Data Encryption Standard

Cryptography

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des.tex, r1966

Contents

Data Encryption Standard

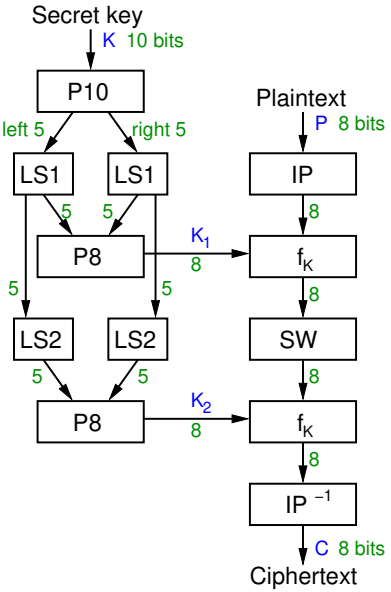
- Symmetric block cipher
- 56-bit key, 64-bit input block, 64-bit output block
- Developed in 1977 by NIST; designed by IBM (Lucifer) with input from NSA
- Principles used in other ciphers, e.g. 3DES, IDEA

Contents

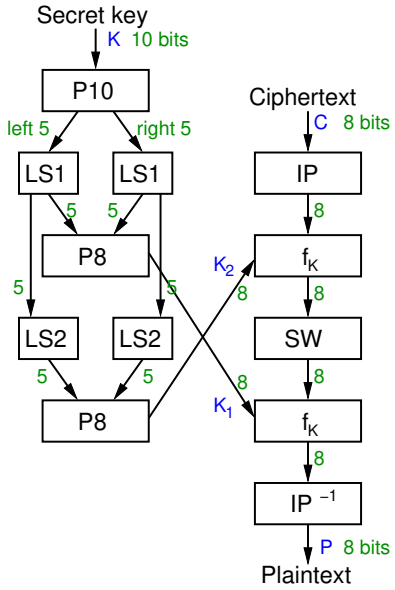
Simplified DES

- Input (plaintext) block: 8-bits
- Output (ciphertext) block: 8-bits
- Key: 10-bits
- Rounds: 2
- Round keys generated using permutations and left shifts
- Encryption: initial permutation, round function, switch halves
- Decryption: Same as encryption, except round keys used in opposite order

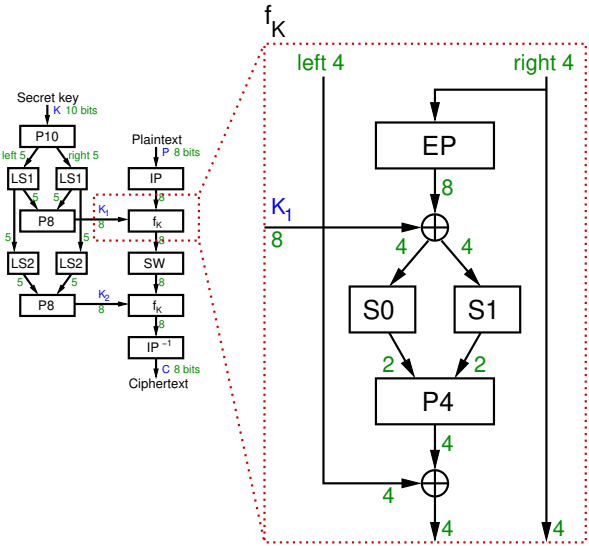
S-DES Key Generation and Encryption



S-DES Key Generation and Decryption



S-DES Round Function Details



S-DES Permutations (definition)

Permutations used in S-DES:

P10 (permutate)

```
Input :  1 2 3 4 5 6 7 8 9 10
Output:  3 5 2 7 4 10 1 9 8 6
```

P8 (select and permutate)

```
Input :  1 2 3 4 5 6 7 8 9 10
Output:  6 3 7 4 8 5 10 9
```

P4 (permutate)

```
Input :  1 2 3 4
Output:  2 4 3 1
```

EP (expand and permutate)

```
Input :  1 2 3 4
Output:  4 1 2 3 2 3 4 1
```

IP (initial permutation)

```
Input :  1 2 3 4 5 6 7 8
Output:  2 6 3 1 4 8 5 7
```

Other Operations in S-DES

- LS-1: left shift by 1 position
- LS-2: left shift by 2 positions
- IP^{-1}: inverse of IP, such that $X = \text{IP}^{-1}(\text{IP}(X))$
- SW: swap the halves
- f_K: a round function using round key K
- F: internal function in each round

S-DES S-Boxes (definition)

S-Box considered as a matrix: input used to select row/column; selected element is output

4-bit input: $bit_1, bit_2, bit_3, bit_4$

$bit_1 bit_4$ specifies row (0, 1, 2 or 3 in decimal)

$bit_2 bit_3$ specifies column

$$S0 = \begin{bmatrix} 01 & 00 & 11 & 10 \\ 11 & 10 & 01 & 00 \\ 00 & 10 & 01 & 11 \\ 11 & 01 & 11 & 10 \end{bmatrix} \quad S1 = \begin{bmatrix} 00 & 01 & 10 & 11 \\ 10 & 00 & 01 & 11 \\ 11 & 00 & 01 & 00 \\ 10 & 01 & 00 & 11 \end{bmatrix}$$

Encrypt with S-DES (exercise)

Show that when the plaintext 01110010 is encrypted using S-DES with key 1010000010 that the ciphertext obtained is 01110111.

S-DES Summary

- Educational encryption algorithm
- S-DES expressed as functions:

$$\text{ciphertext} = \text{IP}^{-1}(f_{K_2}(\text{SW}(f_{K_1}(\text{IP}(\text{plaintext})))))$$

$$\text{plaintext} = \text{IP}^{-1}(f_{K_1}(\text{SW}(f_{K_2}(\text{IP}(\text{ciphertext})))))$$

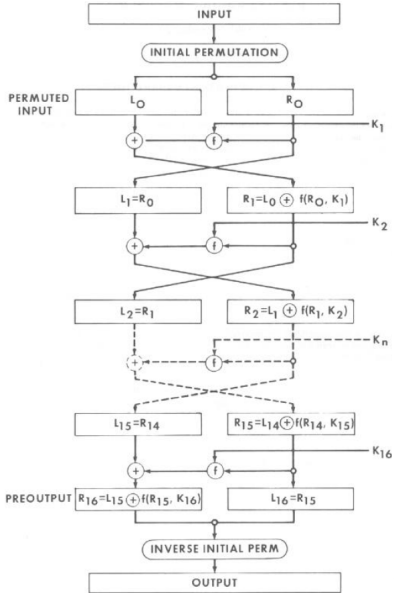
- Brute force attack on S-DES is easy since only 10-bit key
- If know plaintext and corresponding ciphertext, can we determine key? *Very hard*

S-DES Compared to Real DES

- S-DES vs DES
- Block size: 8 bits vs 64 bits
- Rounds: 2 vs 16
- IP: 8 bits vs 64 bits
- F: 4 bits vs 32 bits
- S-Boxes: 2 vs 8
- Round key: 8 bits vs 48 bits

Contents

General DES Encryption Algorithm



Initial Permutation Tables for DES

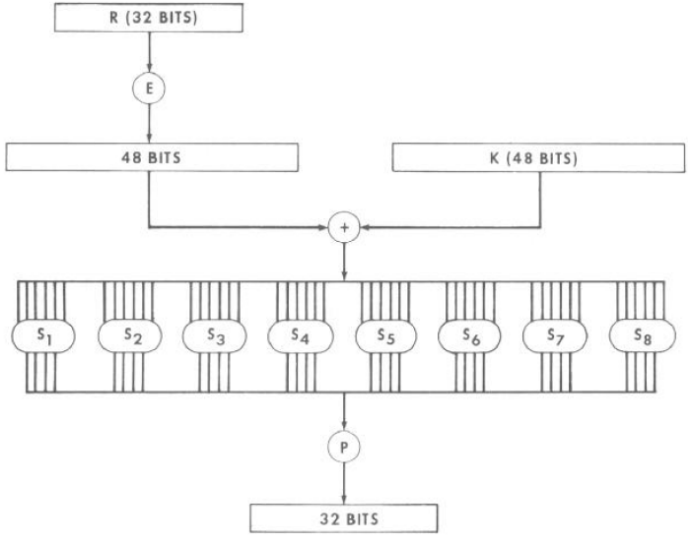
IP

58	50	42	34	26	18	10	2
60	52	44	36	28	20	12	4
62	54	46	38	30	22	14	6
64	56	48	40	32	24	16	8
57	49	41	33	25	17	9	1
59	51	43	35	27	19	11	3
61	53	45	37	29	21	13	5
63	55	47	39	31	23	15	7

IP^{-1}

40	8	48	16	56	24	64	32
39	7	47	15	55	23	63	31
38	6	46	14	54	22	62	30
37	5	45	13	53	21	61	29
36	4	44	12	52	20	60	28
35	3	43	11	51	19	59	27
34	2	42	10	50	18	58	26
33	1	41	9	49	17	57	25

Calculation of F(R,K)



Permutation Tables for DES

E BIT-SELECTION TABLE

32	1	2	3	4	5
4	5	6	7	8	9
8	9	10	11	12	13
12	13	14	15	16	17
16	17	18	19	20	21
20	21	22	23	24	25
24	25	26	27	28	29
28	29	30	31	32	1

P

16	7	20	21
29	12	28	17
1	15	23	26
5	18	31	10
2	8	24	14
32	27	3	9
19	13	30	6
22	11	4	25

Definition of DES S-Boxes 1 to 4

S_1

14	4	13	1	2	15	11	8	3	10	6	12	5	9	0	7
0	15	7	4	14	2	13	1	10	6	12	11	9	5	3	8
4	1	14	8	13	6	2	11	15	12	9	7	3	10	5	0
15	12	8	2	4	9	1	7	5	11	3	14	10	0	6	13

S_2

15	1	8	14	6	11	3	4	9	7	2	13	12	0	5	10
3	13	4	7	15	2	8	14	12	0	1	10	6	9	11	5
0	14	7	11	10	4	13	1	5	8	12	6	9	3	2	15
13	8	10	1	3	15	4	2	11	6	7	12	0	5	14	9

S_3

10	0	9	14	6	3	15	5	1	13	12	7	11	4	2	8
13	7	0	9	3	4	6	10	2	8	5	14	12	11	15	1
13	6	4	9	8	15	3	0	11	1	2	12	5	10	14	7
1	10	13	0	6	9	8	7	4	15	14	3	11	5	2	12

S_4

7	13	14	3	0	6	9	10	1	2	8	5	11	12	4	15
13	8	11	5	6	15	0	3	4	7	2	12	1	10	14	9
10	6	9	0	12	11	7	13	15	1	3	14	5	2	8	4
3	15	0	6	10	1	13	8	9	4	5	11	12	7	2	14

Definition of DES S-Boxes 5 to 6

S_5

2	12	4	1	7	10	11	6	8	5	3	15	13	0	14	9
14	11	2	12	4	7	13	1	5	0	15	10	3	9	8	6
4	2	1	11	10	13	7	8	15	9	12	5	6	3	0	14
11	8	12	7	1	14	2	13	6	15	0	9	10	4	5	3

S_6

12	1	10	15	9	2	6	8	0	13	3	4	14	7	5	11
10	15	4	2	7	12	9	5	6	1	13	14	0	11	3	8
9	14	15	5	2	8	12	3	7	0	4	10	1	13	11	6
4	3	2	12	9	5	15	10	11	14	1	7	6	0	8	13

S_7

4	11	2	14	15	0	8	13	3	12	9	7	5	10	6	1
13	0	11	7	4	9	1	10	14	3	5	12	2	15	8	6
1	4	11	13	12	3	7	14	10	15	6	8	0	5	9	2
6	11	13	8	1	4	10	7	9	5	0	15	14	2	3	12

S_8

13	2	8	4	6	15	11	1	10	9	3	14	5	0	12	7
1	15	13	8	10	3	7	4	12	5	6	11	0	14	9	2
7	11	4	1	9	12	14	2	0	6	10	13	15	3	5	8
2	1	14	7	4	10	8	13	15	12	9	0	3	5	6	11

DES Permutated Choice 1 and 2

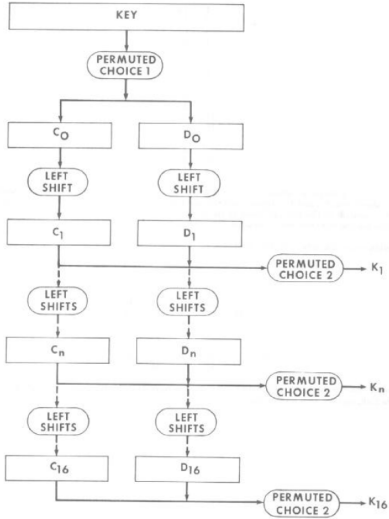
PC-1

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

PC-2

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

DES Key Generation Schedule



DES Schedule of Left Shifts in Key Generation

Iteration Number	Number of Left Shifts
1	1
2	1
3	2
4	2
5	2
6	2
7	2
8	2
9	1
10	2
11	2
12	2
13	2
14	2
15	2
16	1

Contents

DES Encryption in OpenSSL

- Encrypt a file with a password using the `enc` operation
- Generate a random key using the `rand` operation
- Disable padding (with exact plaintext correct size)
- Encrypt with key and IV using `enc` operation
- View binary data (e.g. ciphertext) with `xxd`

DES Key Generation (exercise)

Generate a shared secret key to be used with DES and share it with another person.

DES Encryption (exercise)

Create a message in a plain text file and after using DES, send the ciphertext to the person you shared the key with.

DES Decryption (exercise)

Decrypt the ciphertext you received.

Contents

AES in Python Cryptography Library

- cryptography.io/en/latest/hazmat/primitives/symmetric-encryption/