Subject Name: Cryptography and Network Security

Unit No: 01 Unit Name: Introduction to Cryptography

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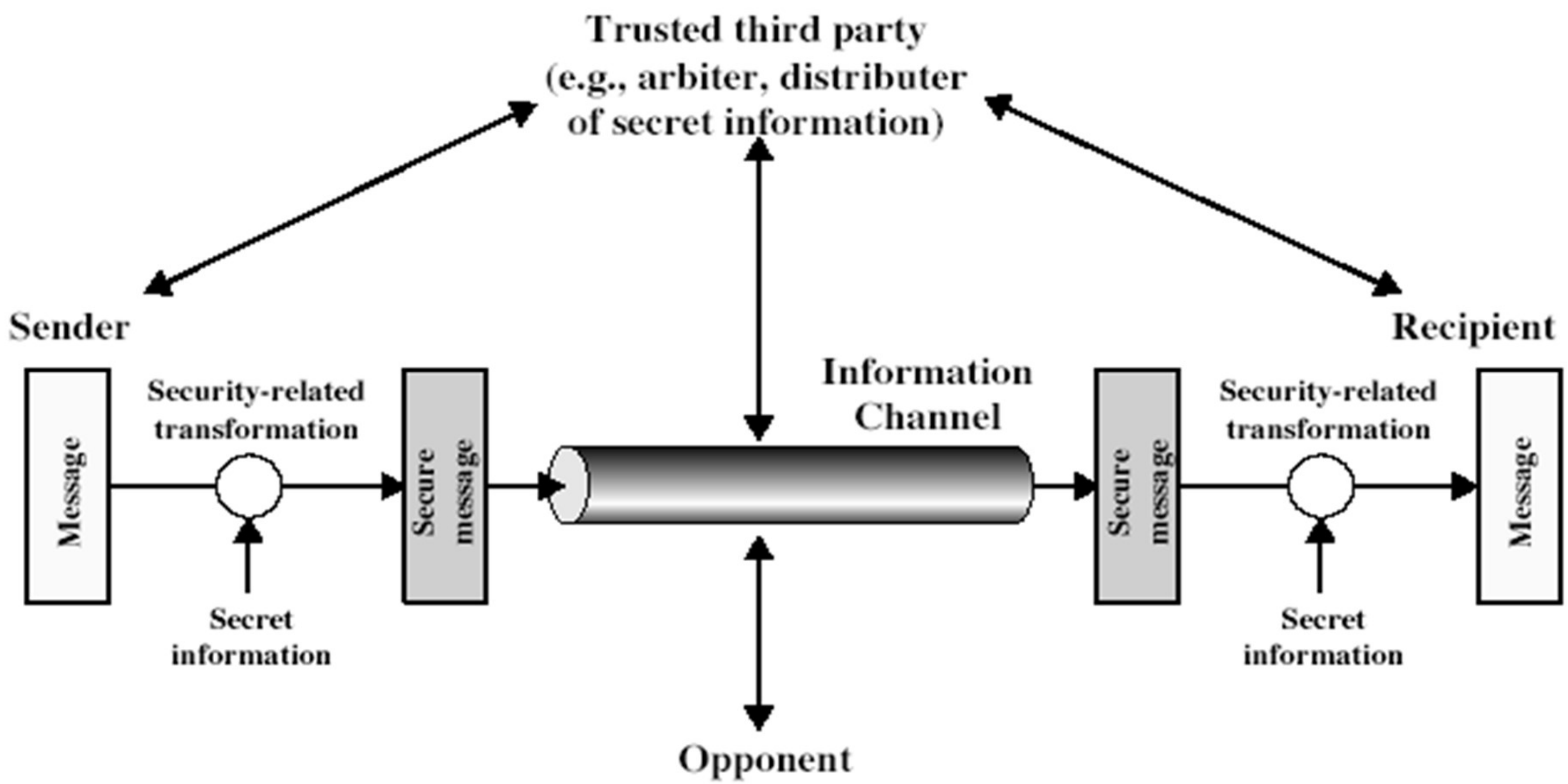
Index

Unit No: 1 Unit Name: Introduction & Number Theory

Lecture No: 1
Classical Encryption techniques, Symmetric cipher model

Model for Network Security



Model for Network Security

This model requires :

1. Design a suitable algorithm for the security transformation
2. Generate the secret information (keys) used by the algorithm
3. Develop methods to distribute and share the secret information
4. Specify a protocol enabling the principals to use the transformation and secret information for a security service

Classical Security Techniques

- Cryptography
- Symmetric Key Encipherment/Secret Key Cryptography/Private Key Cryptography
- Asymmetric Key Encipherment/ Shared Key Cryptography/ Public Key Cryptography
- Steganography

Cryptography

- ***Symmetric(Secret/Private key)***

$$C = E_k(M)$$

$$M = D_k(C)$$

- ***Asymmetric(Shared/Public key)***

$$C = E_{pu.k}(M)$$

$$M = D_{pr.k}(C)$$

Basic Terminologies

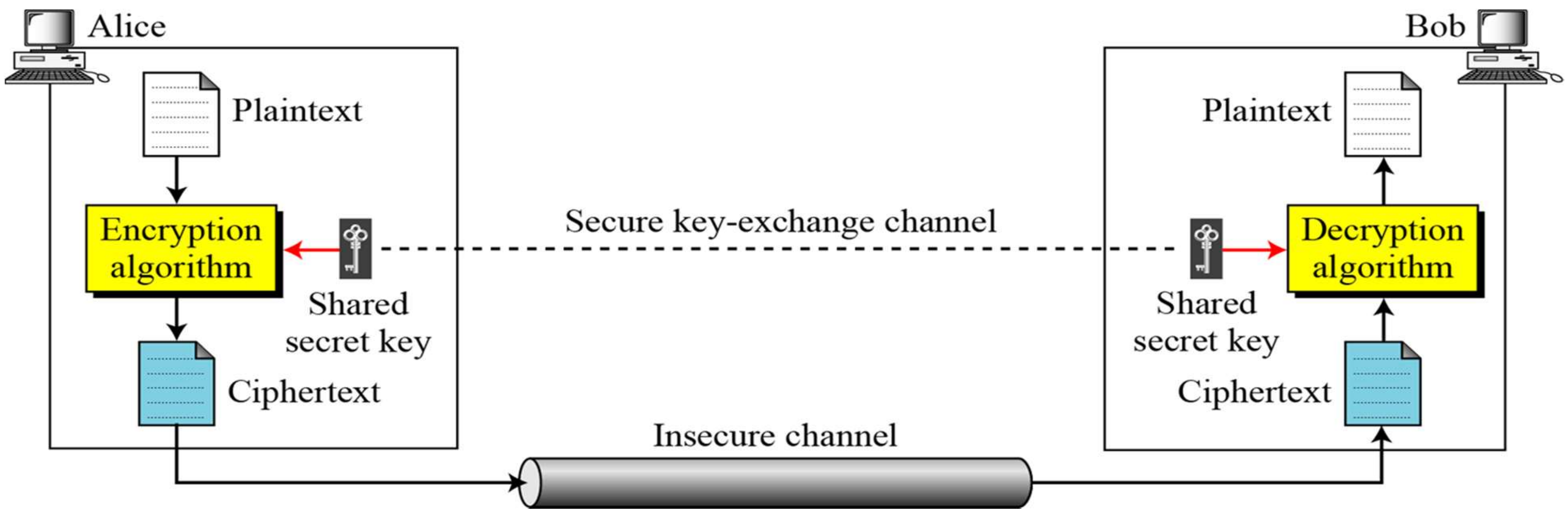
- **Plaintext** - original message
- **Ciphertext** - coded message
- **Cipher** - algorithm for transforming plaintext to ciphertext
- **Key** - info used in cipher known only to sender/receiver
- **Encipher (encrypt)** - converting plaintext to ciphertext
- **Decipher (decrypt)** - recovering plaintext from ciphertext
- **Cryptanalysis (code breaking)** - study of principles/ methods of deciphering ciphertext *without* knowing key
- **Cryptology** - field of both cryptography and cryptanalysis

Requirements of Classical Security Techniques

- Strong encryption algorithm
  - An opponent who knows one or more ciphertexts would not be able to find the plaintexts or the key
  - Ideally, even if he knows one or more pairs of plaintext-ciphertext, he would not be able to find the key
- Sender and receiver must share the key. Once the key is compromised, all communications using that key are readable
- Encryption algorithm is not a secret. It is impractical to decrypt the message on the basis of the ciphertext plus the knowledge of the encryption algorithm (**Kerckhoff's principle**)

Classical Symmetric Ciphers(Encryption Techniques)

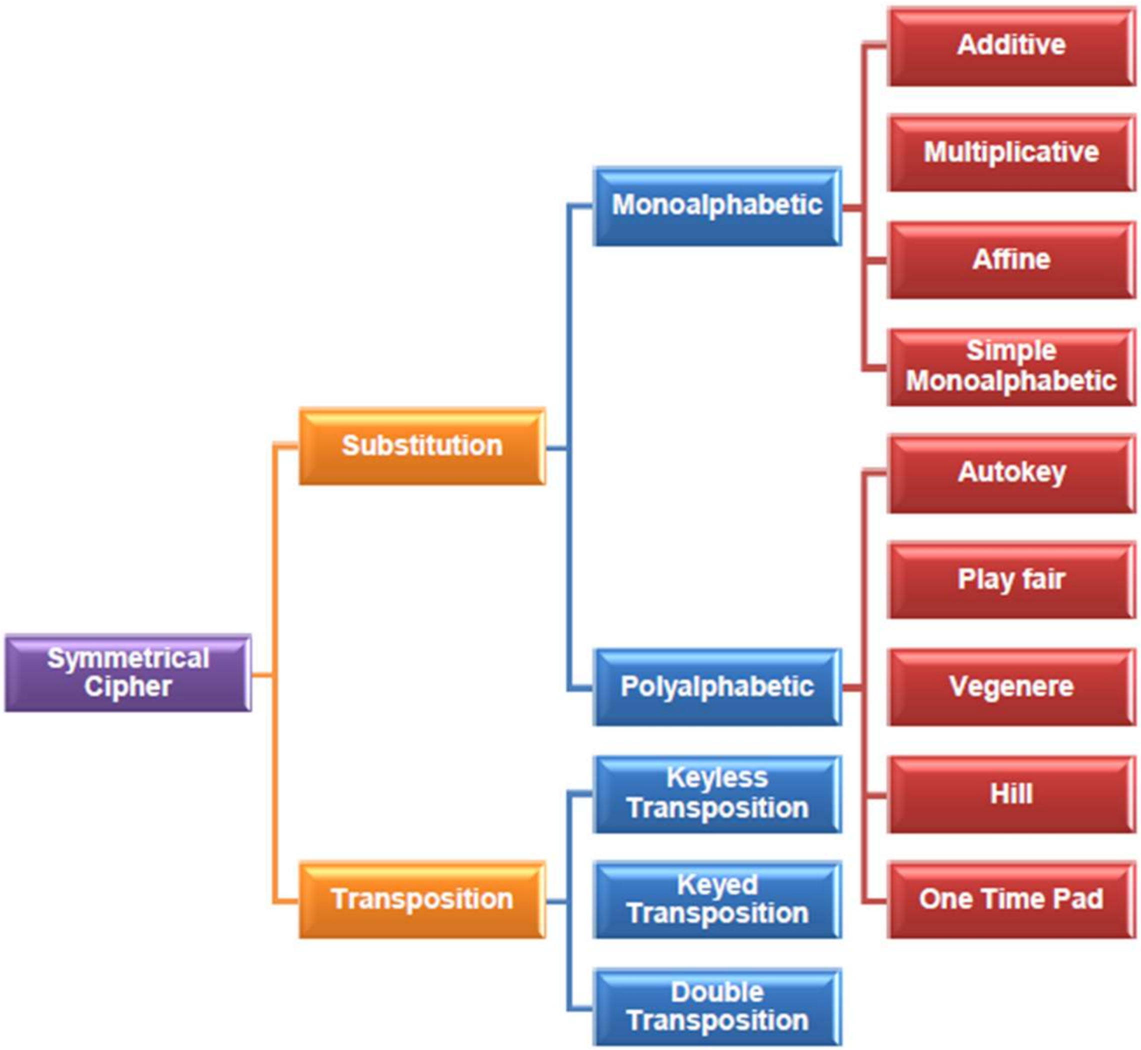
- Classical (historical) algorithms are based on substitution & permutation.



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

In which, $D_k(E_k(x)) = E_k(D_k(x)) = x$

Classical Symmetric Ciphers



Unit No: 1

Unit Name: Introduction & Number Theory

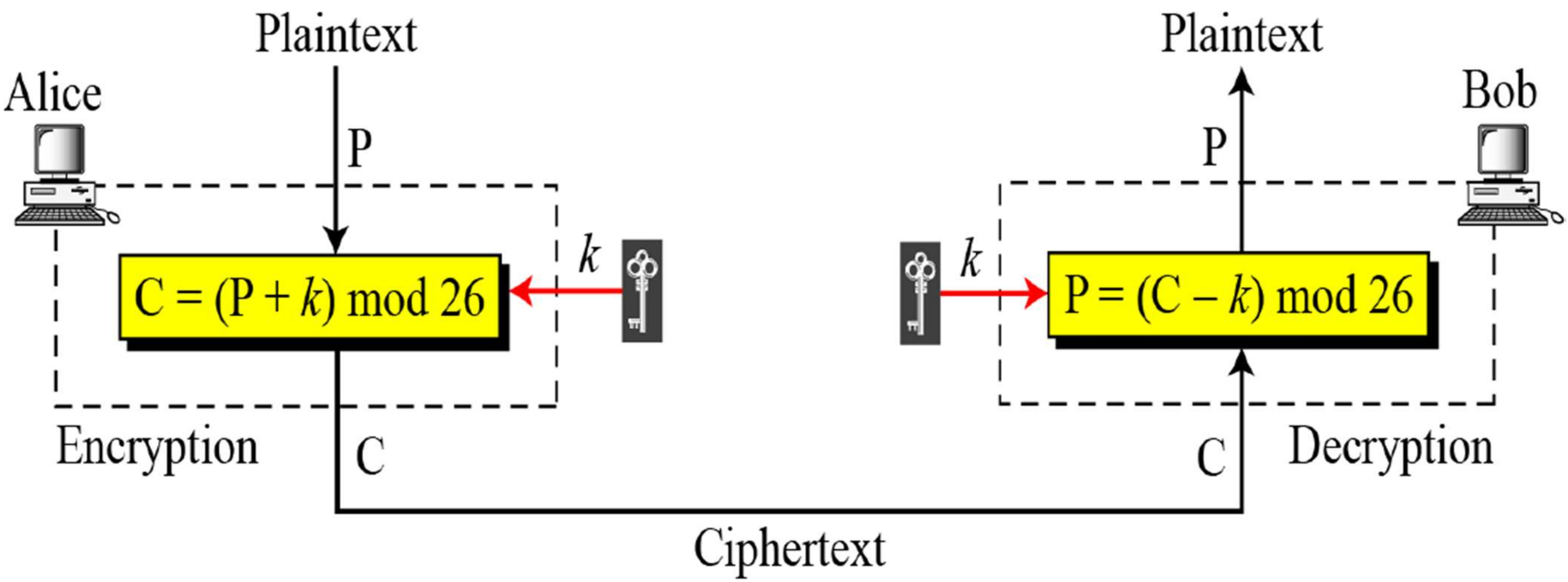
Lecture No: 2
Monoalphabetic Ciphers

Caesar Ciphers (Additive/Shift ciphers)

- The simplest monoalphabetic cipher is the additive cipher.
- This cipher is sometimes called a shift cipher and sometimes a Caesar cipher, but the term additive cipher better reveals its mathematical nature.

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	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
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

Caesar Ciphers (Additive/Shift ciphers)



Caesar Ciphers (Additive/Shift ciphers)

Use the additive cipher with key = 5 to encrypt the message "SECURITY".

Solution

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

Plaintext: S -> 18	Encryption: (18+5)mod 26	Ciphertext: 23 -> X
Plaintext: E -> 4	Encryption: (4+5)mod 26	Ciphertext: 9 -> J
Plaintext: C -> 2	Encryption: (2+5)mod 26	Ciphertext: 7 -> H
Plaintext: U -> 20	Encryption: (20+5)mod 26	Ciphertext: 25 -> Z
Plaintext: R -> 17	Encryption: (17+5)mod 26	Ciphertext: 22 -> W
Plaintext: I -> 8	Encryption: (8+5)mod 26	Ciphertext: 13 -> N
	Encryption: (19+5)mod 26	Ciphertext: 24 -> Y
24	Encryption: (24+5)mod 26	Ciphertext: 3 -> D

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	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
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

Caesar Ciphers (Additive/Shift ciphers)

Use the additive cipher with key = 5 to decrypt the message "XJHZWNYD".

Solution

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

Ciphertext: X -> 23
Ciphertext: J -> 9
Ciphertext: H -> 7
Ciphertext: Z -> 25
Ciphertext: W -> 22
Ciphertext: N -> 13
Ciphertext: Y -> 24
Ciphertext: D -> 3

Decryption: (23 - 5)mod 26
Decryption : (9 - 5)mod 26
Decryption : (7 - 5)mod 26
Decryption : (25 - 5)mod 26
Decryption : (22 - 5)mod 26
Decryption : (13 -5)mod 26
Decryption : (24 - 5)mod 26
Decryption : (3- 5) mod 26

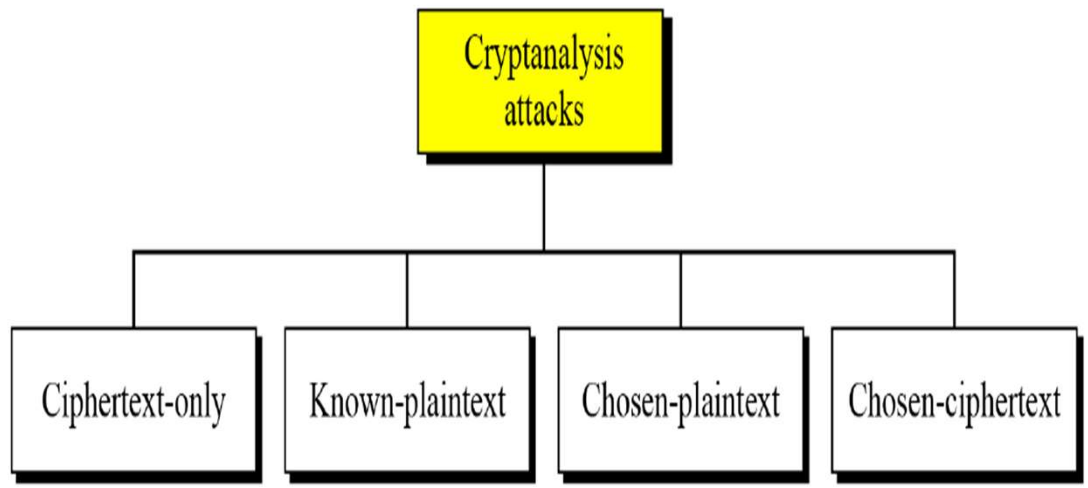
Plaintext: 18 -> S
Plaintext: 4 -> E
Plaintext: 2 -> C
Plaintext: 20 -> U
Plaintext: 17 -> R
Plaintext: 8 -> I
Y

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	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
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

Cryptanalysis

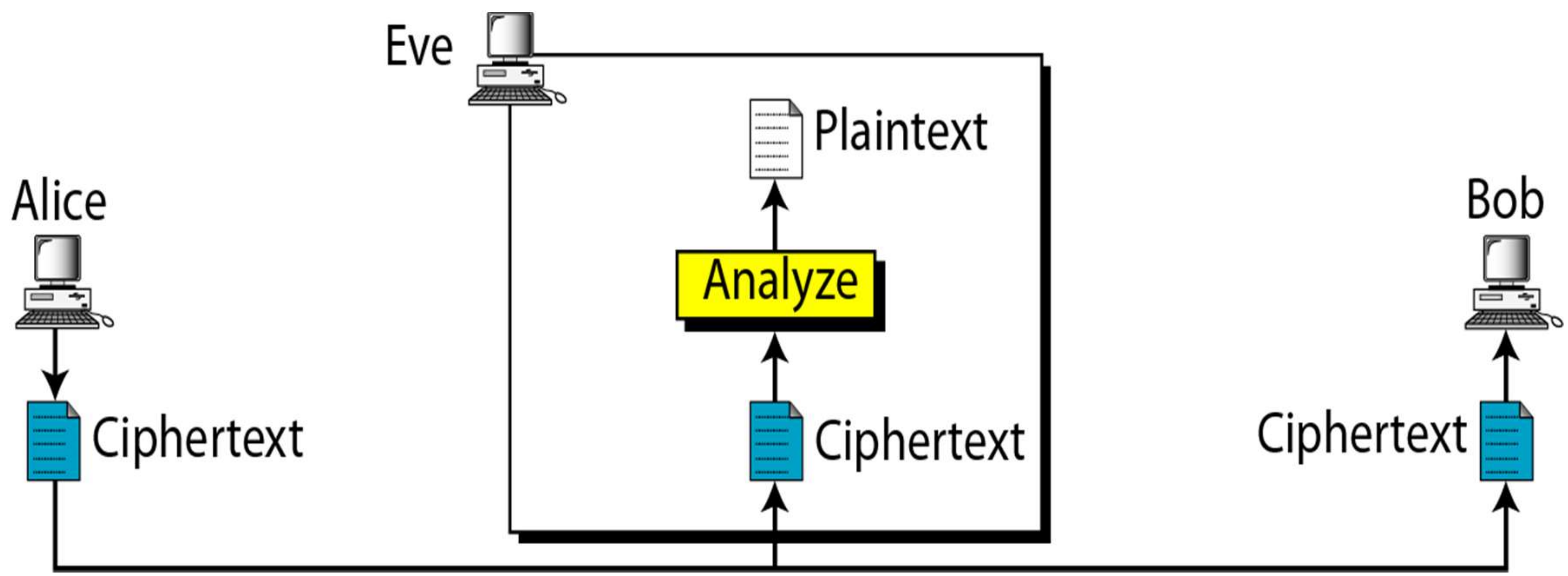
"Cryptanalysis is the science and art of breaking secret codes created by Cryptography"

- Objective - to recover key not just message
- Approaches:
  - ➢ Cryptanalytic attack
  - ➢ Brute-force attack
  - ➢ Statistical attack
  - ➢ Pattern attack



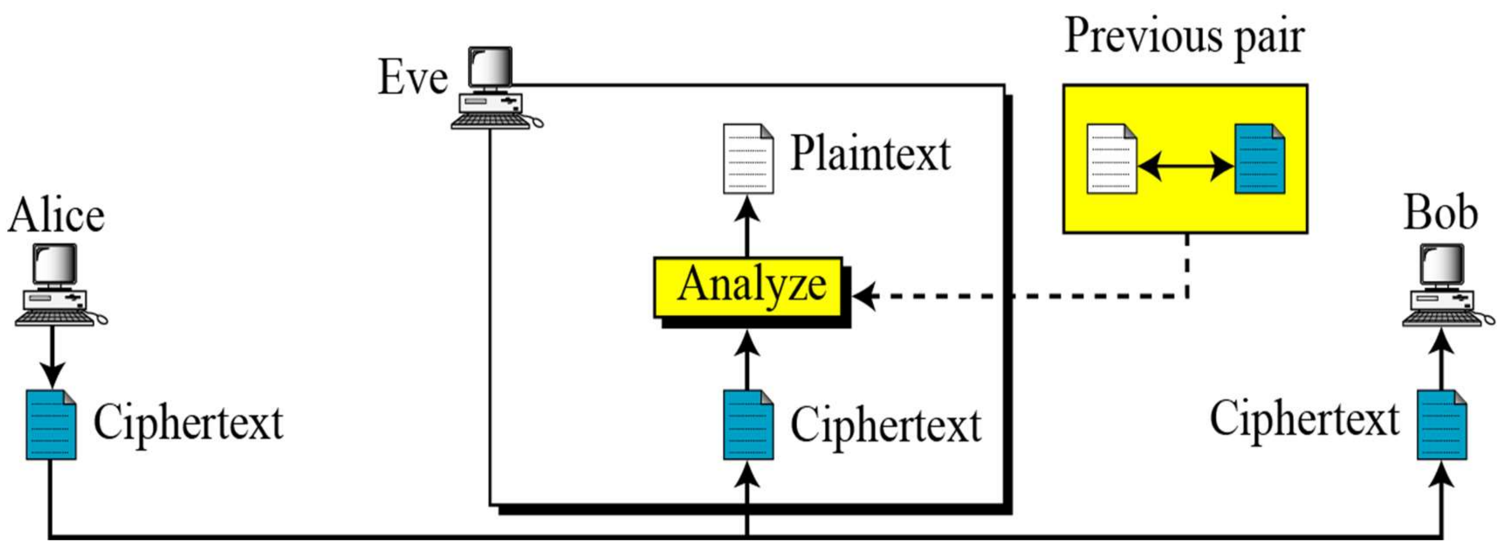
Cryptanalytic Attacks

Ciphertext only - only ciphertext is known to attacker



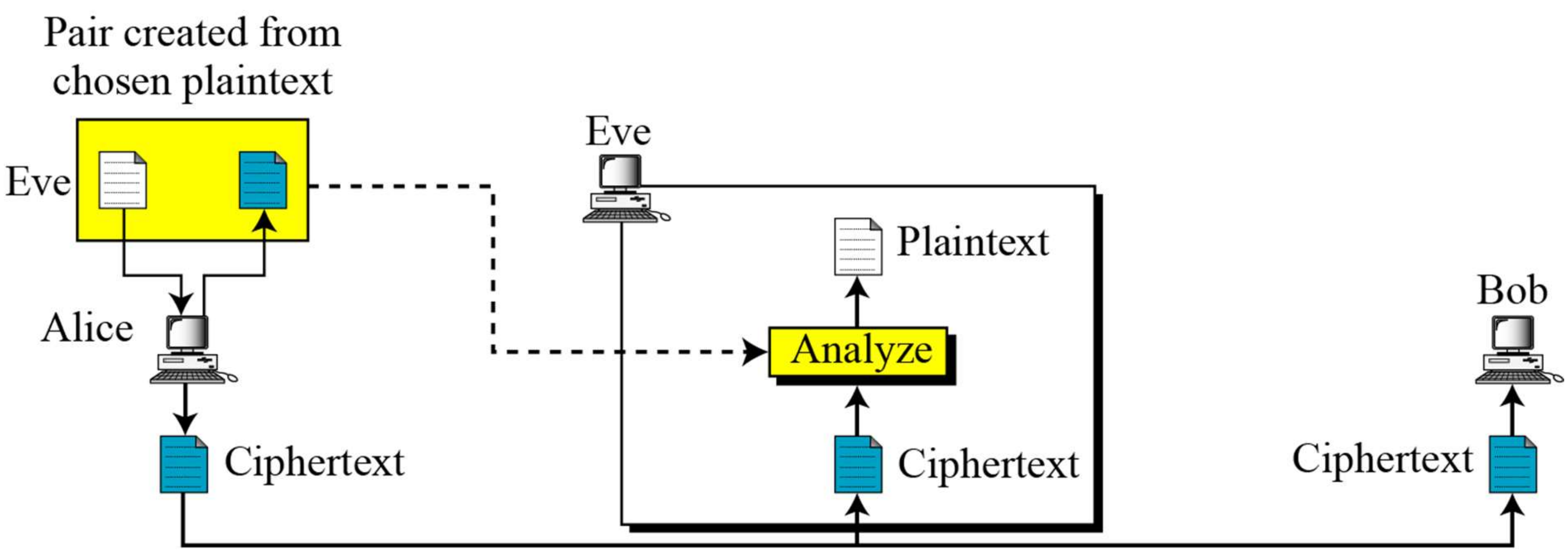
Cryptanalytic Attacks

Known Plaintext - pairs of ciphertext and corresponding to plaintext is known to attacker



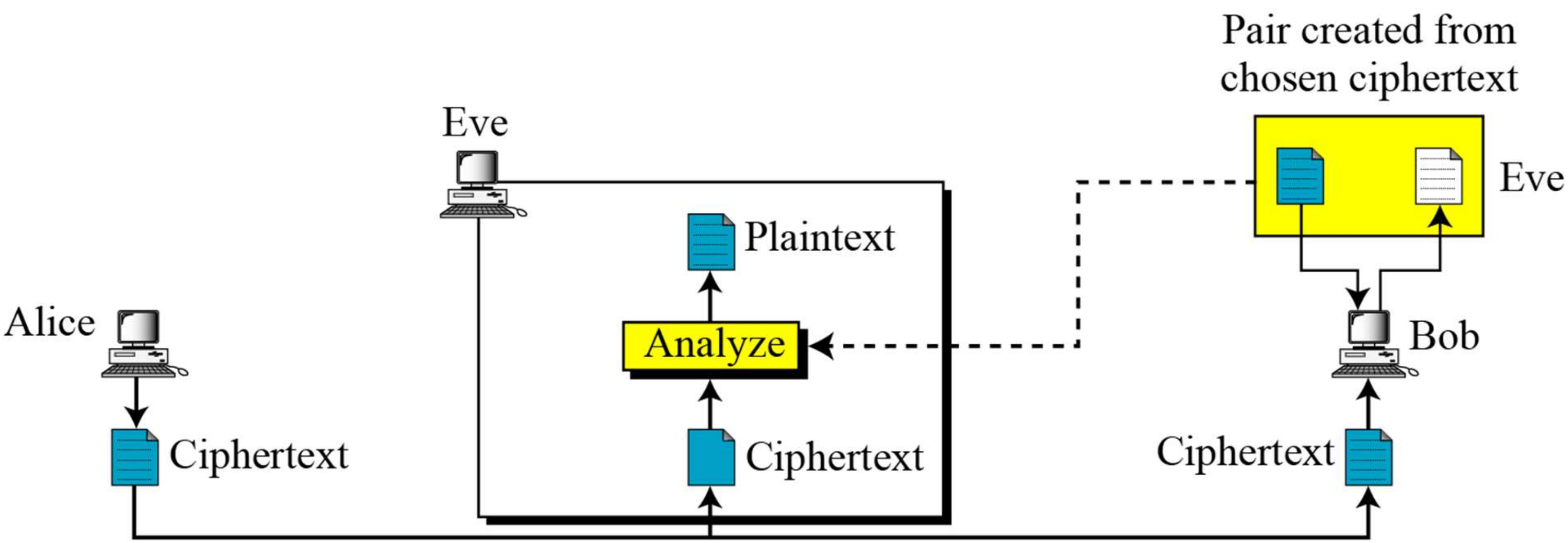
Cryptanalytic Attacks

Chosen Plaintext - attacker selects a plaintext



Cryptanalytic Attacks

Chosen Ciphertext - attacker selects a ciphertext



Cryptanalysis of Caesar Cipher

- only have 25 possible ciphers
  - A maps to B,C,...Z
- could simply try each in turn
- a **brute force search**
- given ciphertext, just try all shifts of letters
- Ciphertext: SGHR HR BRR BKZRR

	S	G	H	R		H	R			B	R	R		B	K	Z	R	R
25	R	F	G	Q		G	Q			A	Q	Q		A	J	Y	Q	Q
24	Q	E	F	P		F	P			Z	P	P		Z	I	X	P	P
23	P	D	E	O		E	O			Y	O	O		Y	H	W	O	O
22	O	C	D	N		D	N			X	N	N		X	G	V	N	N
21	N	B	C	M		C	M			W	M	M		W	F	U	M	M
20	M	A	B	L		B	L			V	L	L		V	E	T	L	L
19	L	Z	A	K		A	K			U	K	K		U	D	S	K	K
18	K	Y	Z	J		Z	J			T	J	J		T	C	R	J	J
17	J	X	Y	I		Y	I			S	I	I		S	B	Q	I	I
16	I	W	X	H		X	H			R	H	H		R	A	P	H	H
15	H	V	W	G		W	G			Q	G	G		Q	Z	O	G	G
14	G	U	V	F		V	F			P	F	F		P	Y	N	F	F
13	F	T	U	E		U	E			O	E	E		O	X	M	E	E
12	E	S	T	D		T	D			N	D	D		N	W	L	D	D
11	D	R	S	C		S	C			M	C	C		M	V	K	C	C
10	C	Q	R	B		R	B			L	B	B		L	U	J	B	B

Statistical Attacks

- Compute frequency of each letter in ciphertext (KHOOR ZRUOG):
- G = 0.1, H = 0.1, K = 0.1, O = 0.3, R = 0.2, U = 0.1, Z = 0.1
- Let Φ (i) be a correlation function of the frequency of each letter in ciphertext with the corresponding letter in English,

$$\phi(i) = \sum_{0 \le c \le 25} f(c)p(c-i)$$

- i is the key

- f (c) is the frequency of character c in ciphertext

- p(x) is the frequency of character x in English

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Statistical Attack

- For ciphertext (KHOOR ZRUOG): G H K O R U Z

  $\phi(i) = 0.1p(6 - i) + 0.1p(7 - i) + 0.1p(10 - i) + 0.3p(14 - i) + 0.2p(17 - i) + 0.1p(20 - i) + 0.1p(25 - i)$

Correlation: φ(i) for 0 ≤ i ≤ 25

i	φ(i)	i	φ(i)	i	φ(i)	i	φ(i)
0	0.0482	7	0.0442	13	0.0520	19	0.0315
1	0.0364	8	0.0202	14	0.0535	20	0.0302
2	0.0410	9	0.0267	15	0.0226	21	0.0517
3	0.0575	10	0.0635	16	0.0322	22	0.0380
4	0.0252	11	0.0262	17	0.0392	23	0.0370
5	0.0190	12	0.0325	18	0.0299	24	0.0316
6	0.0660					25	0.0430

Most probable keys, based on :

$\varphi(6) = 0.0660$ plaintext: EBIIL TLOLA

$\varphi(10) = 0.0635$ plaintext AXEEH PHKEW

$\varphi(3) = 0.0575$ plaintext HELLO WORLD

$\varphi(14) = 0.0535$ plaintext WTAAD LDGAS

The only English phrase is for i = 3 (key = 3 or 'D')

Pattern Attack

- Human languages are **redundant**
- Letters are not equally commonly used
- In english **e** is by far the most common letter and then t, r, n, i, o, a, s
- It have tables of single, double & triple letter frequencies

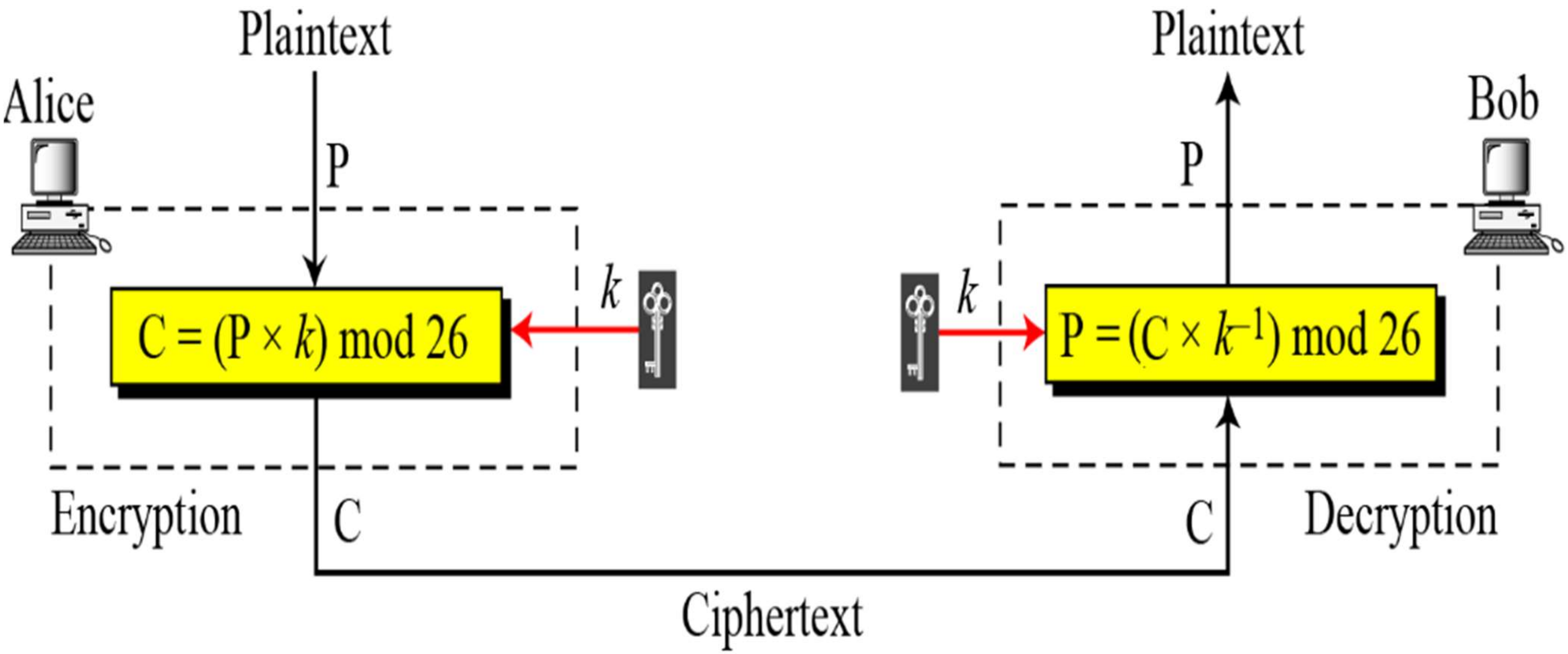
Pattern Attack

- Given ciphertext:
  - **UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETS XAIZVUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZH SXEPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ**
- count relative letter frequencies
- Guess: P & Z are e and t
- guess ZW is TH and hence ZWP is THE
- proceeding with trial and error finally get:
  - **it was disclosed yesterday that several informal but direct contacts have been made with political representatives of the viet cong in moscow**

Caesar Cipher- Shortcomings

- Key is too short
- Key can be found by exhaustive search
- Statistical frequencies not concealed well
- They look too much like regular English letters

Multiplicative Cipher



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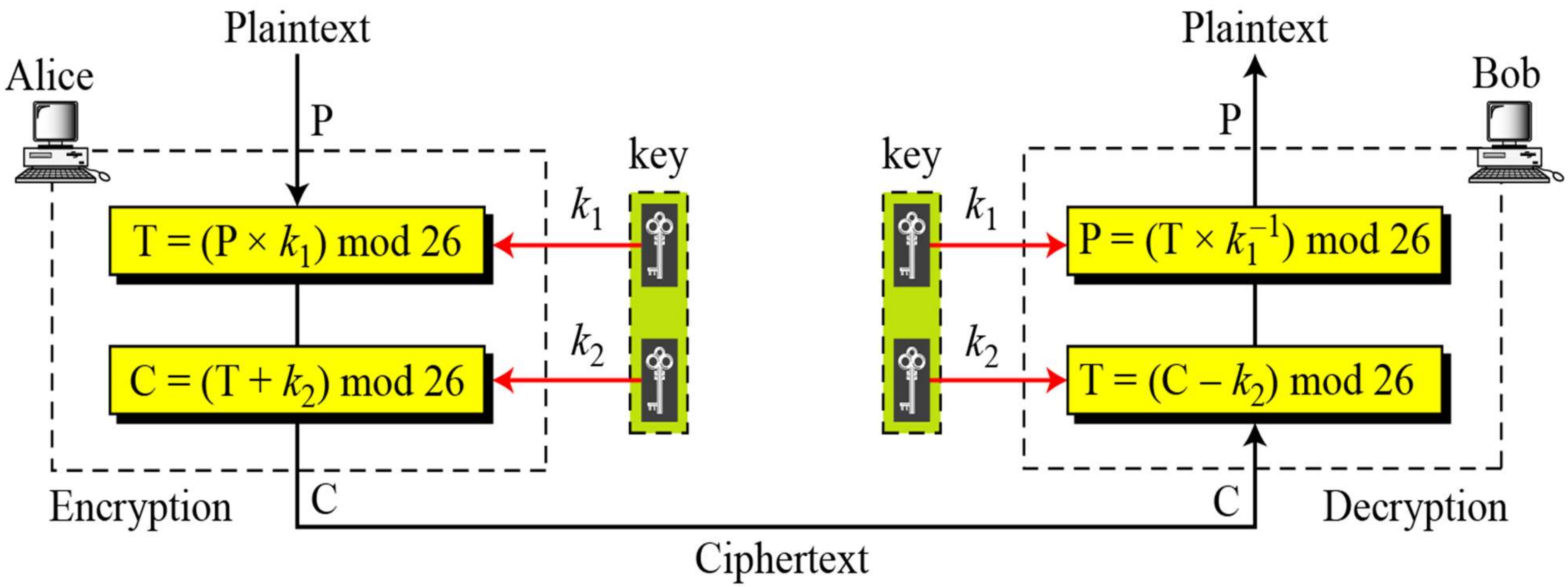
Affine Cipher



Affine Cipher

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

Encryption:

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

Affine Cipher

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

Decryption:

Multiplicative Inverse of 7=15

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

Simple Monoalphabetic Cipher

Instead of shifting the letters with a fixed amount, any permutation of the alphabet is done.

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

Plaintext: cryptography

Ciphertext: VYZXUHBYDMJZ

Number of keys ?

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Simple Monoalphabetic Cipher

- Keys are 26! = 4×10^{26}
- Decryption without a key would need to try all the 26! Possibilities.
- With so many keys, it might be secure
- The problem is that
  - language characteristics can be used to speed up the process of decryption

Unit No: 1

Unit Name: Introduction & Number Theory

Lecture No: 3
Polyalphabetic substitution techniques: Vigenère cipher

Polyalphabetic Substitution Cipher

- 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.

- Makes cryptanalysis harder with more alphabets (substitutions) to guess and flattens frequency distribution

- A key determines which substitution is used in each step

Autokey Cipher

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

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

Plaintext = attack is today

$K_1 = 12$

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**

Ciphertext = mtmtcm sa lhrdy

Vigenère Cipher

- Proposed by Giovan Batista Belaso (1553) and reinvented by Blaisede Vigenère (1586)
- Multiple caesar ciphers
- key is multiple letters long K = k1 k2 ... kd
- i^{th} letter specifies i^{th} alphabet to use
- use each alphabet in turn
- repeat from start after d letters in message
- decryption simply works in reverse

Vigenère Cipher

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

Encryption: $C_i = P_i + k_i$ Decryption: $P_i = C_i - k_i$

Example: Encrypt the message "She is listening" using the 6-character keyword "PASCAL".

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**

Vigenère Cipher

keyword : deceptive

key: de cep tivedecept ived eceptive

plaintext: we are discovered save yourself

ciphertext: ZI CVT WQNGRZGVTW AVZH CQYGLMGJ

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

Vigenère Cipher

- Its strength lays in the fact that each plaintext letter has multiple ciphertext letters

  - Letter frequencies are obscured (but not totally lost)

- The Vigenère Cipher can be broken using the following steps:

  1. Find the period (key length); call it n

  2. Break ciphertext into n parts

     - Each part is enciphered using the same key letter (Caesar cipher)

  3. Solve each part as a Caesar cipher!

One Time Pad

- Idea: use a (truly) random key as long as the plaintext
- It is unbreakable since the ciphertext bears no statistical relationship to the plaintext
- Moreover, for any plaintext & any ciphertext there exists a key mapping one to the other
- Thus, a ciphertext can be decrypted to any plaintext of the same length
- The cryptanalyst is in an impossible situation

One Time Pad

- The security is entirely given by the randomness of the key
  - If the key is truly random, then the ciphertext is random
  - A key can only be used once if the cryptanalyst is to be kept in the "dark"
- Problems with this "perfect" cryptosystem
  - Making large quantities of truly random characters is a significant task
  - Key distribution is enormously difficult: for any message to be sent, a key of equal length must be

Thank You

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