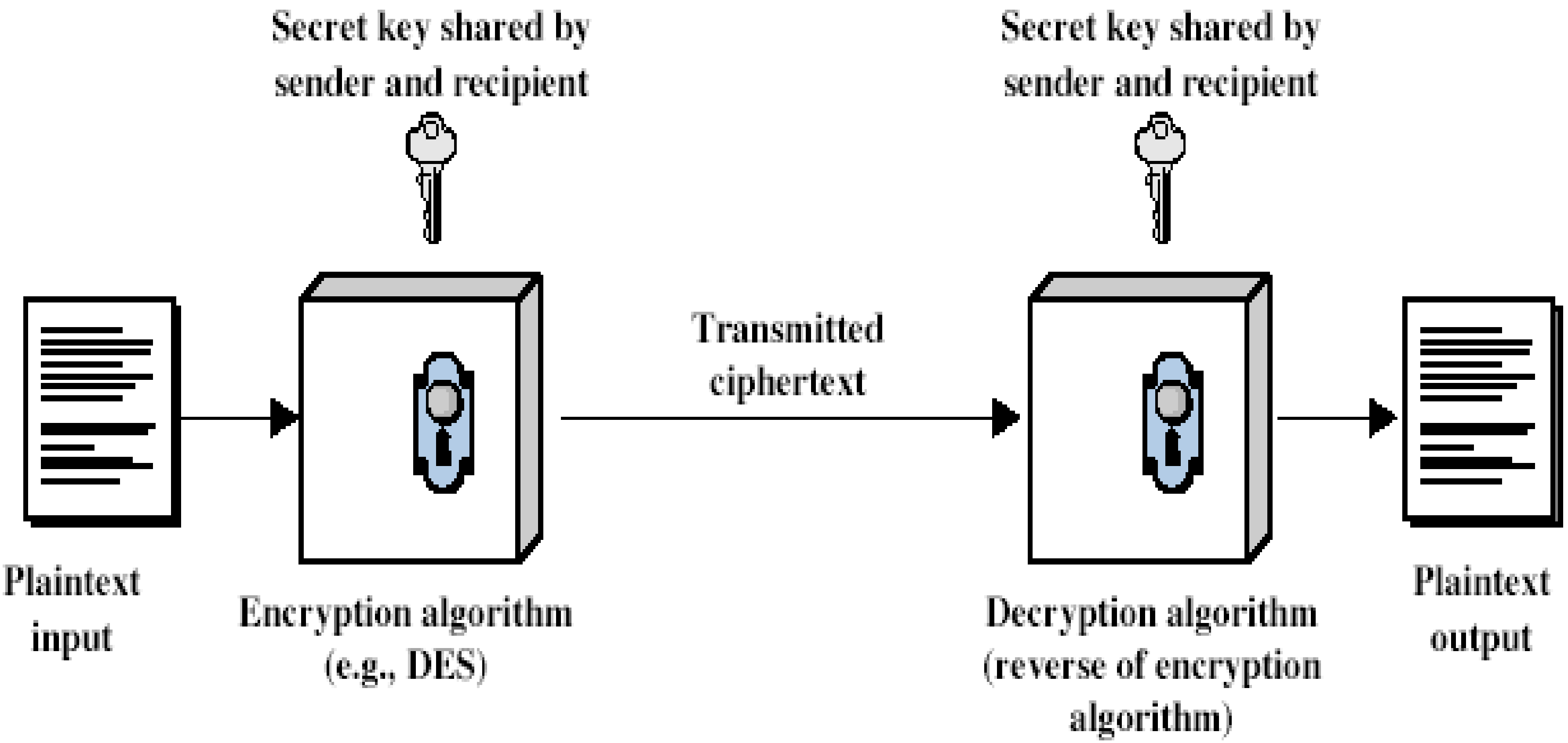
信息安全（02）

Introduction to Cryptography

-Classical Encryption Techniques (cont.)

Symmetric Cipher Model


Secret key shared by sender and recipient
Secret key shared by sender and recipient
Transmitted ciphertext
Plaintext input
Encryption algorithm (e.g., DES)
Decryption algorithm (reverse of encryption algorithm)
Plaintext output

Discussion

- 模型合理吗?
- 什么当保密；什么当公开?
  - 19世纪荷兰人A.Kerckhoffs就提出了一个在密码学界被公认为基础的假设，也就是著名的“Kerckhoffs假设”：秘密必须全寓于密钥。
- Other Models?

Discussion

- “谁是我们的敌人，谁是我们的朋友，这个问题是革命的首要问题”——毛选
- 易用性
- 秘密全部寓于密钥≠算法当公开，要看应用环境(商用，军用，……)
- 开放的系统更安全，??

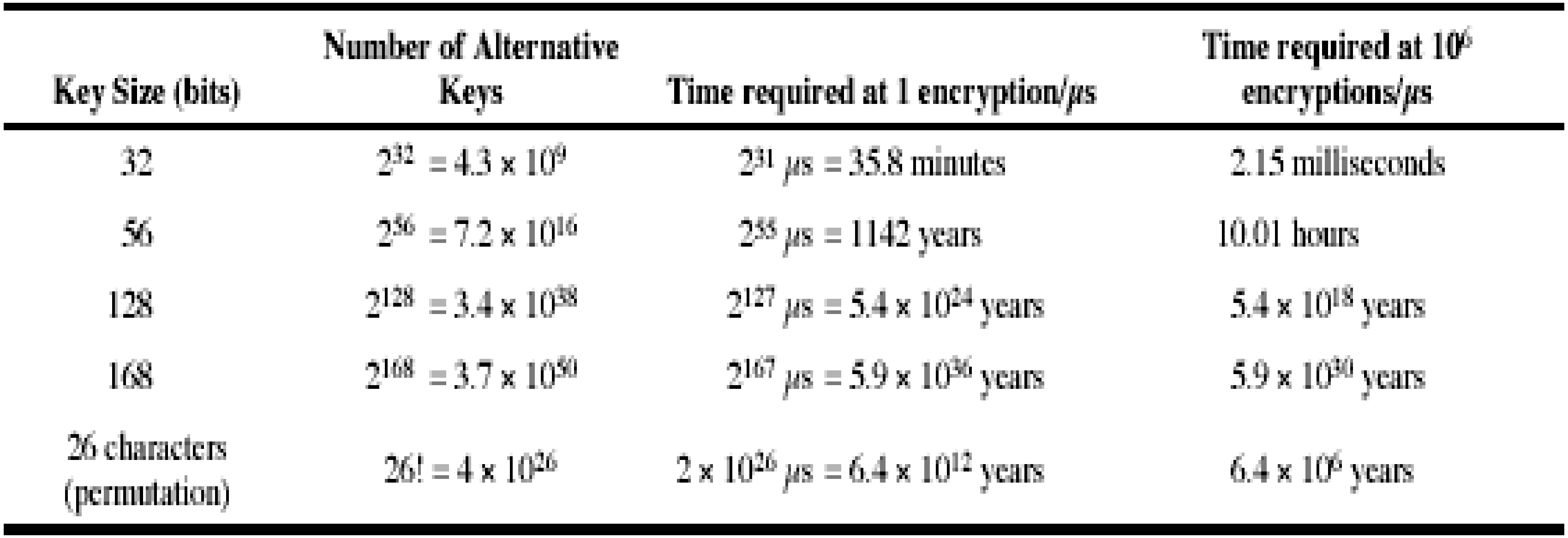
Cryptanalytic Attacks

- 对于对手而言
  - 最坏情况下，仍有一种攻击方法可用

- **Brute Force Search，穷举法**

Brute Force Search

- always possible to simply try every key
- most basic attack, proportional to key size
- assume either know or recognise plaintext



Key Size (bits)	Number of Alternative Keys	Time required at 1 encryption/μs	Time required at 10^6 encryptions/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	5.4×10^{18} years
168	$2^{168} = 3.7 \times 10^{50}$	2^{167} μs = 5.9×10^{36} years	5.9×10^{30} years
26 characters (permutation)	$26! = 4 \times 10^{26}$	2×10^{26} μs = 6.4×10^{12} years	6.4×10^6 years

Monoalphabetic Cipher Security

- now have a total of 26! = 4 x 10^{26} keys
- with so many keys, might think is secure
-
- but would be **!!!WRONG!!!**
- problem is language **characteristics**

Example Cryptanalysis

- given ciphertext:

```
UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ
```

- count relative letter frequencies (see text)
- 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 vietcong in moscow
```

More Definitions

- **unconditional security**
  - no matter how much computer power is available, the cipher cannot be broken since the ciphertext provides insufficient information to uniquely determine the corresponding plaintext
- **computational security**
  - given limited computing resources (eg. time needed for calculations is greater than age of universe), the cipher cannot be broken
- Unconditional security would be nice, but the only known such cipher is the **one-time pad** (later).
  - For all reasonable encryption algorithms, have to assume computational security where it either takes too long, or is too expensive, to bother breaking the cipher.

Types of Cryptanalytic Attacks

- **ciphertext only**
  - Encryption algorithm
  - Ciphertext to be decoded
- **known plaintext**
  - Encryption algorithm
  - Ciphertext to be decoded
  - One or more plaintext-ciphertext pairs formed with the secret key
- **chosen plaintext**
  - Encryption algorithm
  - Ciphertext to be decoded
  - Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key

Types of Cryptanalytic Attacks

- **chosen ciphertext**
  - Encryption algorithm
  - Ciphertext to be decoded
  - Purported ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key
- **chosen text**
  - Encryption algorithm
  - Ciphertext to be decoded
  - Plaintext message chosen by cryptanalyst, together with its corresponding Ciphertext with the secret key
  - Purported cipehrtext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key.

Monoalphabetic Cipher

```
K:
  Plain:  abcdefghijklmnopqrstuvwxyz
  Cipher: DKVQFIBJWPESCXHTMYAUOLRGZN


Plaintext:
  ifwewishtoreplaceletters
Ciphertext:
  WIRFRWAJUHYFTSDVFSFUUFYA
```

- **hence key is 26 letters long**

An Improvement

- Homophone

- Assign each letter a number of different cipher symbols

- The number of symbols assigned to each letter is proportional to the relative frequency of that letter

提高单字母表密码安全性

- 两个角度
  - “多”对“一” → Playfair
  - “一”对“多” → **Vigenère**

Playfair Cipher

- not even the large number of keys in a monoalphabetic cipher provides security
- one approach to improving security was to encrypt multiple letters
- the **Playfair Cipher** is an example
- invented by Charles Wheatstone in 1854, but named after his friend Baron Playfair

Playfair Key Matrix

- a 5X5 matrix of letters based on a keyword
- fill in letters of keyword (sans duplicates)
- fill rest of matrix with other letters
- eg. using the keyword MONARCHY

```
MONAR
CHYBD
EFGIK
LPQST
UVWXZ
```

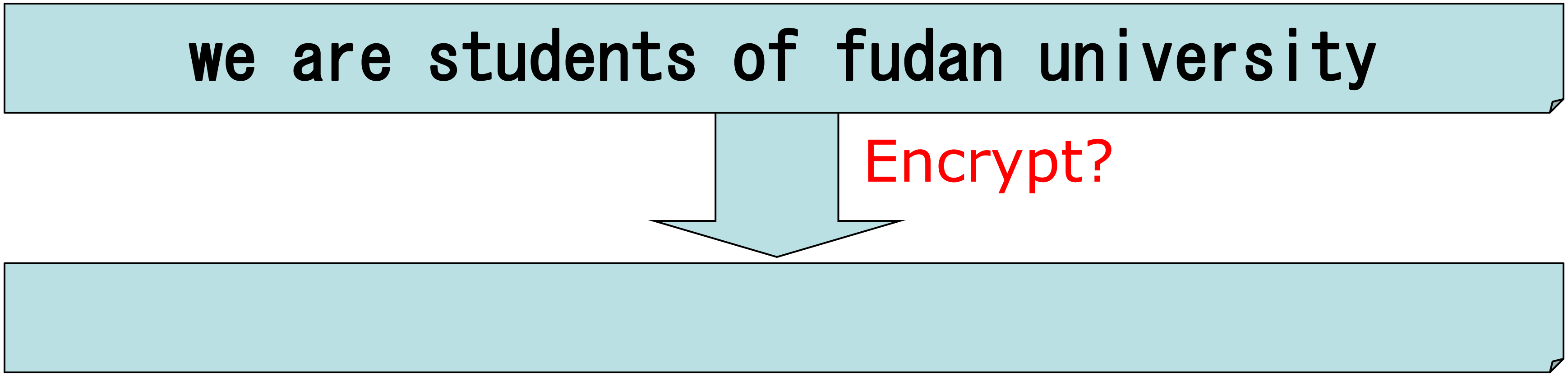
Encrypting and Decrypting

- plaintext encrypted two letters at a time:

1. if a pair is a repeated letter, insert a filler like 'X',
   eg. "balloon" encrypts as "ba lx lo on"
2. if both letters fall in the same row, replace each with letter to right (wrapping back to start from end),
   eg. “ar" encrypts as "RM"
3. if both letters fall in the same column, replace each with the letter below it (again wrapping to top from bottom), eg. “mu" encrypts to "CM"
4. otherwise each letter is replaced by the one in **its row** in **the column of the other letter** of the pair, eg. “hs" encrypts to "BP", and “ea" to "IM" or "JM" (as desired)

Exercise

- Play fair, with key: encrypt
- Please Encrypt



we are students of fudan university

Encrypt?

Security of the Playfair Cipher

- security much improved over monoalphabetic
- since have 26 x 26 = **676** digrams
- would need a 676 entry frequency table to analyse (verses 26 for a monoalphabetic)
- and correspondingly more ciphertext
- was widely used for many years (eg. US & British military in WW1)
- it **can** be broken, given **a few hundred** letters
- since still has much of plaintext structure

Polyalphabetic Ciphers

- another approach to improving security is to use multiple cipher alphabets
- called polyalphabetic substitution ciphers
- makes cryptanalysis harder with more alphabets to guess and flatter frequency distribution
- use a key to select which alphabet is used for each letter of the message
- use each alphabet in turn
- repeat from start after end of key is reached

Vigenère Cipher

- simplest polyalphabetic substitution cipher is the **Vigenère Cipher**
- effectively multiple caesar ciphers
- key is multiple letters long K = k1 k2 ... kd
- ith letter specifies ith alphabet to use
- use each alphabet in turn
- repeat from start after d letters in message
- decryption simply works in reverse

Vigenère 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
Key	*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

Example

- write the plaintext out
- write the keyword repeated above it
- use each key letter as a caesar cipher key
- encrypt the corresponding plaintext letter
- eg using keyword ***deceptive***

Key:	deceptivedeceptivedeceptive
Plaintext:	wearediscoveredsaveyourself
Ciphertext:	

Example

- write the plaintext out
- write the keyword repeated above it
- use each key letter as a caesar cipher key
- encrypt the corresponding plaintext letter
- eg using keyword ***deceptive***

```
Key:        deceptivedeceptivedeceptive
Plaintext:  wearediscoveredsaveyourself
Ciphertext: ZICVTWQNGRZGVTWAVZHCQYGLMGJ
```

Autokey Cipher

- ideally want a key as long as the message
- Vigenère proposed the **autokey** cipher
- with keyword is prefixed to message as key
- knowing keyword can recover the first few letters
- use these in turn on the rest of the message
- but still have frequency characteristics to attack
- eg. given key *deceptive*

key:	deceptivewearediscoveredsav
Plaintext:	wearediscoveredsaveyourself
ciphertext:	ZICVTWQNGKZEIIGASXSTSLVVWLA

Security of Vigenère Ciphers

- have multiple ciphertext letters for each plaintext letter
- hence letter **frequencies** are **obscured**
- but **not totally lost**
- The ultimate defence against such a cryptanalysis is to choose a keyword that is as long as the plaintext and has no statistical relationship to it
  - AT&T, Vernam cipher

G. Vernam 1918

$$C_i = P_i \oplus K_i$$

$$P_i = C_i \oplus K_i$$

- Shannon在他的经典论文([Shannon 49]和[Shannon 51])中已经证明了一次一密所提供的绝对安全性

One-Time Pad

- if a truly random key as long as the message is used, the cipher will be secure
- called a **One-Time pad**
- is unbreakable since ciphertext bears no statistical relationship to the plaintext
- since for **any** **plaintext** & **any** **ciphertext** there exists a key mapping one to other
- can only use the key **once** though
- have problem of safe distribution of key

One-Time Pad example

Plain-text: heilhitler
Key: wclnbtdefj
Cipher-textDGTYIBWPJA

Message from spy

Cipher-text: DGTYIBWPJA
Key: wggsbtdefj
Plain-text: hanghiter

Lie of spy

Cipher text: DCYTIBWPJA
Key: wclnbtdefj
Plain-text: hanghitler

Cheat Spy

Transposition Ciphers

- now consider classical **transposition** or **permutation** ciphers
- these hide the message by rearranging the letter order
- without altering the actual letters used
- can recognise these since have the same frequency distribution as the original text

Rail Fence cipher

- write message letters out diagonally over a number of rows
- then read off cipher row by row
- eg. write message out as:

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

- giving ciphertext

```
MEMATRHTGPRYETEFETEOAAT
```

Row Transposition Ciphers

- a more complex scheme
- write letters of message out in rows over a specified number of columns
- then reorder the columns according to some key before reading off the rows

```
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
```

Product Ciphers

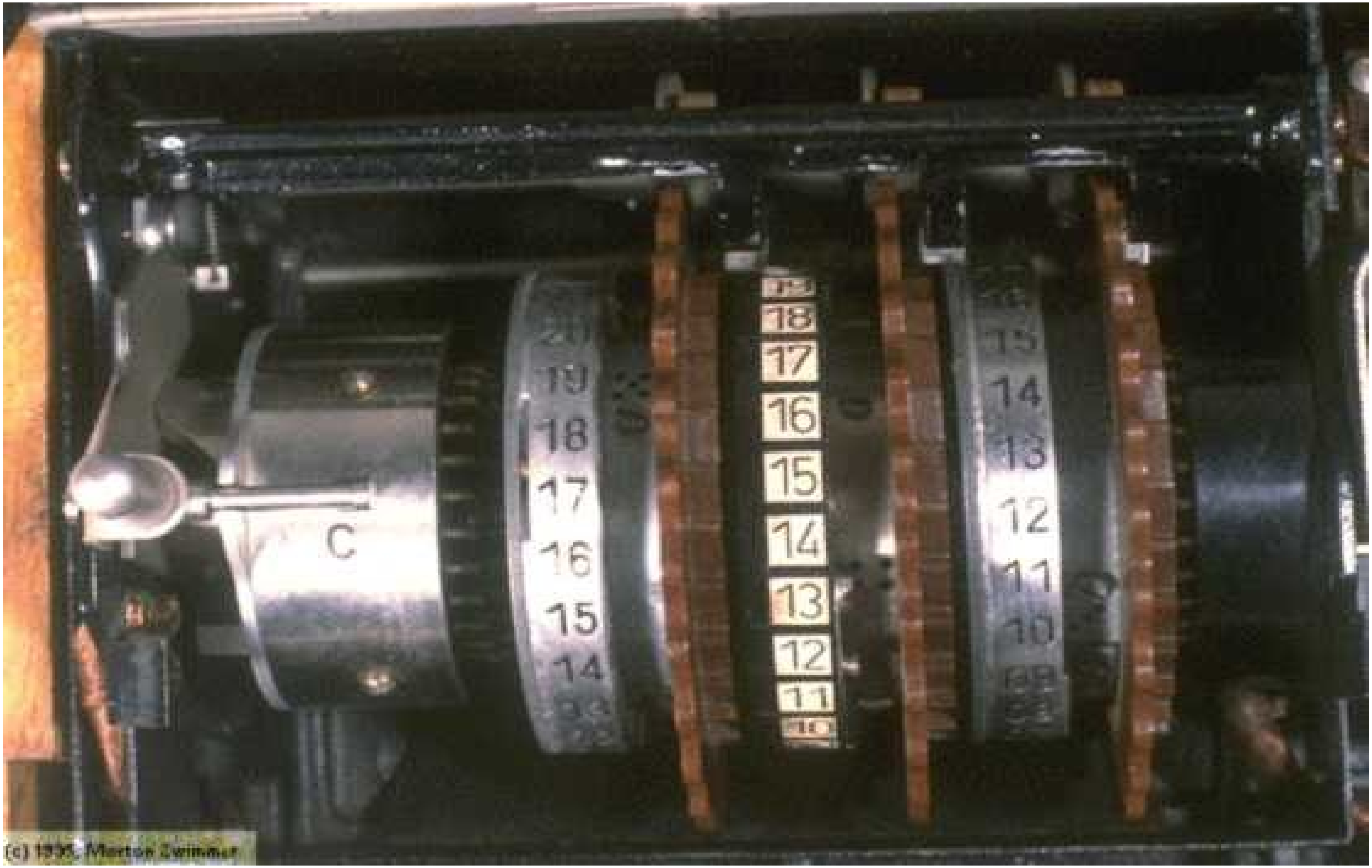
- ciphers using substitutions or transpositions are not secure because of language characteristics
- hence consider using several ciphers in succession to make harder:
  - two substitutions make a more complex substitution
  - two transpositions make more complex transposition
  - but a substitution followed by a transposition makes a new much harder cipher
- this is bridge from classical to modern ciphers

Rotor Machines

- before modern ciphers, rotor machines were most common product cipher
- were widely used in WW2
  - German Enigma, Allied Hagelin, Japanese Purple
- implemented a very complex, varying substitution cipher
- used a series of cylinders, each giving one substitution, which rotated and changed after each letter was encrypted
- with 3 cylinders have 26^3=17576 alphabets

Enigma

Enigma-Rotors



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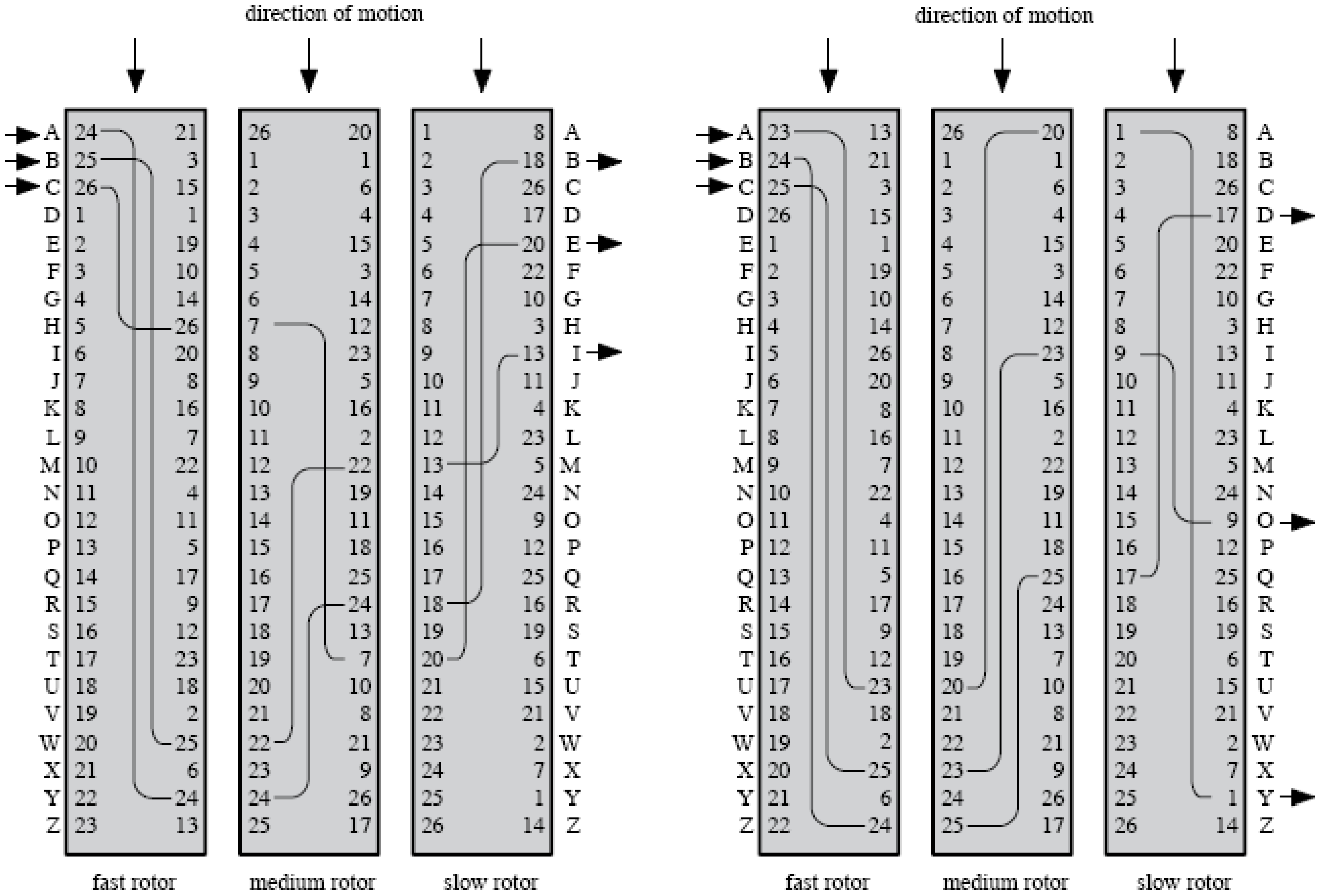
Enigma



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

(a) Initial setting

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

(b) Setting after one keystroke

Steganography

- an alternative to encryption
- hides existence of message
  - using only a subset of letters/words in a longer message marked in some way
  - using invisible ink
  - hiding in noise in graphic image or sound file
- has drawbacks
  - high overhead to hide relatively few info bits

现代隐写术的变迁

- 一方面，网上传输的大量多媒体信息，如图像、声音、视频，甚至文本信息，对于人类的视觉、听觉感知系统，都或多或少存在着一些冗余空间，而利用这些冗余空间，就可以进行信息的秘密传递，同时不影响载体的视觉或听觉效果，因此就可以实现信息的隐蔽传递。

现代隐写术的变迁

- 另一方面，数字产品的无失真复制，越来越多的数字产品在网上传播，如电影、音乐等；
- 造成了版权保护方面存在很大的漏洞。
- 如何既能够充分利用互联网的优势，实现信息共享，同时又不损害数字产品所有者的利益，因此就出现了数字水印的技术。

信息隐藏技术

- 伪装式保密通信
- 数字水印

伪装式保密通信

- 目前在这一研究领域中主要研究在图像、视频、声音以及文本中隐藏信息。如：
- 在一幅普通图像中隐藏一幅机密图像。
- 在一段普通谈话中隐藏一段机密谈话或各种数据。
- 在一段视频流中隐藏各种信息等。
- 文本中的冗余空间比较小，但利用文本的一些特点也可以隐藏一些信息。

数字水印

- 目前存在两种基本的数字版权标记手段，数字水印和数字指纹。
- 数字水印是嵌入在数字作品中的一个版权信息，它可以给出作品的作者、所有者、发行者以及授权使用者等等版权信息。
- 数字指纹可以作为数字作品的序列码，用于跟踪盗版者。

Summary

- Cryptography is a good tool to ensure the confidentiality of sensitive message
- Cryptography has two basic command: encrypt/encipher, decrypt/decipher
- Classical Cryptography include:
  - Julius Caesar
  - Playfair
  - Vigenère
  - Transposition Ciphers
  - One-time Padding