Hashing

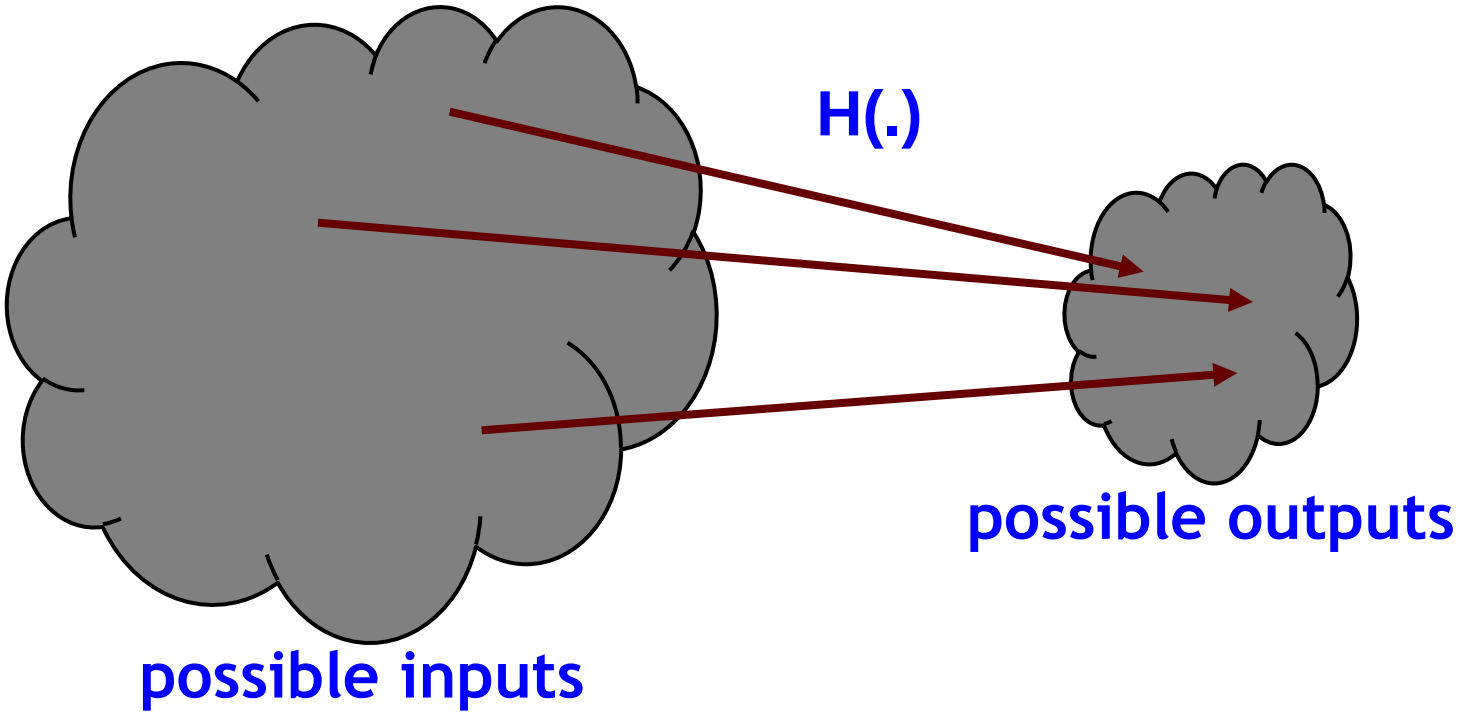
Hash function:

mathematical function

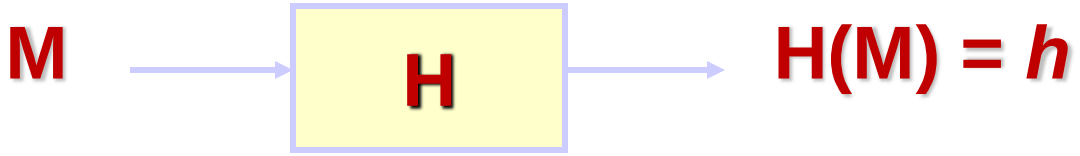
takes any string as input

fixed-size output (we'll use 256 bits)

efficiently computable (say, O(n))



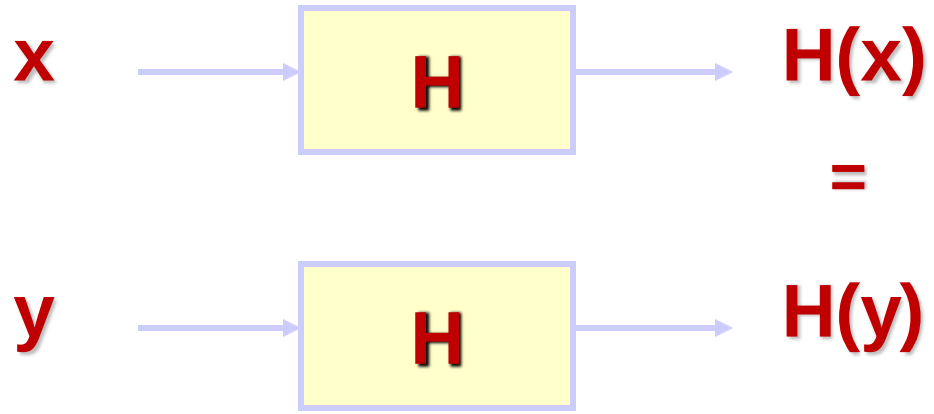
One-Way Hash Functions



Example

- M = “Elvis”
- H(M) = (“E” + “L” + “V” + “I” + “S”) mod 26
- H(M) = (5 + 12 + 22 + 9 + 19) mod 26
- H(M) = 67 mod 26
- H(M) = 15

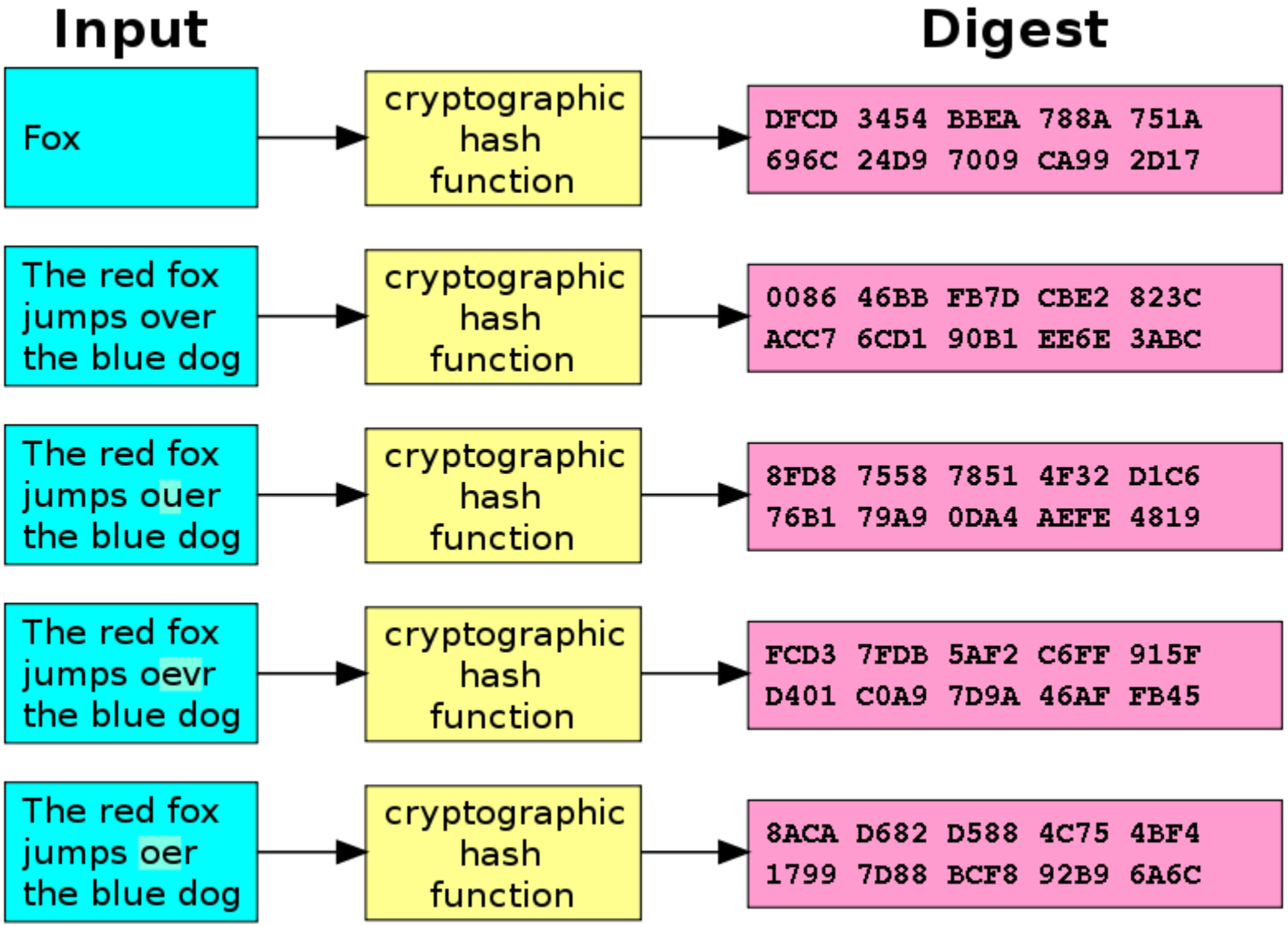
Collision



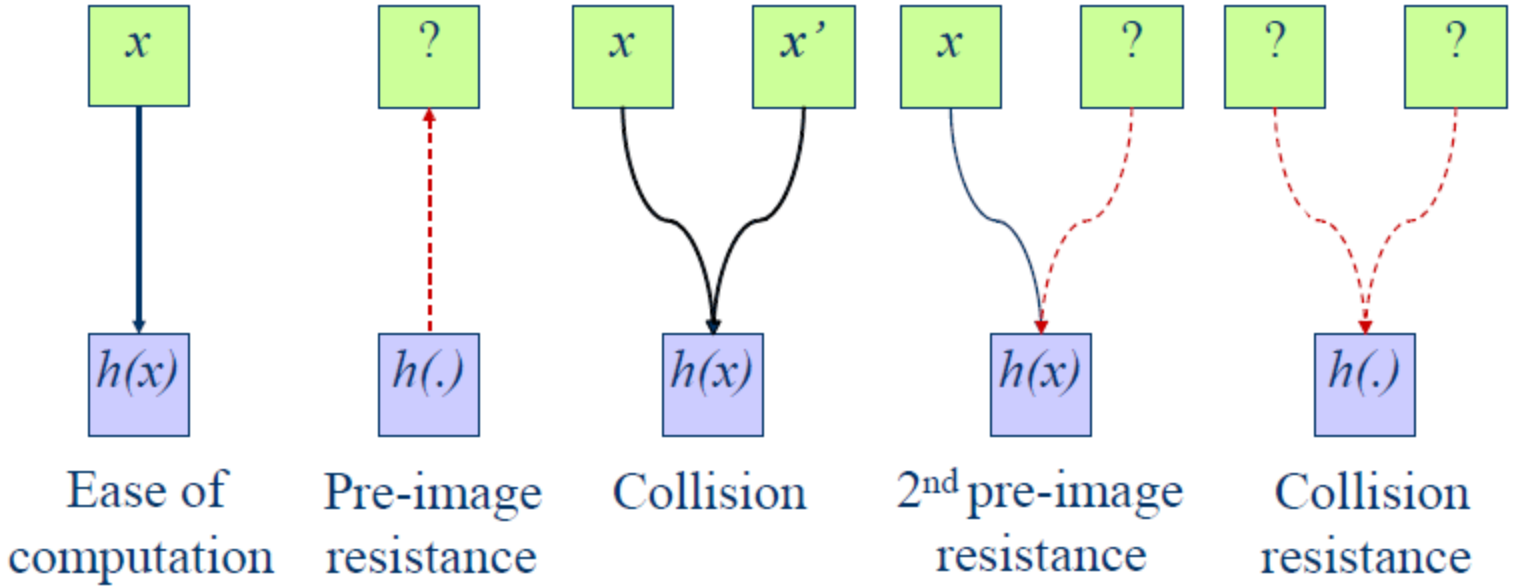
Example

- x = “Viva”
- Y = “Vegas”
- H(x) = H(y) = 2

avalanche effect



HASH PROPERTIES



- Collision resistance implies 2nd pre-image resistance
- Collision resistance does not imply pre-image resistance

Authentication

Basics

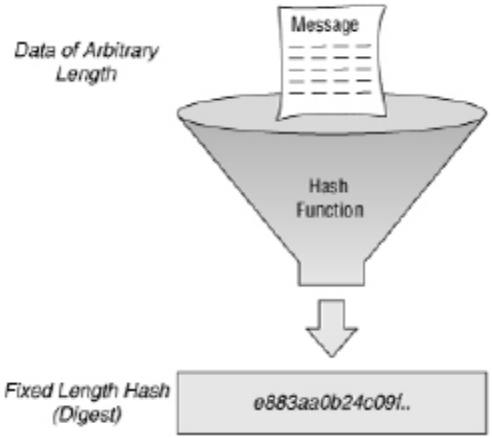
- Authentication is the process of validating the **identity** of a user (Authenticity) or the **integrity** of a piece of data (Integrity).

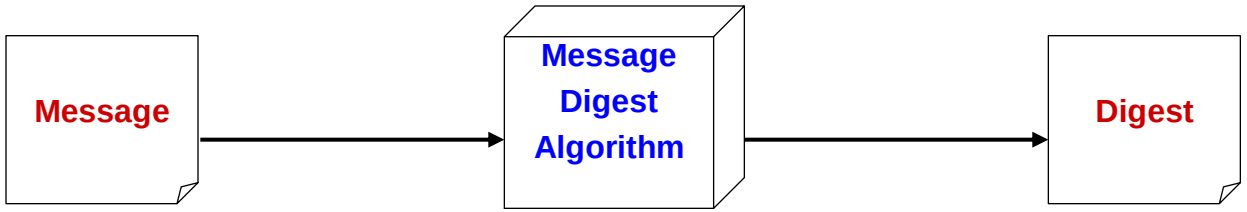
- Technologies that provide authentication
  - Message Digests (MD)
  - Message Authentication Codes (MAC)
  - Digital Signatures
  - Others….

Authentication

Message Digests (MD)

- A message digest is a fingerprint for a document.
- Purpose of the message digest is to provide proof that data has not altered - Integrity.
- Process of generating a message digest from data is called **hashing**

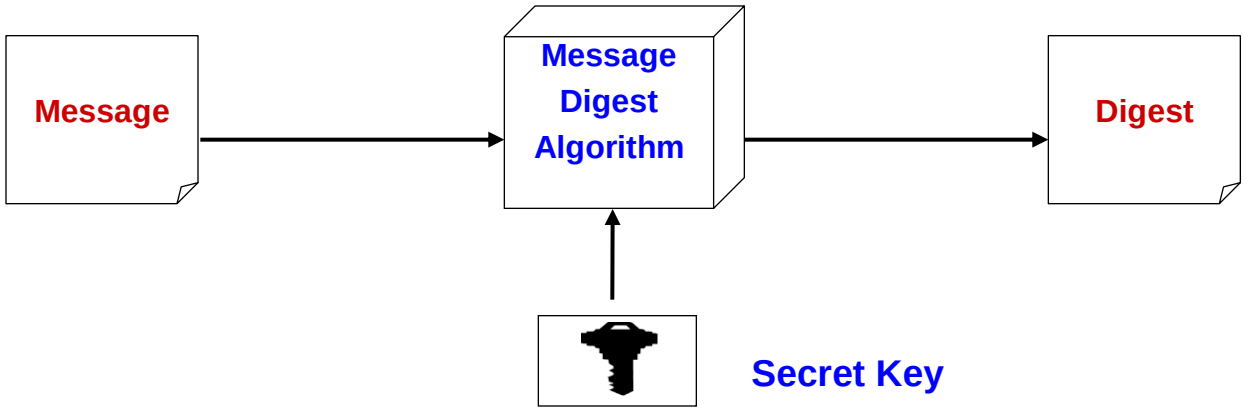




Authentication

Message Authentication Codes (MAC)

- A message digest created with a key
- Creates security by requiring a secret key to be possesses by both parties in order to retrieve the message
- A MAC is a short string used to verify the message integrity and authentication



COMMONLY USED HASH FUNCTIONS

- **MD** (Message Digest)
  - MD5
    - Max message < 2^{64}
    - Output: 128-bit
- **SHA** (Secure Hash Algorithm)
  - SHA-1
    - Max message < 2^{64}
    - Output: 160-bit
  - SHA-2
    - Max message < 2^{128}
    - Max output: 512-bit
  - SHA-3
    - Max message: Unlimited
    - Max output: 512-bit

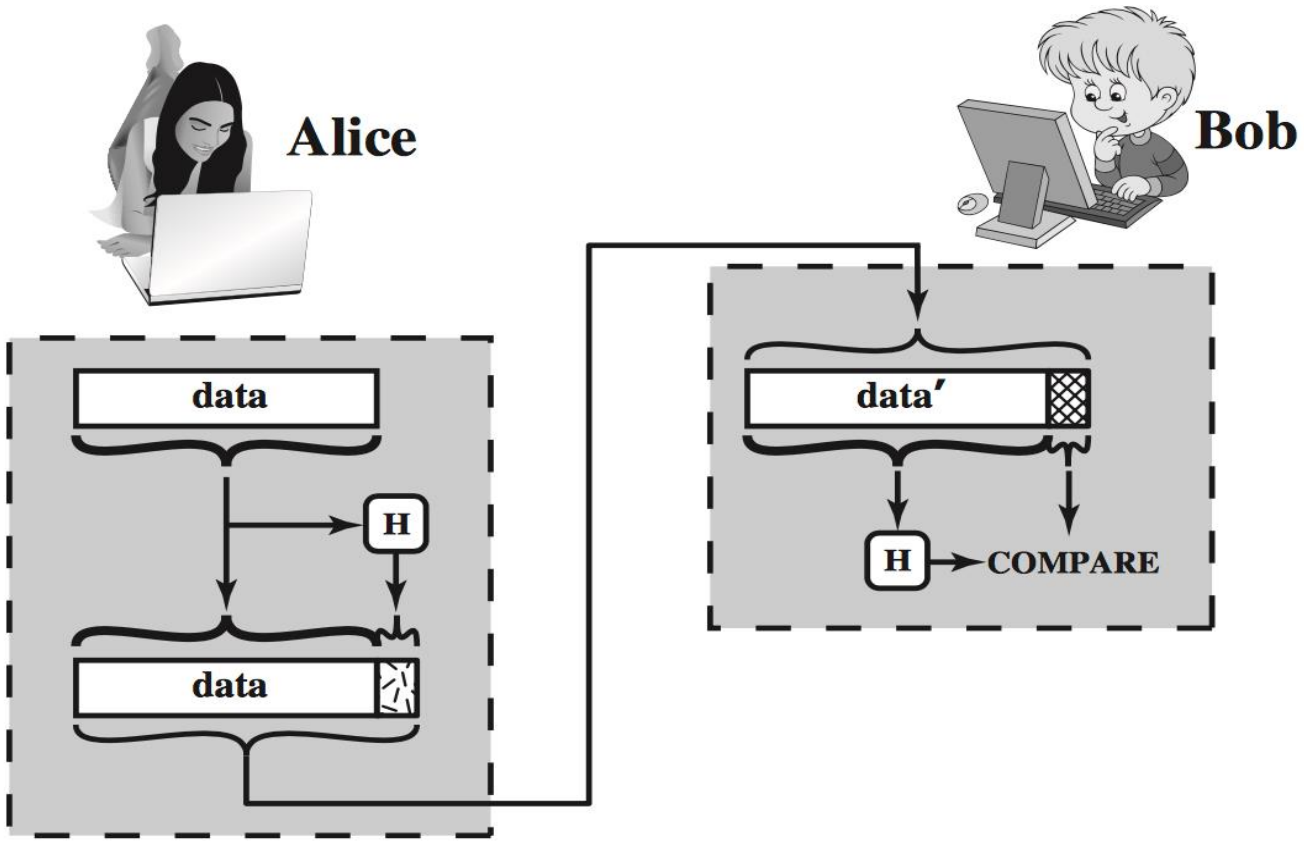
HASH VS. ENCRYPTION

- Hashing is a one-way
  - No unhashing
- Publicly known and there is no key used
- Efficient
- Deterministic (compared)
  - H(m) == H(m')
  - Of course, hashes with salts are not!
    - H(m || s1) and H(m || s2)

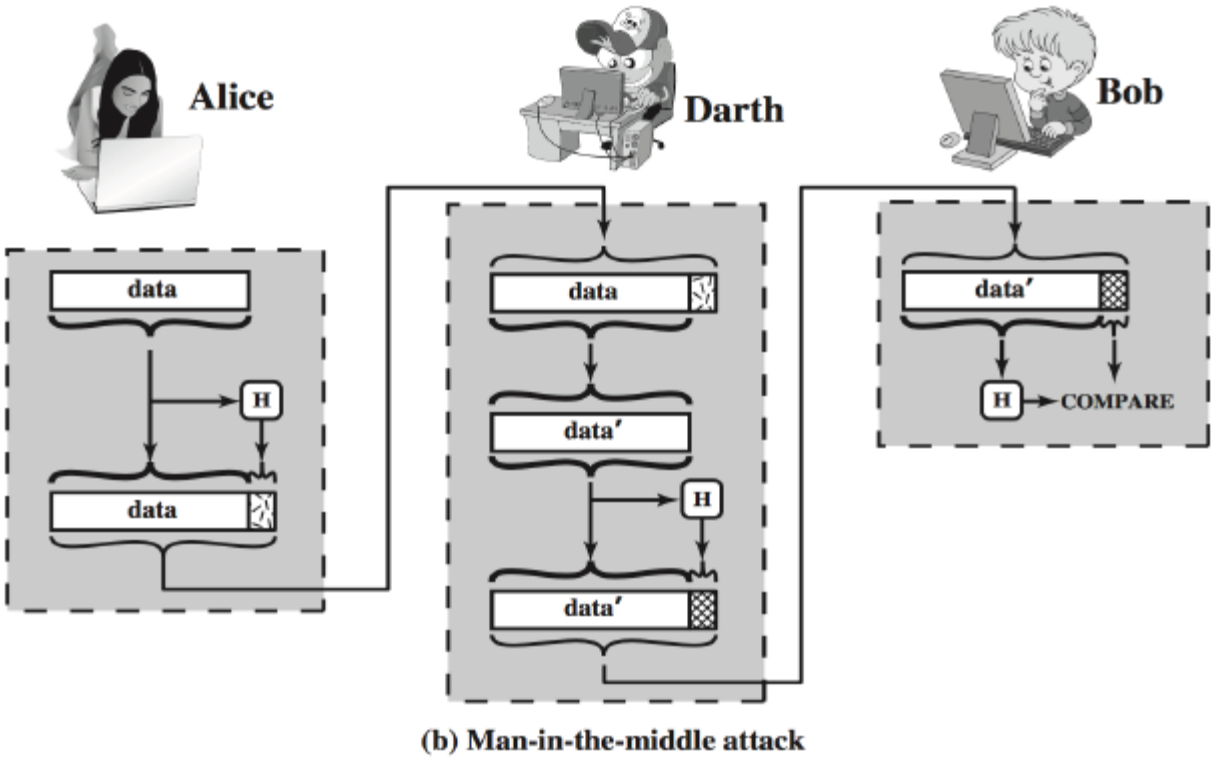
- Encryption is not one-way
  - Decryption renders the original message
- Publicly known algorithms but the key is kept secret
- Slower
- May or may not be deterministic (compared)
  - Randomised encryption
    - Enc(k, t1 || m) and Enc(k, t2 || m)

Cryptographic Hash Functions: Applications

- Integrity

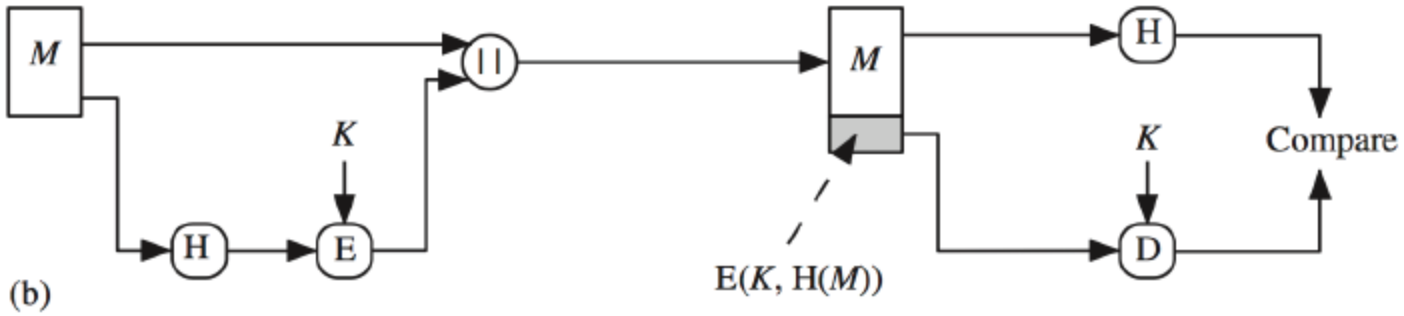


Attack Against Cryptographic Function

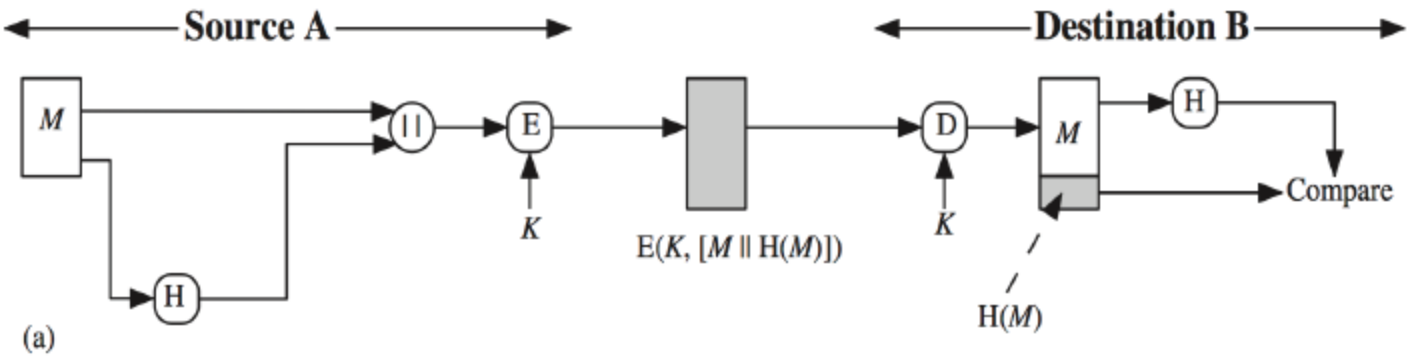


(b) Man-in-the-middle attack

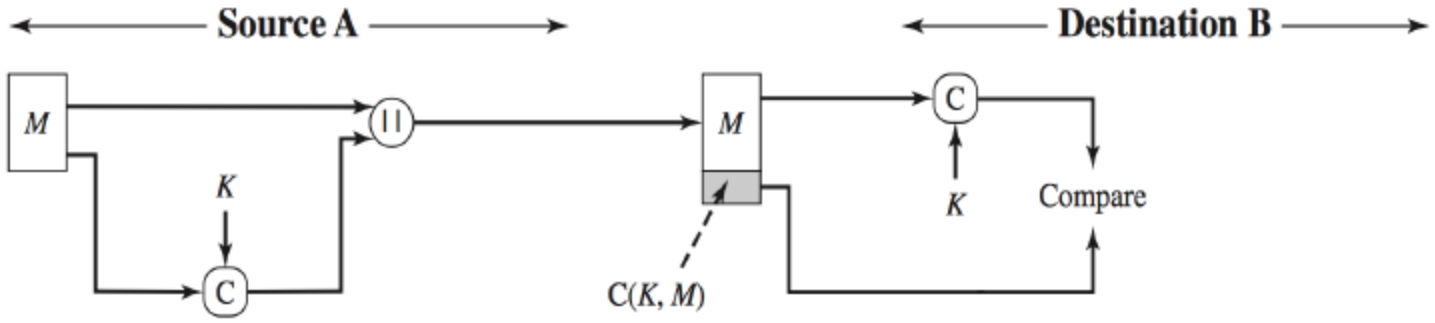
The hash value must be **protected**.



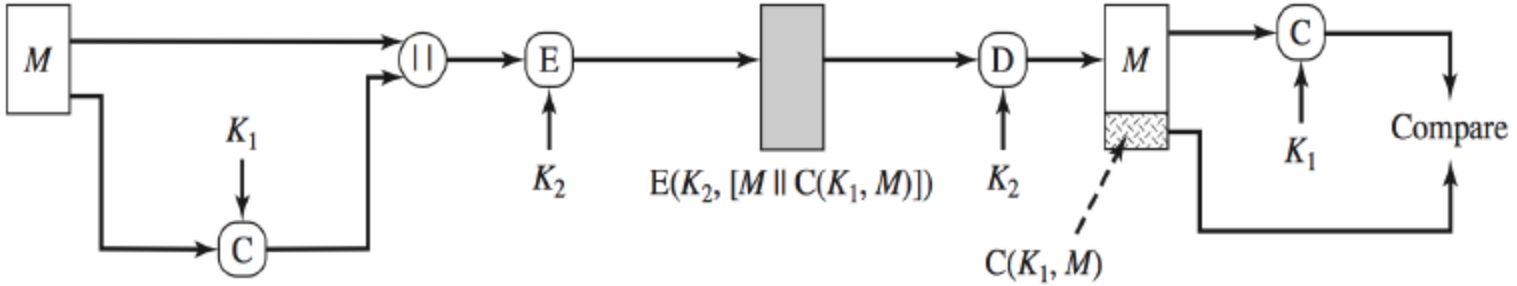
Integrity



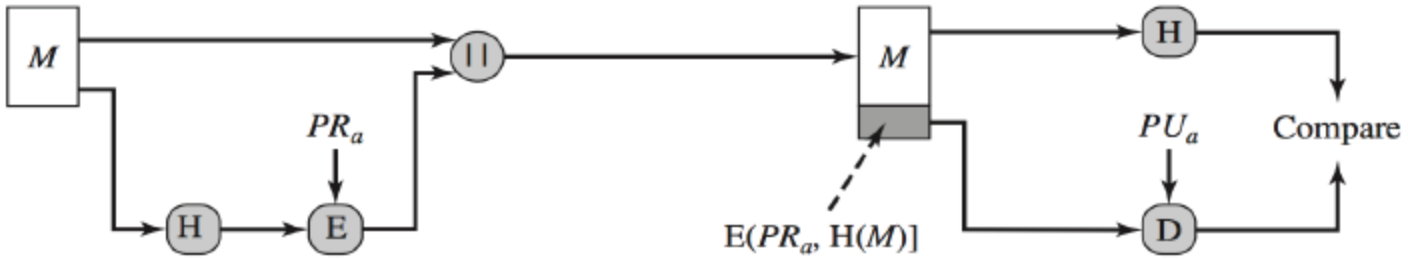
Confidentiality & Integrity



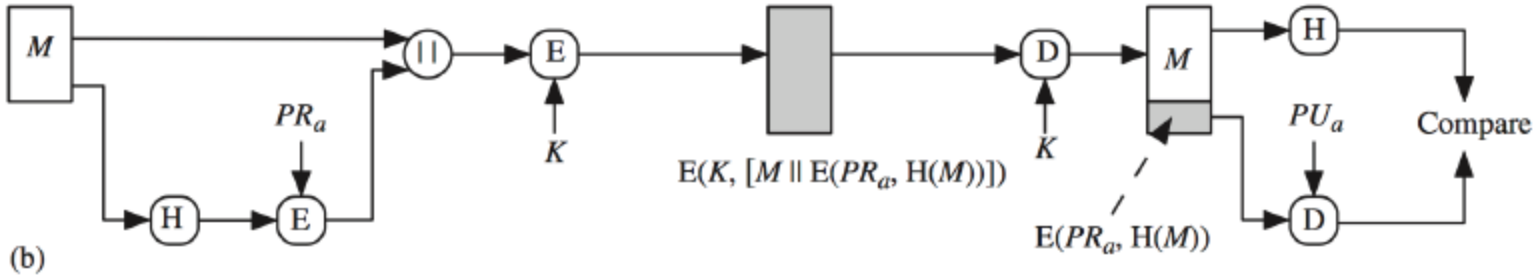
Integrity & Authenticity



Confidentiality & Integrity & Authenticity



Integrity & Authenticity & Accountability



(b)

Confidentiality & Integrity & Authenticity & Accountability

Authentication

Message Digests (MD)

- Standards:

  MD5 : 128 bit hashing algorithm by Ron Rivest of RSA
  - Broken since 2004 by Xiaoyun Wang
  - Collisions can be constructed in seconds on a laptop

  SHA & SHA-1 : 160 bit hashing algorithm developed by NIST
  - Considered insecure
  - Practically broken since 2005 by Xiaoyun Wang

Do not use them in your security products!

Authentication

Message Digests (MD)

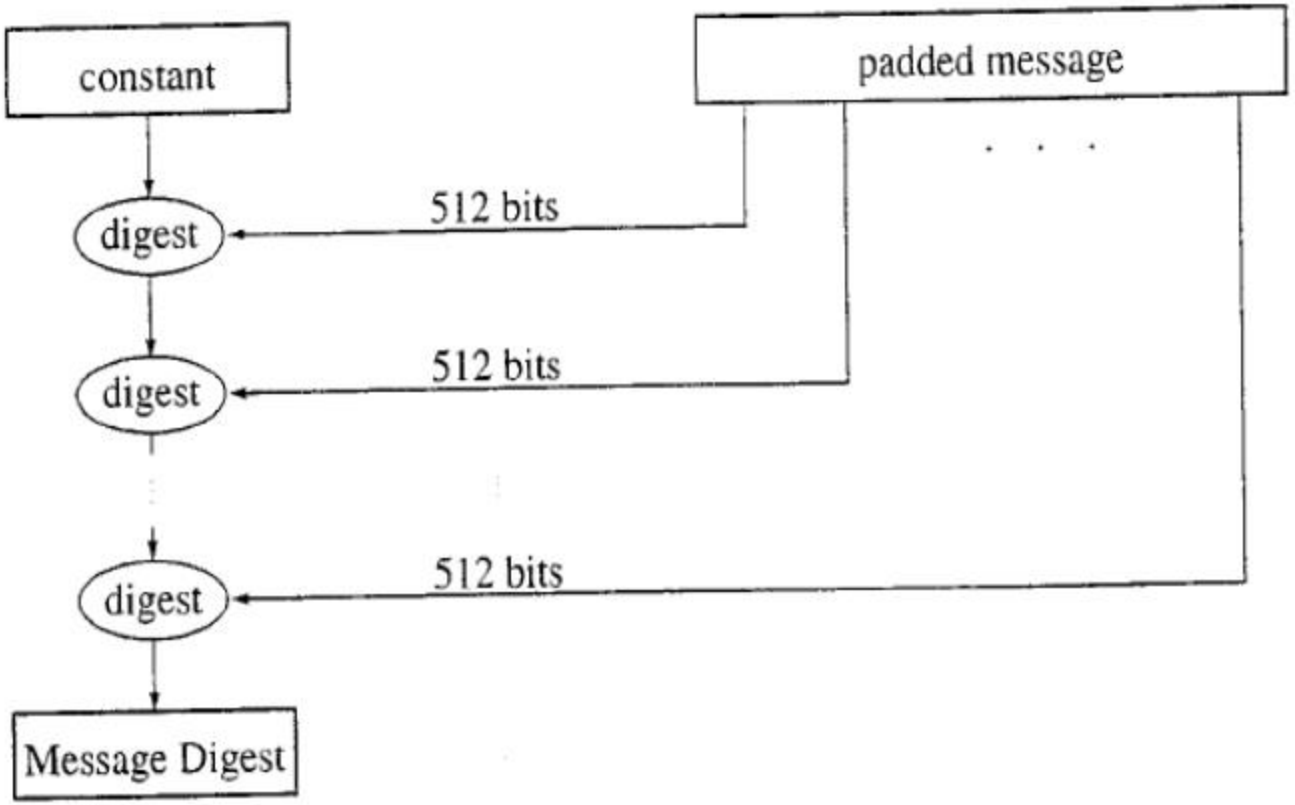
- SHA-2 family: 224, 256, 384 or 512 bits

- SHA-3 family output can be arbitrary size
  - NIST started a competition for SHA-3 in 2007.
  - NIST's original concern was that SHA-2 would soon be broken, although in fact SHA-2 is still fine.
- SHA-3 (Secure Hash Algorithm 3) is the latest member of the Secure Hash Algorithm family of standards, released by NIST on August 5, 2015.

MD5: Message Digest Version 5

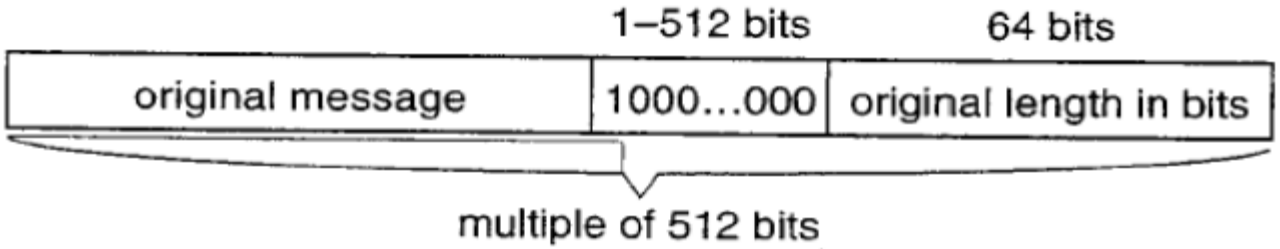
- Author: R. Rivest, 1992
- 128-bit hash
  - based on earlier, weaker MD4 (1990)
- **Collision resistance (B-day attack resistance)**
  - only 64-bit
- Output size not long enough today (due to various attacks)

MD5 Overview



Similar for MD4/MD5/SHA-1

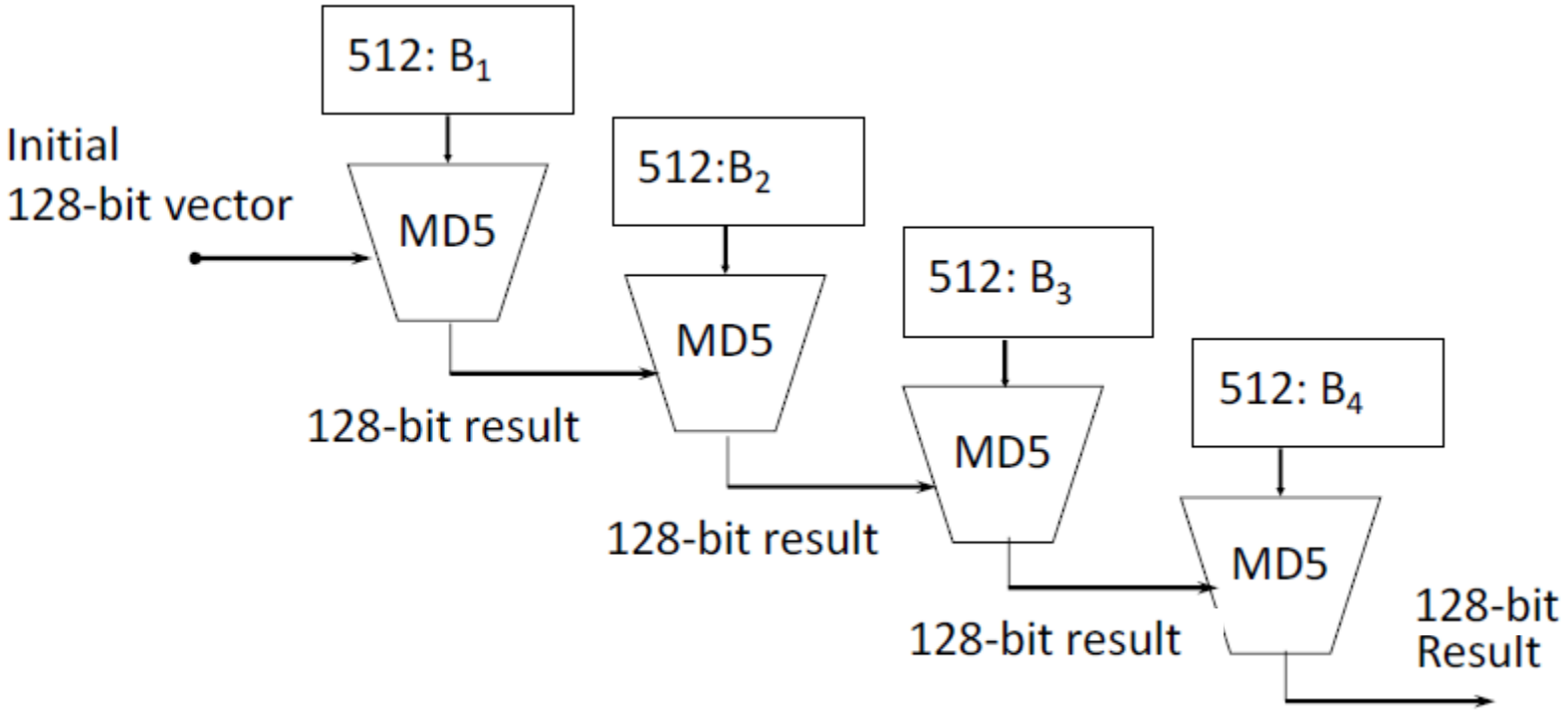
MD5: Padding



- Given original message M, add padding bits "100…" such that resulting length is 64 bits less than a multiple of 512 bits.
- Append *original length in bits* to the padded message
- Final message chopped into 512-bit blocks

MD5: Blocks

- As many stages as the number of 512-bit blocks in the final padded message



Secure Hash Algorithm (SHA)

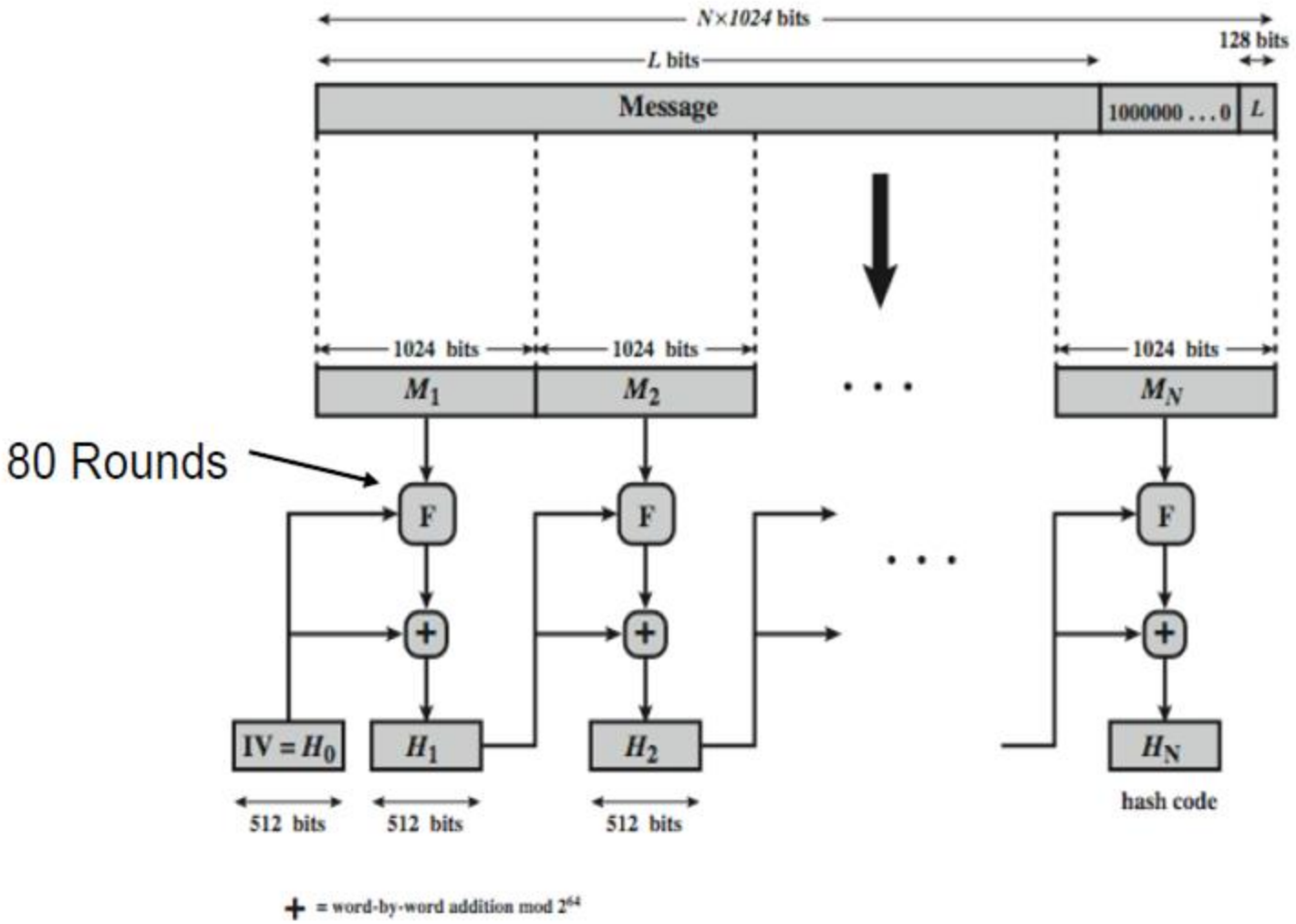
- SHA originally designed by NIST & NSA in 1993
- was revised in 1995 as SHA-1
- US standard for use with DSA signature scheme
  - standard is FIPS 180-1 1995, also Internet RFC3174

- based on design of MD4 with key differences
- produces 160-bit hash values
- 2005 results on security of SHA-1 raised concerns on its use in future applications

Revised Secure Hash Standard

- NIST issued revision FIPS 180-2 in 2002
- adds 4 additional versions of SHA
  - SHA-224, SHA-256, SHA-384, SHA-512
- designed for compatibility with increased security provided by the AES cipher
- structure & detail is similar to SHA-1
- hence analysis should be similar
- but security levels are rather higher

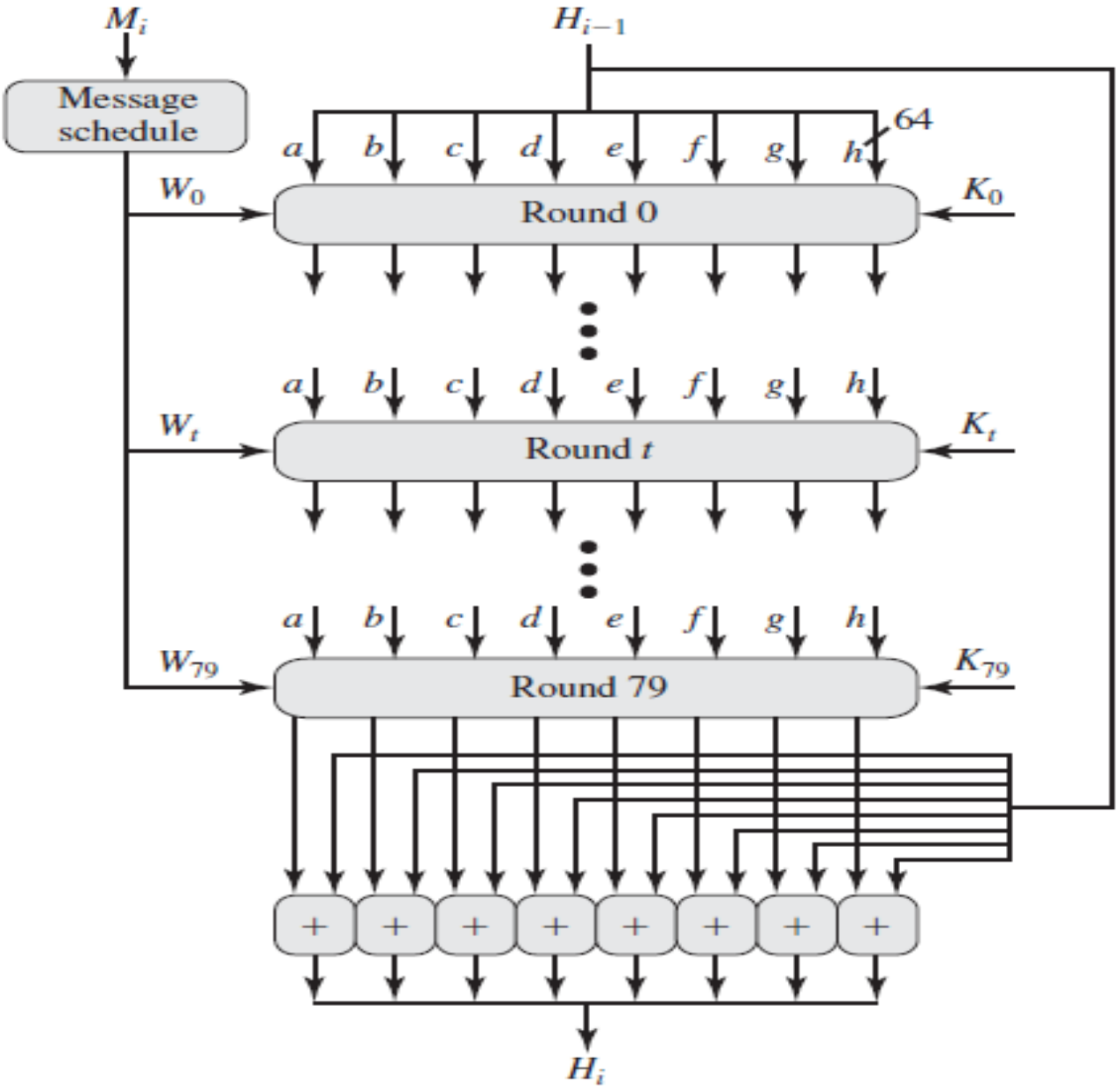
SHA-512 Overview



SHA-512 Compression Function

- heart of the algorithm
- processing message in 1024-bit blocks
- consists of 80 rounds
  - updating a 512-bit buffer
  - using a 64-bit value w_t derived from the current message block
  - and a round constant based on cube root of first 80 prime numbers

SHA-512 Compression Function



SHA

	Output size (bits)	Internal state size (bits)	Block size (bits)	Max message size (bits)	Word size (bits)	Rounds	Operations	Collisions found
SHA-0	**160**	**160**	**512**	**$2^{64} - 1$**	**32**	**80**	**+, and, or, xor, rot**	**Yes**
SHA-1	**160**	**160**	**512**	**$2^{64} - 1$**	**32**	**80**	**+, and, or, xor, rot**	**None (2^{52} attack)**
SHA-2	**256/224**	**256**	**512**	**$2^{64} - 1$**	**32**	**64**	**+, and, or, xor, shr, rot**	**None**
	512/384	**512**	**1024**	**$2^{128} - 1$**	**64**	**80**	**+, and, or, xor, shr, rot**	**None**