Cryptography

Some constraints in military organizations :

- Ability of the code clerk to perform necessary transformations, often on a battlefield with little equipment
- Difficulty in switching over quickly from one cryptographic method to another one. Requires retraining a large number of people.
- Danger : code clerk may be captured by the enemy. Necessity to change the cryptographic method, if required.

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Cryptography

Some useful terms and definitions

Plaintext : Messages to be encrypted

Ciphertext : The output of the encryption process.

Cryptanalysis : The art of breaking ciphers.

Cryptography : The art of devising ciphers.

Cryptology : The art of devising ciphers (cryptography) and the art of breaking ciphers (cryptanalysis) is collectively known as cryptology.

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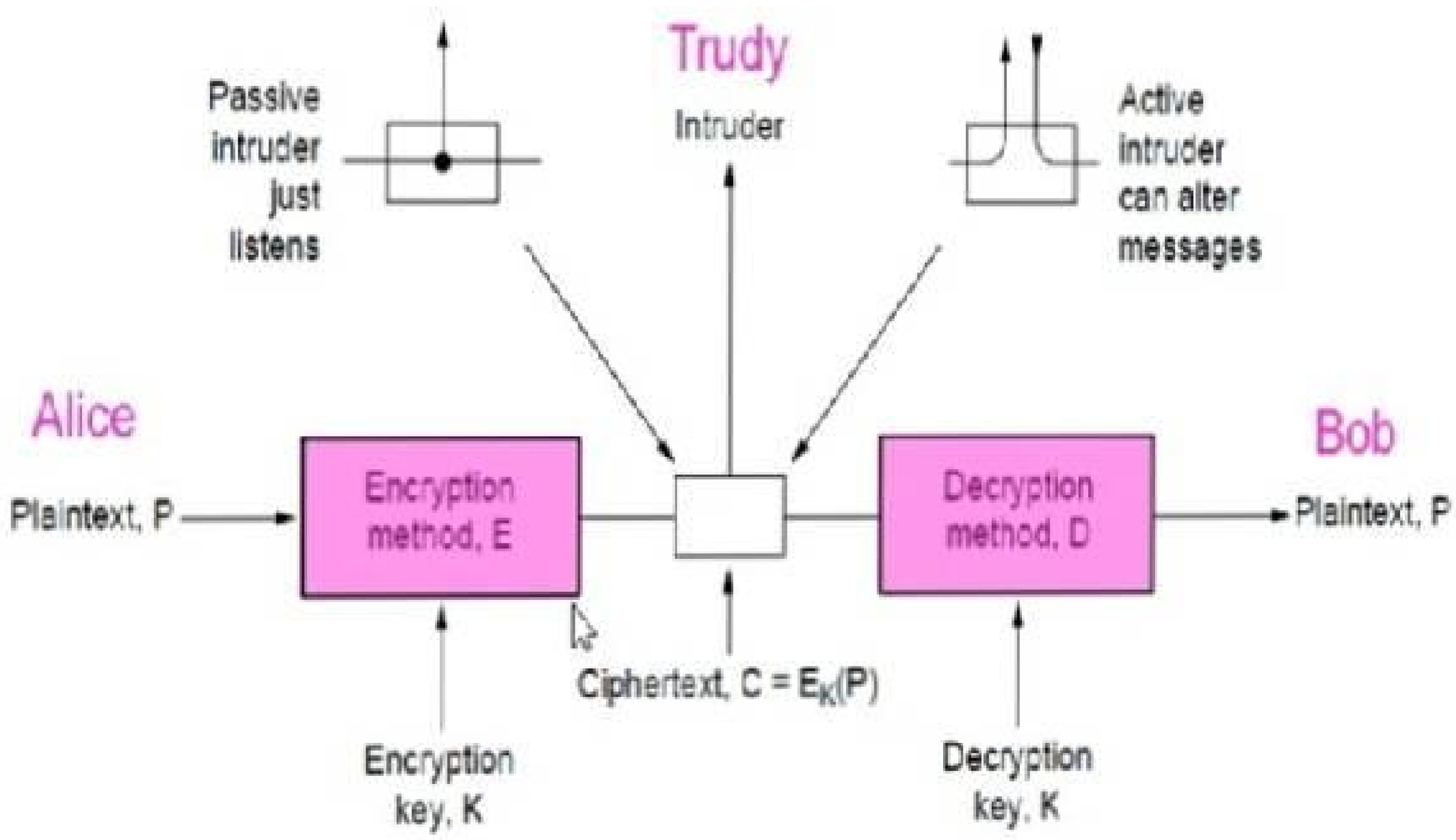

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Cryptography

Some useful notations

The encryption of the plaintext P using key K gives the ciphertext C.

$$\mathbf{C = E_k(P)}$$

The decryption of the ciphertext C using the key K gives the plaintext P.

$$\mathbf{P = D_k(C)}$$

Cryptography Basics

- Plaintext is transformed by a function that is parametrized by a key.

$$\mathbf{D_k(E_k(P)) = P}$$

where E and D are mathematical functions.

- **Key** : a short string that selects one of many potential encryptions.

  It can be changed as often as required.

- Secrecy lies in the key.
- **Length of key** : a major design issue. The longer the key, the higher the **work factor** the cryptanalyst has to deal with. The work factor for breaking the system by exhaustive search of key space is exponential in key length.
- **Basic model** : a stable and **publicly-known general method** parameterized b [screen-sharing notice] Stop sharing [Hide] **d key**.

Cryptography Basics

- Plaintext is transformed by a function that is parametrized by a key.

$$\mathbf{D_k(E_k(P)) = P}$$

where E and D are mathematical functions.

- **Basic model** : a stable and **publicly-known general method** parameterized by **a secret and easily changed key**.

- The cryptanalyst knows the algorithms and the secrecy lies exclusively in the keys.

Kerckhoff's principle : All algorithms must be public; only the keys are secret.

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Cryptography Basics

- Amount of effort necessary to invent, test and install a new method
- Difficulty in switching over quickly from one cryptographic method to another one.
- Ability of a code clerk to perform necessary transformations, without computer systems.
- Ciphertext only problem : availability of a quantity of ciphertext and no plaintext.
- Known plaintext problem : some matched ciphertext and plaintext.
- Chosen plaintext problem : Cryptanalyst has an ability to encrypt pieces of plaintext of his own choosing.
- Two major categories of encryption methods : substitution ciphers and transposition ciphers.

Cryptography

- Two major categories of encryption methods :

  substitution ciphers and transposition ciphers

- Substitution Ciphers
  - preserve the order of plaintext symbols
  - each letter or a group of letters is replaced by another letter or a group of letters to disguise it.
- Example : Caesar cipher

  Usage of a circularly shifted alphabet.
- Slight generalization of the Caesar cipher :

  Ciphertext alphabet may be shifted by k letters instead of always 3.

  K becomes a key.

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Substitution Ciphers

- Monoalphabetic substitution :

  Have each letter or symbol in the plaintext map onto some other letter or symbol.
- Letter for letter substitution.
- Example :

  plaintext : a b c d … … … z

  ciphertext : Q W E R… … … M

  Key : 26-letter string corresponding to the full alphabet.
- 26 ! possible keys. Trying all of them ? Not a promising approach.
- General method may be known. No problem.

Substitution Ciphers

Substitution ciphers replace each group of letters in the message with another group of letters to disguise it

plaintext:	a b c d e f g h i j k l m n o p q r s t u v w x y z
ciphertext:	Q W E R T Y U I O P A S D F G H J K L Z X C V B N M

Simple single-letter substitution cipher

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Transposition Cipher

- Reorder the symbols, but do not disguise them.
- Every letter represents itself.
- Example : Columnar transposition cipher.
- Cipher is keyed by a word/phrase not containing any repeated letters.
- Number the columns. Culumn 1 being under the key letter closest to the start of the lphabet, and so on.
- Plaintext is written horizontally in rows.
- Ciphertext is read out by columns.

Transposition Cipher

Transposition ciphers reorder letters to disguise them

M	E	G	A	B	U	C	K
7	4	5	1	2	8	3	6
p	l	e	a	s	e	t	r
a	n	s	f	e	r	o	n
e	m	i	l	l	i	o	n
d	o	l	l	a	r	s	t
o	m	y	s	w	i	s	s
b	a	n	k	a	c	c	o
u	n	t	s	i	x	t	w
o	t	w	o	a	b	c	d

← Key gives column order

Plaintext

pleasetransferonemilliondollarsto
myswissbankaccountsixtwotwo

Ciphertext

AFLLSKSOSELAWAIATOOSSCTCLNMOMANT
ESILYNTWRNNTSOWDPAEDOBUOERIRICXB

Column 5 6 7 8

Simple column transposition cipher

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Fundamental Cryptographic Principles

1. Messages must contain some redundancy.

All encrypted messages decrypt to something.

Redundancy lets receiver recognize a valid message.

However, redundancy helps attackers break the design.

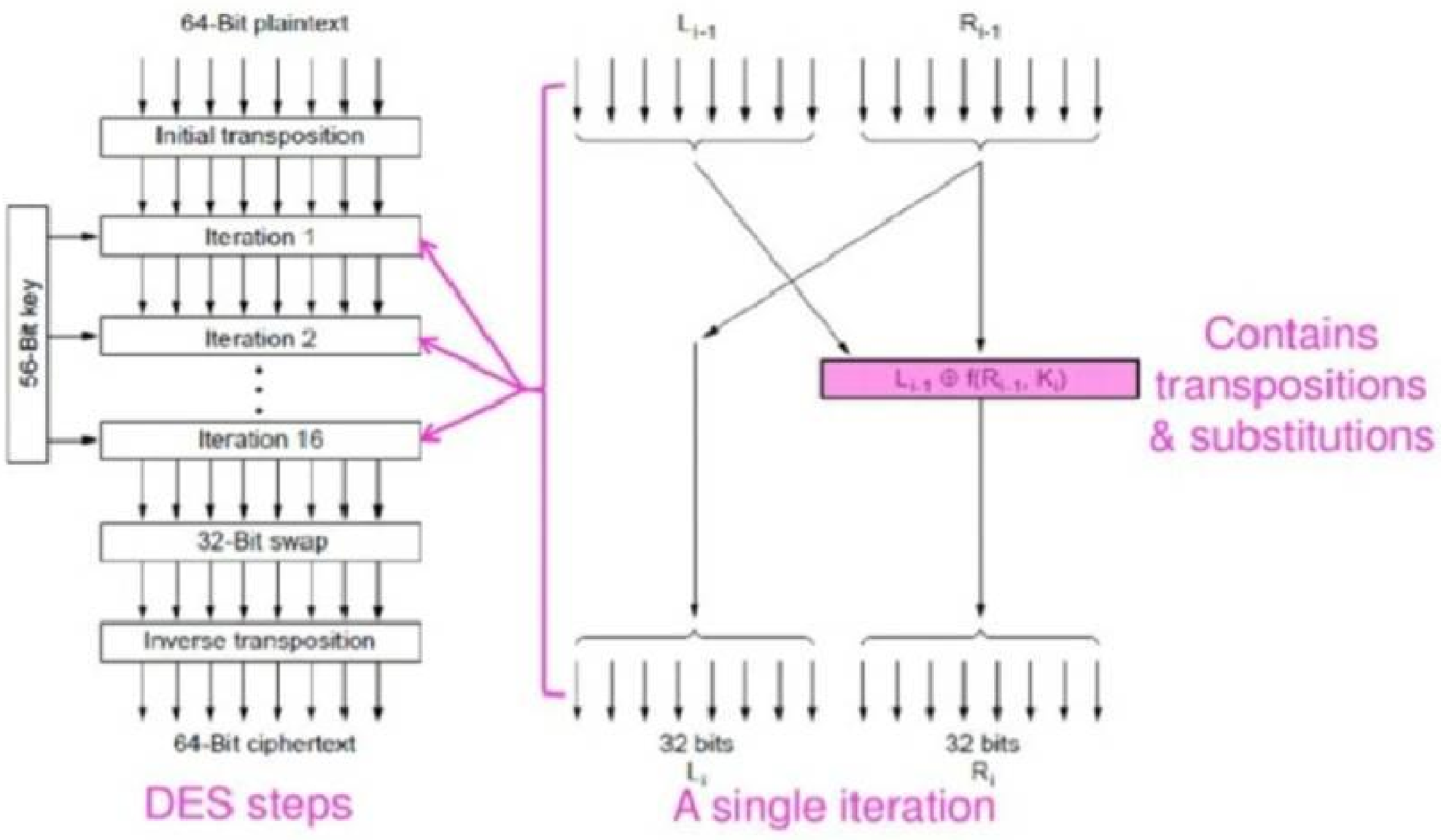
2. Some method is needed to foil replay attacks.

Without a way to check if messages are fresh then old messages can be copied and resent.

For example, add a date stamp to messages.

DES-The Data Encryption Standard

DES encryption was widely used (but no longer secure)



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Public-Key Algorithms

Public-Key Algorithms

Encryption in which each party publishes a public part of their key and keep secret a private part of it

- RSA (by Rivest, Shamir, Adleman) »

Public-Key Algorithms

Downsides of keys for symmetric-key designs:

- Key must be secret, yet be distributed to both parties
- For N users there are N^2 pairwise keys to manage

Public key schemes split the key into public and private parts that are mathematically related:

- Private part is not distributed; easy to keep secret
- Only one public key per user needs to be managed

Security depends on the chosen mathematical property

- Much slower than symmetric-key, e.g., 1000X
- So use it to set up per-session symmetric keys

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Public-Key Algorithms

- Diffie and Hellman (1976), Stanford University, proposed a new kind of cryptosystem :
- Encryption and decryption keys are different
- Decryption key cannot be feasibly derived from the encryption key.
- The (keyed) encryption algorithm, E, and the (keyed) decryption algorithm, D, have to meet the following three requirements :

1. D(E(P)) = P.
2. It is exceedingly difficult to deduce D from E.
3. E cannot be broken by a chosen plaintext attack.

RSA

RSA is a widely used public-key encryption method whose security is based on the difficulty of factoring large numbers

Key generation:

- Choose two large primes, p and q
- Compute $n = p \times q$ and $z = (p - 1) \times (q - 1)$.
- Choose d to be relatively prime to z
- Find e such that $e \times d = 1 \bmod z$
- Public key is (e, n), and private key is (d, n)

Encryption (of k bit message, for numbers up to n):

- $\text{Cipher} = \text{Plain}^e \pmod n$

Decryption:

- $\text{Plain} = \text{Cipher}^d \pmod n$

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RSA

Small-scale example of RSA encryption

- For p=3, q=11 → n=33, z=20 → d=7, e=3

Plaintext (P)			Ciphertext (C)		After decryption	
Symbolic	Numeric	P^3	P^3 (mod 33)	C^7	C^7 (mod 33)	Symbolic
S	19	6859	28	13492928512	19	S
U	21	9261	21	1801088541	21	U
Z	26	17576	20	1280000000	26	Z
A	01	1	1	1	01	A
N	14	2744	5	78125	14	N
N	14	2744	5	78125	14	N
E	05	125	26	8031810176	05	E
		Sender's computation		Receiver's computation		

Encryption: $C = P^3 \bmod 33$

Decryption: $P = C^7 \bmod 33$

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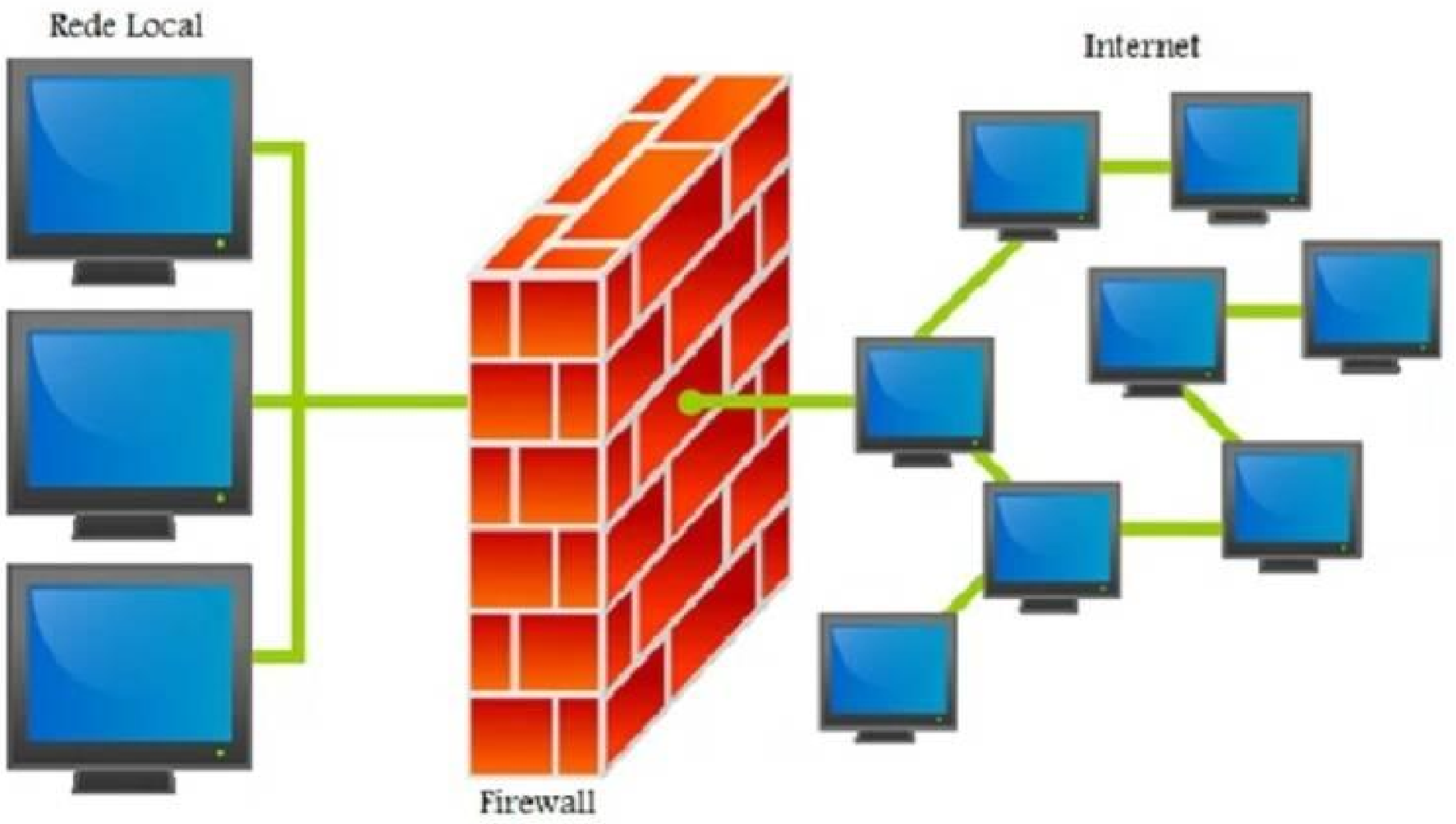
Firewalls

- Security mechanism used to protect your internal network from an external network.
- **Typical configuration :** two routers (used for packet filtering) and an application gateway (for further examination).
- Every packet must transit two filters and an application gateway to go in or out.
- Only one route exists.

Firewalls



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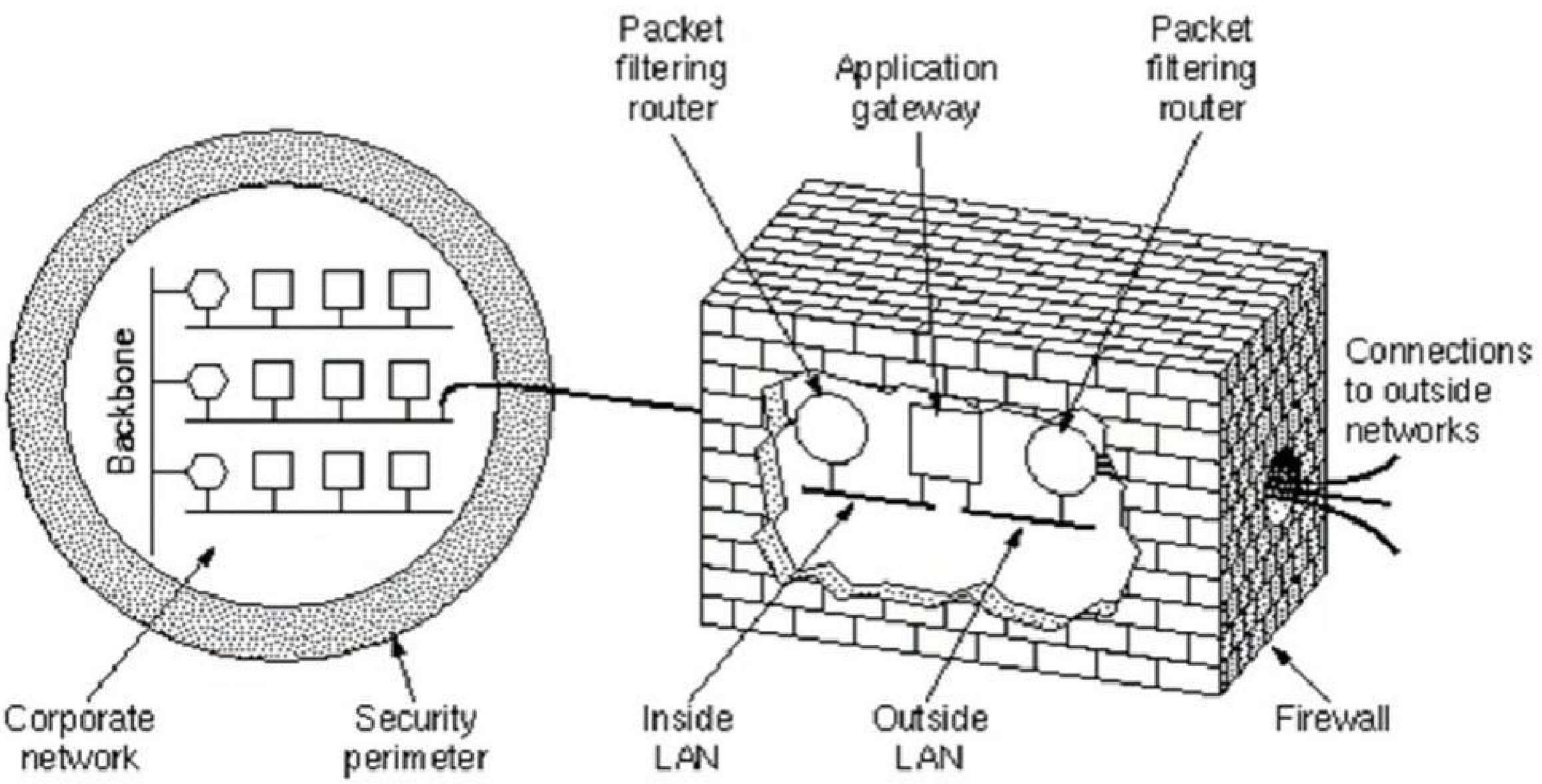
Firewalls



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Firewalls

Usage of packet filters :

- standard routers equipped with some extra functionalities.
- driven by tables configured by system administrators.
- contain information about sources/destinations that are acceptable/blocked, specification of default rules regarding what to do with packets coming from or going to other machines.

Firewalls

Firewalls

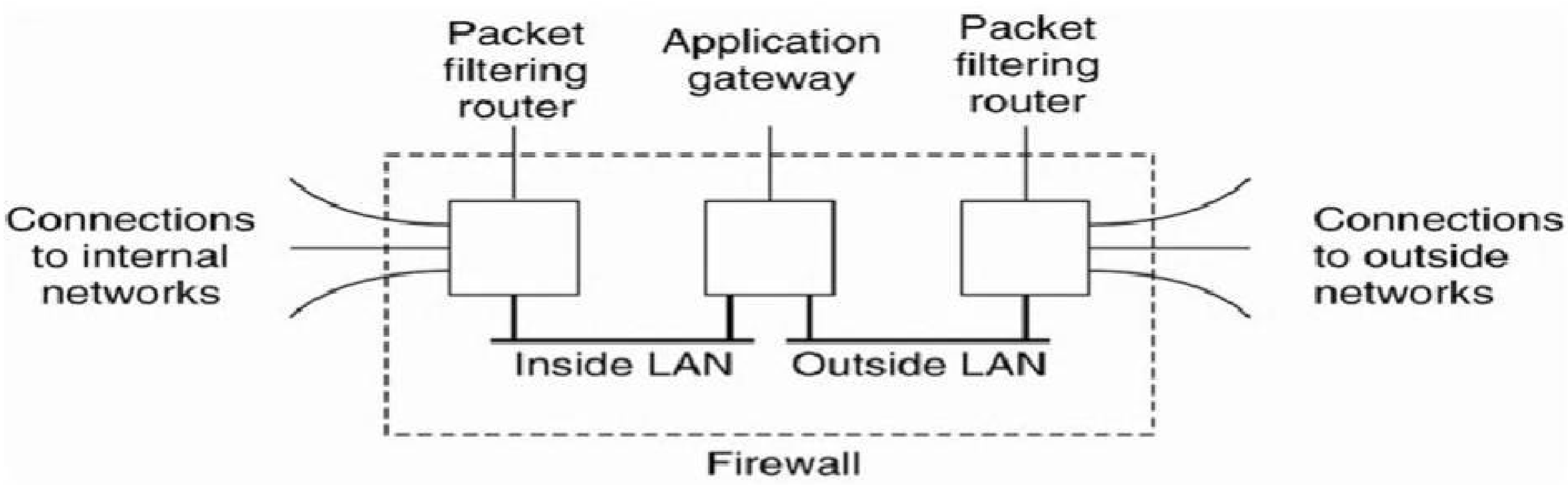

Figure 9-28. A common implementation of a firewall.

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Firewalls

- Blocking incoming packets
- A common case of a TCP/IP setting

  Source/destinations address : IP address and a port number.

  TCP port Service

  23 : Telnet

  79 : Finger

  119 : USENET news

- An organization may block incoming packets for all IP addresses combined with selected ports.

Firewalls

- Blocking outgoing packets
- Standard port naming conventions
- FTP service : dynamic assignment of port #s.
- Blocking TCP/UDP connections.
- Usage of an application gateway : examining each message at an application level. Inspecting header fields, message size, message content, etc.

Firewalls

- Usage of an application gateway :
- examining each message at an application level.
- A mail gateway can be set up to examine each message going in or coming out.
- For each message, the gateway decides whether to transmit or discard the message based on

  header fields,

  message size,

  message content.

Firewalls

- Commonly used techniques :
  - packet filtering
  - IP masquerading
  - proxy services
  - encrypted tunneling
  - encrypted authentication