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(Pseudo) Preimage Attack on Reduced-Round Grøstl Hash Function and Others

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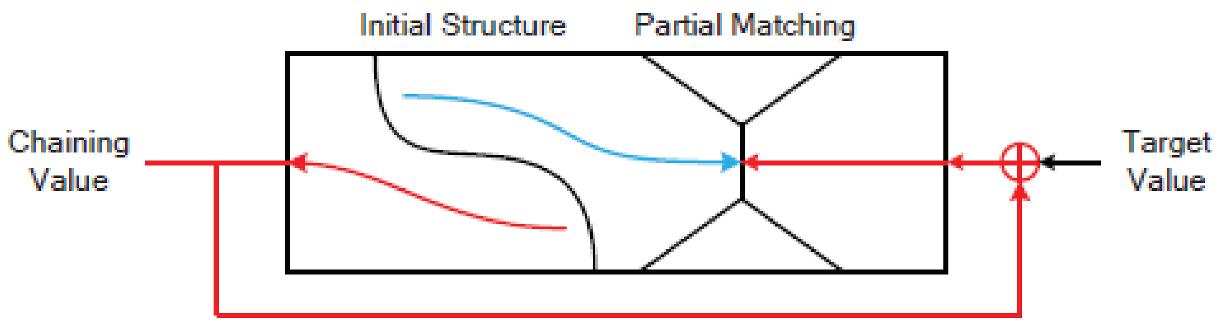
Outline

- Introduction
- Attack on Grøstl
- Other results
- Conclusion

Introduction

- Meet-in-the-Middle pre-image attacks
  - Applied to full MD4, MD5,HAVAL-3/4,Tiger and reduced-round HAS-160, RIPEMD, SHA-0/1, SHA-2 etc.
  - Tricks:
    - Splice and Cut Techniques
    - Bicliques, Initial Structure (Message Stealing), local collision
    - Partial-Matching (Relations between deterministic values)



Introduction

- Meet-in-the-Middle pre-image attacks
  - Yu Sasaki proposed the MitM preimage attack on AES-like structures for the first time at FSE 2011
    - Target: Whirlpool and AES hash modes
  - Use freedom degrees of the state for chunk separation

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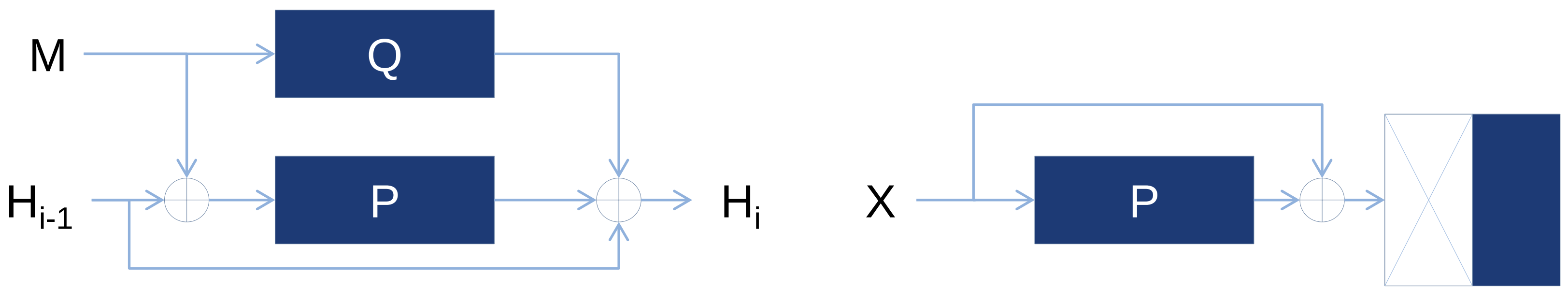
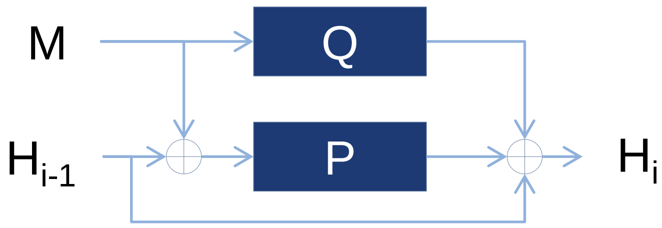
Pseudo-Preimage Attack on 5-round Grøstl-256

- Specification of Grøstl hash function
  - Wide-pipe MD structure with output transformation
  - Permutations P and Q are AES-like structures with 8×8 states(Grøstl-256) and 8×16 states(Grøstl-512)
    - 10 rounds for Grøstl-256 and 14 rounds for Grøstl-512



Pseudo-Preimage Attack on 5-round Grøstl-256

- Properties of the compression function
  - 2n-bit state, $F(H,M) = P(H \oplus M) \oplus Q(M) \oplus H$
    - With $H' = H \oplus M$, $F(H',M) = P(H') \oplus H' \oplus Q(M) \oplus M$
  - Bounds for generic attacks
    - Pre-image attack: 2^n
      - $P(H') \oplus H' \oplus Q(M) \oplus M = T$
      - birthday attack on 2n-bit state
    - Collision attack: $2^{\frac{2n}{3}}$
      - $P(H_1') \oplus H_1' \oplus Q(M_1) \oplus M_1 \oplus P(H_2') \oplus H_2' \oplus Q(M_2) \oplus M_2 = 0$
      - generalized birthday attack on 2n-bit state with four entries

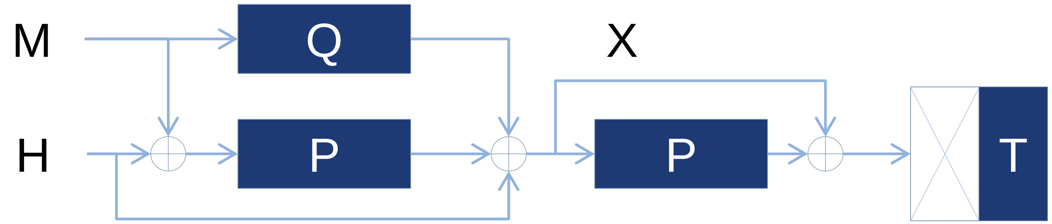


Outline of the attack

Pseudo-Preimage Attack on 5-round Grøstl-256

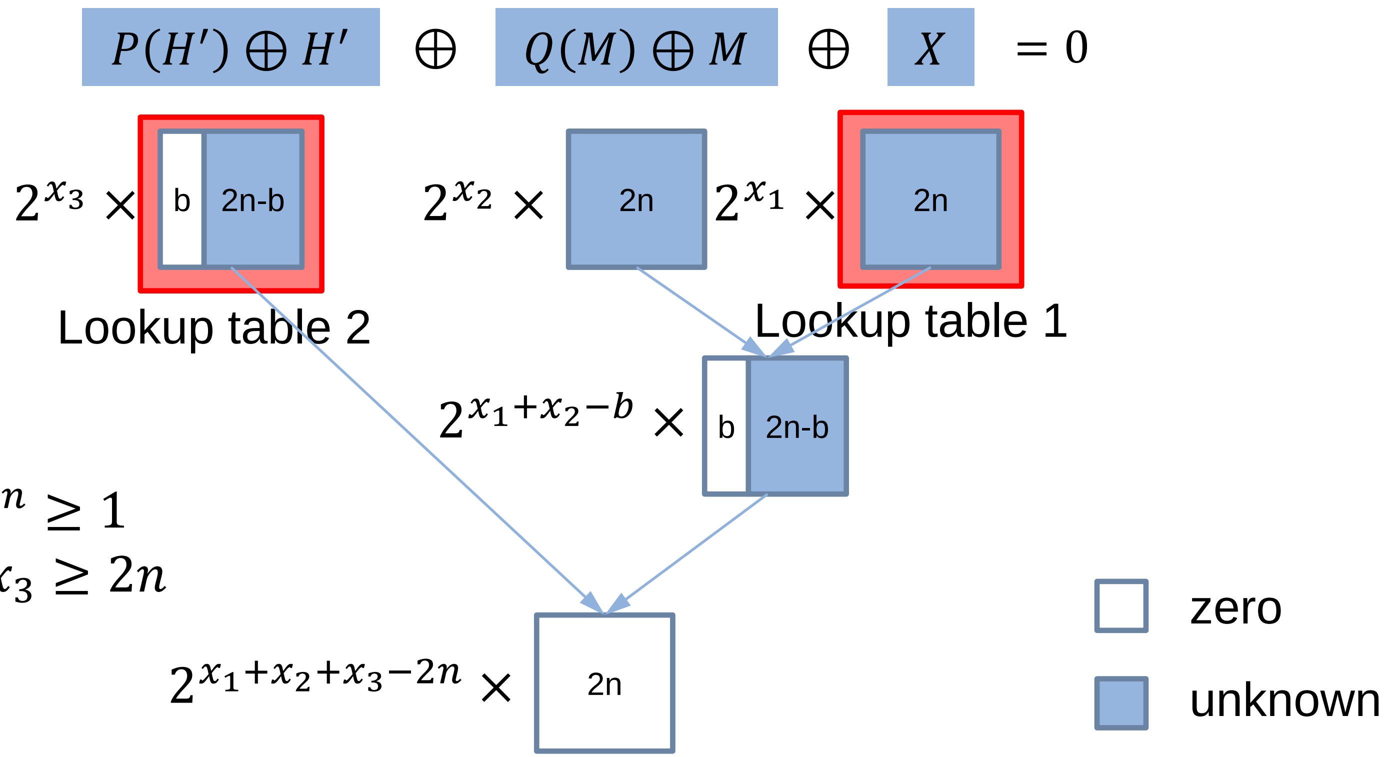
- Attack outline
  - Pseudo pre-image (H,M)
    - $F(H,M) = X, P(X) \oplus X =* ||T$
    - X is a pre-image of the output transformation
  - With $H' = H \oplus M$,

$$P(H') \oplus H' \oplus Q(M) \oplus M \oplus X = 0$$



Pseudo-Preimage Attack on 5-round Grøstl-256

- How to convert the partial pre-images of $P(X) \oplus X$ into pseudo pre-image of the hash function



$$2^{x_1+x_2+x_3-2n} \geq 1$$
$$\Rightarrow x_1 + x_2 + x_3 \geq 2n$$

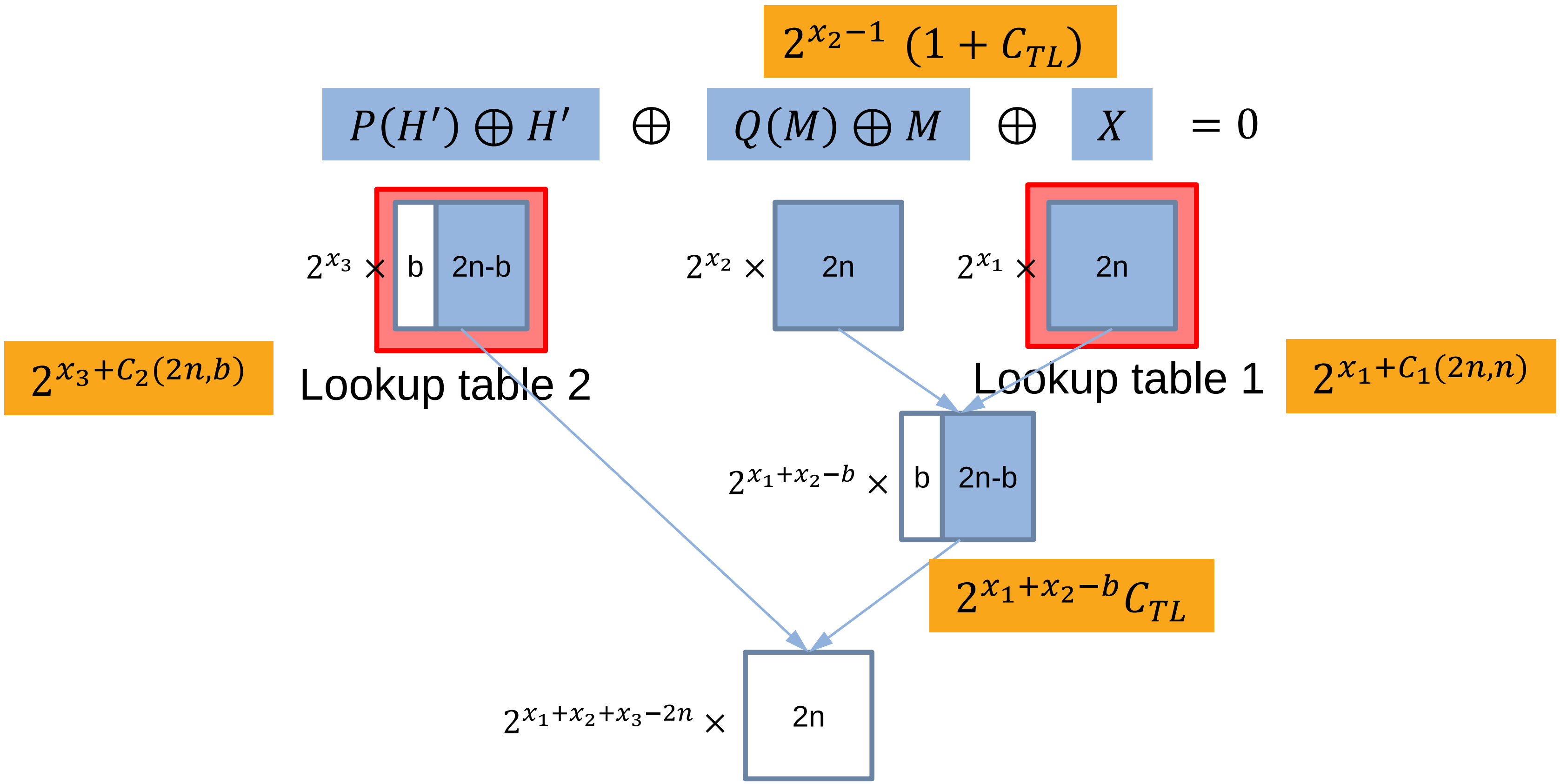
Pseudo-Preimage Attack on 5-round Grøstl-256

- Complexity evaluation
  - X: Fixed position partial preimage (n-bit) of $P(X) \oplus X$
    - Let complexity to find one X be $2^{C_1(2n,n)}$
  - M: Randomly chosen message with padding
    - Complexity=one Q call=1/2 compression function call
  - H': Chosen position partial preimage (b-bit) of $P(H') \oplus H'$
    - Let complexity to find one H' be $2^{C_2(2n,b)}$

Pseudo-Preimage Attack on 5-round Grøstl-256

- Overall complexity of the attack is

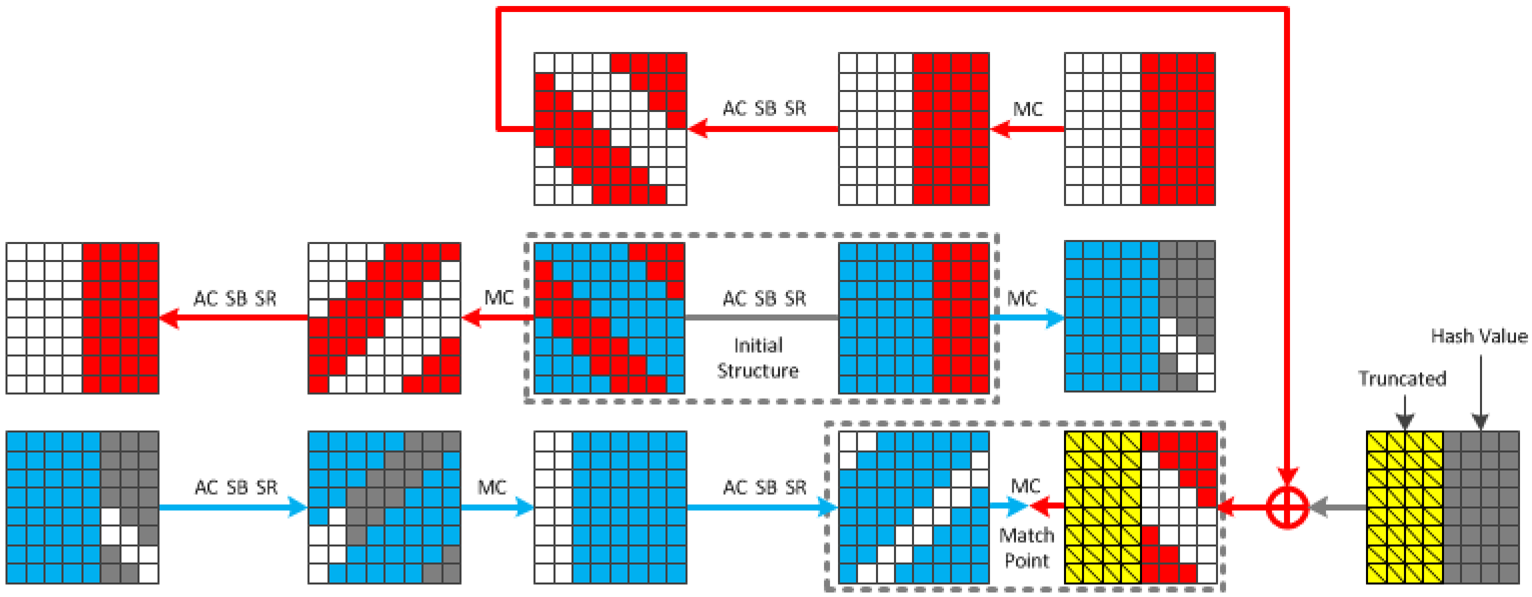
$$2^{x_1+C_1(2n,n)} + 2^{x_3+C_2(2n,b)} + 2^{x_2-1} + 2^{x_1+x_2-b}C_{TL}$$



Partial preimage attacks on $P(X) \oplus X$

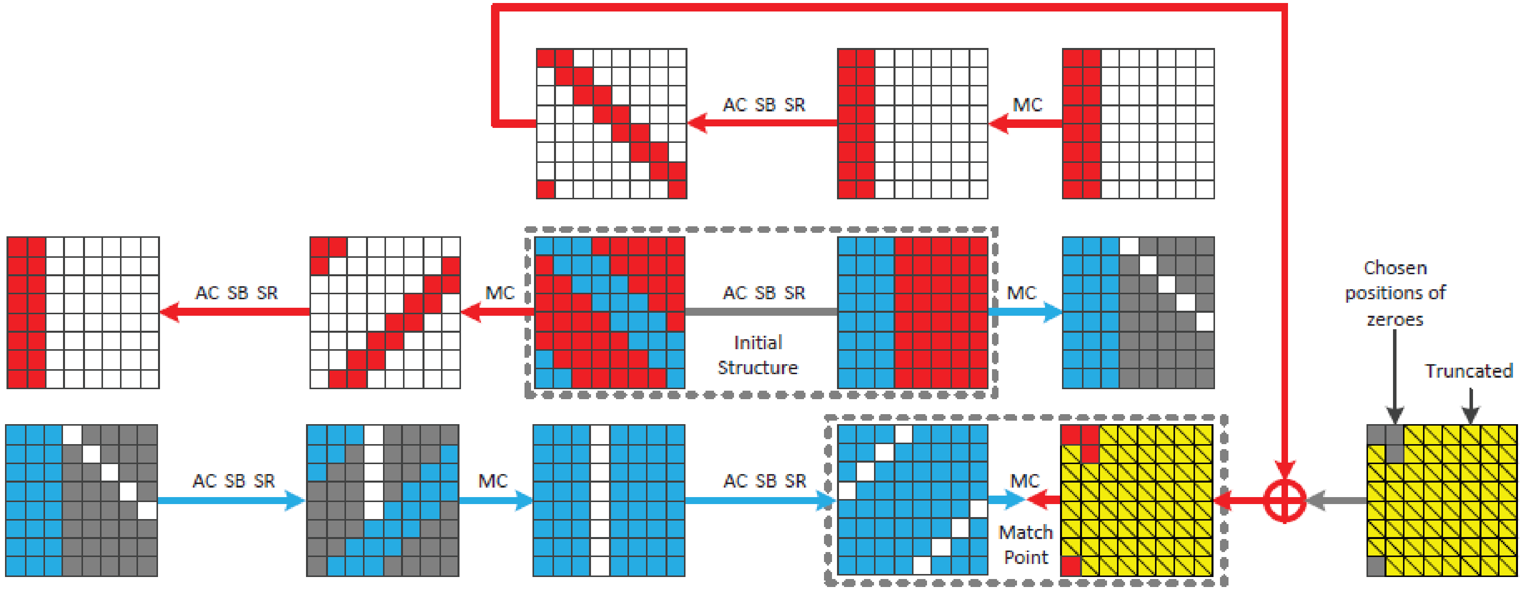
Pseudo-Preimage Attack on 5-round Grøstl-256

- Evaluation of $C_1(2n, n)$ (fixed position partial preimage)
  - Freedom degrees in blue and red bytes: 64 and 48 bits
  - Size of the matching point: 64 bits
  - Size of the full match: 256 bits
  - Complexity: 2^{207} P(X) calls = 2^{206} compression function calls



Pseudo-Preimage Attack on 5-round Grøstl-256

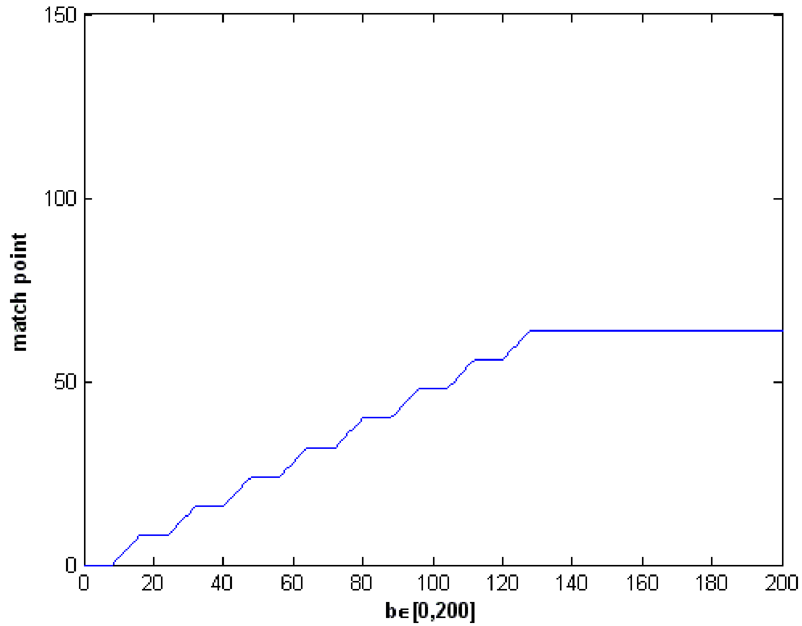
- Evaluation of $C_2(2n, b)$ (chosen position partial preimage)
  - Note: we can choose the positions of the target zero bits
  - Choose optimal positions to maximize the size of the matching point

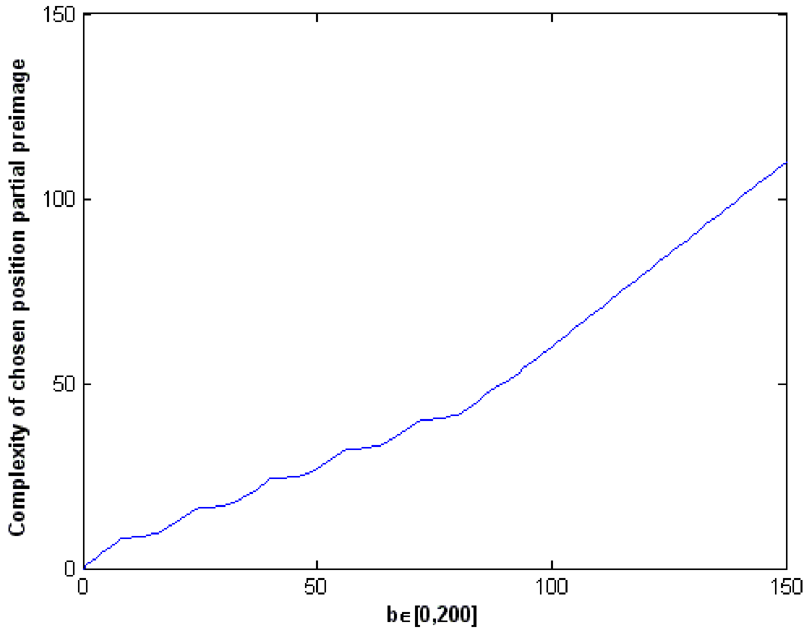


Pseudo-Preimage Attack on 5-round Grøstl-256

- Graphs of $m(b)$ and $C_2(2n, b)$ for different b

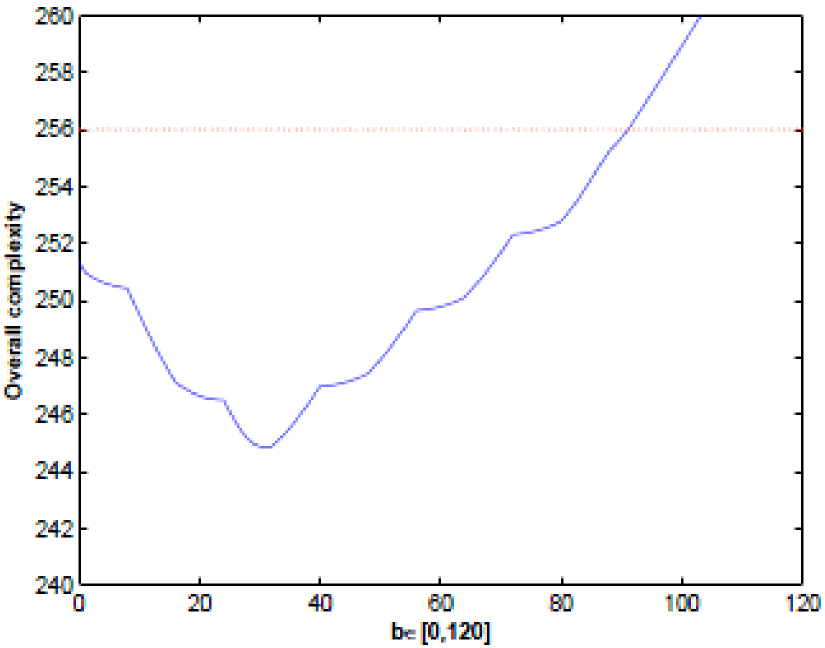
Grøstl-256





Pseudo-Preimage Attack on 5-round Grøstl-256

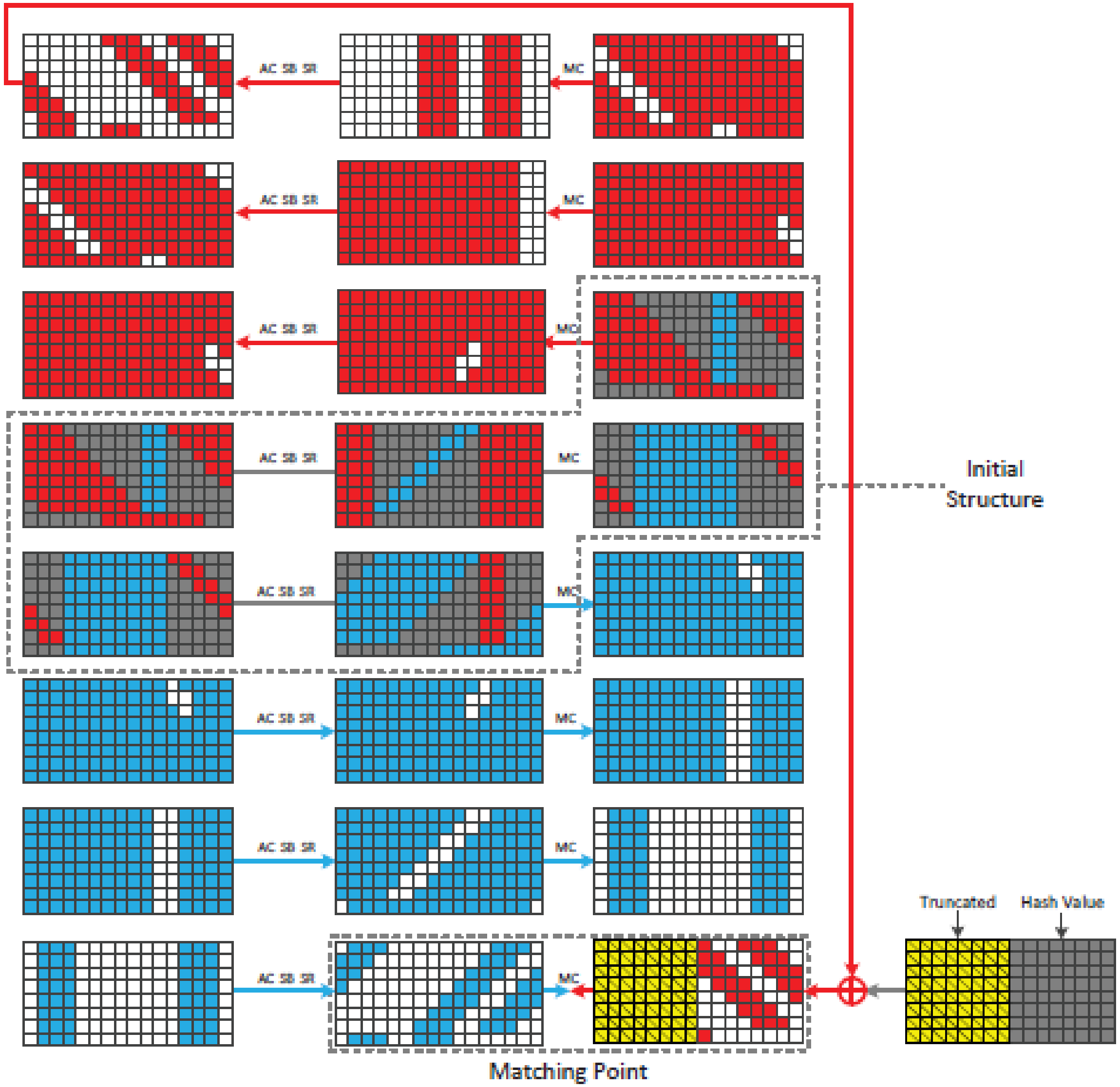
- Overall complexity of pseudo-preimage attack on 5-round Grøstl-256
  - When $b = 35$, the overall complexity reaches its minimum value $2^{244.85}$



Results on Grøstl-512

Pseudo-Preimage Attack on 8-round Grøstl-512

- Preimage attack on the output transformation



Summary of results

Algorithm	Target	Type	Rounds	Time	Memory	Source
Grøstl-256	Hash Function	Collision	3	2^{64}	-	Martin Schlæffer
	Compression Function	Semi-Free-Start Collision	6	2^{112}	2^{64}	Martin Schlæffer
	Permutation	Distinguisher	9	2^{368}	2^{64}	Jérémy Jean et al.
	Permutation	Zero-Sum Distinguisher	10	2^{509}	-	Christina Boura et al.
	Output Transformation	Preimage	5	2^{206}	2^{48}	Ours
	Hash Function	Pseudo Preimage	5	$2^{244.85}$	$2^{230.13}$	Ours
Grøstl-512	Hash Function	Collision	3	2^{192}	-	Martin Schlæffer
	Compression Function	Semi-Free-Start Collision	7	2^{152}	2^{56}	Yu Sasaki
	Permutation	Distinguisher	10	2^{392}	2^{64}	Jérémy Jean et al.
	Output Transformation	Preimage	8	2^{495}	2^{16}	Ours
	Hash Function	Pseudo Preimage	8	$2^{507.32}$	$2^{507.00}$	Ours

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Other results in this paper

Algorithm	Target	Type	Rounds	Time	Memory	Source
Whirlpool	Hash Function	2nd Preimage	5	2^{504}	2^{8}	Yu Sasaki
	Hash Function	2nd Preimage	5	2^{448}	2^{64}	Ours
	Hash Function	Preimage	5	$2^{481.5}$	2^{64}	Ours

Algorithm	Hash Mode	Type	Rounds	Time	Memory	Message Length	Source
AES	MMO,MP	2nd Preimage	7	2^{120}	2^{8}	-	Yu Sasaki
	MMO,MP,DM	2nd Preimage	7	2^{128-k}	2^{k}	2^{k} blocks	John Kelsey et at.
	MMO,MP,DM	2nd Preimage	7	$2^{120-\min(k,24)}$	2^{16}	2^{k} blocks	Ours
	DM	Preimage	7	2^{125}	2^{8}	-	Yu Sasaki
	DM	Preimage	7	$2^{122.7}$	2^{16}	$>2^{8}$ blocks	Ours

New Related Result Announcement

- Converting partial pre-images into pseudo collisions
  - The technique is proposed by Ji Li et al.
  - Target: 8-round Grøstl-512 output transformation
  - The complexity is 2^{248}

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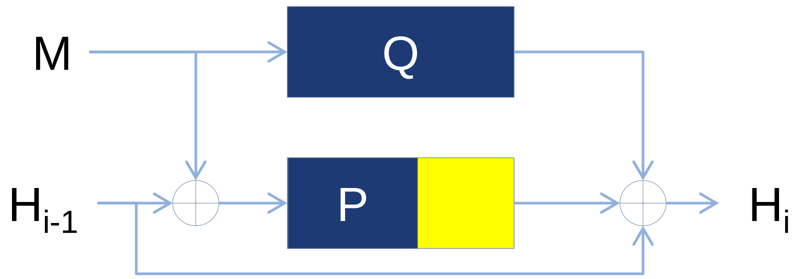
Conclusion

- We proposed:
  - Pseudo preimage attack on 5-round Grøstl-256 and 8-round Grøstl-512 for the first time
    - We found that partial preimage attack on $P(X) \oplus X$ (n-bit size) can be converted in to pseudo preimage attack on the hash function
    - An interesting observation: Properties of the permutation Q are not concerned in this attack, i.e. this attack works with any Q.
      - So, our attack works on Grøstl-256 with 5-round P and full 10-round Q and Grøstl-512 with 8-round P and full 14-round Q.



Thank you!

Any questions?