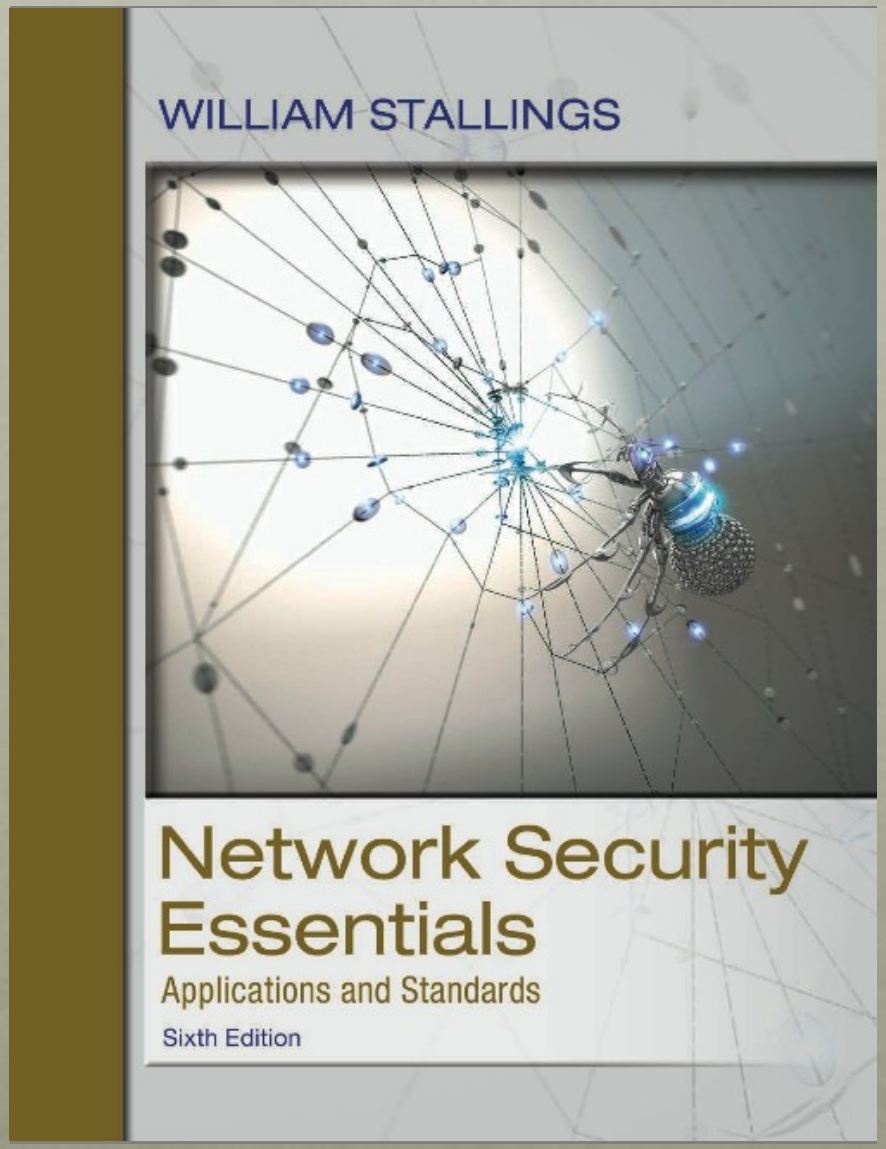
Network Security Essentials

Sixth Edition

by William Stallings



Chapter 1

Introduction

Computer Security Concepts

- Before the widespread use of data processing equipment, the security of information valuable to an organization was provided primarily by physical and administrative means
- With the introduction of the computer, the need for automated tools for protecting files and other information stored on the computer became evident
- Another major change that affected security is the introduction of distributed systems and the use of networks and communications facilities for carrying data between terminal user and computer and between computer and computer
- Computer security
  - The generic name for the collection of tools designed to protect data and to thwart hackers
- internet security (lower case “i” refers to any interconnected collection of network)
  - Consists of measures to deter, prevent, detect, and correct security violations that involve the transmission of information

Computer Security

The NIST *Computer Security Handbook* defines the term computer security as:

"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)"

Computer Security Objectives

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.

CIA Triad

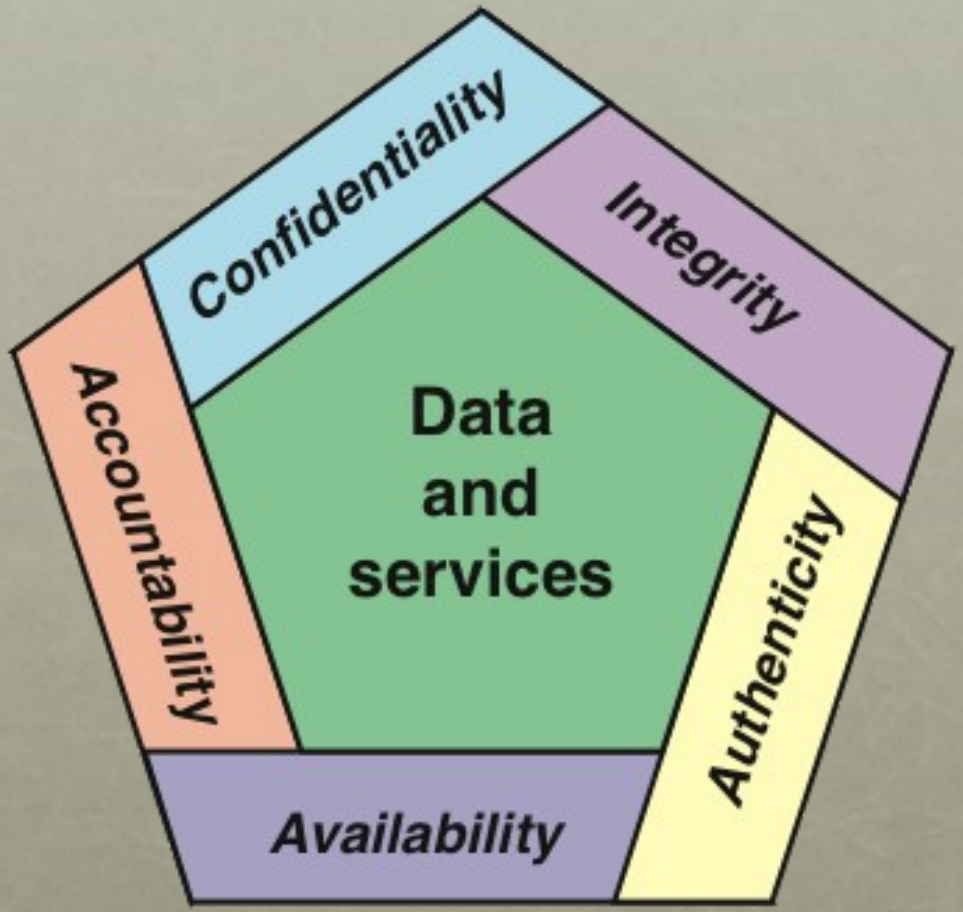


Figure 1.1 Essential Network and Computer Security Requirements

Possible additional concepts:

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 nonrepudiation, deterrence, fault isolation, intrusion detection and prevention, and after action recovery and legal action. Because truly secure systems are not yet an achievable goal, we must be able to trace a security breach to a responsible party. Systems must keep records of their activities to permit later forensic analysis to trace security breaches or to aid in transaction disputes.

Breach of Security Levels of Impact

We use three levels of impact on organizations or individuals should there be a breach of security (i.e., a loss of confidentiality, integrity, or availability). These levels are defined in FIPS PUB 199:

- Low: The loss could be expected to have a limited adverse effect on organizational operations, organizational assets, or individuals. A limited adverse effect means that, for example, the loss of confidentiality, integrity, or availability might (i) cause a degradation in mission capability to an extent and duration that the organization is able to perform its primary functions, but the effectiveness of the functions is noticeably reduced; (ii) result in minor damage to organizational assets; (iii) result in minor financial loss; or (iv) result in minor harm to individuals.

- Moderate: The loss could be expected to have a serious adverse effect on organizational operations, organizational assets, or individuals. A serious adverse effect means that, for example, the loss might (i) cause a significant degradation in mission capability to an extent and duration that the organization is able to perform its primary functions, but the effectiveness of the functions is significantly reduced; (ii) result in significant damage to organizational assets; (iii) result in significant financial loss; or (iv) result in significant harm to individuals that does not involve loss of life or serious, life-threatening injuries.

- High: The loss could be expected to have a severe or catastrophic adverse effect on organizational operations, organizational assets, or individuals. A severe or catastrophic adverse effect means that, for example, the loss might (i) cause a severe degradation in or loss of mission capability to an extent and duration that the organization is not able to perform one or more of its primary functions; (ii) result in major damage to organizational assets; (iii) result in major financial loss; or (iv) result in severe or catastrophic harm to individuals involving loss of life or serious, life-threatening injuries.

Examples of Security Requirements

Confidentiality

Student grade information is an asset whose confidentiality is considered to be highly important by students. In the United States, the release of such information is regulated by the Family Educational Rights and Privacy Act (FERPA). Grade information should only be available to students, their parents, and employees that require the information to do their job. Student enrollment information may have a moderate confidentiality rating. While still covered by FERPA, this information is seen by more people on a daily basis, is less likely to be targeted than grade information, and results in less damage if disclosed. Directory information (such as lists of students, faculty, or departmental lists) may be assigned a low confidentiality rating or indeed no rating. This information is typically freely available to the public and published on a school's Web site.

Integrity

Several aspects of integrity are illustrated by the example of a hospital patient's allergy information stored in a database. The doctor should be able to trust that the information is correct and current. Now suppose that an employee (e.g., a nurse) who is authorized to view and update this information deliberately falsifies the data to cause harm to the hospital. The database needs to be restored to a trusted basis quickly, and it should be possible to trace the error back to the person responsible. Patient allergy information is an example of an asset with a high requirement for integrity. Inaccurate information could result in serious harm or death to a patient and expose the hospital to massive liability.

An example of an asset that may be assigned a moderate level of integrity requirement is a Web site that offers a forum to registered users to discuss some specific topic. Either a registered user or a hacker could falsify some entries or deface the Web site. If the forum exists only for the enjoyment of the users, brings in little or no advertising revenue, and is not used for something important such as research, then potential damage is not severe. The Web master may experience some data, financial, and time loss.

An example of a low-integrity requirement is an anonymous online poll. Many Web sites, such as news organizations, offer these polls to their users with very few safeguards. However, the inaccuracy and unscientific nature of such polls are wellunderstood.

Availability

The more critical a component or service, the higher is the level of availability required. Consider a system that provides authentication services for critical systems, applications, and devices. An interruption of service results in the inability for customers to access computing resources and for the staff to access the resources they need to perform critical tasks. The loss of the service translates into a large financial loss due to lost employee productivity and potential customer loss.

An example of an asset that typically would be rated as having a moderate availability requirement is a public Web site for a university; the Web site provides information for current and prospective students and donors. Such a site is not a critical component of the university's information system, but its unavailability will cause some embarrassment.

An online telephone directory lookup application would be classified as a low availability requirement. Although the temporary loss of the application may be an annoyance, there are other ways to access the information, such as a hardcopy directory or the operator.

Computer Security Challenges

- Security is not simple
- Potential attacks on the security features need to be considered
- Procedures used to provide particular services are often counter-intuitive
- It is necessary to decide where to use the various security mechanisms
- Requires constant monitoring
- Is too often an afterthought
- Security mechanisms typically involve more than a particular algorithm or protocol
- Security is essentially a battle of wits between a perpetrator and the designer
- Little benefit from security investment is perceived until a security failure occurs
- Strong security is often viewed as an impediment to efficient and user-friendly operation

OSI Security Architecture

- 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
  - Intended to counter security attacks, and they make use of one or more security mechanisms to provide the service

Table 1.1
Threats and Attacks (RFC 4949)

Threat

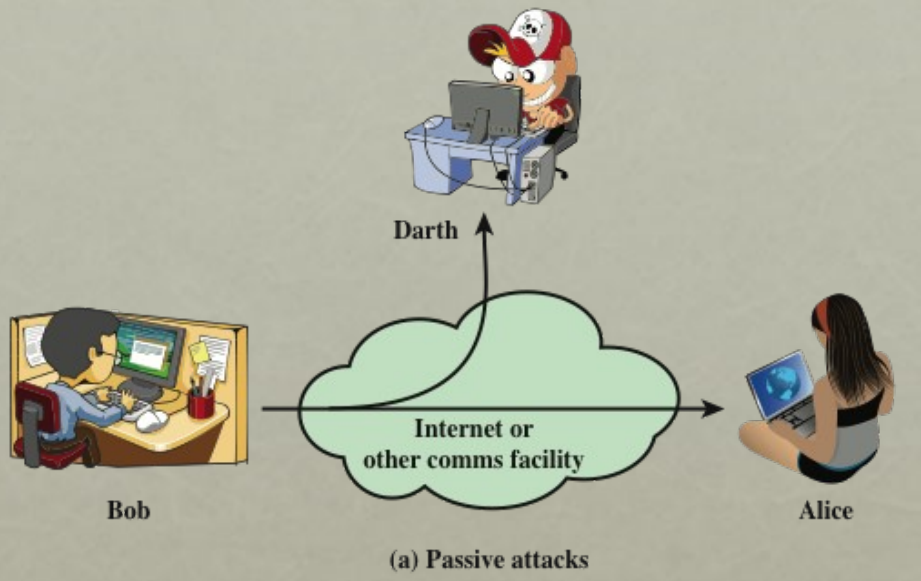
A potential for violation of security, which exists when there is a circumstance, capability, action, or event that could breach security and cause harm. That is, a threat is a possible danger that might exploit a vulnerability.

Attack

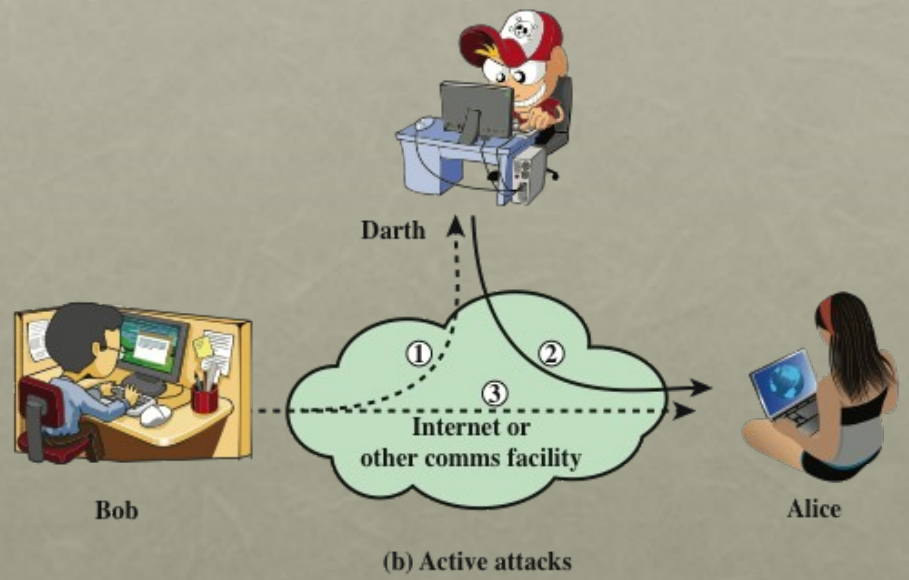
An assault on system security that derives from an intelligent threat; that is, an intelligent act that is a deliberate attempt (especially in the sense of a method or technique) to evade security services and violate the security policy of a system.

Security Attacks

- A means of classifying security attacks, used both in X.800 and RFC 4949, is in terms of *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



(a) Passive attacks



(b) Active attacks

Figure 1.2 Security Attacks

Passive Attacks

- Are in the nature of eavesdropping on, or monitoring of, transmissions
- Goal of the opponent is to obtain information that is being transmitted

- Two types of passive attacks are:
  - The release of message contents
  - Traffic analysis

Active Attacks

- Involve some modification of the data stream or the creation of a false stream
- Difficult to prevent because of the wide variety of potential physical, software, and network vulnerabilities
- Goal is to detect attacks and to recover from any disruption or delays caused by them

Security Services

- Defined by X.800 as:
  - A service provided by a protocol layer of communicating open systems and that ensures adequate security of the systems or of data transfers
- Defined by RFC 4949 as:
  - A processing or communication service provided by a system to give a specific kind of protection to system resources

X.800 Service Categories

- Authentication
- Access control
- Data confidentiality
- Data integrity
- Nonrepudiation

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.

Table 1.2

Security Services (X.800)

(This table is found on page 12 in the textbook)

Authentication

- Concerned with assuring that a communication is authentic
  - In the case of a single message, assures the recipient that the message is from the source that it claims to be from
  - In the case of ongoing interaction, assures the two entities are authentic and that the connection is not interfered with in such a way that a third party can masquerade as one of the two legitimate parties

Access Control

- The ability to limit and control the access to host systems and applications via communications links
- To achieve this, each entity trying to gain access must first be indentified, or authenticated, so that access rights can be tailored to the individual

Data Confidentiality

- The protection of transmitted data from passive attacks
  - Broadest service protects all user data transmitted between two users over a period of time
  - Narrower forms of service include the protection of a single message or even specific fields within a message
- The protection of traffic flow from analysis
  - This requires that an attacker not be able to observe the source and destination, frequency, length, or other characteristics of the traffic on a communications facility

Data Integrity

As with confidentiality, integrity can apply to a stream of messages, a single message, or selected fields within a message. Again, the most useful and straightforward approach is total stream protection.

A connection-oriented integrity service, one that deals with a stream of messages, assures that messages are received as sent with no duplication, insertion, modification, reordering, or replays. The destruction of data is also covered under this service. Thus, the connection-oriented integrity service addresses both message stream modification and denial of service. On the other hand, a connectionless integrity service, one that deals with individual messages without regard to any larger context, generally provides protection against message modification only.

We can make a distinction between service with and without recovery. Because the integrity service relates to active attacks, we are concerned with detection rather than prevention. If a violation of integrity is detected, then the service may simply report this violation, and some other portion of software or human intervention is required to recover from the violation. Alternatively, there are mechanisms available to recover from the loss of integrity of data, as we will review subsequently. The incorporation of automated recovery mechanisms is, in general, the more attractive alternative.

Nonrepudiation

- Prevents either sender or receiver from denying a transmitted message
- When a message is sent, the receiver can prove that the alleged sender in fact sent the message
- When a message is received, the sender can prove that the alleged receiver in fact received the message

Availability service

- Availability
  - The property of a system or a system resource being accessible and usable upon demand by an authorized system entity, according to performance specifications for the system
- Availability service
  - One that protects a system to ensure its availability
  - Addresses the security concerns raised by denial-of-service attacks
  - Depends on proper management and control of system resources

SPECIFIC SECURITY MECHANISMS

May be incorporated into the appropriate protocol layer in order to provide some of the OSI security services.

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.

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).

Access Control
A variety of mechanisms that enforce access rights to resources.

Data Integrity
A variety of mechanisms used to assure the integrity of a data unit or stream of data units.

Authentication Exchange
A mechanism intended to ensure the identity of an entity by means of information exchange.

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.

PERVASIVE SECURITY MECHANISMS

Mechanisms that are not specific to any particular OSI security service or protocol layer.

Trusted Functionality
That which is perceived to be correct with respect to some criteria (e.g., as established by a security policy).

Security Label
The marking bound to a resource (which may be a data unit) that names or designates the security attributes of that resource.

Event Detection
Detection of security-relevant events.

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.

Security Recovery
Deals with requests from mechanisms, such as event handling and management functions, and takes recovery actions.

Table 1.3

Security Mechanisms (X.800)

(This table is found on page 15 in the textbook)

Table 1.4 Relationship Between Security Services and Mechanisms

SERVICE \ MECHANISM	Encipherment	Digital signature	Access control	Data integrity	Authentication exchange	Traffic padding	Routing control	Notarization
Peer entity authentication	Y	Y			Y			
Data origin authentication	Y	Y						
Access control			Y					
Confidentiality	Y						Y	
Traffic flow confidentiality	Y					Y	Y	
Data integrity	Y	Y		Y				
Nonrepudiation		Y		Y				Y
Availability				Y	Y			

Fundamental security design principles

- The National Centers of Academic Excellence in Information Assurance/Cyber Defense, which is jointly sponsored by the U.S. Department of Homeland Security, list the following as fundamental security design principles:
  - Economy of mechanism
  - Fail-safe defaults
  - Complete mediation
  - Open design separation of privilege
  - Least privilege
  - Least common mechanism
  - Psychological acceptability
  - Isolation
  - Encapsulation
  - Modularity
  - Layering
  - Least astonishment

Fundamental security design principles

- Economy of mechanism
  - The design of security measures embodied in both hardware and software should be as simple and small as possible
- Fail-safe default
  - Access decisions should be based on permission rather than exclusion—the default situation is lack of access, and the protection scheme identifies conditions under which access is permitted
- Complete mediation
  - Every access must be checked against the access control mechanism
- Open design
  - The design of a security mechanism should be open rather than secret
- Separation of privilege
  - A practice in which multiple privilege attributes are required to achieve access to a restricted resource
- Least privilege
  - Every process and every user of the system should operated using the least set of privileges necessary to perform the task
- Least common mechanism
  - The design should minimize the functions shared by different users, providing mutual security
- Psychological acceptability
  - Implies that the security mechanisms should not interfere unduly with the work of users, while at the same time meeting the needs of those who authorize access

Fundamental security design principles

- Isolation
  - A principle that applies in three contexts: first, public access systems should be isolated from critical resources to prevent disclosure to tampering; second, the processes and files of individual users should be isolated from one another except where it is explicitly desired; third, security mechanisms should be isolated in the sense of preventing access to those mechanisms
- Encapsulation
  - Viewed as a specific form of isolation based on object-oriented functionality
- Modularity
  - Refers both to the development of security functions as separate, protected modules and to the use of a modular architecture for mechanism design and implementation
- Layering
  - Refers to the use of multiple, overlapping protection approaches addressing the people, technology, and operational aspects of information systems
- Least privilege
  - Every process and every user of the system should operated using the least set of privileges necessary to perform the task
- Least astonishment
  - A program or user interface should always respond in the way that is least likely to astonish the user

Attack surface

- Consists of the reachable and exploitable vulnerabilities in a system
  - Examples:
    - Open ports on outward facing Web and other servers, and code listening on those ports
    - Services available on the inside of a firewall
    - Code that processes incoming data, e-mail, XLM, office documents, and industry-specific custom data exchange formats
    - Interfaces, SQL, and Web forms
    - An employee with access to sensitive information vulnerable to a social engineering attack
- Can be categorized in the following way:
  - Network attack surface
    - This category refers to vulnerabilities over an enterprise network, wide-area network, or Internet
  - Software attack surface
    - Vulnerabilities in application, utility, or operating system code
  - Human attack surface
    - Refers to vulnerabilities created by personnel or outsiders, such as social engineering, human error, and trusted insiders

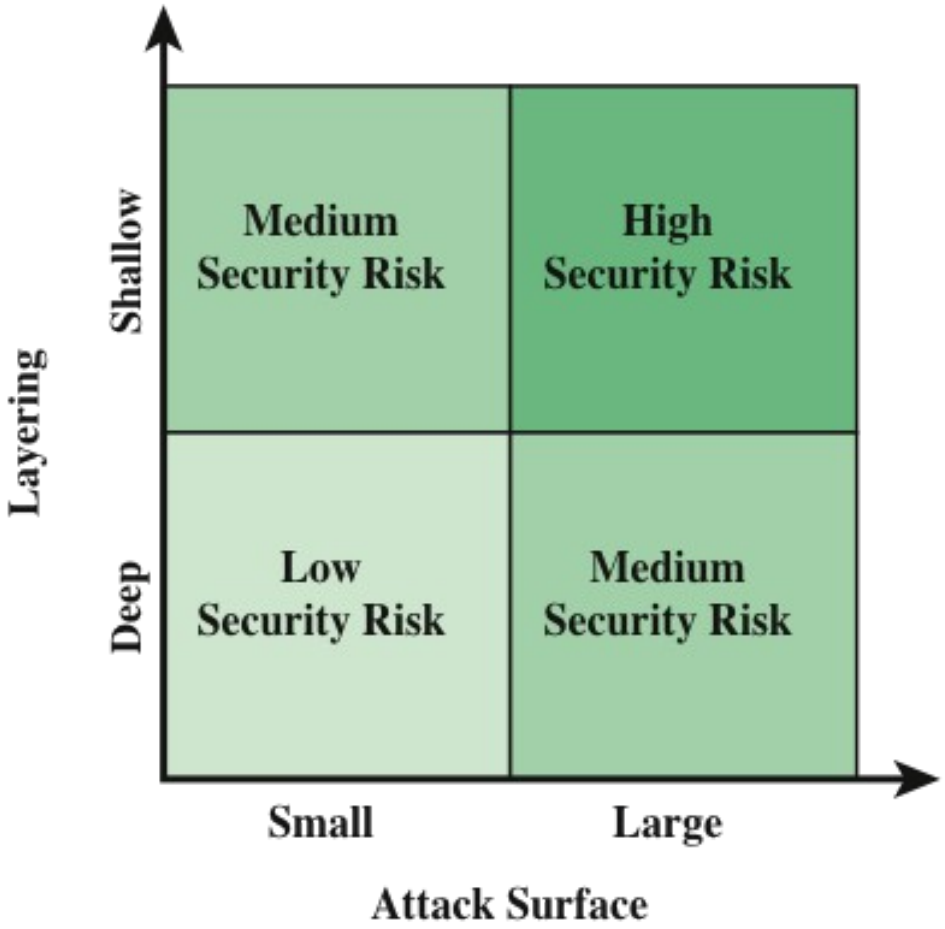


Figure 1.3 Defense in Depth and Attack Surface

Attack trees

An attack tree is a branching, hierarchical data structure that represents a set of potential techniques for exploiting security vulnerabilities [MAUW05, MOOR01, SCHN99]. The security incident that is the goal of the attack is represented as the root node of the tree, and the ways that an attacker could reach that goal are iteratively and incrementally represented as branches and subnodes of the tree. Each subnode defines a subgoal, and each subgoal may have its own set of further subgoals, etc. The final nodes on the paths outward from the root, that is, the leaf nodes, represent different ways to initiate an attack. Each node other than a leaf is either an AND-node or an OR-node. To achieve the goal represented by an AND-node, the subgoals represented by all of that node's subnodes must be achieved; and for an OR-node, at least one of the subgoals must be achieved. Branches can be labeled with values representing difficulty, cost, or other attack attributes, so that alternative attacks can be compared.

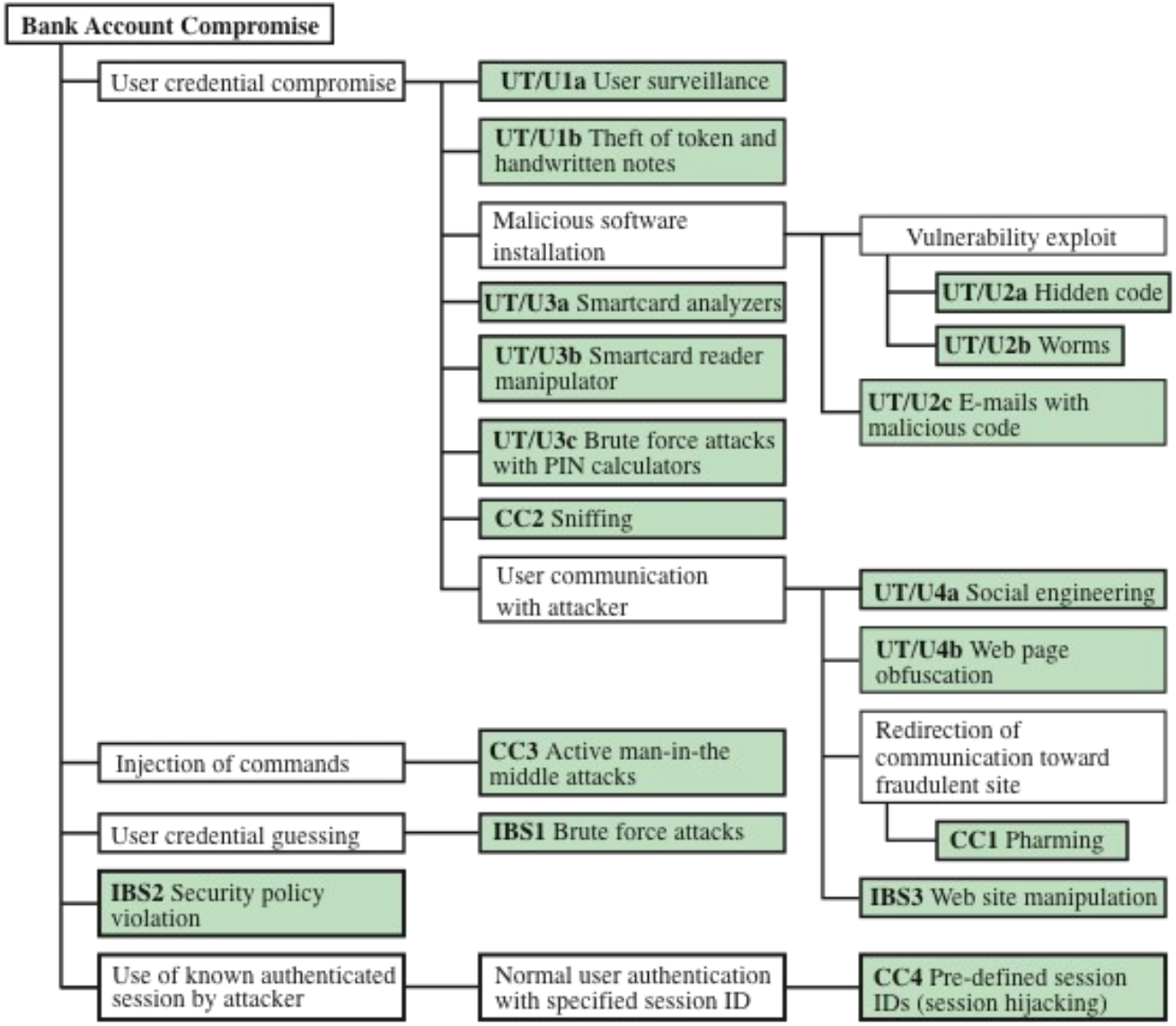


Figure 1.4 An Attack Tree for Internet Banking Authentication

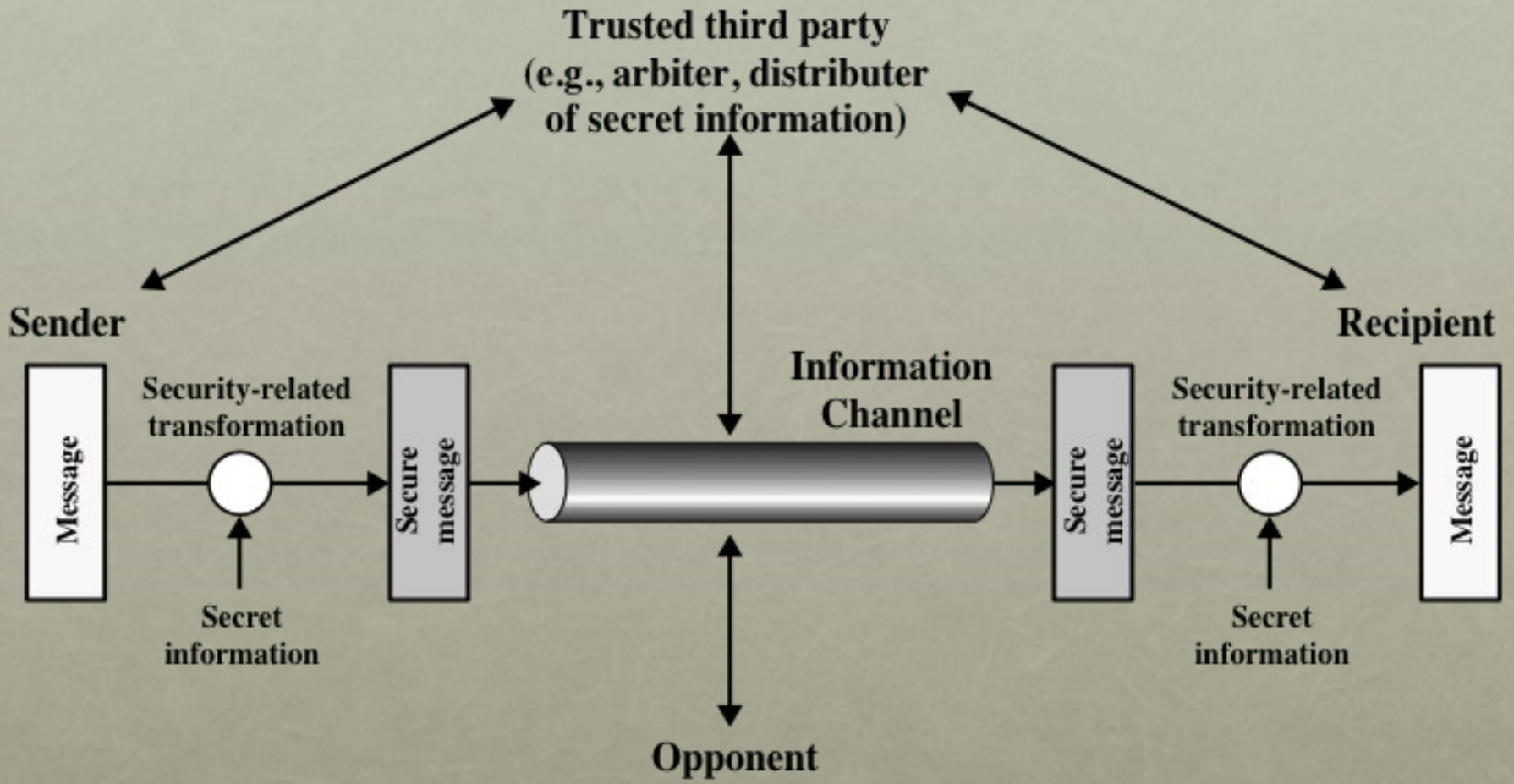


Figure 1.5 Model for Network Security

Figure 1.6 Network Access Security Model

Unwanted Access

- Placement in a computer system of logic that exploits vulnerabilities in the system and that can affect application programs as well as utili[illegible]grams

standards

NIST

- National Institute of Standards and Technology
- U.S. federal agency that deals with measurement science, standards, and technology related to U.S. government use and to the promotion of U.S. private-sector innovation
- NIST Federal Information Processing Standards (FIPS) and Special Publications (SP) have a worldwide impact

ISOC

- Internet Society
- Professional membership society with worldwide organizational and individual membership
- Provides leadership in addressing issues that confront the future of the Internet
- Is the organization home for the groups responsible for Internet infrastructure standards, including the Internet Engineering Task Force (IETF) and the Internet Architecture Board (IAB)
- Internet standards and related specifications are published as Requests for Comments (RFCs)

Summary

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  - Attack trees