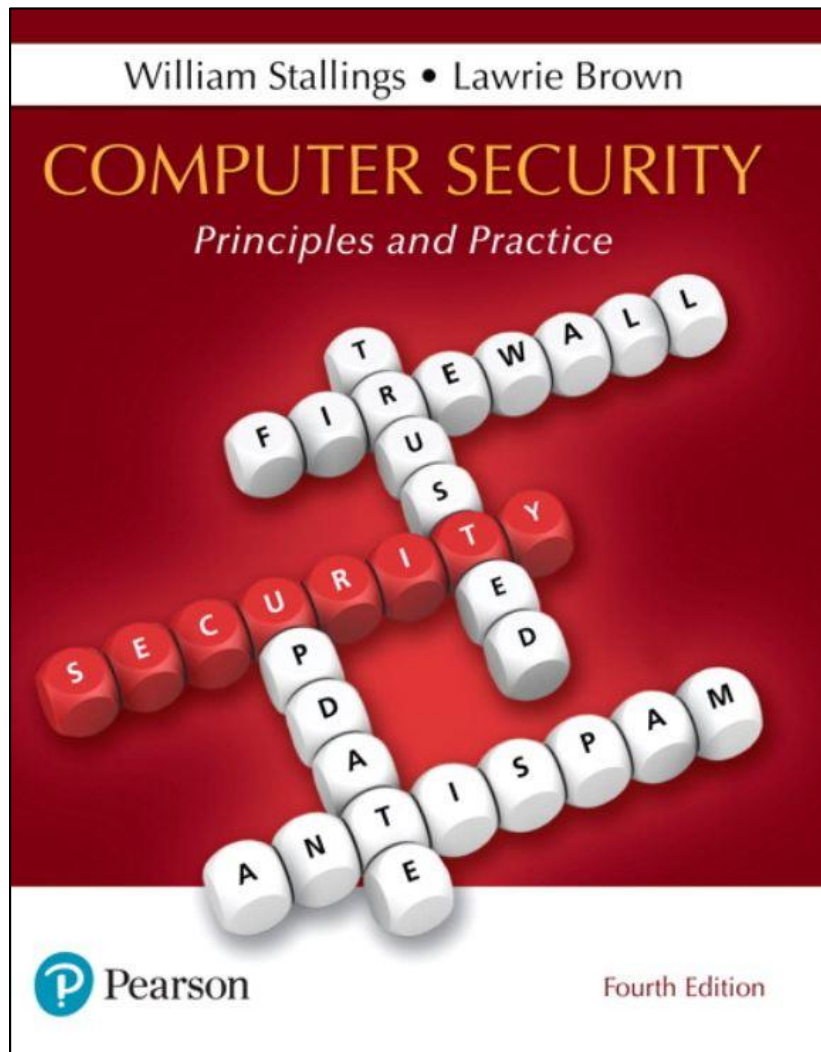


# Computer Security: Principles and Practice

Fourth Edition



## Chapter 2

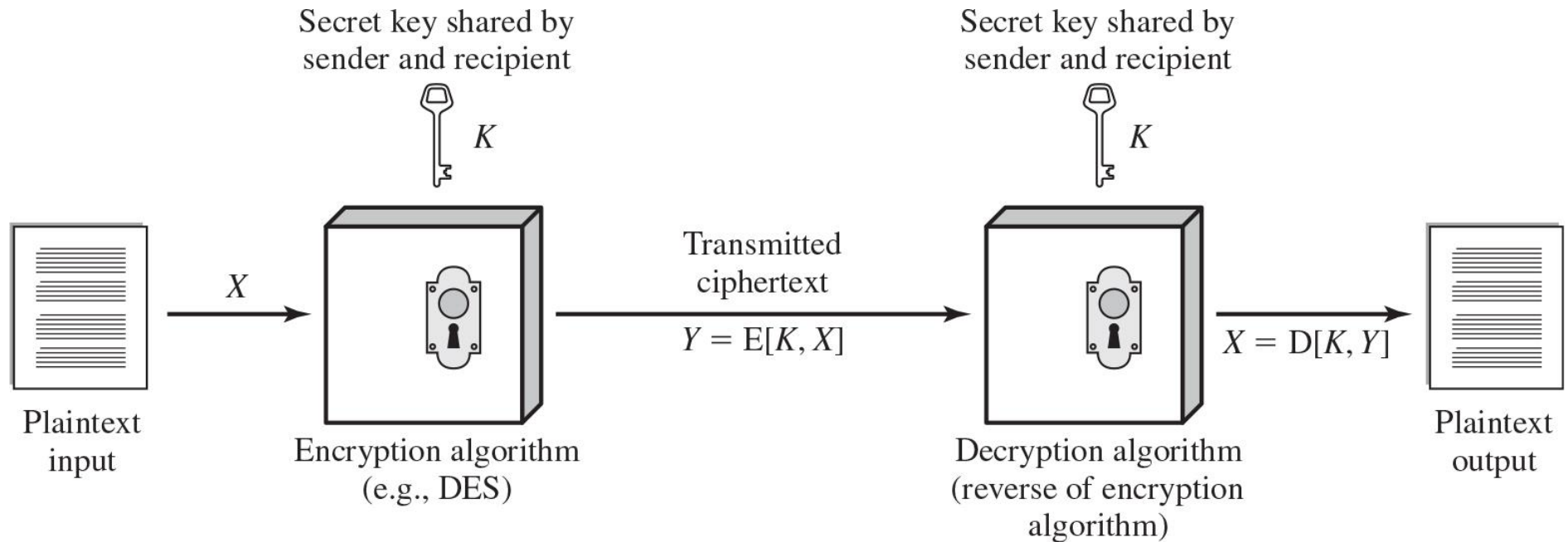
### Cryptographic Tools

# One Key / The CKDK Key

## Symmetric Encryption

- The universal technique for providing confidentiality for transmitted or stored data
- Also referred to as conventional encryption or single-key encryption
- Two requirements for secure use:
  - Need a strong encryption algorithm
  - Sender and receiver must have obtained copies of the secret key in a secure fashion and must keep the key secure

# Figure 2.1 Simplified Model of Symmetric Encryption



# Attacking Symmetric Encryption

## Cryptanalytic Attacks

- Rely on:
  - Nature of the algorithm
  - Some knowledge of the general characteristics of the plaintext
  - Some sample plaintext-ciphertext pairs
- Exploits the characteristics of the algorithm to attempt to deduce a specific plaintext or the key being used
  - If successful all future and past messages encrypted with that key are compromised

## Brute-Force Attacks

- Try all possible keys on some ciphertext until an intelligible translation into plaintext is obtained
  - On average half of all possible keys must be tried to achieve success

# Table 2.1 Comparison of Three Popular Symmetric Encryption Algorithms

	<b>DES</b>	<b>Triple DES</b>	<b>AES</b>
<b>Plaintext block size (bits)</b>	64	64	128
<b>Ciphertext block size (bits)</b>	64	64	128
<b>Key size (bits)</b>	56	112 or 168	128, 192, or 256

DES = Data Encryption Standard

AES = Advanced Encryption Standard

# Data Encryption Standard (DES)



- Until recently was the most widely used encryption scheme
  - FIPS PUB 46
  - Referred to as the Data Encryption Algorithm (DEA)
  - Uses 64 bit plaintext block and 56 bit key to produce a 64 bit ciphertext block



- Strength concerns:
  - Concerns about the algorithm itself
    - DES is the most studied encryption algorithm in existence
  - Concerns about the use of a 56-bit key
    - The speed of commercial off-the-shelf processors makes this key length woefully inadequate

# Table 2.2 Average Time Required for Exhaustive Key Search

Key Size (bits)	Cipher	Number of Alternative Keys	Time Required at $10^9$ decryptions / $\mu s$	Time Required at $10^{13}$ decryptions / $\mu s$
56	DES	$2^{56} \approx 7.2 \times 10^{16}$	$2^{55} \mu s = 1.125$ years	1 hour
128	AES	$2^{128} \approx 3.4 \times 10^{38}$	$2^{127} \mu s = 5.3 \times 10^{21}$ years	$5.3 \times 10^{17}$ years
168	Triple DES	$2^{168} \approx 3.7 \times 10^{50}$	$2^{167} \mu s = 5.8 \times 10^{33}$ years	$5.8 \times 10^{29}$ years
192	AES	$2^{192} \approx 6.3 \times 10^{57}$	$2^{191} \mu s = 9.8 \times 10^{40}$ years	$9.8 \times 10^{36}$ years
256	AES	$2^{256} \approx 1.2 \times 10^{77}$	$2^{255} \mu s = 1.8 \times 10^{60}$ years	$1.8 \times 10^{56}$ years

# Triple DES (3DES)

- Repeats basic DES algorithm three times using either two or three unique keys
- First standardized for use in financial applications in ANSI standard X9.17 in 1985
- Attractions:
  - 168-bit key length overcomes the vulnerability to brute-force attack of DES
  - Underlying encryption algorithm is the same as in DES
- Drawbacks:
  - Algorithm is sluggish in software
  - Uses a 64-bit block size



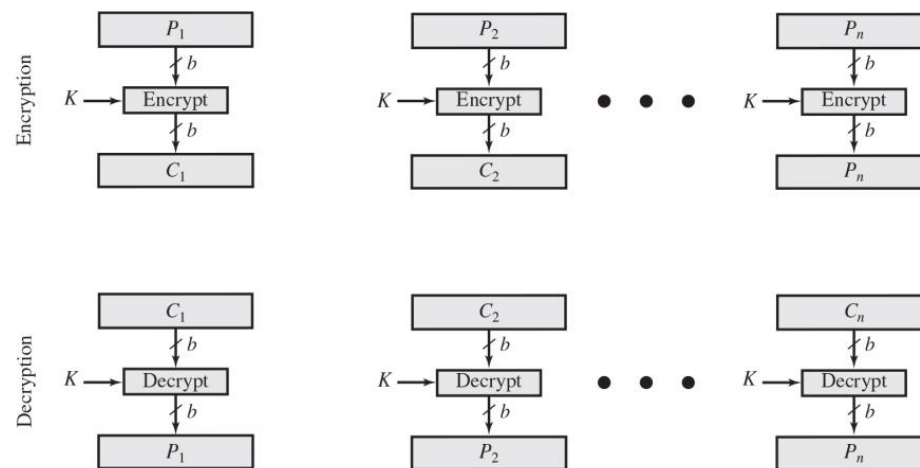
# Advanced Encryption Standard (AES)

- Needed a replacement for 3DES
  - 3DES was not reasonable for long term use
- NIST called for proposals for a new AES in 1997
  - Should have a security strength equal to or better than 3DES
  - Significantly improved efficiency
  - Symmetric block cipher
  - 128 bit data and 128/192/256 bit keys
- Selected Rijndael in November 2001
  - Published as FIPS 197

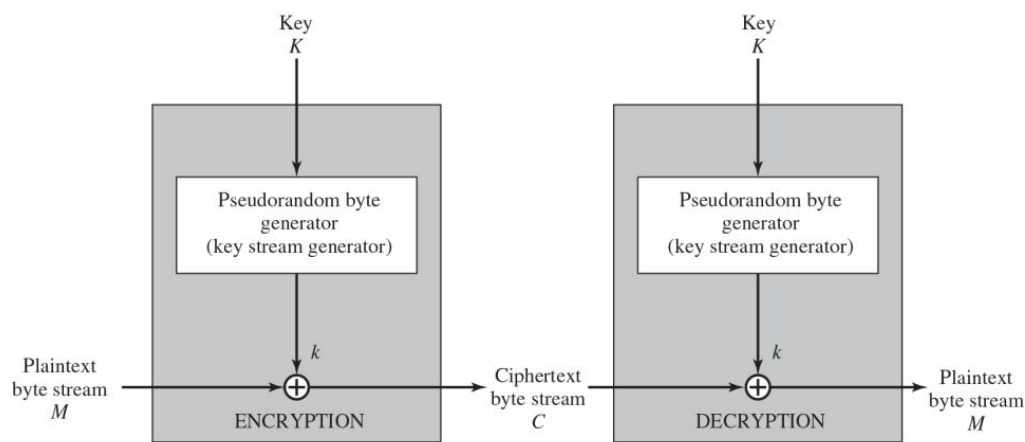
# Practical Security Issues

- Typically symmetric encryption is applied to a unit of data larger than a single 64-bit or 128-bit block
- Electronic codebook (ECB) mode is the simplest approach to multiple-block encryption
  - Each block of plaintext is encrypted using the same key
  - Cryptanalysts may be able to exploit regularities in the plaintext
- Modes of operation
  - Alternative techniques developed to increase the security of symmetric block encryption for large sequences
  - Overcomes the weaknesses of ECB

# Figure 2.2 Types of Symmetric Encryption



(a) Block cipher encryption (electronic codebook mode)



(b) Stream encryption

# Block & Stream Ciphers

- Block Cipher
  - Processes the input one block of elements at a time
  - Produces an output block for each input block
  - Can reuse keys
  - More common
- Stream Cipher
  - Processes the input elements continuously
  - Produces output one element at a time
  - Primary advantage is that they are almost always faster and use far less code
  - Encrypts plaintext one byte at a time
  - Pseudorandom stream is one that is unpredictable without knowledge of the input key

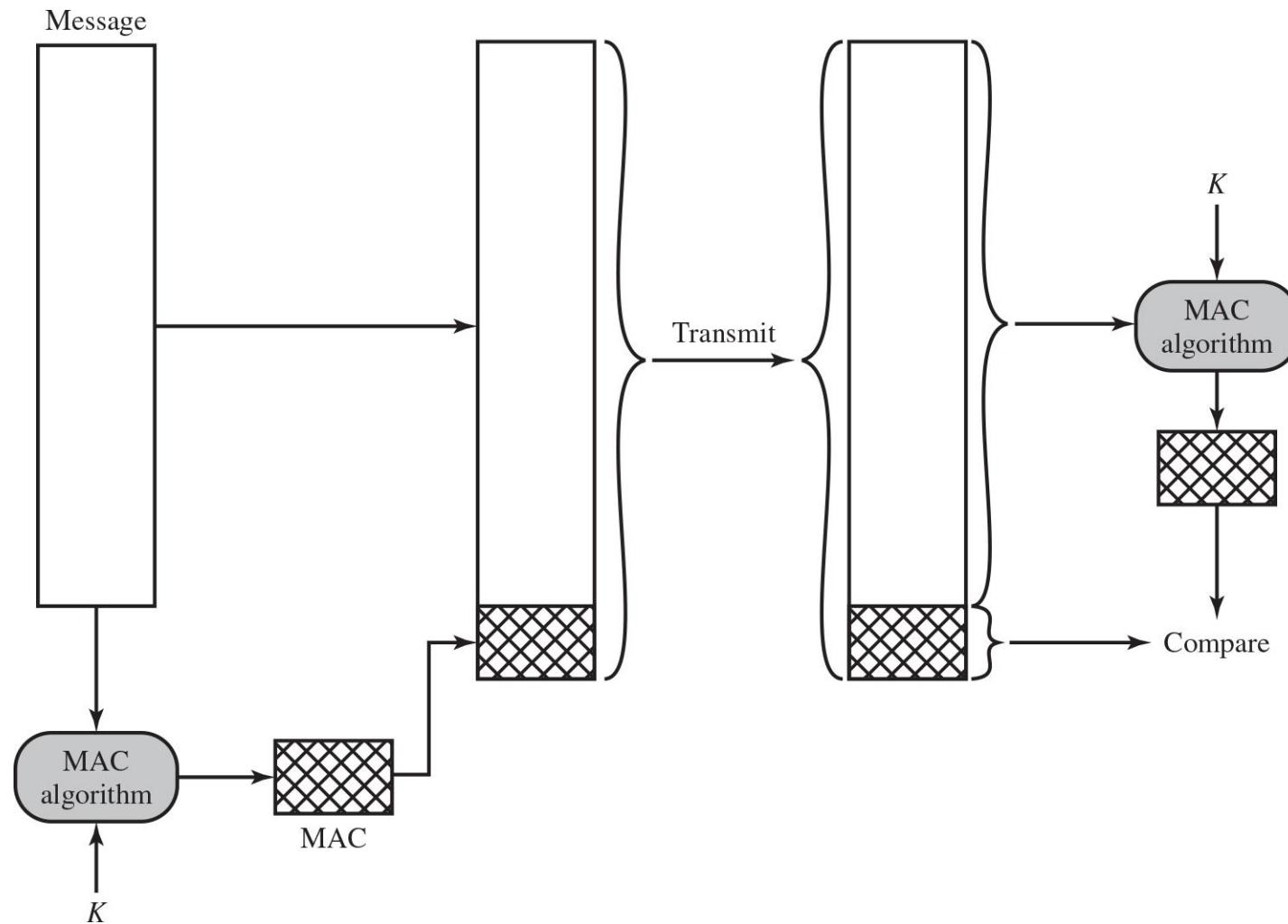
# Message Authentication

- Protects against active attacks
- Verifies received message is authentic
  - Contents have not been altered
  - From authentic source
  - Timely and in correct sequence
- Can use conventional encryption
  - Only sender and receiver share a key

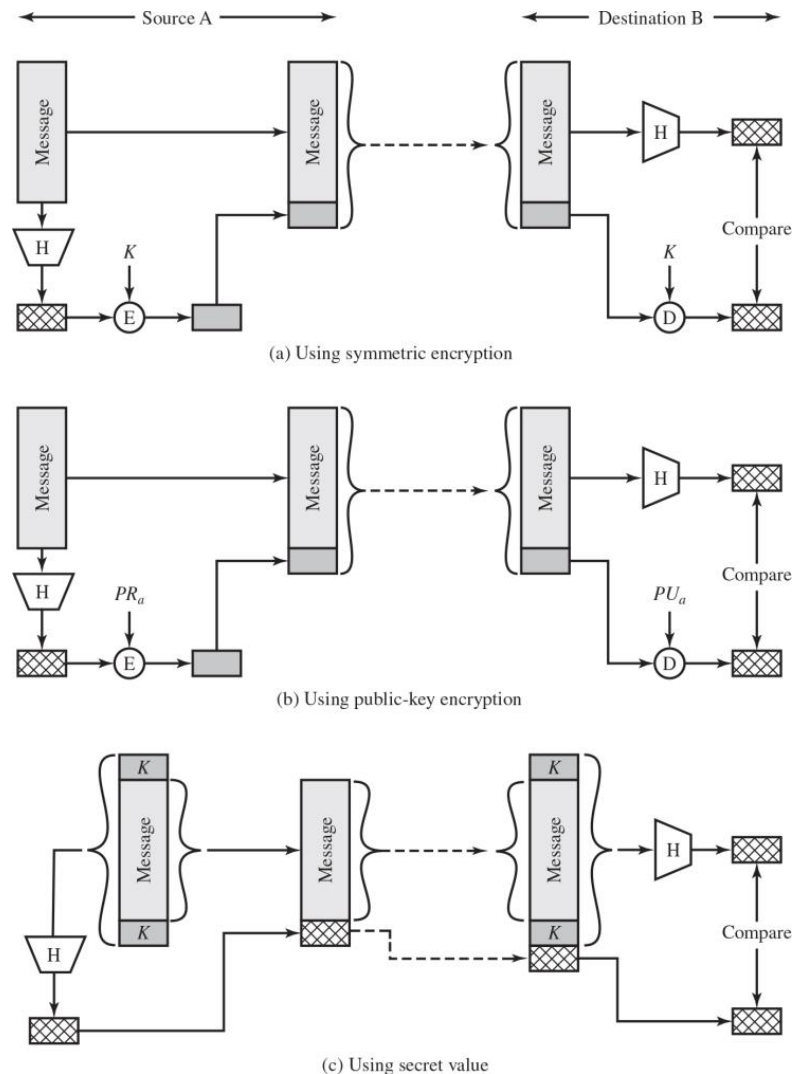
# Message Authentication Without Confidentiality

- Message encryption by itself does not provide a secure form of authentication
- It is possible to combine authentication and confidentiality in a single algorithm by encrypting a message plus its authentication tag
- Typically message authentication is provided as a separate function from message encryption
- Situations in which message authentication without confidentiality may be preferable include:
  - There are a number of applications in which the same message is broadcast to a number of destinations
  - An exchange in which one side has a heavy load and cannot afford the time to decrypt all incoming messages
  - Authentication of a computer program in plaintext is an attractive service
- Thus, there is a place for both authentication and encryption in meeting security requirements

# Figure 2.3 Message Authentication Using a Message Authentication Code (MAC)



# Figure 2.5 Message Authentication Using a One-Way Hash Function





# To Be Useful for Message Authentication, a Hash Function $H$ Must Have the Following Properties:

- Can be applied to a block of data of any size
- Produces a fixed-length output
- $H(x)$  is relatively easy to compute for any given  $x$
- One-way or pre-image resistant
  - Computationally infeasible to find  $x$  such that  $H(x) = h$
- Computationally infeasible to find  $y \neq x$  such that  $H(y) = H(x)$
- Collision resistant or strong collision resistance
  - Computationally infeasible to find any pair  $(x, y)$  such that  $H(x) = H(y)$

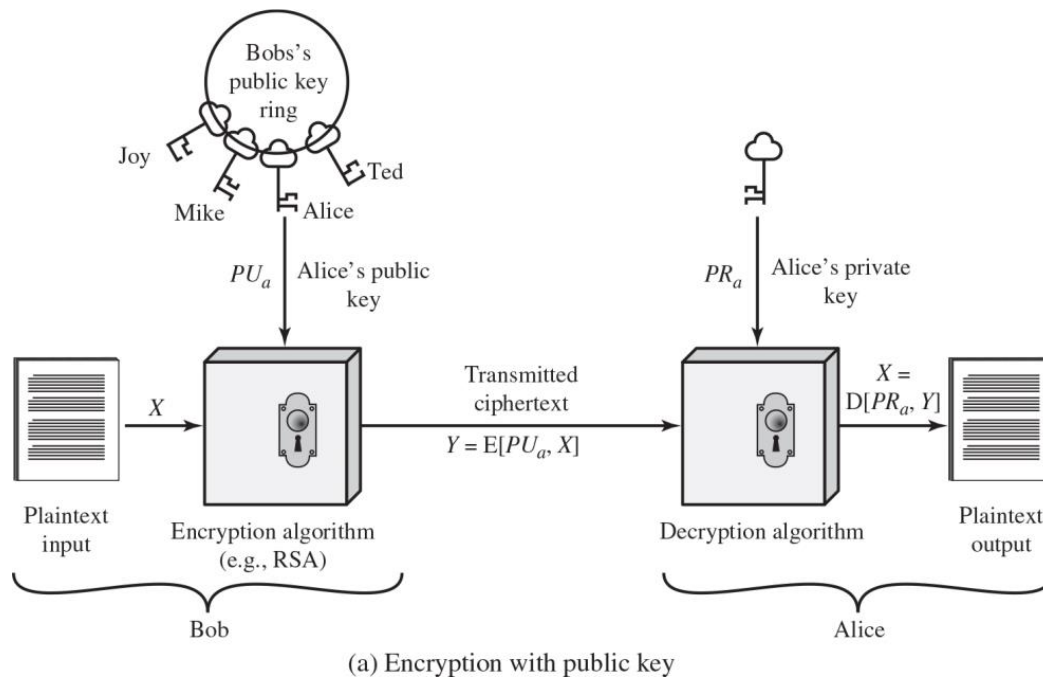
# Security of Hash Functions

- There are two approaches to attacking a secure hash function:
  - Cryptanalysis
    - Exploit logical weaknesses in the algorithm
  - Brute-force attack
    - Strength of hash function depends solely on the length of the hash code produced by the algorithm
- SHA most widely used hash algorithm
- Additional secure hash function applications:
  - Passwords
    - Hash of a password is stored by an operating system
  - Intrusion detection
    - Store  $H(F)$  for each file on a system and secure the hash values

# Public-Key Encryption Structure

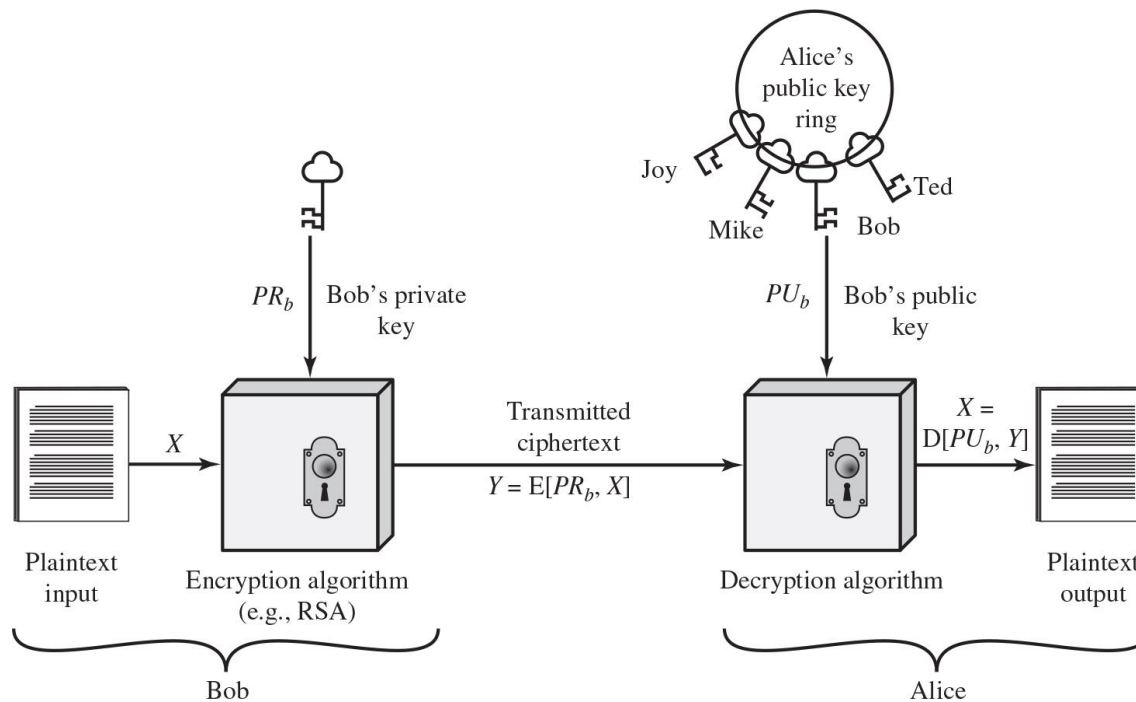
- Publicly proposed by Diffie and Hellman in 1976
- Based on mathematical functions
- Asymmetric
  - Uses two separate keys
  - Public key and private key
  - Public key is made public for others to use
- Some form of protocol is needed for distribution

# Figure 2.6 Public-Key Cryptography (1 of 2)



- Plaintext
  - Readable message or data that is fed into the algorithm as input
- Encryption algorithm
  - Performs transformations on the plaintext
- Public and private key
  - Pair of keys, one for encryption, one for decryption
- Ciphertext
  - Scrambled message produced as output
- Decryption key
  - Produces the original plaintext

## Figure 2.6 Public-Key Cryptography (2 of 2)



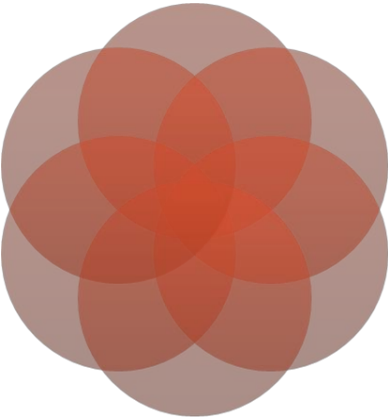
(b) Encryption with private key

- User encrypts data using his or her own private key
- Anyone who knows the corresponding public key will be able to decrypt the message

## Table 2.3 Applications for Public-Key Cryptosystems

Algorithm	Digital Signature	Symmetric Key Distribution	Encryption of Secret Keys
RSA	Yes	Yes	Yes
Diffie–Hellman	No	Yes	No
DSS	Yes	No	No
Elliptic Curve	Yes	Yes	Yes

# Requirements for Public-Key Cryptosystems

- Computationally easy to create key pairs
  - Useful if either key can be used for each role
  - Computationally easy for sender knowing public key to encrypt messages
  - Computationally easy for receiver knowing private key to decrypt ciphertext
  - Computationally infeasible for opponent to otherwise recover original message
  - Computationally infeasible for opponent to determine private key from public key
- 

# Asymmetric Encryption Algorithms (1 of 2)

- RSA (Rivest, Shamir, Adleman)
  - Developed in 1977
  - Most widely accepted and implemented approach to public-key encryption
  - Block cipher in which the plaintext and ciphertext are integers between 0 and  $n - 1$  for some  $n$ .
- Diffie-Hellman key exchange algorithm
  - Enables two users to securely reach agreement about a shared secret that can be used as a secret key for subsequent symmetric encryption of messages
  - Limited to the exchange of the keys



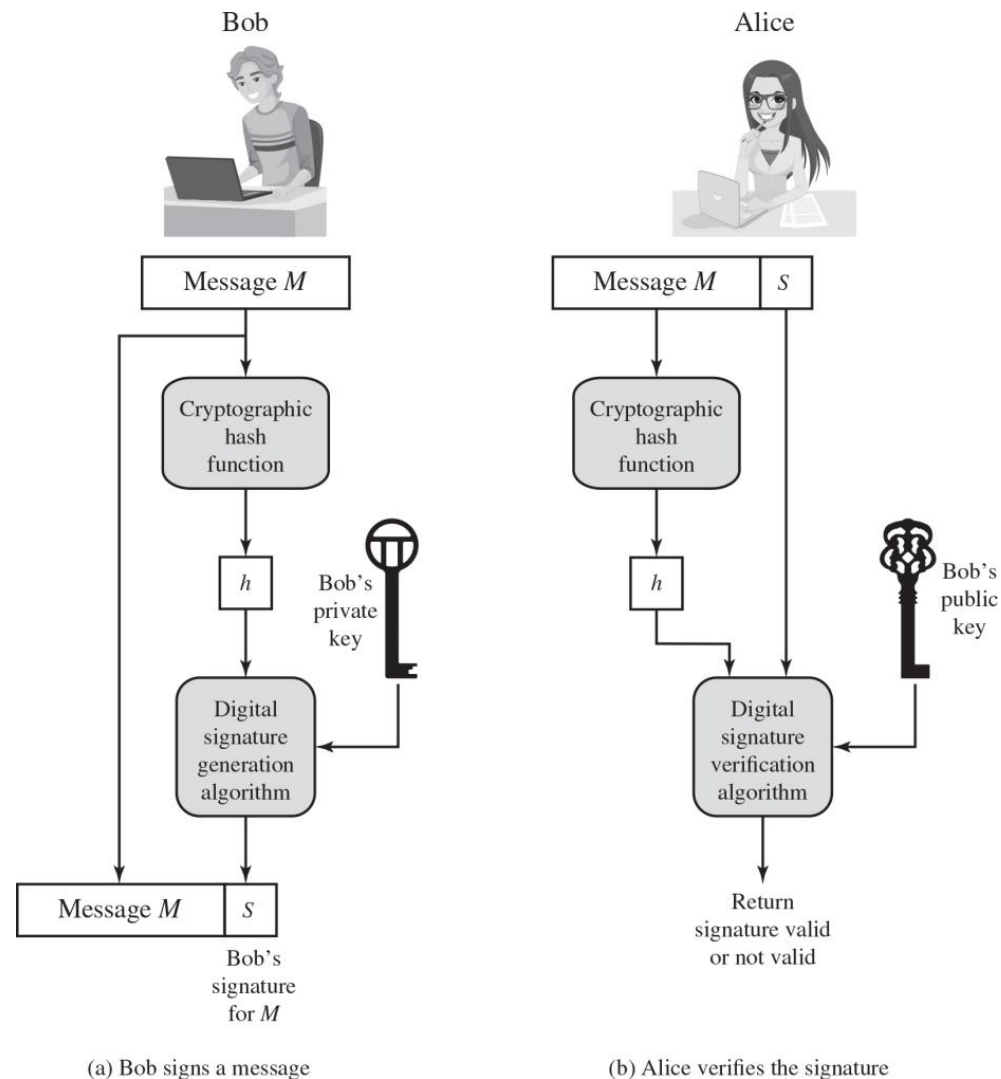
# Asymmetric Encryption Algorithms (2 of 2)

- Digital Signature Standard (DSS)
  - Provides only a digital signature function with SHA-1
  - Cannot be used for encryption or key exchange
- Elliptic curve cryptography (ECC)
  - Security like RSA, but with much smaller keys

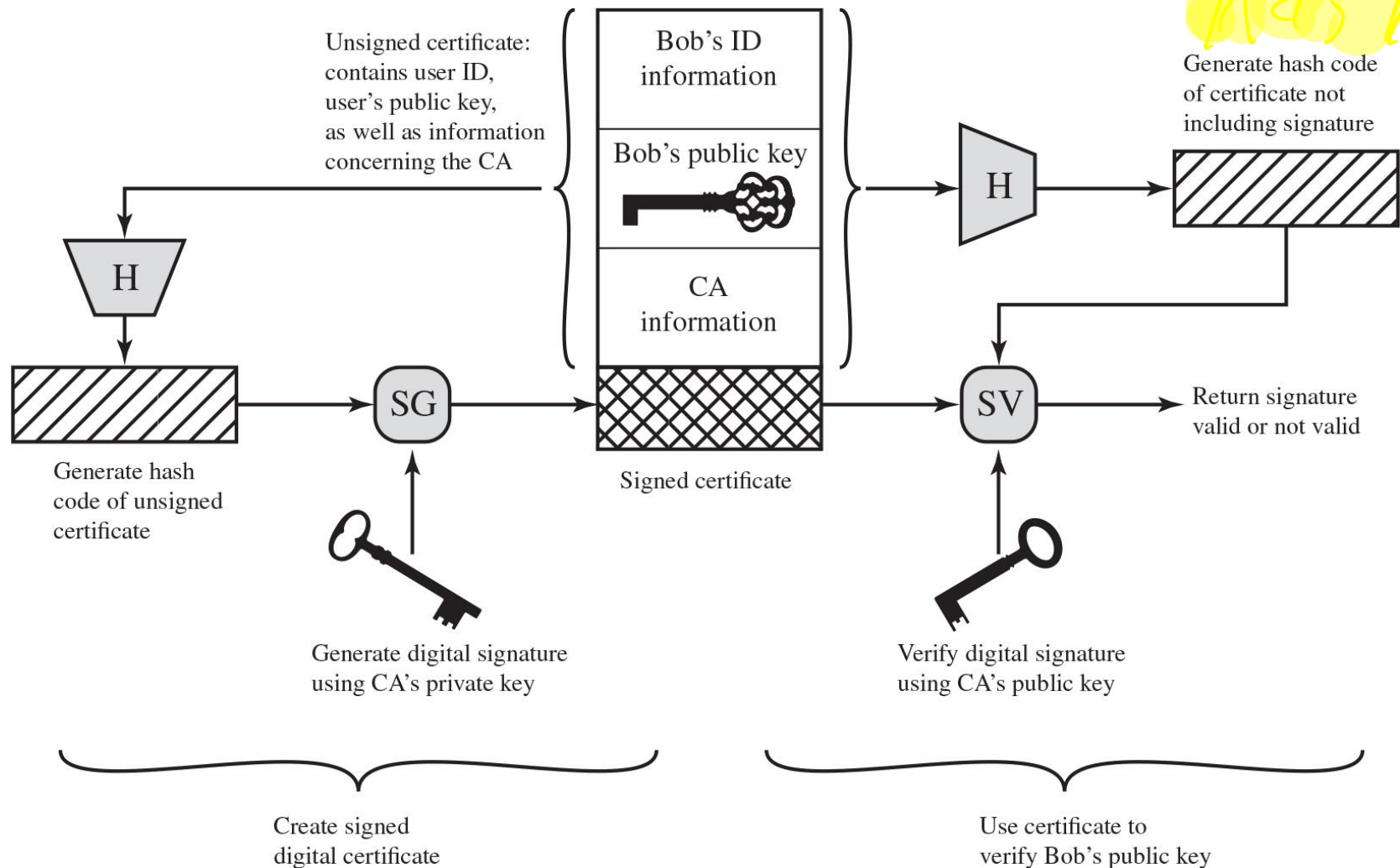
# Digital Signatures

- NIST FIPS PUB 186-4 defines a digital signature as:
  - "The result of a cryptographic transformation of data that, when properly implemented, provides a mechanism for verifying origin authentication, data integrity and signatory non-repudiation."
- Thus, a digital signature is a data-dependent bit pattern, generated by an agent as a function of a file, message, or other form of data block
- FIPS 186-4 specifies the use of one of three digital signature algorithms:
  - Digital Signature Algorithm (DSA)
  - RSA Digital Signature Algorithm
  - Elliptic Curve Digital Signature Algorithm (ECDSA)

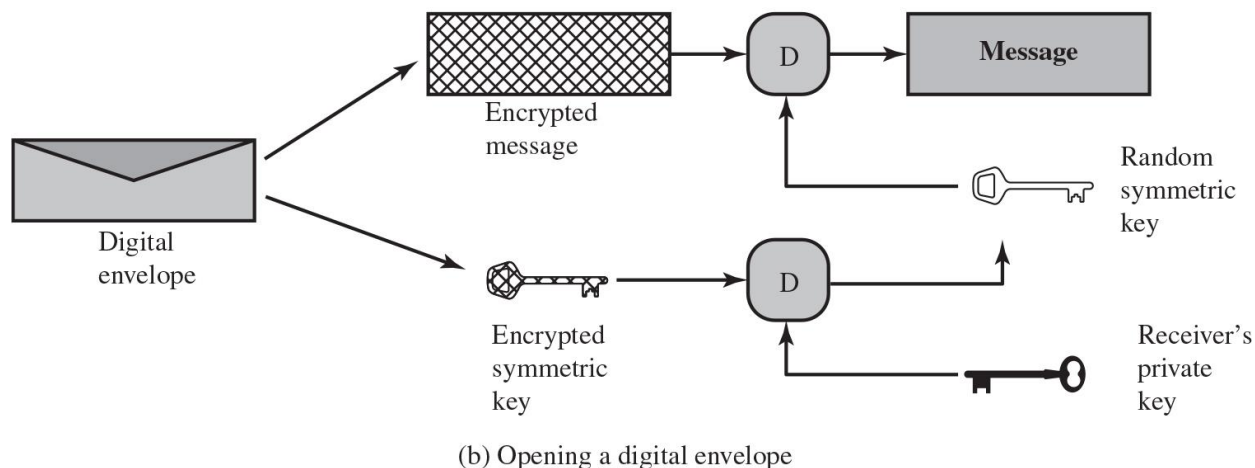
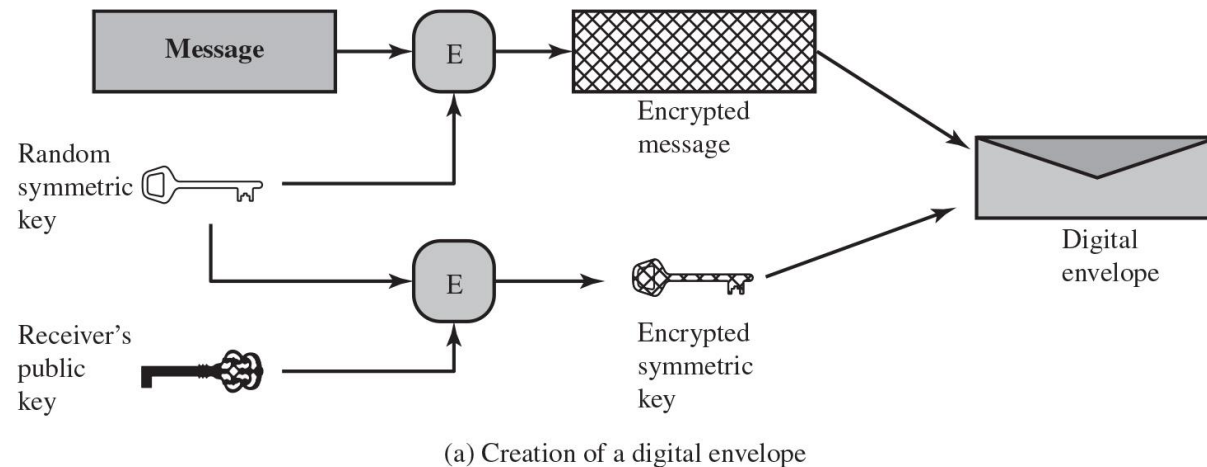
# Figure 2.7 Simplified Depiction of Essential Elements of Digital Signature Process



# Figure 2.8 Public-Key Certificate Use



# Figure 2.9 Digital Envelopes



# Random Numbers

Uses include generation of:

- Keys for public-key algorithms
- Stream key for symmetric stream cipher
- Symmetric key for use as a temporary session key or in creating a digital envelope
- Handshaking to prevent replay attacks
- Session key

# Random Number Requirements

## Randomness

- Criteria:
  - Uniform distribution
    - Frequency of occurrence of each of the numbers should be approximately the same
  - Independence
    - No one value in the sequence can be inferred from the others

## Unpredictability

- Each number is statistically independent of other numbers in the sequence
- Opponent should not be able to predict future elements of the sequence on the basis of earlier elements

# Random Versus Pseudorandom

bit locker

- Cryptographic applications typically make use of algorithmic techniques for random number generation
  - Algorithms are deterministic and therefore produce sequences of numbers that are not statistically random
- Pseudorandom numbers are:
  - Sequences produced that satisfy statistical randomness tests
  - Likely to be predictable
- True random number generator (TRNG):
  - Uses a nondeterministic source to produce randomness
  - Most operate by measuring unpredictable natural processes
    - e.g. radiation, gas discharge, leaky capacitors
  - Increasingly provided on modern processors



# Practical Application: Encryption of Stored Data

- Common to encrypt transmitted data
- Much less common for stored data
  - There is often little protection beyond domain authentication and operating system access controls
  - Data are archived for indefinite periods
  - Even though erased, until disk sectors are reused data are recoverable
- Approaches to encrypt stored data:
  - Use a commercially available encryption package
  - Back-end appliance
  - Library based tape encryption
  - Background laptop/PC data encryption

# Summary (1 of 2)

- Confidentiality with symmetric encryption
  - Symmetric encryption
  - Symmetric block encryption algorithms
  - Stream ciphers
- Message authentication and hash functions
  - Authentication using symmetric encryption
  - Message authentication without message encryption
  - Secure hash functions
  - Other applications of hash functions
- Random and pseudorandom numbers
  - The use of random numbers
  - Random versus pseudorandom

# Summary (2 of 2)

- Public-key encryption
  - Structure
  - Applications for public-key cryptosystems
  - Requirements for public-key cryptography
  - Asymmetric encryption algorithms
- Digital signatures and key management
  - Digital signature
  - Public-key certificates
  - Symmetric key exchange using public-key encryption
  - Digital envelopes
- Practical Application: Encryption of Stored Data

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