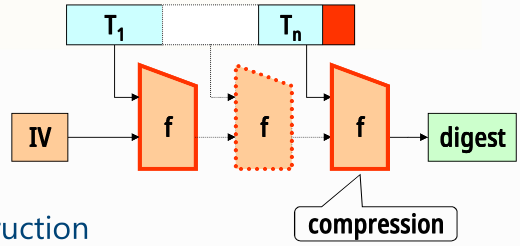
Cryptographic Hashing

Digest functions

- Give a fixed-length value from a variable-length text
  - Sort of text "fingerprint"
- Produce very different values for similar texts
  - Cryptographic one-way hash functions
- Relevant properties:
  - Preimage resistance
    - Given a digest, it is infeasible to find an original text producing it
  - 2nd-preimage resistance
    - Given a text, it is infeasible to find another one with the same digest
  - Collision resistance
    - It is infeasible to find any two texts with the same digest
    - Birthday paradox

Digest functions: aproaches



▷ Merkle-Damgård construction
- Iterative compression
- Collision-resistent, one-way compression functions
- Length padding (1, followed by zeros, followed by length)

▷ Sponge functions
- **Absorption**: update a finite internal state (entropy pool) from a variable-length, padded input stream
- **Squeezing**: produce an arbitrary-length output from the internal state

Digest functions: common algorithms

▷ MD5 (128 bits)
- No longer secure! It's easy to find collisions!
- Disclaimer: it can be used when collisions are not an issue

▷ SHA-1 (Secure Hash Algorithm, 160 bits)
- Also no longer secure … (collisions found in 2017)

▷ RIPEMD (128 and 160)

▷ SHA-2, aka SHA-256 / SHA-348 / SHA-512

▷ SHA-3 (Keccak)

Rainbow tables

- We can invert a digest function with a table
  - For all possible input, we compute and store the digest
  - But the table size is given by the digest length
    - Not usually applicable
- Solution: rainbow tables
  - Trade space with time
  - Store only part of the outputs
    - For direct matching
  - Find for more matches using computation

Rainbow tables

- They are based on a reverse function R
  - Which is not the inverse of H
  - The goal of R is to produce a new input given a hashing result

$$\boxed{I_0} \xrightarrow{H} \boxed{O_1} \xrightarrow{R} \boxed{I_1} \xrightarrow{H} \boxed{O_2} \xrightarrow{R} \boxed{I_2} \cdots\cdots \xrightarrow{R} \boxed{I_k}$$

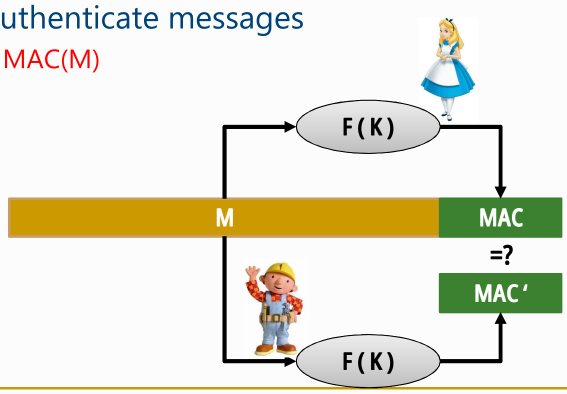
- R functions are likely to produce collisions
  - But we can use many different R functions
  - Collisions scan still occur
    - But will not create a problem unless occurring at the exact same column
    - And that case can be identified (and discarded) by identical outputs
- A table with m k-length rows can invert k×m hashes
  - At most
  - Only I_0 and I_k is stored per row

Rainbow tables: exploitation

- A set of **m** random inputs is generated
  - $I_0 = \{I_{0,1}, \ldots I_{0,m}\}$
- A set of **m** k-length chain outputs is computed
  - $I_k = \{I_{k,1}, \ldots I_{k,m}\}$
- Given a target o
  - Look for R(o) in I_k
  - If found in row r, compute chain from $I_{0,r}$
    - until finding i such that H(i) = o
  - If not found, compute o_r from o using H and R for each row r
    - and see if $o_r = I_{k,r}$
    - H and R are applied 1 to k times, using different R functions

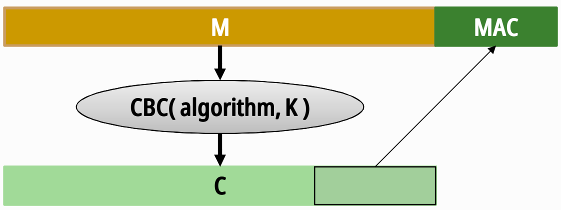
Message Authentication Codes (MAC)

- Hash, or digest, computed with a key
  - Only key holders can generate and validate the MAC
- Used to authenticate messages
  - M' = M | MAC(M)



Message Authentication Codes (MAC): Approaches

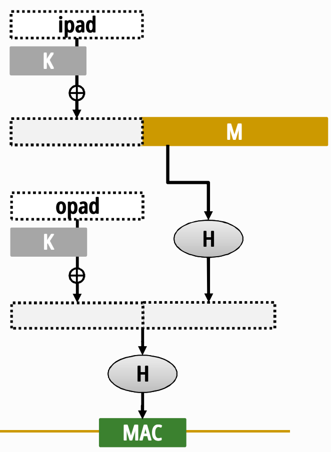
- Encryption of an ordinary digest
  - Using, for instance, a symmetric block cipher
- Using encryption with feedback & error propagation
  - ANSI X9.9 (or DES-MAC) with DES CBC (64 bits)
  - CBC-MAC



Message Authentication Codes (MAC): Approaches

- Adding a key to the hashed data
  - Keyed-MD5 (128 bits)
    - MD5(K, keyfill, text, K, MD5fill)
  - HMAC (Hashed-based MAC)
    - Generic construction, uses a hash function H
    - Output length depends on H
    - HMAC-MD5, HMAC-SHA, etc.

    - H (K, opad, H (K, ipad, text))
    - ipad = 0x36 B times
    - opad = 0x5C B times

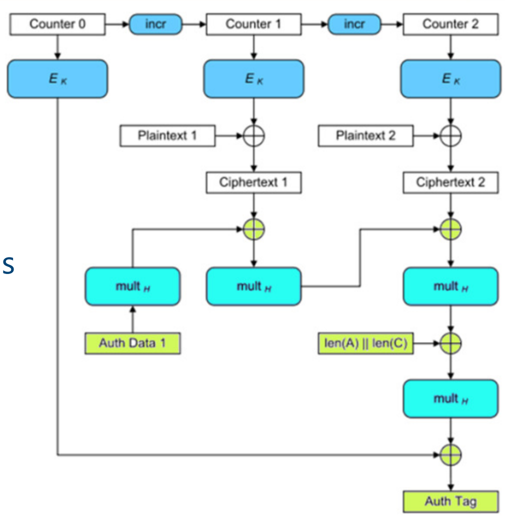


Authenticated encryption

- Encryption mixed with integrity control
  - Error propagation
  - Authentication tags
- Examples
  - GCM (Galois/Counter Mode)
  - CCM (Counter with CBC-MAC)

GCM

- CTR mode encryption
- Successive multiplications for integrity control
  - Multiplications in $GF(2^n)$
  - $H = E_k(0)$



Encryption + authentication

- Encrypt-then-MAC
  - MAC is computed from cryptogram
  - Should use two different keys
  - IPSec uses it
- Encrypt-and-MAC
  - MAC is computed from plaintext
  - MAC is not encrypted
  - SSH uses it
- MAC-then-Encrypt
  - MAC is computed from plaintext
  - MAC is encrypted
  - TLS uses it