Cryptography and Network Security

UNIT-1

Chapter 1 – Introduction

The art of war teaches us to rely not on the likelihood of the enemy's not coming, but on our own readiness to receive him; not on the chance of his not attacking, but rather on the fact that we have made our position unassailable.

***—The Art of War,* Sun Tzu**

Background

- Information Security requirements have changed in recent times
- traditionally provided by physical and administrative mechanisms
- computer use requires automated tools to protect files and other stored information
- use of networks and communications links requires measures to protect data during transmission

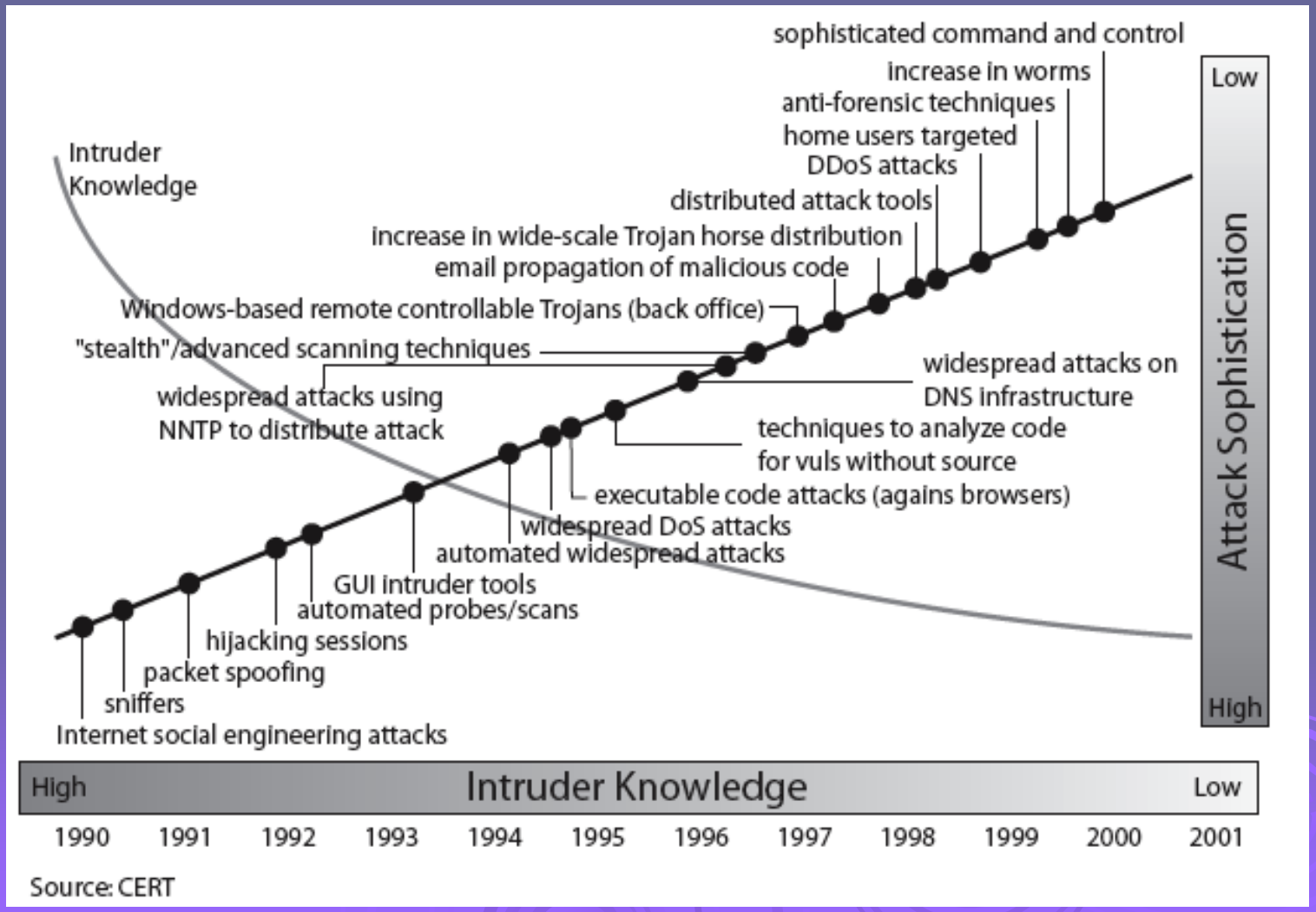
Definitions

- **Computer Security** - generic name for the collection of tools designed to protect data and to thwart hackers
- **Network Security** - measures to protect data during their transmission
- **Internet Security** - measures to protect data during their transmission over a collection of interconnected networks

Aim of Course

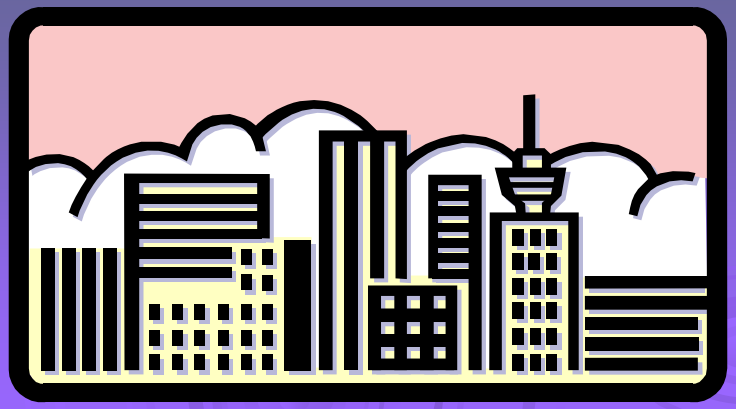
- our focus is on **Internet Security**
- which consists of measures to deter, prevent, detect, and correct security violations that involve the transmission & storage of information

Security Trends



OSI Security Architecture

- ITU-T X.800 “Security Architecture for OSI”
- defines a systematic way of defining and providing security requirements
- for us it provides a useful, if abstract, overview of concepts we will study



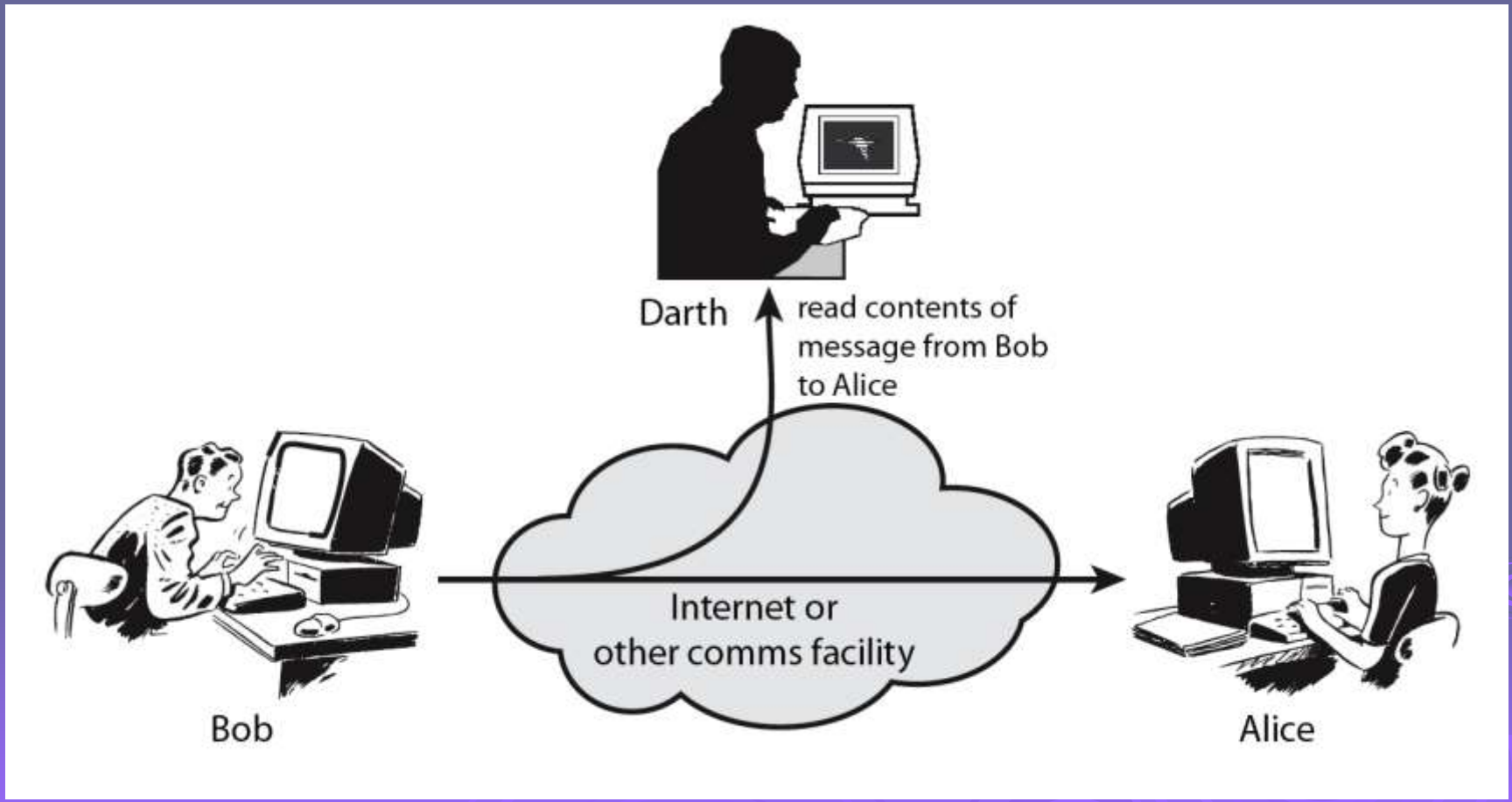
Aspects of Security

- consider 3 aspects of information security:
  - **security attack**
  - **security mechanism**
  - **security service**

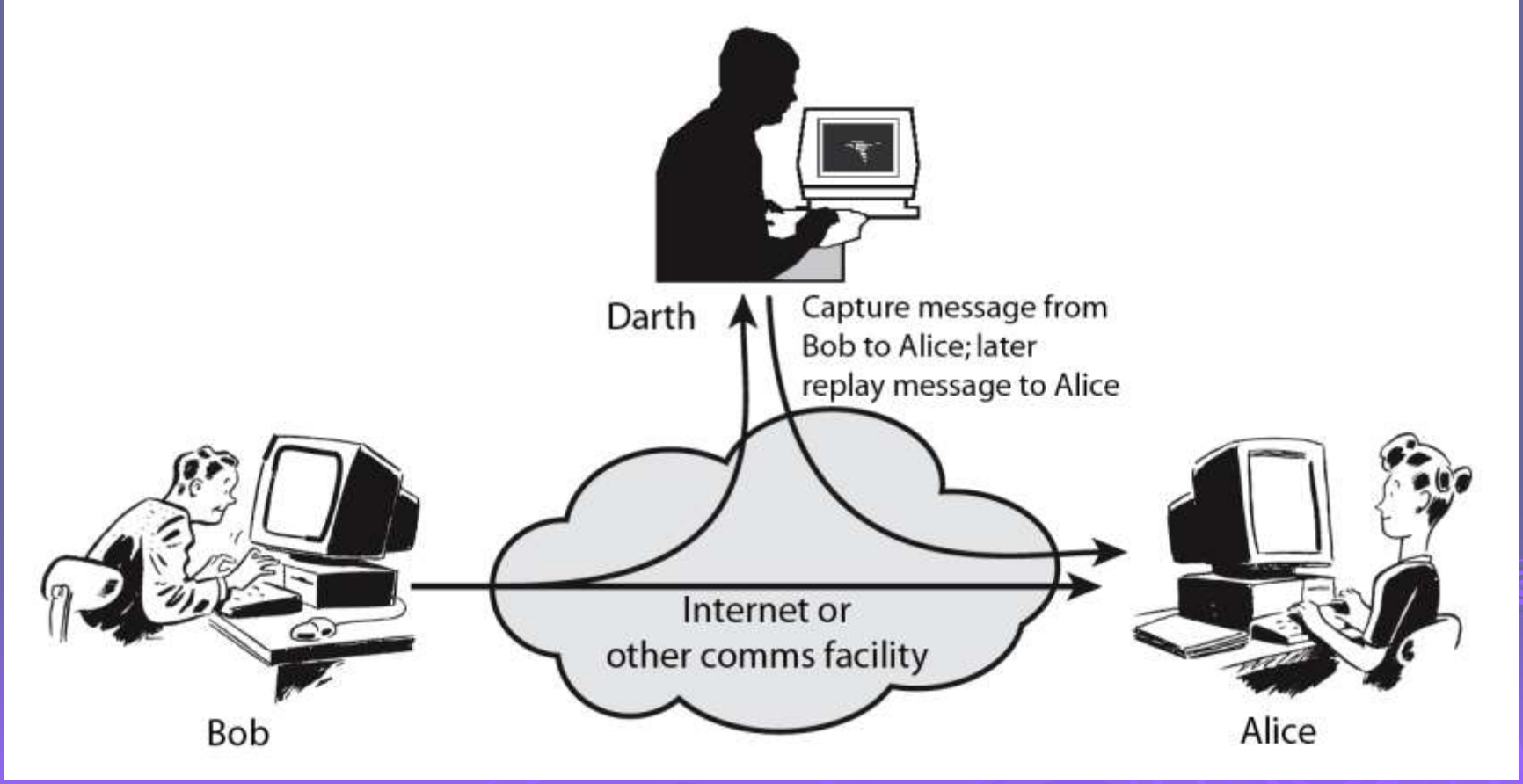
Security Attack

- any action that compromises the security of information owned by an organization
- information security is about how to prevent attacks, or failing that, to detect attacks on information-based systems
- often *threat* & *attack* used to mean same thing
- have a wide range of attacks
- can focus of generic types of attacks
  - passive
  - active

Passive Attacks



Active Attacks



Security Service

- enhance security of data processing systems and information transfers of an organization
- intended to counter security attacks
- using one or more security mechanisms
- often replicates functions normally associated with physical documents
  - which, for example, have signatures, dates; need protection from disclosure, tampering, or destruction; be notarized or witnessed; be recorded or licensed

Security Services

- X.800:

  "a service provided by a protocol layer of communicating open systems, which ensures adequate security of the systems or of data transfers"

- RFC 2828:

  "a processing or communication service provided by a system to give a specific kind of protection to system resources"

Security Services (X.800)

- **Authentication** - assurance that the communicating entity is the one claimed
- **Access Control** - prevention of the unauthorized use of a resource
- **Data Confidentiality** –protection of data from unauthorized disclosure
- **Data Integrity** - assurance that data received is as sent by an authorized entity
- **Non-Repudiation** - protection against denial by one of the parties in a communication

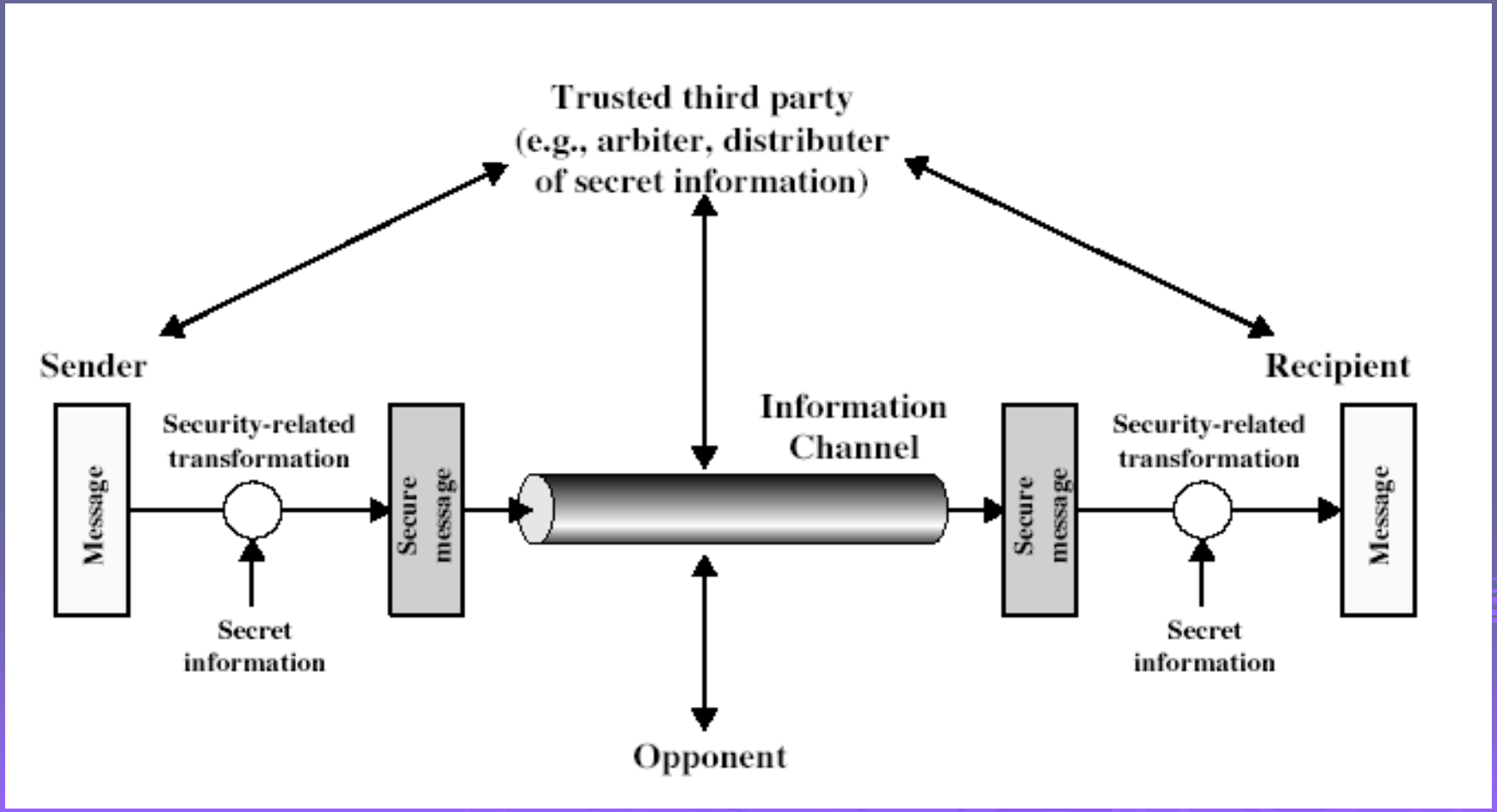
Security Mechanism

- feature designed to detect, prevent, or recover from a security attack
- no single mechanism that will support all services required
- however one particular element underlies many of the security mechanisms in use:
  - **cryptographic techniques**
- hence our focus on this topic

Security Mechanisms (X.800)

- specific security mechanisms:
  - encipherment, digital signatures, access controls, data integrity, authentication exchange, traffic padding, routing control, notarization
- pervasive security mechanisms:
  - trusted functionality, security labels, event detection, security audit trails, security recovery

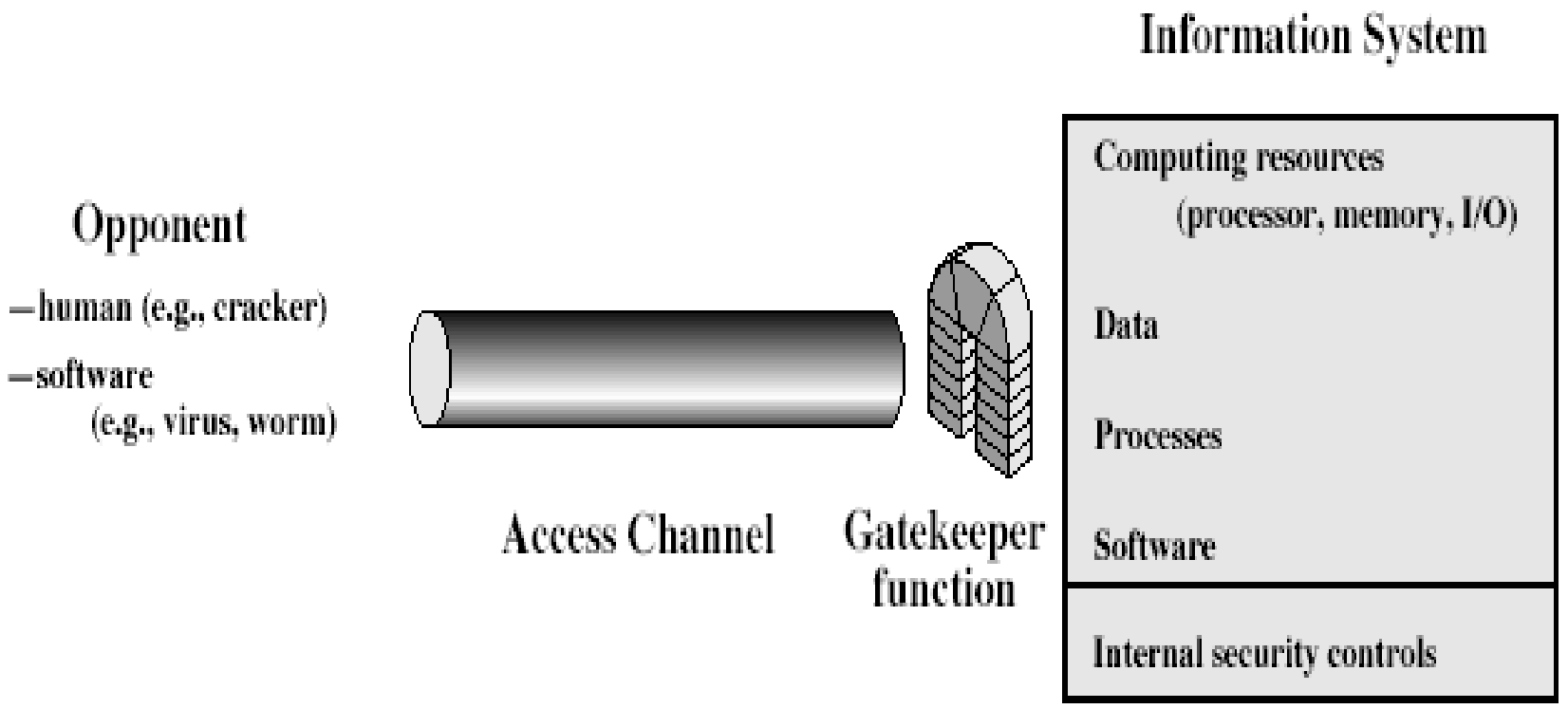
Model for Network Security



Model for Network Security

- using this model requires us to:
  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

Model for Network Access Security



Model for Network Access Security

- using this model requires us to:
  1. select appropriate gatekeeper functions to identify users
  2. implement security controls to ensure only authorised users access designated information or resources
- trusted computer systems may be useful to help implement this model

Summary

- have considered:
  - definitions for:
    - computer, network, internet security
- X.800 standard
- security attacks, services, mechanisms
- models for network (access) security

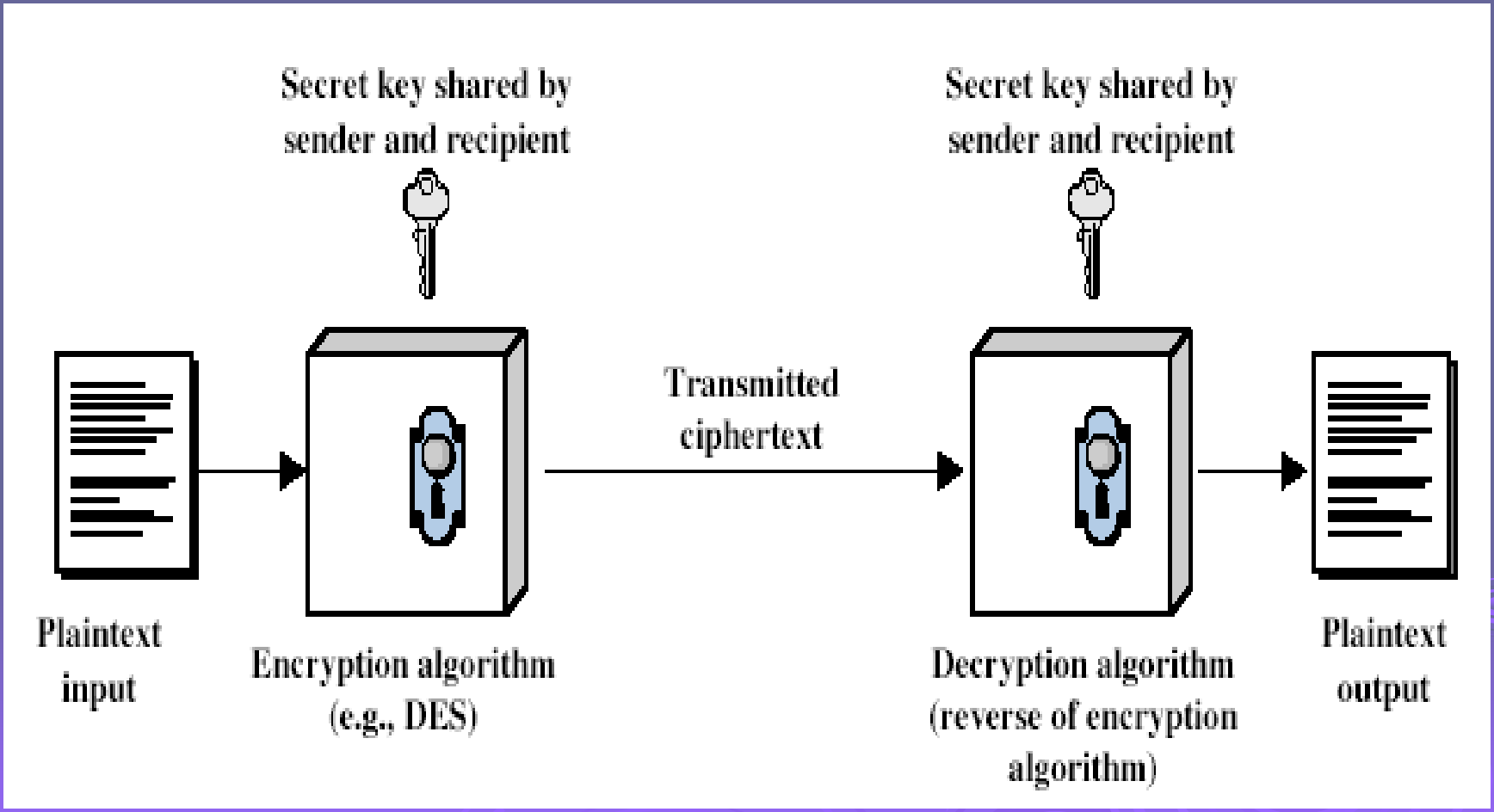
Symmetric Encryption

- or conventional / private-key / single-key
- sender and recipient share a common key
- all classical encryption algorithms are private-key
- was only type prior to invention of public-key in 1970's
- and by far most widely used

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
- **encipher (encrypt)** - converting plaintext to ciphertext
- **decipher (decrypt)** - recovering ciphertext from plaintext
- **cryptography** - study of encryption principles/methods
- **cryptanalysis (codebreaking)** - study of principles/ methods of deciphering ciphertext *without* knowing key
- **cryptology** - field of both cryptography and cryptanalysis

Symmetric Cipher Model



Requirements

- two requirements for secure use of symmetric encryption:
  - a strong encryption algorithm
  - a secret key known only to sender / receiver
- mathematically have:

  $Y = E_K(X)$

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

Cryptography

- characterize cryptographic system by:
  - type of encryption operations used
    - substitution / transposition / product
  - number of keys used
    - single-key or private / two-key or public
  - way in which plaintext is processed
    - block / stream

Cryptanalysis

- objective to recover key not just message
- general approaches:
  - cryptanalytic attack
  - brute-force attack

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

More Definitions

- **unconditional security**
  - no matter how much computer power or time 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

Brute Force Search

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

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	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

Classical Substitution Ciphers

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

Caesar Cipher

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

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

Caesar Cipher

- 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:

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

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

Cryptanalysis of Caesar Cipher

- only have 26 possible ciphers
  - A maps to A,B,..Z
- could simply try each in turn
- a **brute force search**
- given ciphertext, just try all shifts of letters
- do need to recognize when have plaintext
- eg. break ciphertext "GCUA VQ DTGCM"

Monoalphabetic Cipher

- rather than just shifting the alphabet
- could shuffle (jumble) the letters arbitrarily
- each plaintext letter maps to a different random ciphertext letter
- hence key is 26 letters long

```
Plain:  abcdefghijklmnopqrstuvwxyz
Cipher: DKVQFIBJWPESCXHTMYAUOLRGZN

Plaintext:  ifwewishtoreplaceletters
Ciphertext: WIRFRWAJUHYFTSDVFSFUUFYA
```

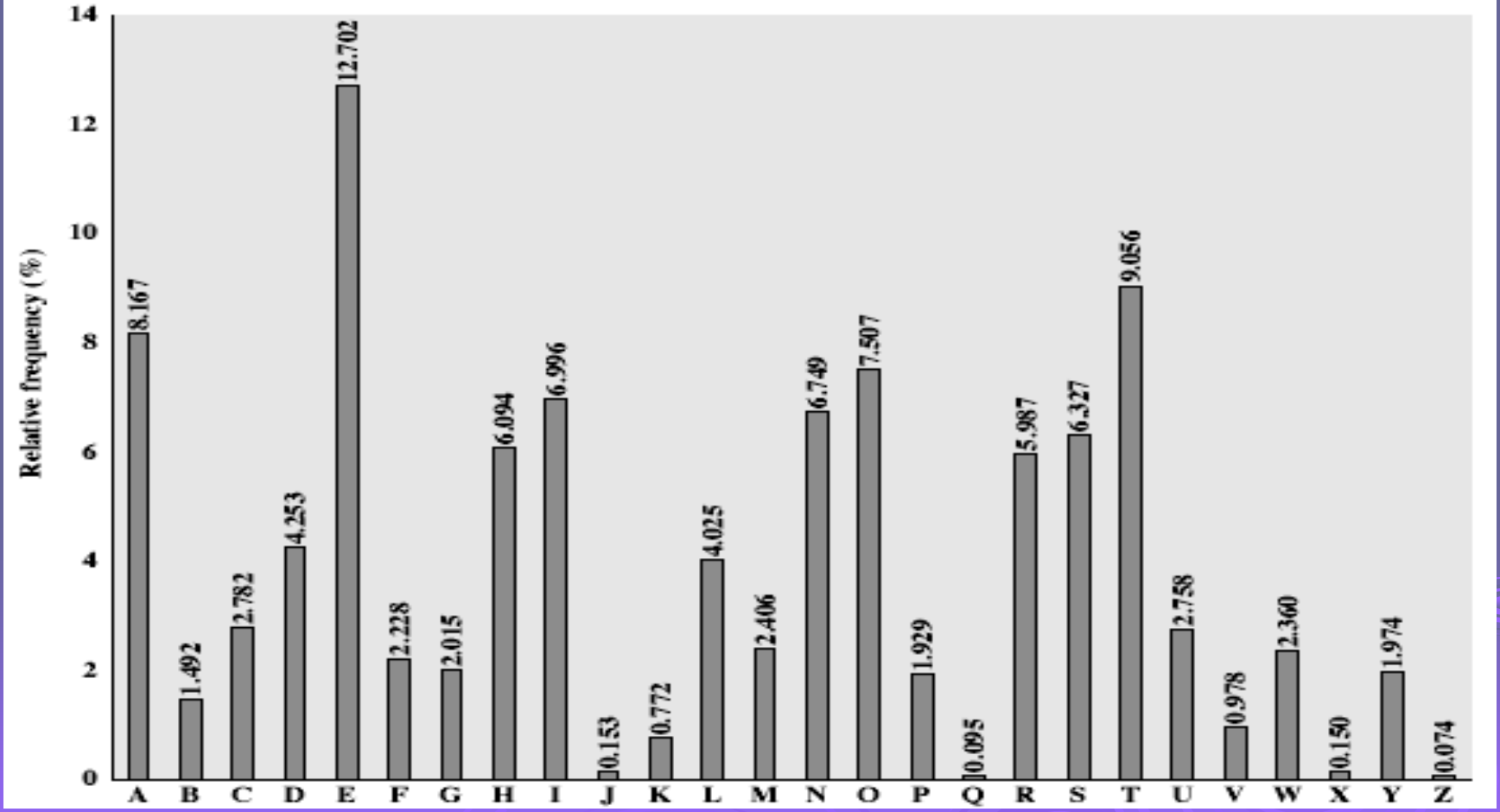
Monoalphabetic Cipher Security

- now have a total of 26! = 4 x 1026 keys
- with so many keys, might think is secure
- but would be **!!!WRONG!!!**
- problem is language characteristics

Language Redundancy and Cryptanalysis

- human languages are **redundant**
- eg "th lrd s m shphrd shll nt wnt"
- letters are not equally commonly 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
- have tables of single, double & triple letter frequencies for various languages

English Letter Frequencies



Use in Cryptanalysis

- key concept - monoalphabetic substitution ciphers do not change relative letter frequencies
- discovered by Arabian scientists in 9th century
- calculate letter frequencies for ciphertext
- compare counts/plots against known values
- if caesar cipher look for common peaks/troughs
  - peaks at: A-E-I triple, NO pair, RST triple
  - troughs at: JK, X-Z
- for monoalphabetic must identify each letter
  - tables of common double/triple letters help

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 viet cong in moscow

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

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

Encrypting and Decrypting

- plaintext is encrypted two letters at a time
  1. if a pair is a repeated letter, insert filler like 'X'
  2. if both letters fall in the same row, replace each with letter to right (wrapping back to start from end)
  3. if both letters fall in the same column, replace each with the letter below it (again wrapping to top from bottom)
  4. otherwise each letter is replaced by the letter in the same row and in the column of the other letter of the pair

Security of 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. by US & British military in WW1
- it **can** be broken, given a few hundred letters
- since still has much of plaintext structure

Polyalphabetic Ciphers

- **polyalphabetic substitution ciphers**
- improve security using multiple cipher alphabets
- make 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
- effectively multiple caesar ciphers
- key is multiple letters long $K = k_1\ k_2\ \ldots\ k_d$
- 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

Example of Vigenère Cipher

- 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
```

Aids

- simple aids can assist with en/decryption
- a **Saint-Cyr Slide** is a simple manual aid
  - a slide with repeated alphabet
  - line up plaintext 'A' with key letter, eg 'C'
  - then read off any mapping for key letter
- can bend round into a **cipher disk**
- or expand into a **Vigenère Tableau**

Security of Vigenère Ciphers

- have multiple ciphertext letters for each plaintext letter
- hence letter frequencies are obscured
- but not totally lost
- start with letter frequencies
  - see if look monoalphabetic or not
- if not, then need to determine number of alphabets, since then can attach each

Kasiski Method

- method developed by Babbage / Kasiski
- repetitions in ciphertext give clues to period
- so find same plaintext an exact period apart
- which results in the same ciphertext
- of course, could also be random fluke
- eg repeated “VTW” in previous example
- suggests size of 3 or 9
- then attack each monoalphabetic cipher individually using same techniques as before

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
```

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 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 transposition
- 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:         3 4 2 1 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, 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 bridge from classical to modern ciphers

Rotor Machines

- before modern ciphers, rotor machines were most common complex ciphers in use
- 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

Hagelin Rotor Machine

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 LSB in graphic image or sound file
- has drawbacks
  - high overhead to hide relatively few info bits

Summary

- have considered:
  - classical cipher techniques and terminology
  - monoalphabetic substitution ciphers
  - cryptanalysis using letter frequencies
  - Playfair cipher
  - polyalphabetic ciphers
  - transposition ciphers
  - product ciphers and rotor machines
  - stenography

UNIT I INTRODUCTION

Security trends - Legal, Ethical and Professional Aspects of Security, Need for Security at Multiple Levels, Security Policies - Model of Network Security - Security Attacks, Services and Mechanisms - OSI security architecture - classical encryption techniques: substitution techniques, transposition techniques, steganography - Foundations of modern cryptography: perfect security - information theory - product cryptosystem - cryptanaysis

1.1 SECURITY TRENDS

The protection afforded to an automated information system in order to attain the applicable objectives of preserving the integrity, availability, and confidentiality of information system resources (includes hardware, software, firmware, information/ data, and telecommunications)

This definition introduces three key objectives that are at the heart of computer security:

- **Confidentiality:** This term covers two related concepts:
- **Data confidentiality:** Assures that private or confidential information is not made available or disclosed to unauthorized individuals.
- **Privacy:** Assures that individuals control or influence what information related to them may be collected and stored and by whom and to whom that information may be disclosed.
- **Integrity:** This term covers two related concepts:
- **Data integrity:** Assures that information and programs are changed only in a specified and authorized manner.
- **System integrity:** Assures that a system performs its intended function in an unimpaired manner, free from deliberate or inadvertent unauthorized manipulation of the system.
- **Availability:** Assures that systems work promptly and service is not denied to authorized users

These three concepts form what is often referred to as the **CIA triad** (Figure 1.1). The three concepts embody the fundamental security objectives for both data and for information and computing services

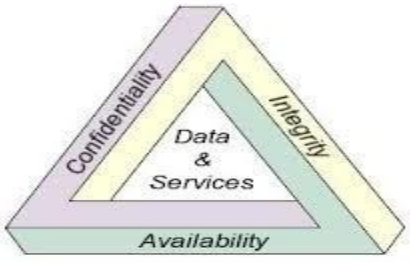


Figure 1.1 CIA triad

Although the use of the CIA triad to define security objectives is well established, some in the security field feel that additional concepts are needed to present a complete picture. Two of the most commonly mentioned are as follows:

• **Authenticity:** The property of being genuine and being able to be verified and trusted; confidence in the validity of a transmission, a message, or message originator. This means verifying that users are who they say they are and that each input arriving at the system came from a trusted source.

• **Accountability:** The security goal that generates the requirement for actions of an entity to be traced uniquely to that entity. This supports non repudiation, deterrence, fault isolation, intrusion detection and prevention, and after-action recovery and legal action.

• **Computer Security** - Generic name for the collection of tools designed to protect data and to thwart hackers**.**

• **Network Security -** Measures to protect data during their transmission.

• **Internet Security** - Measures to protect data during their transmission over a collection of interconnected networks Our Focus is on Internet Security which consists of measures to deter, prevent, detect and correct security violations that involve the transmission and storage of information

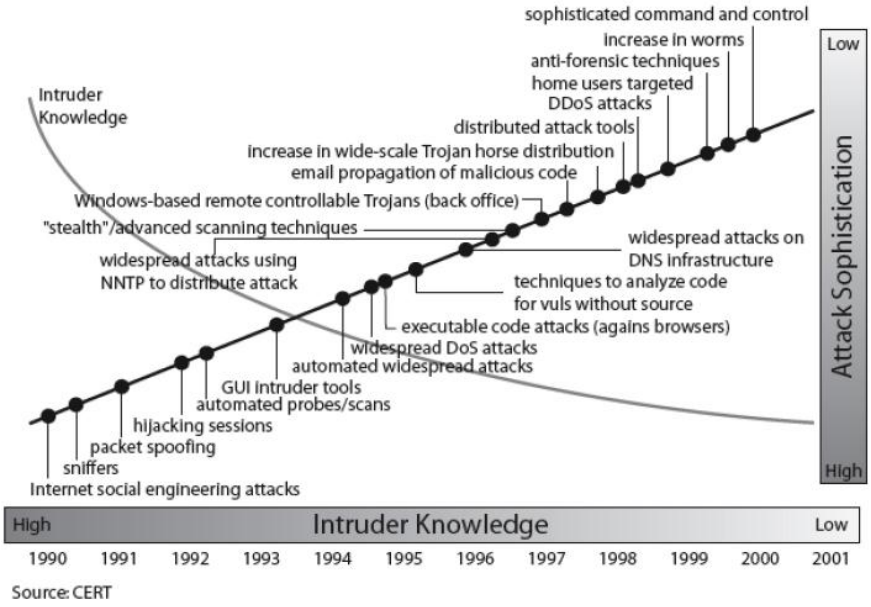


Figure 1.2 Security Trends

1.1.1 THE CHALLENGES OF COMPUTER SECURITY

Computer and network security is both fascinating and complex. Some of the reasons follow:

1. Security is not as simple as it might first appear to the novice. The requirements seem to be straightforward; indeed, most of the major requirements for security services can be given self-explanatory, one-word labels: confidentiality, authentication, non repudiation, or integrity

2. In developing a particular security mechanism or algorithm, one must always consider potential attacks on those security features.

3. Typically, a security mechanism is complex, and it is not obvious from the statement of a particular requirement that such elaborate measures are needed.

4. Having designed various security mechanisms, it is necessary to decide where to use them. This is true both in terms of physical placement and in a logical sense

.

5. Security mechanisms typically involve more than a particular algorithm or protocol

6. Computer and network security is essentially a battle of wits between a perpetrator who tries to find holes and the designer or administrator who tries to close them. The great advantage that the attacker has is that he or she need only find a single weakness, while the designer must find and eliminate all weaknesses to achieve perfect security.

7. There is a natural tendency on the part of users and system managers to perceive little benefit from security investment until a security failure occurs.

8. Security requires regular, even constant, monitoring, and this is difficult in today‟s short-term, overloaded environment.

9. Security is still too often an afterthought to be incorporated into a system after the design is complete rather than being an integral part of the design process.

10. Many users and even security administrators view strong security as an impediment to efficient and user-friendly operation of an information system or use of information.

1.2 LEGAL, ETHICAL AND PROFESSIONAL ASPECTS OF SECURITY

Today millions of people perform online transactions every day. There many ways to attack computer and networks to take advantage of what has made shopping, banking, transformation of messages, investments and leisure pursuits a simple matter of dragging and clicking for many people. Thus, the laws and ethics are important aspects in data and network security. The legal system has adapted quite well to computer technology by reusing some old forms of legal protection (copyrights and patents) and creating laws where no adequate one existed (malicious access). Still the courts are not a perfect form of protection for computer, for two reasons, first court tends to be reactive instead of proactive. That is, we have to wait for regression to occur and then adjudicative it, rather than try to prevent it in first place. Second fixing a problem through the courts can be time consuming and more expensive.

The latter characteristic prevents all but the wealthy from addressing most wealthy. On other hand, 1ethics has not had to change , because ethic is more situational and personal than the law, for example the privacy of personal information becoming important part of computer network security and although technically this issue is just an aspect of confidentiality, practically it has a long history in both law and ethics.

Law and security are related in several ways. First international, national, state, city laws affect privacy, secrecy. These statutes often apply to the rights of individuals to keep personal matters private. Second law regulates the use of development, and ownership of data and programs. Patents, copy rights, and trade secrets are legal devices to protect the right of developers and owners of the information and data.

1.2.1 Cryptography and Law

Cyber-Crime: - Criminal activities or attacks in which computer and computer networks are tool, target, or place of criminal activity. Cybercrime categorize based on computer roles such as target, storage device and communication tool.

Computers as targets: To get the information from the computer system or control the computer system without the authorization or payment or alter the interfaces or data in the particular system with use of server.

Computers as storage devices: Computers can be used to further unlawful activity by using a computer or a computer device as a passive storage medium. For example, the computer can be used to store stolen password lists, credit card details and proprietary corporate information.

Computers as communications tools: Many of the crimes falling within this category are simply traditional crimes that are committed online. Examples include the illegal sale of prescription drugs, controlled substances, alcohol, and guns; fraud; gambling; and child pornography. Other than these crimes there are more specific crimes in computer networks. There are:

Illegal access: The access to the whole or any part of a computer system without right. Illegal interception: The interception without right, made by technical means, of non-public transmissions of computer data to, from or within a computer system, including electromagnetic emissions from a computer system carrying such computer data.

Data interference: The damaging, deletion, deterioration, alteration or suppression of computer data without right.

System interference: The serious hindering without right of the functioning of a computer system by inputting, transmitting, damaging, deleting, deteriorating, altering or suppressing computer data.

Computer-related forgery: The input, alteration, deletion, or suppression of computer data, resulting in inauthentic data with the intent that it be considered or acted upon for legal purposes as if it were authentic, regardless whether or not the data is directly readable and intelligible.

Crime related to child pornography: Producing child pornography or distribution through a computer system and making available or distributing or transmitting child pornography through a computer system.

The relative lack of success in bringing cyber-criminals to justice has led to an increase in their numbers, boldness, and the global scale of their operations. It is difficult to profile cybercriminals in the way that is often done with other types of repeat offenders. The success of cybercriminals and the relative lack of success of law enforcement, influence the behaviour of cybercrime victims. As with law enforcement, many organizations that may be the target of attack have not invested sufficiently in technical, physical, and human-factor resources to prevent attacks.

The law is used regulate people for their own good and for the greater good of society. Cryptography also regulated activity.

Some Example laws which are forced on cryptography.

Control use of cryptography: Closely related to restrictions on content are restrictions on the use of cryptography imposed on users in certain countries. For examples, 2 In China, state council order 273 requires foreign organizations or individuals to apply permission to use encryption in China. Pakistan requires that all encryption hardware and software be inspected and approved by the Pakistan telecommunication authority.

Cryptography and Free speech: The Cryptography involve not just products, it involves ideas too, although governments effectively control the flow of products across borders, controlling the floe ideas either head or on the internet, is also impossible.

Cryptography and Escrow: Although laws enable governments to read encrypted communications. In 1996, US government offered to relax the export restriction for so called escrowed encryption, in which the government would able to obtain the encryption key for any encrypted communication.

The victory in use of law enforcement depends much more on technical skills of the people. Management needs to understand the criminal investigation process, the inputs that investigators need, and the ways in which the victim can contribute positively to the investigation.

1.2.2 Intellectual Properties.

There are three main types of intellectual property for which legal protection is available. **Copy rights:** Copyright law protects the tangible or fixed expression of an idea, not the idea itself. Copy right properties exists when proposed work is original and creator has put original idea in concrete form and the copyright owner has these exclusive rights, protected against infringement such as reproduction right, modification right, distribution right

Patents: A patent for an invention is the grant of a property right to the inventor. There are 3 types in patents:-

- Utility (any new and useful process, machine, article of manufacture, or composition of matter).
- Design (new, original, and ornamental design for an article of manufacture)
- Plant (discovers and asexually reproduces any distinct and new variety of plant).

Trade-Marks: A trademark is a word, name, symbol or expression which used to identify the products or services in trade uniquely from others. Trade mark rights used to prevent others from using a confusingly similar mark, but not to prevent others from making the same goods or from selling the same goods or services under a clearly different mark.

- Intellectual Property Relevant to Network and Computer Security
  A number of forms of intellectual property are relevant in the context of network and computer security.
- Software programs: software programs are protected by using copyright, perhaps patent.
- Digital content: audio / video / media / web protected by copy right
  Algorithms: algorithms may be able to protect by patenting
- Privacy Law and Regulation: An issue with considerable overlap with computer security is that of privacy. Concerns about the extent to which personal privacy has been and may be compromised have led to a variety of legal and technical approaches to reinforcing privacy rights. A number of international organizations and national governments have introduced laws and regulations intended to protect individual privacy.
- European Union Data Protection Directive was adopted in 1998 to ensure member states protect fundamental privacy rights when processing personal info and prevent member states from restricting the free flow of personal info within EU organized around principles of notice, consent, consistency, access, security, onward transfer and enforcement. US Privacy Law have Privacy Act of 1974 which permits individuals to determine records kept, forbid records being used for other purposes, obtain access to records, ensures agencies properly collect, maintain, and use personal info and creates a private right of action for individuals.
  Cryptography and Ethics.

- There are many potential misuses and abuses of information and electronic communication that create privacy and security problems. Ethics refers to a system of moral principles that relates to the benefits and harms of particular actions. An ethic an objectively defined standard of right and wrong. Ethical standards are often idealistic principles because they focus on one objective. Even though religious group and professional organization promote certain standards of ethical behaviour, ultimately each person is responsible for deciding what do in a specific situation.

1.2.3 Ethical issues related to computer and info systems

Computers have become the primary repository of both personal information and negotiable assets, such as bank records, securities records, and other financial information.

Repositories and processors of information: Unauthorized use of otherwise unused computer services or of information stored in computers raises questions of appropriateness or fairness.

Producers of new forms and types of assets: For example, computer programs are entirely new types of assets, possibly not subject to the same concepts of ownership as other assets.

Symbols of intimidation and deception: The images of computers as thinking machines, absolute truth producers, infallible, subject to blame, and as anthropomorphic replacements of humans who err should be carefully considered.

1.3 NEED FOR SECURITY AT MULTIPLE LEVELS

Multilevel security or multiple levels of security (MLS) is the application of a computer system to process information with incompatible classifications (i.e., at different security levels), permit access by users with different security clearances and needs-to-know, and prevent users from obtaining access to information for which they lack authorization.

There are two contexts for the use of multilevel security.

One is to refer to a system that is adequate to protect itself from subversion and has robust mechanisms to separate information domains, that is, trustworthy.

Another context is to refer to an application of a computer that will require the computer to be strong enough to protect itself from subversion and possess adequate mechanisms to separate information domains, that is, a system we must trust. This distinction is important because systems that need to be trusted are not necessarily trustworthy.

A threat is an object, person, or other entity that represents a constant danger to an asset.

1.3.1 Security Policies

The Cryptography Policy sets out when and how encryption should be used. It includes protection of sensitive information and communications, key management, and procedures to ensure encrypted information can be recovered by the organisation if necessary.

Role of the Security Policy in Setting up Protocols

Following are some pointers which help in setting u protocols for the security policy of an organization.

- Who should have access to the system?
- How it should be configured?
- How to communicate with third parties or systems?

Policies are divided in two categories:

- User policies
- IT policies.

User policies generally define the limit of the users towards the computer resources in a workplace. For example, what are they allowed to install in their computer, if they can use removable storages?

Whereas, IT policies are designed for IT department, to secure the procedures and functions of IT fields.

- **General Policies** − This is the policy which defines the rights of the staff and access level to the systems. Generally, it is included even in the communication protocol as a preventive measure in case there are any disasters.
- **Server Policies** − This defines who should have access to the specific server and with what rights. Which software's should be installed, level of access to internet, how they should be updated?
- **Firewall Access and Configuration Policies** − It defines who should have access to the firewall and what type of access, like monitoring, rules change. Which ports and services should be allowed and if it should be inbound or outbound?
- **Backup Policies** − It defines who is the responsible person for backup, what should be the backup, where it should be backed up, how long it should be kept and the frequency of the backup.
- **VPN Policies** − These policies generally go with the firewall policy; it defines those users who should have a VPN access and with what rights. For site-to-site connections with partners, it defines the access level of the partner to your network, type of encryption to be set.

1.3.2 Structure of a Security Policy

When you compile a security policy you should have in mind a basic structure in order to make something practical. Some of the main points which have to be taken into consideration are:

- Description of the Policy and what is the usage for?
- Where this policy should be applied?
- Functions and responsibilities of the employees that are affected by this policy.
- Procedures that are involved in this policy.
- Consequences if the policy is not compatible with company standards.

Types of Policies

- **Permissive Policy** − It is a medium restriction policy where we as an administrator block just some well-known ports of malware regarding internet access and just some exploits are taken in consideration.
- **Prudent Policy** − This is a high restriction policy where everything is blocked regarding the internet access, just a small list of websites is allowed, and now extra services are allowed in computers to be installed and logs are maintained for every user.

- **Acceptance User Policy** − This policy regulates the behavior of the users towards a system or network or even a webpage, so it is explicitly said what a user can do and cannot in a system. Like are they allowed to share access codes, can they share resources, etc.
- **User Account Policy** − This policy defines what a user should do in order to have or maintain another user in a specific system. For example, accessing an e-commerce webpage. To create this policy, you should answer some questions such as −
    - Should the password be complex or not?
    - What age should the users have?
    - Maximum allowed tries or fails to log in?
    - When the user should be deleted, activated, blocked?
- **Information Protection Policy** − This policy is to regulate access to information, hot to process information, how to store and how it should be transferred.
- **Remote Access Policy** − This policy is mainly for big companies where the user and their branches are outside their headquarters. It tells what should the users access, when they can work and on which software like SSH, VPN, RDP.
- **Firewall Management Policy** − This policy has explicitly to do with its management, which ports should be blocked, what updates should be taken, how to make changes in the firewall, how long should be the logs be kept.
- **Special Access Policy** − This policy is intended to keep people under control and monitor the special privileges in their systems and the purpose as to why they have it. These employees can be team leaders, managers, senior managers, system administrators, and such high designation based people.
- **Network Policy** − This policy is to restrict the access of anyone towards the network resource and make clear who all will access the network. It will also ensure whether that person should be authenticated or not. This policy also includes other aspects like, who will authorize the new devices that will be connected with network? The documentation of network changes. Web filters and the levels of access. Who should have wireless connection and the type of authentication, validity of connection session?
- **Email Usage Policy** − This is one of the most important policies that should be done because many users use the work email for personal purposes as well. As a result information can leak outside. Some of the key points of this policy are the employees should know the importance of this system that they have the privilege to use. They should not open any attachments that look suspicious. Private and confidential data should not be sent via any encrypted email.
- **Software Security Policy** − This policy has to do with the software's installed in the user computer and what they should have. Some of the key points of this policy are Software of the company should not be given to third parties. Only the white list of software's should be allowed, no other software's should be installed in the computer. Warez and pirated software's should not be allowed.

1.4 A MODEL FOR NETWORK SECURITY

A model for much of what we will be discussing is captured, in very general terms, in Figure 1.3. A message is to be transferred from one party to another across some sort of Internet service.

A security-related transformation on the information to be sent, Examples include the encryption of the message, which scrambles the message so that it is unreadable by the opponent, and the addition of a code based on the contents of the message, which can be used to verify the identity of the sender

Some secret information shared by the two principals and, it is hoped, unknown to the opponent. An example is an encryption key used in conjunction with the transformation to scramble the message before transmission and unscramble it on reception.

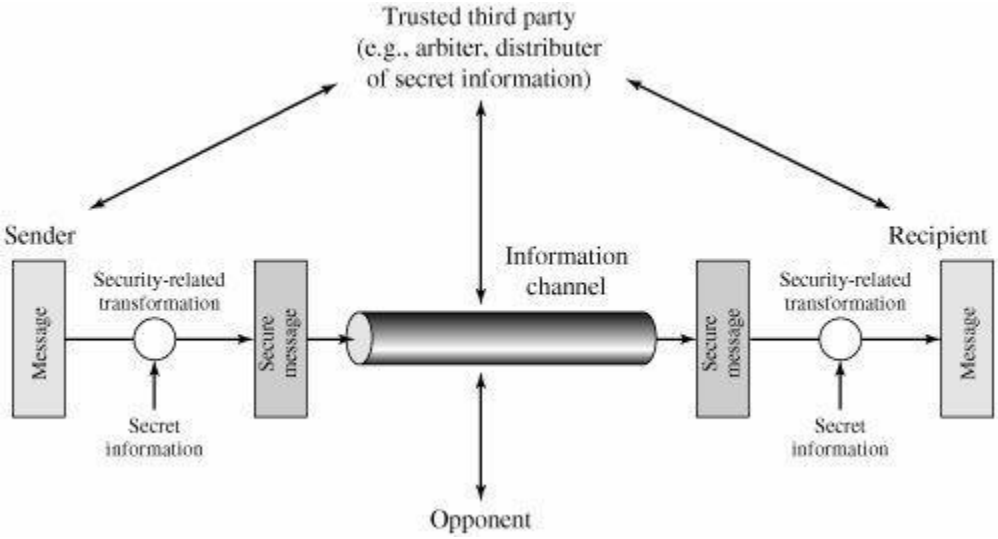


Figure 1.3 Model for Network Security

All the techniques for providing security have two components:
This general model shows that there are four basic tasks in designing a particular security service:

1. Design an algorithm for performing the security-related transformation.
The algorithm should be such that an opponent cannot defeat its purpose.
2. Generate the secret information to be used with the algorithm.
3. Develop methods for the distribution and sharing of the secret information.
4. Specify a protocol to be used by the two principals that makes use of the security algorithm and the secret information to achieve a particular security service

A general model of these other situations is illustrated by Figure 1.4, which reflects a concern for protecting an information system from unwanted access. Most readers are familiar with the concerns caused by the existence of hackers, who attempt to penetrate systems that can be accessed over a network. The hacker can be someone who, with no malign intent, simply gets satisfaction from breaking and entering a computer system. The intruder can be a disgruntled employee who wishes to do damage or a criminal who seeks to exploit computer assets for financial gain (e.g., obtaining credit card numbers or performing illegal money transfers).

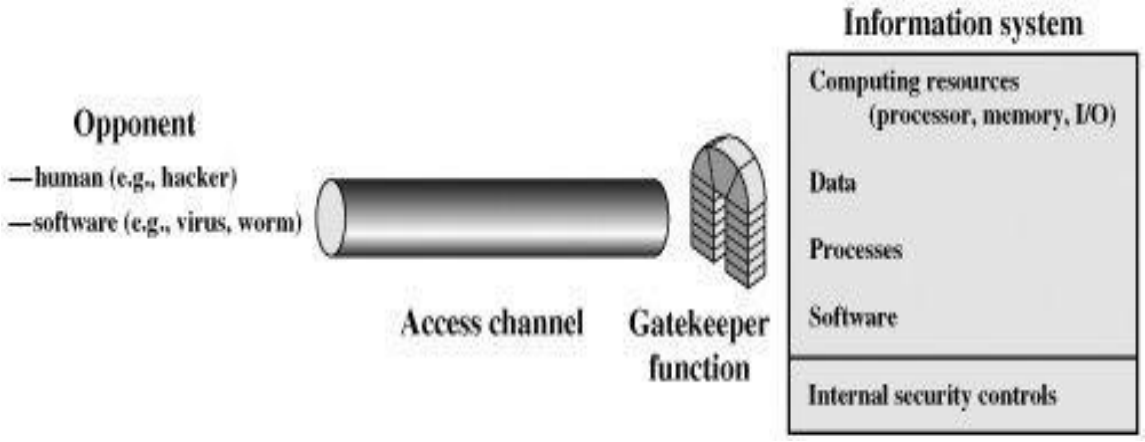


Figure 1.4 Network Access Security Model

Another type of unwanted access is the placement in a computer system of logic that exploits vulnerabilities in the system and that can affect application programs as well as utility programs, such as editors and compilers. Programs can present two kinds of threats:

• **Information access threats:** Intercept or modify data on behalf of users who should not have access to that data.

• **Service threats:** Exploit service flaws in computers to inhibit use by legitimate users.

Viruses and worms are two examples of software attacks. Such attacks can be introduced into a system by means of a disk that contains the unwanted logic concealed in otherwise useful software.

The security mechanisms needed to cope with unwanted access fall into two broad categories (see Figure 1.4).The first category might be termed a gatekeeper function. It includes password-based login procedures that are designed to deny access to all but authorized users and screening logic that is designed to detect and reject worms, viruses, and other similar attacks. Once either an unwanted user or unwanted software gains access,

The second line of defense consists of a variety of internal controls that monitor activity and analyze stored information in an attempt to detect the presence of unwanted intruders.

1.5 THE OSI SECURITY ARCHITECTURE

ITU-T Recommendation X.800, *Security Architecture for OSI*, defines such a systematic approach. The OSI security architecture is useful to managers as a way of organizing the task of providing security. This architecture was developed as an international standard, computer and communications vendors have developed security features for their products and services that relate to this structured definition of services and mechanisms.

The OSI security architecture focuses on security attacks, mechanisms, and services. These can be defined briefly as

• **Security attack:** Any action that compromises the security of information owned by an organization.

• **Security mechanism:** A process (or a device incorporating such a process) that is designed to detect, prevent, or recover from a security attack.

• **Security service:** A processing or communication service that enhances the security of the data processing systems and the information transfers of an organization. The services are intended to counter security attacks, and they make use of one or more security mechanisms to provide the service. In the literature, the terms *threat* and *attack* are commonly used to mean more or less the same thing.

•

Table 1.1 provides definitions taken from RFC 2828, *InternetSecurity Glossary.*

Threat
A potential for violation of security, which exists when there is a circumstance, capability, action, or event that could breach security and cause harm. That is, a threat is a possible danger that might exploit a vulnerability.
Attack
An assault on system security that derives from an intelligent threat; that is, an intelligent act that is a deliberate attempt (especially in the sense of a method or technique) to evade security services and violate the security policy of a system.

1.5.1 ATTACKS

The security attacks can be classified into two types' *passive attacks* and *active attacks.* A passive attack attempts to learn or make use of information from the system but does not affect system resources. An active attack attempts to alter system resources or affect their operation.

Passive Attacks

Two types of passive attacks are the release of message contents and traffic analysis.

The **release of message contents** is easily understood (Figure 1.5a).A telephone conversation, an electronic mail message, and a transferred file may contain sensitive or confidential information. We would like to prevent an opponent from learning the contents of these transmissions.

A second type of passive attack, **traffic analysis**, is subtler (Figure 1.5b). Suppose that we had a way of masking the contents of messages or other information traffic so that opponents, even if they captured the message, could not extract the information from the message. The common technique for masking contents is encryption. If we had encryption protection in place, an opponent might still be able to observe the pattern of these messages.

Passive attacks are very difficult to detect, because they do not involve any alteration of the data. Typically, the message traffic is not sent and received in an apparently normal fashion and the sender nor receiver is aware that a third party has read the messages or observed the traffic pattern.

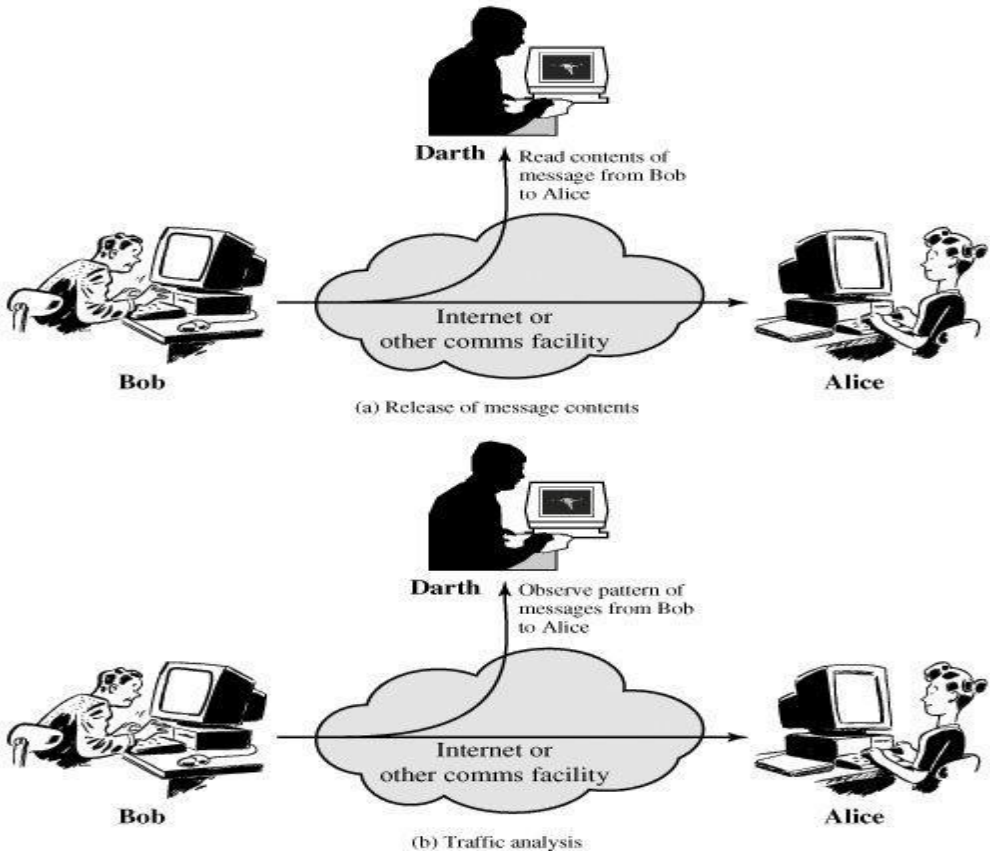


Figure 1.5 Passive Attacks

Active Attacks

Active attacks involve some modification of the data stream or the creation of a false stream and can be subdivided into four categories: masquerade, replay, modification of messages, and denial of service.

A **masquerade** takes place when one entity pretends to be a different entity (Figure 1.6a). A masquerade attack usually includes one of the other forms of active attack. For example, authentication sequences can be captured and replayed after a valid authentication sequence has taken place, thus enabling an authorized entity with few privileges to obtain extra privileges by impersonating an entity that has those privileges.

Replay involves the passive capture of a data unit and its subsequent retransmission to produce an unauthorized effect (Figure 1.6b).

Modification of messages simply means that some portion of a legitimate message is altered, or that messages are delayed or reordered, to produce an unauthorized effect (Figure 1.6c). For example, a message meaning “Allow John Smith to read confidential file *accounts*” is modified to mean “Allow Fred Brown to read confidential file *account.*

The **denial of service** prevents or inhibits the normal use or management of communications facilities (Figure 1.6d). This attack may have a specific target.

Active attacks present the opposite characteristics of passive attacks. Whereas passive attacks are difficult to detect, measures are available to prevent their success.

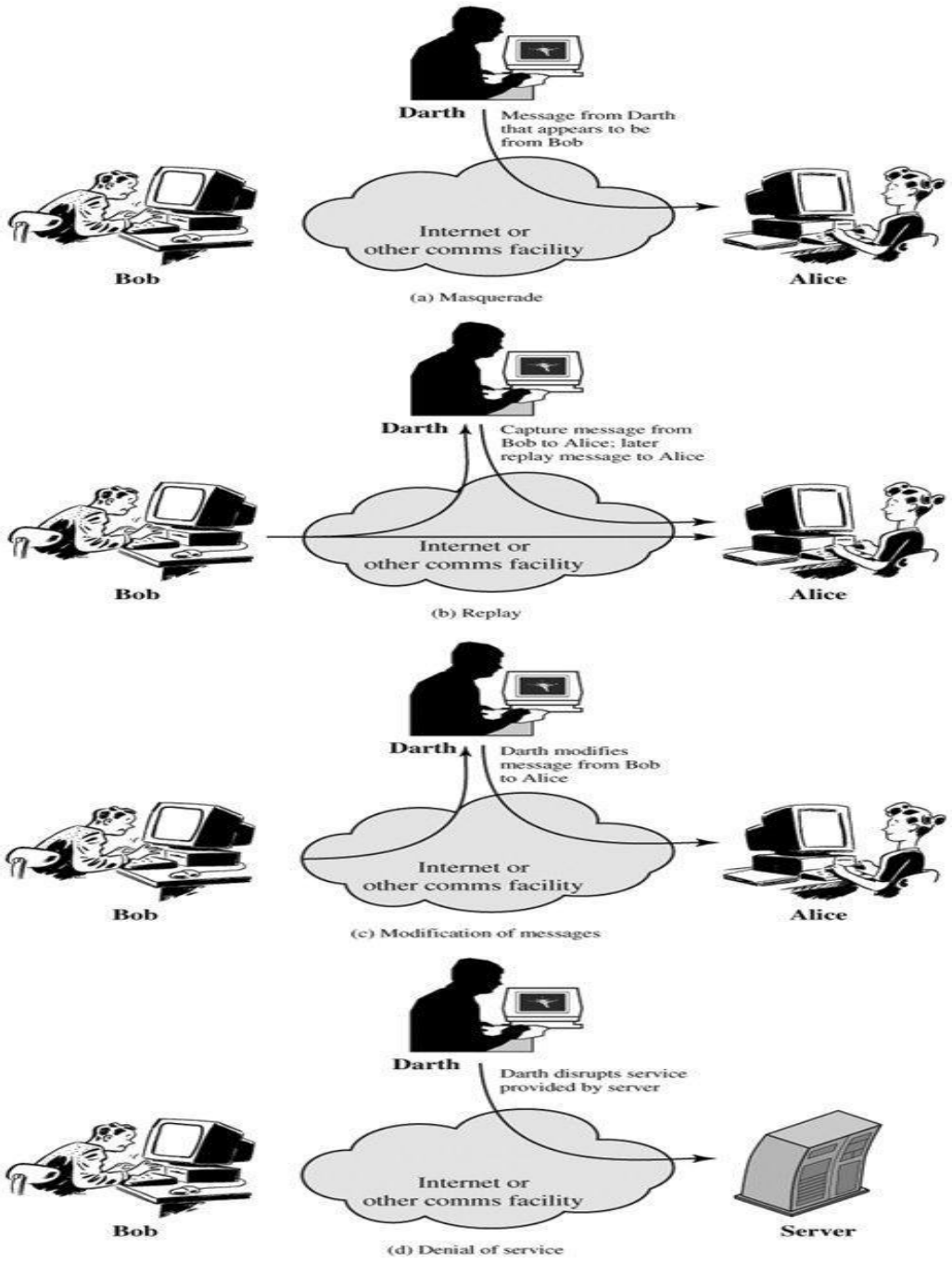


Figure 1.6 Active Attacks

1.5.2 SERVICES

X.800 defines a security service as a service that is provided by a protocol layer of communicating open systems and that ensures adequate security of the systems or of data transfers. Perhaps a clearer definition is found in RFC 2828, which provides the following definition: a processing or communication service that is provided by a system to give a specific kind of protection to system resources; security services implement security policies and are implemented by security mechanisms.

X.800 divides these services into five categories and fourteen specific services (Table 1.2)

Table 1.2 Security Services (X.800)

AUTHENTICATION The assurance that the communicating entity is the one that it claims to be. **Peer Entity Authentication** Used in association with a logical connection to provide confidence in the identity of the entities connected. **Data-Origin Authentication** In a connectionless transfer, provides assurance that the source of received data is as claimed. **ACCESS CONTROL** The prevention of unauthorized use of a resource (i.e., this service controls who can have access to a resource, under what conditions access can occur, and what those accessing the resource are allowed to do). **DATA CONFIDENTIALITY** The protection of data from unauthorized disclosure. **Connection Confidentiality** The protection of all user data on a connection. **Connectionless Confidentiality** The protection of all user data in a single data block **Selective-Field Confidentiality** The confidentiality of selected fields within the user data on a connection or in a single data block. **Traffic-Flow Confidentiality** The protection of the information that might be derived from observation of traffic flows.	**DATA INTEGRITY** The assurance that data received are exactly as sent by an authorized entity (i.e., contain no modification, insertion, deletion, or replay). **Connection Integrity with Recovery** Provides for the integrity of all user data on a connection and detects any modification, insertion, deletion, or replay of any data within an entire data sequence, with recovery attempted. **Connection Integrity without Recovery** As above, but provides only detection without recovery. **Selective-Field Connection Integrity** Provides for the integrity of selected fields within the user data of a data block transferred over a connection and takes the form of determination of whether the selected fields have been modified, inserted, deleted, or replayed. **Connectionless Integrity** Provides for the integrity of a single connectionless data block and may take the form of detection of data modification. Additionally, a limited form of replay detection may be provided. **Selective-Field Connectionless Integrity** Provides for the integrity of selected fields within a single connectionless data block; takes the form of determination of whether the selected fields have been modified. **NONREPUDIATION** Provides protection against denial by one of the entities involved in a communication of having participated in all or part of the communication. **Nonrepudiation, Origin** Proof that the message was sent by the specified party. **Nonrepudiation, Destination** Proof that the message was received by the specified party.

1.5.3 MECHANISMS

Table 1.3 lists the security mechanisms defined in X.800. The mechanisms are divided into those that are implemented in a specific protocol layer, such as TCP or an application-layer protocol, and those that are not specific to any particular protocol layer or security service

. Table 1.3 Security Mechanisms (X.800)

SPECIFIC SECURITY MECHANISMS May be incorporated into the appropriate protocol layer in order to provide some of the OSI security services.	PERVASIVE SECURITY MECHANISMS Mechanisms that are not specific to any particular OSI security service or protocol layer.
Encipherment The use of mathematical algorithms to transform data into a form that is not readily intelligible. The transformation and subsequent recovery of the data depend on an algorithm and zero or more encryption keys.	**Trusted Functionality** That which is perceived to be correct with respect to some criteria (e.g., as established by a security policy).
Digital Signature Data appended to, or a cryptographic transformation of, a data unit that allows a recipient of the data unit to prove the source and integrity of the data unit and protect against forgery (e.g., by the recipient).	**Security Label** The marking bound to a resource (which may be a data unit) that names or designates the security attributes of that resource.
Access Control A variety of mechanisms that enforce access rights to resources.	**Event Detection** Detection of security-relevant events.
Data Integrity A variety of mechanisms used to assure the integrity of a data unit or stream of data units.	**Security Audit Trail** Data collected and potentially used to facilitate a security audit, which is an independent review and examination of system records and activities.
Authentication Exchange A mechanism intended to ensure the identity of an entity by means of information exchange.	**Security Recovery** Deals with requests from mechanisms, such as event handling and management functions, and takes recovery actions.
Traffic Padding The insertion of bits into gaps in a data stream to frustrate traffic analysis attempts.	
Routing Control Enables selection of particular physically secure routes for certain data and allows routing changes, especially when a breach of security is suspected.	
Notarization The use of a trusted third party to assure certain properties of a data exchange.	

1.6 CLASSICAL ENCRYPTION TECHNIQUES

Symmetric encryption is a form of cryptosystem in which encryption and decryption are performed using the same key. It is also known as conventional encryption.

- Symmetric encryption transforms plaintext into ciphertext using a secret key and an encryption algorithm. Using the same key and a decryption algorithm, the plaintext is recovered from the ciphertext.
- The two types of attack on an encryption algorithm are cryptanalysis, based on properties of the encryption algorithm, and brute-force, which involves trying all possible keys.
- Traditional (precomputer) symmetric ciphers use substitution and/or transposition techniques. Substitution techniques map plaintext elements (characters, bits) into ciphertext elements. Transposition techniques systematically transpose the positions of plaintext elements.

- Rotor machines are sophisticated precomputer hardware devices that use substitution techniques.
- Steganography is a technique for hiding a secret message within a larger one in such a way that others cannot discern the presence or contents of the hidden message.

An original message is known as the **plaintext**, while the coded message is called the **ciphertext**. The process of converting from plaintext to ciphertext is known as **enciphering** or **encryption**; restoring the plaintext from the ciphertext is **deciphering** or **decryption**. The many schemes used for encryption constitute the area of study known as **cryptography**.

Such a scheme is known as a **cryptographic system** or a **cipher**. Techniques used for deciphering a message without any knowledge of the enciphering details fall into the area of **cryptanalysis**. Cryptanalysis is what the layperson calls “breaking the code” The areas of cryptography and cryptanalysis together are called **cryptology**.

1.6.1 SYMMETRIC CIPHER MODEL

A symmetric encryption scheme has five ingredients (Figure 1.7):

• **Plaintext:** This is the original intelligible message or data that is fed into the algorithm as input.

• **Encryption algorithm:** The encryption algorithm performs various substitutions and transformations on the plaintext.

• **Secret key:** The secret key is also input to the encryption algorithm. The key is a value independent of the plaintext and of the algorithm. The algorithm will produce a different output depending on the specific key being used at the time. The exact substitutions and transformations performed by the algorithm depend on the key

• **Ciphertext:** This is the scrambled message produced as output. It depends on the plaintext and the secret key. For a given message, two different keys will produce two different ciphertexts. The ciphertext is an apparently random stream of data and, as it stands, is unintelligible.

• **Decryption algorithm:** This is essentially the encryption algorithm run in reverse. It takes the cipher text and the secret key and produces the original plaintext.

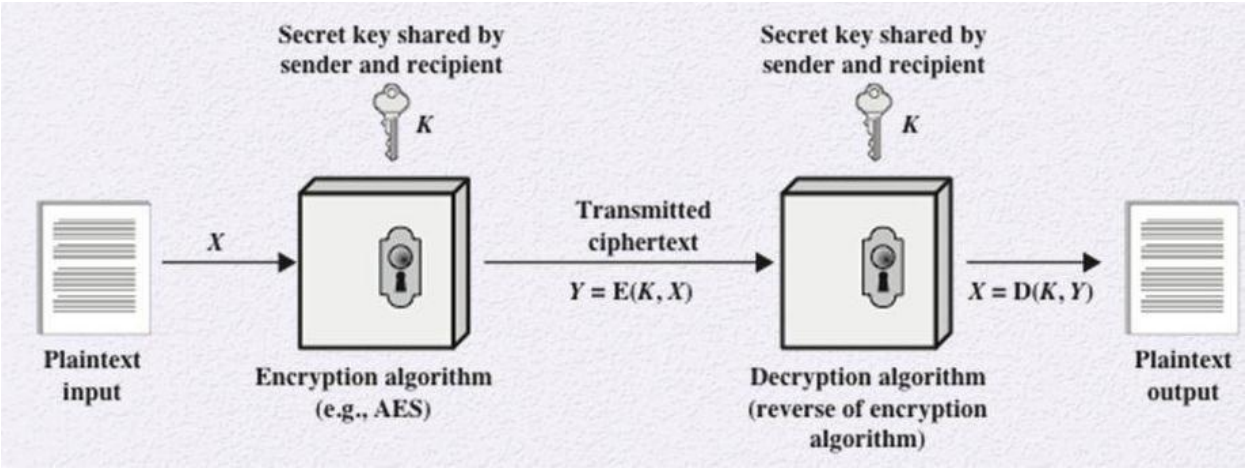


Figure 1.7 Simplified Model of Symmetric Encryption

There are two requirements for secure use of conventional encryption:

1. We need a strong encryption algorithm. At a minimum, we would like the algorithm to be such that an opponent who knows the algorithm and has access to one or more ciphertexts would be unable to decipher the ciphertext or figure out the key. This requirement is usually stated in a stronger form: The opponent should be unable to decrypt ciphertext or discover the key even if he or she is in possession of a number of ciphertexts together with the plaintext that produced each ciphertext.

2. Sender and receiver must have obtained copies of the secret key in a secure fashion and must keep the key secure. If someone can discover the key and knows the algorithm, all communication using this key is readable.

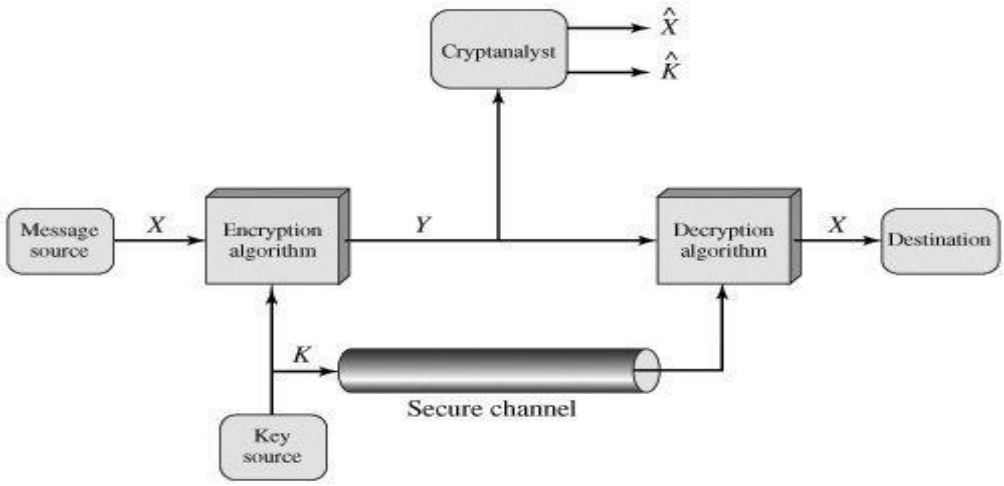


Figure 1.8 Model of Symmetric Cryptosystem

With the message X and the encryption key K as input, the encryption algorithm forms the ciphertext Y=[Y1,Y2,…….Y_N] .We can write this as Y=E(K,X)This notation indicates that is produced by using encryption algorithm E as a function of the plaintext X , with the specific function determined by the value of the key K .

The intended receiver, in possession of the key, is able to invert the transformation:

X=D(K,Y)

An opponent, observing Y but not having access K to X or, may attempt to recover X or K or both X and K. It is assumed that the opponent knows the encryption (E) and decryption (D) algorithms. If the opponent is interested in only this particular message, then the focus of the effort is to recover X by generating a plaintext estimate X. Often, however, the opponent is interested in being able to read future messages as well, in which case an attempt is made to recover K by generating an estimate K.

1.6.2 Cryptography

Cryptographic systems are characterized along three independent dimensions:

The type of operations used for transforming plaintext to ciphertext:

All encryption algorithms are based on two general principles: substitution, in which each element in the plaintext (bit, letter, group of bits or letters) is mapped into another element, and transposition, in which elements in the plaintext are rearranged. The fundamental requirement is that no information be lost (that is, that all operations are reversible). Most systems, referred to as *product systems*, involve multiple stages of substitutions and transpositions.

1. The number of keys used. If both sender and receiver use the same key, the system is referred to as symmetric, single-key, secret-key, or conventional encryption. If the sender and receiver use different keys, the system is referred to as asymmetric, two-key, or public-key encryption.

2. The way in which the plaintext is processed. A *block cipher* processes the input one block of elements at a time, producing an output block for each input block. A *stream cipher* processes the input elements continuously, producing output one element at a time, as it goes along.

3. Cryptanalysis and Brute-Force Attack

Typically, the objective of attacking an encryption system is to recover the key in use rather than simply to recover the plaintexts of a single ciphertext. There are two general approaches to attacking a conventional encryption scheme:

• **Cryptanalysis:** Cryptanalytic attacks rely on the nature of the algorithm plusperhaps some knowledge of the general characteristics of the plaintext oreven some sample plaintext–ciphertext pairs. This type of attack exploits the characteristics of the algorithm to attempt to deduce a specific plaintext or to deduce the key being used.

• **Brute-force attack**: The attacker tries every possible key on a piece of cipher text until an intelligible translation into plaintext is obtained. On average, half of all possible keys must be tried to achieve success.

Table 1.4 summarizes the various types of cryptanalytic attacks based on the amount of information known to the cryptanalyst. The most difficult problem is presented when all that is available is the ciphertext only.

Table 1.4 Types of Attacks on Encrypted Messages

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

A **brute-force attack** involves trying every possible key until an intelligible translation of the ciphertext into plaintext is obtained.

1.6.3 SUBSTITUTION TECHNIQUES

The two basic building blocks of all encryption techniques are substitution and transposition. A substitution technique is one in which the letters of plaintext are replaced by other letters or by numbers or symbols.1 If the plaintext is viewed as a sequence of bits, then substitution involves replacing plaintext bit patterns with ciphertext bit patterns.

1. Caesar Cipher

The earliest known, and the simplest, use of a substitution cipher was by Julius Caesar. The Caesar cipher involves replacing each letter of the alphabet with the letter standing three places further down the alphabet. For example,

plain: meet me after the toga party
cipher: PHHW PH DIWHU WKH WRJD SDUWB

Note that the alphabet is wrapped around, so that the letter following Z is A. We can define the transformation by listing all possibilities, as follows:

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 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

Let us assign a numerical equivalent to each letter:
When letters are involved, the following conventions are used in this book. Plaintext is always in lowercase; ciphertext is in uppercase; key values are in italicized lowercase.

Let us assign a numerical equivalent to each letter:

a	b	c	d	e	f	g	h	i	j	k	l	m
0	1	2	3	4	5	6	7	8	9	10	11	12

n	o	p	q	r	s	t	u	v	w	x	y	z
13	14	15	16	17	18	19	20	21	22	23	24	25

Then the algorithm can be expressed as follows. For each plaintext letter, substitute the cipher text letter:

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

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

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

where takes on a value in the range 1 to 25.The decryption algorithm is simply

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

If it is known that a given ciphertext is a Caesar cipher, then a brute-force cryptanalysis is easily performed: simply try all the 25 possible keys. Three important characteristics of this problem enabled us to use a bruteforce cryptanalysis:

1. The encryption and decryption algorithms are known.

2. There are only 25 keys to try.

3. The language of the plaintext is known and easily recognizable.

KEY	PHHW PH DIWHU WKH WRJD SDUWB
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	eww1 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

Figure 1.9 Brute-Force Cryptanalysis of Caesar Cipher

2. Monoalphabetic Ciphers

With only 25 possible keys, the Caesar cipher is far from secure.A dramatic increasein the key space can be achieved by allowing an arbitrary substitution. A **permutation** of a finite set of elements is an ordered sequence of all the elements of, with each element appearing exactlyonce. For example, if S ={a,b,c} , there are six permutations of :

abc, acb, bac, bca, cab, cba

In general, there are n! permutations of a set of elements, because the first element can be chosen in one of *n* ways, the second in n-1 ways, the third in n-2 ways, and so on.

Recall the assignment for the Caesar cipher:

plain: a b c d e f g h I j kl m n o p q r s t u v w x y z

cipher: 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

If, instead, 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 and would seem to eliminate brute-force techniques for cryptanalysis. Such an approach is referred to as a **monoalphabetic substitution cipher**, because a single cipher alphabet (mapping from plain alphabetto cipher alphabet) is used per message.

The ciphertext to be solved is

UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ

VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX

EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ

As a first step, the relative frequency of the letters can be determined and compared to a standard frequency distribution for English, such as is shown in Figure 1.9. If the message were long enough, this technique alone might be sufficient, but because this is a relatively short message, we cannot expect an exact match. In any case, the relative frequencies of the letters in the ciphertext (in percentages) are as follows:

P 13.33	H 5.83	F 3.33	B 1.67	C 0.00
Z 11.67	D 5.00	W 3.33	G 1.67	K 0.00
S 8.33	E 5.00	Q 2.50	Y 1.67	L 0.00
U 8.33	V 4.17	T 2.50	I 0.83	N 0.00
O 7.50	X 4.17	A 1.67	J 0.83	R 0.00
M 6.67				

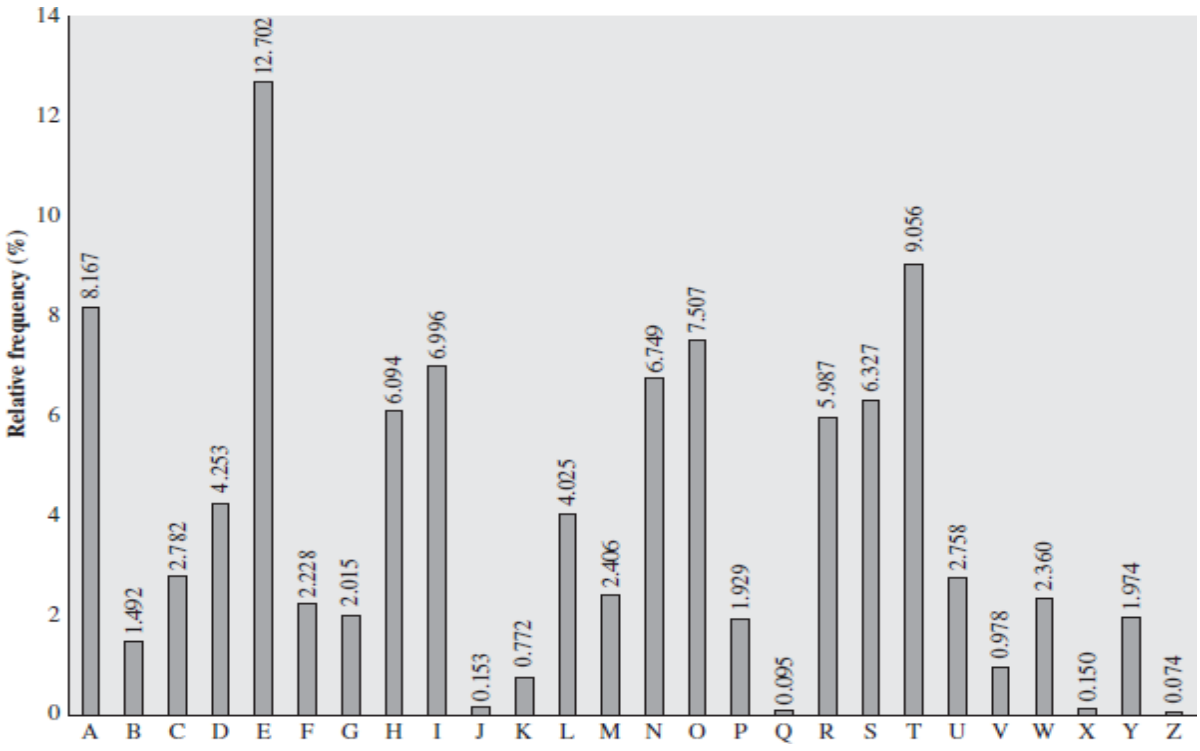


Figure 1.10 Relative Frequencies of Letters in English Text

That cipher letters P and Z are the equivalents of plain letters e and t, but it is not certain which is which. The letters S, U, O, M, and H are all of relatively high frequency and probably correspond to plain letters from the set {a, h, i, n, o, r, s}. The letters with the lowest frequencies (namely A, B, G, Y, I, J) are likely included in the set {b, j, k, q, v, x, z}.

A powerful tool is to look at the frequency of two-letter combinations, known as **digrams.** The most common such digram is th. In our ciphertext, the most common digram is ZW, which appears three times. So we make the correspondence of Z with t and W with h. Then, by our earlier hypothesis, we can equate P with e. Now notice that the sequence ZWP appears in the ciphertext, and we can translate that sequence as “the.” This is the most frequent trigram (three-letter combination). Next, notice the sequence ZWSZ in the first line. We do not know that these four letters form a complete word, but if they do, it is of the form th_t. If so, Sequates with a.
So far, then, we have

```
UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
 t a        e  e te  a that e e a       a
VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX
   e t   ta t ha e ee  a e  th    t  a
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ
 e  e e tat  e   the   t
```

Only four letters have been identified, but already we have quite a bit of the message. Continued analysis of frequencies plus trial and error should easily yield a solution from this point. The complete plaintext, with spaces added between words, follows:

it was disclosed yesterday that several informal but
direct contacts have been made with political
representatives of the viet cong in moscow

Monoalphabetic ciphers are easy to break because they reflect the frequency data of the original alphabet. A countermeasure is to provide multiple substitutes, known as homophones, for a single letter.

3. Playfair Cipher

The best-known multiple-letter encryption cipher is the Playfair, which treats digrams in the plaintext as single units and translates these units into ciphertext digrams. The Playfair algorithm is based on the use of a 5 × 5 matrix of letters constructed using a keyword. Here is an example, solved by Lord Peter Wimsey inDorothy Sayers"s *Have His Carcase*

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

In this case, the keyword is *monarchy*. The matrix is constructed by filling in the letters of the keyword (minus duplicates) from left to right and from top to bottom, and then filling in the remainder of the matrix with the remaining letters in alphabetic order. The letters I and J count as one letter. Plaintext is encrypted two letters at a time, according to the following rules:

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).

The Playfair cipher is a great advance over simple monoalphabetic ciphers. For one thing, whereas there are only 26 letters, there are 26 × 26 = 676 digrams, so that identification of individual digrams is more difficult. Furthermore, the relative frequencies of individual letters exhibit a much greater range than that of digrams, making frequency analysis much more difficult. For these reasons, the Playfair cipher was for a long time considered unbreakable. It was used as the standard field system by the British Army in World War I and still enjoyed considerable use by the U.S. Army and other Allied forces during World War II.

4. Hill Cipher

Another interesting multiletter cipher is the Hill cipher, developed by the mathematician Lester Hill in 1929. Define the inverse $\mathbf{M}^{-1}$of a square matrix **M** by the equation $\mathbf{M}(\mathbf{M}^{-1}) = \mathbf{M}^{-1}\mathbf{M} = \mathbf{I}$, where **I** is the identity matrix. **I** is a square matrix that is all zeros except for ones along the main diagonal from upper left to lower right. The inverse of a matrix does not always exist, but when

$$\mathbf{A} = \begin{pmatrix} 5 & 8 \\ 17 & 3 \end{pmatrix} \qquad \mathbf{A}^{-1} \bmod 26 = \begin{pmatrix} 9 & 2 \\ 1 & 15 \end{pmatrix}$$

$$\mathbf{A}\mathbf{A}^{-1} = \begin{pmatrix} (5 \times 9) + (8 \times 1) & (5 \times 2) + (8 \times 15) \\ (17 \times 9) + (3 \times 1) & (17 \times 2) + (3 \times 15) \end{pmatrix}$$
$$= \begin{pmatrix} 53 & 130 \\ 156 & 79 \end{pmatrix} \bmod 26 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

it does, it satisfies the preceding equation. For example,

To explain how the inverse of a matrix is computed, we begin by with the concept of determinant. For any square matrix (*m* × m), the **determinant** equals the sum of all the products that can be formed by taking exactly one element from each row and exactly one element from each column, with certain of the product terms preceded by a minus sign. For a 2 × 2 matrix,

$$\begin{pmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{pmatrix}$$

The determinant is $k_{11}k_{22} - k_{12}k_{21}$. For a 3×3 matrix, the value of the determinant is $.k_{11}k_{22}k_{33} + k_{21}k_{32}k_{13} + k_{31}k_{12}k_{23} - k_{31}k_{22}k_{13} - k_{21}k_{12}k_{33} - k_{11}k_{32}k_{23}$. If a square matrix **A** has a nonzero determinant, then the inverse of the matrix is computed as $[A^{-1}]_{ij}=(\det A)^{-1}\ (-1)^{i+j}$ $(D_{ij})$where (D_{ij}) is the subdeterminant formed by deleting the jth row and the ith column of **A**, det(**A**) is the determinant of **A**, and $(\det A)^{-1}$ is the multiplicative inverse of (det **A**) mod 26. Continuing our example,

$$\det \begin{pmatrix} 5 & 8 \\ 17 & 3 \end{pmatrix} = (5 \times 3) - (8 \times 17) = -121 \bmod 26 = 9$$

We can show that 9^{-1}mod26=3, because9×3=27mod26=1.Therefore, we compute the inverse of **A** as

$$\mathbf{A} = \begin{pmatrix} 5 & 8 \\ 17 & 3 \end{pmatrix}$$
$$\mathbf{A}^{-1} \bmod 26 = 3\begin{pmatrix} 3 & -8 \\ -17 & 5 \end{pmatrix} = 3\begin{pmatrix} 3 & 18 \\ 9 & 5 \end{pmatrix} = \begin{pmatrix} 9 & 54 \\ 27 & 15 \end{pmatrix} = \begin{pmatrix} 9 & 2 \\ 1 & 15 \end{pmatrix}$$

THE HILLALGORITHM This encryption algorithm takes m successive plaintext letters and substitutes for them m ciphertext letters. The substitution is determined by m linear equations in

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

which each character is assigned a numerical value (a=0,b=1,…z=25). For m=3, the system can be described as

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

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

or

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

where **C** and **P** are row vectors of length 3 representing the plaintext and ciphertext, and **K** is a 3 ×3 matrix representing the encryption key. Operations are performed mod 26.For example, consider the plaintext “paymoremoney” and use the encryption Key

$$\mathbf{K} = \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix}$$

The first three letters of the plaintext are represented by the vector (15 0 24). Then $(15\ 0\ 24)\mathbf{K} = (303\ 303\ 531) \bmod 26 = (17\ 17\ 11)$ = RRL. Continuing in this fashion, the ciphertext for the entire plaintext is RRLMWBKASPDH.

Decryption requires using the inverse of the matrix **K**. We can compute $\det \mathbf{K} = 23$, and therefore, $(\det \mathbf{K})^{-1} \bmod 26 = 17$. We can then compute the inverse as

$$\mathbf{K}^{-1} = \begin{pmatrix} 4 & 9 & 15 \\ 15 & 17 & 6 \\ 24 & 0 & 17 \end{pmatrix}$$

This is demonstrated as

$$\begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix}\begin{pmatrix} 4 & 9 & 15 \\ 15 & 17 & 6 \\ 24 & 0 & 17 \end{pmatrix} = \begin{pmatrix} 443 & 442 & 442 \\ 858 & 495 & 780 \\ 494 & 52 & 365 \end{pmatrix} \bmod 26 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

It is easily seen that if the matrix $\mathbf{K}^{-1}$ is applied to the ciphertext, then the plaintext is recovered.

In general terms, the Hill system can be expressed as

$$\mathbf{C} = \mathrm{E}(\mathbf{K}, \mathbf{P}) = \mathbf{PK} \bmod 26$$
$$\mathbf{P} = \mathrm{D}(\mathbf{K}, \mathbf{C}) = \mathbf{CK}^{-1} \bmod 26 = \mathbf{PKK}^{-1} = \mathbf{P}$$

As with Playfair, the strength of the Hill cipher is that it completely hides single-letter frequencies. Indeed, with Hill, the use of a larger matrix hides more frequency information. Thus, a 3 ×3 Hill cipher hides not only single-letter but also two-letter frequency information.

Consider this example. Suppose that the plaintext "hillcipher" is encrypted using a Hill cipher to yield the ciphertext HCRZSSXNSP. Thus, we know that (78) Kmod26=(72)11 11)Kmod26=(17 25); and so on. Using the first two plaintext–ciphertext pairs, we have

$$\begin{pmatrix} 7 & 2 \\ 17 & 25 \end{pmatrix} = \begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix} \mathbf{K} \bmod 26$$

The inverse of **X** can be computed

$$\begin{pmatrix} 7 & 8 \\ 11 & 11 \end{pmatrix}^{-1} = \begin{pmatrix} 25 & 22 \\ 1 & 23 \end{pmatrix}$$

so

$$\mathbf{K} = \begin{pmatrix} 25 & 22 \\ 1 & 23 \end{pmatrix} \begin{pmatrix} 7 & 2 \\ 17 & 25 \end{pmatrix} = \begin{pmatrix} 549 & 600 \\ 398 & 577 \end{pmatrix} \bmod 26 = \begin{pmatrix} 3 & 2 \\ 8 & 5 \end{pmatrix}$$

This result is verified by testing the remaining plaintext–ciphertext pairs.

5. One Time Pad Cipher (or) Vernam Cipher

It is an unbreakable cryptosystem, described by Frank Miller in 1882, the one-time pad was reinvented by Gilbert Vernam in 1917 and it was later improved by the US Amry Major Joseph. It represents the message as a sequence of 0s and 1s. This can be accomplished by writing all numbers in binary, for example, or by using ASCII. The key is a random sequence of 0"s and 1"s of same length as the message.

Once a key is used, it is discarded and never used again. The system can be expressed as follows:

$$C_i = P_i \oplus K_i$$

C_i - i^{th} binary digit of cipher text

P_i - i^{th} binary digit of plaintext

K_i - i^{th} binary digit of key

$\oplus$ – exclusive OR opearaiton

Thus the cipher text is generated by performing the bitwise XOR of the plaintext and the key. Decryption uses the same key. Because of the properties of XOR, decryption simply involves the same bitwise operation:

$$P_i = C_i \oplus K_i$$

Example

Alice wishes to send the message "HELLO" to Bob. If key material begins with "XMCKL" and the message is "HELLO", then use Vernam One Time Pad to Decrypt and Show the Encryption Process.

MESSAGE	H	E	L	L	O
POSITION	7	4	11	11	14
KEY	X	M	C	K	L
POSITION	23	12	2	10	11

OTP Encryption

H	E	L	L	O	Message
7 (H)	4 (E)	11 (L)	11 (L)	14 (O)	Message
23 (X)	12 (M)	2 (C)	10 (K)	11 (L)	Key
30	16	13	21	25	Message + Key
4 (E)	16 (Q)	13 (N)	21 (V)	25 (Z)	Message + Key (mod 26)
E	Q	N	V	Z	Ciphertext

Note: If a number is larger than 25, then the remainder afer subtraction of 26 is taken in Modular Arithmetic fashion

OTP Decryption

E	Q	N	V	Z	Ciphertext
4 (E)	16 (Q)	13 (N)	21 (V)	25 (Z)	Ciphertext
23 (X)	12 (M)	2 (C)	10 (K)	11 (L)	Key
-19	4	11	11	14	Ciphertext - Key
7 (H)	4 (E)	11 (L)	11 (L)	14 (O)	Ciphertext - Key (mod 26)
H	E	L	L	O	Message

Note: If a number is negative then 26 is added to make the number positive

Example

Encryption

Plaintext is 00101001 and the key is 10101100, we obtain the ciphertext is,

Plaintext	00101001
Key	10101100
Ciphertext	10000101

Decryption

Ciphertext	10000101
Key	10101100
Plaintext	00101001

Advantages

- Encryption method is completely unbreakable for a cipher-text only known attack
- Chosen Plaintext (or) Ciphertext attacks is not possible

Disadvantages

- It requires a very long key which is expensive to produce and expensive to transmit.
- Once a key is used it is dangerous to reuse it for second message.

6. Polyalphabetic Ciphers

Another way to improve on the simple monoalphabetic technique is to use different monoalphabetic substitutions as one proceeds through the plaintext message. The general name for this approach is **polyalphabetic substitution cipher**. All these techniques have the following features in common:

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

VIGEN`ERE CIPHER The best known, and one of the simplest, polyalphabetic ciphers is the Vigenère cipher. 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. Thus, a Caesar cipher with a shift of 3 is denoted by the key value.

Express the Vigenère cipher in the following manner. Assume a sequence of plaintext letters and a key consisting of the sequence of letters, where typically < .The sequence of ciphertext letters is calculated as follows

$$\begin{aligned} C = C_0, C_1, C_2, \ldots, C_{n-1} &= \mathrm{E}(K, P) = \mathrm{E}[(k_0, k_1, k_2, \ldots, k_{m-1}), (p_0, p_1, p_2, \ldots, p_{n-1})] \\ &= (p_0 + k_0) \bmod 26, (p_1 + k_1) \bmod 26, \ldots, (p_{m-1} + k_{m-1}) \bmod 26, \\ &\quad (p_m + k_0) \bmod 26, (p_{m+1} + k_1) \bmod 26, \ldots, (p_{2m-1} + k_{m-1}) \bmod 26, \ldots \end{aligned}$$

Thus, the first letter of the key is added to the first letter of the plaintext, mod 26, the second letters are added, and so on through the first letters of the plaintext. For the next letters of the plaintext, the key letters are repeated. This process continues until all of the plaintext sequence is encrypted. A general equation of the encryption process is

$$Ci = (pi + ki \bmod m) \bmod 26$$

Decryption is a generalization of Equation

$$pi = (Ci - ki \bmod m) \bmod 26$$

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

1.6.4 TRANSPOSITION TECHNIQUES

All the techniques examined so far involve the substitution of a ciphertext symbol for a plaintext symbol. A very different kind of mapping is achieved by performing some sort of permutation on the plaintext letters. This technique is referred to as a transposition cipher. The simplest such cipher is the **rail fence** technique, in which the plaintext is written down as a sequence of diagonals and then read off as a sequence of rows. For example, to encipher the message “meet me after the toga party” with a rail fence of depth 2, we write the following:

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

The encrypted message is

MEMATRHTGPRYETEFETEOAAT

This sort of thing would be trivial to cryptanalyze. A more complex scheme is to 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. For example,

```
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
```

Thus, in this example, the key is 4312567.To encrypt, start with the column that is labeled 1, in this case column 3.Write down all the letters in that column. Proceed to column 4, which is labeled 2, then column 2, then column 1, then columns 5, 6, and 7.A pure transposition cipher is easily recognized because it has the same letter frequencies as the original plaintext. For the type of columnar transposition just shown, cryptanalysis is fairly straightforward and involves laying out the ciphertext in a matrix and playing around with column positions. Digram and trigram frequency tables can be useful.

The transposition cipher can be made significantly more secure by performing more than one stage of transposition. The result is a more complex permutation that is not easily reconstructed. Thus, if the foregoing message is reencrypted using the same algorithm,

```
Key:        4 3 1 2 5 6 7
Input:      t t n a a p t
            m t s u o a o
            d w c o i x k
            n l y p e t z
Output:     NSCYAUOPTTWLTMDNAOIEPAXTTOKZ
```

To visualize the result of this double transposition, designate the letters in the original plaintext message by the numbers designating their position. Thus, with 28 letters in the message, the original sequence of letters is

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 26 27 28

After the first transposition, we have

03 10 17 24 04 11 18 25 02 09 16 23 01 08
15 22 05 12 19 26 06 13 20 27 07 14 21 28

MEMATRHTGPRYETEFETEOAAT

1.7 STEGANOGRAPHY

A plaintext message may be hidden in one of two ways. The methods of **steganography** conceal the existence of the message, whereas the methods of cryptography render the message unintelligible to outsiders by various transformations of the text.

A simple form of steganography, but one that is time-consuming to construct, is one in which an arrangement of words or letters within an apparently innocuous text spells out the real message. For example, the sequence of first letters of each word of the overall message spells out the hidden message. Figure shows an example in which a subset of the words of the overall message is used to convey the hidden message.

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.

Various other techniques have been used historically; some examples are the following:

Character marking: Selected letters of printed or typewritten text are overwritten 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 has a number of drawbacks when compared to encryption. It requires a lot of overhead to hide a relatively few bits of information, although using a scheme like that proposed in the preceding paragraph may make it more effective. Also, once the system is discovered, it becomes virtually worthless. This problem, too, can be overcome if the insertion method depends on some sort of key.

The advantage of steganography is that 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.

1.8 Foundations of modern cryptography

Modern encryption is the key to advanced computer and communication security. This stream of cryptography is completely based on the ideas of mathematics such as number theory and computational complexity theory as well as concepts of probability.

Characteristics of Modern Cryptography

There are four major characteristics that separate modern cryptography from the classical approach.

Table 1.5 Differences between Traditional Encryption and Modern Encryption

Traditional Encryption	**Modern Encryption**
For making ciphertext, manipulation is done in the characters of the plaintext	For making ciphertext, operations are performed on binary bit sequence
The whole of the ecosystem is required to communicate confidentiality	Here, only the parties who want to execute secure communication possess the secret key
These are weaker as compared to modern encryption	The encryption algorithm formed by this encryption technique is stronger as compared to traditional encryption algorithms
It believes in the concept of security through obscurity	Its security depends on the publicly known mathematical algorithm

Context of Cryptography

Cryptology, the study of cryptosystems, can be subdivided into two branches −

- Cryptography
- Cryptanalysis

Cryptography

Cryptography is the art and science of making a cryptosystem that is capable of providing information security. Cryptography deals with the actual securing of digital data. It refers to the design of mechanisms based on mathematical algorithms that provide fundamental information security services.

Cryptanalysis

The art and science of breaking the cipher text is known as cryptanalysis. Cryptanalysis is the sister branch of cryptography and they both co-exist. The cryptographic process results in the cipher text for transmission or storage. It involves the study of cryptographic mechanism with the intention to break them. Cryptanalysis is also used during the design of the new cryptographic techniques to test their security strengths.

Note − Cryptography concerns with the design of cryptosystems, while cryptanalysis studies the breaking of cryptosystems.

Types of Modern Cryptography

Different algorithms have come up with powerful encryption mechanisms incorporated in them. It gave rise to two new ways of encryption mechanism for data security. These are:

- Symmetric key encryption
- Asymmetric key encryption

Key

It can be a number, word, phrase, or any code that will be used for encrypting as well as decrypting any ciphertext information to plain text and vice versa.

Symmetric and asymmetric key cryptography is based on the number of keys and the way these keys work. Let us know about both of them in details:

Symmetric key encryption

Symmetric key encryption technique uses a straight forward method of encryption. Hence, this is the simpler among these two practices. In the case of symmetric key encryption, the encryption is done through only one secret key, which is known as "Symmetric Key", and this key remains to both the parties.

The same key is implemented for both encodings as well as decoding the information. So, the key is used first by the sender prior to sending the message, and on the receiver side, that key is used to decipher the encoded message.

One of the good old examples of this encryption technique is Caesar's Cipher. Modern examples and algorithms that use the concept of symmetric key encryption are RC4, QUAD, AES, DES, Blowfish, 3DES, etc.

Asymmetric Key Encryption

Asymmetric Encryption is another encryption method that uses two keys, which is a new and sophisticated encryption technique. This is because it integrates two cryptographic keys for implementing data security. These keys are termed as Public Key and Private Key.

The "public key", as the name implies, is accessible to all who want to send an encrypted message. The other is the "private key" that is kept secure by the owner of that public key or the one who is encrypting.

Encryption of information is done through public key first, with the help of a particular algorithm. Then the private key, which the receiver possesses, will use to decrypt that encrypted information. The same algorithm will be used in both encodings as well as decoding.

Examples of asymmetric key encryption algorithms are Diffie-Hellman and RSA algorithm.

Security Services of Cryptography

- Confidentiality of information.
- Data Integrity.
- Authentication.
  - Message authentication.
  - Entity authentication.
- Non-repudiation.

Cryptography Primitives

Cryptography primitives are nothing but the tools and techniques in Cryptography that can be selectively used to provide a set of desired security services −

- Encryption
- Hash functions
- Message Authentication codes (MAC)
- Digital Signatures

The following table shows the primitives that can achieve a particular security service on their own.

Table 1.6 Primitives and Security Service

Primitives ⇨ / ⇩ Service	Encryption	Hash Function	MAC	Digital Signature
Confidentiality	Yes	No	No	No
Integrity	No	Sometimes	Yes	Yes
Authentication	No	No	Yes	Yes
Non Reputation	No	No	Sometimes	Yes

1.8.1 Perfect Security

Perfect Secrecy (or information-theoretic secure) means that the ciphertext conveys no information about the content of the plaintext. ... However, part of being provably secure is that you need as much key material as you have plaintext to encrypt.

1.8.2 Information Theory

Information theory studies the quantification, storage, and communication of information. It was originally proposed by Claude Shannon in 1948 to find fundamental limits on signal processing and communication operations such as data compression.

Its impact has been crucial to the success of the Voyager missions to deep space, the invention of the compact disc, the feasibility of mobile phones, the development of the Internet, the study of linguistics and of human perception, the understanding of black holes, and numerous other fields. The field is at the intersection of mathematics, statistics, computer science, physics, neurobiology, information engineering, and electrical engineering.

The theory has also found applications in other areas, including statistical inference, natural language processing, cryptography, neurobiology, human vision, the evolution and function of molecular codes (bioinformatics), model selection in statistics, thermal physics, quantum computing, linguistics, plagiarism detection, pattern recognition, and anomaly detection.

Important sub-fields of information theory include source coding, algorithmic complexity theory, algorithmic information theory, information-theoretic security, Grey system theory and measures of information.

Applications of fundamental topics of information theory include lossless data compression (e.g. ZIP files), lossy data compression (e.g. MP3s and JPEGs), and channel coding (e.g. for DSL).

Information theory is used in information retrieval, intelligence gathering, gambling, and even in musical composition.

A key measure in information theory is entropy. Entropy quantifies the amount of uncertainty involved in the value of a random variable or the outcome of a random process. For example, identifying the outcome of a fair coin flip (with two equally likely outcomes) provides less information (lower entropy) than specifying the outcome from a roll of a die (with six equally likely outcomes). Some other important measures in information theory are mutual information, channel capacity, error exponents, and relative entropy.

1.8.3 Product Cryptosystems

A product cipher combines two or more transformations in a manner intending that the resulting cipher is more secure than the individual components to make it resistant to cryptanalysis.

The product cipher combines a sequence of simple transformations such as substitution (S-box), permutation (P-box), and modular arithmetic. For transformation involving reasonable number of n message symbols, both of the foregoing cipher systems (the S-box and P-box) are by themselves wanting.

The combination could yield a cipher system more powerful than either one alone. This approach of alternatively applying substitution and permutation transformation has been used by IBM in the Lucifer cipher system, and has become the standard for national data encryption standards such as the Data Encryption Standard and the Advanced Encryption Standard. A product cipher that uses only substitutions and permutations is called a SP-network. Feistel ciphers are an important class of product ciphers.

1.9 CRYPTANALYSIS

Cryptanalysis is the art of trying to decrypt the encrypted messages without the use of the key that was used to encrypt the messages. Cryptanalysis uses mathematical analysis & algorithms to decipher the ciphers.

The success of cryptanalysis attacks depends

- Amount of time available
- Computing power available
- Storage capacity available

The following is a list of the commonly used Cryptanalysis attacks;

Brute force attack– this type of attack uses algorithms that try to guess all the possible logical combinations of the plaintext which are then ciphered and compared against the original cipher.

Dictionary attack– this type of attack uses a wordlist in order to find a match of either the plaintext or key. It is mostly used when trying to crack encrypted passwords.

Rainbow table attack– this type of attack compares the cipher text against pre-computed hashes to find matches.

Other Attacks using Cryptanalysis

Known-Plaintext Analysis (KPA): Attacker decrypts ciphertext with known partial plaintext.

Chosen-Plaintext Analysis (CPA): Attacker uses ciphertext that matches arbitrarily selected plaintext via the same algorithm technique.

Ciphertext-Only Analysis (COA): Attacker uses known ciphertext collections.

Man-in-the-Middle (MITM) Attack: Attack occurs when two parties use message or key sharing for communication via a channel that appears secure but is actually compromised. Attacker employs this attack for the interception of messages that pass through the communications channel. Hash functions prevent MITM attacks.

Adaptive Chosen-Plaintext Attack (ACPA): Similar to a CPA, this attack uses chosen plaintext and ciphertext based on data learned from past encryptions.