Latin Dances Reloaded: Improved Cryptanalysis against Salsa and ChaCha, and the proposal of Forró

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3 National Laboratory for Scientific Computing, Petrópolis, Brazil

Cryptography Research Center

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Agenda

- Review ChaCha and Salsa
- Review cryptanalysis against Chacha and Salsa
- Review best attack techniques against ChaCha and Salsa
- Our contributions
  - Cryptanalysis against Salsa and ChaCha
  - New cipher Forró
- Conclusions

Background

Salsa description

- Stream cipher Invented by Daniel J. Bernstein in 2005
- 20 rounds
- Fast in software
- Resistance against timing attacks and cache attacks
- You can generate 2^{64} streams

Background

ChaCha description

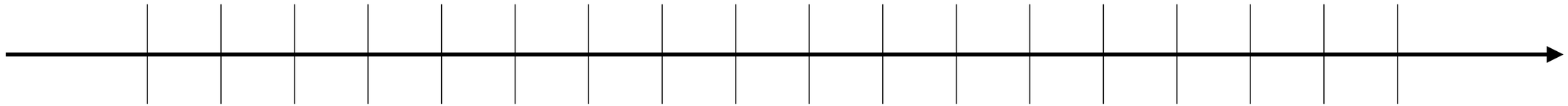
- Stream cipher invented by Daniel J. Bernstein
- Fast in software environment
- Resistance against timing attacks and cache attacks
- 20 rounds
- Better Diffusion than Salsa
- Actually used in TLS v1.3

Related Works

Attacking Salsa

Related Works

Attacking Salsa



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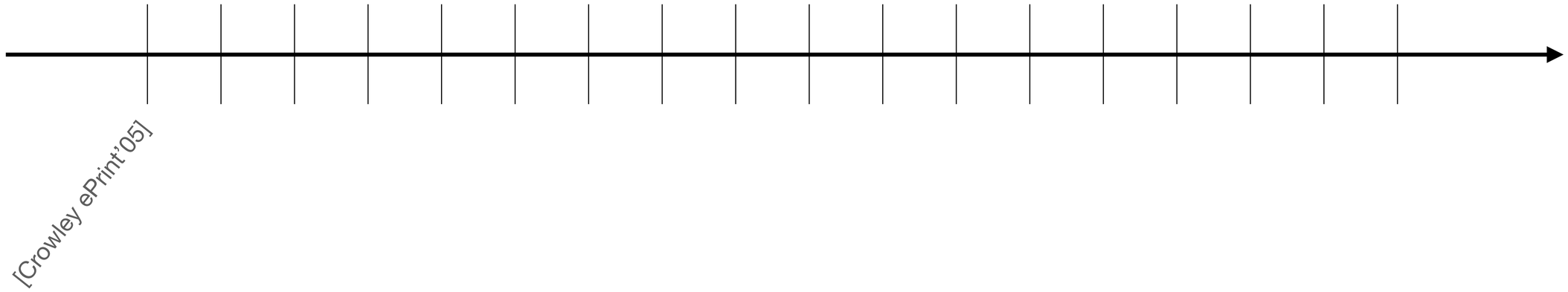

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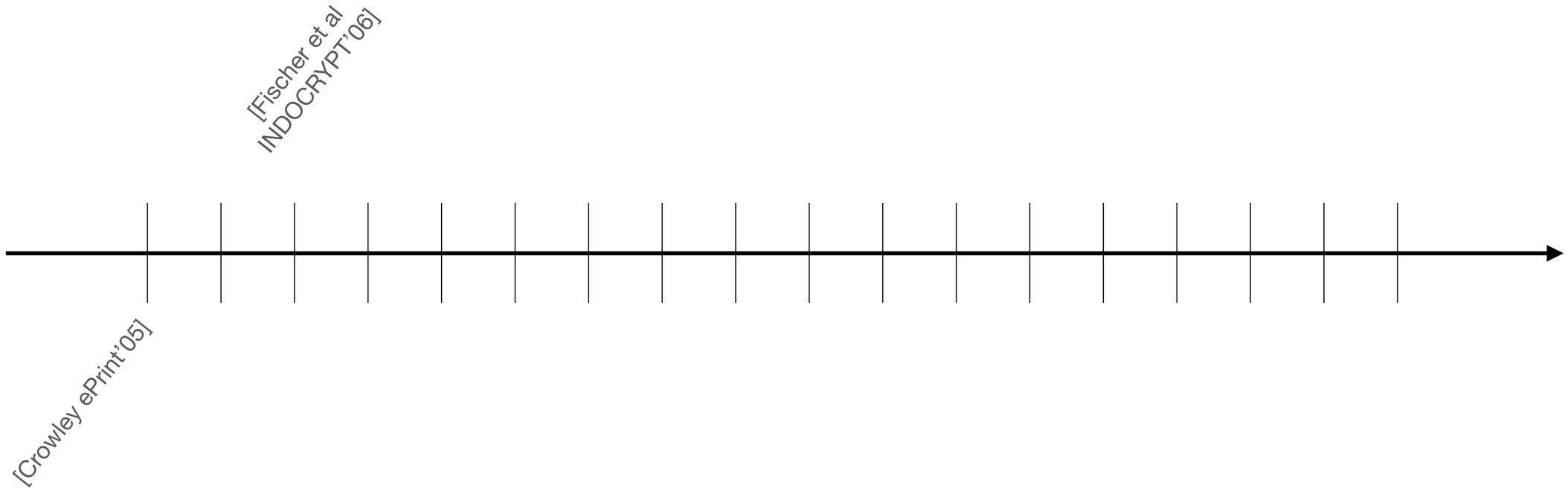

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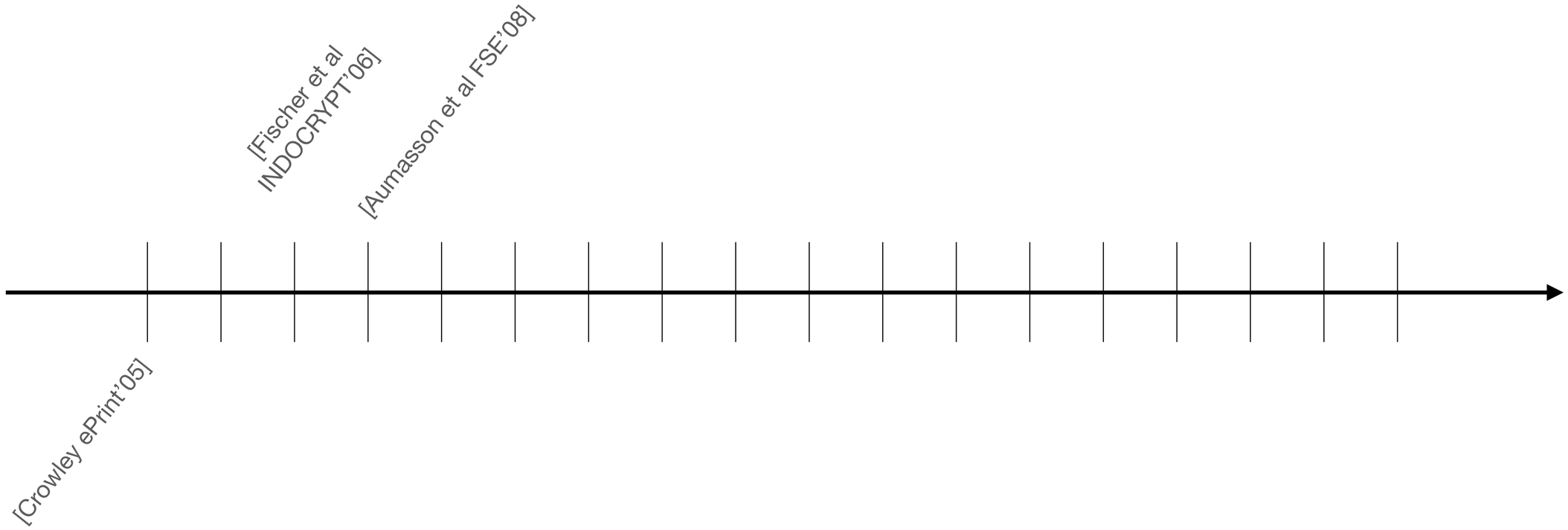

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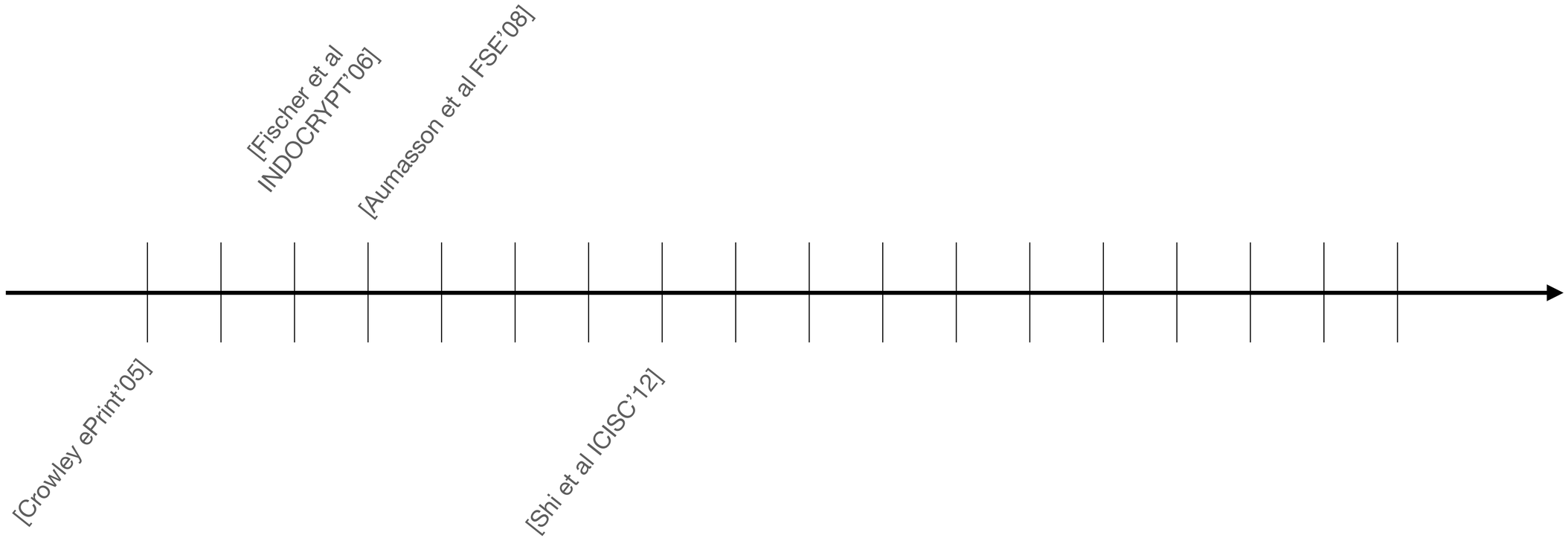

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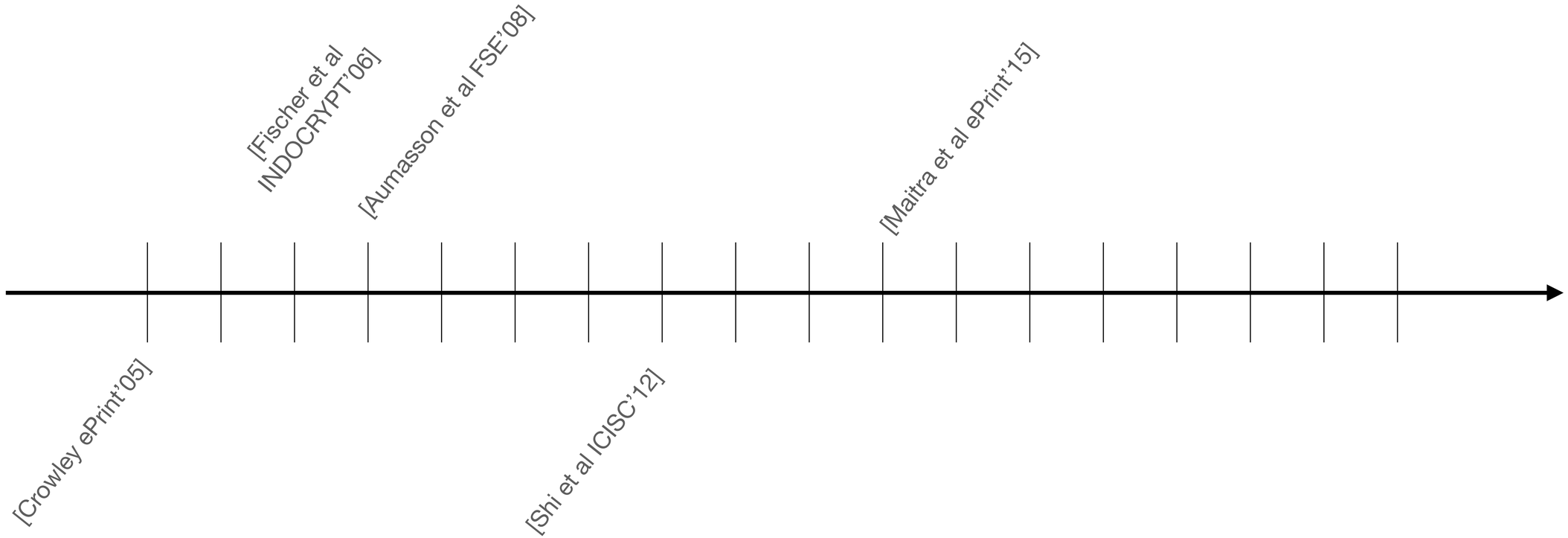

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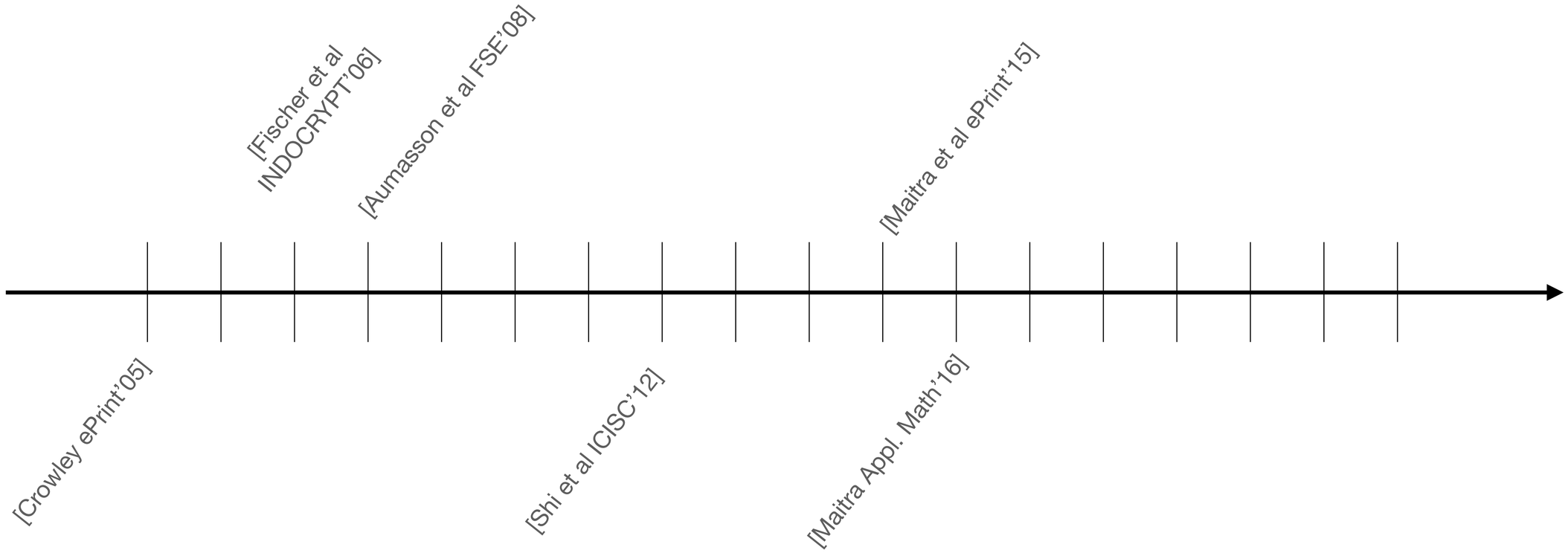

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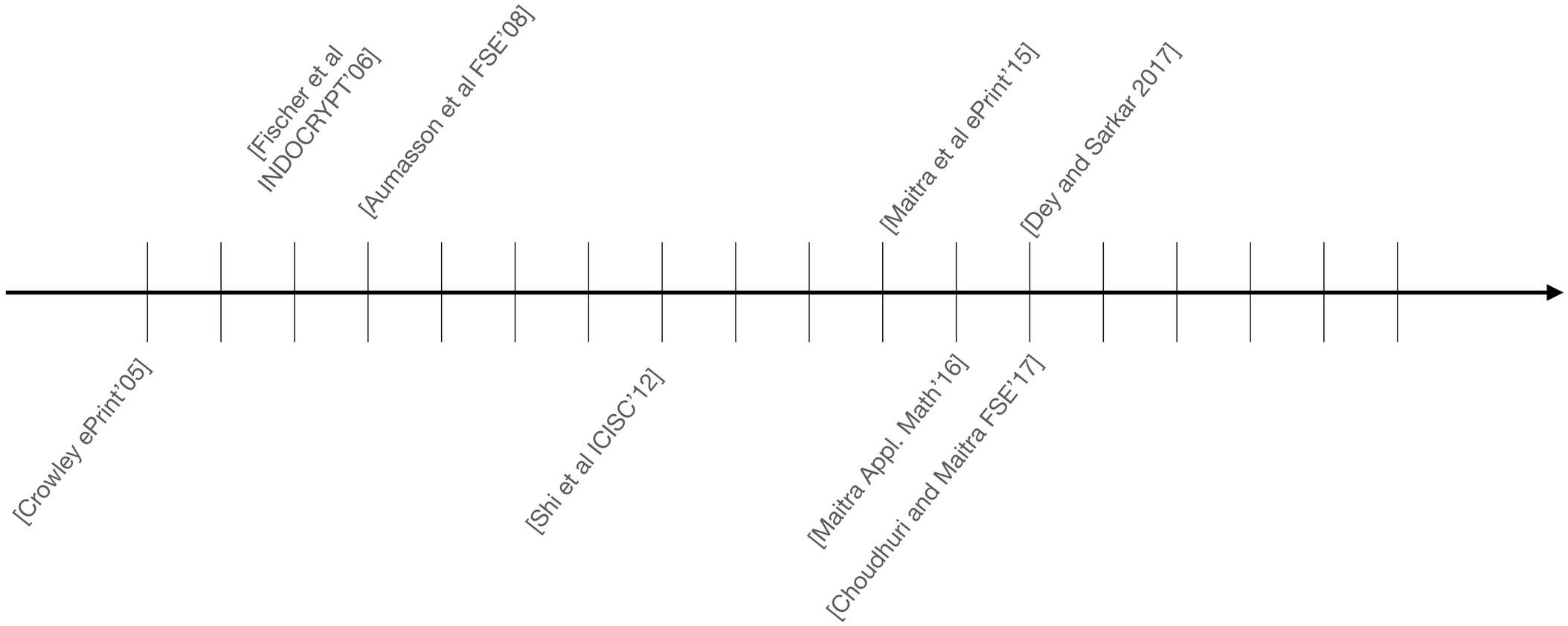

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Attacking ChaCha

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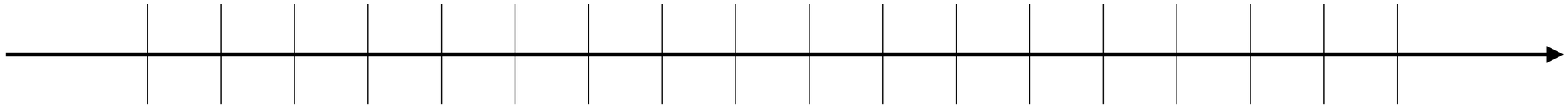

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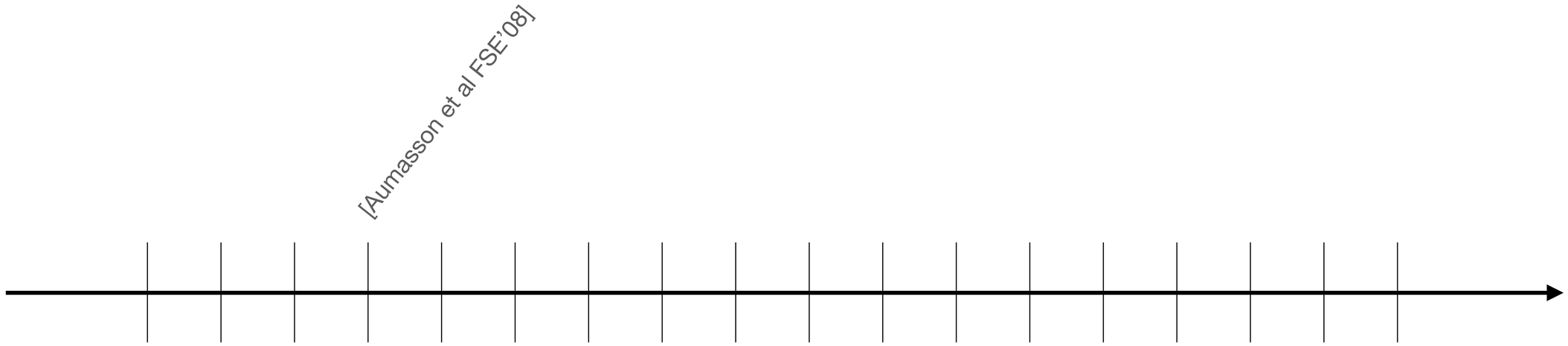

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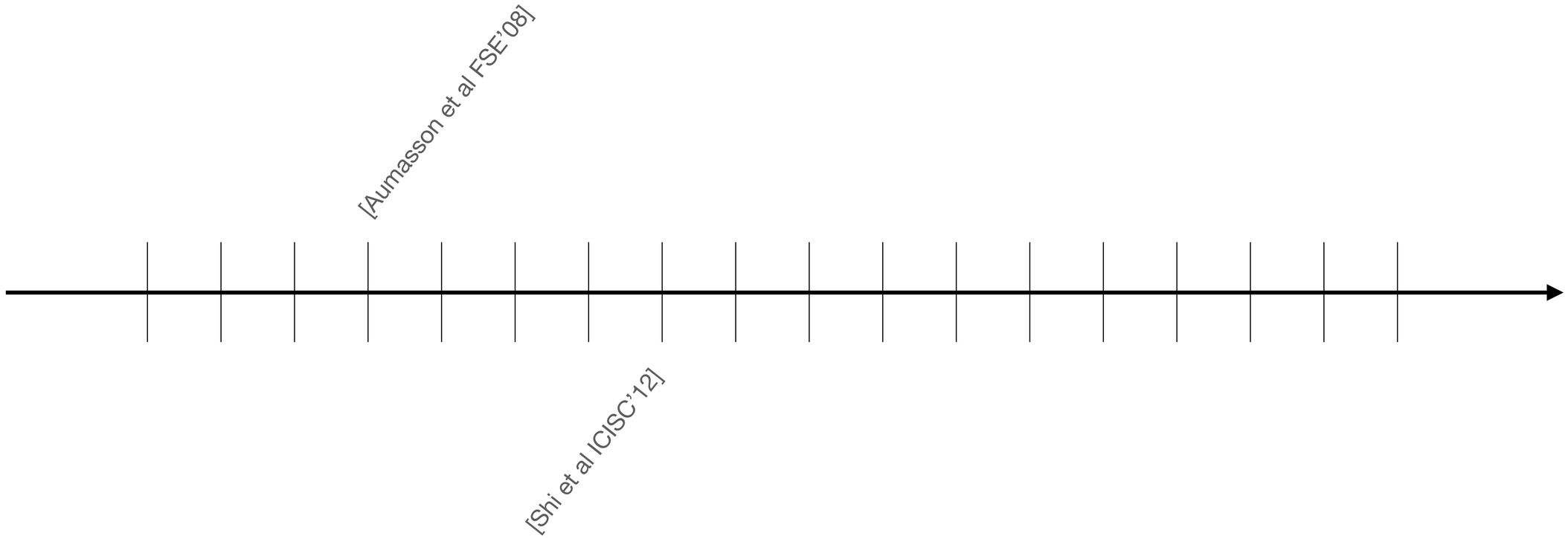

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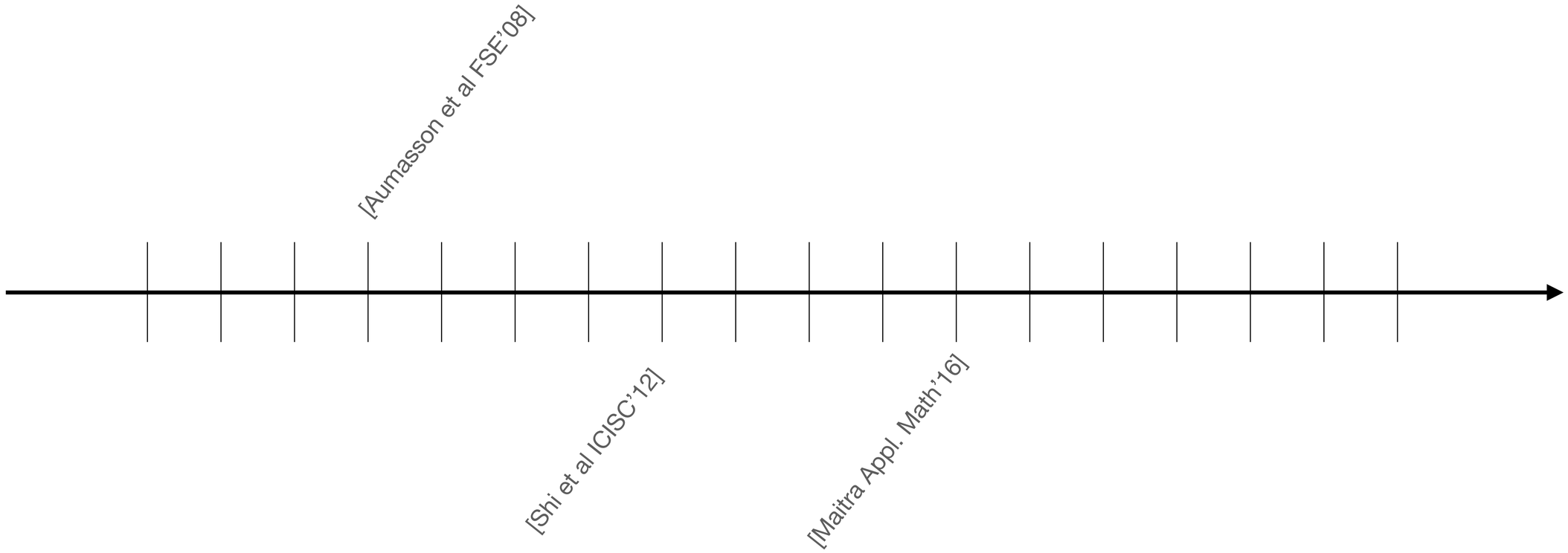

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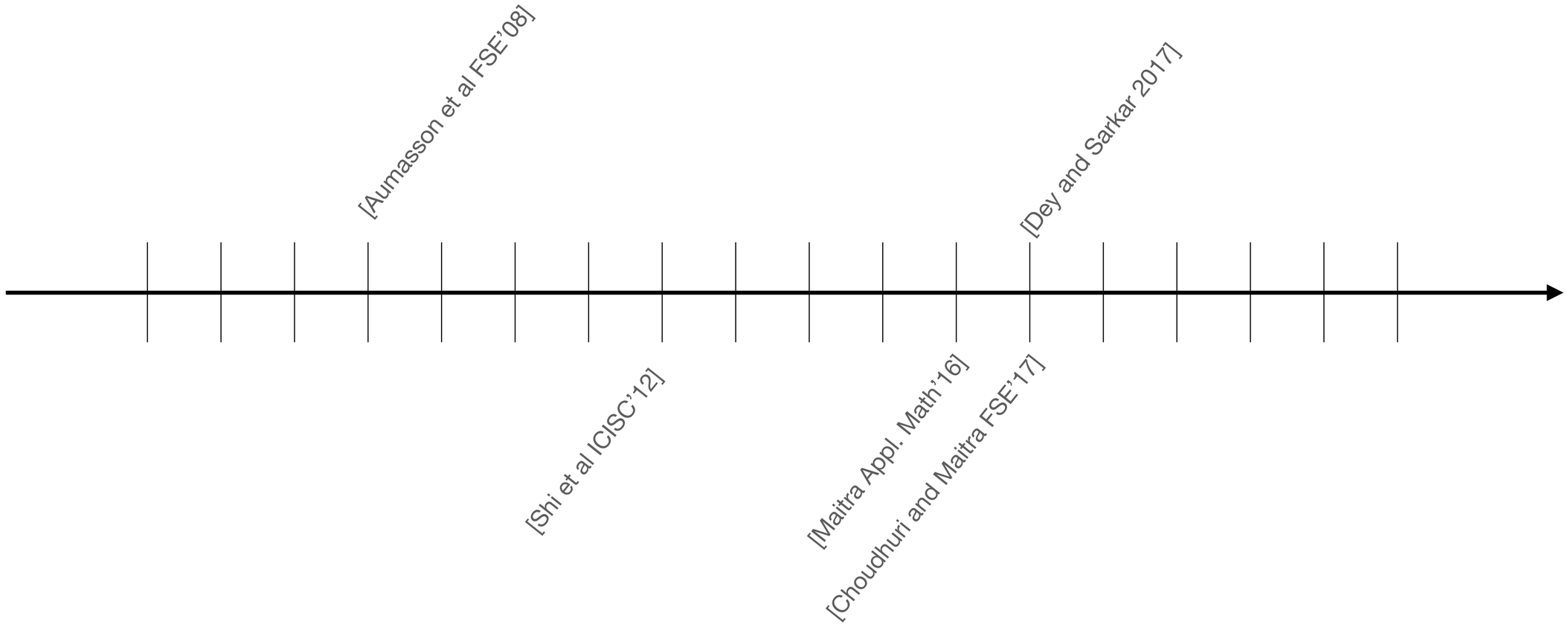

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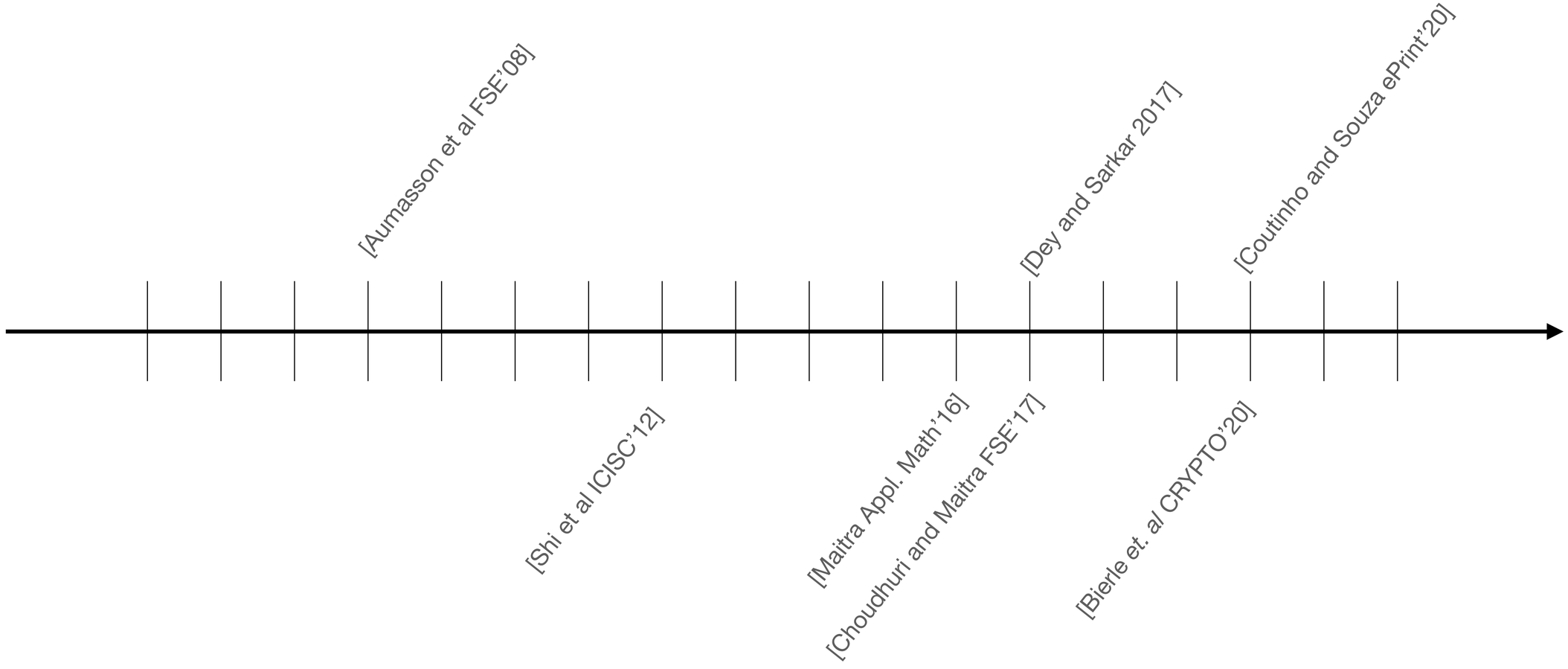

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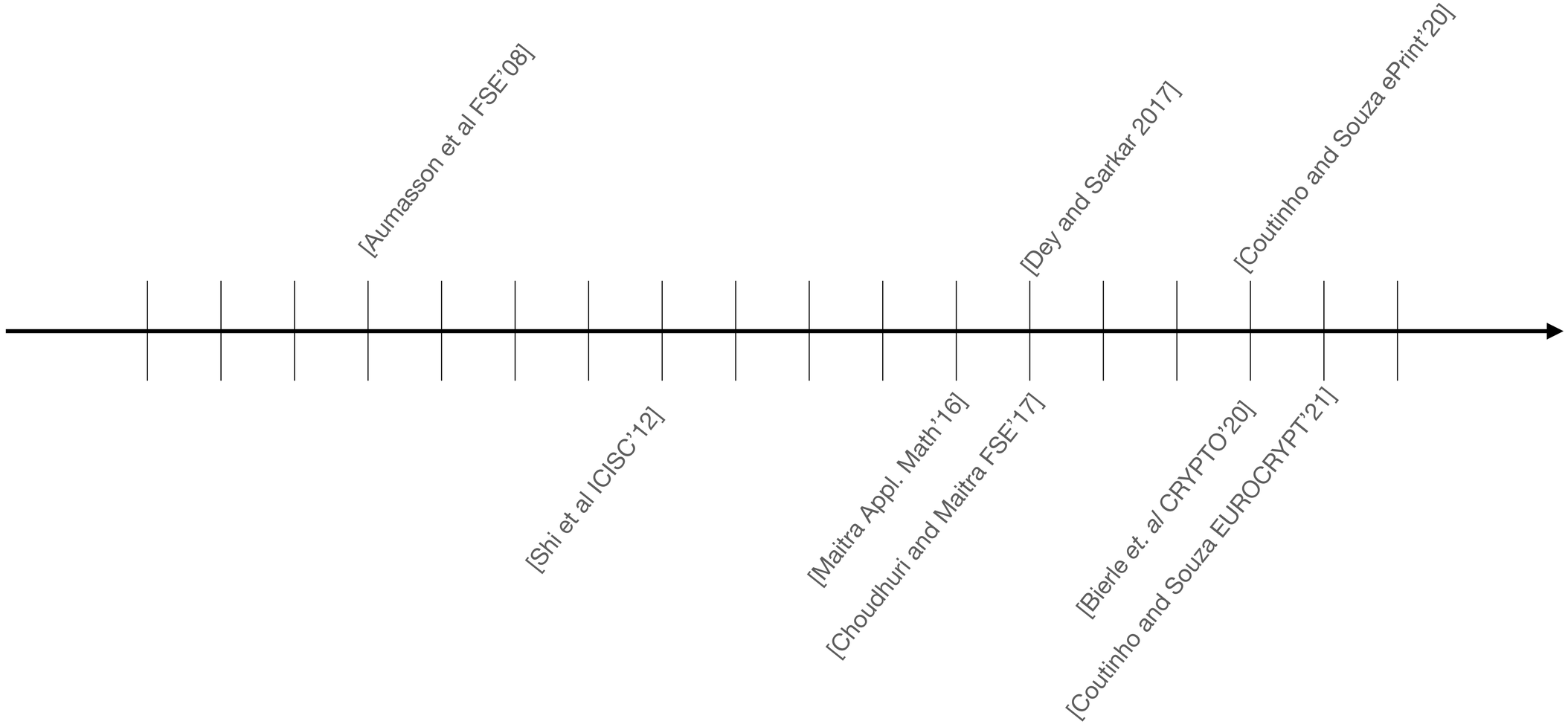

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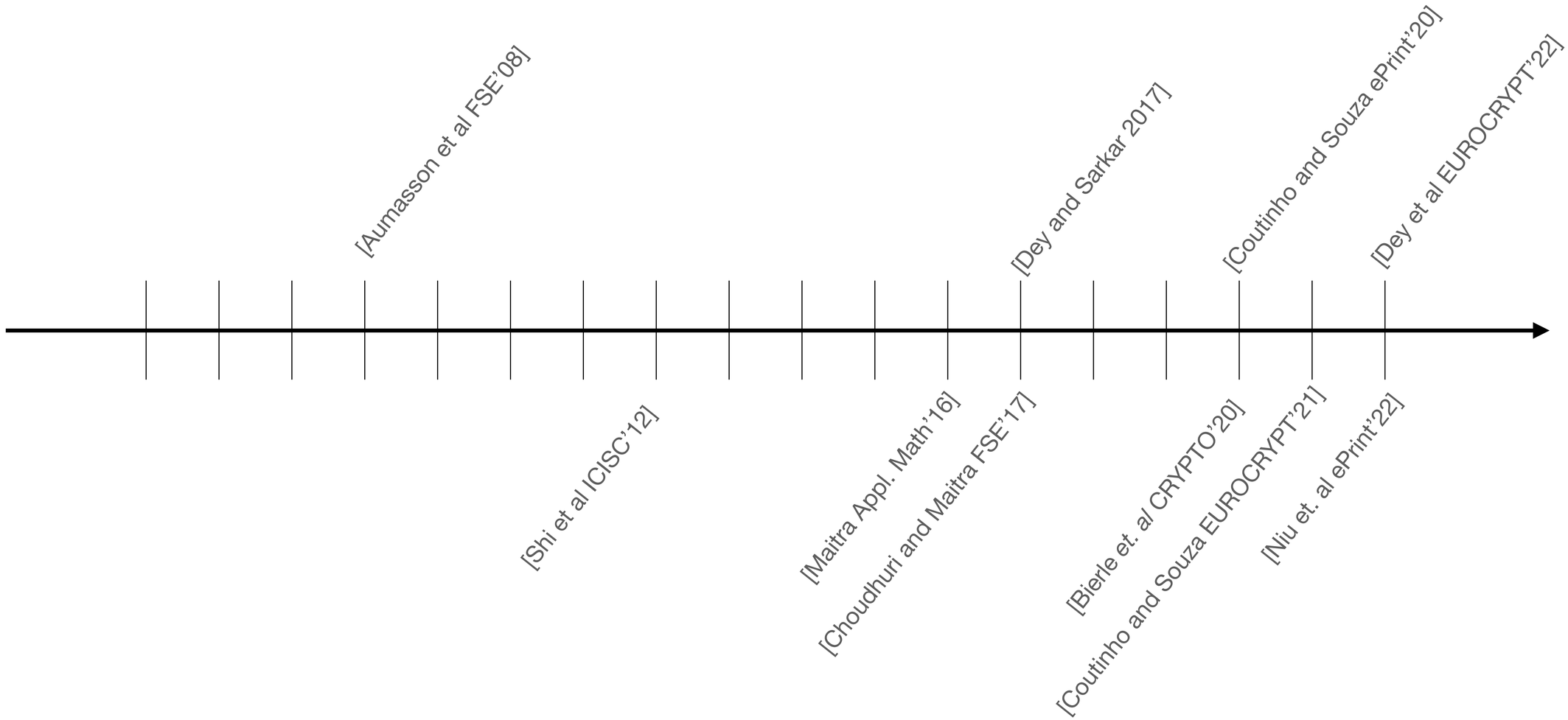
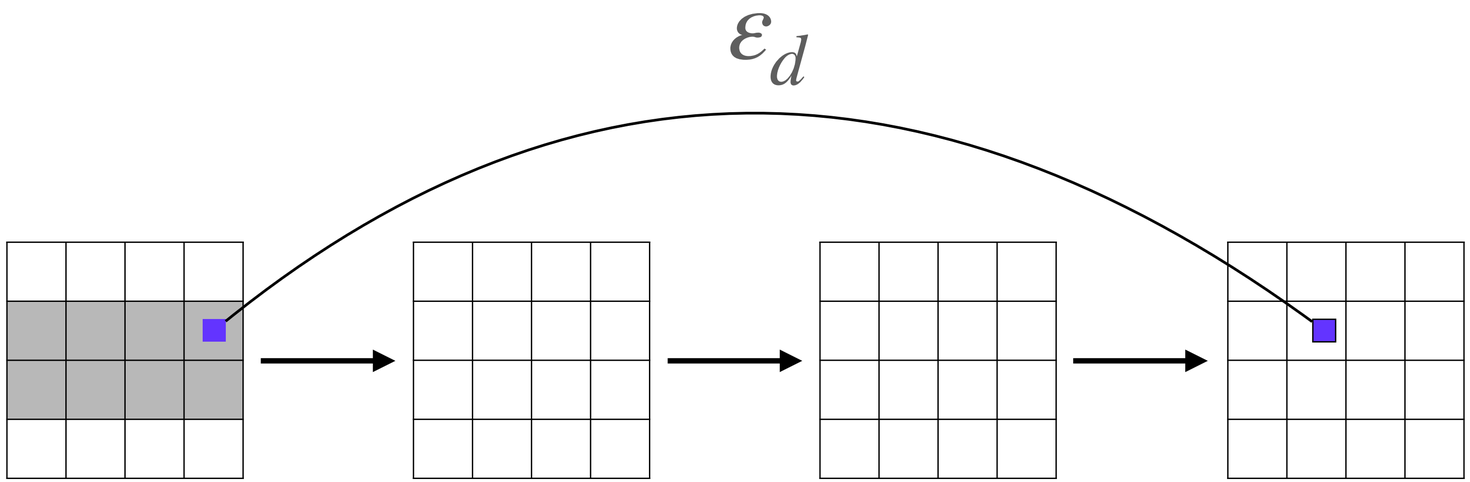


Background

Probabilistic Neutral Bits attack (PNB)



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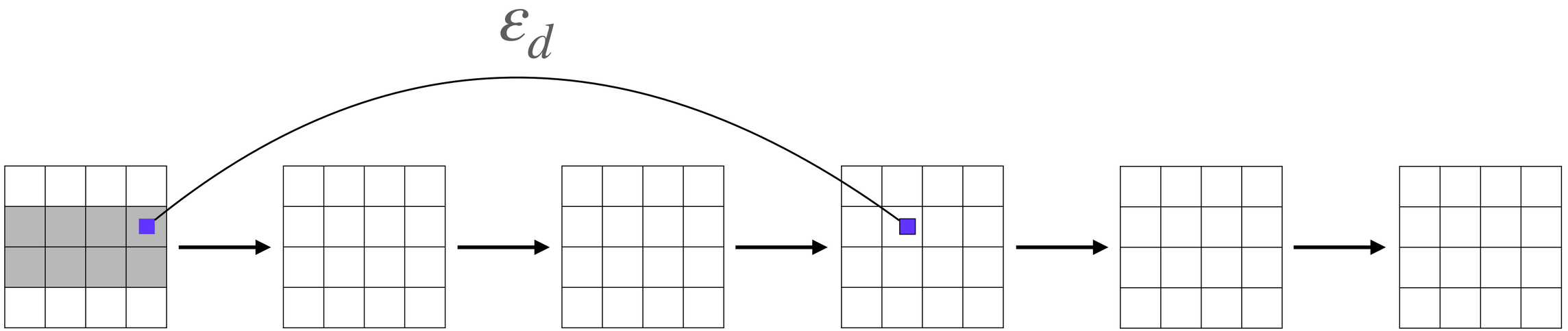

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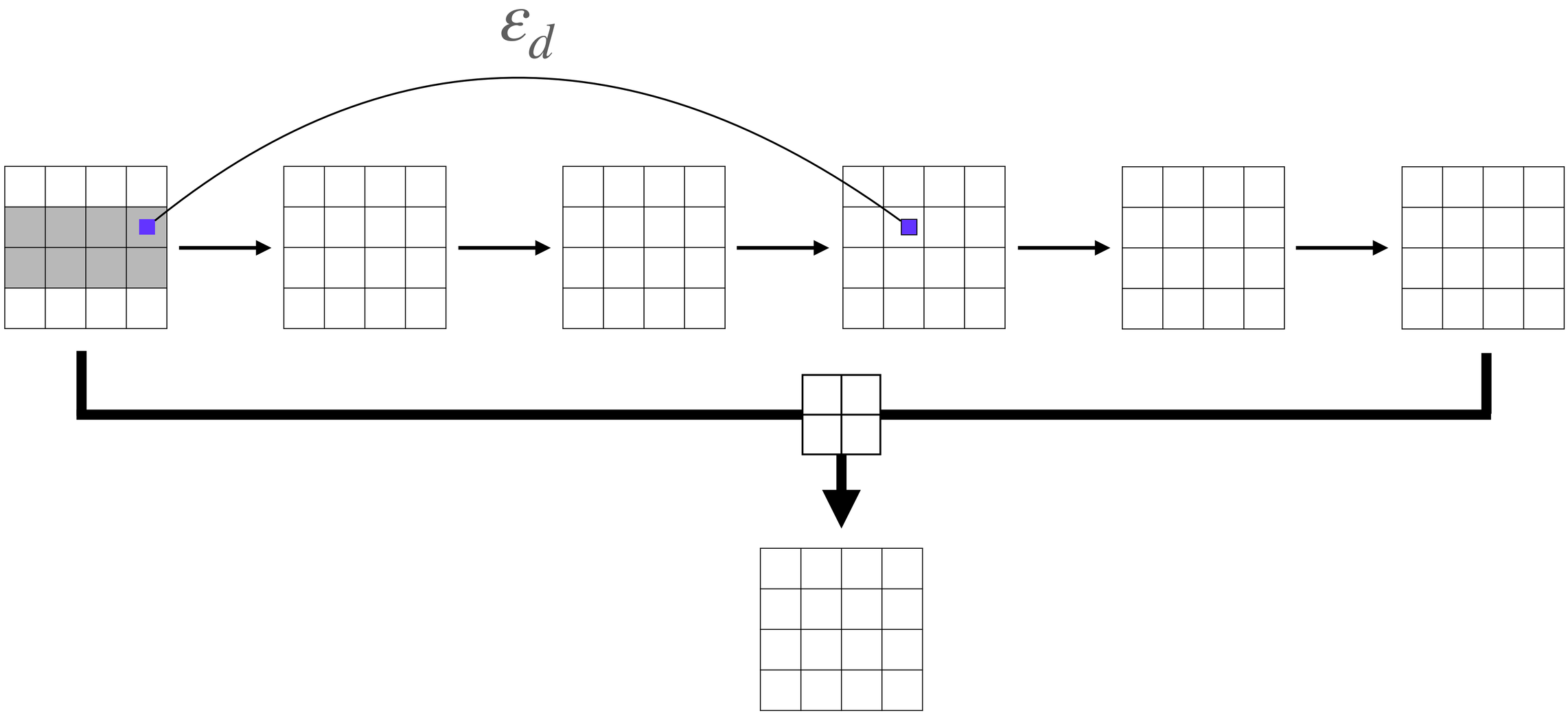

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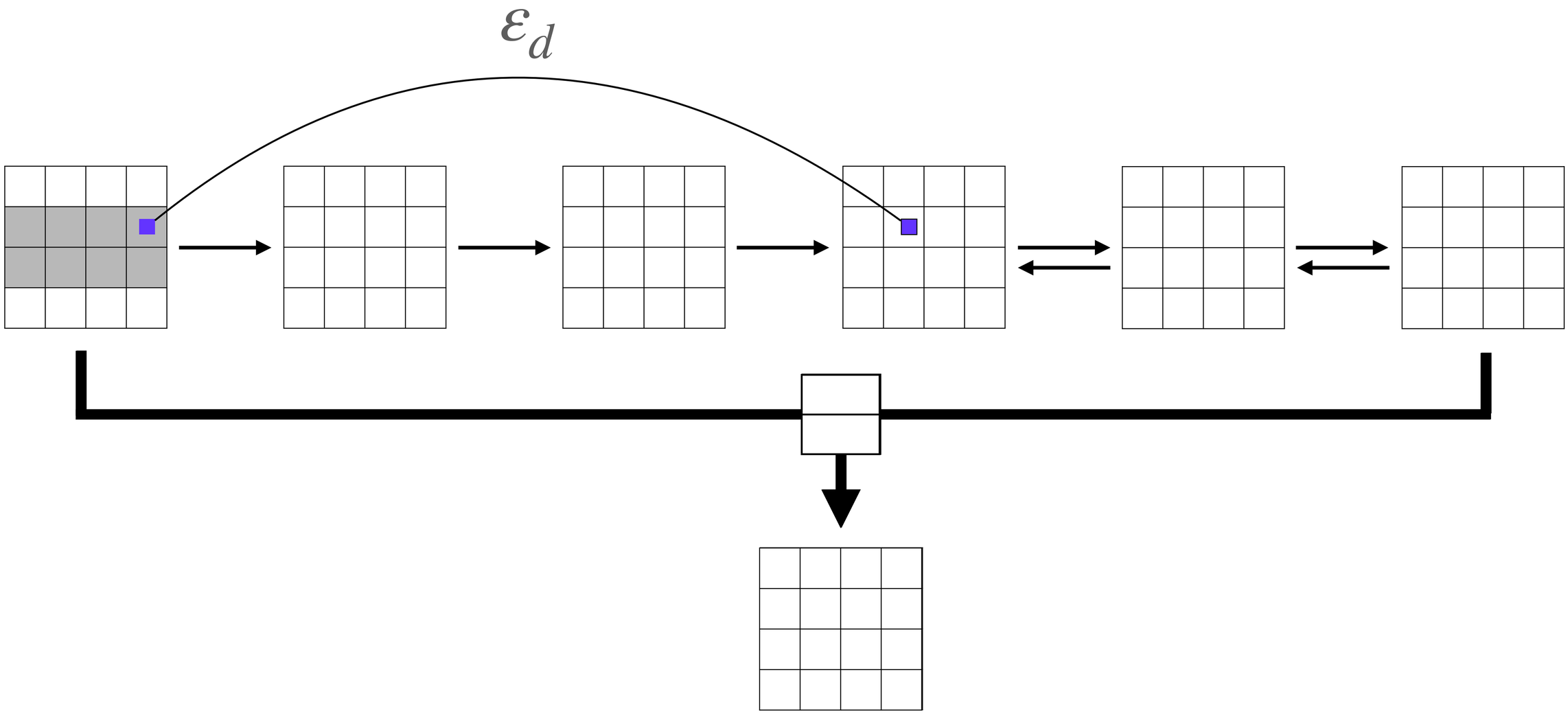

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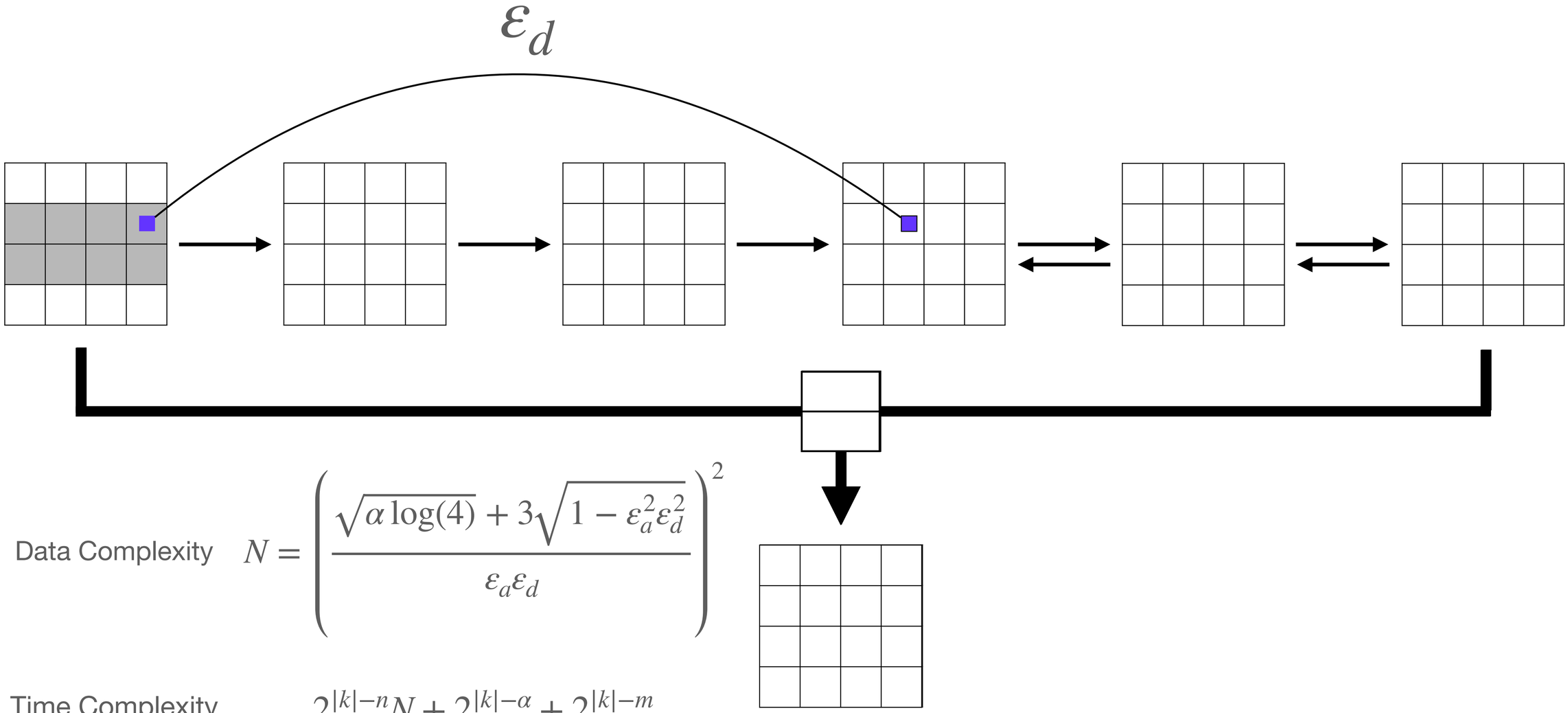
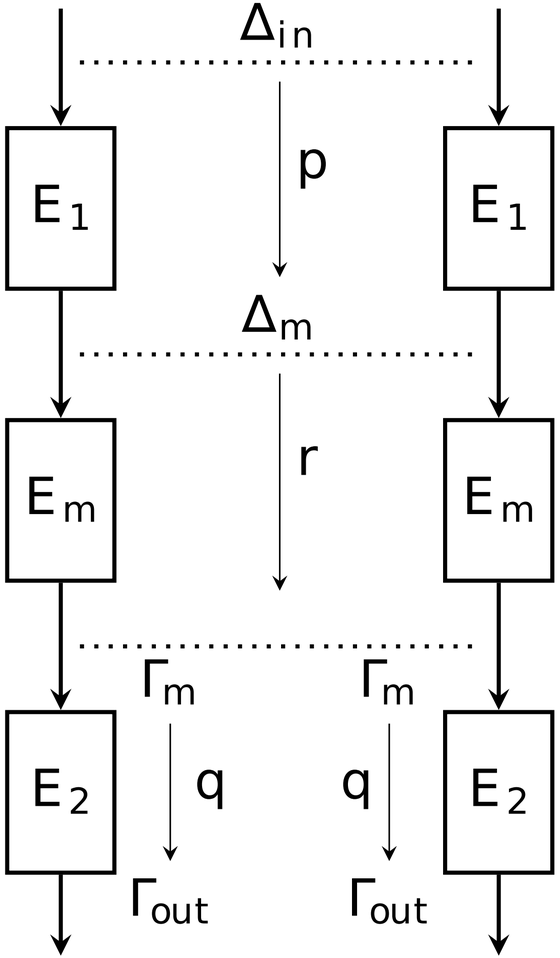


Data Complexity $N = \left(\frac{\sqrt{\alpha \log(4)} + 3\sqrt{1 - \varepsilon_a^2 \varepsilon_d^2}}{\varepsilon_a \varepsilon_d} \right)^2$

Time Complexity $2^{|k|-n}N + 2^{|k|-\alpha} + 2^{|k|-m}$

Background

Differential-Linear Attack

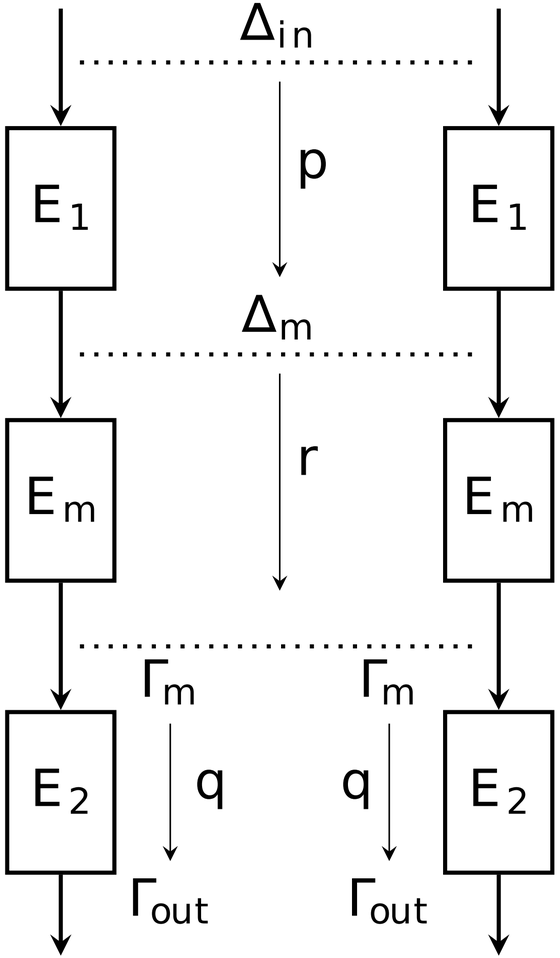


Correlation

$$prq^2$$

Background

Differential-Linear Attack



Correlation

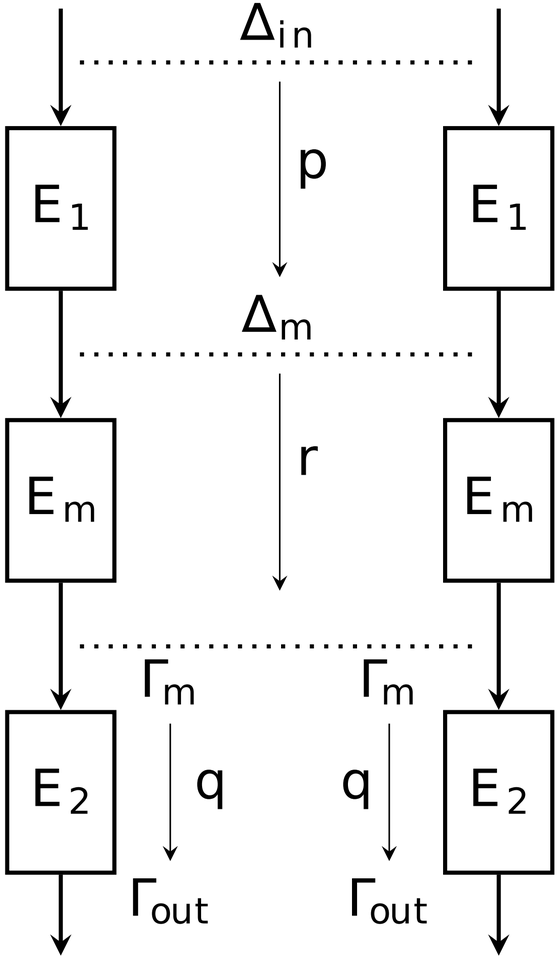
$$prq^2$$

Complexity

$$O\left(\frac{1}{p^2r^2q^4}\right)$$

Background

Differential-Linear Attack



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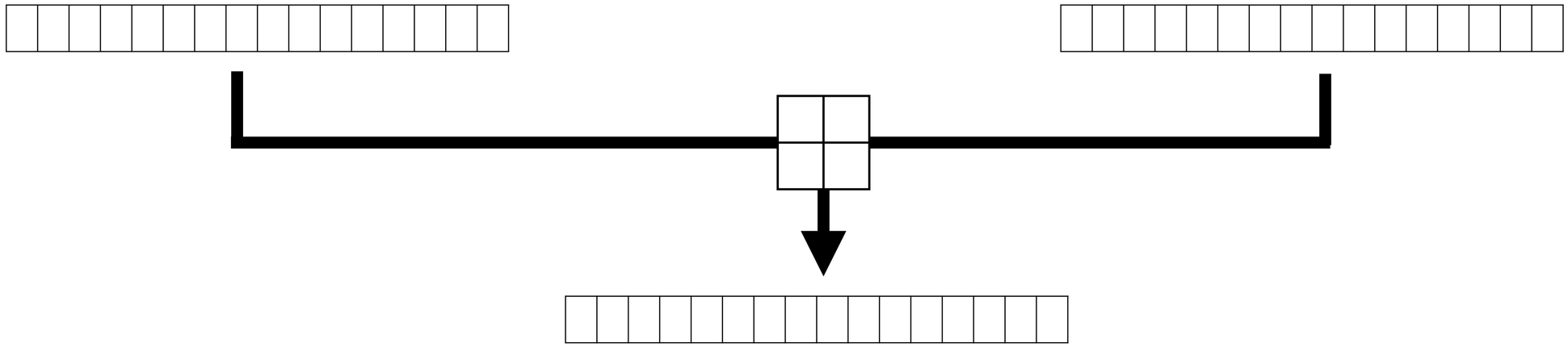
Linear Approximations of Modular Addition



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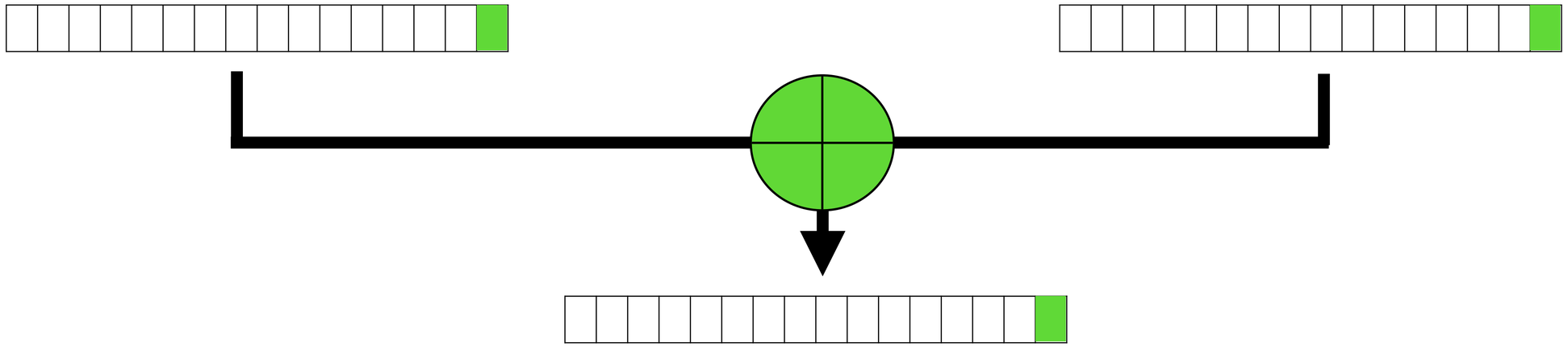
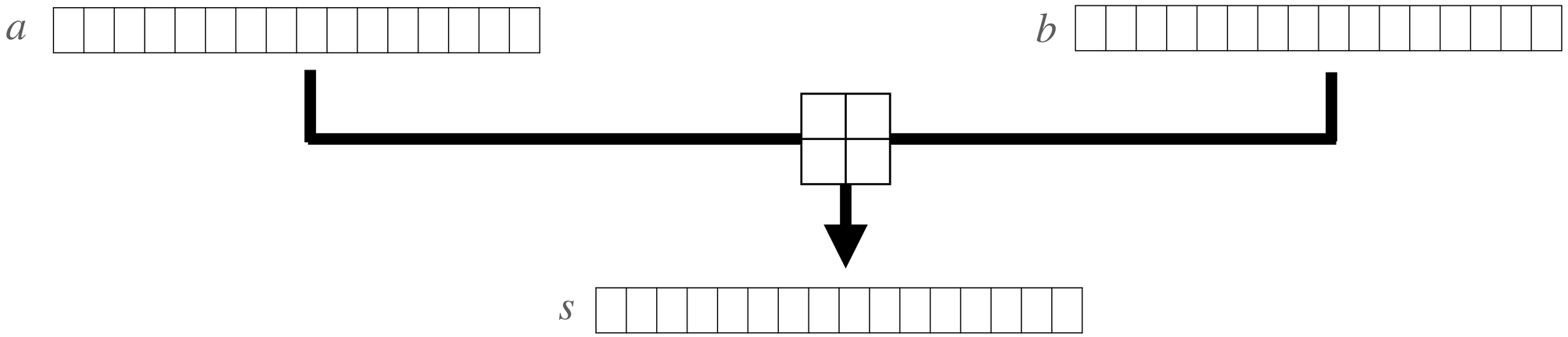


$$s_0 = a_0 \oplus b_0$$

Background

Linear Approximations of Modular Addition



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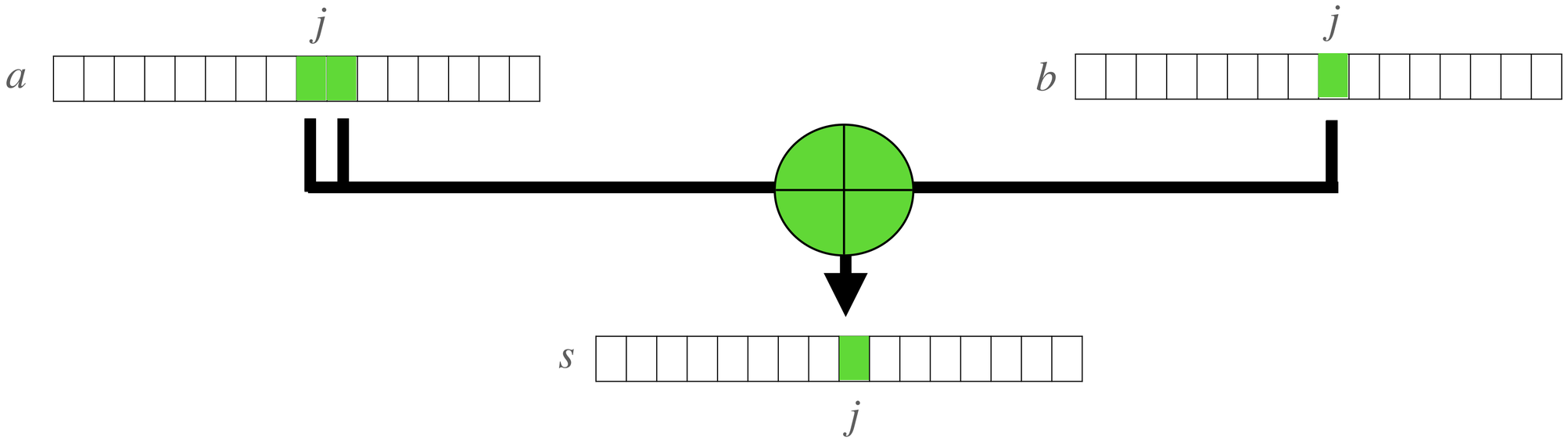

$$s_j = a_j \oplus b_j \oplus a_{j-1} \text{ w.p. } \frac{3}{4}$$

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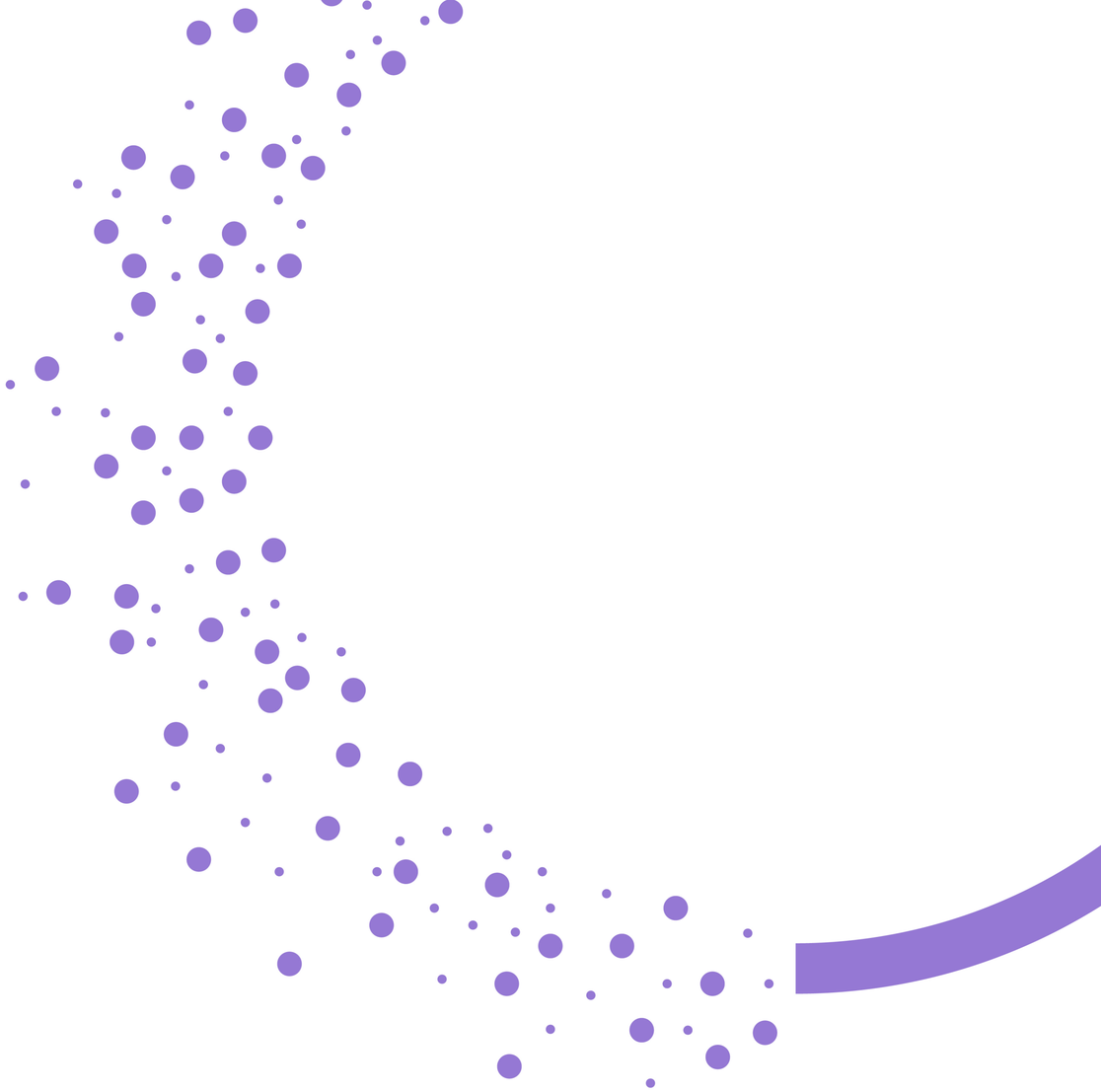
Our contributions
Cryptanalysis



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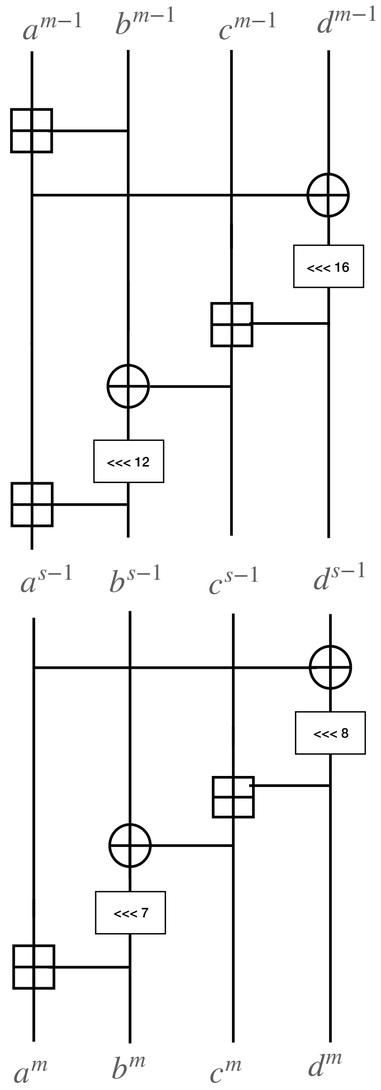
New Linear Approximations for ChaCha

Reducing the number of rules

- [Choudhuri and Maitra FSE'17]
  - 8 rules
- [Coutinho et al EUROCRYPT'21]
  - 18 rules
- This work
  - 3 rules



Attacking 7 rounds ChaCha

Differential-Linear distinguisher ChaCha

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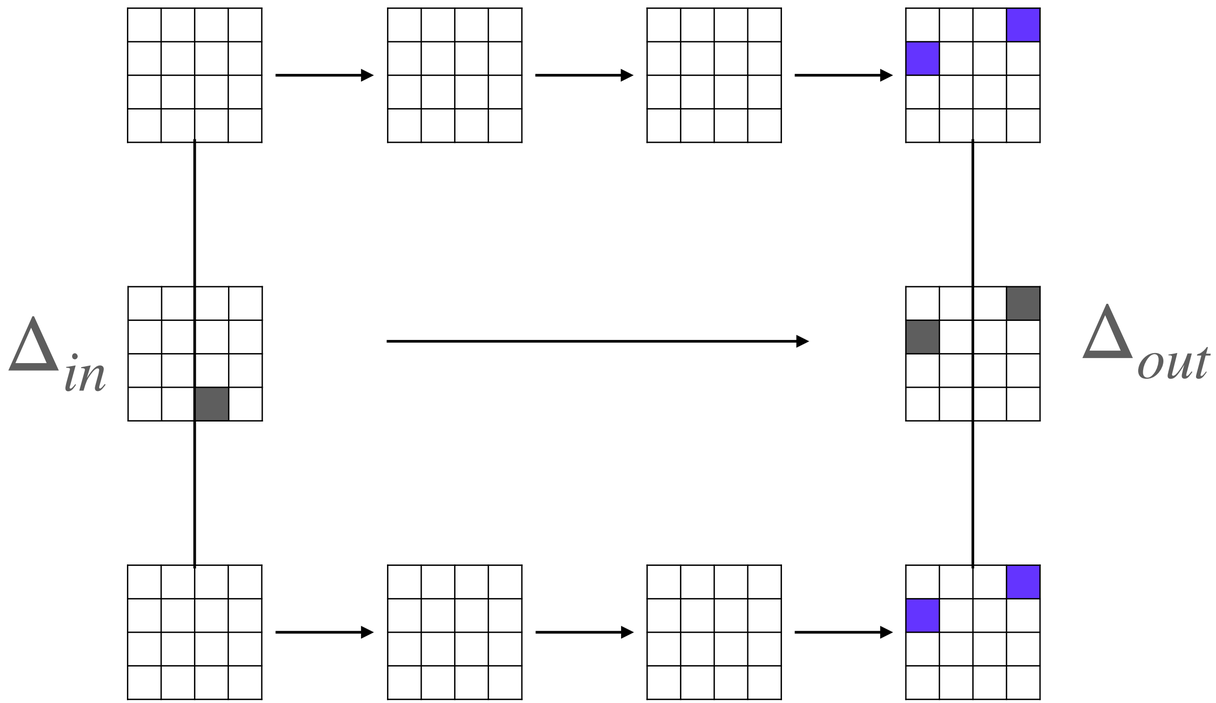

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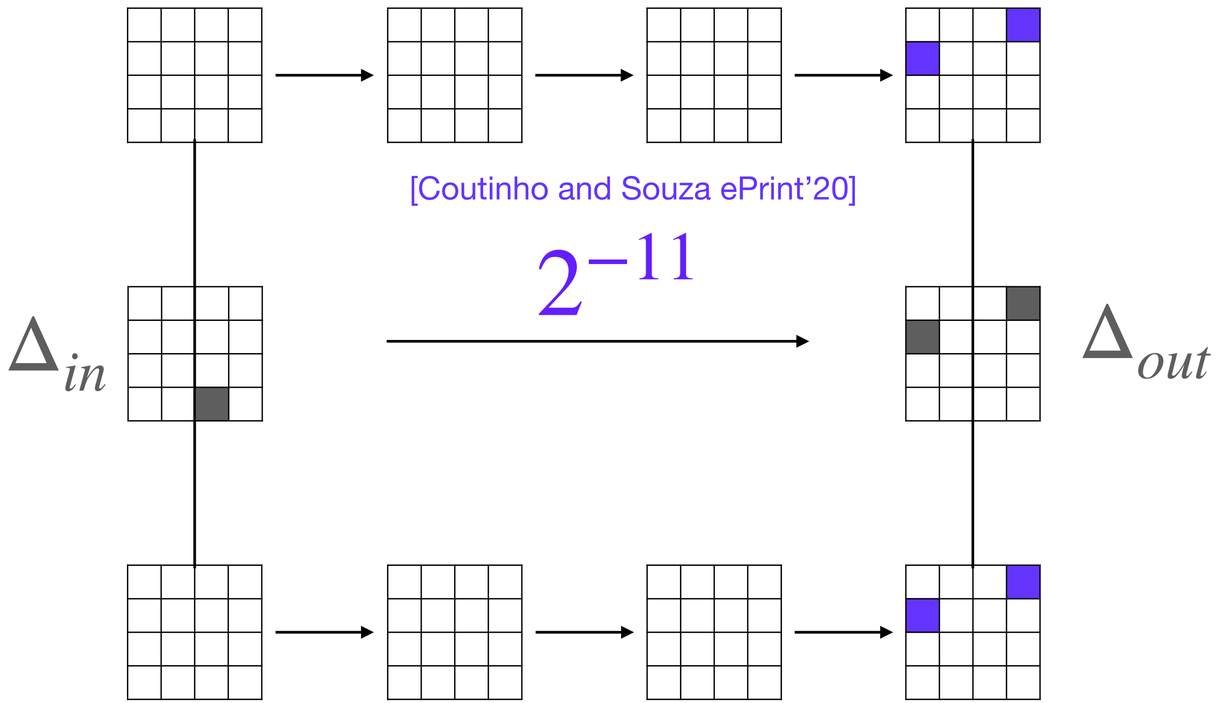

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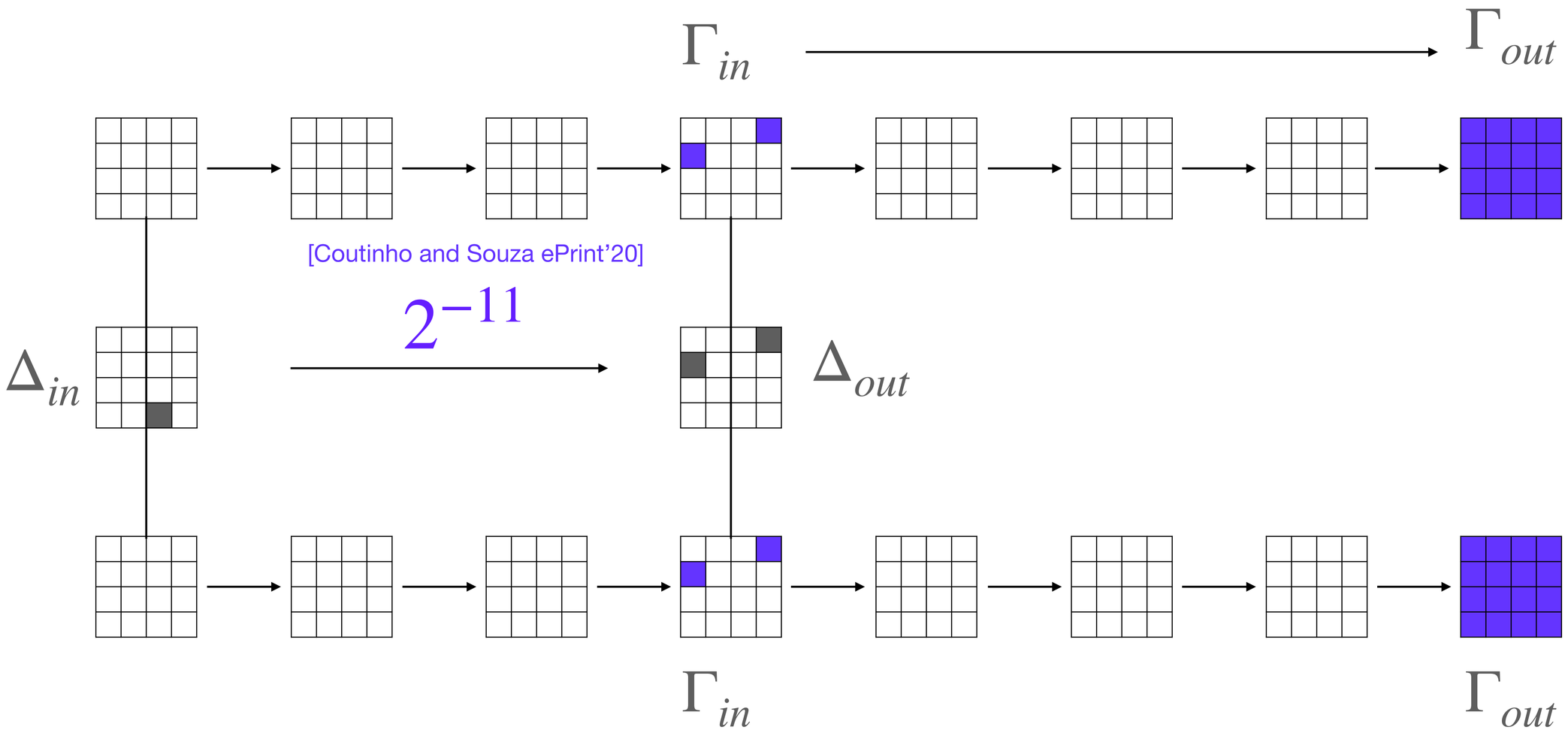

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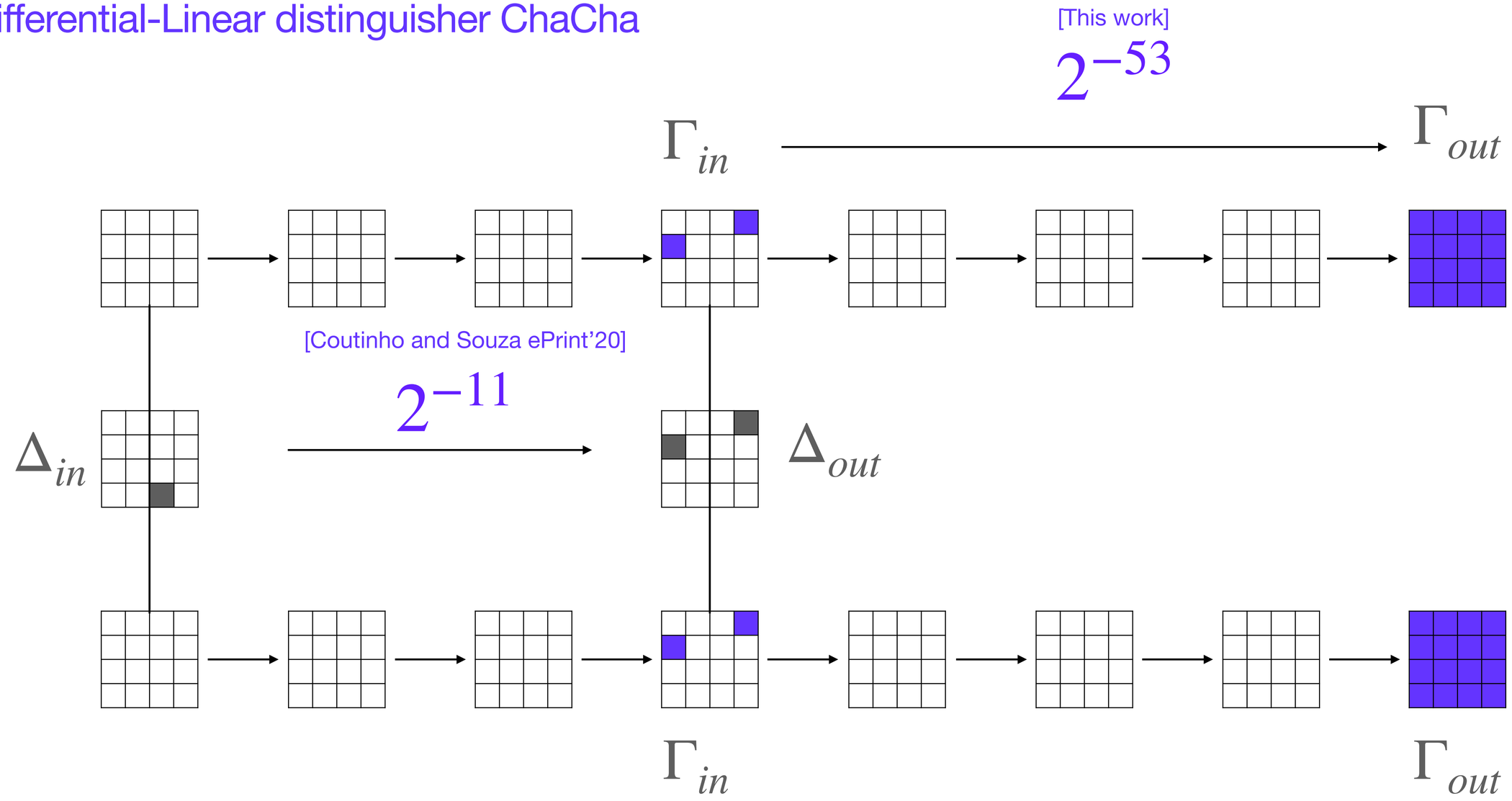

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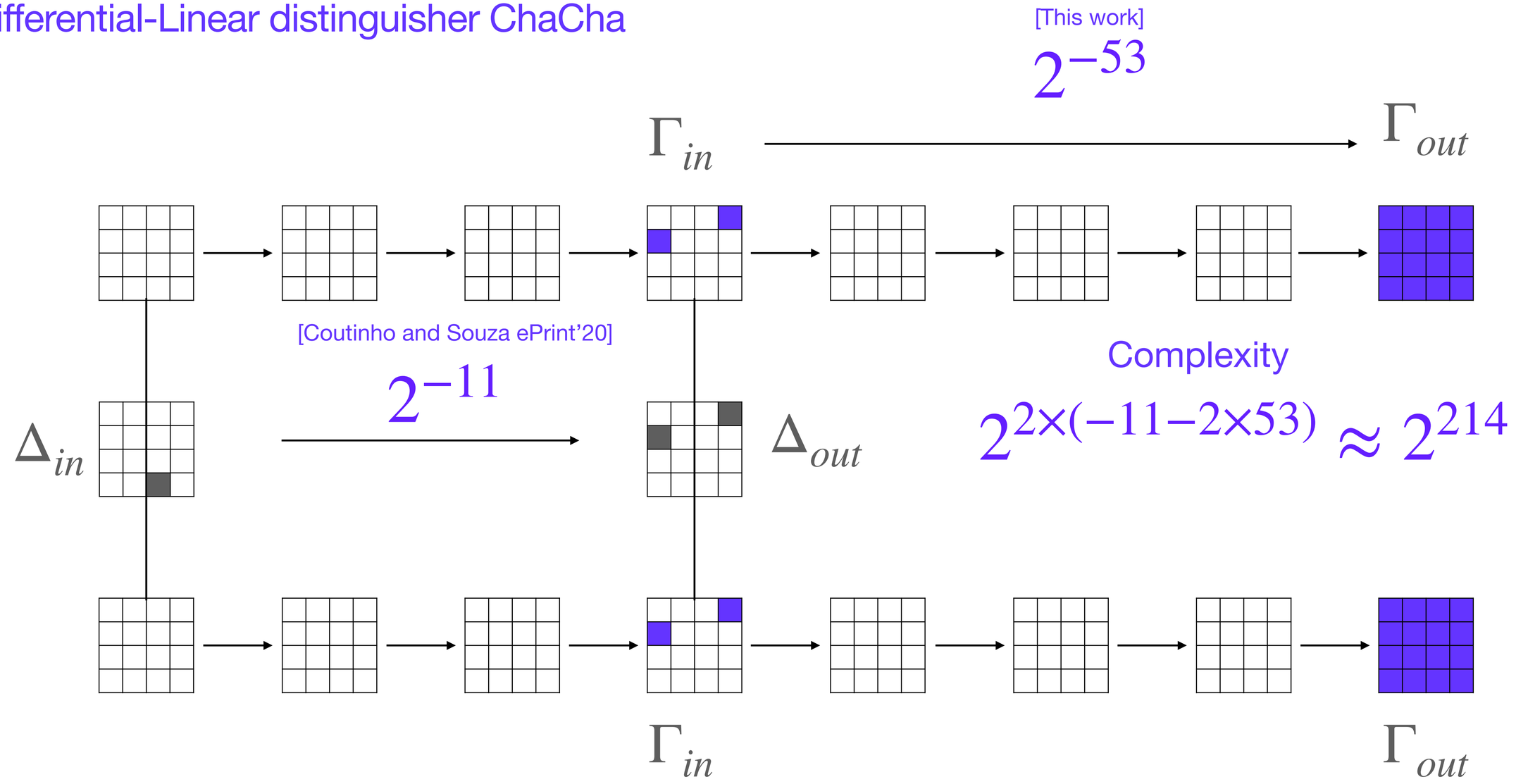

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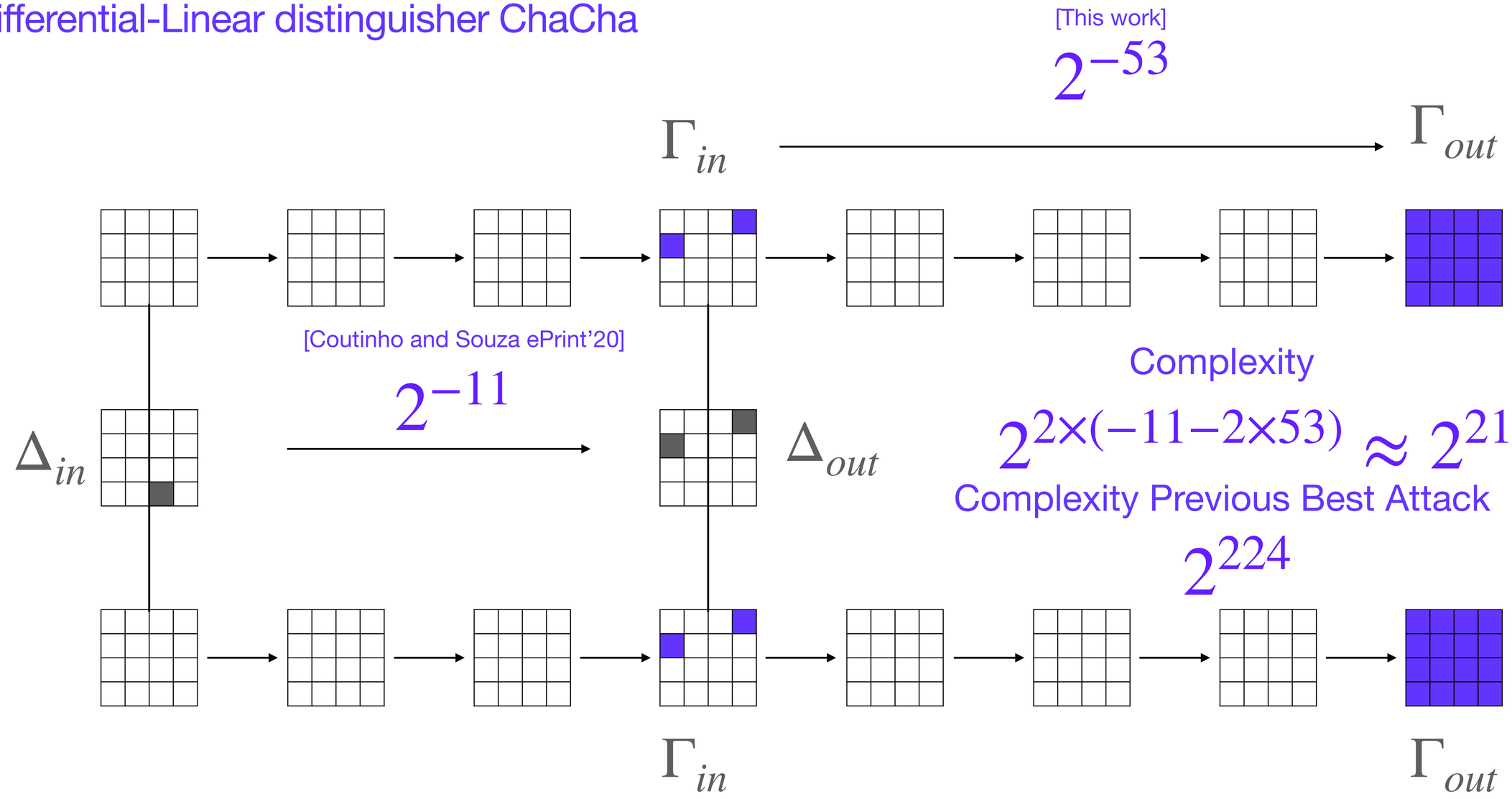

Complexity

$2^{2\times(-11-2\times53)} \approx 2^{214}$

Complexity Previous Best Attack

2^{224}

Attacking 8 rounds of Salsa

Bidirectional Linear Expansion (BLE)

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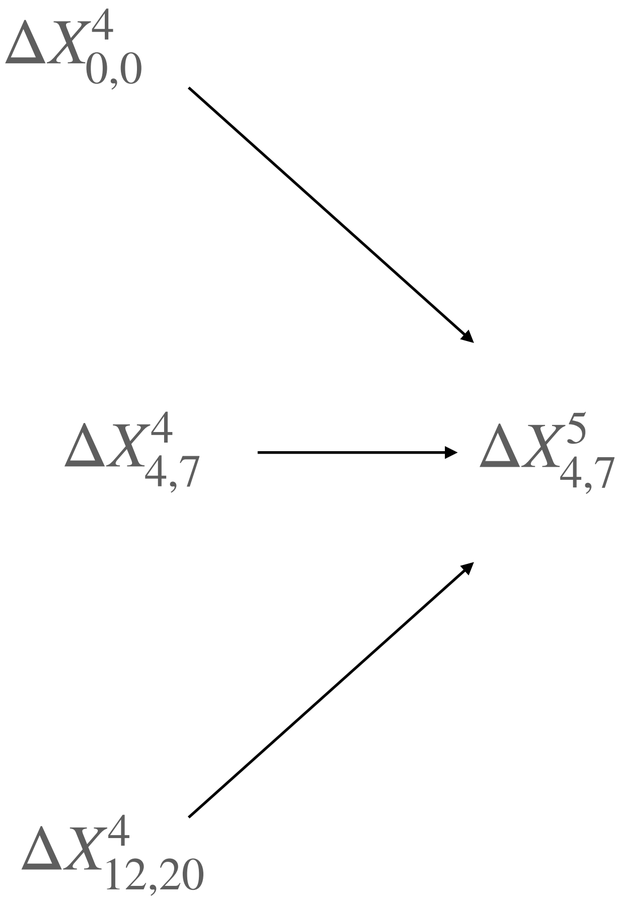
$$\Delta X^5_{4,7}$$

Attacking 8 rounds of Salsa

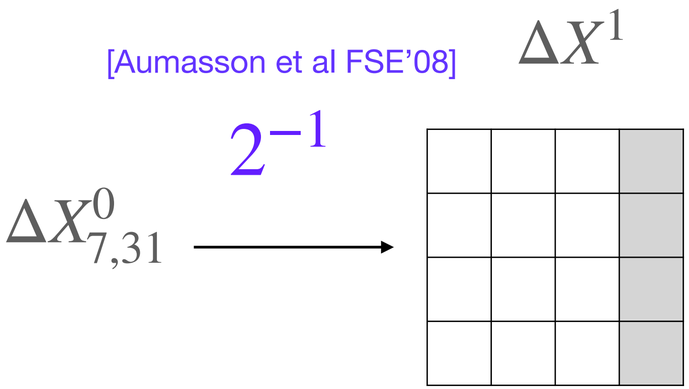
Bidirectional Linear Expansion (BLE)

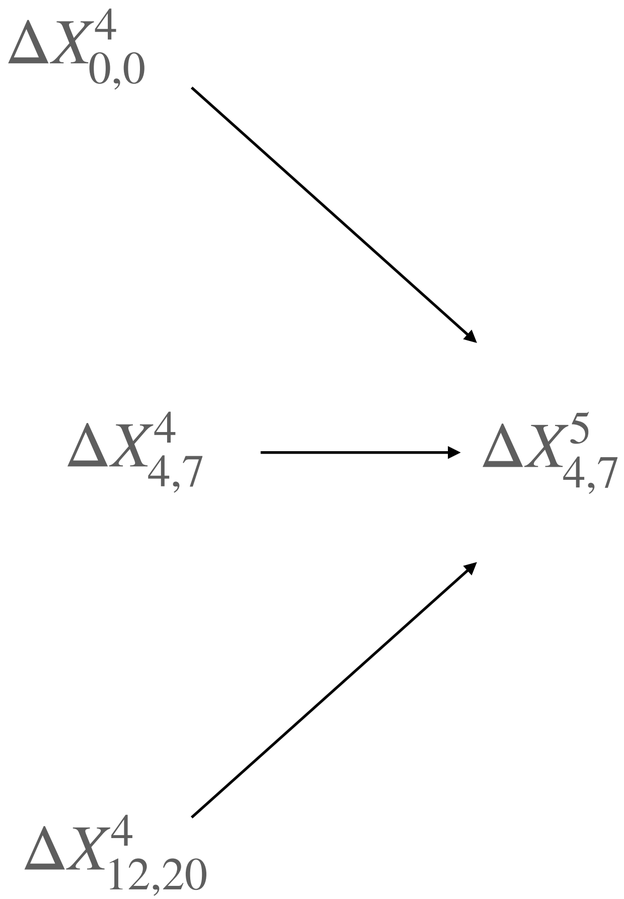


Attacking 8 rounds of Salsa

Bidirectional Linear Expansion (BLE)

[Aumasson et al FSE'08]





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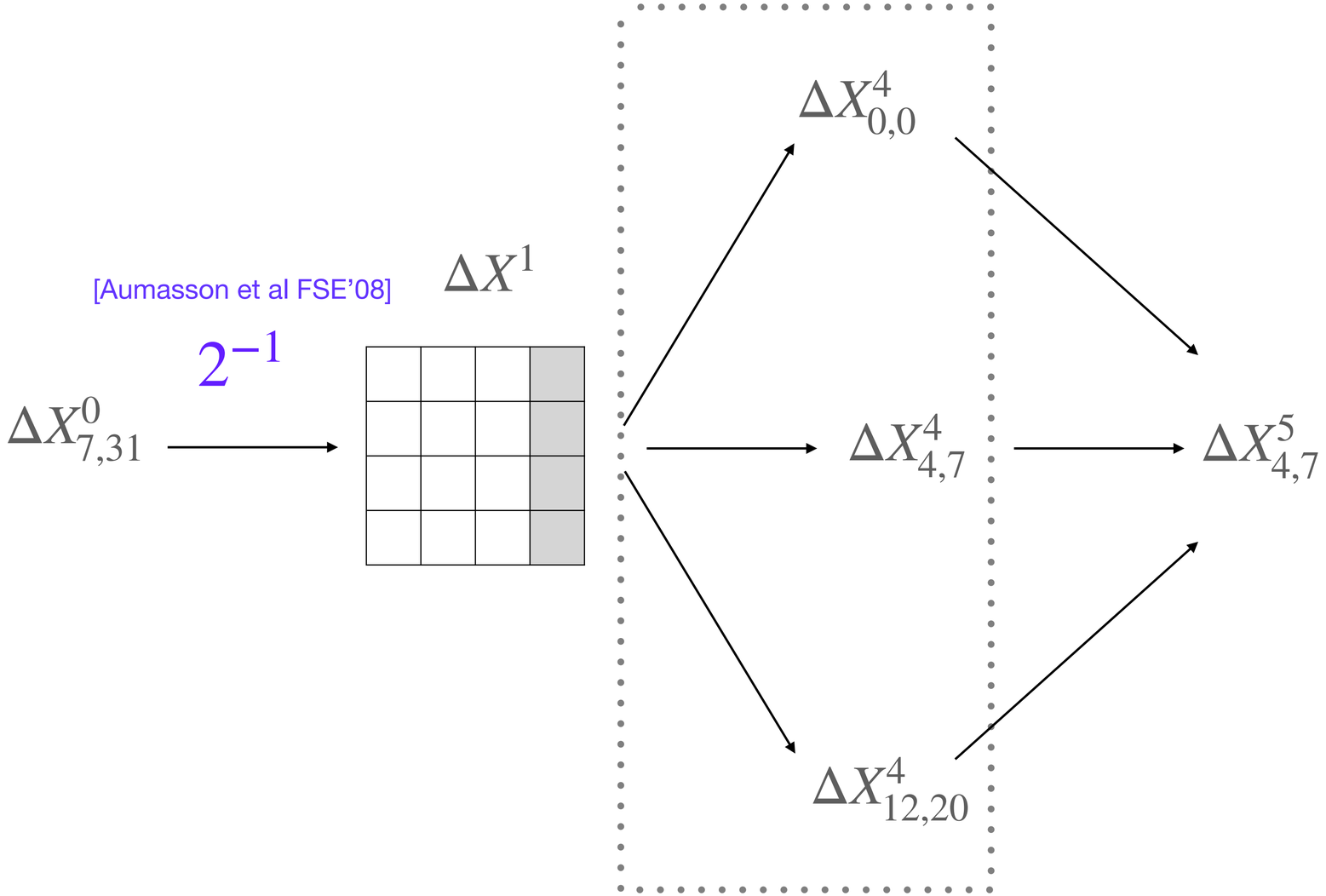

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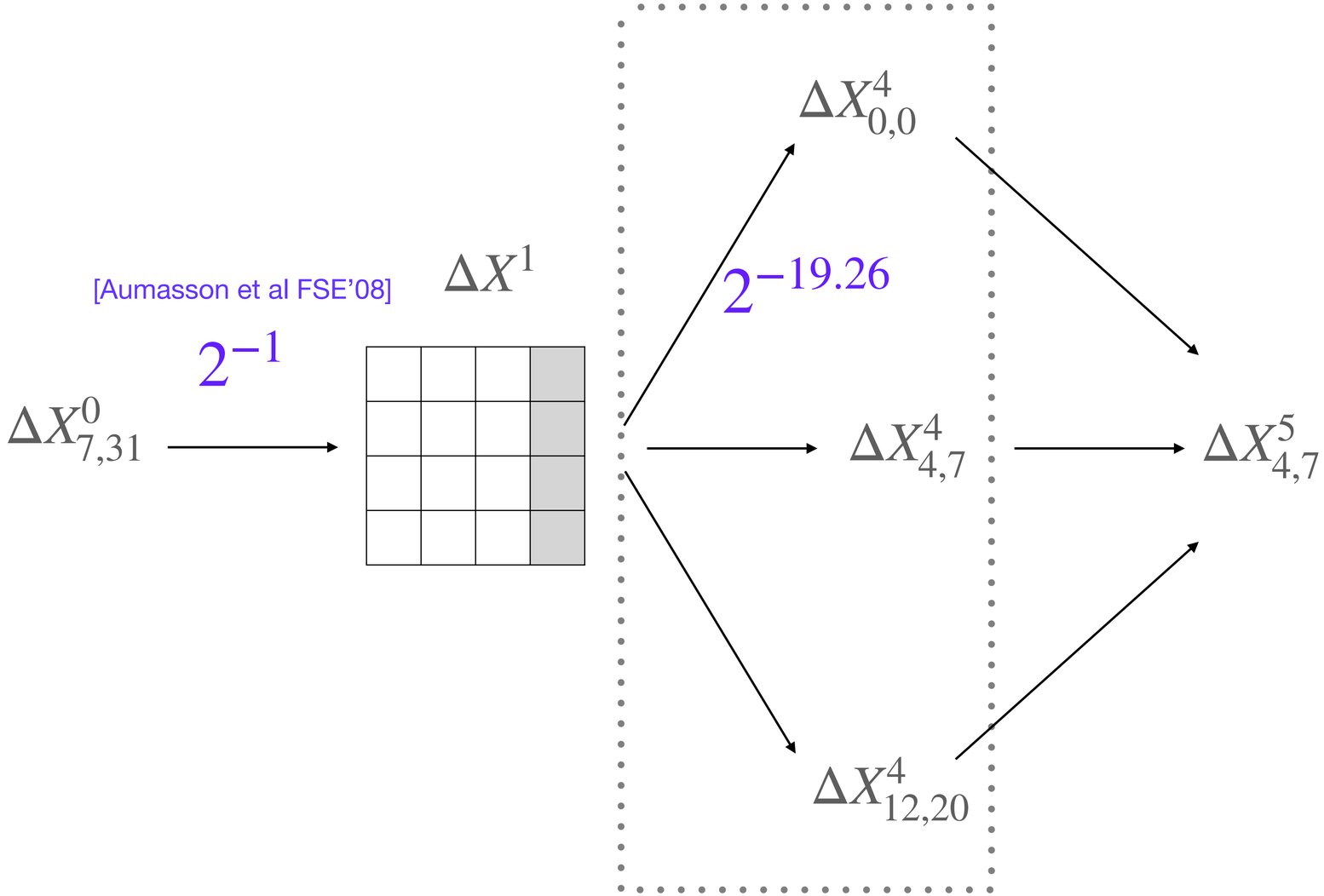

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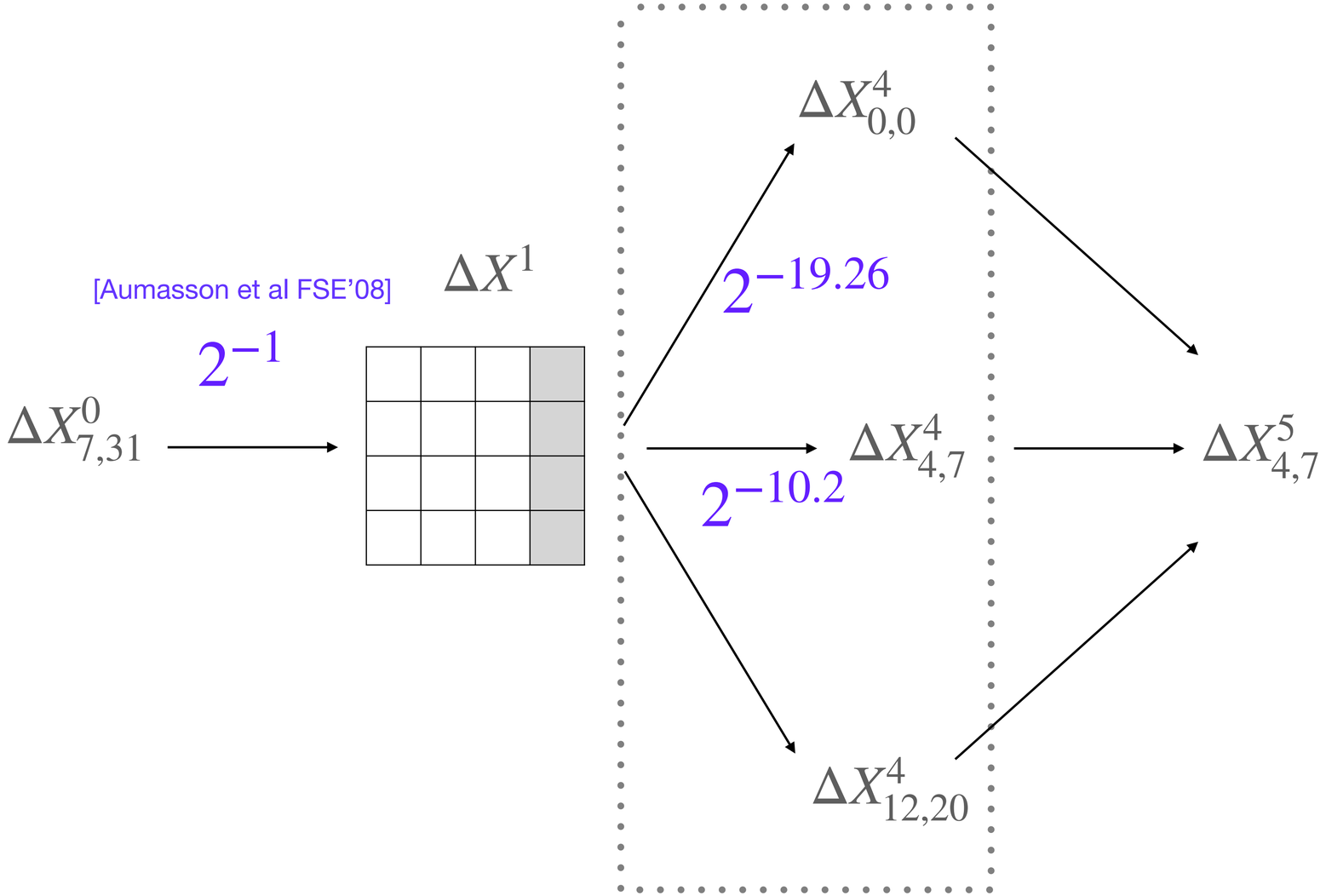

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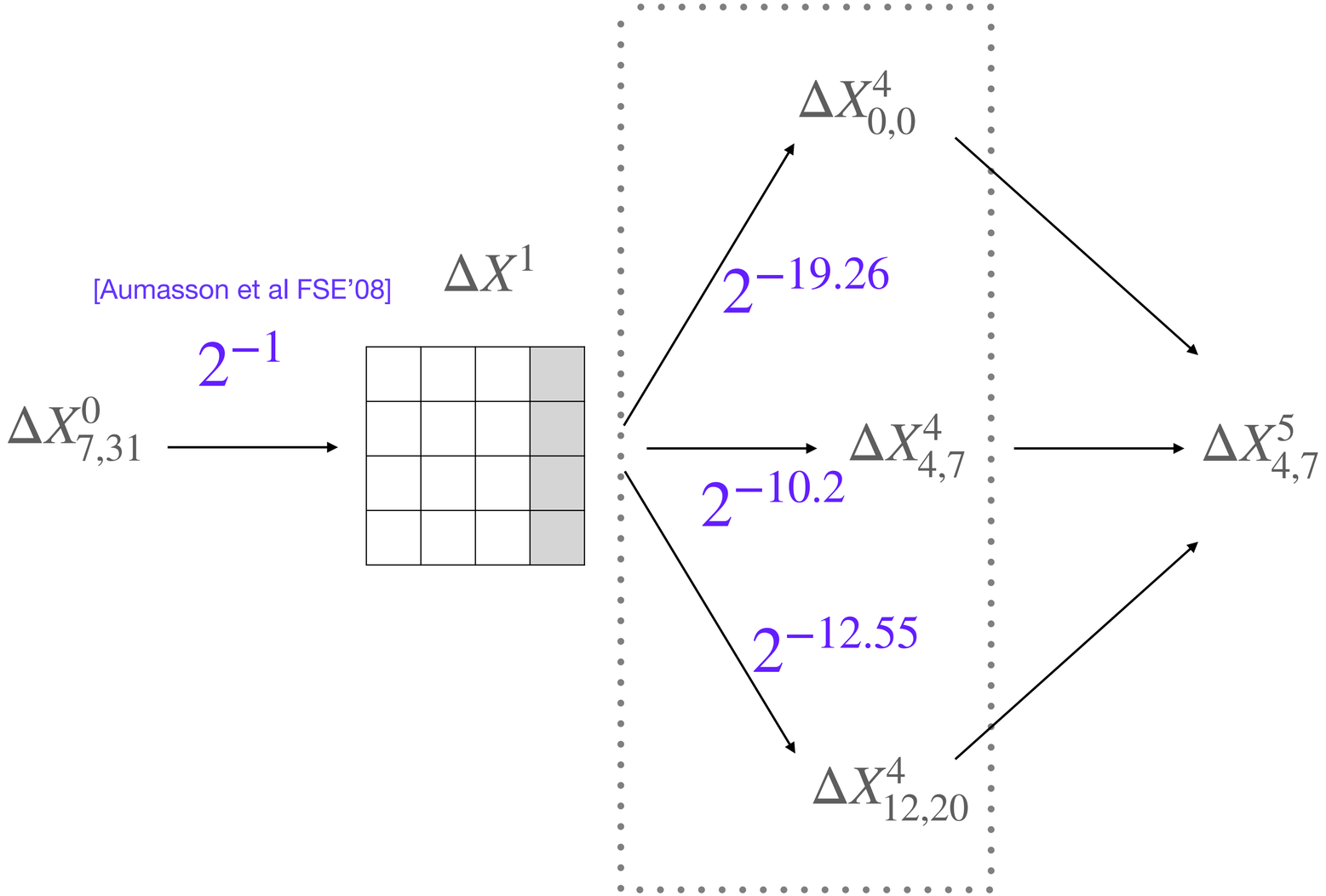

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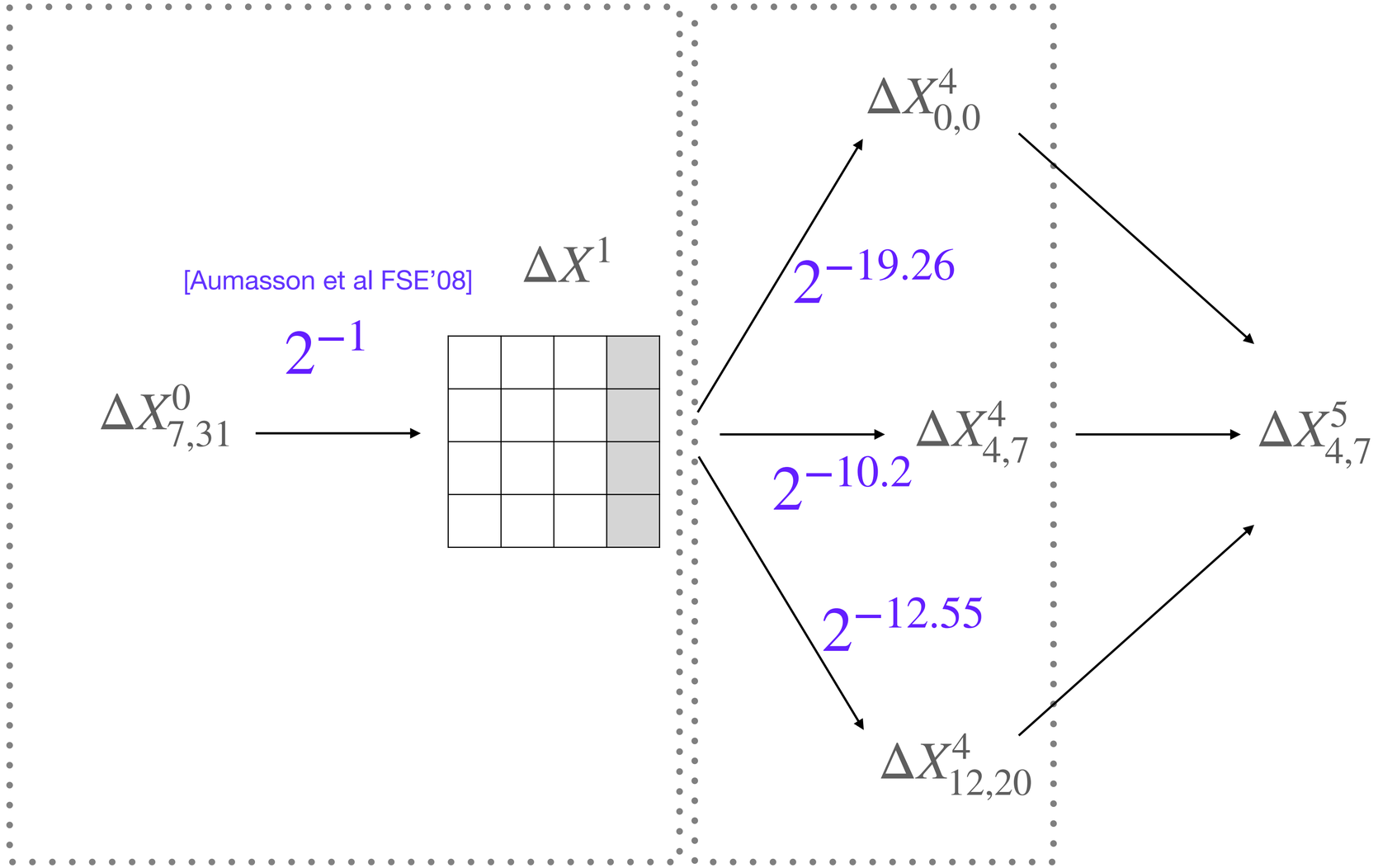

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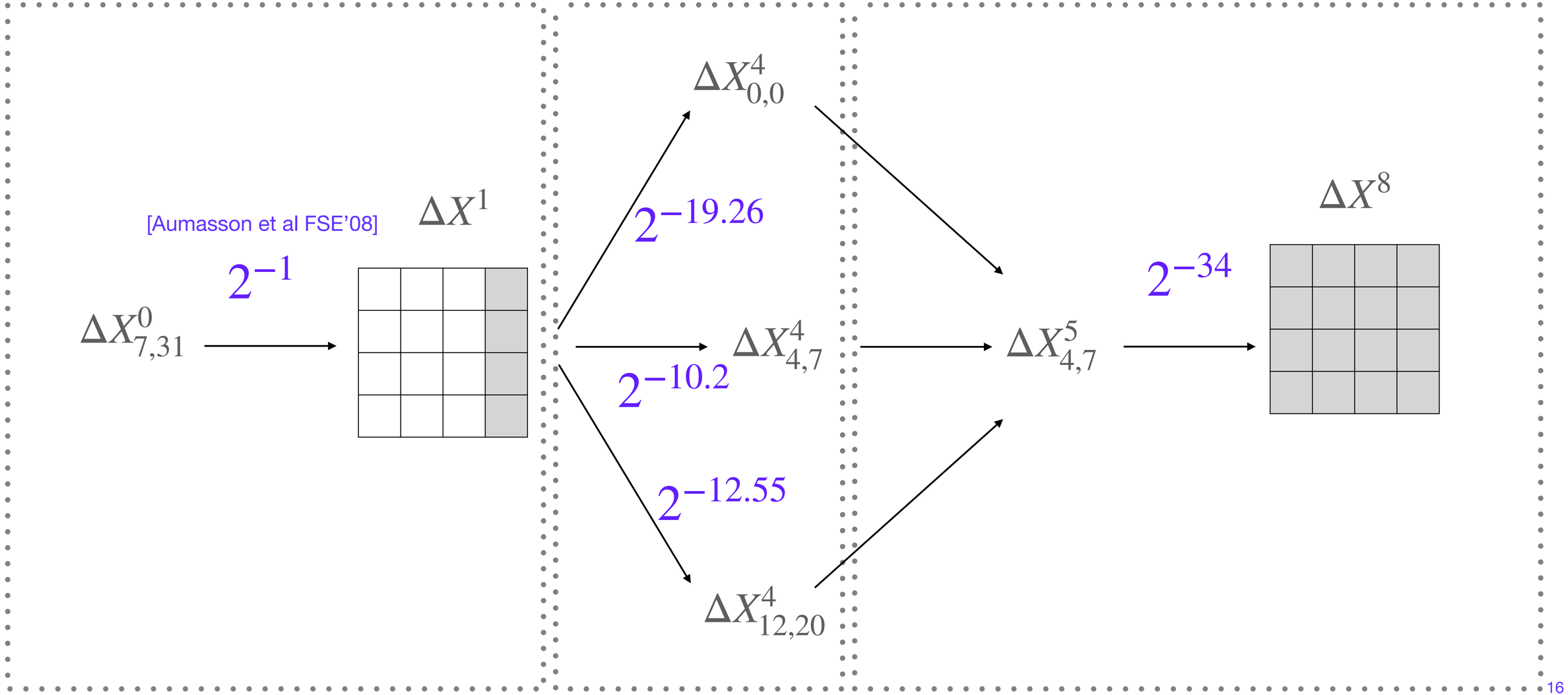

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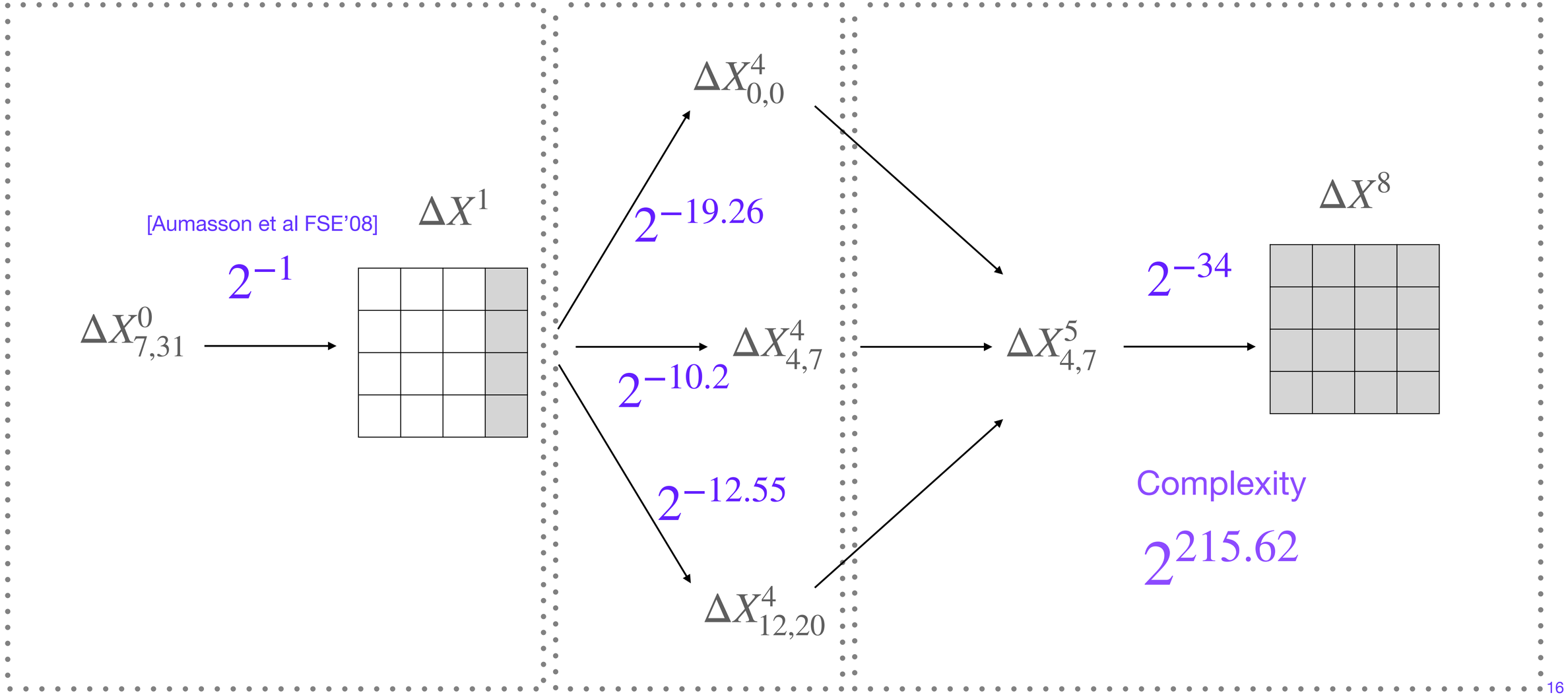

Attacking Salsa

Differential-Linear distinguisher Salsa

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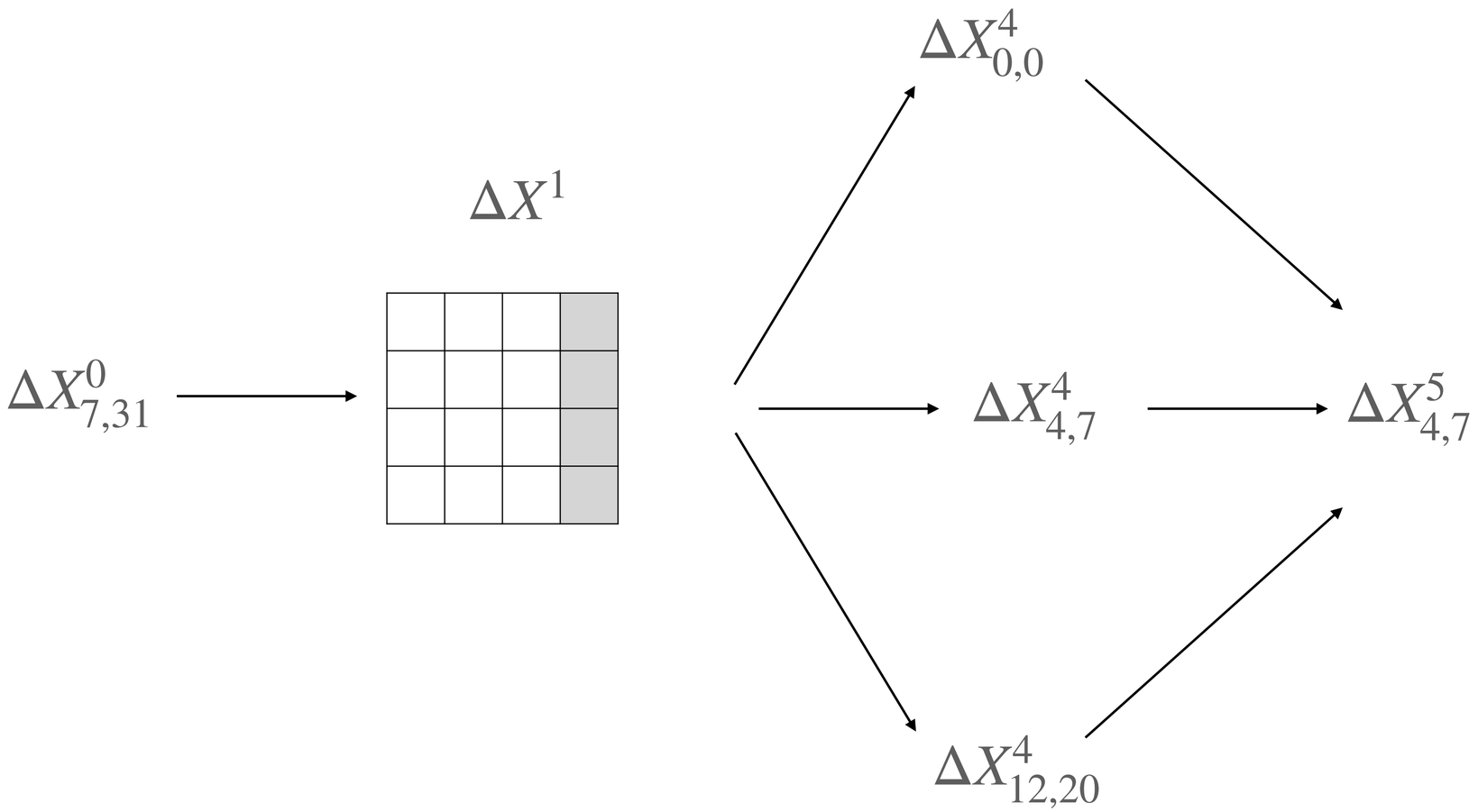

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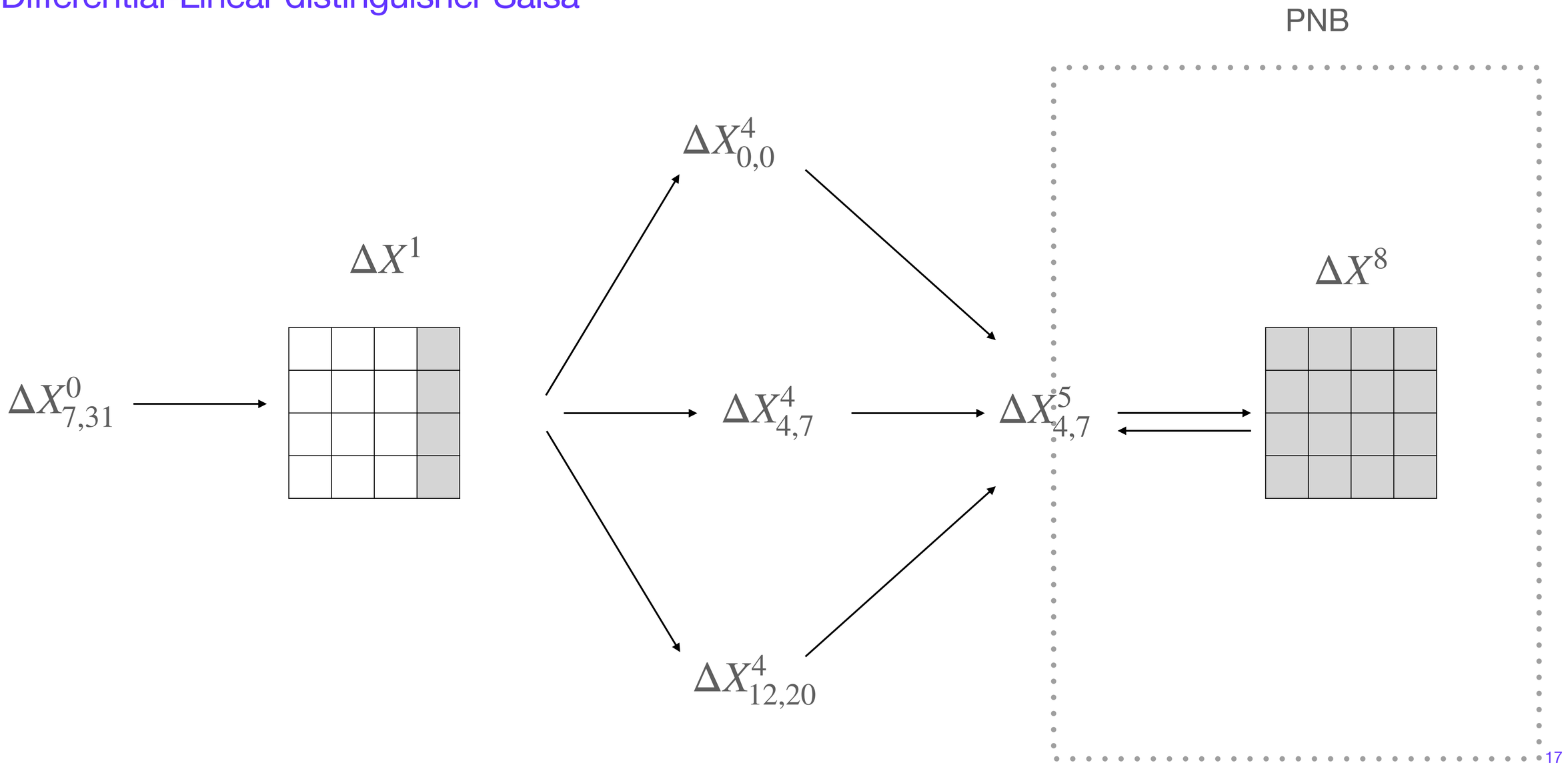

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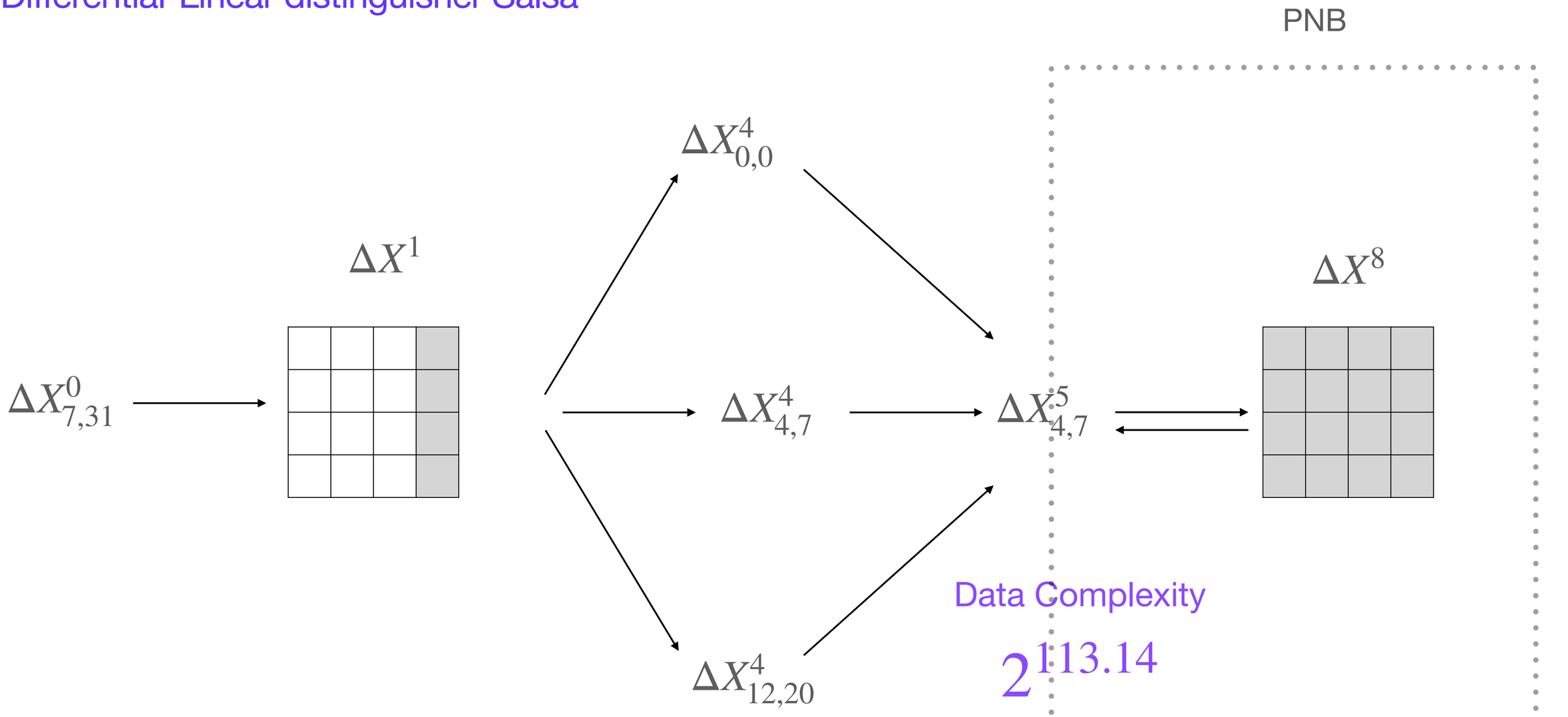
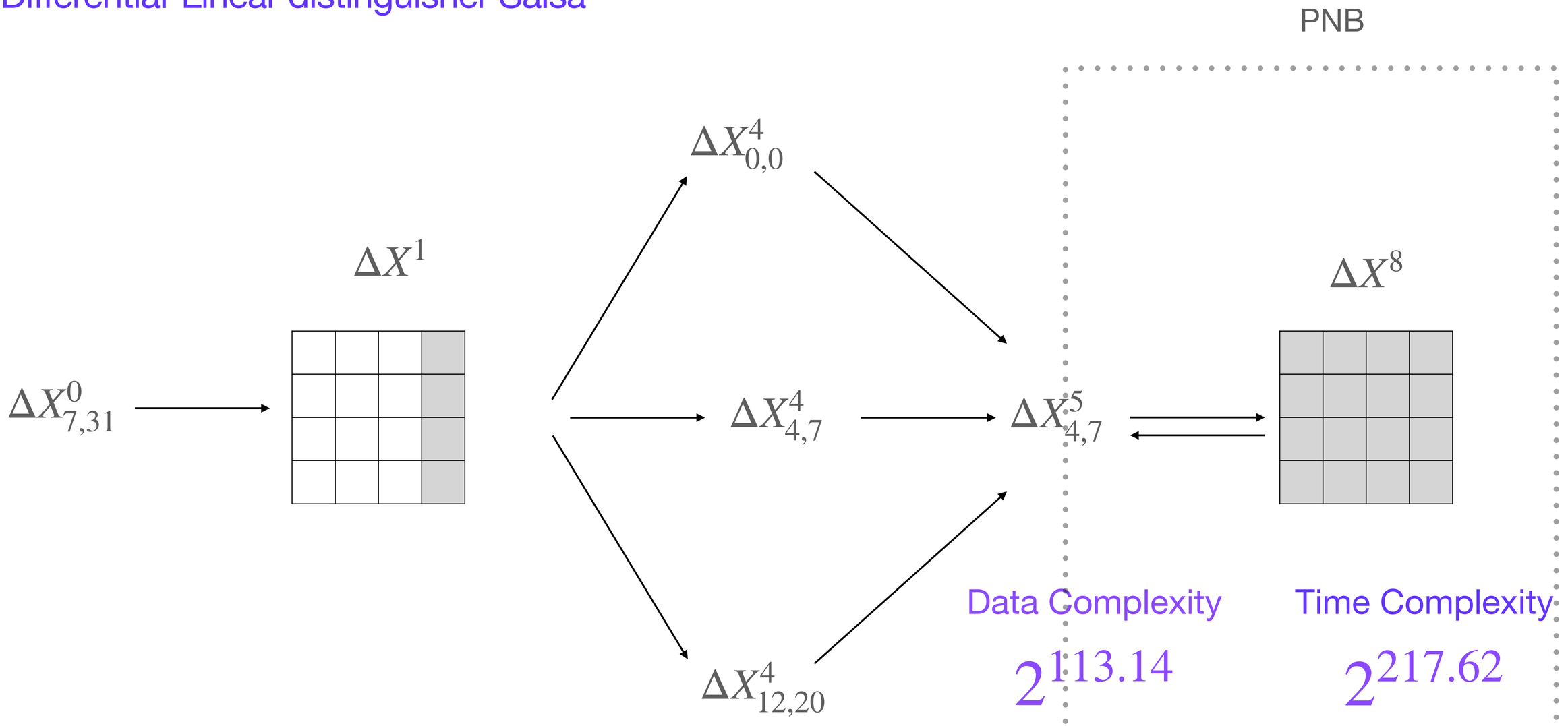


Data Complexity

$2^{113.14}$

Attacking Salsa

Differential-Linear distinguisher Salsa



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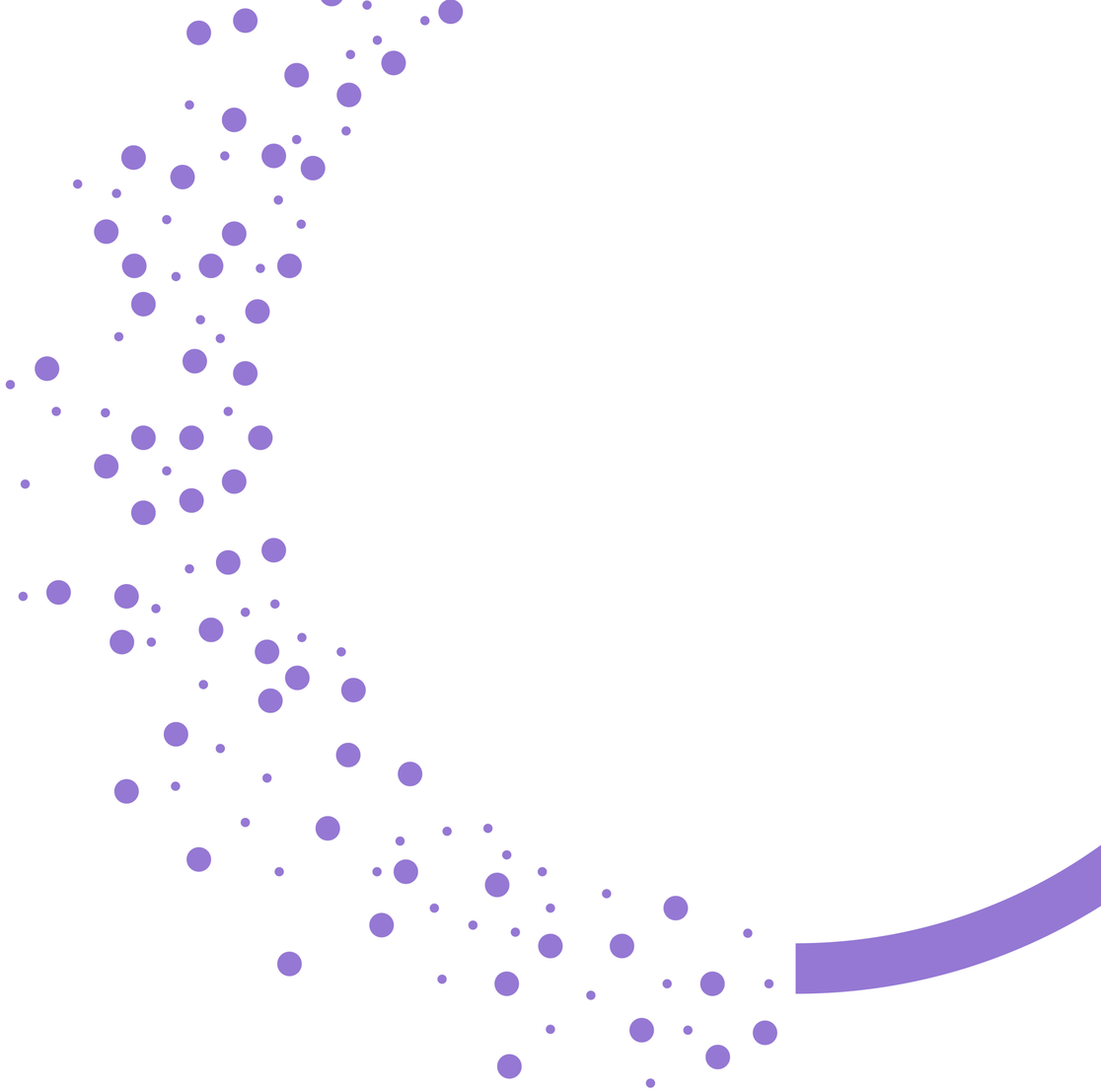
Our contributions

New cipher Forró



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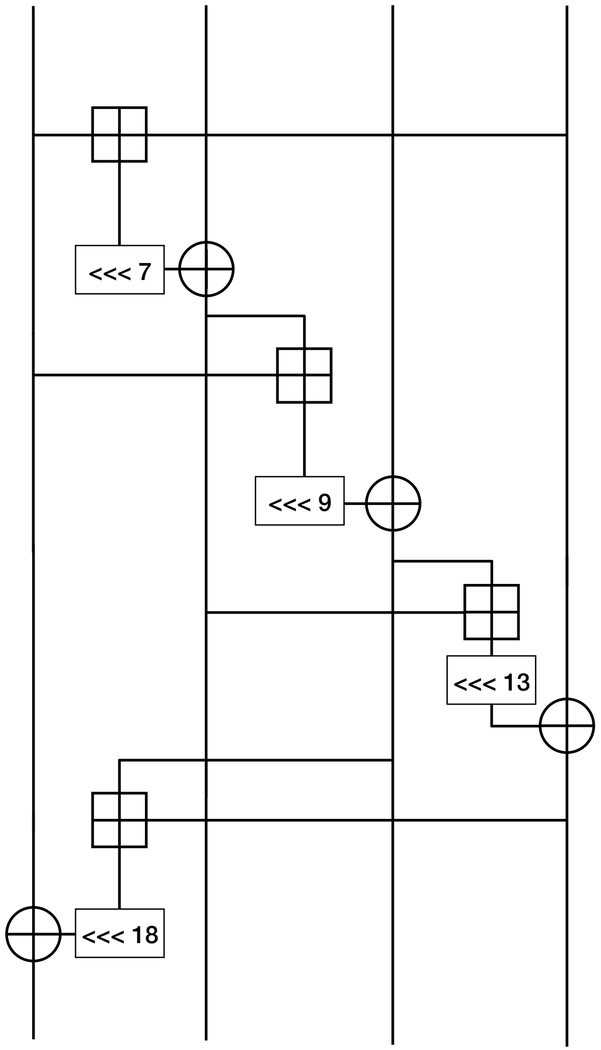
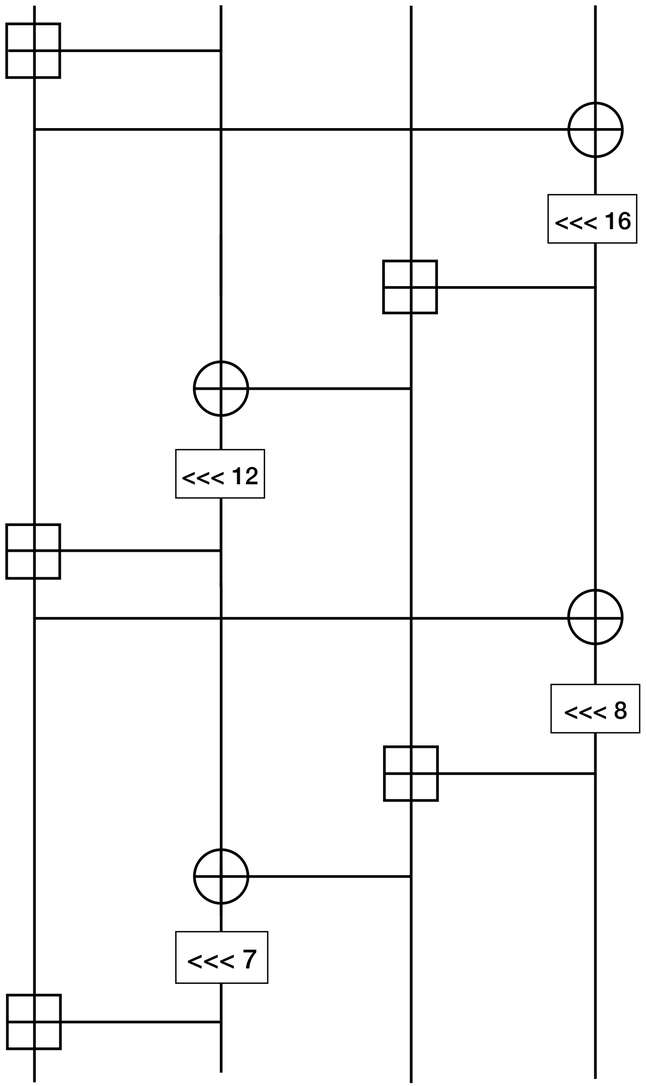
Salsa and ChaCha

Quarter Rounds

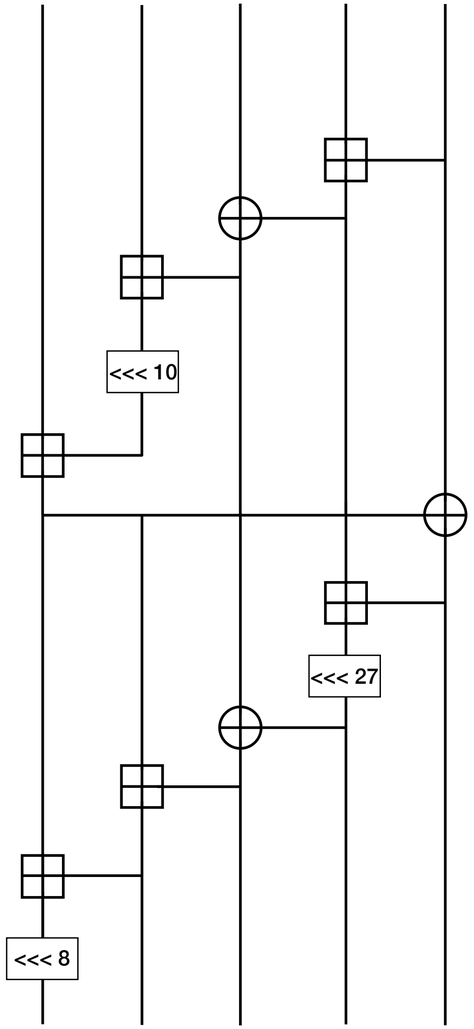




Forró

Description

- 256 key bits
- Same number of components as ChaCha and Salsa (12 components)
- Daniel J. Bernstein advice [Bernstein, D.J.’08] -> “Replacing some of the rotations with a comparable number of additions might achieve comparable diffusion in less time.”
- Better Diffusion than ChaCha -> Less rounds -> 14 rounds



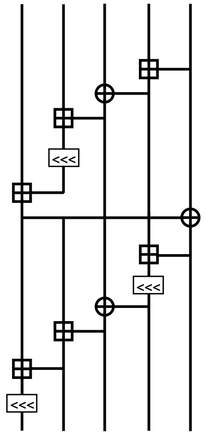
Forró

Design

Forró

Design

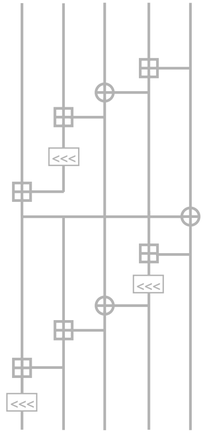
x_0			x_3
x_4			
x_8			
x_{12}			



Forró

Design

x_0			x_3
x_4			
x_8			
x_{12}			



Forró

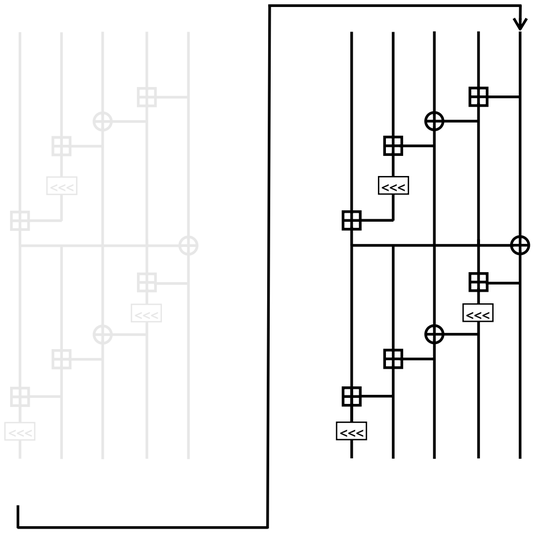
Design

x_0			x_3
x_4			
x_8			
x_{12}			

Forró

Design

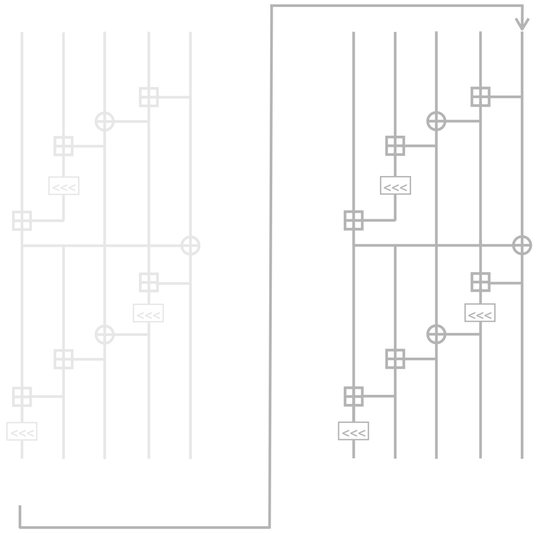
x_0	x_1		x_3
x_4	x_5		
x_8	x_9		
x_{12}	x_{13}		



Forró

Design

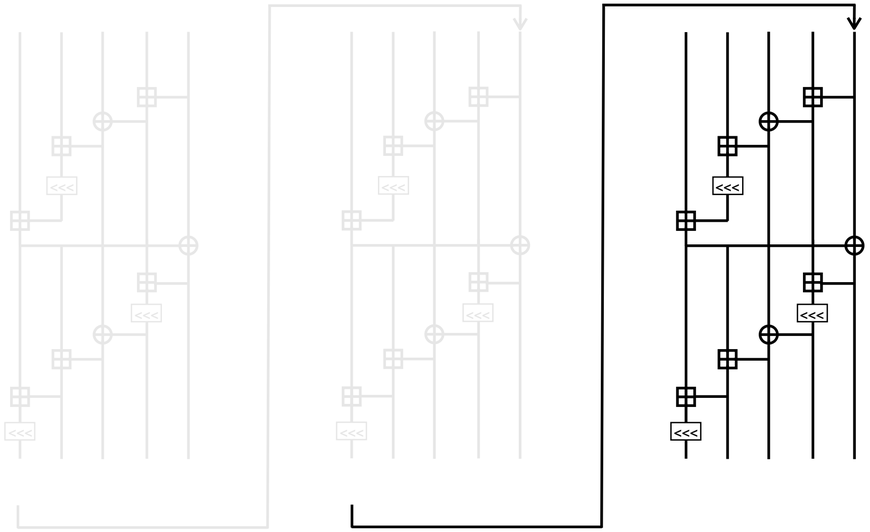
x_0	x_1		x_3
x_4	x_5		
x_8	x_9		
x_{12}	x_{13}		



Forró

Design

x_0	x_1	x_2	x_3
x_4	x_5	x_6	
x_8	x_9	x_{10}	
x_{12}	x_{13}	x_{14}	



Forró

Design

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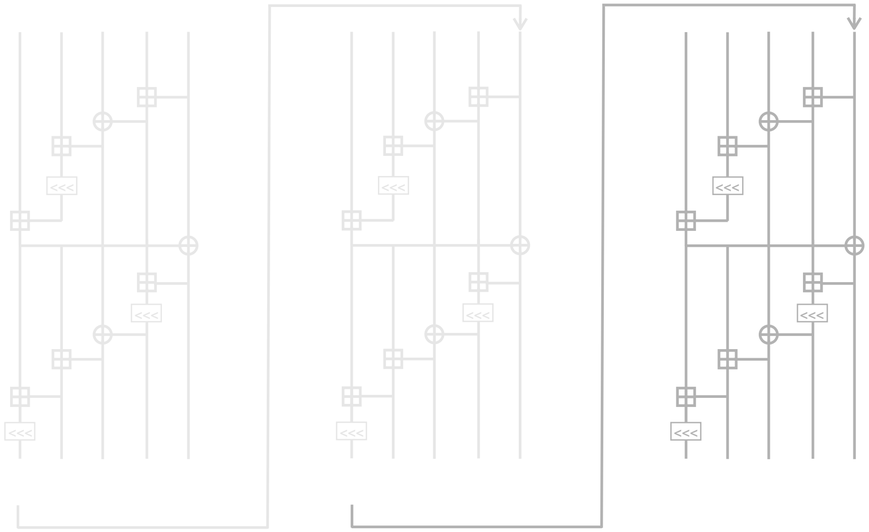
x_4	x_5	x_6	
x_8	x_9	x_{10}	
x_{12}	x_{13}	x_{14}	



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Forró

Design

x_0	x_1	x_2	x_3
x_4	x_5	x_6	x_7
x_8	x_9	x_{10}	x_{11}
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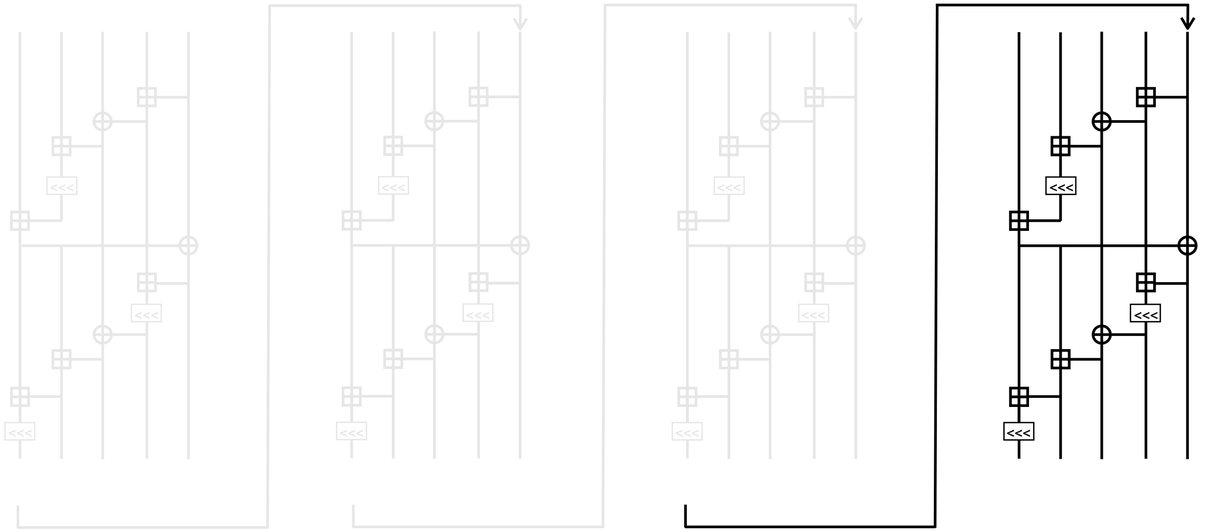

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Design

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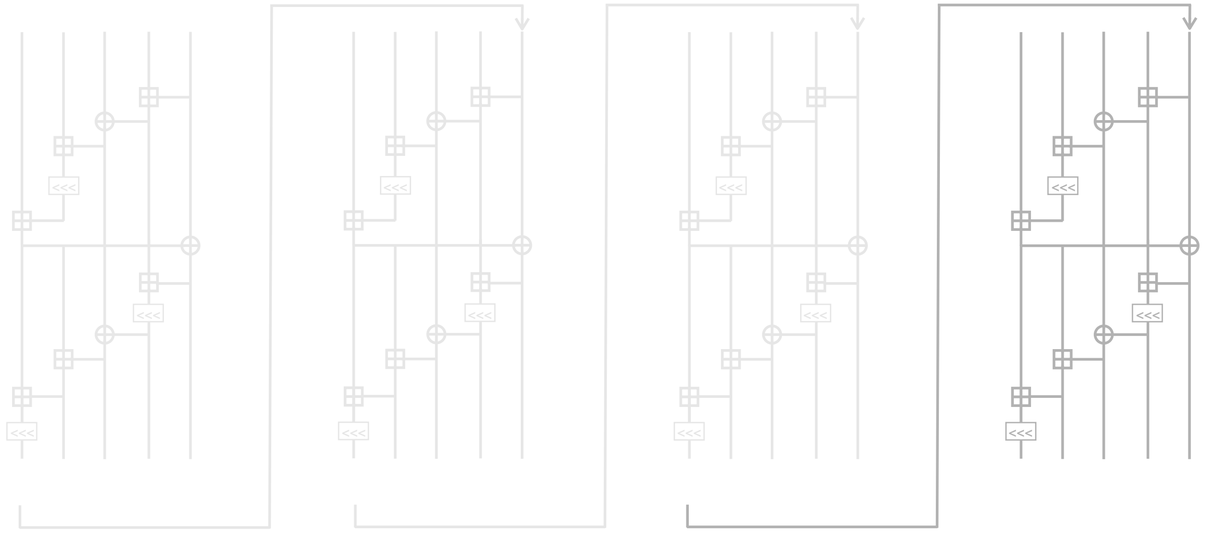

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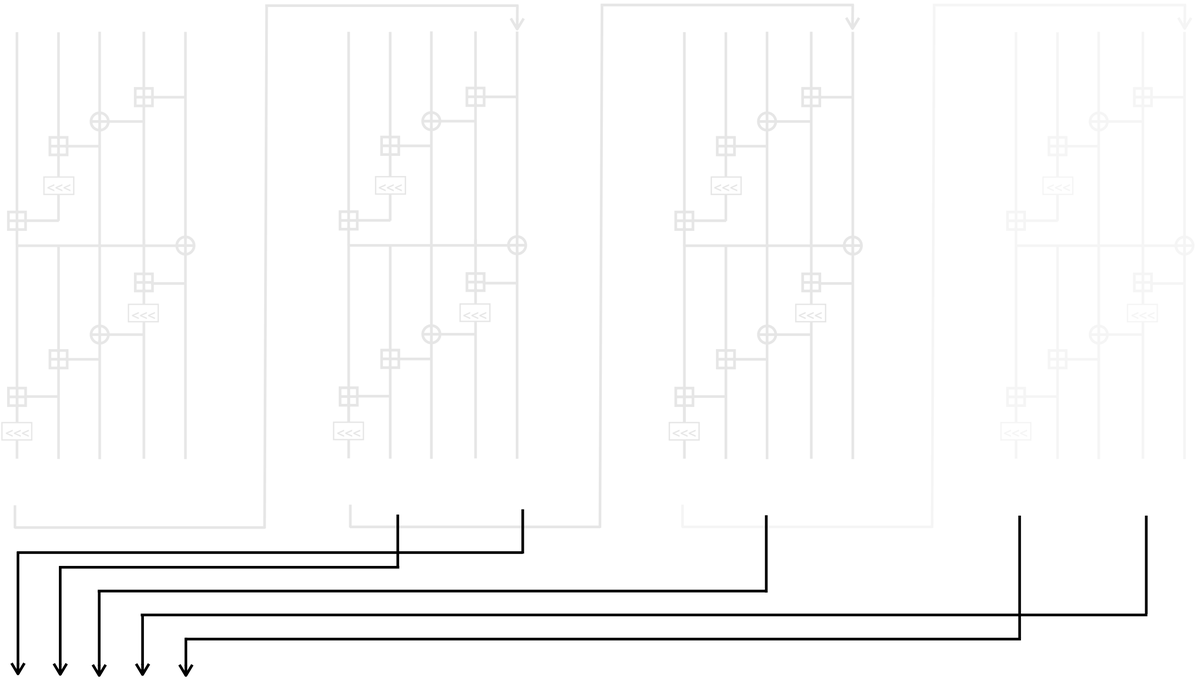

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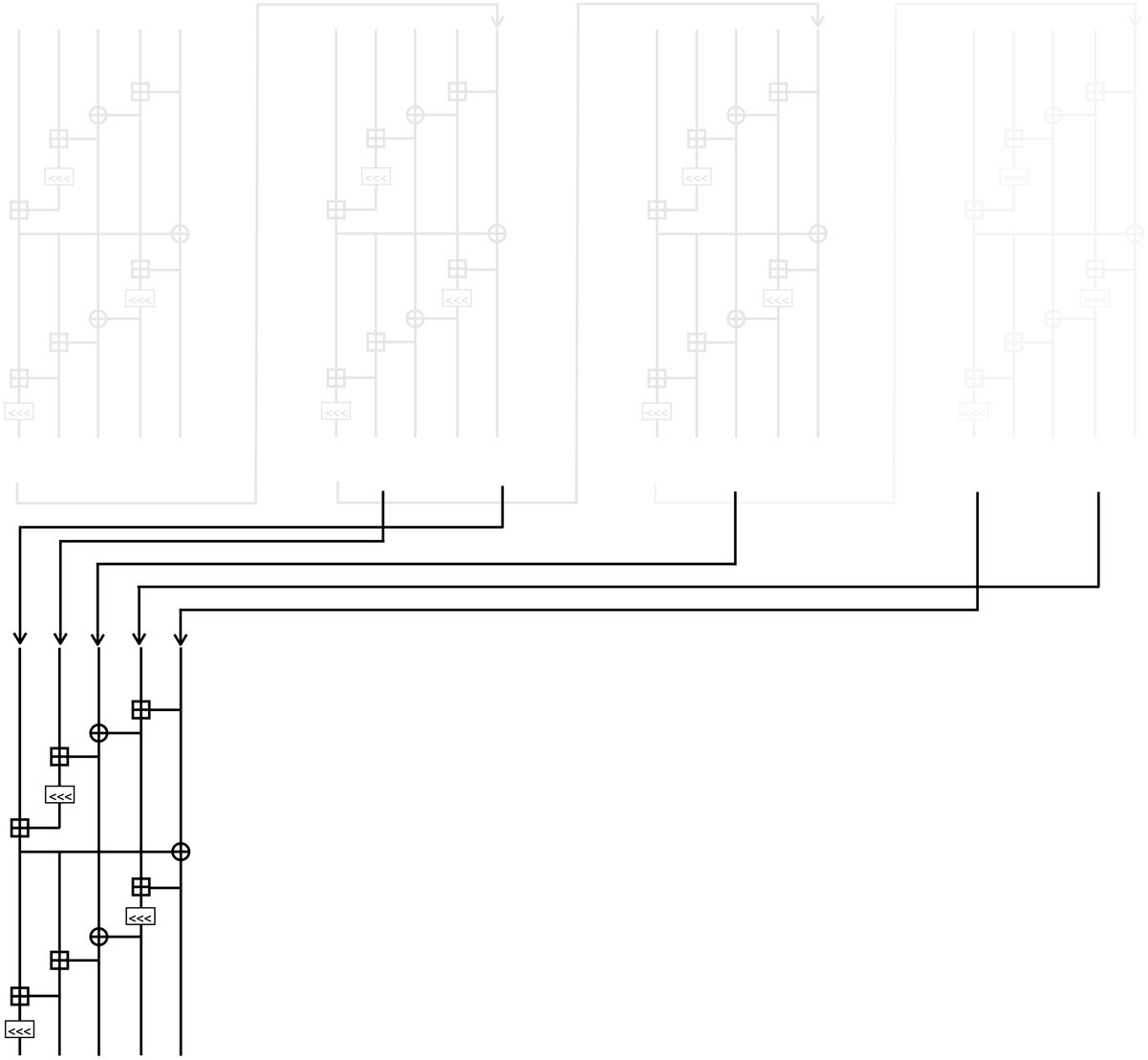

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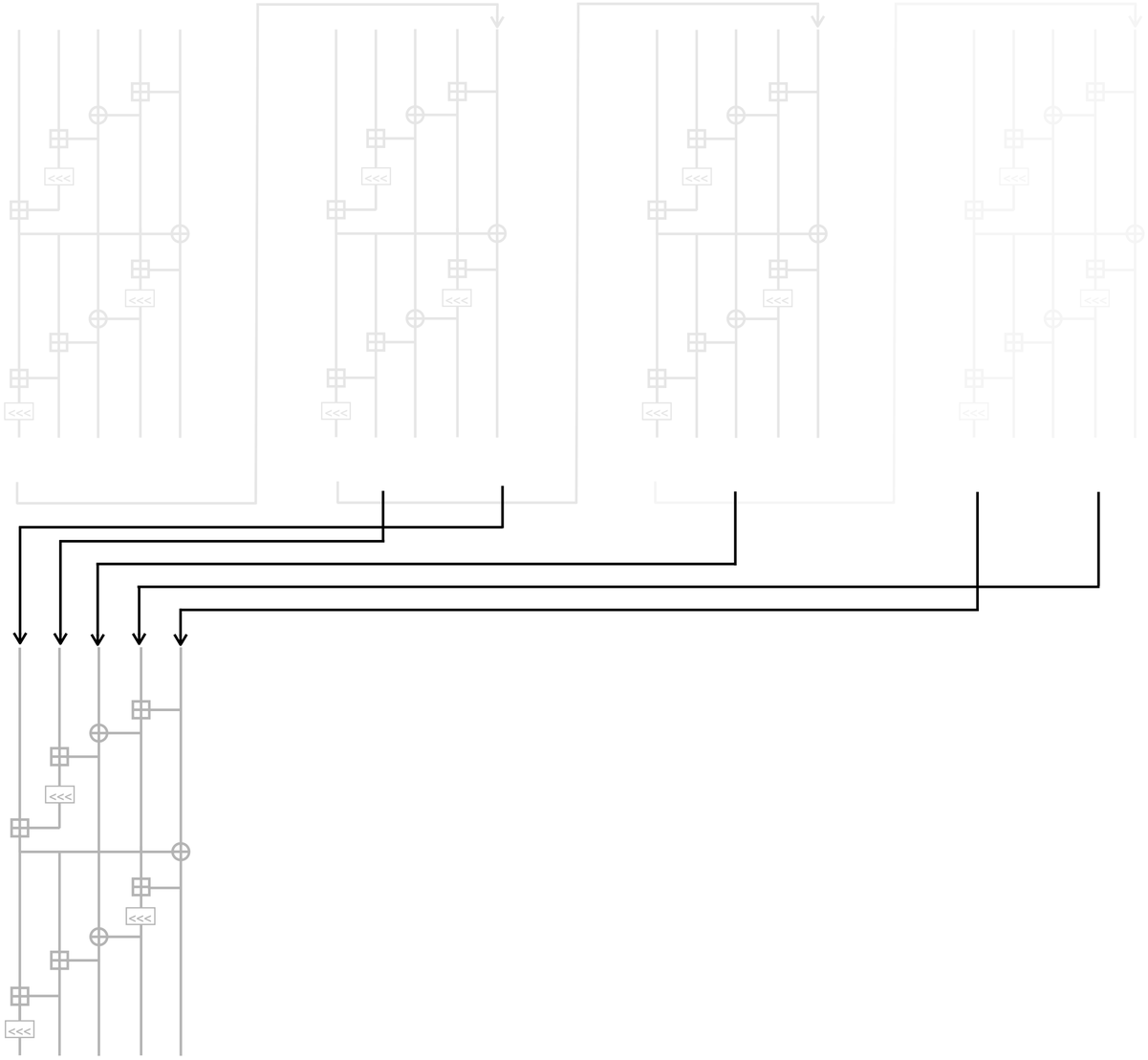

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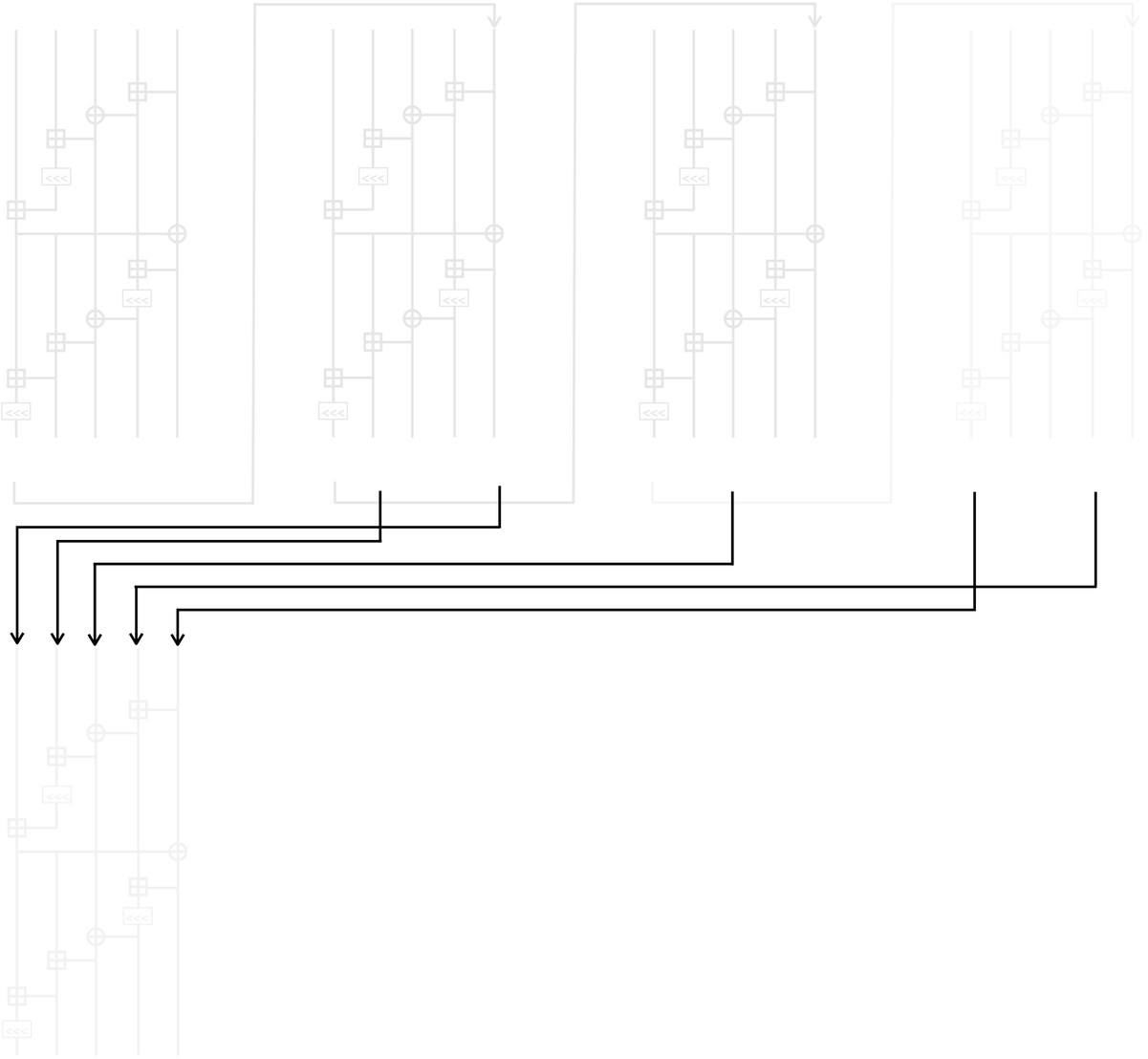

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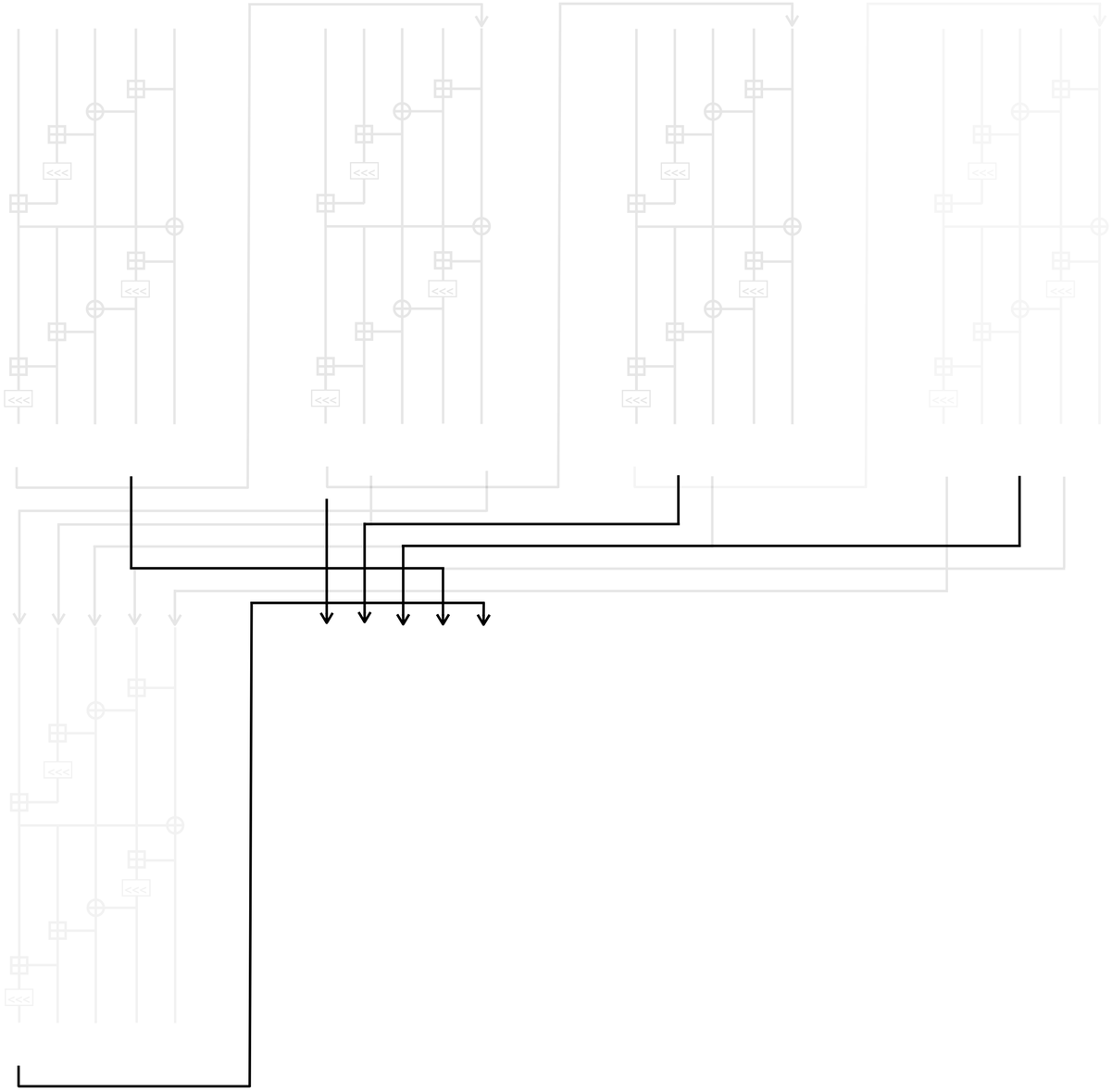

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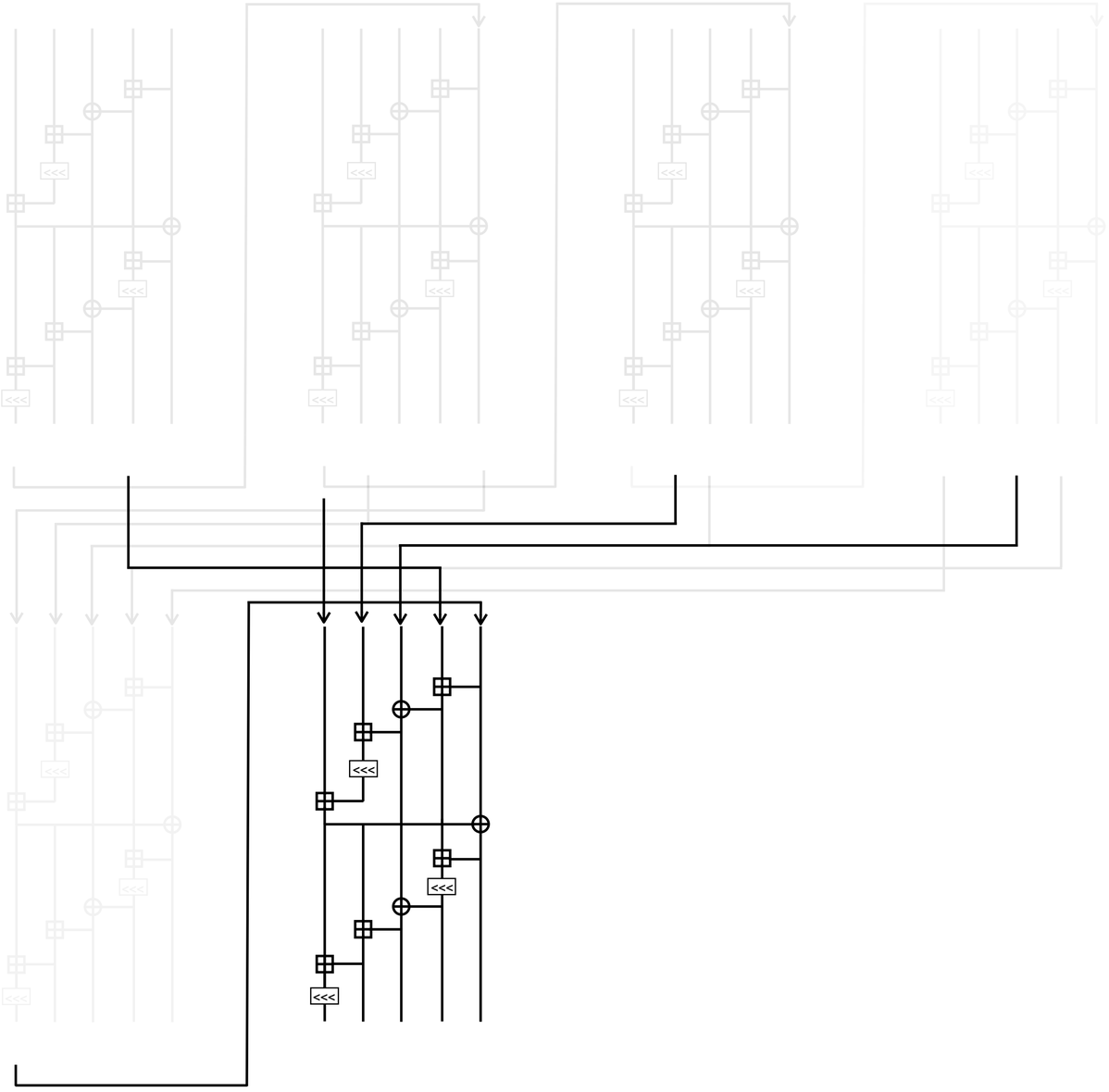

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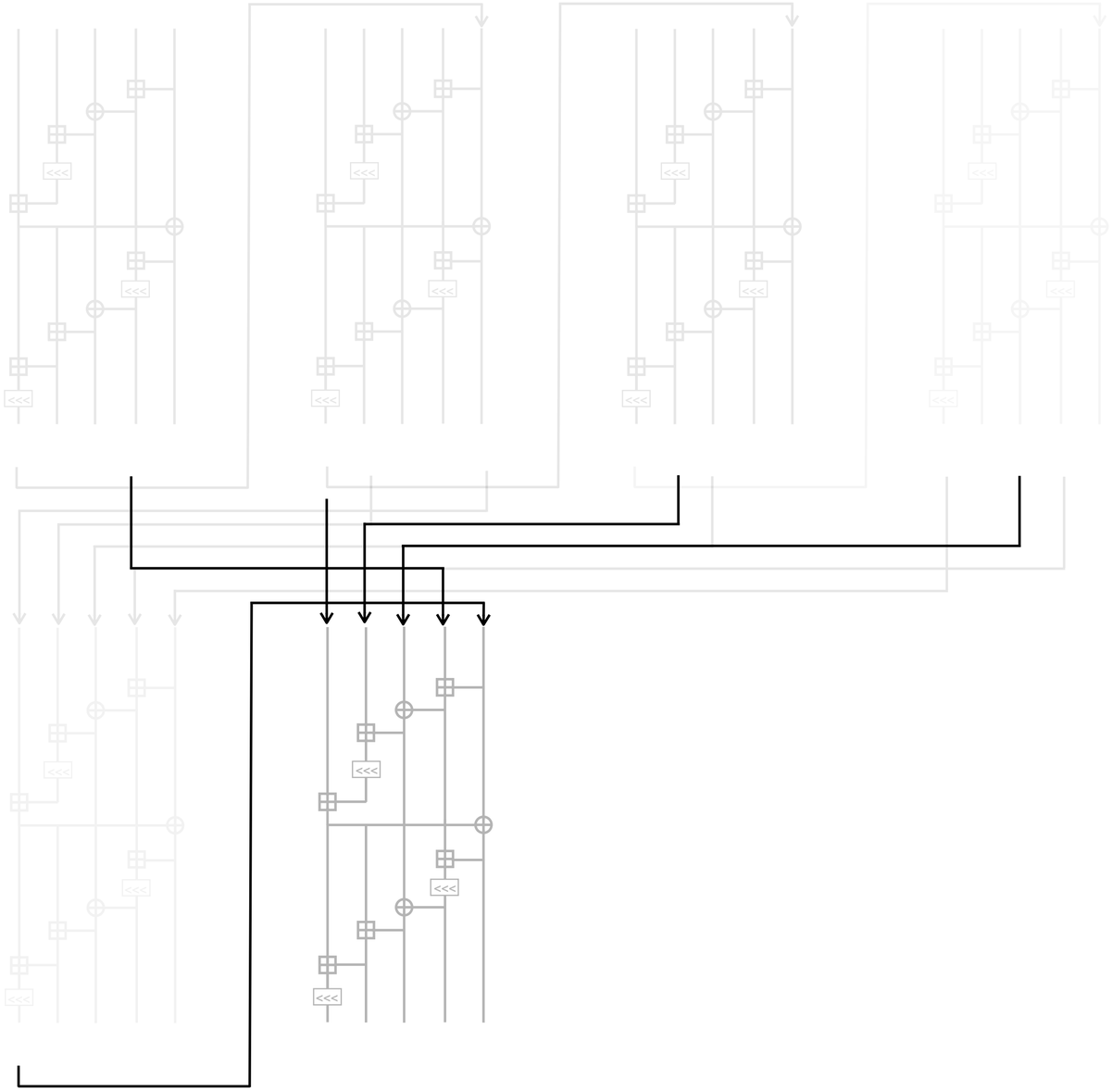

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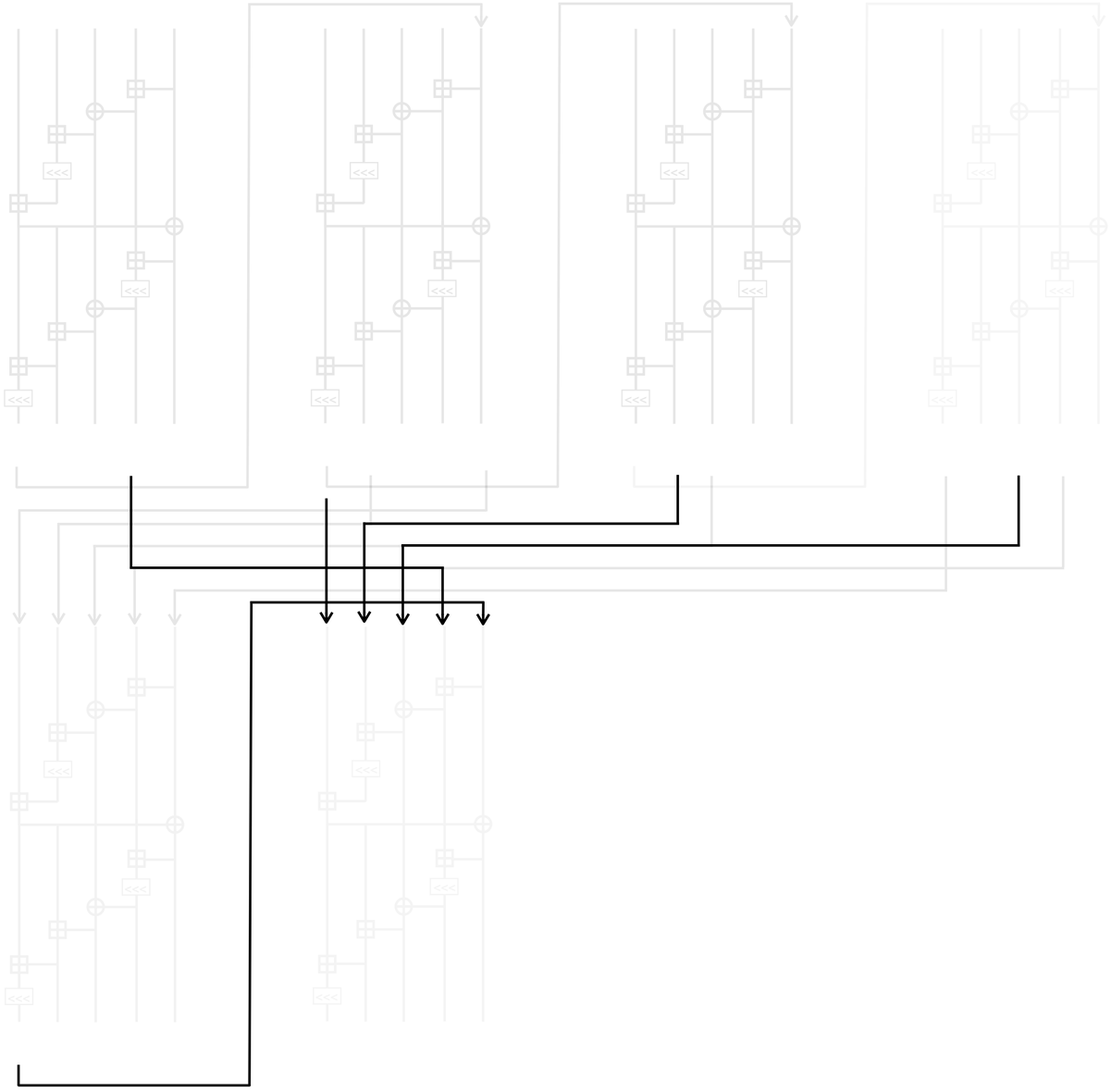

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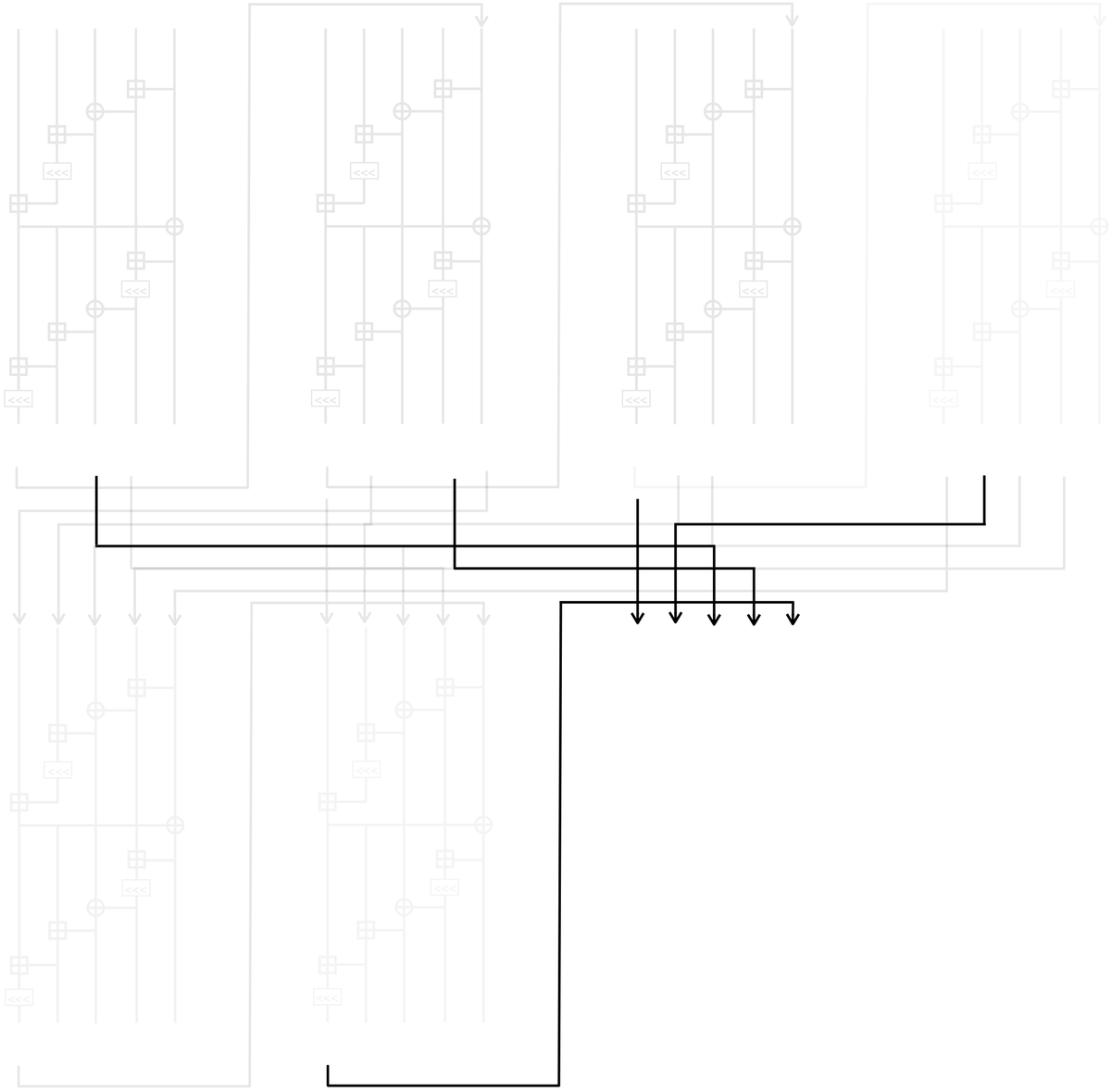

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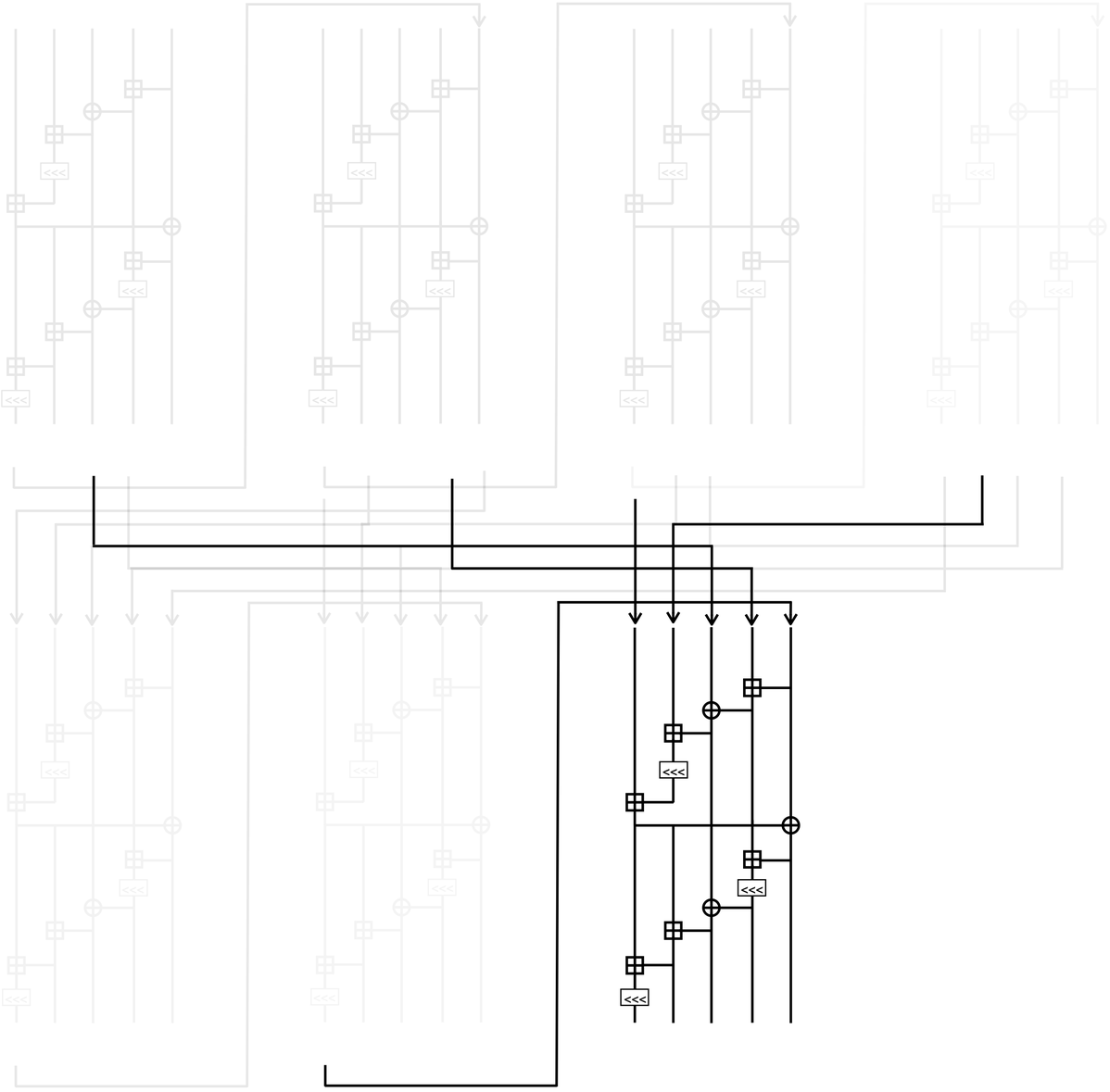

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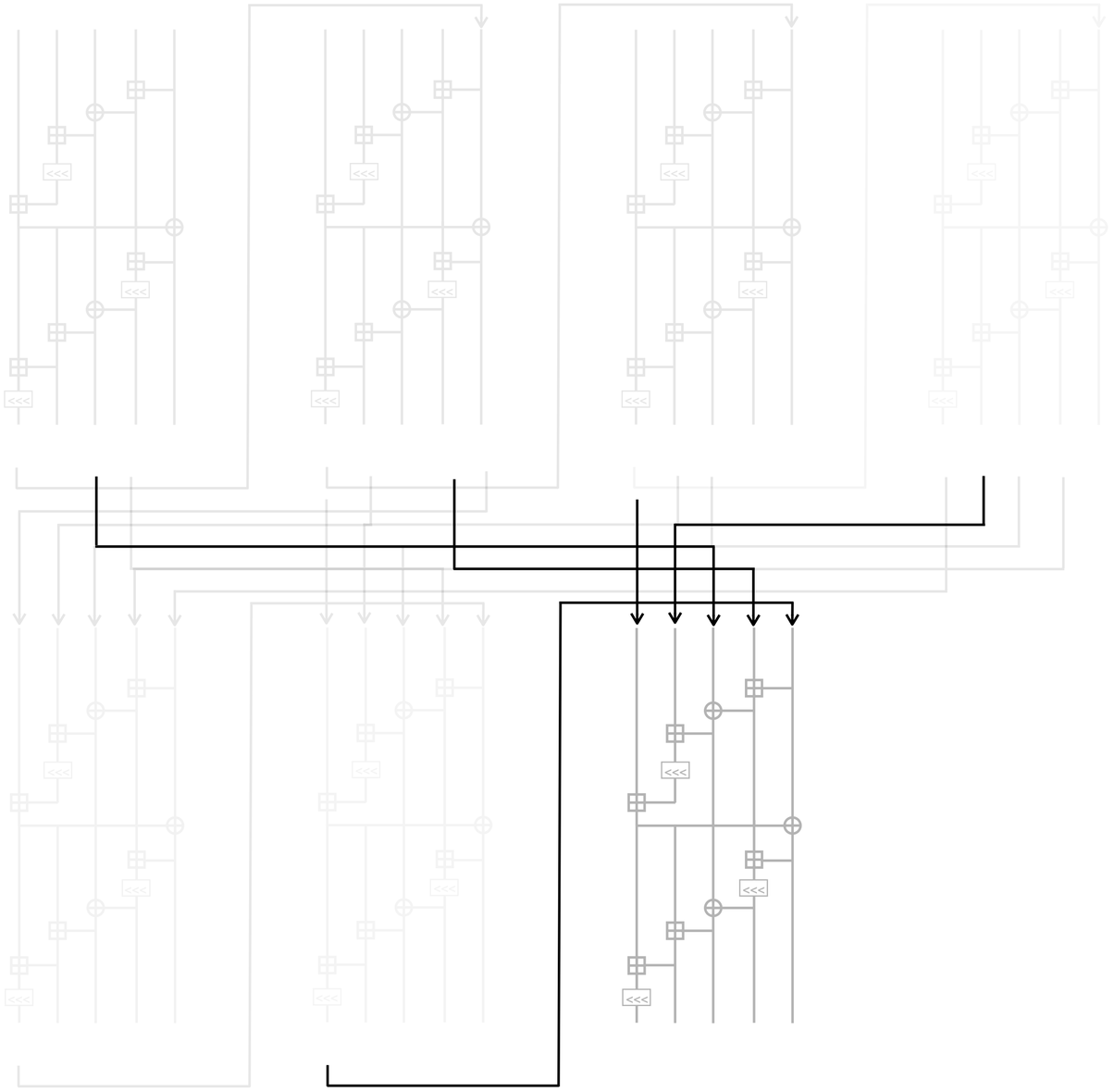

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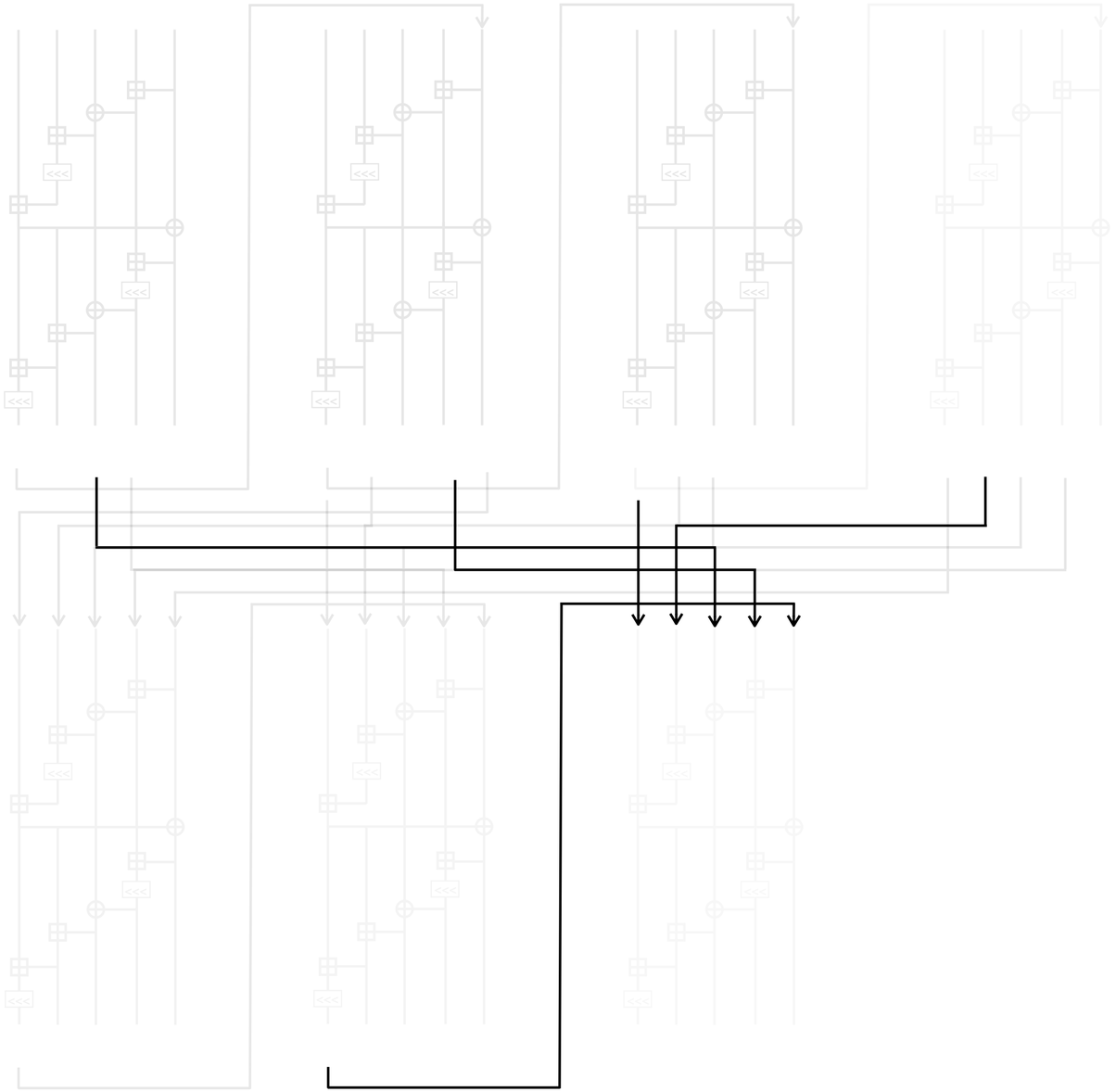

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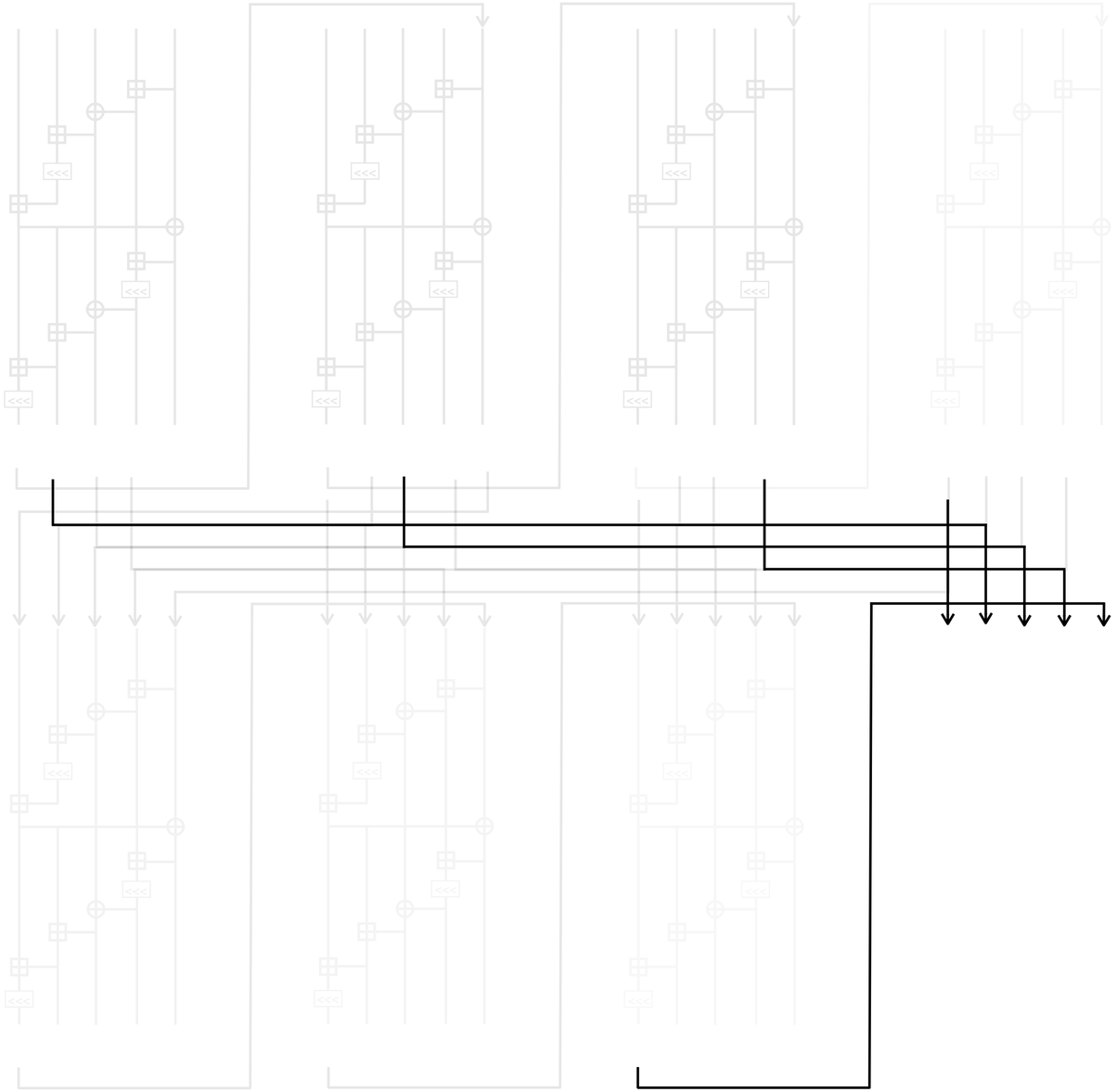

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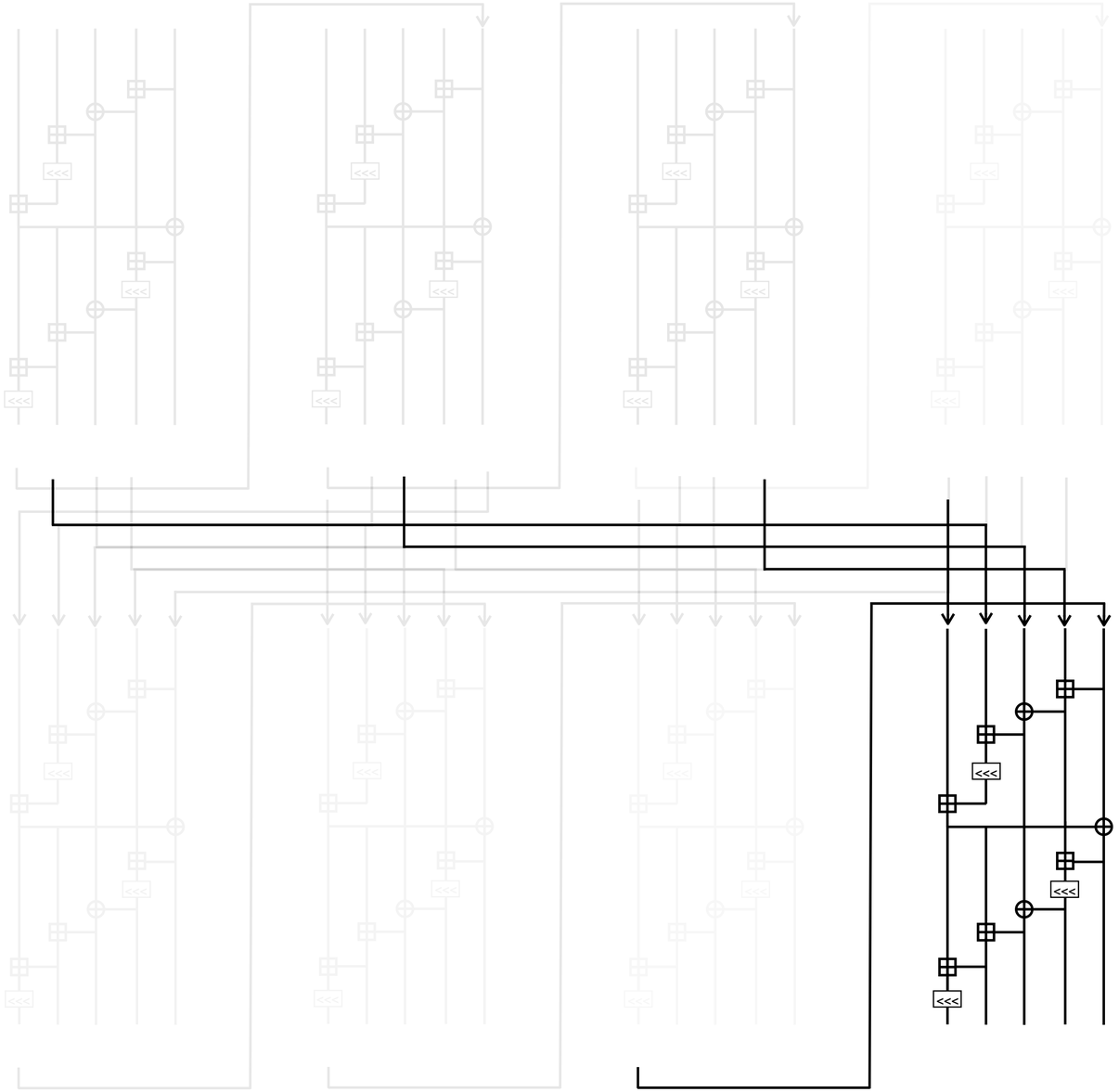

Forró

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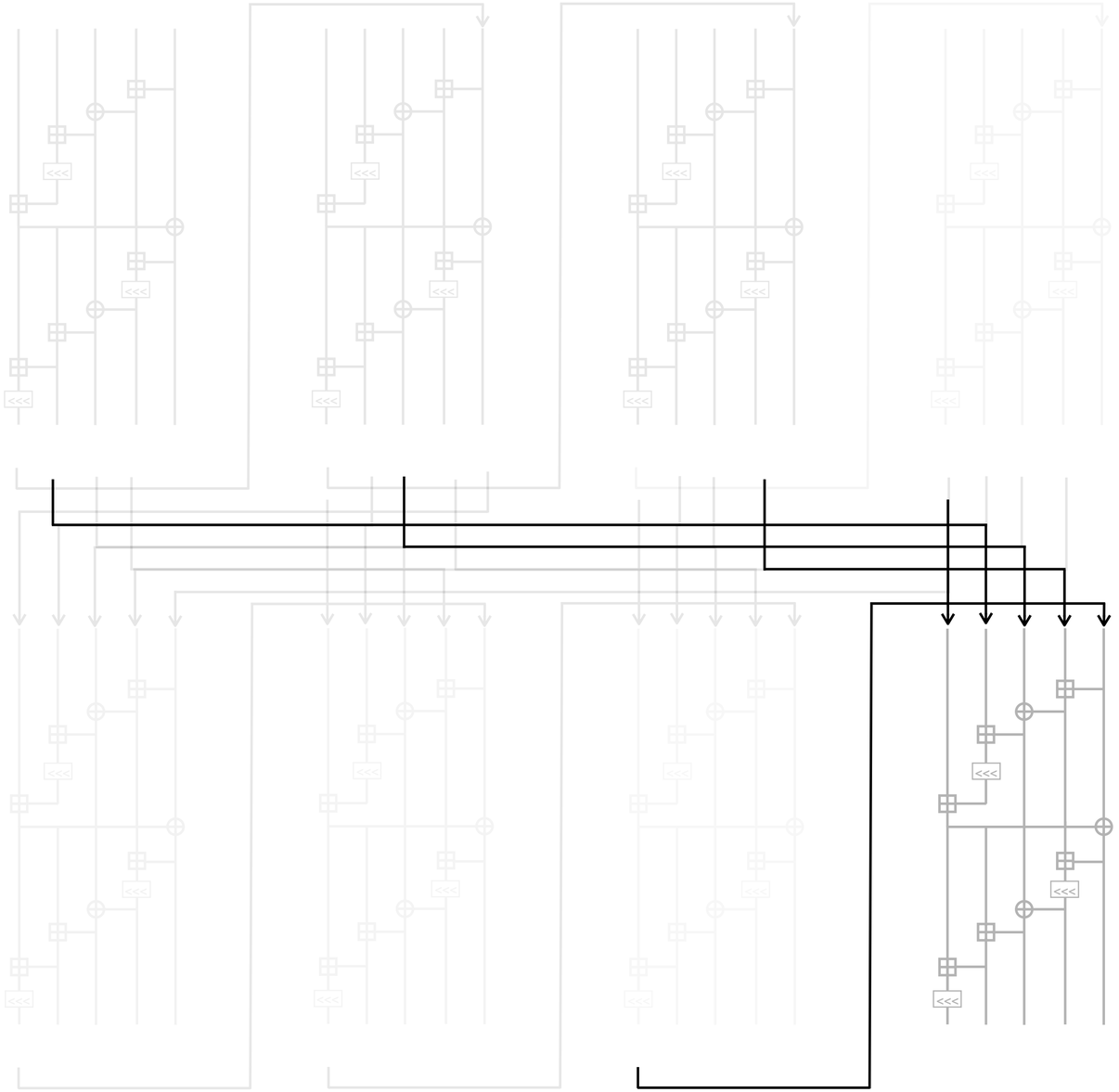

Forró

Security and Performance

- We reach up to 5 and 5.25 rounds against Forró by using the state of the art attacks against Salsa and ChaCha
- We attack 5 rounds of Forró in the key-recovery setting why using PNBs
- We implemented Forró in several hardware architectures and we conclude that Forró has slightly better performance than ChaCha and Salsa in hardware using some contained architectures (for example ARMv7).
- In some Intel architectures Forró has a comparable performance to ChaCha and Salsa

Conclusion

- New technique to attack Salsa
  - First time ever reaching 8-round using a “pure” differential-linear distinguisher
  - Our key-recovery attack against 8-round improve previous by a factor of 2^32
- Less rules to derive linear approximations in ChaCha
  - Our attack is 2^10 times faster
- Looking forward to apply in other ciphers
- New cipher with better diffusion called Forró
- New tool https://github.com/MurCoutinho/forro_cipher