On Variable Bit-Rotations in SHA-1-like Hash Functions

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Information Society Technologies

MAIN THEME

Why was SHA-1 designed the way it is?

Overview

- Design history of SHA-1
- Review of basic design elements of SHA-1
  - Rotation in the Message Expansion
  - Recurrence-relation of the Message Expansion
  - Non-linear functions in the State Update
  - **Rotations in the State Update**
- Comparing variable and constant rotations
- Comparing constant rotations
- Conclusions

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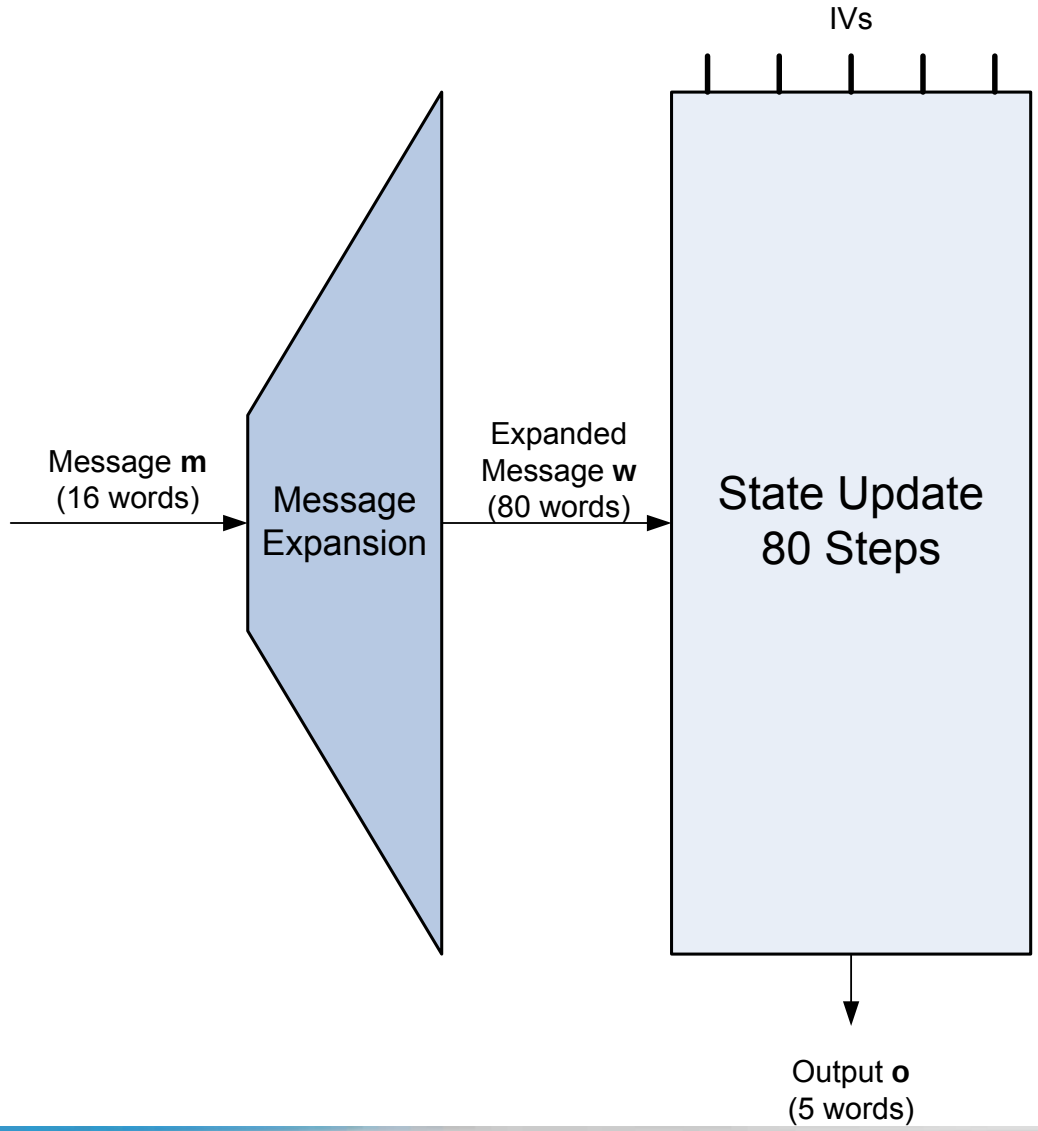
Outline of SHA-1



Design history of SHA-1

		Steps	#Chaining Variables	Message Expansion	Rotations
MD4	1990	48	4	Permutation	variable
MD5	1991	64	4	Permutation	variable
SHA-0	1992	80	5	Recurrence	const
SHA-1	1994	80	5	Recurrence + Bit-Rotation	const

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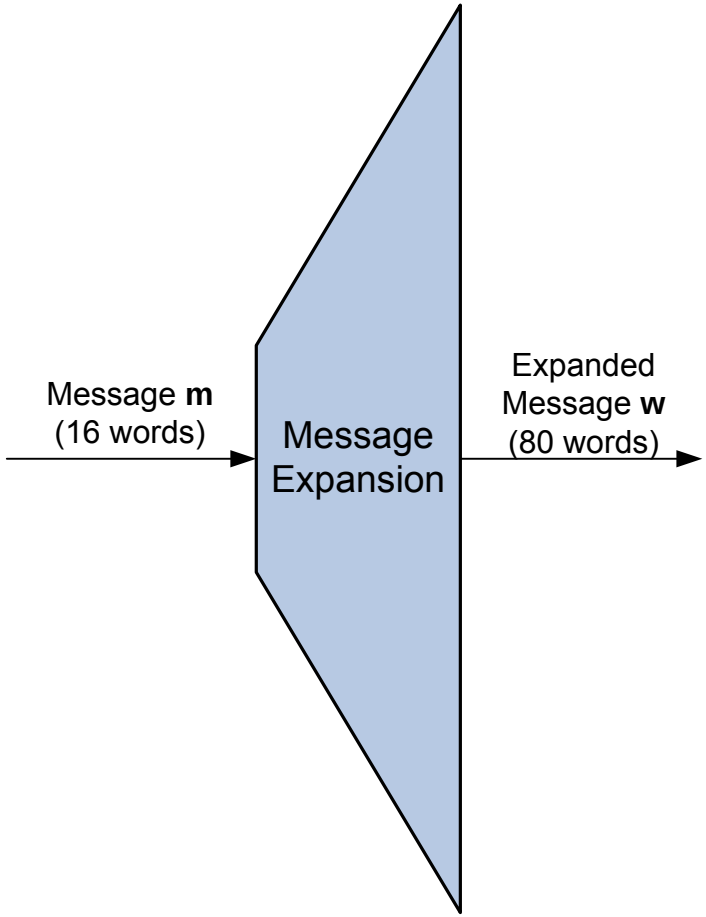
Outline of SHA-1 – Message Expansion



Recurrence relation

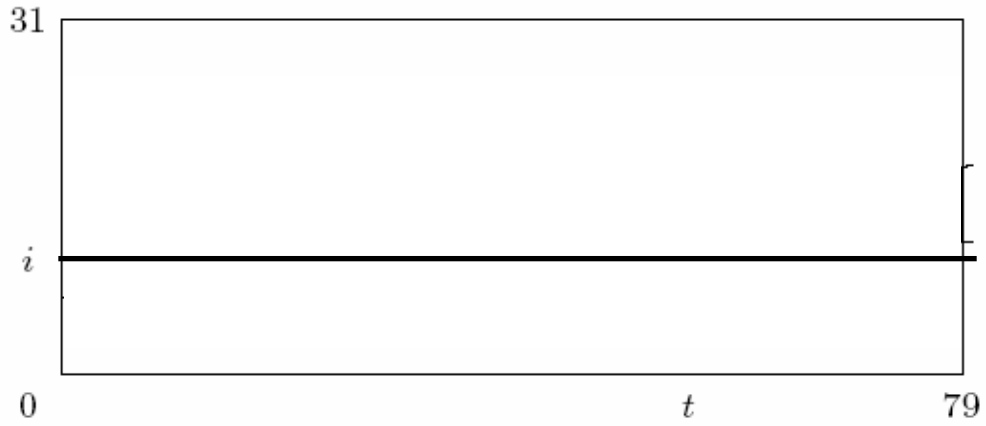
$$W_N = \begin{cases} M_N & for\,(0 \le N \le 15) \\ (W_{N-3} \oplus W_{N-8} \oplus W_{N-14} \oplus W_{N-16}) <<1 & for\,(16 \le N \le 79) \end{cases}$$

Effect of rotation

- Bits get connected over the 80 steps
- Bigger search space

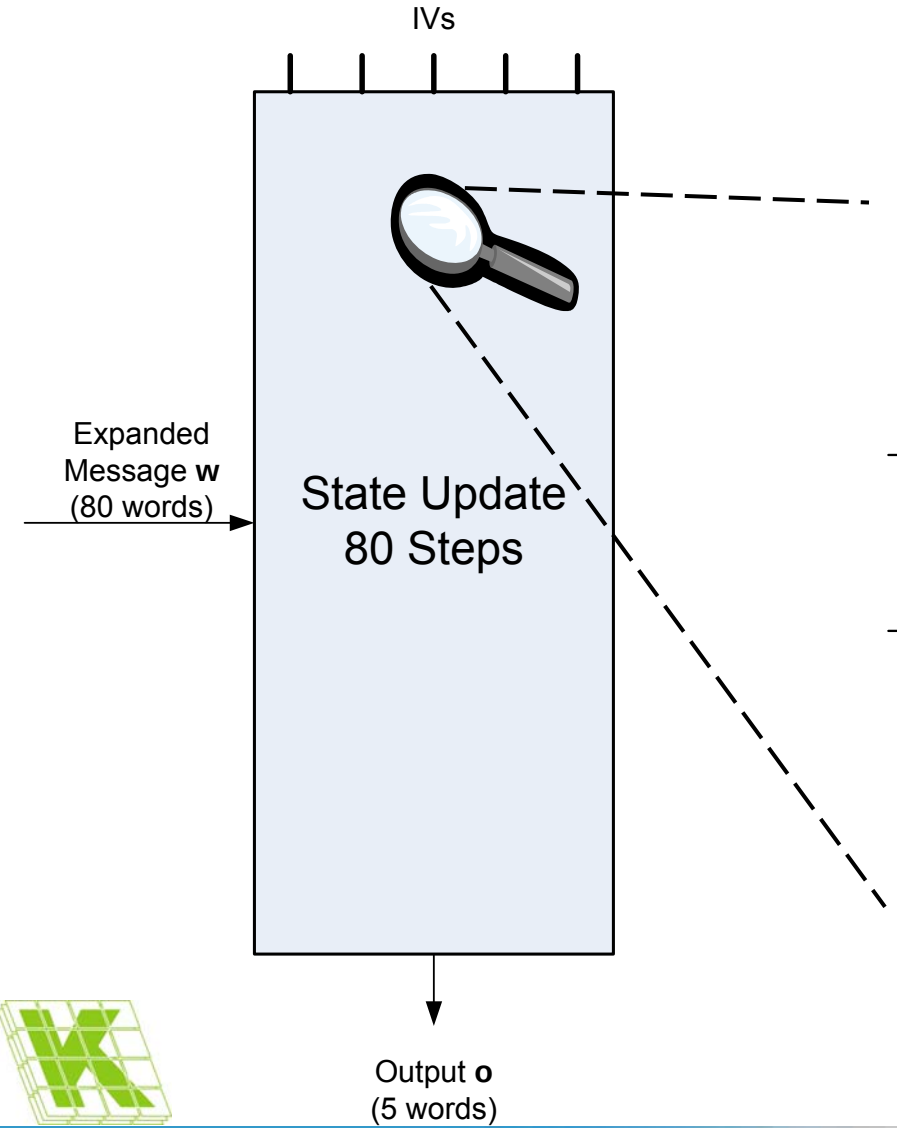
Diffusion Property of the SHA-0/1 Message Expansion

How does a change of one bit in the expanded message affect other bits?

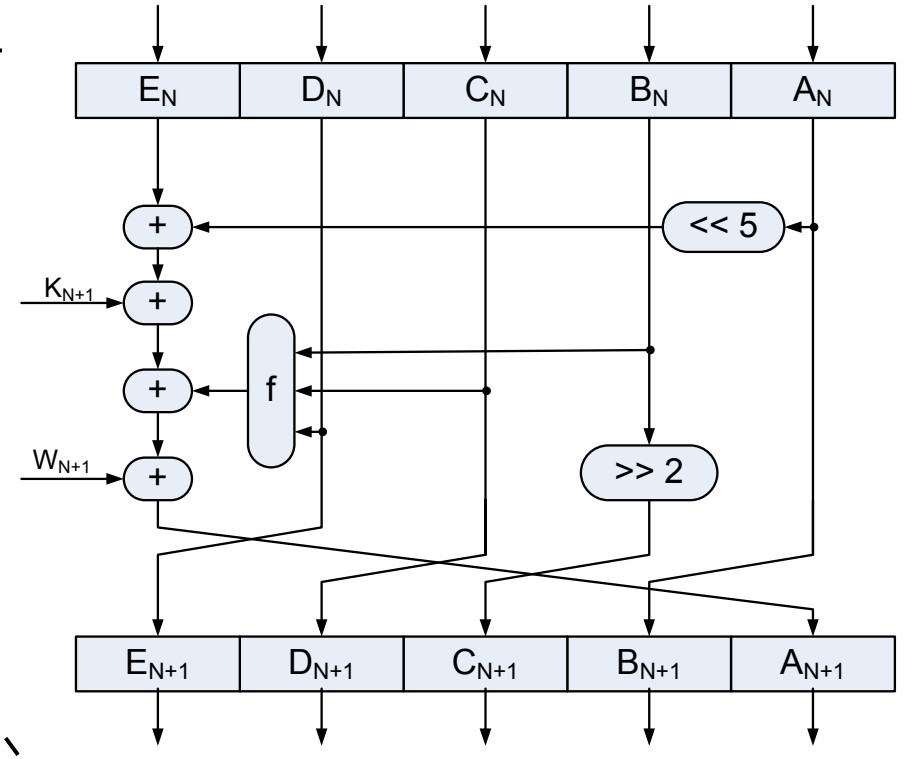


In the case of SHA-0, there is no such diffusion

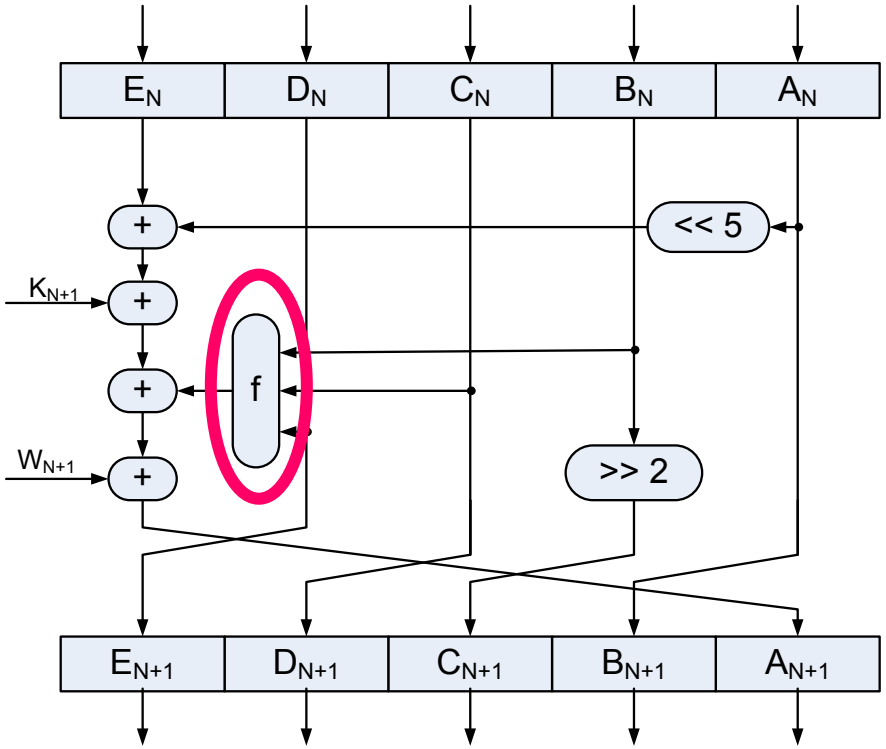
Outline of SHA – State Update



One round of the State Update



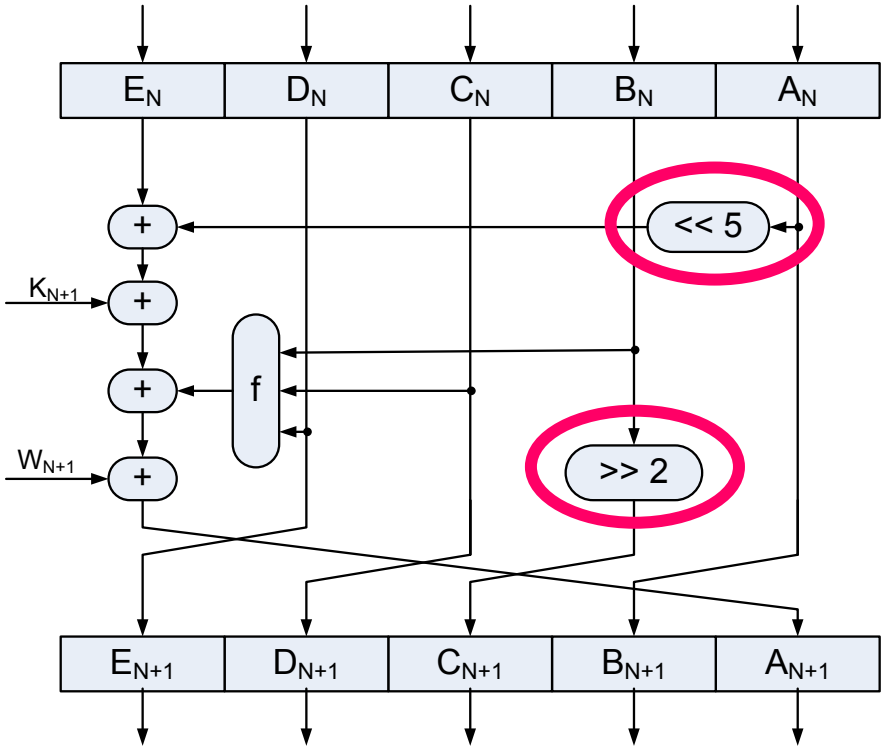
Non-linear functions in the State Update



Step i	Function f(i)	
	Name	Definition
0-19	IF	BC+(-B)D
20-39	XOR	B+C+D
40-59	MAJ	BC+BD+CD
60-79	XOR	B+C+D

Being 0-1 balanced is the only known design-criterion

Rotations in the State Update



How are these values chosen?

→ Could be ad-hoc

→ They could be the result of an optimization process!

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The working principle of a collision attack applied to SHA

1. A linear approximation for SHA is constructed. → **Linear Approximation**
2. (Near)Collisions for the linear approximation are determined. → **Input Differential**
3. A collision for the real SHA is searched among the collisions for the linear approximation. → **Conditions & Final Collision Search**

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Method to assess attack complexity

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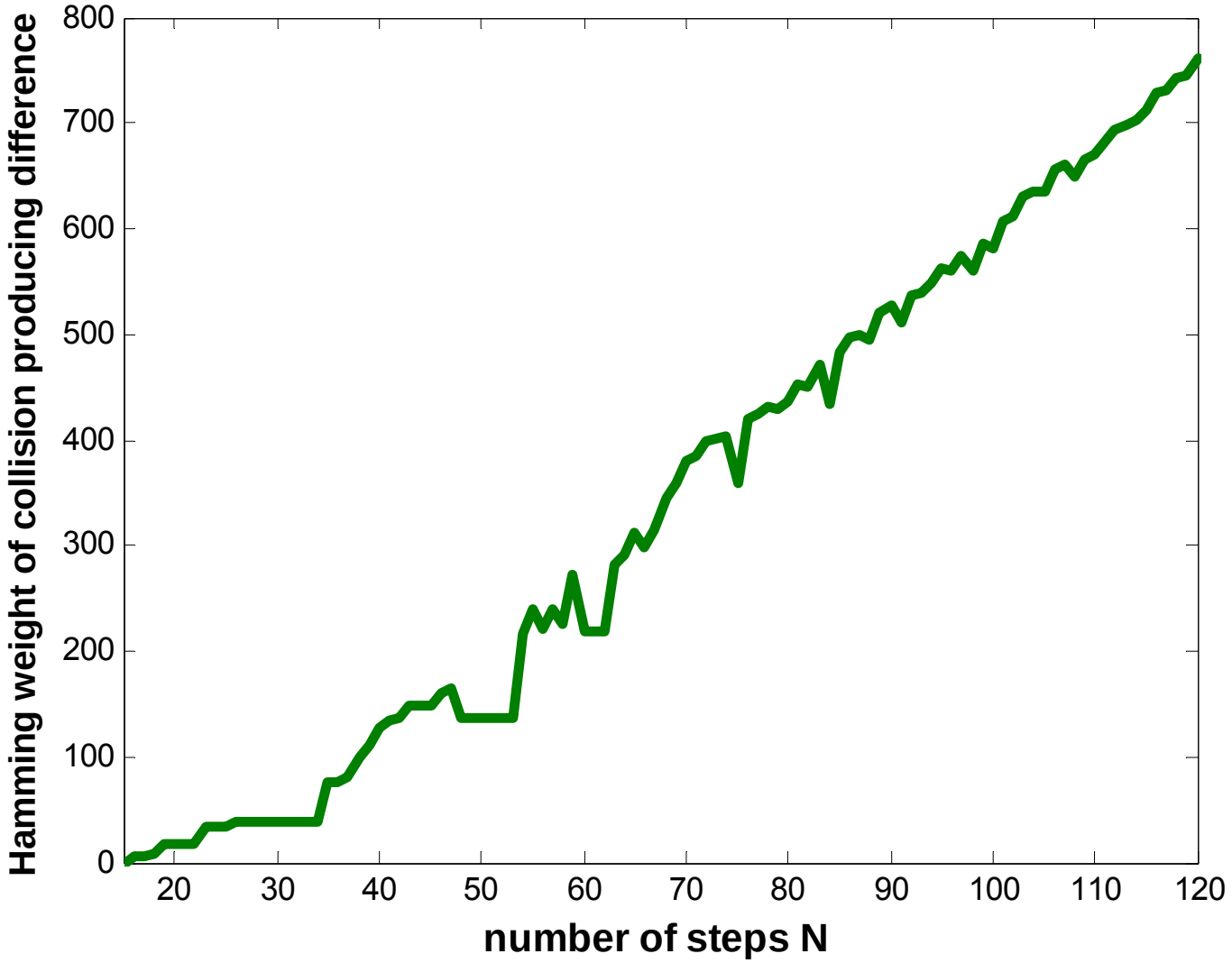
↓

Strong correlation between

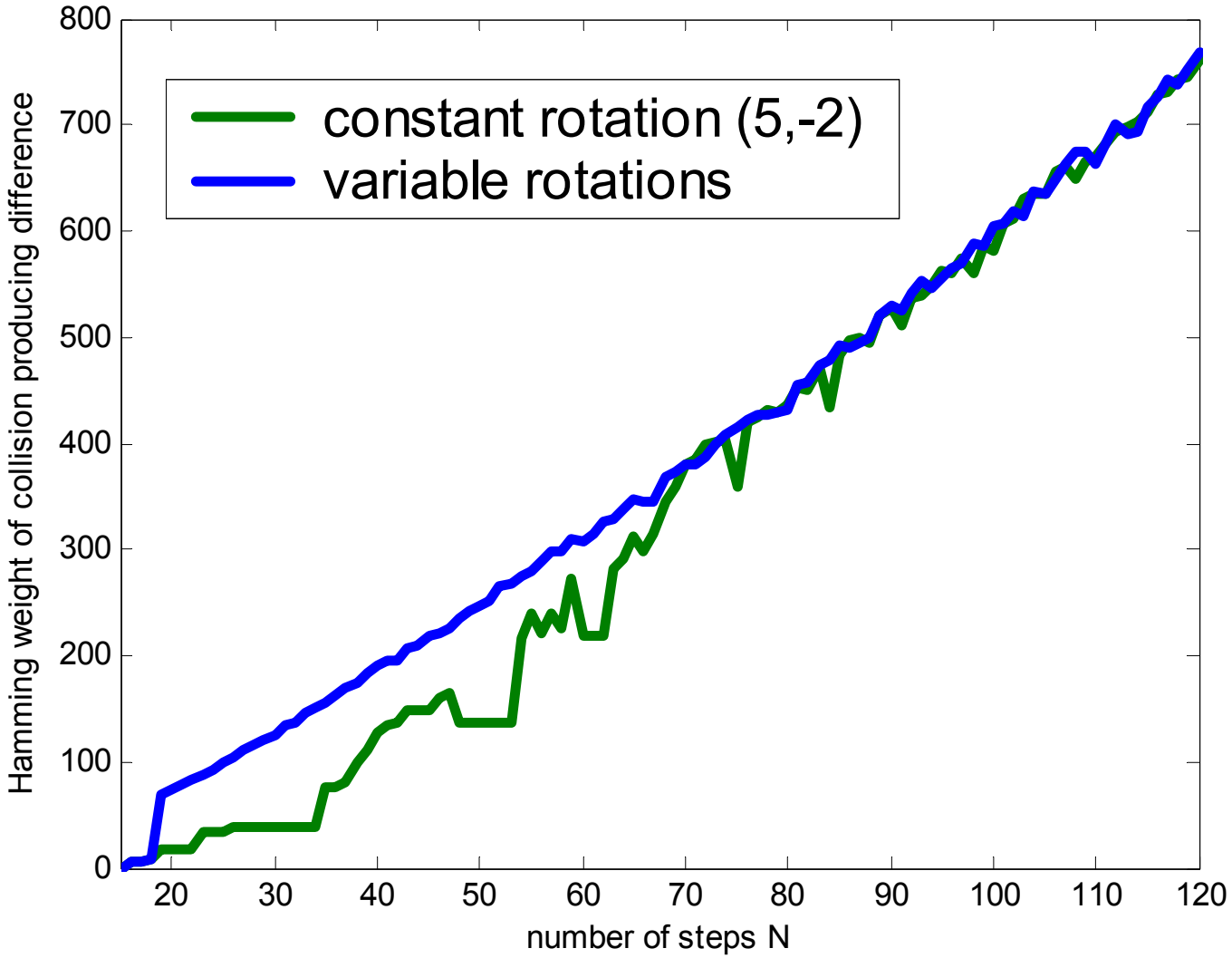
lowest weight of input difference(2) *and* #conditions(3)

Hamming weight of input difference is enough for our purposes

Hamming weights for variants of SHA-1



Comparison of constant and variable rotations



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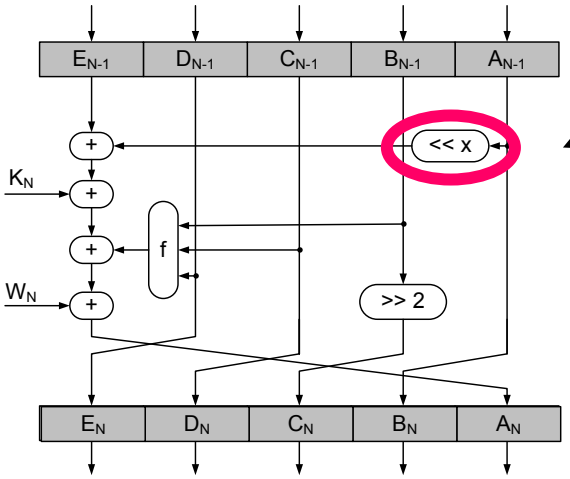
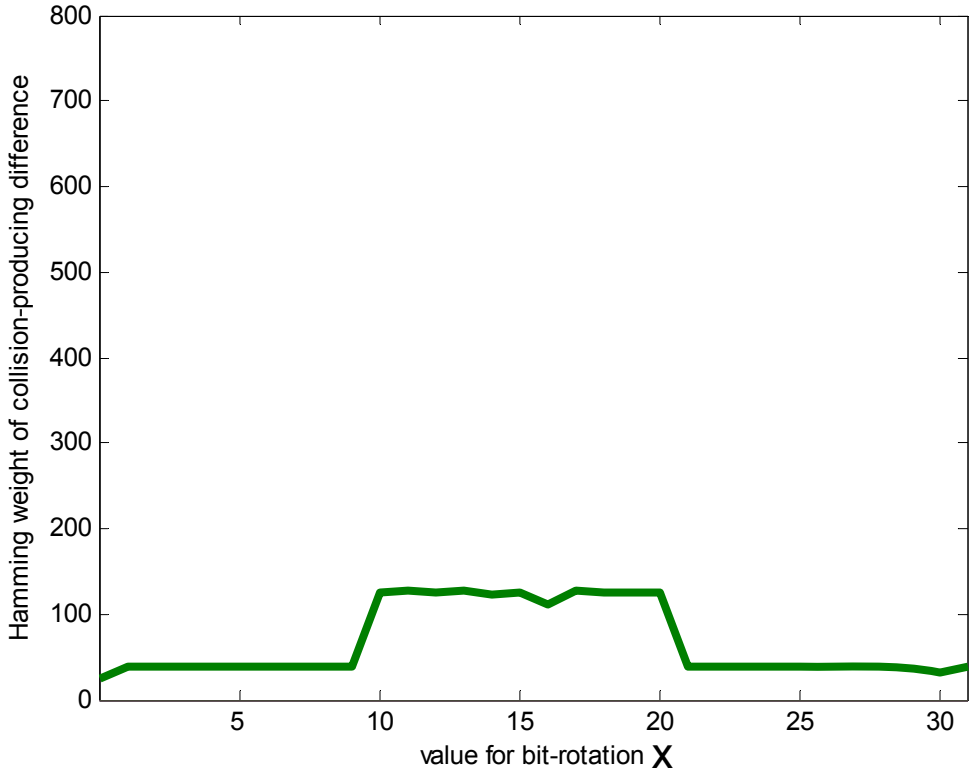
Comparing different constant rotations – Results for A



Rotating ***A*** by ***x*** bits to the left

$0 \leq x \leq 31$



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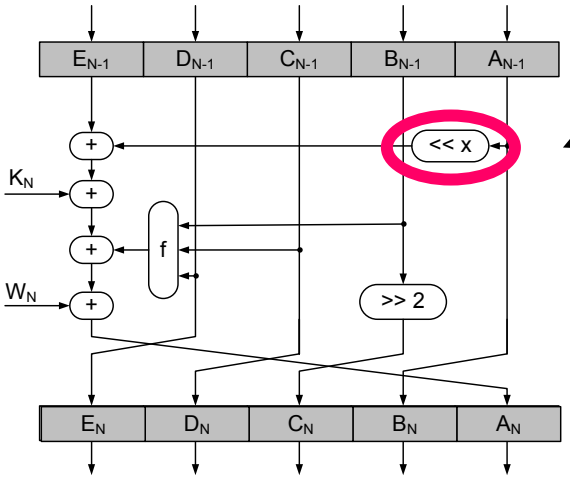

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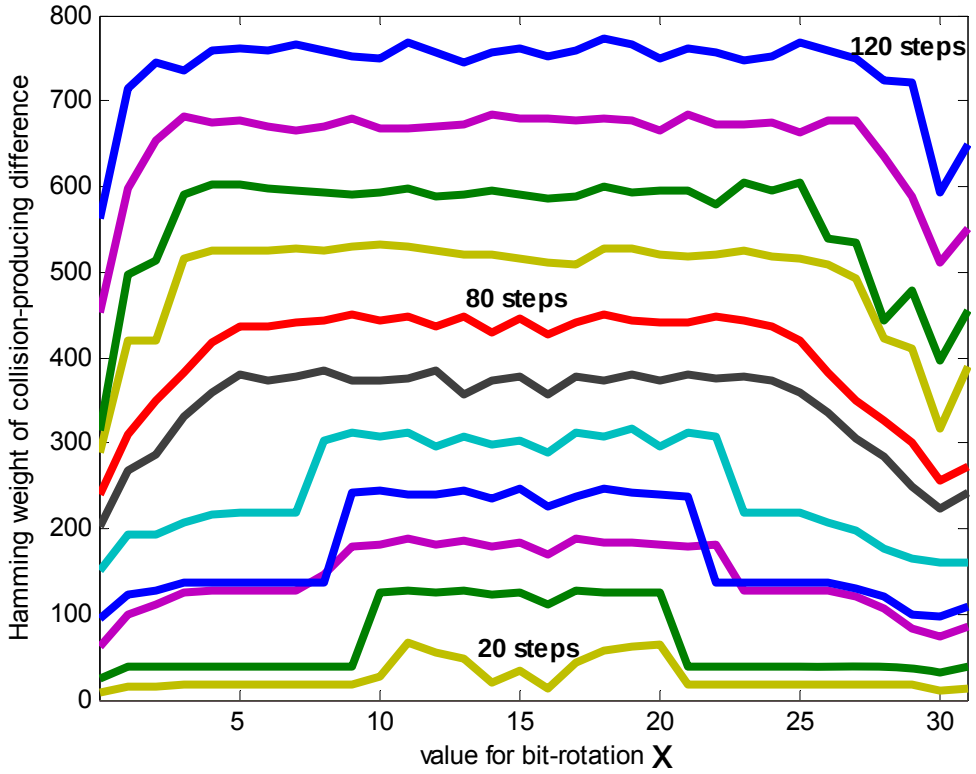

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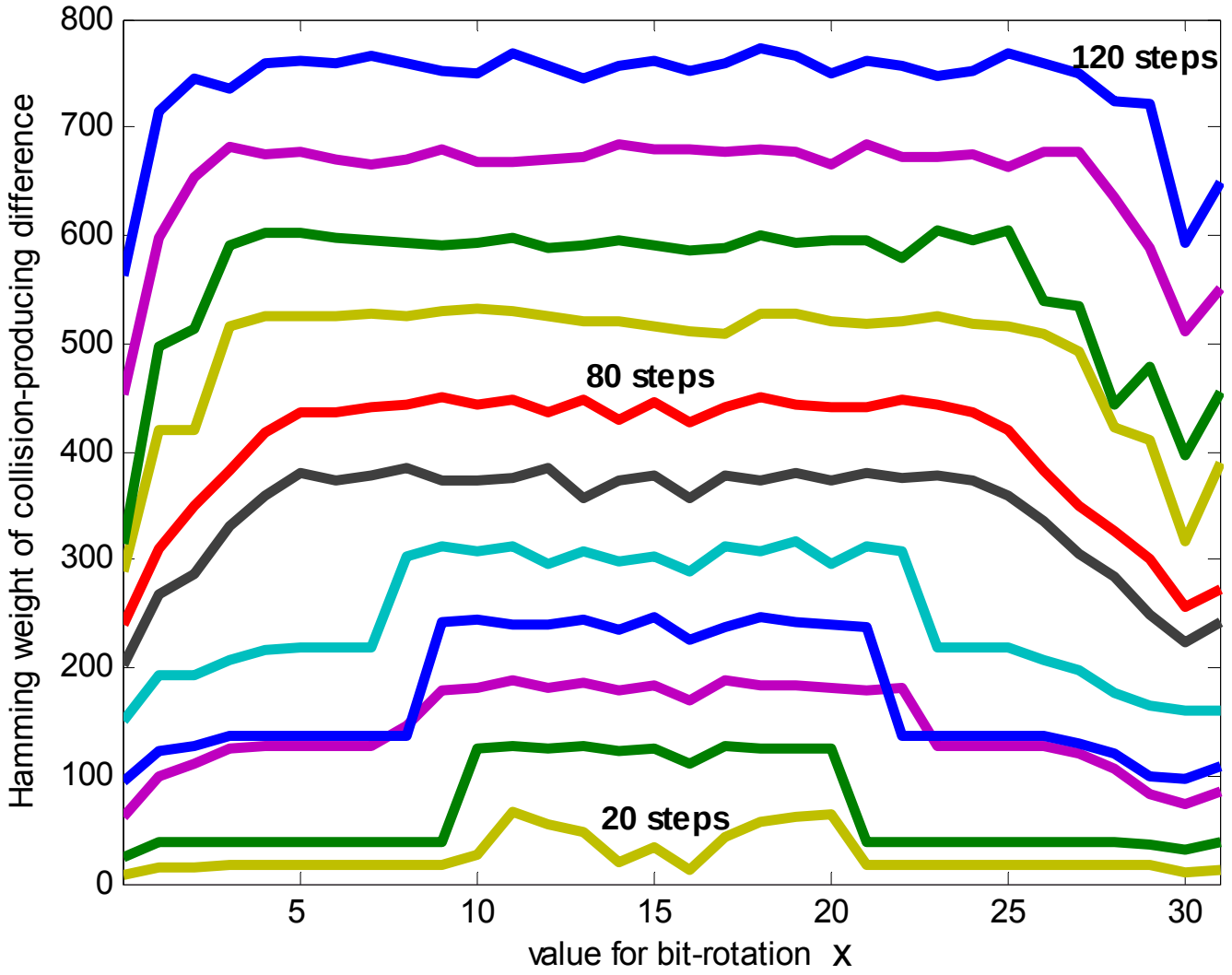

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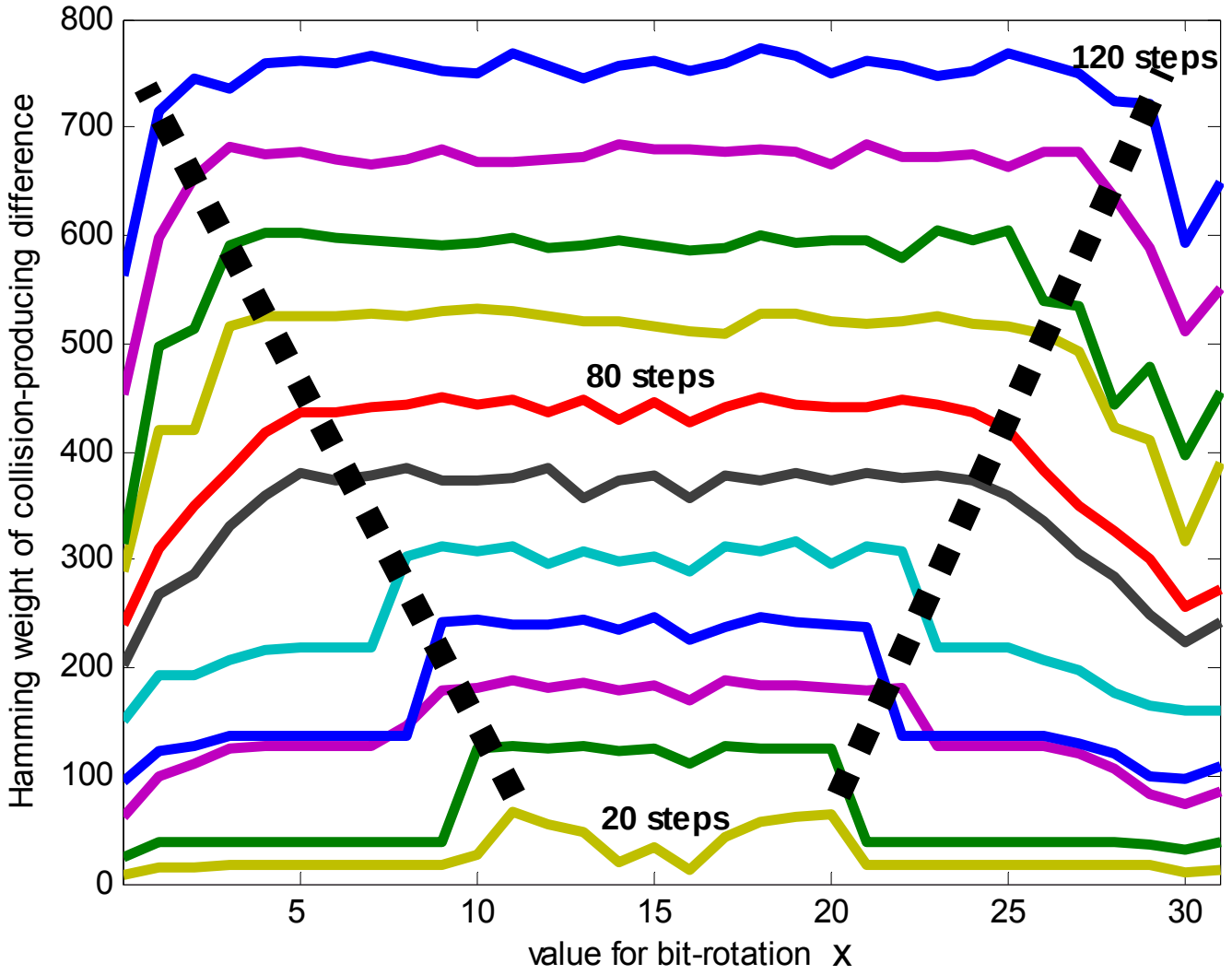

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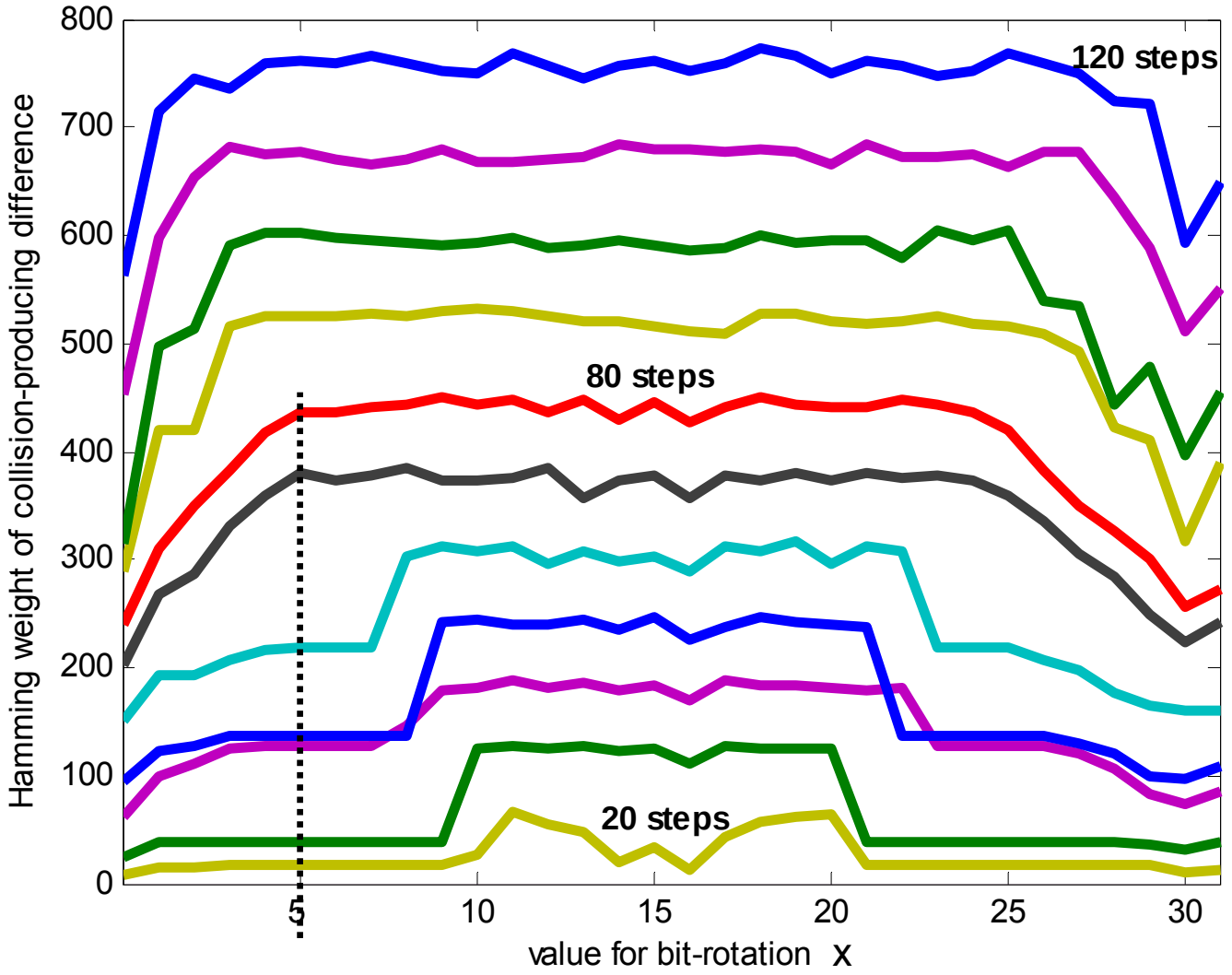
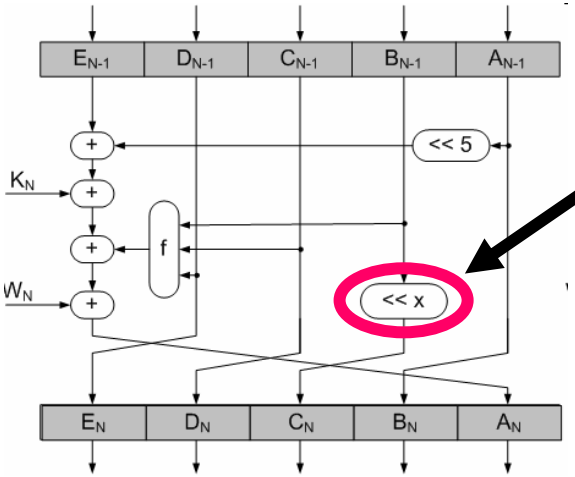
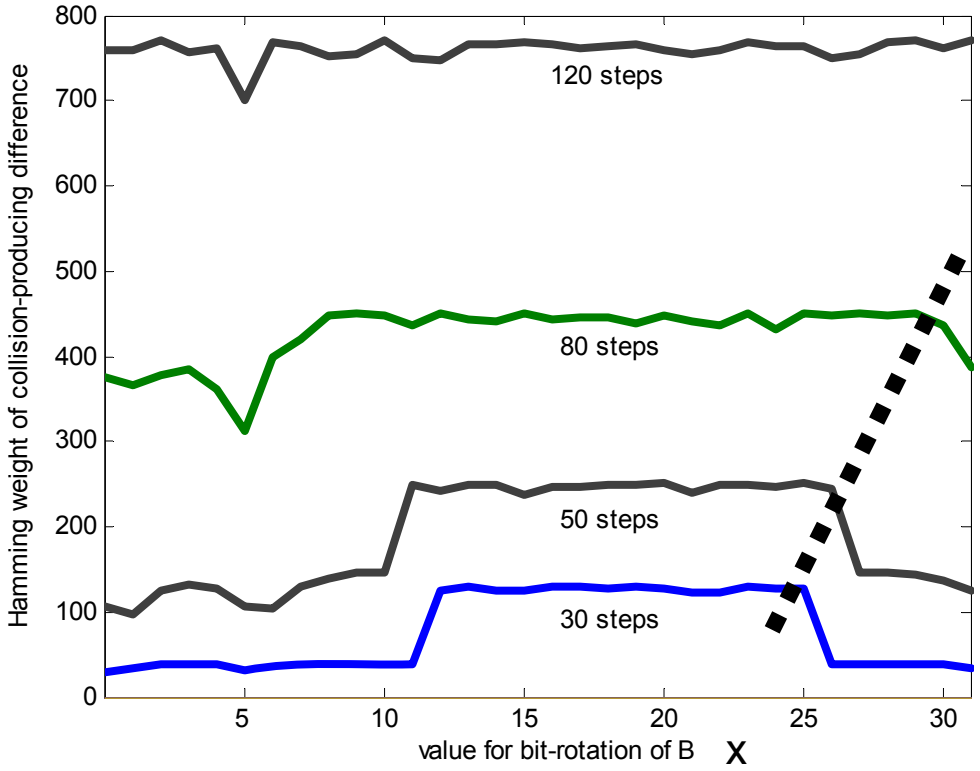


Comparing different constant rotations – Results for B



Rotating ***B*** by *x* bits to the left

$0 \le x \le 31$



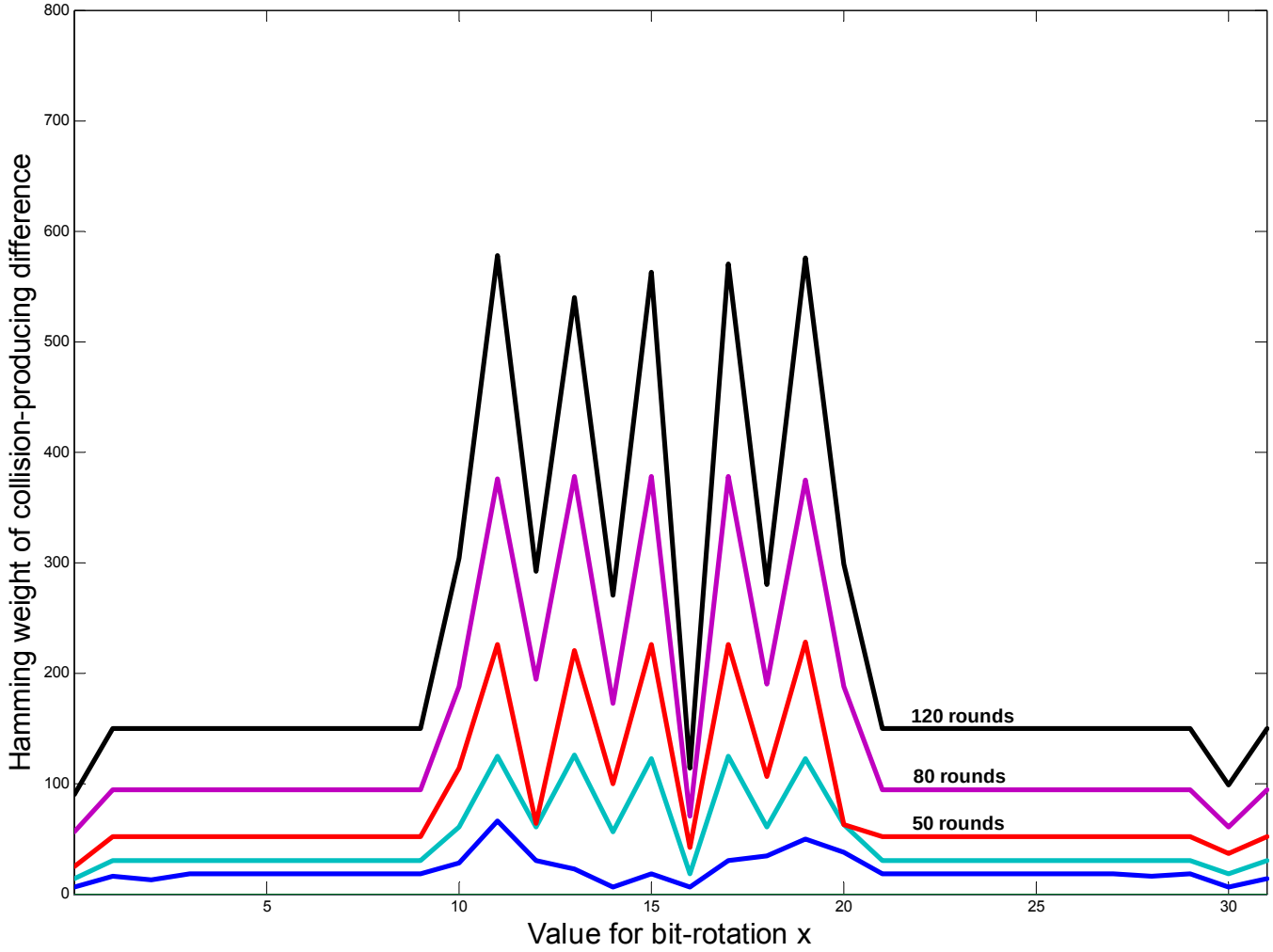
Why minimizing bit-rotations?

„*It‘s not only about security, it is also about performance*“

Consider platforms where constant-time shifter/rotators are not available.

e.g. i286, Pentium IV

Explanation does not hold for SHA-0



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Conclusions

- Design criteria for SHA-1 are unknown
- SHA-1 is based on MD4/MD5, but uses constant rotations instead of variable rotations
  - Both have advantages and disadvantages

- Particular values of the rotation (+5 and -2) could be the result of an optimization process
  - Given the 80 steps of the SHA-1 State Update, these are the minimal values to result in comparatively high attack complexities
  - Why? Advantages for platforms without constant-time shifters
  - Explanation does not hold for SHA-0 design