CSE 484 / CSE M 584 (Winter 2013)

(Continue) Cryptography

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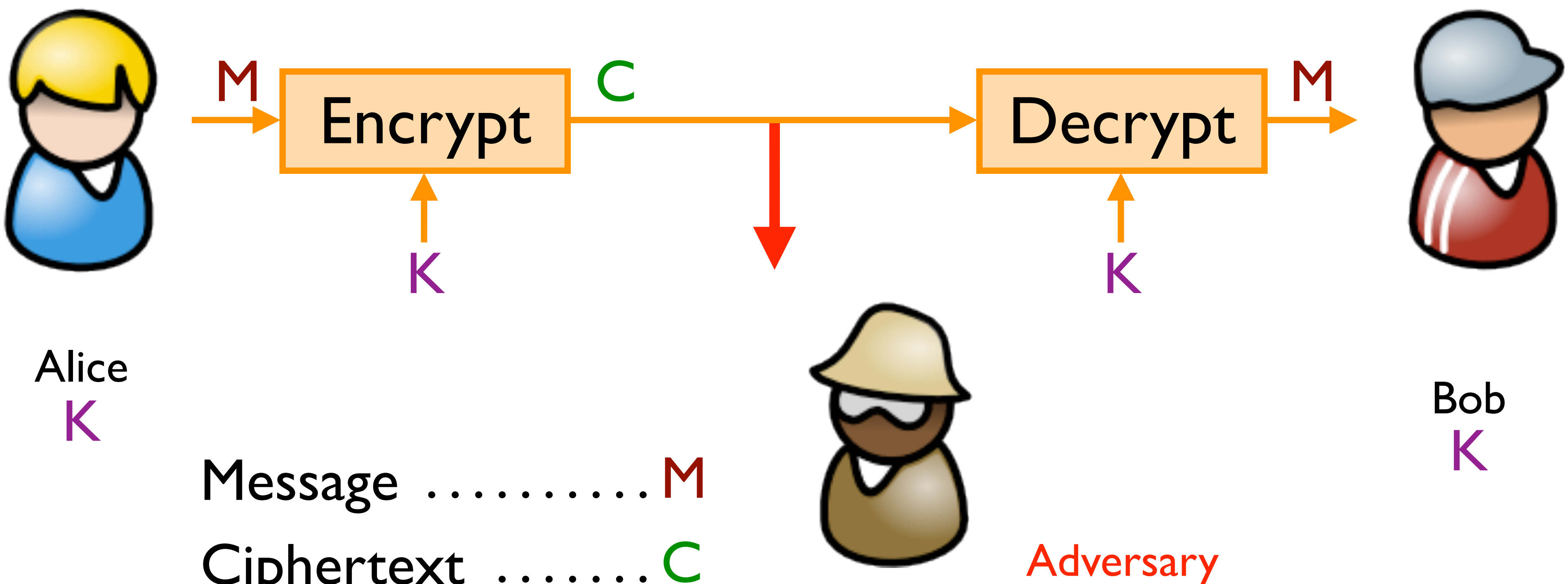
Goals for Today

- Cryptography

Achieving Privacy (Symmetric)

Encryption schemes: A tool for protecting privacy.



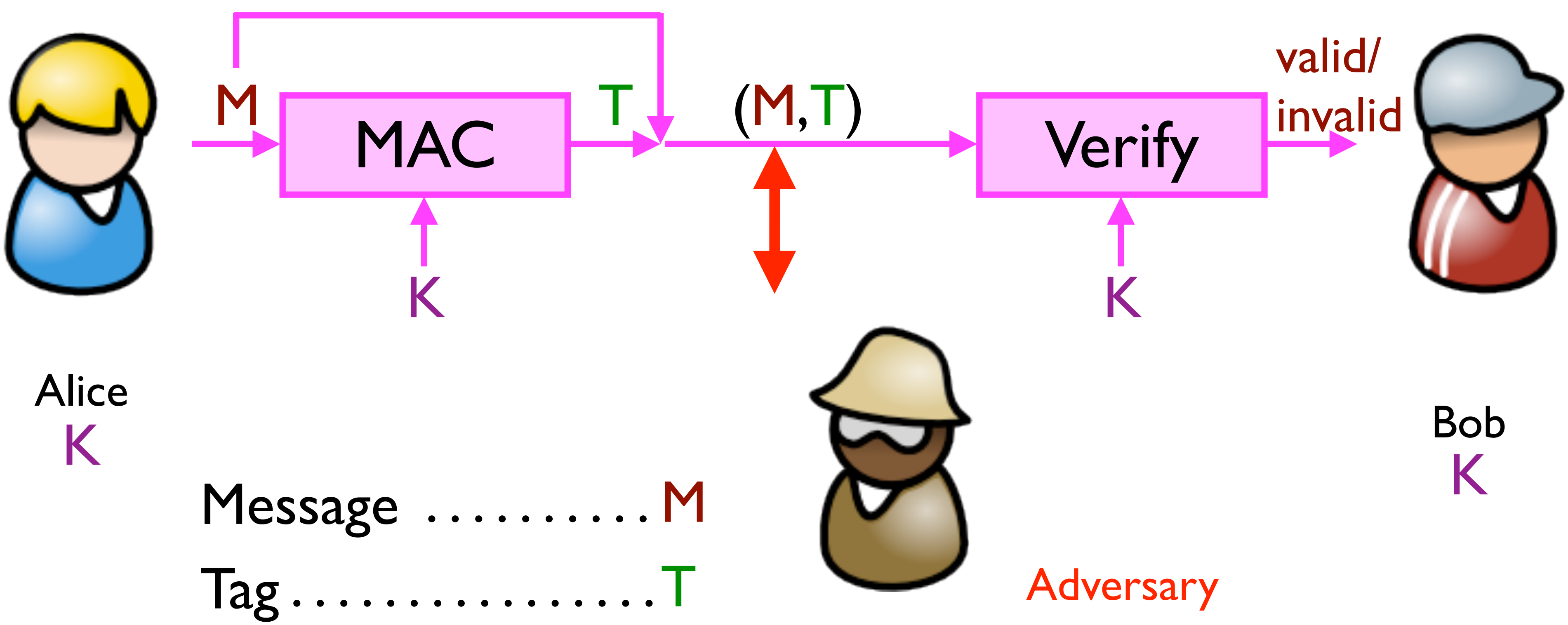
Message . . . . M

Ciphertext C

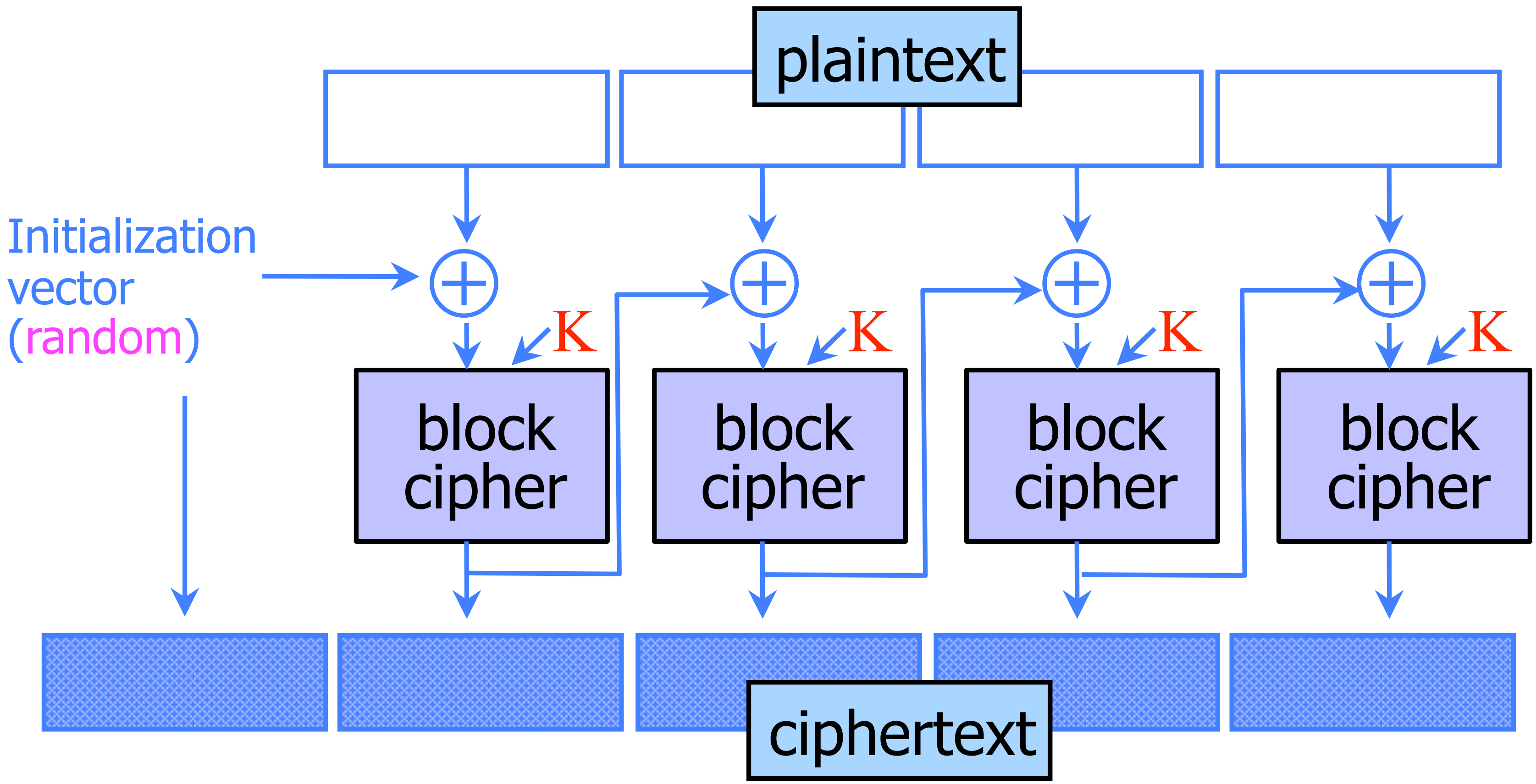
Achieving Integrity (Symmetric)

Message authentication schemes: A tool for protecting integrity.

(Also called message authentication codes or MACs.)

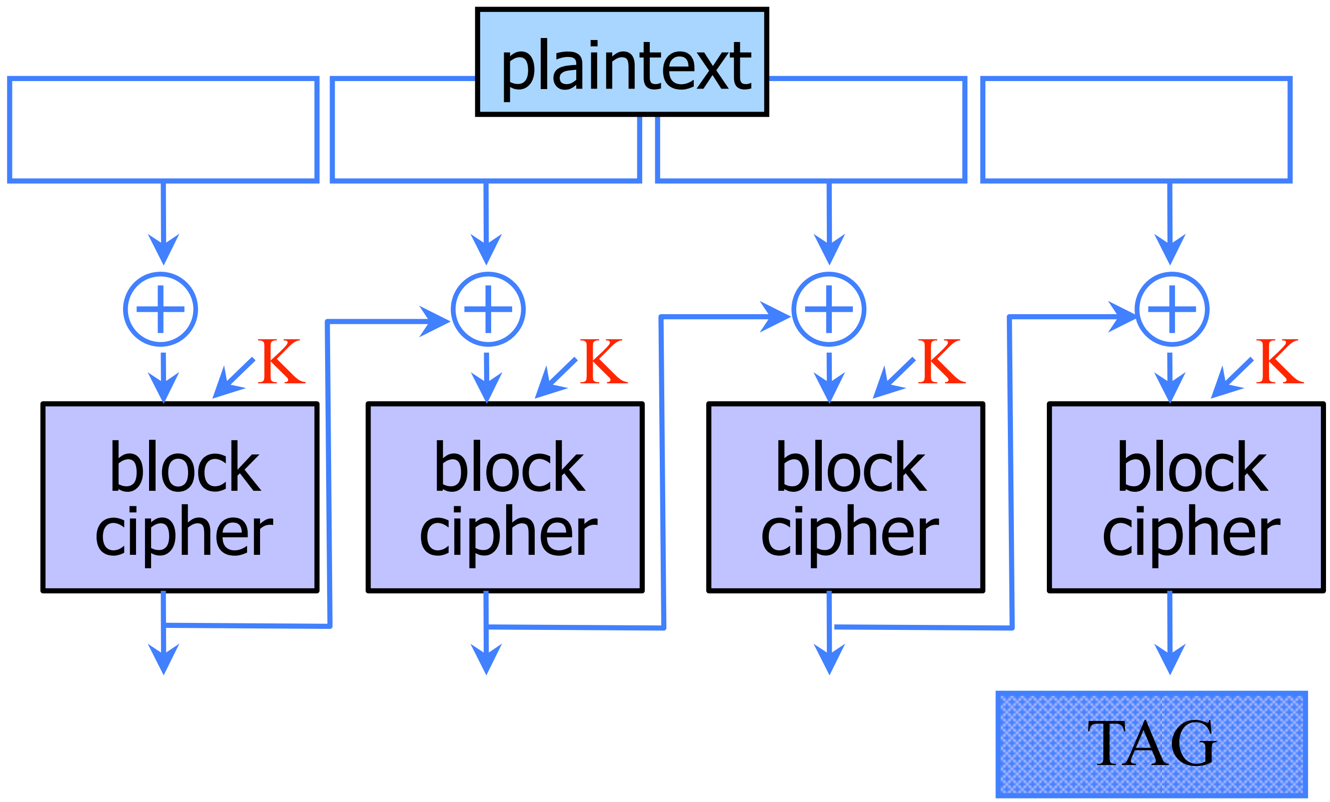


CBC Mode: Encryption



- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
  - Still does not guarantee integrity

CBC-MAC



- Not secure when system may MAC messages of different lengths.
  - NIST recommends a derivative called CMAC (not required)

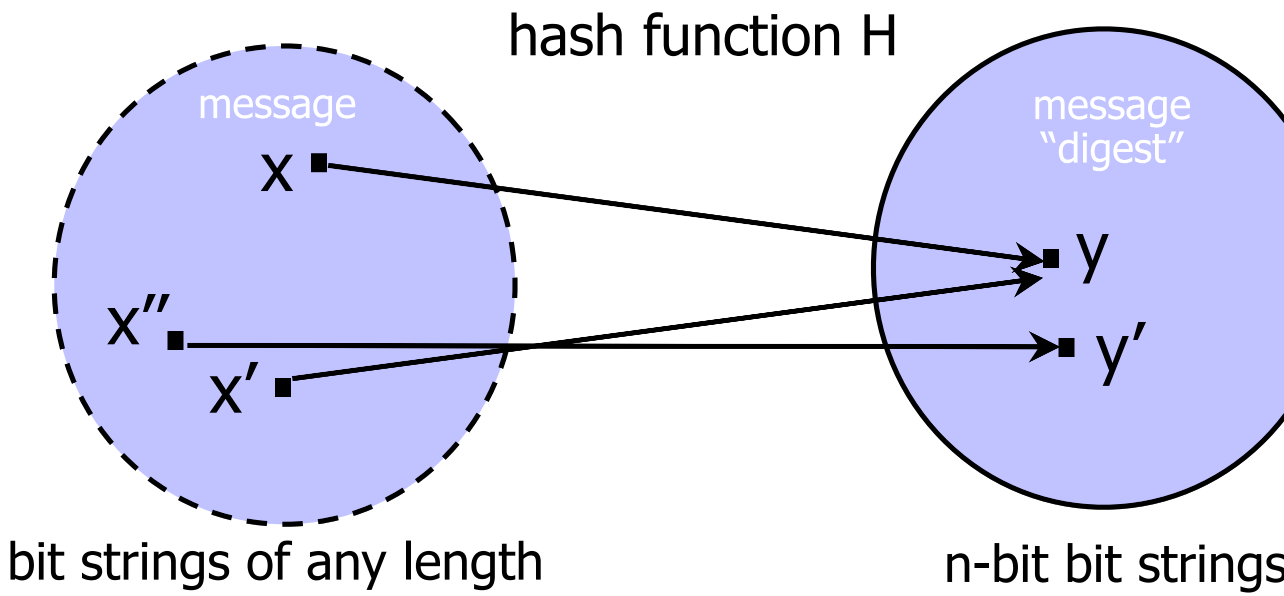
Birthday attacks

- Are there two people in the first 1/3 of this classroom that have the same birthday?
  - Yes?
  - No?

Birthday attacks

- Why is this important for cryptography?
  - 365 days in a year (366 some years)
    - Pick one person. To find another person with same birthday would take on the order of 365/2 = 182.5 people
    - Expect "collision" -- two people with same birthday -- with a room of only 23 people
    - For simplicity, approximate when we expect a collision as the square root of 365.
  - 2^{128} different 128-bit keys (or other random values)
    - Pick one key at random. To exhaustively search for this key requires trying on average 2^{127} keys.
    - Expect a "collision" after selecting approximately 2^{64} random keys.
    - 64 bits of security against collision attacks, not 128 bits.

Broad Class of Hash Functions



- H is a lossy compression function
  - Collisions: h(x)=h(x') for distinct inputs x, x'
  - Result of hashing should "look random" (make this precise later)
    - Intuition: half of digest bits are "1"; any bit in digest is "1" half the time
- Cryptographic hash function needs a few properties…

One-Way

- Intuition: hash should be hard to invert
  - "Preimage resistance"
  - Let $h(x')=y\in\{0,1\}^n$ for a random x'
  - Given y, it should be hard to find any x such that h(x)=y
- How hard?
  - Brute-force: try every possible x, see if h(x)=y
  - SHA-1 (common hash function) has 160-bit output
    - Expect to try 2^{159} inputs before finding one that hashes to y.

Collision Resistance

- Should be hard to find distinct x, x′ such that h(x)=h(x′)
  - Brute-force collision search is only $O(2^{n/2})$, not $O(2^n)$
  - For SHA-1, this means $O(2^{80})$ vs. $O(2^{160})$
- Birthday paradox (informal)
  - Let t be the number of values x,x′,x″… we need to look at before finding the first pair x,x′ s.t. h(x)=h(x′)
  - What is probability of collision for each pair x,x′? $1/2^n$
  - How many pairs would we need to look at before finding the first collision? $O(2^n)$
  - How many pairs x,x′ total? Choose(t,2)=t(t-1)/2 ~ $O(t^2)$
  - What is t? $2^{n/2}$

One-Way vs. Collision Resistance

- One-wayness does <u>not</u> imply collision resistance
  - Suppose g is one-way
  - Define h(x) as g(x′) where x′ is x except the last bit
    - h is one-way (to invert h, must invert g)
    - Collisions for h are easy to find: for any x, h(x0)=h(x1)
- Collision resistance does <u>not</u> imply one-wayness
  - Suppose g is collision-resistant
  - Define h(x) to be 0x if x is n-bit long, 1g(x) otherwise
    - Collisions for h are hard to find: if y starts with 0, then there are no collisions, if y starts with 1, then must find collisions in g
    - h is not one way: half of all y's (those whose first bit is 0) are easy to invert (how?); random y is invertible with probab. 1/2

Weak Collision Resistance

- Given randomly chosen x, hard to find x′ such that h(x)=h(x′)
  - Attacker must find collision for a specific x. By contrast, to break collision resistance it is enough to find any collision.
  - Brute-force attack requires $O(2^n)$ time
  - AKA second-preimage collision resistance
- Weak collision resistance does not imply collision resistance

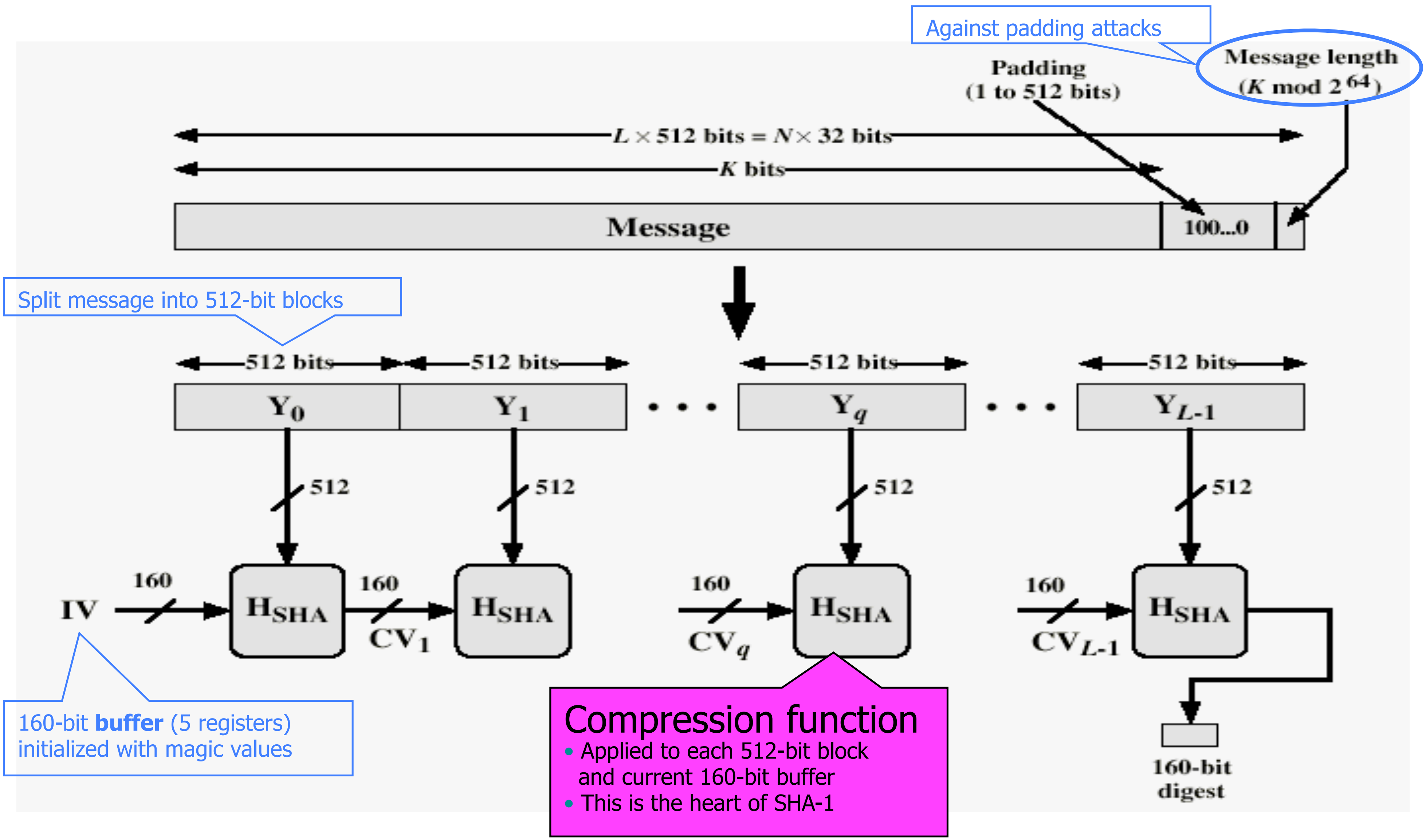
Which Property Do We Need?

- UNIX passwords stored as hash(password)
  - One-wayness: hard to recover the/a valid password
- Integrity of software distribution
  - Weak collision resistance (second-preimage resistance)
  - But software images are not really random…
  - Collision resistance if considering malicious developers
- Auction bidding
  - Alice wants to bid B, sends H(B), later reveals B
  - One-wayness: rival bidders should not recover B (this may mean that she needs to hash some randomness with B too)
  - Collision resistance: Alice should not be able to change her mind to bid B′ such that H(B)=H(B′)

Common Hash Functions

- MD5 (deprecated)
  - 128-bit output
  - Designed by Ron Rivest, used very widely
  - Collision-resistance broken (summer of 2004)
- RIPEMD-160
  - 160-bit variant of MD5
- SHA-1 (Secure Hash Algorithm) (deprecated)
  - 160-bit output
  - US government (NIST) standard as of 1993-95
  - Also recently broken! (Theoretically -- not practical.)
- SHA-256, SHA-512, SHA-224, SHA-384
- SHA-3: Just picked -- not an official standard yet

Basic Structure of SHA-1 (Not Required)



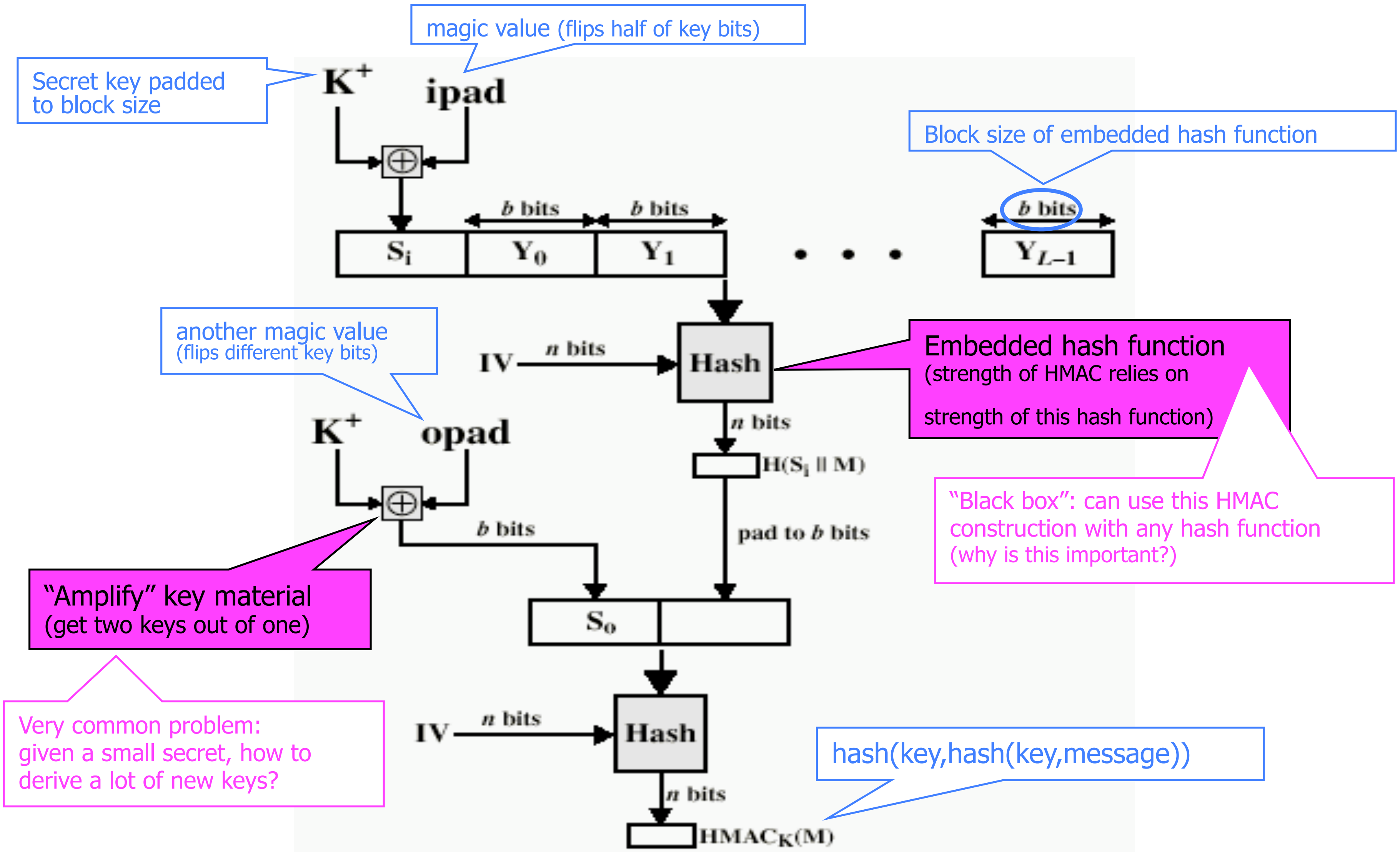
How Strong Is SHA-1?

- Every bit of output depends on every bit of input
  - Very important property for collision-resistance
- Brute-force inversion requires 2^{160} ops, birthday attack on collision resistance requires 2^{80} ops
- Some weaknesses, e.g., collisions can be found in 2^{63} ops (2005)

HMAC

- Construct MAC by applying a cryptographic hash function to message and key
- Invented by Bellare, Canetti, and Krawczyk (1996)
- Mandatory for IP security, also used in SSL/TLS

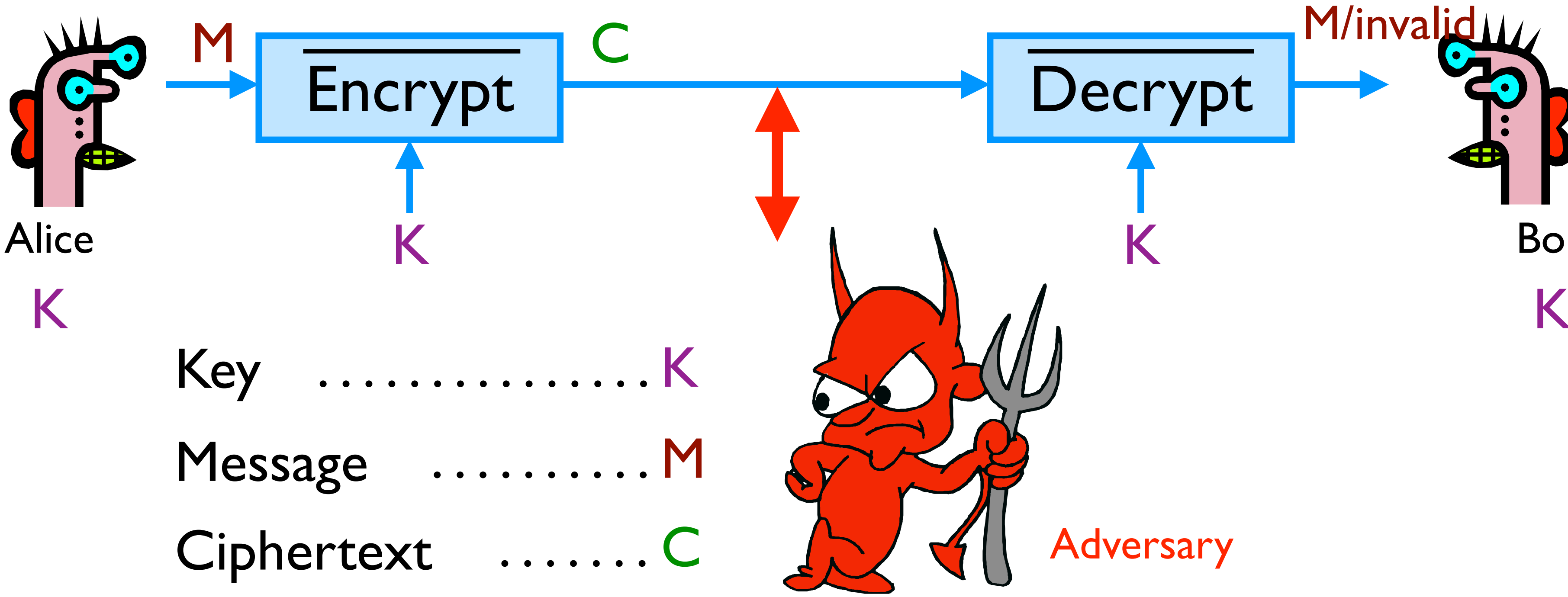
Structure of HMAC



Achieving Both Privacy and Integrity

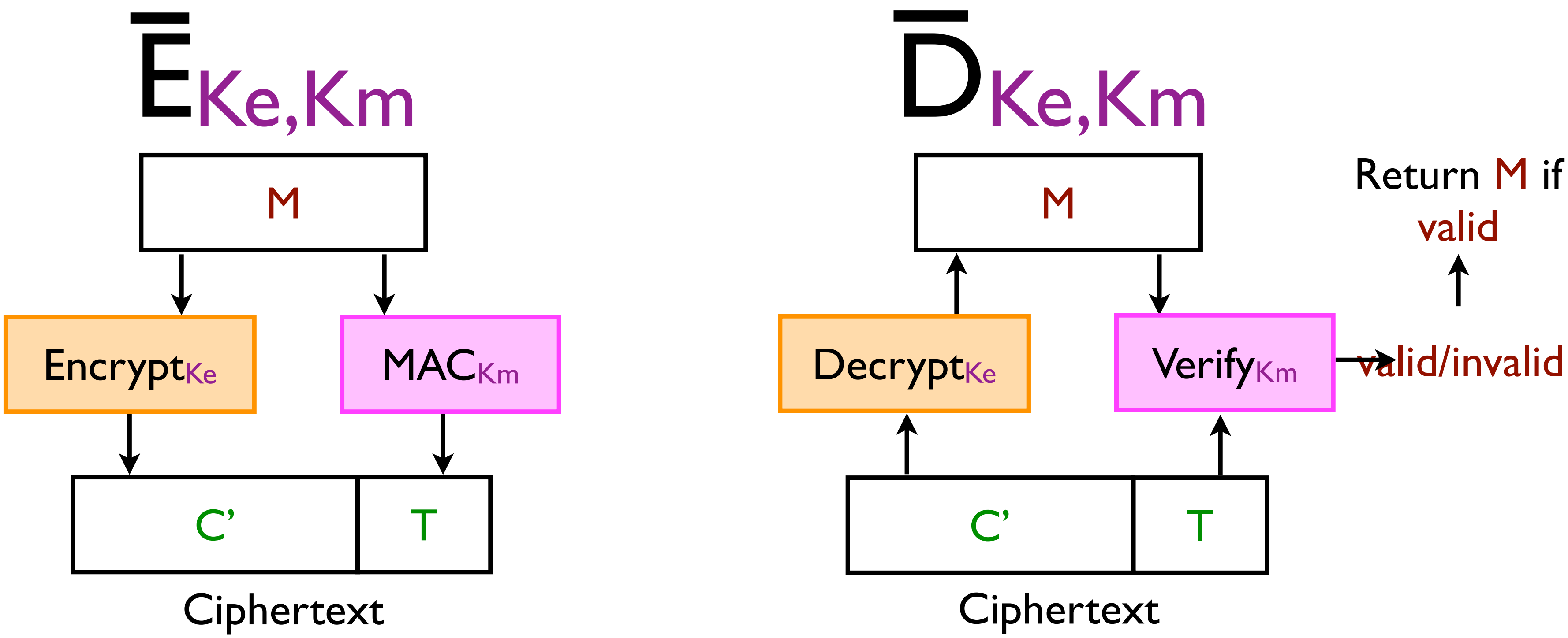
Authenticated encryption scheme

Recall: Often desire both privacy and integrity. (For SSH, SSL, IPsec, etc.)



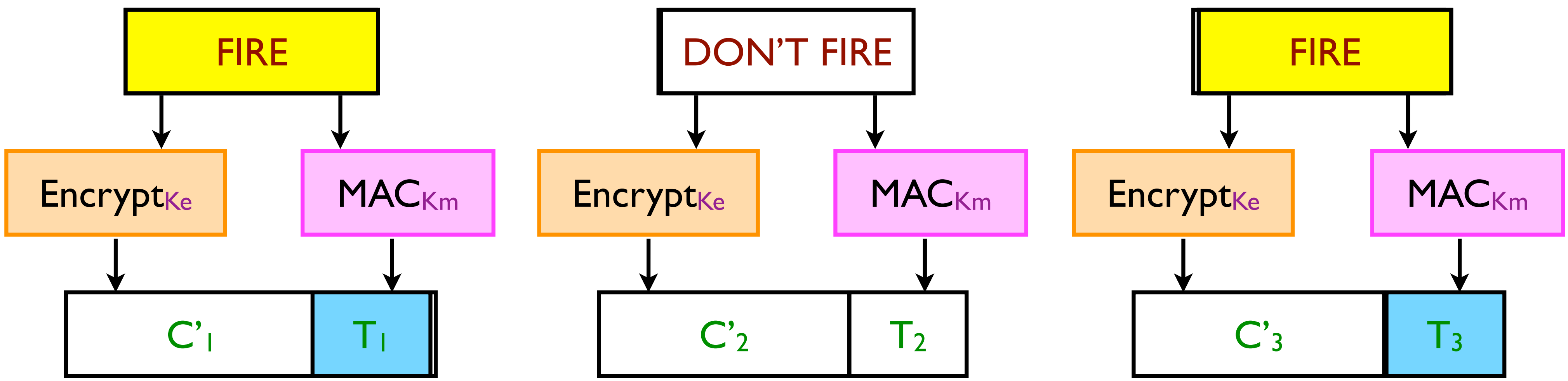
Some subtleties! Encrypt-and-MAC

Natural approach for authenticated encryption: Combine an encryption scheme and a MAC.



But insecure! [BN, Kra]

Assume Alice sends messages:

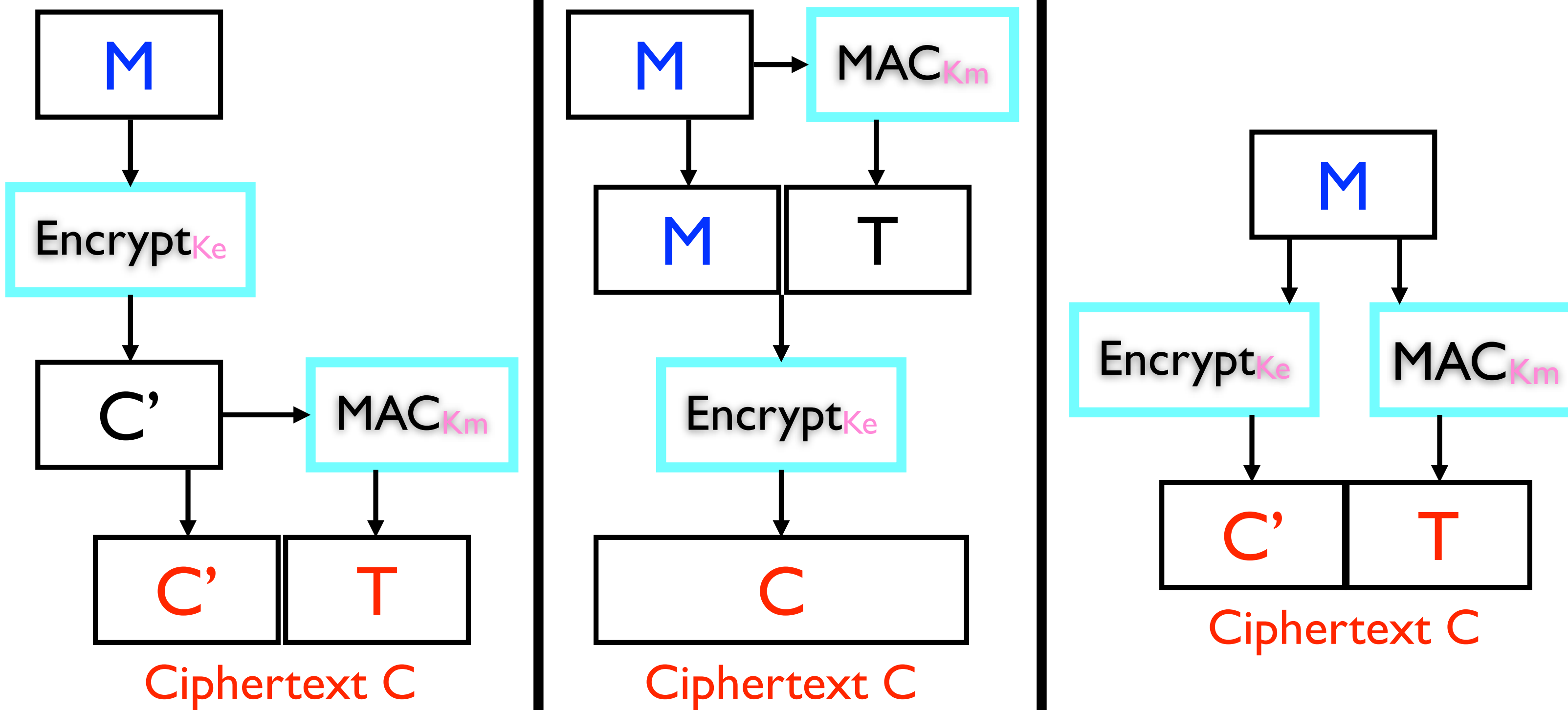


If $T_i = T_j$ then $M_i = M_j$

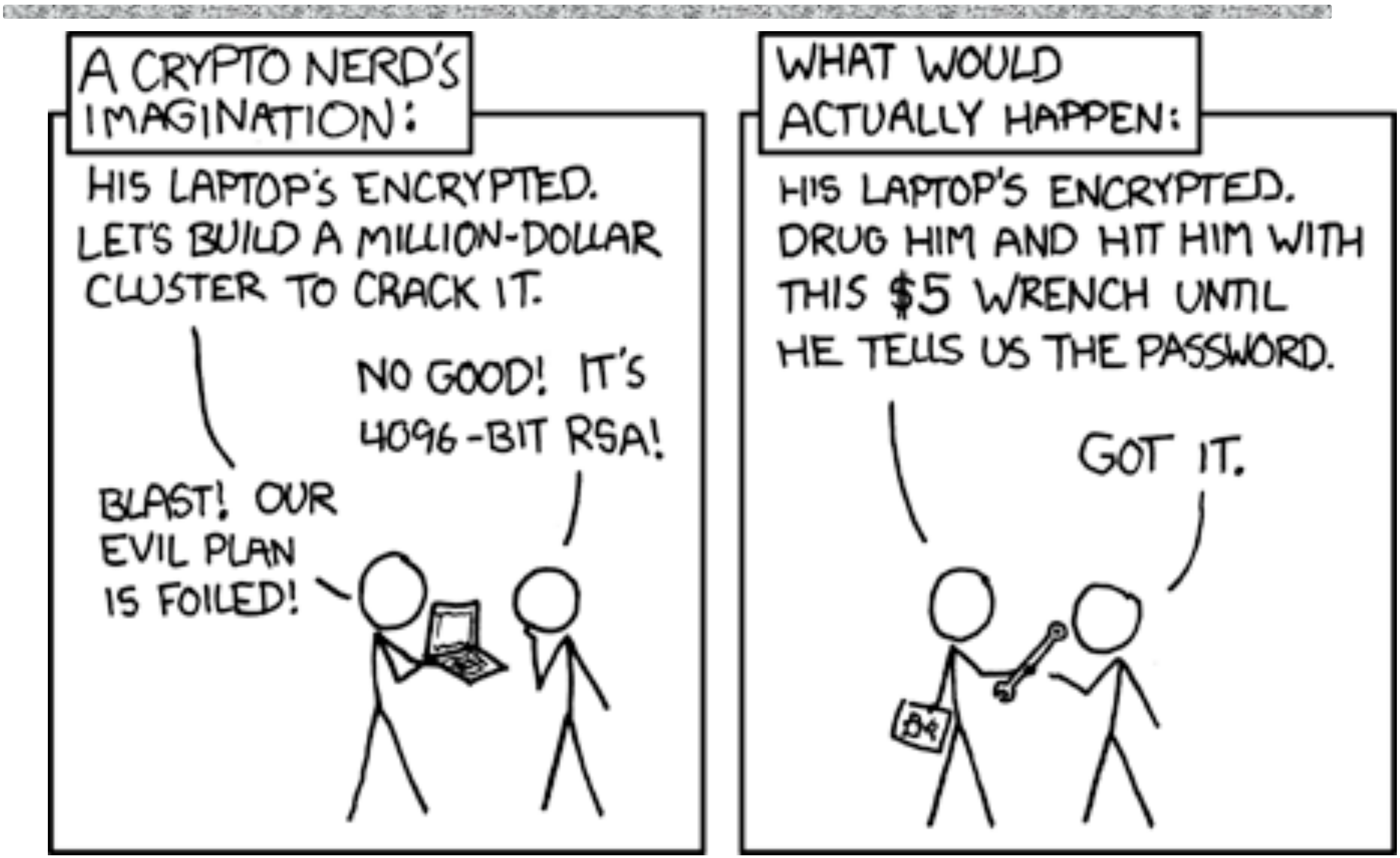
Adversary learns whether two plaintexts are equal.

Especially problematic when M_1, M_2, ... take on only a small number of possible values.

Results of [BN00,Kra01] (Don't need to know technical terms, like CCA)



	Encrypt-then-MAC	MAC-then-Encrypt	Encrypt-and-MAC
Privacy	Strong (CCA)	Weak (CPA)	Insecure
Integrity	Strong (CTXT)	Weak (PTXT)	Weak (PTXT)


A CRYPTO NERD'S IMAGINATION:
HIS LAPTOP'S ENCRYPTED. LET'S BUILD A MILLION-DOLLAR CLUSTER TO CRACK IT.
NO GOOD! IT'S 4096-BIT RSA!
BLAST! OUR EVIL PLAN IS FOILED!
WHAT WOULD ACTUALLY HAPPEN:
HIS LAPTOP'S ENCRYPTED. DRUG HIM AND HIT HIM WITH THIS $5 WRENCH UNTIL HE TELLS US THE PASSWORD.
GOT IT.