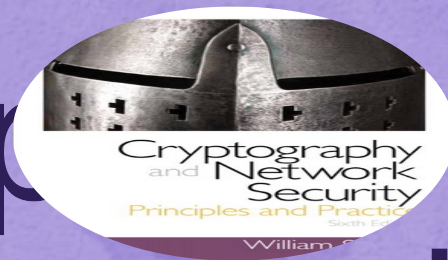
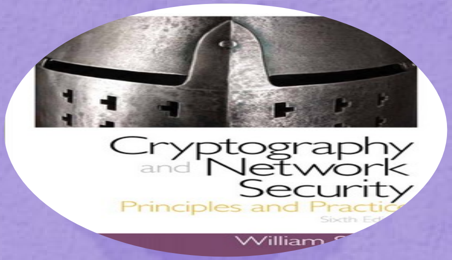


Cryptography and Network Security

Seventh Edition

by William Stallings



Chapter 11

Cryptographic Hash Functions

Hash Functions

- A hash function H accepts a variable-length block of data *M* as input and produces a fixed-size hash value
  - $h = \mathrm{H}(M)$
  - Principal object is data integrity
- Cryptographic hash function
  - An algorithm for which it is computationally infeasible to find either:

    (a) a data object that maps to a pre-specified hash result (the one-way property)

    (b) two data objects that map to the same hash result (the collision-free property)

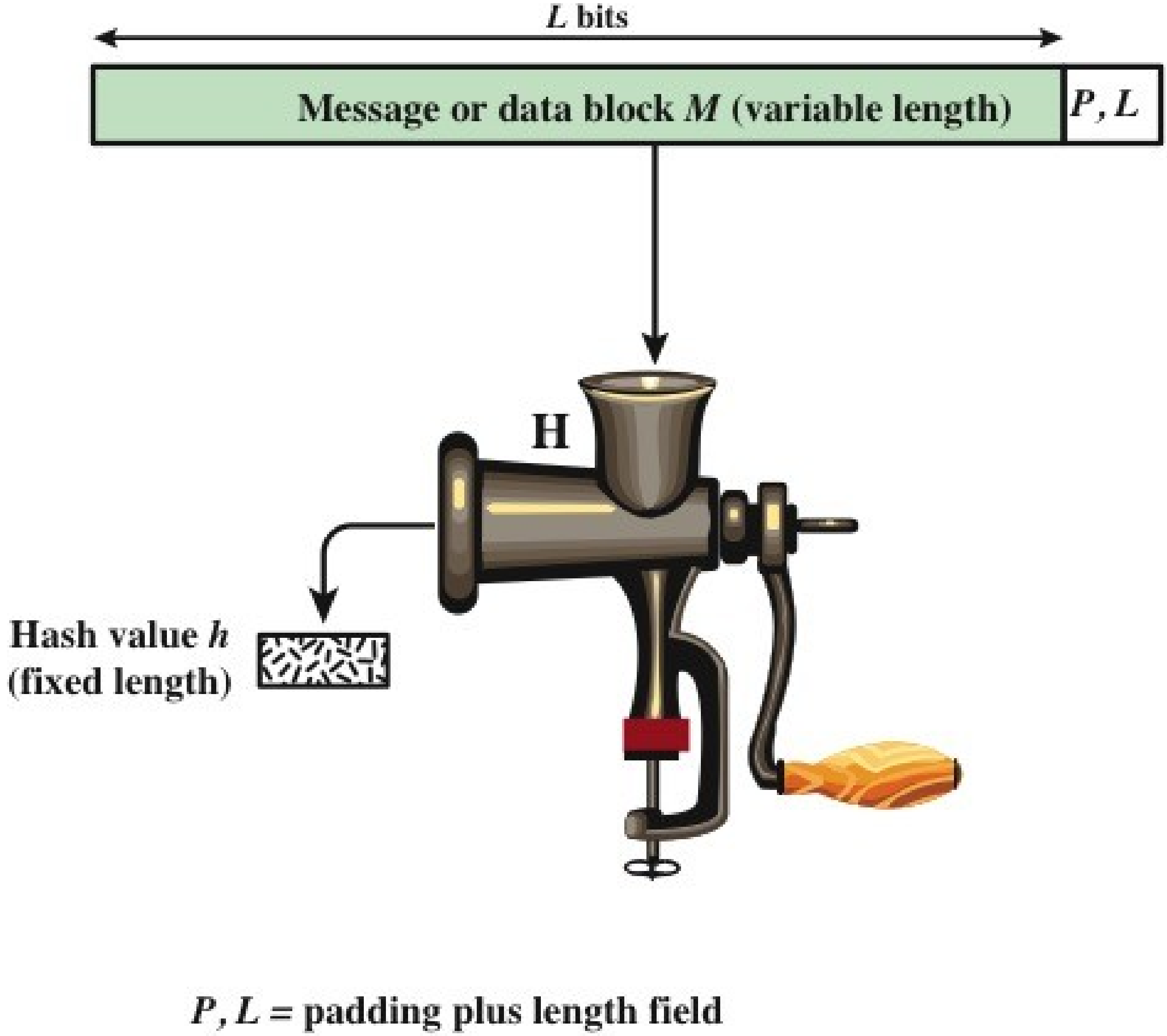


Figure 11.1 Cryptographic Hash Function; $h = \mathrm{H}(M)$

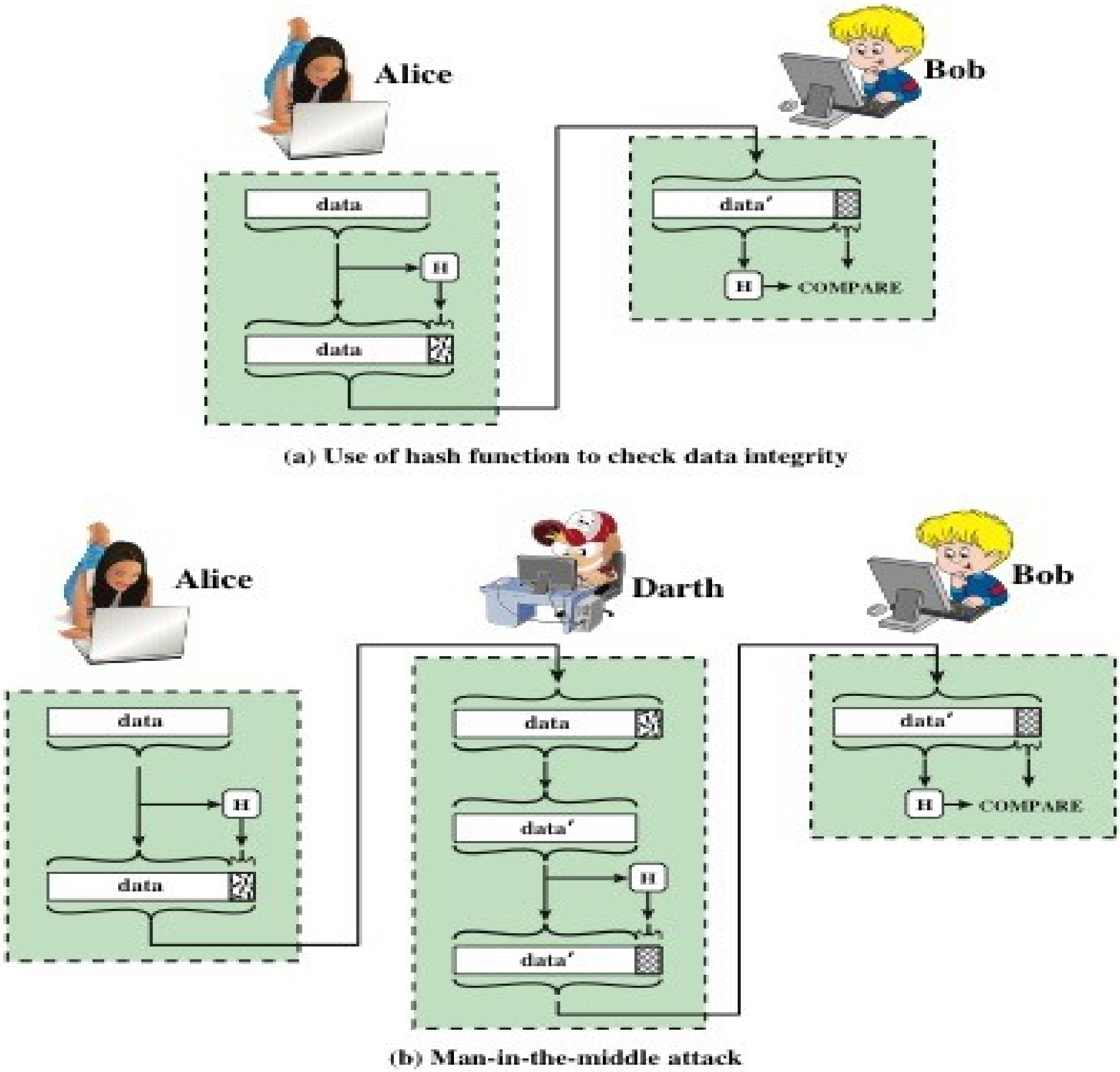


Figure 11.2 Attack Against Hash Function

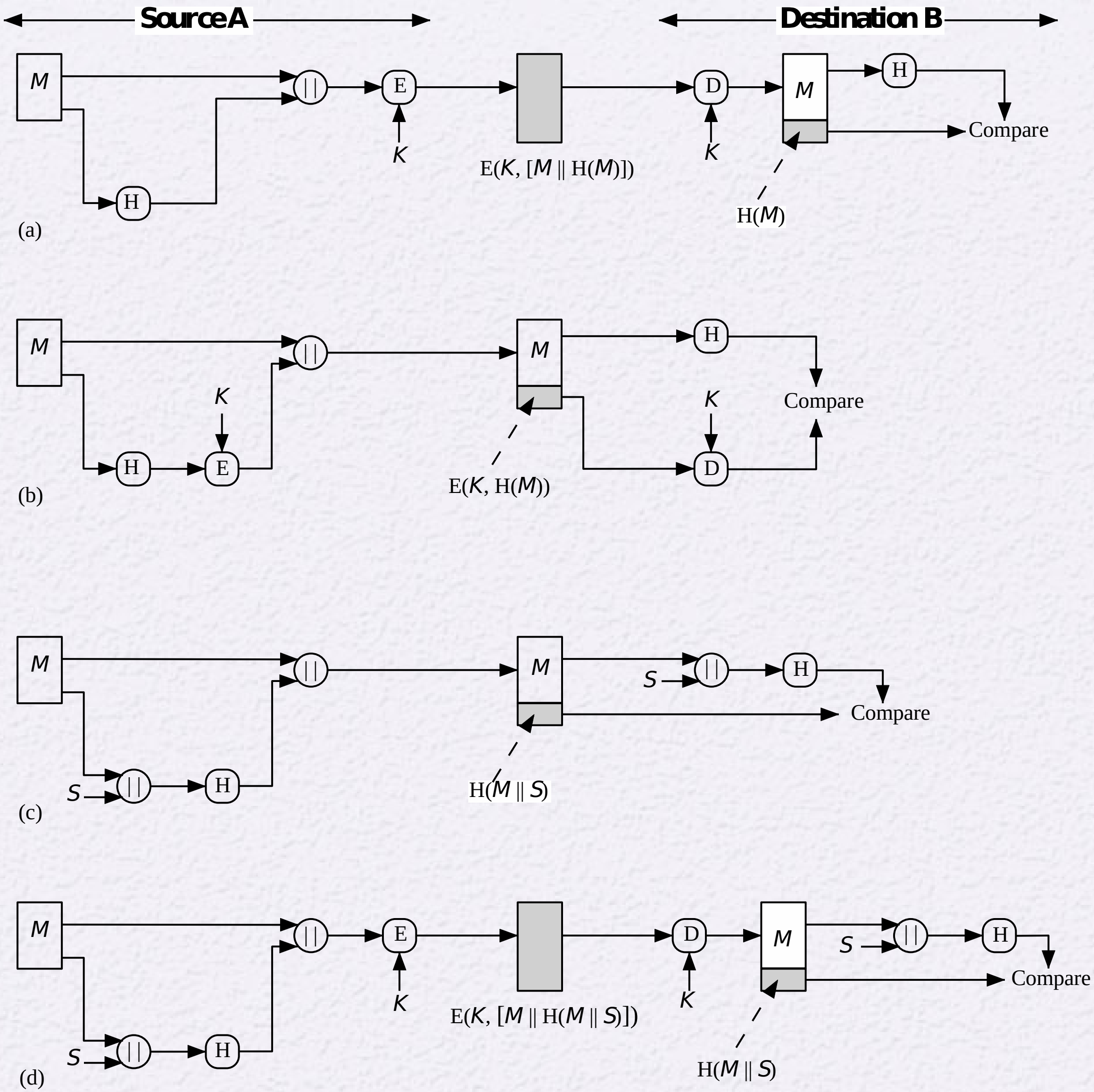


Figure 11.3 Simplified Examples of the Use of a Hash Function for Message Authentication

Message Authentication Code (MAC)

- Also known as a *keyed hash function*
- Typically used between two parties that share a secret key to authenticate information exchanged between those parties

Takes as input a secret key and a data block and produces a hash value (MAC) which is associated with the protected message

- If the integrity of the message needs to be checked, the MAC function can be applied to the message and the result compared with the associated MAC value
- An attacker who alters the message will be unable to alter the associated MAC value without knowledge of the secret key

Digital Signature

- Operation is similar to that of the MAC
- The hash value of a message is encrypted with a user's private key
- Anyone who knows the user's public key can verify the integrity of the message
- An attacker who wishes to alter the message would need to know the user's private key
- Implications of digital signatures go beyond just message authentication

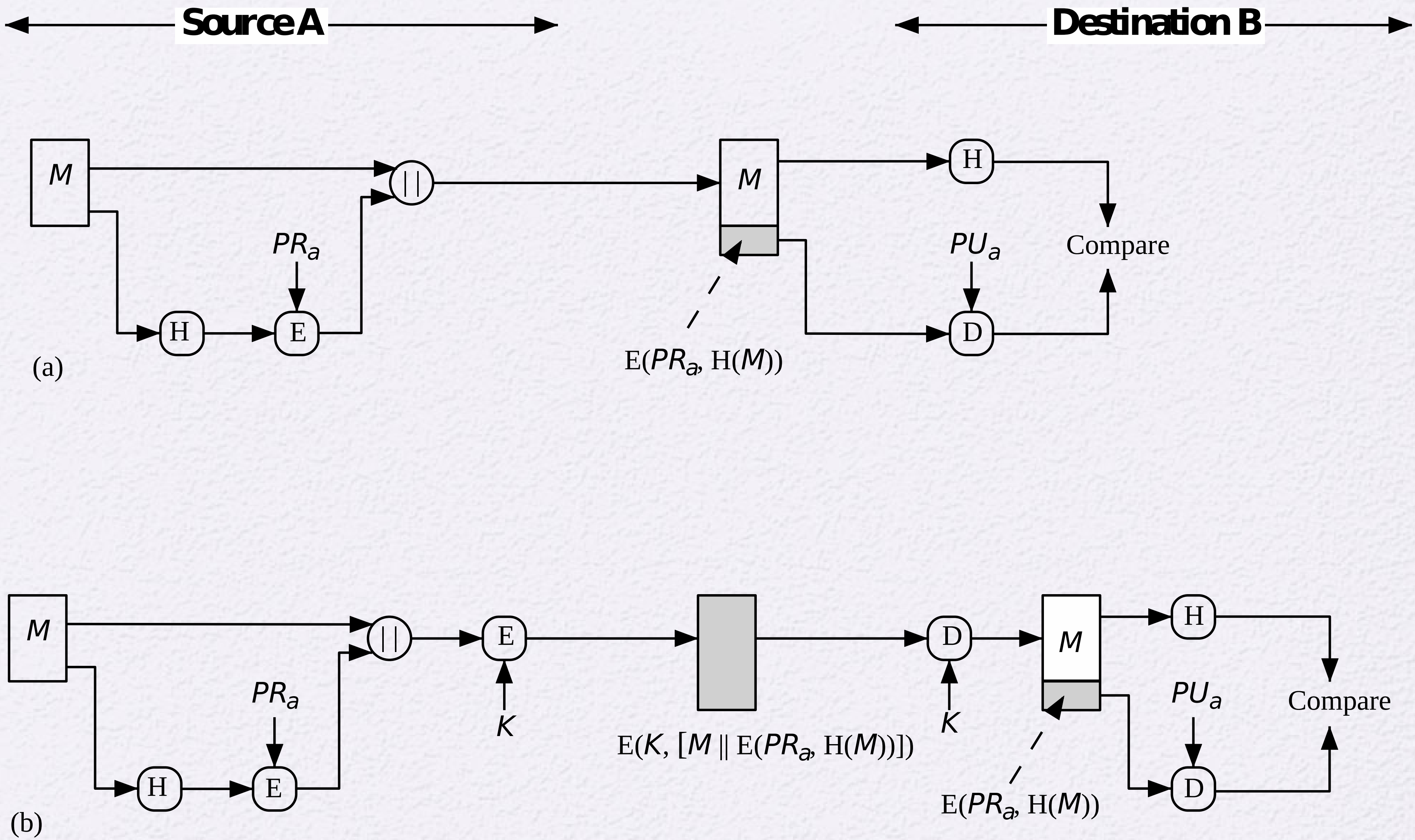


Figure 11.4 Simplified Examples of Digital Signatures

Other Hash Function Uses

Commonly used to create a one-way password file

- When a user enters a password, the hash of that password is compared to the stored hash value for verification
- This approach to password protection is used by most operating systems

Can be used for intrusion and virus detection

- Store H(F) for each file on a system and secure the hash values
- One can later determine if a file has been modified by recomputing H(F)
- An intruder would need to change F without changing H(F)

Can be used to construct a pseudorandom function (PRF) or a pseudorandom number generator (PRNG)

- A common application for a hash-based PRF is for the generation of symmetric keys

Two Simple Hash Functions

- Consider two simple insecure hash functions that operate using the following general principles:
  - The input is viewed as a sequence of *n*-bit blocks
  - The input is processed one block at a time in an iterative fashion to produce an *n*-bit hash function
- Bit-by-bit exclusive-OR (XOR) of every block
  - $C_i = b_{i1} \text{ xor } b_{i2} \text{ xor } \ldots \text{ xor } b_{im}$
  - Produces a simple parity for each bit position and is known as a longitudinal redundancy check
  - Reasonably effective for random data as a data integrity check
- Perform a one-bit circular shift on the hash value after each block is processed
  - Has the effect of randomizing the input more completely and overcoming any regularities that appear in the input

Two Simple Hash Functions

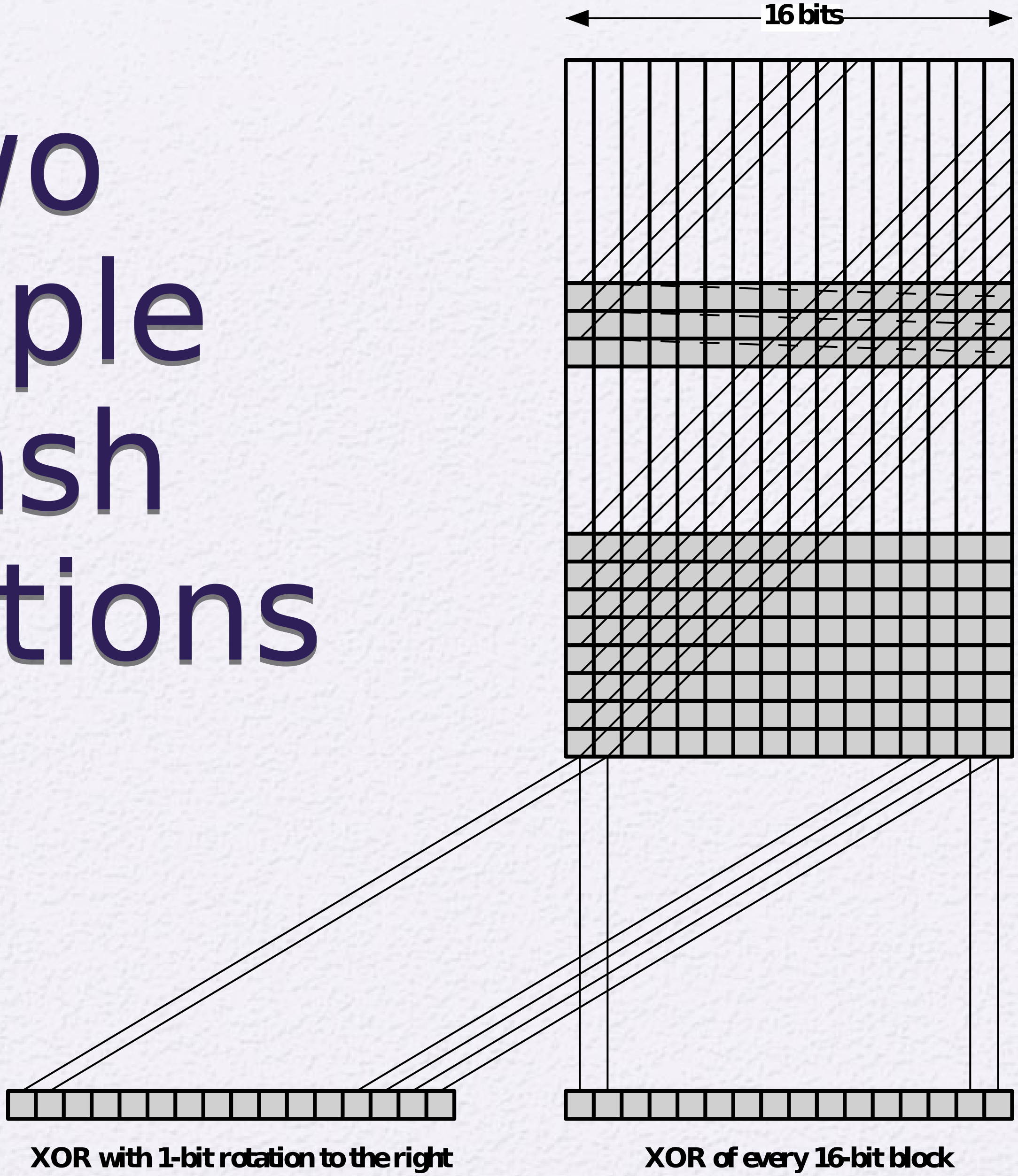


Figure 11.5 Two Simple Hash Functions

Requirements and Security

Preimage

- *x* is the preimage of *h* for a hash value $h = H(x)$
- Is a data block whose hash function, using the function H, is *h*
- Because H is a many-to-one mapping, for any given hash value *h*, there will in general be multiple preimages

Collision

- Occurs if we have $x \neq y$ and $H(x) = H(y)$
- Because we are using hash functions for data integrity, collisions are clearly undesirable

Table 11.1

Requirements for a Cryptographic Hash Function H

Requirement	Description
Variable input size	H can be applied to a block of data of any size.
Fixed output size	H produces a fixed-length output.
Efficiency	H(x) is relatively easy to compute for any given x, making both hardware and software implementations practical.
Preimage resistant (one-way property)	For any given hash value h, it is computationally infeasible to find y such that H(y) = h.
Second preimage resistant (weak collision resistant)	For any given block x, it is computationally infeasible to find $y \neq x$ with H(y) = H(x).
Collision resistant (strong collision resistant)	It is computationally infeasible to find any pair (x, y) such that H(x) = H(y).
Pseudorandomness	Output of H meets standard tests for pseudorandomness

(Table can be found on page 323 in textbook.)

Table 11.2

Hash Function Resistance Properties Required for Various Data Integrity Applications

	Preimage Resistant	Second Preimage Resistant	Collision Resistant
Hash + digital signature	yes	yes	yes*
Intrusion detection and virus detection		yes	
Hash + symmetric encryption			
One-way password file	yes		
MAC	yes	yes	yes*

* Resistance required if attacker is able to mount a chosen message attack

Attacks on Hash Functions

Brute-Force Attacks

- Does not depend on the specific algorithm, only depends on bit length
- In the case of a hash function, attack depends only on the bit length of the hash value
- Method is to pick values at random and try each one until a collision occurs

Cryptanalysis

- An attack based on weaknesses in a particular cryptographic algorithm
- Seek to exploit some property of the algorithm to perform some attack other than an exhaustive search

Secure Hash Algorithm (SHA)

- SHA was originally designed by the National Institute of Standards and Technology (NIST) and published as a federal information processing standard (FIPS 180) in 1993
- Was revised in 1995 as SHA-1
- Based on the hash function MD4 and its design closely models MD4
- Produces 160-bit hash values
- In 2002 NIST produced a revised version of the standard that defined three new versions of SHA with hash value lengths of 256, 384, and 512
  - Collectively known as SHA-2

Table 11.3

Comparison of SHA Parameters

Algorithm	Message Size	Block Size	Word Size	Message Digest Size
SHA-1	$< 2^{64}$	512	32	160
SHA-224	$< 2^{64}$	512	32	224
SHA-256	$< 2^{64}$	512	32	256
SHA-384	$< 2^{128}$	1024	64	384
SHA-512	$< 2^{128}$	1024	64	512
SHA-512/224	$< 2^{128}$	1024	64	224
SHA-512/256	$< 2^{128}$	1024	64	256

Note: All sizes are measured in bits.

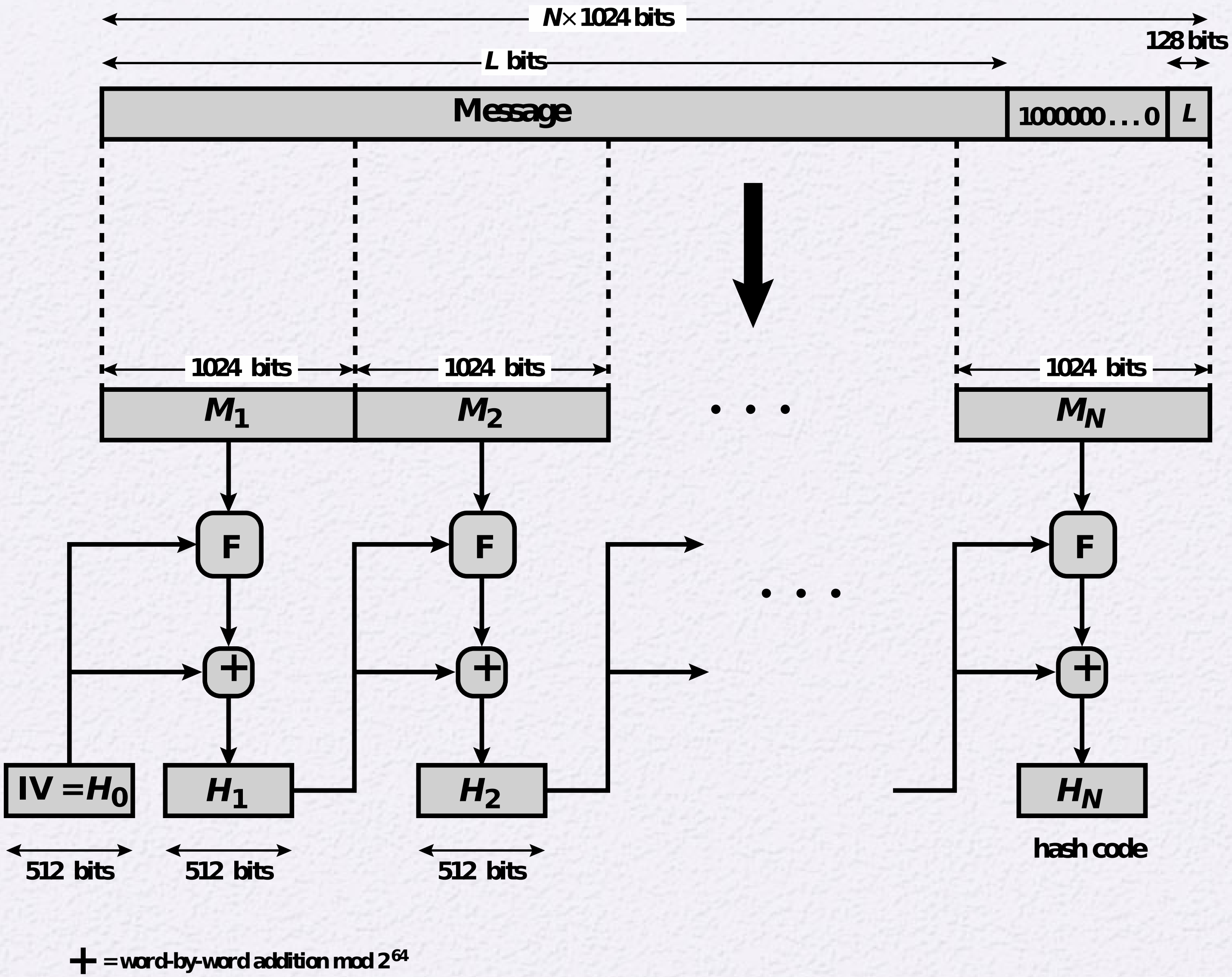


Figure 11.9 Message Digest Generation Using SHA-512

Message Authentication Requirements

- Disclosure
  - Release of message contents to any person or process not possessing the appropriate cryptographic key
- Traffic analysis
  - Discovery of the pattern of traffic between parties
- Masquerade
  - Insertion of messages into the network from a fraudulent source
- Content modification
  - Changes to the contents of a message, including insertion, deletion, transposition, and modification
- Sequence modification
  - Any modification to a sequence of messages between parties, including insertion, deletion, and reordering
- Timing modification
  - Delay or replay of messages
- Source repudiation
  - Denial of transmission of message by source
- Destination repudiation
  - Denial of receipt of message by destination

Message Authentication Functions

- Two levels of

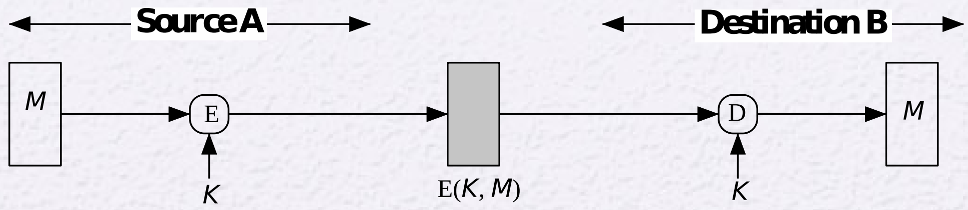
Lower level

- There must be some sort of function that produces an authenticator

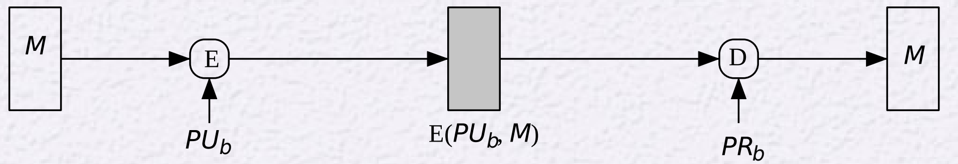
Higher-level

- Uses the lower-level function as a primitive in an authentication protocol that enables a receiver to verify the authenticity of a message

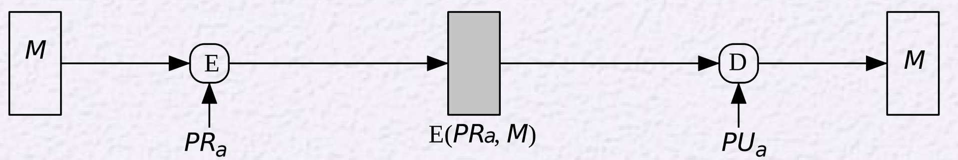
- Hash function
  - A function that maps a message of any length into a fixed-length hash value which serves as the authenticator
- Message encryption
  - The ciphertext of the entire message serves as its authenticator
- Message authentication code (MAC)
  - A function of the message and a secret key that produces a fixed-length value that serves as the authenticator



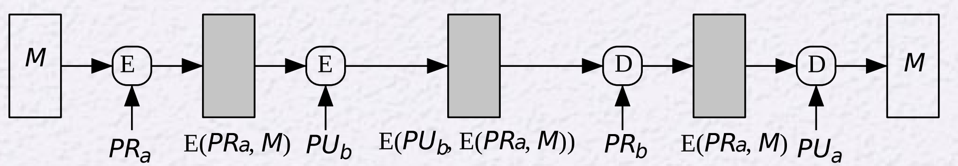
(a) Symmetric encryption: confidentiality and authentication



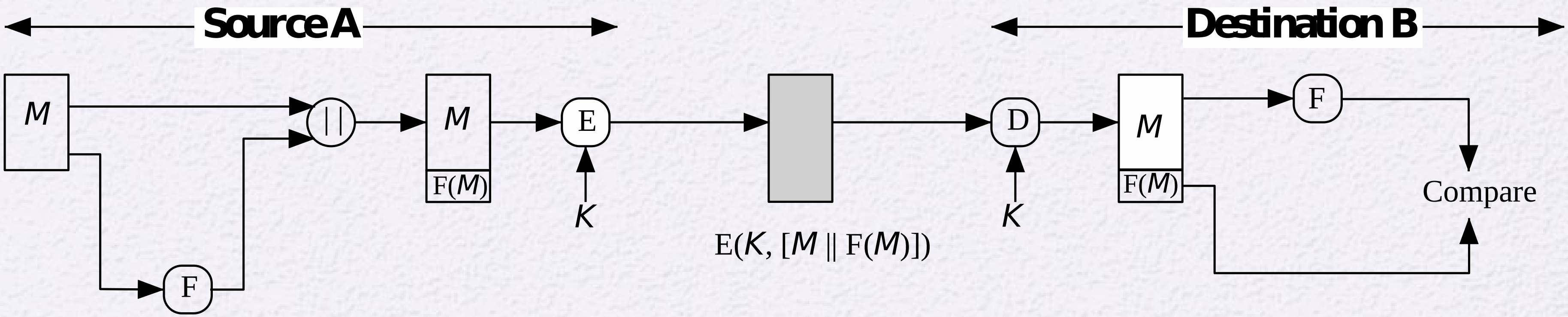
(b) Public-key encryption: confidentiality



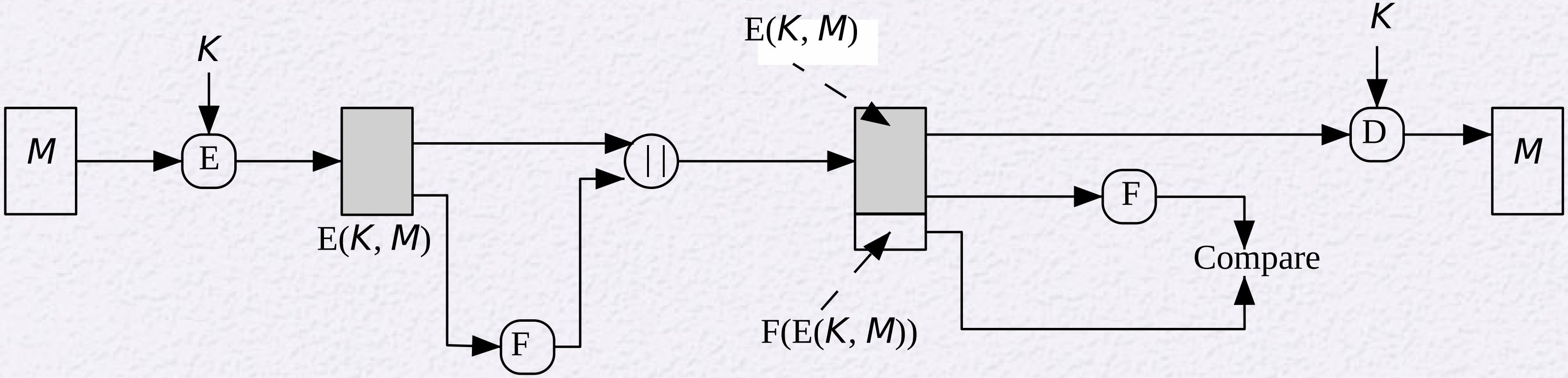
(c) Public-key encryption: authentication and signature



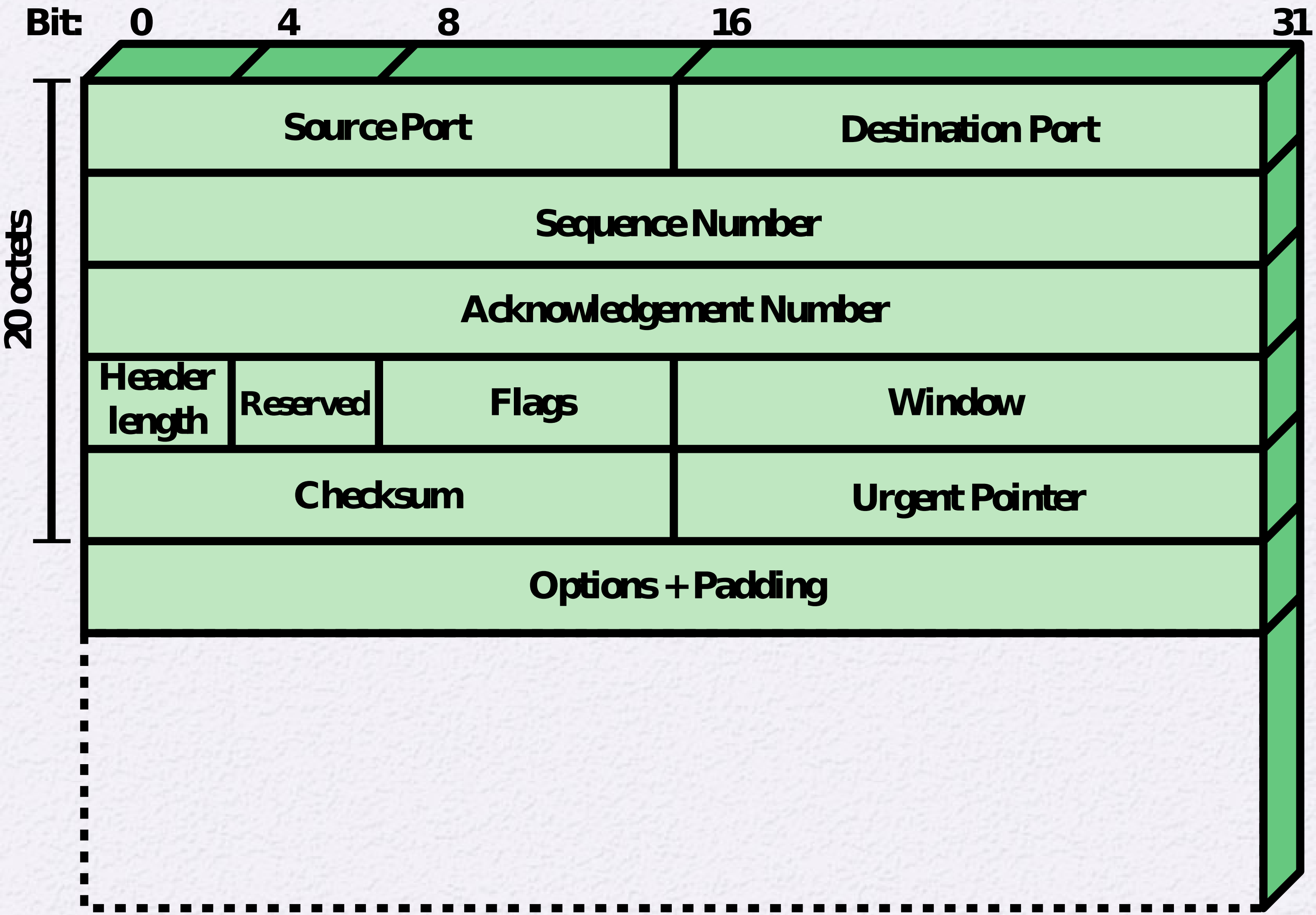
(d) Public-key encryption: confidentiality, authentication, and signature



(a) Internal error control



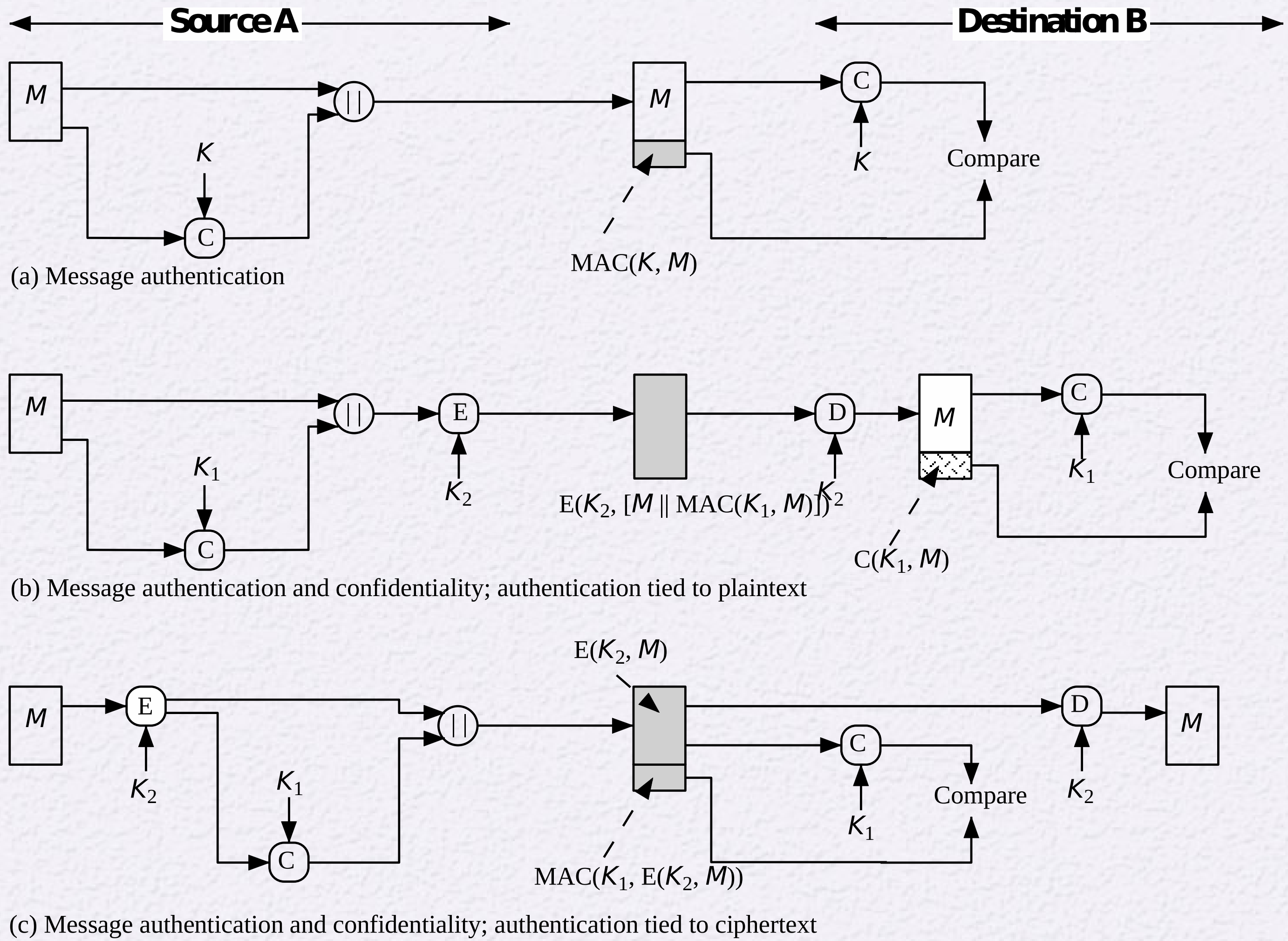
(b) External error control



Bit:
0
4
8
16
31
20 octets
Source Port
Destination Port
Sequence Number
Acknowledgement Number
Header length
Reserved
Flags
Window
Checksum
Urgent Pointer
Options + Padding

Public-Key Encryption

- The straightforward use of public-key encryption provides confidentiality but not authentication
- To provide both confidentiality and authentication, A can encrypt *M* first using its private key which provides the digital signature, and then using B's public key, which provides confidentiality
- Disadvantage is that the public-key algorithm must be exercised four times rather than two in each communication



Message Authentication Codes (MAC)