}_L(X) = X^{20} + X^{18} + X^{16} + X^{14} + X^{12} + X^8 + X^6 + X^4 + X^2 + 1$$

$$\max_d \dim W_L(d) = 20$$

Midori.

$$\text{Min}_L(X) = (X + 1)^6 \Rightarrow \max_d \dim W_L(d) = 6$$

Some conclusions on lightweight cryptography

- standardization process launched by NIST in December
- risky
- clarifies the design criteria.