CHAPTER 1

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- National Institute of Standards and Technology (NIST)
- International Telecommunication Union Telecommunication Standardization Sector (ITU-T)
- Common Criteria for Information Technology Security Evaluation
- Internet Standards and the Internet Society

This chapter provides an overview of computer security. We begin with a discussion of what we mean by computer security. In essence, computer security deals with computer-related assets that are subject to a variety of threats and for which various measures are taken to protect those assets. Accordingly, the next section of this chapter provides a brief overview of the categories of computer-related assets that users and system managers wish to preserve and protect, and a look at the various threats and attacks that can be made on those assets. Then we survey the measures that can be taken to deal with such threats and attacks. This we do from three different viewpoints, in Sections 1.3 through 1.5. We then look at some recent trends in computer security and lay out in general terms a computer security strategy. An appendix to this chapter cites a number of important security standards and specifications.

The focus of this chapter, and indeed this book, is on three fundamental questions:

1. What assets do we need to protect?
2. How are those assets threatened?
3. What can we do to counter those threats?

1.1 COMPUTER SECURITY CONCEPTS

A Definition of Computer Security

The NIST Computer Security Handbook [NIST95] defining the term *computer security* as follows:

> **Computer Security:** 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[1] 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.

[1]RFC 2828 defines *information* as "facts and ideas, which can be represented (encoded) as various forms of data," and *data* as "information in a specific physical representation, usually a sequence of symbols that have meaning; especially a representation of information that can be processed or produced by a computer." Security literature typically does not make much of a distinction, nor does this book.

- **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. For example, the NIST standard FIPS 199 (*Standards for Security Categorization of Federal Information and Information Systems*) lists confidentiality, integrity, and availability as the three security objectives for information and for information systems. FIPS PUB 199 provides a useful characterization of these three objectives in terms of requirements and the definition of a loss of security in each category:

- **Confidentiality:** Preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information. A loss of confidentiality is the unauthorized disclosure of information.
- **Integrity:** Guarding against improper information modification or destruction, including ensuring information non-repudiation and authenticity. A loss of integrity is the unauthorized modification or destruction of information.

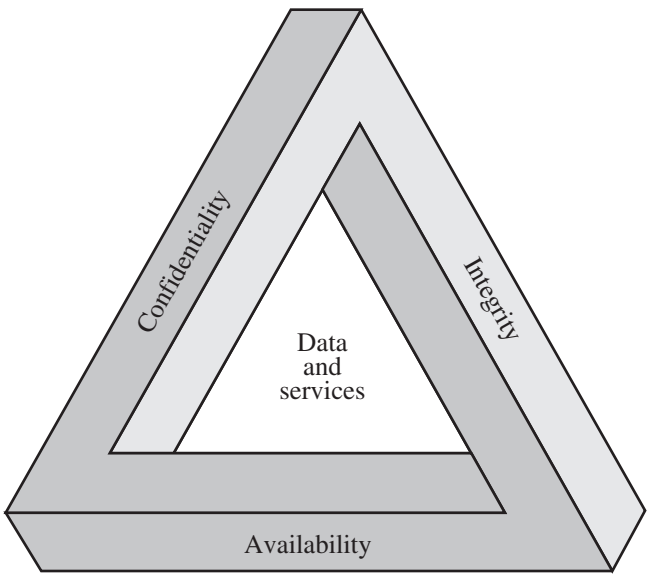

Figure 1.1 The Security Requirements Triad

- **Availability:** Ensuring timely and reliable access to and use of information. A loss of availability is the disruption of access to or use of information or an information system.

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 aren't 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.

  Note that FIPS PUB 199 includes authenticity under integrity.

Examples

We now provide some examples of applications that illustrate the requirements just enumerated.[2] For these examples, 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.

[2]These examples are taken from a security policy document published by the Information Technology Security and Privacy Office at Purdue University.

- **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.

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 or 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 is well understood.

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 staff to access the resources they need to perform critical tasks. The loss of the service translates into a large financial loss in lost employee productivity and potential customer loss.

An example of an asset that would typically 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.

The Challenges of Computer Security

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

1. Computer 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, integrity. But the mechanisms used to meet those requirements can be quite complex, and understanding them may involve rather subtle reasoning.
2. In developing a particular security mechanism or algorithm, one must always consider potential attacks on those security features. In many cases, successful attacks are designed by looking at the problem in a completely different way, therefore exploiting an unexpected weakness in the mechanism.
3. Because of point 2, the procedures used to provide particular services are often counterintuitive. Typically, a security mechanism is complex, and it is not obvious from the statement of a particular requirement that such elaborate measures are needed. It is only when the various aspects of the threat are considered that elaborate security mechanisms make sense.
4. Having designed various security mechanisms, it is necessary to decide where to use them. This is true both in terms of physical placement (e.g., at what points in a network are certain security mechanisms needed) and in a logical sense [e.g., at what layer or layers of an architecture such as TCP/IP (Transmission Control Protocol/Internet Protocol) should mechanisms be placed].
5. Security mechanisms typically involve more than a particular algorithm or protocol. They also require that participants be in possession of some secret information (e.g., an encryption key), which raises questions about the creation, distribution, and protection of that secret information. There may also be a reliance on communications protocols whose behavior may complicate the task of developing the security mechanism. For example, if the proper functioning of the security mechanism requires setting time limits on the transit time of a message from sender to receiver, then any protocol or network that introduces variable, unpredictable delays may render such time limits meaningless.
6. Computer 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.

The difficulties just enumerated will be encountered in numerous ways as we examine the various security threats and mechanisms throughout this book.

A Model for Computer Security

We now introduce some terminology that will be useful throughout the book, relying on RFC 2828, *Internet Security Glossary*.[3] Table 1.1 defines terms and Figure 1.2 [CCPS04a] shows the relationship among some of these terms. We start with the concept of a **system resource**, or **asset**, that users and owners wish to protect. The assets of a computer system can be categorized as follows:

- **Hardware:** Including computer systems and other data processing, data storage, and data communications devices
- **Software:** Including the operating system, system utilities, and applications
- **Data:** Including files and databases, as well as security-related data, such as password files
- **Communications facilities and networks:** Local and wide area network communication links, bridges, routers, and so on.

In the context of security, our concern is with the **vulnerabilities** of system resources. [NRC02] lists the following general categories of vulnerabilities of a computer system or network asset:

- It can be **corrupted**, so that it does the wrong thing or gives wrong answers. For example, stored data values may differ from what they should be because they have been improperly modified.
- It can become **leaky**. For example, someone who should not have access to some or all of the information available through the network obtains such access.
- It can become **unavailable** or very slow. That is, using the system or network becomes impossible or impractical.

These three general types of vulnerability correspond to the concepts of integrity, confidentiality, and availability, enumerated earlier in this section.

[3]See Appendix 1A for an explanation of RFCs.

Table 1.1 Computer Security Terminology, from RFC 2828, *Internet Security Glossary*, May 2000

Adversary (threat agent)
An entity that attacks, or is a threat to, a system.

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.

Countermeasure
An action, device, procedure, or technique that reduces a threat, a vulnerability, or an attack by eliminating or preventing it, by minimizing the harm it can cause, or by discovering and reporting it so that corrective action can be taken.

Risk
An expectation of loss expressed as the probability that a particular threat will exploit a particular vulnerability with a particular harmful result.

Security Policy
A set of rules and practices that specify or regulate how a system or organization provides security services to protect sensitive and critical system resources.

System Resource (Asset)
Data contained in an information system; or a service provided by a system; or a system capability, such as processing power or communication bandwidth; or an item of system equipment (i.e., a system component—hardware, firmware, software, or documentation); or a facility that houses system operations and equipment.

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.

Vulnerability
A flaw or weakness in a system's design, implementation, or operation and management that could be exploited to violate the system's security policy.

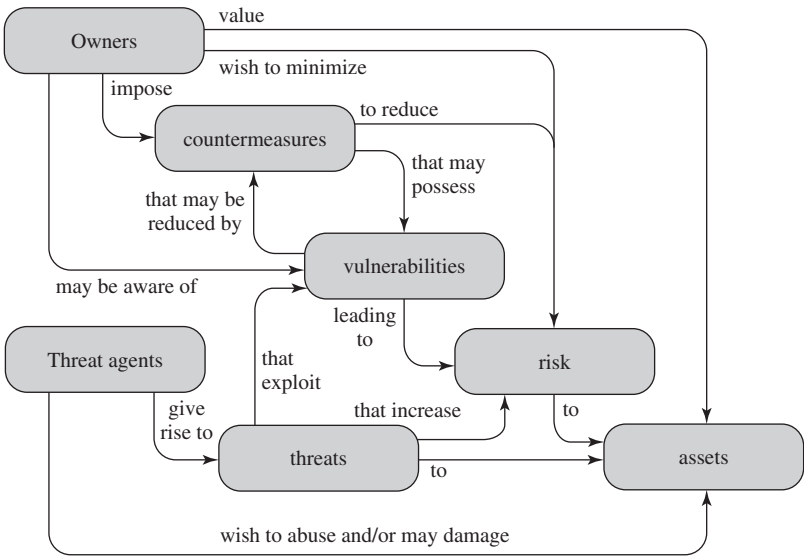

Figure 1.2 Security Concepts and Relationships

Corresponding to the various types of vulnerabilities to a system resource are **threats** that are capable of exploiting those vulnerabilities. A threat represents a potential security harm to an asset. An **attack** is a threat that is carried out (threat action) and, if successful, leads to an undesirable violation of security, or threat consequence. The agent carrying out the attack is referred to as an attacker, or **threat agent**. We can distinguish two type of attacks:

- **Active attack:** An attempts to alter system resources or affect their operation
- **Passive attack:** An attempts to learn or make use of information from the system that not affect system resources

We can also classify attacks based on the origin of the attack:

- **Inside attack:** Initiated by an entity inside the security perimeter (an "insider") (The inside is authorized to access system resources but uses them in a way not approved by those who granted the authorization).
- **Outside attack:** Initiated from outside the perimeter, by an unauthorized or illegitimate user of the system (an "outsider"). On the Internet, potential outside attackers range from amateur pranksters to organized criminals, international terrorists, and hostile governments.

Finally, a **countermeasure** is any means taken to deal with a security attack. Ideally, a countermeasure can be devised to **prevent** a particular type of attack from succeeding. When prevention is not possible, or fails in some instance, the goal is to **detect** the attack, and then **recover** from the effects of the attack. A countermeasure may itself introduce new vulnerabilities. In any case, residual vulnerabilities may remain after the imposition of countermeasures. Such vulnerabilities may be exploited by threat agents representing a residual level of **risk** to the assets. Owners will seek to minimize that risk given other constraints.

1.2 THREATS, ATTACKS, AND ASSETS

We now turn to a more detailed look at threats, attacks, and assets. First, we look at the types of security threats that must be dealt with, and then give some examples of the types of threats that apply to different categories of assets.

Threats and Attacks

Table 1.2, based on RFC 2828, describes four kinds of threat consequences and lists the kinds of attacks that result in each consequence.

Unauthorized disclosure is a threat to confidentiality. The following types of attacks can result in this threat consequence:

- **Exposure:** This can be deliberate, as when an insider intentionally releases sensitive information, such as credit card numbers, to an outsider. It can also be the result of a human, hardware, or software error, which results in an entity gaining unauthorized knowledge of sensitive data. There have been numerous

Table 1.2 Threat Consequences, and the Types of Threat Actions That Cause Each Consequence, Based on RFC 2828

Threat Consequence	Threat Action (attack)
Unauthorized Disclosure A circumstance or event whereby an entity gains access to data for which the entity is not authorized.	**Exposure:** Sensitive data are directly released to an unauthorized entity. **Interception:** An unauthorized entity directly accesses sensitive data traveling between authorized sources and destinations. **Interence:** A threat action whereby an unauthorized entity indirectly accesses sensitive data (but not necessarily the data contained in the communication) by reasoning from characteristics or by products of communications. **Intrusion:** An unauthorized entity gains access to sensitive data by circumventing a system's security protections.
Deception A circumstance or event that may result in an authorized entity receiving false data and believing it to be true.	**Masquerade:** An unauthorized entity gains access to a system or performs a malicious act by posing as an authorized entity. **Falsification:** False data deceive an authorized entity. **Repudiation:** An entity deceives another by falsely denying responsibility for an act.
Disruption A circumstance or event that interrupts or prevents the correct operation of system services and functions.	**Incapacitation:** Prevents or interrupts system operation by disabling a system component. **Corruption:** Undesirably alters system operation by adversely modifying system functions or data. **Obstruction:** A threat action that interrupts delivery of system services by hindering system operation.
Usurpation A circumstance or event that results in control of system services or functions by an unauthorized entity.	**Misappropriation:** An entity assumes unauthorized logical or physical control of a system resource. **Misuse:** Causes a system component to perform a function or service that is detrimental to system security.

instances of this, such as universities accidentally posting student confidential information on the Web.

- **Interception:** Interception is a common attack in the context of communications. On a shared local area network (LAN), such as a wireless LAN or a broadcast Ethernet, any device attached to the LAN can receive a copy of packets intended for another device. On the Internet, a determined hacker can gain access to email traffic and other data transfers. All of these situations create the potential for unauthorized access to data.
- **Inference:** An example of inference is known as traffic analysis, in which an adversary is able to gain information from observing the pattern of traffic on a network, such as the amount of traffic between particular pairs of hosts on the network. Another example is the inference of detailed information from a database by a user who has only limited access; this is accomplished by repeated queries whose combined results enable inference.

- **Intrusion:** An example of intrusion is an adversary gaining unauthorized access to sensitive data by overcoming the system's access control protections.

Deception is a threat to either system integrity or data integrity. The following types of attacks can result in this threat consequence:

- **Masquerade:** One example of masquerade is an attempt by an unauthorized user to gain access to a system by posing as an authorized user; this could happen if the unauthorized user has learned another user's logon ID and password. Another example is malicious logic, such as a Trojan horse, that appears to perform a useful or desirable function but actually gains unauthorized access to system resources or tricks a user into executing other malicious logic.
- **Falsification:** This refers to the altering or replacing of valid data or the introduction of false data into a file or database. For example, a student my alter his or her grades on a school database.
- **Repudiation:** In this case, a user either denies sending data or a user denies receiving or possessing the data.

Disruption is a threat to availability or system integrity. The following types of attacks can result in this threat consequence:

- **Incapacitation:** This is an attack on system availability. This could occur as a result of physical destruction of or damage to system hardware. More typically, malicious software, such as Trojan horses, viruses, or worms, could operate in such a way as to disable a system or some of its services.
- **Corruption:** This is an attack on system integrity. Malicious software in this context could operate in such a way that system resources or services function in an unintended manner. Or a user could gain unauthorized access to a system and modify some of its functions. An example of the latter is a user placing back door logic in the system to provide subsequent access to a system and its resources by other than the usual procedure.
- **Obstruction:** One way to obstruct system operation is to interfere with communications by disabling communication links or altering communication control information. Another way is to overload the system by placing excess burden on communication traffic or processing resources.

Usurpation is a threat to system integrity. The following types of attacks can result in this threat consequence:

- **Misappropriation:** This can include theft of service. An example is an a distributed denial of service attack, when malicious software is installed on a number of hosts to be used as platforms to launch traffic at a target host. In this case, the malicious software makes unauthorized use of processor and operating system resources.
- **Misuse:** Misuse can occur either by means of malicious logic or a hacker that has gained unauthorized access to a system. In either case, security functions can be disabled or thwarted.

Threats and Assets

The assets of a computer system can be categorized as hardware, software, data, and communication lines and networks. In this subsection, we briefly describe these four categories and relate these to the concepts of integrity, confidentiality, and availability introduced in Section 1.1 (see Figure 1.3 and Table 1.3).

Hardware A major threat to computer system hardware is the threat to availability. Hardware is the most vulnerable to attack and the least susceptible to automated controls. Threats include accidental and deliberate damage to equipment as well as theft. The proliferation of personal computers and workstations and the widespread use of LANs increase the potential for losses in this area. Theft of CD-ROMs and DVDs can lead to loss of confidentiality. Physical and administrative security measures are needed to deal with these threats.

Software Software includes the operating system, utilities, and application programs. A key threat to software is an attack on availability. Software, especially application software, is often easy to delete. Software can also be altered or damaged to render it useless. Careful software configuration management, which includes making backups of the most recent version of software, can maintain high availability. A more difficult problem to deal with is software modification that results in a program that still functions but that behaves differently than before,

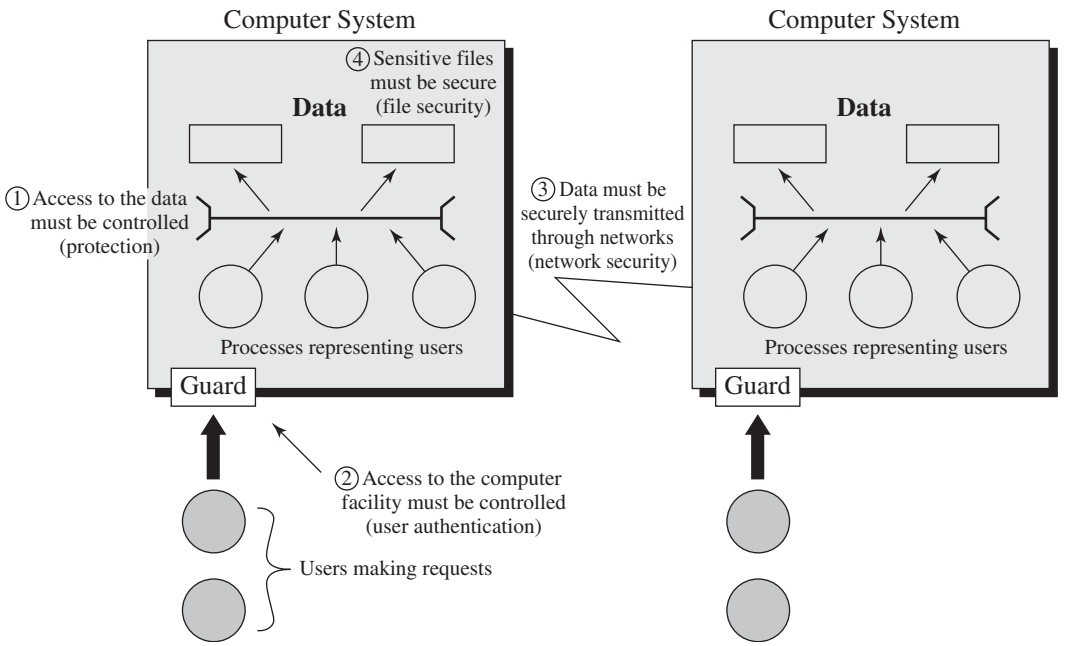

Figure 1.3 Scope of Computer Security This figure depicts security concerns other than physical security, including control of access to computers systems, safeguarding of data transmitted over communications systems, and safeguarding of stored data.

Table 1.3 Computer and Network Assets, with Examples of Threats

	Availability	Confidentiality	Integrity
Hardware	Equipment is stolen or disabled, thus denying service.		
Software	Programs are deleted, denying access to users.	An unauthorized copy of software is made.	A working program is modified, either to cause it to fail during execution or to cause it to do some unintended task.
Data	Files are deleted, denying access to users.	An unauthorized read of data is performed. An analysis of statistical data reveals underlying data.	Existing files are modified or new files are fabricated.
Communication Lines	Messages are destoryed or deleted. Communication lines or networks are rendered unavailable.	Messages are read. The traffic pattern of messages is observed.	Messages are modified, delayed, reordered, or duplicated. False messages are fabricated.

which is a threat to integrity/authenticity. Computer viruses and related attacks fall into this category. A final problem is protection against software piracy. Although certain countermeasures are available, by and large the problem of unauthorized copying of software has not been solved.

Data Hardware and software security are typically concerns of computing center professionals or individual concerns of personal computer users. A much more widespread problem is data security, which involves files and other forms of data controlled by individuals, groups, and business organizations.

Security concerns with respect to data are broad, encompassing availability, secrecy, and integrity. In the case of availability, the concern is with the destruction of data files, which can occur either accidentally or maliciously.

The obvious concern with secrecy is the unauthorized reading of data files or databases, and this area has been the subject of perhaps more research and effort than any other area of computer security. A less obvious threat to secrecy involves the analysis of data and manifests itself in the use of so-called statistical databases, which provide summary or aggregate information. Presumably, the existence of aggregate information does not threaten the privacy of the individuals involved. However, as the use of statistical databases grows, there is an increasing potential for disclosure of personal information. In essence, characteristics of constituent individuals may be identified through careful analysis. For example, if one table records the aggregate of the incomes of respondents A, B, C, and D and another records the aggregate of the incomes of A, B, C, D, and E, the difference between the two aggregates would be the income of E. This problem is exacerbated by the increasing desire to combine data sets. In many cases, matching several sets of data for consistency at different levels of aggregation requires access to individual units. Thus, the individual units, which are the subject of privacy concerns, are available at various stages in the processing of data sets.

Finally, data integrity is a major concern in most installations. Modifications to data files can have consequences ranging from minor to disastrous.

Communication Lines and Networks Network security attacks can be classified as *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 are in the nature of eavesdropping on, or monitoring of, transmissions. The goal of the attacker is to obtain information that is being transmitted. Two types of passive attacks are release of message contents and traffic analysis.

The **release of message contents** is easily understood. 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. 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. The opponent could determine the location and identity of communicating hosts and could observe the frequency and length of messages being exchanged. This information might be useful in guessing the nature of the communication that was taking place.

Passive attacks are very difficult to detect because they do not involve any alteration of the data. Typically, the message traffic is sent and received in an apparently normal fashion and neither the sender nor receiver is aware that a third party has read the messages or observed the traffic pattern. However, it is feasible to prevent the success of these attacks, usually by means of encryption. Thus, the emphasis in dealing with passive attacks is on prevention rather than detection.

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

Replay involves the passive capture of a data unit and its subsequent retransmission to produce an unauthorized effect.

A **masquerade** takes place when one entity pretends to be a different entity. 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.

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. For example, a message stating "Allow John Smith to read confidential file `accounts`" is modified to say "Allow Fred Brown to read confidential file `accounts`."

The **denial of service** prevents or inhibits the normal use or management of communications facilities. This attack may have a specific target; for example, an entity may suppress all messages directed to a particular destination (e.g., the security audit service). Another form of service denial is the disruption of an entire network, either by disabling the network or by overloading it with messages so as to degrade performance.

Active attacks present the opposite characteristics of passive attacks. Whereas passive attacks are difficult to detect, measures are available to prevent their success. On the other hand, it is quite difficult to prevent active attacks absolutely,

because to do so would require physical protection of all communications facilities and paths at all times. Instead, the goal is to detect them and to recover from any disruption or delays caused by them. Because the detection has a deterrent effect, it may also contribute to prevention.

1.3 SECURITY FUNCTIONAL REQUIREMENTS

There are a number of ways of classifying and characterizing the countermeasures that may be used to reduce vulnerabilities and deal with threats to system assets. It will be useful for the presentation in the remainder of the book to look at several approaches, which we do in this and the next two sections. In this section, we view countermeasures in terms of functional requirements, and we follow the classification defined in FIPS PUB 200 (*Minimum Security Requirements for Federal Information and Information Systems*). This standard enumerates seventeen security-related areas with regard to protecting the confidentiality, integrity, and availability of information systems and the information processed, stored, and transmitted by those systems. The areas are defined in Table 1.4.

The requirements listed in FIPS PUB 200 encompass a wide range of countermeasures to security vulnerabilities and threats. Roughly, we can divide these

Table 1.4 Security Requirements (FIPS PUB 200)

Access control: Limit information system access to authorized users, processes acting on behalf of authorized users, or devices (including other information systems) and to the types of transactions and functions that authorized users are permitted to exercise.
Awareness and training: (i) Ensure that managers and users of organizational information systems are made aware of the security risks associated with their activities and of the applicable laws, regulation, and policies related to the security of organizational information systems; and (ii) ensure that personnel are adequately trained to carry out their assigned information security-related duties and responsibilities.
Audit and accountability: (i) Create, protect, and retain information system audit records to the extent needed to enable the monitoring, analysis, investigation, and reporting of unlawful, unauthorized, or inappropriate information system activity; and (ii) ensure that the actions of individual information system users can be uniquely traced to those users so they can be held accountable for their actions.
Certification, accreditation, and security assessments: (i) Periodically assess the security controls in organizational information systems to determine if the controls are effective in their application; (ii) develop and implement plans of action designed to correct deficiencies and reduce or eliminate vulnerabilities in organizational information systems; (iii) authorize the operation of organizational information systems and associated information system connections; and (iv) monitor information system security controls on an ongoing basis to ensure the continued effectiveness of the controls.
Configuration management: (i) Establish and maintain baseline configurations and inventories of organizational information systems (including hardware, software, firmware, and documentation) throughout the respective system development life cycles; and (ii) establish and enforce security configuration settings for information technology products employed in organizational information systems.
Contingency planning: Establish, maintain, and implement plans for emergency response, backup operations, and postdisaster recovery for organizational information systems to ensure the availability of critical information resources and continuity of operations in emergency situations.
Identification and authentication: Identify information system users, processes acting on behalf of users, or devices and authenticate (or verify) the identities of those users, processes, or devices, as a prerequisite to allowing access to organizational information systems.

Incident response: (i) Establish an operational incident handling capability for organizational information systems that includes adequate preparation, detection, analysis, containment, recovery, and user response activities; and (ii) track, document, and report incidents to appropriate organizational officials and/or authorities.

Maintenance: (i) Perform periodic and timely maintenance on organizational information systems; and (ii) provide effective controls on the tools, techniques, mechanisms, and personnel used to conduct information system maintenance.

Media protection: (i) Protect information system media, both paper and digital; (ii) limit access to information on information system media to authorized users; and (iii) sanitize or destroy information system media before disposal or release for reuse.

Physical and environmental protection: (i) Limit physical access to information systems, equipment, and the respective operating environments to authorized individuals; (ii) protect the physical plant and support infrastructure for information systems; (iii) provide supporting utilities for information systems; (iv) protect information systems against environmental hazards; and (v) provide appropriate environmental controls in facilities containing information systems.

Planning: Develop, document, periodically update, and implement security plans for organizational information systems that describe the security controls in place or planned for the information systems and the rules of behavior for individuals accessing the information systems.

Personnel security: (i) Ensure that individuals occupying positions of responsibility within organizations (including third-party service providers) are trustworthy and meet established security criteria for those positions; (ii) ensure that organizational information and information systems are protected during and after personnel actions such as terminations and transfers; and (iii) employ formal sanctions for personnel failing to comply with organizational security policies and procedures.

Risk assessment: Periodically assess the risk to organizational operations (including mission, functions, image, or reputation), organizational assets, and individuals, resulting from the operation of organizational information systems and the associated processing, storage, or transmission of organizational information.

Systems and services acquisition: (i) Allocate sufficient resources to adequately protect organizational information systems; (ii) employ system development life cycle processes that incorporate information security considerations; (iii) employ software usage and installation restrictions; and (iv) ensure that third party providers employ adequate security measures to protect information, applications, and/or services outsourced from the organization.

System and communications protection: (i) Monitor, control, and protect organizational communications (i.e., information transmitted or received by organizational information systems) at the external boundaries and key internal boundaries of the information systems; and (ii) employ architectural designs, software development techniques, and systems engineering principles that promote effective information security within organizational information systems.

System and information integrity: (i) Identify, report, and correct information and information system flaws in a timely manner; (ii) provide protection from malicious code at appropriate locations within organizational information systems; and (iii) monitor information system security alerts and advisories and take appropriate actions in response.

countermeasures into two categories: those that require computer security technical measures (covered in this book in Parts One and Two), either hardware or software, or both; and those that are fundamentally management issues (covered in Part Three).

Each of the functional areas may involve both computer security technical measures and management measures. Functional areas that are primarily require computer security technical measures include access control, identification and authentication, system and communication protection, and system and information integrity. Functional areas that primarily involve management controls and procedures include awareness and training; audit and accountability; certification, accreditation, and security assessments; contingency planning; maintenance; physical and environmental protection; planning; personnel security; risk assessment; and

systems and services acquisition. Functional areas that overlap computer security technical measures and management controls include configuration management, incident response, and media protection.

Note that the majority of the functional requirements areas in FIP PUB 200 are either primarily issues of management or at least have a significant management component, as opposed to purely software or hardware solutions. This may be new to some readers and is not reflected in many of the books on computer and information security. Bus as one computer security expert observed, "If you think technology can solve your security problems, then you don't understand the problems and you don't understand the technology" [SCHN00]. This book reflects the need to combine technical and managerial approaches to achieve effective computer security.

FIPS PUB 200 provides a useful summary of the principal areas of concern, both technical and managerial, with respect to computer security. This book attempts to cover all of these areas.

1.4 A SECURITY ARCHITECTURE FOR OPEN SYSTEMS

To assess effectively the security needs of an organization and to evaluate and choose various security products and policies, the manager responsible for security needs a systematic way of defining the requirements for security and characterizing the approaches to satisfying those requirements. This is difficult enough in a centralized data processing environment; with the use of local area and wide area networks, the problem is magnified.

ITU-T[4] 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. Furthermore, because 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. Although X.800 focus on security in the context of networks and communications, the concepts apply also to computer security.

For our purposes, the OSI security architecture provides a useful, if abstract, overview of many of the concepts that this book deals with. The OSI security architecture focuses on security attacks, mechanisms, and services. These can be defined briefly as follows:

- **Security attack:** Any action that compromises the security of information owned by an organization.
- **Security mechanism:** A mechanism that is designed to detect, prevent, or recover from a security attack.
- **Security service:** A 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.

[4]The International Telecommunication Union (ITU) Telecommunication Standardization Sector (ITU-T) is a United Nations–sponsored agency that develops standards, called Recommendations, relating to telecommunications and to open systems interconnection (OSI). See Appendix D for a discussion.

The subsection on threats to communication lines and networks in Section 1.2 is based on the X.800 categorization of security threats. The next two sections examine security services and mechanisms, using the X.800 architecture.

Security 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 six categories and fourteen specific services (Table 1.5). We look at each category in turn.[5] Keep in mind that to a considerable extent, X.800 is focused on distributed and networked systems and so emphasizes network security over single-system computer security. Nevertheless, Table 1.5 is a useful checklist of security services.

Authentication The authentication service is concerned with assuring that a communication is authentic. In the case of a single message, such as a warning or alarm signal, the function of the authentication service is to assure the recipient that the message is from the source that it claims to be from. In the case of an ongoing interaction, such as the connection of a terminal to a host, two aspects are involved. First, at the time of connection initiation, the service assures that the two entities are authentic; that is, that each is the entity that it claims to be. Second, the service must assure that the connection is not interfered with in such a way that a third party can masquerade as one of the two legitimate parties for the purposes of unauthorized transmission or reception.

Two specific authentication services are defined in the standard:

- **Peer entity authentication:** Provides for the corroboration of the identity of a peer entity in an association. Two entities are considered peer if they implement the same protocol in different systems (e.g., two TCP users in two communicating systems). Peer entity authentication is provided for use at the establishment of, or at times during the data transfer phase of, a connection. It attempts to provide confidence that an entity is not performing either a masquerade or an unauthorized replay of a previous connection.
- **Data origin authentication:** Provides for the corroboration of the source of a data unit. It does not provide protection against the duplication or modification of data units. This type of service supports applications like electronic mail where there are no prior interactions between the communicating entities.

Access Control In the context of network security, access control is 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 identified, or authenticated, so that access rights can be tailored to the individual.

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[5]There is no universal agreement about many of the terms used in the security literature. For example, the term *integrity* is sometimes used to refer to all aspects of information security. The term *authentication* is sometimes used to refer both to verification of identity and to the various functions listed under integrity in the this chapter. Our usage here agrees with both X.800 and RFC 2828.

Table 1.5 Security Services, from X.800, *Security Architecture for OSI*

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 Anthentication** 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. **AVAILABILITY** Eusures that there is no denial of authorized access to network elements, stored information, information flows, services and applications due to events impacting the network. Disaster recovery solutions are included in this category.	**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.

Data Confidentiality In the context of network security, confidentiality is the protection of transmitted data from passive attacks. With respect to the content of a data transmission, several levels of protection can be identified. The broadest service protects all user data transmitted between two users over a period of time. For example, when a TCP connection is set up between two systems, this broad

protection prevents the release of any user data transmitted over the TCP connection. Narrower forms of this service can also be defined, including the protection of a single message or even specific fields within a message. These refinements are less useful than the broad approach and may even be more complex and expensive to implement.

The other aspect of confidentiality is 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 In the context of network security, as with data confidentiality, data 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 need to make a distinction between the 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.

Non-repudiation Non-repudiation prevents either sender or receiver from denying a transmitted message. Thus, when a message is sent, the receiver can prove that the alleged sender in fact sent the message. Similarly, when a message is received, the sender can prove that the alleged receiver in fact received the message.

Availability Both X.800 and RFC 2828 define availability to be 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 (i.e., a system is available if it provides services according to the system design whenever users request them). A variety of attacks can result in the loss of or reduction in availability. Some of these attacks are amenable to automated countermeasures, such as authentication and encryption, whereas others require a physical action to prevent or recover from loss of availability.

X.800 treats availability as a property to be associated with various security services. X.805, *Security Architecture for Systems Providing End-to-End Communications*, refers specifically to an availability service. An availability service is one that protects a system to ensure its availability. This service addresses the security concerns raised by denial-of-service attacks. It depends on proper management and control of system resources and thus depends on access control service and other security services.

Security Mechanisms

Table 1.6 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. These mechanisms will be covered in the appropriate places in the book and so we do not elaborate now, except to comment on the definition of encipherment. X.800 distinguishes between reversible encipherment mechanisms and irreversible encipherment mechanisms. A reversible encipherment mechanism is an

Table 1.6 Security Mechanisms (X. 800)

SPECIFIC SECURITY MECHANISMS	PERVASIVE SECURITY MECHANISMS
May be incorporated into the appropriate protocol layer in order to provide some of the OSI security services.	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 of an entiy 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.	

encryption algorithm that allows data to be encrypted and subsequently decrypted. Irreversible encipherment mechanisms include hash algorithms and message authentication codes, which are used in digital signature and message authentication applications.

1.5 THE SCOPE OF COMPUTER SECURITY

Throughout this book, we focus at one time or another on some aspect or some detail of the overall security problem. It is very useful to be able to place any particular portion of the discussion into the context of a big picture that endeavors to illustrate all of the elements of computer security. Perhaps the most useful effort to construct a big picture is the effort to develop a common vocabulary for all of the elements that go into computer security incident reporting. A number of organizations have contributed to this effort and one generally agreed-upon approach is used by the CERT (Computer Emergency Response Team) Coordination Center and other organizations concerned with computer security. This approach is referred to as the computer and network security incident taxonomy [HOWA98, HOWA02b].

Figure 1.4 depicts the overall scope of computer security using this taxonomy. The key elements are as follows:

- **Action:** A step taken by a user or process in order to achieve a result
- **Target:** A computer or network logical entity or physical entity
- **Event:** An action directed at a target that is intended to result in a change of state, or status, of the target
- **Tool:** A means of exploiting a computer or network vulnerability
- **Vulnerability:** A weakness in a system allowing unauthorized action
- **Unauthorized result:** An unauthorized consequence of an event
- **Attack:** A series of steps taken by an attacker to achieve an unauthorized result
- **Attacker:** An individual who attempts one or more attacks in order to achieve an objective
- **Objectives:** The purpose or end goal of an incident
- **Incident:** A group of attacks that can be distinguished from other attacks because of the distinctiveness of the attackers, attacks, objectives, sites, and timing

At a top level of detail, an attacker, or group of attackers, achieves its objectives by performing attacks. An incident may be comprised of one single attack or may be made of multiple attacks, as illustrated by the return loop in Figure 1.4.

Figure 1.4 shows the relationship of events to attacks and to incidents and suggests that preventing attackers from achieving objectives could be accomplished by ensuring that an attacker can't make any complete connections through the seven steps depicted. For example, investigations could be conducted of suspected vandalism by a disgruntled employee, systems could be searched periodically for attacker

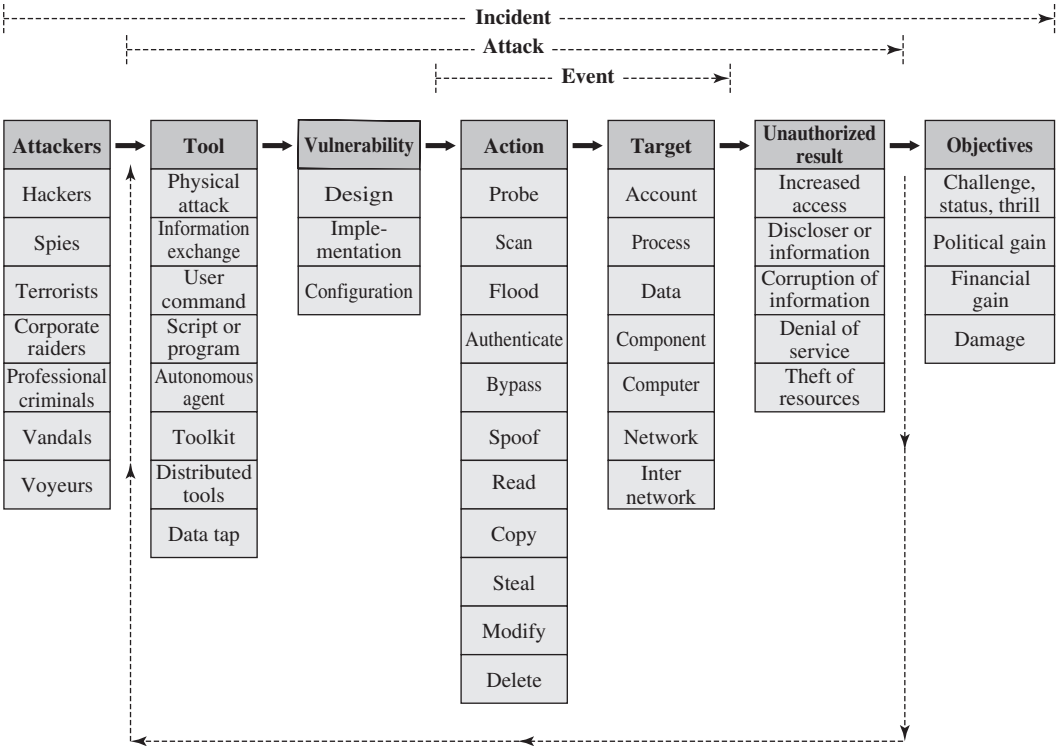


Figure 1.4 **Computer and Network Security Incident Taxonomy**

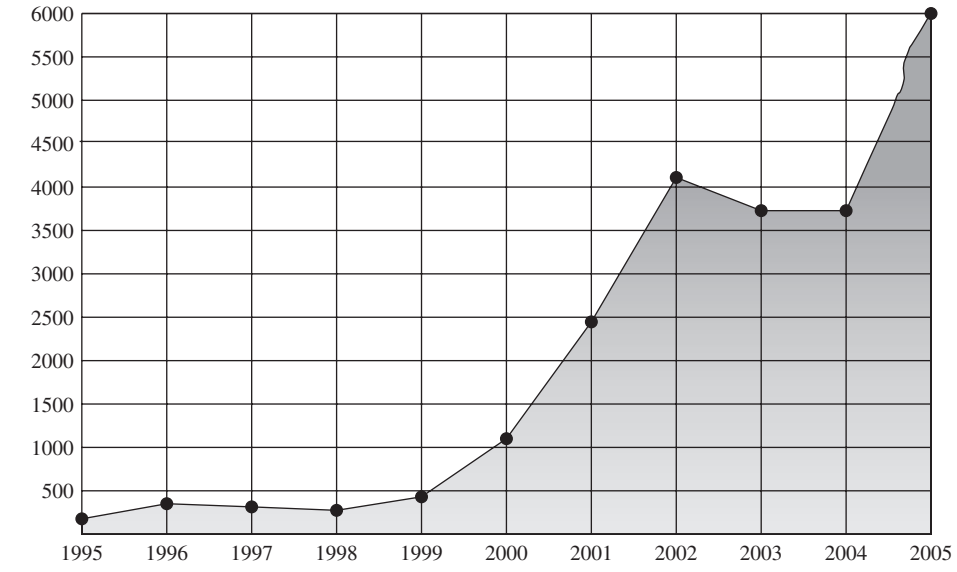
tools, system vulnerabilities could be patched, access controls could be strengthened to prevent actions by an attacker to access a targeted account, files could be encrypted so as not to result in disclosure, and an employee awareness program could be initiated to prevent vandals from achieving an objective of damage.

1.6 COMPUTER SECURITY TRENDS

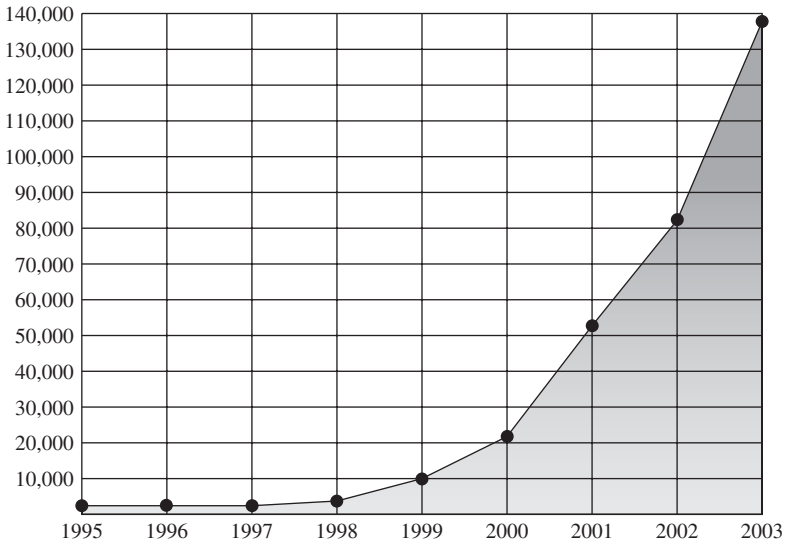
An Internet Perspective

In 1994, the Internet Architecture Board (IAB) issued a report entitled *Security in the Internet Architecture* (RFC 1636). The report stated the general consensus that the Internet needs more and better security, and it identified key areas for security mechanisms. Among these were the need to secure the network infrastructure from unauthorized monitoring and control of network traffic and the need to secure end-user-to-end-user traffic using authentication and encryption mechanisms.

These concerns are fully justified. As confirmation, consider the trends reported by the Computer Emergency Response Team (CERT) Coordination Center (CERT/CC). Figure 1.5a shows the trend in Internet-related vulnerabilities reported to CERT over a 10-year period. These include security weaknesses in the



(a) Vulnerabilities reported



(b) Incidents reported

Figure 1.5 **CERT Statistics** CERT monitors the Internet for reported security vulnerabilities and incidents of security attacks.

operating systems of attached computers (e.g., Windows, Linux) as well as vulnerabilities in Internet routers and other network devices. Figure 1.5b shows the number of security-related incidents reported to CERT. These include denial-of-service attacks; IP spoofing, in which intruders create packets with false IP addresses and exploit applications that use authentication based on IP; and various forms of

eavesdropping and packet sniffing, in which attackers read transmitted information, including logon information and database contents.[6]

Over time, the attacks on the Internet and Internet-attached systems have grown more sophisticated while the amount of skill and knowledge required to mount an attack has declined (Figure 1.6). Attacks have become more automated and can cause greater amounts of damage.

This increase in attacks coincides with an increased use of the Internet and with increases in the complexity of protocols, applications, and the Internet itself. Critical infrastructures increasingly rely on the Internet for operations. Individual users rely on the security of the Internet, e-mail, the Web, and Web-based applications to a greater extent than ever. Thus, a wide range of technologies and tools are needed to counter the growing threat. At a basic level, cryptographic algorithms for confidentiality and authentication assume greater importance. Also, designers need to focus on Internet-based protocols and the

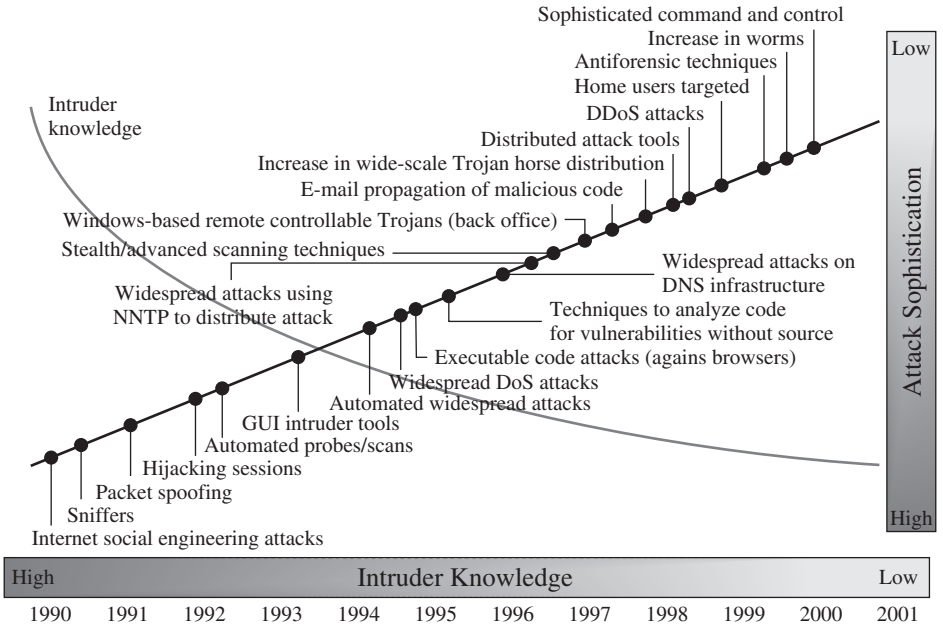


Figure 1.6 Trends in Attack Sophistication and Intruder Knowledge Increasing straight line indicates types of tools readily available to attackers. Decreasing curved line indicates relative amount of knowledge attacker must have to launch a successful attack.
Source: CERT

[6]Given the widespread use of automated attack tools, attacks against Internet-connected systems have become so commonplace that counts of the number of incidents reported provides little information with regard to assessing the scope and impact of attacks. Therefore, as of 2004, CERT no longer publishes the number of incidents reported.

vulnerabilities of attached operating systems and applications. This book surveys all of these technical areas.

The CSI/FBI Computer Crime and Security Survey

Another useful view of trends in computer security is provided by the CSI/FBI Computer Crime and Security Survey for 2006, conducted by the Computer Security Institute, a private organization, and the U.S. Federal Bureau of Investigation (FBI). The respondents consisted of over 600 U.S.-based companies, nonprofit organizations, and public sector organizations.

Figure 1.7 shows the estimated losses caused by various types of computer security incidents. The top four categories of losses (viruses, unauthorized access, laptop or mobile hardware theft, and theft of proprietary information) accounted for nearly three-quarters of the total loss. Note that these attacks need to be countered by technical measures (in the case of viruses and unauthorized access); physical security measures (laptop or mobile hardware theft); or a combination (theft of proprietary information, which could include electronic as well as paper assets). Other management controls would also come into play.

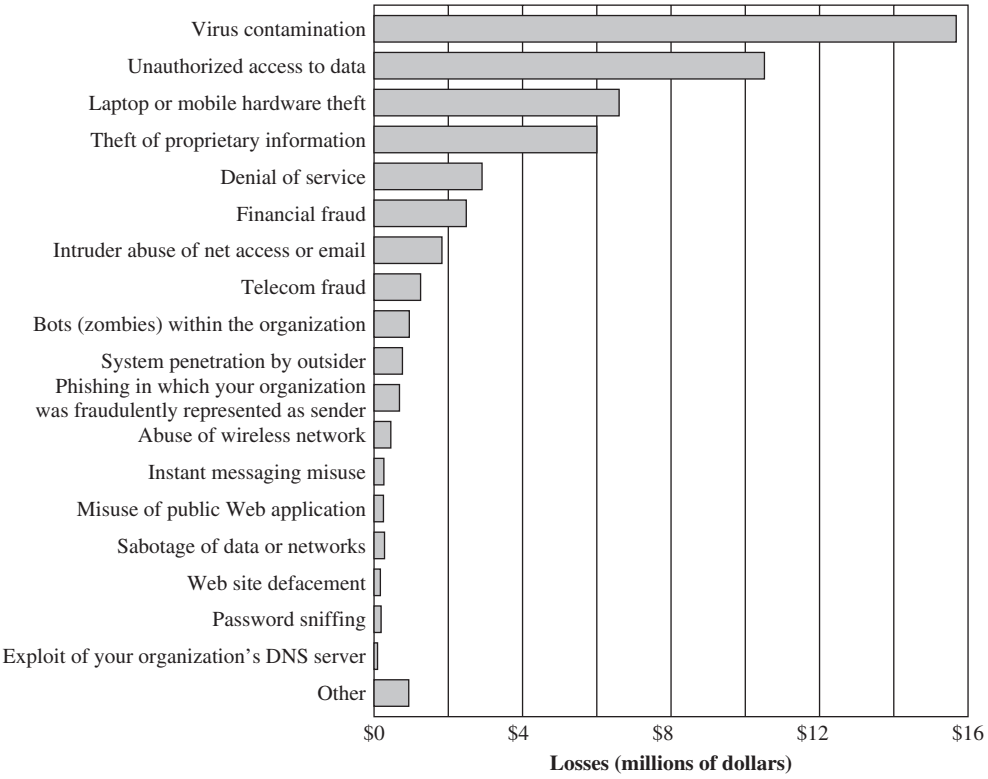


Figure 1.7 Dollar Amount Losses by Type
Source: Computer Security Institute/FBI 2006 Computer Crime and Security Survey

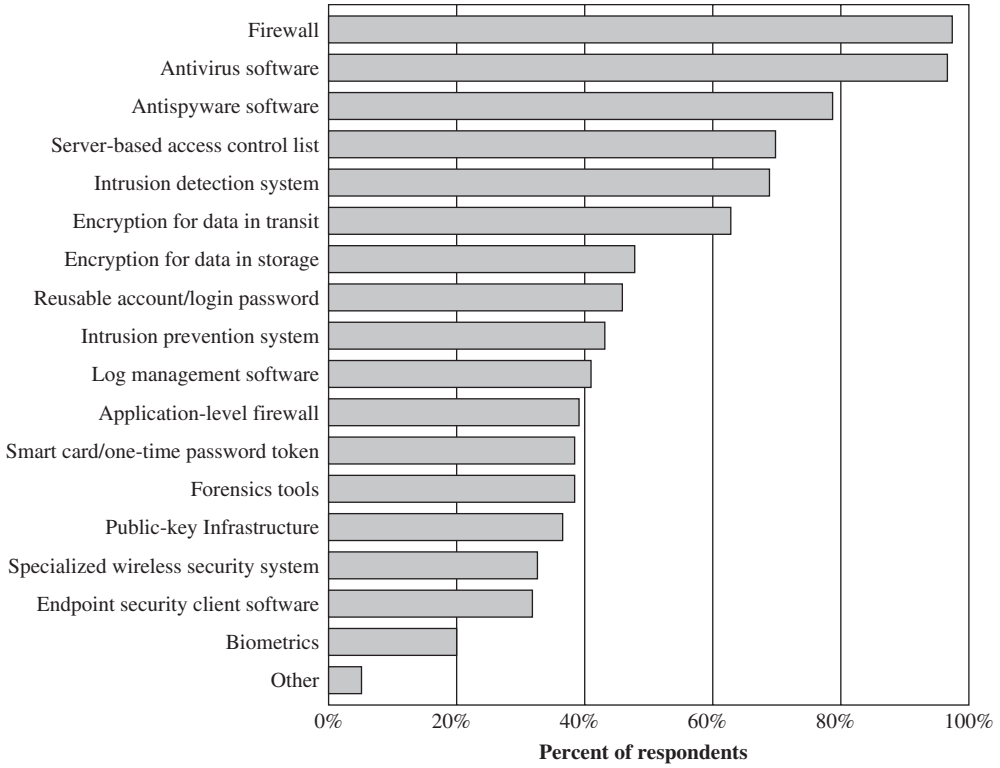


Figure 1.8 Security Technologies Used
Source: Computer Security Institute/FBI 2006 Computer Crime and Security Survey

Figure 1.8 indicates the types of security technology used by organizations to counter threats. Both firewalls and antivirus software are used almost universally. This popularity reflects a number of factors:

- The maturity of these technologies means that security administrators are very familiar with the products and are confident of their effectiveness.
- Because these technologies are mature and there are a number of vendors, costs tend to be quite reasonable and user-friendly interfaces are available.
- The threats countered by these technologies are among the most significant facing security administrators.

1.7 COMPUTER SECURITY STRATEGY

We conclude this chapter with a brief look at the overall strategy for providing computer security. [LAMP04] suggests that a comprehensive security strategy involves three aspects:

- **Specification/policy:** What is the security scheme supposed to do?
- **Implementation/mechanisms:** How does it do it?
- **Correctness/assurance:** Does it really work?

Security Policy

The first step in devising security services and mechanisms is to develop a security policy. Those involved with computer security use the term *security policy* in various ways. At the least, a security policy is an informal description of desired system behavior [NRC91]. Such informal policies may reference requirements for security, integrity, and availability. More usefully, a security policy is a formal statement of rules and practices that specify or regulate how a system or organization provides security services to protect sensitive and critical system resources (RFC 2828). Such a formal security policy lends itself to being enforced by the system's technical controls as well as its management and operational controls.

In developing a security policy, a security manager needs to consider the following factors:

- The value of the assets being protected
- The vulnerabilities of the system
- Potential threats and the likelihood of attacks

Further, the manager must consider the following tradeoffs:

- **Ease of use versus security:** Virtually all security measures involve some penalty in the area of ease of use. The following are some examples. Access control mechanisms require users to remember passwords and perhaps perform other access control actions. Firewalls and other network security measures may reduce available transmission capacity or slow response time. Virus-checking software reduces available processing power and introduces the possibility of system crashes or malfunctions due to improper interaction between the security software and the operating system.
- **Cost of security versus cost of failure and recovery:** In addition to ease of use and performance costs, there are direct monetary costs in implementing and maintaining security measures. All of these costs must be balanced against the cost of security failure and recovery if certain security measures are lacking. The cost of security failure and recovery must take into account not only the value of the assets being protected and the damages resulting from a security violation, but also the risk, which is the probability that a particular threat will exploit a particular vulnerability with a particular harmful result.

Security policy is thus a business decision, possibly influenced by legal requirements.

Security Implementation

Security implementation involves four complementary courses of action:

- **Prevention:** An ideal security scheme is one in which no attack is successful. Although this is not practical in all cases, there is a wide range of threats in which prevention is a reasonable goal. For example, consider the transmission of encrypted data. If a secure encryption algorithm is used, and if measures are in place to prevent unauthorized access to encryption keys, then attacks on confidentiality of the transmitted data will be prevented.

- **Detection:** In a number of cases, absolute protection is not feasible, but it is practical to detect security attacks. For example, there are intrusion detection systems designed to detect the presence of unauthorized individuals logged onto a system. Another example is detection of a denial-of-service attack, in which communications or processing resources are consumed so that they are unavailable to legitimate users.
- **Response:** If security mechanisms detect an ongoing attack, such as a denial-of-service attack, the system may be able to respond in such a way as to halt the attack and prevent further damage.
- **Recovery:** An example of recovery is the use of backup systems, so that if data integrity is compromised, a prior, correct copy of the data can be reloaded.

Assurance and Evaluation

Those who are "consumers" of computer security services and mechanisms (e.g., system managers, vendors, customers, end users) desire a belief that the security measures in place work as intended. That is, security consumers want to feel that the security infrastructure of their systems meet security requirements and enforce security policies. These considerations bring us to the concepts of assurance and evaluation.

The NIST Computer Security Handbook [NIST95] defines **assurance** as the degree of confidence one has that the security measures, both technical and operational, work as intended to protect the system and the information it processes. This encompasses both system design and system implementation. Thus, assurance deals with the questions, "Does the security system design meet its requirements?" and "Does the security system implementation meet its specifications?"

Note that assurance is expressed as a degree of confidence, not in terms of a formal proof that a design or implementation is correct. With the present state of the art, it is very difficult if not impossible to move beyond a degree of confidence to absolute proof. Much work has been done in developing formal models that define requirements and characterize designs and implementations, together with logical and mathematical techniques for addressing these issues. But assurance is still a matter of degree.

Evaluation is the process of examining a computer product or system with respect to certain criteria. Evaluation involves testing and may also involve formal analytic or mathematical techniques. The central thrust of work in this area is the development of evaluation criteria that can be applied to any security system (encompassing security services and mechanisms) and that are broadly supported for making product comparisons.

1.8 RECOMMENDED READING AND WEB SITES

It is useful to read some of the classic tutorial papers on computer security; these provide a historical perspective from which to appreciate current work and thinking. The papers to read are [WARE79], [BROW72], [SALT75], [SHAN77], and [SUMM84]. Two more recent, short treatments of computer security are [ANDR04] and [LAMP04]. [NIST95] is an exhaustive (290 pages) treatment of the subject. Another good treatment is [NRC91]. Also useful is [FRAS97].

ANDR04 Andrews, M., and Whittaker, J. "Computer Security." *IEEE Security and Privacy*, September/October 2004.

BROW72 Browne, P. "Computer Security—A Survey." *ACM SIGMIS Database*, Fall 1972.

FRAS97 Fraser, B. *Site Security Handbook.* RFC 2196, September 1997.

LAMP04 Lampson, B. "Computer Security in the Real World," *Computer*, June 2004.

NIST95 National Institute of Standards and Technology. *An Introduction to Computer Security: The NIST Handbook.* Special Publication 800–12. October 1995.

NRC91 National Research Council. *Computers at Risk: Safe Computing in the Information Age.* Washington, DC: National Academy Press, 1991.

SALT75 Saltzer, J., and Schroeder, M. "The Protection of Information in Computer Systems." *Proceedings of the IEEE*, September 1975.

SHAN77 Shanker, K. "The Total Computer Security Problem: An Overview." *Computer*, June 1977.

SUMM84 Summers, R. "An Overview of Computer Security." *IBM Systems Journal*, Vol. 23, No. 4, 1984.

WARE79 Ware, W., ed. *Security Controls for Computer Systems.* RAND Report 609–1. October 1979. http://www.rand.org/pubs/reports/R609–1/R609.1.html

Recommended Web sites:[7]

- **IETF Security Area:** Material related to Internet security standardization efforts.
- **Computer and Network Security Reference Index:** A good index to vendor and commercial products, FAQs, newsgroup archives, papers, and other Web sites.
- **IEEE Technical Committee on Security and Privacy:** Copies of their newsletter, information on IEEE-related activities.
- **Computer Security Resource Center:** Maintained by the National Institute of Standards and Technology (NIST); contains a broad range of information on security threats, technology, and standards.
- **Security Focus:** A wide variety of security information, with an emphasis on vendor products and end-user concerns. Maintains the Internet Storm Center, which provides a warning service to Internet users and organizations concerning security threats.
- **SANS Institute:** Similar to Security Focus. Extensive collection of white papers. Maintains Bugtraq, a mailing list for the detailed discussion and announcement of computer security vulnerabilities.
- **Risks Digest:** Forum on risks to the public in computers and related systems.
- **CERT Coordination Center:** The organization that grew from the computer emergency response team formed by the Defense Advanced Research Projects Agency. Site provides good information on Internet security threats, vulnerabilities, and attack statistics.
- **Packet Storm:** Resource of up-to-date and historical security tools, exploits, and advisories.
- **Institute for Security and Open Methodologies:** An open, collaborative security research community. Lots of interesting information.

[7]Because URLs sometimes change, they are not included. For all of the Web sites listed in this and subsequent chapters, the appropriate link is at this book's Web site at williamstallings.com/CompSec/CompSec1e.html.

1.9 KEY TERMS, REVIEW QUESTIONS, AND PROBLEMS

Key Terms

access control	evaluation	passive attack
active attack	exposure	prevent
adversary	falsification	privacy
asset	incapacitation	replay
assurance	inference	repudiation
attack	inside attack	security attack
authentication	integrity	security mechanism
authenticity	interception	security policy
availability	intruder	security service
confidentiality	intrusion	system integrity
corruption	masquerade	system resource
countermeasure	misappropriation	threat
data confidentiality	misuse	traffic analysis
data integrity	non-repudiation	unauthorized disclosure
denial of service	obstruction	usurpation
disruption	OSI security architecture	vulnerabilities
encryption	outside attack	

Review Questions

1.1 Define *computer security*.
1.2 What is the OSI security architecture?
1.3 What is the difference between passive and active security threats?
1.4 List and briefly define categories of passive and active network security attacks.
1.5 List and briefly define categories of security services.
1.6 List and briefly define categories of security mechanisms.

Problems

1.1 Consider an automated tell machine (ATM) in which users provide a personal identification number (PIN) and a card for account access. Give examples of confidentiality, integrity, and availability requirements associated with the system and, in each case, indicate the degree of importance of the requirement.
1.2 Repeat Problem 1.1 for a telephone switching system that routes calls through a switching network based on the telephone number requested by the caller.
1.3 Consider a desktop publishing system used to produce documents for various organizations.
- **a.** Give an example of a type of publication for which confidentiality of the stored data is the most important requirement.
- **b.** Give an example of a type of publication in which data integrity is the most important requirement.
- **c.** Give an example in which system availability is the most important requirement.

1.4 For each of the following assets, assign a low, moderate, or high impact level for the loss of confidentiality, availability, and integrity, respectively. Justify your answers.
- **a.** An organization managing public information on its Web server.
- **b.** A law enforcement organization managing extremely sensitive investigative information.
- **c.** A financial organization managing routine administrative information (not privacy-related information).
- **d.** An information system used for large acquisitions in a contracting organization contains both sensitive, pre–solicitation phase contract information and routine administrative information. Assess the impact for the two data sets separately and the information system as a whole.
- **e.** A power plant contains a SCADA (supervisory control and data acquisition) system controlling the distribution of electric power for a large military installation. The SCADA system contains both real-time sensor data and routine administrative information. Assess the impact for the two data sets separately and the information system as a whole.

1.5 Use a matrix format to show the relationship between X.800 security services and security mechanisms. The matrix columns correspond to mechanisms and the matrix rows correspond to services. Each cell in the matrix should be checked, or not, to indicate whether the corresponding mechanism is used in providing the corresponding service.

1.6 Draw a matrix similar to that for the preceding problem that shows the relationship between X.800 security services and network security attacks.

1.7 Draw a matrix similar to that for the preceding problem that shows the relationship between X.800 security mechanisms and network security attacks.

APPENDIX 1A SIGNIFICANT SECURITY STANDARDS AND DOCUMENTS

There is an overwhelming amount of material, including books, papers, and online resources, on computer security. Perhaps the most useful and definitive source of information is a collection of standards and specifications from standards-making bodies and from other sources whose work has widespread industry and government approval. We list some of the most important sources in this appendix.

The standards organizations mentioned in this appendix are described in Appendix D.

International Organization for Standardization (ISO)

An increasingly popular standard for writing and implementing security policies is **ISO 17799** (*Code of Practice for Information Security Management*). [8] ISO 17799 is a comprehensive set of controls comprising best practices in information security. It is essentially an internationally recognized generic information security standard. The standard covers the following areas in some detail: risk assessment; policy; organization of information security; asset management; human resources

[8] ISO 17799 is currently being revised, and will be reissued as ISO 27002 in the new ISO 27000 family of security standards.

security; physical security; communications security; access control; IS acquisition, development, and maintenance; security incident management; business continuity management; and compliance.

With the increasing interest in security, ISO 17799 certification, provided by various accredited bodies, has been established as a goal for many corporations, government agencies, and other organizations around the world. ISO 17799 offers a convenient framework to help security policy writers structure their policies in accordance with an international standard.

National Institute of Standards and Technology (NIST)

NIST has produced a large number of Federal Information Processing Standards Publications (FIPS PUBs) and special publications (SPs) that are enormously useful to security managers, designers, and implementers. We mention here a few of the most significant and general. **FIPS PUB 200** (*Minimum Security Requirements for Federal Information and Information Systems*) is a standard that specifies minimum security requirements in seventeen security-related areas with regard to protecting the confidentiality, integrity, and availability of federal information systems and the information processed, stored, and transmitted by those systems. FIPS PUB 200 is discussed in Section 1.3.

NIST **SP 800-100** (*Information Security Handbook: A Guide for Managers*) provides a broad overview of information security program elements to assist managers in understanding how to establish and implement an information security program. Its topical coverage overlaps considerably with ISO 17799.

Several other NIST publications are of general interest. **SP 800-55** (*Security Metrics Guide for Information Technology Systems*) provides guidance on how an organization, through the use of metrics, identifies the adequacy of in-place security controls, policies, and procedures. **SP 800-27** [*Engineering Principles for Information Technology Security* (*A Baseline for Achieving Security*)] presents a list of system-level security principles to be considered in the design, development, and operation of an information system. **SP 800-53** (*Recommended Security Controls for Federal Information Systems*) lists management, operational, and technical safeguards or countermeasures prescribed for an information system to protect the confidentiality, integrity, and availability of the system and its information.

International Telecommunication Union Telecommunication Standardization Sector (ITU-T)

ITU-T has issued the X.800 series of Recommendations covering security for data networks. Perhaps the most important is **X.800** (*Security Architecture for Open Systems Interconnection*), which provides a detailed overview of security threats, services, and mechanisms. X.800 is discussed in Section 1.4. **X.810** (*Security Frameworks for Open Systems: Overview*) provides more detail on the topics introduced in X.800 and introduces a framework for security services implementation.

There are currently 20 Recommendations in the X.800 series. In addition to the Recommendations just mentioned, there are Recommendations that cover

authentication, access control, non-repudiation, confidentiality, integrity, and audit and alarms.

Common Criteria for Information Technology Security Evaluation

The Common Criteria is a joint international effort by a number of national standards organizations and government agencies. U.S participation is by NIST and the National Security Agency (NSA). CC defines a set of IT requirements of known validity that can be used in establishing security requirements for prospective products and systems. The CC also defines the Protection Profile (PP) construct that allows prospective consumers or developers to create standardized sets of security requirements that will meet their needs. We discuss the Common Criteria in detail in Chapter 10 and reference these documents in a number of chapters.

Internet Standards and the Internet Society

Many of the protocols that make up the TCP/IP protocol suite have been standardized or are in the process of standardization. By universal agreement, an organization known as the Internet Society is responsible for the development and publication of these standards. The Internet Society is a professional membership organization that oversees a number of boards and task forces involved in Internet development and standardization.

All official publications from the Internet Society are issued as Requests for Comments (RFCs). Some are informational; others are Internet Standards or specifications that may become Internet Standards. **RFC 2196** (*Site Security Handbook*) covers some of the same ground as ISO 17799 and SP 800-100. It is a guide to developing computer security policies and procedures for sites that have systems on the Internet. RFC 3552 (*Guidelines for Writing RFC Text on Security Considerations*) provides guidelines to RFC authors on how to include security considerations in the RFC. It discusses the goals of security, the Internet threat model, and common security issues.