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M.S. Ramaiah Institute of Technology
(Autonomous Institute, Affiliated to VTU)
Department of Computer Science and Engineering

Course Name: Cryptography and Network Security

Course Code – CSE555

Credits - 3:0:0

UNIT -2

Term: Oct 2024 – Jan 2025

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Textbooks

1. **Behrouz A. Forouzan, DebdeepMukhopadhyay** - Cryptography and Network Security, Tata McGraw-Hill, 3rd Edition, 2015
2. **William Stallings** - Cryptography and Network Security, Pearson Education, 7th Edition, 2018

Reference Books:

1. **Bernard Menezes**: Cryptography, Network Security and Cyber Laws , Cengage Learning, First edition, 2018.
2. **AtulKahate**: Cryptography and Network Security", 4th Edition, Tata McGraw Hill, 2019.
3. **William Stallings**: Network Security Essentials: Applications and Standards by, 6th edition, Pearson Education, 2018.

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Unit II (Text1)

Traditional Symmetric-Key Ciphers: (Chapter 3)

- Introduction
- Substitution Ciphers
- Trans positional Ciphers
- Stream and Block Ciphers

Data Encryption Standard (DES): (Chapter 6)

- Introduction
- DES Structure
- DES Analysis
- Multiple of DES
- Security of DES

Introduction -Symmetric Key ciphers

Traditional Symmetric-key ciphers are not used today, but we study for several reason:

1. They are simpler than modern ciphers and easier to understand
2. They show basic foundation of cryptography and encipherment.
3. They provide rationale for using modern ciphers, traditional ciphers can be easily attacked using computer

Introduction -Symmetric Key ciphers

The original message from Alice to Bob is called plaintext;

The message that is sent through the channel is called the ciphertext.

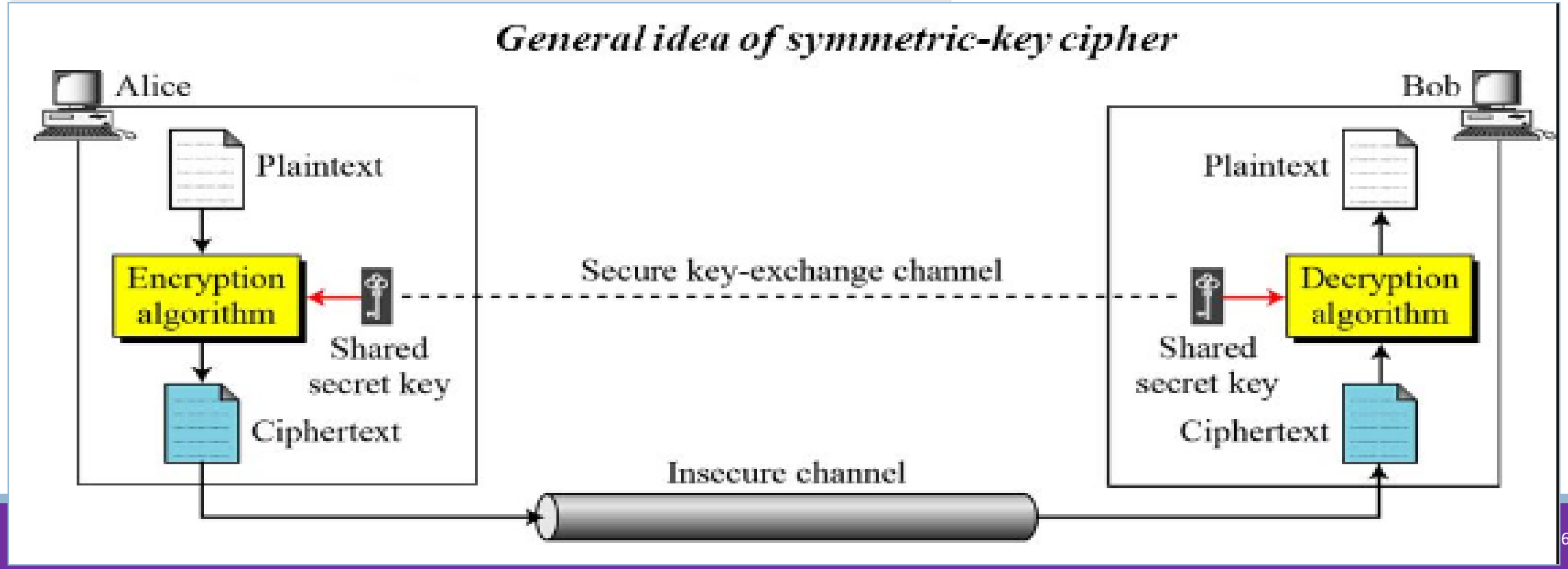
To create the ciphertext from the plaintext, Alice uses an encryption algorithm and a shared secret key.

To create the plaintext from ciphertext, Bob uses a decryption algorithm and the same secret key.

Introduction -Symmetric Key ciphers

If P is the plaintext, C is the ciphertext, and K is the key,

Encryption: $C = E_k(P)$ Decryption: $P = D_k(C)$



Introduction -Symmetric Key ciphers

Kerckhoff's Principle

- According to Kerckhoff's principle, it is better to make encryption and decryption public, but keep the shared key secret.
- Based on Kerckhoff's principle, one should always assume that the adversary, Eve, knows the encryption/decryption algorithm.
- The resistance of the cipher to attack must be based only on the secrecy of the key.

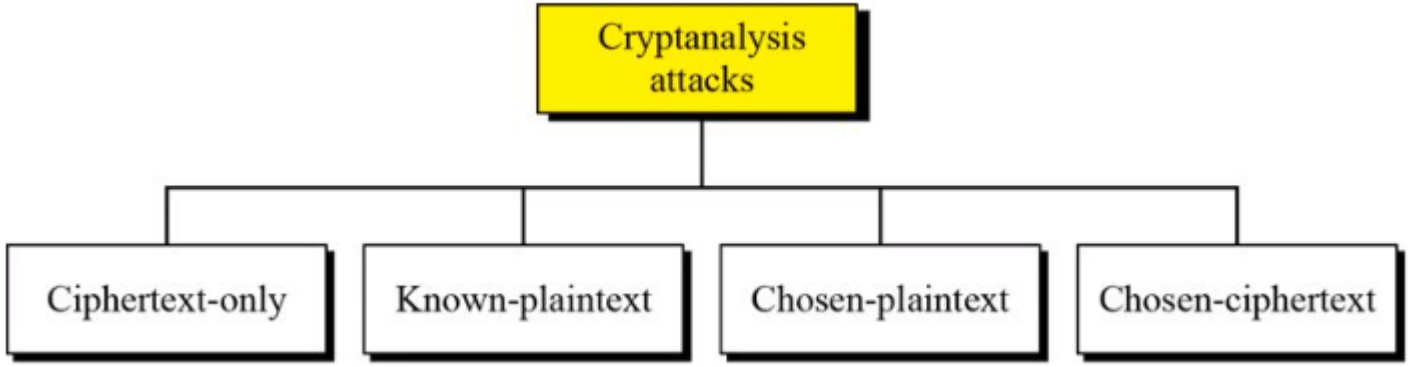
Introduction -Symmetric Key ciphers

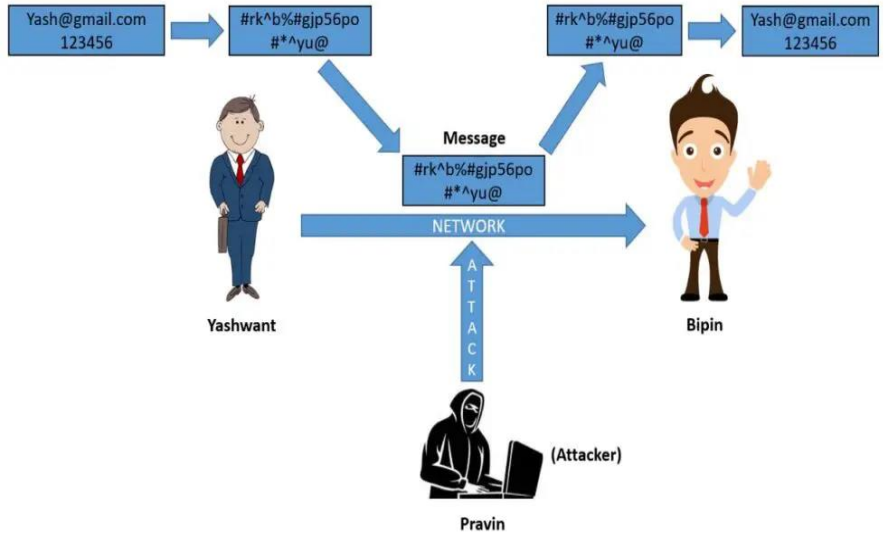
Cryptanalysis

Cryptography is the science and art of creating secret codes.

Cryptanalysis is the science and art of breaking those codes.

Figure shows Cryptanalysis attack forms

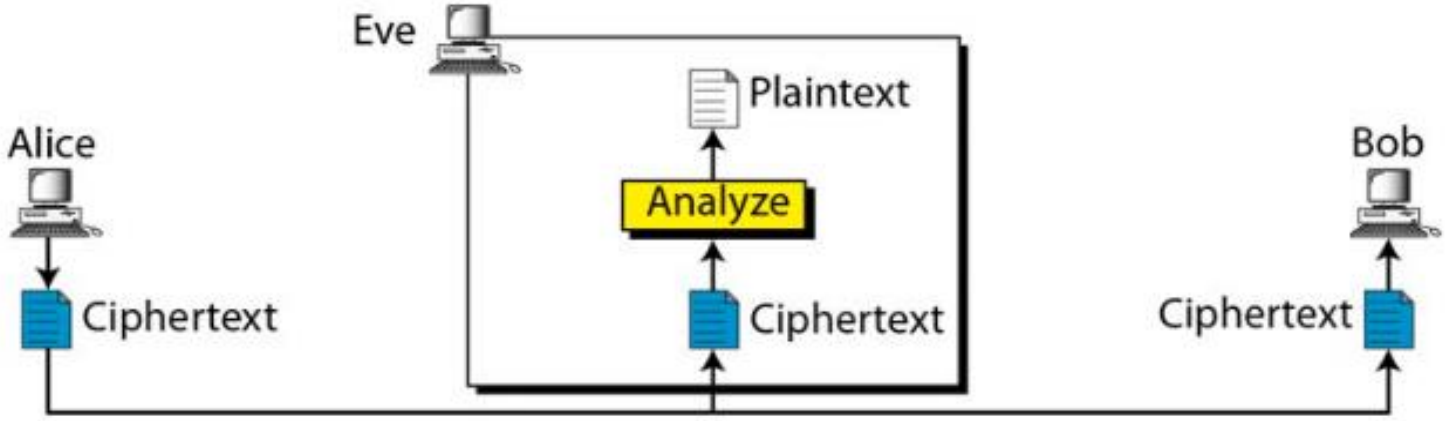




Introduction -Symmetric Key ciphers

Cryptanalysis - Ciphertext-only attack

- Eve has access to only some cipher text, then finds the key and plaintext.
- Assume eve knows the encryption algorithm



Introduction -Symmetric Key ciphers

Cryptanalysis - Ciphertext-only attack

Various methods can be used in Ciphertext-only attack

1. Brute-Force attack: exhaustive key search attack
2. Statistical attack: benefit from inherent characteristics of the plaintext language. E.g. E is the most frequently used letter.
3. Pattern attack: discover pattern in ciphertext.

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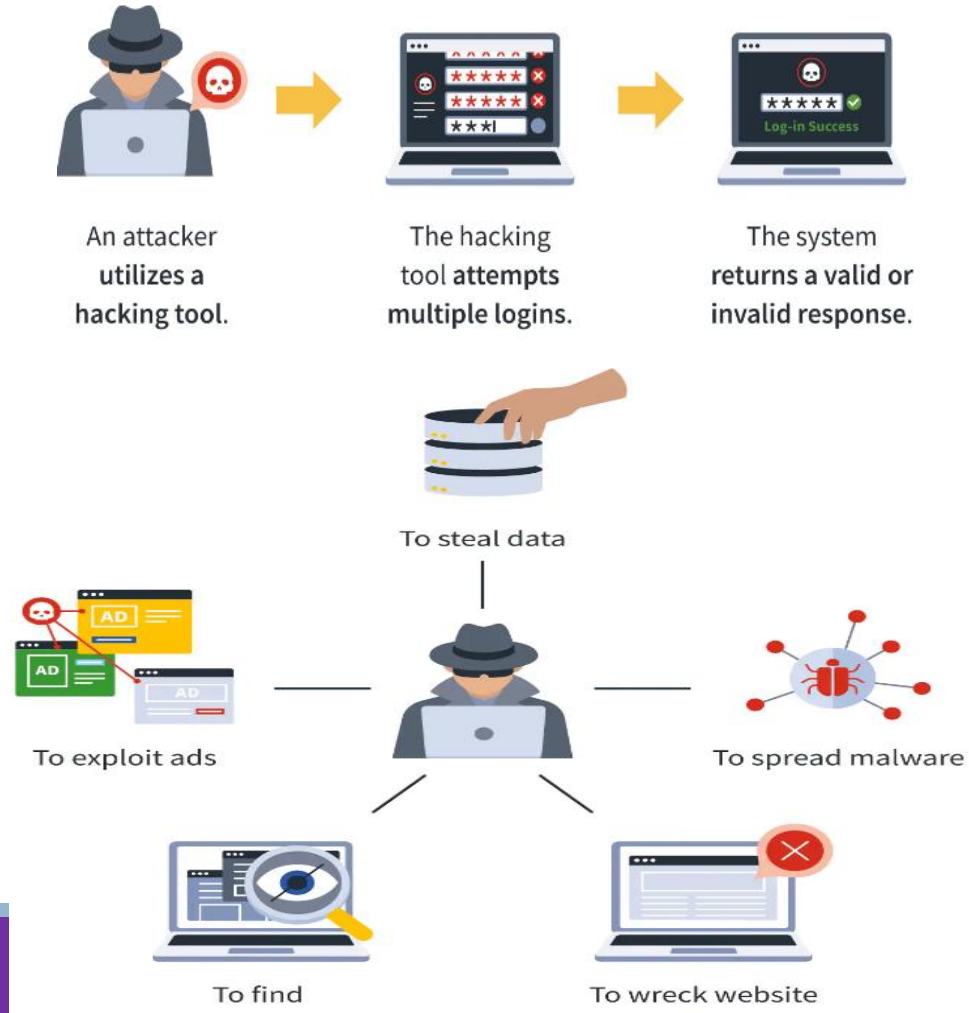
Introduction -Symmetric Key ciphers

1. Brute-Force attack:

If the key is 8 bits long, then the number of possible keys is $2^8 = 256$keys

Often target popular platforms where many users store data.

Email domains, online tax services, or food apps could be likely targets.



Introduction -Symmetric Key ciphers

2. Statistical attack:

It is the study of the frequency of letters or groups of letters in a ciphertext.

Benefit from inherent characteristics of the plaintext language.

E.g. E is the most frequently used letter.

Statistical attacks target vulnerabilities in the operating systems or hardware hosting the functional cryptography tool.

Introduction -Symmetric Key ciphers

2. Statistical attack:

   For example:

   Database containing employee details may be used by others to calculate the average salary of employees based on particular criteria.

   If a user discovered a criterion which only holds for one employee, and uses this information to find the average salary of all employees, then the employee's salary could be easily discovered.

Introduction -Symmetric Key ciphers

3. Pattern attack:

Some ciphers may hide the characteristics of the language, but create some patterns in the ciphertext

Cryptanalyst will use pattern to break the cipher

Example :

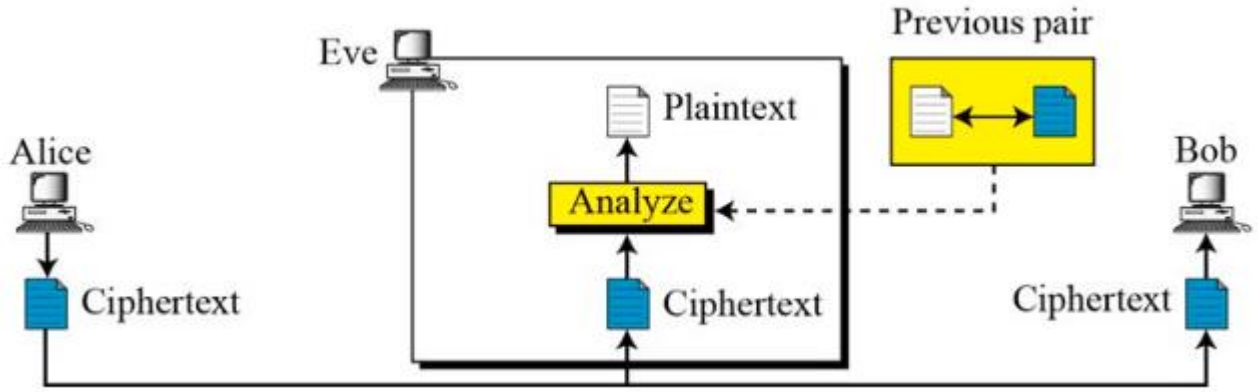
Password123

abc123

Introduction -Symmetric Key ciphers

Cryptanalysis -Known-Plaintext Attack

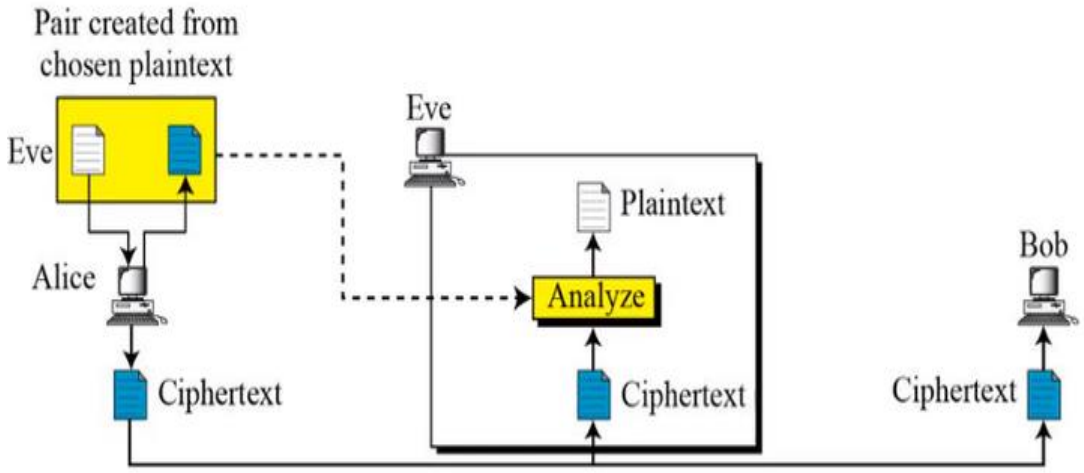
- Eve has access to some plaintext/ciphertext pairs in addition to the intercepted ciphertext that he/she wants to break.
- Plaintext/Ciphertext pairs have been collected earlier.



Introduction -Symmetric Key ciphers

Cryptanalysis -Chosen-Plaintext Attack

- Eve has access to Alice computer
- Cryptanalyst chose some plaintext and intercept the created ciphertext.
- Observing the Plaintext/ciphertext gives Eve a strong foothold into the inner workings of the algorithm and secret key.



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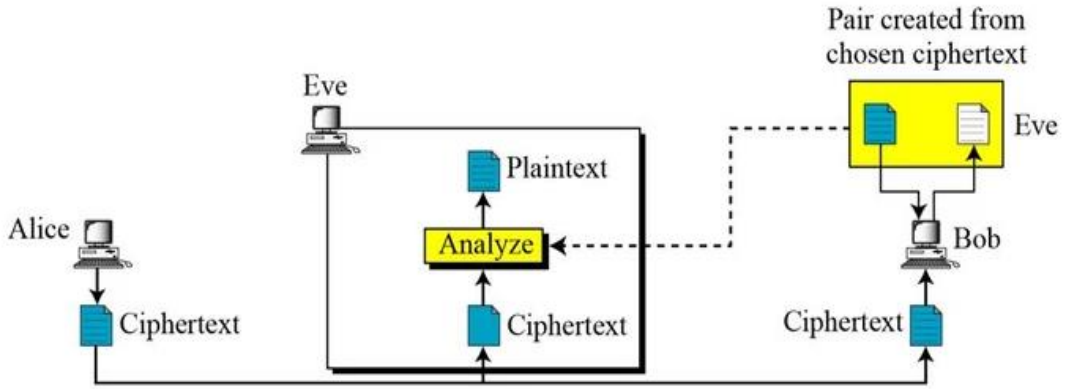
Introduction -Symmetric Key ciphers

Cryptanalysis -Chosen-Ciphertext Attack

- Eve has access to Bob computer
- Cryptanalyst chose some ciphertext and decrypts to form the pair plaintext/ciphertext.
- Cryptanalyst is not necessarily trying to find the plaintext, but rather they are trying to decipher the algorithm and secret key used to encrypt the plaintext. .



Introduction -Symmetric Key ciphers

Type of Attack	Known to cryptanalyst
Ciphertext Only	★ Encryption Algorithm ★ Ciphertext
Known Plaintext	★ Encryption Algorithm ★ Ciphertext ★ One or more PT-CT pairs formed with secret key
Chosen Plaintext	★ Encryption Algorithm ★ Ciphertext ★ PT message chosen by cryptanalyst, together with its CT generated with the secret key
Chosen Ciphertext	★ Encryption Algorithm ★ Ciphertext ★ CT chosen by cryptanalyst, together with its corresponding decrypted PT generated with the secret key

Substitution Ciphers

A substitution cipher replaces one symbol with another.

If the symbols in the plaint text are alphabetic characters, replaces one character with another.

Substitution ciphers can be categorized as either

a. Monoalphabetic ciphers
b. Polyalphabetic ciphers

Substitution Ciphers

Monoalphabetic ciphers

a. Additive cipher(Shift cipher/Ceasar cipher)
b. Multiplicative ciphers
c. Affine cipher

Substitution Ciphers

Monoalphabetic ciphers

A Character in the plaint text is changed to some character in the ciphertext regardless of its position in the plaintext

The relationship between a symbol in the plaintext to a symbol in the ciphertext is always one-to-one.

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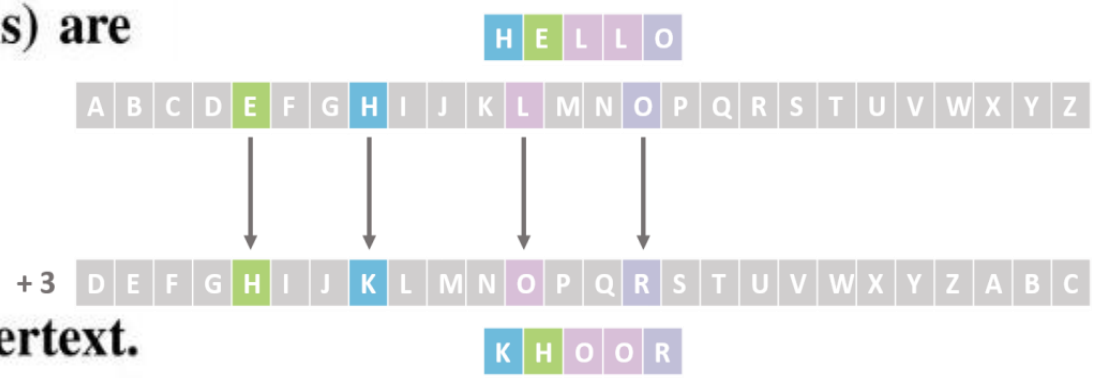
Substitution Ciphers

Monoalphabetic ciphers

The following shows a plaintext and its corresponding ciphertext. The cipher is probably monoalphabetic because both *l*'s (els) are encrypted as *O*'s.

Plaintext: hello **Ciphertext:** KHOOR



The following shows a plaintext and its corresponding ciphertext. The cipher is not monoalphabetic because each *l* (el) is encrypted by a different character.

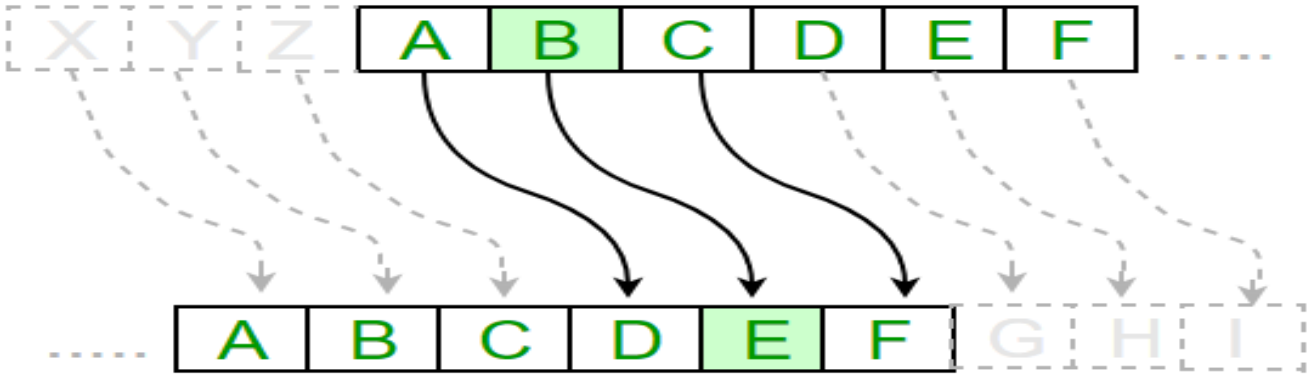
Plaintext: hello **Ciphertext:** JKQNZ

Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

Shift Cipher

A **shift cipher** involves replacing each letter in the message by a letter that is some fixed number of positions further along in the alphabet.



Substitution Ciphers

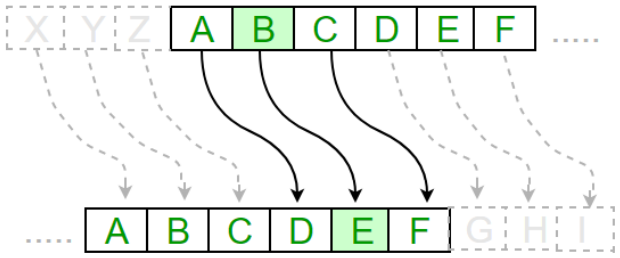
Monoalphabetic ciphers – Additive cipher

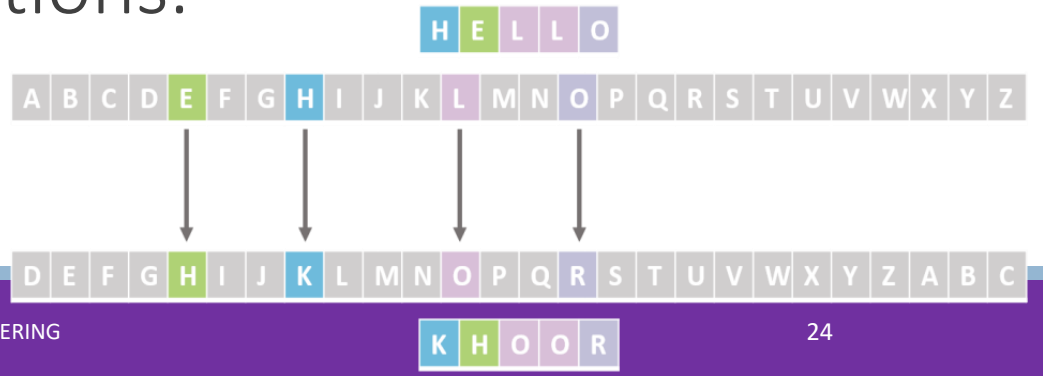
Caesar Cipher

Caesar used an additive cipher to communicate with his officers.

For this reason, additive ciphers are sometimes referred to as the Caesar cipher.

Caesar used a key of 3 for his communications.





Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

- It's a type of substitution cipher where each letter in the plaintext is shifted by a certain number of positions in the alphabet to produce the ciphertext.
- The additive cipher was famously used by Julius Caesar to communicate securely with his generals by shifting letters in the Roman alphabet.
- This use of the cipher was one of the earliest recorded applications of encryption for military communication.
- This cipher is commonly used in simple **puzzles** and **treasure hunts** where clues are encrypted. Players can decrypt the message by figuring out the shift used.

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Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

The simplest monoalphabetic cipher is the additive cipher.

This cipher is sometimes called a shift cipher/Caesar cipher, but the term additive cipher better reveals its mathematical nature.

To apply mathematical operations on PT/CT, assign numerical values to each letter

Each character is assigned an integer in Z_{26}

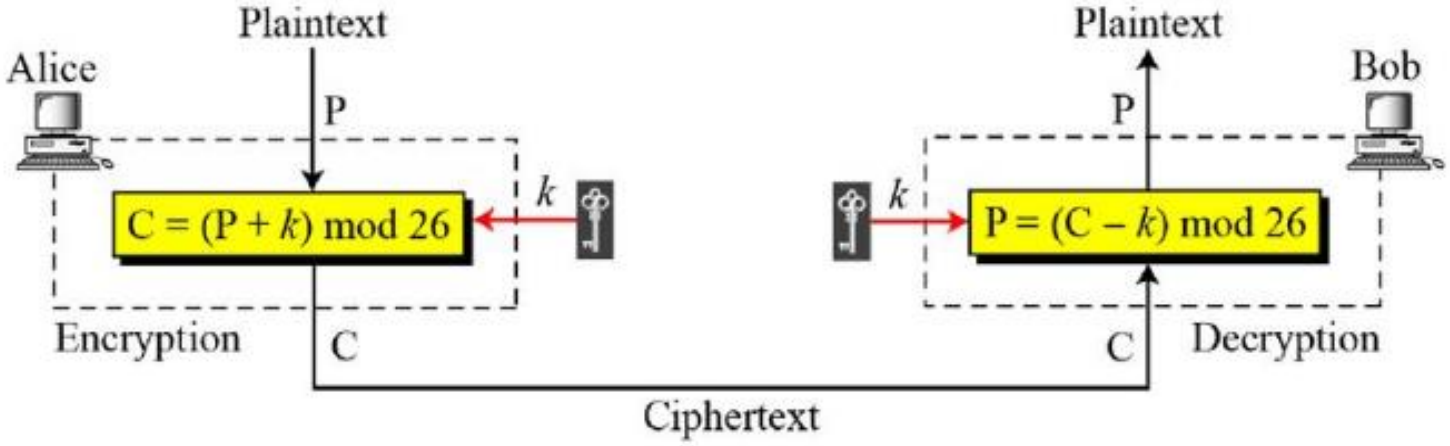
Plaintext and ciphertext in Z_{26}

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25



When the cipher is additive, the plaintext, ciphertext, and key are integers in Z_{26}.

41 mod 5

1)Divide the number by the modulus

41/5 =8.2

2)Remove the integer part of the answer

0.2

3) Multiply by the modulus

0.2∗5

=1

12345 % 100

1)Divide the number by the modulus

12345/100 =123.45

2)Remove the integer part of the answer

0.45

3) Multiply by the modulus

0.45∗100

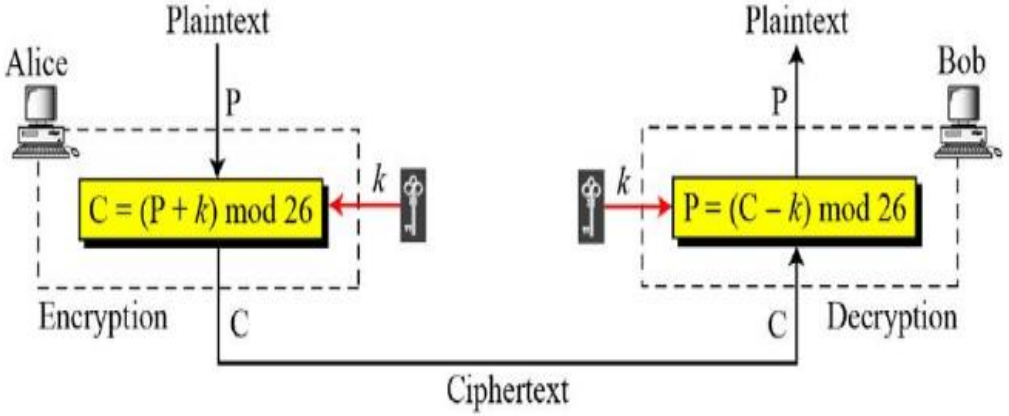
=45

Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Use the additive cipher with key = 15 to encrypt the message "hello".



Substitution Ciphers

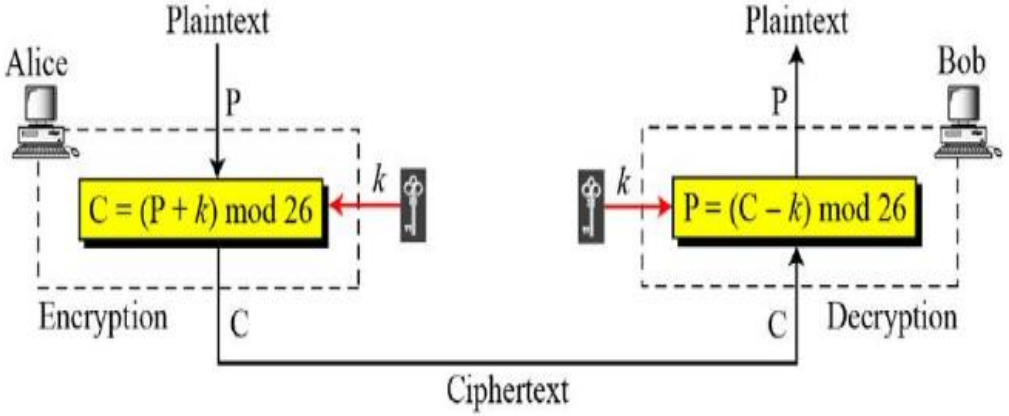
Monoalphabetic ciphers – Additive cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Solution

We apply the encryption algorithm to the plaintext, character by character:

Plaintext: h → 07	Encryption: (07 + 15) mod 26	Ciphertext: 22 → W



Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

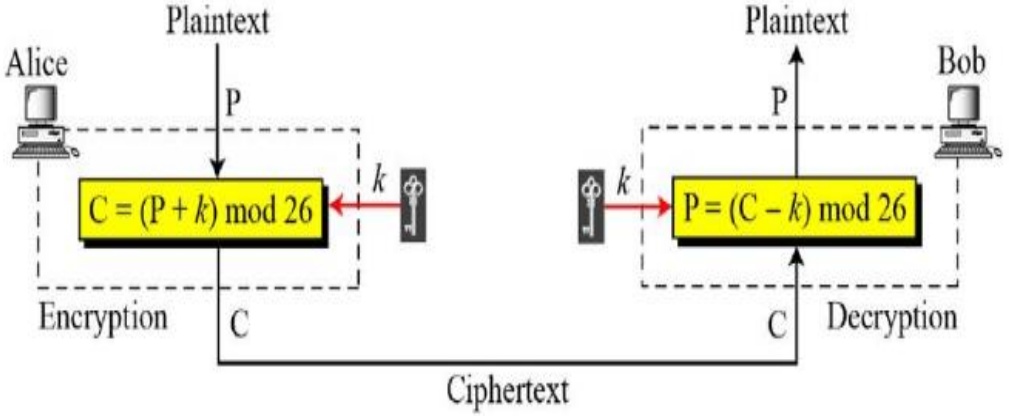
Plaintext →	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
Ciphertext →	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Use the additive cipher with key = 15 to encrypt the message "hello".

Solution

We apply the encryption algorithm to the plaintext, character by character:

Plaintext: h → 07	Encryption: (07 + 15) mod 26	Ciphertext: 22 → W
Plaintext: e → 04	Encryption: (04 + 15) mod 26	Ciphertext: 19 → T
Plaintext: l → 11	Encryption: (11 + 15) mod 26	Ciphertext: 00 → A
Plaintext: l → 11	Encryption: (11 + 15) mod 26	Ciphertext: 00 → A
Plaintext: o → 14	Encryption: (14 + 15) mod 26	Ciphertext: 03 → D



Substitution Ciphers

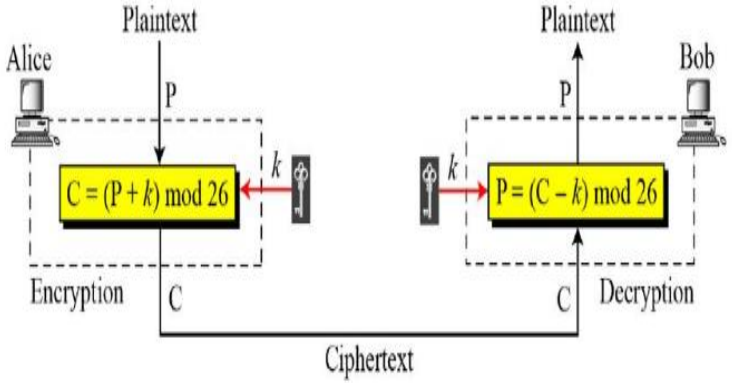
Monoalphabetic ciphers – Additive cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Solution

We apply the decryption algorithm to the plaintext character by character:

Ciphertext: W → 22 Decryption: (22 – 15) mod 26 Plaintext: 07 → h



Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

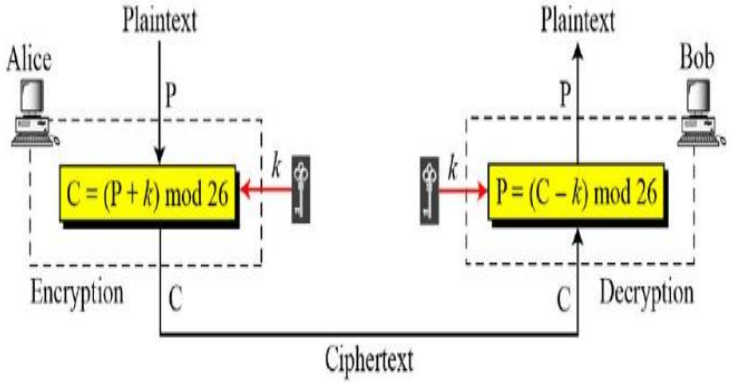
Solution

We apply the decryption algorithm to the plaintext character by character:

Ciphertext: W → 22 Decryption: (22 – 15) mod 26 Plaintext: 07 → h

Ciphertext: A → 00 Decryption: (00 – 15) mod 26 Plaintext: 11 → l

-15 MOD 26
-15 +26 =11



Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

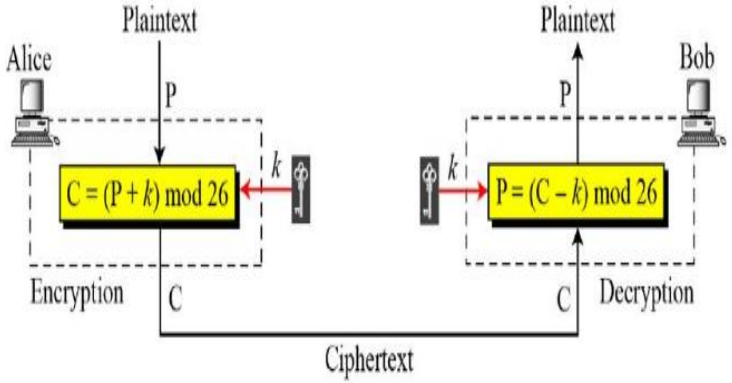
Plaintext →	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
Ciphertext →	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Use the additive cipher with key = 15 to decrypt the message "WTAAD".

Solution

We apply the decryption algorithm to the plaintext character by character:

Ciphertext: W → 22	Decryption: (22 – 15) mod 26	Plaintext: 07 → h
Ciphertext: T → 19	Decryption: (19 – 15) mod 26	Plaintext: 04 → e
Ciphertext: A → 00	Decryption: (00 – 15) mod 26	Plaintext: 11 → l
Ciphertext: A → 00	Decryption: (00 – 15) mod 26	-15+26 = Plaintext: 11 → l
Ciphertext: D → 03	Decryption: (03 – 15) mod 26	Plaintext: 14 → o

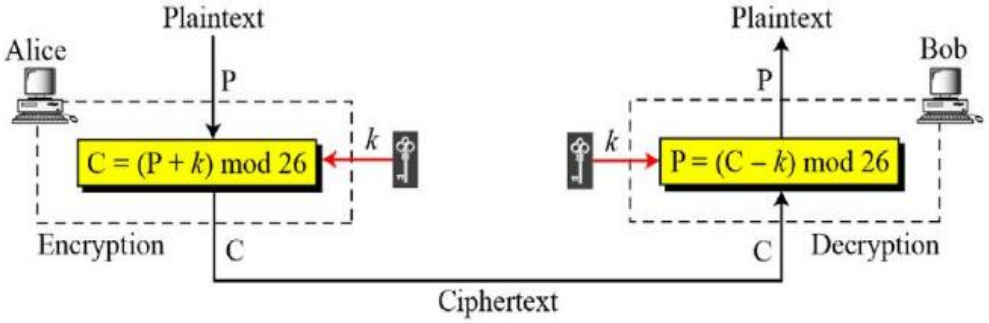


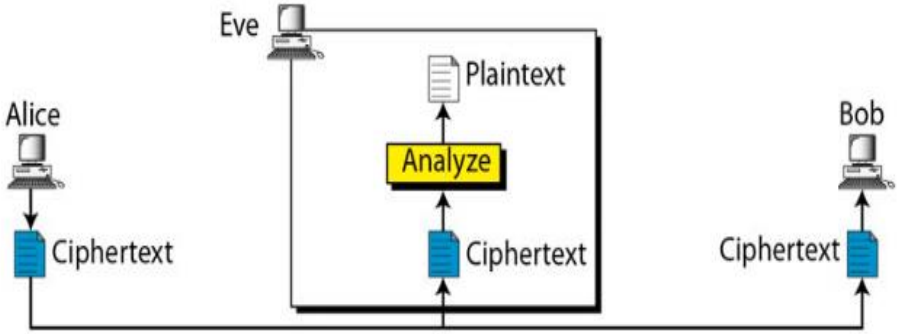
Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

Cryptanalysis -Vulnerable to cipher-text only attack (Brute force attack)

Eve has intercepted the ciphertext "UVACLYFZLJBYL". Show how she can use a brute-force attack to break the cipher.

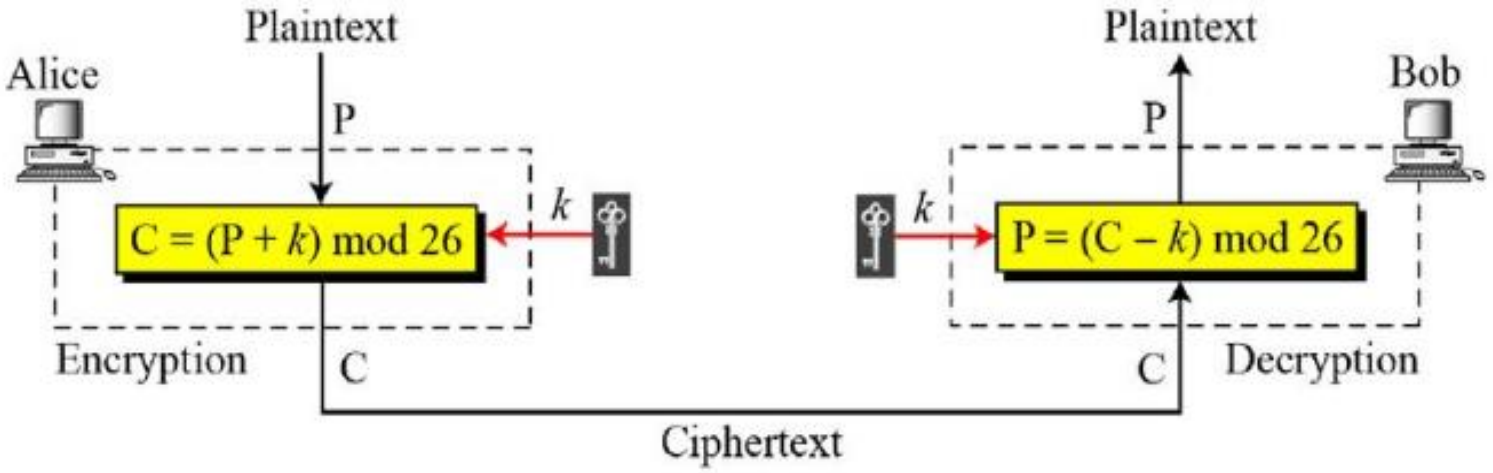




Plaintext →	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
Ciphertext →	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Ciphertext: UVACLYFZLJBYL

K = 1 → Plaintext: tuzbkxeykiaxk



U = 20-1 mod 26 = 19 mod 26 = 19 = t
V = 21 -1 mod 26 = 20 mod 26 = 20 = u
A
C
L

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Eve has intercepted the ciphertext "UVACLYFZLJBYL". Show how she can use a brute-force attack to break the cipher.

Solution

Eve tries keys from 1 to 7. With a key of 7, the plaintext is "not very secure", which makes sense.

Ciphertext: UVACLYFZLJBYL

K = 1 → **Plaintext:** tuzbkxeykiaxk
K = 2 → **Plaintext:** styajwdxjhzwj
K = 3 → **Plaintext:** rsxzivcwigyvi
K = 4 → **Plaintext:** qrwyhubvhfxuh
K = 5 → **Plaintext:** pqvxgtaugewtg
K = 6 → **Plaintext:** opuwfsztfdvsf
K = 7 → **Plaintext:** notverysecure

Substitution Ciphers

Monoalphabetic ciphers – Additive cipher

Cryptanalysis

- Vulnerable to cipher-text only attack (Statistical attack)

Frequency of characters in English

Letter	*Frequency*	*Letter*	*Frequency*	*Letter*	*Frequency*	*Letter*	*Frequency*
E	12.7	H	6.1	W	2.3	K	0.08
T	9.1	R	6.0	F	2.2	J	0.02
A	8.2	D	4.3	G	2.0	Q	0.01
O	7.5	L	4.0	Y	2.0	X	0.01
I	7.0	C	2.8	P	1.9	Z	0.01
N	6.7	U	2.8	B	1.5		
S	6.3	M	2.4	V	1.0		

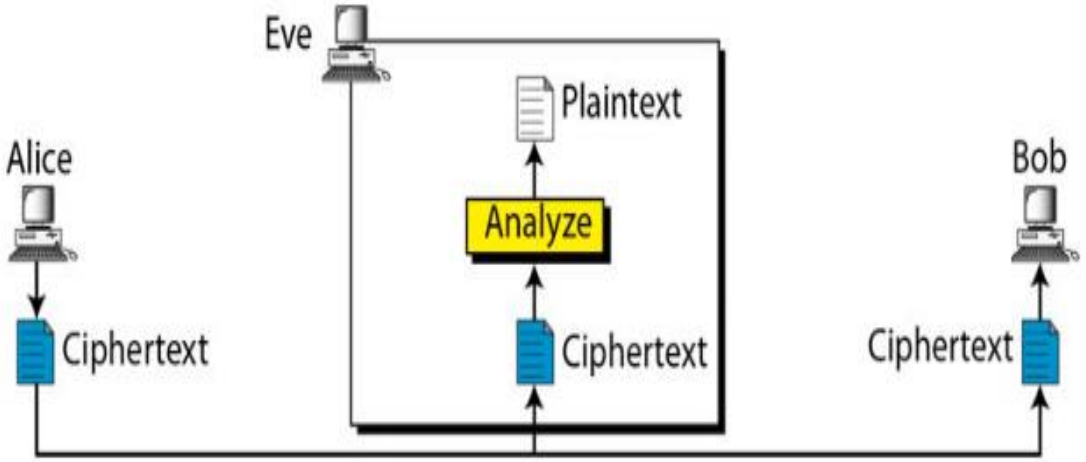
Frequency of diagrams and trigrams

Digram	TH, HE, IN, ER, AN, RE, ED, ON, ES, ST, EN, AT, TO, NT, HA, ND, OU, EA, NG, AS, OR, TI, IS, ET, IT, AR, TE, SE, HI, OF
Trigram	THE, ING, AND, HER, ERE, ENT, THA, NTH, WAS, ETH, FOR, DTH

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Eve has intercepted the following ciphertext. Using a statistical attack, find the plaintext.

XLILSYWIMWRSAJSVWEPIJSVJSYVQMPPMSRHSPPEVWMXMWASVX-LQSVILY-
VVCFIJSVIXLIWIPPIVVIGIMZIWQSVISJJIVW



Eve tabulate the frequency of letter in this ciphertext

I= 14 occurrences

V= 13 occurrences

S =12 and so on

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Eve has intercepted the following ciphertext. Using a statistical attack, find the plaintext.

XLILSYWIMWRSAJSVWEPIJSVJSYVQMPPMSRHSPPEVWMXMWASVX-LQSVILY-
VVCFIJSVIXLIWIPPIVVIGIMZIWQSVISJJIVW

I = 14 occurrences
This shows that character I in the ciphertext probably corresponds to the character e in plaintext.
This means key = 4.

Letter	*Frequency*	*Letter*	*Frequency*	*Letter*	*Frequency*	*Letter*	*Frequency*
E	12.7	H	6.1	W	2.3	K	0.08
T	9.1	R	6.0	F	2.2	J	0.02
A	8.2	D	4.3	G	2.0	Q	0.01
O	7.5	L	4.0	Y	2.0	X	0.01
I	7.0	C	2.8	P	1.9	Z	0.01
N	6.7	U	2.8	B	1.5		
S	6.3	M	2.4	V	1.0		

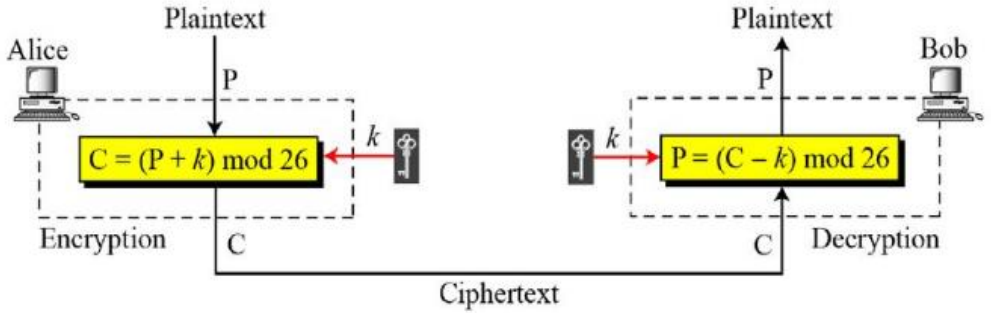
Plaintext →	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
Ciphertext →	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

XLILSYWIMWRSAJSVWEPIJSVJSYVQMPPMSRHSPPEVWMXMWASVX-LQSVILY-
VVCFIJSVIXLIWIPPIVVIGIMZIWQSVISJJIVW

X → 23 – 4 mod 26 → 19 mod 26 = 19 → T

L → 11 – 4 mod 26 → 7 mod 26 = 7 → H

I → 8 -4 mod 26 → 4 mod 26 = 4 → E



Substitution Ciphers

Solution

When Eve tabulates the frequency of letters in this ciphertext, she gets: I =14, V =13, S =12, and so on. The most common character is I with 14 occurrences. This shows that character I in the ciphertext probably corresponds to the character e in plaintext. This means key = 4. Eve deciphers the text to get

the house is now for sale for four million dollars it is worth more hurry before the seller receives more offers

21. Encrypt the message "this is an exercise" using one of the following ciphers. Ignore the space between words. Decrypt the message to get the original plaintext.

    a. Additive cipher with key = 20

Substitution Ciphers

Monoalphabetic ciphers

a. Additive cipher(Shift cipher/Ceasar cipher)
b. Multiplicative ciphers
c. Affine cipher

Substitution Ciphers

Monoalphabetic ciphers - Multiplicative ciphers

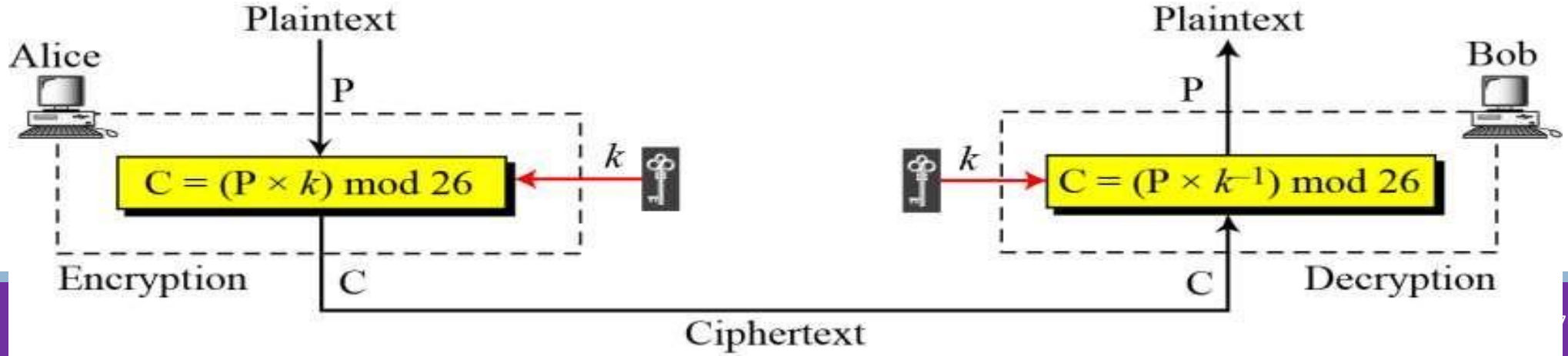
Multiplicative cipher is often used in **educational settings** to introduce more advanced encryption concepts, such as **modular arithmetic** and **inverses in modular systems**.

It’s a good stepping stone to understand more complex ciphers like the **Affine Cipher**, which combines both additive and multiplicative ciphers.

Substitution Ciphers

Monoalphabetic ciphers - Multiplicative ciphers

- The encryption algorithm specifies multiplication of PT with key
- The decryption algorithm specifies division of CT by key
- Since operations are in Z_{26} Decryption here means multiplying PT with multiplicative inverse of key



Substitution Ciphers

In Cryptography use

Z_n when additive inverse are needed

Z_n^* when multiplicative inverse are needed

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Substitution Ciphers

What is the key domain for any multiplicative inverse

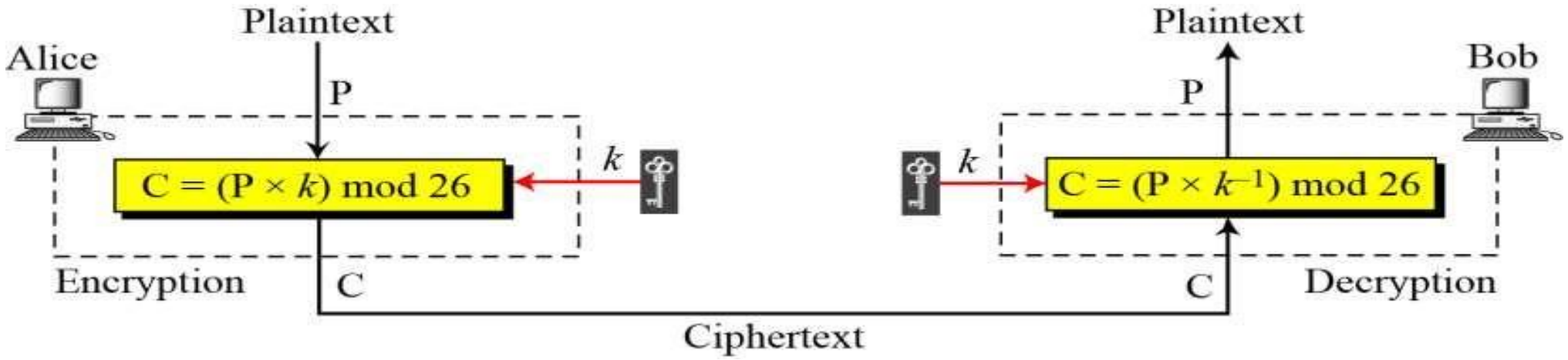
Key needs to be in Z_n^*

$Z_{26}^* = \{ 1,3,5,7,9,11,15,17,19,21,23,25\}$

Substitution Ciphers

Monoalphabetic ciphers - Multiplicative ciphers

Use multiplicative cipher to encrypt the message “hello” with a key of 7.



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Substitution Ciphers

Monoalphabetic ciphers - Multiplicative ciphers

Use multiplicative cipher to encrypt the message “hello” with a key of 7.

The ciphertext is “XCZZU”.

Plaintext: h $\rightarrow$ 07 Encryption: $(07 \times 07) \bmod 26$ ciphertext: $23 \rightarrow$ X

Substitution Ciphers

Monoalphabetic ciphers - Multiplicative ciphers

Use multiplicative cipher to encrypt the message “hello” with a key of 7.

The ciphertext is “XCZZU”.

Plaintext: h → 07	Encryption: (07 × 07) mod 26	ciphertext: 23 → X
Plaintext: e → 04	Encryption: (04 × 07) mod 26	ciphertext: 02 → C
Plaintext: l → 11	Encryption: (11 × 07) mod 26	ciphertext: 25 → Z
Plaintext: l → 11	Encryption: (11 × 07) mod 26	ciphertext: 25 → Z
Plaintext: o → 14	Encryption: (14 × 07) mod 26	ciphertext: 20 → U

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Substitution Ciphers

Monoalphabetic ciphers - Multiplicative ciphers

Encrypt the message “hello” with a key of 7.

Decipher the ciphertext is “XCZZU”

Key = 7 , so Find 7^{-1}

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Substitution Ciphers

Monoalphabetic ciphers - Multiplicative ciphers

Encrypt the message “hello” with a key of 7.

Decipher the ciphertext is “XCZZU”

Key = 7 , so Find 7^{-1}

7^{-1} mod 26 → 7 (?????) mod 26 = 1

= 15

X → 23 * 15 mod 26 = 7 → H
C → 2 * 15 mod 26 = 4 → E
Z
Z
U

(7 * x) / 26 = 1
the product of 7 and x
should leave a remainder of 1 when divided by 26.

Encrypt the message "this is an exercise" using one of the following ciphers. Ignore the space between words. Decrypt the message to get the original plaintext.

Multiplicative cipher with key = 15

$K^{-1} = 7$

Substitution Ciphers

Monoalphabetic ciphers

a. Additive cipher(Shift cipher/Ceasar cipher)
b. Multiplicative ciphers
c. Affine cipher

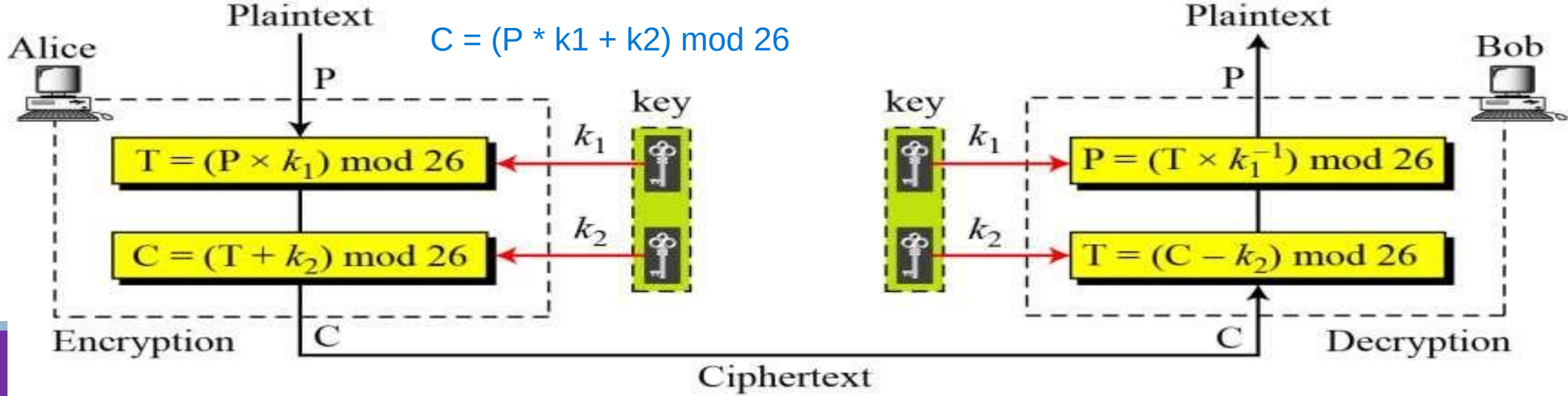
Substitution Ciphers

Monoalphabetic ciphers – Affine cipher

- Combination of both cipher with a pair of keys
- First key is used with multiplicative cipher
- Second key is used with additive cipher

C = (P * k1 + k2) mod 26

P =((C - k2) * k-1) mod 26



Substitution Ciphers

What is the key domain for any affine inverse

First key is Z_n^* and second key needs to be in Z_{26}

As we know that Z_{26}^* = { 1,3,5,7,9,11,15,17,19,21,23,25}

Size of key domain = 12 * 26 ➔ 312

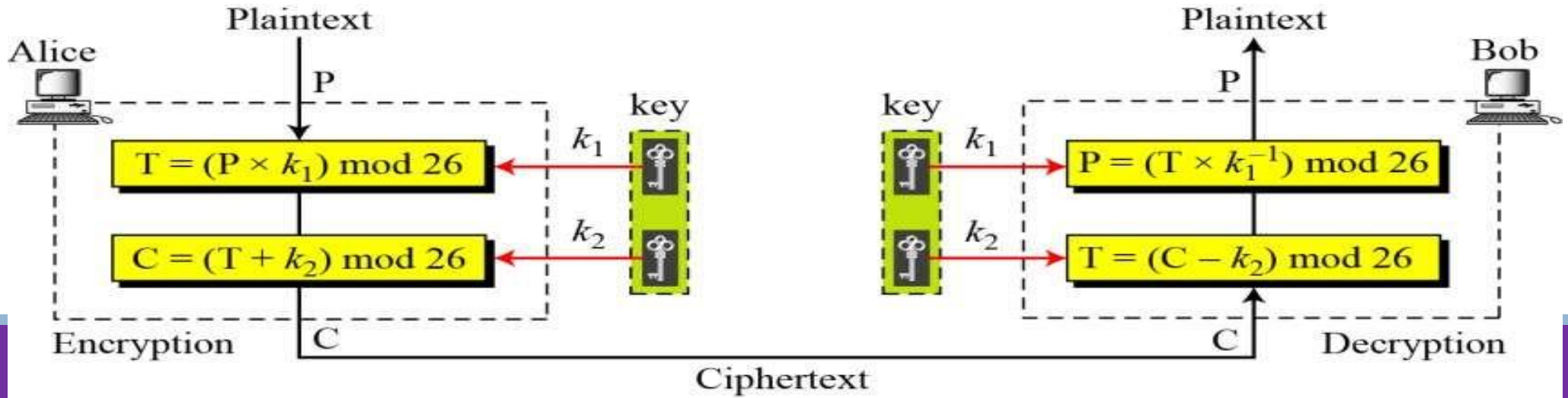
Substitution Ciphers

Use an affine cipher to encrypt the message “hello” with the key pair (7, 2).

P: h $\rightarrow$ 07

Encryption: $(07 \times 7 + 2) \bmod 26$

C: 25 $\rightarrow$ Z



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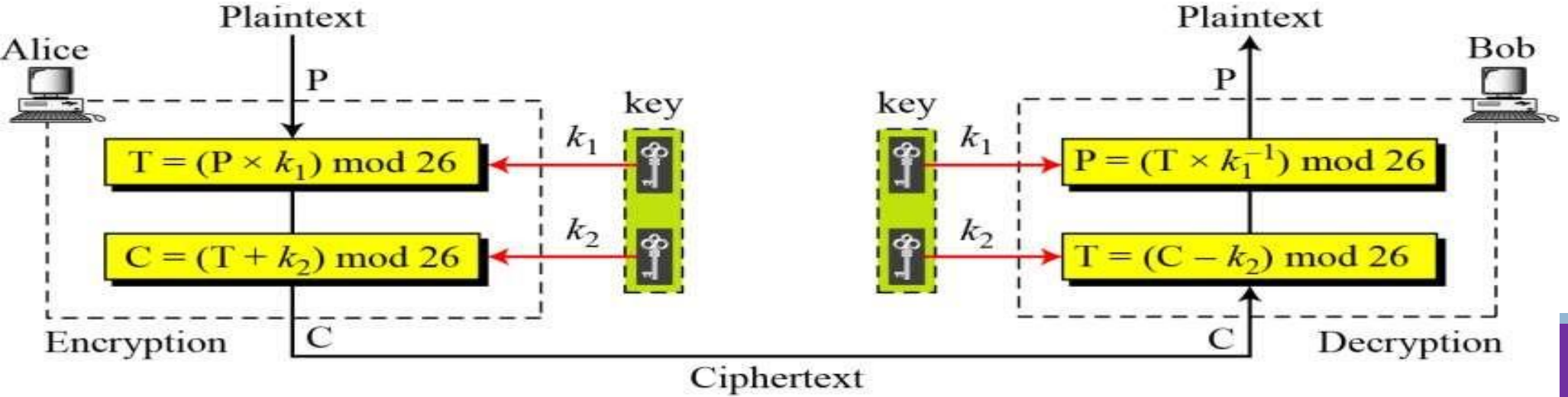
Substitution Ciphers

$C = (P * k1 + k2) \bmod 26$

Use an affine cipher to encrypt the message “hello” with the key pair (7, 2).

P: h → 07	Encryption: $(07 \times 7 + 2) \bmod 26$	C: 25 → Z
P: e → 04	Encryption: $(04 \times 7 + 2) \bmod 26$	C: 04 → E
P: l → 11	Encryption: $(11 \times 7 + 2) \bmod 26$	C: 01 → B
P: l → 11	Encryption: $(11 \times 7 + 2) \bmod 26$	C: 01 → B
P: o → 14	Encryption: $(14 \times 7 + 2) \bmod 26$	C: 22 → W



Cipher = ZEBBW

C = Z → 25

=((25 - 2) x 7^{-1}) mod 26

= (23 x 7^{-1}) mod 26

= (23 x 15) mod 26

= 345 mod 26

= 7

= H

C = E → 04

=((4 - 2) x 7^{-1}) mod 26

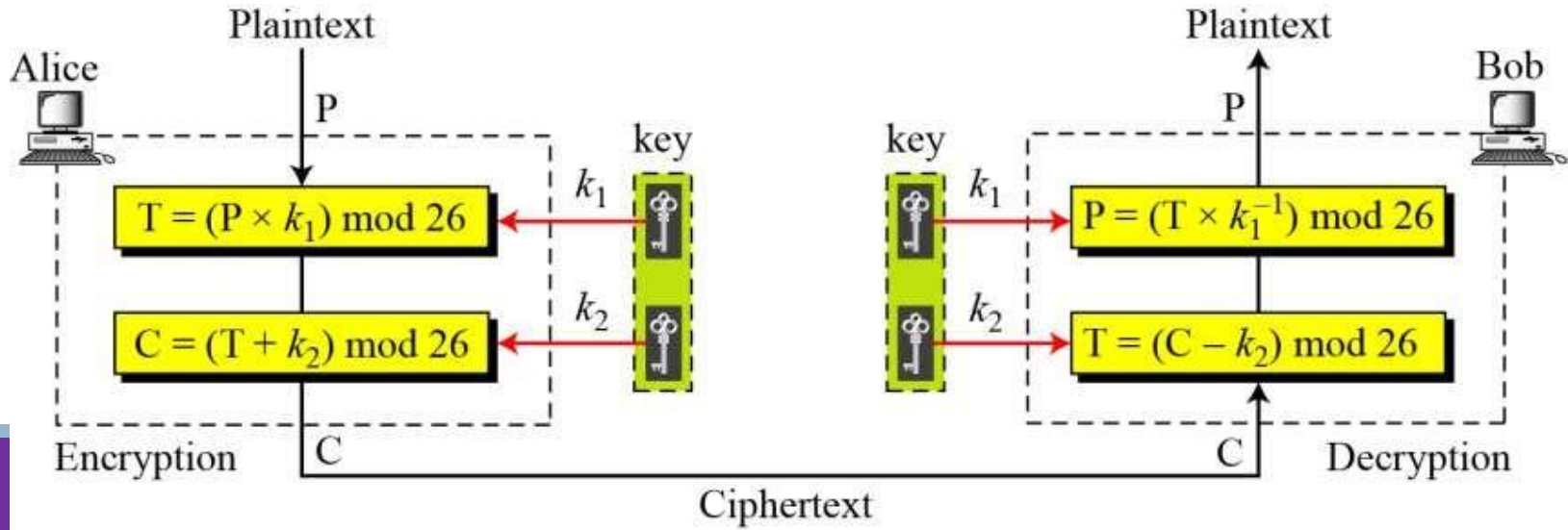
= (2 x 7^{-1}) mod 26

= (2 x 15) mod 26

= 30 mod 26

= 4

= E

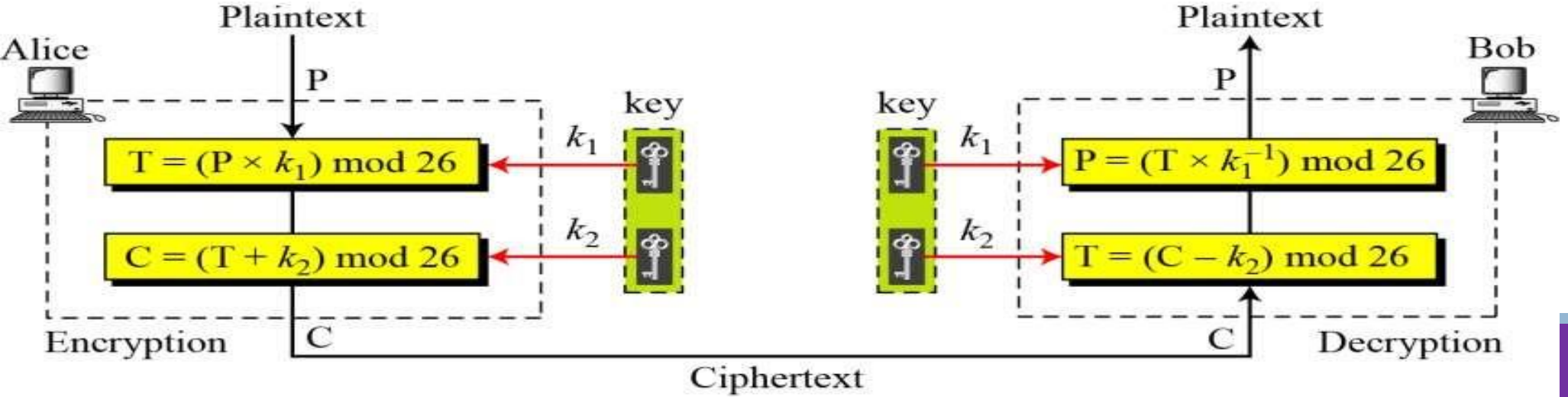


$$P = ((C - k2) * k^{-1}) \bmod 26$$

Substitution Ciphers

Use the affine cipher to decrypt the message "ZEBBW" with the key pair (7, 2) in modulus 26.

C: Z → 25	Decryption: $((25 - 2) \times 7^{-1}) \bmod 26$	P:07 → h
C: E → 04	Decryption: $((04 - 2) \times 7^{-1}) \bmod 26$	P:04 → e
C: B → 01	Decryption: $((01 - 2) \times 7^{-1}) \bmod 26$	P:11 → l
C: B → 01	Decryption: $((01 - 2) \times 7^{-1}) \bmod 26$	P:11 → l
C: W → 22	Decryption: $((22 - 2) \times 7^{-1}) \bmod 26$	P:14 → o



Use an Affine Cipher to encrypt the message “MSRIT” with the key pairs (7,2)

Using Affine cipher calculate the cipher text when the keys are given K1 -21 K2- 7 and the plain text is “CSEMSRIT”.

Encrypt the message "this is an exercise" using one of the following ciphers. Ignore the space between words. Decrypt the message to get the original plaintext.

Affine cipher with key = (15, 20)

29. Use a brute-force attack to decipher the following message. Assume that you know it is an affine cipher and that the plaintext "ab" is enciphered to "GL".

XPALASXYFGFUKPXUSOGEUTKCDGFXANMGNVS

Substitution Ciphers

In general, In additive cipher

- First key k1 is used with multiplicative cipher
- Second key k2 is used with additive cipher

The additive cipher is a special case of an affine cipher in which $k_1 = 1$.

The multiplicative cipher is a special case of affine cipher in which $k_2 = 0$.

Substitution Ciphers

Because additive, multiplicative, and affine ciphers have small key domains, they are very vulnerable to brute-force attack.

A better solution is to create a mapping between each plaintext character and the corresponding ciphertext character.

Alice and Bob can agree on a table showing the mapping for each character.

An example key for monoalphabetic substitution cipher

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

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Substitution Ciphers

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

We can use the key to encrypt the message

this message is easy to encrypt but hard to find the key

The ciphertext is

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Substitution Ciphers

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

We can use the key to encrypt the message

this message is easy to encrypt but hard to find the key

The ciphertext is

ICFVQRVVNEFVRNVSIYRGAHSLIOJICNHTIYBFGTICRXRS

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Polyalphabetic Ciphers

- In polyalphabetic substitution, each occurrence of a character may have a different substitute.
- The relationship between a character in the plaintext to a character in the ciphertext is one-to-many.

PT = WELCOME

CT = XGPHUTR

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

Substitution Ciphers

Polyalphabetic ciphers

a. Autokey cipher
b. Playfair cipher
c. Vigener cipher
d. Hill cipher
e. One time pad
f. Rotor cipher

Polyalphabetic Ciphers

Autokey cipher

- In this cipher, key is a stream of subkeys, in which each subkey is used to encrypt the corresponding character in the plaintext.

- The first subkey is predetermined secret value agreed between Sender and receiver

$$P = P_1P_2P_3 \ldots \qquad C = C_1C_2C_3 \ldots \qquad k = (k_1, P_1, P_2, \ldots)$$

Encryption: $C_i = (P_i + k_i) \bmod 26$ Decryption: $P_i = (C_i - k_i) \bmod 26$

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Assume that Alice and Bob agreed to use an autokey cipher with initial key value k1 = 12.

Now Alice wants to send Bob the message "Attack is today".

Enciphering is done character by character.

Plaintext:	a	t	t	a	c	k	i	s	t	o	d	a	y
P's Values:	00	19	19	00	02	10	08	18	19	14	03	00	24
Key stream:	12	00	19										
C's Values:	12	19	12										
Ciphertext:	**M**	**T**	**M**										

C = (P+K) mod 26
= 0 + 12 mod 26
= 12 mod 26
= 12
= M

C = (P+K) mod 26
= 19 + 0 mod 26
= 19 mod 26
= 19
= T

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Assume that Alice and Bob agreed to use an autokey cipher with initial key value k1 = 12.

Now Alice wants to send Bob the message "Attack is today". Enciphering is done character by character.

Plaintext:	a	t	t	a	c	k	i	s	t	o	d	a	y
P's Values:	00	19	19	00	02	10	08	18	19	14	03	00	24
Key stream:	*12*	*00*	*19*	*19*	*00*	*02*	*10*	*08*	*18*	*19*	*14*	*03*	*00*
C's Values:	12	19	12	19	02	12	18	00	11	7	17	03	24
Ciphertext:	**M**	**T**	**M**	**T**	**C**	**M**	**S**	**A**	**L**	**H**	**R**	**D**	**Y**

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Plaintext:	a	t	t	a	c	k	i	s	t	o	d	a	y
P's Values:	00	19	19	00	02	10	08	18	19	14	03	00	2
Key stream:	*12*	*00*	*19*										
C's Values:	12	19	12										
Ciphertext:	**M**	**T**	**M**										

Decryption: $P_i = (C_i - k_i) \bmod 26$

P = (C- K) mod 26
= 12 - 12 mod 26
= 0 mod 26
= 0
= A

P = (C - K) mod 26
= 19 - 0 mod 26
= 19 mod 26
= 19
= T

P = (C - K) mod 26
= 12 - 19 mod 26
= -7 mod 26
= -7 + 26 = 19
= T

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Plaintext:	a	t	t	a	c	k	i	s	t	o	d	a	y
P's Values:	00	19	19	00	02	10	08	18	19	14	03	00	24
Key stream:	*12*	*00*	*19*	*19*	*00*	*02*	*10*	*08*	*18*	*19*	*14*	*03*	*00*
C's Values:	12	19	12	19	02	12	18	00	11	7	17	03	24
Ciphertext:	**M**	**T**	**M**	**T**	**C**	**M**	**S**	**A**	**L**	**H**	**R**	**D**	**Y**

Decryption: $P_i = (C_i - k_i) \bmod 26$

P = (C- K) mod 26
= 12 - 12 mod 26
= 0 mod 26
= 0
= A

P = (C - K) mod 26
= 19 - 0 mod 26
= 19 mod 26
= 19
= T

P = (C - K) mod 26
= 12 - 19 mod 26
= -7 mod 26
= -7 + 26
= 19
= T

22. Encrypt the message "the house is being sold tonight" using one of the following ciphers. Ignore the space between words. Decrypt the message to get the plaintext:

Autokey cipher with key = 7

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Polyalphabetic Ciphers

Playfair cipher

- The best-known digraph substitution cipher, invented in 1854 by Charles Wheatstone but was named after Lord Playfair who promoted the use of the cipher.
- Used by British army during World war I.
- Secret key is made up of 25 characters arranged in 5*5 matrix (I and J are considered same)

Secret Key =

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

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Polyalphabetic Ciphers

The Playfair Cipher Encryption Algorithm:

1.Generate the key Square(5×5):

The key square is a 5×5 grid of alphabets that acts as the key for encrypting the plaintext.

The initial alphabets in the key square are the unique alphabets of the key in the order in which they appear followed by the remaining letters of the alphabet in order.

keyword = **ATHENS**

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

Polyalphabetic Ciphers

The Playfair Cipher Encryption Algorithm:

Before encryption:

- Divide the plaint text into digraphs
- If two letters in a pair are the same, a bogus letter is inserted to separate them
- if number of character is odd, one extra bogus character is added at the end to make number of characters even

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Polyalphabetic Ciphers

- Divide the plaint text into digraphs

PT = attack

Digrams → at ta ck

Polyalphabetic Ciphers

If two letters in a pair are the same, a bogus letter is inserted to separate them

PT = balloon

Digrams → ba ll oo n → ba lx lo on

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Polyalphabetic Ciphers

If number of character is odd, one extra bogus character is added at the end to make number of characters even

PT = msit academy

Digrams → ms it ac ad em yx

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Polyalphabetic Ciphers

The Playfair Cipher Encryption Algorithm:

2.Encrypt the Plaintext → Three cipher rules

a) If the two letters in a pair are located in the same row of the secret key, the corresponding encrypted character for each character is the next letter to the right in the same row(wrap to beginning of row)

b) If the two letters in a pair are located in the same column of the secret key, the corresponding encrypted character for each character is the letter beneath in the same column(wrap to beginning of column)

c) If the two letter in a pair are not in the same row or column of the secret, the corresponding encrypted character for each letter is a letter that is in its own row but in the same column as the other letter. (Form a rectangle)

Polyalphabetic Ciphers

Encrypt the plaintext “HELLO” using the key shown

PT = HELLO

Digraphs = HELLO

HE LX LO

EC QZ BX

Secret Key =

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

he → EC lx → QZ lo → BX

Plaintext: hello Ciphertext: ECQZBX

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Polyalphabetic Ciphers

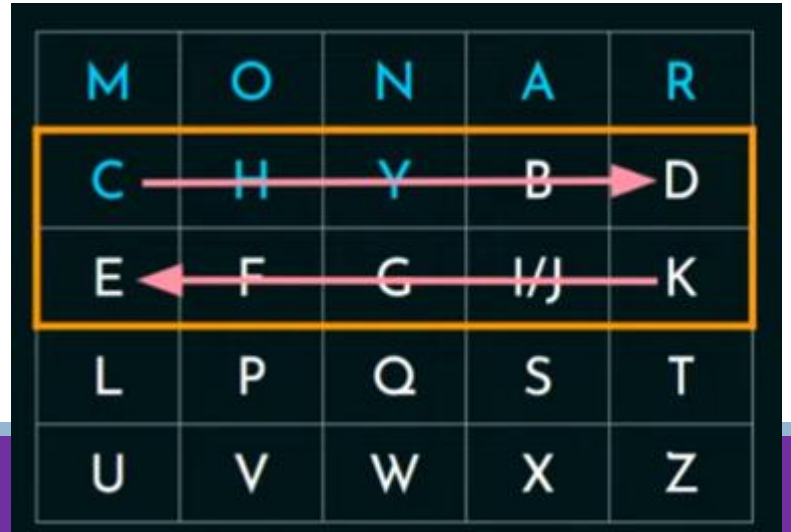
Example 1: attack

Digrams: at ta ck

at	ta	ck
RS	SR	DE

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

1. Digrams.
2. Repeating Letters - Filler letter.
3. Same Column | ↓ | Wrap around
4. Same row | → | Wrap around.
5. Rectangle | ⇆ | Swap



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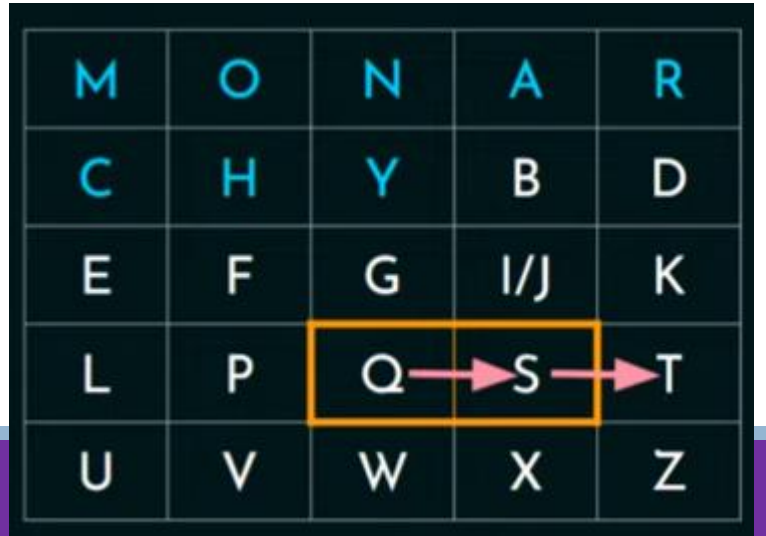
Polyalphabetic Ciphers

Example 2: mosque

mo	sq	ue
ON	TS	ML

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

1. Digrams.
2. Repeating Letters - Filler letter.
3. Same Column | ↓ | Wrap around
4. Same row | → | Wrap around.
5. Rectangle | ⇆ | Swap



3.10 a. Construct a Playfair matrix with the key *algorithm*.

b. Construct a Playfair matrix with the key *cryptography*. Make a reasonable assumption about how to treat redundant letters in the key.

3.11 a. Using this Playfair matrix:

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

Encrypt this message:

I only regret that I have but one life to give for my country.

22. Encrypt the message "the house is being sold tonight" using one of the following ciphers. Ignore the space between words. Decrypt the message to get the plaintext:

c. Playfair cipher with the key created in the text (see Figure 3.13)

Figure 3.13 *An example of a secret key in the Playfair cipher*

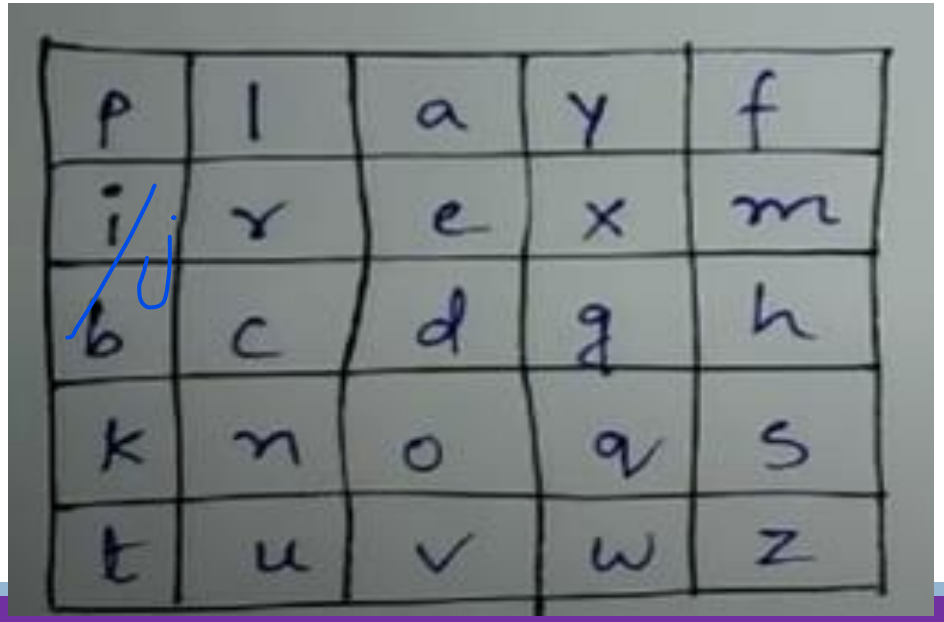
Secret Key =

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

24. Use the Playfair cipher to encipher the message "The key is hidden under the door pad". The secret key can be made by filling the first and part of the second row with the word "GUIDANCE" and filling the rest of the matrix with the rest of the alphabet.

Polyalphabetic Ciphers

Encrypt the
plaintext "**HIDE THE GOAL IN THE TREE STUMP**" using the key = PLAYFAIR EXAMPLE



Polyalphabetic Ciphers

Encrypt the
plaintext "**HIDE THE GOAL IN THE TREE STUMP**" using the key = PLAYFAIR EXAMPLE

Vigenere Cipher

- Designed by Blaise de Vigenere, mathematician
- Vigenere cipher uses a different strategy to create the key stream .
- Keystream is a repetition of an initial secret key stream of length m, where 1 ≤ m ≤ 26.
- Suppose Alice and Bob agree k= (k1,k2,k3…….km)

$$P = P_1P_2P_3 \ldots \qquad C = C_1C_2C_3 \ldots \qquad K = [(k_1, k_2, \ldots, k_m), (k_1, k_2, \ldots, k_m), \ldots]$$

$$\text{Encryption: } C_i = P_i + k_i \qquad \text{Decryption: } P_i = C_i - k_i$$

Encrypt the message “She is listening” using the 6-character keyword “PASCAL”.

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

"She is listening" using the 6-character keyword "PASCAL".

The initial key stream is (15, 0, 18, 2, 0, 11). The key stream is the repetition of this initial key stream (as many times as needed).

Plaintext:	s	h	e	i	s	l	i	s	t	e	n	i	n	g
P's values:	18	07	04	08	18	11	08	18	19	04	13	08	13	06
Key stream:	***15***	***00***	***18***	***02***	***00***	***11***								
C's values:	**07**	**07**	**22**	**10**	**18**	**22**								
Ciphertext:	**H**	**H**	**W**	**K**	**S**	**W**								

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

"She is listening" using the 6-character keyword "PASCAL".

The initial key stream is (15, 0, 18, 2, 0, 11). The key stream is the repetition of this initial key stream (as many times as needed).

Plaintext:	s	h	e	i	s	l	i	s	t	e	n	i	n	g
P's values:	18	07	04	08	18	11	08	18	19	04	13	08	13	06
Key stream:	***15***	***00***	***18***	***02***	***00***	***11***	***15***	***00***	***18***	***02***	***00***	***11***	***15***	***00***
C's values:	**07**	**07**	**22**	**10**	**18**	**22**	**23**	**18**	**11**	**6**	**13**	**19**	**02**	**06**
Ciphertext:	**H**	**H**	**W**	**K**	**S**	**W**	**X**	**S**	**L**	**G**	**N**	**T**	**C**	**G**

22. Encrypt the message "the house is being sold tonight" using one of the following ciphers. Ignore the space between words. Decrypt the message to get the plaintext:
    a. Vigenere cipher with key: "dollars"
    b. Autokey cipher with key = 7

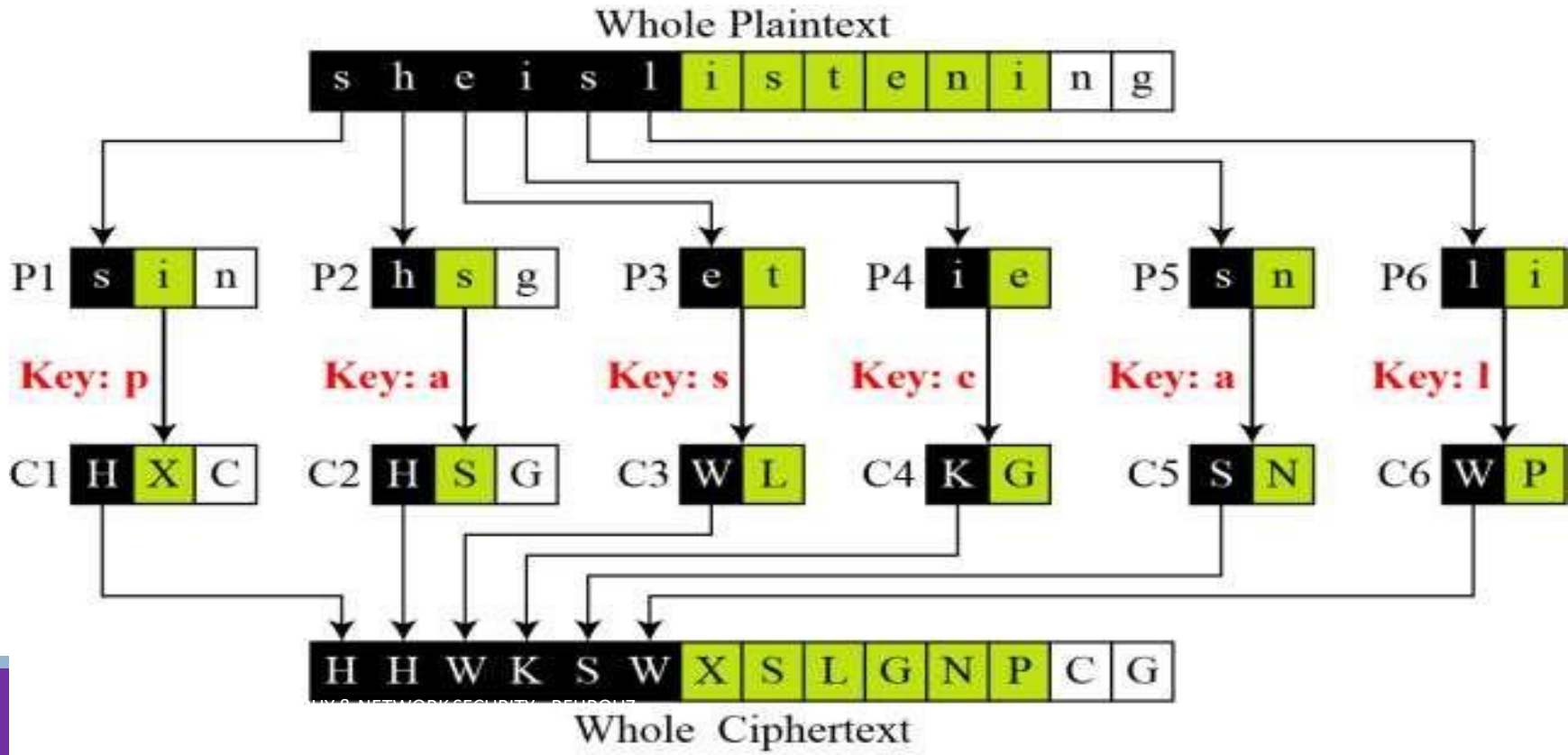
23. Use the Vigenere cipher with keyword "HEALTH" to encipher the message "Life is full of surprises".

Vigenere cipher can be seen as combinations of m additive ciphers.

PT "She is listening"

Keyword "PASCAL".

A Vigenere cipher as a combination of m additive ciphers



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We can say that the additive cipher is a special case of Vigenere cipher in which m = 1.

A Vigenere Tableau

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	v	v	w	x	y	z
A	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
B	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	A
C	C	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
D	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
E	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	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	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

Cryptanalysis of Vigenere Ciphers

Eve can use technique to decipher the intercepted cipher text.

The cryptanalysis consist of :

- Finding the length of key
- Finding the key

Cryptanalysis of Vigenere Ciphers

Several methods to find the length of key

- Kasiski test

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Vigenere Cipher (Crypanalysis)

The Kasiski test for repetition of three-character segments

Let us assume eve intercepted the following ciphertext:

```
LIOMWGFEGGDVWGHHCQUCRHRWAGWIOWQLKGZETKKMEVLWPCZVGTH-
VTSGXQOVGCSVETQLTJSUMVWVEUVLXEWSLGFZMVVWLGYHCUSWXQH-
KVGSHEEVFLCFDGVSUMPHKIRZDMPHHBVWVWJWIXGFWLTSHGJOUEEHH-
VUCFVGOWICQLTJSUXGLW
```

```
LIOMWGFEGGDVWGHHCQUCRHRWAGWIOWQLKGZETKKMEVLWPCZVGTH-
VTSGXQOVGCSVETQLTJSUMVWVEUVLXEWSLGFZMVVWLGYHCUSWXQH-
KVGSHEEVFLCFDGVSUMPHKIRZDMPHHBVWVWJWIXGFWLTSHGJOUEEHH-
VUCFVGOWICQLTJSUXGLW
```

Vigenere Cipher (Crypanalysis)

The Kasiski test for repetition of three-character segments yields the results shown in Table

LIOMWGFEGGDVWGHHCQUCRHRWAGWIOWQLKGZETKKMEVLWPCZVGTH-
VTSGXQOVGCSVETQLTJSUMVWVEUVLXEWSLGFZMVVWLGYHCUSWXQH-
KVGSHEEVFLCFDGVSUMPHKIRZDMPHHBVWVWJWIXGFWLTSHGJOUEEHH-
VUCFVGOWICQLTJSUXGLW

String	*First Index*	*Second Index*	*Difference*
JSU	68	168	100
SUM	69	117	48
VWV	72	132	60
MPH	119	127	8

Find Common Factors: The greatest common divisor (GCD) of the distances between the repeated sequences can suggest the possible length of the key.

One Time pad

- One of the goals of cryptography is perfect secrecy.
- A study by Shannon has shown that perfect secrecy can be achieved if each plaintext symbol is encrypted with a key randomly chosen from a key domain.
- This idea is used in a cipher called one-time pad, invented by Vernam.

One Time pad

- It is a method of encrypting alphabetic plain text.
- It is one of the Substitution techniques which converts plain text into ciphertext.
- In this mechanism, we assign a number to each character of the Plain-Text.

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

One Time pad

- The key must be the same size as the message being sent.
- The key must be truly random.
- Keys must be securely shared between the sending and receiving parties.

Because of these strict conditions, the use of one-time pad over digital media is impracticable

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One Time pad

- The relation between the key and plain text: In this algorithm, the length of the key should be equal to that of plain text.

- Encrypt the Plaintext = HELLO and Key = MONEY

- HELLO → 7 4 11 11 14
- MONEY→ 12 14 13 4 24

---

19 18 24 15 (38 – 26)

19 18 24 15 12 → **T S Y P M**

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

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One Time pad

CT= TSYPM → 19 18 24 15 12

KEY=MONEY → 12 14 3 4 24

---

7 4 11 11 -12 + 26

7 4 11 11 14

H E L L O

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

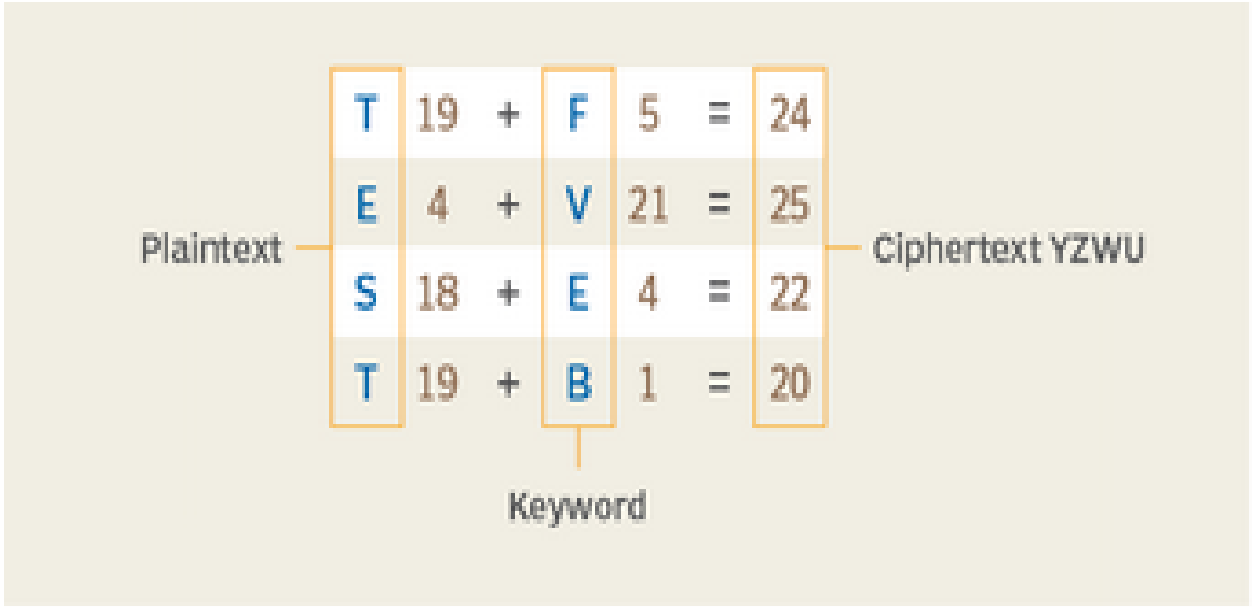
One Time pad

Plaintext = TEST

Key = FVEB

PT = ENIGMA

Key = KEYWOR



One Time pad

When a message is to be sent, the sender uses the secret key to encrypt each character one at a time.

If a computer is used, each bit in the character, which is usually eight bits in length is exclusively OR'ed with the corresponding bit in the secret key.

With a one-time pad, the encryption algorithm is simply the XOR operation.

One Time pad

A	B	A **XOR** B
0	0	0
0	1	1
1	0	1
1	1	0

ENCRYPT

```
  00110101  Plaintext
⊕ 11100011  Secret Key
----------
= 11010110  Ciphertext
```

DECRYPT

```
  11010110  Ciphertext
⊕ 11100011  Secret Key
----------
= 00110101  Plaintext
```

Hill Cipher

- The Hill Cipher was invented by Lester S. Hill in 1929
- It acts on groups of letters.
- It is a polygraphic substitution cipher, as it can work on digraphs, trigraphs (3 letter blocks) or theoretically any sized blocks.
- The Hill cipher belongs to a category of ciphers called block ciphers.

Hill Cipher

- Key is a square matrix of size m x m matrix in which m is the size of the block(2 x 2 matrix for digraphs, a 3 x 3 matrix for trigraphs).
  - We should be aware that not all square matrices have multiplicative inverses in Z26, so Alice and Bob should be careful in selecting the key.
  - Bob will not be able to decrypt the ciphertext sent by Alice if the matrix does not have a multiplicative inverse.

The key matrix in the Hill cipher needs to have a multiplicative inverse.

$$\mathrm{K} = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1m} \\ k_{21} & k_{22} & \cdots & k_{2m} \\ \vdots & \vdots & & \vdots \\ k_{\mathrm{m1}} & k_{\mathrm{m2}} & \cdots & k_{mm} \end{bmatrix}$$

Hill Cipher

Encryption

- Plaintext is divided into equal-size blocks.
- The blocks are encrypted one at a time in such a way that each character in the block contributes to the encryption of other characters in the block.
- How one block of the ciphertext is encrypted.

If we call the m characters in the plaintext block P1, P2, …, Pm,

the corresponding characters in the ciphertext block are C1, C2, …, Cm

$$\mathbf{K} = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1m} \\ k_{21} & k_{22} & \cdots & k_{2m} \\ \vdots & \vdots & & \vdots \\ k_{m1} & k_{m2} & \cdots & k_{mm} \end{bmatrix}$$

Then we have

$$\begin{aligned} C_1 &= P_1 k_{11} + P_2 k_{21} + \cdots + P_m k_{m1} \\ C_2 &= P_1 k_{12} + P_2 k_{22} + \cdots + P_m k_{m2} \\ &\cdots \\ C_m &= P_1 k_{1m} + P_2 k_{2m} + \cdots + P_m k_{mm} \end{aligned}$$

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Hill Cipher

Encryption

- Plaintext is divided into equal-size blocks.
- The blocks are encrypted one at a time in such a way that each character in the block contributes to the encryption of other characters in the block.
- How one block of the ciphertext is encrypted.

If we call the m characters in the plaintext block P1, P2, …, Pm,

the corresponding characters in the ciphertext block are C1, C2, …, Cm

$$\mathbf{K} = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1m} \\ k_{21} & k_{22} & \cdots & k_{2m} \\ \vdots & \vdots & & \vdots \\ k_{m1} & k_{m2} & \cdots & k_{mm} \end{bmatrix}$$

Then we have

$$\begin{aligned} C_1 &= P_1 k_{11} + P_2 k_{21} + \cdots + P_m k_{m1} \\ C_2 &= P_1 k_{12} + P_2 k_{22} + \cdots + P_m k_{m2} \\ &\cdots \\ C_m &= P_1 k_{1m} + P_2 k_{2m} + \cdots + P_m k_{mm} \end{aligned}$$

Hill Cipher

- **Encryption**

  Turn the plaintext into digraphs (or trigraphs) and each of these into a column vector.

  To encrypt a message, each block of n letters is multiplied by an $m \times m$ matrix, against modulus 26. $C = K*P \bmod 26$

- **Decryption**

  To decrypt the message, each block is multiplied by the inverse of the matrix

$P = K^{-1} * C \bmod 26$

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Encrypt the plaintext message "ACT"(n=3) using the keyword GYBNQKURP

Hill Cipher

Encrypt the plaintext message “ACT“(n=3) using the keyword GYBNQKURP

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

$$\begin{bmatrix} G & Y & B \\ N & Q & K \\ U & R & P \end{bmatrix} \rightarrow \begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 10 \\ 20 & 17 & 15 \end{bmatrix}$$

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

C = K*P mod 26

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 10 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 0 \\ 2 \\ 19 \end{bmatrix}$$

Mod 26

6*0 + 24 *2 + 1*19
13*0+16*2+10*19
20*0+17*2+15*19

$$\begin{bmatrix} 67 \\ 222 \\ 319 \end{bmatrix}$$

Mod 26 → $\begin{bmatrix} 15 \\ 14 \\ 7 \end{bmatrix}$ → P O H

Hill Cipher

Encrypt the plaintext message "short example" using the keyword hill with a 2 x 2 matrix.

Hill Cipher

- The first step is to turn the keyword hill into a matrix.
- hill → 7 8 11 11

$$\begin{pmatrix} H & I \\ L & L \end{pmatrix} \rightarrow \begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix}$$

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Hill Cipher

Split the plaintext into digraphs, and write these as column vectors.

short example → sh or te xa mp l e

18 7 14 17 19 4 23 0 12 15 11 4

$$\begin{pmatrix} s \\ h \end{pmatrix} \begin{pmatrix} o \\ r \end{pmatrix} \begin{pmatrix} t \\ e \end{pmatrix} \begin{pmatrix} x \\ a \end{pmatrix} \begin{pmatrix} m \\ p \end{pmatrix} \begin{pmatrix} l \\ e \end{pmatrix}$$

$$\begin{pmatrix} 18 \\ 7 \end{pmatrix} \begin{pmatrix} 14 \\ 17 \end{pmatrix} \begin{pmatrix} 19 \\ 4 \end{pmatrix} \begin{pmatrix} 23 \\ 0 \end{pmatrix} \begin{pmatrix} 12 \\ 15 \end{pmatrix} \begin{pmatrix} 11 \\ 4 \end{pmatrix}$$

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Encryption : Perform matrix multiplication, multiply the key matrix by each column vector in turn.

$$\begin{pmatrix}18\\7\end{pmatrix}\begin{pmatrix}14\\17\end{pmatrix}\begin{pmatrix}19\\4\end{pmatrix}\begin{pmatrix}23\\0\end{pmatrix}\begin{pmatrix}12\\15\end{pmatrix}\begin{pmatrix}11\\4\end{pmatrix} \qquad \text{Key} = \begin{pmatrix}7 & 8\\11 & 11\end{pmatrix}$$

C = K*P mod 26

$$= \begin{pmatrix}7 & 8\\11 & 11\end{pmatrix}\begin{pmatrix}18\\7\end{pmatrix} \bmod 26$$

$$= \quad 7\times 18 + 8\times 7 = 182$$

$$11\times 18 + 11\times 7 = 275$$

$$\begin{pmatrix}7 & 8\\11 & 11\end{pmatrix}\begin{pmatrix}18\\7\end{pmatrix} = \begin{pmatrix}182\\275\end{pmatrix}$$

$$= \begin{pmatrix}182\\275\end{pmatrix} \bmod 26$$

$$= \begin{pmatrix}0\\15\end{pmatrix} \quad = \begin{pmatrix}A\\P\end{pmatrix}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

C = K*P mod 26

$$\begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix} \begin{pmatrix} 14 \\ 17 \end{pmatrix} mod\ 26$$

$$7 \times 14 + 8 \times 17 = 234$$

$$11 \times 14 + 11 \times 17 = 341$$

$$= \begin{pmatrix} 234 \\ 341 \end{pmatrix} mod\ 26$$

$$= \begin{pmatrix} 0 \\ 3 \end{pmatrix} = \begin{pmatrix} A \\ D \end{pmatrix}$$

$$\begin{pmatrix} 18 \\ 7 \end{pmatrix} \begin{pmatrix} 14 \\ 17 \end{pmatrix} \begin{pmatrix} 19 \\ 4 \end{pmatrix} \begin{pmatrix} 23 \\ 0 \end{pmatrix} \begin{pmatrix} 12 \\ 15 \end{pmatrix} \begin{pmatrix} 11 \\ 4 \end{pmatrix}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

C = K*P mod 26

$$\begin{pmatrix}7 & 8\\ 11 & 11\end{pmatrix}\begin{pmatrix}19\\ 4\end{pmatrix} \; mod\ 26$$

$$7 \times 19 + 8 \times 4 = 165$$

$$11 \times 19 + 11 \times 4 = 253$$

$$= \begin{pmatrix}165\\ 253\end{pmatrix} mod\ 26$$

$$= \begin{pmatrix}9\\ 19\end{pmatrix} = \begin{pmatrix}J\\ T\end{pmatrix}$$

$$\begin{pmatrix}18\\ 7\end{pmatrix}\begin{pmatrix}14\\ 17\end{pmatrix}\begin{pmatrix}19\\ 4\end{pmatrix}\begin{pmatrix}23\\ 0\end{pmatrix}\begin{pmatrix}12\\ 15\end{pmatrix}\begin{pmatrix}11\\ 4\end{pmatrix}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

C = K*P mod 26

$$\begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix}\begin{pmatrix} 23 \\ 0 \end{pmatrix} = \begin{pmatrix} 161 \\ 253 \end{pmatrix} \ mod\ 26$$

$$\begin{pmatrix} 5 \\ 19 \end{pmatrix} = \begin{pmatrix} F \\ T \end{pmatrix}$$

$$\begin{pmatrix} 18 \\ 7 \end{pmatrix}\begin{pmatrix} 14 \\ 17 \end{pmatrix}\begin{pmatrix} 19 \\ 4 \end{pmatrix}\begin{pmatrix} 23 \\ 0 \end{pmatrix}\begin{pmatrix} 12 \\ 15 \end{pmatrix}\begin{pmatrix} 11 \\ 4 \end{pmatrix}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

C = K*P mod 26

$$\begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix}\begin{pmatrix} 12 \\ 15 \end{pmatrix} = \begin{pmatrix} 204 \\ 297 \end{pmatrix} mod\ 26$$

$$= \begin{pmatrix} 22 \\ 11 \end{pmatrix} = \begin{pmatrix} W \\ L \end{pmatrix}$$

$$\begin{pmatrix} 18 \\ 7 \end{pmatrix}\begin{pmatrix} 14 \\ 17 \end{pmatrix}\begin{pmatrix} 19 \\ 4 \end{pmatrix}\begin{pmatrix} 23 \\ 0 \end{pmatrix}\begin{pmatrix} 12 \\ 15 \end{pmatrix}\begin{pmatrix} 11 \\ 4 \end{pmatrix}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

C = K*P mod 26

$$\begin{pmatrix}18\\7\end{pmatrix}\begin{pmatrix}14\\17\end{pmatrix}\begin{pmatrix}19\\4\end{pmatrix}\begin{pmatrix}23\\0\end{pmatrix}\begin{pmatrix}12\\15\end{pmatrix}\begin{pmatrix}11\\4\end{pmatrix}$$

$$\begin{pmatrix}7 & 8\\11 & 11\end{pmatrix}\begin{pmatrix}11\\4\end{pmatrix} = \begin{pmatrix}109\\165\end{pmatrix} mod\ 26 = \begin{pmatrix}5\\9\end{pmatrix} = \begin{pmatrix}F\\J\end{pmatrix}$$

Cipher text = APADJTFTWLFJ

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Decryption : Perform inverse matrix multiplication

Cipher text = APADJTFTWLFJ

Key = $\begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix} \begin{bmatrix} a & b \\ c & d \end{bmatrix}$

$P = K^{-1} * C \bmod 26$

Find out inverse matrix of given key matrix.

$$K^{-1} = \frac{1}{|K|} * K_{adj}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Cipher text = APADJTFTWLFJ

$$K = \begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix} \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

Find out inverse matrix of given key matrix.

$$K^{-1} = \frac{1}{|K|} * K_{adj}$$

$|K|$ = ad- bc = 7*11 - 8*11 = 77 - 88 → -11 mod 26 =15

$$K_{adj} = \begin{bmatrix} d & -b \\ -c & a \end{bmatrix} \begin{pmatrix} 11 & -8 \\ -11 & 7 \end{pmatrix}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Cipher text = APADJTFTWLFJ

$$K = \begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix} \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

Find out inverse matrix of given key matrix.

$$K^{-1} = \frac{1}{|K|} * K_{adj}$$

$$= \frac{1}{15} * \begin{pmatrix} 11 & -8 \\ -11 & 7 \end{pmatrix}$$

$$= 15^{-1} * \begin{pmatrix} 11 & -8 \\ -11 & 7 \end{pmatrix} \text{ mod } 26$$

$15^{-1} \bmod 26 = ?$

$15 (?) \bmod 26 = 1$

$15(1) \bmod 26 = 15$ not equal to 1

$15(2) \bmod 26 = 4$ not equal to 1

.

.

.

$15(7) \bmod 26 = 1$

So, $15^{-1} \bmod 26 = 7$

Find the multiplicative inverse of 15 in Z_{26}.

q	r1	r2	r	t1	t2	t
1	26	15	11	0	1	-1
1	15	11	4	1	-1	2
2	11	4	3	-1	2	-5
1	4	3	1	2	-5	7
3	3	1	0	-5	7	-26
	1	0		7	-26	

$r_1 \leftarrow n; \quad r_2 \leftarrow b;$
$t_1 \leftarrow 0; \quad t_2 \leftarrow 1;$

while $(r_2 > 0)$
{
$q \leftarrow r_1 / r_2;$

$r \leftarrow r_1 - q \times r_2;$
$r_1 \leftarrow r_2; \quad r_2 \leftarrow r;$

$t \leftarrow t_1 - q \times t_2;$
$t_1 \leftarrow t_2; \quad t_2 \leftarrow t;$

}
if $(r_1 = 1)$ then $b^{-1} \leftarrow t_1$

The gcd (26, 15) is 1; the inverse of 15 is 7

Hill Cipher

Find out inverse matrix of given key matrix.

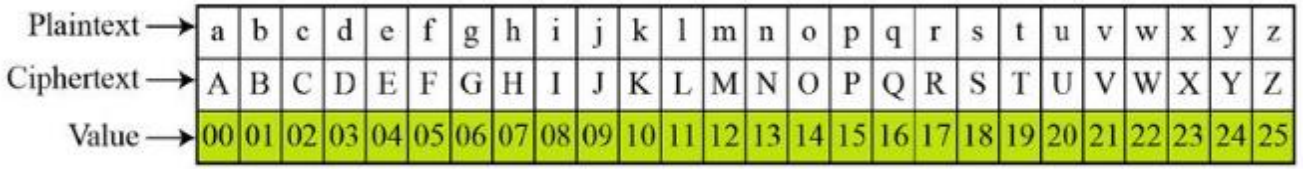
$$K^{-1} = \frac{1}{|K|} * K_{adj}$$

$$= 7 * \begin{pmatrix} 11 & -8 \\ -11 & 7 \end{pmatrix} \text{ mod } 26$$

$$= 7 * \begin{pmatrix} 11 & 18 \\ 15 & 7 \end{pmatrix} \text{ mod } 26$$

$$= \begin{pmatrix} 77 & 126 \\ 105 & 49 \end{pmatrix} \text{ mod } 26 \qquad = \begin{pmatrix} 25 & 22 \\ 1 & 23 \end{pmatrix}$$

Hill Cipher



Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Cipher text = APADJTFTWLFJ

$$P = K^{-1} * C \bmod 26 = \begin{pmatrix} 25 & 22 \\ 1 & 23 \end{pmatrix} \begin{pmatrix} 0 \\ 15 \end{pmatrix}$$

$=25*0 + 22*15 \rightarrow 330 \bmod 26 = 18 \rightarrow S$

$= 1*0 + 23*15 \rightarrow 345 \text{ mode } 26 = 7 \rightarrow H$

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Hill Cipher

3. Encrypt the plaintext "SAFE MESSA GES"

Plain Text = SAF EME SSA GES

Cipher text = HDS IOE YQO CAA

$$K = \begin{pmatrix} 2 & 8 & 15 \\ 7 & 4 & 17 \\ 8 & 13 & 6 \end{pmatrix}$$

$P = K^{-1} * C \bmod 26$

Find out inverse matrix of given key matrix.

$$K^{-1} = \frac{1}{|K|} * K_{adj}$$

Hill Cipher

Plaintext →	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
Ciphertext →	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
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Cipher text = HDS IOE YQO CAA

Find out inverse matrix of given key matrix.

$$K^{-1} = \frac{1}{|K|} * K_{adj}$$

$$K = \begin{pmatrix} 2 & 8 & 15 \\ 7 & 4 & 17 \\ 8 & 13 & 6 \end{pmatrix}$$

$$|K| = \begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} = a\begin{vmatrix} e & f \\ h & i \end{vmatrix} - b\begin{vmatrix} d & f \\ g & i \end{vmatrix} + c\begin{vmatrix} d & e \\ g & h \end{vmatrix}$$

$$= a(ei - fh) - b(di - fg) + c(dh - eg)$$

$$= aei - afh - bdi + bfg + cdh - ceg$$

$$= (aei + bfg + cdh) - (afh + bdi + ceg)$$

Hill Cipher

Plaintext	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
Ciphertext	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
Value	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

$$|K| = \begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} = a\begin{vmatrix} e & f \\ h & i \end{vmatrix} - b\begin{vmatrix} d & f \\ g & i \end{vmatrix} + c\begin{vmatrix} d & e \\ g & h \end{vmatrix}$$

$$= a(ei - fh) - b(di - fg) + c(dh - eg)$$

= 2(4*6 -17*13) – 8 (7*6 -17*8) + 15(7*13 -4*8)

= 1243 mod 26

= 21

$$= \begin{pmatrix} 2 & 8 & 15 \\ 7 & 4 & 17 \\ 8 & 13 & 6 \end{pmatrix}$$

$21^{-1} \bmod 26 = ?$
$21 (?) \bmod 26 = 1$
$21(1) \bmod 26 = 21$ not equal to 1
$21 (2) \bmod 26 = 42$ not equal to 1
.
. .
$21(5) \bmod 26 = 1$

So, $21^{-1} \bmod 26 = 5$

$$K^{-1} = \frac{1}{|D|}\,\text{adj}\,(K)$$

$$= \frac{1}{|D|}\begin{bmatrix} +(ei - fh) & -(di - fg) & +(dh - eg) \\ -(bi - ch) & +(ai - cg) & -(ah - bg) \\ +(bf - ce) & -(af - cd) & +(ae - bd) \end{bmatrix}^{T}$$

Hill Cipher

$$\begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} :$$

$$K_{adj} = \begin{pmatrix} 2 & 8 & 15 \\ 7 & 4 & 17 \\ 8 & 13 & 6 \end{pmatrix} \begin{bmatrix} +(ei-fh) & -(di-fg) & +(dh-eg) \\ -(bi-ch) & +(ai-cg) & -(ah-bg) \\ +(bf-ce) & -(af-cd) & +(ae-bd) \end{bmatrix}^T$$

$$= \begin{pmatrix} 4*6 - 17*13 & 7*6 - 17*8 & 7*13 - 4*8 \\ 8*6 - 15*13 & 2*6 - 15*8 & 2*13 - 8*8 \\ 8*17 - 15*4 & 2*17 - 15*7 & 2*4 - 8*7 \end{pmatrix}$$

$$\begin{pmatrix} -197 & -94 & 59 \\ 147 & -108 & 38 \\ 76 & 71 & -48 \end{pmatrix} \quad \begin{pmatrix} + & - & + \\ - & + & - \\ + & - & + \end{pmatrix}$$

$$\begin{matrix} -197 & 94 & 59 \\ 147 & -108 & 38 \\ 76 & 71 & -48 \end{matrix}$$

Hill Cipher

$$\begin{pmatrix} -197 & 94 & 59 \\ 147 & -108 & 38 \\ 76 & 71 & -48 \end{pmatrix}$$

-197/26 = -7.57692308
(1-0.57692308)*26
=10.999

Take transpose

$$\begin{pmatrix} -197 & 147 & 76 \\ 94 & -108 & 71 \\ 59 & 38 & -48 \end{pmatrix}$$

$$\begin{pmatrix} 11 & 147 & 76 \\ 94 & 22 & 38 \\ 59 & 71 & 4 \end{pmatrix}$$

Repeatedly add +26 to make negative to positive

Hill Cipher

$$= 5 * \begin{pmatrix} 11 & 147 & 76 \\ 94 & 22 & 38 \\ 59 & 71 & 4 \end{pmatrix}$$

multiply mat with det -1

$$\begin{pmatrix} 55 & 735 & 380 \\ 470 & 110 & 355 \\ 295 & 190 & 20 \end{pmatrix}$$

Mod 26 →

$$\begin{pmatrix} 3 & 7 & 16 \\ 2 & 6 & 17 \\ 9 & 8 & 20 \end{pmatrix}$$

$$P = K^{-1} C \bmod 26 = \begin{bmatrix} 3 & 7 & 16 \\ 2 & 6 & 17 \\ 9 & 8 & 20 \end{bmatrix} \begin{bmatrix} 7 \\ 3 \\ 18 \end{bmatrix} \bmod 26$$

$$= \begin{bmatrix} 3(7) + 7(3) + 16 \\ 2(7) + 6(3) + 17 \\ 9(7) + 8(3) + 20 \end{bmatrix} = \begin{bmatrix} 330 \\ 338 \\ 447 \end{bmatrix} \bmod 26 = \begin{bmatrix} 18 \\ 0 \\ 5 \end{bmatrix} = \begin{bmatrix} s \\ a \\ f \end{bmatrix}.$$

$$= \begin{bmatrix} 330 \\ 338 \\ 447 \end{bmatrix} \bmod 26 = \begin{bmatrix} 18 \\ 0 \\ 5 \end{bmatrix} = \begin{bmatrix} s \\ a \\ f \end{bmatrix}.$$

$$P = K^{-1} C \bmod 26 = \begin{bmatrix} 3 & 7 & 16 \\ 2 & 6 & 17 \\ 9 & 8 & 20 \end{bmatrix} \begin{bmatrix} 8 \\ 14 \\ 4 \end{bmatrix} \bmod 26 = \begin{bmatrix} 3(8)+7(14)+16(4) \\ 2(8)+6(14)+17(4) \\ 9(8)+8(14)+20(4) \end{bmatrix} \bmod 26 = \begin{bmatrix} 186 \\ 168 \\ 264 \end{bmatrix} \bmod 26 = \begin{bmatrix} 4 \\ 12 \\ 4 \end{bmatrix} = \begin{bmatrix} e \\ m \\ e \end{bmatrix}.$$

$$P = K^{-1} C \bmod 26 = \begin{bmatrix} 3 & 7 & 16 \\ 2 & 6 & 17 \\ 9 & 8 & 20 \end{bmatrix} \begin{bmatrix} 24 \\ 16 \\ 14 \end{bmatrix} \bmod 26 = \begin{bmatrix} 3(24)+7(16)+16(14) \\ 2(24)+6(16)+17(14) \\ 9(24)+8(16)+20(14) \end{bmatrix} \bmod 26 = \begin{bmatrix} 18 \\ 18 \\ 0 \end{bmatrix} = \begin{bmatrix} s \\ s \\ a \end{bmatrix}.$$

$$P = K^{-1} C \bmod 26 = \begin{bmatrix} 3 & 7 & 16 \\ 2 & 6 & 17 \\ 9 & 8 & 20 \end{bmatrix} \begin{bmatrix} 2 \\ 0 \\ 0 \end{bmatrix} \bmod 26 = \begin{bmatrix} 3(2)+7(0)+16(0) \\ 2(2)+6(0)+17(0) \\ 9(2)+8(0)+20(0) \end{bmatrix} \bmod 26 = \begin{bmatrix} 6 \\ 4 \\ 18 \end{bmatrix} = \begin{bmatrix} g \\ e \\ s \end{bmatrix}.$$

Encrypt the plaintext “attack”, using Hill cipher for the given key = $\begin{bmatrix} 2 & 3 \\ 3 & 6 \end{bmatrix}$.

Ciphertext: “FKMFIO”.

Encrypt the message **"retreat now"** using the keyphrase **back up** and a 3 x 3 matrix.

$$\begin{pmatrix} r \\ e \\ t \end{pmatrix} \begin{pmatrix} r \\ e \\ a \end{pmatrix} \begin{pmatrix} t \\ n \\ o \end{pmatrix} \begin{pmatrix} w \\ x \\ x \end{pmatrix}$$

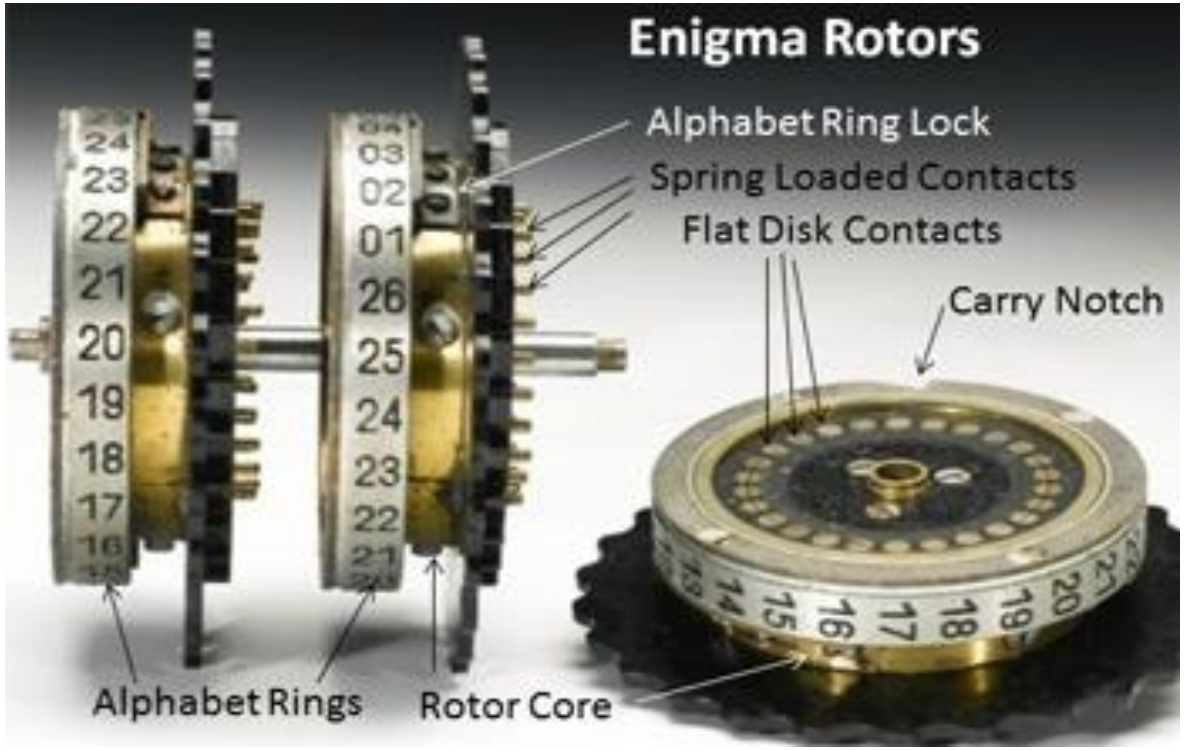
$$\begin{pmatrix} B & A & C \\ K & U & P \\ A & B & C \end{pmatrix} \quad \begin{pmatrix} 1 & 0 & 2 \\ 10 & 20 & 15 \\ 0 & 1 & 2 \end{pmatrix}$$

ROTOR CIPHER

- The **Rotor Cipher(Enigma machine cipher)** is a type of polyalphabetic substitution cipher that uses mechanical components to encrypt messages.
- It became famous due to its use by Nazi Germany during World War II.
- The machine uses a series of rotating disks (rotors) to create complex substitution patterns, which change with each letter typed, making the encryption highly sophisticated.

ROTOR CIPHER

A rotor is a thick disk that has near its outer circumference on both sides as many electric contacts as letters in the alphabet (usually 26—early versions of the Enigma used 28 or 29 letters).



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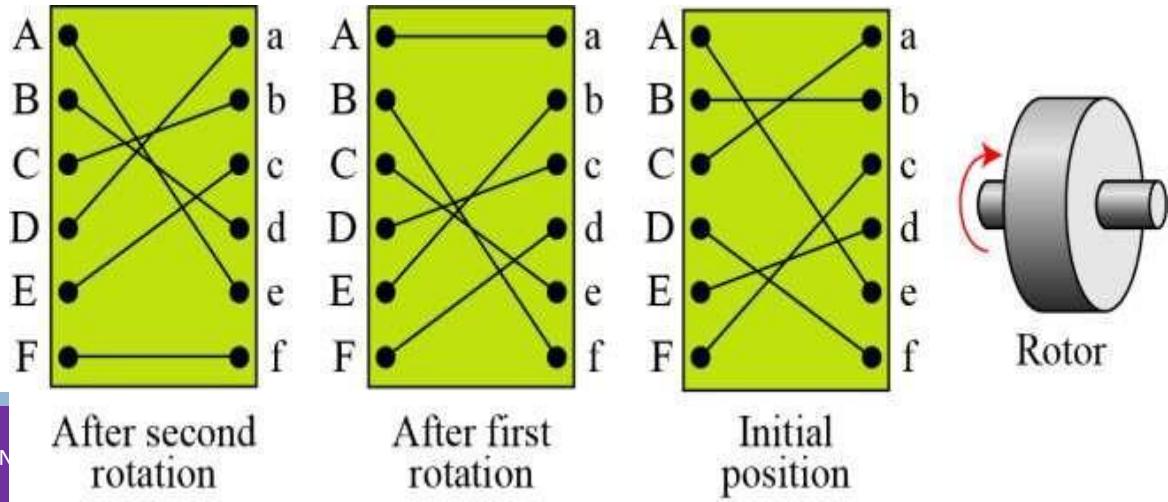
ROTOR CIPHER

- Rotor uses only 6 letters
- Initial setting is key agreed between sender and receiver
- First character is encrypted using initial position
- Second character after first rotation
- Third character after second rotation
- Example : bee → BCA

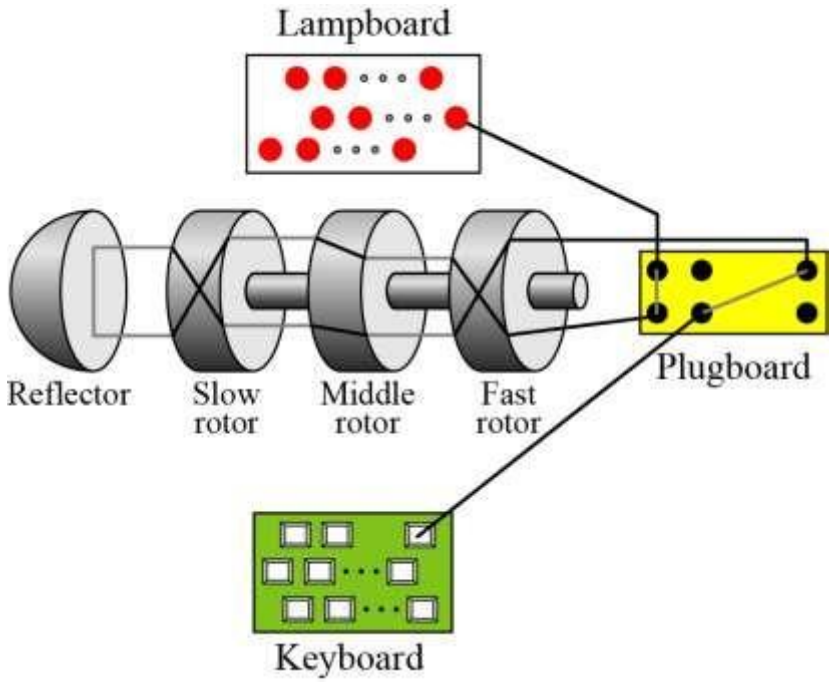
A rotor cipher



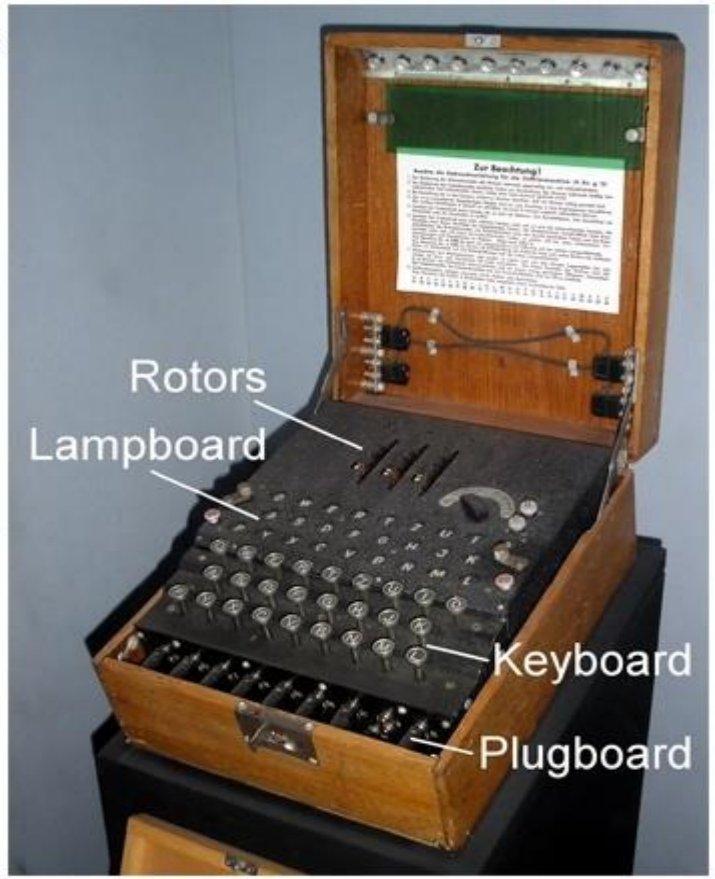
ROTOR CIPHER

Main components of Enigma machine

1. Keyboard = 26keys
2. Lampboard =26 lamps
3. Plugboard = 26plugs
4. Three rotors
5. Reflector



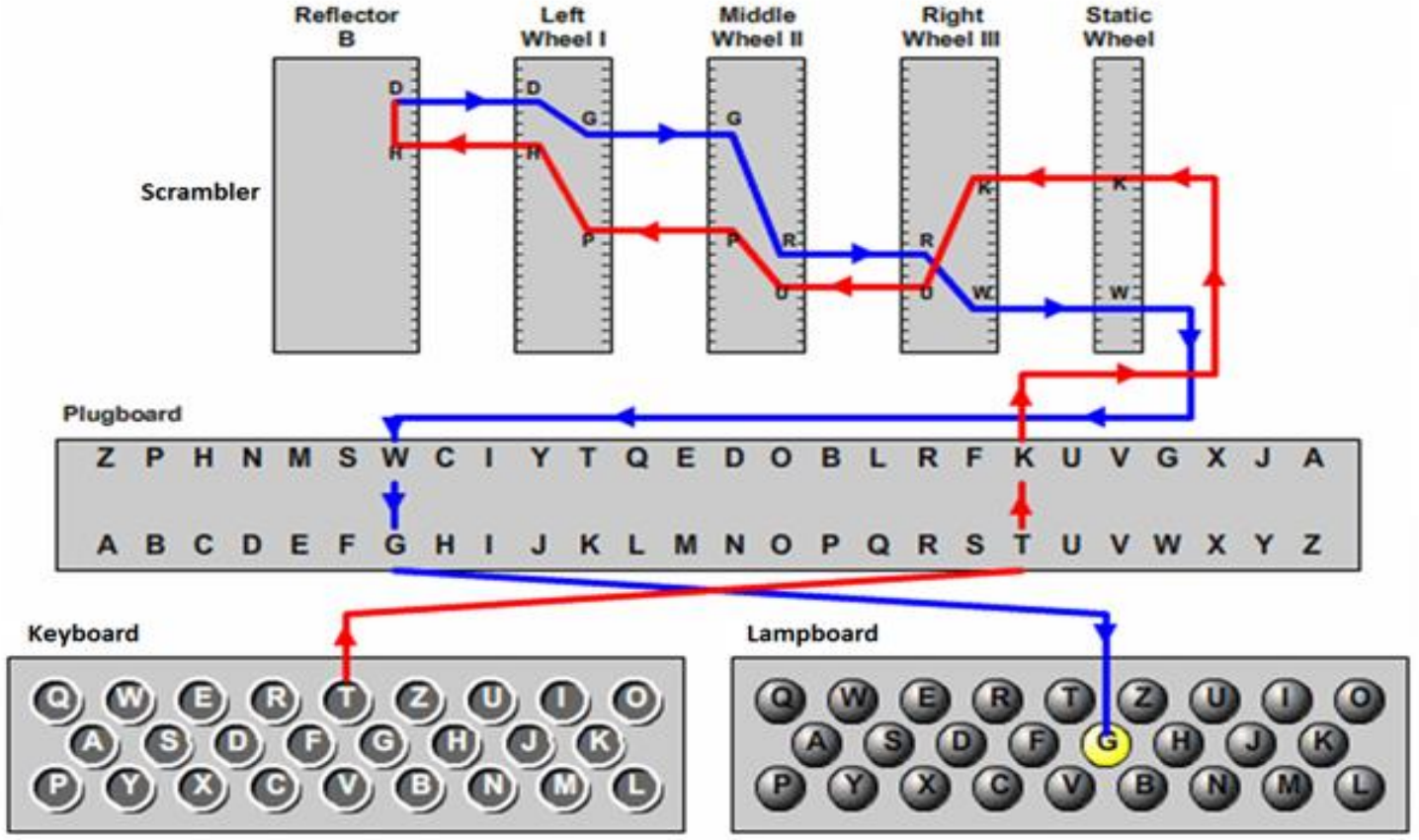
The Enigma Ciphertext Machine



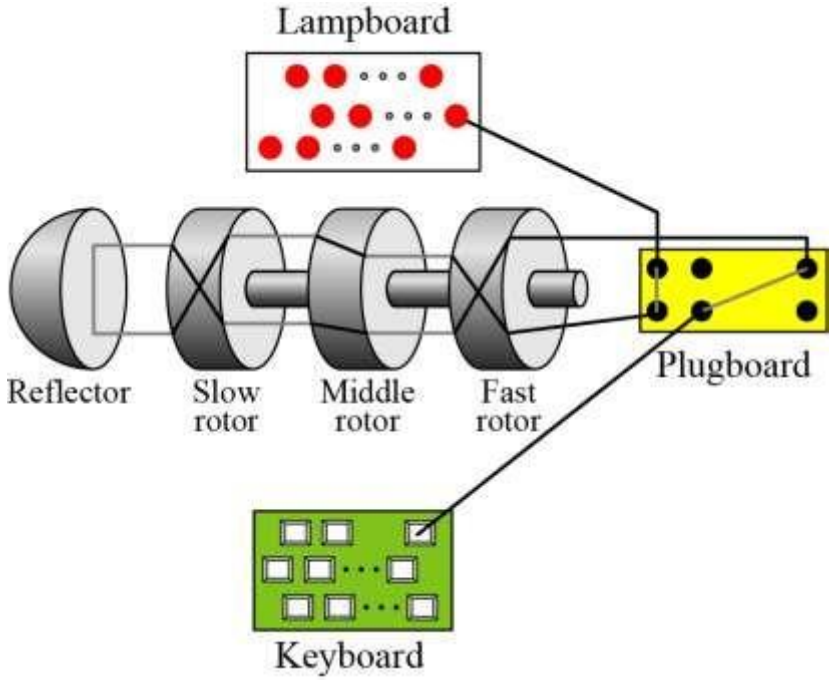
ROTOR CIPHER

- Keyboard (input)
- Lampboard (output)
- Rotors (polyalphabetic encryption)
  - 3 - 4 rotors (depending on Enigma type)
  - 1 reflector
  - 26 contacts at both sides
  - Wired unregularly
  - Turns one step at each letter
  - Turnover is based on ring setting
  - Exchangeable
- Plugboard (monoalphabetic encryption)
  - Interchanges letters

ROTOR CIPHER



A schematic of the Enigma machine



ROTOR CIPHER

To use Engima machine , a code book is published that gives several settings for each day

a. 3 rotor to be chosen, out of 5 available
b. The order in which rotor to be installed
c. Setting for plugboard
d. A three letter code for the day

ROTOR CIPHER

Procedure for Encrypting message

1. Set starting position of rotor to code of the day. For example code was “HUA”
2. Choose a random 3 letter code such as ACF

   Encrypt **ACFACF**(repeated code) using code from step1

   Encrypted code is OPNABT
3. Set the starting position to OPN(half of encrypted code)
4. Append encrypted code to message →ACFOPNABT
5. Encrypt the message →ACFOPNABT. Send the encrypted message

ROTOR CIPHER

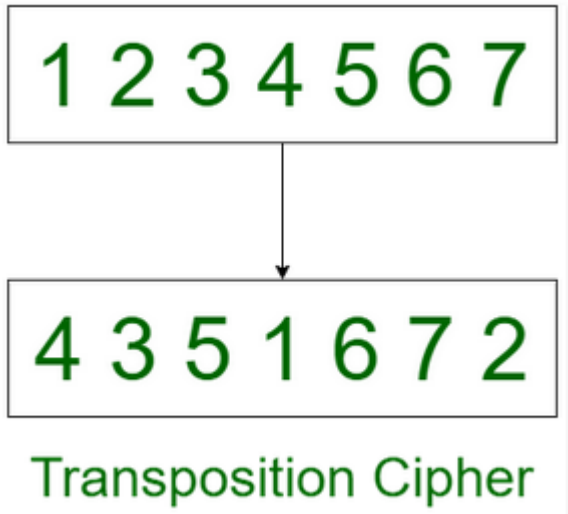
Procedure for Decrypting message

1. Receive the message and separate the first six letters
2. Set the starting position of the rotor to the code of the day
3. Decrypt the first six letter using initial setting in step2
4. Set the position of the rotor to the first half of the decrypted code
5. Decrypt the message (without the first six letter)

TRANSPOSITION CIPHERS

Transposition Cipher rearranges the position of the characters of plain text.

It changes the position of the character but it does not change the identity of the character.



TRANSPOSITION CIPHERS

A transposition cipher does not substitute one symbol for another, instead it changes the location of the symbols.

A transposition cipher reorders symbols.

1. Keyless Transposition Ciphers
2. Keyed Transposition Ciphers
3. Combining Two Approaches

Keyless Transposition Ciphers

Simple transposition ciphers, which were used in the past, are keyless.

Two Methods are

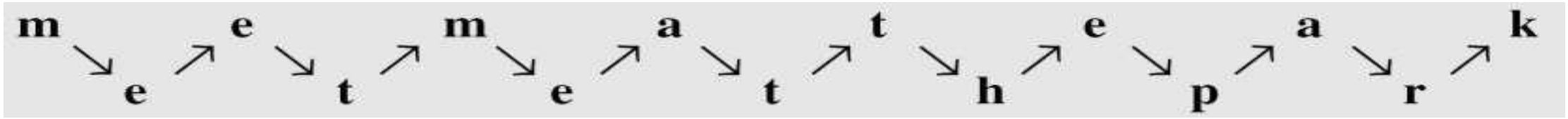
1. Text is written into table column by column and transmit row by row(Rail Fence cipher)
2. Text is written into table row by row and transmit column by column

Keyless Transposition Ciphers

Rail fence cipher

PT is arranged in two line as a zigzag pattern(Column by column)

For example: “Meet me at the park”



8

7

The ciphertext is created reading the pattern row by row.

Ciphertext “MEMATEAKETETHPR”.

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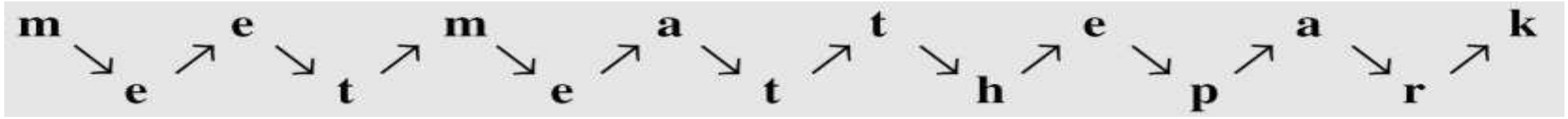
Keyless Transposition Ciphers

Rail fence cipher

Ciphertext "MEMATEAKETETHPR"

Receiver divides into half (first half form the first row and second half second row) and reads in zigzag



TRANSPOSITION CIPHERS

Alice and Bob can agree on the number of columns.

Alice writes the plaintext, row by row, in a table of four columns.

For example: "Meet me at the park"

m	e	e	t
m	e	a	t
t	h	e	p
a	r	k	

Ciphertext "MMTAEEHREAEKTTP".

Meet me at the park MMTAEEHREAEKTTP

The following shows the permutation of each character in the plaintext into the ciphertext based on the positions.

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
01	05	09	13	02	06	10	13	03	07	11	15	04	08	12

The second character in the plaintext has moved to the fifth position in the ciphertext; the third character has moved to the ninth position; and so on.

Although the characters are permuted, there is a pattern in the permutation: (01, 05, 09, 13), (02, 06, 10, 13), (03, 07, 11, 15), and (08, 12).

In each section, the difference between the two adjacent numbers is 4.

Keyed Transposition Ciphers

- Divide the plaintext into groups of predetermined size, called blocks, and then use a key to permute the characters in each block separately.
- Alice needs to send the message "Enemy attacks tonight" to Bob.
- Alice and Bob agrees with block size =5

e n e m y a t t a c k s t o n i g h t z

- The key used for encryption and decryption is a permutationkey, which shows how the character are permuted.

Keyed Transposition Ciphers

- Divide the plaintext into groups of predetermined size, called blocks, and then use a key to permute the characters in each block separately.
- Alice needs to send the message "Enemy attacks tonight" to Bob.
- Alice and Bob agrees with block size =5

e n e m y a t t a c k s t o n i g h t z

Keyed Transposition Ciphers

e n e m y a t t a c k s t o n i g h t z

Encryption ↓

3	1	4	5	2
1	2	3	4	5

↑ Decryption

1 2 3 4 5
E N E M Y

E E M Y N

The permutation yields

E E M Y N T A A C T T K O N S H I T Z G

Keyed Transposition Ciphers

Encryption ↓

3	1	4	5	2
1	2	3	4	5

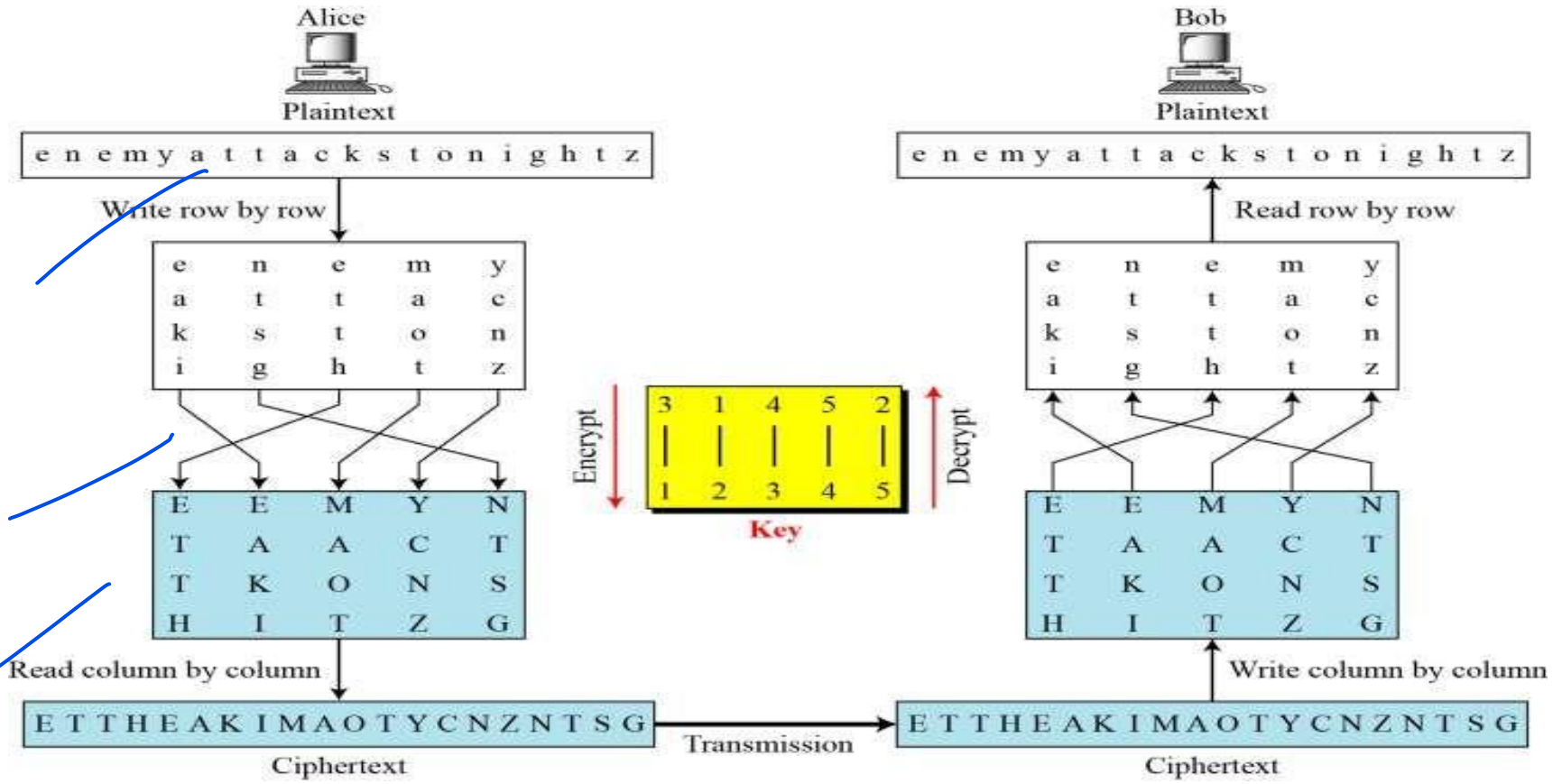
↑ Decryption

The permutation yields

E E M Y N T A A C T T K O N S H I T Z G

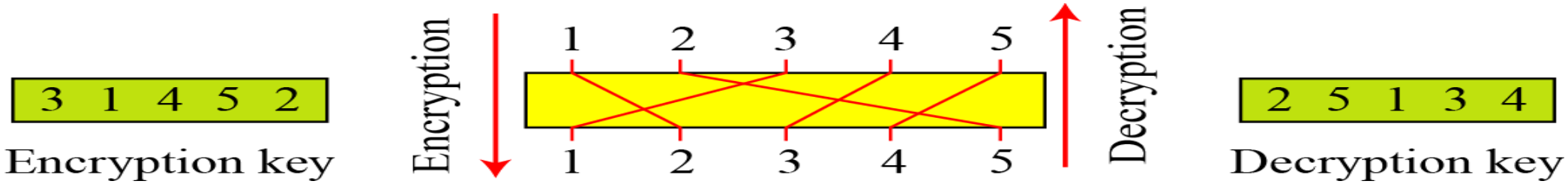
e n e m y a t t a c k s t o n i g h t z

Combining Two Approaches



Keys

A single key was used in two directions for the column exchange: downward for encryption, upward for decryption. It is customary to create two keys.



Encryption/decryption keys in transpositional ciphers

Encryption ↓

3	1	4	5	2
1	2	3	4	5

↑ Decryption

STREAM AND BLOCK CIPHERS

The literature divides the symmetric ciphers into two broad categories:

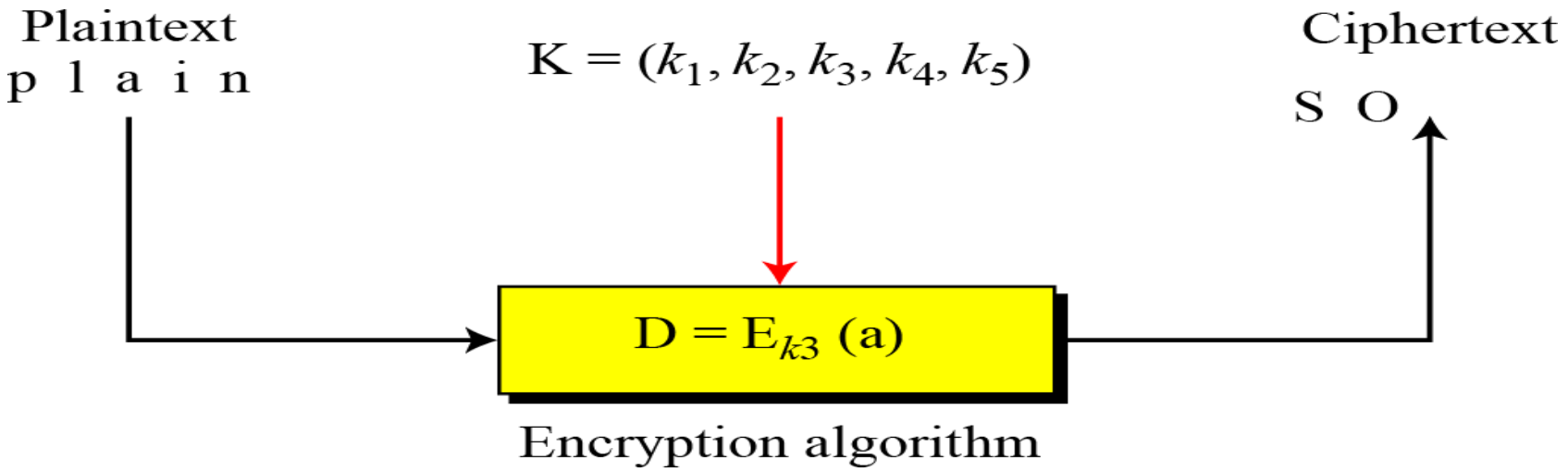
- Stream ciphers
- Block ciphers

STREAM CIPHERS

Stream ciphers - Call the plaintext stream P, the ciphertext stream C, and the key stream K.

$$P = P_1P_2P_3, \ldots \qquad C = C_1C_2C_3, \ldots \qquad K = (k_1, k_2, k_3, \ldots)$$

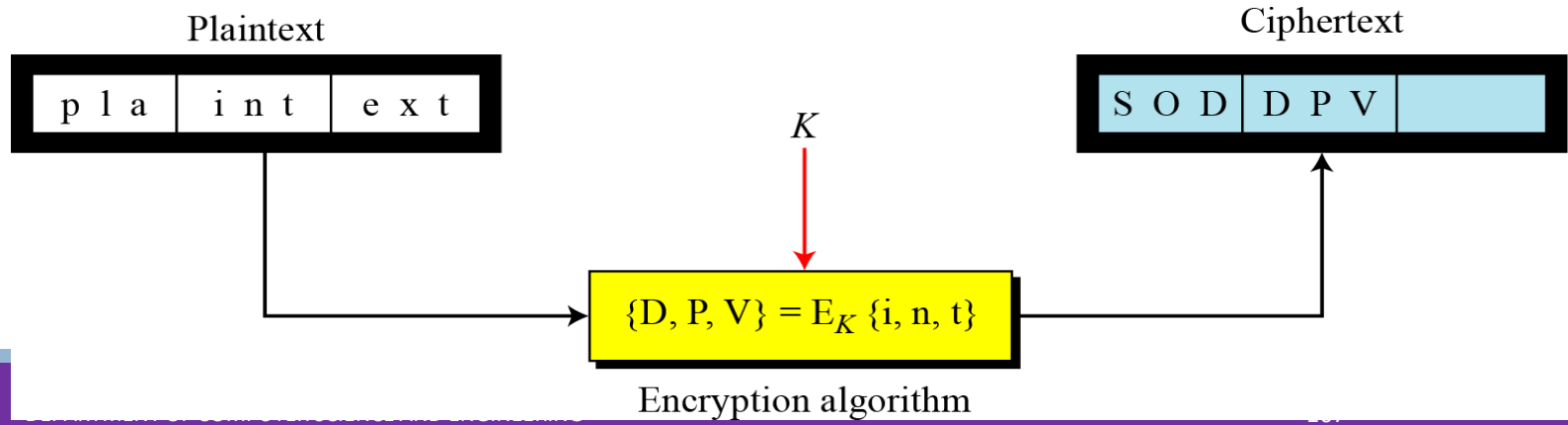
$$C_1 = E_{k1}(P_1) \qquad C_2 = E_{k2}(P_2) \qquad C_3 = E_{k3}(P_3) \ldots$$



Block Ciphers

In a block cipher, a group of plaintext symbols of size m (m > 1) are encrypted together creating a group of ciphertext of the same size.

A single key is used to encrypt the whole block even if the key is made of multiple values.



Block Cipher	Stream Cipher
Processing or encoding of the plain text is done as a fixed length block one by one. A block for example could be 64 or 128 bits in size.	Processing or encoding of plain text is done bit by bit. The block size here is simply one bit.
The same key is used to encrypt each of the blocks	A different key is used to encrypt each of the bits.
A Pad added to short length blocks	Bits are processed one by one in as in a chain
Uses Symmetric Encryption and is NOT used in asymmetric encryption	High speed and low hardware complexity
Confusion factor: The key to the cipher text relationship could be really very complicated.	Key is often combined with an initialization vector
Diffusion Factor: output depends on the input in a very complex method.	Long period with no repetition
Most block ciphers are based on Feistel cipher in structure	Statistically random
Looks more like an extremely large substitution and Using the idea of a product cipher	Depends on a large key and Large liner complexity
More secure in most cases	Equally secure if properly designed
Usually more complex and slower in operation	Usually very simple and much faster
Examples of Block Cipher are: Lucifer / DES,IDEA, RC5, Blowfish etc.	Examples of Stream Cipher are: FISH, RC4, ISAAC, SEAL, SNOW etc.

UNIT 2

Traditional Symmetric-Key Ciphers: (Chapter 3)

- Introduction
- Substitution Ciphers
- Trans positional Ciphers
- Stream and Block Ciphers

Data Encryption Standard (DES): (Chapter 6)

- Introduction
- DES Structure
- DES Analysis
- Multiple DES
- Security of DES

UNIT 2

Data Encryption Standard (DES): (Chapter 6)

- Introduction
- DES Structure
- DES Analysis
- Security of DES

History

•In 1973, NIST published a request for proposals for a national symmetric-key cryptosystem.

•A proposal from IBM, a modification of a project called Lucifer, was accepted as DES.

•DES was published in the Federal Register in March 1975 as a draft of the Federal Information Processing Standard (FIPS).

DES Overview

The Data Encryption Standard (DES) is a symmetric-key block cipher published by the National Institute of Standards and Technology (NIST).

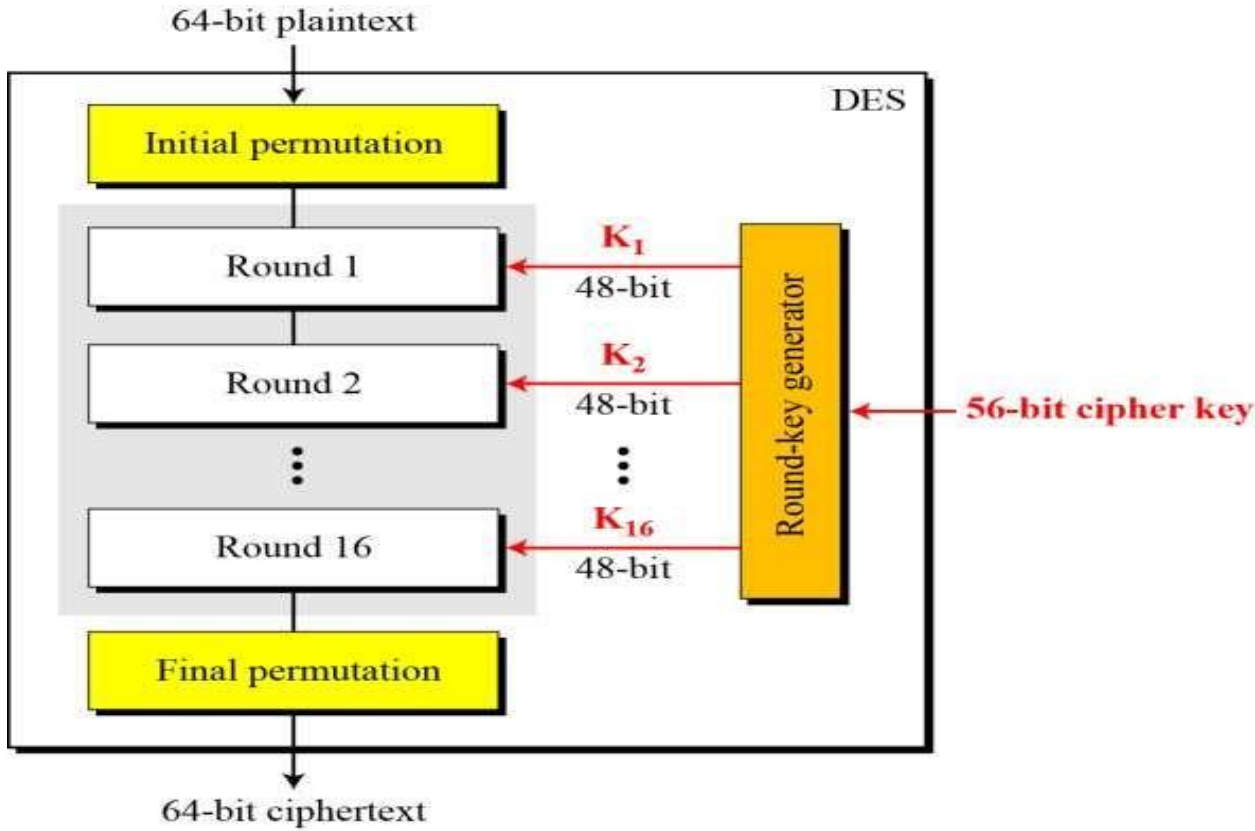
DES is a block cipher. The block size is 64-bit.

DES Structure

DES is an implementation of a Feistel Cipher.

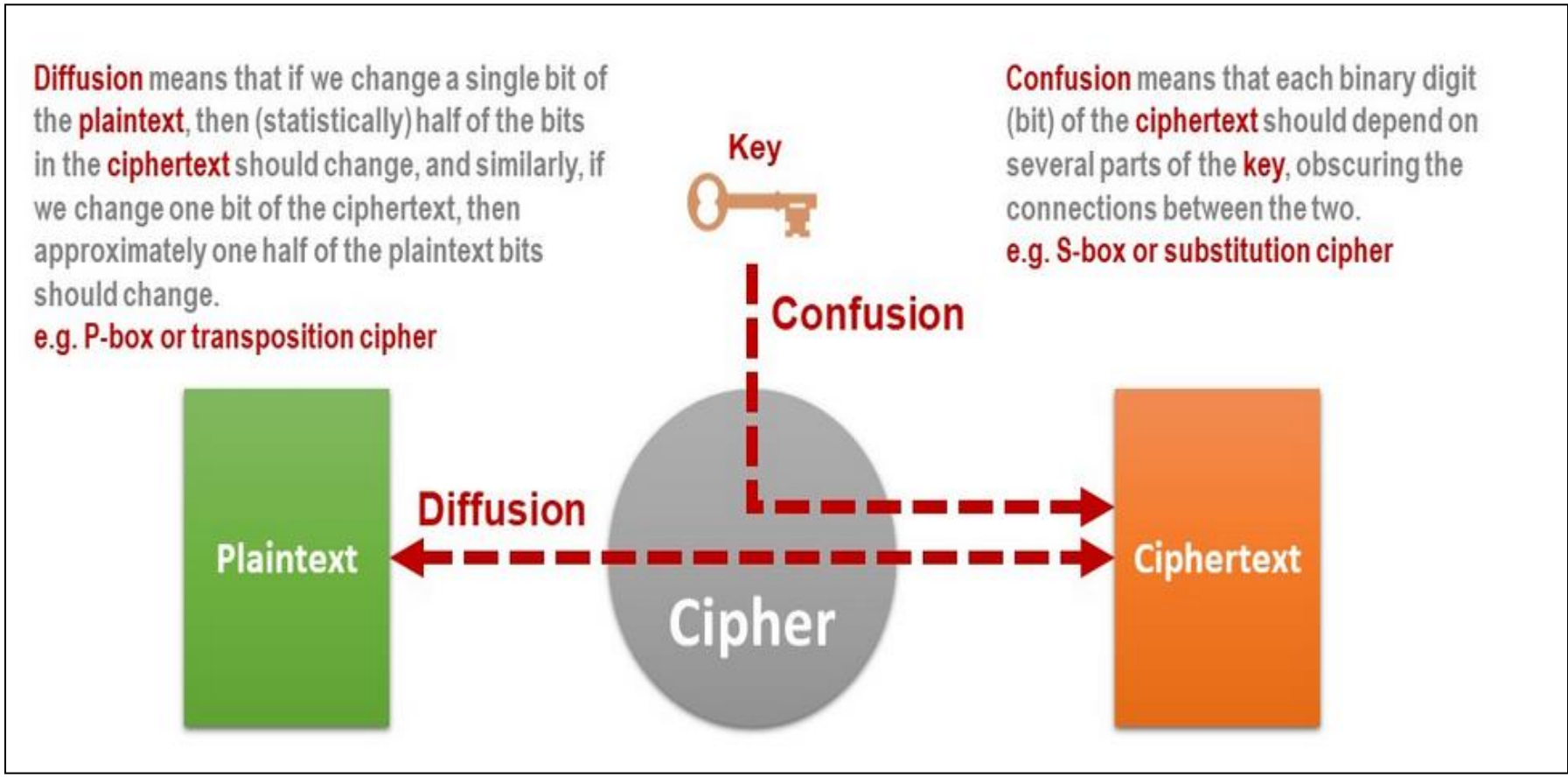
It uses 16 round Feistel structure.

Key length is 64-bit, DES has an effective key length of 56 bits, since 8 of the 64 bits of the key are not used by the encryption algorithm



DES Structure – Two properties

1. Diffusion -If a single symbol in the plaintext is changed, several or all symbol in the ciphertext will also be changed
2. Confusion - If a single bit in the key is changed, most or all bits in the ciphertext will also be changed



DES Structure

DES uses a 56-bit key.

Actually, the initial key consists of 64 bits.

However, before the DES process even starts, every 8th bit of the key is discarded to produce a 56-bit key. That is bit positions 8, 16, 24, 32, 40, 48, 56, and 64 are discarded.

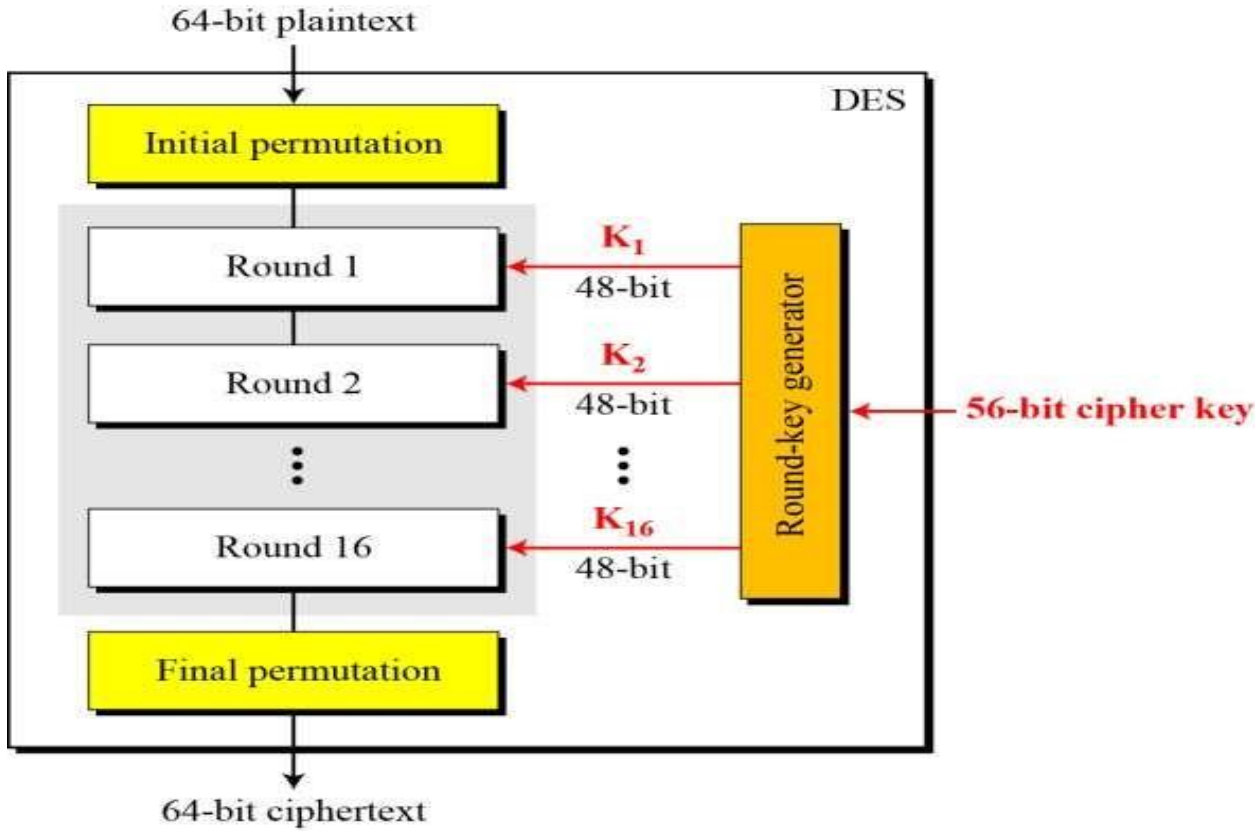
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64

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

DES Structure

DES is based on the Feistel Cipher

- Initial and final permutation
- Round function
- Round Key Generator



DES Structure

Initial and final permutation

- The initial permutation (IP) happens only once and it happens before the first round.
- Transposition in IP is done, Both are keyless and predetermined.
- IP replaces the
  - first bit of the original plain text block with the 58th bit of the original plain text,
  - the second bit with the 50th bit of the original plain text block,
  - and so on.

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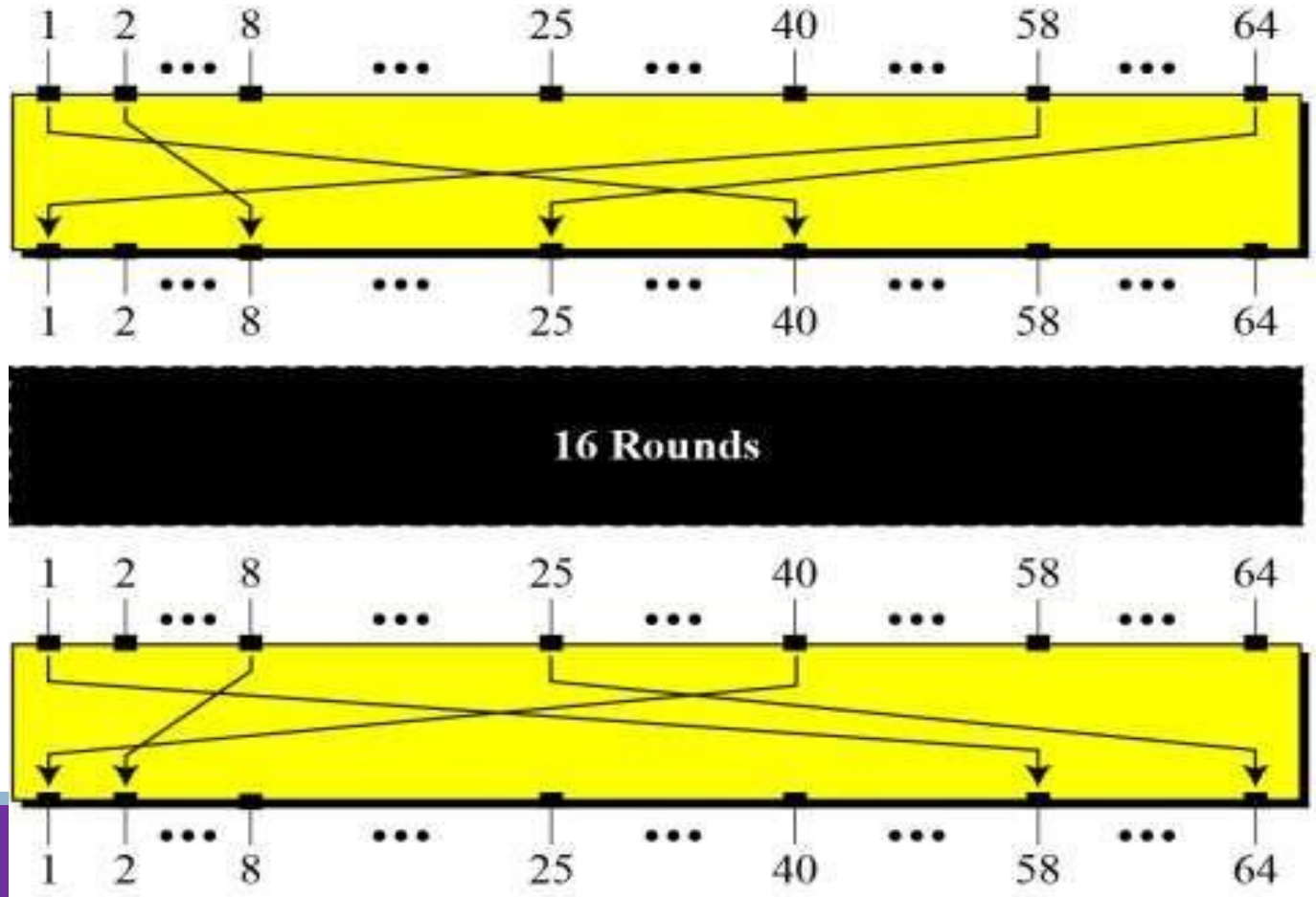
DES Structure

Initial and final permutation step



Permutation Box

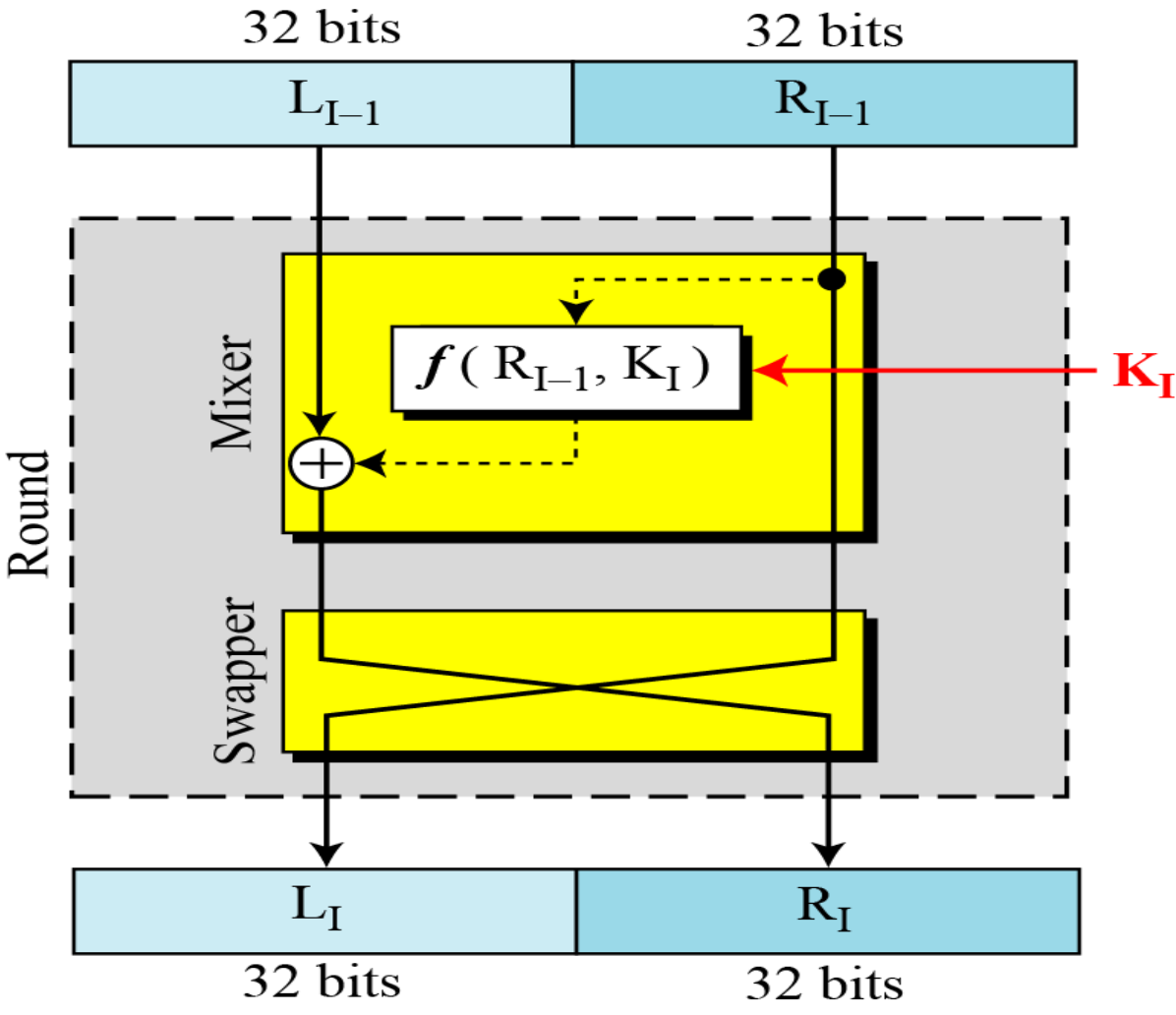
Initial Permutation							
58	50	42	34	26	18	10	02
60	52	44	36	28	20	12	04
62	54	46	38	30	22	14	06
64	56	48	40	32	24	16	08
57	49	41	33	25	17	09	01
59	51	43	35	27	19	11	03
61	53	45	37	29	21	13	05
63	55	47	39	31	23	15	07

Final Permutation							
40	08	48	16	56	24	64	32
39	07	47	15	55	23	63	31
38	06	46	14	54	22	62	30
37	05	45	13	53	21	61	29
36	04	44	12	52	20	60	28
35	03	43	11	51	19	59	27
34	02	42	10	50	18	58	26
33	01	41	09	49	17	57	25

DES Structure

Round function

- DES uses 16 rounds
- Each round is a Feistel cipher is the DES function *f*.



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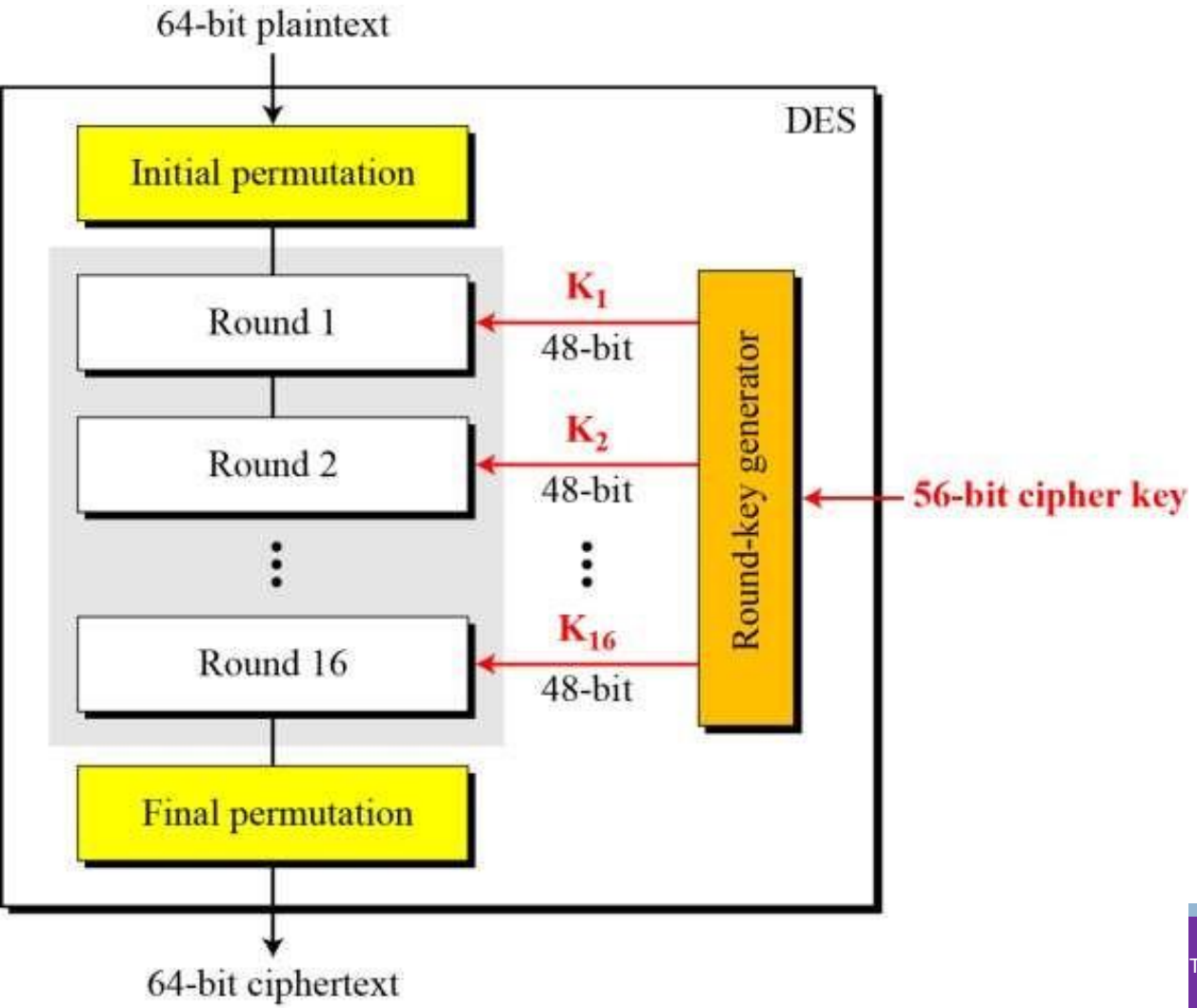
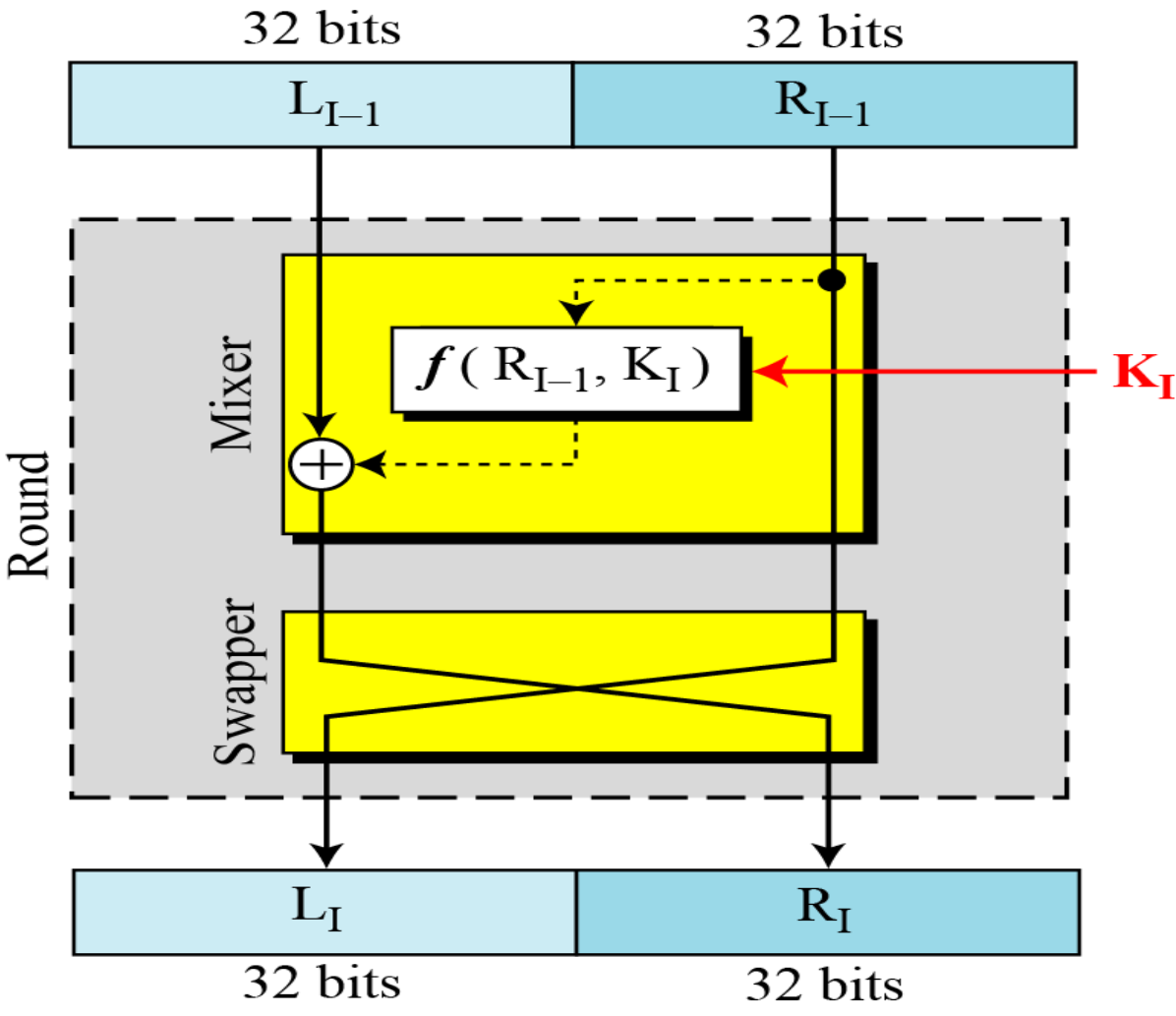
DES Structure

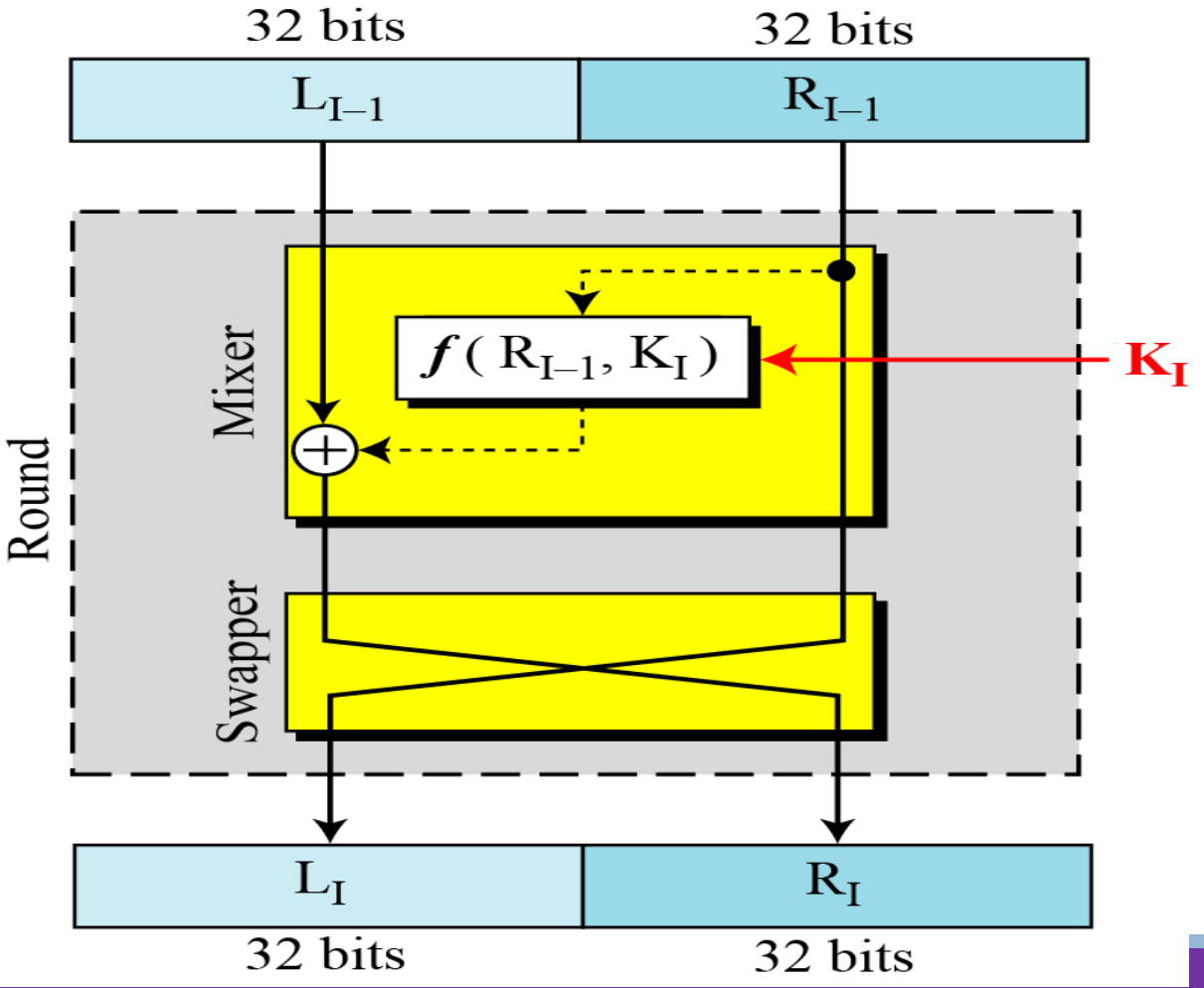




DES Structure

Round function

- The heart of this cipher is the DES **function *f***.
- The DES function applies a
  - 48-bit key to the rightmost 32 bits to produce a 32-bit output.



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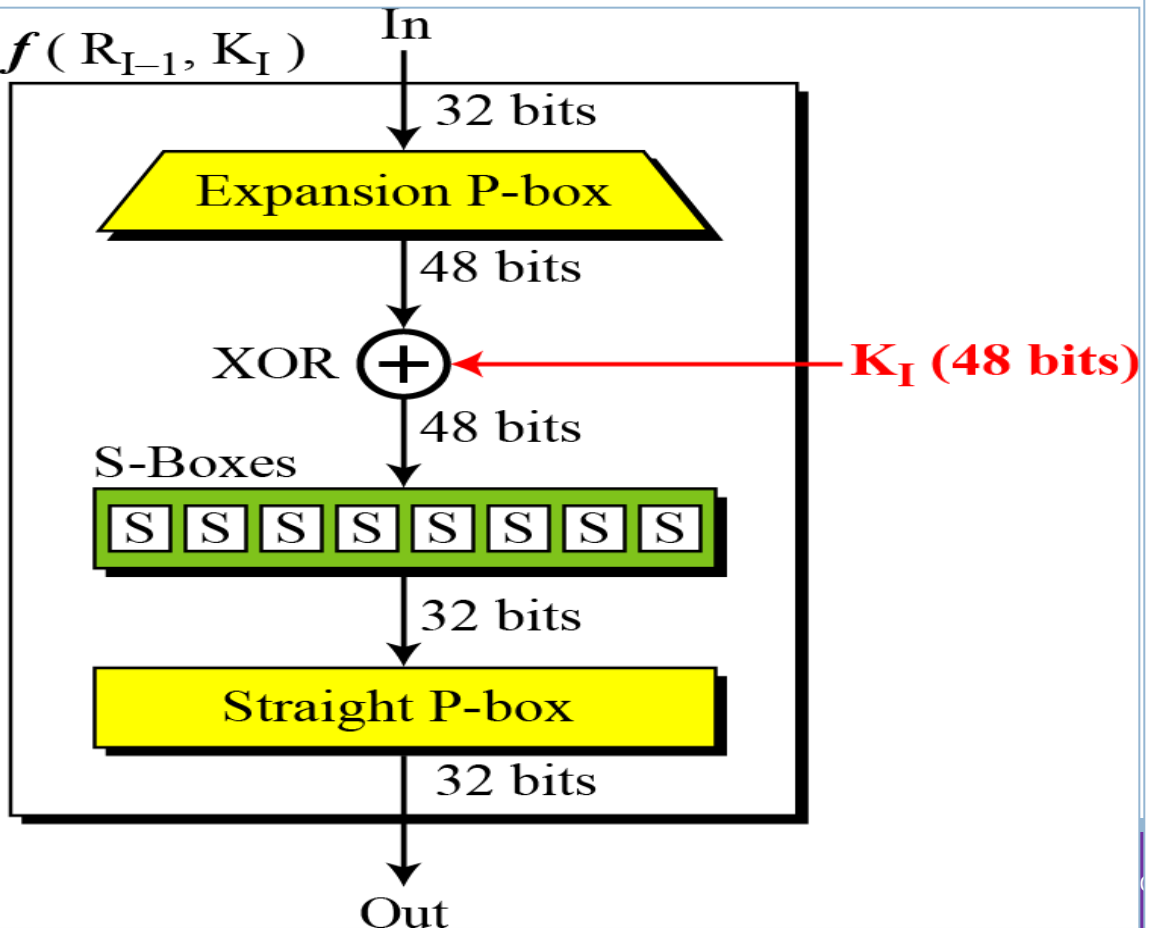
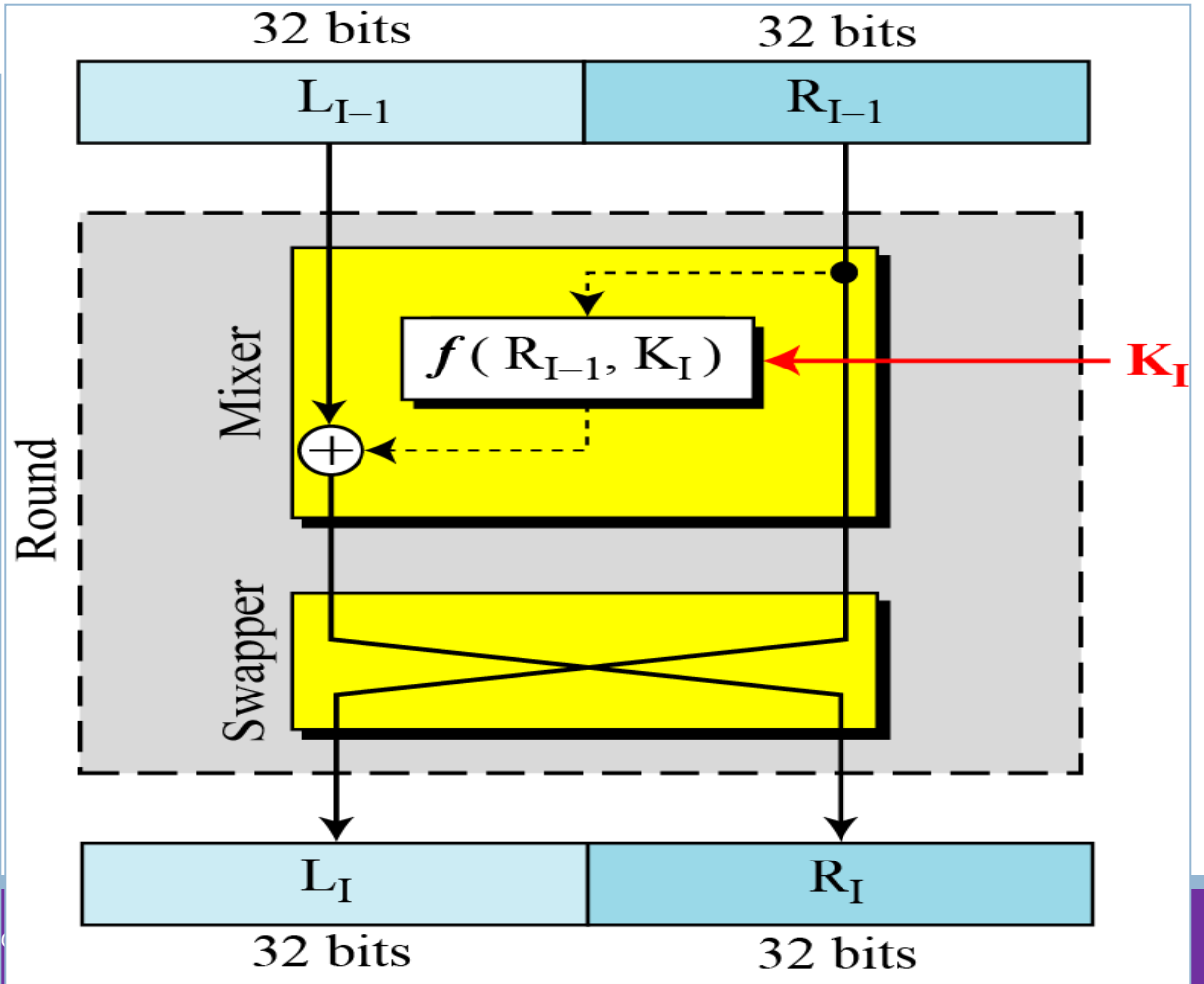
DES Structure

DES function

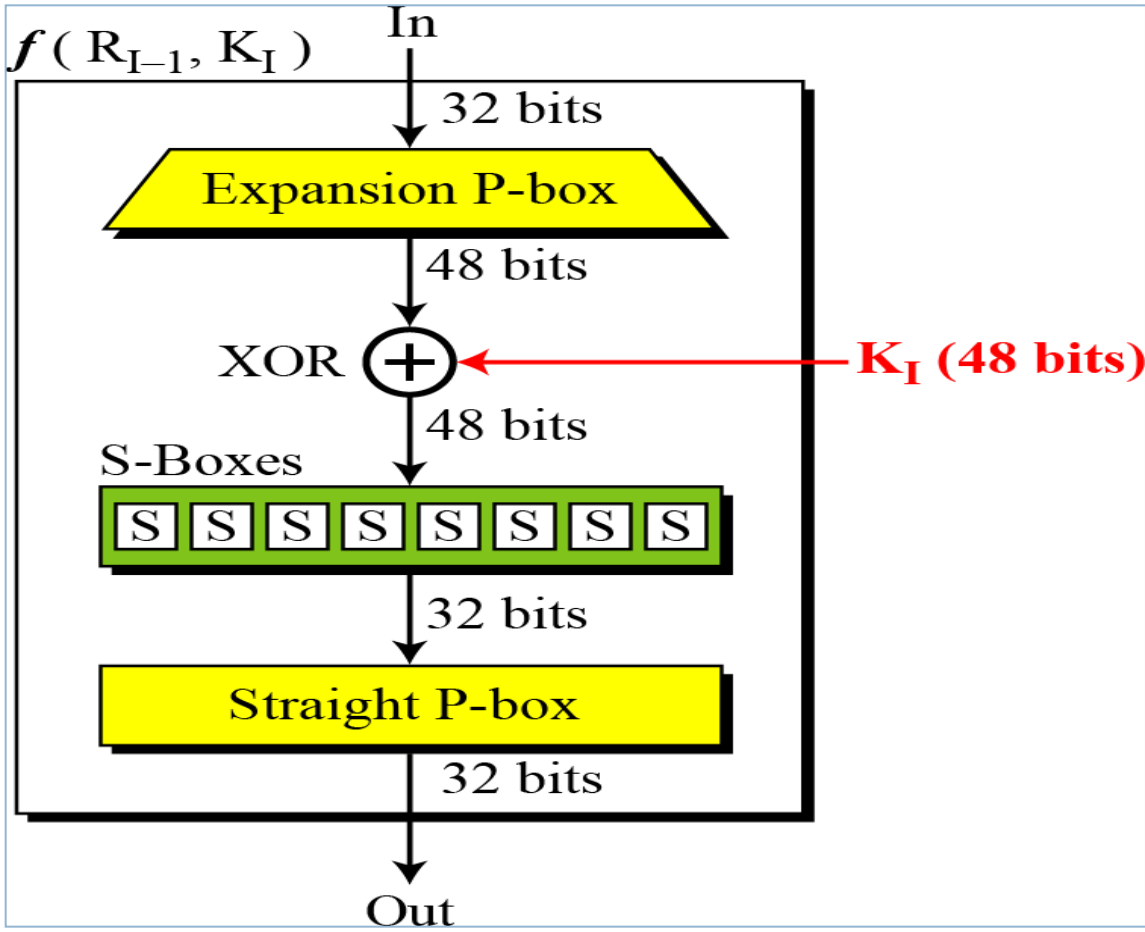




DES Structure

DES function

- Expansion P-Box
- Whitener (XOR)
- S-Boxes
- Straight P-Box



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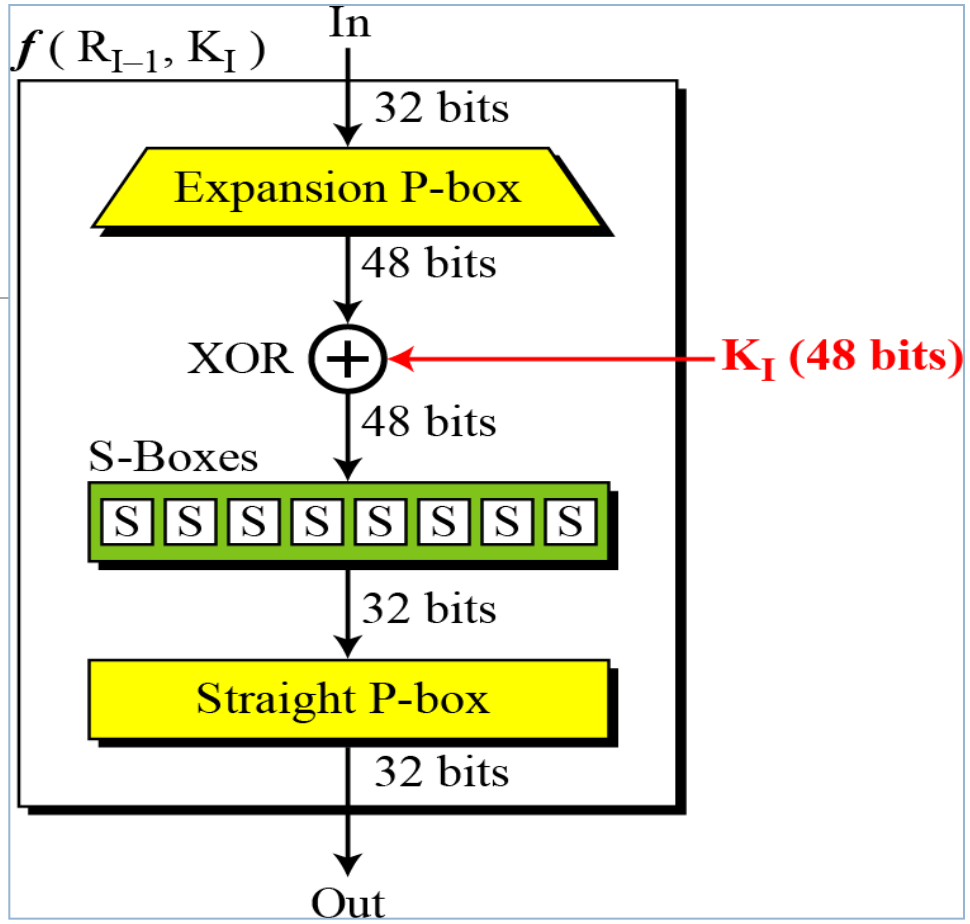
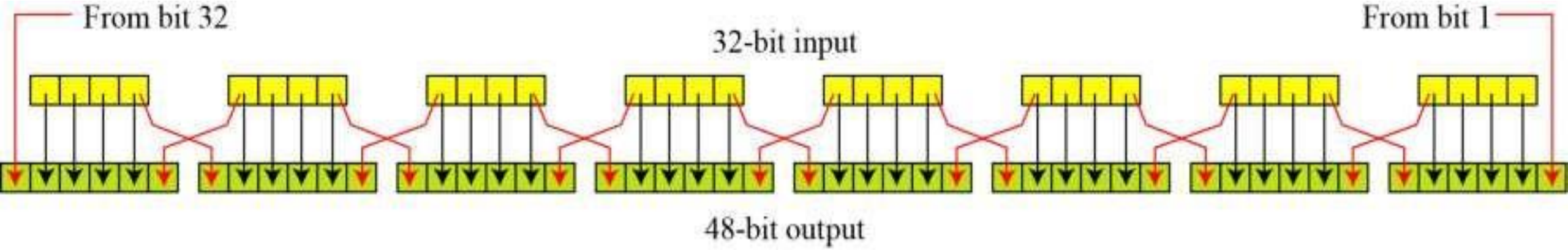
DES Structure

DES function - Expansion P-Box

- RPT is expanded from 32 bits to 48 bits.
- Bits are permuted as well hence called expansion permutation.
- This happens as the 32-bit RPT is divided into 8 blocks, with each block consisting of 4 bits.
- Then, each 4-bit block of the previous step is then expanded to a corresponding 6-bit block, i.e., per 4-bit block, 2 more bits are added.





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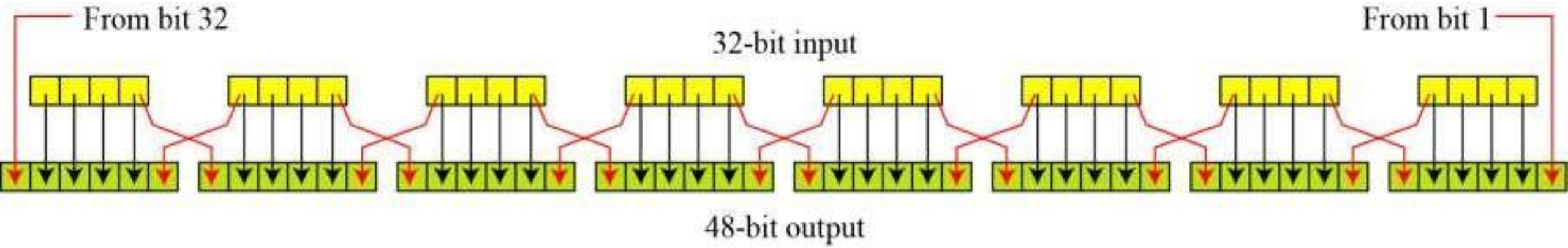
DES Structure

DES function - Expansion P-Box

- RPT is expanded from 32 bits to 48 bits.
- Bits are permuted as well hence called expansion permutation.
- This happens as the 32-bit RPT is divided into 8 blocks, with each block consisting of 4 bits.
- Then, each 4-bit block of the previous step is then expanded to a corresponding 6-bit block, i.e., per 4-bit block, 2 more bits are added.

32	01	02	03	04	05
04	05	06	07	08	09
08	09	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	31	31	32	01

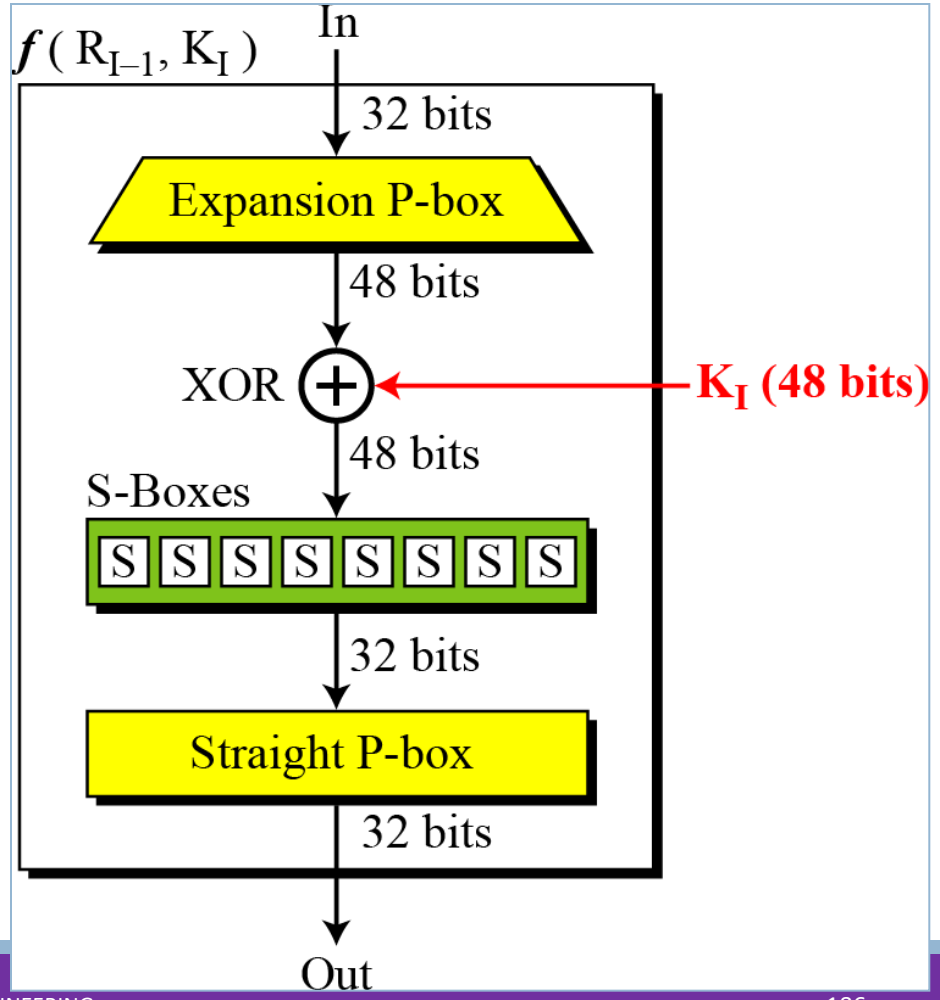


DES Structure

DES function - Whitener (XOR)

After the expansion permutation, DES does XOR operation on the expanded right section and the round key.

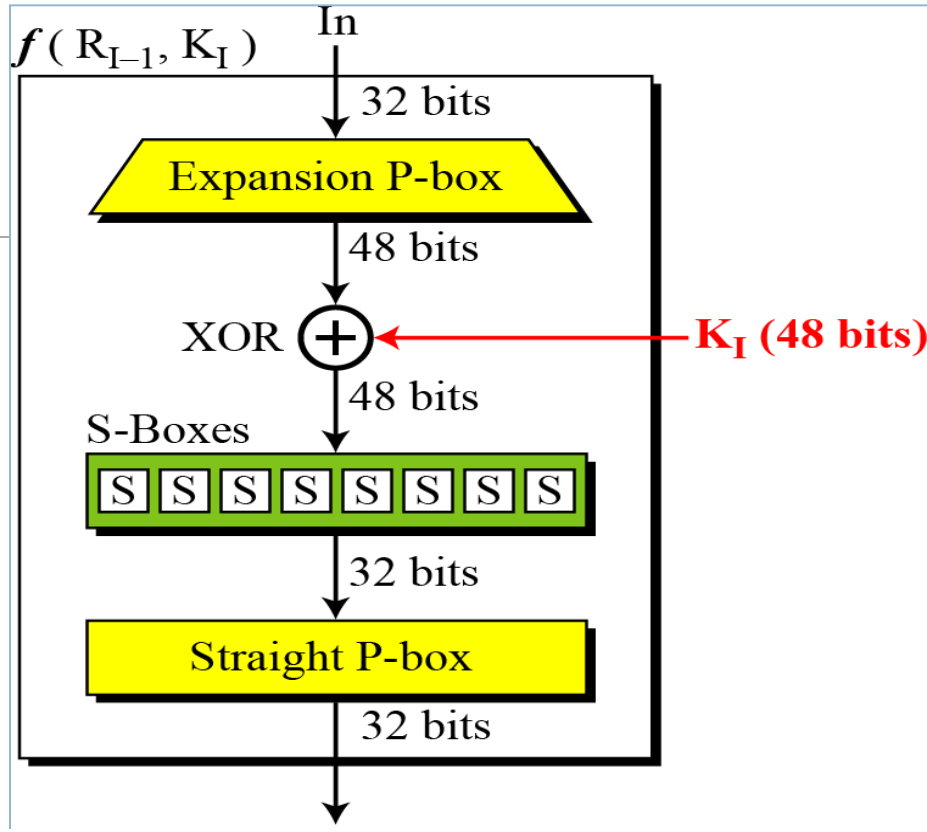
The round key is used only in this operation.

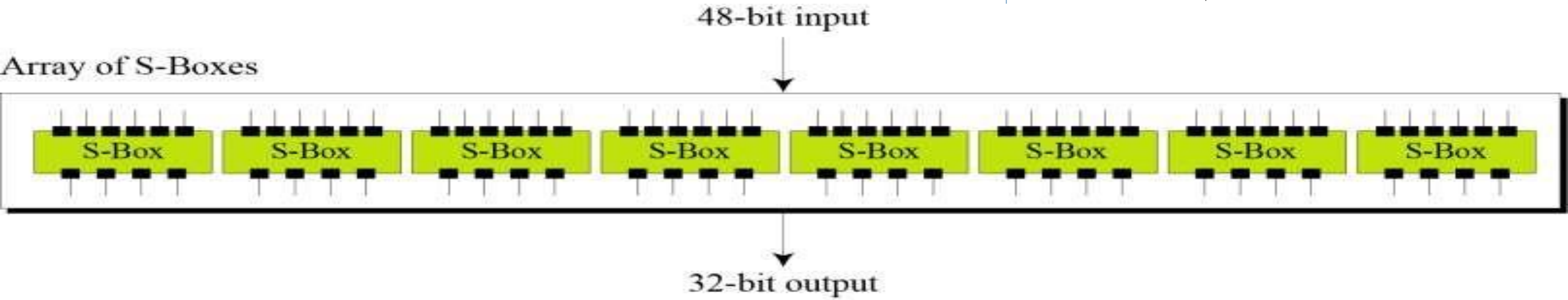


DES Structure

DES function - S-Boxes

- The S-boxes carry out the real mixing (confusion).
- DES uses 8 S-boxes, each with a 6-bit input and a 4-bit output.





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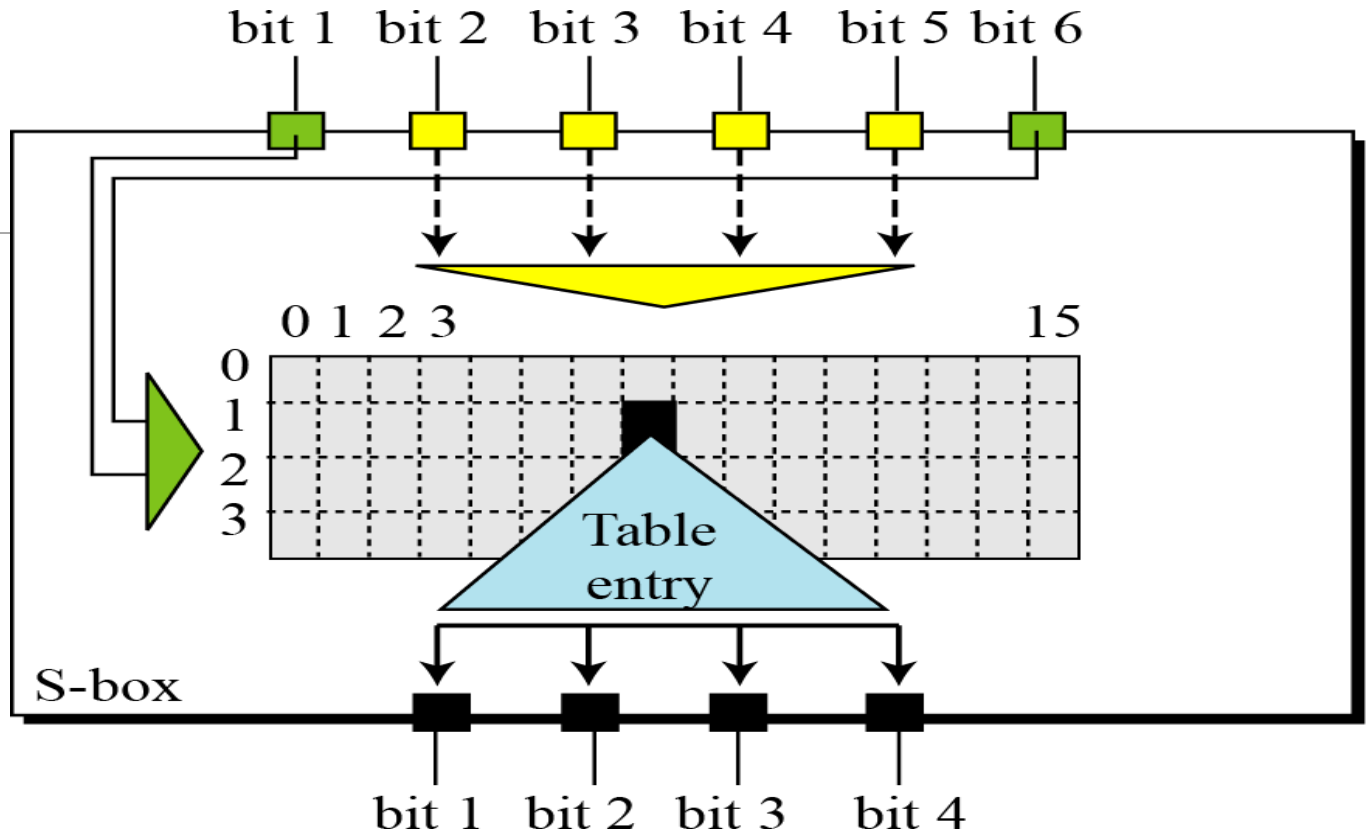
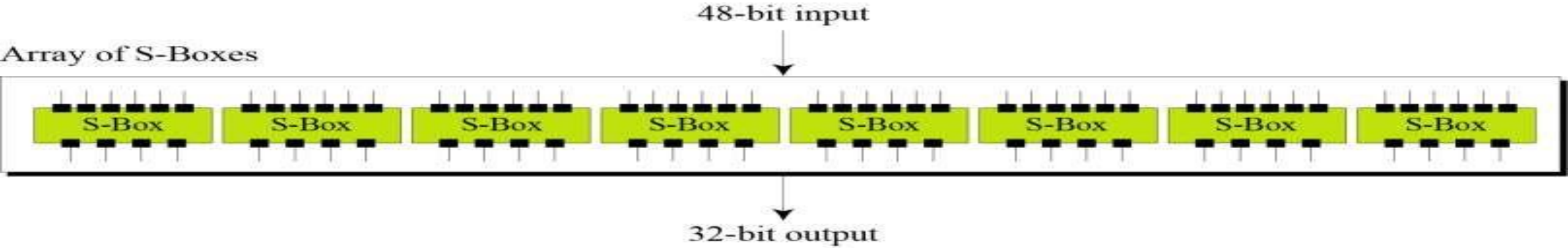
DES Structure

DES function - **S-Boxes**





DES Structure

DES function - S-Boxes

B = 011011 the first bit is "0" and the last bit "1" giving 01 as the row. This is row 1.

The middle four bits are "**1101**". This is the binary equivalent of decimal 13, so the column is column number 13.

In row 1, column 13 appears 5. This determines the output; 5 is binary 0101, so that the output is 0101.

Hence $\mathbf{S_1}(011011) = 0101$.

S-box 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	14	04	13	01	02	15	11	08	03	10	06	12	05	09	00	07
1	00	15	07	04	14	02	13	10	03	06	12	11	09	05	03	08
2	04	01	14	08	13	06	02	11	15	12	09	07	03	10	05	00
3	15	12	08	02	04	09	01	07	05	11	03	14	10	00	06	13

DES Structure

DES function - S-Boxes

S-box 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	15	01	08	14	06	11	03	04	09	07	02	13	12	00	05	10
1	03	13	04	07	15	02	08	14	12	00	01	10	06	09	11	05
2	00	14	07	11	10	04	13	01	05	08	12	06	09	03	02	15
3	13	08	10	01	03	15	04	02	11	06	07	12	00	05	14	09

S-box 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	10	00	09	14	06	03	15	05	01	13	12	07	11	04	02	08
1	13	07	00	09	03	04	06	10	02	08	05	14	12	11	15	01
2	13	06	04	09	08	15	03	00	11	01	02	12	05	10	14	07
3	01	10	13	00	06	09	08	07	04	15	14	03	11	05	02	12

S-box 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	07	13	14	03	00	6	09	10	1	02	08	05	11	12	04	15
1	13	08	11	05	06	15	00	03	04	07	02	12	01	10	14	09
2	10	06	09	00	12	11	07	13	15	01	03	14	05	02	08	04
3	03	15	00	06	10	01	13	08	09	04	05	11	12	07	02	14

DES Structure

DES function - S-Boxes

S-box 6

	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
0	12	01	10	15	09	02	06	08	00	13	03	04	14	07	05	11
1	10	15	04	02	07	12	09	05	06	01	13	14	00	11	03	08
2	09	14	15	05	02	08	12	03	07	00	04	10	01	13	11	06
3	04	03	02	12	09	05	15	10	11	14	01	07	10	00	08	13

S-box 7

	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
0	4	11	2	14	15	00	08	13	03	12	09	07	05	10	06	01
1	13	00	11	07	04	09	01	10	14	03	05	12	02	15	08	06
2	01	04	11	13	12	03	07	14	10	15	06	08	00	05	09	02
3	06	11	13	08	01	04	10	07	09	05	00	15	14	02	03	12

S-box 8

	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
0	13	02	08	04	06	15	11	01	10	09	03	14	05	00	12	07
1	01	15	13	08	10	03	07	04	12	05	06	11	10	14	09	02
2	07	11	04	01	09	12	14	02	00	06	10	10	15	03	05	08
3	02	01	14	07	04	10	8	13	15	12	09	09	03	05	06	11

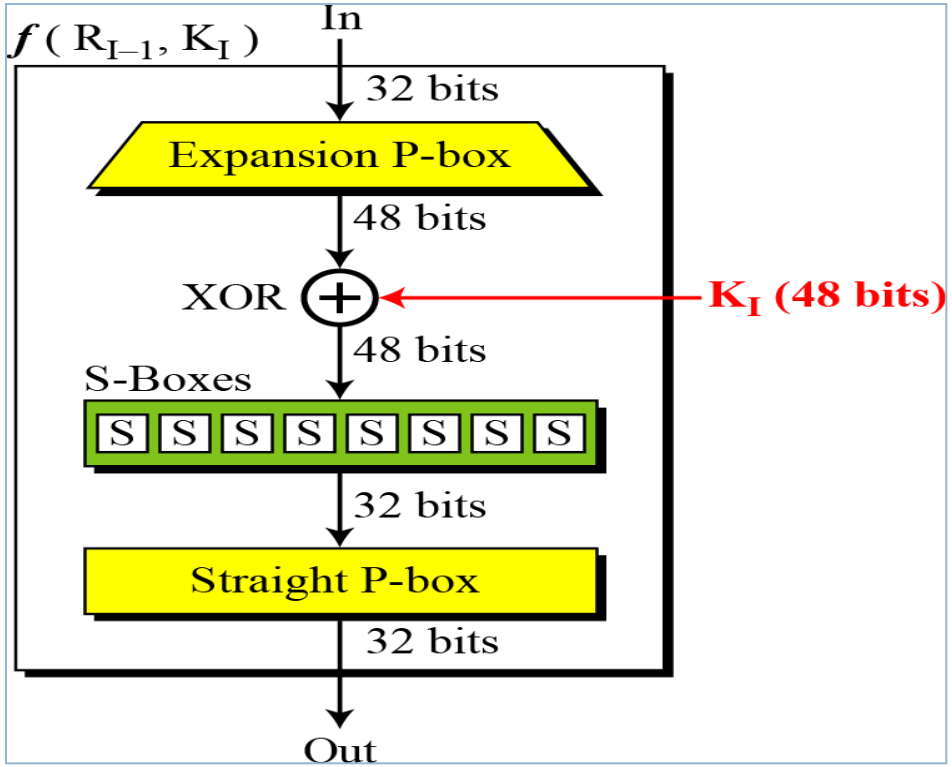
DES Structure

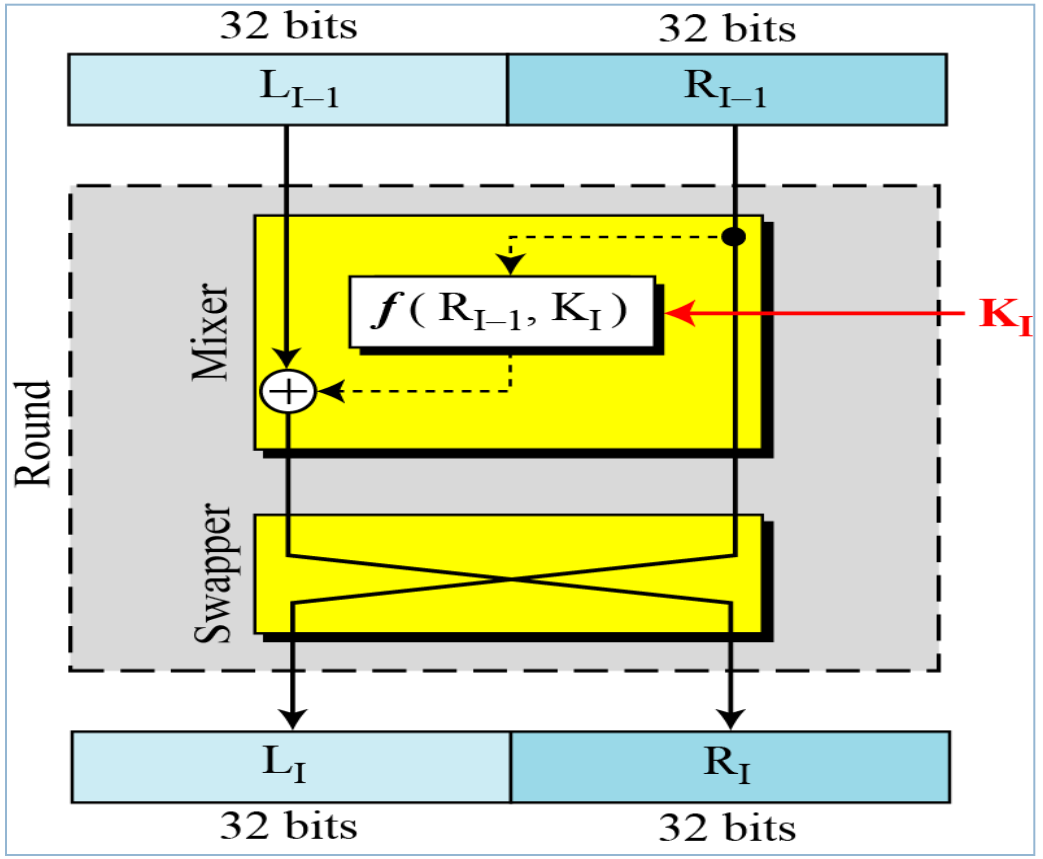
DES function - Straight P-Box

The 32 bit output of S-boxes is then subjected to the straight permutation with rule shown in the following illustration:

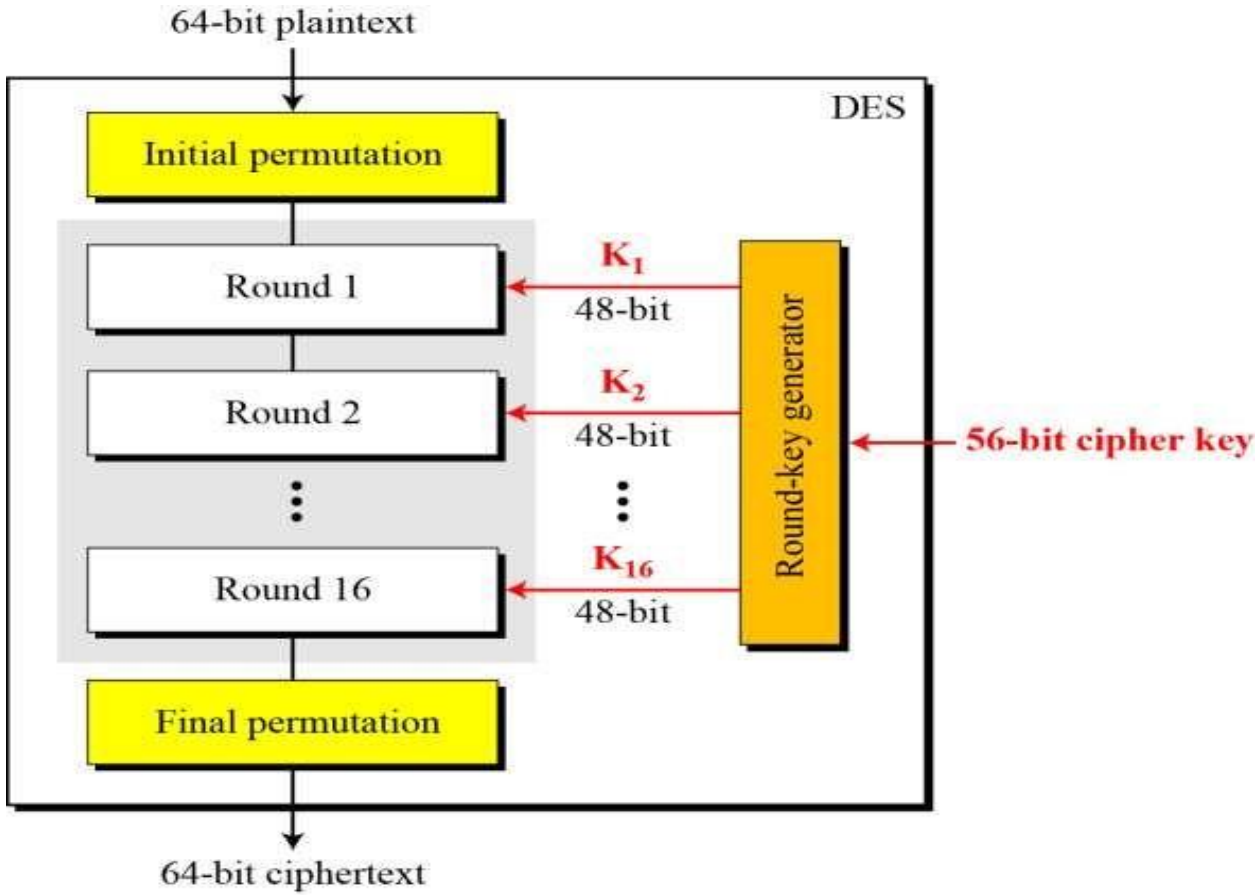
16	07	20	21	29	12	28	17
01	15	23	26	05	18	31	10
02	08	24	14	32	27	03	09
19	13	30	06	22	11	04	25

DES Structure



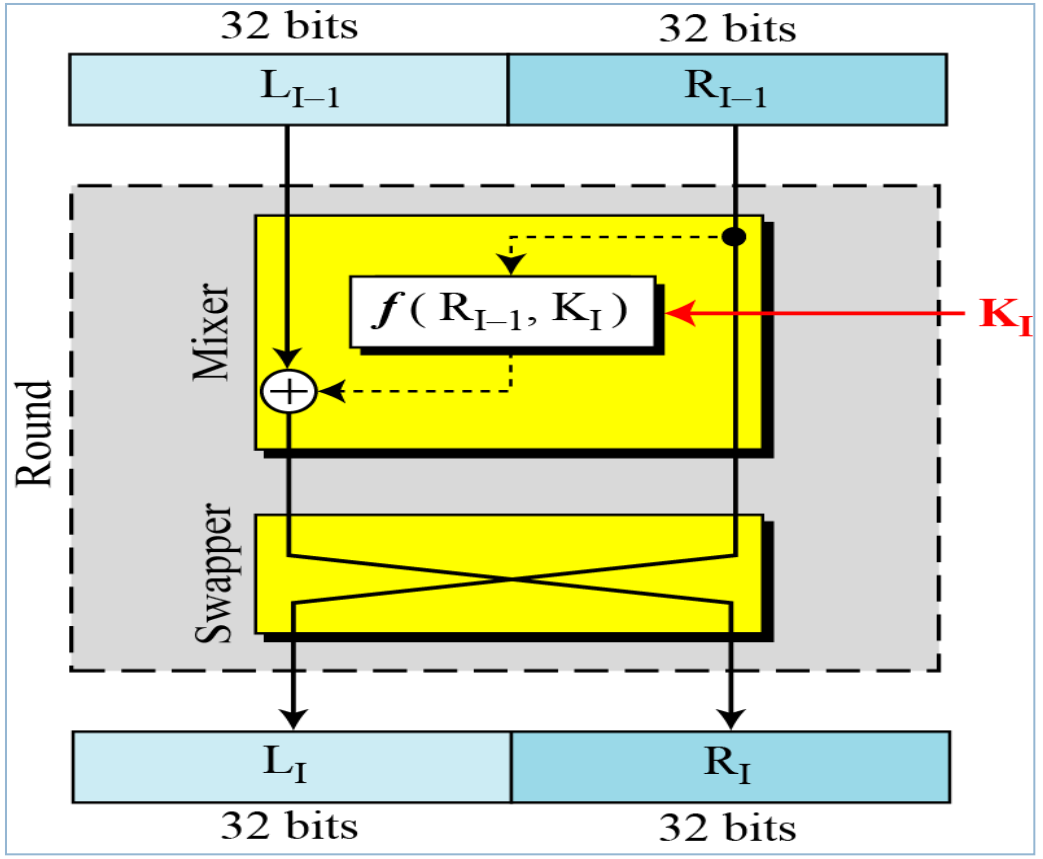


DES Structure



Cipher and Reverse Cipher

- Using Mixer and Swapper, we can
  - create the cipher and
  - reverse cipher, each having 16rounds.
- Cipher is used at encryption site
- Reverse cipher is used at decryption site
- Whole idea is to make cipher and reverse cipher similar



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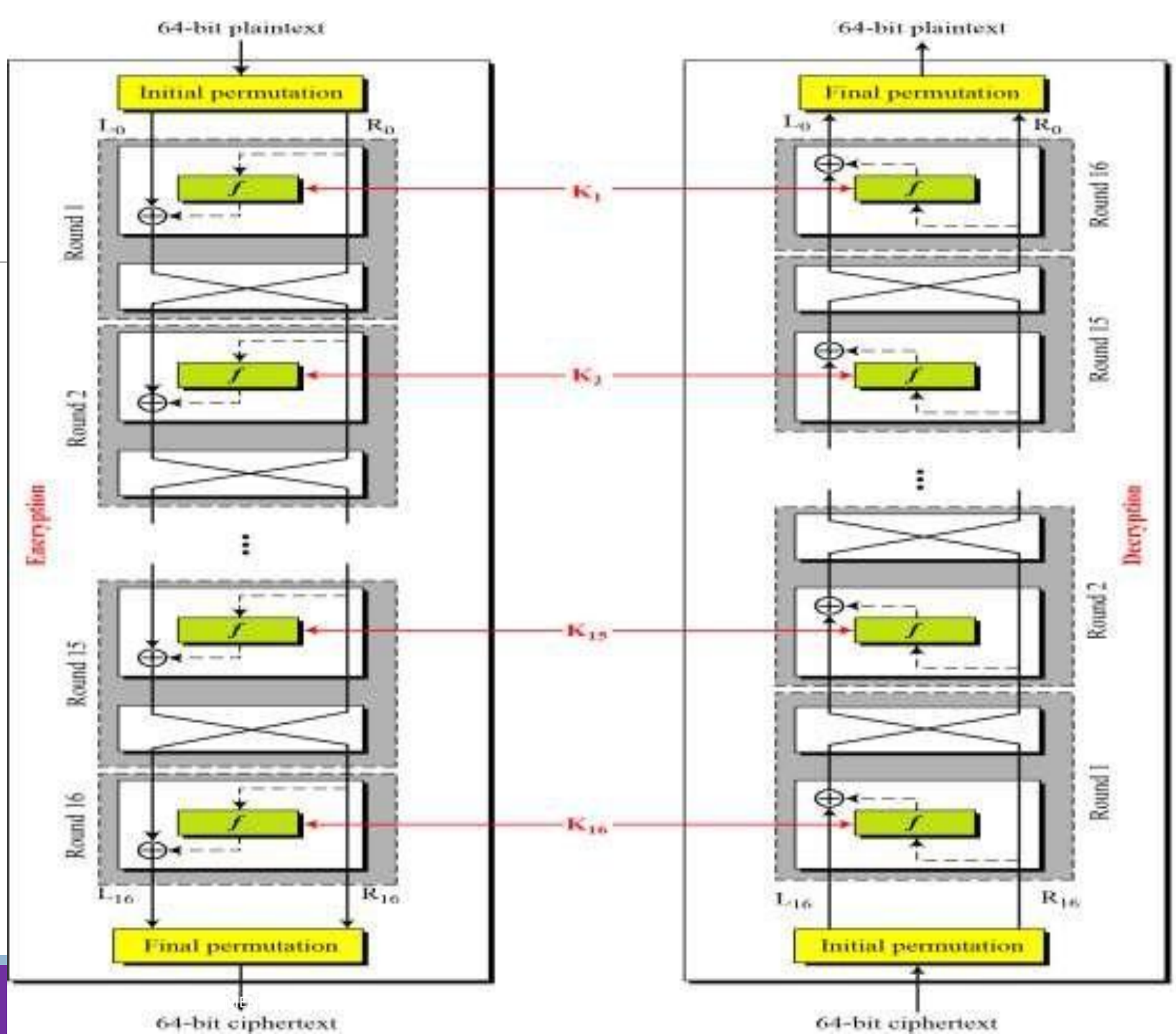
First Approach

Make the last round (round 16) different from others, it has only mixer and no swapper



Pseudocode for cipher – First approach

```
Cipher (plainBlock[64], RoundKeys[16, 48], cipherBlock[64])
{
    permute (64, 64, plainBlock, inBlock, InitialPermutationTable)
    split (64, 32, inBlock, leftBlock, rightBlock)
     for (round = 1 to 16)
     {
          mixer (leftBlock, rightBlock, RoundKeys[round])
           if (round!=16) swapper (leftBlock, rightBlock)
    }
     combine (32, 64, leftBlock, rightBlock, outBlock)
     permute (64, 64, outBlock, cipherBlock, FinalPermutationTable)
}
```

Pseudocode for cipher – First approach

```
mixer (leftBlock[48], rightBlock[48], RoundKey[48])
{
    copy (32, rightBlock, T1)
    function (T1, RoundKey, T2)
    exclusiveOr (32, leftBlock, T2, T3)
    copy (32, T3, rightBlock)
}
swapper (leftBlock[32], rigthBlock[32])
{
    copy (32, leftBlock, T)
    copy (32, rightBlock, leftBlock)
    copy (32, T, rightBlock)
}
```

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Pseudocode for cipher – First approach

```
function (inBlock[32], RoundKey[48], outBlock[32])
{
    permute (32, 48, inBlock, T1, ExpansionPermutationTable)
    exclusiveOr (48, T1, RoundKey, T2)
    substitute (T2, T3, SubstituteTables)
    permute (32, 32, T3, outBlock, StraightPermutationTable)
}
```

```
substitute (inBlock[32], outBlock[48], SubstitutionTables[8, 4, 16])
{
    for (i = 1 to 8)
    {
        row ← 2 × inBlock[i × 6 + 1] + inBlock [i × 6 + 6]
        col ← 8 × inBlock[i × 6 + 2] + 4 × inBlock[i × 6 + 3] +
              2 × inBlock[i × 6 + 4] + inBlock[i × 6 + 5]

        value = SubstitutionTables [i][row][col]

        outBlock[[i × 4 + 1] ← value / 8;        value ← value mod 8
        outBlock[[i × 4 + 2] ← value / 4;        value ← value mod 4
        outBlock[[i × 4 + 3] ← value / 2;        value ← value mod 2
        outBlock[[i × 4 + 4] ← value
    }
}
```

Cipher and Reverse Cipher

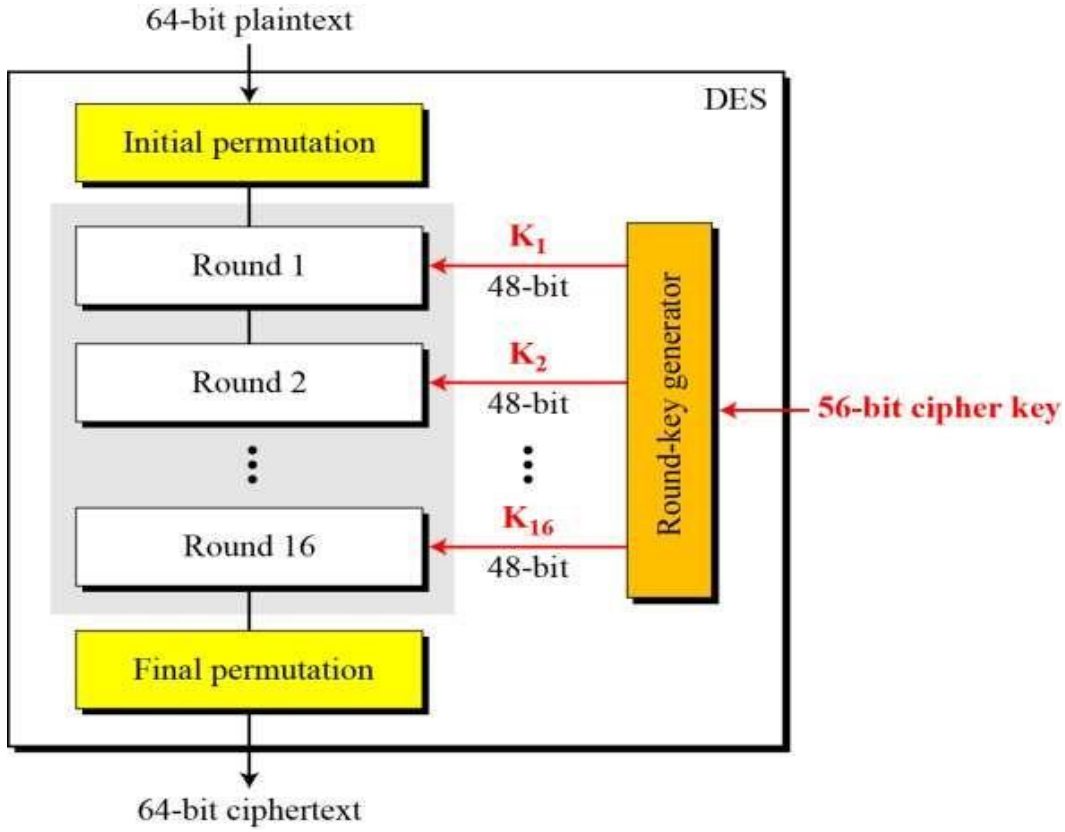
Alternative Approach

Make the all 16 rounds the same by including one swapper to the 16^{th} round and an extra swapper after that .

DES Structure

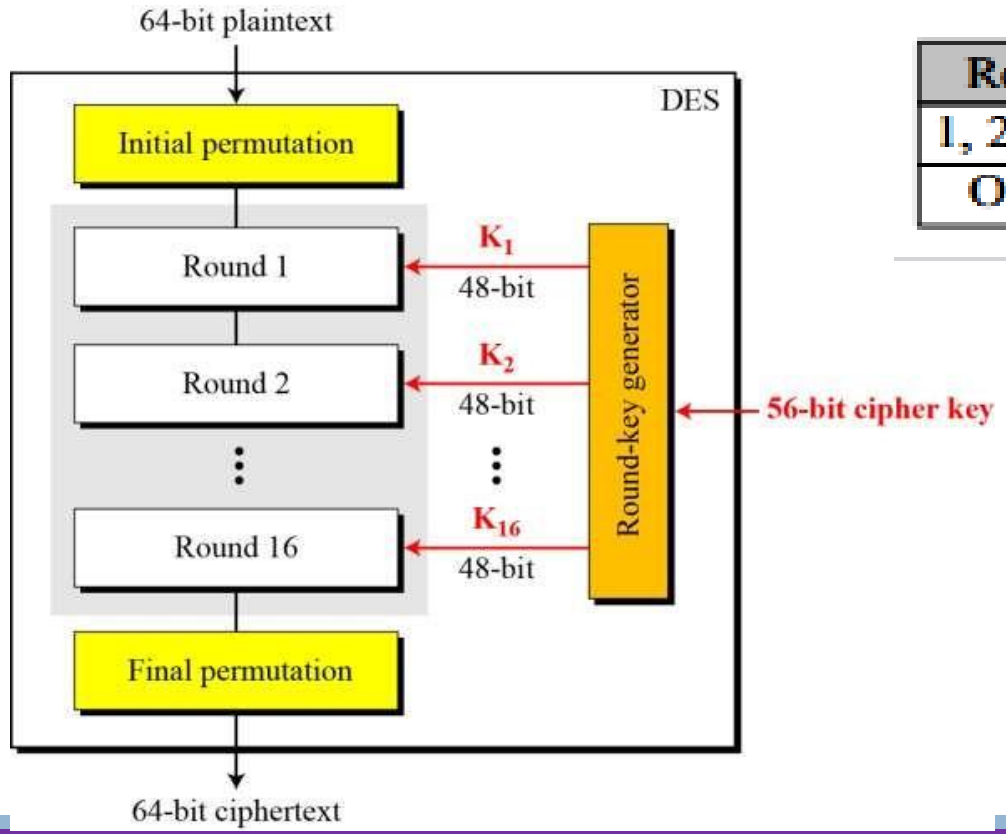
Round Key Generator

- The round-key generator creates sixteen 48-bit keys out of a 56-bit cipher key.
- The process of key generation is depicted in the following illustration



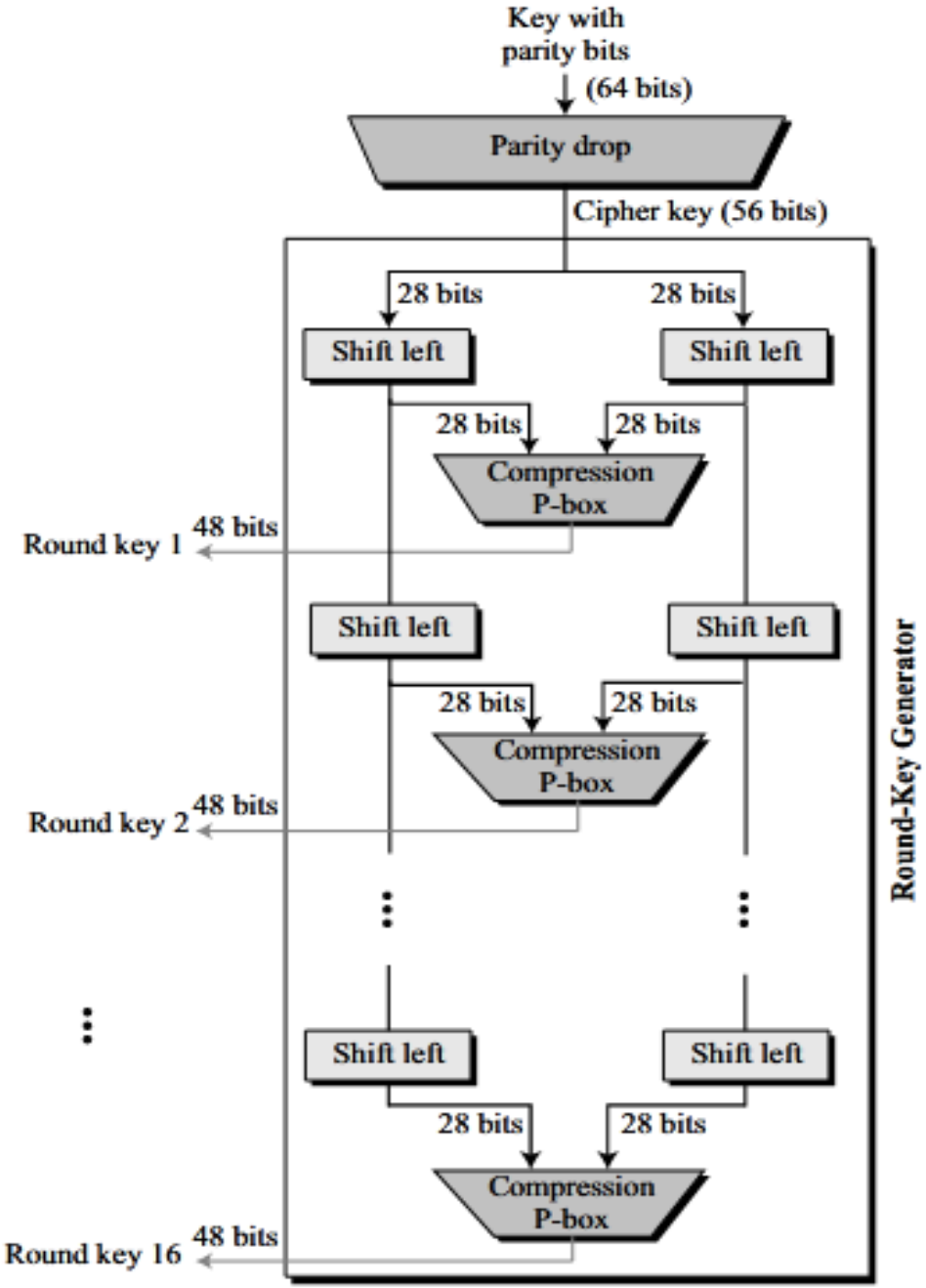
DES Structure

Round Key Generator



Shifting

Rounds	Shift
1, 2, 9, 16	one bit
Others	two bits



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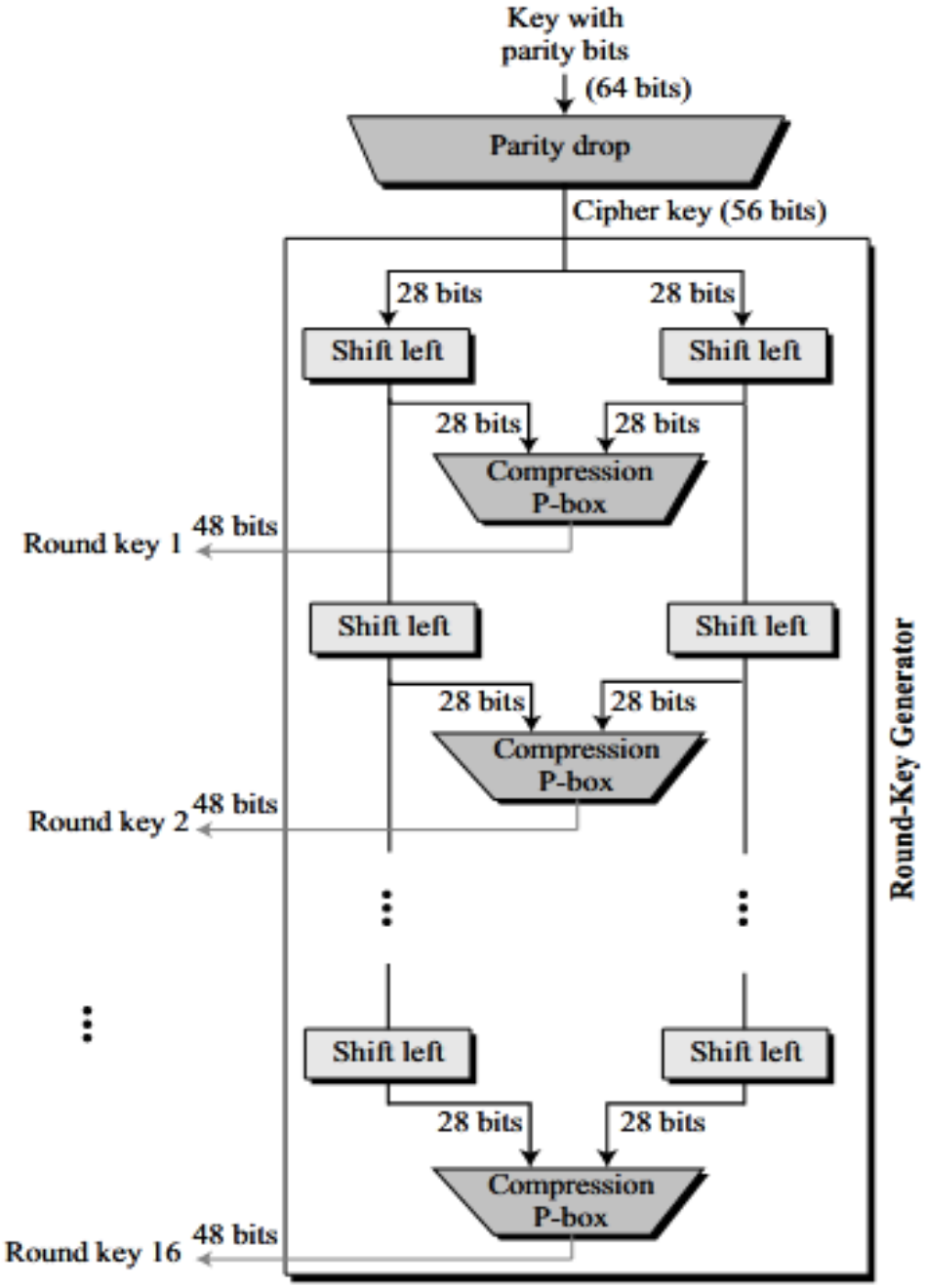
DES Structure

Round Key Generator

- The round-key generator creates sixteen 48-bit keys out of a 56-bit cipher key.
- However, the cipher key is normally given as a 64-bit key in which 8 extra bits are the parity bits, which are dropped before the actual key-generation process,



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DES Structure

Parity Drop

The preprocess before key expansion is a compression permutation that we call parity bit drop.

It drops the parity bits (bits 8, 16, 24, 32, ..., 64) from the 64-bit key and permutes the rest of the bits according to Table 6.12

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

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

Table 6.12 *Parity-bit drop table*

57	49	41	33	25	17	09	01
58	50	42	34	26	18	10	02
59	51	43	35	27	19	11	03
60	52	44	36	63	55	47	39
31	23	15	07	62	54	46	38
30	22	14	06	61	53	45	37
29	21	13	05	28	20	12	04

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DES Structure

Shift Left

The key is divided into two 28-bit parts.

Each part is shifted left (circular shift) one or two bits.

In rounds 1, 2, 9, and 16, shifting is one bit;

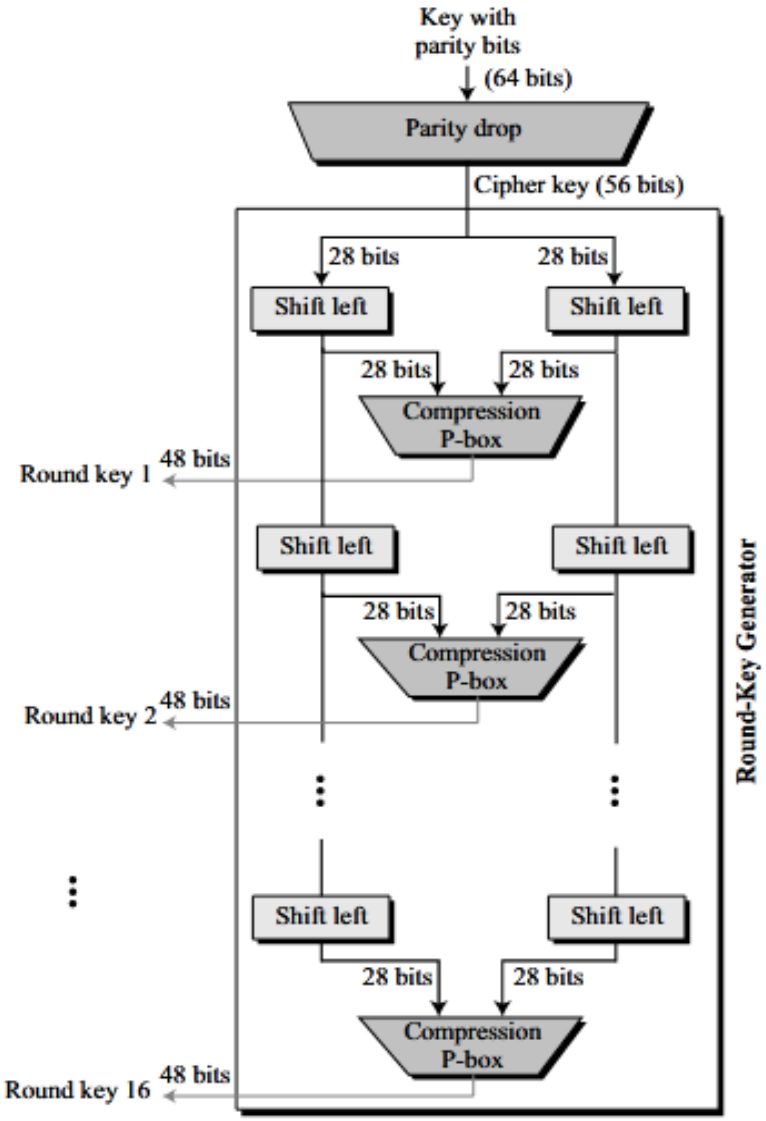
in the other rounds, it is two bits.

Shifting

Rounds	Shift
1, 2, 9, 16	one bit
Others	two bits

The two parts are then combined to form a 56-bit part.

Table 6.13 shows the number of shifts for each round.



Round	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bit shifts	1	1	2	2	2	2	2	2	1	2	2	2	2	2	2	1

DES Structure

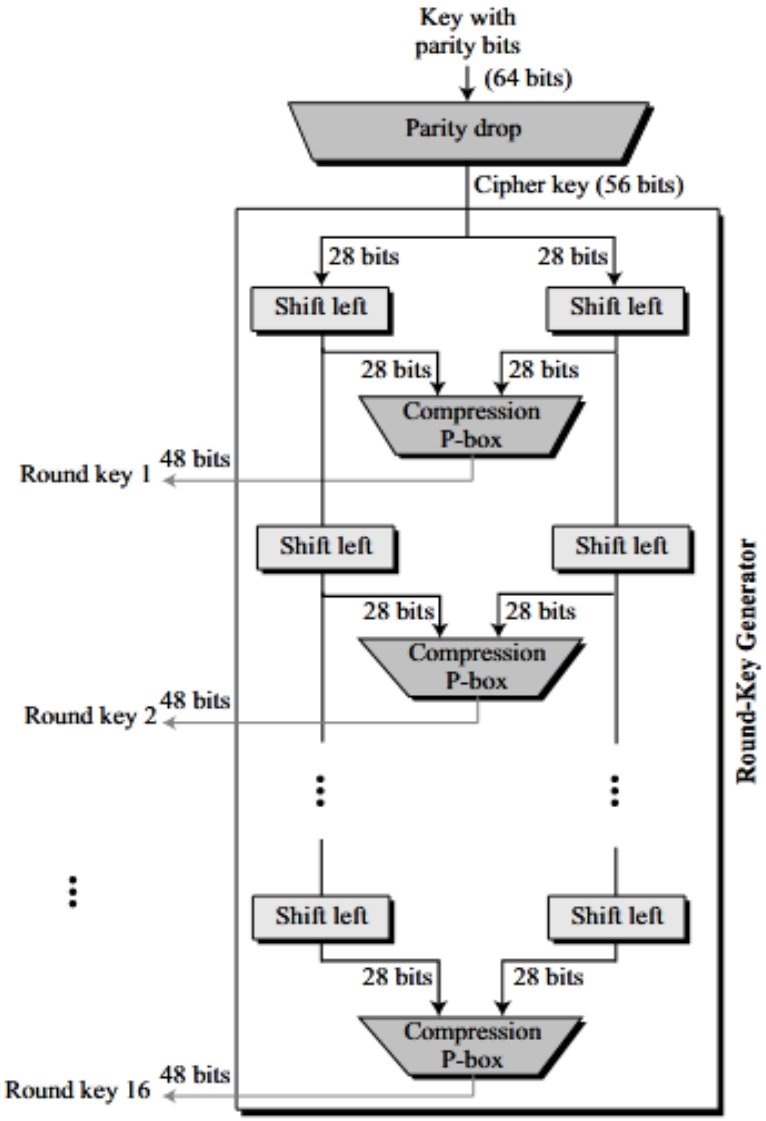
Compression Permutation

The compression permutation (P-box) changes the 58 bits to 48 bit which are used as a key for a round.

The compression permutation is shown in Table 6.14.

Table 6.14 *Key-compression table*

14	17	11	24	01	05	03	28
15	06	21	10	23	19	12	04
26	08	16	07	27	20	13	02
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 Structure

Round Key Generator

```
Key_Generator (keyWithParities[64], RoundKeys[16, 48], ShiftTable[16])
{
    permute (64, 56, keyWithParities, cipherKey, ParityDropTable)
    split (56, 28, cipherKey, leftKey, rightKey)
     for (round = 1 to 16)
     {
          shiftLeft (leftKey, ShiftTable[round])
          shiftLeft (rightKey, ShiftTable[round])
          combine (28, 56, leftKey, rightKey, preRoundKey)
          permute (56, 48, preRoundKey, RoundKeys[round], KeyCompressionTable)
     }
}
```

DES Analysis

Properties of a Block Cipher

1. Avalanche Effect
2. Completeness Effect

Design Criteria

- S-Boxes
- P-Boxes
- Number of rounds

DES Weakness

1. Weakness in cipher design
   - S-Boxes
   - P-Boxes
2. Weakness in cipher key
   - Key size
   - Weak keys
   - Semi-weak keys
   - Possible Weak keys

DES Analysis

Properties of a Block Cipher - Avalanche Effect

- Avalanche effect is considered as one of the desirable property of any encryption algorithm.
- A slight change in either the key or the plain-text should result in a significant change in the cipher-text. This property is termed as avalanche effect.

DES Analysis

Properties of a Block Cipher - Avalanche Effect

Plaintext: 0000000000000000 Key: 22234512987ABB23
Ciphertext: 4789FD476E82A5F1

Plaintext: 0000000000000001 Key: 22234512987ABB23
Ciphertext: 0A4ED5C15A63FEA3

DES Analysis

Properties of a Block Cipher - Completeness Effect

Each bit of cipher text depends on many bits of plaintext.

The diffusion and confusion produced by P-Box and S-Box in DES, shows strong completeness effect

DES Analysis

Design Criteria

- S-Boxes
- P-Boxes
- Number of rounds

DES Analysis

S-box 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	14	04	13	01	02	15	11	08	03	10	06	12	05	09	00	07
1	00	15	07	04	14	02	13	10	03	06	12	11	09	05	03	08
2	04	01	14	08	13	06	02	11	15	12	09	07	03	10	05	00
3	15	12	08	02	04	09	01	07	05	11	03	14	10	00	06	13

Design Criteria - S-Boxes

1. The entries of each row are permutations of values between 0 and 15.
2. S-boxes are nonlinear.
3. If we change a single bit in the input, two or more bits will be changed in the output.
4. If two inputs to an S-box differ only in two middle bits (bits 3 and 4), the output must differ in at least two bits.
5. If two inputs to an S-box differ in first two middle bits (bits 1 and 2) and the same in the last two bits (bits 5 and 6), the two outputs must different.

B = 011011

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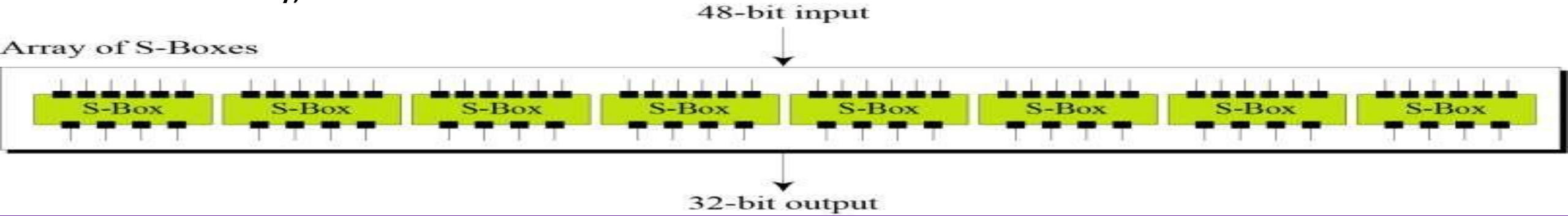
DES Analysis

Design Criteria - S-Boxes

6. There are only 32 6-bit input-word pairs (xi and xj), in which xi $\oplus$ xj $\neq (000000)_2$. These 32 input pairs create 32 4-bit output-word pairs. If we create the difference between the 32 output pairs, d = yi $\oplus$ yj, no more than 8 of these d's should be the same.

7. A criterion similar to #6 is applied to three S-boxes.

8. In any S-box, if a single input bit is held constant (0 or 1) and other bits are changed randomly, the differences between the numbers of 0s and 1s are minimized.



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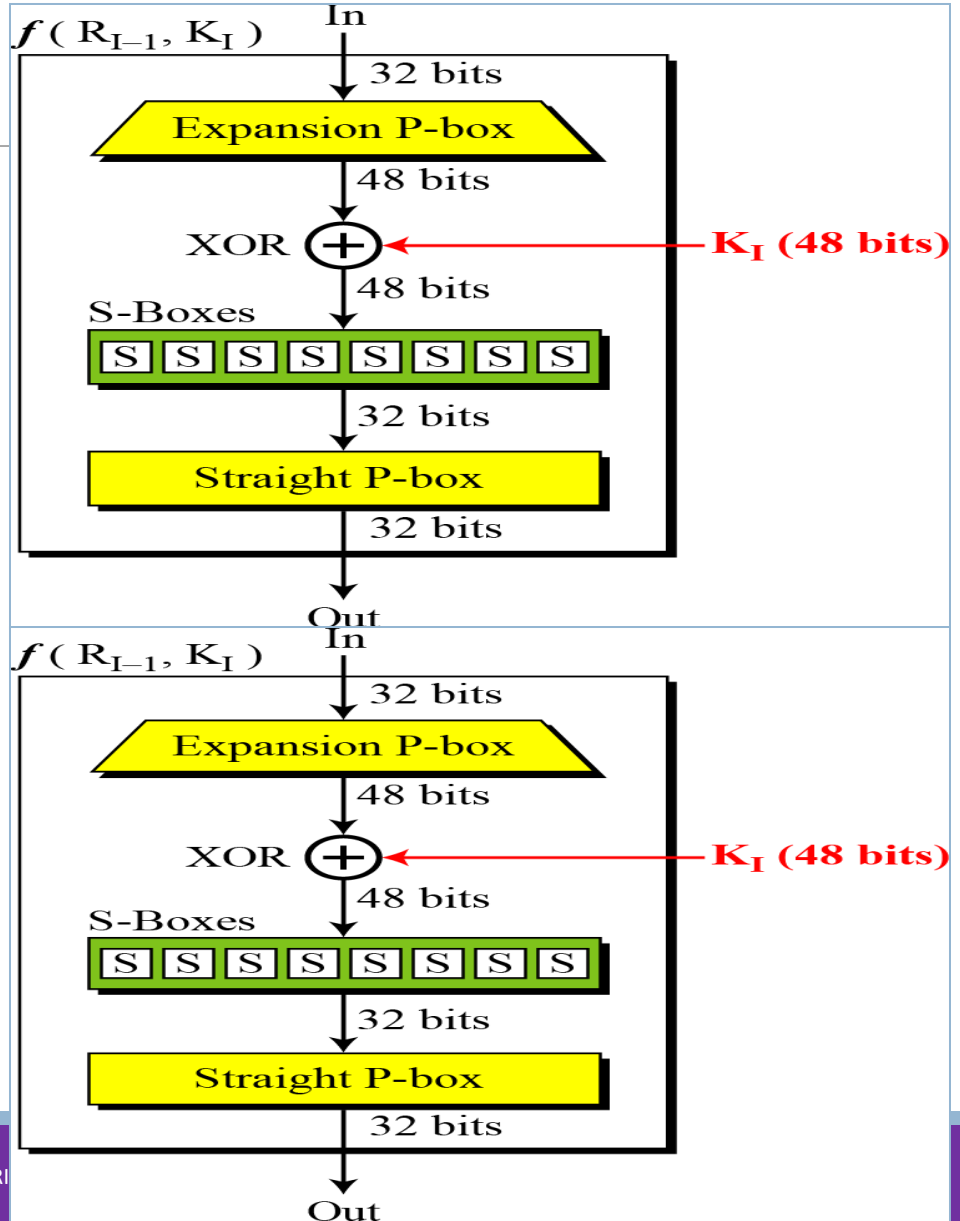
DES Analysis

Design Criteria - P-Boxes

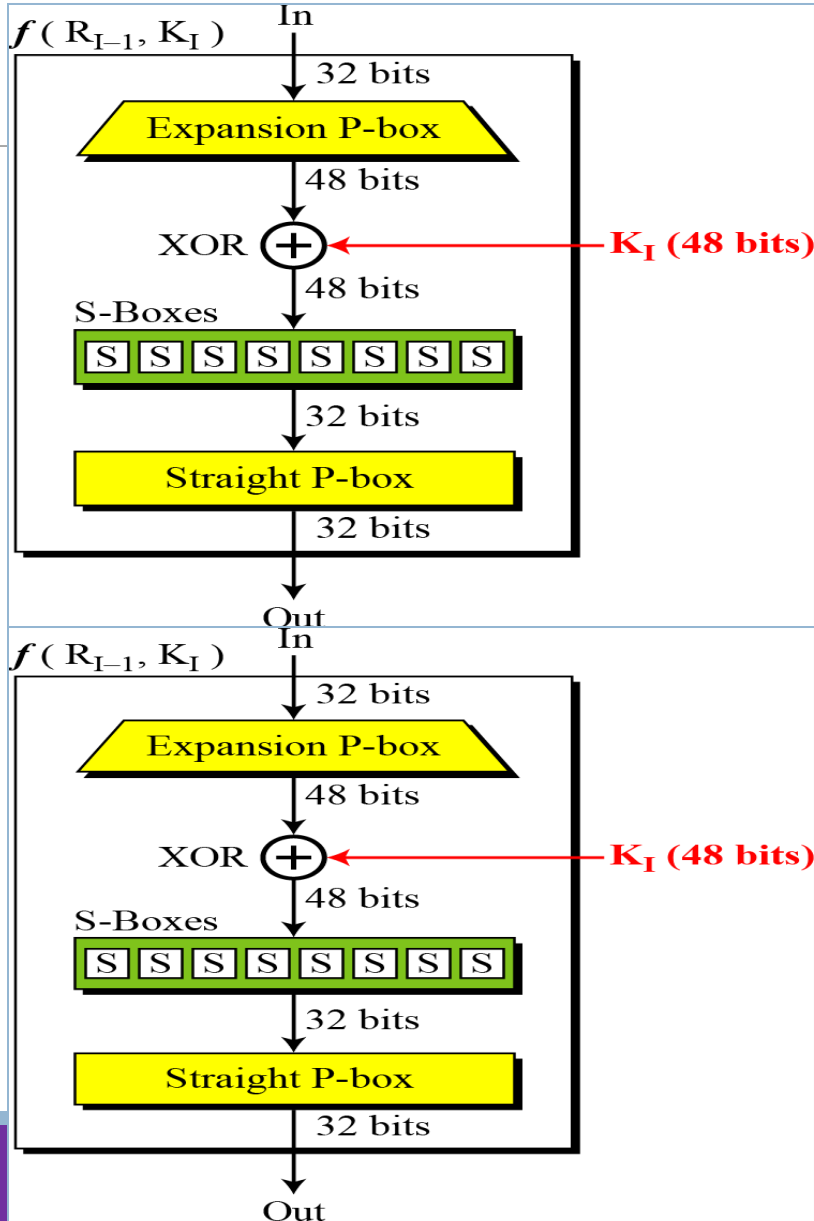
- Between two rows of S-boxes (in two subsequent rounds), there are one straight P-box and one expansion P-box.
- These two P-boxes provide diffusion of bits.



DES Analysis

Design Criteria - P-Boxes

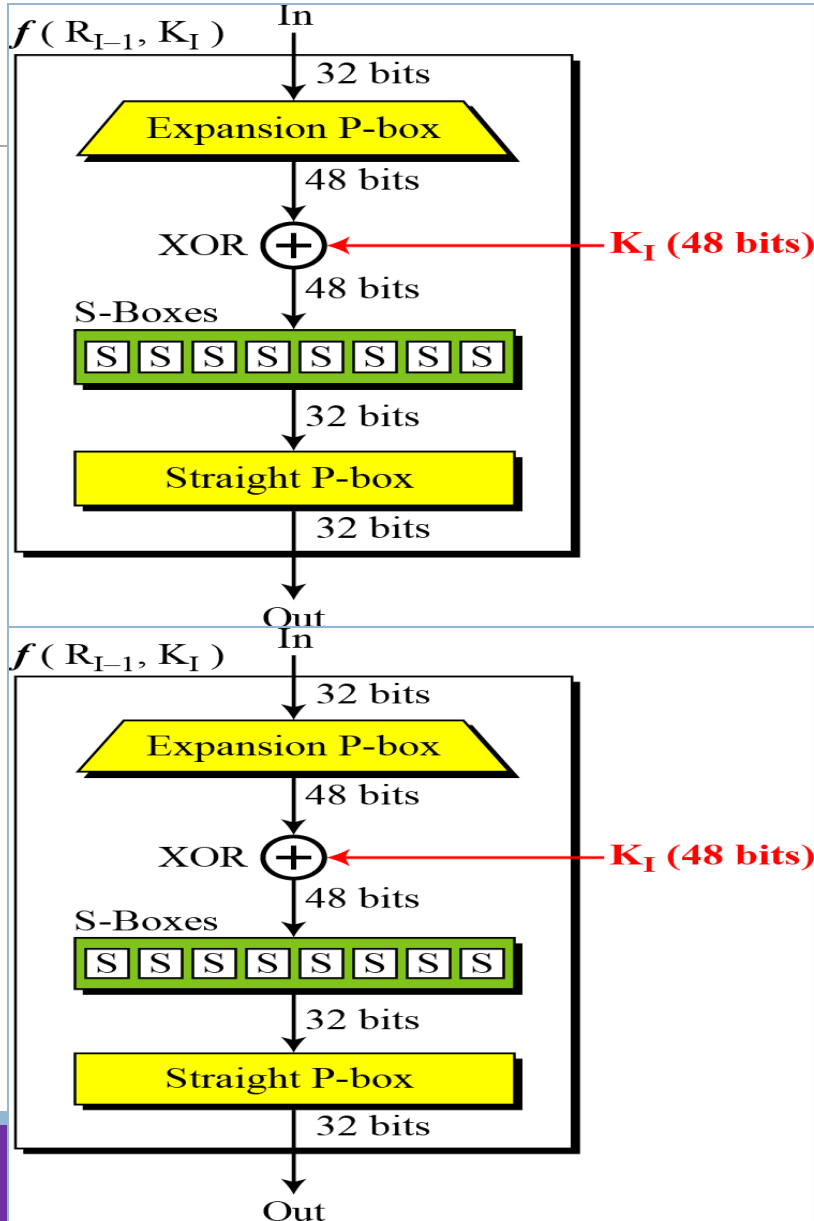
- Each S-box input comes from the output of a different S-box.
- No input to a given S-box comes from the output from the same box (in the previous round).
- The four outputs from each S-box go to six different S-boxes (in the next round).
- No two output bits from an S-box go to the same S-box (in the next round).



DES Analysis

Design Criteria - P-Boxes

- If we number the eight S-boxes, S1, S2,S3,S4 …, S8,
  - An output of S_{j-2} goes to one of the first two bits of Sj (in the next round).
  - An output of S_{j-1} goes to one of the last two bits of Sj (in the next round).
  - An output of S_{j+1} goes to one of the two middle bits of Sj (in the next round).



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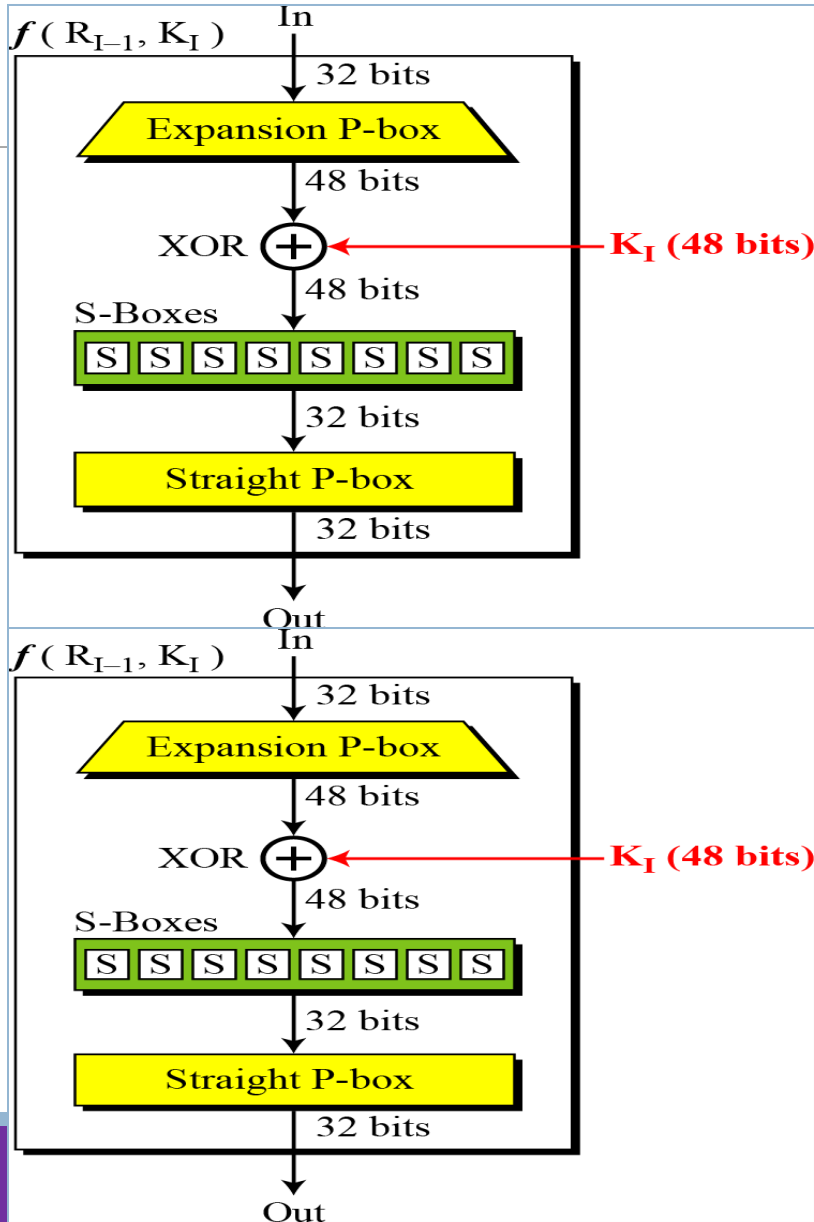
DES Analysis

Design Criteria - P-Boxes

- For each S-box, the two output bits go to the first or last two bits of an S-box in the next round. The other two output bits go to the middle bits of an S-box in the next round.
- If an output bit from Sj goes to one of the middle bits in Sk (in the next round), then an output bit from Sk cannot go to the middle bit of Sj. If we let j=k, this implies that none of the middle bits of an S-box can go to one of the middle bits of the same S-box the next round.



DES Analysis

Design Criteria - Number of rounds

- DES uses sixteen rounds of Feistel ciphers.
- It has been proved that after eight rounds, each ciphertext is a function of every plaintext bit and every key bit; the ciphertext is thoroughly a random function of plaintext and ciphertext.
- Therefore, it looks like 8 rounds should be enough.
- However, experiments have found that DES versions with less than 16 rounds are even more vulnerable to known-plaintext than brute-force attack, which justify the use of 16 rounds by the designers of DES.

DES Analysis

DES Weakness

1. Weakness in cipher design
   - S-Boxes
   - P-Boxes
2. Weakness in cipher key
   - Key size
   - Weak keys
   - Semi-weak keys
   - Possible weak keys

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DES Analysis

DES Weakness - Weakness in cipher design

S-Boxes

- In S-box 4, the last three output bits can be derived in the same way as the first output bit by complementing some of the input bits.
- Two specifically chosen inputs to an S-box array can create the same output.
- It is possible to obtain the same output in a single round by changing bits in only three neighboring S-boxes.

S-box 4

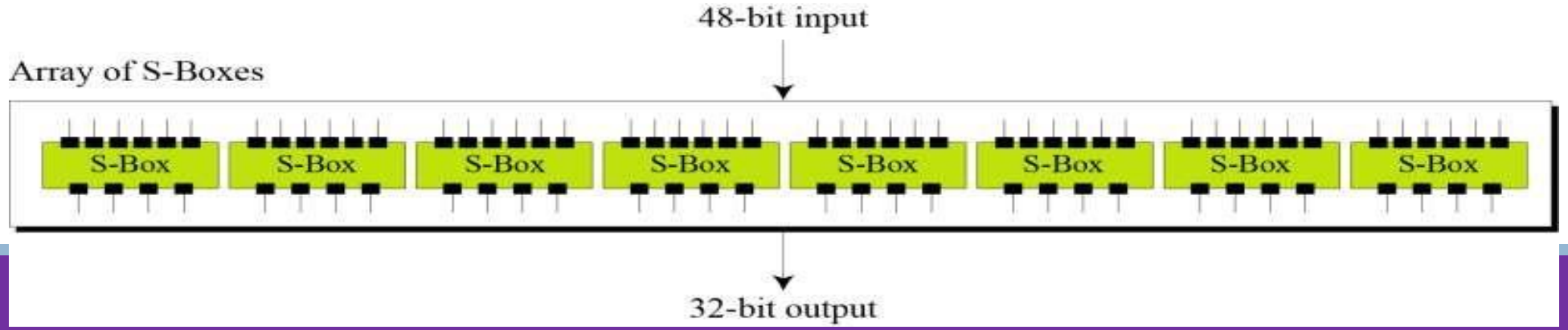
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	07	13	14	03	00	6	09	10	1	02	08	05	11	12	04	15
1	13	08	11	05	06	15	00	03	04	07	02	12	01	10	14	09
2	10	06	09	00	12	11	07	13	15	01	03	14	05	02	08	04
3	03	15	00	06	10	01	13	08	09	04	05	11	12	07	02	14

DES Analysis

DES Weakness - Weakness in cipher design

P-Boxes

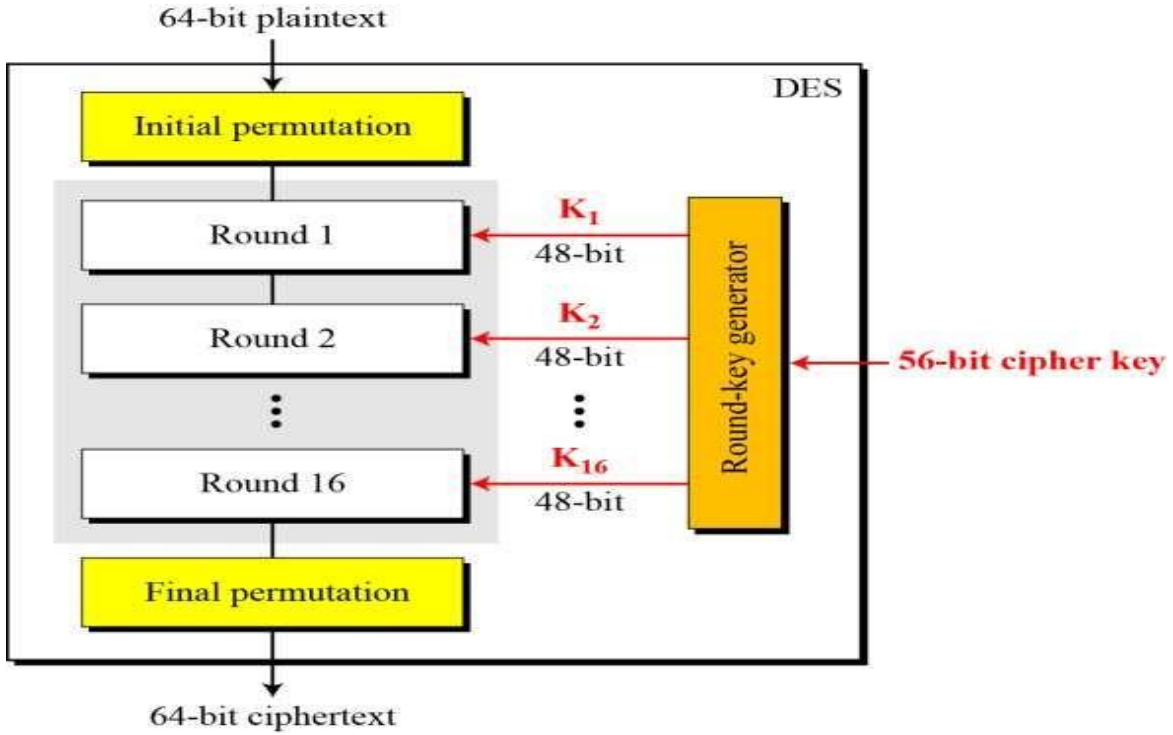
- It is not clear why designers of DES used the initial and final permutations; these have no security benefits.
- In the expansion permutation (inside the function), the first and fourth bits of every 4- bit series are repeated.



DES Analysis

DES Weakness - Weakness in cipher key

- Key size
- Weak keys
- Semi-weak keys
- Possible weak keys



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DES Analysis

Weakness in cipher key - Key size(56 bits)

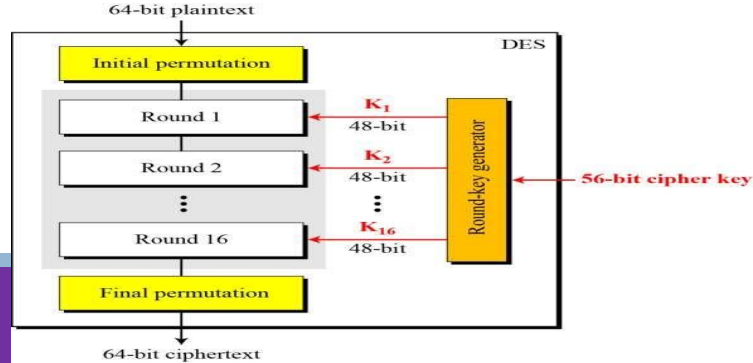
Brute force attack adversary will check with – 2^{56} keys

- One computer with processor → more than thousand years
- Computer network with parallel processing, . In 1977 a team of researchers used 3500 computers attached to the Internet to find a key challenged by RSA Laboratories → 120 days (key challenged by RSA Laboratories)
- If we can make a computer with one million chips (parallel processing), then we can test the whole key domain in approximately 20 hours. → 20 hours

Solution :

3DES with two keys(112bits) (56+56 = 112)

3DES with three keys(168 bits) (56+56+56 =168)



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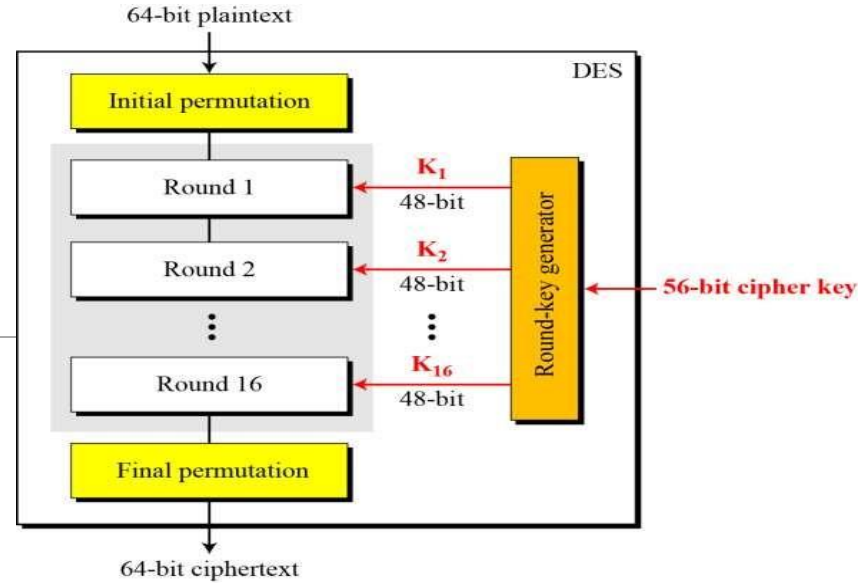
DES Analysis



Weakness in cipher key-Weak keys

- Four out of 2^{56} keys are called weak keys
- A weak key is the one that, after parity drop operation (using Table 6.12), consists either of all 0s, all 1s,or half 0s and half 1s.

Table 6.12 *Parity-bit drop table*

57	49	41	33	25	17	09	01
58	50	42	34	26	18	10	02
59	51	43	35	27	19	11	03
60	52	44	36	63	55	47	39
31	23	15	07	62	54	46	38
30	22	14	06	61	53	45	37
29	21	13	05	28	20	12	04

Table 6.18 *Weak keys*

Keys before parities drop (64 bits)	*Actual key (56 bits)*
0101 0101 0101 0101	0000000 0000000
1F1F 1F1F 0E0E 0E0E	0000000 FFFFFFF
E0E0 E0E0 F1F1 F1F1	FFFFFFF 0000000
FEFE FEFE FEFE FEFE	FFFFFFF FFFFFFF

DES Analysis

Weakness in cipher key-Weak keys

- The round keys created from any of these weak keys are the same and have the same pattern as the cipher key.
- For example:
  - The sixteen round keys created from the first key is all made of 0s
  - The sixteen round keys created from second from the second is made of half 0s and half 1s.

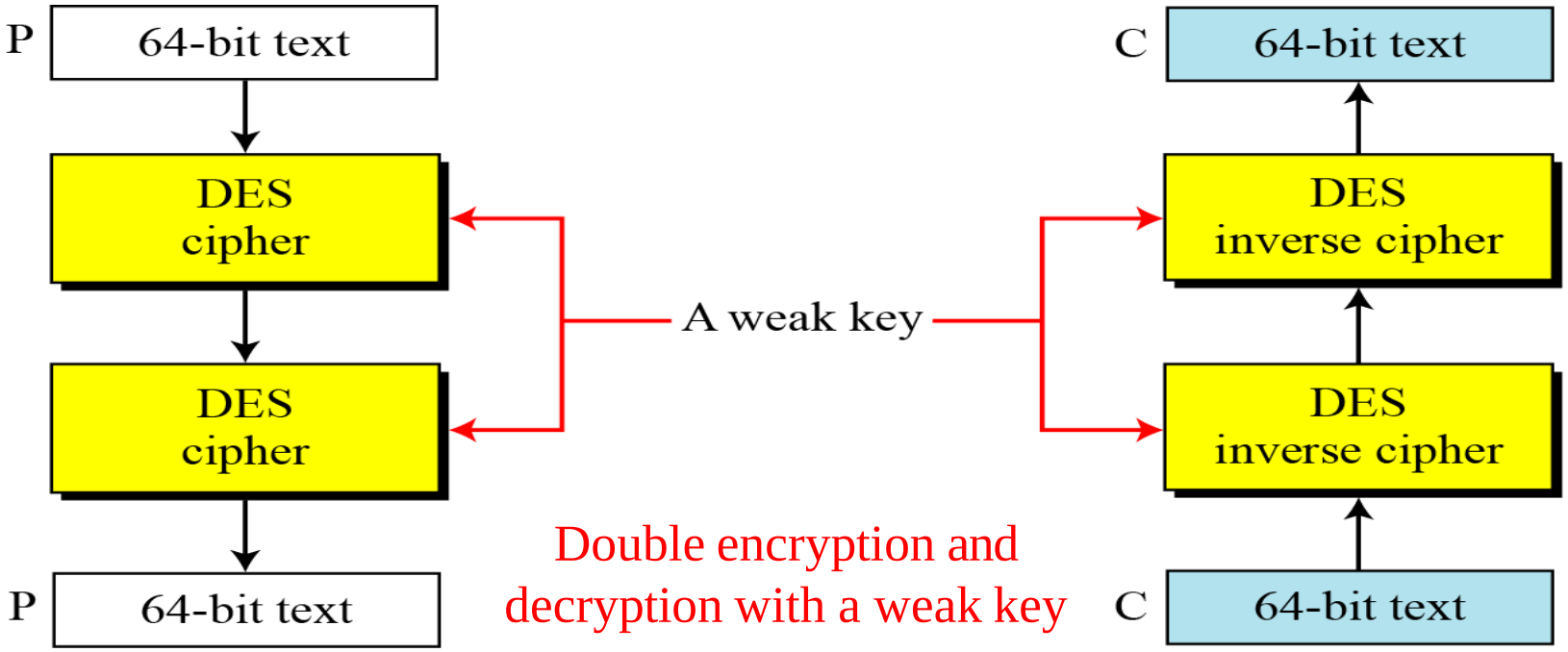
Table 6.18 *Weak keys*

Keys before parities drop (64 bits)	*Actual key (56 bits)*
0101 0101 0101 0101	0000000 0000000
1F1F 1F1F 0E0E 0E0E	0000000 FFFFFFF
E0E0 E0E0 F1F1 F1F1	FFFFFFF 0000000
FEFE FEFE FEFE FEFE	FFFFFFF FFFFFFF

DES Analysis

Weakness in cipher key-Weak keys

- What is the disadvantage of using weak keys



Double encryption and decryption with a weak key

- Weak keys should be avoided because the adversary can easily try them on the intercepted ciphertext.
- If after two decryptions the result is the same, the adversary has found the key

DES Analysis

Table 6.18 *Weak keys*

Keys before parities drop (64 bits)	*Actual key (56 bits)*
0101 0101 0101 0101	0000000 0000000
1F1F 1F1F 0E0E 0E0E	0000000 FFFFFFF
E0E0 E0E0 F1F1 F1F1	FFFFFFF 0000000
FEFE FEFE FEFE FEFE	FFFFFFF FFFFFFF

Weakness in cipher key-Weak keys

Let us try the first weak key in Table 6.18 to encrypt a block two times.

After two encryptions with the same key the original plaintext block is created. Note that we have used the encryption algorithm two times, not one encryption followed by another decryption.

Key: 0x0101010101010101
Plaintext: *0x1234567887654321* ⟶ Ciphertext: 0x814FE938589154F7

Key: 0x0101010101010101
Plaintext: 0x814FE938589154F7 ⟶ Ciphertext: *0x1234567887654321*

$$E_k(E_k(P)) = P$$

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DES Analysis

Weakness in cipher key - Semi-weak keys

- There are six key pairs called semi weak keys
- A Semi weak keys creates two different round keys and each of them is repeated eight times
- Round key created from each pair are the same with different order

These six pairs are shown in Table (64-bit format before dropping the parity bits).

First key in the pair	*Second key in the pair*
01FE 01FE 01FE 01FE	FE01 FE01 FE01 FE01
1FE0 1FE0 0EF1 0EF1	E01F E01F F10E F10E
01E0 01E1 01F1 01F1	E001 E001 F101 F101
1FFE 1FFE 0EFE 0EFE	FE1F FE1F FE0E FE0E
011F 011F 010E 010E	1F01 1F01 0E01 0E01
E0FE E0FE F1FE F1FE	FEE0 FEE0 FEF1 FEF1

DES Analysis

Weakness in cipher key - Semi-weak keys

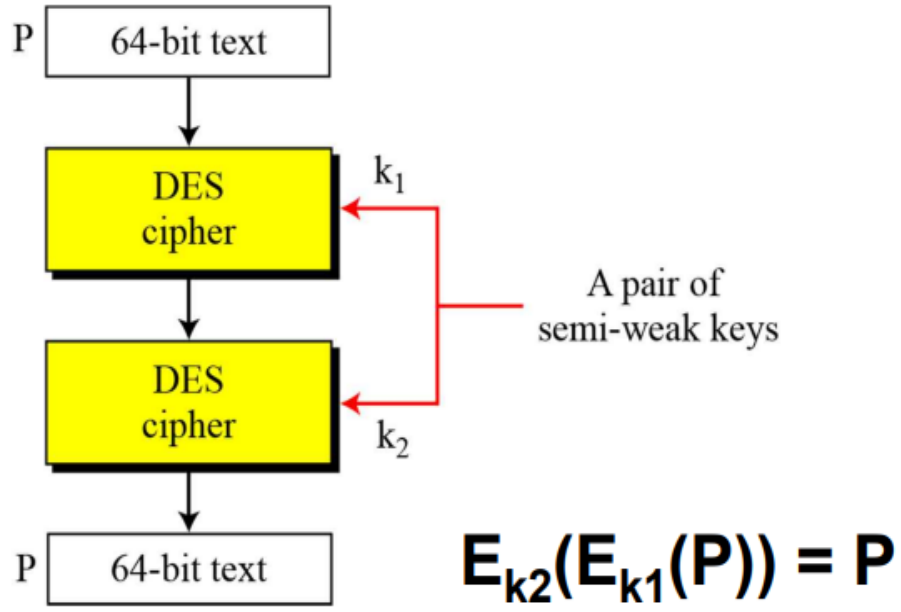
Round key 1	9153E54319BD	6EAC1ABCE642
Round key 2	6EAC1ABCE642	9153E54319BD
Round key 3	6EAC1ABCE642	9153E54319BD
Round key 4	6EAC1ABCE642	9153E54319BD
Round key 5	6EAC1ABCE642	9153E54319BD
Round key 6	6EAC1ABCE642	9153E54319BD
Round key 7	6EAC1ABCE642	9153E54319BD
Round key 8	6EAC1ABCE642	9153E54319BD
Round key 9	9153E54319BD	6EAC1ABCE642
Round key 10	9153E54319BD	6EAC1ABCE642
Round key 11	9153E54319BD	6EAC1ABCE642
Round key 12	9153E54319BD	6EAC1ABCE642
Round key 13	9153E54319BD	6EAC1ABCE642
Round key 14	9153E54319BD	6EAC1ABCE642
Round key 15	9153E54319BD	6EAC1ABCE642
Round key 16	6EAC1ABCE642	9153E54319BD

First key in the pair	*Second key in the pair*
01FE 01FE 01FE 01FE	FE01 FE01 FE01 FE01
1FE0 1FE0 0EF1 0EF1	E01F E01F F10E F10E
01E0 01E1 01F1 01F1	E001 E001 F101 F101
1FFE 1FFE 0EFE 0EFE	FE1F FE1F FE0E FE0E
011F 011F 010E 010E	1F01 1F01 0E01 0E01
E0FE E0FE F1FE F1FE	FEE0 FEE0 FEF1 FEF1

DES Analysis

Weakness in cipher key - Semi-weak keys

A pair of semi-weak keys in encryption and decryption



$$E_{k2}(E_{k1}(P)) = P$$

Round key 1	9153E54319BD	6EAC1ABCE642
Round key 2	6EAC1ABCE642	9153E54319BD
Round key 3	6EAC1ABCE642	9153E54319BD
Round key 4	6EAC1ABCE642	9153E54319BD
Round key 5	6EAC1ABCE642	9153E54319BD
Round key 6	6EAC1ABCE642	9153E54319BD
Round key 7	6EAC1ABCE642	9153E54319BD
Round key 8	6EAC1ABCE642	9153E54319BD
Round key 9	9153E54319BD	6EAC1ABCE642
Round key 10	9153E54319BD	6EAC1ABCE642
Round key 11	9153E54319BD	6EAC1ABCE642
Round key 12	9153E54319BD	6EAC1ABCE642
Round key 13	9153E54319BD	6EAC1ABCE642
Round key 14	9153E54319BD	6EAC1ABCE642
Round key 15	9153E54319BD	6EAC1ABCE642
Round key 16	6EAC1ABCE642	9153E54319BD

DES Analysis

Weakness in cipher key – Possible weak keys

- 48 Keys are possible weak keys
- A possible weak key is a key that creates four distinct round keys
- 16round keys = 4 groups → each group 4 equal round key

DES Analysis

Weakness in cipher key – Key clustering

- 2 or more different keys can create same ciphertext from the same plaintext.

UNIT 2

Traditional Symmetric-Key Ciphers: (Chapter 3)

- Introduction
- Substitution Ciphers
- Trans positional Ciphers
- Stream and Block Ciphers

Data Encryption Standard (DES): (Chapter 6)

- Introduction
- DES Structure
- DES Analysis
- MULTIPLE DES
- Security of DES

MULTIPLE DES

Major criticism of DES regards its key length.

1. One solution to improve the security of DES is to abandon DES and design a new cipher.
2. The second solution is to use multiple (cascaded) instances of DES with multiple keys

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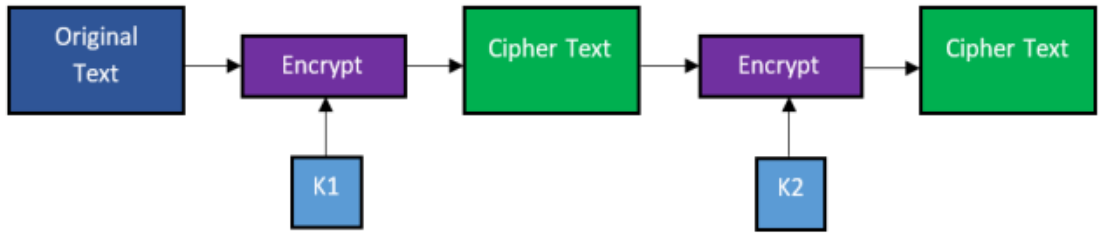
MULTIPLE DES

Double DES(2DES)

In this approach, we use two instances of DES ciphers for encryption and two instances of reverse ciphers for decryption.

Each instance uses a different key, which means that the size of the key is now doubled (112 bits).

However, double DES is vulnerable to a known-plain text attack

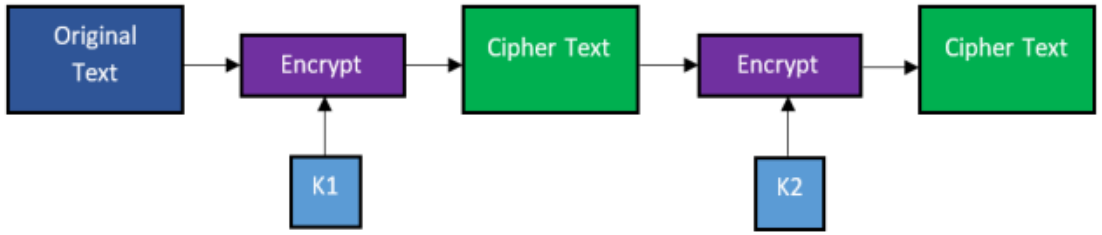


Double DES

MULTIPLE DES

Double DES(2DES) - Meet-in-the-Middle Attack

At first glance, it looks like double DES increases the number of tests for key search from 2^{56} (in single DES) to 2^{112} (in double DES).



Double DES

MULTIPLE DES

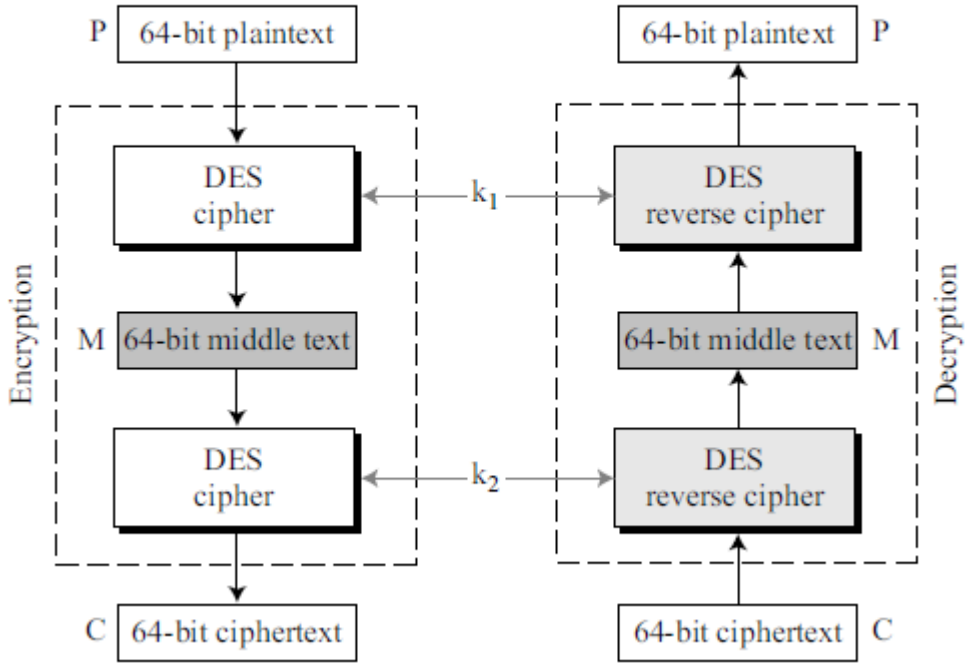
Double DES(2DES) - Meet-in-the-Middle Attack

known-plaintext attack (meet-in-the-middle attack)proves that double DES improves thes vulnerability

Figure shows the diagram for the double DES.

- Alice uses two keys k1 and k2 to encrypt Plaintext
- Bob to ciphertext C uses two keys k2 and k1 to recover Plaintext.

Meet-in-the-middle attack for double DES



MULTIPLE DES

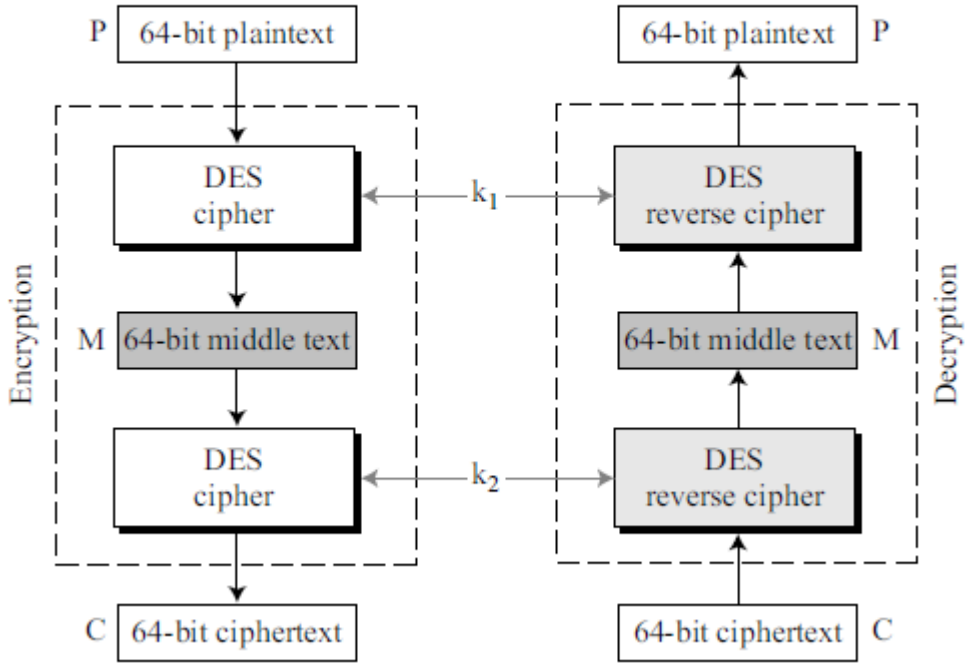
Double DES(2DES) - Meet-in-the-Middle Attack

The point is that the middle text(M), the text created by the first encryption or first decryption, M, should be the same for encryption and decryption to work.

In other words, we have two relationships:

$$M = E_{k_1}(P) \quad \text{and} \quad M = D_{k_2}(C)$$

Meet-in-the-middle attack for double DES



MULTIPLE DES

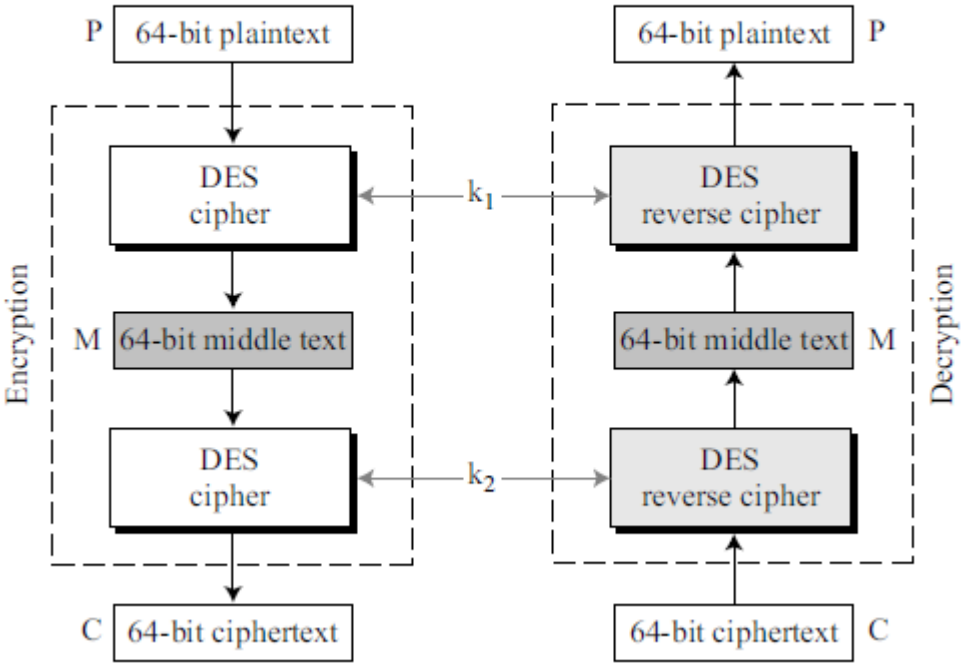
Double DES(2DES) - Meet-in-the-Middle Attack

Assume that Eve has intercepted a previous pair P and C (known-plaintext attack).

Based on the first relationship mentioned above, Eve encrypts P using all possible values (2^{56}) of k1 and records all values obtained for M.

Based on the second relationship mentioned above, Eve decrypts C using all possible values (2^{56}) of k2 and records all values obtained for M Eve creates two tables sorted by M values.

Meet-in-the-middle attack for double DES



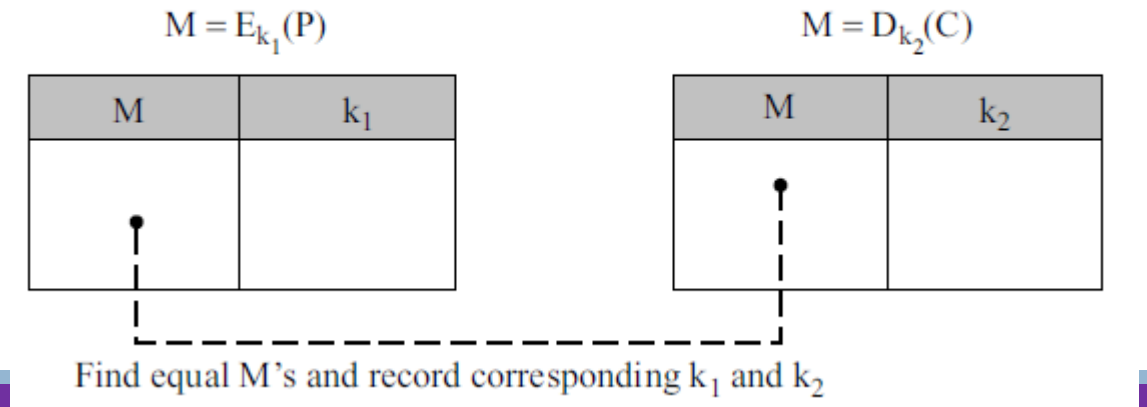
$$M = E_{k_1}(P) \quad \text{and} \quad M = D_{k_2}(C)$$

MULTIPLE DES

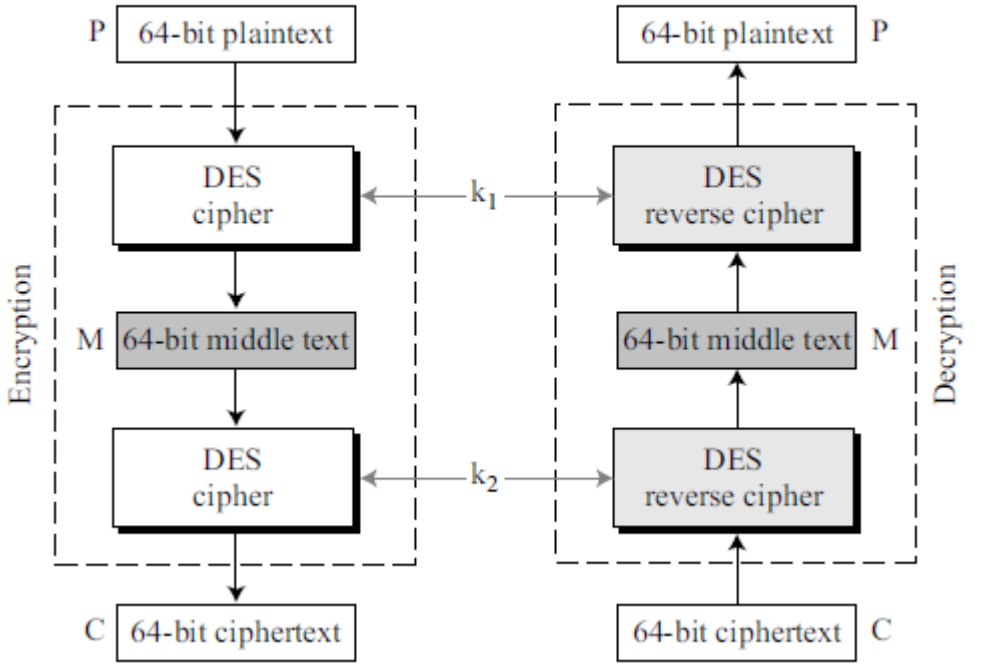
Double DES(2DES) - Meet-in-the-Middle Attack

She then compares the values for M until she finds those pairs of k1 and k2 for which the value of M is the same in both tables as shown in Figure 6.15.

Tables for meet-in-the-middle attack



Meet-in-the-middle attack for double DES



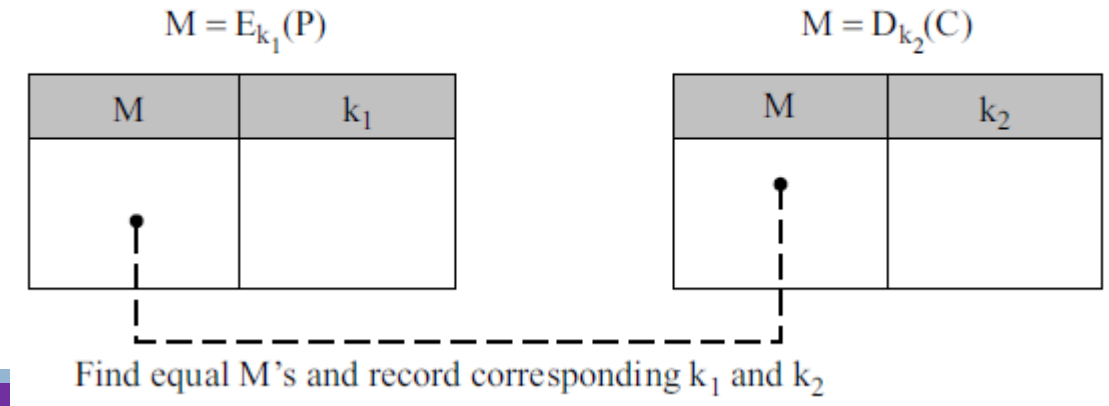
$M = E_{k_1}(P)$ and $M = D_{k_2}(C)$

MULTIPLE DES

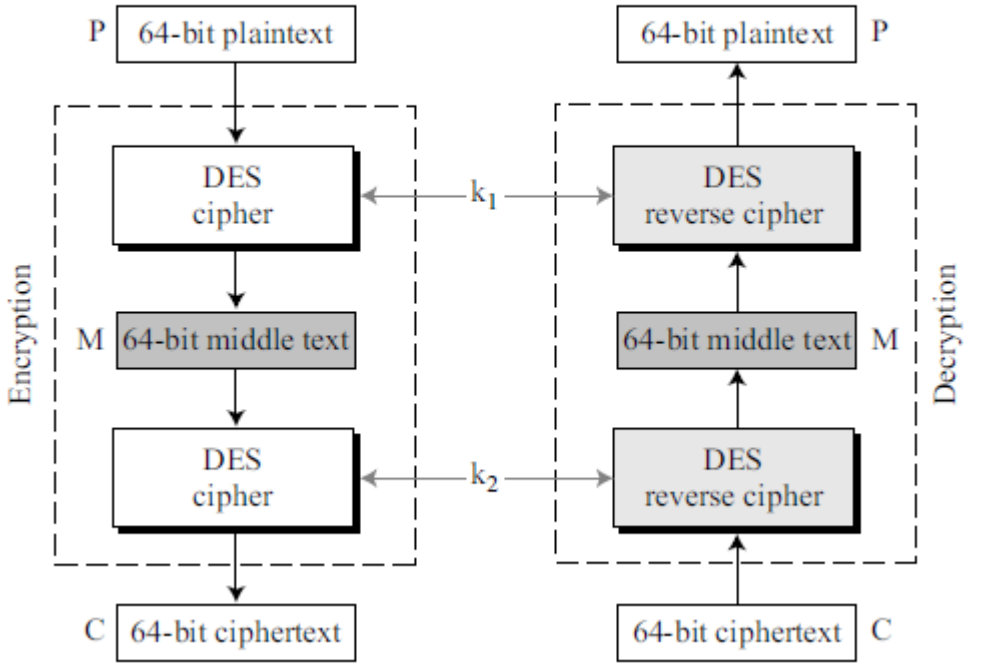
Double DES(2DES) - Meet-in-the-Middle Attack

She then compares the values for M until she finds those pairs of k1 and k2 for which the value of M is the same in both tables as shown in Figure 6.15.

Tables for meet-in-the-middle attack



Meet-in-the-middle attack for double DES



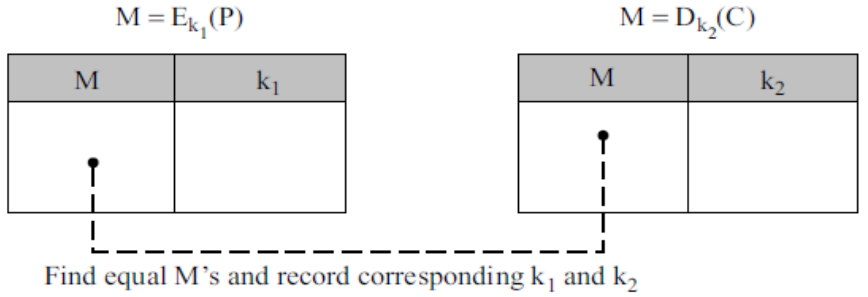
$M = E_{k_1}(P)$ and $M = D_{k_2}(C)$

MULTIPLE DES

Double DES(2DES) - Meet-in-the-Middle Attack

1. If there is only one match, Eve has found the two keys (k1 and k2). If there is more than one candidate, Eve moves to the next step.
2. She takes another intercepted plaintext-ciphertext pair and uses each of the candidate key pairs to see if she can get the ciphertext from the plaintext. If she finds more than one candidate key pair, she repeats step 2 until she finally finds a unique pair.

Tables for meet-in-the-middle attack



$$M = E_{k_1}(P) \quad \text{and} \quad M = D_{k_2}(C)$$

MULTIPLE DES

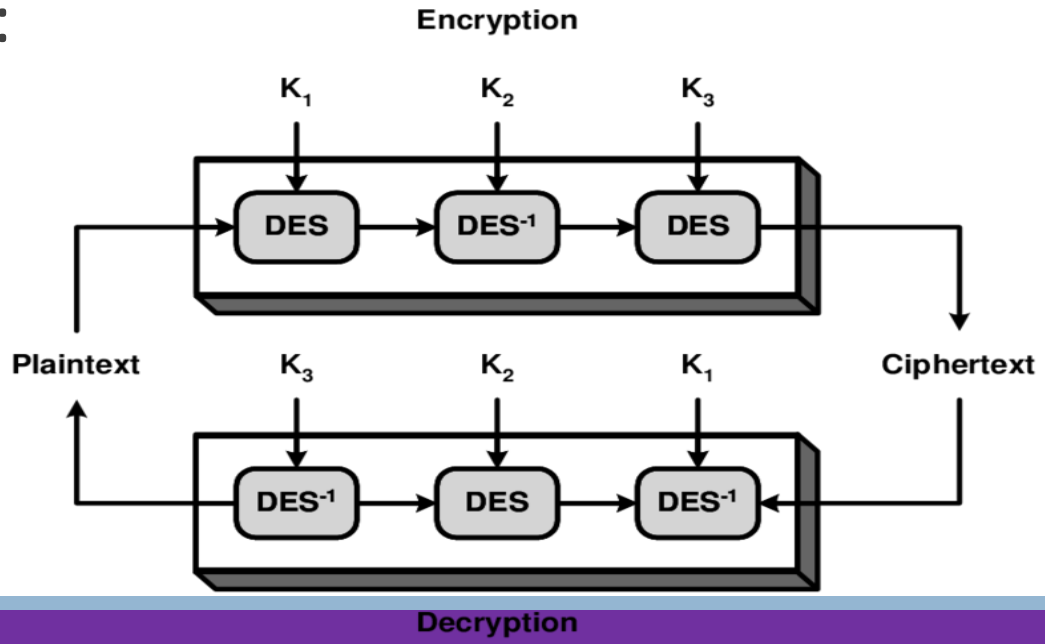
Triple DES

To improve the security of DES, triple DES (3DES) was proposed.

This uses three stages of DES for encryption and decryption.

Two versions of triple DES are in use today:

1. triple DES with two keys
2. triple DES with three keys.

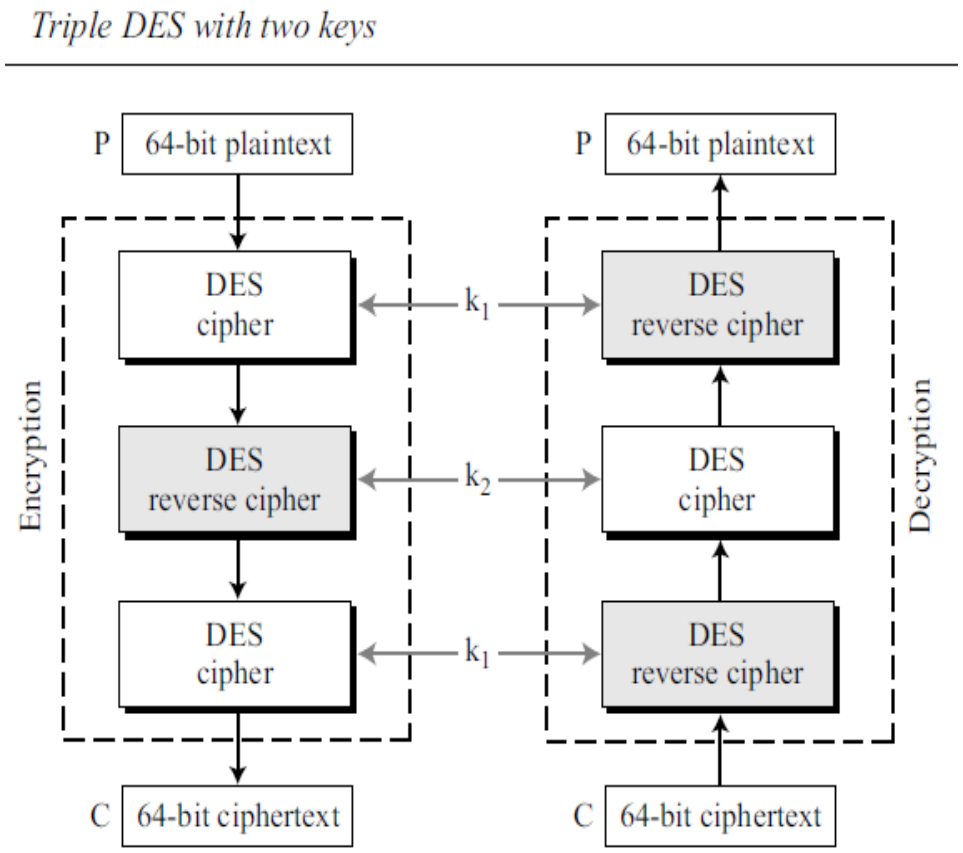


MULTIPLE DES

Triple DES with Two Keys

- There are only two keys: k1 and k2.
- The first and the third stages use k1; the second stage uses k2.
- To make triple DES compatible with single DES, the middle stage uses decryption (reverse cipher) in the encryption site and encryption (cipher) in the decryption site.

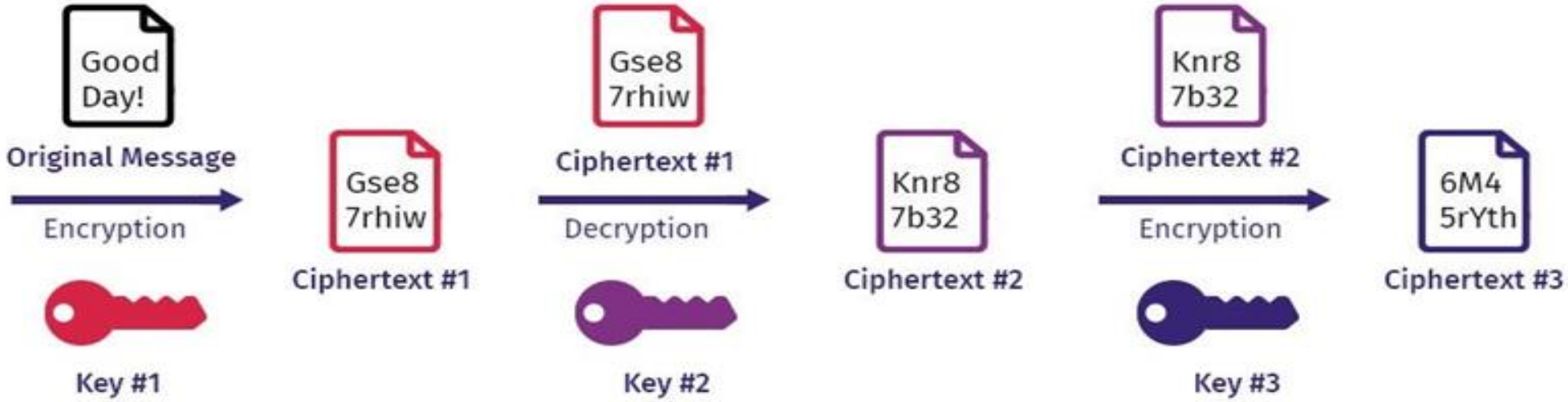
Although triple DES with two keys is also vulnerable to a known-plaintext attack, it is much stronger than double DES.



MULTIPLE DES

Triple DES with Three Keys

Triple DES with three keys is used by many applications such as PGP.



UNIT 2

Traditional Symmetric-Key Ciphers: (Chapter 3)

- Introduction
- Substitution Ciphers
- Trans positional Ciphers
- Stream and Block Ciphers

Data Encryption Standard (DES): (Chapter 6)

- Introduction
- DES Structure
- DES Analysis
- MULTIPLE DES
- Security of DES

Security of DES

DES, as the first important block cipher, has gone through much scrutiny.

Among the attempted attacks, three are of interest

- Brute Force attack
- Differential cryptanalysis
- Linear cryptanalysis

Security of DES

Brute Force attack

- DES can be broken using 2^{56}

Cryptanalysis is the process of transforming or decoding communications from non-readable to readable format without having access to the real key.

Different Forms of Cryptanalysis:

1. Differential Cryptanalysis:The use of differential cryptanalysis is to get clues about some critical bits, reducing the need for an extensive search.
2. Linear Cryptanalysis: The use of linear cryptanalysis is to figure out what is the linear relationship present between some plaintext bits, ciphertext bits, and unknown key bits very easily.

Security of DES

Differential cryptanalysis

- It has been revealed that the designers of DES already knew about this type of attack and
  - designed S-boxes and
  - chose 16 as the number of rounds to make DES specifically resistant to this type of attack.

Security of DES

Linear cryptanalysis

- DES is more vulnerable to linear cryptanalysis than to differential cryptanalysis.
- S-boxes are not very resistant to linear cryptanalysis.

Unit II (Text1)

Traditional Symmetric-Key Ciphers: (Chapter 3)

- Introduction
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Data Encryption Standard (DES): (Chapter 6)

- Introduction
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- Multiple of DES
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THANK YOU