Anna Grocholewska-Czuryło

Division of Information System Security
Poznań University of Technology

HaF - A new family of hash functions

Poznan University of Technology

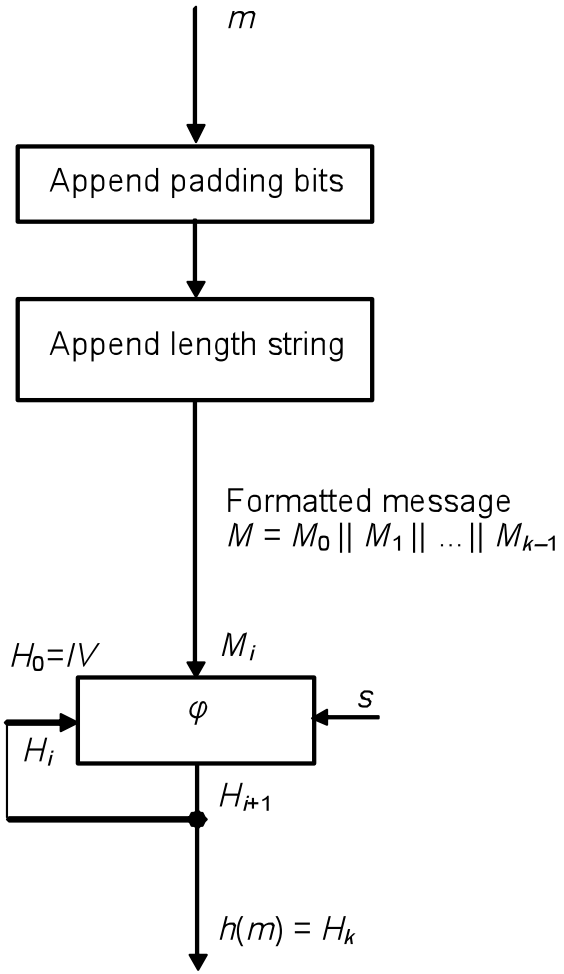
Introduction

- Hash functions
- HAF – a family of parameterized hash functions
- Design principles
- Security considerations

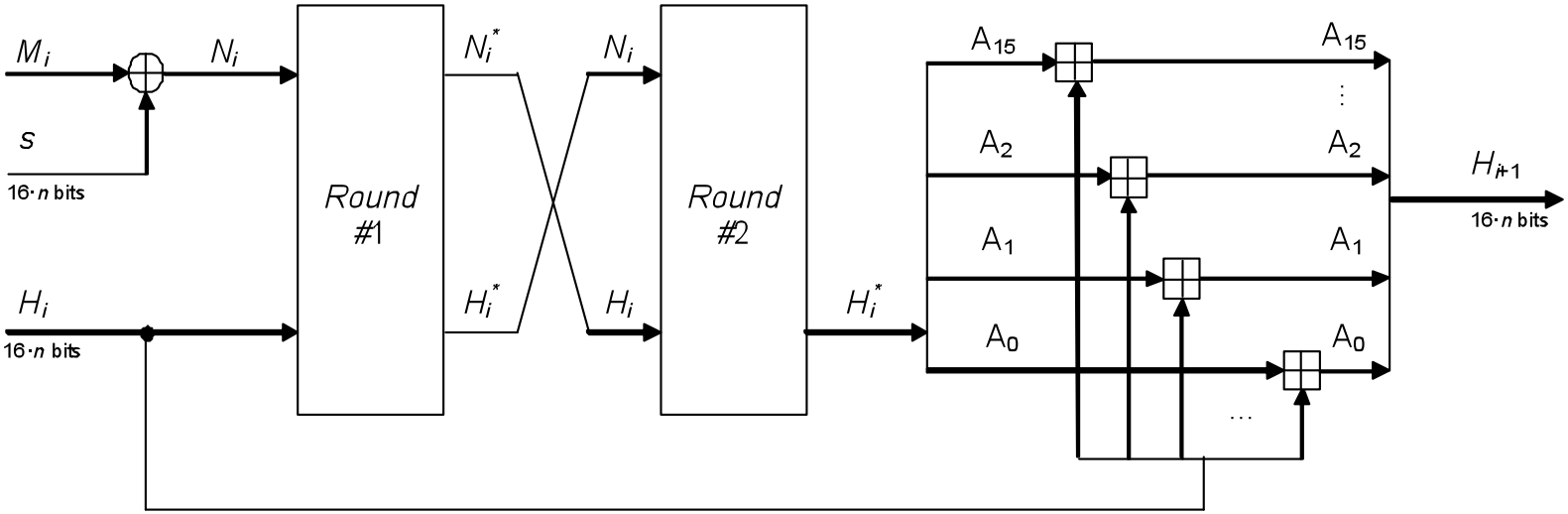
Design Principles

- Parametrization
- Selectable message digest length
- Flexibility between security and performance
- Resistance to known attacks
- HAIFA iteration mode

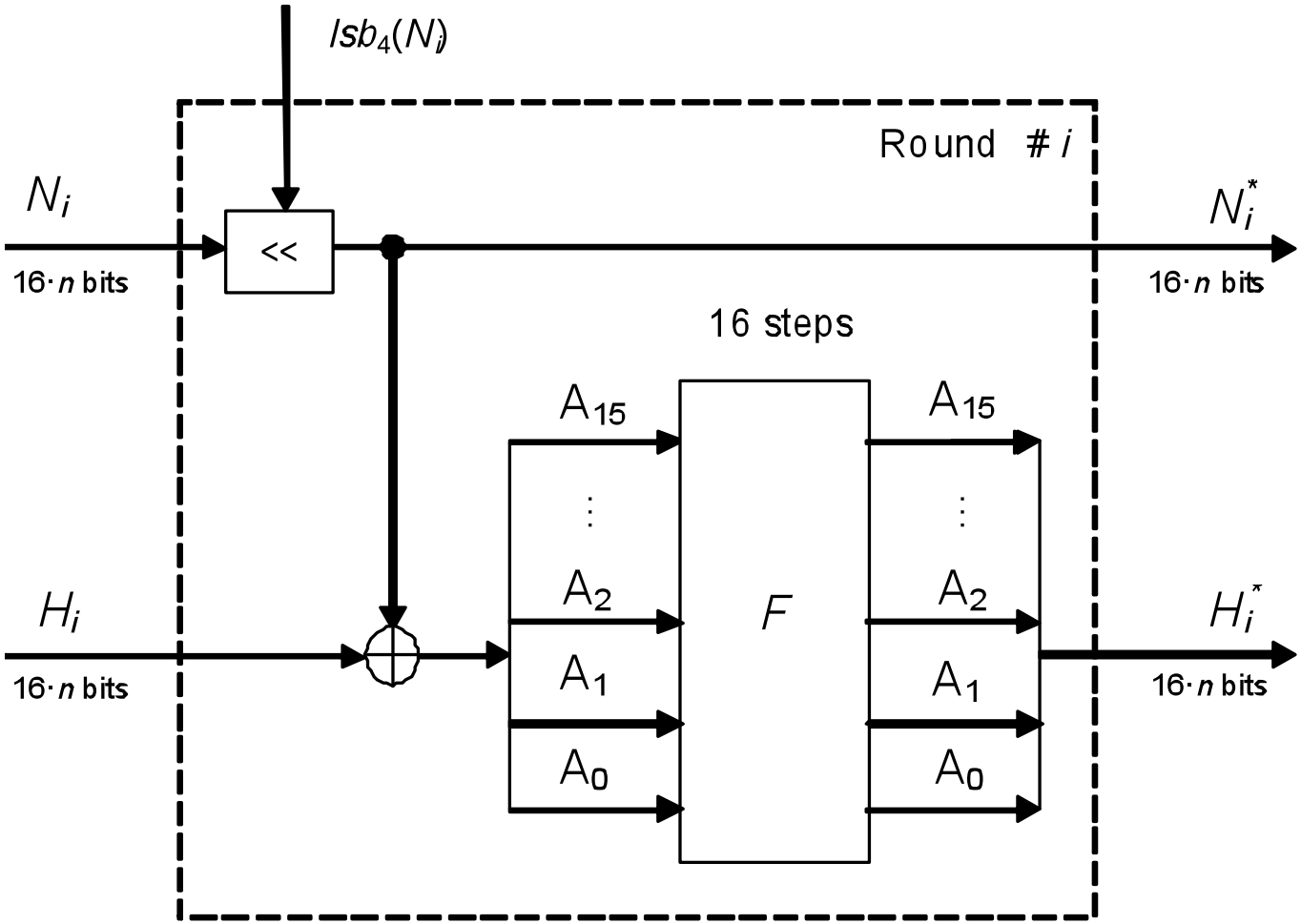
General model of HaF



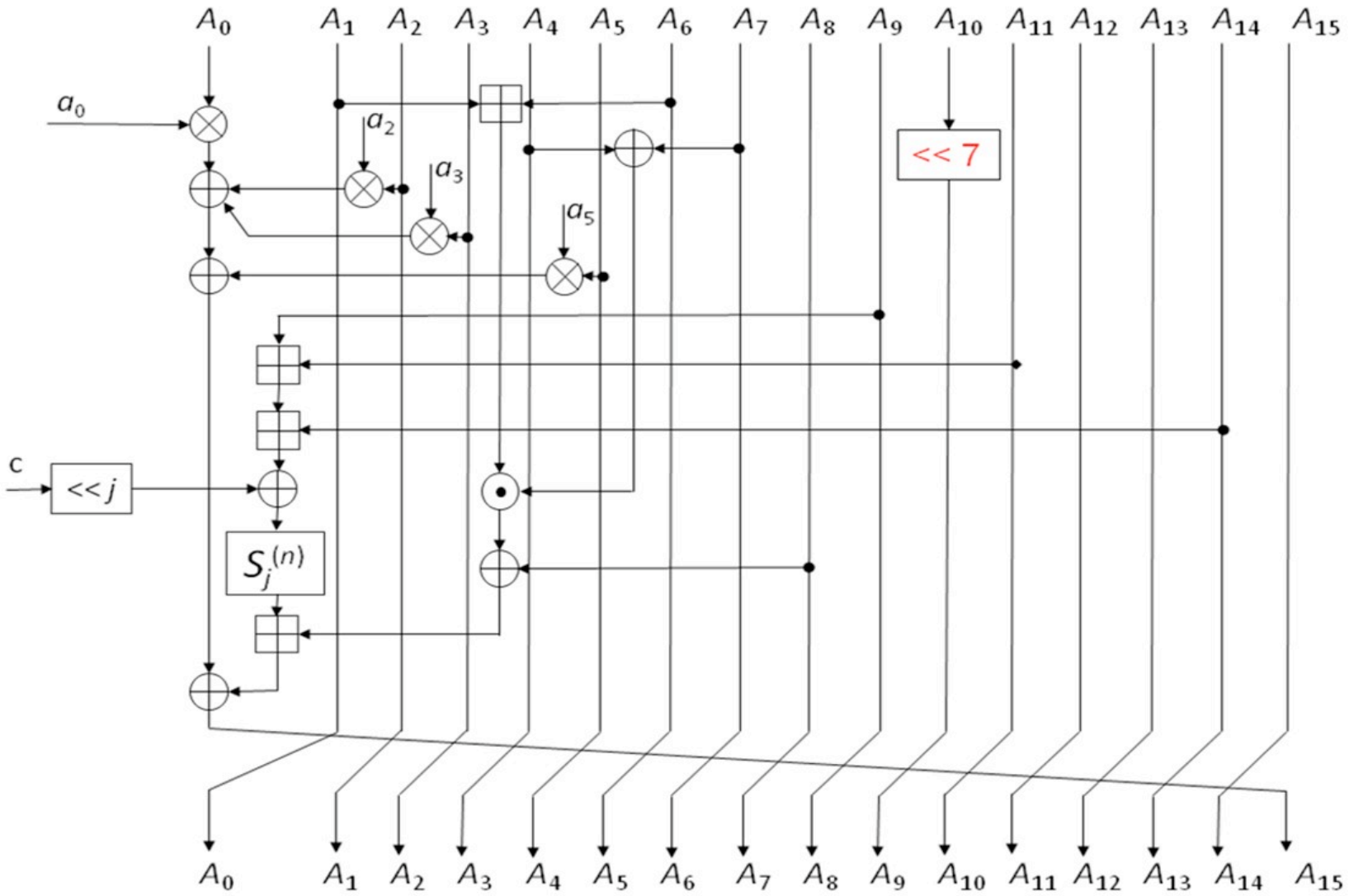
Compression Function



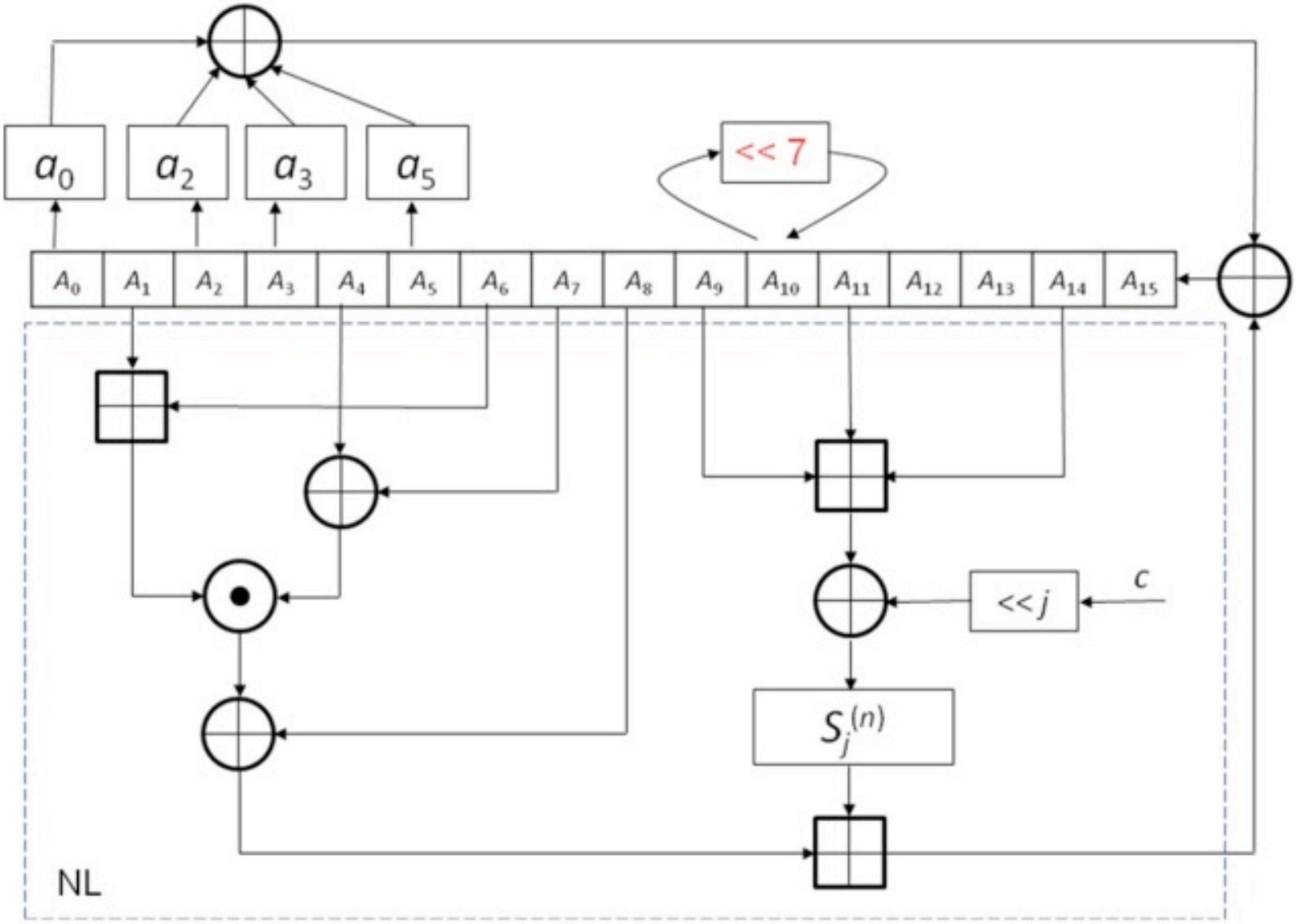
Round Function



Step Function



Security Considerations



HaF S-boxes

- S-boxes based on inversion mapping with modifications to remove affine equivalence between component functions
- balancedness
- lowest possible value in XOR profile
- complex agebraic description
- No cycles
- Size: 16x16 bits
- S-box nonlinearity: 32510
- Degree: 15

Inverse mapping

- Irreducible polynomial to define Galois Field (in AES it is $11b)
- Another polynomial as generator
- n-bit elements treates as polynomials:
  - $b_7b_6b_5b_4b_3b_2b_1b_0$ ->
  - $b_7x^7+b_6x^6+b_5x^5+b_4x^4+b_3x^3+b_2x^2+b_1x^1+b_0$

Inverse mapping continued

- An multiplicative inverse of polynomial *g* in GF(2^n) is such a polynomial *h* that *gh*=$01
- Element $00 doesn't have an inverse in GF. Inverse of $01 is $01
- Nonlinearity of such a mapping is $2^{n-1}-2^{n/2}$
  - 112 for *n*=8, 32512 for *n*=16
- Inverse mapping is different for every irreducible polynomial. It doesn't depend on a selected generator polynomial.

Affine transform

- To avoid algebraic attack
- Must be a full permutation
- in AES:

$$b_i' = b_i \oplus b_{(i+4) \bmod 8} \oplus b_{(i+5) \bmod 8} \oplus b_{(i+6) \bmod 8} \oplus b_{(i+7) \bmod 8} \oplus c_i$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \end{bmatrix}$$

Removing cycles

- Each HaF S-box should be just one cycle

- Removal of cycles done in two steps:
  - Selecting such affine transformation so that the resulting S-box has only two cycles
  - Joining the two cycles while removing affine equivalence from the S-box

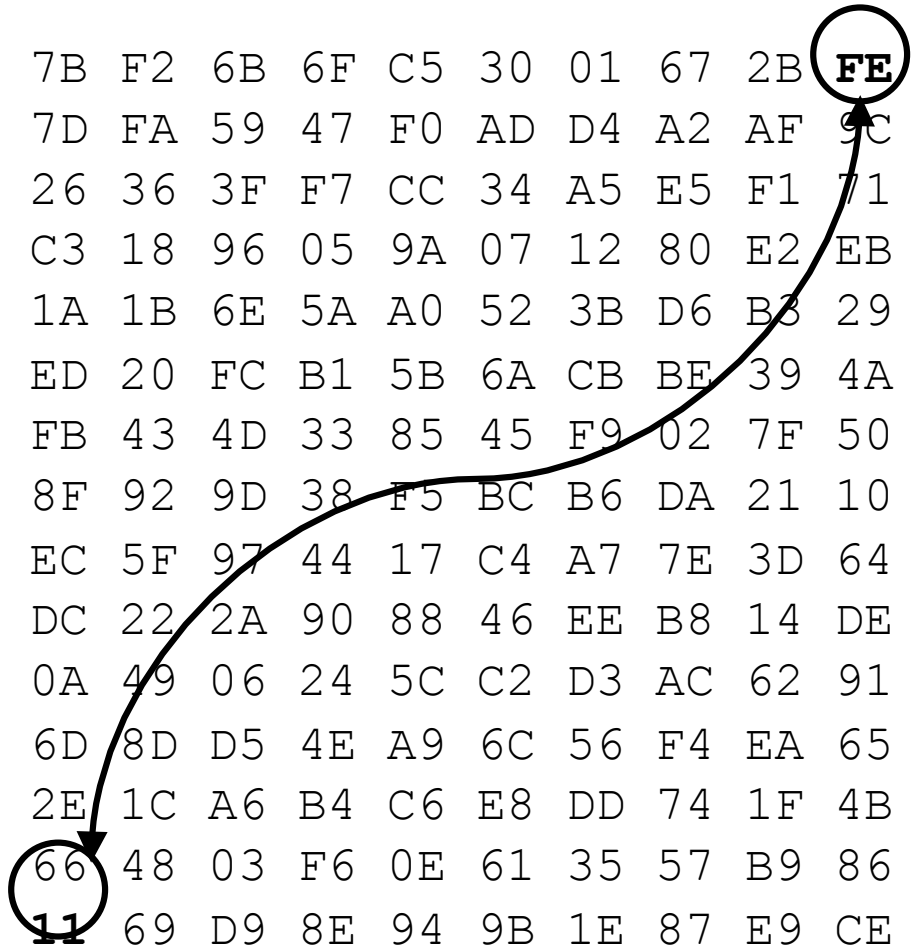
Removing affine equivalence

- All S-boxes based on inverse mapping have linear redundancy
- To remove: find two pairs of S-box elements that, when switched, remove this affine equivalance
- Mariginal loss of nonlinearity - reduced by 2.
- Joining two cycles of an S-box into one.

How to check if affine equivalance exists in a S-box?

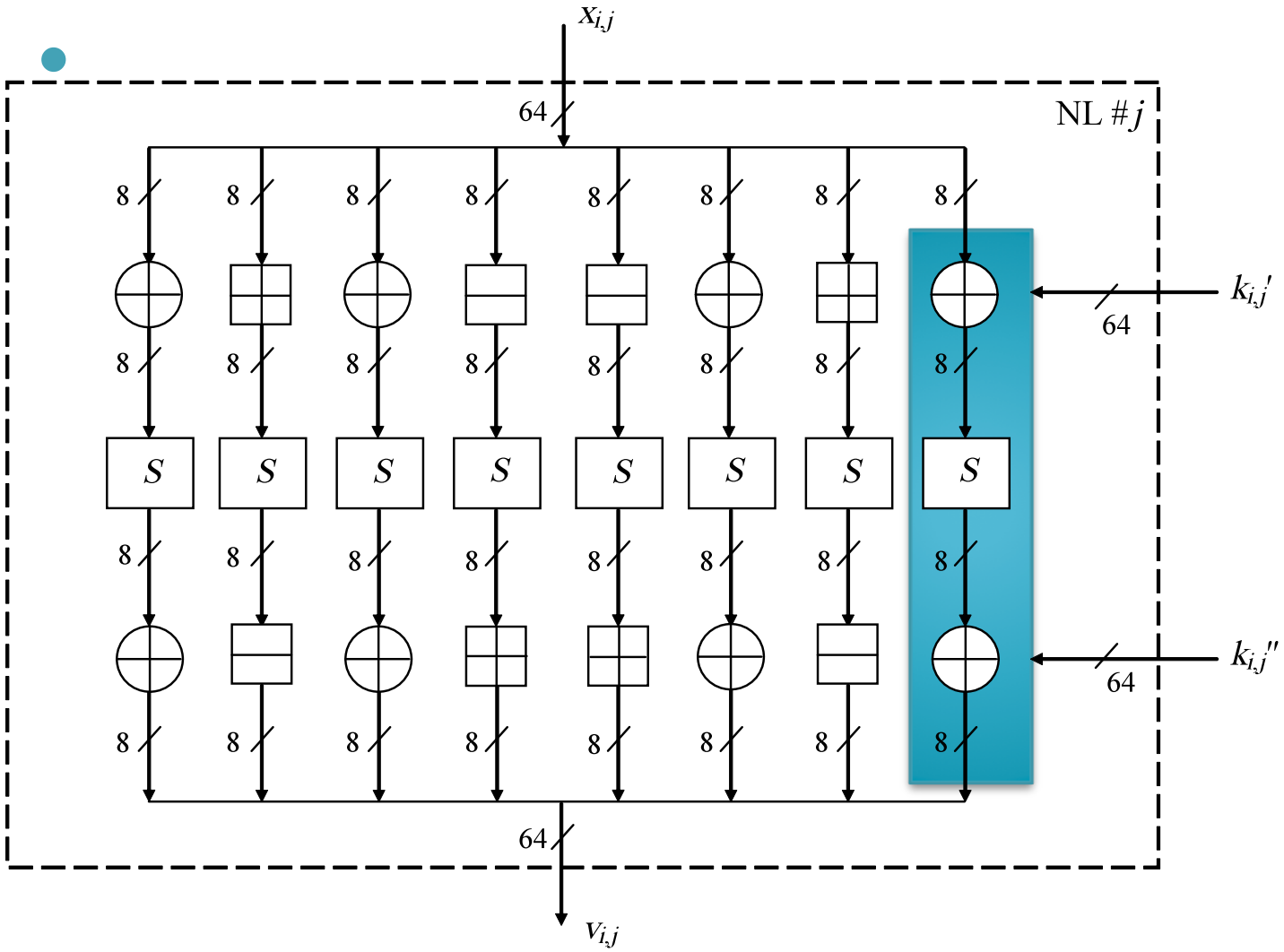
- Algebraic degree and nonlinearity remain unchanged by affine transform
- Absolute values of Walsh transform and autocorrelation function are both rearranged

Modified AES S-box example



63	7C	77	7B	F2	6B	6F	C5	30	01	67	2B	**FE**	D7	AB	76
CA	82	C9	7D	FA	59	47	F0	AD	D4	A2	AF	9C	A4	72	C0
B7	FD	93	26	36	3F	F7	CC	34	A5	E5	F1	71	D8	31	15
04	C7	23	C3	18	96	05	9A	07	12	80	E2	EB	27	B2	75
09	83	2C	1A	1B	6E	5A	A0	52	3B	D6	B3	29	E3	2F	84
53	D1	00	ED	20	FC	B1	5B	6A	CB	BE	39	4A	4C	58	CF
D0	EF	AA	FB	43	4D	33	85	45	F9	02	7F	50	3C	9F	A8
51	A3	40	8F	92	9D	38	F5	BC	B6	DA	21	10	FF	F3	D2
CD	0C	13	EC	5F	97	44	17	C4	A7	7E	3D	64	5D	19	73
60	81	4F	DC	22	2A	90	88	46	EE	B8	14	DE	5E	0B	DB
E0	32	3A	0A	49	06	24	5C	C2	D3	AC	62	91	95	E4	79
E7	C8	37	6D	8D	D5	4E	A9	6C	56	F4	EA	65	7A	AE	08
BA	78	25	2E	1C	A6	B4	C6	E8	DD	74	1F	4B	BD	8B	8A
70	3E	B5	66	48	03	F6	0E	61	35	57	B9	86	C1	1D	9E
E1	F8	98	**11**	69	D9	8E	94	9B	1E	87	E9	CE	55	28	DF
8C	A1	89	0D	BF	E6	42	68	41	99	2D	0F	B0	54	BB	16

Association with round key



Conclusions 1

- AES-like S-boxes are an excellent base for generating cryptographically strong S-boxes for various purposes
- Affine equivalence can be removed at relatively low cost (reduced nonlienarity)
- Cycles can be removed without any influence to nonlinear properties

Conclusions II

- Elaborated scheme of HaF hash function family
- Currently experimenting with fault attacks on HaF to verify advantages

Thank you..

http://css.umcs.lublin.pl/publications/index.html