Cryptology: Data Encryption Standard

Dr. Chuck Rocca
roccac@wcsu.edu

http://sites.wcsu.edu/roccac

WESTERN CONNECTICUT STATE UNIVERSITY
MACRICOSTAS SCHOOL OF ARTS & SCIENCES

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Encipherment

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- "Add" the left half, L, to $f(R, K_i)$, where K_i is the round key and shift right

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- Split the input into left and right halves: L and R
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- Repeat the previous steps except for the last round

Encipherment

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- Split the input into left and right halves: L and R
- Shift the right half, R, to the left
- "Add" the left half, L, to $f(R, K_i)$, where K_i is the round key and shift right
- Repeat the previous steps except for the last round
- In the last round swap the left and right halves then rejoin them

Encipherment

"hi"$\equiv$ (11010001101001)

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$L_0 = (1101000)$ $\quad$ $R_0 = (1101001)$

Encipherment

$$\text{“hi”} \equiv (11010001101001)$$

$$L_0 = (1101000) \qquad R_0 = (1101001)$$

$$R_1 = L_0 \oplus R_0 \oplus K_0 = (1101000) \oplus (1101001) \oplus (1110011)$$

Encipherment

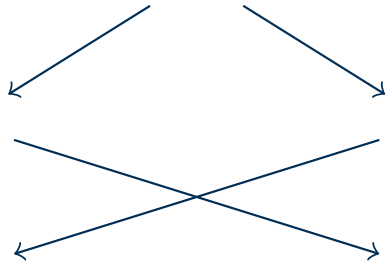
$$\text{“hi”} \equiv (11010001101001)$$

$$L_0 = (1101000) \qquad R_0 = (1101001)$$

$$R_1 = L_0 \oplus R_0 \oplus K_0 = (1110010)$$

Encipherment

"hi" $\equiv (11010001101001)$



$L_0 = (1101000)$ $\quad R_0 = (1101001)$

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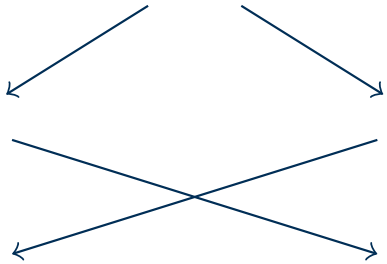

$L_0 = (1101000)$ $\quad R_0 = (1101001)$

$L_1 = (1101001)$ $\quad R_1 = L_0 \oplus f(R_0, K_0) = (1110010)$

$$R_2 = L_1 \oplus R_1 \oplus K_1 = (1101001) \oplus (1110010) \oplus (1100111)$$

Encipherment

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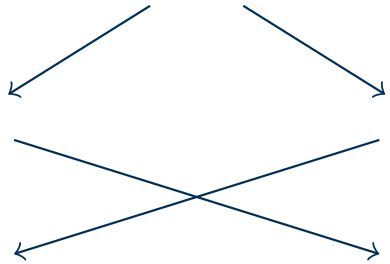

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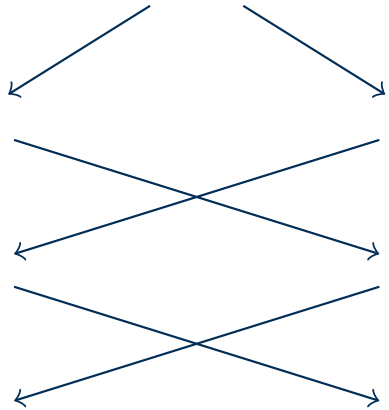

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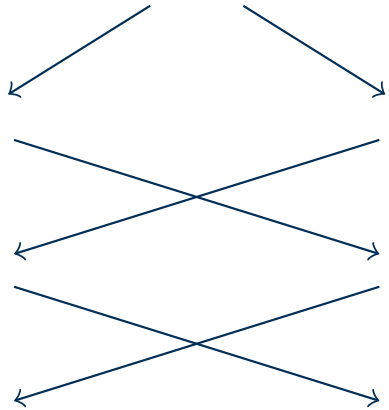

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$$R_3 = L_2 \oplus R_2 \oplus K_2 = (1110010) \oplus (1111100) \oplus (1001111)$$

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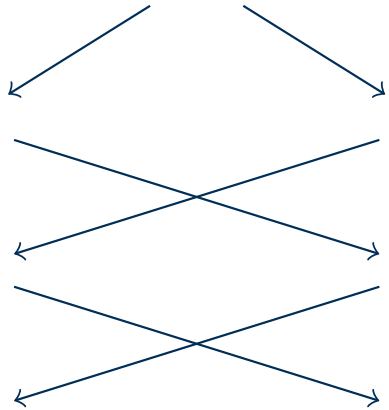

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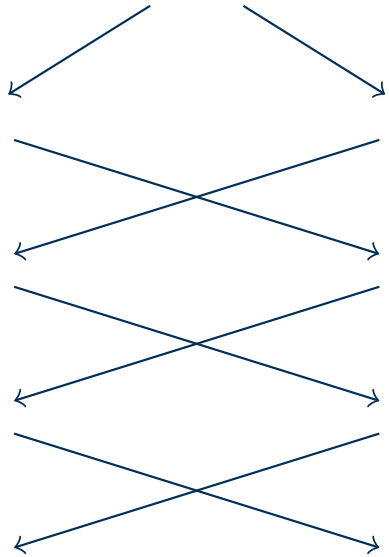

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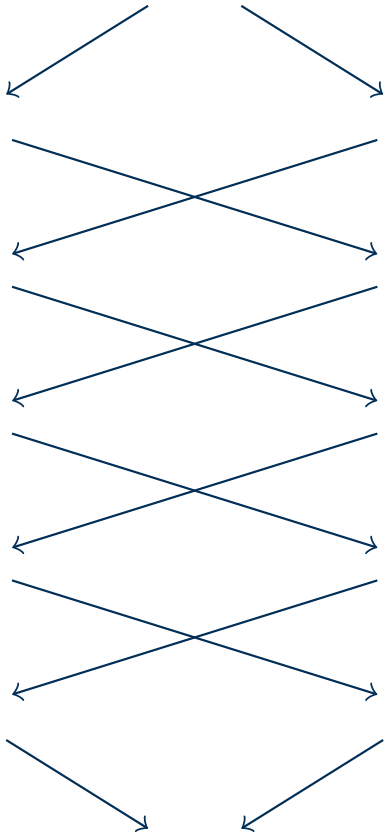

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$L_4 = (1000001)$ $R_4 = (1111100)$

$(1111100\ 1110010)$

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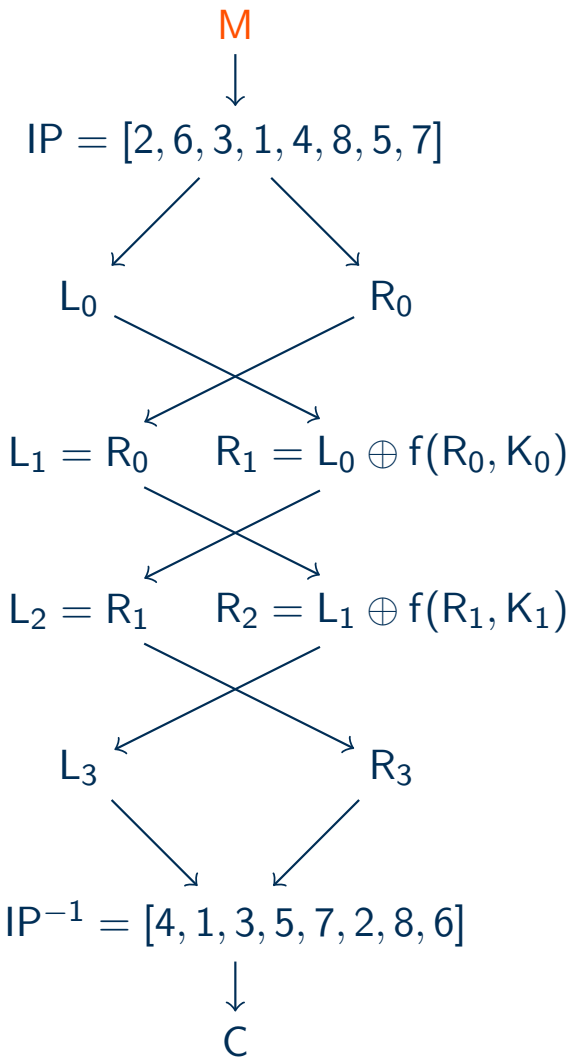

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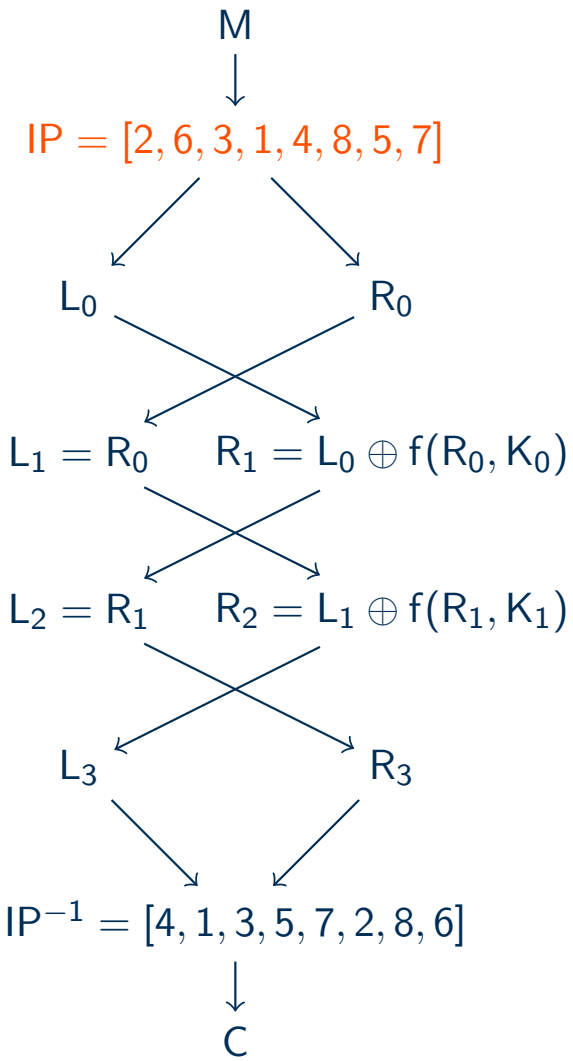

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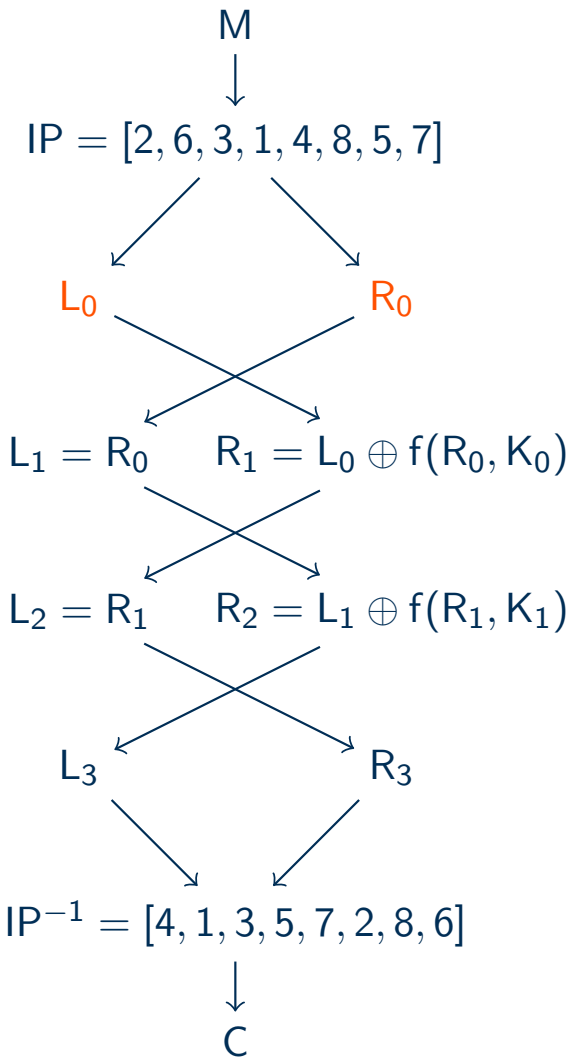

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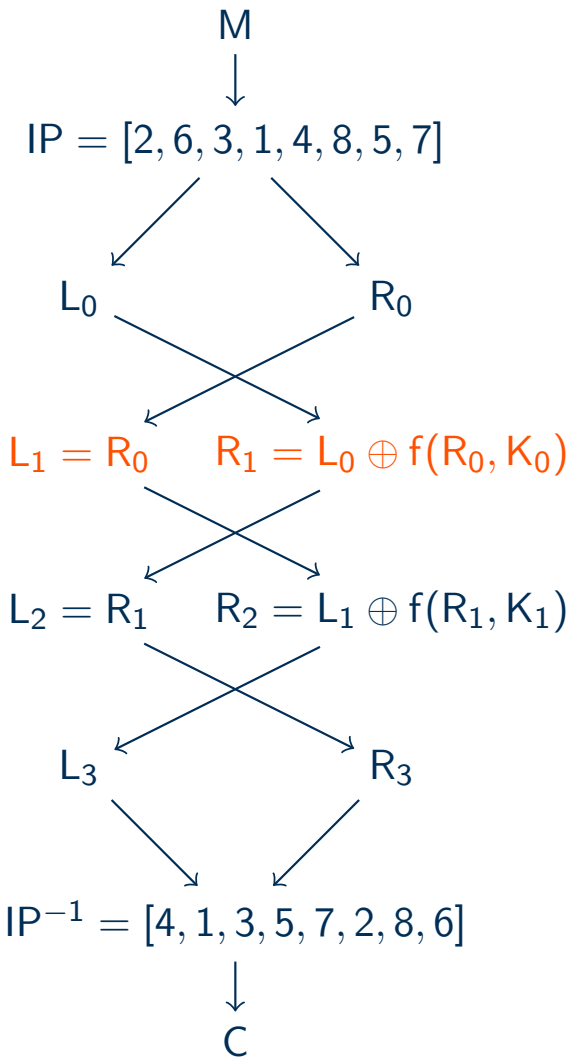

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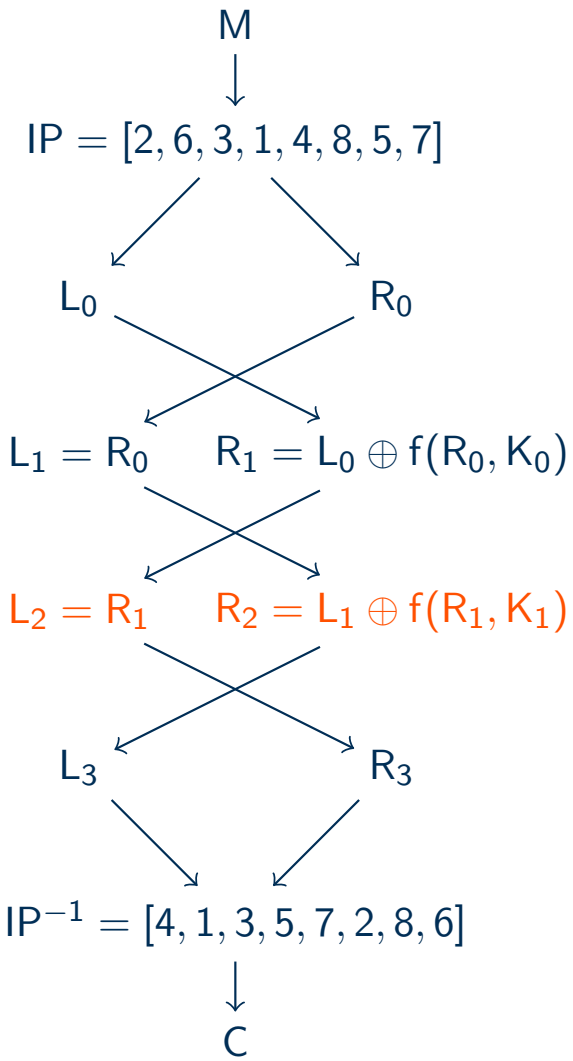

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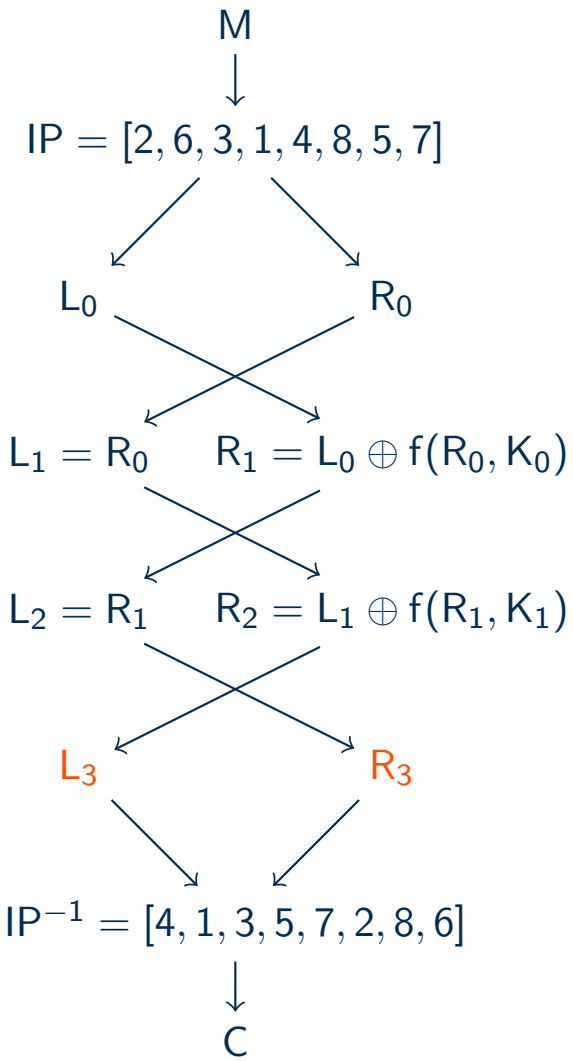

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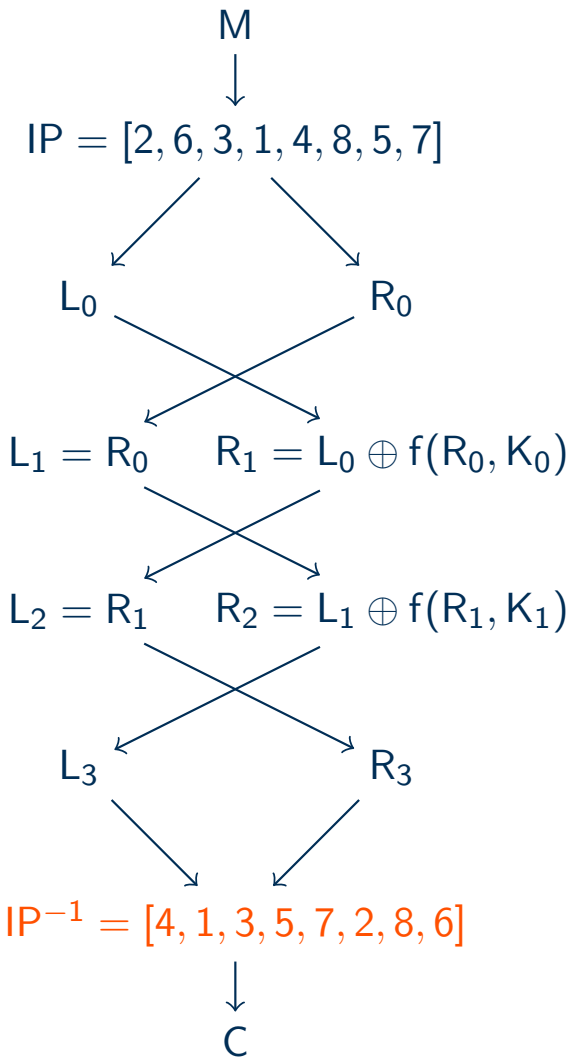

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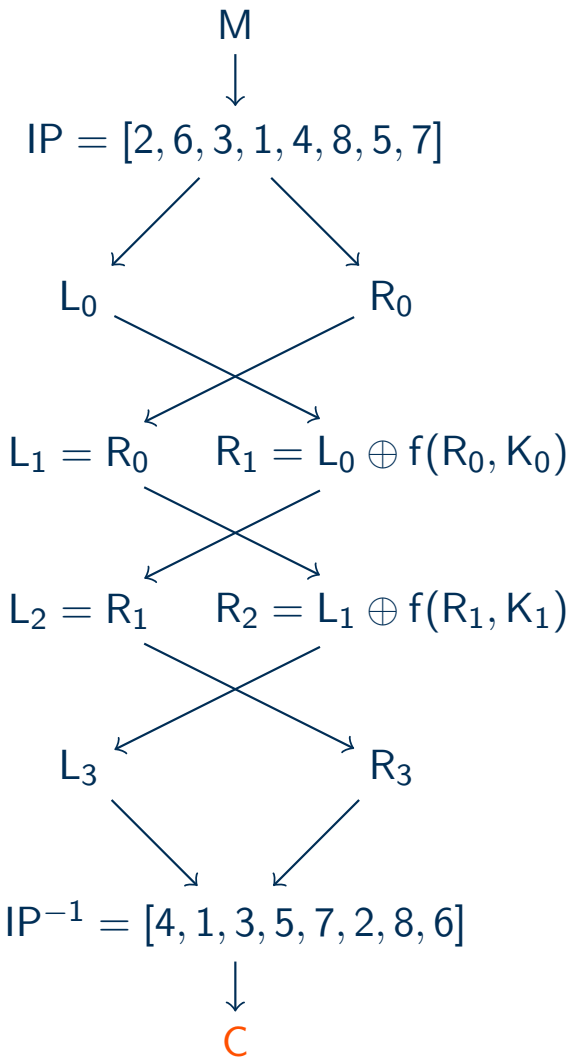

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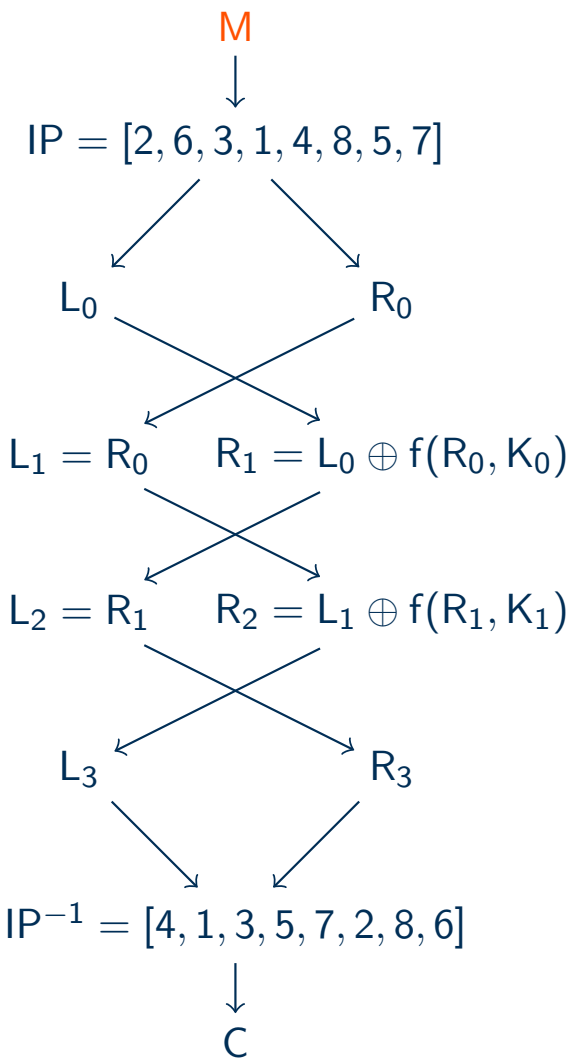

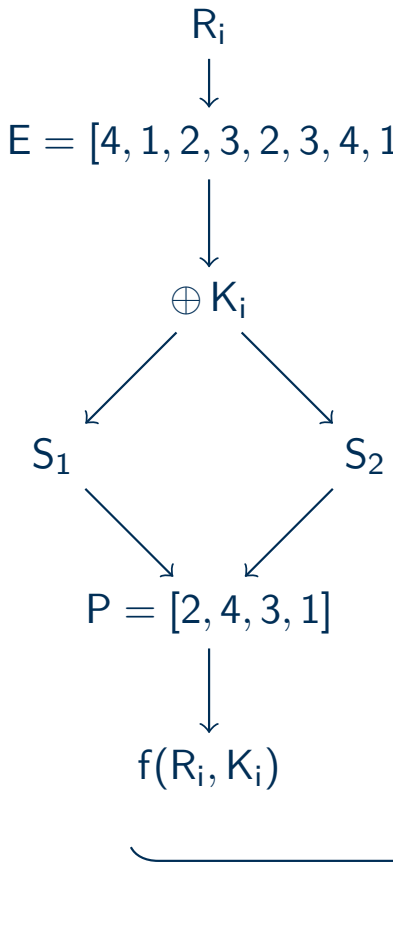

$f(R_i, K_i)$

Key Schedule

Key 0: (11100111)

Key 1: (11001111)

S-Box 1

	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

S-Box 2

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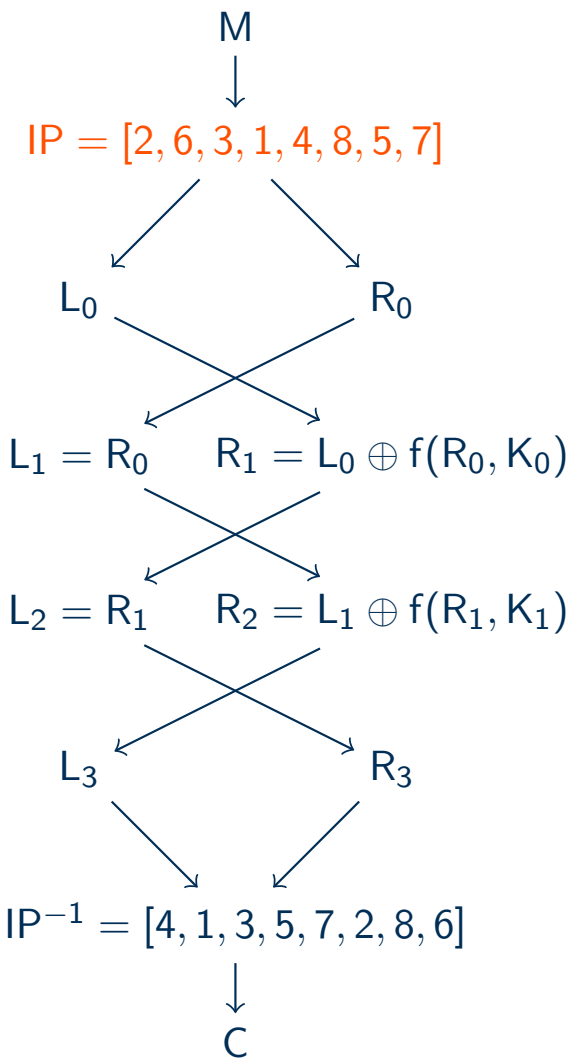

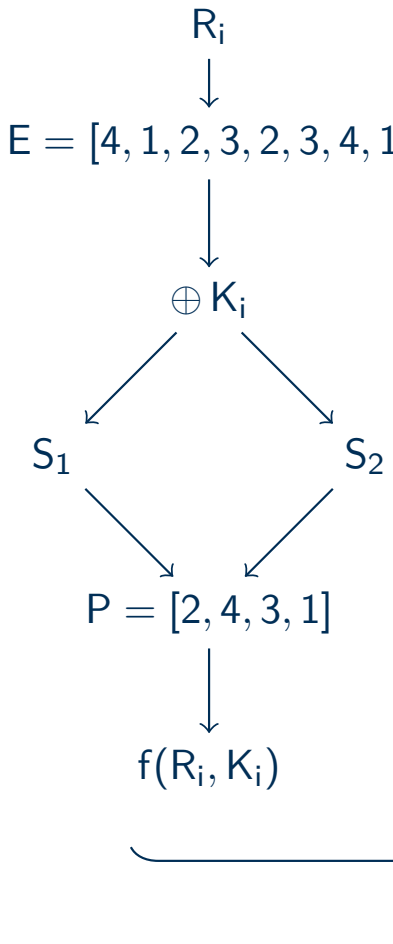

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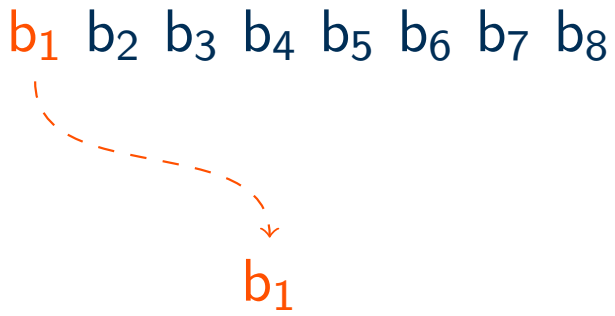
Permutations

$$b_1 \; b_2 \; b_3 \; b_4 \; b_5 \; b_6 \; b_7 \; b_8$$

Permutations

$$\text{IP} = [2, 6, 3, 1, 4, 8, 5, 7]$$



Permutations

$$\begin{array}{c} \\ \mathrm{IP} = [2,6,3,1,4,8,5,7] \end{array} \left\{ \begin{array}{cccccccc} b_1 & b_2 & b_3 & b_4 & b_5 & b_6 & b_7 & b_8 \\ \downarrow & & & & & & & \\ b_2 & & & & & & & b_1 \end{array} \right.$$

Permutations

$$\text{IP} = [2, 6, 3, 1, 4, 8, 5, 7] \left\{ \begin{array}{cccccccc} b_1 & b_2 & b_3 & b_4 & b_5 & b_6 & b_7 & b_8 \\ & & \downarrow & & & & & \\ b_2 & & b_3 & b_1 & & & & \end{array} \right.$$

Permutations

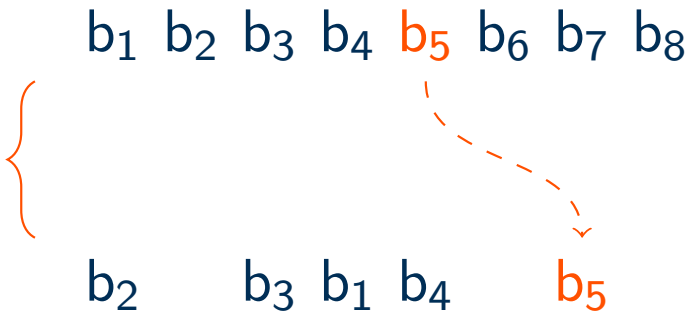
$$IP = [2, 6, 3, 1, 4, 8, 5, 7]$$

$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$$

$$b_2 \quad b_3\ b_1\ b_4$$

Permutations

$$IP = [2, 6, 3, 1, 4, 8, 5, 7]$$



Permutations

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$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$$

$$b_2\ b_6\ b_3\ b_1\ b_4\ \ \ b_5$$

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$$IP = [2, 6, 3, 1, 4, 8, 5, 7]$$

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$$\text{IP} = [2, 6, 3, 1, 4, 8, 5, 7]$$

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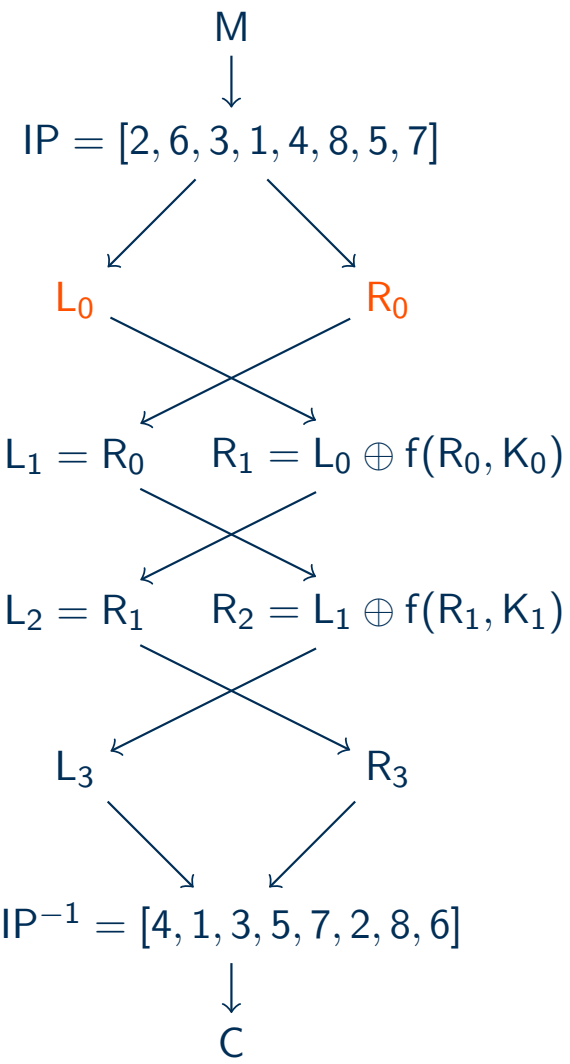

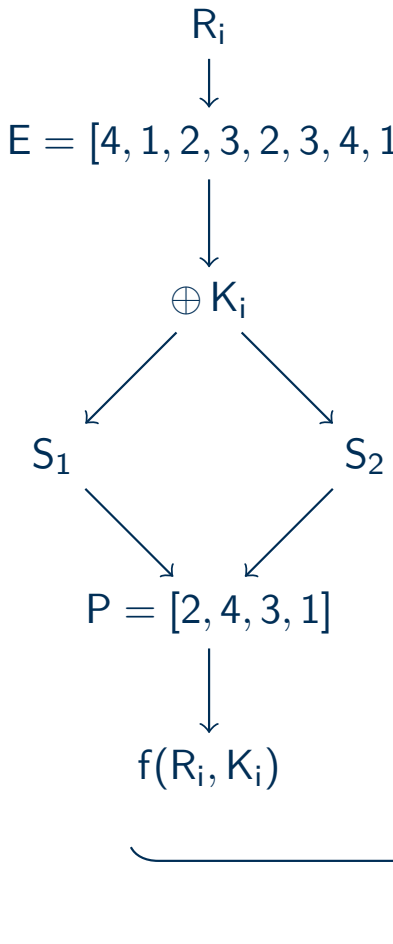

$f(R_i, K_i)$

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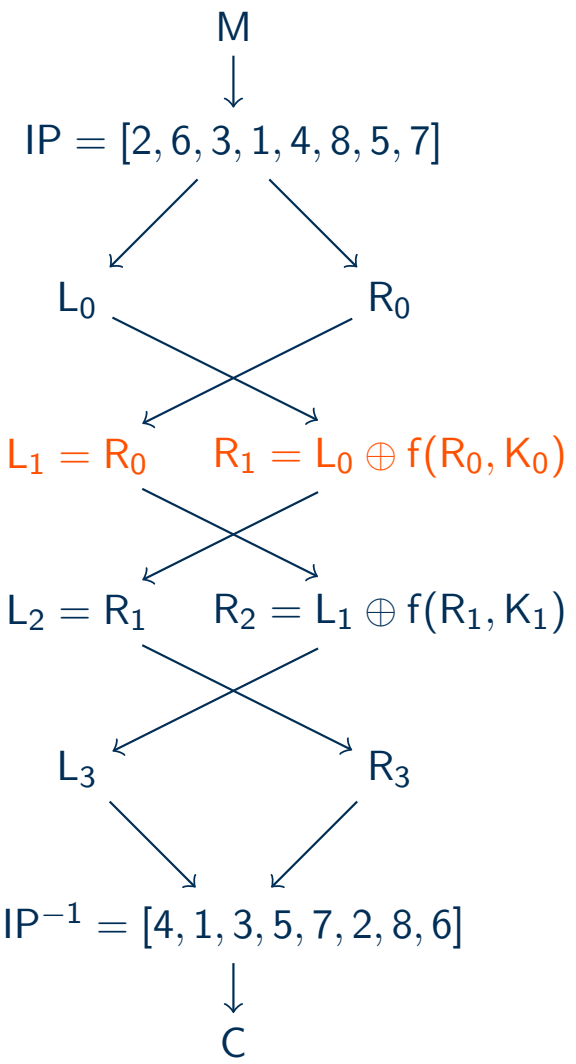

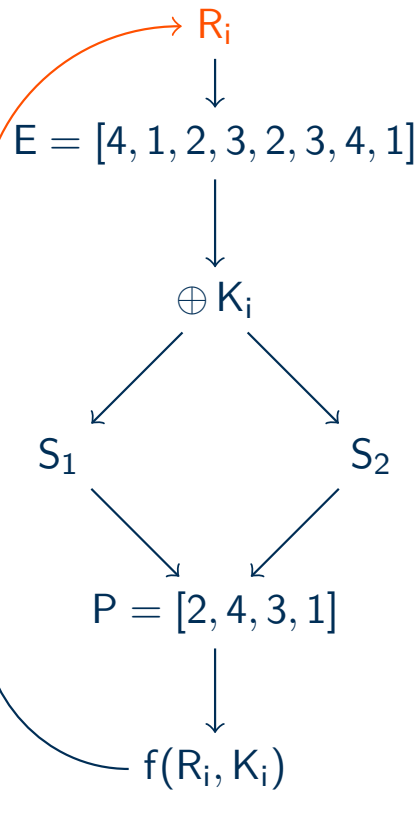

f(Ri, Ki)

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	00	01	10	11
00	01	11	10	11
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00	00	01	10	11
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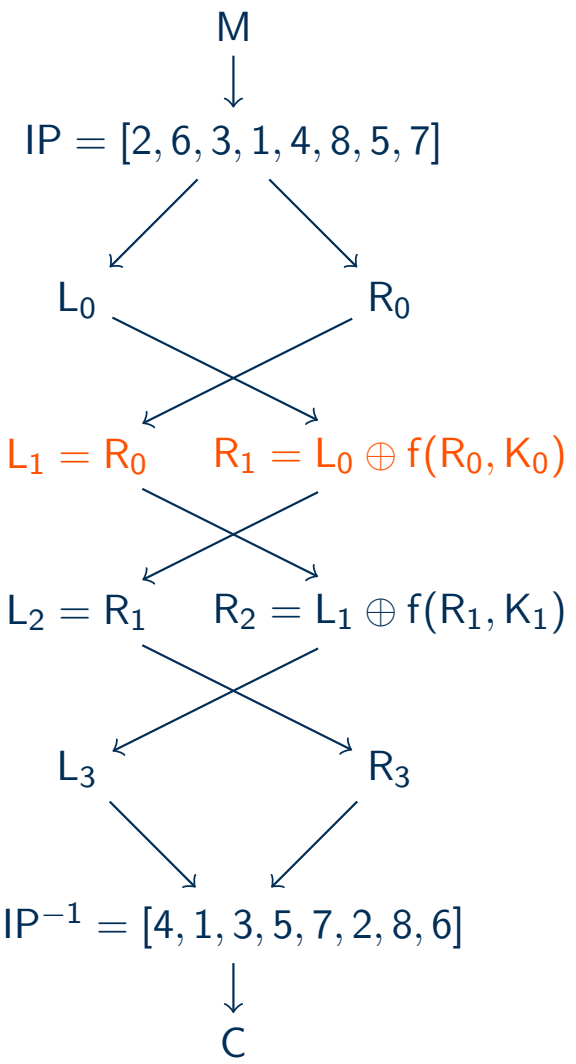

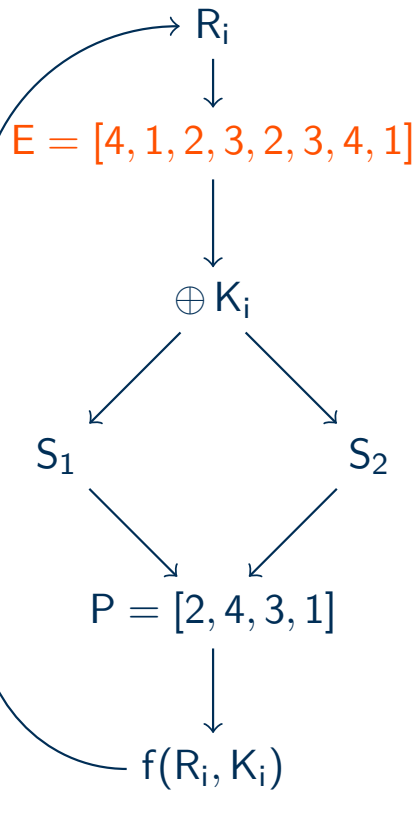

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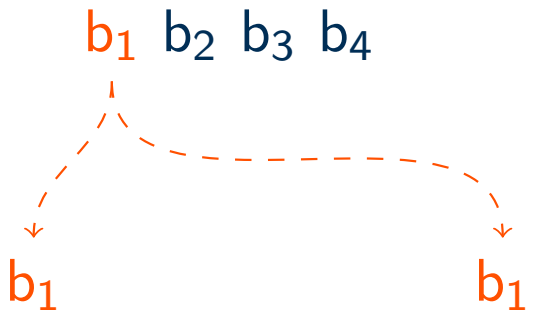
Expansion from 4 to 8 bits

$b_1\ b_2\ b_3\ b_4$

Expansion from 4 to 8 bits

$$E = [4, 1, 2, 3, 2, 3, 4, 1]$$



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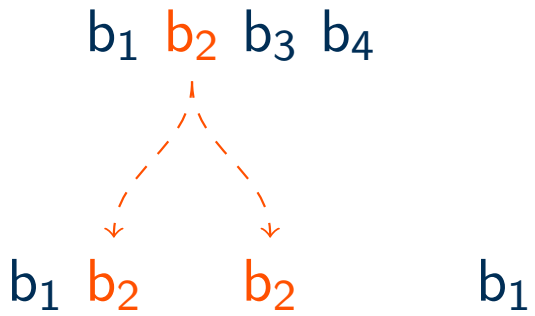

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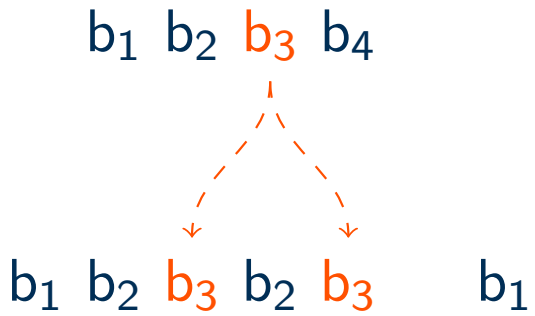

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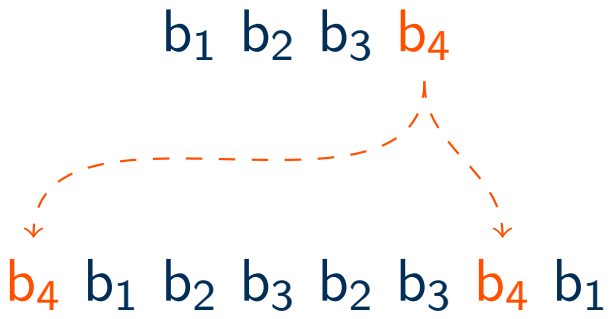

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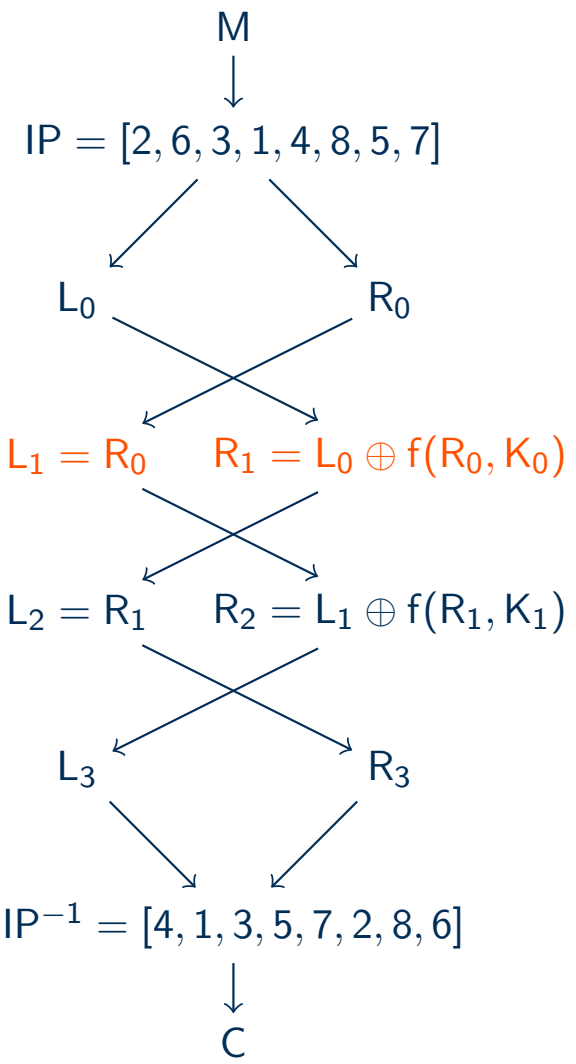

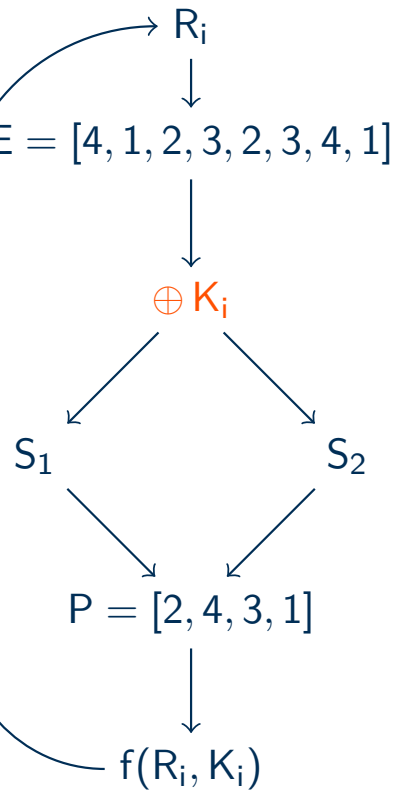

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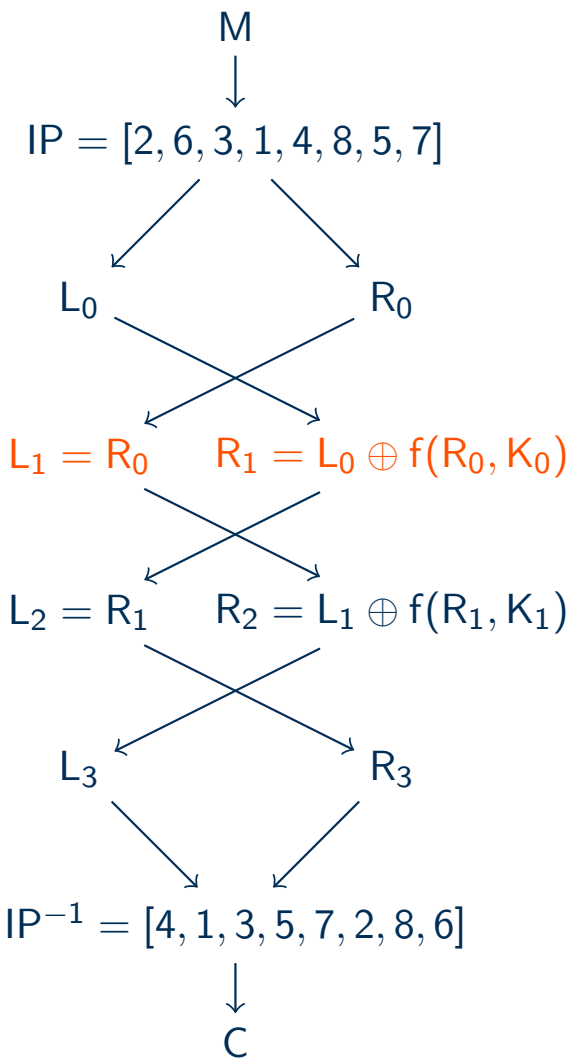

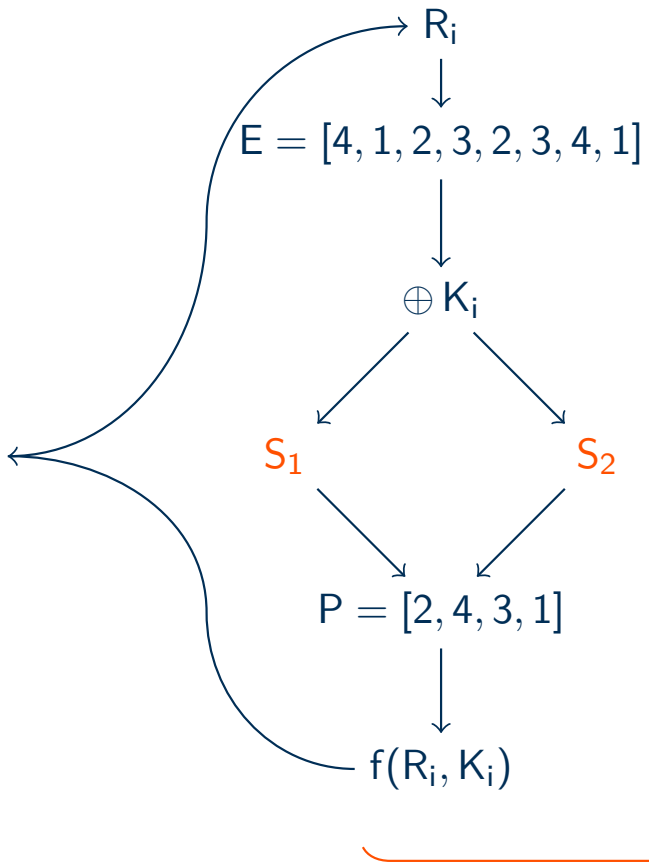

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10	00	10	01	11
11	11	01	11	10

S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

$f(R_i, K_i)$

Using S-Boxes

Look up (1101) in S-Box 1:

	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

Using S-Boxes

Look up (1101) in S-Box 1:

	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

Using S-Boxes

Look up (1101) in S-Box 1:

	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

Using S-Boxes

Look up (1101) in S-Box 1:

	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

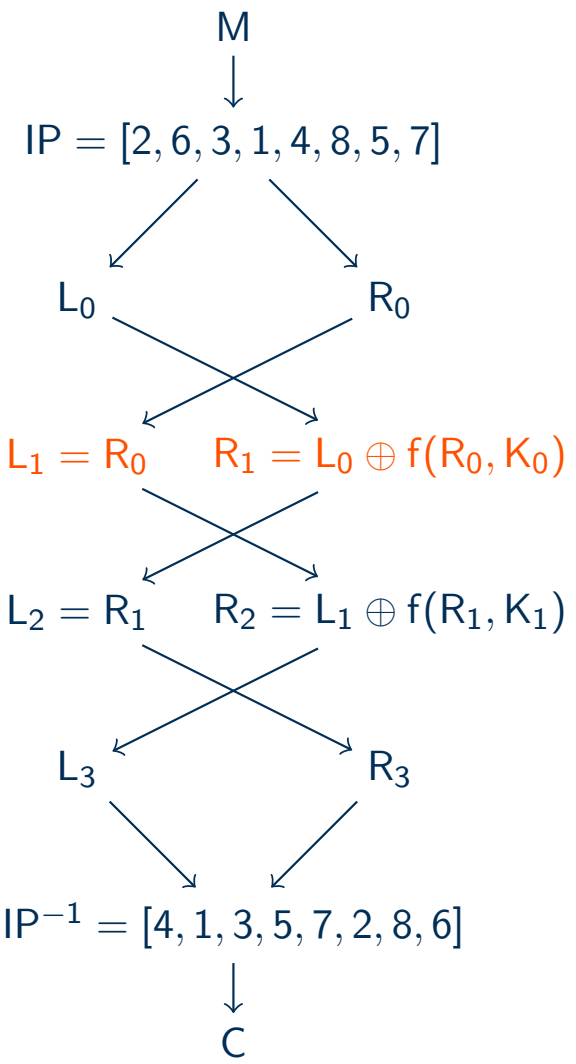
Using S-Boxes

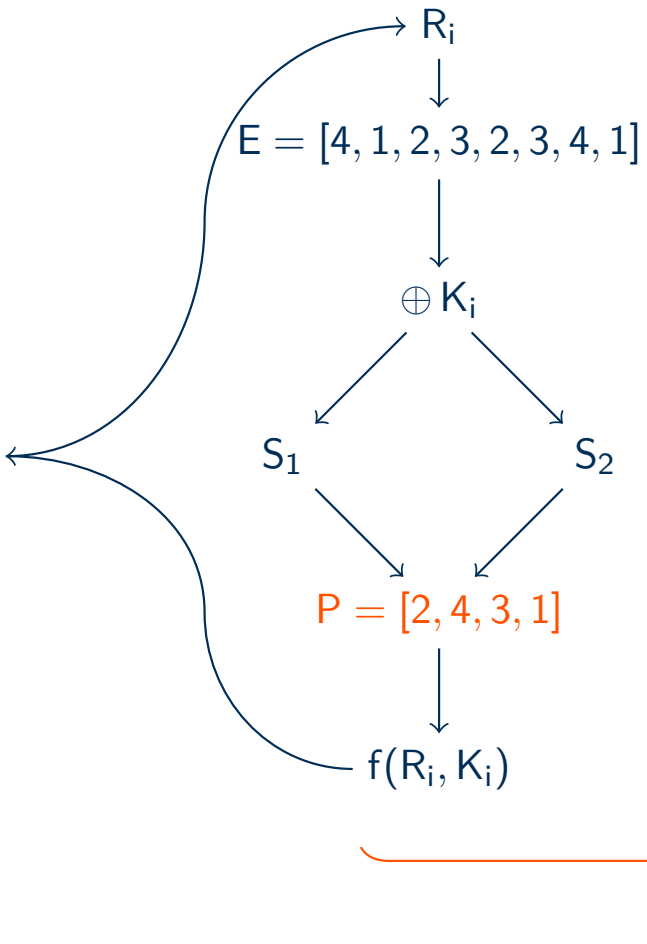
Look up (1101) in S-Box 1:

	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

So the output is (01)

Really Simple DES





f(Ri, Ki)

Key Schedule

Key 0: (11100111)

Key 1: (11001111)

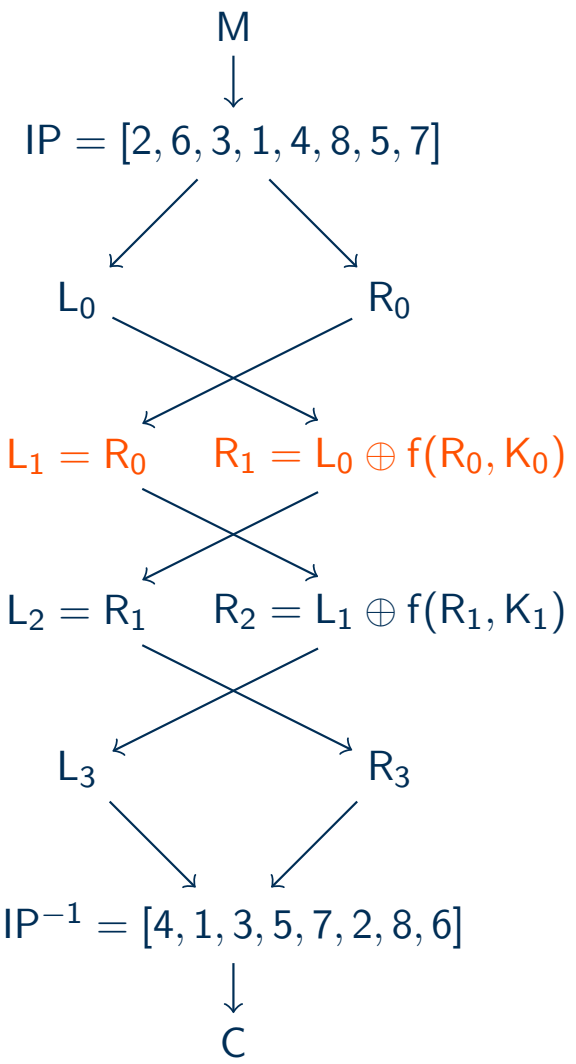
S-Box 1

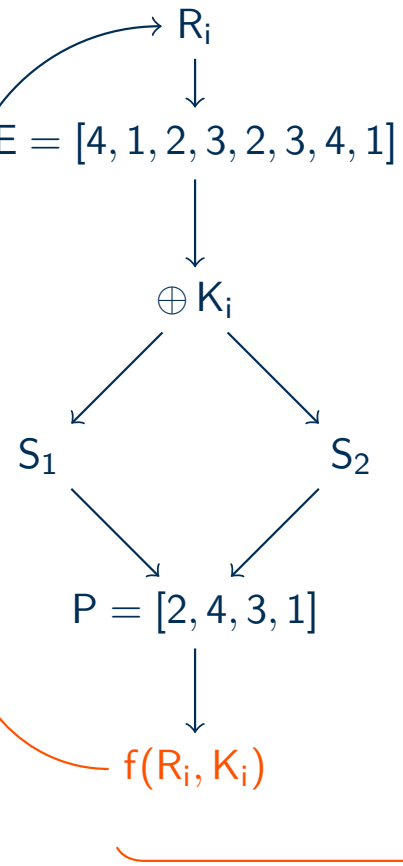
	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

Really Simple DES





f(Ri, Ki)

Key Schedule

Key 0: (11100111)

Key 1: (11001111)

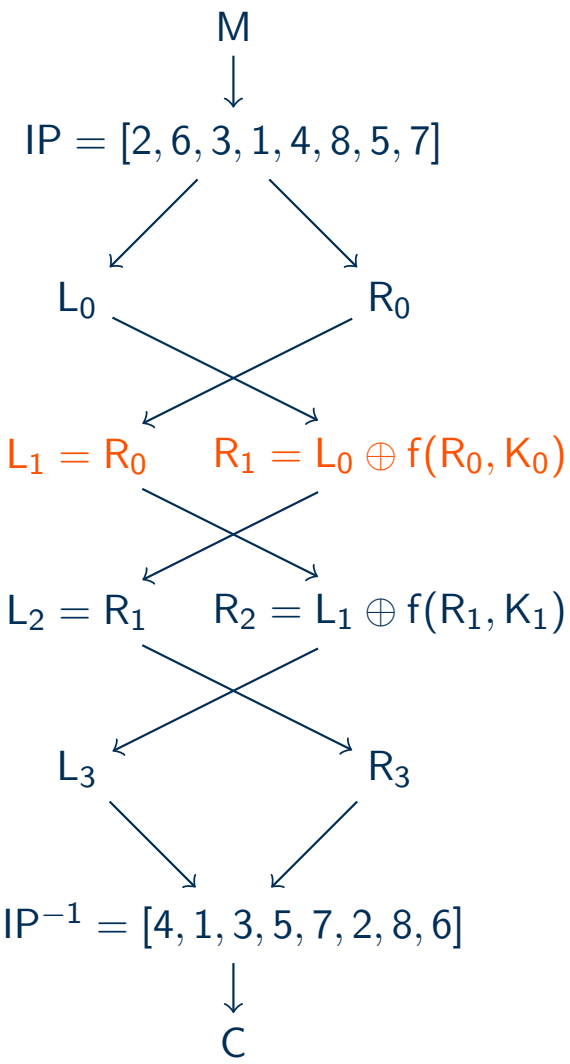
S-Box 1

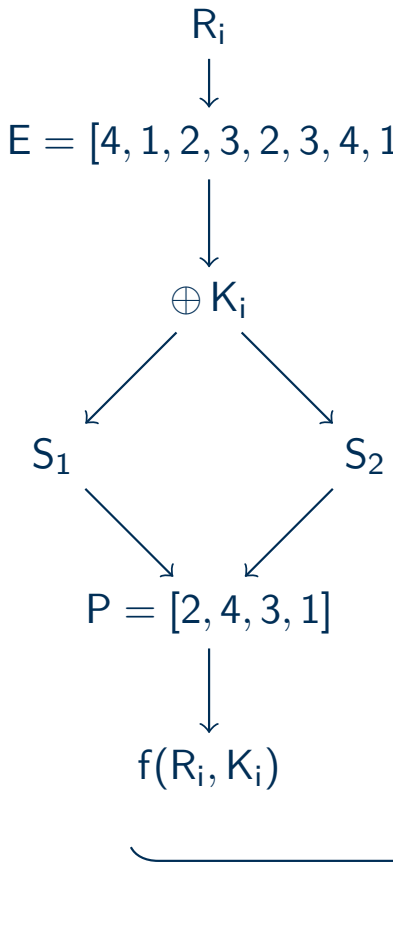
	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

Really Simple DES





$f(R_i, K_i)$

Key Schedule

Key 0: (11100111)

Key 1: (11001111)

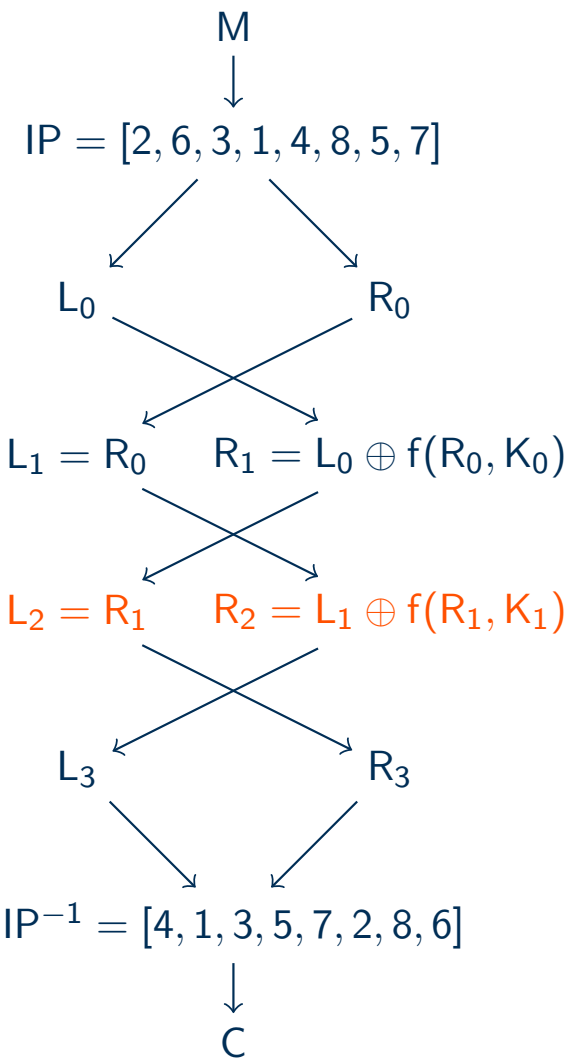
S-Box 1

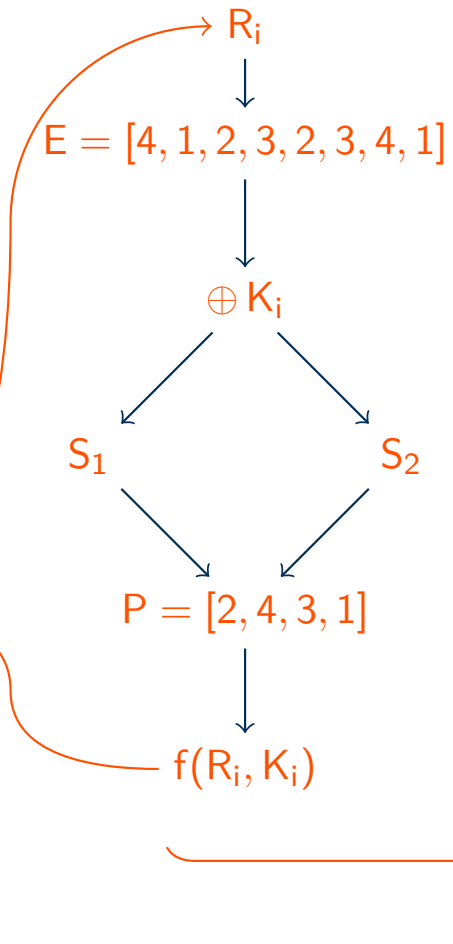
	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

Really Simple DES





Key Schedule

Key 0: (11100111)

Key 1: (11001111)

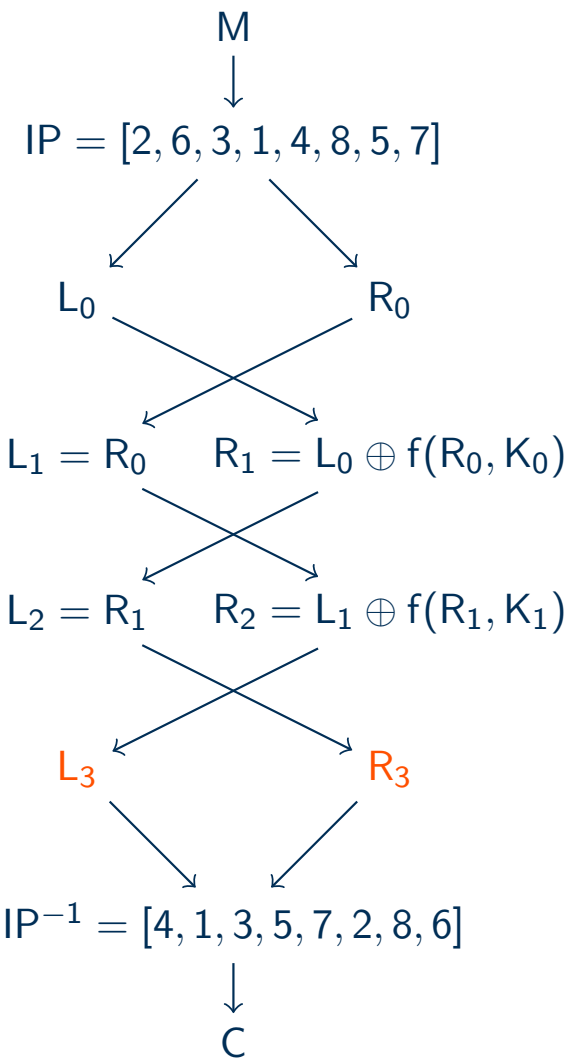
S-Box 1

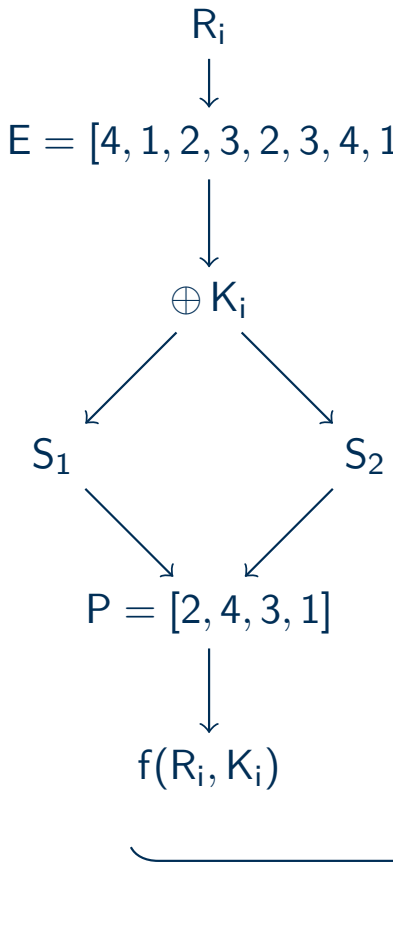
	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

Really Simple DES





Key Schedule

Key 0: (11100111)

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S-Box 1

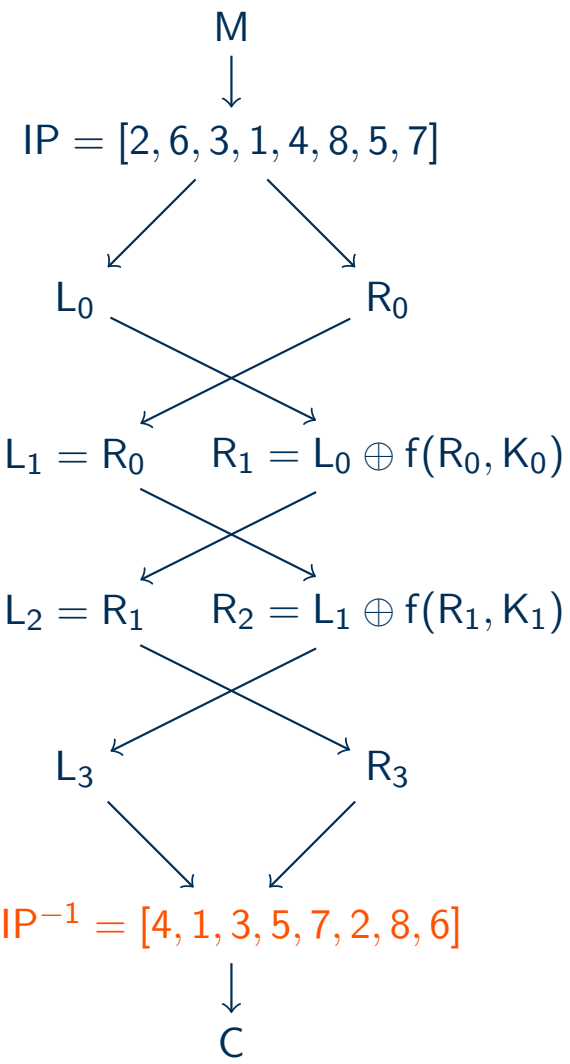
	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

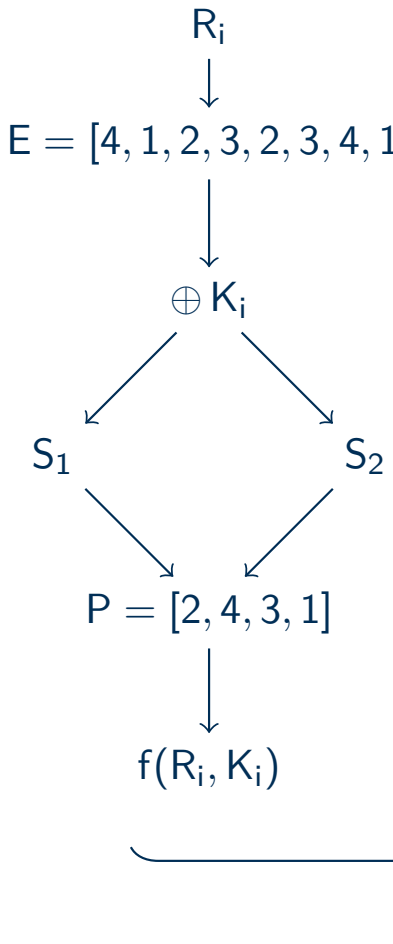
S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

$f(R_i, K_i)$

Really Simple DES





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	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

Permutations

$$\text{IP} = [2, 6, 3, 1, 4, 8, 5, 7] \begin{cases} b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8 \\ \\ b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7 \end{cases}$$

Permutations

$$\mathrm{IP} = [2, 6, 3, 1, 4, 8, 5, 7] \begin{cases} b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8 \\ \\ \\ \\ \\ \\ \\ \\ b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7 \end{cases}$$

$$\mathrm{IP}^{-1} = [4, 1, 3, 5, 7, 2, 8, 6]$$

Permutations

$$\begin{array}{rl} & b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8 \\ \mathrm{IP} = [2,6,3,1,4,8,5,7] & \Big\{ \\ & b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7 \\ \mathrm{IP}^{-1} = [4,1,3,5,7,2,8,6] & \Big\{ \\ & b_1 \end{array}$$

Permutations

$$\mathrm{IP} = [2, 6, 3, 1, 4, 8, 5, 7]$$

$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$$

$$b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7$$

$$\mathrm{IP}^{-1} = [4, 1, 3, 5, 7, 2, 8, 6]$$

$$b_1\ b_2$$

Permutations

$$\begin{array}{rl} & b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8 \\ \mathrm{IP} = [2,6,3,1,4,8,5,7] & \Big\{ \\ & b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7 \\ \mathrm{IP}^{-1} = [4,1,3,5,7,2,8,6] & \Big\{ \\ & b_1\ b_2\ b_3 \end{array}$$

Permutations

$$\mathrm{IP} = [2, 6, 3, 1, 4, 8, 5, 7]$$

$$\mathrm{IP}^{-1} = [4, 1, 3, 5, 7, 2, 8, 6]$$

$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$

$b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7$

$b_1\ b_2\ b_3\ b_4$

Permutations

$$\mathrm{IP} = [2, 6, 3, 1, 4, 8, 5, 7]$$

$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$$

$$b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7$$

$$\mathrm{IP}^{-1} = [4, 1, 3, 5, 7, 2, 8, 6]$$

$$b_1\ b_2\ b_3\ b_4\ b_5$$

Permutations

$$\mathrm{IP} = [2, 6, 3, 1, 4, 8, 5, 7]$$

$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$$

$$b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7$$

$$\mathrm{IP}^{-1} = [4, 1, 3, 5, 7, 2, 8, 6]$$

$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6$$

Permutations

$$\begin{array}{rl} & b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8 \\ \mathrm{IP} = [2,6,3,1,4,8,5,7] & \Big\{ \\ & b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7 \\ \mathrm{IP}^{-1} = [4,1,3,5,7,2,8,6] & \Big\{ \\ & b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7 \end{array}$$

Permutations

$$\mathrm{IP} = [2, 6, 3, 1, 4, 8, 5, 7]$$

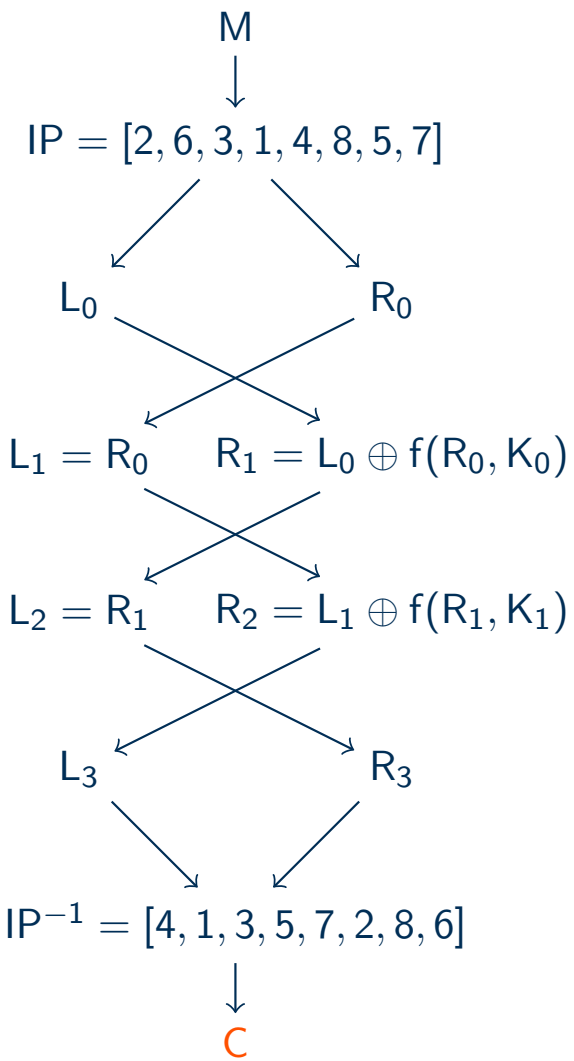
$$\mathrm{IP}^{-1} = [4, 1, 3, 5, 7, 2, 8, 6]$$

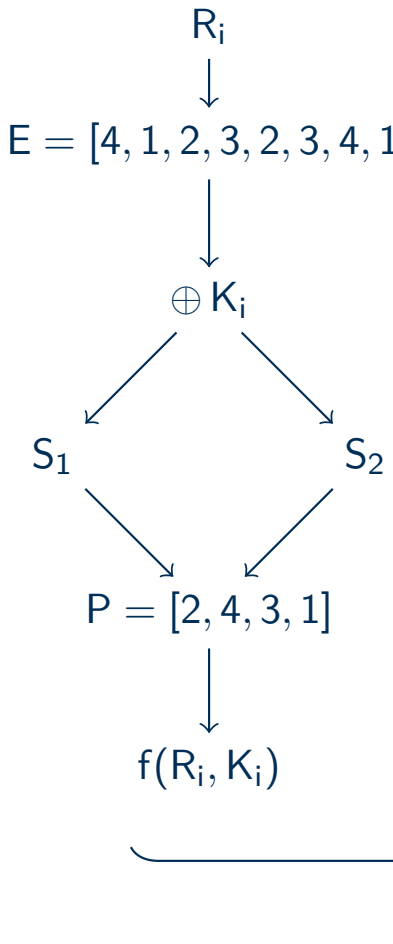
$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$$

$$b_2\ b_6\ b_3\ b_1\ b_4\ b_8\ b_5\ b_7$$

$$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$$

Really Simple DES





$f(R_i, K_i)$

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Key 1: (11001111)

S-Box 1

	00	01	10	11
00	01	11	10	11
01	11	10	01	00
10	00	10	01	11
11	11	01	11	10

S-Box 2

	00	01	10	11
00	00	01	10	11
01	10	00	01	11
10	11	00	01	00
11	10	01	10	11

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- Expansions and S-Boxes

Cryptology: Data Encryption Standard

Dr. Chuck Rocca
roccac@wcsu.edu

http://sites.wcsu.edu/roccac

WESTERN CONNECTICUT STATE UNIVERSITY
MACRICOSTAS SCHOOL OF ARTS & SCIENCES