Lecture 14
Security and Protection

Prof. Yinqian Zhang

Spring 2023

Goals of Protection

- Computer consists of a collection of objects (hardware objects or software objects)
- Each object has a unique name and can be accessed through a well-defined set of operations
- Protection problem - ensure that each object is accessed correctly and only by those that are allowed to do so

Principles of Protection

- Guiding principle – **principle of least privilege**
  - Programs, users and systems should be given **just** enough **privileges** to perform their tasks
  - Limits damage if entity has a bug, gets abused
  - Can be static (during life of system, during life of process)
  - Or dynamic (changed by process as needed) – **privilege escalation**

Access Matrix

- View protection as a matrix (**access matrix**)
- Rows represent domains (e.g. users or processes)
- Columns represent objects
- **`Access(i, j)`** is the set of operations that a process executing in Domain_i can invoke on Object_j

object / domain	F_1	F_2	F_3	printer
D_1	read		read	
D_2				print
D_3		read	execute	
D_4	read write		read write	

Use of Access Matrix

- If a process in Domain D_i tries to do "op" on object O_j, then "op" must be in the access matrix
- User who creates object can define access column for that object
- Can be expanded to dynamic protection
  - Operations to add, delete access rights
- **Access matrix** design separates mechanism from policy
  - Mechanism
    - Operating system provides access-matrix + rules
    - It ensures that the matrix is only manipulated by authorized agents and that rules are strictly enforced
  - Policy
    - User dictates policy
    - Who can access what object and in what mode

Implementation of Access Matrix

- Generally, a sparse matrix
- Option 1 – Global table
  - Store ordered triples **`<domain, object, rights-set>`** in table
  - A requested operation M on object O_j within domain D_i -> search table for $< D_i, O_j, R_k >$
    - with $M \in R_k$
  - But table could be large -> won't fit in main memory
  - Difficult to group objects (consider an object that all domains can read)

Implementation of Access Matrix (Cont.)

- Option 2 – Access-control lists for objects ACL
  - Each column implemented as an access-control list for one object
  - Resulting per-object list consists of ordered pairs **`<domain, rights-set>`** defining all domains with non-empty set of access rights for the object

Implementation of Access Matrix (Cont.)

- Option 3 – Capability list for domains
  - Instead of object-based, list is domain based
  - **Capability list** for domain is list of objects together with operations allows on them
  - Object represented by its name or address, called a **capability**
  - Execute operation M on object O_j, process requests operation and specifies capability as parameter
    - Possession of capability means access is allowed

Implementation of Access Matrix (Cont.)

- Each column = Access-control list for one object
  Defines who can perform what operation

  Domain 1 = Read, Write
  Domain 2 = Read
  Domain 3 = Read

- Each Row = Capability List (like a key)
  For each domain, what operations allowed on what objects

  Object F1 – Read

  Object F4 – Read, Write, Execute

  Object F5 – Read, Write, Delete, Copy

Implementation of Access Matrix (Cont.)

- Most systems use combination of access-control lists and capabilities
  - First access to an object -> access-control list searched
    - If allowed, capability created and attached to process
      - Additional accesses need not be checked
    - After last access, capability destroyed

The Security Problem

- System **secure** if resources used and accessed as intended under all circumstances
- **Intruders** (**crackers or hackers**) attempt to breach security
- **Threat** is potential security violation
- **Attack** is attempt to breach security

Security Violation Categories

- **Breach of confidentiality**
  - Unauthorized reading of data
- **Breach of integrity**
  - Unauthorized modification of data
- **Breach of availability**
  - Unauthorized destruction of data
- **Theft of service**
  - Unauthorized use of resources
- **Denial of service (DOS)**
  - Prevention of legitimate use

Security Measure Levels

- Impossible to have absolute security, but make cost to perpetrator sufficiently high to deter most intruders
- Security must occur at four levels to be effective:
  - **Physical**
    - Data centers, servers, connected terminals
  - **Human**
    - Avoid **social engineering**, **phishing**, **dumpster diving**
  - **Operating System**
    - Protection mechanisms, debugging
  - **Network**
    - Intercepted communications, interruption, DOS
- Security is as weak as the weakest link in the chain

Malware

- **Trojan Horse**
  - Code segment that misuses its environment
- **Trap Door**
  - Specific user identifier or password that circumvents normal security procedures
- **Virus**
  - Code fragment embedded in legitimate program
  - Self-replicating, designed to infect other computers
- **Logic Bomb**
  - Program that initiates a security incident under certain circumstances

Program Security

- **Stack** and **Buffer Overflow**
  - Exploits a bug in a program (overflow either the stack or memory buffers)
  - Failure to check bounds on inputs, arguments
  - Write past arguments on the stack into the return address on stack
  - When routine returns from call, returns to hacked address
    - Pointed to code loaded onto stack that executes malicious code
  - Unauthorized user or privilege escalation

System and Network Threats (Cont.)

- **Port scanning**
  - Automated attempt to connect to a range of ports on one or a range of IP addresses
  - Detection of answering service protocol
  - Detection of OS and version running on system
  - `nmap` scans all ports in a given IP range for a response
  - `nessus` has a database of protocols and bugs (and exploits) to apply against a system

System and Network Threats (Cont.)

- **Denial of Service**
  - Overload the targeted computer preventing it from doing any useful work
  - **Distributed denial-of-service** (**DDOS**) come from multiple sites at once
  - Consider traffic to a web site
    - How can you tell the difference between being a target and being really popular?
  - Accidental – CS students writing bad `fork()` code
  - Purposeful – extortion, punishment

User Authentication

- Crucial to identify user correctly, as protection systems depend on user ID
- User identity most often established through **passwords**, can be considered a special case of either keys or capabilities
- Passwords must be kept secret
  - Frequent change of passwords
  - History to avoid repeats
  - Use of “non-guessable” passwords
  - Log all invalid access attempts (but not the passwords themselves)
  - Unauthorized transfer

Implementing Security Defenses

- Intrusion detection endeavors to detect attempted or successful intrusions
  - **Signature-based** detection spots known bad patterns
  - **Anomaly detection** spots differences from normal behavior
    - Can detect **zero-day** attacks
  - **False-positives** and **false-negatives** a problem
- Virus protection
  - Searching all programs or programs at execution for known virus patterns
  - Or run in **sandbox** so can't damage system

Firewalling to Protect Systems and Networks

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

Attacks against Network Communication

- **Eavesdropping**
  - Stealing the content of network communication
- **Replay attack**
  - Resend a previously intercepted message
- **Man-in-the-middle attack**
  - Intruder sits in data flow, masquerading as sender to receiver and vice versa
- **Session hijacking**
  - Intercept an already-established session to bypass authentication

Cryptography

- Encryption
- Authentication
- Key distribution

- These topics are covered in “Network security”

Encryption

- Protect **confidentiality** of a message
- Encryption algorithm consists of
  - Set K of keys
  - Set M of Messages
  - Set C of ciphertexts (encrypted messages)
  - A function $E : K \rightarrow (M \rightarrow C)$. That is, for each $k \in K$, E_k is a function for generating ciphertexts from messages
    - Both E and E_k for any k should be efficiently computable functions
  - A function $D : K \rightarrow (C \rightarrow M)$. That is, for each $k \in K$, D_k is a function for generating messages from ciphertexts
    - Both D and D_k for any k should be efficiently computable functions

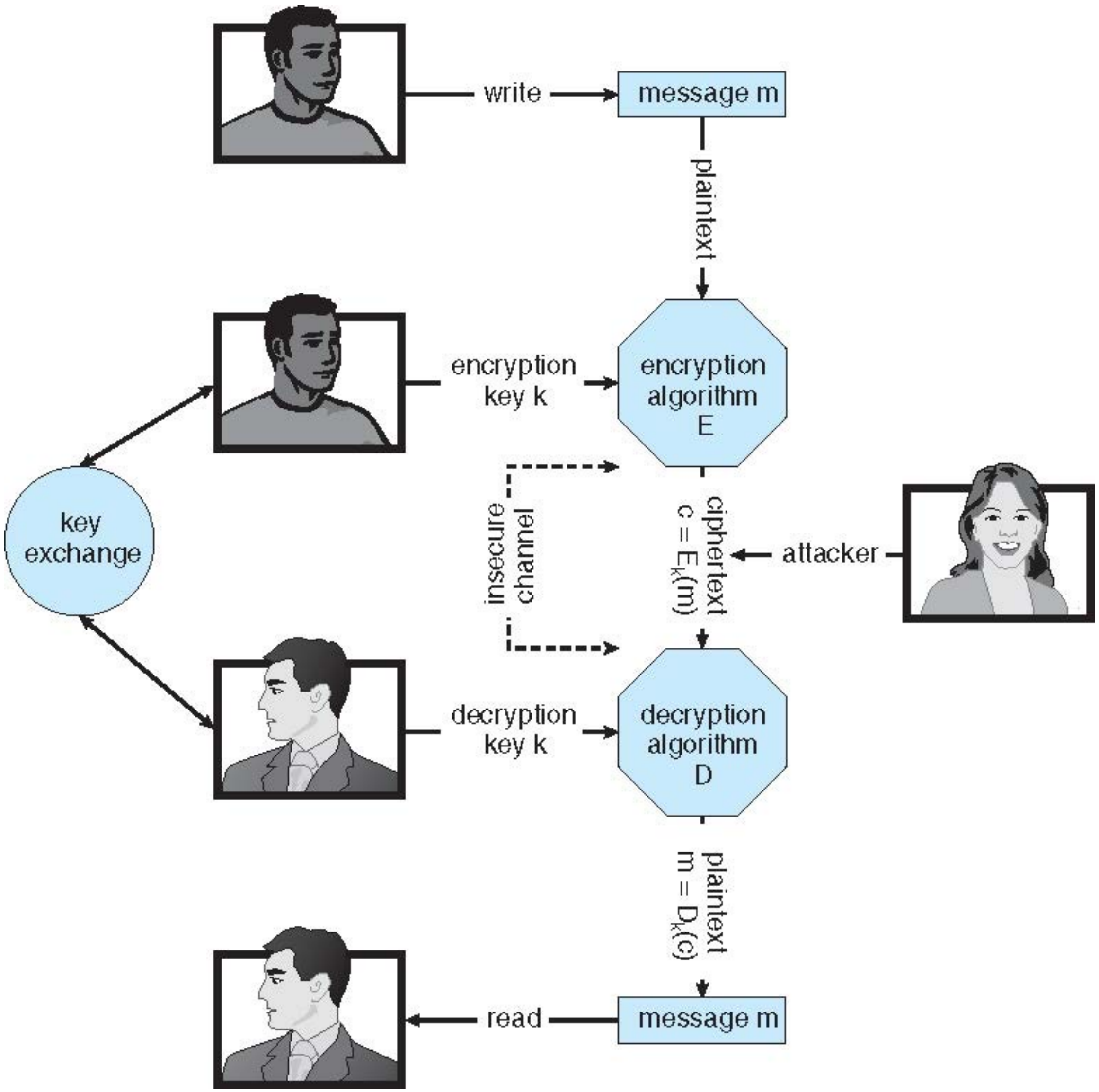
Encryption (Cont.)

- An encryption algorithm must provide this essential property: Given a ciphertext $c \in C$, a computer can compute m such that $E_k(m) = c$ only if it possesses *k*
  - Thus, a computer holding *k* can decrypt ciphertexts to the plaintexts used to produce them, but a computer not holding *k* cannot decrypt ciphertexts
  - Since ciphertexts are generally exposed (for example, sent on the network), it is important that it be infeasible to derive *k* from the ciphertexts

Symmetric Encryption

- Same key used to encrypt and decrypt
  - Therefore *k* must be kept secret
- Block cipher (messages encrypted block-by-block)
  - DES was most commonly used symmetric block-encryption algorithm
    - Keys too short so now considered insecure
  - 2001 NIST adopted new block cipher - Advanced Encryption Standard (**AES**)
    - Keys of 128, 192, or 256 bits, works on 128 bit blocks
- Stream cipher (message encrypted bit-by-bit or byte-by-byte)
  - RC4 is most common symmetric stream cipher, but known to have vulnerabilities

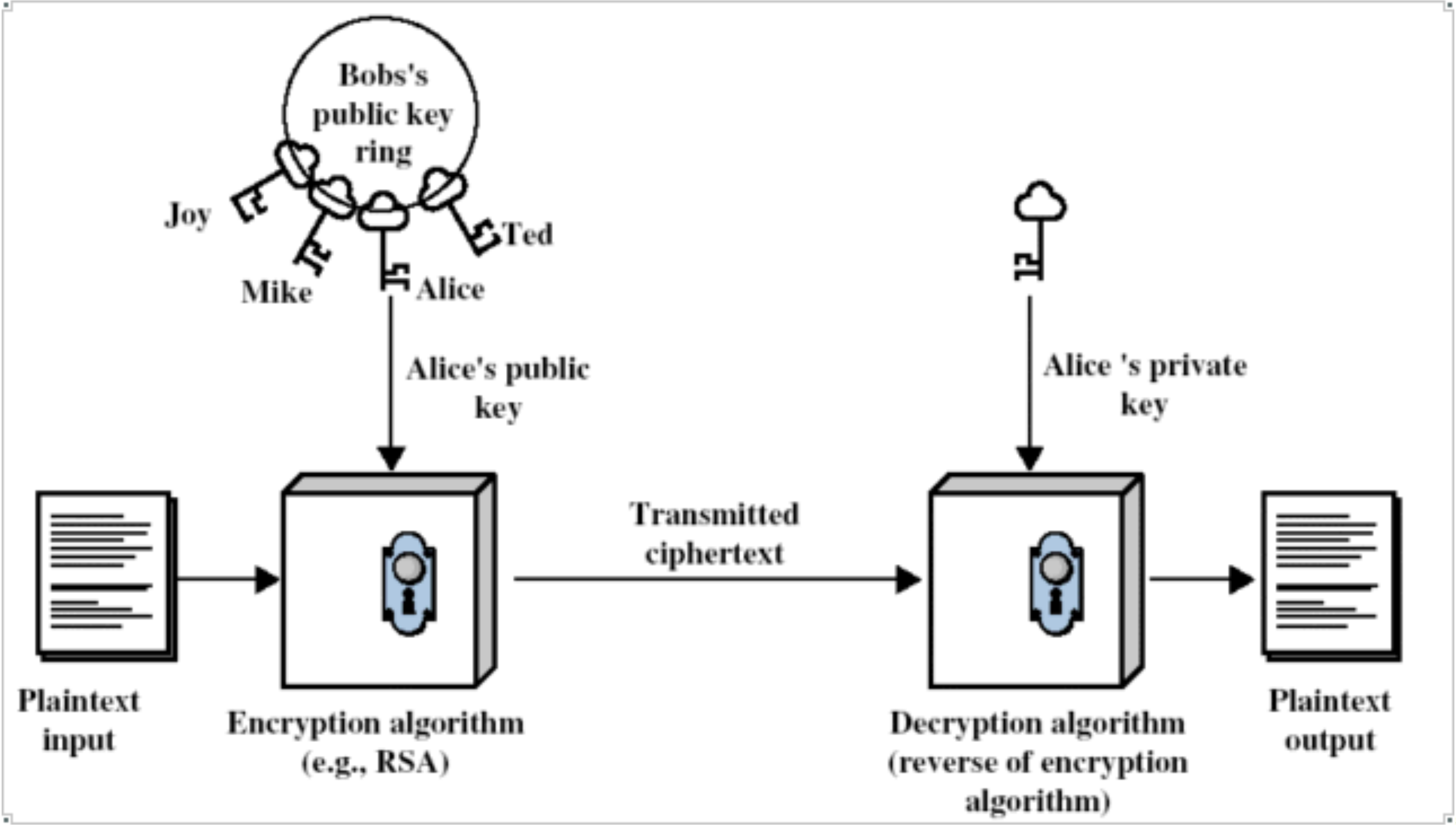
Secure Communication over Insecure Medium



Asymmetric Encryption

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

Encryption using Asymmetric Cryptography



Authentication

- Protect integrity of a message
- Algorithm components
  - A set K of keys
  - A set M of messages
  - A set A of authenticators
  - A function $S : K \rightarrow (M \rightarrow A)$
    - That is, for each $k \in K$, S_k is a function for generating authenticators from messages
    - Both S and S_k for any k should be efficiently computable functions
  - A function $V : K \rightarrow (M \times A \rightarrow \{\text{true, false}\})$. That is, for each $k \in K$, V_k is a function for verifying authenticators on messages
    - Both V and V_k for any k should be efficiently computable functions

Authentication (Cont.)

- For a message *m*, a computer can generate an authenticator $a \in A$ such that $V_k(m, a) =$ `true` only if it possesses *k*
- Thus, computer holding *k* can generate authenticators on messages so that any other computer possessing *k* can verify them
- Computer not holding *k* cannot generate authenticators on messages that can be verified using V_k
- Since authenticators are generally exposed (for example, they are sent on the network with the messages themselves), it must not be feasible to derive *k* from the authenticators
- Practically, if $V_k(m,a) =$ **`true`** then we know *m* has not been modified and that send of message has *k*
  - If we share *k* with only one entity, know where the message originated

Authentication

- **Message-authentication code (MAC)** authentication algorithm
  - Based on symmetric encryption
  - Both parties share secret keys
- **Digital signatures** authentication algorithm
  - Based on asymmetric encryption
  - ***anyone*** can verify authenticity of a message using the public key

Key Distribution

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

Digital Certificates

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

Encryption Example – SSL/TLS

- Used between web servers and browsers for secure communication (credit card numbers)
- The server is verified with a **certificate** assuring client is talking to correct server
- Asymmetric cryptography used to establish a secure **session key** (symmetric encryption) for bulk of communication during session
- Communication between each computer then uses symmetric key cryptography