Symmetric Key Cryptography

- Block ciphers (DES)
  - Substituition cipher
  - Transposition cipher
  - Product cipher
  - Feistel cipher
- Stream cipher = block cipher with |block| =1 (RC4)

Substitution ciphers

simple

a b c d e f g h i j k l m n o p q r s t u v w x y z

d e f g h i j k l m n o p q r s t u v w x y z a b c

M= thisc ipher iscert tainl ynots ecure

C= wklvf lskhu lvfhu wdlqo bqrwv hfxuh

Shift ciphers

Es. *shift cipher*

$|A|=s$, $m_i \in A$ with $0 \leq i \leq s-1$ then

$$Ci = e(mi) = mi + k \bmod s$$

$$mi = d(Ci) = Ci - k \bmod s$$

CAESAR cipher $s=26$, $k=3$

m = BrunoCrispo

c = EuxqrFulsr

Polyalphabetic substitutions

$|A|=s$, period t, keys k_i, $0 \le k_i \le t-1$

k keys consisting of permutations

$$C_i = e(m_i) = m_i + k_i \bmod s$$

$$m_i = d(C_i) = C_i - k_i \bmod s$$

Vigenere ciphers

VIGENERE cipher t=3

$k_0=1$, $k_1=2$, $k_2=3$

m= THI SCI PHE RIS NOT SEC URE

c = UJL TEL QJH SKV OQW TGF WTH

Language statistics

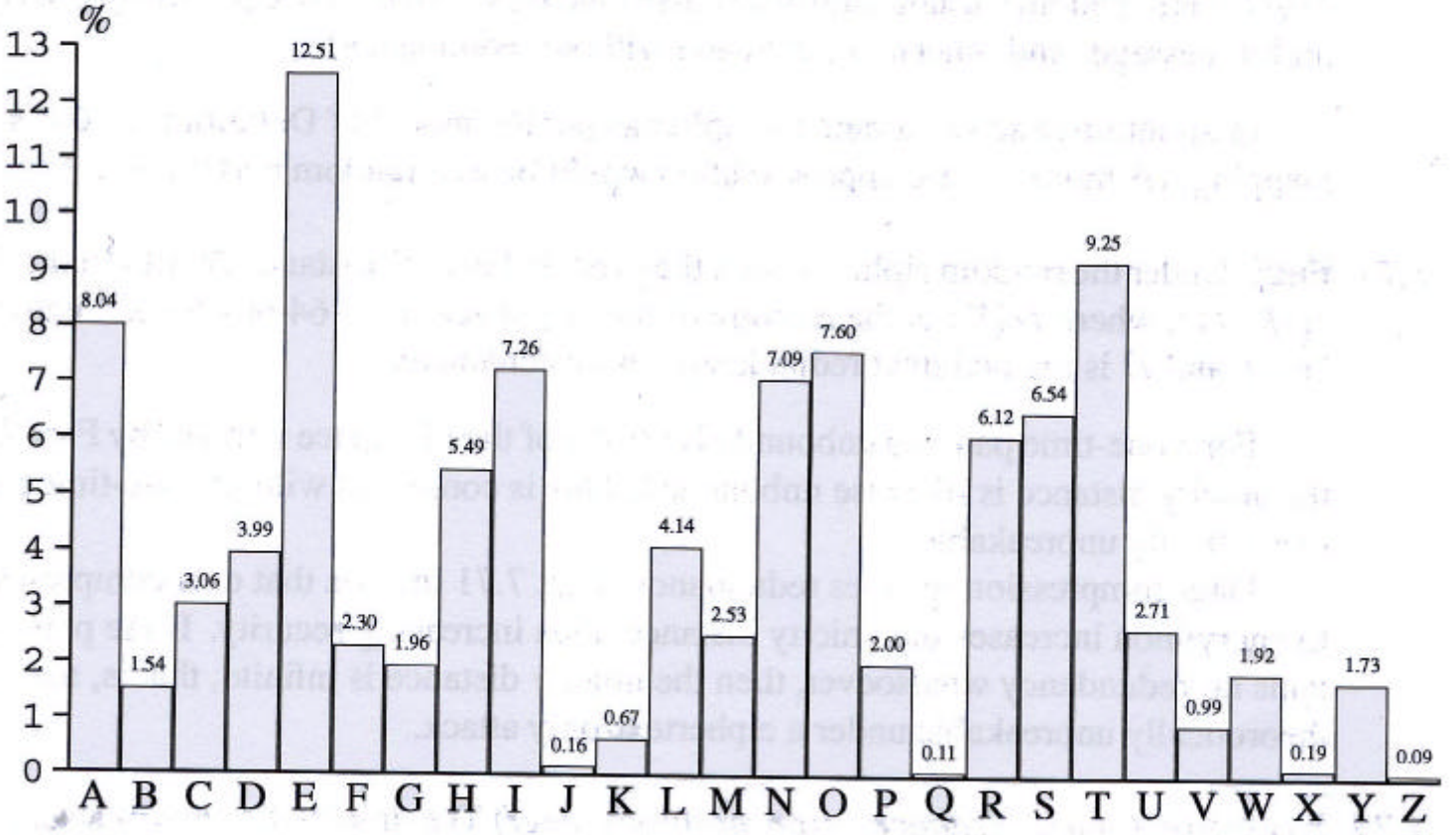


Figure 7.5: *Frequency of single characters in English text.*

Polygram ciphers

Playfair

M	O	N	A	R
C	H	Y	B	D
E	F	G	I/J	K
L	P	Q	S	T
U	V	W	X	Z

M= ea hs ar mu

C= IM BP RM CM

Language statistics

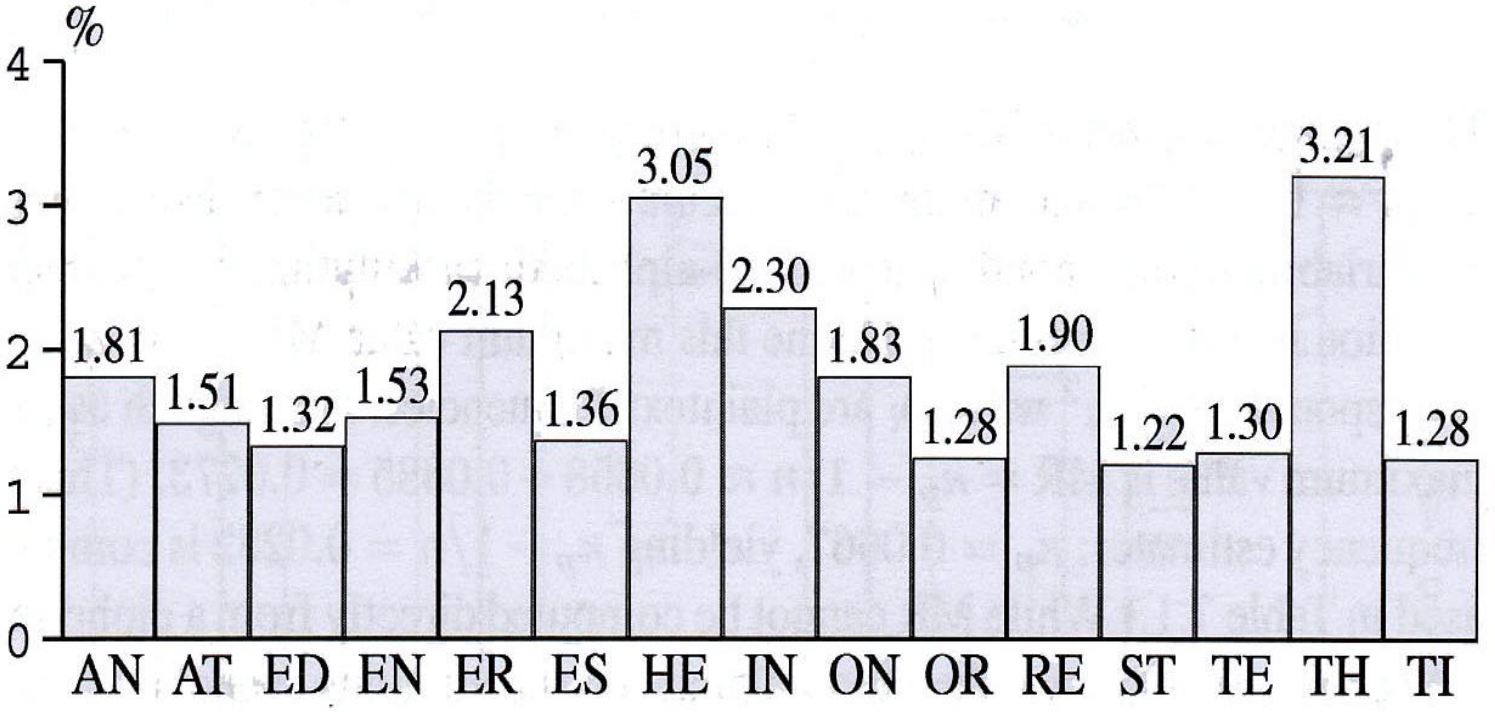


Figure 7.6: *Frequency of 15 common digrams in English text.*

Statistical cryptanalysis

- Unicity distance (UD): minimum amount of ciphertext to recover a key given unlimited computational power

carried information lg26 = 4.7bit/char

entropy=1.5 redundancy=D=4.7-1.5=3.2

Es. simple sub.

$$UD=H(K)/D=\lg(26!)/D=88.4/3.2\approx 28$$

H(*k*) entropy of the key space

Transposition ciphers

M= attack postponed until two am

Key:	4	3	1	2	5	6	7
Plaintext:	a	t	t	a	c	k	p
	o	s	t	p	o	n	e
	d	u	n	t	i	l	t
	w	o	a	m	x	y	z

Cipher: ttnaaptmtsuoaodwcoixknlypetz

Exercises

M=?

C=ftqcguowndaizrajvgybahqdftqxmlkpas

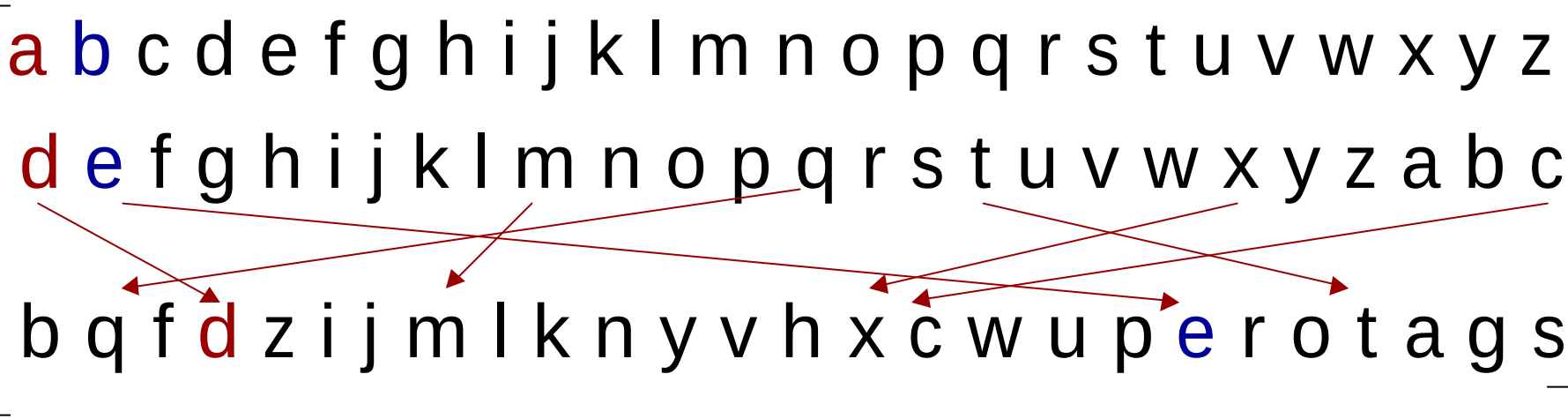
M=?

C=uzqsovuohxmopvgpozpevsgzwszopfpesx
udbmetsxaizvuephzhmdzshzowsfpappdtsv
pquzwymxuzuhsxepyepopdzszufpo

English trigram: the, and, tha, ent, ion

Product ciphers

- Substitution $\rightarrow$ confusion $K \leftrightarrow C$
- Permutation $\rightarrow$ diffusion $M \leftrightarrow C$



SP-Networks

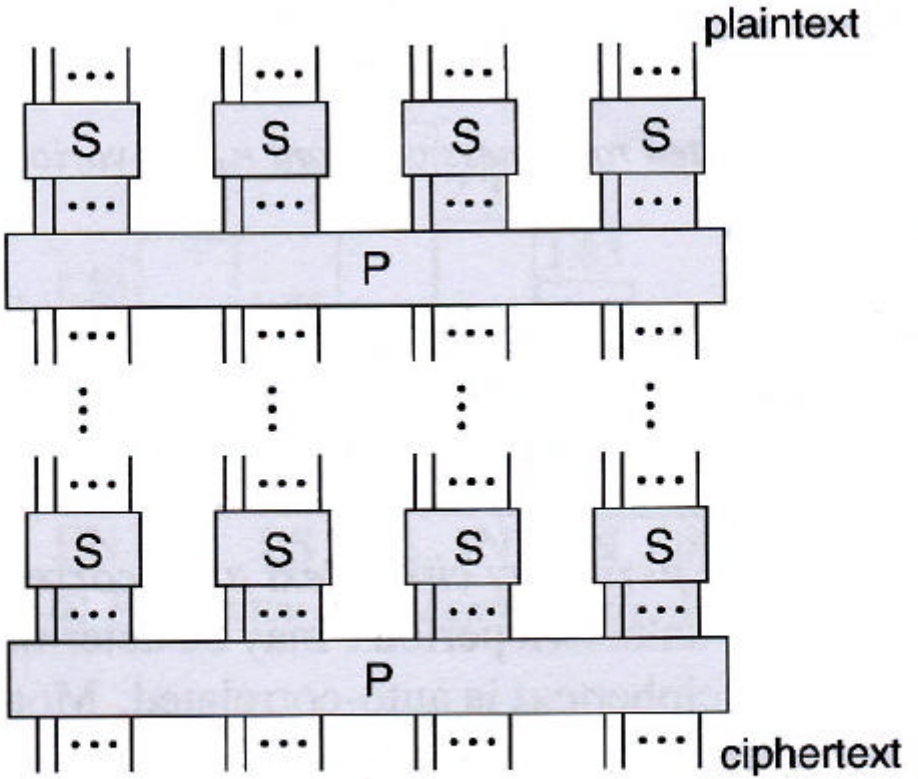
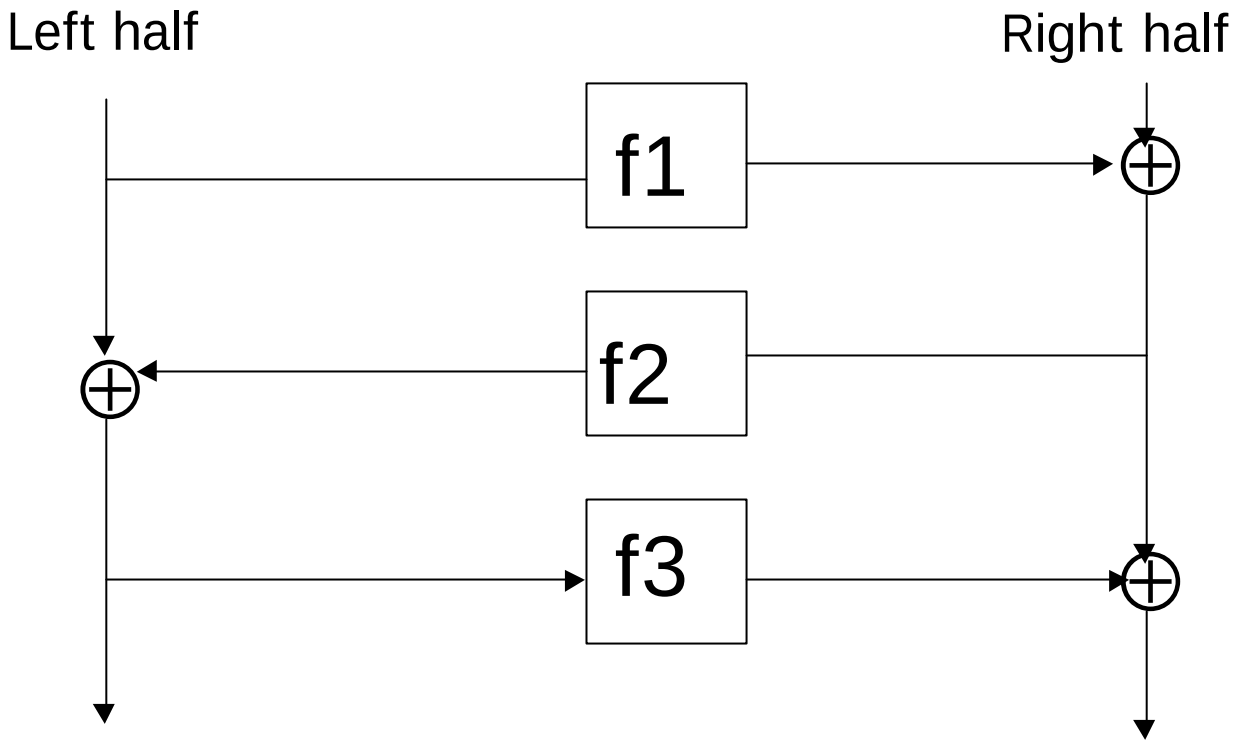


Figure 7.7: *Substitution-permutation (SP) network.*

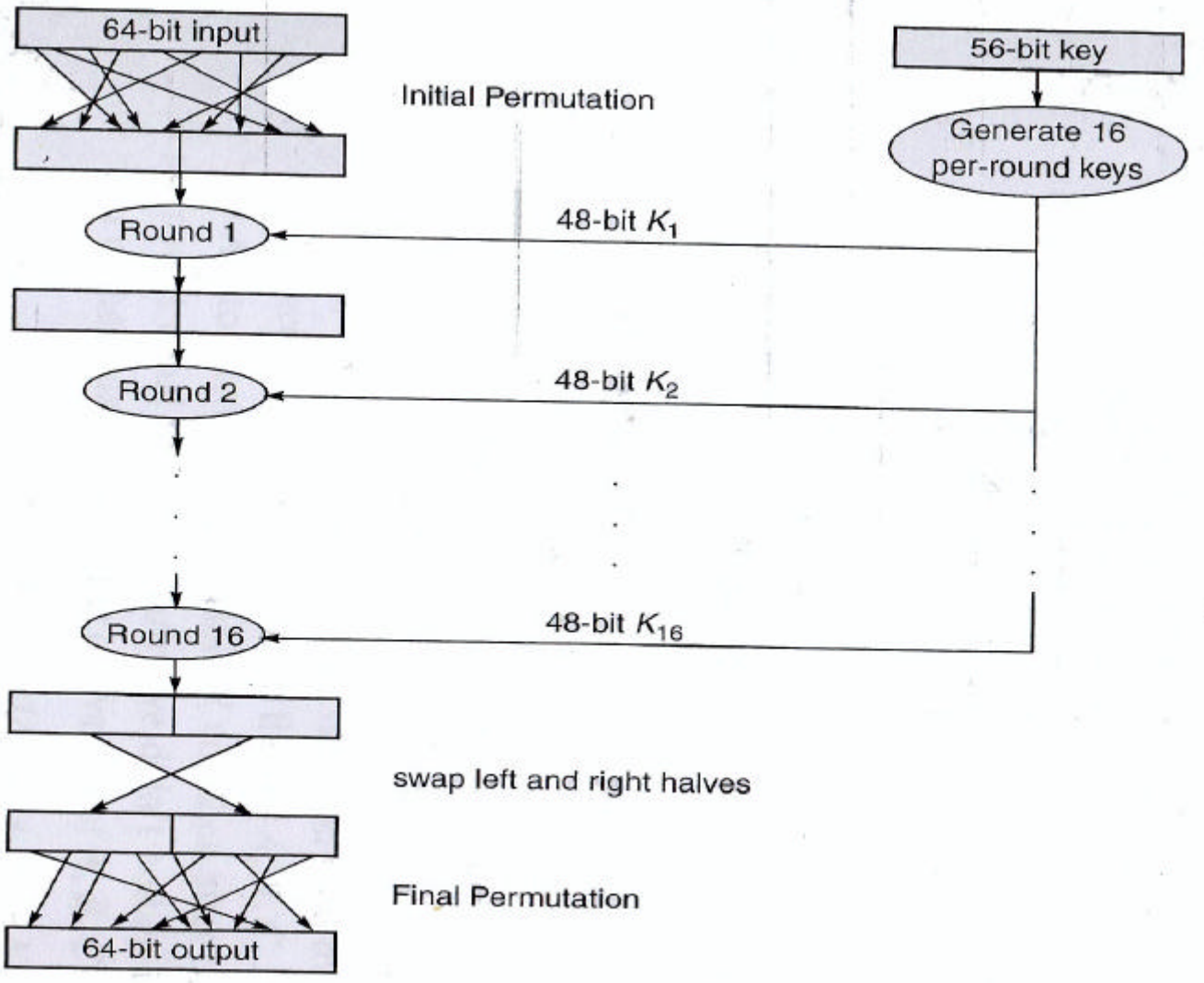
Feistel ciphers



$L_i = R_{i-1}$, $R_i = L_{i-1} \oplus f(R_{i-1})$

$\Psi^{-1}(f1,f2,f3) = \Psi(f3,f2,f1)$

DES: Data Encryption Standard



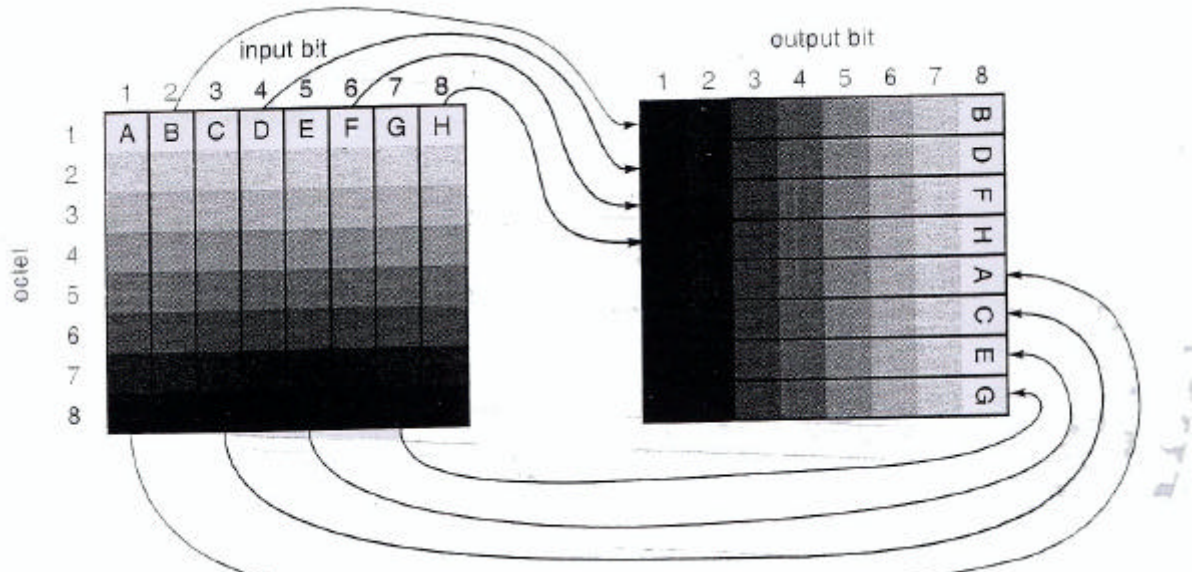
DES Permutations

Initial Permutation (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

Final Permutation (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



DES per-round keys

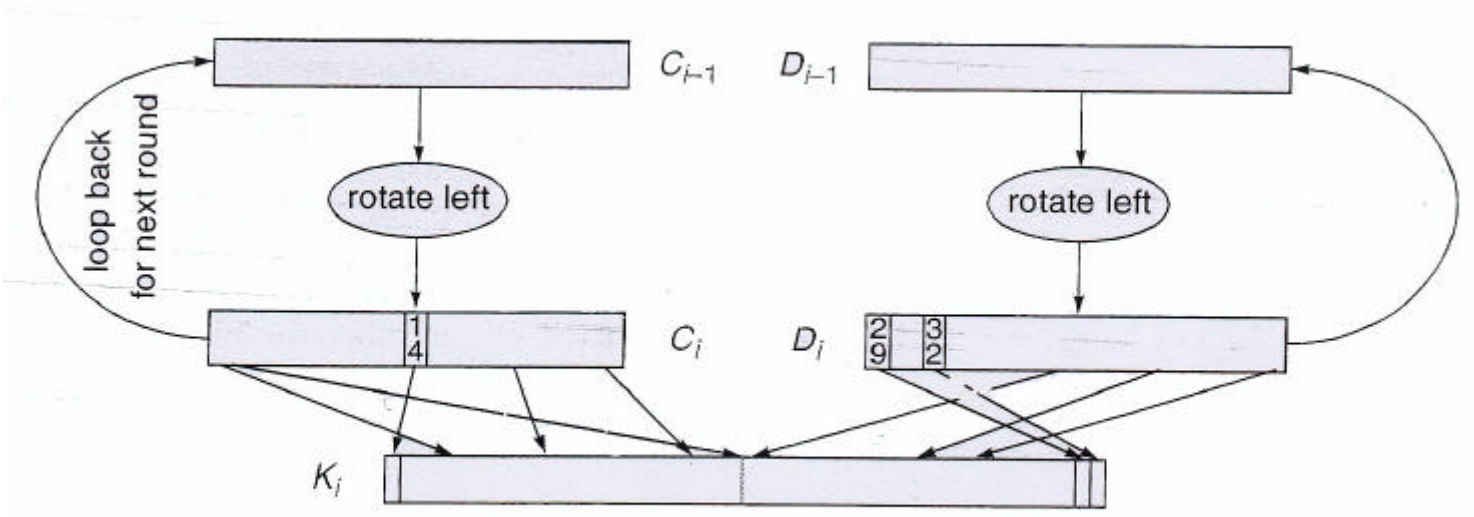


Figure 3-5. Round i for generating K_i

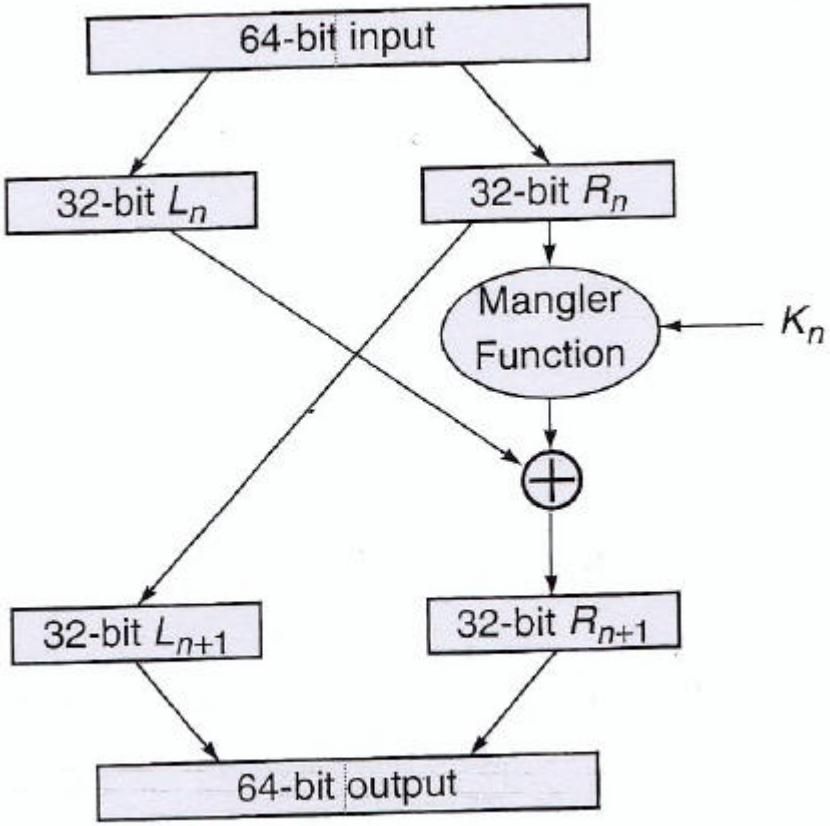
C_0

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

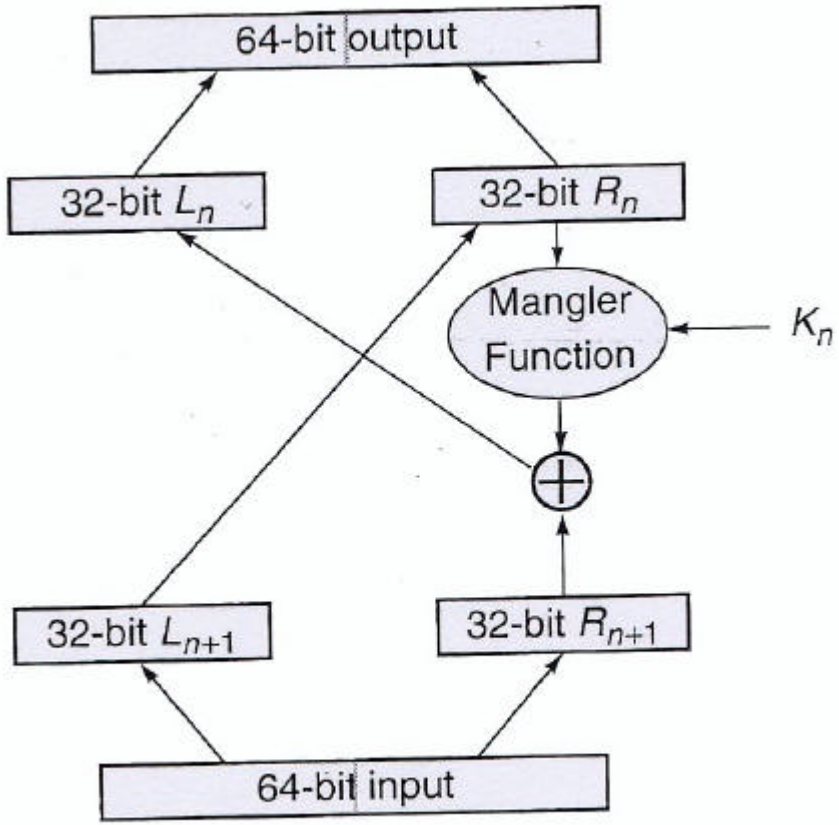
D_0

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

DES round



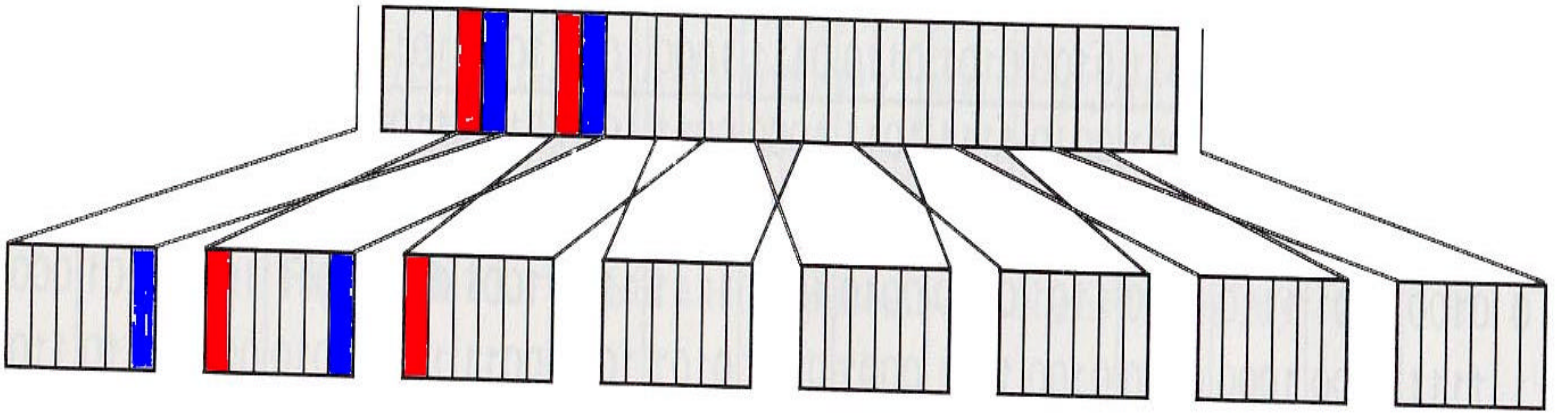
Encryption

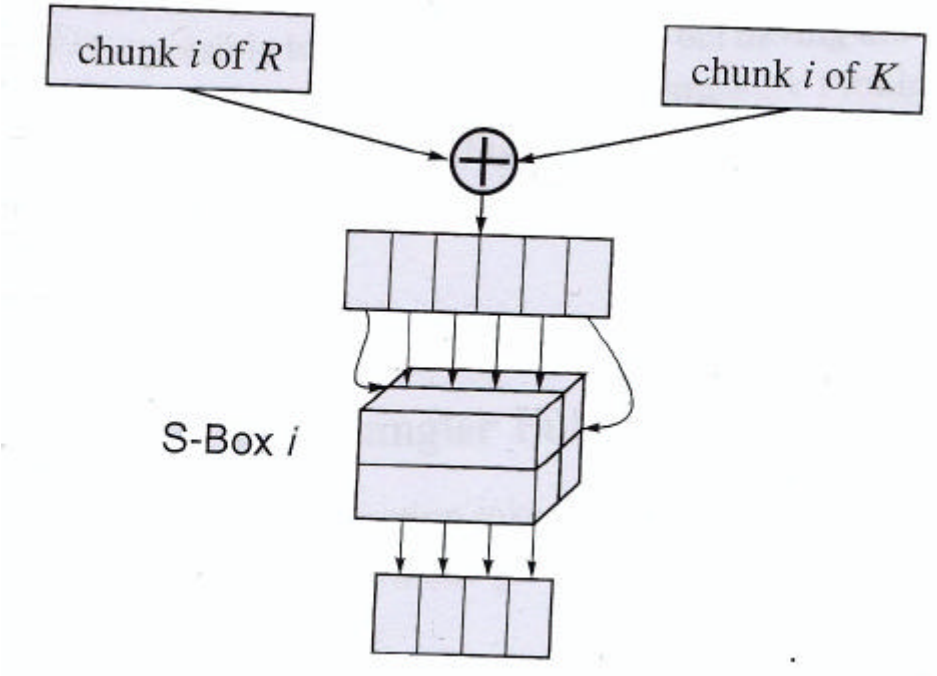


Decryption

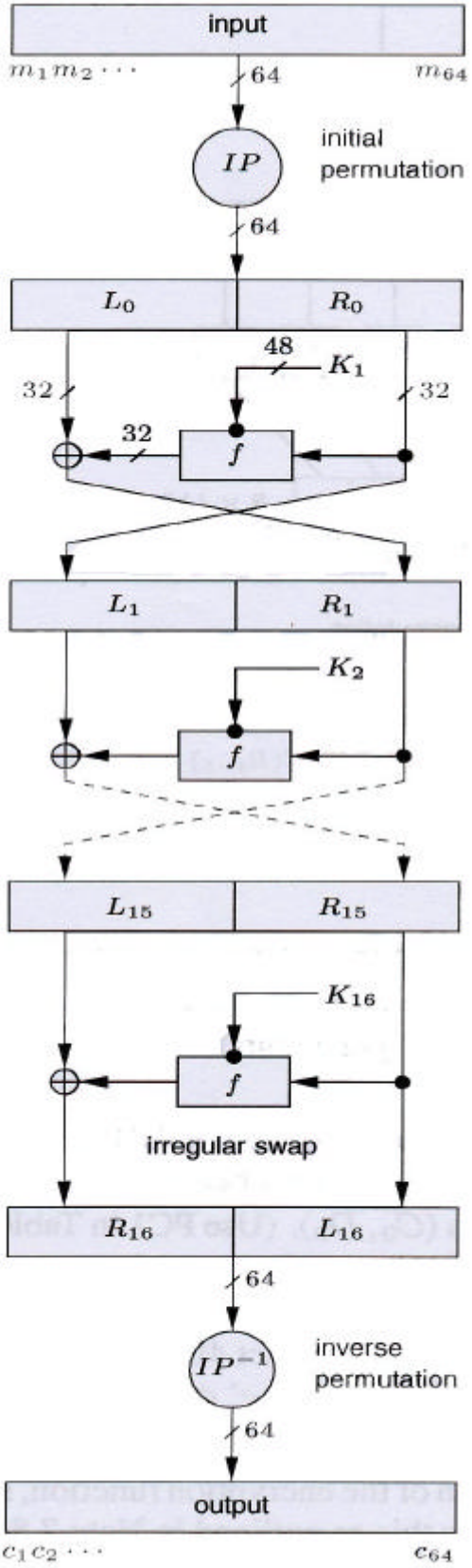
$L_i = R_{i-1}$, $R_i = L_{i-1} \oplus f(R_{i-1}, K_i)$

DES round





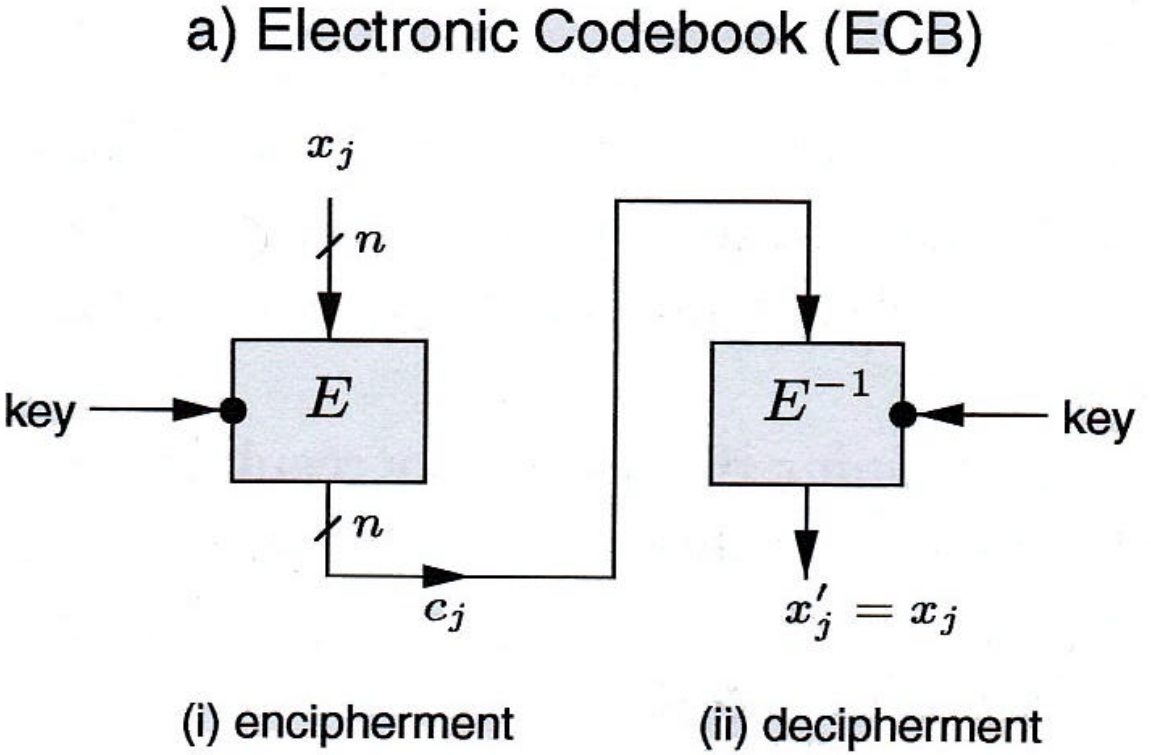
DES


input
$m_1 m_2 \cdots$
64
m_{64}
IP
initial permutation
64
L_0
R_0
48
K_1
32
32
32
f
L_1
R_1
K_2
f
L_{15}
R_{15}
K_{16}
f
irregular swap
R_{16}
L_{16}
64
IP^{-1}
inverse permutation
64
output
$c_1 c_2 \cdots$
c_{64}

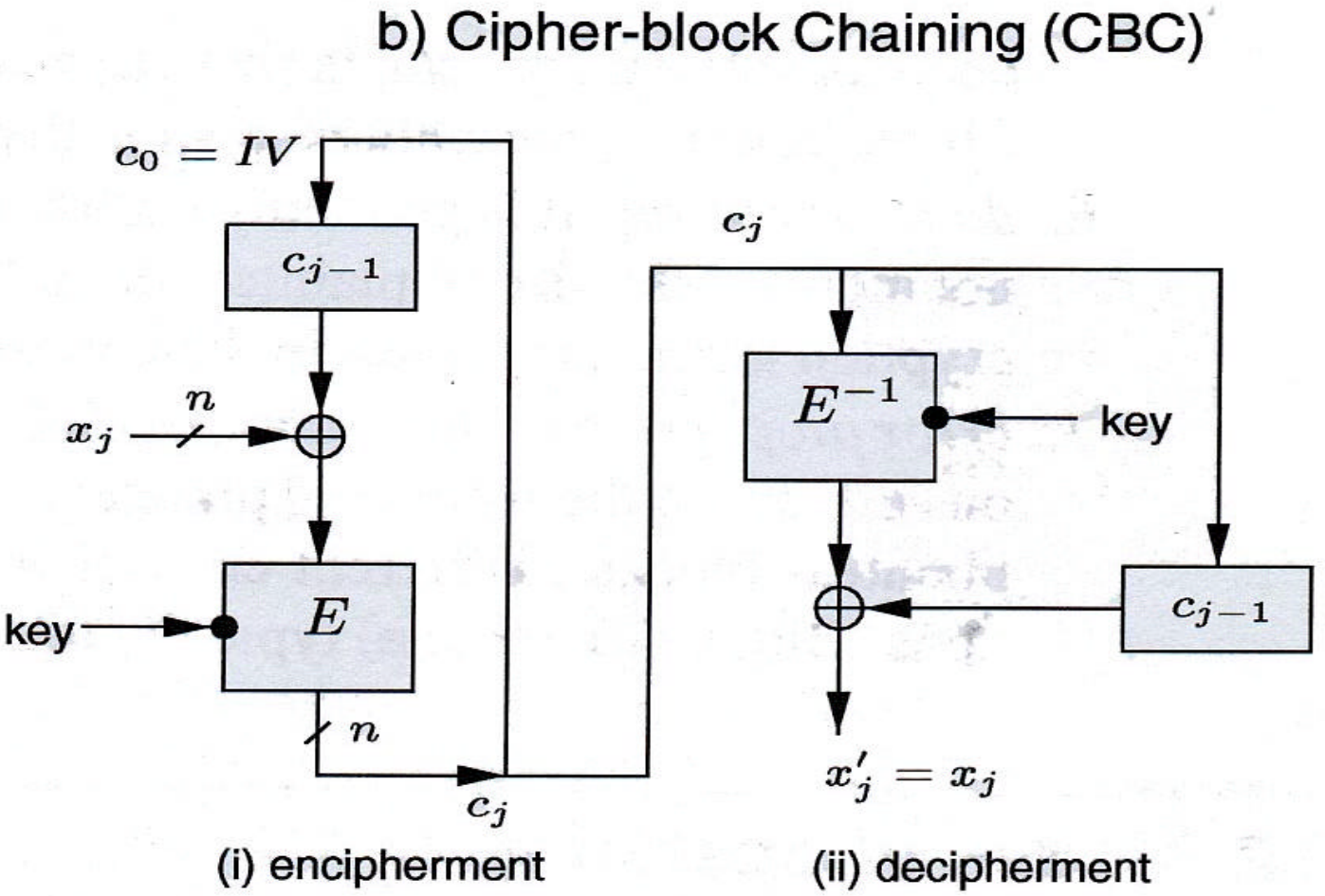
Modes of Operation

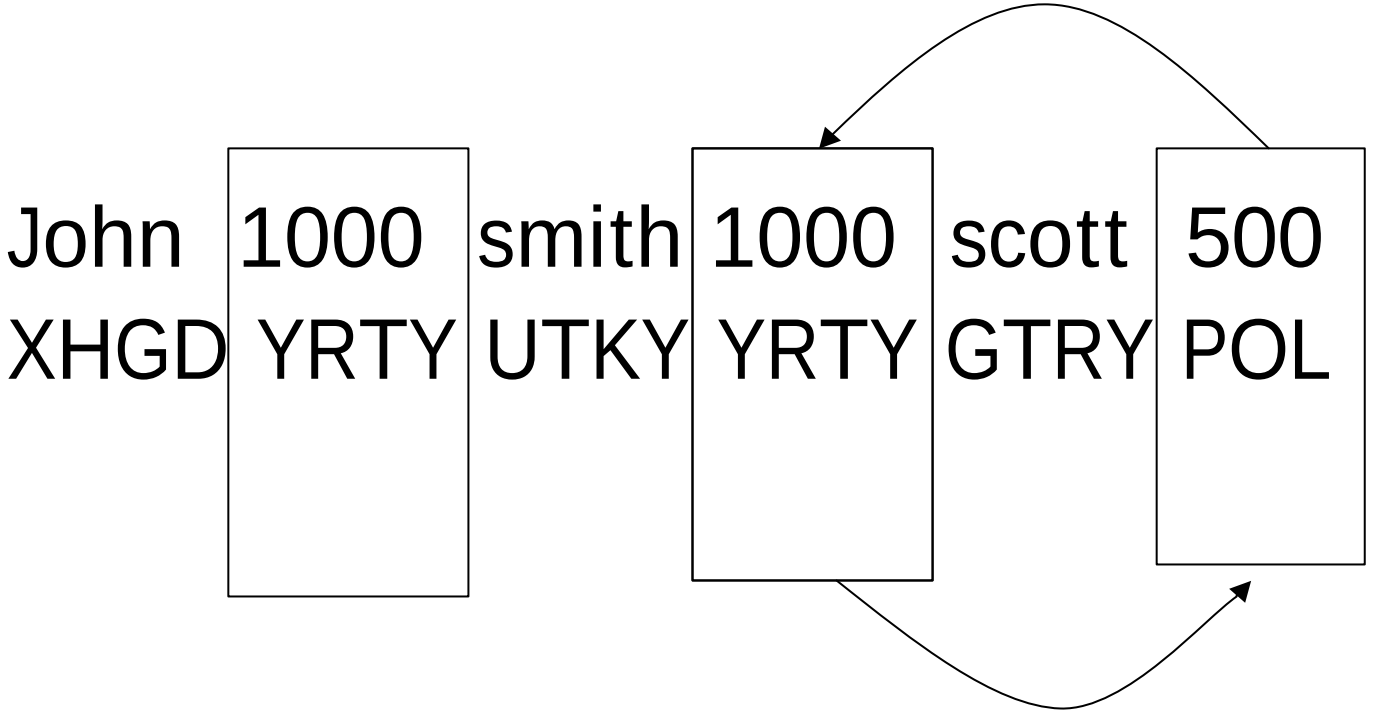
- Electronic Codebook *ECB*
- Cipher-block Chaining *CBC*
- Cipher feedback *CFB*
- Output feedback *OFB*
  - Counter mode

ECB


a) Electronic Codebook (ECB)
x_j
n
key
E
n
c_j
E^{-1}
key
$x'_j = x_j$
(i) encipherment
(ii) decipherment

CBC

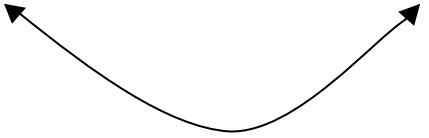

b) Cipher-block Chaining (CBC)
$c_0 = IV$
c_{j-1}
x_j
n
key
E
n
c_j
(i) encipherment
c_j
E^{-1}
key
c_{j-1}
$x'_j = x_j$
(ii) decipherment



John 1000 smith 500 scott 1000
XHGD YRTY UTKY POL GTRY YRTY

John 1000 smith 1000 scott 500

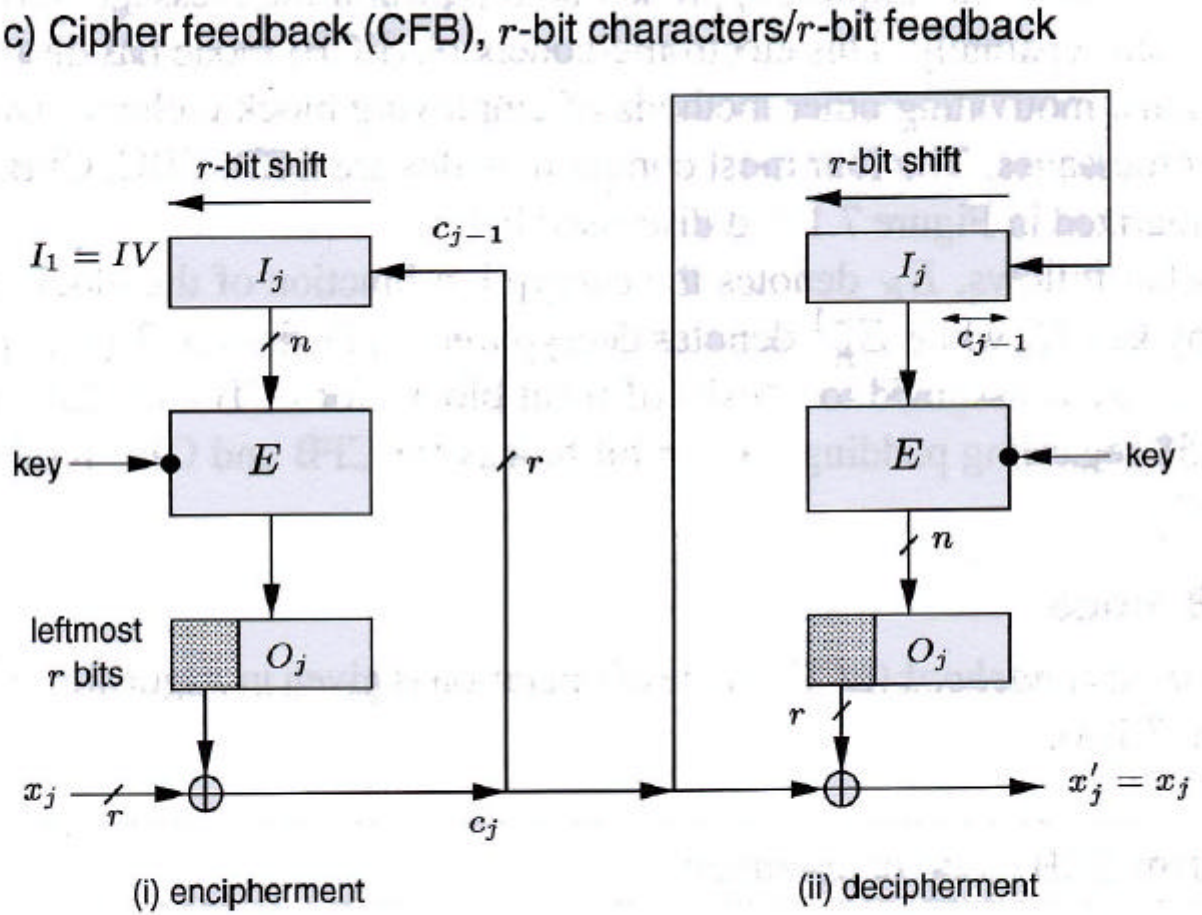
UYGB XZPL AWSI JQTY ERWK EDW



John 1000 smith $%& (*))_ t!@4

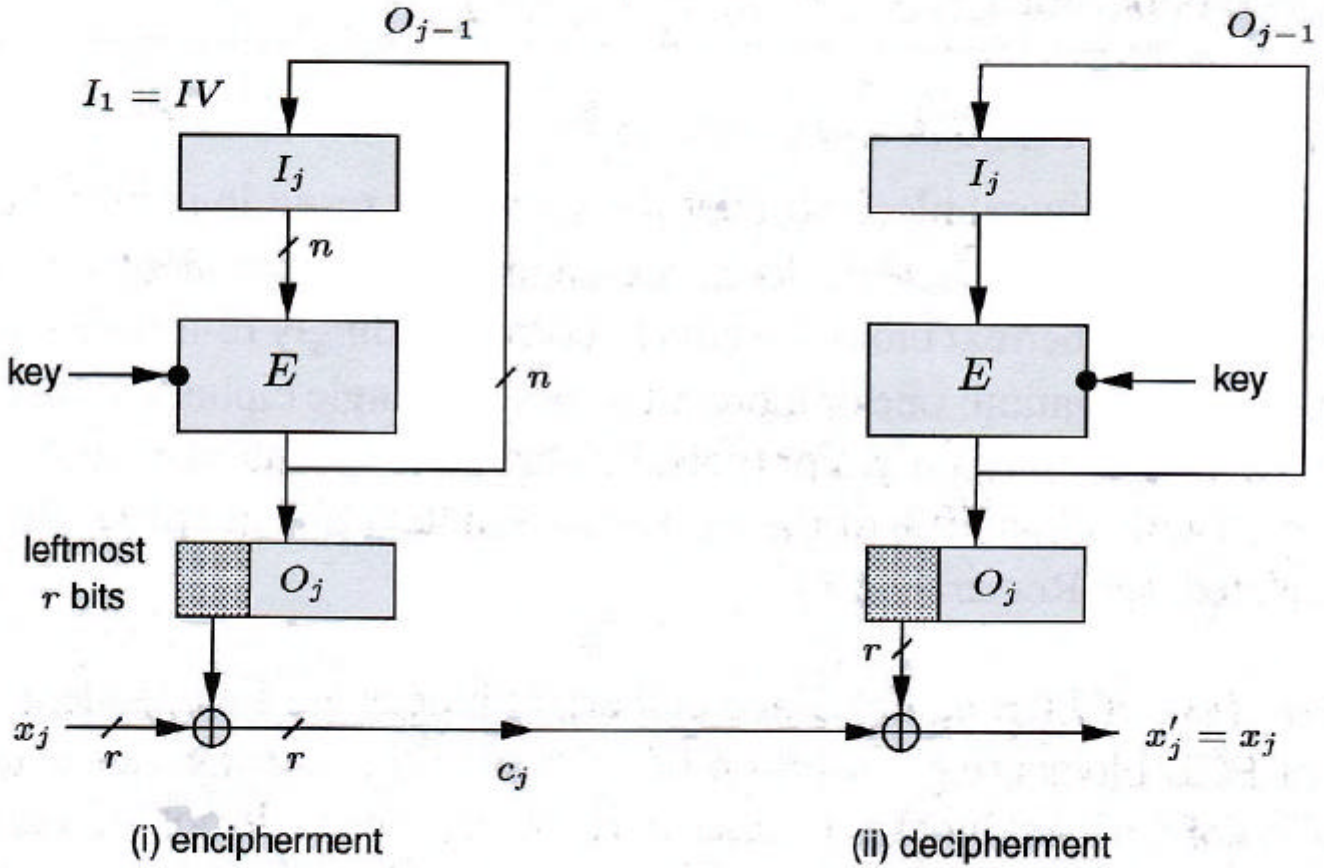
UYGB XZPL AWSQ EDW ERWK JQTY

CFB


c) Cipher feedback (CFB), r-bit characters/r-bit feedback
r-bit shift
$I_1 = IV$
I_j
c_{j-1}
n
key
E
r
leftmost
r bits
O_j
x_j
r
c_j
(i) encipherment
r-bit shift
I_j
c_{j-1}
E
key
n
O_j
r
$x'_j = x_j$
(ii) decipherment

OFB

d) Output feedback (OFB), r-bit characters/n-bit feedback



MAC:Message Authentication Code

- DES CBC

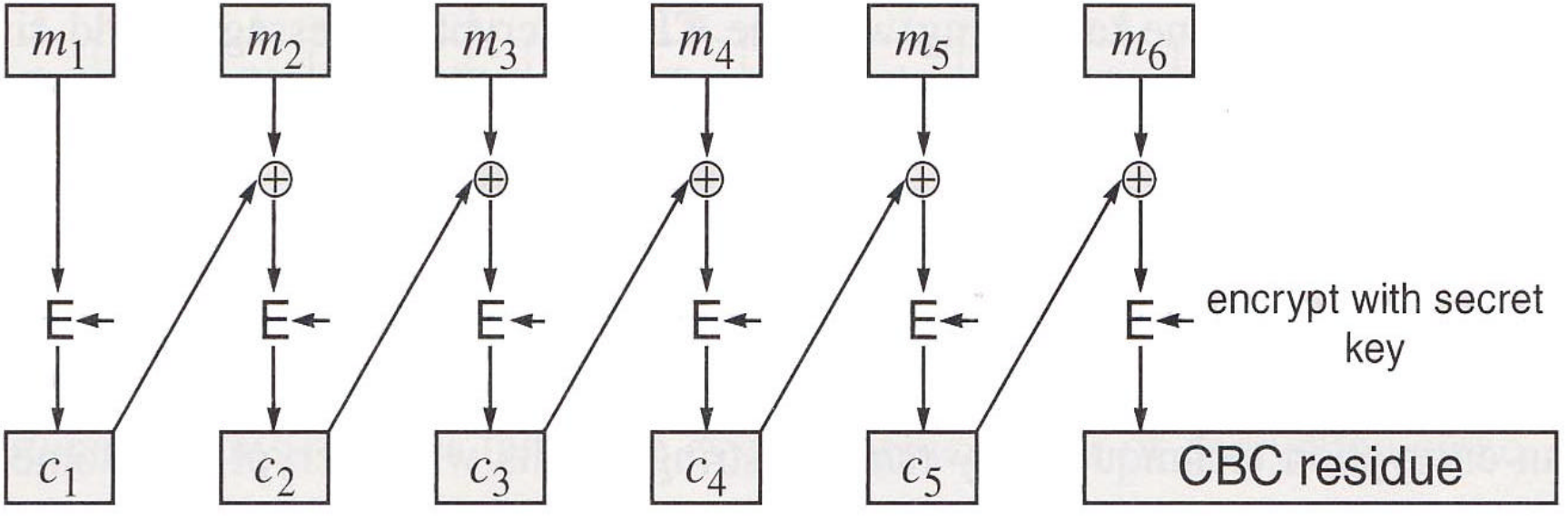
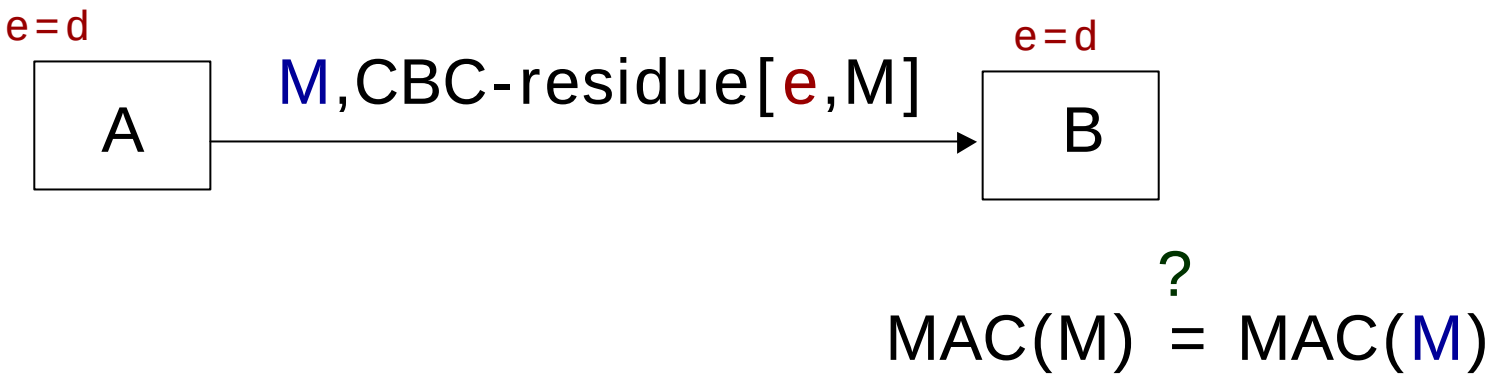


Figure 4-11. Cipher Block Chaining Residue

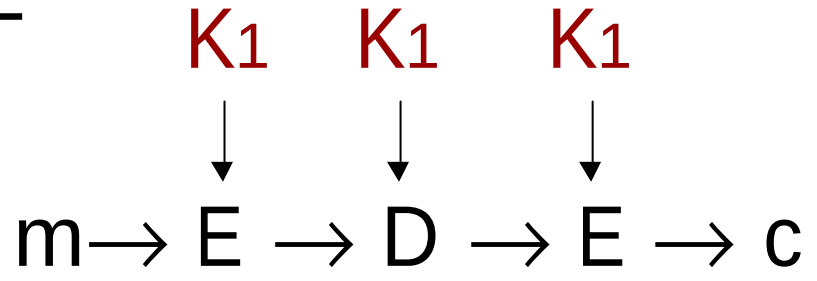
Integrity with SK



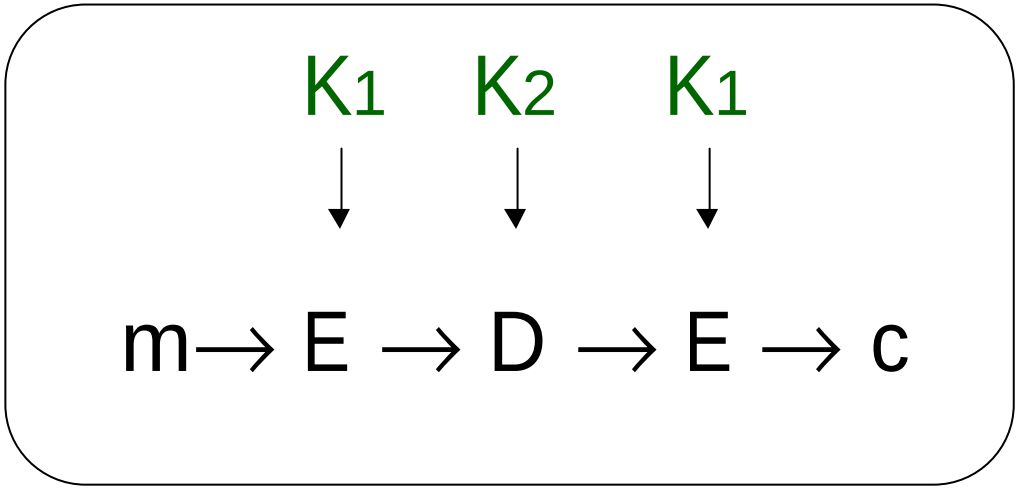
MAC=message authentication code

Multiple encryption

- 3DES EDE

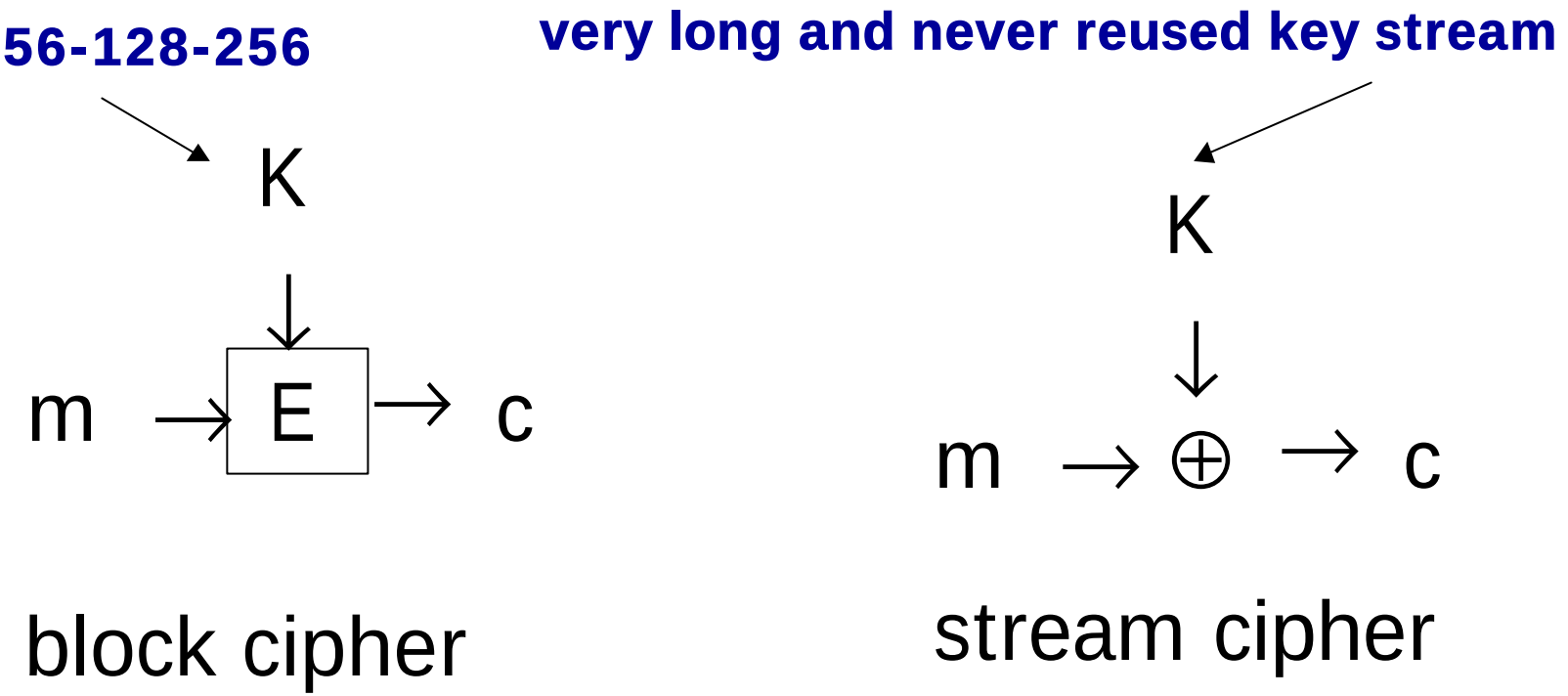


56 bits



112 bits

Stream ciphers



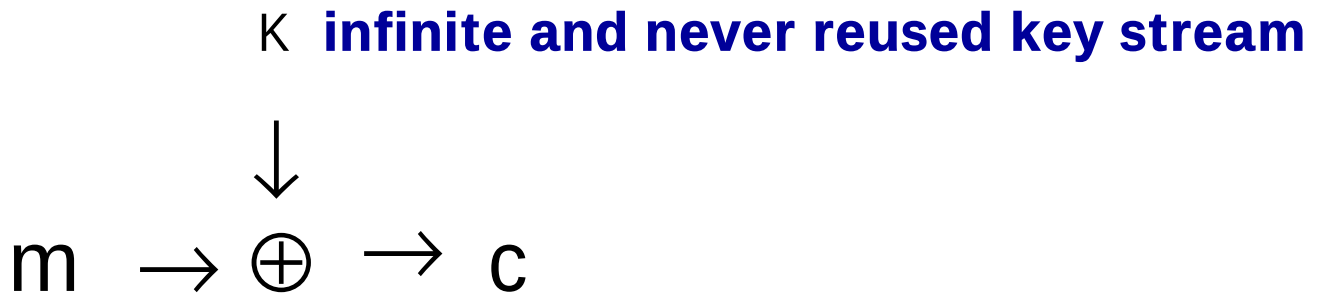
block cipher

stream cipher

Stream ciphers

- One time pad (OTP)

  Perfect secrecy but no integrity



RC4

```
typedef unsigned char uns8;
typedef unsigned short uns16;

static uns8 state[256], x, y;    /* 258 octets of state information */

void
rc4init (key, length)    /* initialize for encryption / decryption */
    uns8 *key;
    uns16 length;
{
    int i;
    uns8 t;
    uns8 j;
    uns8 k = 0;

    for (i = 256; i--; )
       state[i] = i;

    for (i = 0, j = 0; i < 256; i++, j = (j + 1) % length)
        t = state[i], state[i] = state[k += key[j] + t], state[k] = t;

    x = 0;
    y = 0;
}

uns8
rc4step ()    /* return next pseudo-random octet */
{
  uns8 t;

  t = state[y += state[++x]], state[y] = state[x], state[x] = t;
  return (state[state[x] + state[y]]);
}
```