Improved Cryptanalysis of GIFT-64

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Overview

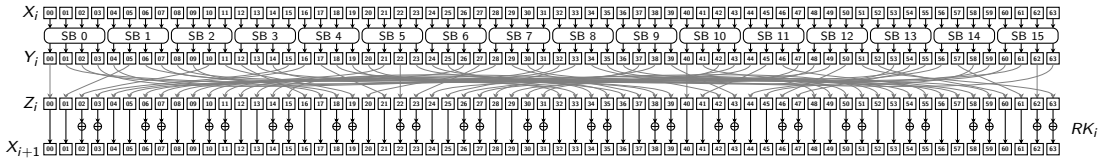
GIFT

Improving differential attacks with parallel matching

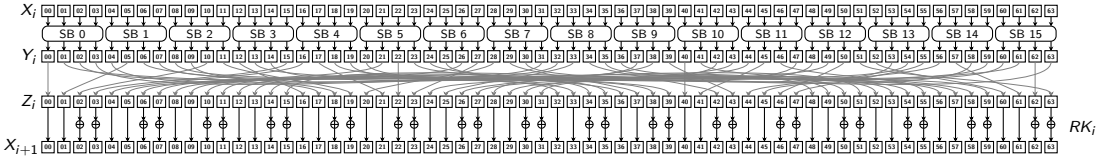
Differential meet-in-the-middle cryptanalysis

Conclusive results

The block cipher GIFT [BPP+17]



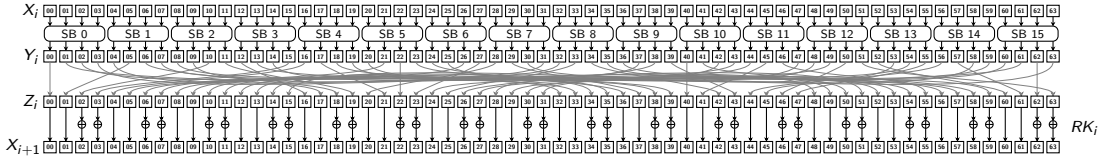
The block cipher GIFT [BPP+17]



$$MK = k_7||k_6||k_5||k_4||k_3||k_2||k_1||k_0$$

$$k_7||k_6||\dots||\underbrace{\boxed{k_1||k_0}}_{RK_i} \longleftarrow k_1 \ggg 2||k_0 \ggg 12||\dots||k_3||k_2$$

The block cipher GIFT [BPP+17]



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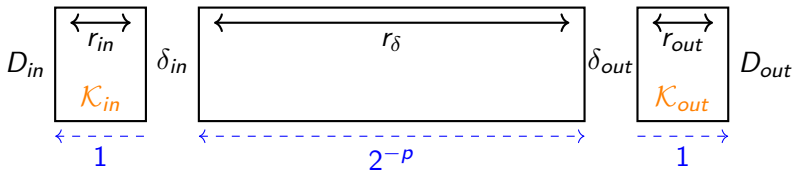
$$k_7||k_6||\dots||\underbrace{k_1||k_0}_{RK_i} \longleftarrow k_1 \ggg 2||k_0 \ggg 12||\dots||k_3||k_2$$

Cipher	Rounds	Setup	Key space size	Time	Data	Memory	Type of Attack	Source
GIFT-64	21	SK	2^{124}	$2^{117.42}$	2^{64}	2^{96}	Differential	[CWWH25]
	26	RK	2^{120}	$2^{120.44}$	$2^{60.96}$	$2^{25.22}$	Differential	[CN25]

A previous lower bound of differential attacks



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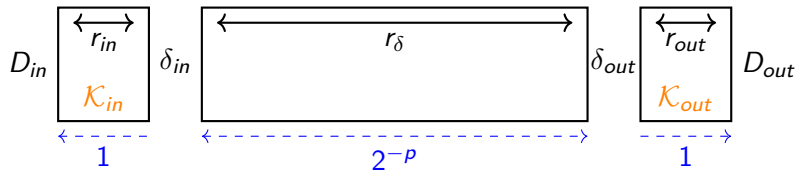
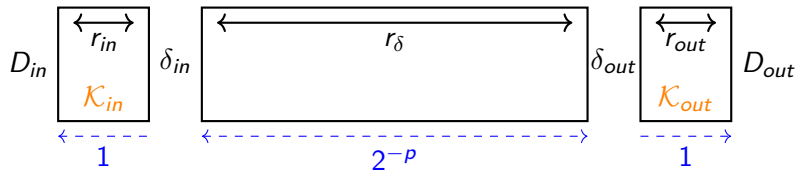


Acquiring data

$\mathcal{D}$

$\mathcal{T} = 2^{p+1} \cdot C_E$

A previous lower bound of differential attacks



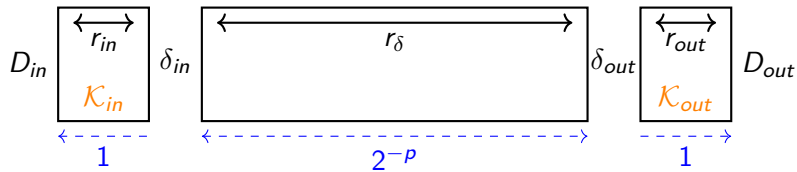
Acquiring data | Filtering and forming the pairs

$\mathcal{D} \longrightarrow \mathcal{N}$

Lin. equ.

$$\mathcal{T} = 2^{p+1} \cdot C_E + \quad 2^{p+d_{in}-n+d_{out}}$$

A previous lower bound of differential attacks

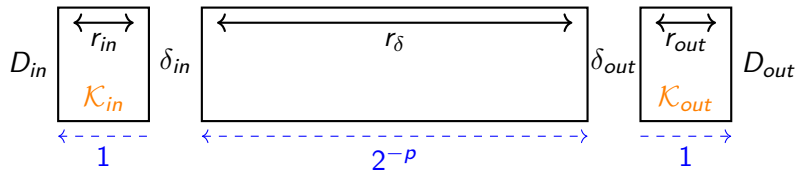


Acquiring data | Filtering and forming the pairs

$\mathcal{D}$ —Lin. equ.→ $\mathcal{N}$ —Non Lin. equ.→ $\mathcal{N}'$

$$\mathcal{T} = 2^{p+1} \cdot C_E + 2^{p+d_{in}-n+d_{out}} \cdot C_S$$

A previous lower bound of differential attacks

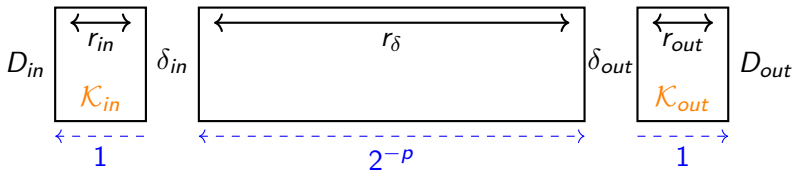


Acquiring data | Filtering and forming the pairs | Key recovery

$\mathcal{D} \xrightarrow{\text{Lin. equ.}} \mathcal{N} \xrightarrow{\text{Non Lin. equ.}} \mathcal{N}' \longrightarrow \mathcal{K}$

$$\mathcal{T} = 2^{p+1} \cdot C_E + 2^{p+d_{in}-n+d_{out}} \cdot C_S + N' \cdot C_{KR}$$

A previous lower bound of differential attacks

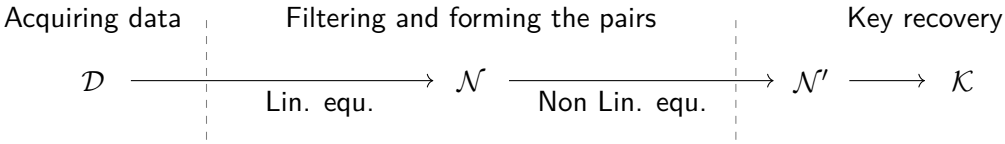


Acquiring data | Filtering and forming the pairs | Key recovery

$\mathcal{D} \xrightarrow{\text{Lin. equ.}} \mathcal{N} \xrightarrow{\text{Non Lin. equ.}} \mathcal{N}' \longrightarrow \mathcal{K}$

$$\mathcal{T} = 2^{p+1} \cdot C_E + \underbrace{2^{p+d_{in}-n+d_{out}} \cdot C_S}_{\text{Lower bound}} + N' \cdot C_{KR}$$

Improving the lower bound with parallel matching



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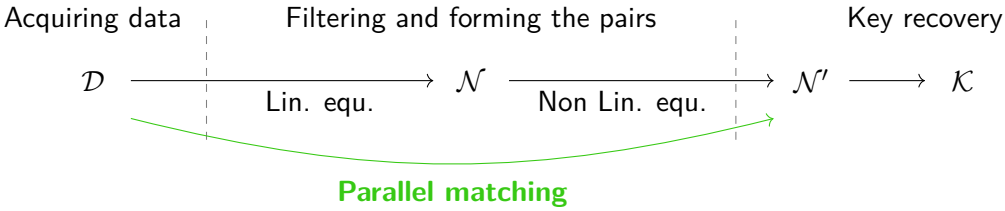

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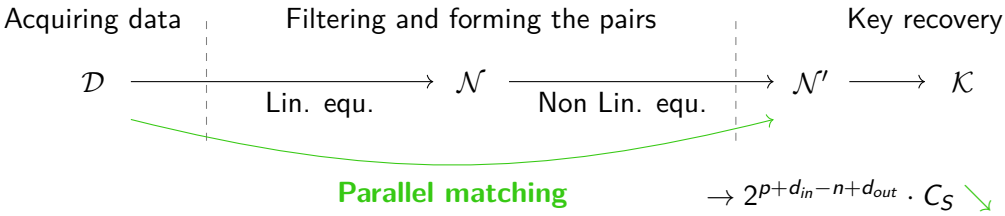

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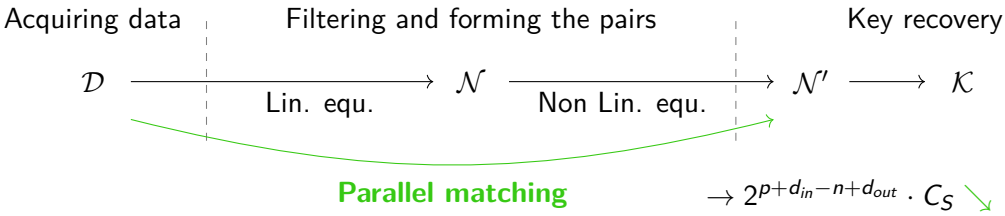
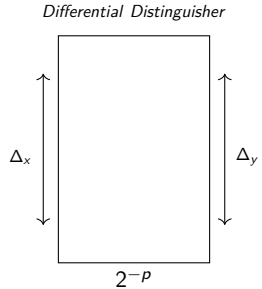
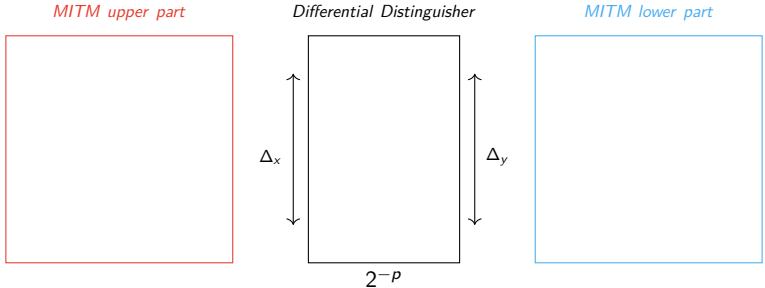


Cipher	Rounds	Setup	Key space size	Time	Data	Memory	Type of Attack	Source
	25	RK	2^{120}	2^{107}	2^{51}	2^{49}	Differential	[BDD+24]
GIFT-64	25	**RK**	$\mathbf{2^{120}}$	$\mathbf{2^{81.59}}$	$\mathbf{2^{51}}$	$\mathbf{2^{50.12}}$	**Differential**	**This Paper**
	26	RK	2^{120}	$2^{113.03}$	$2^{61.96}$	$2^{95.15}$	Differential	[CN25]

Differential Meet-in-the-middle Framework [BDD+23]



Differential Meet-in-the-middle Framework [BDD+23]



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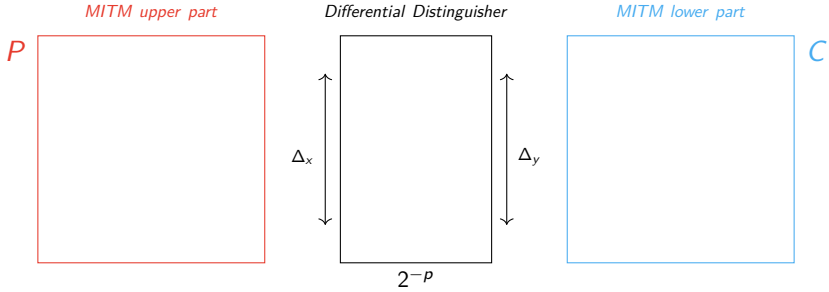

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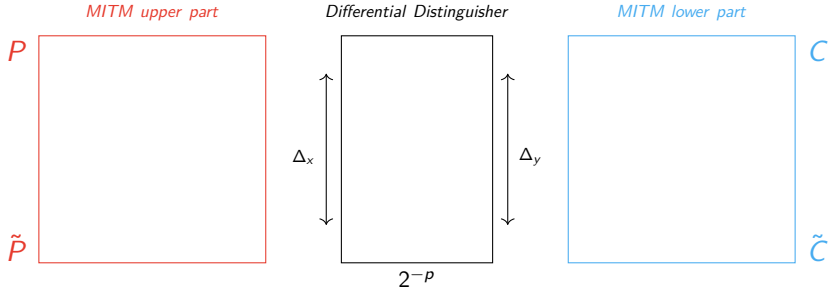

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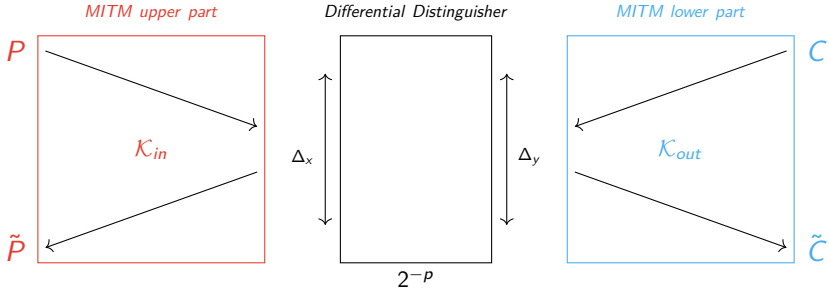

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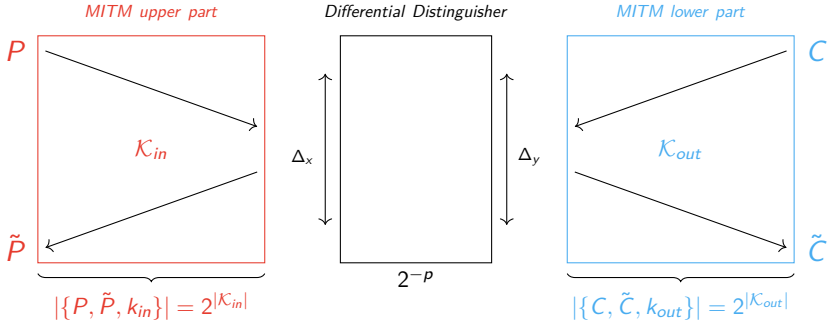

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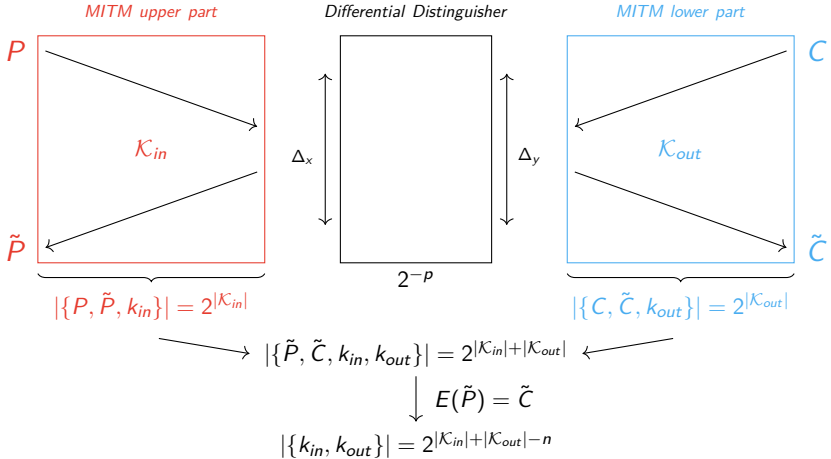

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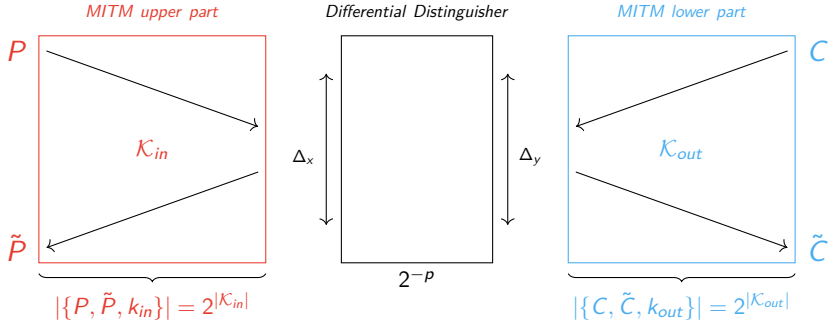

$\mathcal{T} = 2^p \left(2^{|\mathcal{K}_{in}|} + 2^{|\mathcal{K}_{out}|} + 2^{|\mathcal{K}_{in}|+|\mathcal{K}_{out}|-|\mathcal{K}_{in}\cap\mathcal{K}_{out}|-n}\right)$, $\mathcal{M} = 2^{min(|\mathcal{K}_{in}|,|\mathcal{K}_{out}|)}, \mathcal{D} = 2^{n-a}$ with $p + a < n - a$

A differential distinguisher of 13 rounds of GIFT 64 [CZD20], [CWWH25]

$$(0000\ 0000\ 0000\ 0202) \xrightarrow[13r]{2^{-57.82}} (0000\ 0005\ 0000\ 0005).$$

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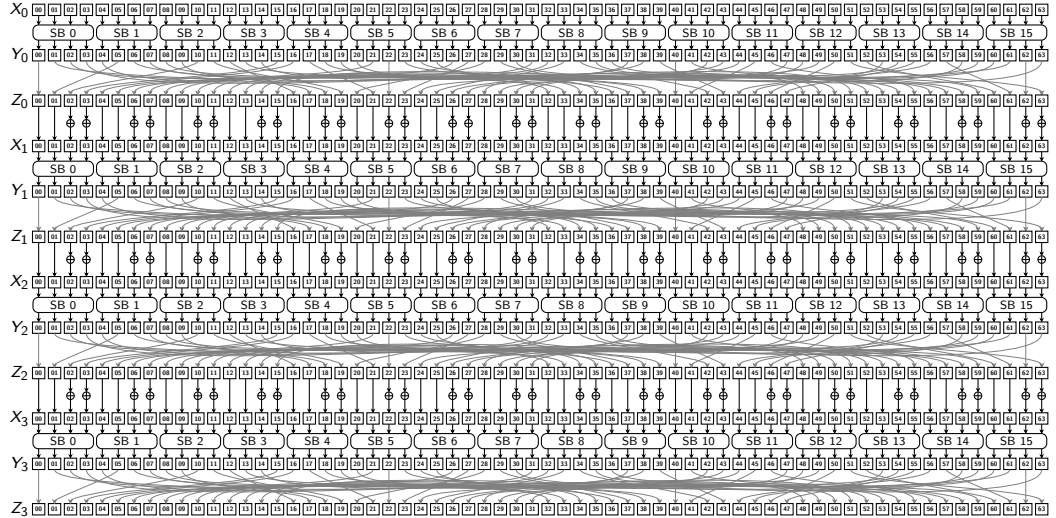
Weak key space : size 2^{124}

$$k_4[4] + k_4[12] = 0, k_4[0] + k_4[8] = 0,$$
$$k_0[5] + k_0[13] = 0, k_0[1] + k_0[9] = 0.$$

Upper extensions of the key recovery part



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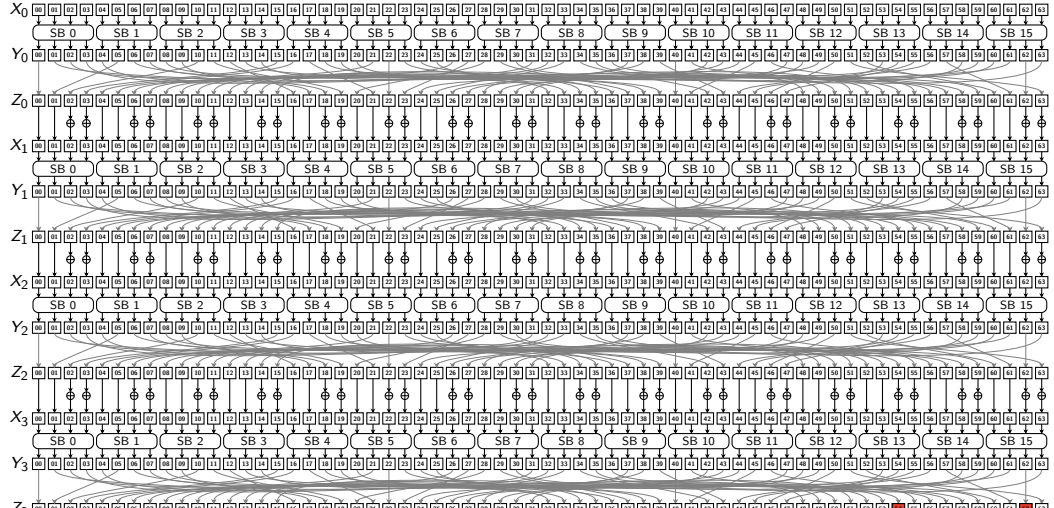

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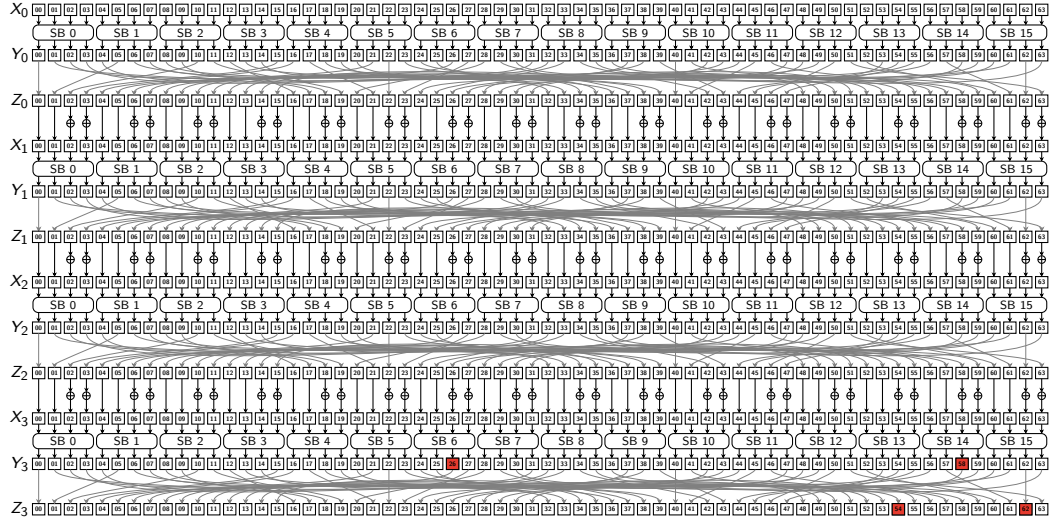

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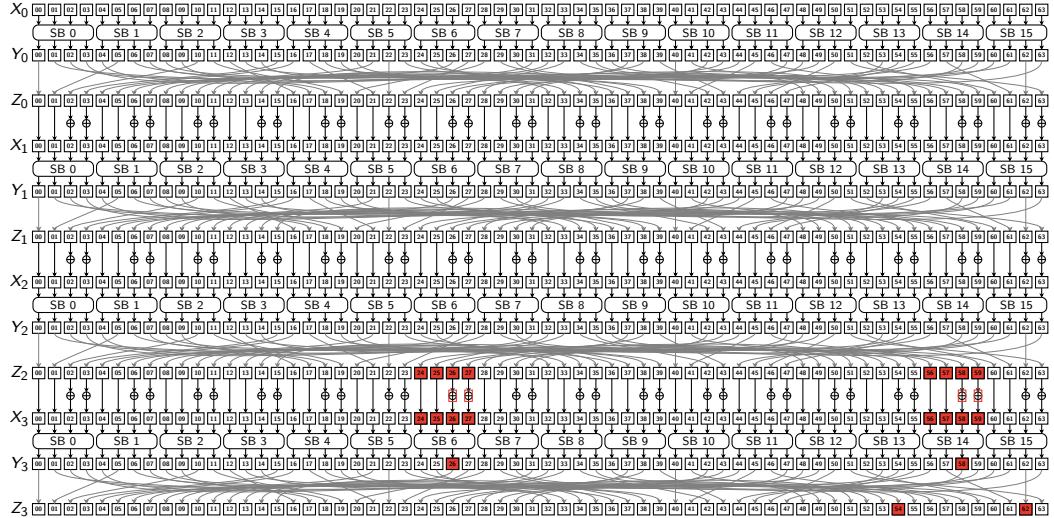

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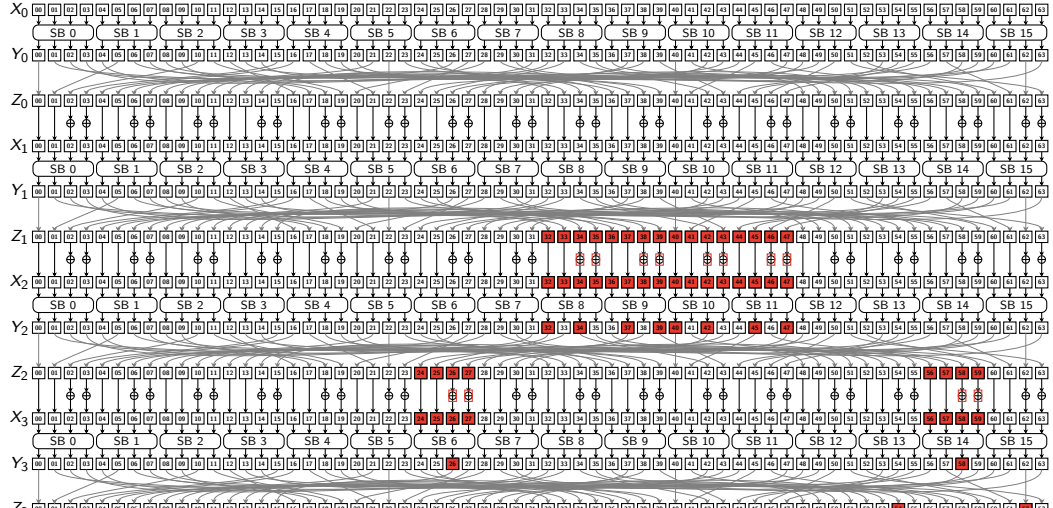

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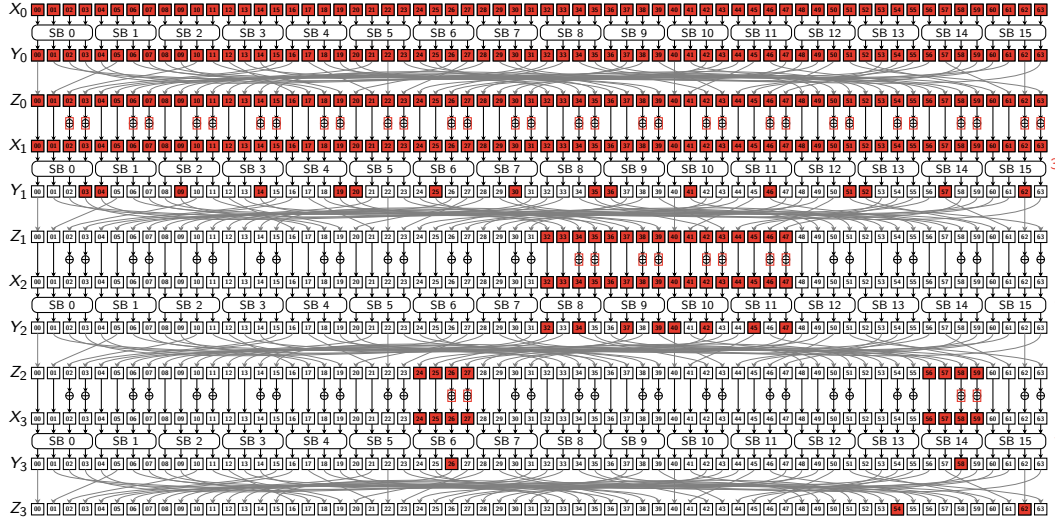
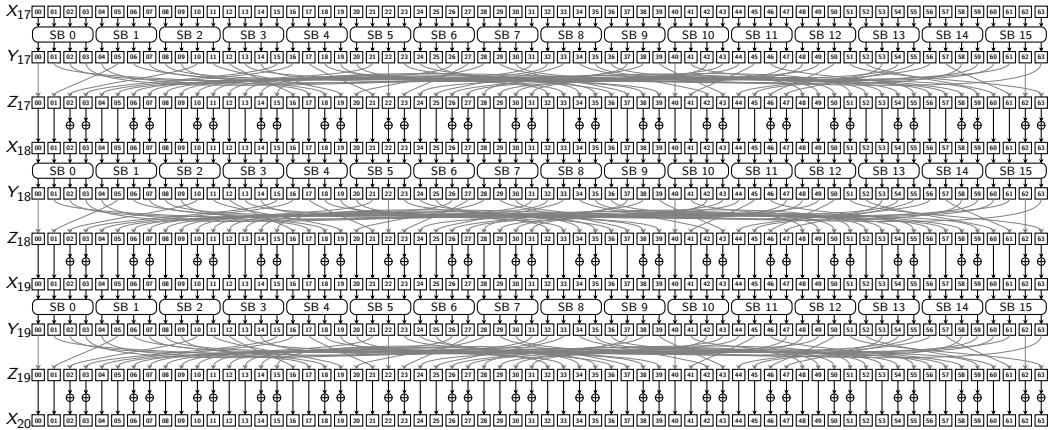
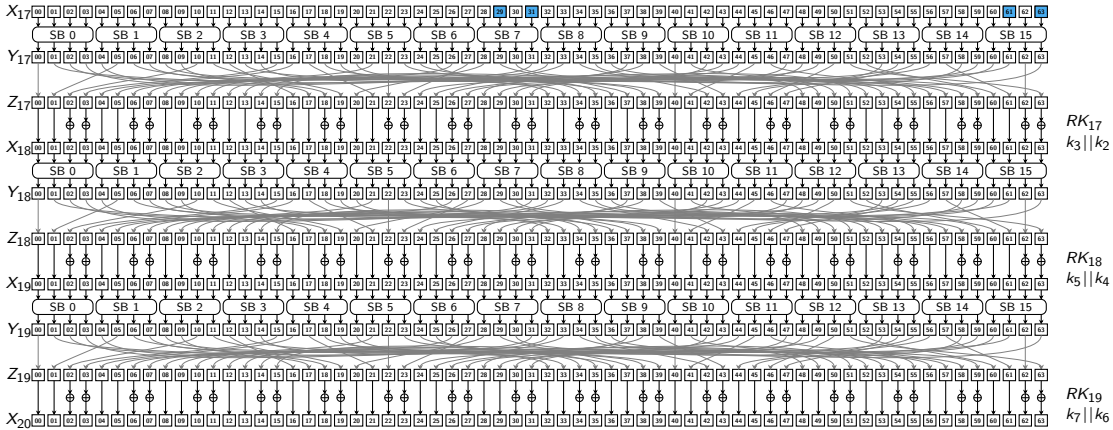


Lower extensions of the key recovery part



Lower extensions of the key recovery part



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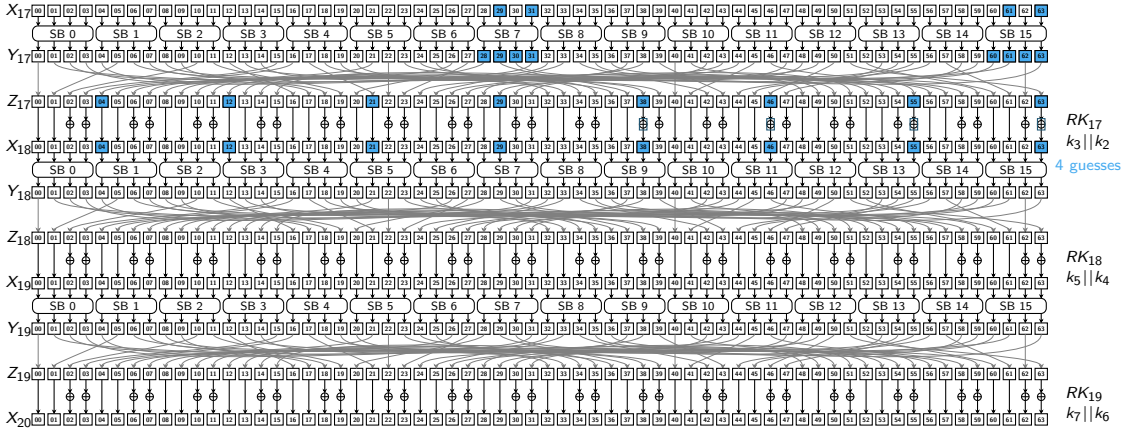

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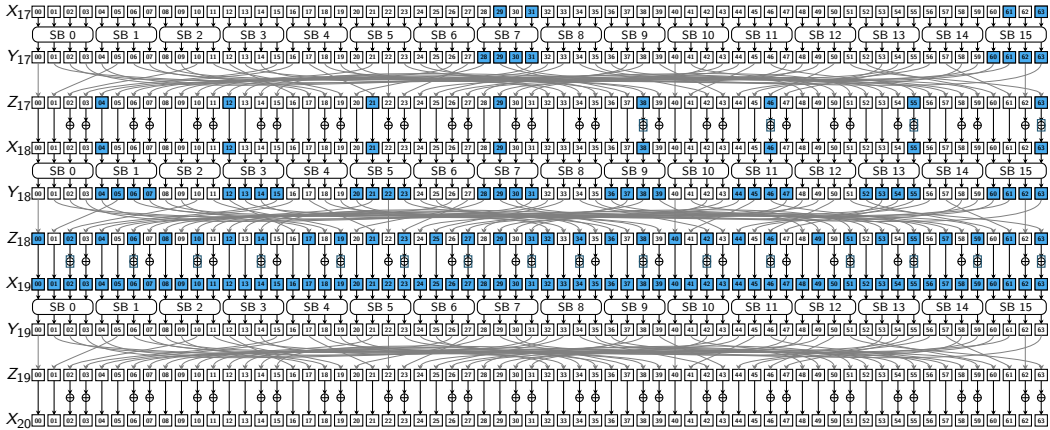

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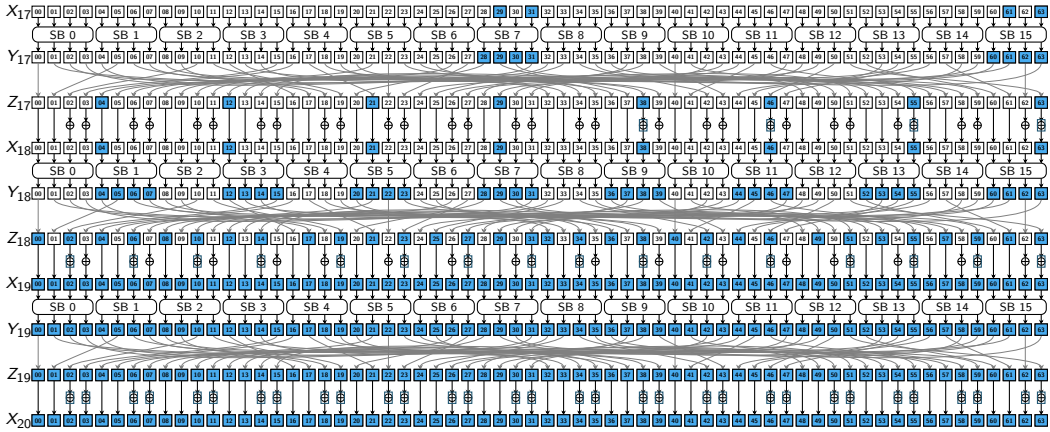

Complexities of Diff MITM attacks

- $\mathcal{R} = 4 + 13 + 3 = 20$.
- $|\mathcal{K}_{in}| = 44$, $|\mathcal{K}_{out}| = 52$, $|\mathcal{K}_{in} \cap \mathcal{K}_{out}| = 4$.

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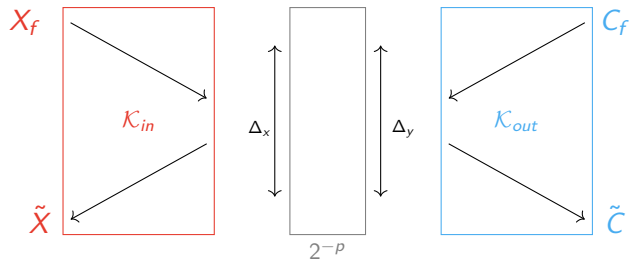
- $\mathcal{R} = 4 + 13 + 3 = 20$.
- $|\mathcal{K}_{in}| = 44$, $|\mathcal{K}_{out}| = 52$, $|\mathcal{K}_{in} \cap \mathcal{K}_{out}| = 4$.
- $\mathcal{T} = 2^{p}(2^{|\mathcal{K}_{in}|} + 2^{|\mathcal{K}_{out}|} + 2^{|\mathcal{K}_{in}|+|\mathcal{K}_{out}|-n}) = 2^{57.82}(2^{44} + 2^{52} + 2^{44+52-64}) = 2^{109.82}$.
- $\mathcal{M} = 2^{min(|\mathcal{K}_{in}|-|\mathcal{K}_{in}\cap\mathcal{K}_{out}|,|\mathcal{K}_{out}|-|\mathcal{K}_{in}\cap\mathcal{K}_{out}|)} = 2^{40}$.
- $\mathcal{D} = 2^{n-a} = 2^{61}, a = 3, p = 57.82$.

Diff MITM framework with structures [BBD+23], [AKM+24]



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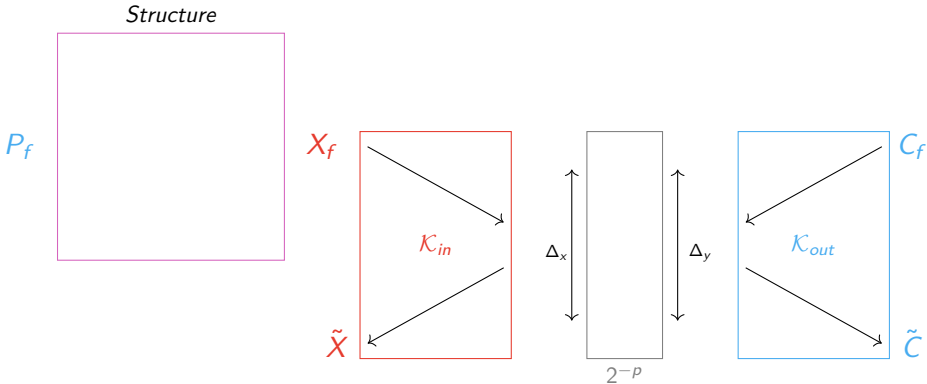

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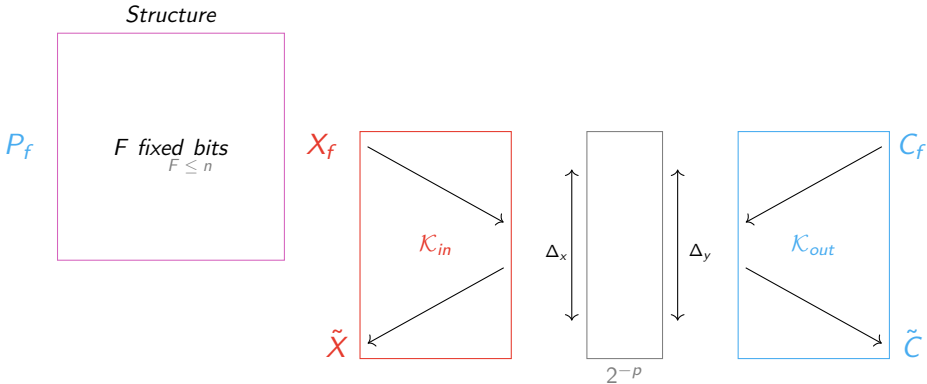

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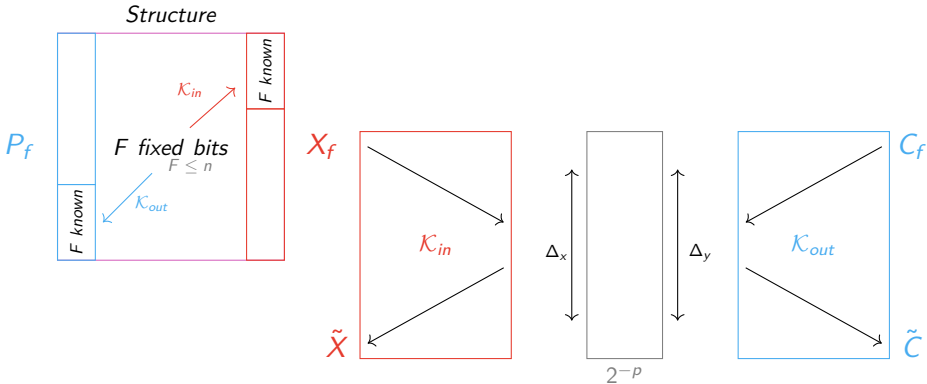

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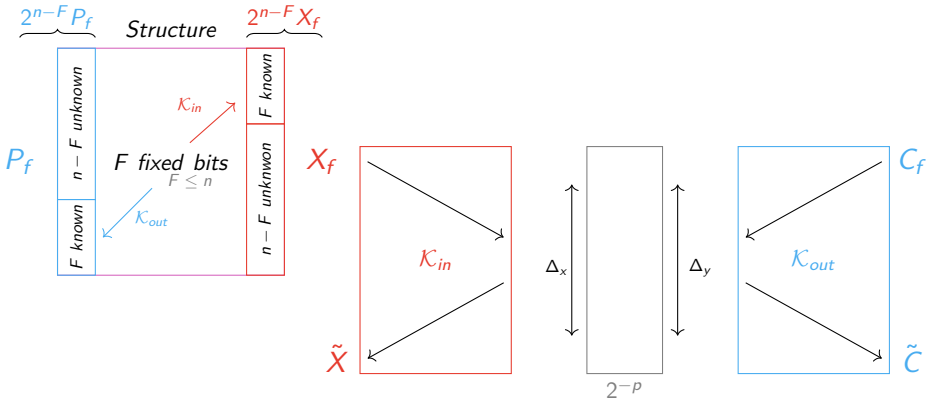

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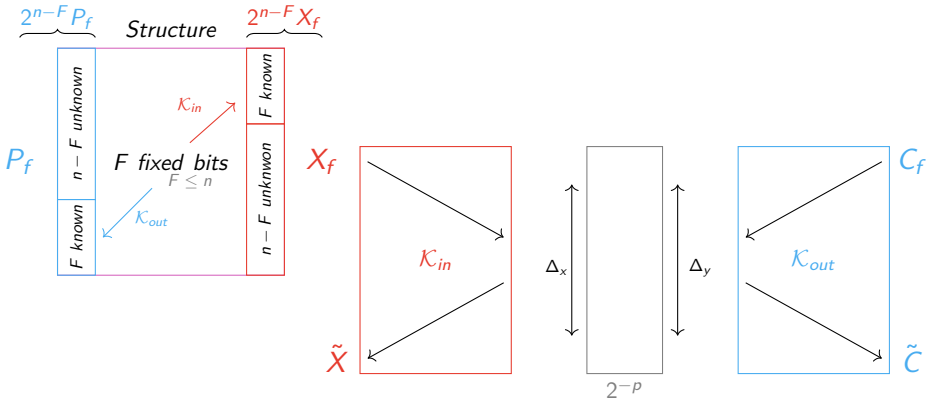
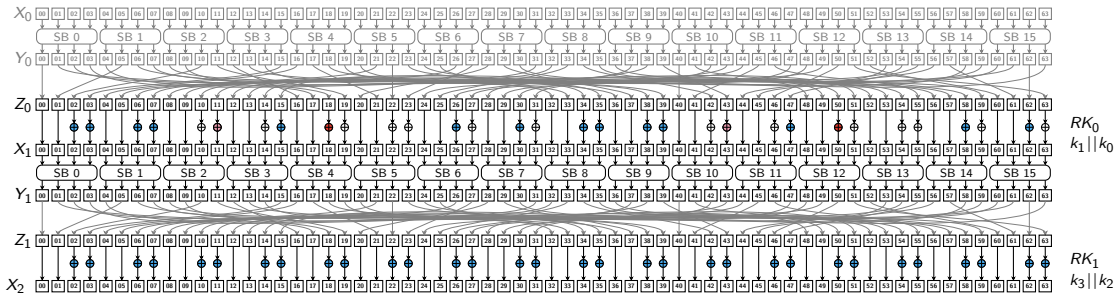


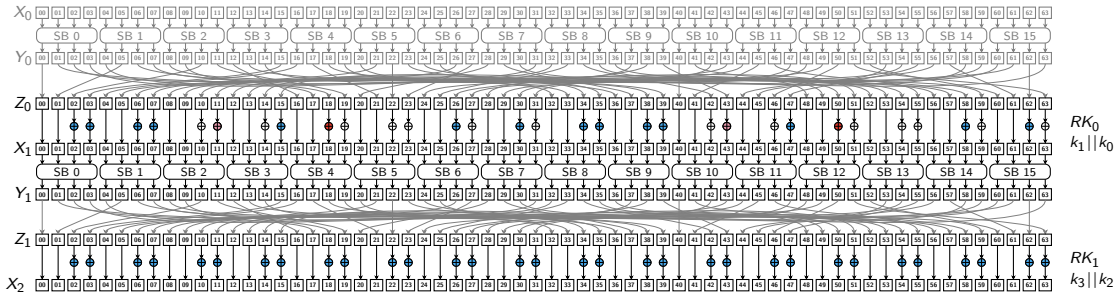
$$\mathcal{T} = 2^{p-(n-F)}\left(2^{n-F}2^{|\mathcal{K}_{in}|} + 2^{n-F}2^{|\mathcal{K}_{out}|} + 2^{2(n-F)+|\mathcal{K}_{in}|+|\mathcal{K}_{out}|-|\mathcal{K}_{in}\cap\mathcal{K}_{out}|-F-F_{add}}\right), \mathcal{M} = 2^{n-F}2^{min(\mathcal{K}_{in},\mathcal{K}_{out})}$$

Building a 2 rounds structure



Building a 2 rounds structure

$|\mathcal{K}_{in}| = 44$ $|\mathcal{K}_{out}| = 52$ $|\mathcal{K}_{in} \cap \mathcal{K}_{out}| = 2$



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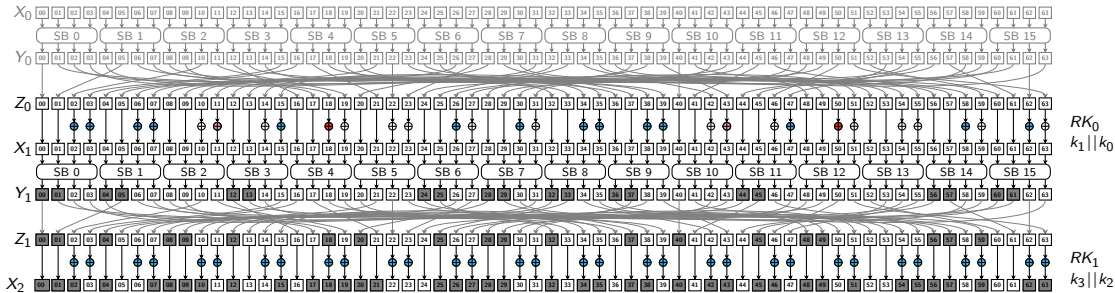

$F_{X_2} = 40$

Building a 2 rounds structure

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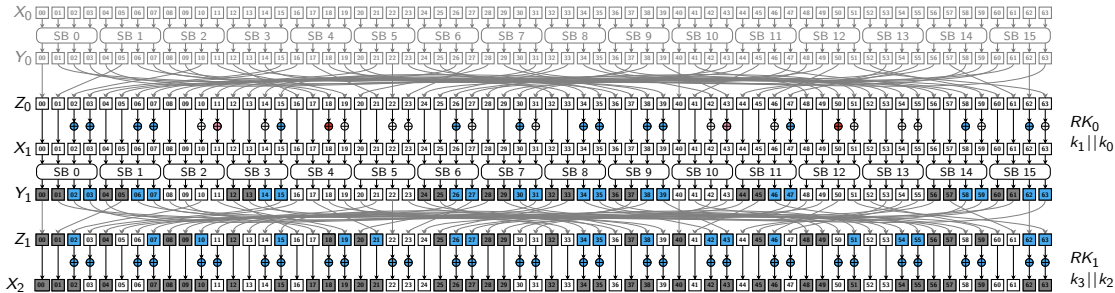

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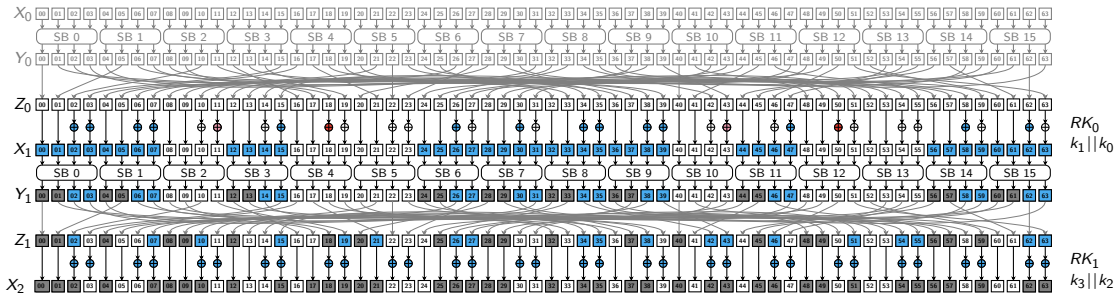

$F_{X_2} = 40$

Building a 2 rounds structure

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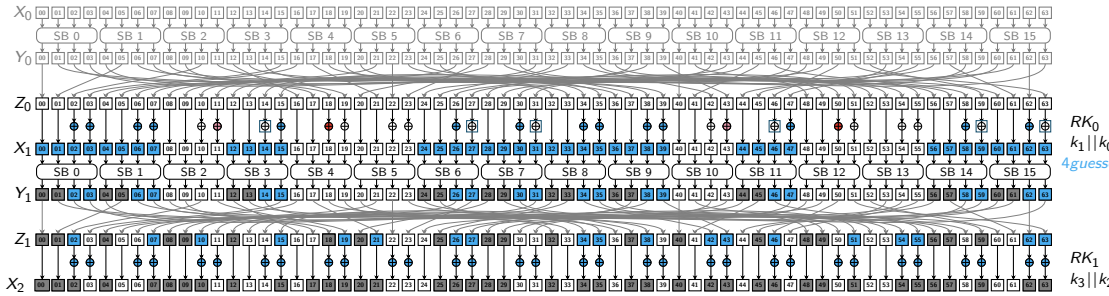

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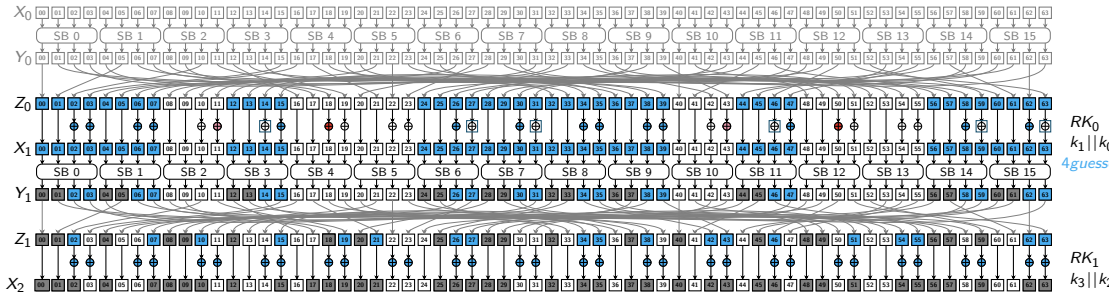

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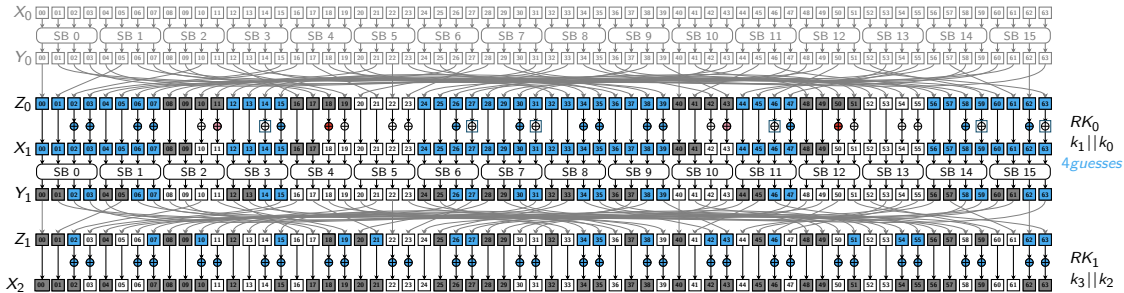

$F_{X_2} = 40$ $F_{Z_0} = 16$

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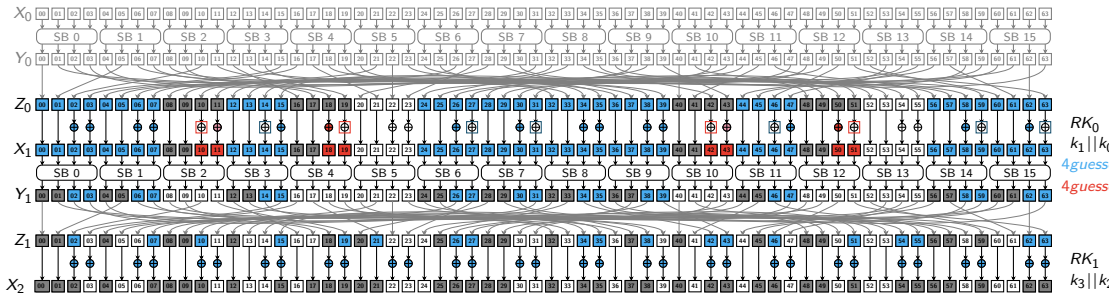

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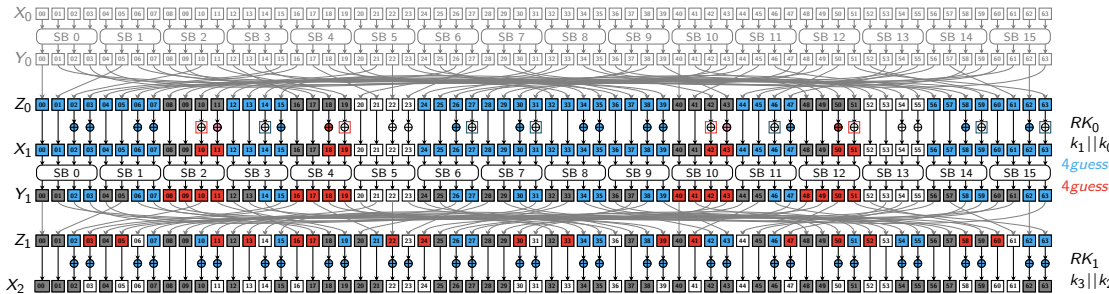

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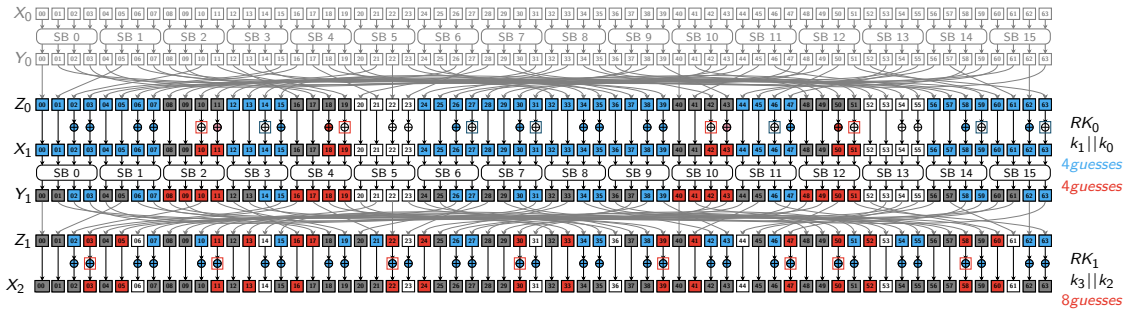
Building a 2 rounds structure

$|\mathcal{K}_{in}| = 44 + 4 + 8$ $|\mathcal{K}_{out}| = 52 + 4$ $|\mathcal{K}_{in} \cap \mathcal{K}_{out}| = 2 + 8$



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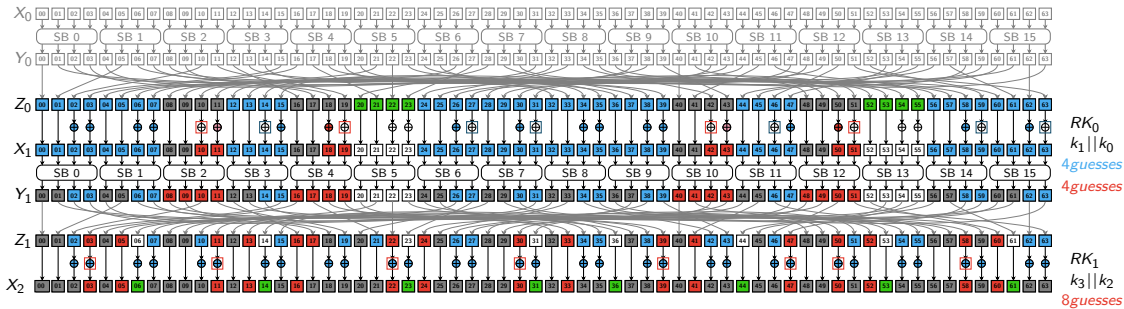

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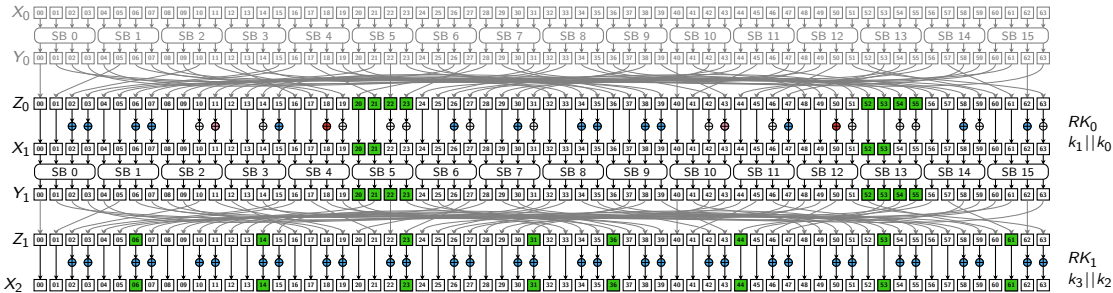

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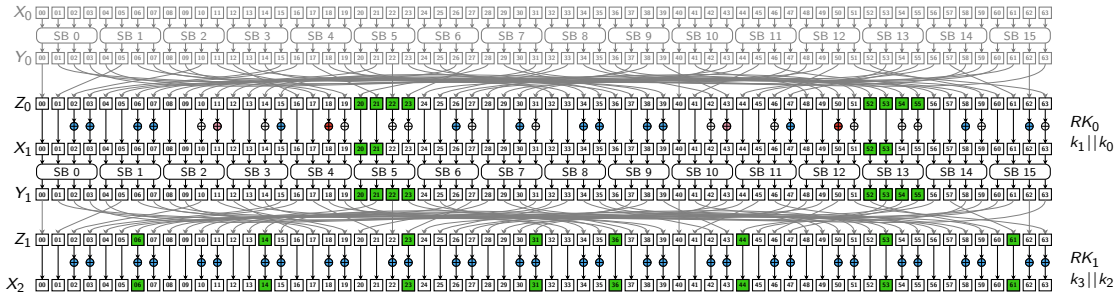
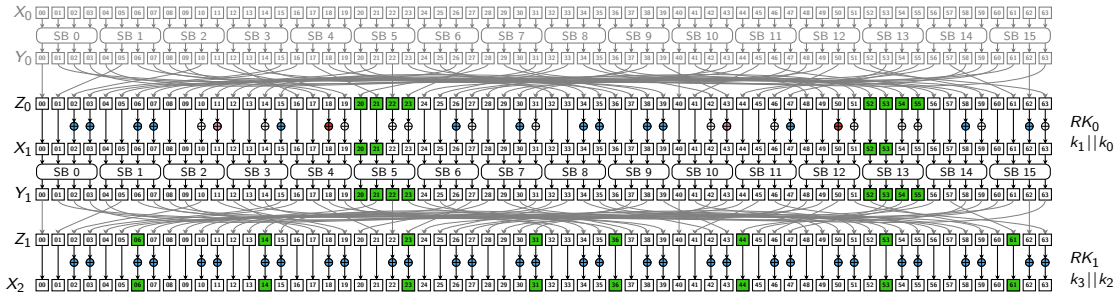


$$f_{add} = 2 \cdot 6$$

Building a 2 rounds structure



$$f_{add} = 2 \cdot 6 \qquad K_{info} = 4$$

Complexities with a structure

- $\mathcal{R} = 2 + 4 + 13 + 3 = 22$
- $|\mathcal{K}_{in}| = 56 - 2$, $|\mathcal{K}_{out}| = 58 - 1$, $|\mathcal{K}_{in} \cap \mathcal{K}_{out}| = 10$
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- $\mathcal{T} = 2^{p}(2^{|\mathcal{K}_{in}|} + 2^{|\mathcal{K}_{out}|} + 2^{|\mathcal{K}_{in}|+|\mathcal{K}_{out}|+n-2*F-f_{add}})$
  $= 2^{57.82}(2^{56-2} + 2^{58-1} + 2^{54+57-10+64-2*56-12}) = 2^{114.82}$

$\rightarrow$ We recovered $54 + 57 - 10 + 4 = 105$ bits of the Master Key.

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$\rightarrow$ We recovered $54 + 57 - 10 + 4 = 105$ bits of the Master Key. To recover the full master key, we test the $2^{98.82}$ remaining pairs on extra data; final complexities are :

$$\mathcal{T} = 2^{98.82+19} = 2^{117.82},\ \mathcal{M} = 2^{8+56-10} = 2^{54},\ \mathcal{D} = 2^{61}$$

More trade-offs...

Results

Cipher	Rounds	Setup	Key space size	Time	Data	Memory	Type of Attack	Source
GIFT-64	21	SK	2^{124}	$2^{117.42}$	2^{64}	2^{96}	Differential	[CWWH25]
	22	**SK**	$\mathbf{2^{124}}$	$\mathbf{2^{117.82}}$	$\mathbf{2^{61}}$	$\mathbf{2^{99}}$	**Diff MITM**	**This Paper**
	25	RK	2^{120}	2^{107}	2^{51}	2^{49}	Differential	[BDD+24]
	25	**RK**	$\mathbf{2^{120}}$	$\mathbf{2^{81.59}}$	$\mathbf{2^{51}}$	$\mathbf{2^{50.12}}$	**Differential**	**This Paper**
	26	RK	2^{120}	$2^{113.03}$	$2^{61.96}$	$2^{95.15}$	Differential	[CN25]

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Thank you for your attention