Higher-order Masking and Shuffling for Software Implementations of Block Ciphers

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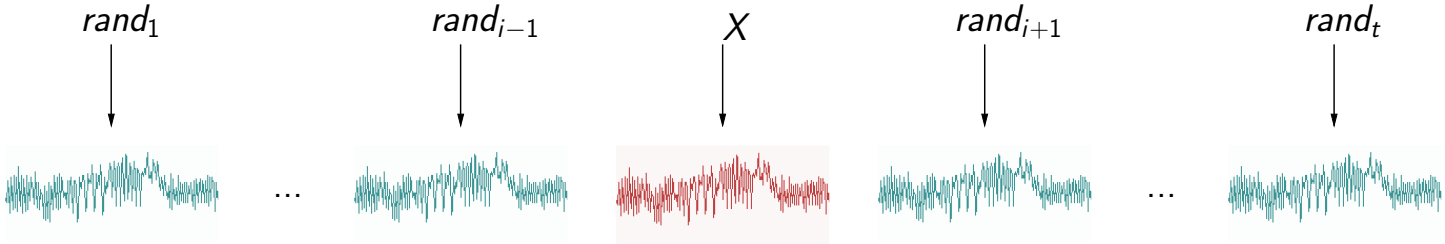

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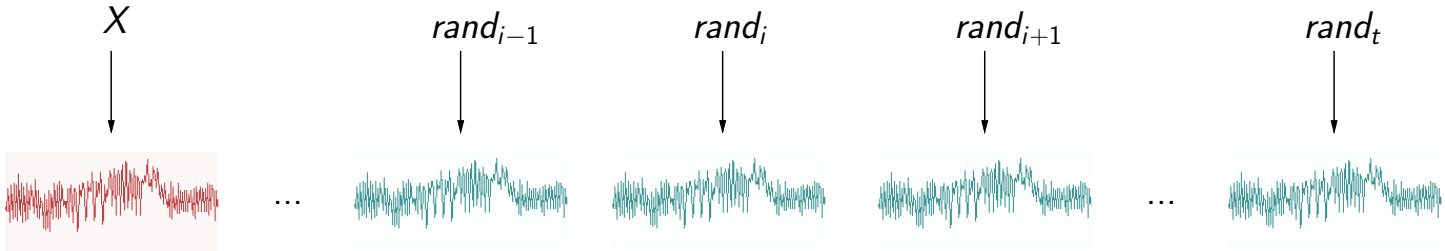

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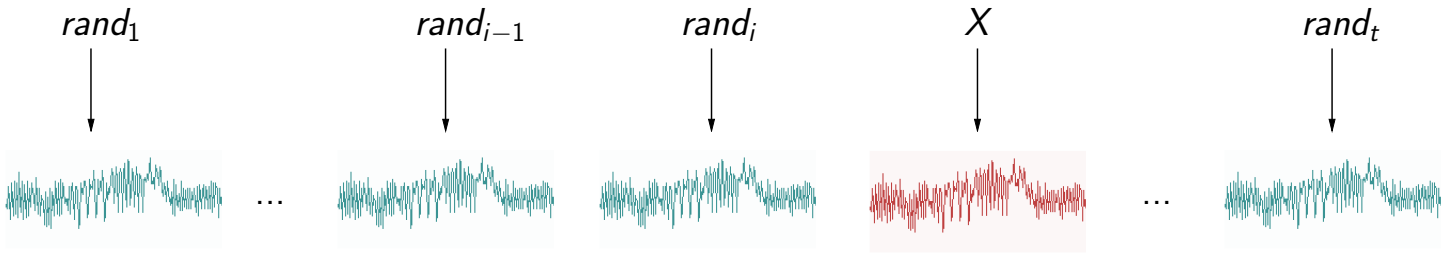

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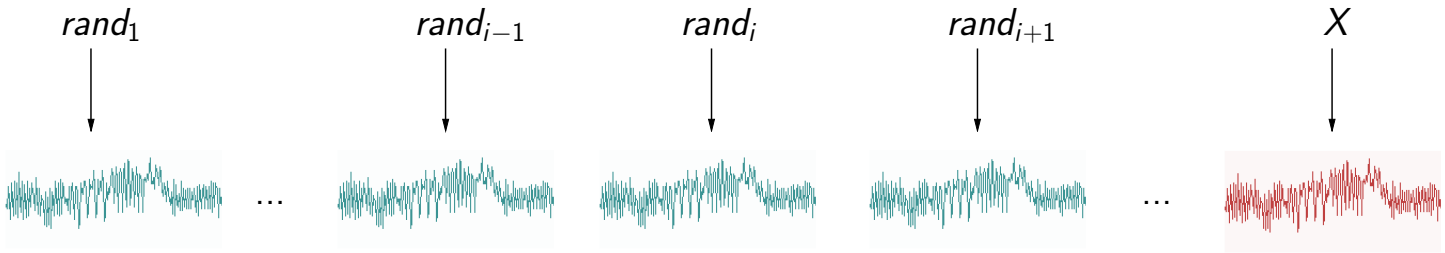

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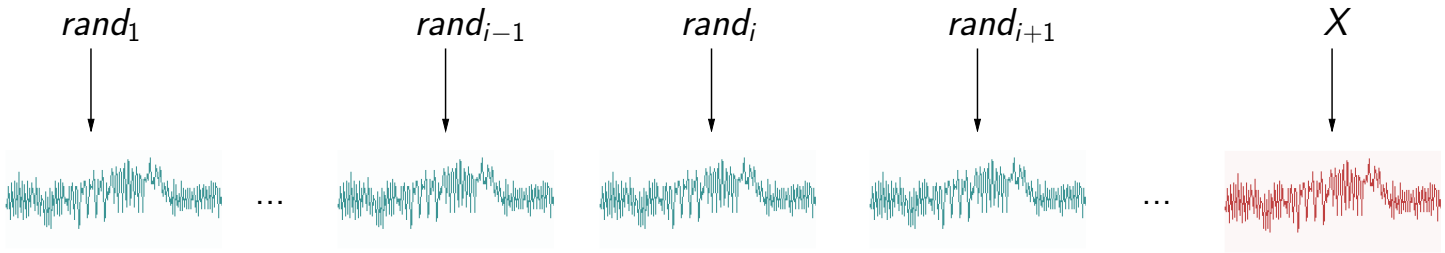

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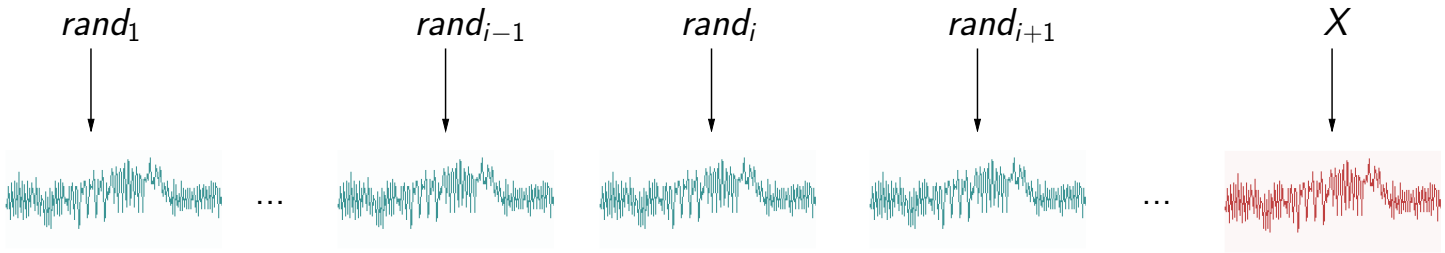

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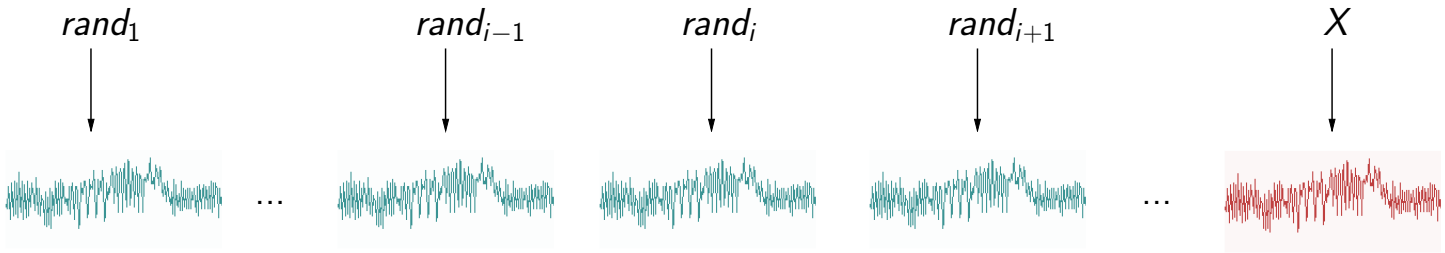

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- Issue: t must be very large to have satisfying security.

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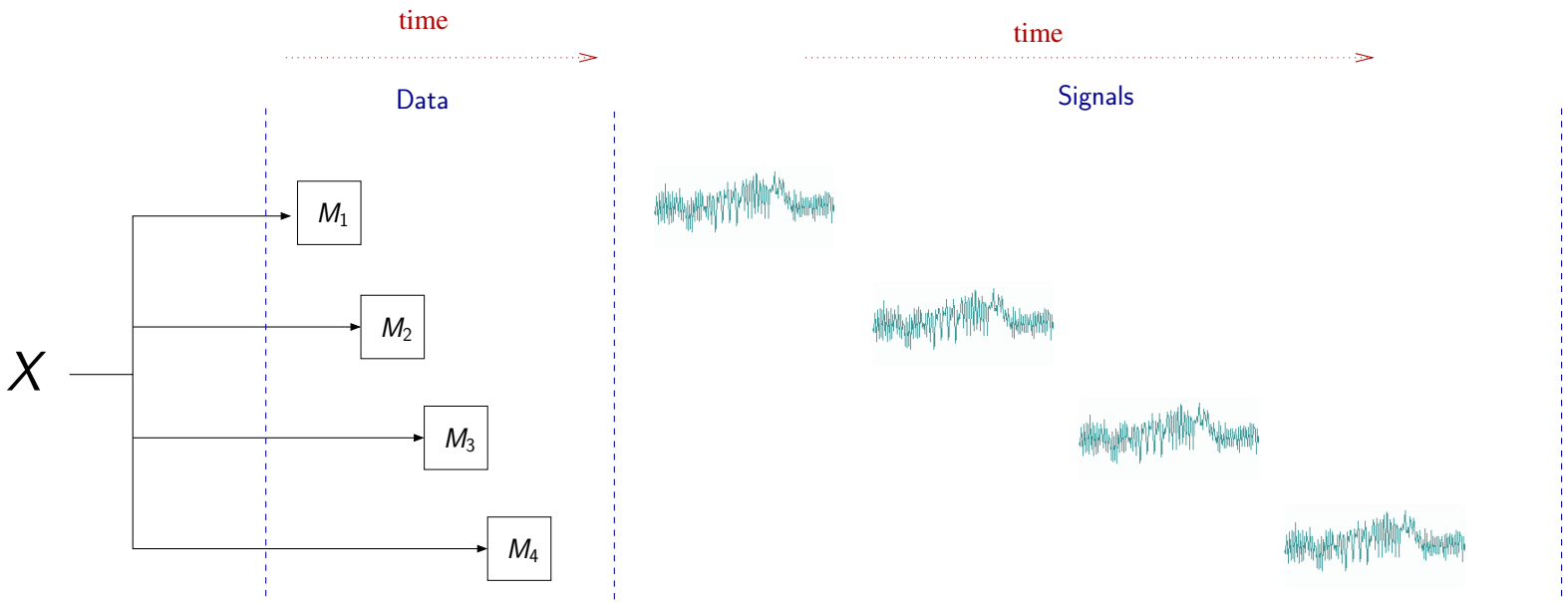

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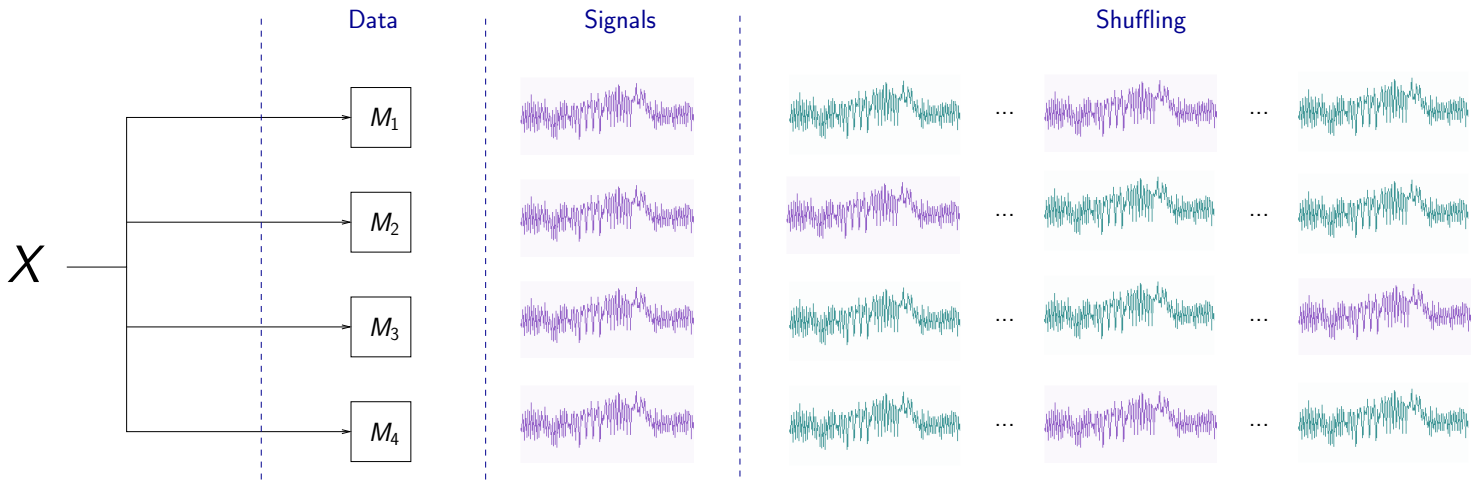
- Asset: dealing with the propagation of the masks when performing $Op(X)$ is easy when Op is linear.
- Issue: even for small d, dealing with the mask propagation is an issue when $Op =$ S-box.
  - Costly solutions exist only for $d \leq 3$ [SchramPaar06,RivainDottaxProuff08b].

Masking-and-Shuffling Method

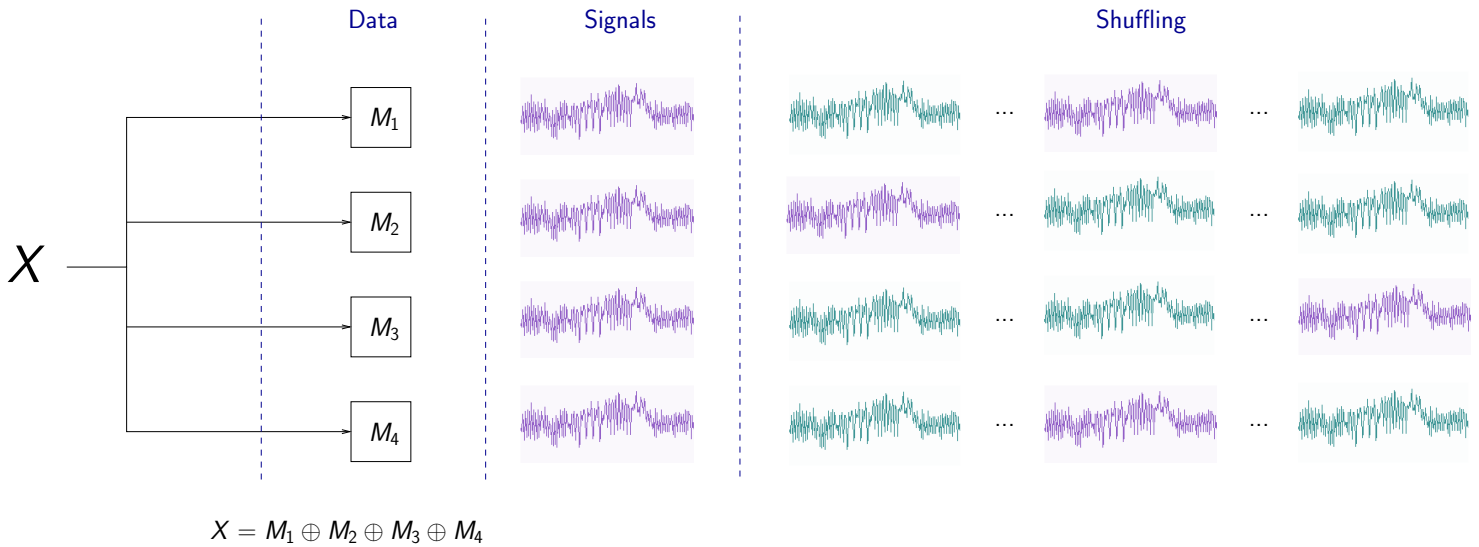
- Core Idea: combine Masking and Shuffling.
- First Proposal: combine 1st-order masking with shuffling [HOM06,TillichHerbstMangard07].
- Analyses in [THM07] and [TillichHerbst08] show that the resulting security is not good.
- Possible Improvement: involve higher-order masking [this paper]

Masking-and-Shuffling Method - Figure



$X = M_1 \oplus M_2 \oplus M_3 \oplus M_4$

Masking-and-Shuffling Method - Figure



Raises two issues

1. How to combine higher-order masking with shuffling?
2. How to quantify the security of the resulting scheme?

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Single difference: the function f.

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- [Hamming Weight Leakage Model] the leakage signal S_i produced by the processing of a variable D_i satisfies:

$$S_i = \delta_i + \beta_i \cdot \mathrm{H}(D_i) + N_i \quad \text{with } N_i \sim \mathcal{N}(0, \sigma) \ .$$

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It is denoted by $\rho(d, \sigma)$.

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Goal: protect block ciphers iterating round function in the form:

$$\lambda \quad \circ \quad \gamma \quad [p \oplus k] \quad] \,,$$

k: round key
p: intermediate state of the ciphering
γ: non-linear layer composed of S-boxes
λ: linear layer composed of L atomic operations.

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Complexity for one round

- Precomputations (random permutations,lookup-tables): $PreComp(t, d, d')$
- Protected Round (layers γ and λ): $RoundSec(t, d, d')$
- Protected Block Cipher:

$$PreComp(t, d, d') + RoundSec(t, d, d') \times \text{nbr of rounds}$$

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4 attack pathes have been identified.

- Targeting the t^{th}order shuffled d^{th}-masking
  - For γ: $\rho_1(t,d) = \frac{1}{\sqrt{t}}\rho(d,\sigma)$
  - For λ (split into L sub-layers): $\rho_2(t,d') = \frac{1}{\sqrt{\binom{(d+1)\cdot L}{d+1}}}\rho(d,\sigma)$
- Targeting the t^{th}order shuffled d'^{th}-masking
  - Target the d' shares simultaneously: $\rho_3(t,d') = \frac{1}{\sqrt{t}}\rho(d',\sigma)$
  - Target 2 masked data, masked with the same sum of masks: $\rho_4(t) = \frac{1}{\sqrt{t\cdot(t-1)}}\rho(2,\sigma)$.

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- Among the 3-tuples (d, d', t) satisfying (1), chose one that minimizes

$$\mathit{PreComp}(t, d, d') + \mathit{RoundSec}(t, d, d') \times \text{nbr of rounds}$$

AES implementation on a 8051-architecture.

Table: Optimal parameters and timings according to SNR and ρ^*.

	$\mathrm{SNR} = 1$				$\mathrm{SNR} = \frac{1}{4}$			
ρ^*	t	d	d'	timings	t	d	d'	timings
10^{-1}	16	1	1	3.66×10^4	16	1	0	2.94×10^4
10^{-2}	20	2	2	6.39×10^4	16	1	1	3.66×10^4
10^{-3}	123	3	3	3.13×10^5	16	2	2	5.75×10^4
10^{-4}	12208	4	3	3.15×10^7	19	3	3	8.35×10^4

Thank you!
Questions and/or Comments?

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- Signals corresponding to shares are spread over t random signals.
  - Atomic operations of λ are performed for every share

Note: no need for conversion d-masking into d'-masking.

Output: [d^{th}-masking] state $[\lambda \circ \gamma](p+k)$ split into d shares $\lambda(m'_i)$

AES implementation on a 8051-architecture.

Table: Cycles Numbers for the different steps of the scheme for an AES implementation on a 8051-architecture.

T Generation	$\mathcal{C}_T = 112 + t\left(6 + 9\sum_{i=0}^{15}\frac{1}{t-i}\right)$
T' Generation	$\mathcal{C}_{T'} = 3q + 2^q(15 + 14q)$
Masked S-box Generation	$\mathcal{C}_{MS} = 4352d'$
Pre-computations	$\mathcal{C}_T + \mathcal{C}_{T'} + \mathcal{C}_{MS}$
γ	$\mathcal{C}_{SL} = t(55 + 37d + 18d')$
Linear Layer	$\mathcal{C}_{LL} = 676(d + 1)$
Protected Round	$\mathcal{C}_{SL} + \mathcal{C}_{LL}$
Unprotected Round	432

Complexity

Complexity

Input: block cipher specifications + implem. characteristics

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Three security parameters:

- t: shuffling order
- d: masking order for linear layers
- d': masking order for S-box computations

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Complexity for one round

Rand. Gen. [Shuffling γ]	$\mathcal{C}_T(t)$
Rand. Gen. [Shuffling λ]	$\mathcal{C}_{T'}(d)$
Masked S-box Generation	$\mathcal{C}_{MS}(d')$
Pre-computations	$\mathcal{C}_T(t) + \mathcal{C}_{T'}(d) + \mathcal{C}_{MS}(d')$
γ	$\mathcal{C}_{SL}(d, d')$
λ	$\mathcal{C}_{LL}(d)$
Protected Round	$\mathcal{C}_{SL}(d', d) + \mathcal{C}_{LL}(d)$