(Second) Preimage Attacks on (Reduced) SHA-0/1

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Outline

1. Background
   - SHA-0/1
   - Collision Attacks
2. (Second) Preimage Attack on Reduced SHA-0
   - General Ideas
   - Basic Technique
   - Complexity
3. Improvements
   - Getting Rid of Those Carries
   - Using More Blocks
   - Using Even More Blocks
4. Example and Final Remarks

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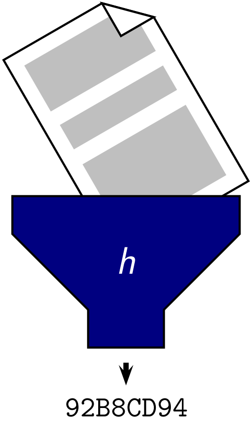
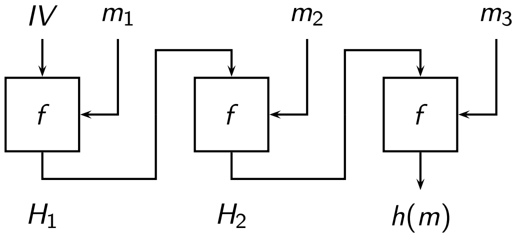
4 Example and Final Remarks

Hash Function

- **Input:**
  message m of arbitrary length
- **Output:**
  hash value $h(m)$ of fixed length n
- Fixed, publicly known function
  (no secret parameters)
- Sufficiently efficient



SHA-0/1 Hash Function



- Iterative hash function.
- 512-bit message blocks m_j.
- 160-bit chaining variable H_j.
- 160-bit hash value $h(m)$.
- Padding, MD-strengthening.

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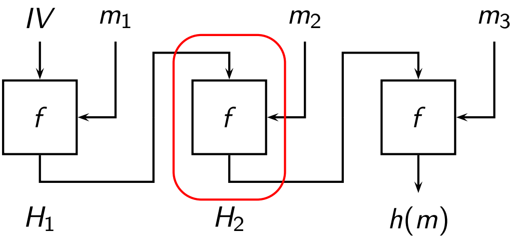

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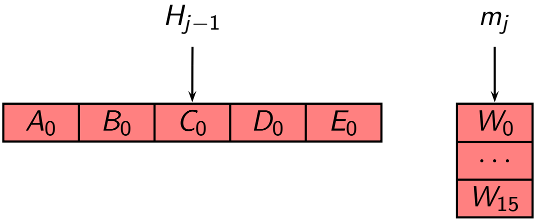
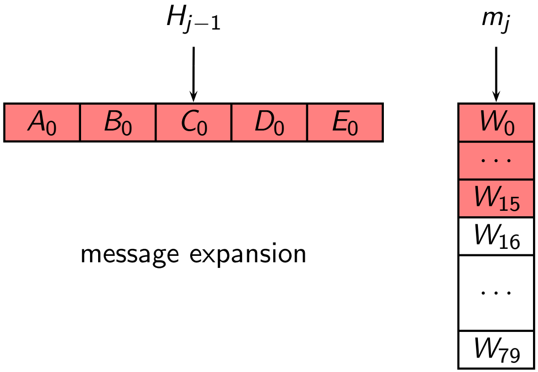
SHA-0/1 Compression Function



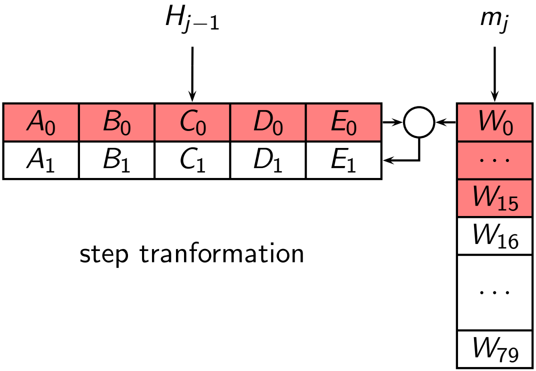
five 32-bit state variables

SHA-0/1 Compression Function



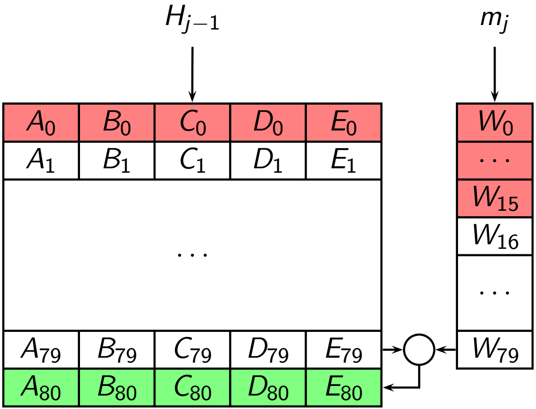
$$W_i = (W_{i-3} \oplus W_{i-8} \oplus W_{i-14} \oplus W_{i-16}) \lll 0/1$$

SHA-0/1 Compression Function



step tranformation

SHA-0/1 Compression Function


H_{j-1}
m_j
A_0 B_0 C_0 D_0 E_0
A_1 B_1 C_1 D_1 E_1
$\dots$
A_{79} B_{79} C_{79} D_{79} E_{79}
A_{80} B_{80} C_{80} D_{80} E_{80}
W_0
$\dots$
W_{15}
W_{16}
$\dots$
W_{79}

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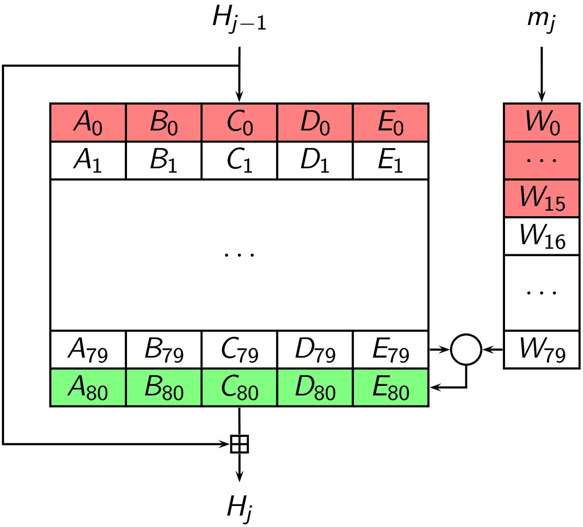
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W_{15}
W_{16}
$\cdots$
W_{79}
$\boxplus$
H_j

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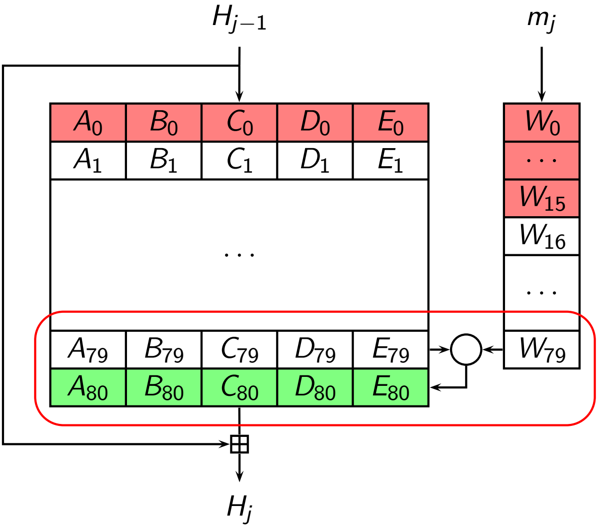
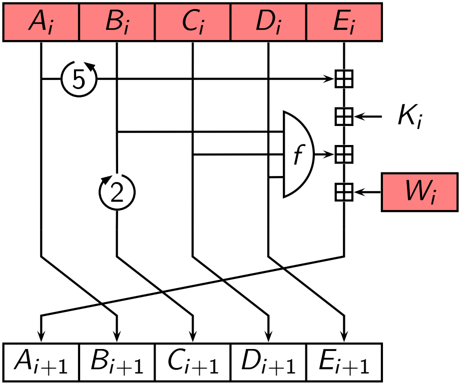


SHA Step Transformation



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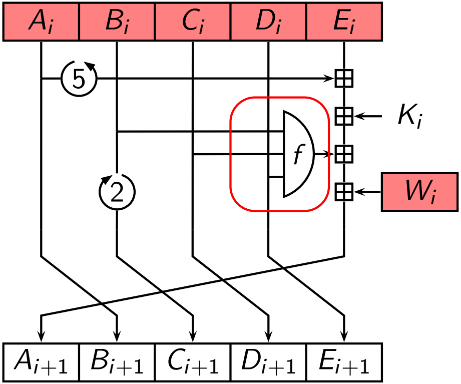


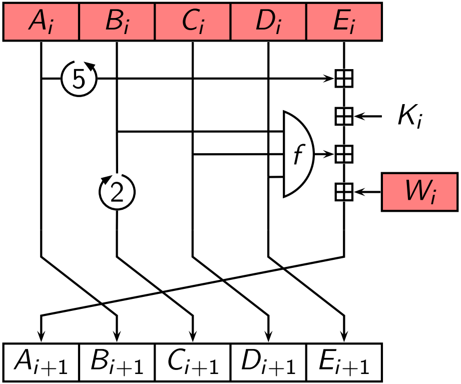
f-Function

- Bitwise boolean function f changes every 20 steps:

$$\begin{aligned}
i = \ \ 0, \ldots, 19: &\quad f_{\mathrm{IF}} = (B \wedge C) \oplus (\neg B \wedge D) \\
i = 20, \ldots, 39: &\quad f_{\mathrm{XOR}} = B \oplus C \oplus D \\
i = 40, \ldots, 59: &\quad f_{\mathrm{MAJ}} = (B \wedge C) \oplus (B \wedge D) \oplus (C \wedge D) \\
i = 60, \ldots, 79: &\quad f_{\mathrm{XOR}} = B \oplus C \oplus D
\end{aligned}$$

SHA Step Function (Recursive in A_i)

- All state variables can be expressed as a function of A_i



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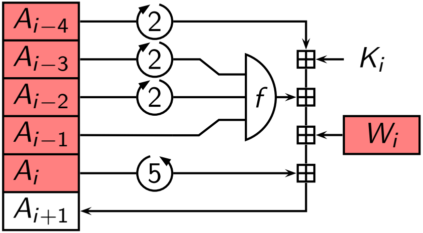

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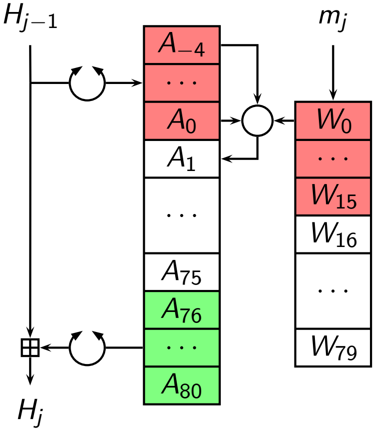

From now on, we only consider state variables A_i.

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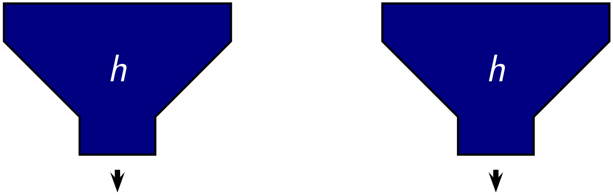
Collision Search Attack

- **Goal:**
  Find two different messages with the same hash value



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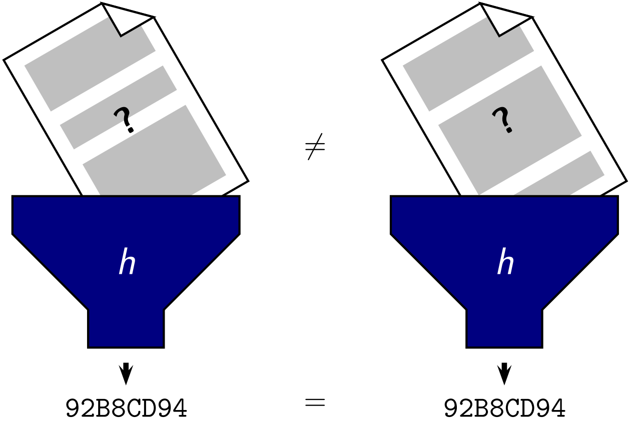
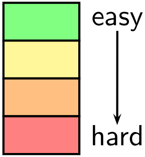
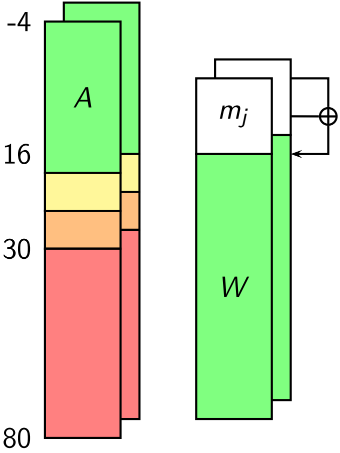


Differential Cryptanalysis: Not All Bits Are Equal

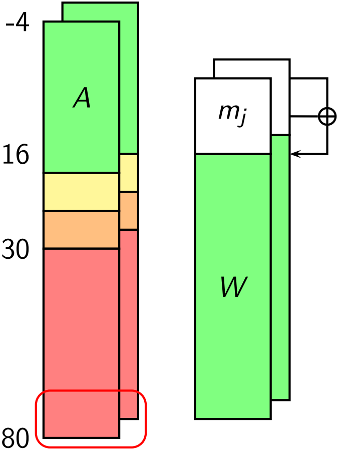
- Limit search space to pairs of messages whose bits are related throughout the hash computation.
- Depending on their position, bits of A_i and W_i depend on m_j in a more or less complex way.





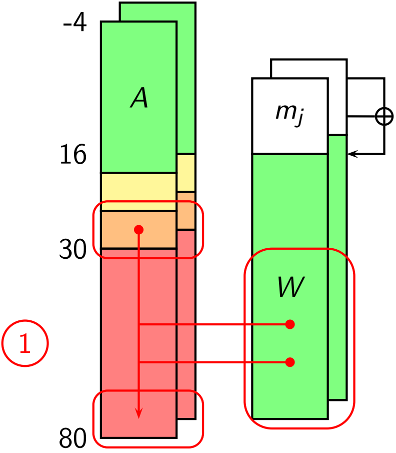
Bottom Part of Characteristic

- Requirement of (near-)collision imposes restrictions in last 5 steps of the "hard" part.



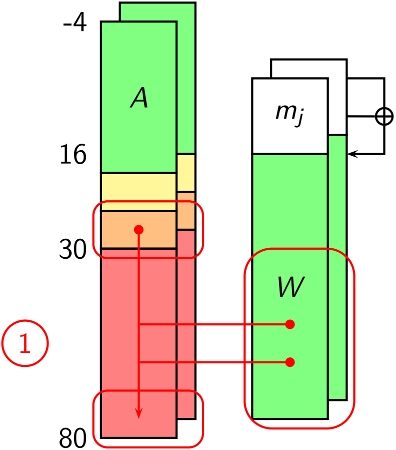
Bottom Part of Characteristic

- Requirement of (near-)collision imposes restrictions in last 5 steps of the "hard" part.
  - → **Stage 1:** impose differences in "easier" parts, which have the highest possible probability to propagate to desired difference in "hard" part.



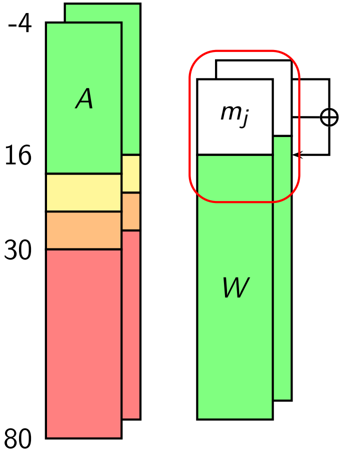
Bottom Part of Characteristic

- Requirement of (near-)collision imposes restrictions in last 5 steps of the “hard” part.
  - → **Stage 1:** impose differences in “easier” parts, which have the highest possible probability to propagate to desired difference in “hard” part.
- Nice sparse char. because of:
  - limited bit-interaction
  - uniformity of linearized SHA-1
  - two-block collision



Top Part of Characteristic

- Difference in second part of W determines difference in first part of W.



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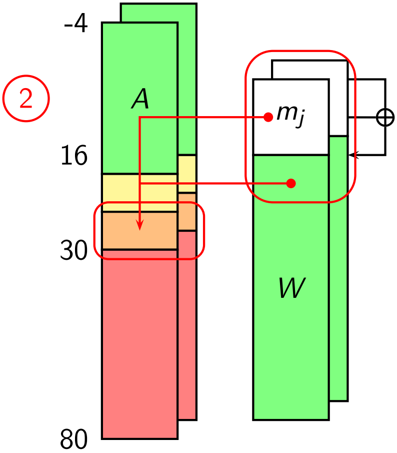
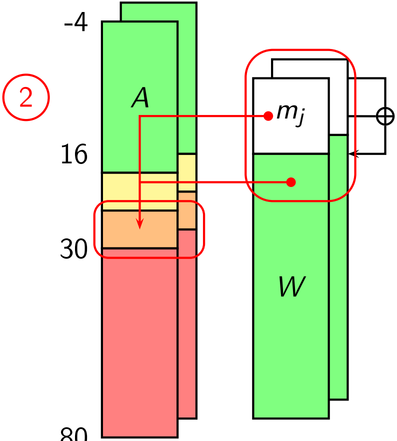
- Difference in second part of W determines difference in first part of W.
  - $\longrightarrow$ **Stage 2:** find generalized characteristic which connects the difference in W to the desired difference in A.



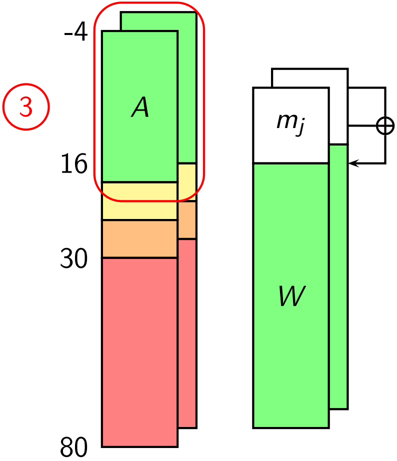
Top Part of Characteristic

- Difference in second part of W determines difference in first part of W.
  - → **Stage 2:** find generalized characteristic which connects the difference in W to the desired difference in A.
- Because of tight restrictions, characteristic needs to exploit nonlinearity.
  - → Not so easy to find. [DCR06]



Finding a Message Pair

- **Stage 3:** construct message pair following the characteristic for first 20+ steps.



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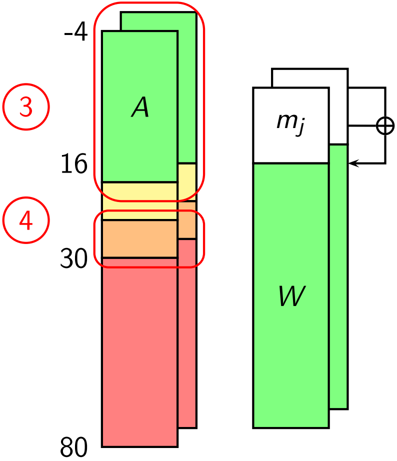
  - → Boomerangs, clusters, . . . [JP07, MRR07].



Finding a Message Pair

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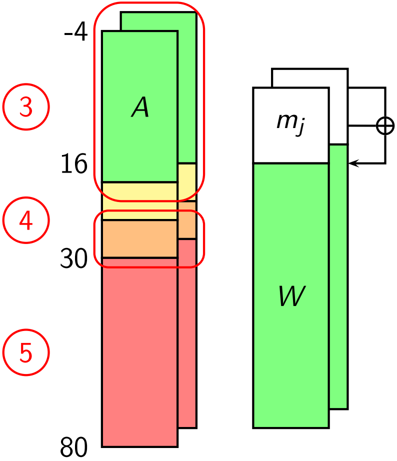
- **Stage 5:** check if characteristic is followed in the last part. If not, try again with different pair.



Achievements

- **2004**:
  - 80-step SHA-0: collision found [Jou04]
  - 53-step SHA-1: better than birthday [OR04], [BC04]
- **2005**:
  - 58-step SHA-1: collision found [WYY05]
  - 80-step SHA-1: first 2^{69}, then 2^{63} hash evaluations [WYY05]
- **2006**:
  - 64-step SHA-1: collision found [DCR06]
- **2007**:
  - 70-step SHA-1: collision found [DCRM07]
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Question: Can we somehow use this for (2nd) preimage attacks?

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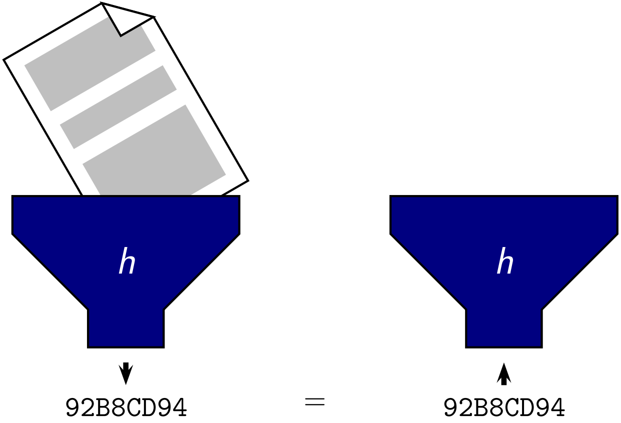
Second Preimage Attack

- **Goal:**
  Given a message, find a different message which produces the same hash value



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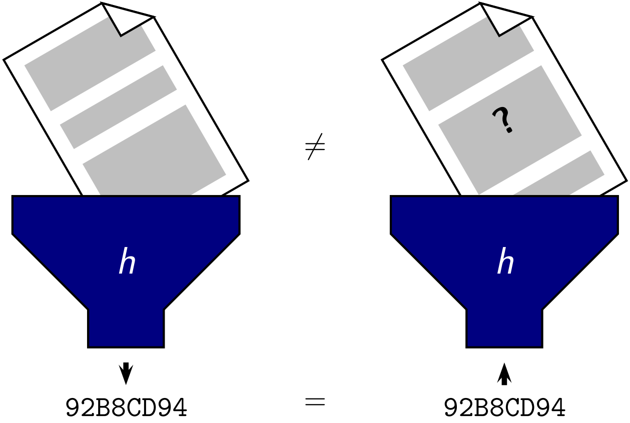

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   Collision Attack **2nd Preimage Attack**

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2. Check for collision.
3. If not, too bad...

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   Preimage Attack

   1. Compute hash value for special message *m*.
   2. Try to correct (parts of it) by applying special differences.
   3. If not successful, try with different special message.

   → Seems to work quite well if one can find many highly probable differential paths for the same special message [Leu08], [Rec08].

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3. **Idea 3:** Turn the problem around.

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Instead of trying to find a message which produces the correct hash value after being expanded and fed through several iterations of the state update transformation;

$\longrightarrow$ Start from state variables which produce the correct hash value, and try to modify them such that the expanded words satisfy the linear recursion.

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   Instead of trying to find a message which produces the correct hash value after being expanded and fed through several iterations of the state update transformation;

   → Start from state variables which produce the correct hash value, and try to modify them such that the expanded words satisfy the linear recursion.

   Why?

Flipping a Bit in the Message

i	A_i	W_i
-4:	00001111010010111000011111000011	
-3:	01000000110010010101000111011000	
-2:	01100010111010110111001111111010	
-1:	11101111110011011010101110001001	
0:	01100111010001010010001100000001	11111000010100100101101101010111
1:	10011000000001101111010000001010	01010101101001101101101111110001
2:	10111101001101100010101001010001	10111110111110100011101110101001
3:	11010100111011100010011101010111	00111000010000100101001100101010
4:	10010001001111101000101100011111	00010100110011011111100101000001
5:	01010111010000000101110011010000	10111110111011011110010111100010
6:	10100111000001001101101000011100	00100011000010011011011000101010
7:	10110001111100001001111011000000	11010011110011011010001111010011
8:	10100110111010101010101000100010	10001111110111000001011001101100
9:	11010001110000111010110111001000	01111111101010010011011110010100
10:	01010101110110101100111101010100	11111010101000010110110001011011
11:	11100111111111101101100011011101	00100110111010101101000110001111
12:	01101010000100001001011001101100	10001110100111110010010110100110
13:	11101010011001000000100110010101	01111111111101110110101000110110
14:	11011000111000110101101010111011	10100000101000100111111011001011
15:	01001000101001100111000100000011	00011010111001111111100000011001

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i	A_i	W_i
-4:	00001111010010111000011111000011	
-3:	01000000110010010101000111011000	
-2:	01100010111010110111001111111010	
-1:	11101111111001101101010111000101001	
0:	01100111010001010010001100000001	11111000010100100101101101010111
1:	10011000000001101111010000001010	01010101101001101101101111110001
2:	10111101001101100010101001010001	10111110111110100011101110100001
3:	11010100111011100010011101001111	00111000010000100101001100101010
4:	10010001001111101000101000011111	00010100110011011111100101000001
5:	01010111010000000100110011001000	10111110111011011110010111100010
6:	10100111000000001101011100011010	00100011000010011011011000101010
7:	10110001011100000001111001101110	11010011110011011010001111010011
8:	10010110110111101001101110011010	10001111110111000000101100110100
9:	01010000010000011101101000100100	01111111101010010011011110010100
10:	10100101100100110100001111111001	11111010101000010110110001011011
11:	01011101011010100010001010101101	00100110111010101101000110001111
12:	11011111010000101000111011111101	10001110100111110010010110100110
13:	11000000100110110111101010001100	01111111111101110110101000110110
14:	01111001011000001000010010011011	10100000101000100111111011001011
15:	11101000011010101111111110000000	00011010111001111111100000011001

Flipping a Bit in the State

i	A_i	W_i
-4:	00001111010010111000011111000011	
-3:	01000000110010010101000111011000	
-2:	01100010111010110111001111111010	
-1:	11101111110011011010101110001001	
0:	01100111010001010010001100000001	11111000010100100101101101010111
1:	10011000000001101111010000001010	01010101101001101101101111110001
2:	10111101001101100010101001010001	10111110111110100011101110101001
3:	11010100111011100010011101010111	00111000010000100101001100101010
4:	10010001001111101000101100011111	00010100110011011111100101000001
5:	01010111010000001011100110100000	10111110111011011110010111100010
6:	10100111000001001101101000011100	00100011000010011011011000101010
7:	10110001111100001001111011000000	11010011110011011010001111010011
8:	10100110111010101010101000100010	100011111101110000001011001101100
9:	11010001110000111010110111001000	01111111101010010011011110010100
10:	01010101110110101100111101010100	11111010101000010110110001011011
11:	11100111111111011011000110111101	00100110111010101101000110001111
12:	01101010000100001001011001101100	10001110100111110010010110100110
13:	111010100110010000001001100101011	01111111111101110110101000110110
14:	11011000111000110101101010111011	101000000101000100111111011001011
15:	01001000101001100111000100000011	00011010111001111111100000011001

Flipping a Bit in the State

i	A_i	W_i
-4:	00001111010010111000011111000011	
-3:	01000000110010010101000111011000	
-2:	01100010111010110111001111111010	
-1:	11101111110011011010101110001001	
0:	01100111010001010010001100000001	11111000010100100101101101010111
1:	10011000000001101111010000001010	01010101101001101101101111110001
2:	10111101001101100010101001010001	10111110111110100011101110101001
3:	11010100111011100010011101010111	00111000010000100101001100100010
4:	10010001001111101000101100010111	00010100110011011111101001000001
5:	01010111010000000101110011010000	10111110111011011110010111100010
6:	10100111000001001101101000011100	00100011000010011011011000101010
7:	10110001111100001001111011000000	11010011110011011010001111010101
8:	10100110111010101010101000100010	10001111110111000000101100110110
9:	11010001110000111010110111001000	01111111101010010011011110010100
10:	01010101110110101100111101010100	11111010101000010110110001011011
11:	11100111111111011011000110111101	00100110111010101101000110001111
12:	01101010000100001001011001101100	10001110100111110010010110100110
13:	11101010011001000001001100101011	01111111111101110110101000110110
14:	11011000111000110101101010111011	10100000101000100111111011001011
15:	01001000101001100111000100000011	00011010111001111111100000011001

Flipping a Bit in the State

i	A_i	$E_i = W_i \oplus W_{i+2} \oplus W_{i+8} \oplus W_{i+13} \oplus W_{i+16}$
-4:	00001111010010111000011111000011	
-3:	01000000110010010101000111011000	
-2:	01100010111010110111001111111010	
-1:	11101111110011011010101110001001	
0:	01100111010001010010001100000001	00000000000000000000000000000010
1:	10011000000001101111010000001010	00000000000000000000000000001000
2:	10111101001101100010101001010001	00000000000000000000001100000000
3:	11010100111011100010011101010111	00000000000000000000000000001000
4:	10010001001111101000101100010111	00000000000000000000001100000000
5:	01010111010000000101110011010000	00000000000000000000000000000110
6:	10100111000001001101101000011100	00000000000000000000000000000010
7:	10110001111100001001111011000000	00000000000000000000000000000110
8:	10100110111010101010101000100010	00000000000000000000000000000010
9:	11010001110000111010110111001000	00000000000000000000000000000000
10:	01010101110110101100111101010100	00000000000000000000000000000000
11:	11100111111111011011000110111101	
12:	01101010000100001001011001101100	
13:	11101010011001000001001100101011	
14:	11011000111000110101101010111011	
15:	01001000101001100111000100000011	

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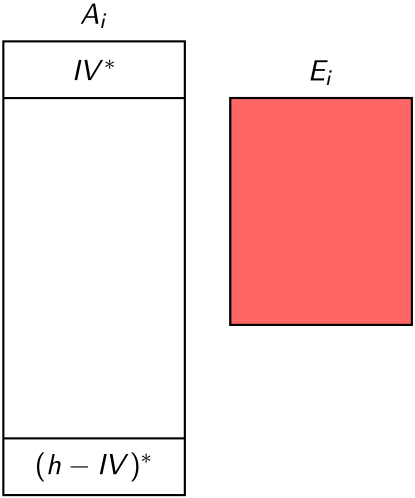
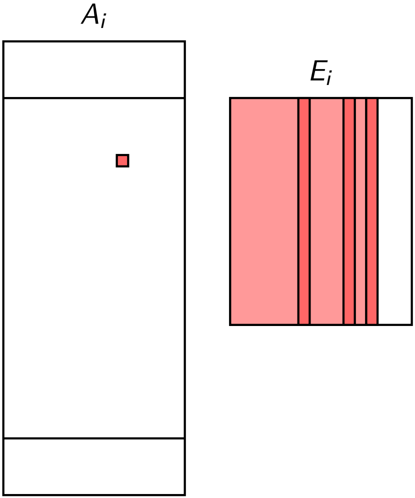
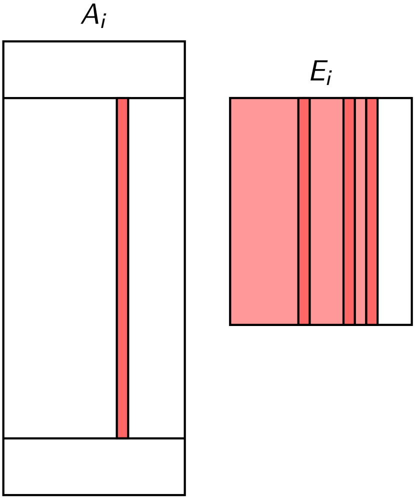
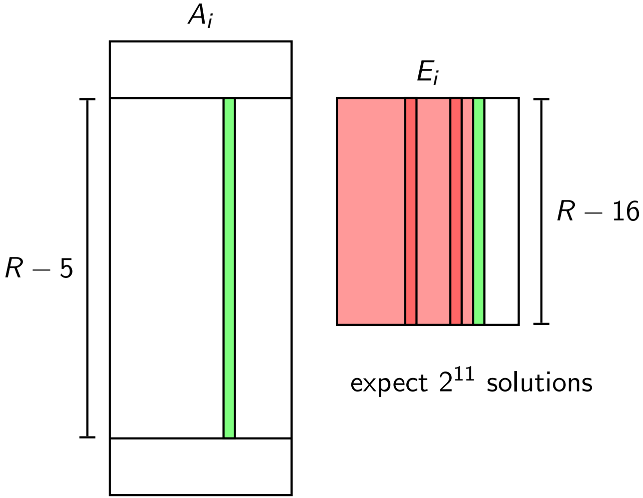
- Using More Blocks
- Using Even More Blocks

4 Example and Final Remarks

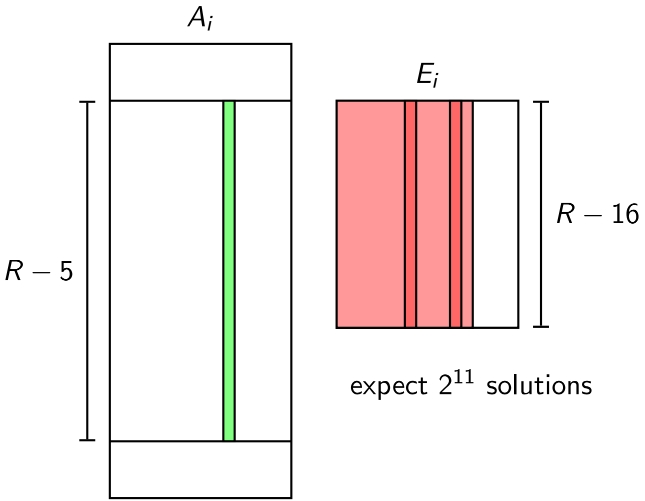

A_i
IV^*
E_i
$(h - IV)^*$


A_i
E_i

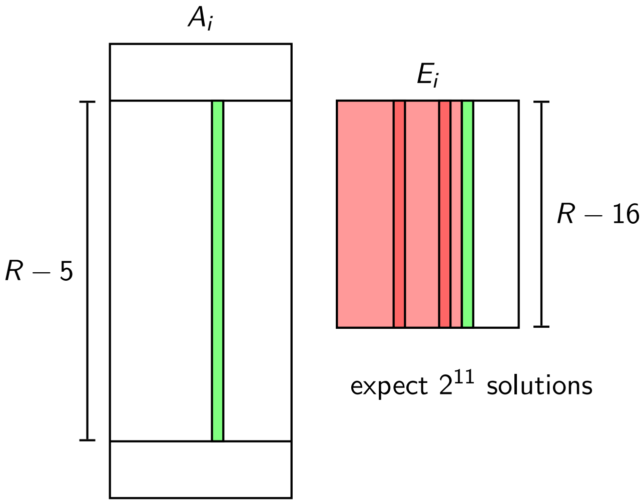

A_i
E_i



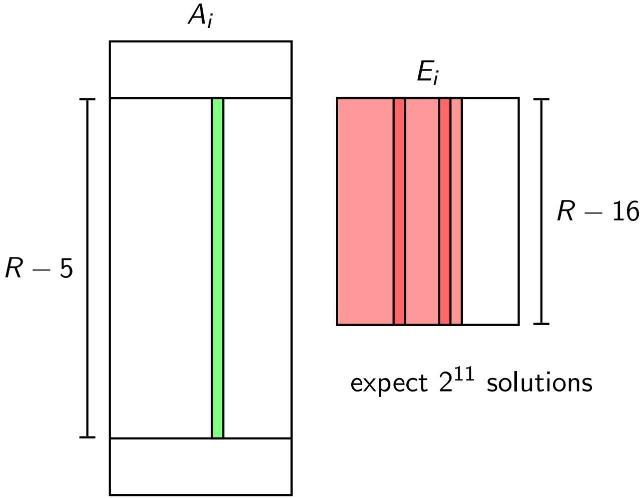
expect 2^{11} solutions



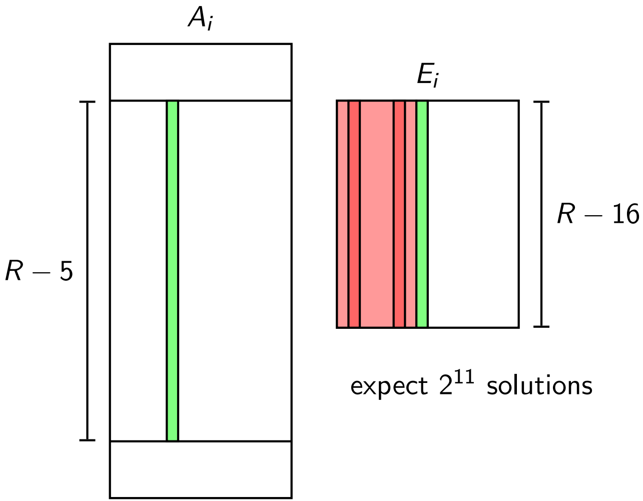
expect 2^{11} solutions



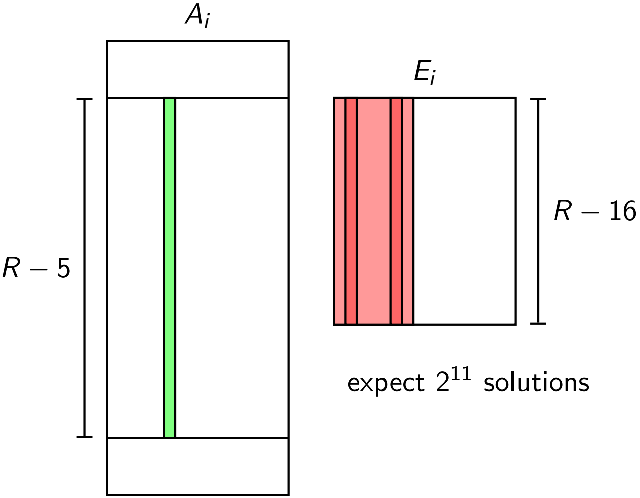
expect 2^{11} solutions



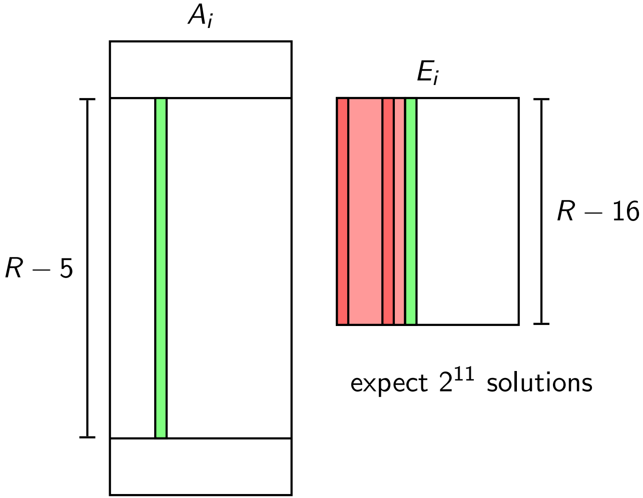
expect 2^{11} solutions



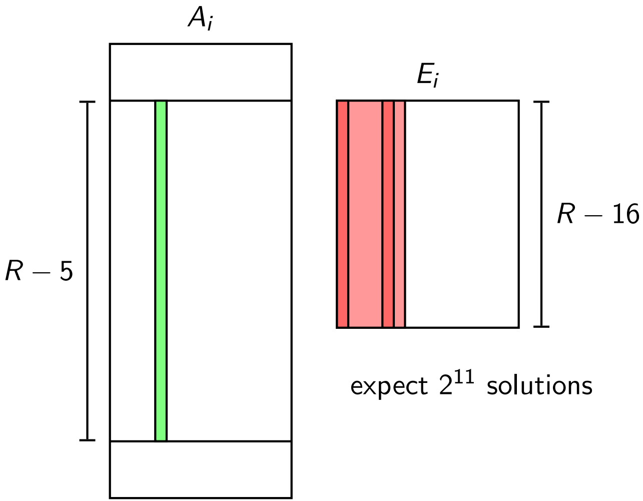
expect 2^{11} solutions

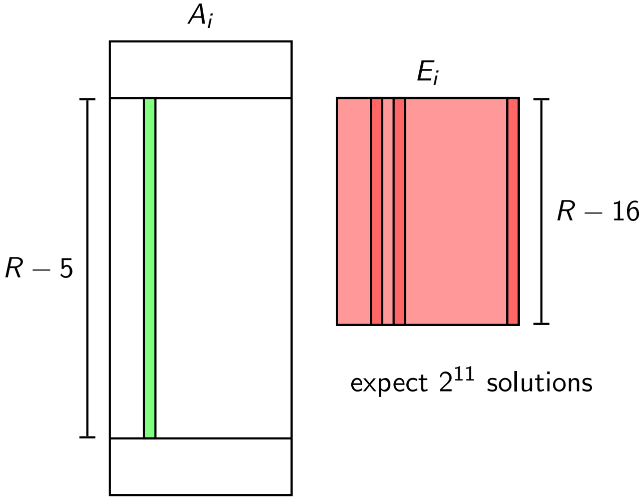


expect 2^{11} solutions

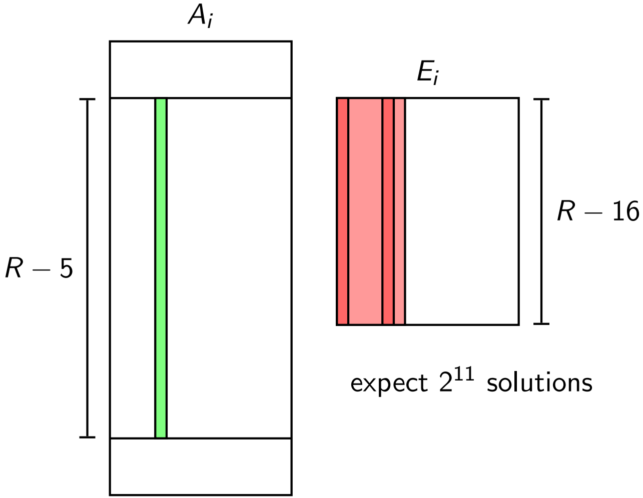


expect 2^{11} solutions


A_i
E_i
$R-5$
$R-16$
expect 2^{11} solutions



expect 2^{11} solutions



expect 2^{11} solutions

Outline

1 Background
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2 (Second) Preimage Attack on Reduced SHA-0
- General Ideas
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- Complexity

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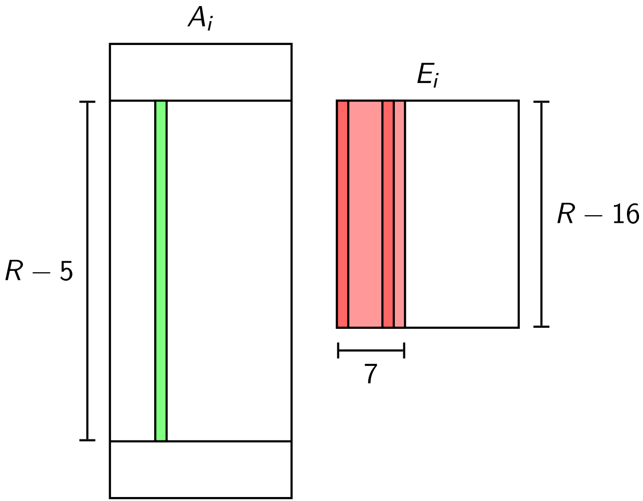
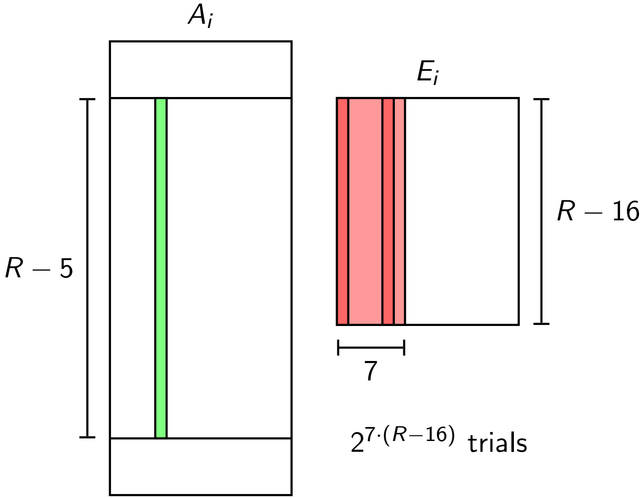
4 Example and Final Remarks


A_i
$R - 5$
E_i
$R - 16$
7



$2^{7\cdot(R-16)}$ trials

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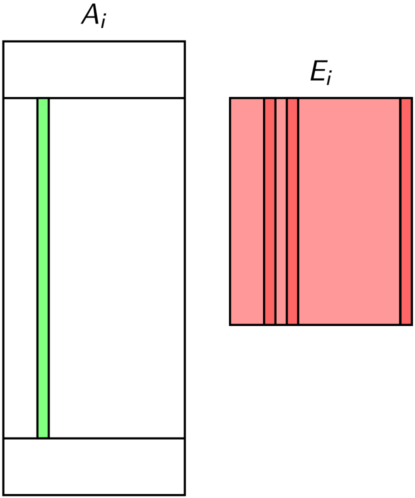
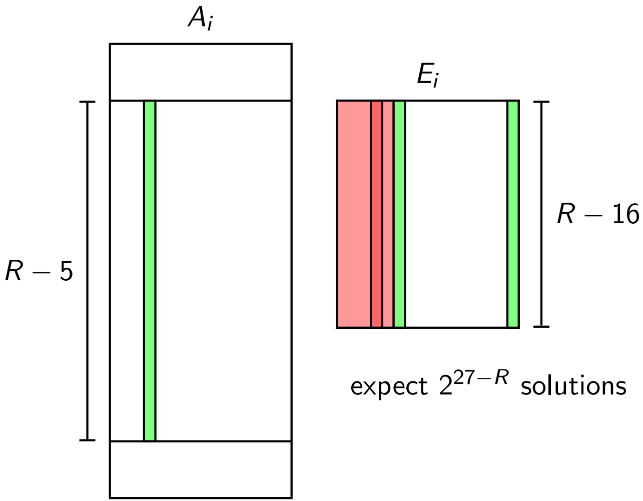
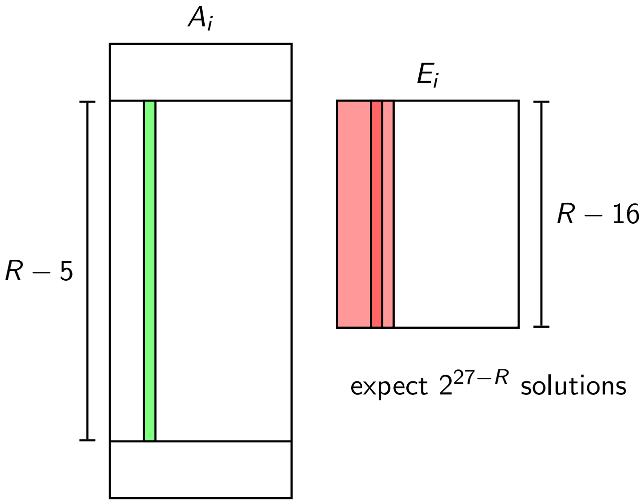
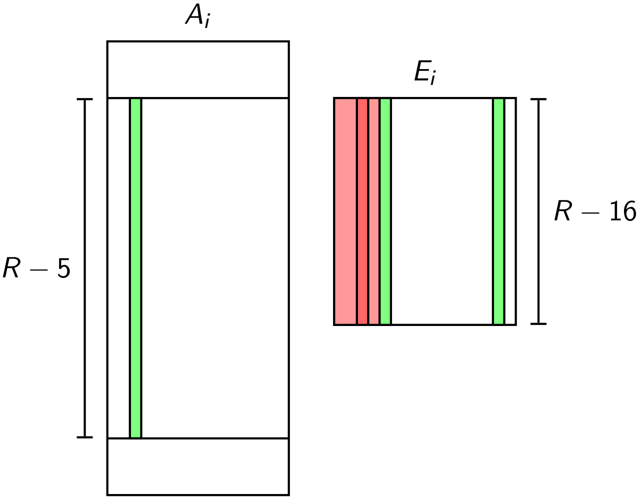

A_i
E_i

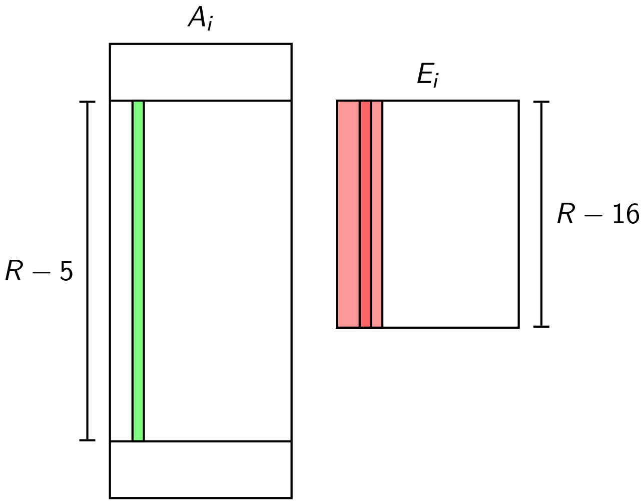


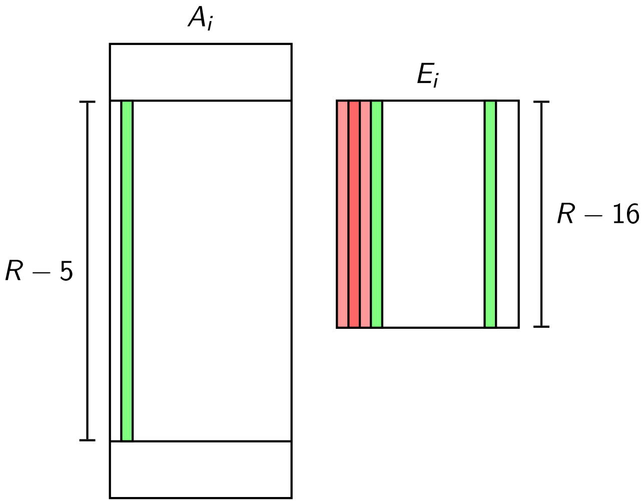
expect 2^{27-R} solutions

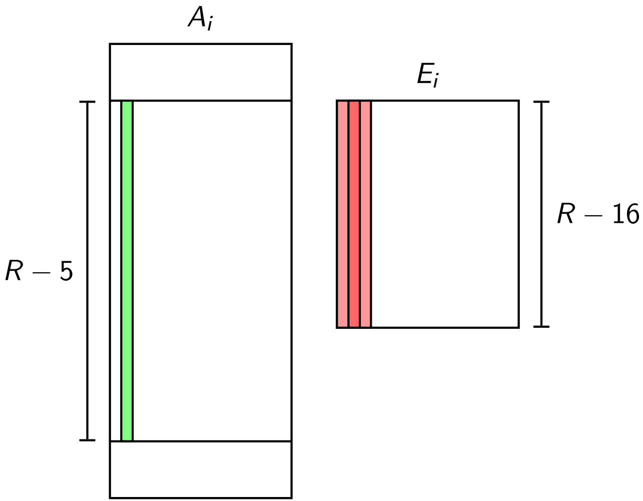


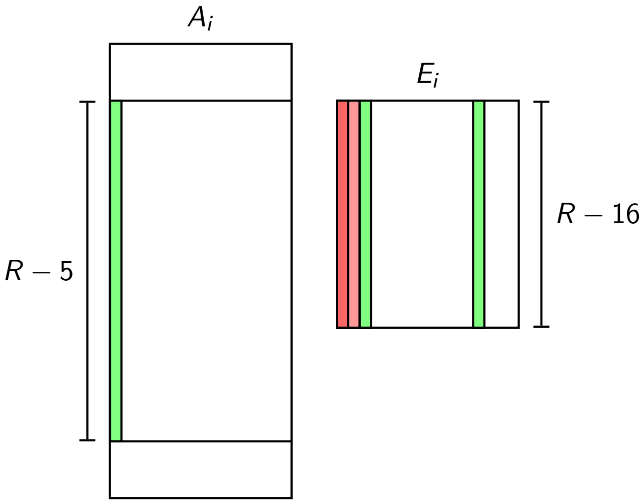
expect 2^{27-R} solutions

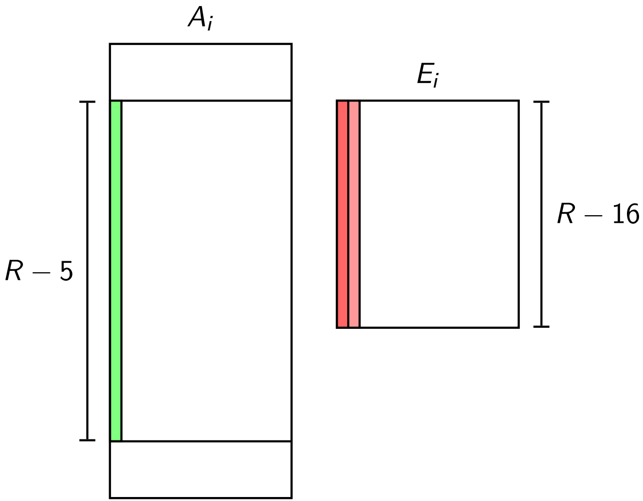

A_i
E_i
$R - 5$
$R - 16$

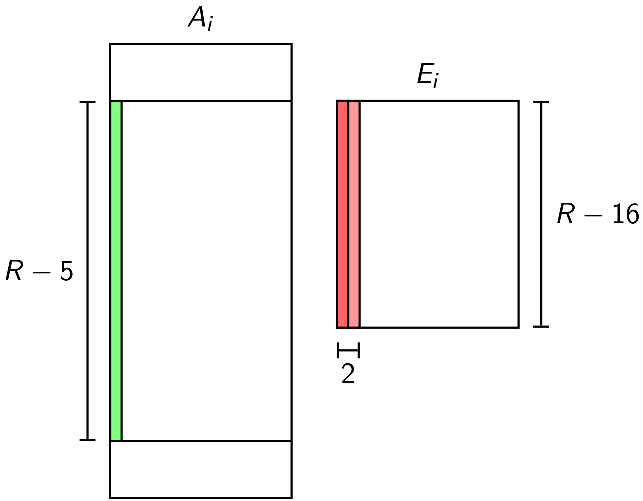

A_i
E_i
$R - 5$
$R - 16$

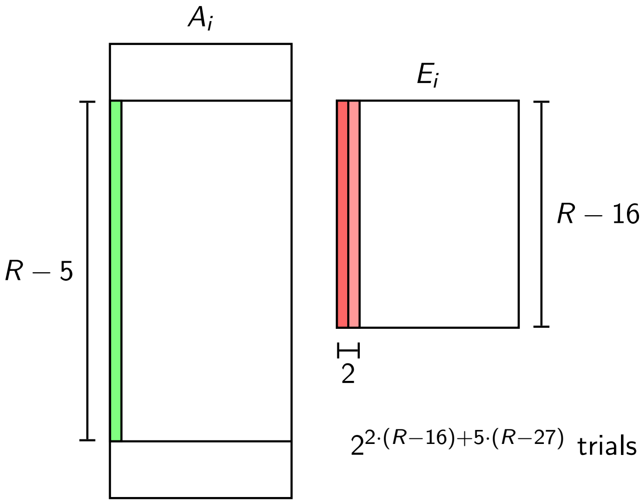

A_i
E_i
$R - 5$
$R - 16$


A_i
$R - 5$
E_i
$R - 16$


A_i
E_i
$R - 5$
$R - 16$


A_i
E_i
$R - 5$
$R - 16$


A_i
$R-5$
E_i
$R-16$
2



$2^{2\cdot(R-16)+5\cdot(R-27)}$ trials

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1. Background
   - SHA-0/1
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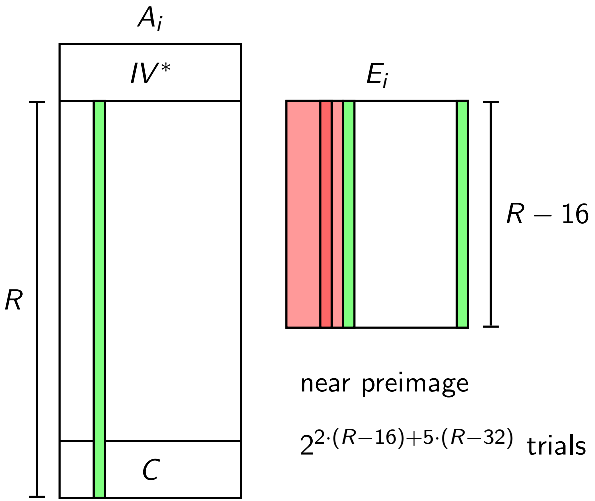
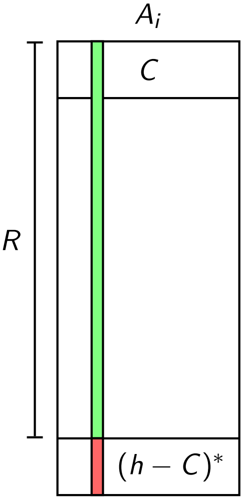
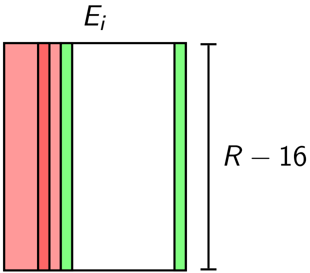
   - Basic Technique
   - Complexity
3. Improvements
   - Getting Rid of Those Carries
   - Using More Blocks
   - Using Even More Blocks
4. Example and Final Remarks



near preimage

$2^{2\cdot(R-16)+5\cdot(R-32)}$ trials





pseudo preimage

$2^{2\cdot(R-16)+5\cdot(R-32)}$ trials

Outline

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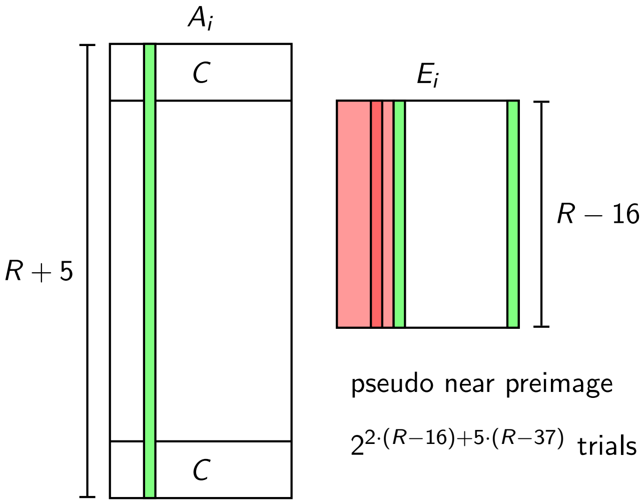
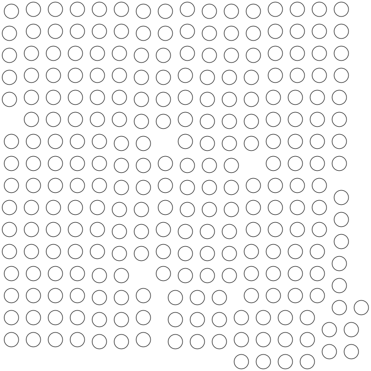


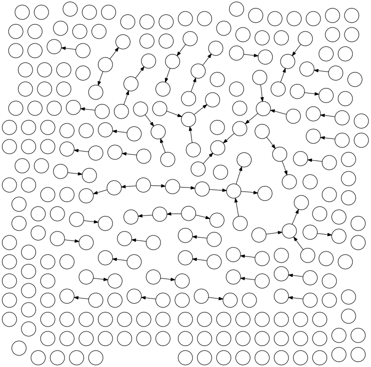
pseudo near preimage

$2^{2\cdot(R-16)+5\cdot(R-37)}$ trials

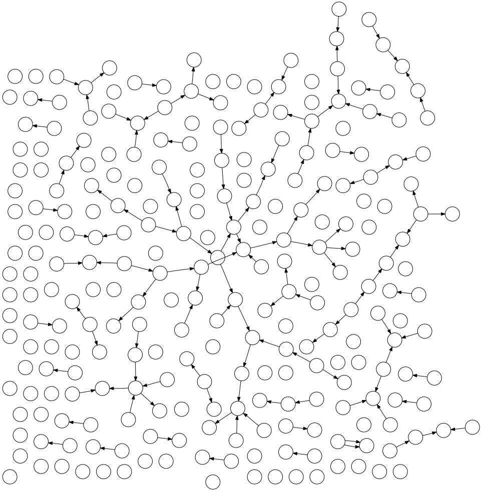
P3Graph (N nodes)



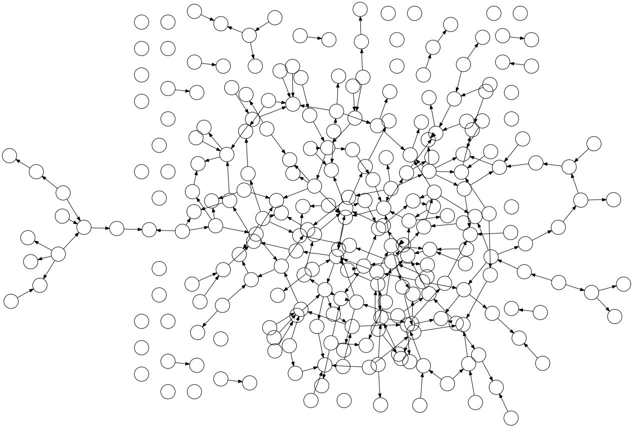
P3Graph ($N/4$ edges)



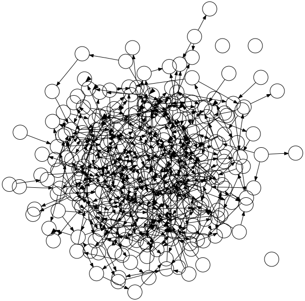
P3Graph ($N/2$ edges)



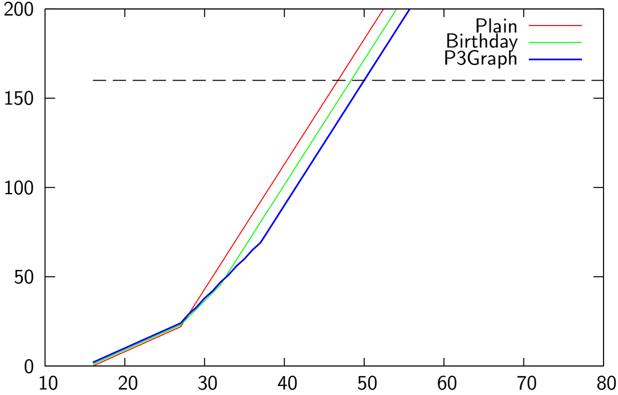
P3Graph (N edges)



P3Graph ($2 \times N$ edges)



Second Preimage Complexities for SHA-0



31-step Example

Given Message

```
0000000: 416c 6963 6520 7761 7320 6265 6769 6e6e  Alice was beginn
0000010: 696e 6720 746f 2067 6574 2076 6572 7920  ing to get very
0000020: 7469 7265 6420 6f66 2073 6974 7469 6e67  tired of sitting
0000030: 2062 7920 6865 7220 7369 7374 6572 206f   by her sister o
0000040: 6e20 7468 6520 6261 6e6b 2c20 616e 6420  n the bank, and
0000050: 6f66 2068 6176 696e 6720 6e6f 7468 696e  of having nothin
0000060: 6720 746f 2064 6f3a 206f 6e63 6520 6f72  g to do: once or
0000070: 2074 7769 6365 2073 6865 2068 6164 2070   twice she had p
0000080: 6565 7065 6420 696e 746f 2074 6865 2062  eeped into the b
0000090: 6f6f 6b20 6865 7220 7369 7374 6572 2077  ook her sister w
00000a0: 6173 2072 6561 6469 6e67 2c20 6275 7420  as reading, but
00000b0: 6974 2068 6164 206e 6f20 7069 6374 7572  it had no pictur
00000c0: 6573 206f 7220 636f 6e76 6572 7361 7469  es or conversati
00000d0: 6f6e 7320 696e 2069 742c 2060 616e 6420  ons in it, ‘and
00000e0: 7768 6174 2069 7320 7468 6520 7573 6520  what is the use
00000f0: 6f66 2061 2062 6f6f 6b2c 2720 7468 6f75  of a book,’ thou
```

```
0000100: 6768 7420 416c 6963 6520 6077 6974 686f  ght Alice ‘witho
0000110: 7574 2070 6963 7475 7265 7320 6f72 2063  ut pictures or c
0000120: 6f6e 7665 7273 6174 696f 6e3f 2720 536f  onversation?’ So
0000130: 2073 6865 2077 6173 2063 6f6e 7369 6465   she was conside
0000140: 7269 6e67 2069 6e20 6865 7220 6f77 6e20  ring in her own 
0000150: 6d69 6e64 2028 6173 2077 656c 6c20 6173  mind (as well as
0000160: 2073 6865 2063 6f75 6c64 2c20 666f 7220   she could, for 
0000170: 7468 6520 686f 7420 6461 7920 6d61 6465  the hot day made
0000180: 2068 6572 2066 6565 6c20 7665 7279 2073   her feel very s
0000190: 6c65 6570 7920 616e 6420 7374 7570 6964  leepy and stupid
00001a0: 292c 2077 6865 7468 6572 2074 6865 2070  ), whether the p
00001b0: 6c65 6173 7572 6520 6f66 206d 616b 696e  leasure of makin
00001c0: 6720 6120 6461 6973 792d 6368 6169 6e20  g a daisy-chain 
00001d0: 776f 756c 6420 6265 2077 6f72 7468 2074  would be worth t
00001e0: 6865 2074 726f 7562 6c65 206f 6620 6765  he trouble of ge
00001f0: 7474 696e 6720 7570 2061 6e64 2070 6963  tting up and pic
```

```
0000200: 6b69 6e67 2074 6865 2064 6169 7369 6573  king the daisies
0000210: 2c20 7768 656e 2073 7564 6465 6e6c 7920  , when suddenly
0000220: 6120 5768 6974 6520 5261 6262 6974 2077  a White Rabbit w
0000230: 6974 6820 7069 6e6b 2065 7965 7320 7261  ith pink eyes ra
0000240: 6e20 636c 6f73 6520 6279 2068 6572 2e20  n close by her.
0000250: 5468 6572 6520 7761 7320 6e6f 7468 696e  There was nothin
0000260: 6720 736f 2056 4552 5920 7265 6d61 726b  g so VERY remark
0000270: 6162 6c65 2069 6e20 7468 6174 3b20 6e6f  able in that; no
0000280: 7220 6469 6420 416c 6963 6520 7468 696e  r did Alice thin
0000290: 6b20 6974 2073 6f20 5645 5259 206d 7563  k it so VERY muc
00002a0: 6820 6f75 7420 6f66 2074 6865 2077 6179  h out of the way
00002b0: 2074 6f20 6865 6172 2074 6865 2052 6162   to hear the Rab
00002c0: 6269 7420 7361 7920 746f 2069 7473 656c  bit say to itsel
00002d0: 662c 2060 4f68 2064 6561 7221 204f 6820  f, ‘Oh dear! Oh
00002e0: 6465 6172 2120 4920 7368 616c 6c20 6265  dear! I shall be
00002f0: 206c 6174 6521 2720 2877 6865 6e20 7368   late!’ (when sh
0000300: 6520 7468 6f75 6768 7420 6974 206f 7665  e thought it ove
0000310: 7220 6166 7465 7277 6172 6473 2c20 6974  r afterwards, it
0000320: 206f 6363 7572 7265 6420 746f 2068 6572   occurred to her
0000330: 2074 6861 7420 7368 6520 6f75 6768 7420   that she ought 
0000340: 746f 2068 6176 6520 776f 6e64 6572 6564  to have wondered
0000350: 2061 7420 7468 6973 2c20 6275 7420 6174   at this, but at
0000360: 2074 6865 2074 696d 6520 6974 2061 6c6c   the time it all
0000370: 2073 6565 6d65 6420 7175 6974 6520 6e61   seemed quite na
0000380: 7475 7261 6c29 3b20 6275 7420 7768 656e  tural); but when
0000390: 2074 6865 2052 6162 6269 7420 6163 7475   the Rabbit actu
00003a0: 616c 6c79 2054 4f4f 4b20 4120 5741 5443  ally TOOK A WATC
00003b0: 4820 4f55 5420 4f46 2049 5453 2057 4149  H OUT OF ITS WAI
00003c0: 5354 434f 4154 2d50 4f43 4b45 542c 2061  STCOAT-POCKET, a
00003d0: 6e64 206c 6f6f 6b65 6420 6174 2069 742c  nd looked at it,
00003e0: 2061 6e64 2074 6865 6e20 6875 7272 6965   and then hurrie
00003f0: 6420 6f6e 2c20 416c 6963 6520 7374 6172  d on, Alice star
```

```
0000400: 7465 6420 746f 2068 6572 2066 6565 742c  ted to her feet,
0000410: 2066 6f72 2069 7420 666c 6173 6865 6420   for it flashed
0000420: 6163 726f 7373 2068 6572 206d 696e 6420  across her mind
0000430: 7468 6174 2073 6865 2068 6164 206e 6576  that she had nev
0000440: 6572 2062 6566 6f72 6520 7365 656e 2061  er before seen a
0000450: 2072 6162 6269 7420 7769 7468 2065 6974   rabbit with eit
0000460: 6865 7220 6120 7761 6973 7463 6f61 742d  her a waistcoat-
0000470: 706f 636b 6574 2c20 6f72 2061 2077 6174  pocket, or a wat
0000480: 6368 2074 6f20 7461 6b65 206f 7574 206f  ch to take out o
0000490: 6620 6974 2c20 616e 6420 6275 726e 696e  f it, and burnin
00004a0: 6720 7769 7468 2063 7572 696f 7369 7479  g with curiosity
00004b0: 2c20 7368 6520 7261 6e20 6163 726f 7373  , she ran across
00004c0: 2074 6865 2066 6965 6c64 2061 6674 6572   the field after
00004d0: 2069 742c 2061 6e64 2066 6f72 7475 6e61   it, and fortuna
00004e0: 7465 6c79 2077 6173 206a 7573 7420 696e  tely was just in
00004f0: 2074 696d 6520 746f 2073 6565 2069 7420   time to see it
```

```
0000500: 706f 7020 646f 776e 2061 206c 6172 6765  pop down a large
0000510: 2072 6162 6269 742d 686f 6c65 2075 6e64   rabbit-hole und
0000520: 6572 2074 6865 2068 6564 6765 2e20 496e  er the hedge. In
0000530: 2061 6e6f 7468 6572 206d 6f6d 656e 7420   another moment 
0000540: 646f 776e 2077 656e 7420 416c 6963 6520  down went Alice 
0000550: 6166 7465 7220 6974 2c20 6e65 7665 7220  after it, never 
0000560: 6f6e 6365 2063 6f6e 7369 6465 7269 6e67  once considering
0000570: 2068 6f77 2069 6e20 7468 6520 776f 726c   how in the worl
0000580: 6420 7368 6520 7761 7320 746f 2067 6574  d she was to get
0000590: 206f 7574 2061 6761 696e 2e0a             out again..
```

31-step Example

2nd Preimage

```
0000000: 6093 e793 8844 423f cf3e 4140 3479 5078  `....DB?.>A@4yPx
0000010: f8ac 0a92 7e6a 1956 d8b7 b004 1bf9 027f  ....~j.V........
0000020: 13fd 7b20 5cbd 783c 9b3d 78d2 e0bd 8106  ..{ \.x<.=x.....
0000030: fee5 2a1d 8efe 23eb 6bd8 7621 354f 0c9c  ..*...#.k.v!5O..
0000040: 9b86 3bbf 6469 db87 b11d 9195 707d 3f5a  ..;.di......p}?Z
0000050: 277b 582e 44fa 9440 a57c be61 14bc 7c39  '{X.D..@.|.a..|9
0000060: aabc 785e 3c7d 85ef 35bd 855d 1b7d 84fd  ..x^<}..5..].}..
0000070: a7d6 c497 a55a d1ae 21ea 5210 19cc f5e1  .....Z..!.R.....
0000080: b6a5 86d7 e20e 085d e7ab ab81 dd74 ffad  .......].....t..
0000090: 6a33 7421 b5cf 5fa2 c709 48b3 836d 6f2a  j3t!.._...H..mo*
00000a0: 8d3d 7e50 eefd 793c 2cbd 84ea d83d 78bc  .=~P..y<,....=x.
00000b0: 7d7b 64a9 483c 18f3 f559 a0d5 bf69 d5f8  }{d.H<...Y...i..
00000c0: 5e7d 920f 9cbe 10a2 0d5d 5bb1 453d 7b31  ^}.......][.E={1
00000d0: d03d 7f7f fe6d 019b 5fa4 fed5 fbf5 79dd  .=...m.._.....y.
00000e0: 37bd 7ced ddfd 79aa 18fd 7da7 063d 8622  7.|...y...}..=."
00000f0: ece1 65d6 0372 499e 9c7c 8472 5267 8c88  ..e..rI..|.rRg..
```

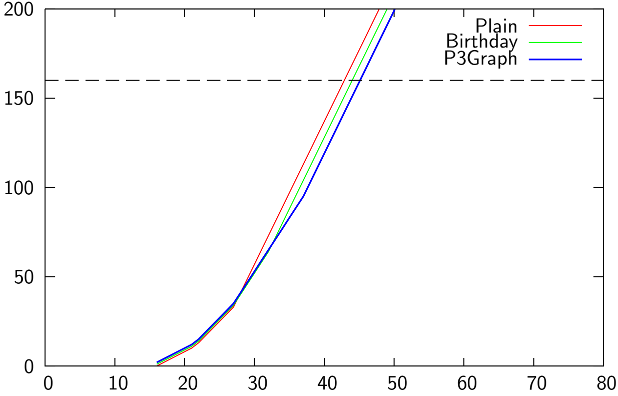
```
0000100: fa9e 8747 255d a7e9 cafd 73dd b87d 3785  ...G%]....s..}7.
0000110: b63d 3c42 2e35 3292 771b 690c a41b 77f1  .=<B.52.w.i...w.
0000120: abfd 84fa d93d 8646 9c3d 7774 b23d 7c79  .....=.F.=wt.=|y
0000130: aef9 1db8 c192 413e d8ef 6d8b b39e f536  ......A>..m....6
0000140: 0fa1 c66f 3ffd 955e 6f3b c780 3265 afa6  ...o?..^o;..2e..
0000150: 76ac 6b63 fa32 6784 510b 5c5d cd0d 5413  v.kc.2g.Q.\]..T.
0000160: babd 6b15 c5fd 7cab b17d 7c12 a97d 7d5a  ..k...|..}|..}}Z
0000170: d313 a994 f376 99d2 49b4 e6df 154a 5d84  .....v..I....J].
0000180: 38a0 0a47 d12e 07c9 9065 778b 1b7d 7f34  8..G.....ew..}.4
0000190: 54bc dbfd 2cb4 96c2 0ebb 3db1 8afb 8442  T...,.....=....B
00001a0: 74bd 7b59 25fd 7951 86fd 7ff1 717d 78be  t.{Y%.yQ....q}x.
00001b0: 5357 37b3 6524 7861 6ab2 ec05 8f4c 966e  SW7.e$xaj....L.n
00001c0: ec5d 8b9f 2d7d 6fb7 f36b fba1 eb6d 7b34  .]..-}o..k...m{4
00001d0: bdc5 8179 08c5 5b61 89fd 3b15 2b7d 59ab  ...y..[a..;.+}Y.
00001e0: f07d 7fcc 36fd 7c85 3cbd 7eac 45fd 85c4  .}..6.|.<.~.E...
00001f0: 752d aeef df79 9808 a886 8285 a5dd ff34  u-...y.........4
```

```
0000200: 5c8d 9e8f b2ba 8079 167d 657a c33d 43bc  \......y.}ez.=C.
0000210: 1db9 76d0 e3e9 70df 986d 7c1e 657d 8363  ..v...p..m|.e}.c
0000220: 613d 7750 3e3d 7944 fa7d 77a5 373d 7765  a=wP>=yD.}w.7=we
0000230: c560 ac62 e5b2 47dd 01fe aebe e8ac e99a  .‘.b..G.........
0000240: 887d 930f 5f7c 0fc3 f789 7790 de7d 7f71  .}.._|....w..}.q
0000250: b4bd 7ba9 4d3d 6c8a 1579 75b8 c439 84d2  ..{.M=l..yu..9..
0000260: 513d 7b27 a3bd 7f43 357d 7fa9 e9bd 7704  Q={’...C5}....w.
0000270: ff1d 6a35 02bd 3859 2703 d027 4915 5452  ..j5..8Y’..’I.TR
0000280: dd05 9eb7 577a 8263 01a2 a46f d8bd 5daa  ....Wz.c...o..].
0000290: eebd 72a2 21db 732a 98b3 f657 d033 fb18  ..r.!.s*...W.3..
00002a0: 987d 82f5 f2bd 7c08 2dfd 85c8 38fd 82ca  .}....|.-...8...
00002b0: 5939 ee8e 140f 5b3d 0cc9 9c81 9c92 5965  Y9....[=......Ye
00002c0: 3b9d 96af 8b47 7d9f e2ff 8392 c6ac ff71  ;....G}........q
00002d0: b5f3 81bd d482 750b 5749 f1aa 4cfc e77a  ......u.WI..L..z
00002e0: b1fd 7ead e23d 7900 aabd 7f55 3cbd 83f5  ..~..=y....U<...
00002f0: 97bb e4dd 6941 50cd 567f 37d0 3e5c 9e26  ....iAP.V.7.>\.&
```

```
0000300: 7a23 d3cf cdbc 6851 fc6b 6fdc 0a73 e75c  z#....hQ.ko..s.\
0000310: 5c53 e94b c211 c83c 9d3b 59c7 77fd 7a5a  \S.K...<.;Y.w.zZ
0000320: 9afd 7b0b 883d 835f c8fd 7f30 98bd 7f34  ..{..=._...0...4
0000330: 570a e920 9bc7 4e38 9d9f 7faa 7e51 9dbd  W.. ..N8....~Q..
0000340: 0f0c c697 20e5 9f98 9c99 fff8 442d 7383  .... .......D-s.
0000350: 583a 2e86 7bc5 a5a9 48e1 57da 0675 61ce  X:..{...H.W..ua.
0000360: 1a3d 78d0 23bd 7ac5 24fd 804e 473d 7aa0  .=x.#.z.$..NG=z.
0000370: b7c3 6cdc 9ce1 2251 87d2 dbef 4739 a47c  ..l..."Q....G9.|
0000380: 9d15 92a7 4a9c bcc5 74a9 579c 41dd 7e99  ....J...t.W.A.~.
0000390: a8db 7a99 398f 4864 1fa4 54bd 9d6c 7c8e  ..z.9.Hd..T..l|.
00003a0: 57bd 7ac7 12fd 84b9 703d 7a02 9cbd 7c37  W.z.....p=z...|7
00003b0: f88f b361 8ec1 1971 f419 9d71 beb2 f4ca  ...a...q...q....
00003c0: 1c42 eccf 31e1 3783 3e6d bf75 3765 83a6  .B..1.7.>m.u7e..
00003d0: 41cc 5f17 c588 0436 df79 4dd9 fafd 752f  A._....6.yM...u/
00003e0: 353d 7fcc fffd 79e5 057d 7cc1 c93d 84b5  5=....y..}|..=..
00003f0: 9080 9f98 75f5 c427 c6d3 ffbb 2d55 00d0  ....u..’....-U..
0000400: 3c01 d6c7 410b 7bcd 8d7c f79e c27d 7b5c  <...A.{..|...}{\
0000410: f6dc 7047 4bd6 6e66 2ab7 84a2 2e7d 8676  ..pGK.nf*....}.v
0000420: b1fd 795b dbbd 7e58 043d 82bf 9b3d 836b  ..y[..~X.=...=.k
0000430: fbc6 0485 29f2 5213 6b02 b802 3b6a 30df  ....).R.k...;j0.
0000440: fa7d 8887 177d 4027 298e 7ba9 145b 7aed  .}...}@').{..[z.
0000450: 303d 8219 9cbd 7c5f 1cf9 36b5 b439 3dee  0=....|_..6..9=.
0000460: b63d 76d4 9bfd 7b6c bdbd 83b8 7e3d 8463  .=v...{l....~=.c
0000470: 93b0 32ab c928 2966 29aa ae16 6ec5 9ad0  ..2..()f)...n...
0000480: 067e 86bf 306d 7b87 f77d ffb8 446d 7bcf  .~..0m{..}..Dm{.
0000490: 143d 35b6 e879 39cf d7b9 5c05 79bd 571f  .=5..y9...\.y.W.
00004a0: 2cfd 8640 4f7d 80d7 bf3d 85b5 7d7d 7e35  ,..@O}...=..}}~5
00004b0: ef2e 8255 95e1 8361 6086 946e e1ce 3da9  ...U...a`..n..=.
00004c0: e88c eab7 23f1 0da3 261b 7baf ce35 6bae  ....#...&.{..5k.
00004d0: 2f39 e040 12a1 a732 463d 693f d915 7566  /9.@...2F=i?..uf
00004e0: bfbd 7d9d 853d 7bee f6bd 7d1e 1e3d 7afe  ..}..={...}..=z.
00004f0: 8ecb 8c22 62eb 7e25 7d3d fbc1 0f75 350d  ..."b.~%}=...u5.
```

```
0000500: d281 c797 9775 6000 77df 9f95 3737 7fbb  .....u‘.w...77..
0000510: 485c 79e1 0b9c 7585 0344 efea 56e4 f0e6  H\y...u..D..V...
0000520: 4b7d 78a6 2efd 7fc3 f03d 80c3 3f3d 827a  K}x......=..?=.z
0000530: 30c8 3047 1144 d3a9 104a 7c41 3947 4120  0.0G.D...J|A9GA
0000540: 49a0 8a9f 5c1d 026b e885 6374 2775 8269  I...\..k..ct’u.i
0000550: cb7d 017c fcb4 c107 50fb 6c2e 37bb 71a6  .}.|....P.l.7.q.
0000560: eb7d 821c d3bd 8633 6ffd 7cbd 81fd 77e7  .}.....3o.|...w.
0000570: b2c4 fef3 1c48 7d72 136a 2995 0afe 99d5  .....H}r.j).....
0000580: 6420 7368 6520 7761 7320 746f 2067 6574  d she was to get
0000590: 206f 7574 2061 6761 696e 2e0a             out again..
```

What About SHA-1?


Plain
Birthday
P3Graph