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Exercise 5

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Problem 1. We consider the Data Encryption Standard (DES) algorithm.

a) How can the same encryption algorithm of DES be used for decryption?

DES encrypts blocks of 64 bits using a key of 56 bits. For each 7 key bits, one (odd) parity bit for error detection is added. The key of a DES cipher is of the form:

$$K_0 = (k_1, \dots, k_7, b_1, k_9, \dots, k_{15}, b_2, k_{17}, \dots, k_{57}, \dots, k_{63}, b_8).$$

From this key K_0, 16 round keys $K_1, K_2, ..., K_{16}$ are generated. The 56 key bits of K_0 are divided into two blocks C_0 and D_0 of 28 bits each as described in the left table below.

1	2	3	4	5	6	7	b_1
9	10	11	12	13	14	15	b_2
17	18	19	20	21	22	23	b_3
25	26	27	28	29	30	31	b_4
33	34	35	36	37	38	39	b_5
41	42	43	44	45	46	47	b_6
49	50	51	52	53	54	55	b_7
57	58	59	60	61	62	63	b_8

$C_0 \uparrow$ $\quad$ $\uparrow D_0$

PC2					
14	17	11	24	1	5
3	28	15	6	21	10
23	19	12	4	26	8
16	7	27	20	13	2
41	52	31	37	47	55
30	40	51	45	33	48
44	49	39	56	34	53
46	42	50	36	29	32

C_0 is read column-wise from 57 to 36 and D_0 column-wise from 63 to 4.

In a second step, C_n and D_n for $n = 1, ..., 16$, are each generated from C_{n-1} and D_{n-1} by a cyclic left-shift of s_n positions, where s_n is defined by:

$$s_n = \begin{cases} 1, & \text{if } n \in \{1, 2, 9, 16\} \\ 2, & \text{otherwise} \end{cases}$$

From each of these (C_n, D_n), with $n = 1, ..., 16$, one now selects 48 key bits as in the above table PC2 on the right to obtain K_n.

In the following, a particular pair of keys for DES is considered[1]:

$$K_0 = (\texttt{01FE 01FE 01FE 01FE}), \quad \hat{K}_0 = (\texttt{FE01 FE01 FE01 FE01})$$

[1]The keys are shown in hexadecimal representation.

b) Determine (C_0, D_0) and (C_1, D_1) from K_0, and $(\hat{C}_0, \hat{D}_0)$ and $(\hat{C}_1, \hat{D}_1)$ from $\hat{K}_0$.

c) Which of the generated subkeys $K_1, K_2, ..., K_{16}$ are identical when K_0 is used?

d) Show that $\mathrm{DES}_{\hat{K}_0}(\mathrm{DES}_{K_0}(M)) = M$ holds for all $M \in \mathcal{M}$.

Problem 2. (*DES Complementation property*) Let M be a block of bits of length 64 and let K be a block of bits of length 56. Let $\mathrm{DES}(M, K)$ denote the encryption of M with key K using the DES cryptosystem. $\overline{x}$ denotes the bitwise complement of a block x.

a) Show that the *complementation property* holds:

$$\mathrm{DES}(M, K) = \overline{\mathrm{DES}(\overline{M}, \overline{K})}$$

b) How does the complementation property help to attack DES?

Problem 3. (*weak DES keys*) There are four so called *weak* DES keys. One of those keys is

$$K = 00011111\ 00011111\ 00011111\ 00011111\ 00001110\ 00001110\ 00001110\ 00001110.$$

a) What happens if you use this key?

b) Can you find the other three weak keys?