CS4614 – INTRODUCTORY NETWORK SECURITY

3. CLASSICAL ENCRYPTION

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Definitions

Plaintext
- An original message

Ciphertext
- The coded message

Enciphering/encryption
- The process of converting from plaintext to ciphertext

Deciphering/decryption
- Restoring the plaintext from the ciphertext

Cryptography
- The area of study of the many schemes used for encryption

Cryptographic system/cipher
- A scheme

Cryptanalysis
- Techniques used for deciphering a message without any knowledge of the enciphering details

Cryptology
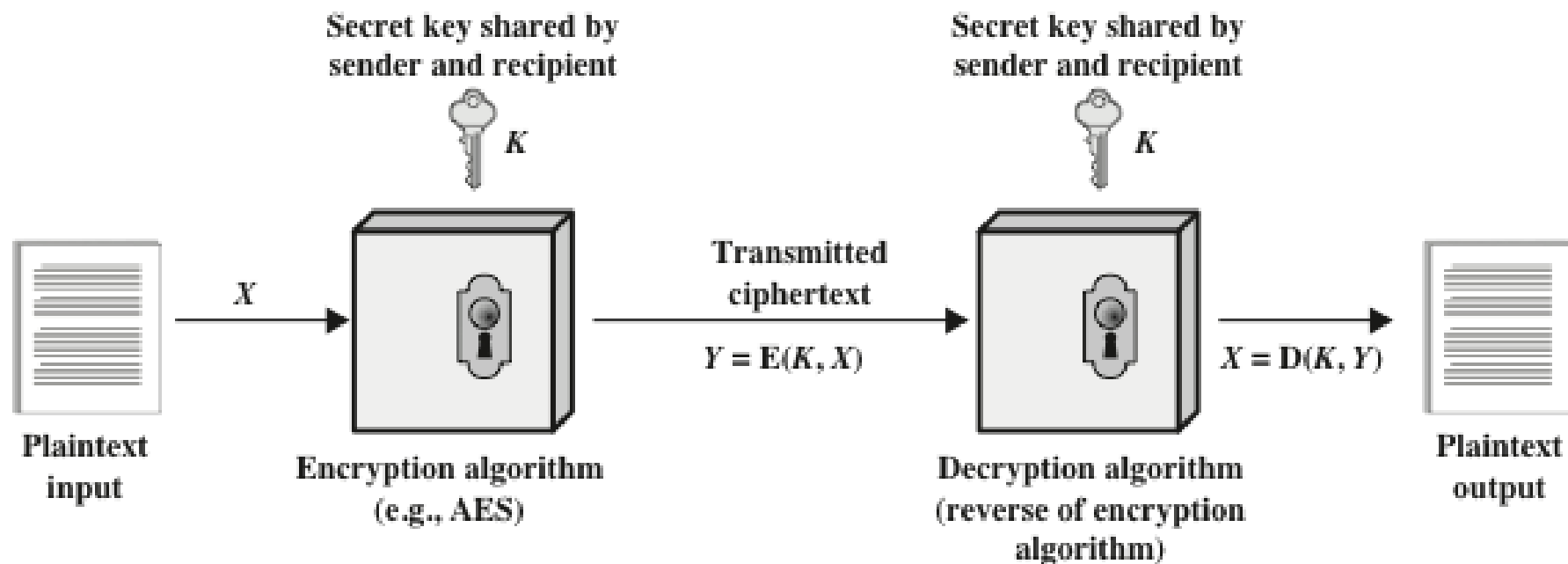- The areas of cryptography and cryptanalysis

Figure 3.1 Simplified Model of Symmetric Encryption

In the figure:
- Plaintext input → X → Encryption algorithm (e.g., AES) → Transmitted ciphertext $Y = E(K, X)$ → Decryption algorithm (reverse of encryption algorithm) → $X = D(K, Y)$ → Plaintext output
- Secret key shared by sender and recipient: K

Symmetric Cipher Model

- There are two requirements for secure use of conventional encryption:

    - A strong encryption algorithm

    - Sender and receiver must have obtained copies of the secret key in a secure fashion and must keep the key secure
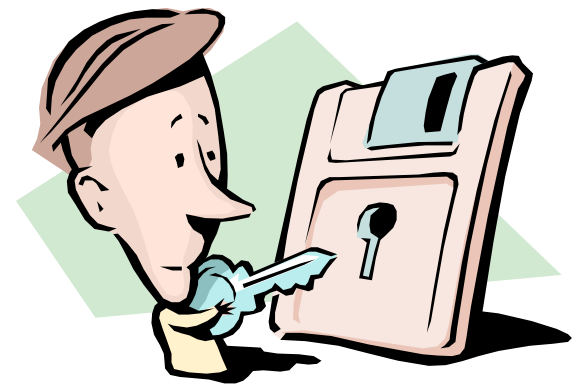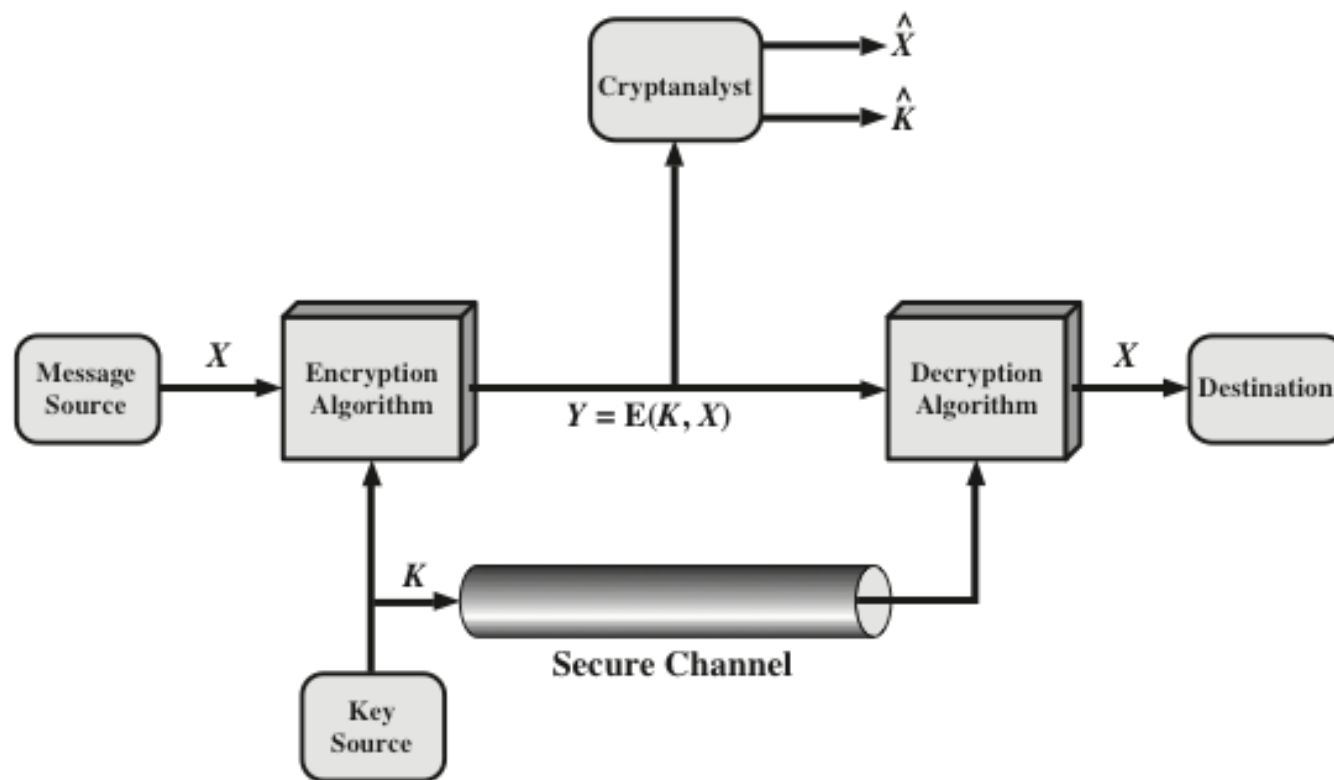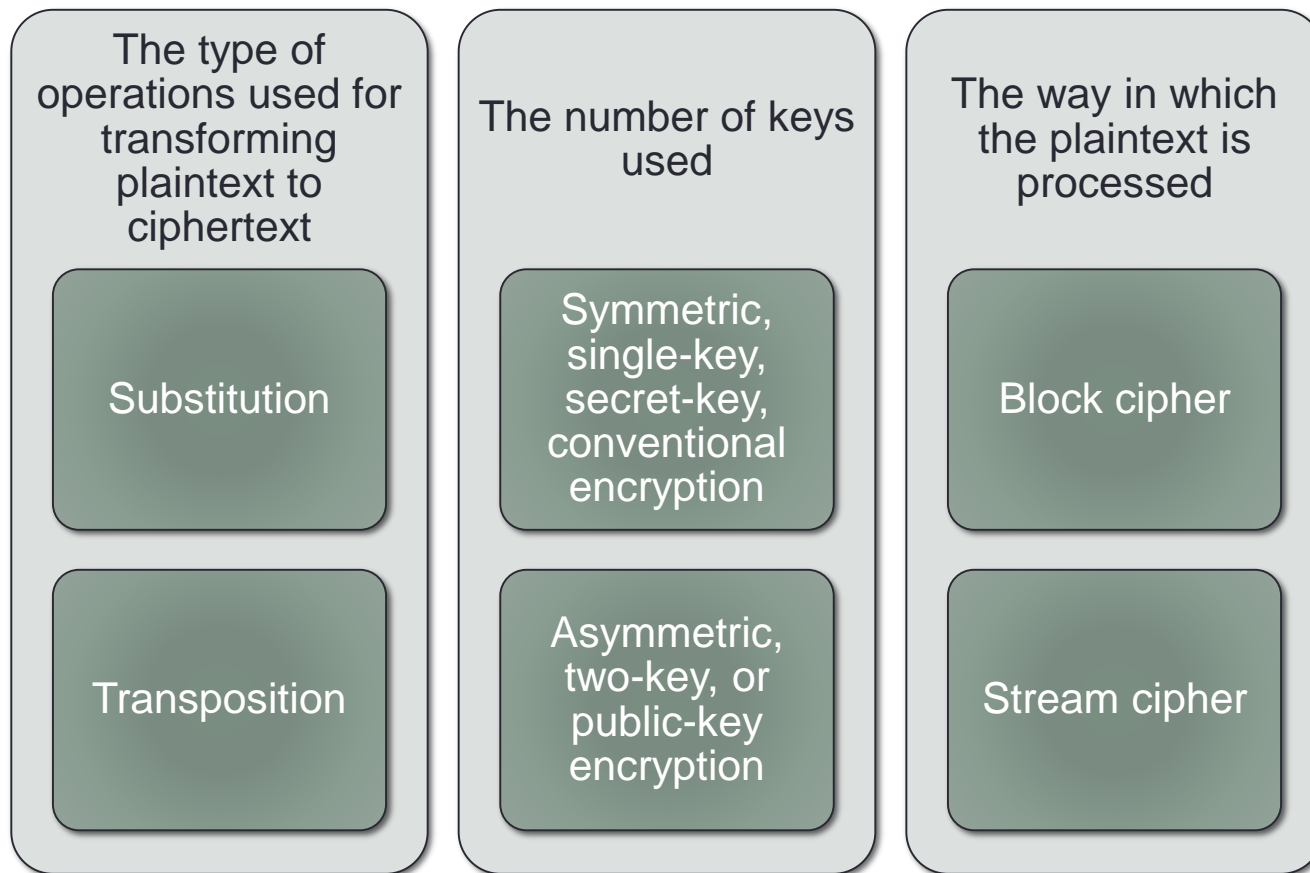
Figure 3.2 Model of Symmetric Cryptosystem

Cryptographic Systems

- Characterized along three independent dimensions:

The type of operations used for transforming plaintext to ciphertext	The number of keys used	The way in which the plaintext is processed
Substitution	Symmetric, single-key, secret-key, conventional encryption	Block cipher
Transposition	Asymmetric, two-key, or public-key encryption	Stream cipher

Cryptanalysis and Brute-Force Attack

Cryptanalysis

- **Attack relies on the nature of the algorithm plus some knowledge of the general characteristics of the plaintext**
- **Attack exploits the characteristics of the algorithm to attempt to deduce a specific plaintext or to deduce the key being used**
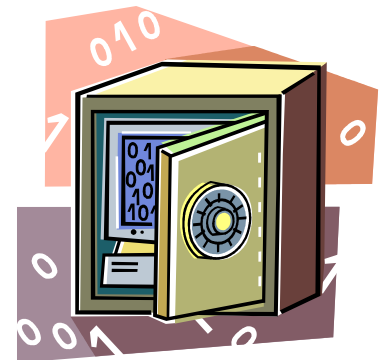
Brute-force attack

- **Attacker tries 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**

Type of Attack	Known to Cryptanalyst
Ciphertext Only	• Encryption algorithm • Ciphertext
Known Plaintext	• Encryption algorithm • Ciphertext • One or more plaintext-ciphertext pairs formed with the secret key
Chosen Plaintext	• Encryption algorithm • Ciphertext • Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key
Chosen Ciphertext	• Encryption algorithm • Ciphertext • Ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key
Chosen Text	• Encryption algorithm • Ciphertext • Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key • Ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key

Encryption Scheme Security

- Unconditionally secure
  - No matter how much time an opponent has, it is impossible for him or her to decrypt the ciphertext simply because the required information is not there

- Computationally secure
  - The cost of breaking the cipher exceeds the value of the encrypted information
  - The time required to break the cipher exceeds the useful lifetime of the information

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

To supplement the brute-force approach, some degree of knowledge about the expected plaintext is needed, and some means of automatically distinguishing plaintext from garble is also needed

Substitution Technique

- Is one in which the letters of plaintext are replaced by other letters or by numbers or symbols
- If the plaintext is viewed as a sequence of bits, then substitution involves replacing plaintext bit patterns with ciphertext bit patterns

Caesar Cipher

- Simplest and earliest known use of a substitution cipher
- Used by Julius Caesar
- Involves replacing each letter of the alphabet with the letter standing three places further down the alphabet
- Alphabet is wrapped around so that the letter following Z is A

plain: `MEET ME AFTER THE TOGA PARTY`

cipher: `PHHW PH DIWHU WKH WRJD SDUWB`

Caesar Cipher Algorithm

- Can define transformation as:

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

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

- Mathematically give each letter a number

```
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
```

- Algorithm can be expressed as:

$$c = E(3, p) = (p + 3) \bmod (26)$$

- A shift may be of any amount, so that the general Caesar algorithm is:

$$C = E(k, p) = (p + k) \bmod 26$$

- Where k takes on a value in the range 1 to 25; the decryption algorithm is:

$$p = D(k, C) = (C - k) \bmod 26$$

Brute-Force Cryptanalysis of Caesar Cipher

(This chart can be found on page 75 in the textbook)

```
         PHHW PH DIWHU WKH WRJD SDUWB
KEY
    1    oggv og chvgt vjg vqic rctva
    2    nffu nf bgufs uif uphb qbsuz
    3    meet me after the toga party
    4    ldds ld zesdq sgd snfz ozqsx
    5    kccr kc ydrcp rfc rmey nyprw
    6    jbbq jb xcqbo qeb qldx mxoqv
    7    iaap ia wbpan pda pkcw lwnpu
    8    hzzo hz vaozm ocz ojbv kvmot
    9    gyyn gy uznyl nby niau julns
   10    fxxm fx tymxk max mhzt itkmr
   11    ewwl ew sxlwj lzw lgys hsjlq
   12    dvvk dv rwkvi kyv kfxr grikp
   13    cuuj cu qvjuh jxu jewq fqhjo
   14    btti bt puitg iwt idvp epgin
   15    assh as othsf hvs hcuo dofhm
   16    zrrg zr nsgre gur gbtn cnegl
   17    yqqf yq mrfqd ftq fasm bmdfk
   18    xppe xp lqepc esp ezrl alcej
   19    wood wo kpdob dro dyqk zkbdi
   20    vnnc vn jocna cqn cxpj yjach
   21    ummb um inbmz bpm bwoi xizbg
   22    tlla tl hmaly aol avnh whyaf
   23    skkz sk glzkx znk zumg vgxze
   24    rjjy rj fkyjw ymj ytlf ufwyd
   25    qiix qi ejxiv xli xske tevxc
```

Compression/Encoding

Friends, Romans, countrymen, lend me your ears; I come to bury Caesar, not to praise him; The evil that men do lives after them, The good is oft interred with their bones, So let it be with Caesar

eNoljkEKwzAMBO+F/mEf4B/kWCj02vYDTq3UglgqspK
S30chJ8HOsKu7MUnpCU9tWeJ+dBG3rZEkzIHQCJsuBs
rWBzxCiMQV42Ibbpl6tgRRP7KfZe6Eym3AuxJo5Rles
0eLoChmXqkjT04WObV0vRzeV7WAO3RysAQ0Kviz10Ni
w6hC8dsrCigMx0gnPvd3tW5E1A==

Monoalphabetic Cipher

- Permutation
  - Of a finite set of elements S is an ordered sequence of all the elements of S, with each element appearing exactly once

- If the "cipher" line can be any permutation of the 26 alphabetic characters, then there are 26! or greater than 4×10^{26} possible keys
  - This is 10 orders of magnitude greater than the key space for DES
  - Approach is referred to as a *monoalphabetic substitution cipher* because a single cipher alphabet is used per message
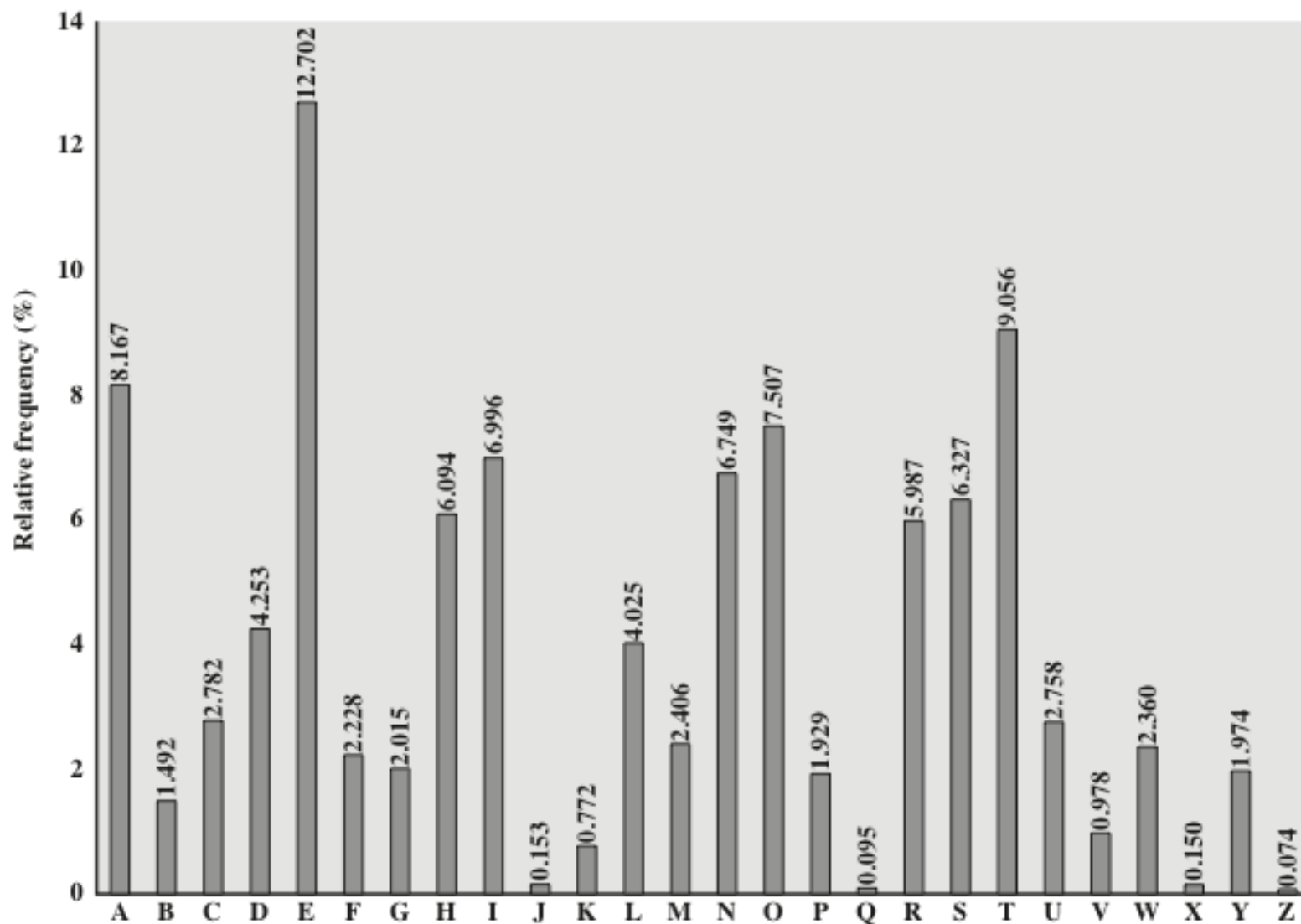
Figure 3.5   Relative Frequency of Letters in English Text

Monoalphabetic Ciphers

- Easy to break because they reflect the frequency data of the original alphabet
- Countermeasure is to provide multiple substitutes (homophones) for a single letter
- Digram
  - Two-letter combination
  - Most common is *th*
- Trigram
  - Three-letter combination
  - Most frequent is *the*
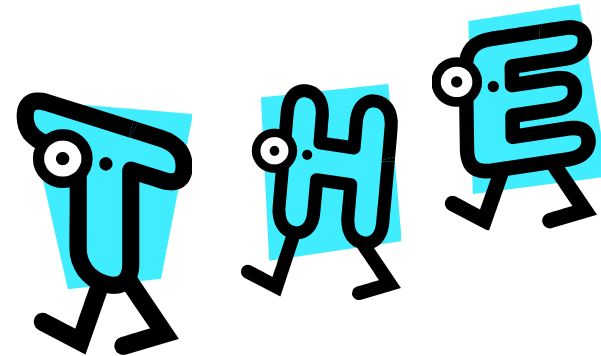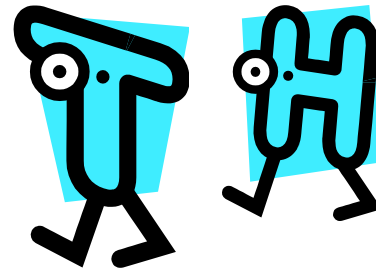
Playfair Cipher

- Best-known multiple-letter encryption cipher

- Treats digrams in the plaintext as single units and translates these units into ciphertext digrams

- Based on the use of a 5 x 5 matrix of letters constructed using a keyword

- Invented by British scientist Sir Charles Wheatstone in 1854

- Used as the standard field system by the British Army in World War I and the U.S. Army and other Allied forces during World War II

Playfair Key Matrix

- Fill in letters of keyword (minus duplicates) from left to right and from top to bottom, then fill in the remainder of the matrix with the remaining letters in alphabetic order
- Using the keyword MONARCHY:

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
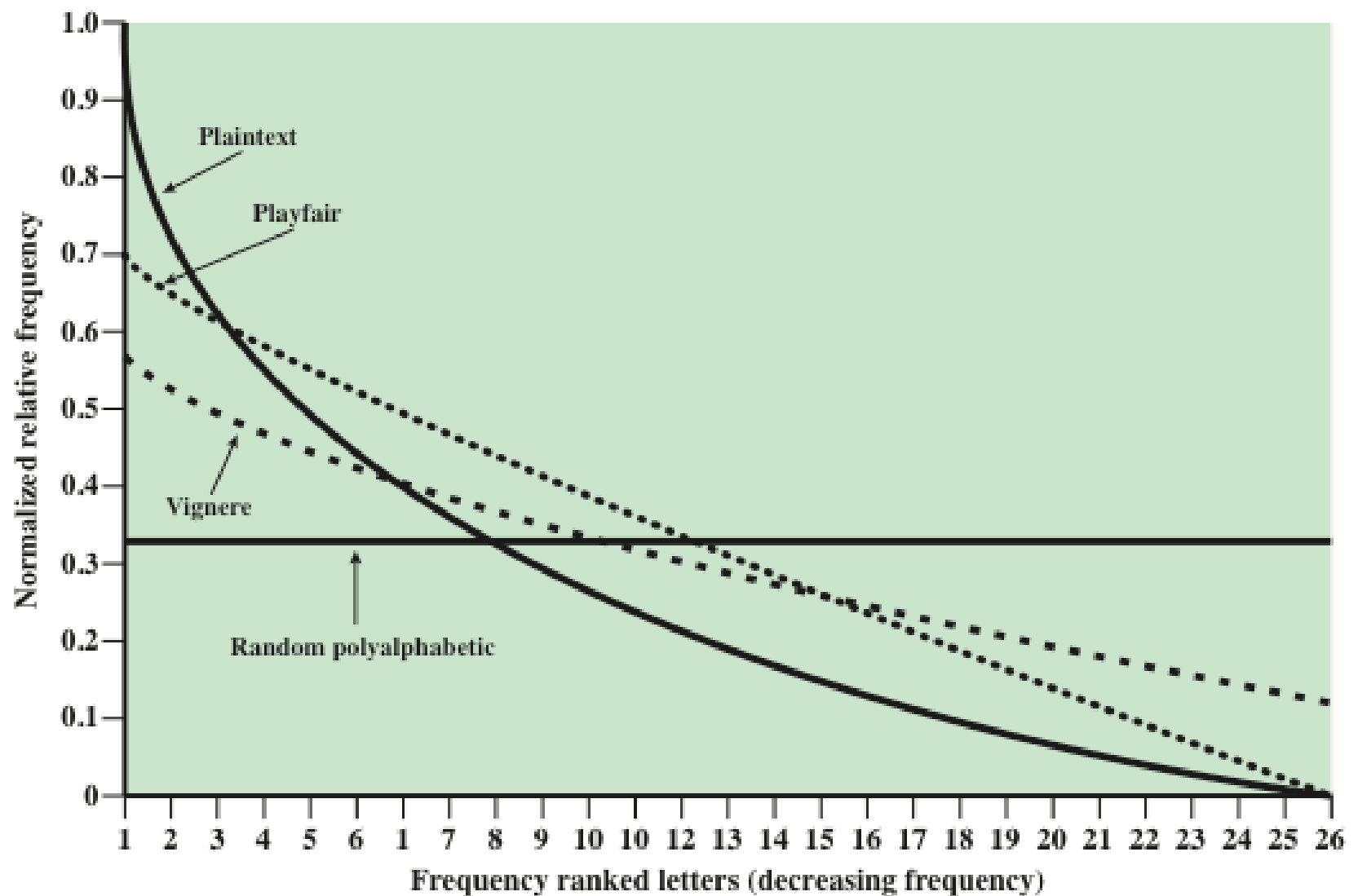
Figure 3.6   Relative Frequency of Occurrence of Letters

Hill Cipher

- Developed by the mathematician Lester Hill in 1929

- Strength is that it completely hides single-letter frequencies

  - The use of a larger matrix hides more frequency information

  - A 3 x 3 Hill cipher hides not only single-letter but also two-letter frequency information

- Strong against a ciphertext-only attack but easily broken with a known plaintext attack

Polyalphabetic Ciphers

- Polyalphabetic substitution cipher
  - Improves on the simple monoalphabetic technique by using different monoalphabetic substitutions as one proceeds through the plaintext message

All these techniques have the following features in common:

- A set of related monoalphabetic substitution rules is used
- A key determines which particular rule is chosen for a given transformation

Vigenère Cipher

- Best known and one of the simplest polyalphabetic substitution ciphers

- In this scheme the set of related monoalphabetic substitution rules consists of the 26 Caesar ciphers with shifts of 0 through 25

- Each cipher is denoted by a key letter which is the ciphertext letter that substitutes for the plaintext letter 'a'

Example of Vigenère Cipher

- To encrypt a message, a key is needed that is as long as the message

- Usually, the key is a repeating keyword

- For example, if the keyword is *deceptive*, the message "we are discovered save yourself" is encrypted as:

key: `deceptivedeceptivedeceptive`

plaintext: `wearediscoveredsaveyourself`

ciphertext: `ZICVTWQNGRZGVTWAVZHCQYGLMGJ`

Vigenère Autokey System

- A keyword is concatenated with the plaintext itself to provide a running key

- Example:

key: `deceptivewarediscoveredsav`

plaintext: `wearediscoveredsaveyourself`

ciphertext: `ZICVTWQNGKZEIIGASXSTSLVVWLA`

- Even this scheme is vulnerable to cryptanalysis

  - Because the key and the plaintext share the same frequency distribution of letters, a statistical technique can be applied

Vernam Cipher
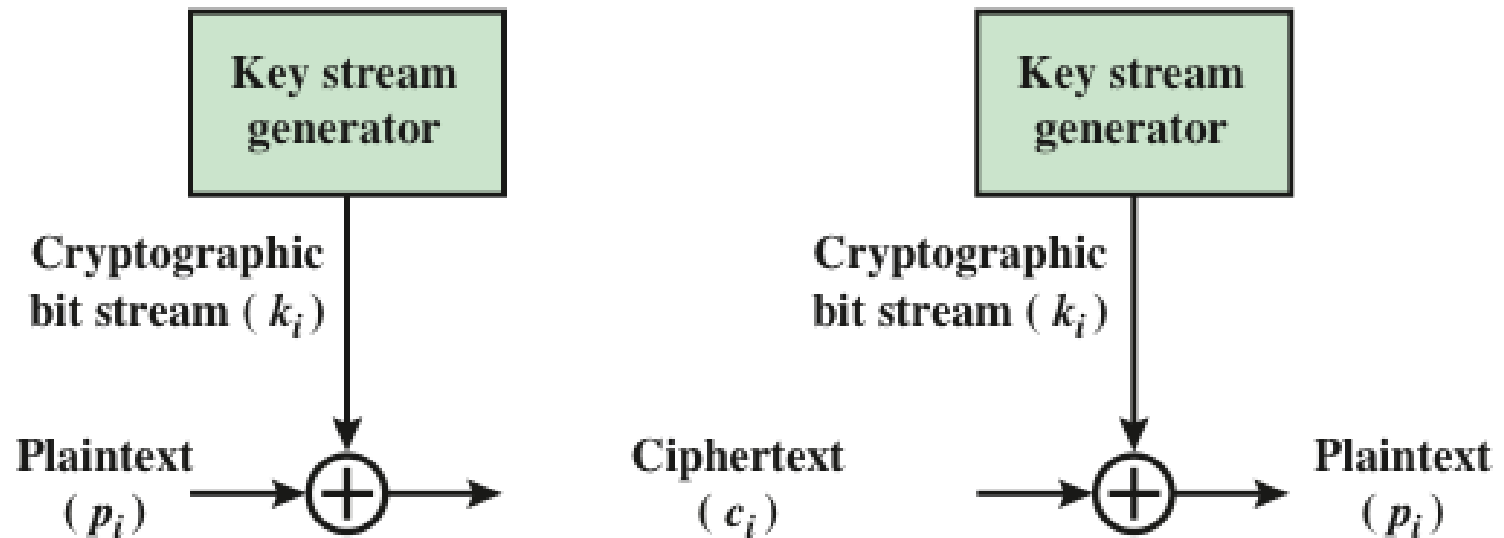
Figure 3.7 Vernam Cipher

One-Time Pad

- Improvement to Vernam cipher proposed by an Army Signal Corp officer, Joseph Mauborgne
- Use a random key that is as long as the message so that the key need not be repeated
- Key is used to encrypt and decrypt a single message and then is discarded
- Each new message requires a new key of the same length as the new message
- Scheme is unbreakable
  - Produces random output that bears no statistical relationship to the plaintext
  - Because the ciphertext contains no information whatsoever about the plaintext, there is simply no way to break the code

Difficulties

- The one-time pad offers complete security but, in practice, has two fundamental difficulties:
  - There is the practical problem of making large quantities of random keys
    - Any heavily used system might require millions of random characters on a regular basis
  - Mammoth key distribution problem
    - For every message to be sent, a key of equal length is needed by both sender and receiver
- Because of these difficulties, the one-time pad is of limited utility
  - Useful primarily for low-bandwidth channels requiring very high security
- The one-time pad is the only cryptosystem that exhibits *perfect secrecy* (see Appendix F)

Rail Fence Cipher

- Simplest transposition cipher

- Plaintext is written down as a sequence of diagonals and then read off as a sequence of rows

- To encipher the message "meet me after the toga party" with a rail fence of depth 3, we would write:

```
m . . . m . . . t . . . o . . . a . . .
. e . t . e . t . h . t . g . p . r . y
. . e . . . a . . . e . . . a . . . t .
```

Encrypted message is:

```
MMTOAETETHTGPRYEAEAT
```
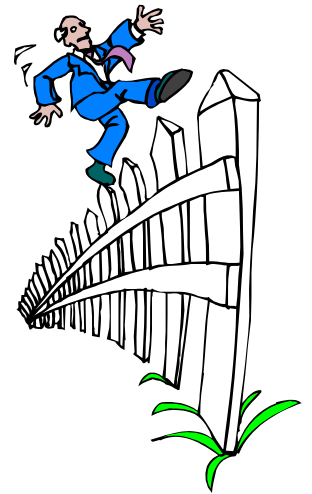
Row Transposition Cipher

- Is a more complex transposition

- Write the message in a rectangle, row by row, and read the message off, column by column, but permute the order of the columns

  - The order of the columns then becomes the key to the algorithm

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

direction of motion

(a) Initial setting

	fast rotor		medium rotor		slow rotor	
A	24	21	26	20	1	8	A
B	25	3	1	1	2	18	B
C	26	15	2	6	3	26	C
D	1	1	3	4	4	17	D
E	2	19	4	15	5	20	E
F	3	10	5	3	6	22	F
G	4	14	6	14	7	10	G
H	5	26	7	12	8	3	H
I	6	20	8	23	9	13	I
J	7	8	9	5	10	11	J
K	8	16	10	16	11	4	K
L	9	7	11	2	12	23	L
M	10	22	12	22	13	5	M
N	11	4	13	19	14	24	N
O	12	11	14	11	15	9	O
P	13	5	15	18	16	12	P
Q	14	17	16	25	17	25	Q
R	15	9	17	24	18	16	R
S	16	12	18	13	19	19	S
T	17	23	19	7	20	6	T
U	18	18	20	10	21	15	U
V	19	2	21	8	22	21	V
W	20	25	22	21	23	2	W
X	21	6	23	9	24	7	X
Y	22	24	24	26	25	1	Y
Z	23	13	25	17	26	14	Z

(b) Setting after one keystroke

	fast rotor		medium rotor		slow rotor	
A	23	13	26	20	1	8	A
B	24	21	1	1	2	18	B
C	25	3	2	6	3	26	C
D	26	15	3	4	4	17	D
E	1	1	4	15	5	20	E
F	2	19	5	3	6	22	F
G	3	10	6	14	7	10	G
H	4	14	7	12	8	3	H
I	5	26	8	23	9	13	I
J	6	20	9	5	10	11	J
K	7	8	10	16	11	4	K
L	8	16	11	2	12	23	L
M	9	7	12	22	13	5	M
N	10	22	13	19	14	24	N
O	11	4	14	11	15	9	O
P	12	11	15	18	16	12	P
Q	13	5	16	25	17	25	Q
R	14	17	17	24	18	16	R
S	15	9	18	13	19	19	S
T	16	12	19	7	20	6	T
U	17	23	20	10	21	15	U
V	18	18	21	8	22	21	V
W	19	2	22	21	23	2	W
X	20	25	23	9	24	7	X
Y	21	6	24	26	25	1	Y
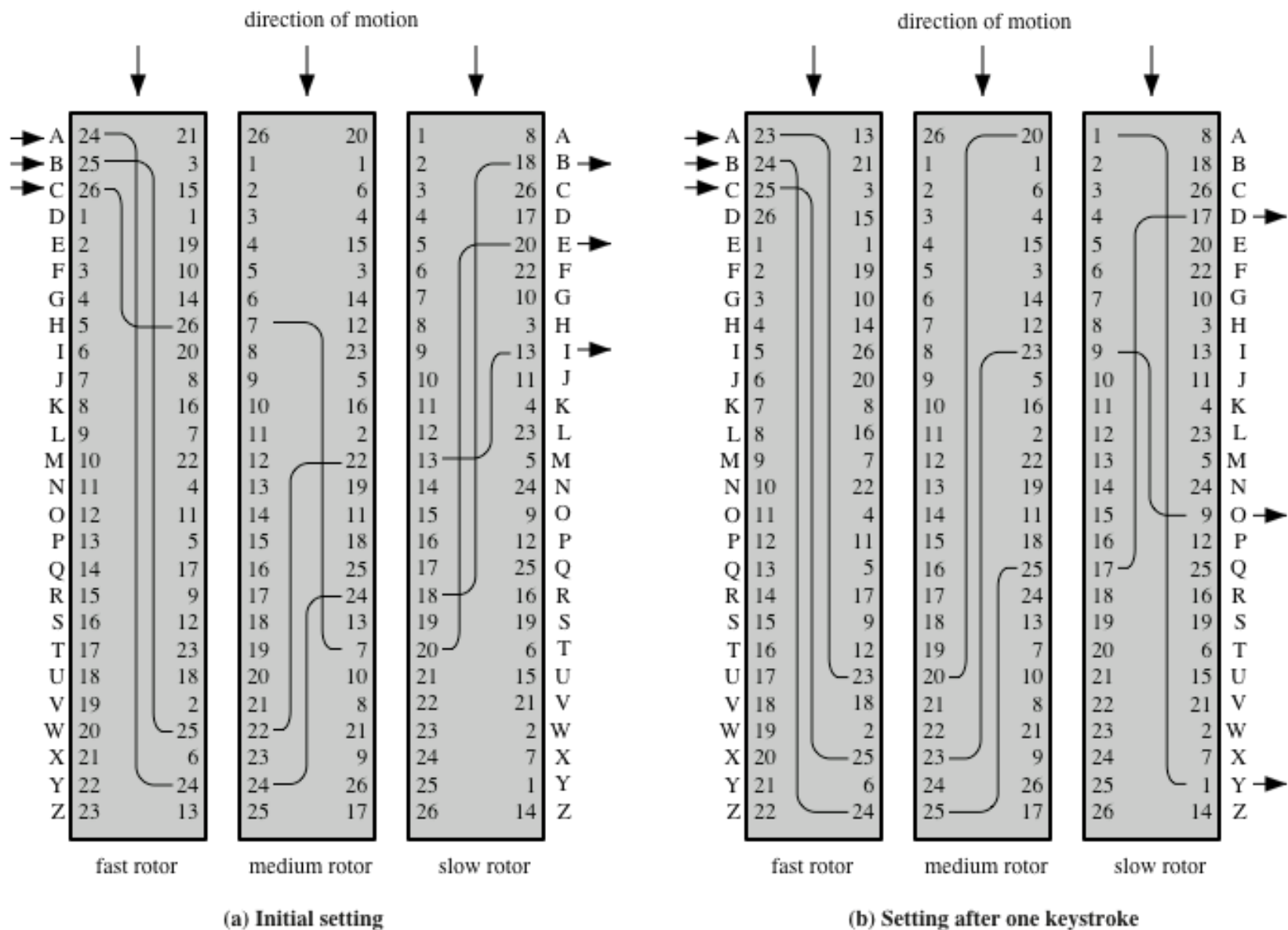| Z | 22 | 24 | 25 | 17 | 26 | 14 | Z

Figure 3.8   Three-Rotor Machine With Wiring Represented by Numbered Contacts

Steganography

3rd March

Dear George,

Greetings to all at Oxford. Many thanks for your
letter and for the Summer examination package.
All Entry Forms and Fees Forms should be ready
for final despatch to the Syndicate by Friday
20th or at the very latest, I'm told, by the 21st.
Admin has improved here, though there's room
for improvement still; just give us all two or three
more years and we'll really show you! Please
don't let these wretched 16+ proposals destroy
your basic O and A pattern. Certainly this
sort of change, if implemented immediately,
would bring chaos.

Sincerely yours,

Figure 2.9 A Puzzle for Inspector Morse
(from *The Silent World of Nicholas Quinn*, by Colin Dexter)

Other Steganography Techniques

- Character marking
  - Selected letters of printed or typewritten text are over-written in pencil
  - The marks are ordinarily not visible unless the paper is held at an angle to bright light
- Invisible ink
  - A number of substances can be used for writing but leave no visible trace until heat or some chemical is applied to the paper
- Pin punctures
  - Small pin punctures on selected letters are ordinarily not visible unless the paper is held up in front of a light
- Typewriter correction ribbon
  - Used between lines typed with a black ribbon, the results of typing with the correction tape are visible only under a strong light

Steganography vs. Encryption

- Steganography has a number of drawbacks when compared to encryption
  - It requires a lot of overhead to hide a relatively few bits of information
  - Once the system is discovered, it becomes virtually worthless

- The advantage of steganography
  - It can be employed by parties who have something to lose should the fact of their secret communication (not necessarily the content) be discovered
- Encryption flags traffic as important or secret or may identify the sender or receiver as someone with something to hide

Summary

- Symmetric Cipher Model
  - Cryptography
  - Cryptanalysis and Brute-Force Attack
- Transposition techniques
- Rotor machines
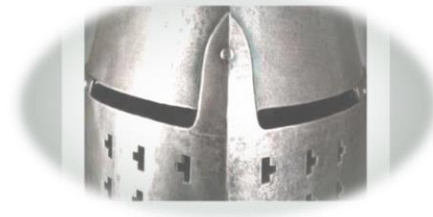
- Substitution techniques
  - Caesar cipher
  - Monoalphabetic ciphers
  - Playfair cipher
  - Hill cipher
  - Polyalphabetic ciphers
  - One-time pad
- Steganography