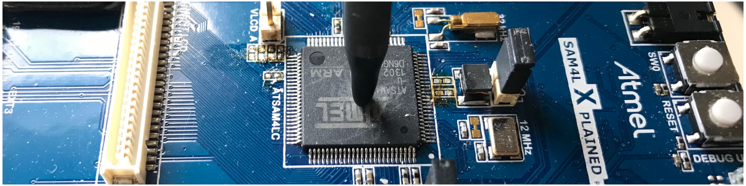


Bitslice Masking and Improved Shuffling: How and When to Mix Them in Software?

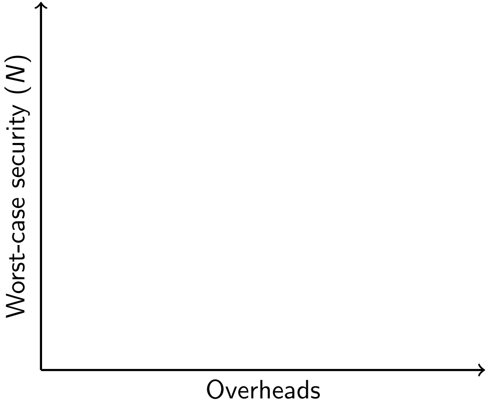
Melissa Azouaoui, Olivier Bronchain, Vincent Grosso
Kostas Papagiannopoulos, François-Xavier Standaert

CHES 2022, Leuven, Belgium

University of Amsterdam NXP UCLouvain

Contents

Design space for side-channel countermeasures



Countermeasures compared on:

- Run time overheads.
- Worst-case security (N).

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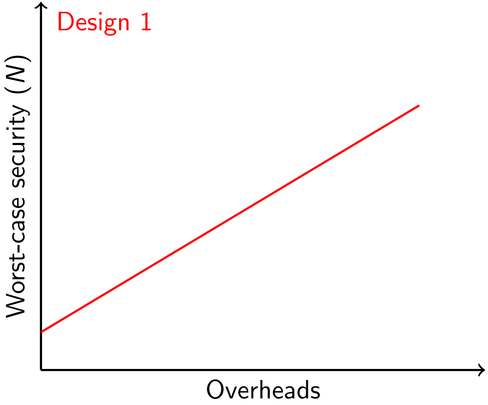

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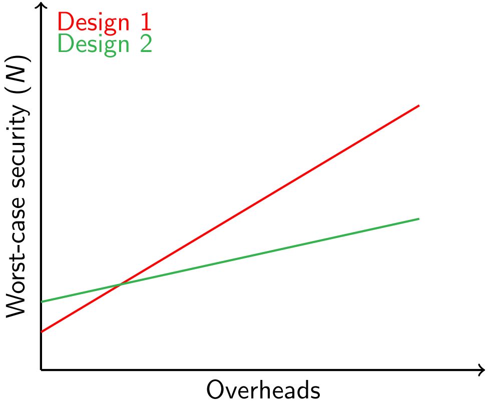

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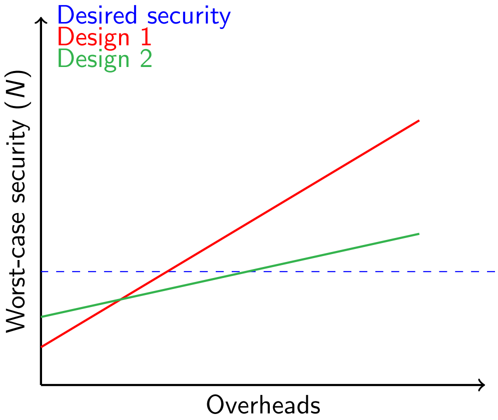

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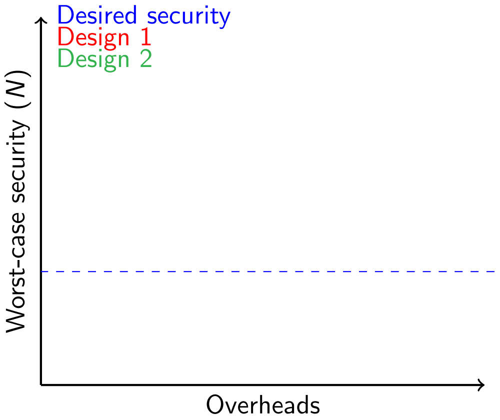
Design space for side-channel countermeasures



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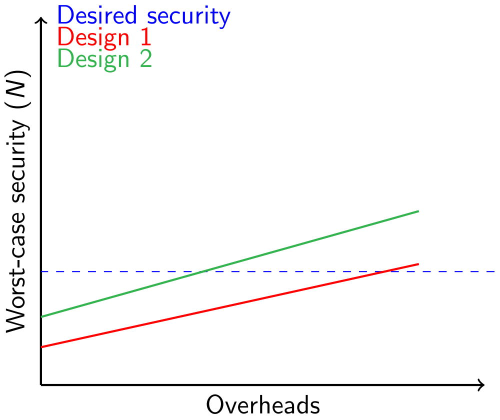
Best design is device dependent:

- Noise level.
- Platform architecture.

Design space for side-channel countermeasures



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Existing side-channel countermeasures $\big(\mathrm{MI}(X; L) < 1\big)$

Masking:

- Randomized the data processed.
- Sharing of $x := (x^0, x^1, \ldots, x^{d-1})$
- Noise amplification:

$$N \approx \frac{c}{\prod_i \mathrm{MI}(X^i; L)} \approx \frac{c}{\mathrm{MI}(X^i; L)^d}$$

- Data Layout:

0-th share	$\boxed{x^0}$
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Perm:					
data:					

indep. data

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Perm:	2	4	1	3	0
data:			x_2		

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$\longleftrightarrow$ indep. data

→ **How to amplify shuffling thanks to masking ? (η^d)**

Design space for side-channel countermeasures

1. Security:
   - Explore design space for shuffling + masking.
   - Evaluate the security:
     - Paper & pencil.
     - Confirmed with simulations.

Rivain et al. [RPD09]:

- Linear layers: $\binom{d\cdot\eta}{d}$
- Non-linear layers: η

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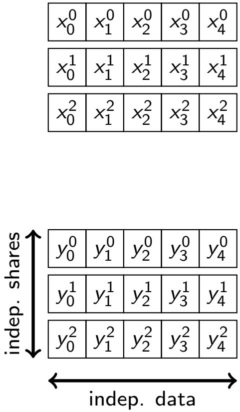
Contents

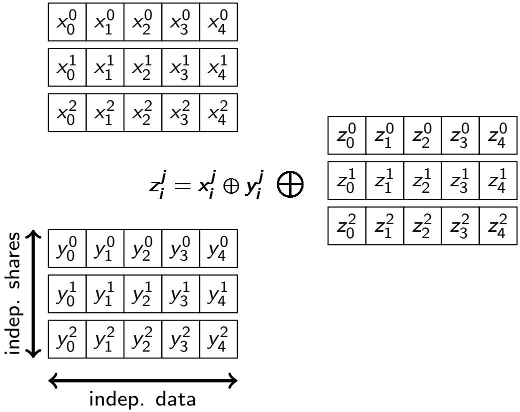
Protecting masked linear layers



Setting:

- $\eta = 5$ independent data x_j and y_j
- $d = 3$ shares x^i and y^i.

Protecting masked linear layers



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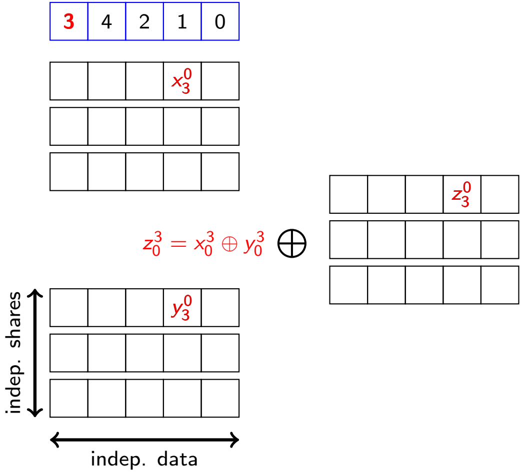
- $d = 3$ shares x^i and y^i.

Goal:

- Compute all: $z_j^i = x_j^i \oplus y_j^i$

Shuffling-tuples on linear layers: description



Description:

- Shuffle between variables
- Permutations:
  - Number: 1.
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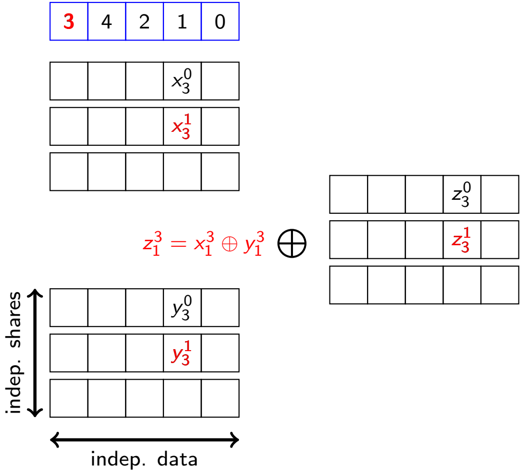
Shuffling-tuples on linear layers: description



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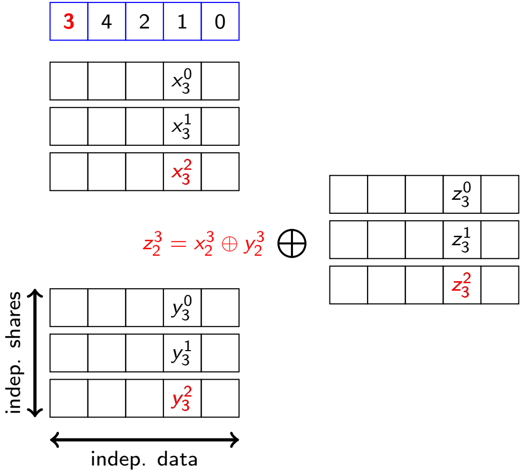

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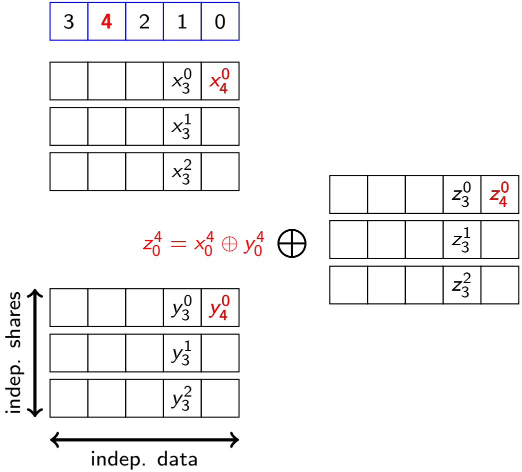

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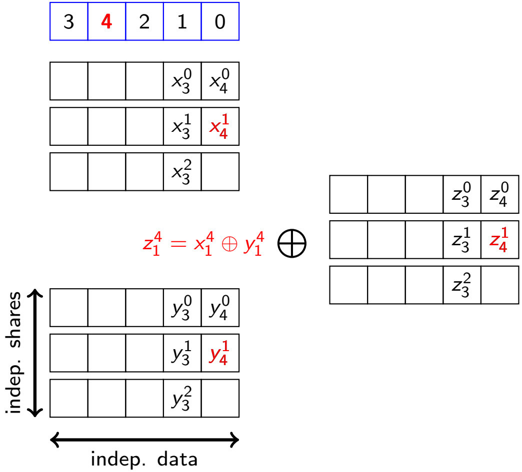

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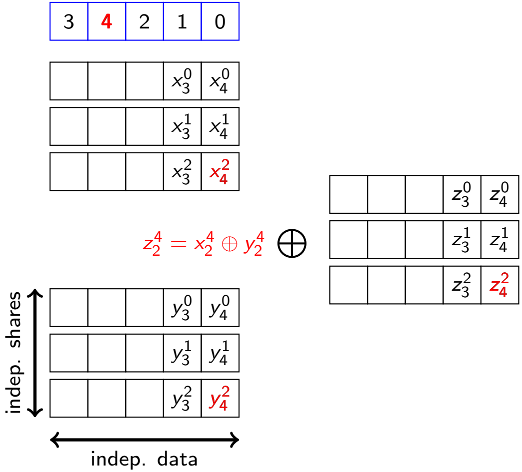

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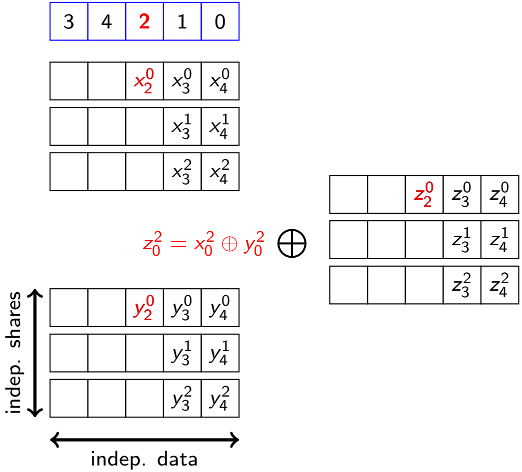

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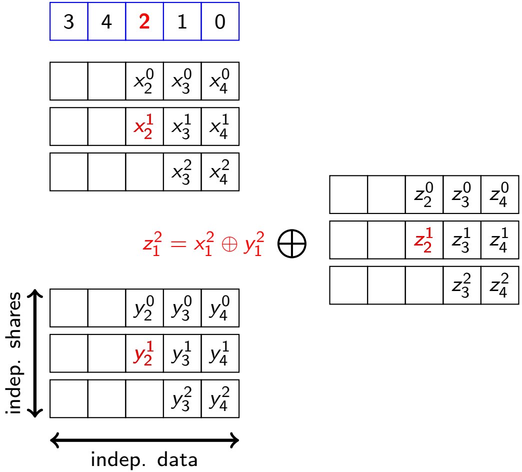

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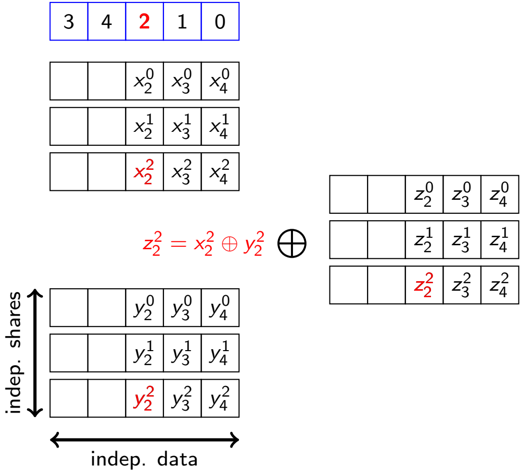

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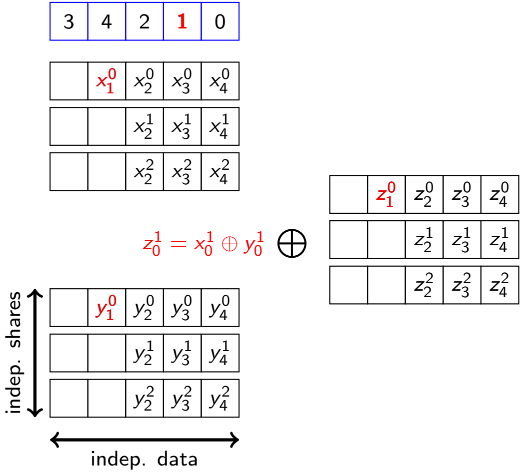

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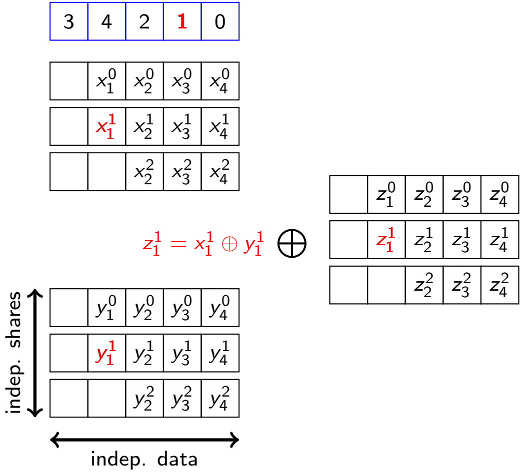

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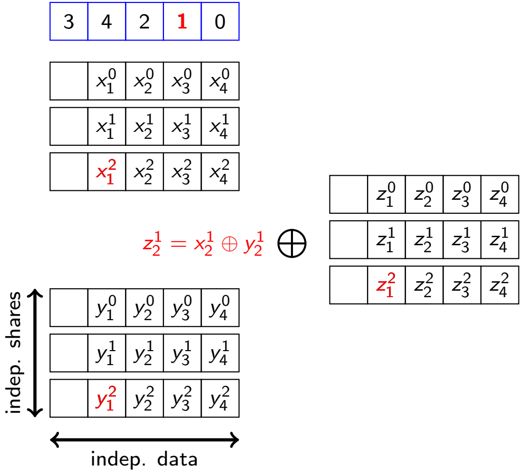

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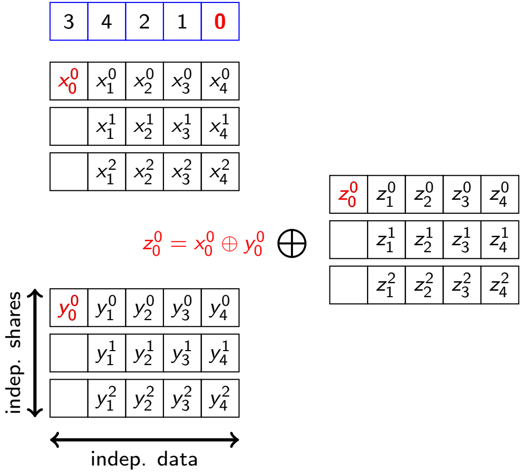

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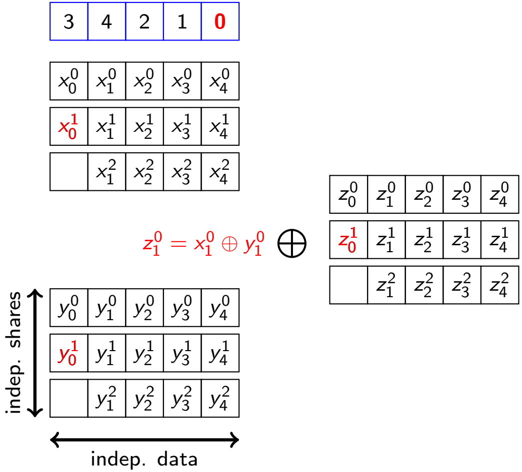

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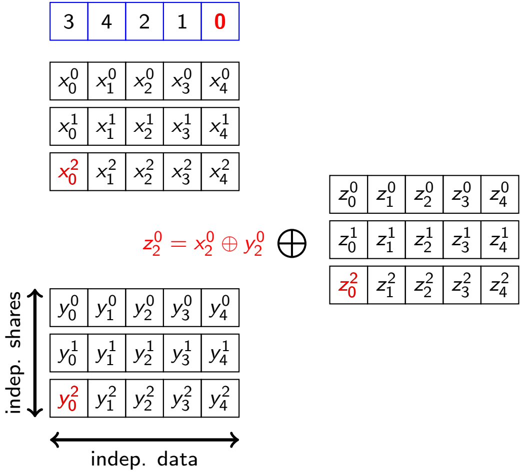

Description:

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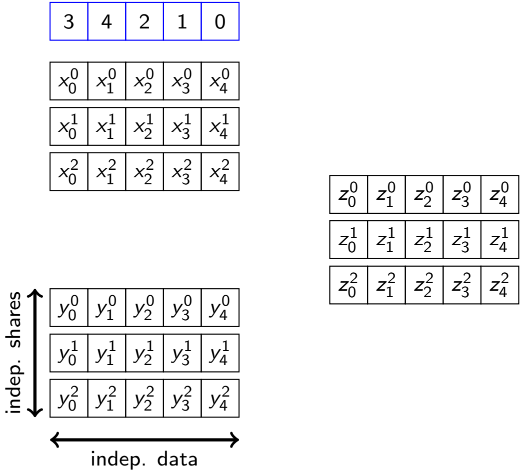
Decrease $\mathrm{MI}(X; L)$ by a factor η.

$$N \approx \frac{c \cdot \eta}{\prod_i \mathrm{MI}(X^i; L)}$$

$\rightarrow$ **Masking does not amplify shuffling.**

Shuffling-tuples on linear layers: description



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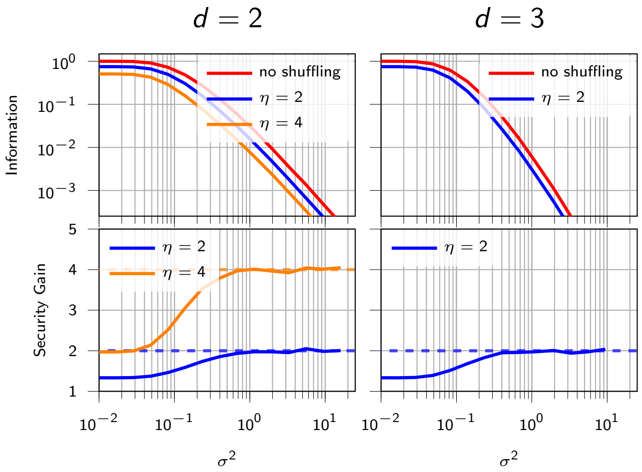
Shuffling-shares on linear layers: simulations



Expected security:

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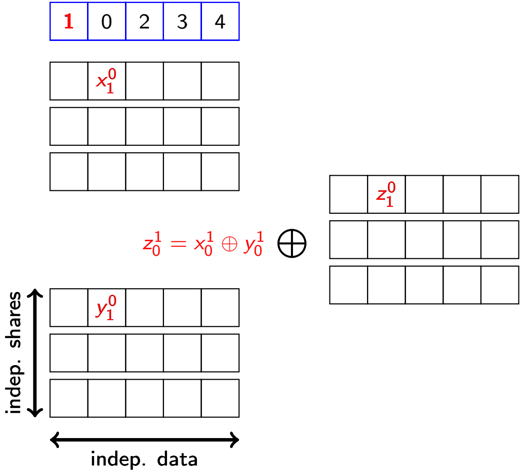

Description:

- Shuffle the i-th share of each x_j.
- Permutations:
  - Number: d.
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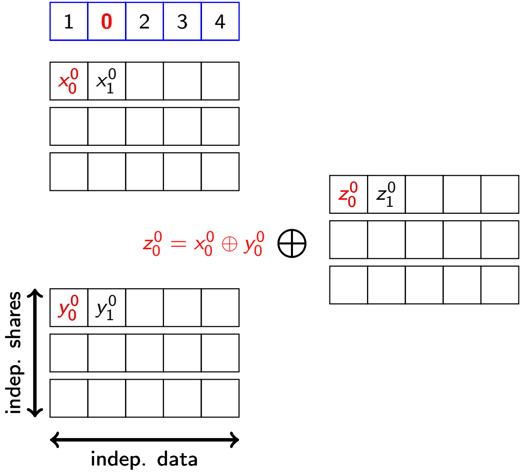
Shuffling-shares on linear layers: description



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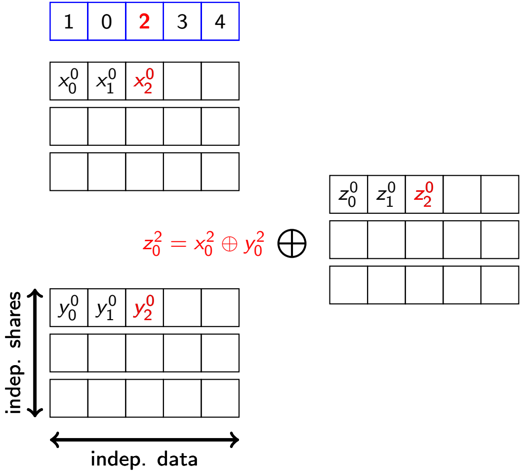

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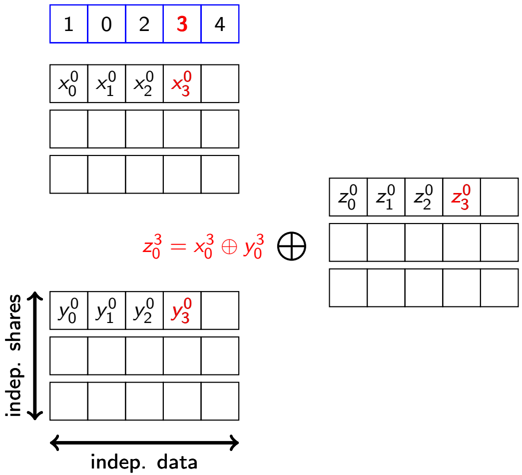

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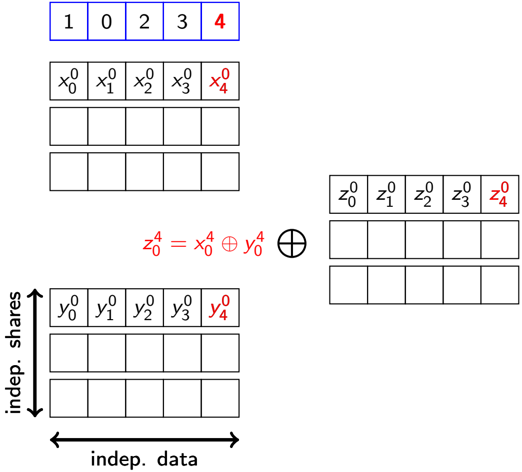

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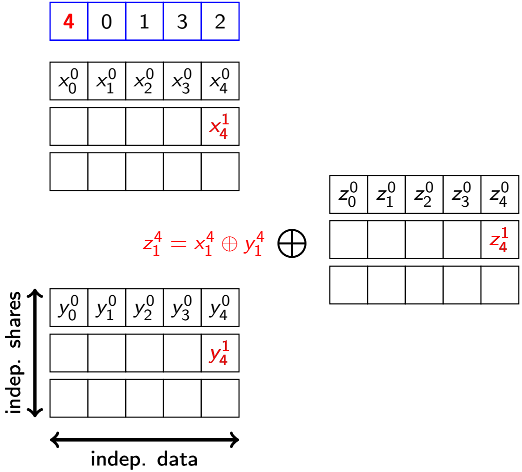

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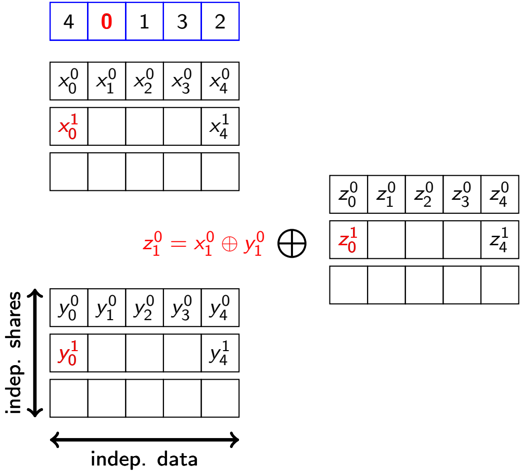

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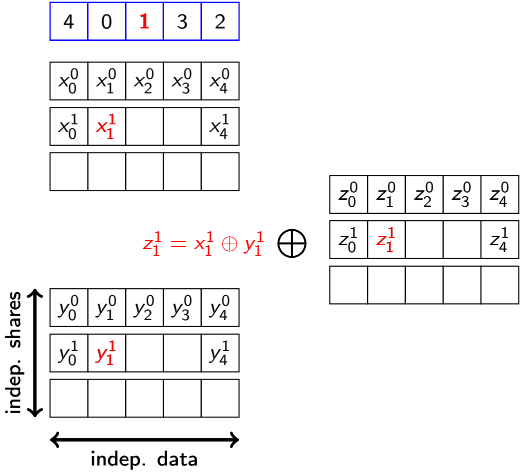

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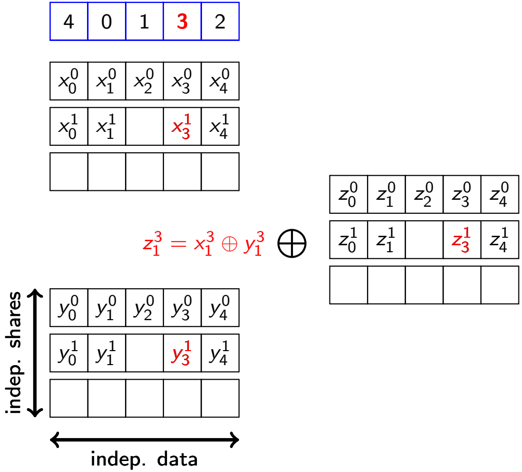

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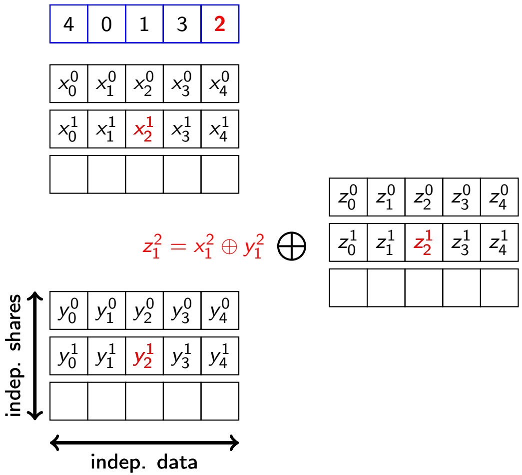

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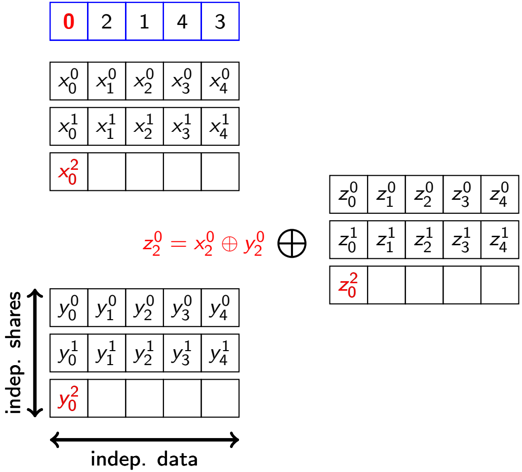

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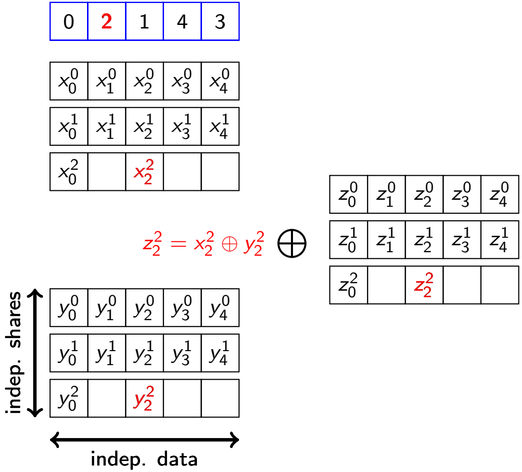
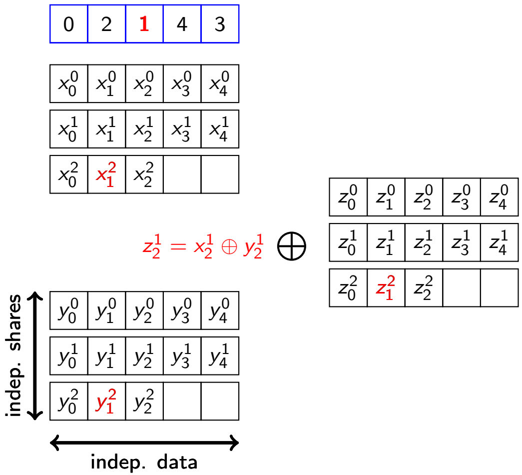
Shuffling-shares on linear layers: description



Description:

- Shuffle the i-th share of each x_j.
- Permutations:
  - Number: d.
  - Size: η.

Shuffling-shares on linear layers: description



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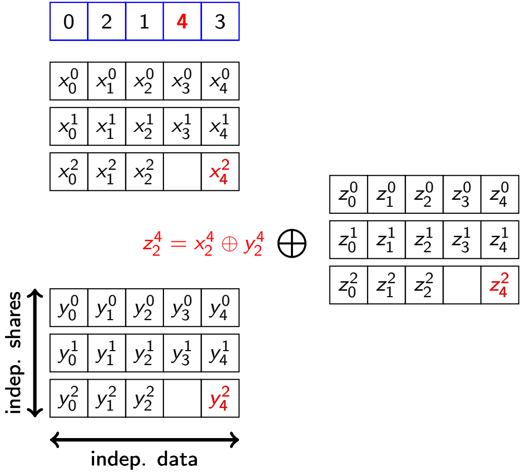

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  - Number: d.
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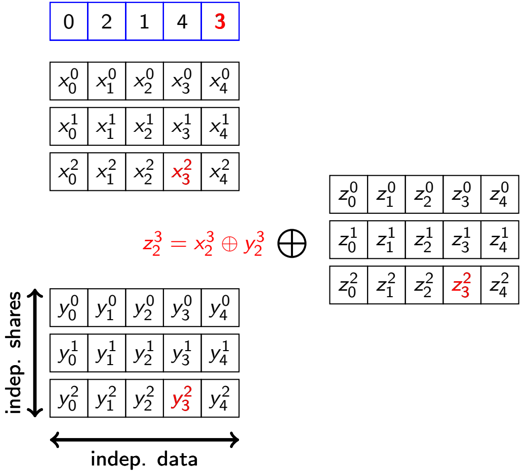
Shuffling-shares on linear layers: description



Description:

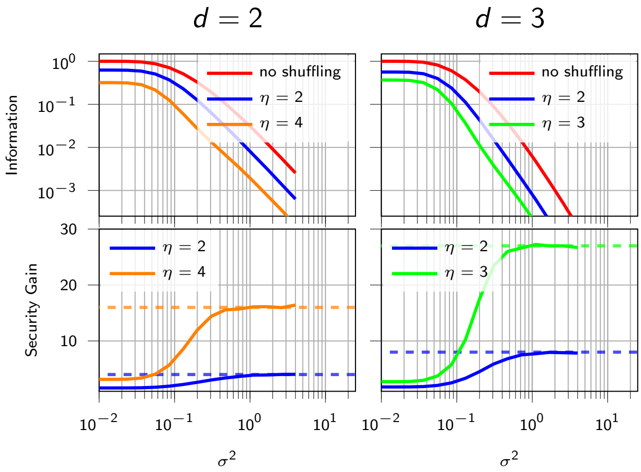
- Shuffle the i-th share of each x_j.
- Permutations:
  - Number: d.
  - Size: η.

Decrease $\mathrm{MI}(X^i; L)$ by a factor η.

$$N \approx \frac{c}{\prod_i \mathrm{MI}(X^i; L)/\eta} \approx \frac{c \cdot \eta^d}{\mathrm{MI}(X^i; L)^d}$$

$\rightarrow$ **Masking amplifies shuffling.**

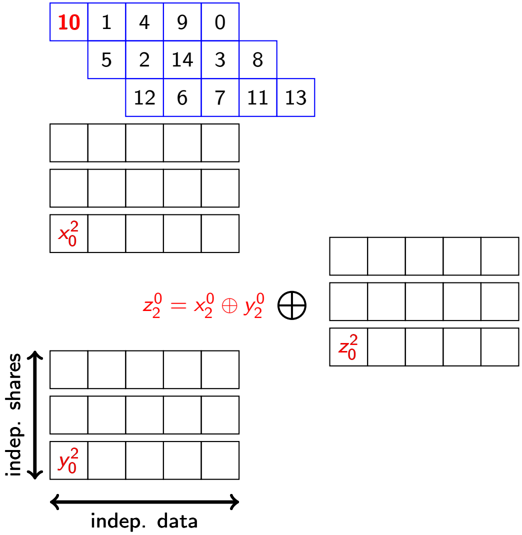
Shuffling-shares on linear layers: simulations



Expected security:

$$N \approx \frac{c \cdot \eta^d}{\mathrm{MI}(X^i; L)^d}$$

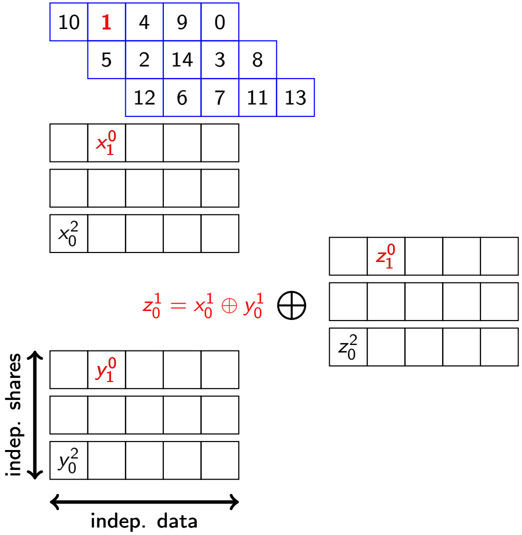
Shuffling-everything on linear layers: description



Description:

- Shuffle all the possible operations.
- Permutations:
  - Number: 1.
  - Size: $d \cdot \eta$.

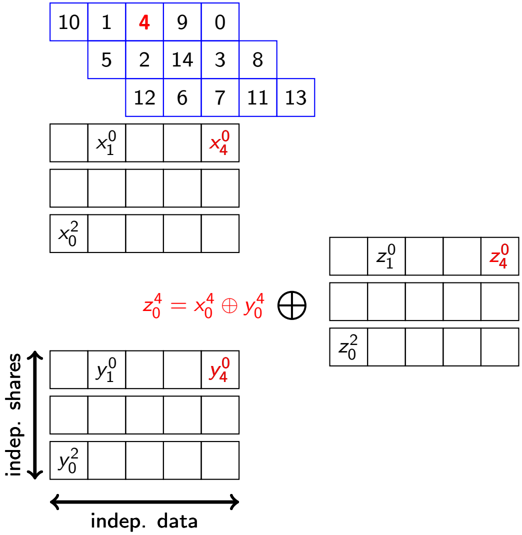
Shuffling-everything on linear layers: description



Description:

- Shuffle all the possible operations.
- Permutations:
  - Number: 1.
  - Size: $d \cdot \eta$.

Shuffling-everything on linear layers: description



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  - Number: 1.
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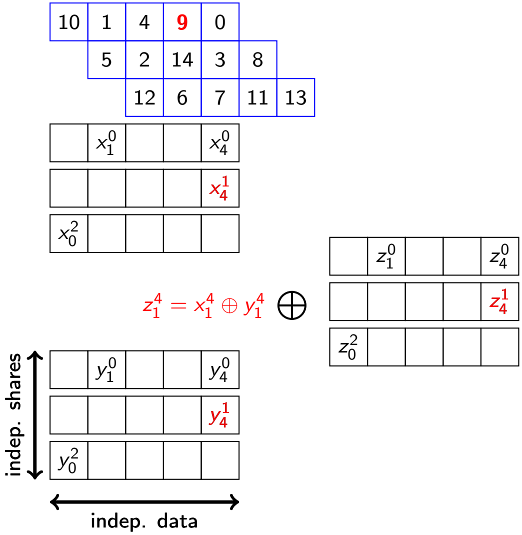
Shuffling-everything on linear layers: description



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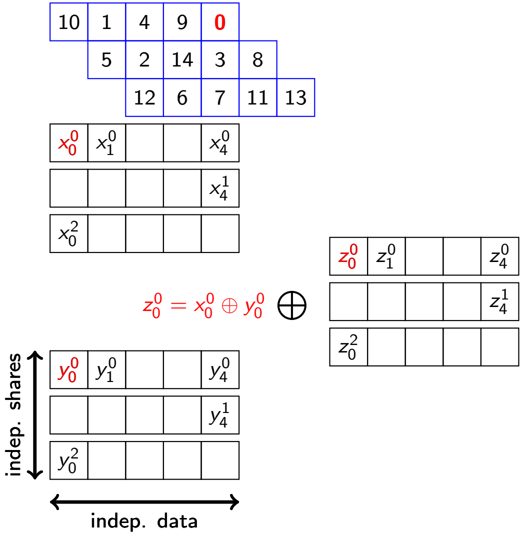

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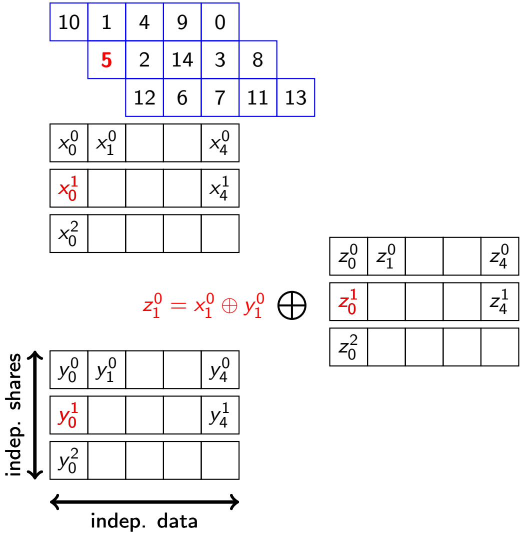

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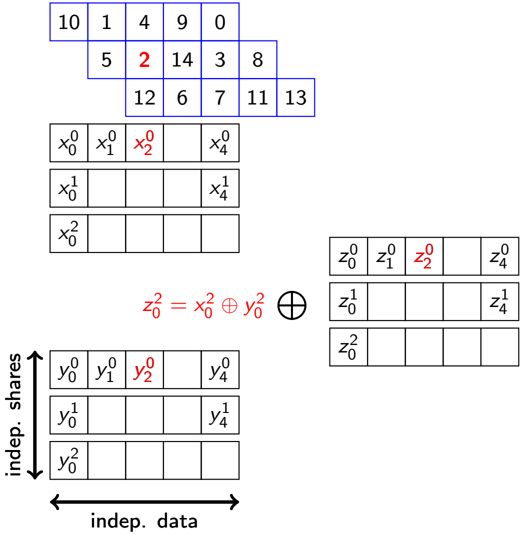

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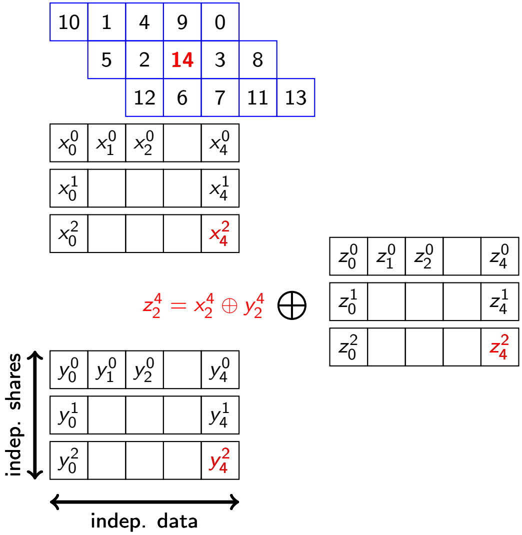

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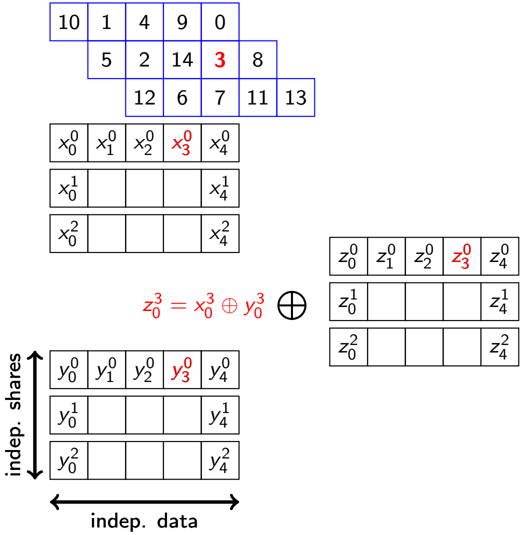

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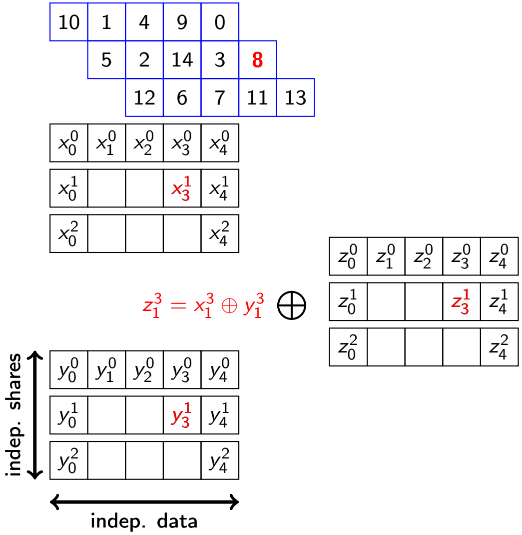

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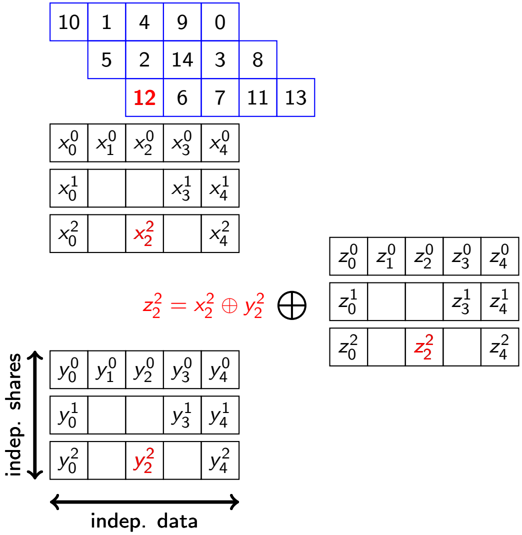

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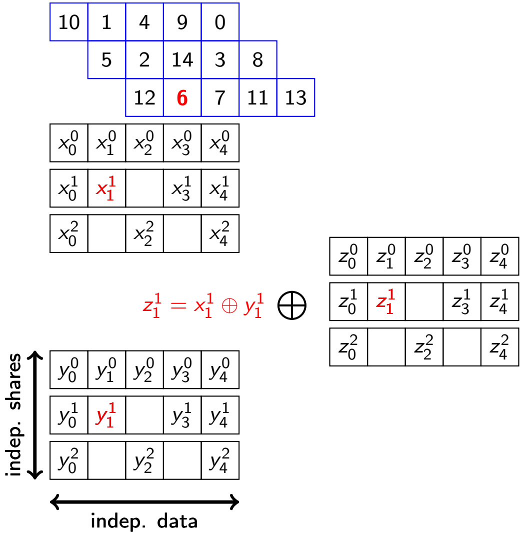

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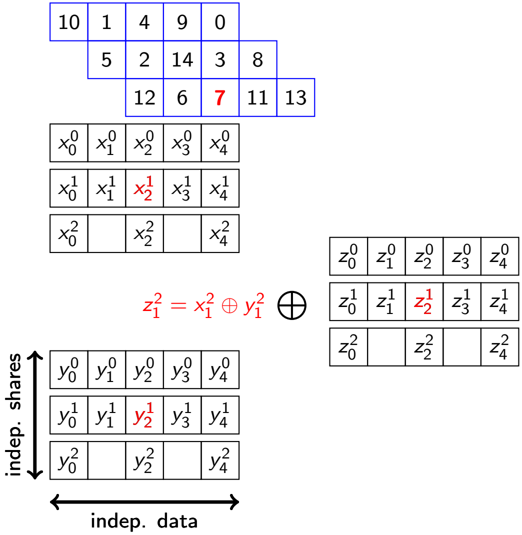

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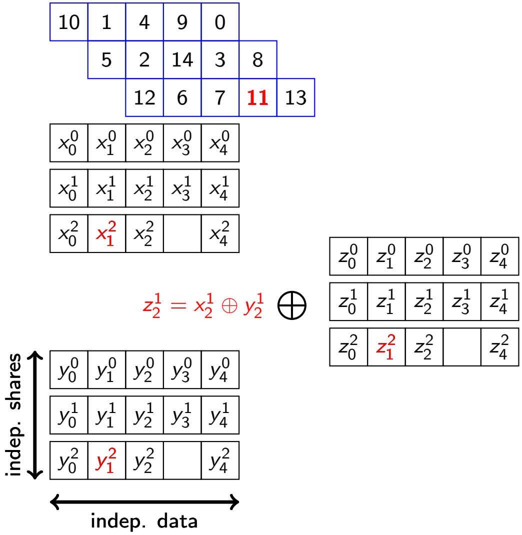

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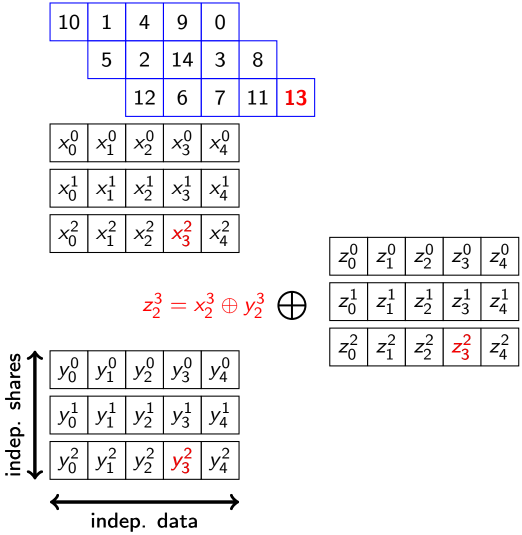

Description:

- Shuffle all the possible operations.
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$$N \approx \frac{c \cdot \binom{d \cdot \eta}{d}}{\prod_i \mathrm{MI}(X^i; L)}$$

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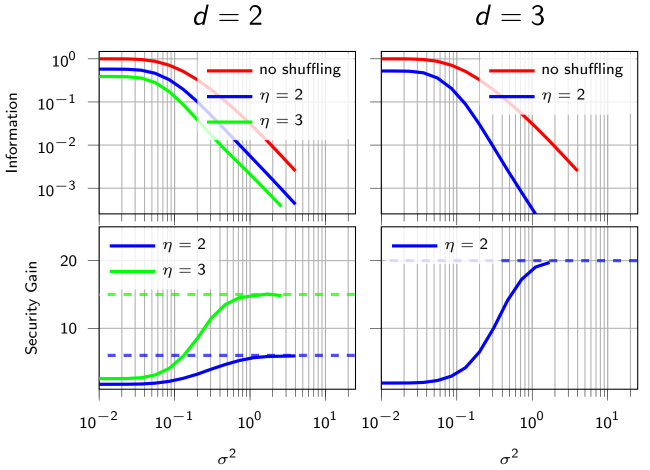
Shuffling-everything on linear layers: simulations



Expected security:

$$N \approx \frac{c \cdot \binom{d\cdot\eta}{d}}{\prod_i \mathrm{MI}(X^i; L)}$$

Contents

Non-linear layers: summary of the results

For shuffled multiplications:

- Shuffling-shares and shuffling-tuples still apply with similar gain.
- Shuffling-everything could not be analyzed with paper & pencil:
  - Permutation on the output shares is not uniform.

	Linear layer			Non-linear layer		
	Gain	$\|$perm.$\|$	# perm.	Gain	$\|$perm.$\|$	# perm.
shuffling-tuples	η	η	1	η	η	1
shuffling-shares	η^d	η	d	η^d	η	d^2
shuffling-everything	$\binom{d\cdot\eta}{d}$	$d \cdot \eta$	1	?	?	?

Table: Summary of the shuffling + masking combinations.

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Table: Summary of the shuffling + masking combinations.

$\rightarrow$ **Next focus on shuffling-shares.**

Contents

Time versus security for shuffled ISW: open questions

Bitslice masking:

- Favors large #ANDs.
- Profits from parallelism.
- Randomness usage:

$$\#\mathrm{AND} \cdot \frac{d \cdot (d-1)}{2}$$

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$$d^2 \cdot \eta \cdot \log_2 \eta$$

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Shuffling:

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- Randomness usage:

$$d^2 \cdot \eta \cdot \log_2 \eta$$

Challenges when protecting ISW:

- Should we favor parallelism or serialization.
- Does it depend on the platform ?
- Does it depend on the primitive to protect ?

Time versus security for shuffled ISW: design space (#AND = 64)

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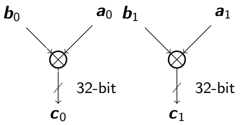
Option 1:

- Only bitsliced ISW.
- 32 bits per reg (full para.).



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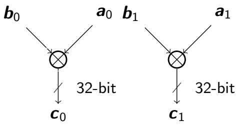

Option 2:

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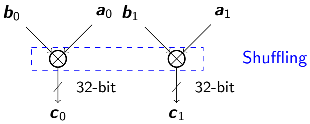

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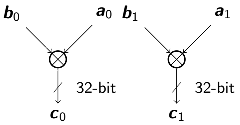

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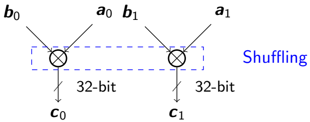
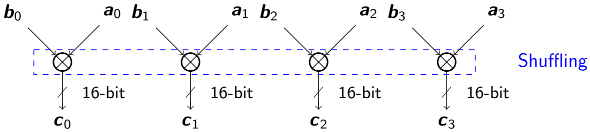
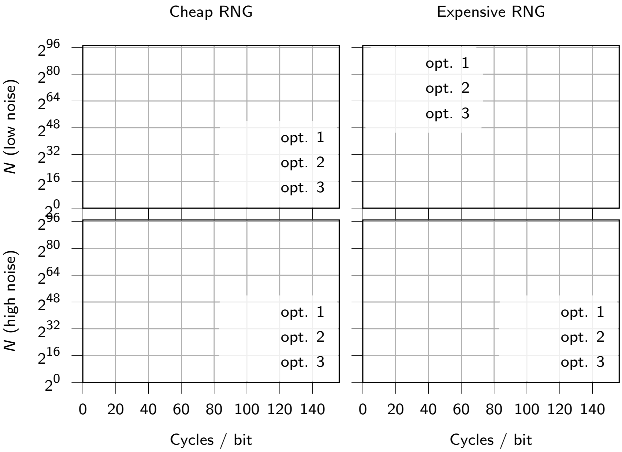


Option 3:

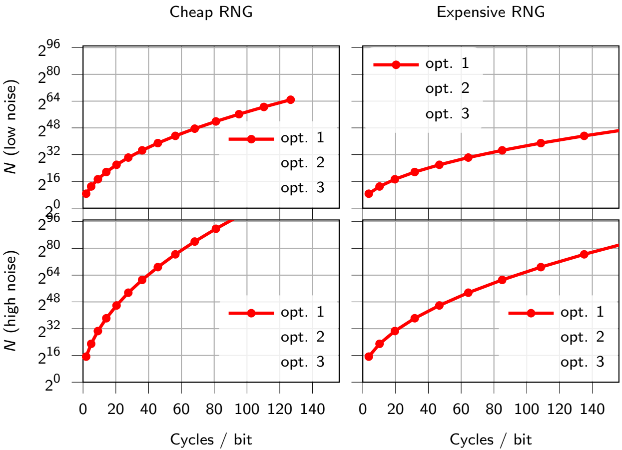
- Shuffled bitsliced ISW.
- 16 bits per reg (inc. ser.).



Time versus security: experimental results

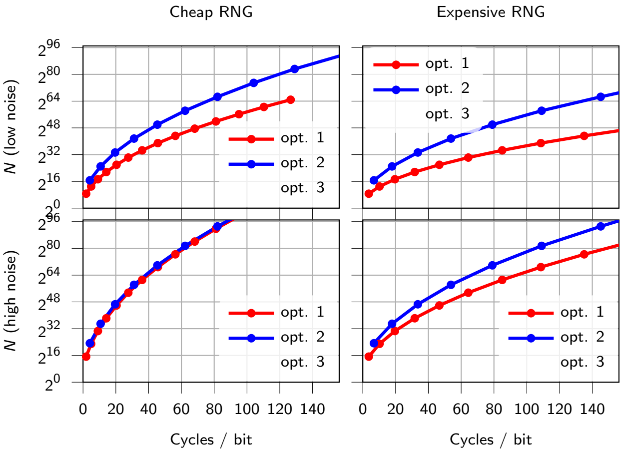


Time versus security: experimental results



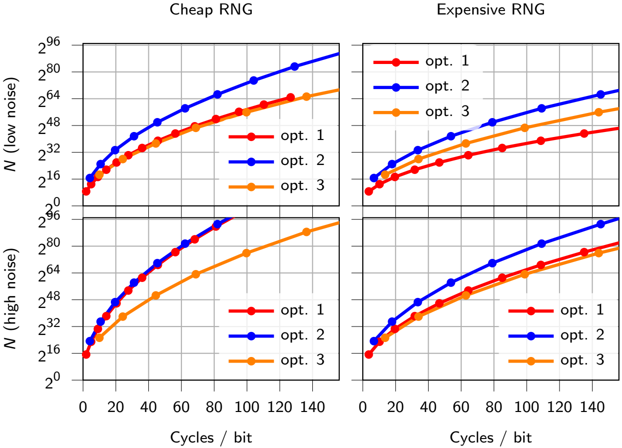
Opt 1: mask. only

Time versus security: experimental results



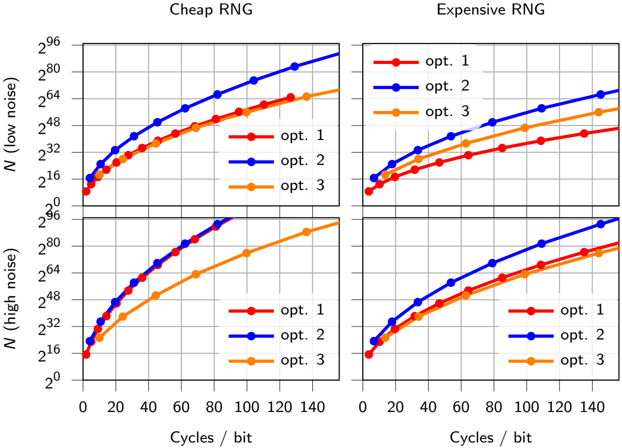
Opt 1: mask. only
Opt 2: mask. & shuffl.

Time versus security: experimental results



Opt 1: mask. only
Opt 2: mask. & shuffl.
Opt 3: lager perm.

Time versus security: experimental results



Opt 1: mask. only
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Take home:
Use fully the registers and then shuffle.

General conclusion for masking and shuffling combination

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Masking or Masking + shuffling:

- ■: masking is faster.
- □: masking + shuffling is faster.

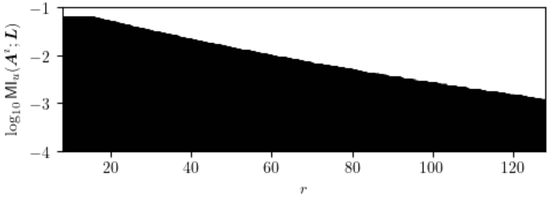

Figure: #AND=128, $N = 2^{64}$

General conclusion for masking and shuffling combination

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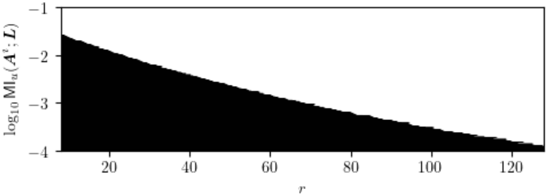

Figure: #AND=256, $N = 2^{64}$

General conclusion for masking and shuffling combination

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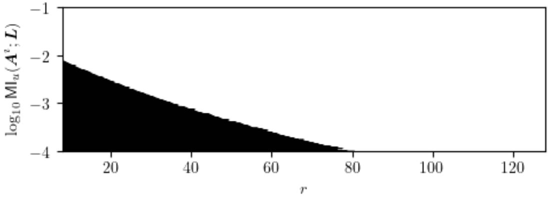

Figure: #AND=512, $N = 2^{64}$

General conclusion for masking and shuffling combination

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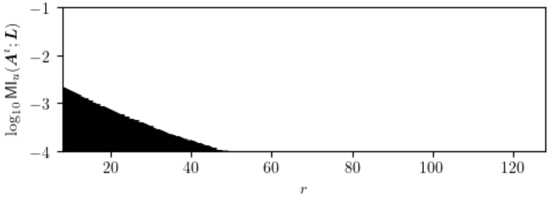

Figure: #AND=1024, $N = 2^{64}$

General conclusion for masking and shuffling combination

When to favor shuffling + masking:

- large of independent $\#AND$.
- expensive randomness r.
- relatively low noise.

Masking or Masking + shuffling:

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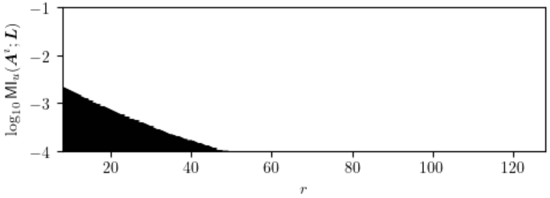

Figure: #AND=1024, $N = 2^{64}$

General conclusion for masking and shuffling combination

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Thanks !

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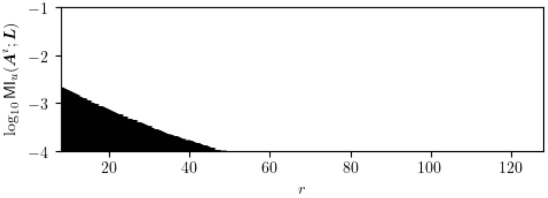

Figure: #AND=1024, $N = 2^{64}$

https://github.com/uclcrypto/bitslice_masking_and_shuffling