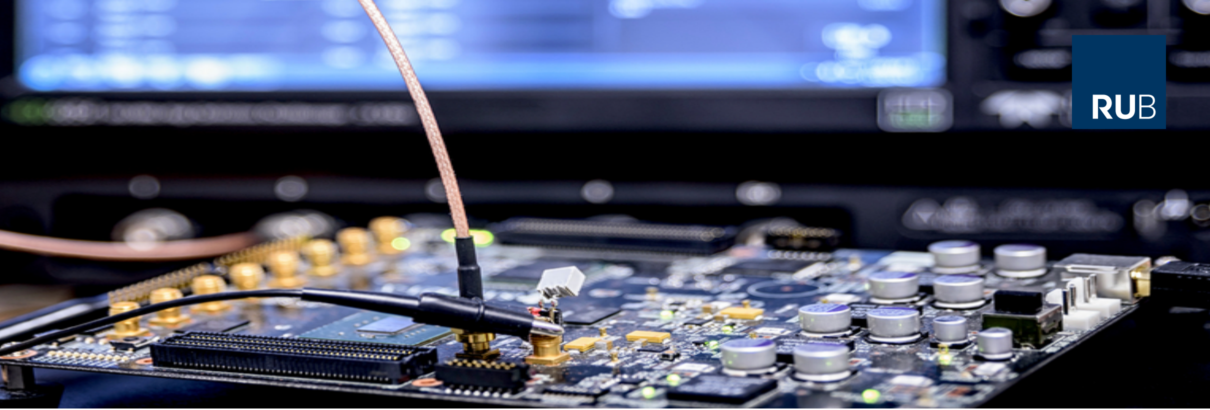

RUHR-UNIVERSITÄT BOCHUM

A Tale of Snakes and Horses: Amplifying Correlation Power Analysis on Quadratic Maps

CASA
CYBER SECURITY IN THE AGE OF LARGE-SCALE ADVERSARIES

Conference on Cryptographic Hardware and Embedded Systems 2024

Anna Guinet[1] **Georg Land[1]** **Gabriel Ioan Bucur[2]** **Tim Güneysu[1]**

[1]Chair of Security Engineering, Faculty of Computer Science, Ruhr-University Bochum, Germany
[2]Institute for Computing and Information Sciences, Radboud University, The Netherlands

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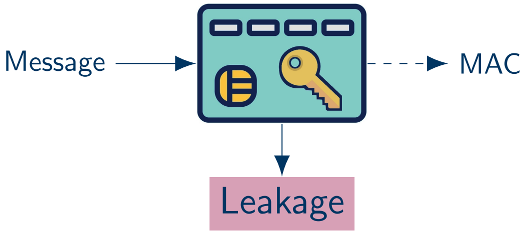
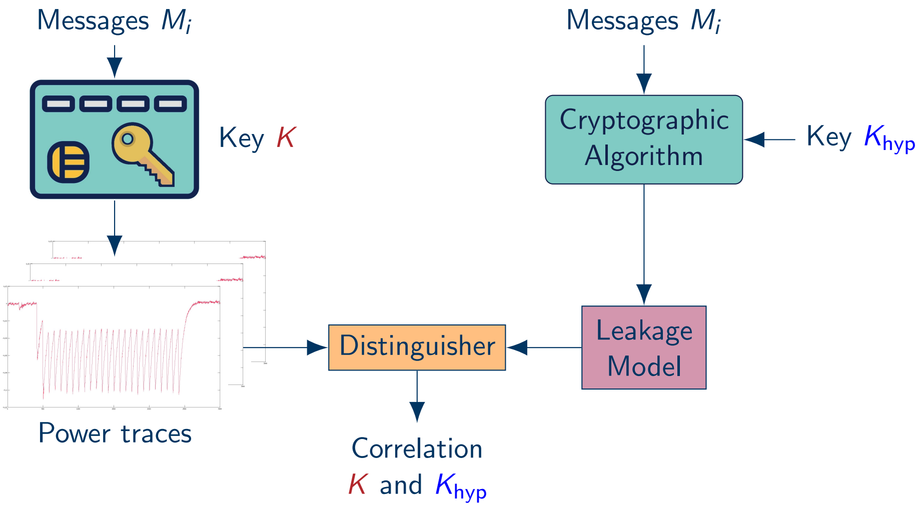
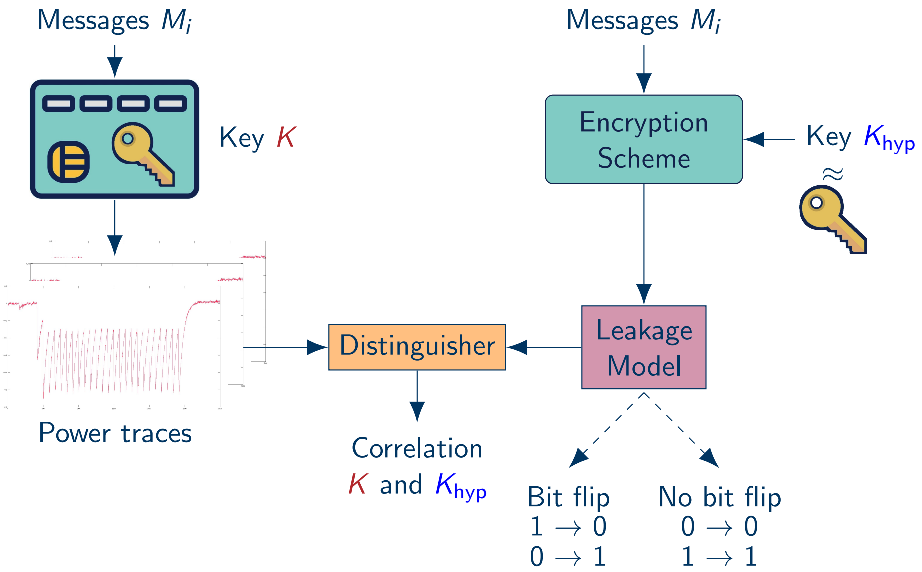
Correlation Power Analysis - An Overview



Recover secret data or key 

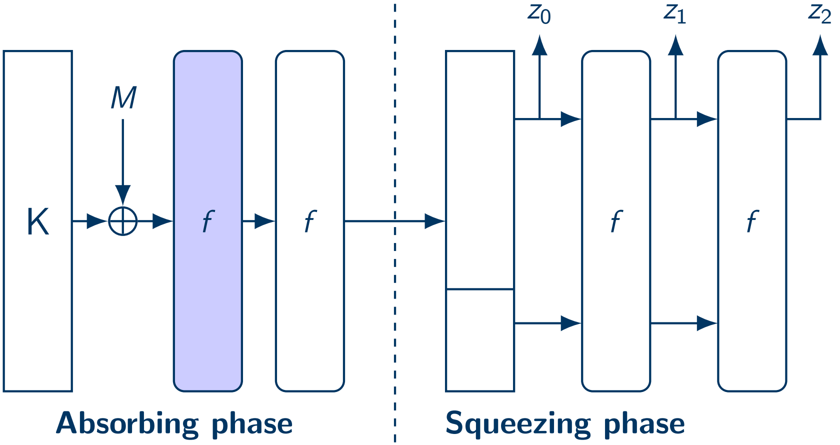
- Power consumption varies according to activity of device components
- **Correlation Power Analysis (CPA)**: statistical analysis of power consumption measurements (traces)

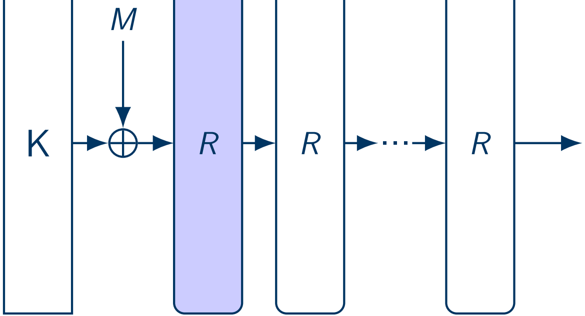

Messages M_i
Key K
Power traces
Messages M_i
Cryptographic Algorithm
Key K_{hyp}
Leakage Model
Distinguisher
Correlation
K and K_{hyp}



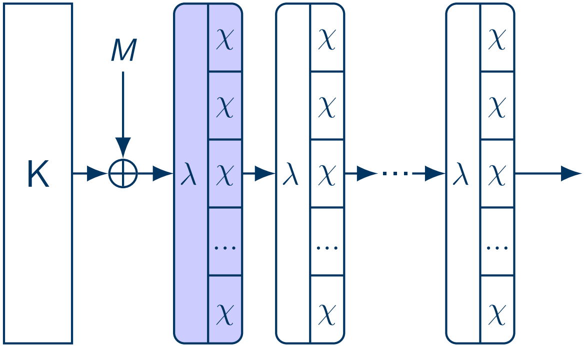
Messages M_i
Key K
Power traces
Messages M_i
Encryption Scheme
Key K_{hyp}
≈
Distinguisher
Leakage Model
Correlation
K and K_{hyp}
Bit flip
$1 \rightarrow 0$
$0 \rightarrow 1$
No bit flip
$0 \rightarrow 0$
$1 \rightarrow 1$

Full State Keyed Sponge-based MAC



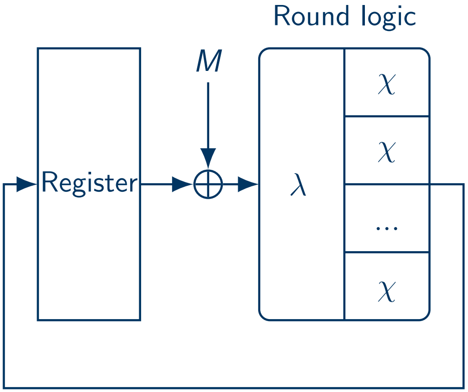


- A permutation f consists of several rounds R

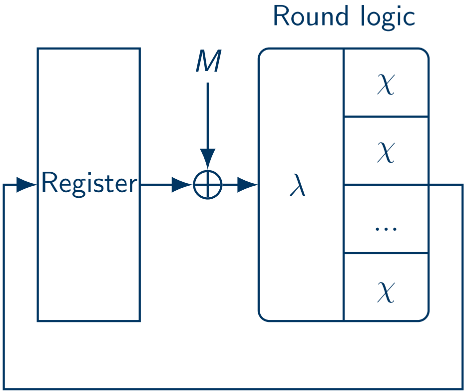


- A round R consists of a linear layer λ and a non-linear one
- **Non-linear layer** consists of χ mappings in parallel (S-boxes)

Round-based Hardware Architecture

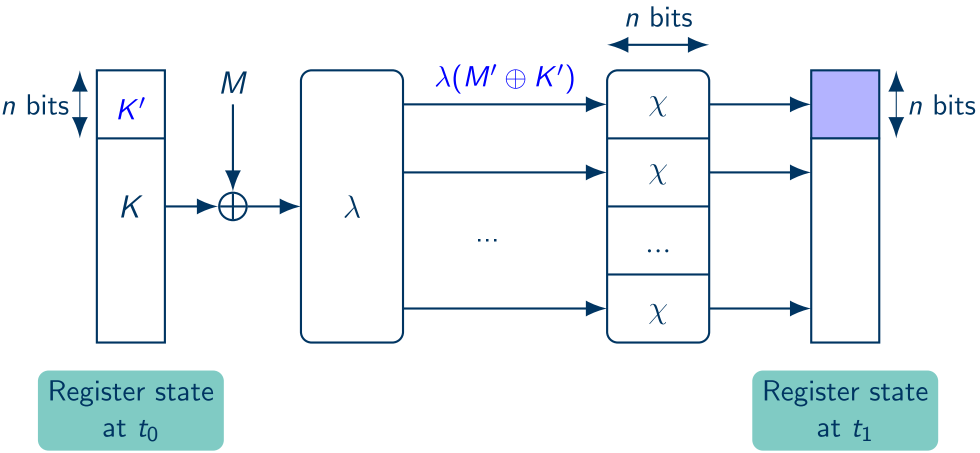


Round-based Hardware Architecture

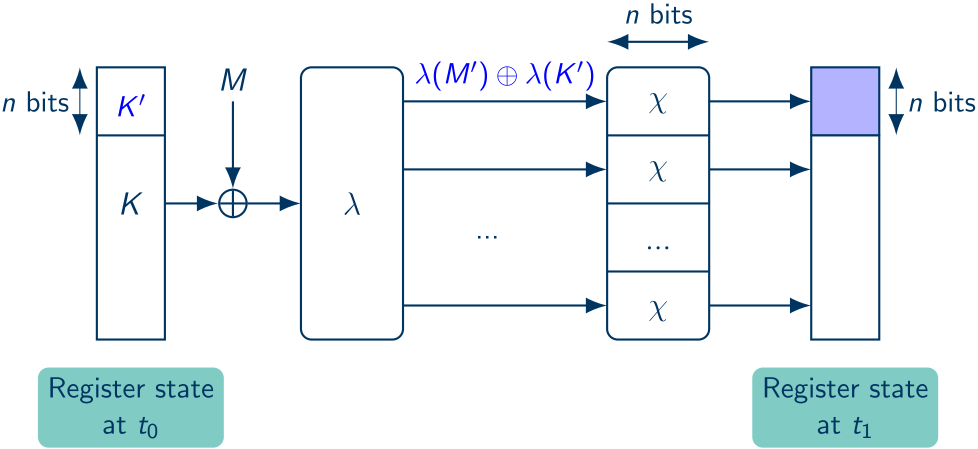


- **Leakage model**:
  - No power consumption from round logic
  - Exploit leakage from register
  - Quantifying noise from somewhere in the device

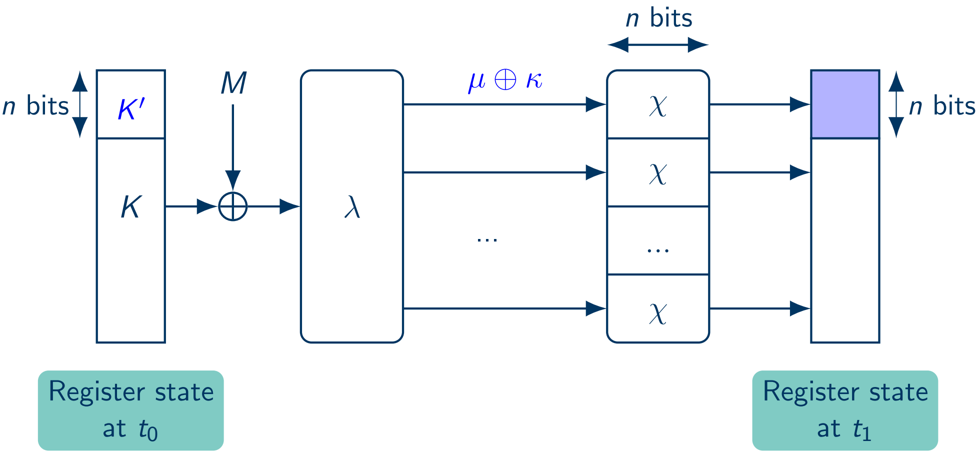
First Round of First Permutation



First Round of First Permutation



First Round of First Permutation



Leakage Model

- Activity of a storage cell: $d_i(K', \kappa, \mu) \in \mathbb{F}_2$ with $i \in \mathbb{Z}/n\mathbb{Z}$

Bit flip	No bit flip
$1 \to 0$	$0 \to 0$
$0 \to 1$	$1 \to 1$
$d_i(K', \kappa, \mu) = 1$	$d_i(K', \kappa, \mu) = 0$

Leakage Model

- Activity of a storage cell: $d_i(K', \kappa, \mu) \in \mathbb{F}_2$ with $i \in \mathbb{Z}/n\mathbb{Z}$

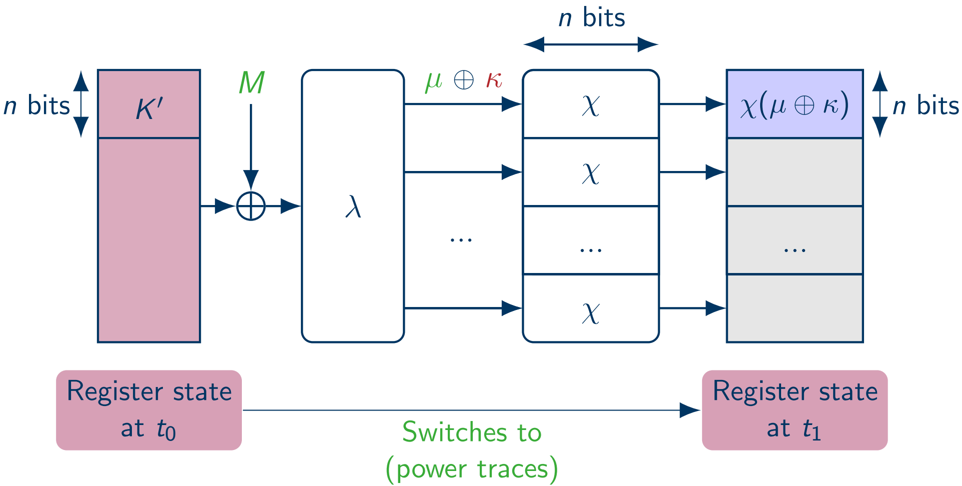
Bit flip	No bit flip
$1 \rightarrow 0$	$0 \rightarrow 0$
$0 \rightarrow 1$	$1 \rightarrow 1$
$d_i(K', \kappa, \mu) = 1$	$d_i(K', \kappa, \mu) = 0$

- Activity of all register bits contributes to **power consumption**:

$$\boxed{P(K', \kappa, \mu) = \sum_i (-1)^{d_i(K', \kappa, \mu)}}$$

Bit flip	No bit flip
$P(K', \kappa, \mu) = -1$	$P(K', \kappa, \mu) = +1$

First n Bits of Register



For the first n bits: $\mu \oplus \kappa = \lambda(M') \oplus \lambda(K') = \lambda(M' \oplus K')$

Refine Leakage Model

- Activity of register after a round for the first storage cell:

$$d_0(K_0', \kappa, \mu) = K_0' \oplus \underbrace{\kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)}_{\textit{first bit of } \chi(\mu \oplus \kappa)}$$

Refine Leakage Model

- Activity of register after a round for the first storage cell:

$$d_0(K_0', \kappa, \mu) = K_0' \oplus \underbrace{\kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)}_{\textit{first bit of } \chi(\mu \oplus \kappa)}$$

- Power consumption $P = S + R$ of a trace

Signal part

$$S(\mu) = \underbrace{\sum_{i=0}^{n-1}}_{n \text{ bits}} (-1)^{d_i\,(K_i, \kappa, \mu)}$$

Noise part

$$R \sim \mathcal{N}(0, \sigma^2)$$

$$\sigma = 1$$

Refine Leakage Model

- Activity of register after a round for the first storage cell:

$$d_0(K'_0, \kappa, \mu) = K'_0 \oplus \underbrace{\kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)}_{\textit{first bit of } \chi(\mu \oplus \kappa)}$$

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Signal part

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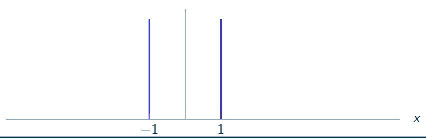
$n = 1$ bit



Noise part

$$R \sim \mathcal{N}(0, \sigma^2)$$

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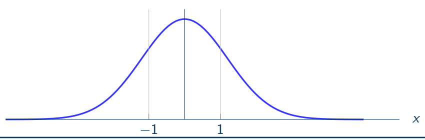


Refine Leakage Model

- Activity of register after a round for the first storage cell:

$$d_0(K'_0, \kappa, \mu) = K'_0 \oplus \underbrace{\kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)}_{\textit{first bit of } \chi(\mu \oplus \kappa)}$$

- Power consumption $P = S + R$ of a trace

Signal part

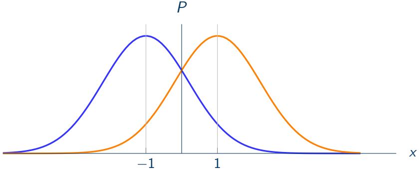
$$S(\mu) = \sum_{i=0}^{n-1} (-1)^{d_i\,(K_i, \kappa, \mu)}$$

$n = 1$ bit

Noise part

$$R \sim \mathcal{N}(0, \sigma^2)$$

$$\sigma = 1$$



Partitioning Power Traces

Messages	Power consumption	Partitions
$\mu_1 = \lambda(M_1)$	$P_1 = S(\mu_1) + R_1$	
$\mu_2 = \lambda(M_2)$	$P_2 = S(\mu_2) + R_2$	
$\mu_3 = \lambda(M_3)$	$P_3 = S(\mu_3) + R_3$	
$\mu_4 = \lambda(M_4)$	$P_4 = S(\mu_4) + R_4$	
$\mu_5 = \lambda(M_5)$	$P_5 = S(\mu_5) + R_5$	Bit flip
$\mu_6 = \lambda(M_6)$	$P_6 = S(\mu_6) + R_6$	
$\mu_7 = \lambda(M_7)$	$P_7 = S(\mu_7) + R_7$	
$\mu_8 = \lambda(M_8)$	$P_8 = S(\mu_8) + R_8$	
$\mu_9 = \lambda(M_9)$	$P_9 = S(\mu_9) + R_9$	No bit flip
$\mu_{10} = \lambda(M_{10})$	$P_{10} = S(\mu_{10}) + R_{10}$	
$\mu_{11} = \lambda(M_{11})$	$P_{11} = S(\mu_{11}) + R_{11}$	
$\mu_{12} = \lambda(M_{12})$	$P_{12} = S(\mu_{12}) + R_{12}$	
$\dots$	$\dots$	
M_{Many}	P_{Many}	

Partitioning Power Traces

RUB

Messages	Power consumption	Partitions
$\mu_1 = \lambda(M_1)$	$P_1 = S(\mu_1) + R_1$	$\mu = 000$
$\mu_2 = \lambda(M_2)$	$P_2 = S(\mu_2) + R_2$	$\mu = 001$
$\mu_3 = \lambda(M_3)$	$P_3 = S(\mu_3) + R_3$	$\mu = 010$
$\mu_4 = \lambda(M_4)$	$P_4 = S(\mu_4) + R_4$	$\mu = 011$
$\mu_5 = \lambda(M_5)$	$P_5 = S(\mu_5) + R_5$	$\mu = 100$
$\mu_6 = \lambda(M_6)$	$P_6 = S(\mu_6) + R_6$	$\mu = 101$
$\mu_7 = \lambda(M_7)$	$P_7 = S(\mu_7) + R_7$	$\mu = 110$
$\mu_8 = \lambda(M_8)$	$P_8 = S(\mu_8) + R_8$	$\mu = 111$
$\mu_9 = \lambda(M_9)$	$P_9 = S(\mu_9) + R_9$	
$\mu_{10} = \lambda(M_{10})$	$P_{10} = S(\mu_{10}) + R_{10}$	
$\mu_{11} = \lambda(M_{11})$	$P_{11} = S(\mu_{11}) + R_{11}$	
$\mu_{12} = \lambda(M_{12})$	$P_{12} = S(\mu_{12}) + R_{12}$	
$\dots$	$\dots$	
M_{Many}	P_{Many}	

Partitioning Power Traces

RUB

Messages

$\mu_1 = \lambda(M_1)$
$\mu_2 = \lambda(M_2)$
$\mu_3 = \lambda(M_3)$
$\mu_4 = \lambda(M_4)$
$\mu_5 = \lambda(M_5)$
$\mu_6 = \lambda(M_6)$
$\mu_7 = \lambda(M_7)$
$\mu_8 = \lambda(M_8)$
$\mu_9 = \lambda(M_9)$
$\mu_{10} = \lambda(M_{10})$
$\mu_{11} = \lambda(M_{11})$
$\mu_{12} = \lambda(M_{12})$
$\dots$
M_{Many}

Power consumption

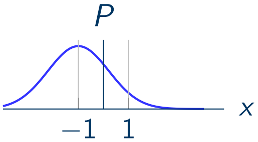
$P_1 = S(\mu_1) + R_1$
$P_2 = S(\mu_2) + R_2$
$P_3 = S(\mu_3) + R_3$
$P_4 = S(\mu_4) + R_4$
$P_5 = S(\mu_5) + R_5$
$P_6 = S(\mu_6) + R_6$
$P_7 = S(\mu_7) + R_7$
$P_8 = S(\mu_8) + R_8$
$P_9 = S(\mu_9) + R_9$
$P_{10} = S(\mu_{10}) + R_{10}$
$P_{11} = S(\mu_{11}) + R_{11}$
$P_{12} = S(\mu_{12}) + R_{12}$
$\dots$
P_{Many}

Partitions

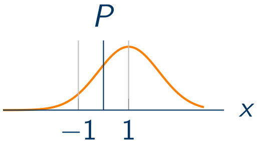
$\mu = 000$
$\mu = 001$
$\mu = 010$
$\mu = 011$
$\mu = 100$
$\mu = 101$
$\mu = 110$
$\mu = 111$

$\rightarrow$ Average of each partition

Few traces



Bit flip



No bit flip

Partitioning Power Traces

Messages

$$\mu_1 = \lambda(M_1)$$
$$\mu_2 = \lambda(M_2)$$
$$\mu_3 = \lambda(M_3)$$
$$\mu_4 = \lambda(M_4)$$
$$\mu_5 = \lambda(M_5)$$
$$\mu_6 = \lambda(M_6)$$
$$\mu_7 = \lambda(M_7)$$
$$\mu_8 = \lambda(M_8)$$
$$\mu_9 = \lambda(M_9)$$
$$\mu_{10} = \lambda(M_{10})$$
$$\mu_{11} = \lambda(M_{11})$$
$$\mu_{12} = \lambda(M_{12})$$
$$\dots$$
$$M_{\mathrm{Many}}$$

Power consumption

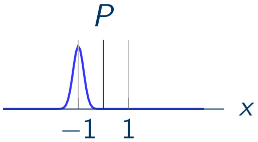
$$P_1 = S(\mu_1) + R_1$$
$$P_2 = S(\mu_2) + R_2$$
$$P_3 = S(\mu_3) + R_3$$
$$P_4 = S(\mu_4) + R_4$$
$$P_5 = S(\mu_5) + R_5$$
$$P_6 = S(\mu_6) + R_6$$
$$P_7 = S(\mu_7) + R_7$$
$$P_8 = S(\mu_8) + R_8$$
$$P_9 = S(\mu_9) + R_9$$
$$P_{10} = S(\mu_{10}) + R_{10}$$
$$P_{11} = S(\mu_{11}) + R_{11}$$
$$P_{12} = S(\mu_{12}) + R_{12}$$
$$\dots$$
$$P_{\mathrm{Many}}$$

Partitions

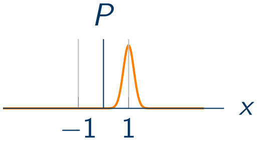
$$\mu = 000$$
$$\mu = 001$$
$$\mu = 010$$
$$\mu = 011$$
$$\mu = 100$$
$$\mu = 101$$
$$\mu = 110$$
$$\mu = 111$$

$\rightarrow$ Average of each partition

Many traces



Bit flip



No bit flip

Correlation

- Activity $d_0(K'_0, \kappa, \mu) = K'_0 \oplus \kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)$

Correlation

- Activity $d_0(K'_0, \kappa, \mu) = K'_0 \oplus \kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)$
- Signal power consumption values S_{ref} for all (κ, μ) possibilities for K'_0

$\mu_0\mu_1\mu_2$	$K'_0 \oplus \kappa_0\ \kappa_1\kappa_2$							
	000	001	010	011	100	101	110	111
000	$+1$	-1	$+1$	$+1$	-1	$+1$	-1	-1
001	-1	$+1$	$+1$	$+1$	$+1$	-1	-1	-1
010	$+1$	$+1$	$+1$	-1	-1	-1	-1	$+1$
011	$+1$	$+1$	-1	$+1$	-1	-1	$+1$	-1
100	-1	$+1$	-1	-1	$+1$	-1	$+1$	$+1$
101	$+1$	-1	-1	-1	-1	$+1$	$+1$	$+1$
110	-1	-1	-1	$+1$	$+1$	$+1$	$+1$	-1
111	-1	-1	$+1$	-1	$+1$	$+1$	-1	$+1$

Correlation

- Activity $d_0(K_0', \kappa, \mu) = K_0' \oplus \kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)$
- Signal power consumption values S_{ref} for all (κ, μ) possibilities for K_0'

$\mu_0\mu_1\mu_2$	$K_0' \oplus \kappa_0\ \kappa_1\kappa_2$							
	000	001	010	011	100	101	110	111
000	$+1$	-1	$+1$	$+1$	-1	$+1$	-1	-1
001	-1	$+1$	$+1$	$+1$	$+1$	-1	-1	-1
010	$+1$	$+1$	$+1$	-1	-1	-1	-1	$+1$
011	$+1$	$+1$	-1	$+1$	-1	-1	$+1$	-1
100	-1	$+1$	-1	-1	$+1$	-1	$+1$	$+1$
101	$+1$	-1	-1	-1	-1	$+1$	$+1$	$+1$
110	-1	-1	-1	$+1$	$+1$	$+1$	$+1$	-1
111	-1	-1	$+1$	-1	$+1$	$+1$	-1	$+1$

- Pearson correlation coefficient $\rho(P, S_{\text{ref}})$: Highest correlation result $max(\rho(P, S_{\text{ref}}))$

Correlation

- Activity $d_0(K'_0, \kappa, \mu) = K'_0 \oplus \kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)$
- Signal power consumption values S_{ref} for all (κ, μ) possibilities for K'_0

$\mu_0\mu_1\mu_2$	$K'_0 \oplus \kappa_0\ \kappa_1\kappa_2$							
	000	001	010	011	100	101	110	111
000	$+1$	-1	$+1$	$+1$	-1	$+1$	-1	-1
001	-1	$+1$	$+1$	$+1$	$+1$	-1	-1	-1
010	$+1$	$+1$	$+1$	-1	-1	-1	-1	$+1$
011	$+1$	$+1$	-1	$+1$	-1	-1	$+1$	-1
100	-1	$+1$	-1	-1	$+1$	-1	$+1$	$+1$
101	$+1$	-1	-1	-1	-1	$+1$	$+1$	$+1$
110	-1	-1	-1	$+1$	$+1$	$+1$	$+1$	-1
111	-1	-1	$+1$	-1	$+1$	$+1$	-1	$+1$

- Pearson correlation coefficient $\rho(P, S_{\mathrm{ref}})$: Highest correlation result $max(\rho(P, S_{\mathrm{ref}}))$

Correlation

- Activity $d_0(K_0', \kappa, \mu) = K_0' \oplus \kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)$
- Signal power consumption values S_{ref} for all (κ, μ) possibilities for K_0'

$\mu_0\mu_1\mu_2$	$* \kappa_1\kappa_2$							
	000	001	010	011	100	101	110	111
000	$+1$	-1	$+1$	$+1$	–	–	–	–
001	-1	$+1$	$+1$	$+1$	–	–	–	–
010	$+1$	$+1$	$+1$	-1	–	–	–	–
011	$+1$	$+1$	-1	$+1$	–	–	–	–
100	-1	$+1$	-1	-1	–	–	–	–
101	$+1$	-1	-1	-1	–	–	–	–
110	-1	-1	-1	$+1$	–	–	–	–
111	-1	-1	$+1$	-1	–	–	–	–

- Pearson correlation coefficient $\rho(P, S_{\text{ref}})$: $max(\rho(P, S_{\text{ref}})^2)$ or $max(|\rho(P, S_{\text{ref}})|)$

Correlation

- Activity $d_0(K_0', \kappa, \mu) = K_0' \oplus \kappa_0 \oplus \mu_0 \oplus (\kappa_1 \oplus \mu_1 \oplus 1)(\kappa_2 \oplus \mu_2)$
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$\mu_0\mu_1\mu_2$	$* \kappa_1\kappa_2$ 000	001	010	011	100	101	110	111
000	$+1$	-1	$+1$	$+1$	–	–	–	–
001	-1	$+1$	$+1$	$+1$	–	–	–	–
010	$+1$	$+1$	$+1$	-1	–	–	–	–
011	$+1$	$+1$	-1	$+1$	–	–	–	–
100	-1	$+1$	-1	-1	–	–	–	–
101	$+1$	-1	-1	-1	–	–	–	–
110	-1	-1	-1	$+1$	–	–	–	–
111	-1	-1	$+1$	-1	–	–	–	–

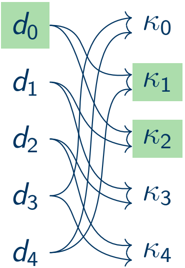
- Pearson correlation coefficient $\rho(P, S_{\text{ref}})$: $max(\rho(P, S_{\text{ref}})^2)$ or $max(|\rho(P, S_{\text{ref}})|)$

Combined CPA or Snake attack: Recovering κ

- Activity function $d_i(K', \kappa, \mu) = K'_i \oplus \kappa_i \oplus \mu_i \oplus (\kappa_{i+1} \oplus \mu_{i+1} \oplus 1)(\kappa_{i+2} \oplus \mu_{i+2})$

$n = 5$ bits

1 attack



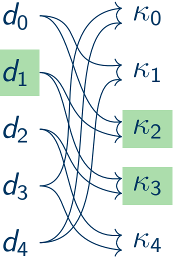
*00**	*01**	*10**	*11**
**00*	**01*	**10*	**11*
***00	***01	***10	***11
0***0	0***1	1***0	1***1
00***	01***	10***	11***

Combined CPA or Snake attack: Recovering κ

- Activity function $d_i(K', \kappa, \mu) = K'_i \oplus \kappa_i \oplus \mu_i \oplus (\kappa_{i+1} \oplus \mu_{i+1} \oplus 1)(\kappa_{i+2} \oplus \mu_{i+2})$

$n = 5$ bits

1 attack



∗00∗∗	∗01∗∗	∗10∗∗	∗11∗∗
∗∗00∗	∗∗01∗	∗∗10∗	∗∗11∗
∗∗∗00	∗∗∗01	∗∗∗10	∗∗∗11
0∗∗∗0	0∗∗∗1	1∗∗∗0	1∗∗∗1
00∗∗∗	01∗∗∗	10∗∗∗	11∗∗∗

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$n = 5$ bits

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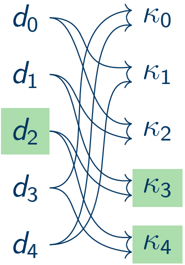

*00**	*01**	*10**	*11**
**00*	**01*	**10*	**11*
***00	***01	***10	***11
0***0	0***1	1***0	1***1
00***	01***	10***	11***

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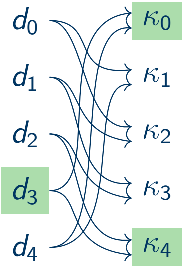

*00**	*01**	*10**	*11**
**00*	**01*	**10*	**11*
***00	***01	***10	***11
0***0	0***1	1***0	1***1
00***	01***	10***	11***

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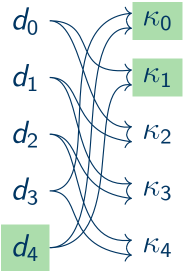
$n = 5$ bits

1 attack



*00**	*01**	*10**	*11**
**00*	**01*	**10*	**11*
***00	***01	***10	***11
0***0	0***1	1***0	1***1
00***	01***	10***	11***

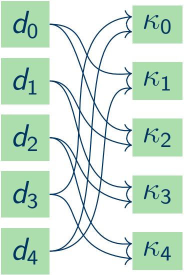
Combined CPA or Snake attack: Recovering κ

RUB

- Activity function $d_i(K', \kappa, \mu) = K'_i \oplus \kappa_i \oplus \mu_i \oplus (\kappa_{i+1} \oplus \mu_{i+1} \oplus 1)(\kappa_{i+2} \oplus \mu_{i+2})$

$n = 5$ bits

5 attacks



∗00∗∗	∗01∗∗	∗10∗∗	∗11∗∗
∗∗00∗	∗∗01∗	∗∗10∗	∗∗11∗
∗∗∗00	∗∗∗01	∗∗∗10	∗∗∗11
0∗∗∗0	0∗∗∗1	1∗∗∗0	1∗∗∗1
00∗∗∗	01∗∗∗	10∗∗∗	11∗∗∗

$\kappa = 00000$ $\quad$ $\kappa = 10101$

The *Snake* Walk

$$\sum \rho(P, S_{ref})^2 \quad \text{or} \quad \sum |\rho(P, S_{ref})|$$

Combined CPA or Snake Attack: Recovering K'

RUB

$n = 5$ bits

Correlation result for $i = 0$:	$K'_0 \oplus \kappa_0$	κ_1	κ_2	–	–
Correlation result for $i = 1$:	–	$K'_1 \oplus \kappa_1$	κ_2	κ_3	–
Correlation result for $i = 2$:	–	–	$K'_2 \oplus \kappa_2$	κ_3	κ_4
Correlation result for $i = 3$:	κ_0	–	–	$K'_3 \oplus \kappa_3$	κ_4
Correlation result for $i = 4$:	κ_0	κ_1	–	–	$K'_4 \oplus \kappa_4$

Combined CPA or Snake Attack: Recovering K'

$n = 5$ bits

Correlation result for $i = 0$:	$K'_0 \oplus \kappa_0$	$\boxed{\kappa_1}$	κ_2	—	—
Correlation result for $i = 1$:	—	$K'_1 \oplus \kappa_1$	κ_2	κ_3	—
Correlation result for $i = 2$:	—	—	$K'_2 \oplus \kappa_2$	κ_3	κ_4
Correlation result for $i = 3$:	κ_0	—	—	$K'_3 \oplus \kappa_3$	κ_4
Correlation result for $i = 4$:	κ_0	$\boxed{\kappa_1}$	—	—	$K'_4 \oplus \kappa_4$

Combined CPA or Snake Attack: Recovering K'

$n = 5$ bits

Correlation result for $i = 0$:	$K'_0 \oplus \kappa_0$	κ_1	κ_2	–	–
Correlation result for $i = 1$:	–	$K'_1 \oplus \kappa_1$	κ_2	κ_3	–
Correlation result for $i = 2$:	–	–	$K'_2 \oplus \kappa_2$	κ_3	κ_4
Correlation result for $i = 3$:	κ_0	–	–	$K'_3 \oplus \kappa_3$	κ_4
Correlation result for $i = 4$:	κ_0	κ_1	–	–	$K'_4 \oplus \kappa_4$

- For each bit i: $K'_i = \underbrace{\epsilon_i}_{\text{known}} \oplus \underbrace{\kappa_i}_{\text{guess}}$ with $\epsilon_i = 1$ if $\rho(P, S_{ref_i}) < 0$, otherwise $\epsilon_i = 0$.

Combined CPA or Snake Attack: Recovering K'

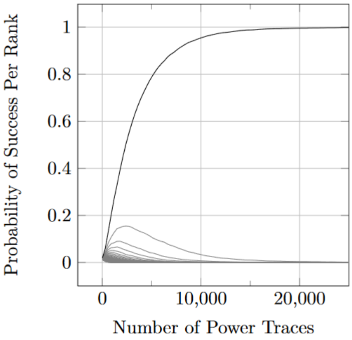
$n = 5$ bits

Correlation result for $i = 0$:	$K'_0 \oplus \kappa_0$	κ_1	κ_2	—	—
Correlation result for $i = 1$:	—	$K'_1 \oplus \kappa_1$	κ_2	κ_3	—
Correlation result for $i = 2$:	—	—	$K'_2 \oplus \kappa_2$	κ_3	κ_4
Correlation result for $i = 3$:	κ_0	—	—	$K'_3 \oplus \kappa_3$	κ_4
Correlation result for $i = 4$:	κ_0	κ_1	—	—	$K'_4 \oplus \kappa_4$

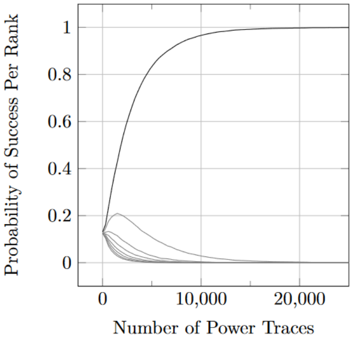
- For each bit i: $K'_i = \underbrace{\epsilon_i}_{\text{known}} \oplus \underbrace{\kappa_i}_{\text{guess}}$ with $\epsilon_i = 1$ if $\rho(P, S_{ref_i}) < 0$, otherwise $\epsilon_i = 0$.
- Reduce computational complexity from 2^{2n} intermediate results to $n2^2 + n$ ones.

Ranked Probabilities of Success for One χ_3 Sequence

$n = 3$ bits



(a) CPA, recovering (K', κ).

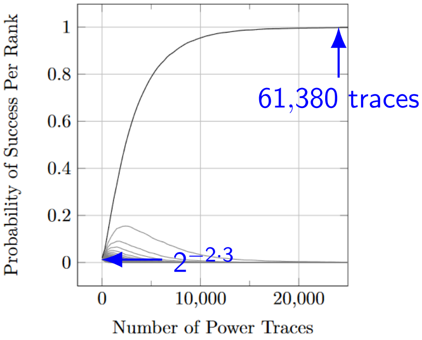


(b) Combined CPA or *Snake* attack recovering κ. Squared correlation coefficient.

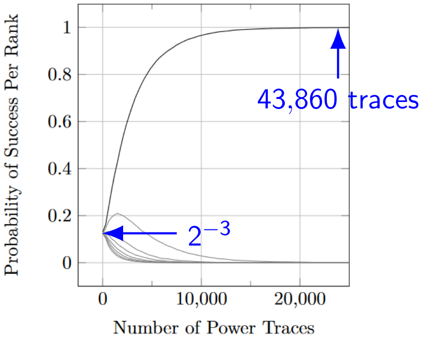
Figure: Ranked success probabilities targeting one χ_3 sequence (Xoodoo).

Ranked Probabilities of Success for One χ_3 Sequence

$n = 3$ bits



(a) CPA, recovering (K', κ).



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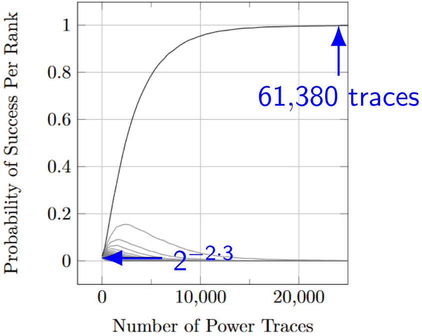

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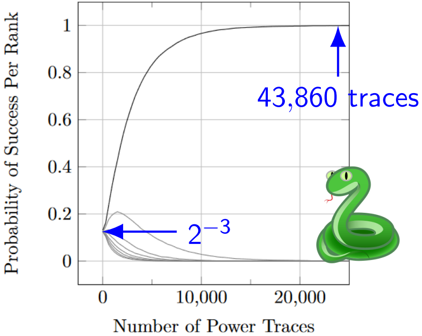

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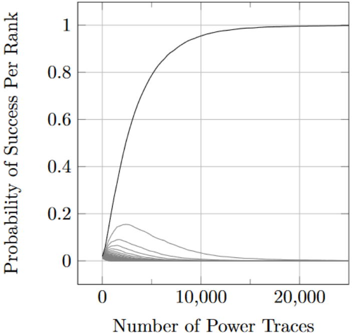

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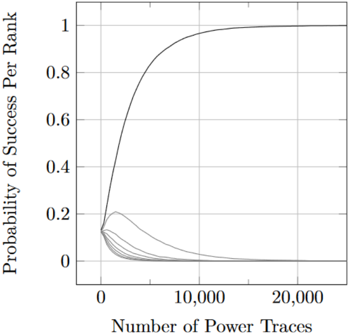


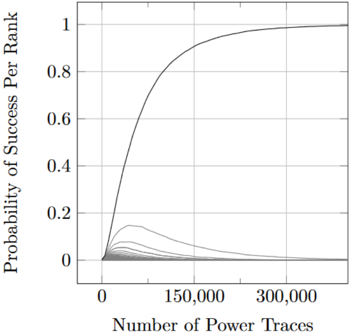
(b) Combined CPA or *Snake* attack recovering κ. Squared correlation coefficient.

Figure: Ranked success probabilities targeting one χ_3 sequence (Xoodoo).

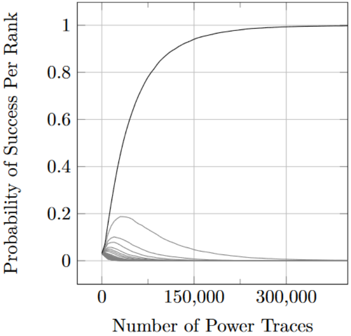
Ranked Probabilities of Success for One χ_5 Sequence

$n = 5$ bits

RUB



(a) CPA, recovering (K', κ).

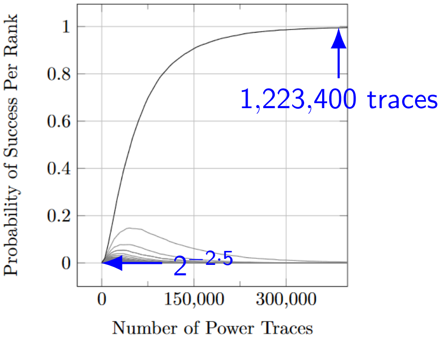


(b) Combined CPA or *Snake* attack recovering κ. Squared correlation coefficient.

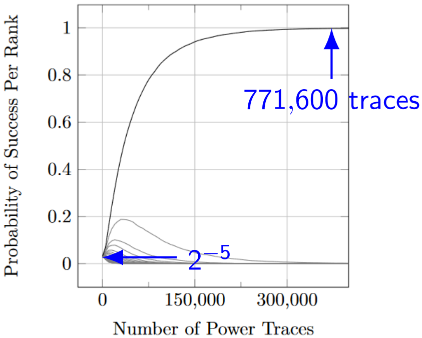
Figure: Ranked success probabilities targeting one χ_5 sequence (Keccak-p).

Ranked Probabilities of Success for One χ_5 Sequence

$n = 5$ bits



(a) CPA, recovering (K', κ).

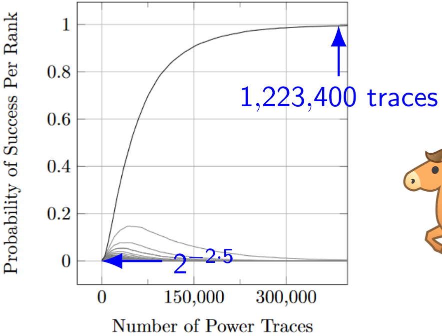


(b) Combined CPA or *Snake* attack recovering κ. Squared correlation coefficient.

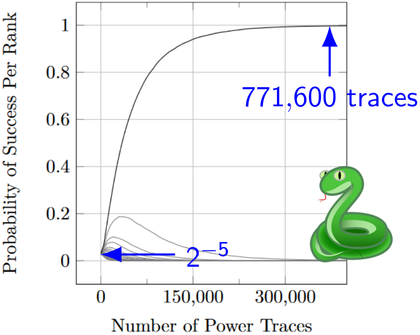
Figure: Ranked success probabilities targeting one χ_5 sequence (Keccak-p).

Ranked Probabilities of Success for One χ_5 Sequence

$n = 5$ bits



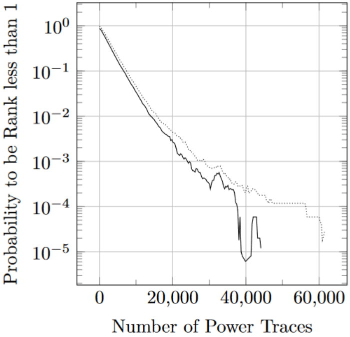
(a) CPA, recovering (K', κ).



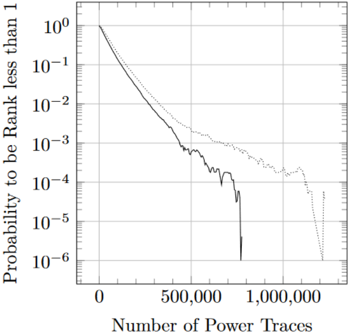
(b) Combined CPA or *Snake* attack recovering κ. Squared correlation coefficient.

Figure: Ranked success probabilities targeting one χ_5 sequence (Keccak-p).

Probability of Not Being Correct: CPA vs. Combined CPA (Snake Attack)



(a) $n = 3$



(b) $n = 5$

Figure: Comparison between CPA (dotted line) and *Snake* attack (solid line) for the probability of the correct hypothesis to *not* be rank 1.

Conclusion

- Improve the CPA computational complexity from 2^{2n} to $n2^2 + n$ intermediate results.
- Combined CPA or *Snake* attack has a higher probability of success than traditional CPA for the same number of power traces.

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Thank you for your attention

Paper

Artifact

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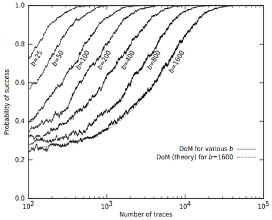
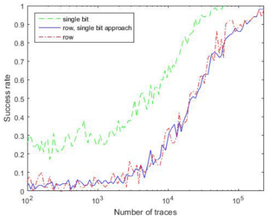
Previous work

- Previous work with DPA on one χ_5 row



Bertoni, Daemen, et al. 2012. Power Analysis of Hardware Implementations Protected with Secret Sharing. MICROW'12.



Samwel and Daemen. 2017. DPA on hardware implementations of Ascon and Keyak. CF'17.