Lecture (02)
Classical Encryption Techniques (I)

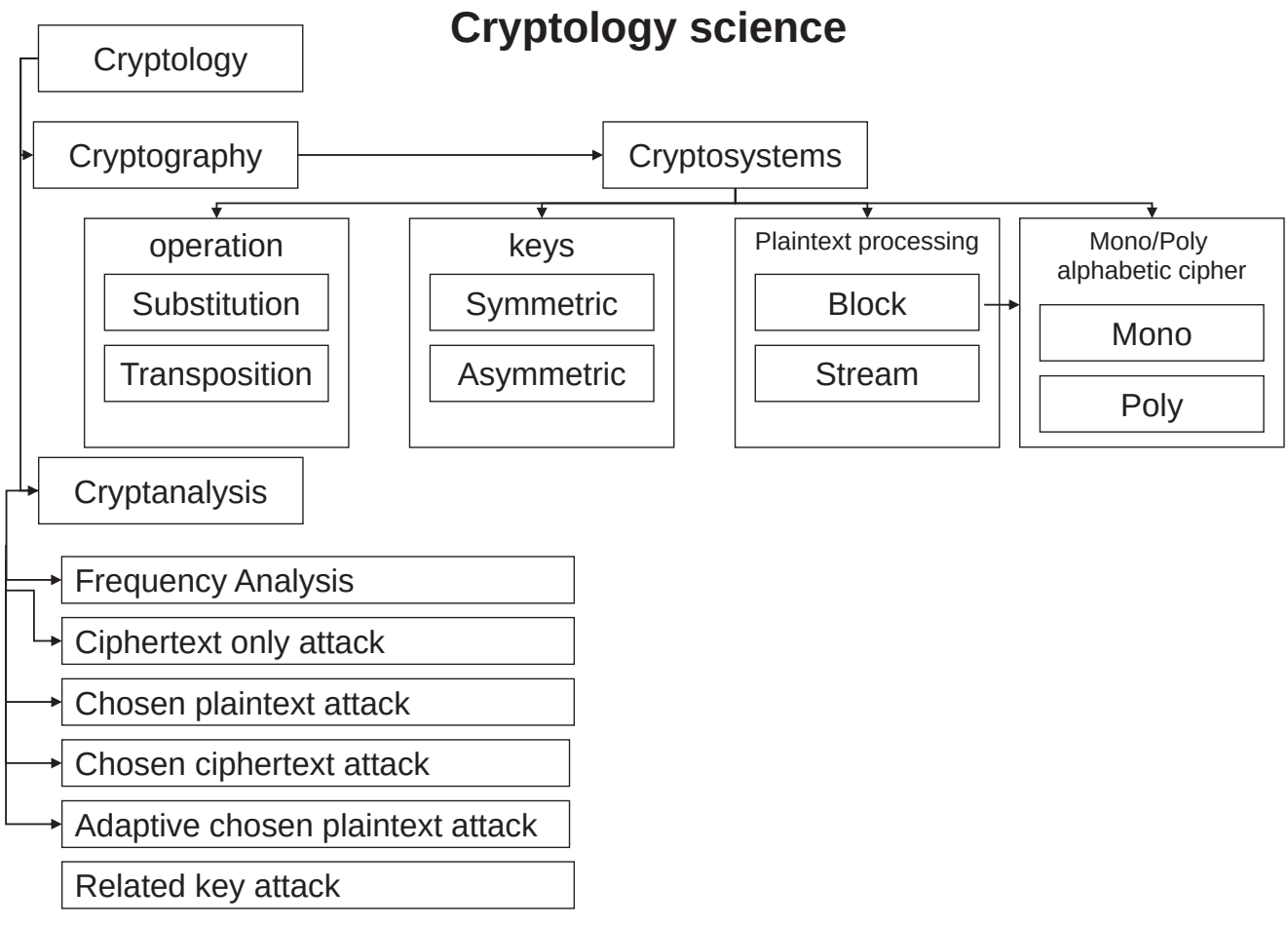
Dr. Ahmed M. ElShafee

Agenda

- Preface
- Cryptography
- Cryptanalysis
- Classical Ciphers

Preface

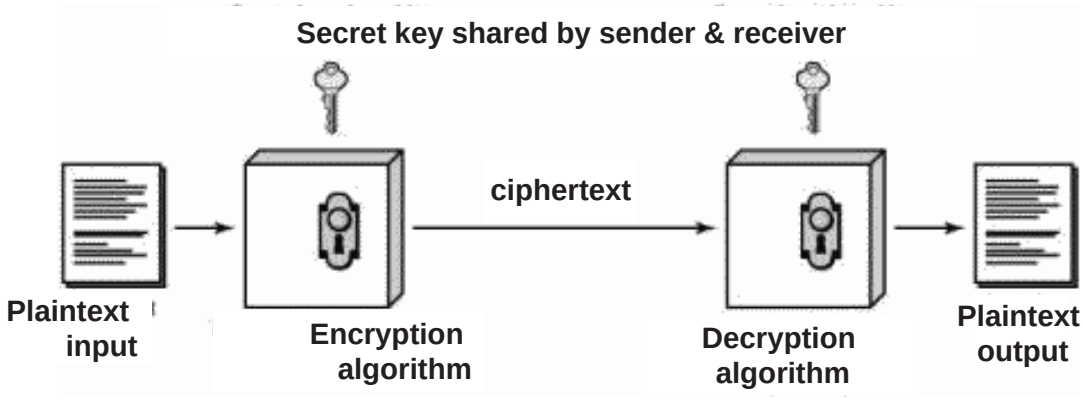
- **cryptology** - field of both cryptography and cryptanalysis
- **cryptography** - study of encryption principles/methods
- **cryptanalysis (codebreaking)** - study of principles/ methods of deciphering ciphertext *without* knowing key



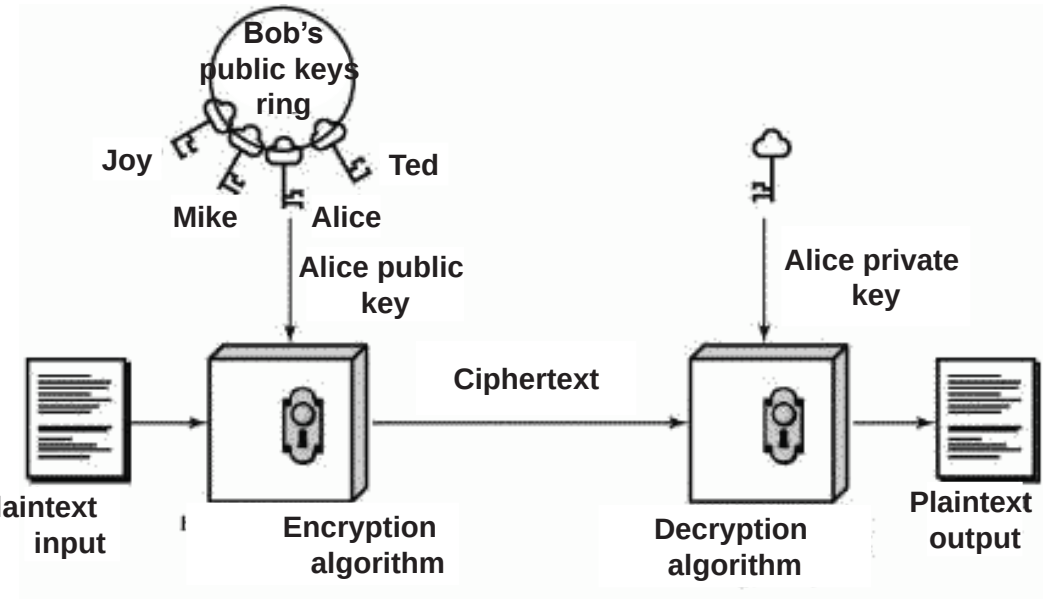
Cryptography

- Cryptographic systems can be characterized along these three independent dimensions.
  - type of encryption operations used
    - Substitution, permutation, or product (later)
  - number of keys used
    - single-key or private (symmetric)
    - two-key or public (Asymmetric)
  - way in which plaintext is processed
    - block / stream (later)

Private key cryptosystem



Public key cryptosystem



Symmetric (private) key

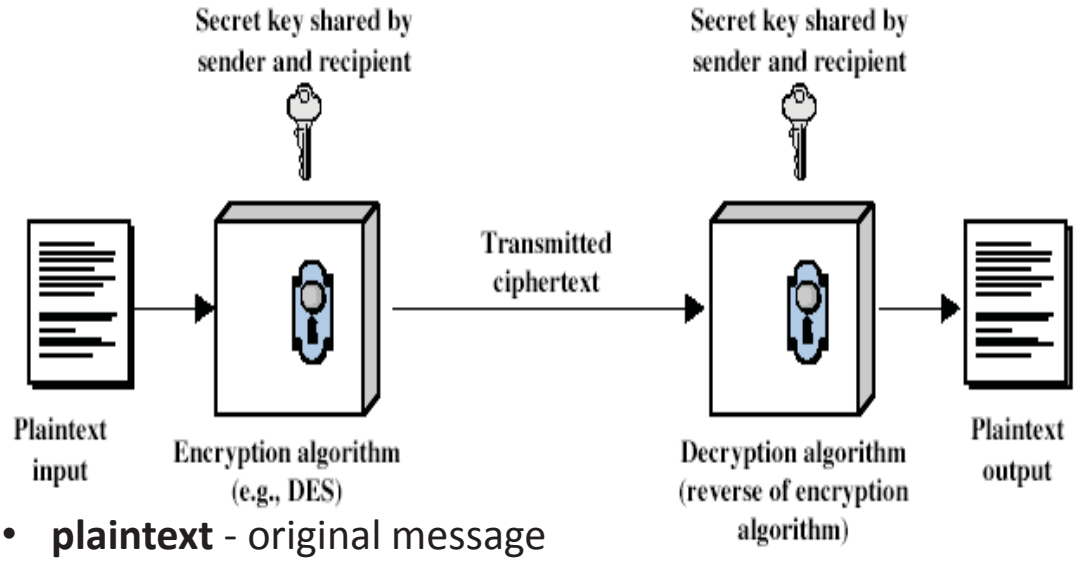
- Symmetric encryption, also referred to as conventional encryption or single key encryption, was the only type of encryption in use prior to the development of public-key encryption in the 1970s.
- It remains by far the most widely used of the two types of encryption.
- *All traditional schemes are **symmetric / single key / private-key** encryption algorithms, with a **single key**, used for both encryption and decryption.*
- *Since both sender and receiver are equivalent, either can encrypt or decrypt messages using that common key.*

- two requirements for secure use of symmetric encryption:
  - a strong encryption algorithm
  - a secret key known only to sender / receiver
- We assume that it is impractical to decrypt a message on the basis of the cipher- text plus knowledge of the encryption/decryption algorithm, and do not need to keep the algorithm secret; rather we only need to keep the key secret.
- This feature of symmetric encryption is what makes it feasible for widespread use.
- It allows easy distribution of s/w and h/w implementations.

- mathematically have:

  $Y = E_K(X)$

  $X = D_K(Y)$
- assume encryption algorithm is known
- implies a secure channel to distribute key



- **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 ciphertext from plaintext

Cryptanalysis

- objective is to recover the key in use rather then simply to recover the plaintext of a single ciphertext.
- general approaches:
  - cryptanalytic attack
    - rely on the nature of the algorithm plus perhaps some knowledge of the general characteristics of the plaintext or even some sample plaintext-ciphertext pairs.

- brute-force attack
  - try every possible key on a piece of ciphertext until an intelligible translation into plaintext is obtained.
  - On average, half of all possible keys must be tried to achieve success

Cryptanalytic Attacks

- ciphertext only

only know algorithm & ciphertext, is statistical, know or can identify plaintext

- known plaintext

know/suspect plaintext & ciphertext

- chosen plaintext

select plaintext and obtain ciphertext

- chosen ciphertext

select ciphertext and obtain plaintext

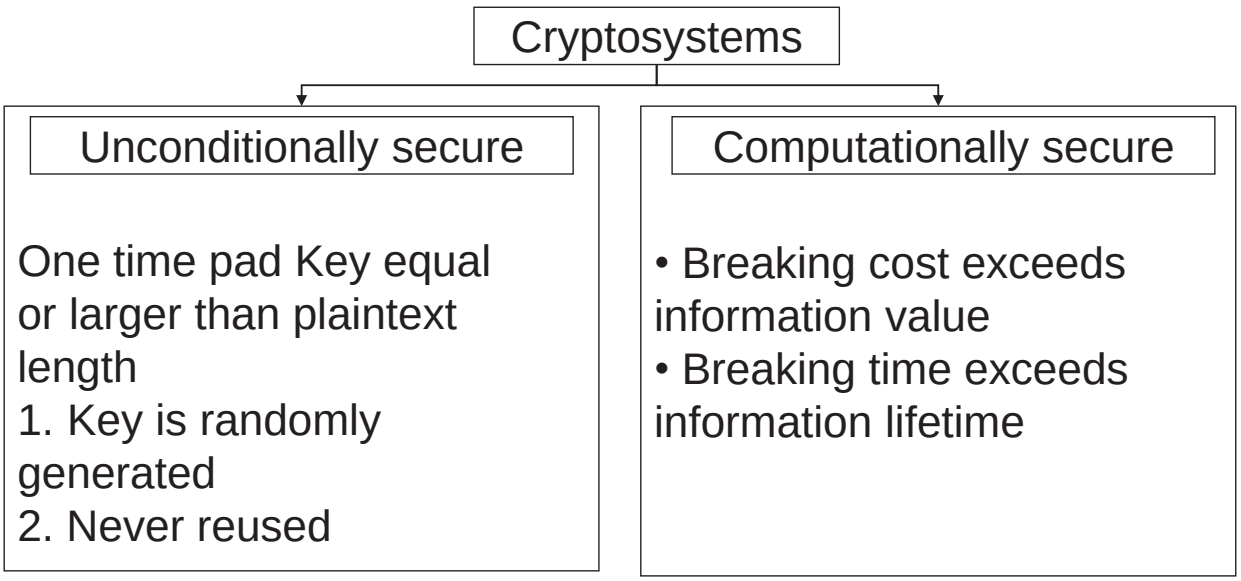
- chosen text

select plaintext or ciphertext to en/decrypt

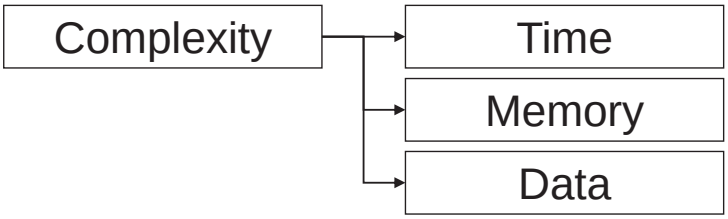
- The most difficult problem is presented when all that is available is the ciphertext only.
- In some cases, not even the encryption algorithm is known, but in general we can assume that the opponent does know the algorithm used for encryption.
- Generally, an encryption algorithm is designed to withstand (resists) a known-plaintext attack.

Shannon's theory

According to cryptanalytic attacks, we can classify cryptosystems into two types



Complexity & weakness



"Breaking cipher, means to find weakness can be exploited with complexity less than brute force attack", Bruce a schneier

Brute Force attack (Excusive key search)

- A brute-force attack involves trying every possible key until an intelligible translation of the ciphertext into plaintext is obtained.
- On average, half of all possible keys must be tried to achieve success.

Key Size (bits)	Number of Alternative Keys	Time required at 1 decryption/μs	Time required at 10^6 decryptions/μs
32			
56			
128			
168			

Brute Force attack (Excusive key search)

- A brute-force attack involves trying every possible key until an intelligible translation of the ciphertext into plaintext is obtained.
- On average, half of all possible keys must be tried to achieve success.

Key Size (bits)	Number of Alternative Keys	Time required at 1 decryption/μs	Time required at 10^6 decryptions/μs
32	$2^{32} = 4.3 \times 10^9$	2^{31} μs = 35.8 minutes	2.15 milliseconds
56	$2^{56} = 7.2 \times 10^{16}$	2^{55} μs = 1142 years	10.01 hours
128	$2^{128} = 3.4 \times 10^{38}$	2^{127} μs = 5.4×10^{24} years	7.6×10^{18} years
168	$2^{168} = 3.7 \times 10^{50}$	2^{167} μs = 5.9×10^{36} years	8.4×10^{30} years

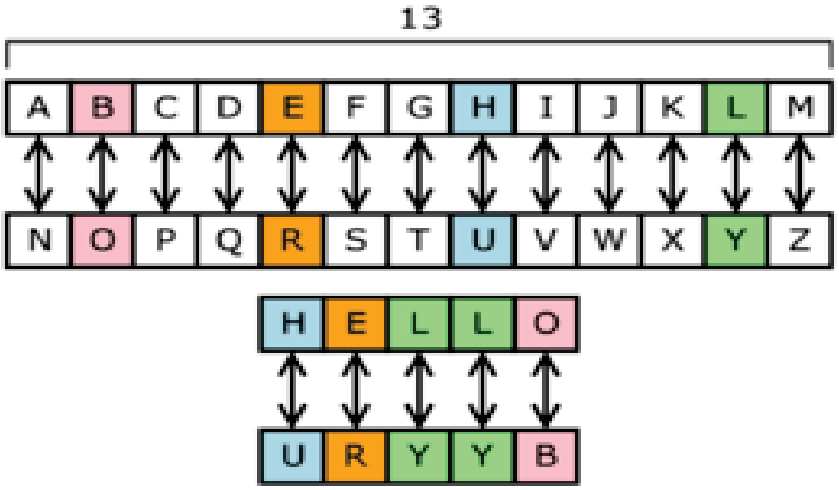
Classical Ciphers

- The two basic building blocks of all encryption technique are substitution and transposition.

Substitution

- where letters of plaintext are replaced by other letters or by numbers or symbols
- if plaintext is viewed as a sequence of bits, then substitution involves replacing plaintext bit patterns with ciphertext bit patterns

Substitution ciphers



Caesar Cipher

- earliest known substitution cipher
- by Julius Caesar
- first use in military affairs
- Example: replaces each letter by 3rd letter on

- Substitution box

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
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

- Mathematically

  $c = E(p) = (p + k) \bmod (26)$

  $p = D(c) = (c - k) \bmod (26)$

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
0	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

- This mathematical description uses **modulo (clock) arithmetic**.
- Here, when you reach Z you go back to A and start again.
- Mod 26 implies that when you reach 26, you use 0 instead (ie the letter after Z, or 25 + 1 goes to A or 0).

Examples

- Encrypt the following message

“meet you at nine PM”,

- using the key

“k”

0	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
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

plaintext

m	**e**	**e**	**t**	**y**	**o**	**u**	**a**	**t**	**n**	**i**	**n**	**e**	**P**	**M**
12	4	4	19	24	14	20	0	19	13	8	13	4	15	12

key

K
10

ciphertext

0	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
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

plaintext

m	**e**	**e**	**t**	**y**	**o**	**u**	**a**	**t**	**n**	**i**	**n**	**e**	**P**	**M**
12	4	4	19	24	14	20	0	19	13	8	13	4	15	12

key

K
10

ciphertext

22	14	14	3	8	24	4	10	3	23	18	23	14	25	22
w	o	o	d	i	y	e	k	d	x	s	x	o	z	w

- Example
- Decrypt the following message

  “**nhfsstyrjjydtzfysnsjqjyxrfpjnyyjs**”
- using the key

“F”

0	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
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	h	f	s	s	t	y	r	j	j	y	d	t	z	f	y	s	n	s	j	q	j	y	x	r	f	p	j	n	y	y	j	s
13	7	5	18	18	19	24	17	9	9	24	3	19	25	5	24	18	13	18	9	16	9	24	23	17	5	15	9	13	24	24	9	18

key

f
5

plaintext

0	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
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	h	f	s	s	t	y	r	j	j	y	d	t	z	f	y	s	n	s	j	q	j	y	x	r	f	p	j	n	y	y	j	s
13	7	5	18	18	19	24	17	9	9	24	3	19	25	5	24	18	13	18	9	16	9	24	23	17	5	15	9	13	24	24	9	18

key

f
5

plaintext

8	2	0	13	13	14	19	12	4	4	19	24	14	20	0	19	13	8	13	4	11	4	19	18	12	0	10	4	8	19	19	4	13
i	c	a	n	n	o	t	m	e	e	t	y	o	u	a	t	n	i	n	e	l	e	t	s	m	a	k	e	i	t	t	e	n

Caesar Cipher cryptanalysis

- With a caesar cipher, there are only 26 possible keys (actually it's 25 only)
- try each of the keys (shifts) in turn, until can recognize the original message
- need to be able to **recognize** when have an original message (ie is it English or whatever).
- Usually easy for humans, hard for computers.

- Break the following ciphertext

"GCUA VQ DTGCM"

0	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
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

G	C	U	A	V	Q	D	T	G	C	M
6	2	20	0	21	16	3	19	6	2	12

Key

plaintext

0	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
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

G	C	U	A	V	Q	D	T	G	C	M
6	2	20	0	21	16	3	19	6	2	12

Key

c
2

plaintext

4	0	18	24	19	14	1	17	4	0	10
e	a	s	y	t	o	b	r	e	a	k

Thanks,..

See you next week (ISA),…