

# Chapter 15: Security





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- The Security Problem
- Program Threats
- System and Network Threats
- Cryptography as a Security Tool
- User Authentication
- Implementing Security Defenses
- Firewalling to Protect Systems and Networks
- Computer-Security Classifications
- An Example: Windows XP





# Objectives

- To discuss security threats and attacks
- To explain the fundamentals of encryption, authentication, and hashing
- To examine the uses of cryptography in computing
- To describe the various countermeasures to security attacks





# The Security Problem

- Security must consider external environment of the system, and protect the system resources
- Intruders (crackers) attempt to breach security
- **Threat** is potential security violation
- **Attack** is attempt to breach security
- Attack can be accidental or malicious
- Easier to protect against accidental than malicious misuse





# Security Violations

## ■ Categories

- **Breach of confidentiality**
- **Breach of integrity**
- **Breach of availability**
- **Theft of service**
- **Denial of service**

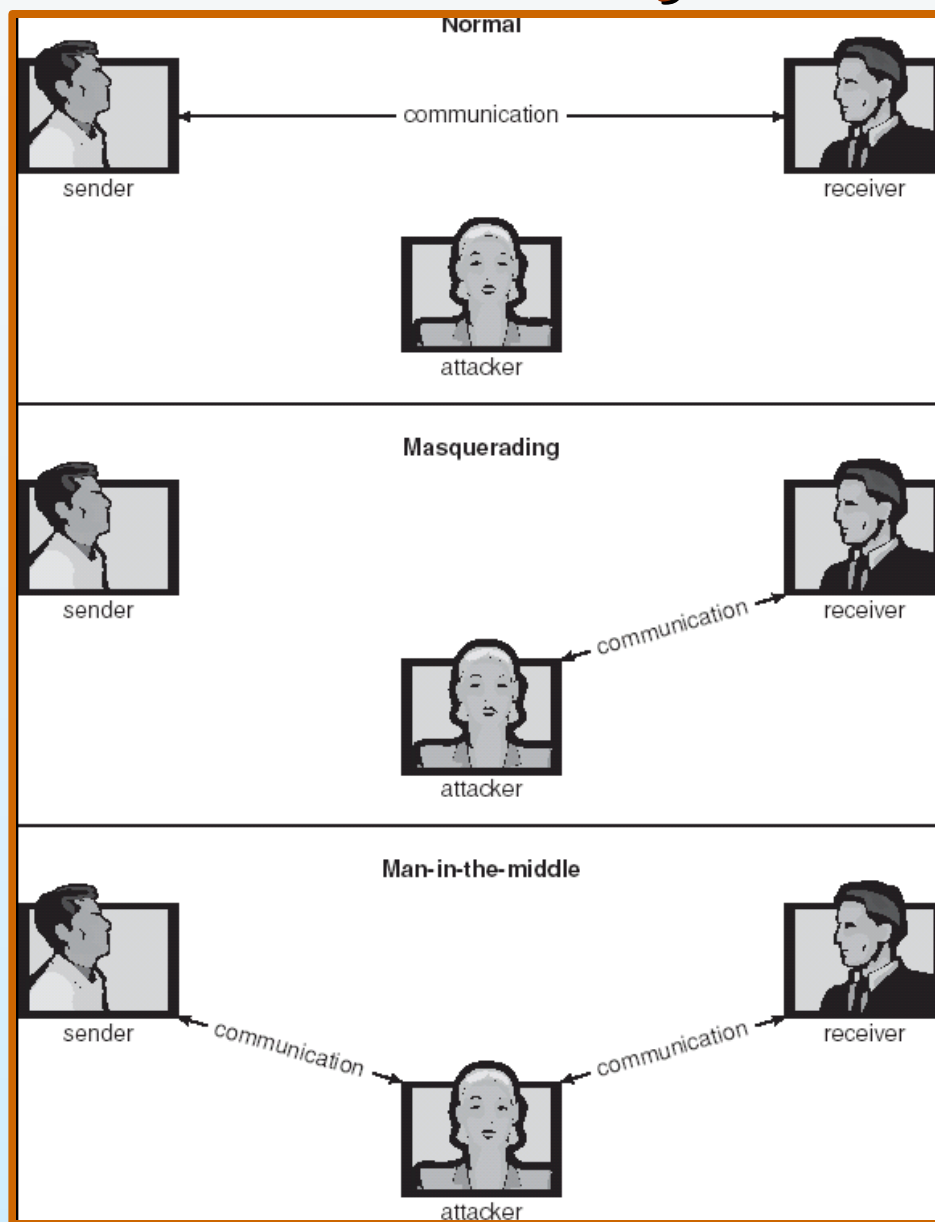
## ■ Methods

- **Masquerading (breach authentication)**
- **Replay attack**
  - ▶ **Message modification**
- **Man-in-the-middle attack**
- **Session hijacking**





# Standard Security Attacks





# Security Measure Levels

- Security must occur at four levels to be effective:
  - Physical
  - Human
    - ▶ Avoid **social engineering, phishing, dumpster diving**
  - Operating System
  - Network
- Security is as weak as the weakest chain





# Program Threats

- Trojan Horse
  - Code segment that misuses its environment
  - Exploits mechanisms for allowing programs written by users to be executed by other users
  - **Spyware, pop-up browser windows, covert channels**
- Trap Door
  - Specific user identifier or password that circumvents normal security procedures
  - Could be included in a compiler
- Logic Bomb
  - Program that initiates a security incident under certain circumstances
- Stack and Buffer Overflow
  - Exploits a bug in a program (overflow either the stack or memory buffers)







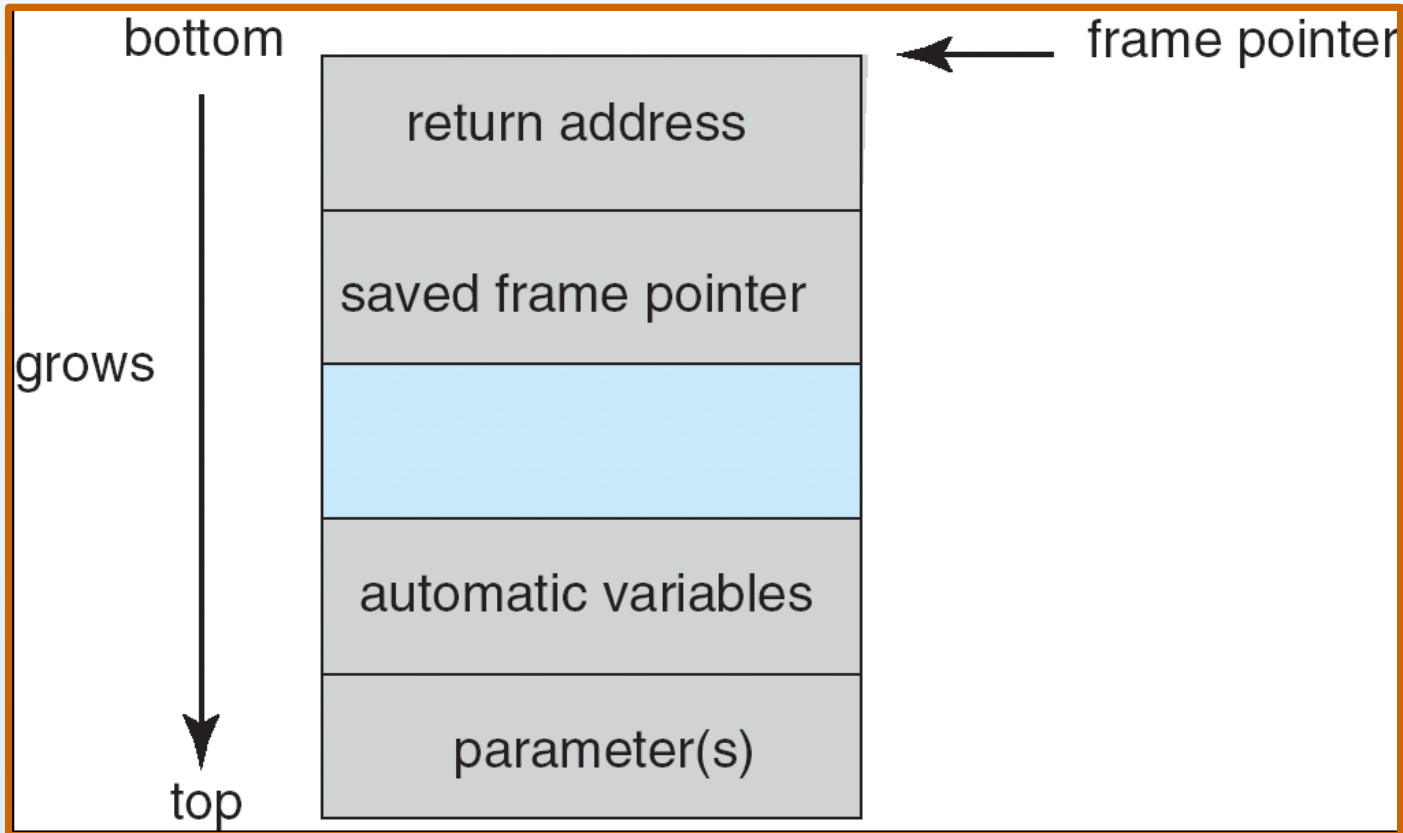
# C Program with Buffer-overflow Condition

```
#include <stdio.h>
#define BUFFER SIZE 256
int main(int argc, char *argv[])
{
    char buffer[BUFFER SIZE];
    if (argc < 2)
        return -1;
    else {
        strcpy(buffer, argv[1]);
        return 0;
    }
}
```





# Layout of Typical Stack Frame





# Modified Shell Code

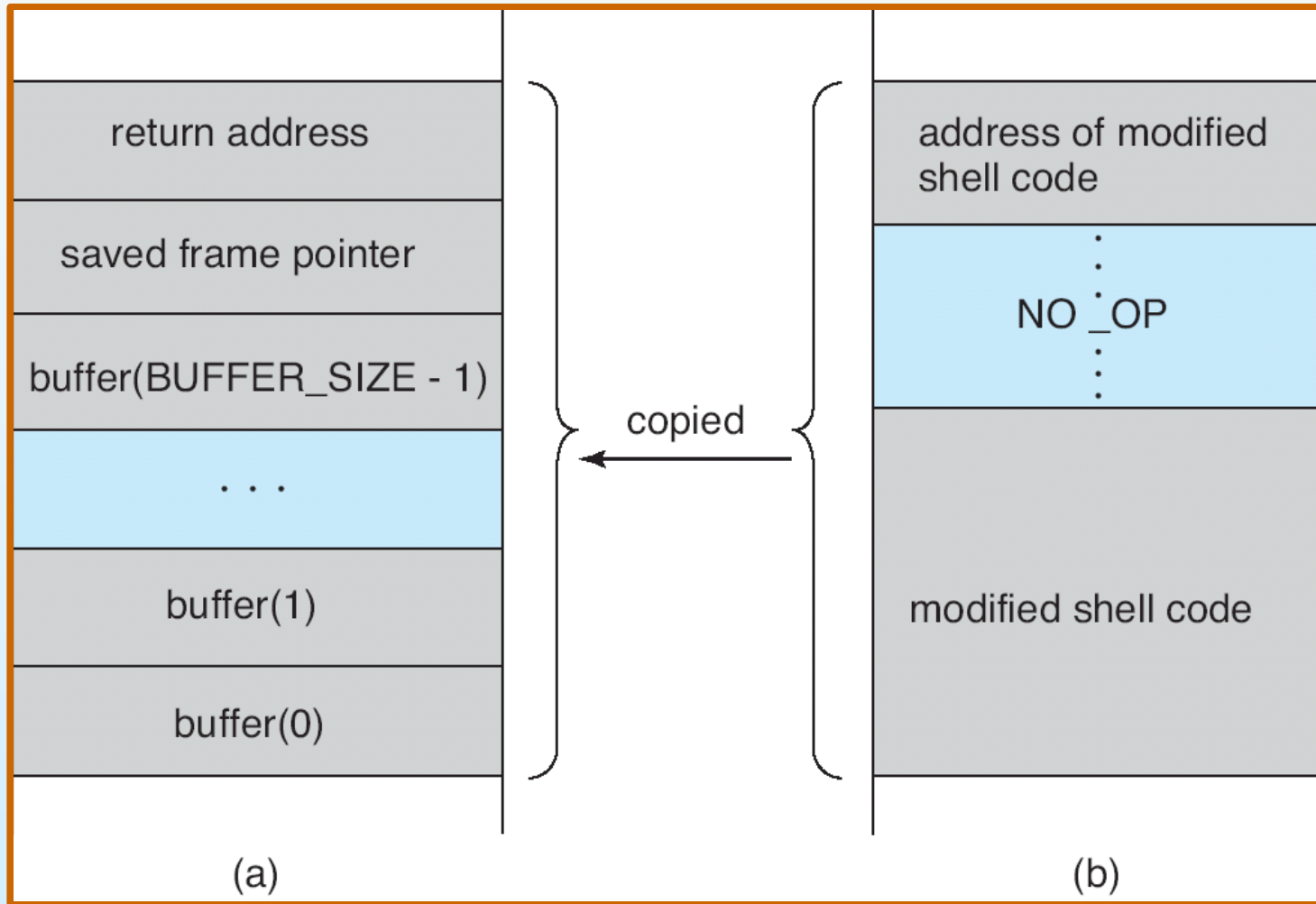
```
#include <stdio.h>

int main(int argc, char *argv[])
{
    execvp(“\bin\sh”, “\bin \sh”, NULL);
    return 0;
}
```





# Hypothetical Stack Frame



Before attack

After attack





# Program Threats (Cont.)

## ■ Viruses

- Code fragment embedded in legitimate program
- Very specific to CPU architecture, operating system, applications
- Usually borne via email or as a macro
  - ▶ Visual Basic Macro to reformat hard drive

```
Sub AutoOpen()  
Dim oFS  
Set oFS =  
CreateObject(''Scripting.FileSystemObject'')  
vs = Shell(''c:command.com /k format  
c:''',vbHide)  
End Sub
```





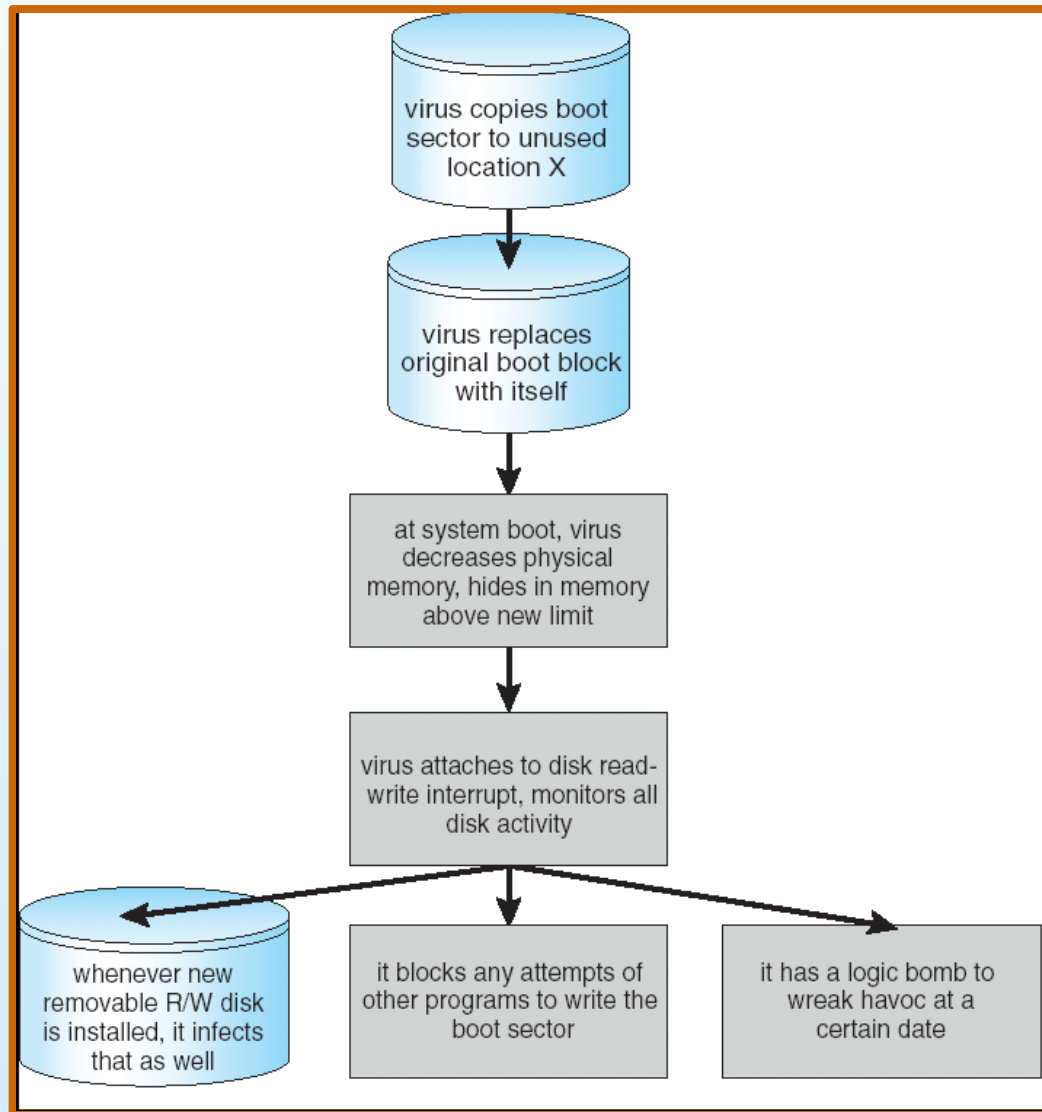
# Program Threats (Cont.)

- **Virus dropper** inserts virus onto the system
- Many categories of viruses, literally many thousands of viruses
  - File
  - Boot
  - Macro
  - Source code
  - Polymorphic
  - Encrypted
  - Stealth
  - Tunneling
  - Multipartite
  - Armored





# A Boot-sector Computer Virus





# System and Network Threats

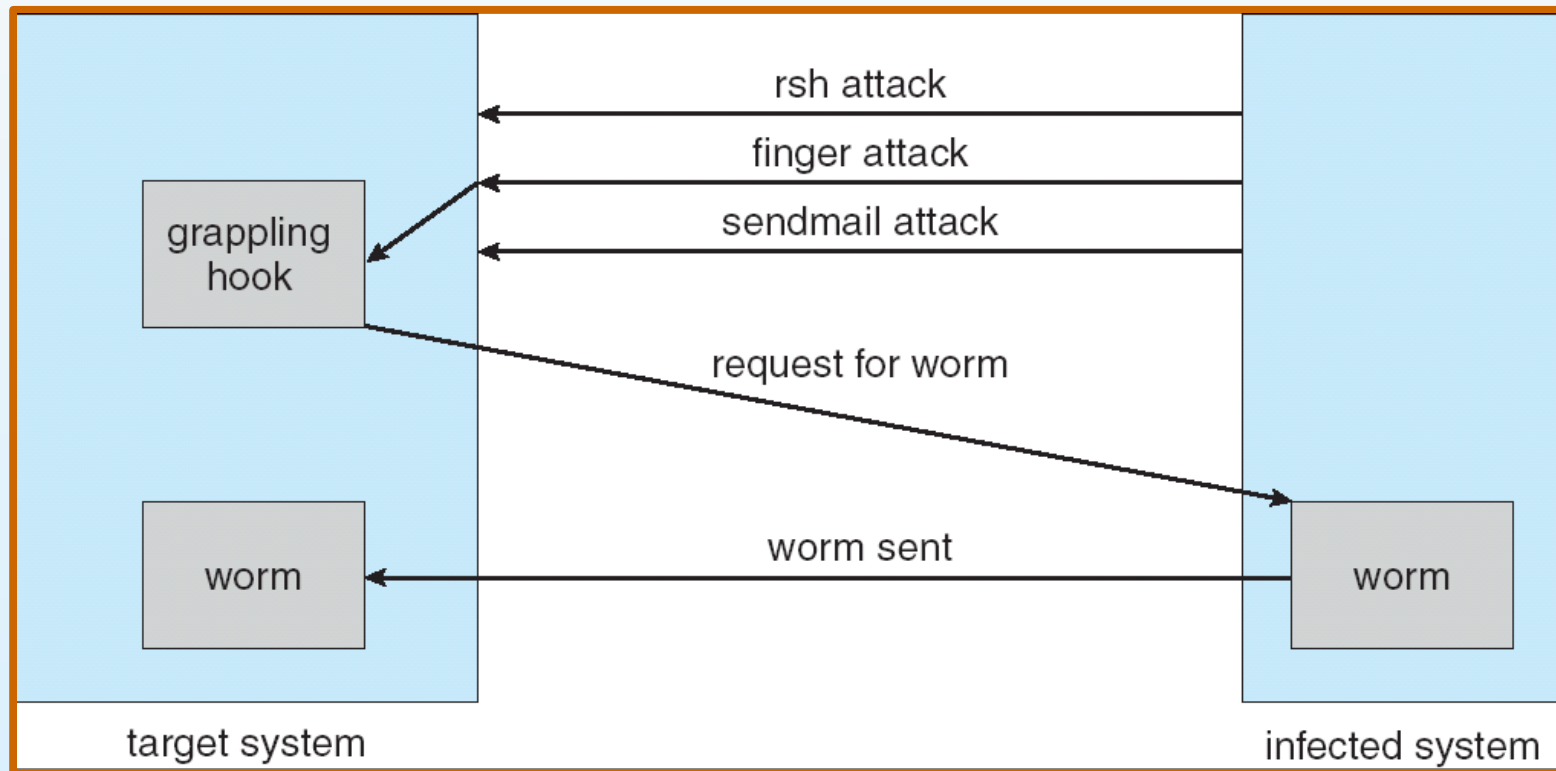
- Worms – use **spawn** mechanism; standalone program
- Internet worm
  - Exploited UNIX networking features (remote access) and bugs in *finger* and *sendmail* programs
  - **Grappling hook** program uploaded main worm program
- Port scanning
  - Automated attempt to connect to a range of ports on one or a range of IP addresses
- Denial of Service
  - Overload the targeted computer preventing it from doing any useful work
  - Distributed denial-of-service (**DDOS**) come from multiple sites at once







# The Morris Internet Worm





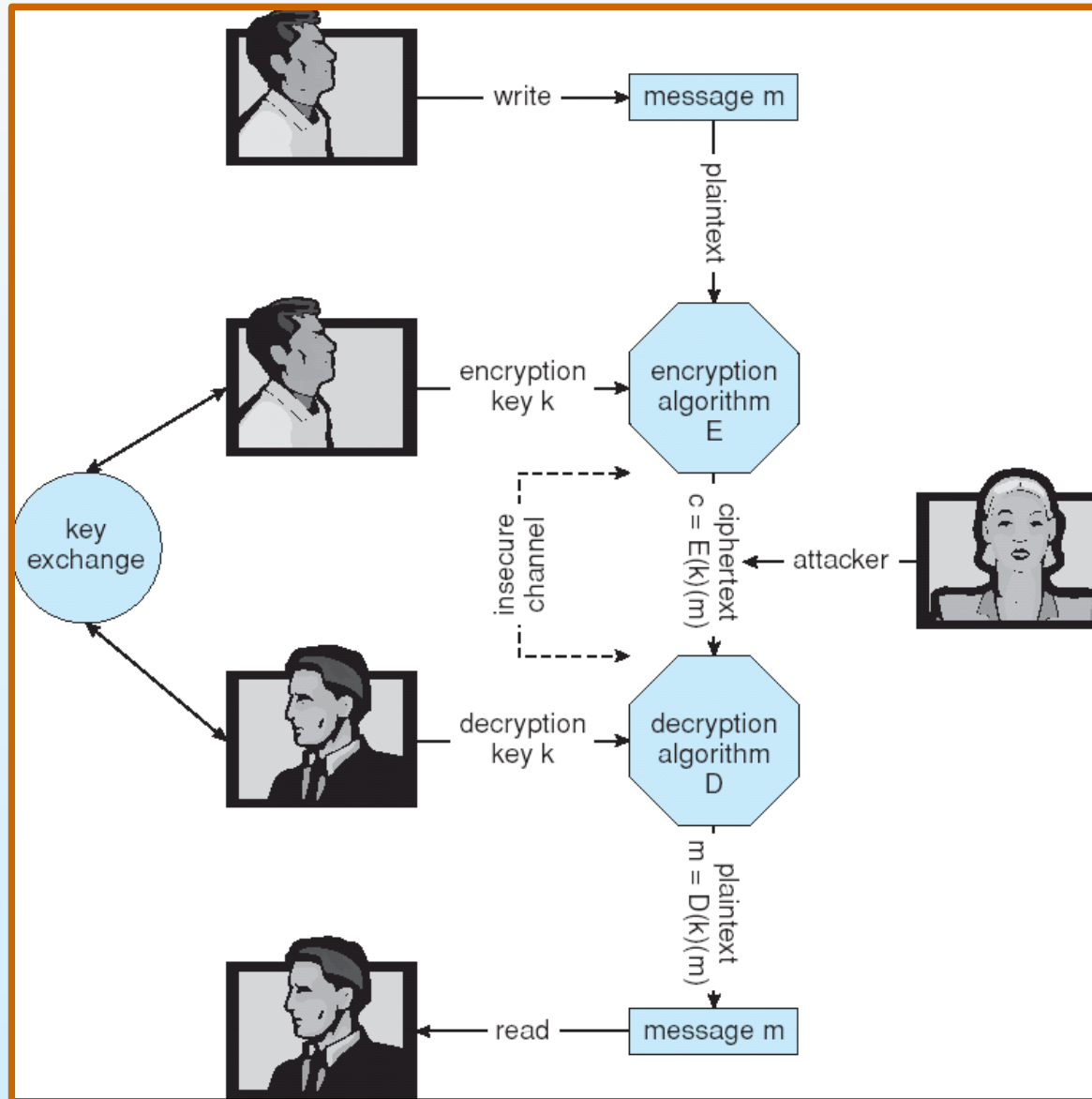
# Cryptography as a Security Tool

- Broadest security tool available
  - Source and destination of messages cannot be trusted without cryptography
  - Means to constrain potential senders (*sources*) and / or receivers (*destinations*) of *messages*
- Based on secrets (**keys**)





# Secure Communication over Insecure Medium





# Encryption

- Encryption algorithm consists of
  - Set of  $K$  keys
  - Set of  $M$  Messages
  - Set of  $C$  ciphertexts (encrypted messages)
  - A function  $E: K \rightarrow M \rightarrow C$ . That is, for each  $k \in K$ ,  $E(k)$  is a function for generating ciphertexts from messages.
    - ▶ Both  $E$  and  $E(k)$  for any  $k$  should be efficiently computable functions.
  - A function  $D: K \rightarrow C \rightarrow M$ . That is, for each  $k \in K$ ,  $D(k)$  is a function for generating messages from ciphertexts.
    - ▶ Both  $D$  and  $D(k)$  for any  $k$  should be efficiently computable functions.
- An encryption algorithm must provide this essential property: Given a ciphertext  $c \in C$ , a computer can compute  $m$  such that  $E(k)(m) = c$  only if it possesses  $D(k)$ .
  - Thus, a computer holding  $D(k)$  can decrypt ciphertexts to the plaintexts used to produce them, but a computer not holding  $D(k)$  cannot decrypt ciphertexts.
  - Since ciphertexts are generally exposed (for example, sent on the network), it is important that it be infeasible to derive  $D(k)$  from the ciphertexts





# Symmetric Encryption

- Same key used to encrypt and decrypt
  - $E(k)$  can be derived from  $D(k)$ , and vice versa
- DES is most commonly used symmetric block-encryption algorithm (created by US Govt)
  - Encrypts a block of data at a time
- Triple-DES considered more secure
- Advanced Encryption Standard (**AES**), **twofish** up and coming
- RC4 is most common symmetric stream cipher, but known to have vulnerabilities
  - Encrypts/decrypts a stream of bytes (i.e wireless transmission)
  - Key is a input to psuedo-random-bit generator
    - ▶ Generates an infinite **keystream**





# Asymmetric Encryption

- Public-key encryption based on each user having two keys:
  - public key – published key used to encrypt data
  - private key – key known only to individual user used to decrypt data
- Must be an encryption scheme that can be made public without making it easy to figure out the decryption scheme
  - Most common is RSA block cipher
  - Efficient algorithm for testing whether or not a number is prime
  - No efficient algorithm is known for finding the prime factors of a number





# Asymmetric Encryption (Cont.)

- Formally, it is computationally infeasible to derive  $D(k_d, M)$  from  $E(k_e, M)$ , and so  $E(k_e, M)$  need not be kept secret and can be widely disseminated
  - $E(k_e, M)$  (or just  $k_e$ ) is the **public key**
  - $D(k_d, M)$  (or just  $k_d$ ) is the **private key**
  - $N$  is the product of two large, randomly chosen prime numbers  $p$  and  $q$  (for example,  $p$  and  $q$  are 512 bits each)
  - Encryption algorithm is  $E(k_e, N)(m) = m^{k_e} \bmod N$ , where  $k_e$  satisfies  $k_e k_d \bmod (p-1)(q-1) = 1$
  - The decryption algorithm is then  $D(k_d, N)(c) = c^{k_d} \bmod N$





# Asymmetric Encryption Example

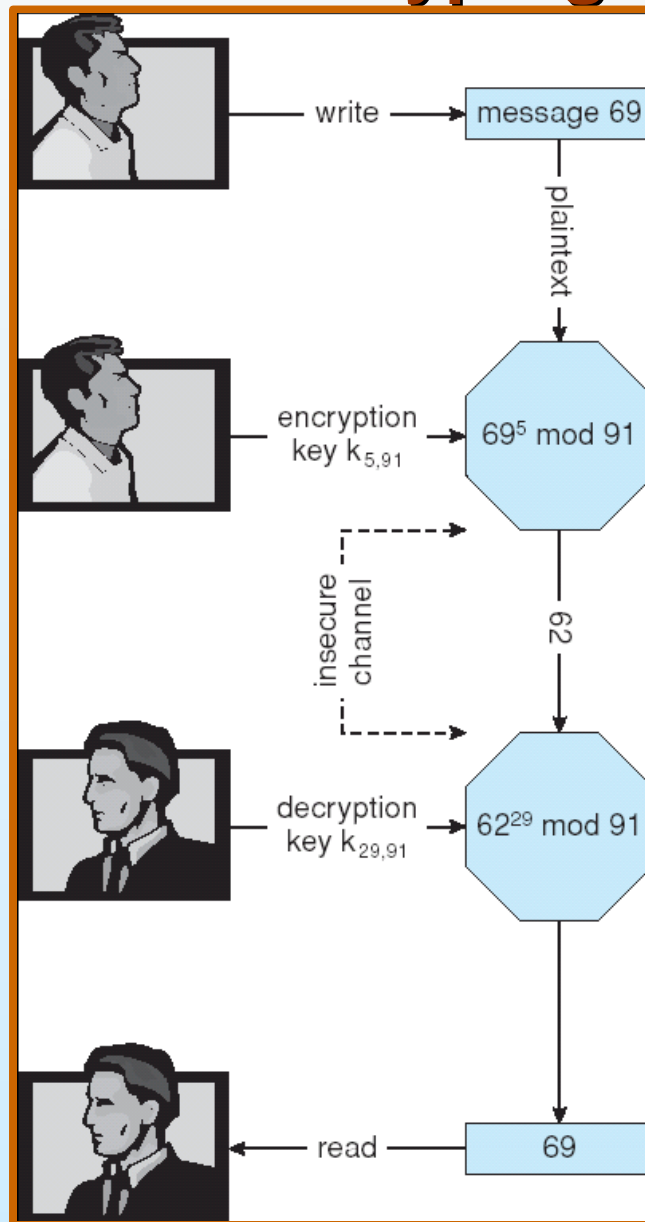
- For example. make  $p = 7$  and  $q = 13$
- We then calculate  $N = 7 * 13 = 91$  and  $(p-1)(q-1) = 72$
- We next select  $k_e$  relatively prime to 72 and  $< 72$ , yielding 5
- Finally, we calculate  $k_d$  such that  $k_e k_d \bmod 72 = 1$ , yielding 29
- We now have our keys
  - Public key,  $k_e, N = 5, 91$
  - Private key,  $k_d, N = 29, 91$
- Encrypting the message 69 with the public key results in the ciphertext 62
- Ciphertext can be decoded with the private key
  - Public key can be distributed in cleartext to anyone who wants to communicate with holder of public key





# Encryption and Decryption using RSA

## Asymmetric Cryptography





# Cryptography (Cont.)

- Note symmetric cryptography based on transformations, asymmetric based on mathematical functions
  - Asymmetric much more compute intensive
  - Typically not used for bulk data encryption





# Authentication

- Constraining set of potential senders of a message
  - Complementary and sometimes redundant to encryption
  - Also can prove message unmodified
- Algorithm components
  - A set  $K$  of keys
  - A set  $M$  of messages
  - A set  $A$  of authenticators
  - A function  $S : K \times M \rightarrow A$ 
    - ▶ That is, for each  $k \in K$ ,  $S(k)$  is a function for generating authenticators from messages
    - ▶ Both  $S$  and  $S(k)$  for any  $k$  should be efficiently computable functions
  - A function  $V : K \times M \times A \rightarrow \{\text{true}, \text{false}\}$ . That is, for each  $k \in K$ ,  $V(k)$  is a function for verifying authenticators on messages
    - ▶ Both  $V$  and  $V(k)$  for any  $k$  should be efficiently computable functions





# Authentication (Cont.)

- For a message  $m$ , a computer can generate an authenticator  $a \in A$  such that  $V(k)(m, a) = \text{true}$  only if it possesses  $S(k)$
- Thus, computer holding  $S(k)$  can generate authenticators on messages so that any other computer possessing  $V(k)$  can verify them
- Computer not holding  $S(k)$  cannot generate authenticators on messages that can be verified using  $V(k)$
- Since authenticators are generally exposed (for example, they are sent on the network with the messages themselves), it must not be feasible to derive  $S(k)$  from the authenticators





# Authentication – Hash Functions

- Basis of authentication
- Creates small, fixed-size block of data (**message digest, hash value**) from  $m$
- Hash Function  $H$  must be collision resistant on  $m$ 
  - Must be infeasible to find an  $m' \neq m$  such that  $H(m) = H(m')$
- If  $H(m) = H(m')$ , then  $m = m'$ 
  - The message has not been modified
- Common message-digest functions include **MD5**, which produces a 128-bit hash, and **SHA-1**, which outputs a 160-bit hash





# Authentication - MAC

- Symmetric encryption used in **message-authentication code (MAC)** authentication algorithm
- Simple example:
  - MAC defines  $S(k)(m) = f(k, H(m))$ 
    - ▶ Where  $f$  is a function that is one-way on its first argument
      - $k$  cannot be derived from  $f(k, H(m))$
    - ▶ Because of the collision resistance in the hash function, reasonably assured no other message could create the same MAC
    - ▶ A suitable verification algorithm is  $V(k)(m, a) \equiv (f(k, m) = a)$
    - ▶ Note that  $k$  is needed to compute both  $S(k)$  and  $V(k)$ , so anyone able to compute one can compute the other





# Authentication – Digital Signature

- Based on asymmetric keys and digital signature algorithm
- Authenticators produced are **digital signatures**
- In a digital-signature algorithm, computationally infeasible to derive  $S(k_s)$  from  $V(k_v)$ 
  - $V$  is a one-way function
  - Thus,  $k_v$  is the public key and  $k_s$  is the private key
- Consider the RSA digital-signature algorithm
  - Similar to the RSA encryption algorithm, but the key use is reversed
  - Digital signature of message  $S(k_s)(m) = H(m)^{k_s} \bmod N$
  - The key  $k_s$  again is a pair  $d, N$ , where  $N$  is the product of two large, randomly chosen prime numbers  $p$  and  $q$
  - Verification algorithm is  $V(k_v)(m, a) \equiv (a^{k_v} \bmod N = H(m))$ 
    - ▶ Where  $k_v$  satisfies  $k_v k_s \bmod (p-1)(q-1) = 1$





# Authentication (Cont.)

- Why authentication is a subset of encryption?
  - Fewer computations (except for RSA digital signatures)
  - Authenticator usually shorter than message
  - Sometimes want authentication but not confidentiality
    - ▶ Signed patches et al
  - Can be basis for **non-repudiation**







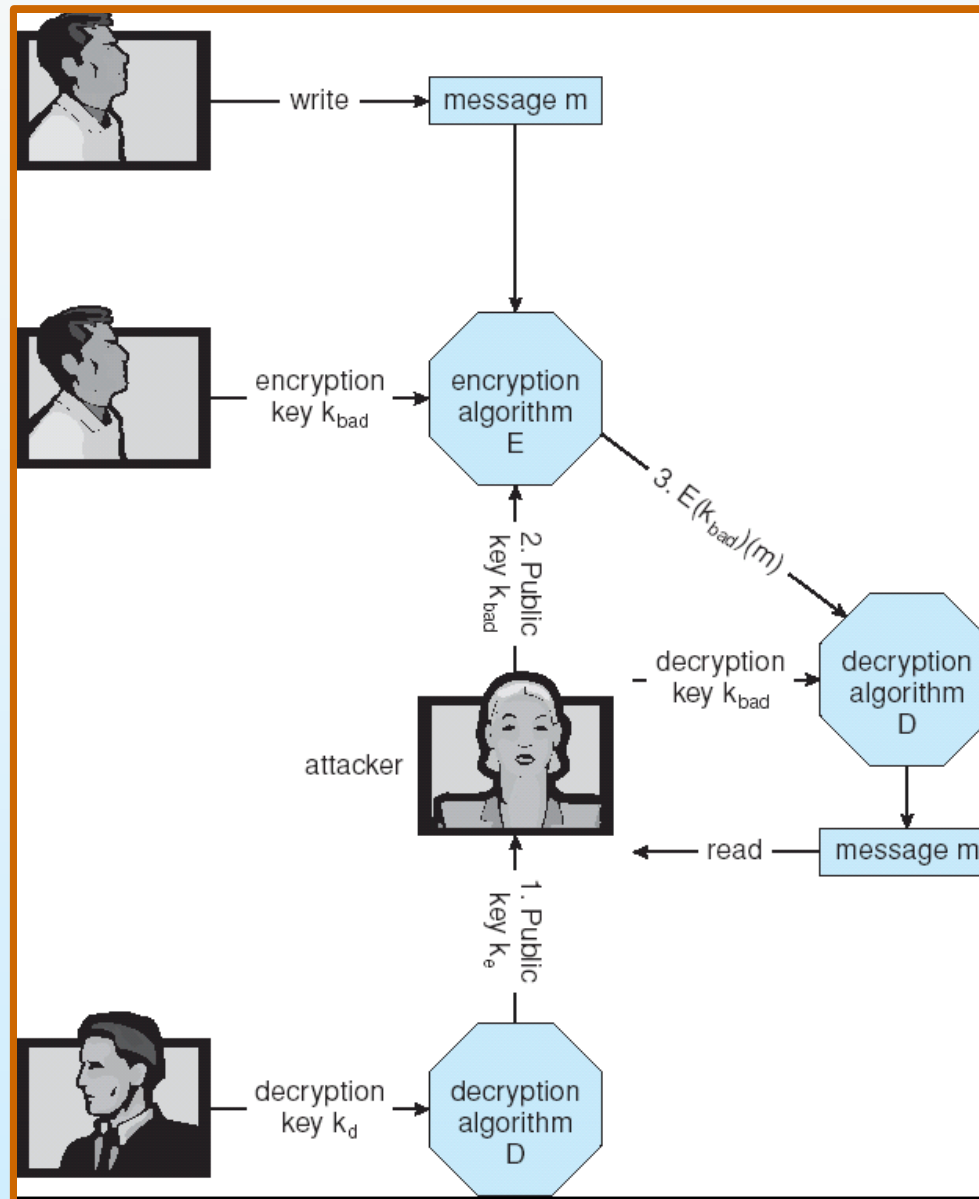
# Key Distribution

- Delivery of symmetric key is huge challenge
  - Sometimes done **out-of-band**
- Asymmetric keys can proliferate – stored on **key ring**
  - Even asymmetric key distribution needs care – man-in-the-middle attack





# Man-in-the-middle Attack on Asymmetric Cryptography





# Digital Certificates

- Proof of who or what owns a public key
- Public key digitally signed a trusted party
- Trusted party receives proof of identification from entity and certifies that public key belongs to entity
- Certificate authority are trusted party – their public keys included with web browser distributions
  - They vouch for other authorities via digitally signing their keys, and so on





# Encryption Example - SSL

- Insertion of cryptography at one layer of the ISO network model (the transport layer)
- SSL – Secure Socket Layer (also called TLS)
- Cryptographic protocol that limits two computers to only exchange messages with each other
  - Very complicated, with many variations
- Used between web servers and browsers for secure communication (credit card numbers)
- The server is verified with a **certificate** assuring client is talking to correct server
- Asymmetric cryptography used to establish a secure **session key** (symmetric encryption) for bulk of communication during session
- Communication between each computer then uses symmetric key cryptography





# User Authentication

- Crucial to identify user correctly, as protection systems depend on user ID
- User identity most often established through *passwords*, can be considered a special case of either keys or capabilities
  - Also can include something user has and /or a user attribute
- Passwords must be kept secret
  - Frequent change of passwords
  - Use of “non-guessable” passwords
  - Log all invalid access attempts
- Passwords may also either be encrypted or allowed to be used only once





# Implementing Security Defenses

- **Defense in depth** is most common security theory – multiple layers of security
- Security policy describes what is being secured
- Vulnerability assessment compares real state of system / network compared to security policy
- Intrusion detection endeavors to detect attempted or successful intrusions
  - **Signature-based** detection spots known bad patterns
  - **Anomaly detection** spots differences from normal behavior
    - ▶ Can detect **zero-day** attacks
  - **False-positives** and **false-negatives** a problem
- Virus protection
- Auditing, accounting, and logging of all or specific system or network activities





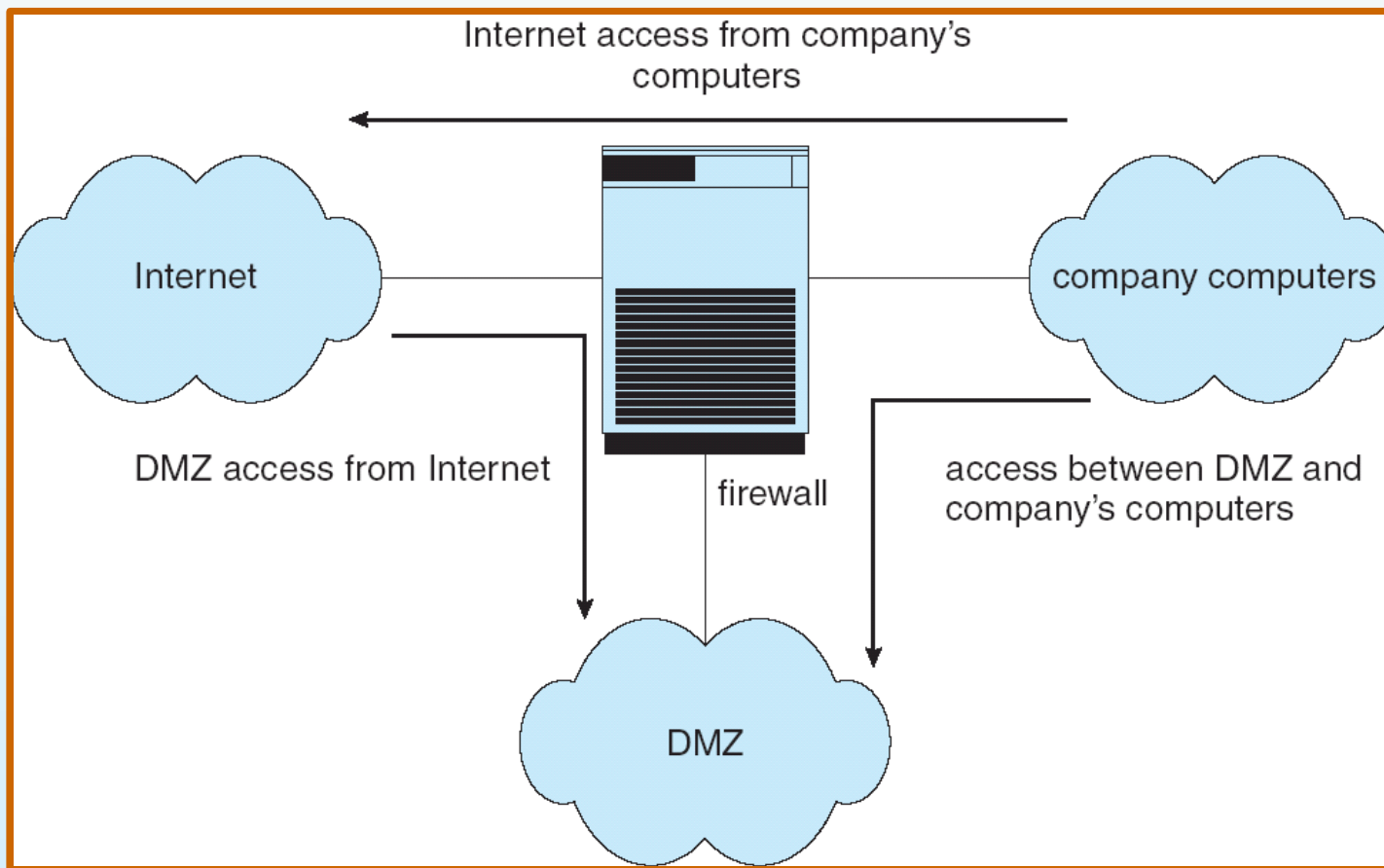
# Firewalling to Protect Systems and Networks

- A network firewall is placed between trusted and untrusted hosts
  - The firewall limits network access between these two security domains
- Can be tunneled or spoofed
  - Tunneling allows disallowed protocol to travel within allowed protocol (i.e. telnet inside of HTTP)
  - Firewall rules typically based on host name or IP address which can be spoofed
- **Personal firewall** is software layer on given host
  - Can monitor / limit traffic to and from the host
- **Application proxy firewall** understands application protocol and can control them (i.e. SMTP)
- **System-call firewall** monitors all important system calls and apply rules to them (i.e. this program can execute that system call)





# Network Security Through Domain Separation Via Firewall







# Computer Security Classifications

- U.S. Department of Defense outlines four divisions of computer security: **A**, **B**, **C**, and **D**.
- **D** – Minimal security.
- **C** – Provides discretionary protection through auditing. Divided into **C1** and **C2**. **C1** identifies cooperating users with the same level of protection. **C2** allows user-level access control.
- **B** – All the properties of **C**, however each object may have unique sensitivity labels. Divided into **B1**, **B2**, and **B3**.
- **A** – Uses formal design and verification techniques to ensure security.





# Example: Windows XP

- Security is based on user accounts
  - Each user has unique security ID
  - Login to ID creates **security access token**
    - ▶ Includes security ID for user, for user's groups, and special privileges
    - ▶ Every process gets copy of token
    - ▶ System checks token to determine if access allowed or denied
- Uses a subject model to ensure access security. A subject tracks and manages permissions for each program that a user runs
- Each object in Windows XP has a security attribute defined by a security descriptor
  - For example, a file has a security descriptor that indicates the access permissions for all users



# End of Chapter 15

