Classical Encryption Techniques

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Overview

1. Symmetric Cipher Model
2. Substitution Techniques
3. Transposition Techniques
4. Product Ciphers
5. Steganography
6. Summary
7. Acknowledgement

What is a Cryptosystem?

Cryptosystem

A cryptosystem is pair of algorithms that take a key and convert plaintext to ciphertext and back.

Plaintext is what you want to protect;
The design and analysis of todays cryptographic algorithms is highly mathematical.

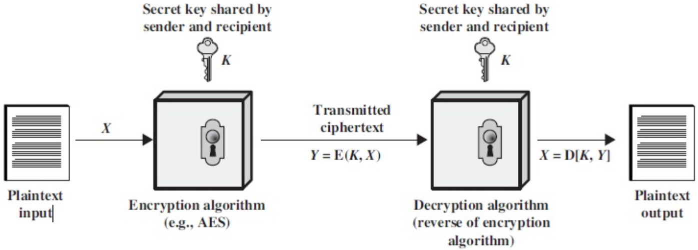
At least not at this stage

Do not try to design your own algorithms.

Some Basic Terminology

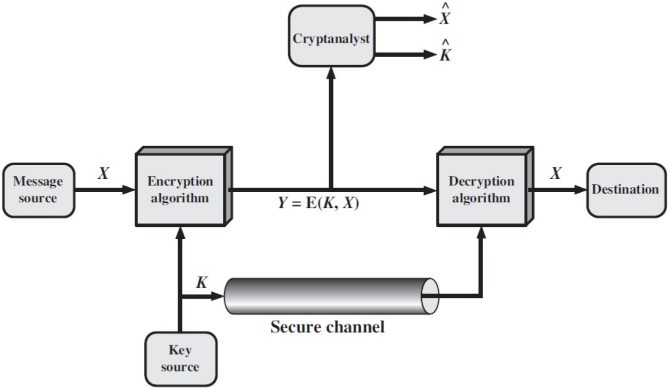
- **Plaintext** - original message
- **Ciphertext** - coded message
- **Cipher** - algorithm for transforming plaintext to ciphertext
- **Key** - info used in cipher; known only to sender/receiver; independent of the plaintext
- **Encipher (encrypt)** - converting plaintext to ciphertext
- **Decipher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

Symmetric Cipher Model


Secret key shared by sender and recipient
K
Secret key shared by sender and recipient
K
X
Transmitted ciphertext
Y = E(K, X)
X = D[K, Y]
Plaintext input
Encryption algorithm (e.g., AES)
Decryption algorithm (reverse of encryption algorithm)
Plaintext output

Simplified Model of Symmetric Encryption

Symmetric Cryptosystem



Model of Symmetric Cryptosystem

Conventional Encryption

There are two requirements for secure use of conventional encryption:

1. We need a strong encryption algorithm. [Everybody knows algorithm and the cipher text]
2. Sender and receiver must have obtained copies of the secret key in a secure fashion and must keep the key secure.

Cryptosystem Classification

By type of encryption operations used

1. Substitution
2. Transposition

By number of keys used

1. Single-key or private
2. Two-key or public

By the way in which plaintext is processed

1. Block
2. Stream

Cryptanalysis

Cryptanalysis

The process of attempting to discover plaintext(X) or key (K) or both is known as cryptanalysis.

Objective: To recover key not just message

Approaches:

- Cryptanalytic attack
- Brute-force attack

Cryptanalysis (Cont.)

Two more definitions are worthy of note.

1. Unconditionally secure
2. Computationally secure

Following criteria should be met to offer *Computationally secure* algorithm.

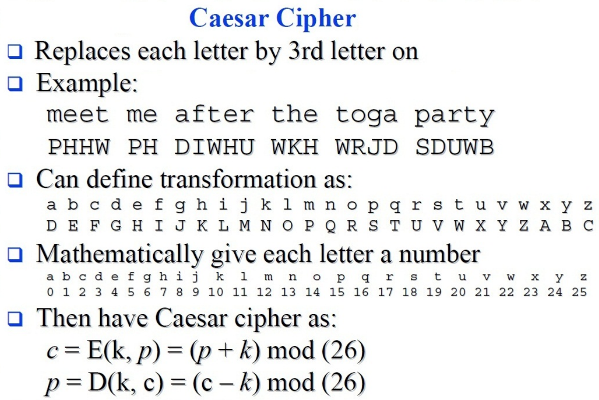
- The cost of breaking the cipher exceeds the value of the encrypted information.
- The time required to break the cipher exceeds the useful lifetime of the information.

Substitution Technique

A substitution technique is one in which the letters of plaintext are replaced by other letters or by numbers or symbols.

- Caesar Cipher
- Monoalphabetic Ciphers
- Playfair Cipher
- Hill Cipher
- Polyalphabetic Ciphers
- One-Time Pad

Substitution Technique (Cont.)



Caesar Cipher

- Replaces each letter by 3rd letter on
- Example:

```
meet me after the toga party
PHHW PH DIWHU WKH WRJD SDUWB
```

- 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

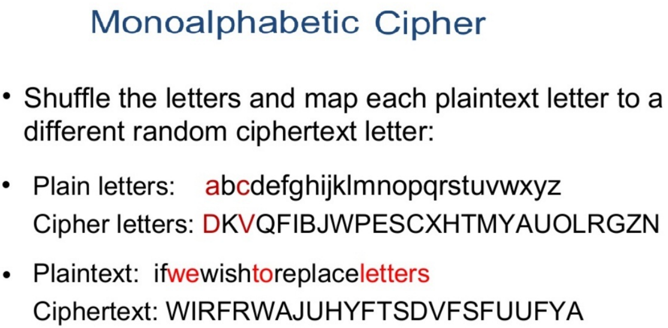
- Then have Caesar cipher as:

$$c = \mathrm{E}(\mathrm{k}, p) = (p + k) \bmod (26)$$

$$p = \mathrm{D}(\mathrm{k}, \mathrm{c}) = (\mathrm{c} - k) \bmod (26)$$

Weakness: Small key space (25 keys)

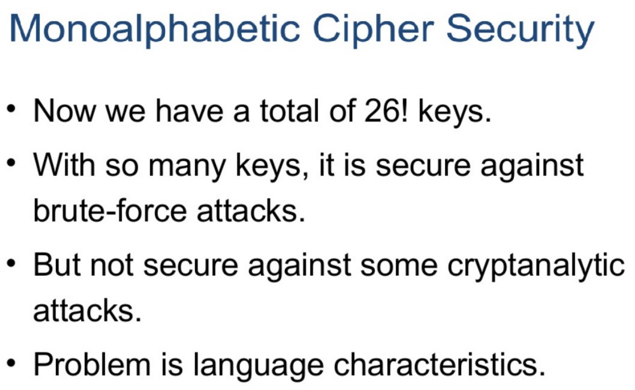
Substitution Technique (Cont.)



Monoalphabetic Cipher

- Shuffle the letters and map each plaintext letter to a different random ciphertext letter:
- Plain letters: abcdefghijklmnopqrstuvwxyz
  Cipher letters: DKVQFIBJWPESCXHTMYAUOLRGZN
- Plaintext: ifwewishtoreplaceletters
  Ciphertext: WIRFRWAJUHYFTSDVFSFUUFYA

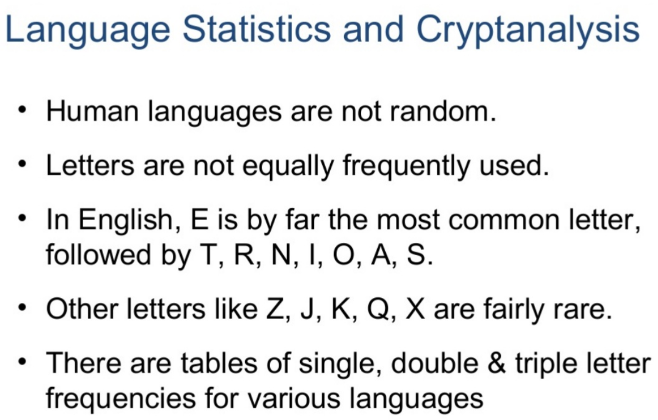
Substitution Technique (Cont.)



Monoalphabetic Cipher Security

- Now we have a total of 26! keys.
- With so many keys, it is secure against brute-force attacks.
- But not secure against some cryptanalytic attacks.
- Problem is language characteristics.

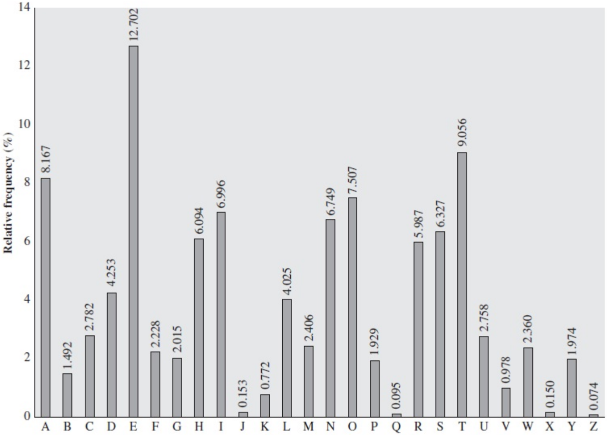
Substitution Technique (Cont.)



Language Statistics and Cryptanalysis

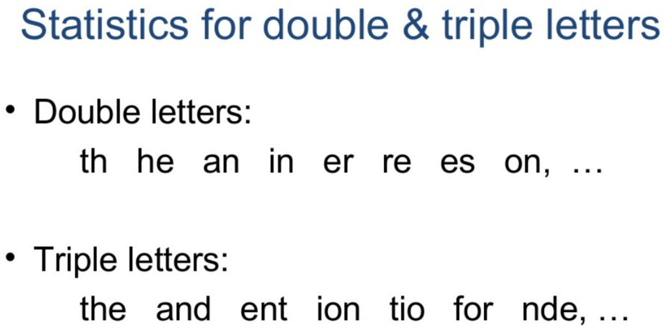
- Human languages are not random.
- Letters are not equally frequently used.
- In English, E is by far the most common letter, followed by T, R, N, I, O, A, S.
- Other letters like Z, J, K, Q, X are fairly rare.
- There are tables of single, double & triple letter frequencies for various languages

Substitution Technique (Cont.)



Relative Frequency of Letters in English Text

Substitution Technique (Cont.)



Statistics for double & triple letters

- Double letters:

  th he an in er re es on, …

- Triple letters:

  the and ent ion tio for nde, …

Substitution Technique (Cont.)

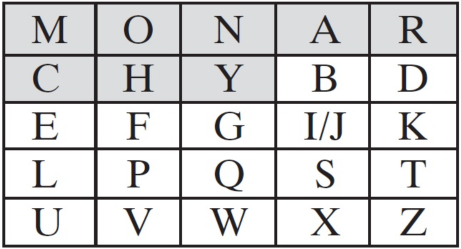
Playfair Cipher

- Not even the large number of keys in a monoalphabetic cipher provides security
- One approach to improving security was to encrypt multiple letters
- Invented by Charles Wheatstone in 1854, but named after his friend Baron Playfair

Substitution Technique (Cont.)

Playfair Key Matrix

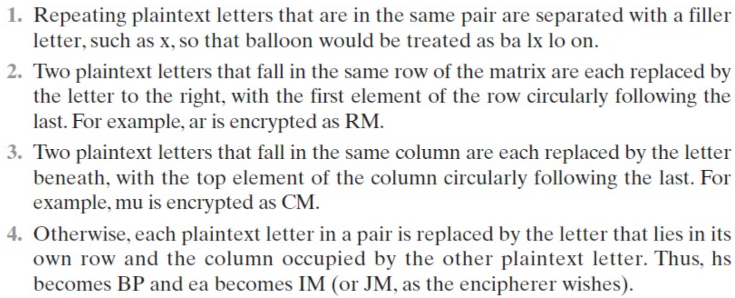
- a 5X5 matrix of letters based on a keyword
- fill in letters of keyword and fill rest of matrix with other letters
- eg. using the keyword MONARCHY



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

Substitution Technique (Cont.)

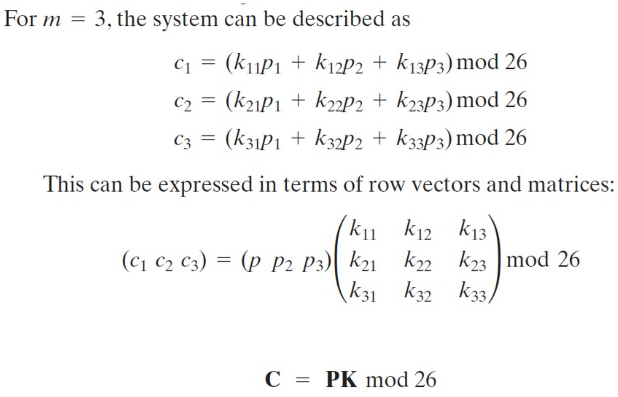
Rules : Plaintext encrypted two letters at a time:



1. Repeating plaintext letters that are in the same pair are separated with a filler letter, such as x, so that balloon would be treated as ba lx lo on.
2. Two plaintext letters that fall in the same row of the matrix are each replaced by the letter to the right, with the first element of the row circularly following the last. For example, ar is encrypted as RM.
3. Two plaintext letters that fall in the same column are each replaced by the letter beneath, with the top element of the column circularly following the last. For example, mu is encrypted as CM.
4. Otherwise, each plaintext letter in a pair is replaced by the letter that lies in its own row and the column occupied by the other plaintext letter. Thus, hs becomes BP and ea becomes IM (or JM, as the encipherer wishes).

Substitution Technique (Cont.)

Hill cipher : This encryption algorithm takes *m* successive plaintext letters and substitutes for them *m* ciphertext letters.



For $m = 3$, the system can be described as

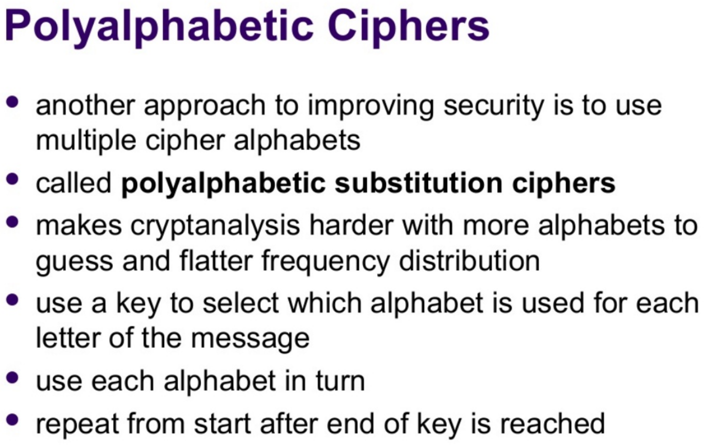
$$\begin{aligned} c_1 &= (k_{11}p_1 + k_{12}p_2 + k_{13}p_3) \bmod 26 \\ c_2 &= (k_{21}p_1 + k_{22}p_2 + k_{23}p_3) \bmod 26 \\ c_3 &= (k_{31}p_1 + k_{32}p_2 + k_{33}p_3) \bmod 26 \end{aligned}$$

This can be expressed in terms of row vectors and matrices:

$$(c_1\ c_2\ c_3) = (p\ \ p_2\ \ p_3)\begin{pmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{pmatrix} \bmod 26$$

$$\mathbf{C} = \mathbf{PK} \bmod 26$$

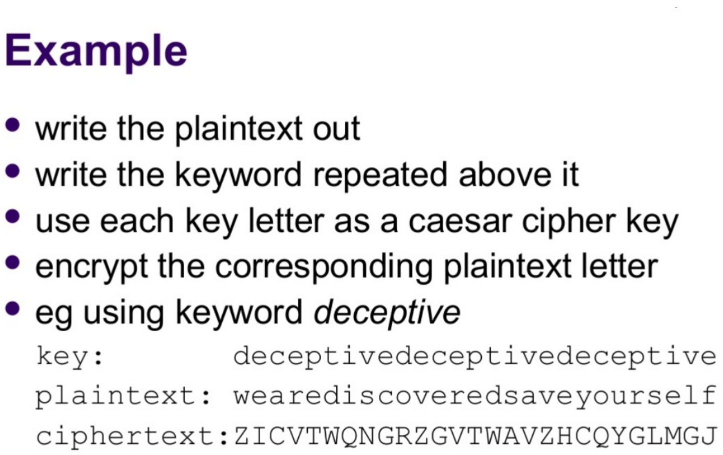
Substitution Technique (Cont.)



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

Substitution Technique (Cont.)



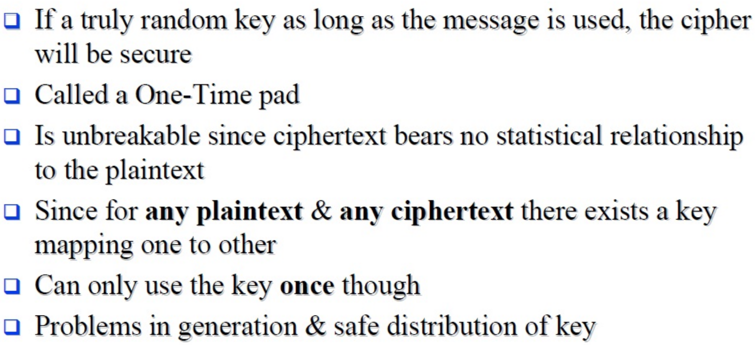
Example

- 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
```

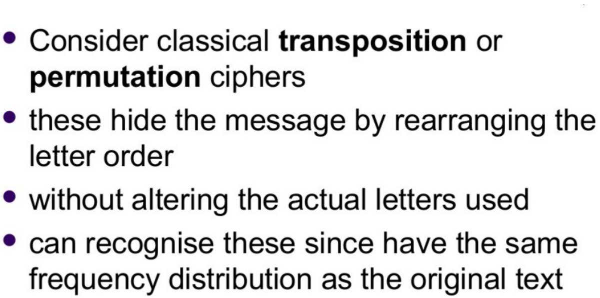
Substitution Technique (Cont.)

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
- Problems in generation & safe distribution of key

Transposition Technique



- 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

Transposition Technique (Cont.)

Network Security

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Symmetric Cipher Model

Substitution Techniques

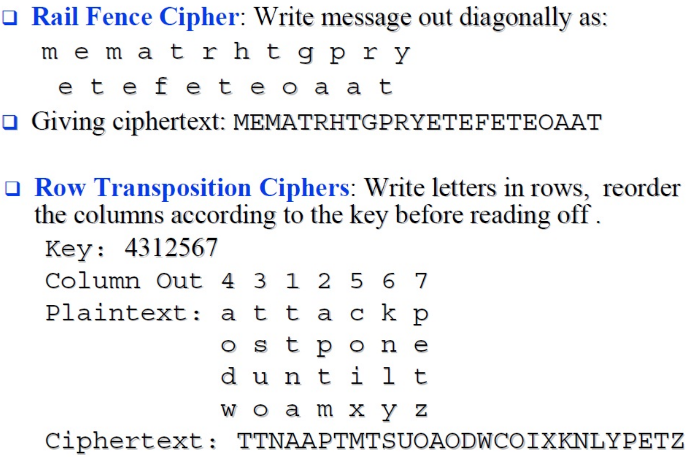
Transposition Techniques

Product Ciphers

Steganography

Summary

Acknowledgement



- **Rail Fence Cipher**: Write message out diagonally as:

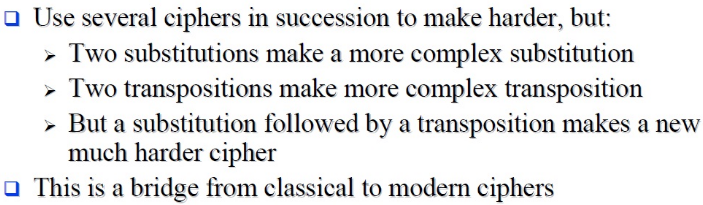
```
m e m a t r h t g p r y
 e t e f e t e o a a t
```

- Giving ciphertext: MEMATRHTGPRYETEFETEOAAT

- **Row Transposition Ciphers**: Write letters in rows, reorder the columns according to the key before reading off .

```
Key:  4312567
Column Out 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 Cipher



❑ Use several ciphers in succession to make harder, but:

- ➢ 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 a bridge from classical to modern ciphers

Steganography

Steganography

The practice of concealing messages or information within other nonsecret text or data.

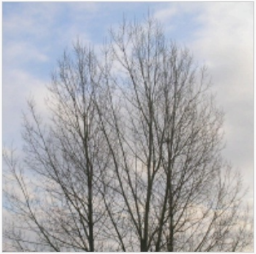


Image of a tree with a steganographically hidden image. The hidden image is revealed by removing all but the two least significant bits of each color component and a subsequent normalization.

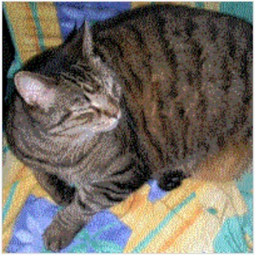


Image of a cat extracted from the tree image

Source: https://en.wikipedia.org/wiki/Steganography

Summary

- The key methods for cryptography are: Substitution and transposition
- Letter frequency can be used to break substitution
- Substitution can be extended to multiple letters and multiple ciphers. Mono Mono-alphabetic = 1 cipher, Poly Poly-alphabetic = multiple ciphers
- Examples: Caesar cipher (1 letter substitution), Playfair (2-letters), Hill (multiple letters).
- Multiple stages of substitution and transposition can be used to form strong ciphers.

Acknowledgement

- Lawrie Browns slides supplied with William Stallings book Cryptography and Network Security: Principles and Practice, 5th Ed, 2011
- Network Security course at Department of Computer Science & Engineering, Washington University in Saint Louis.
- Network Security course at Department of Computer Science, Columbia University, New York.
- http://www.slideshare.net/mohammedarif89/cipher-techniques