

CSE 484 / CSE M 584 (Spring 2012)

Symmetric Cryptography

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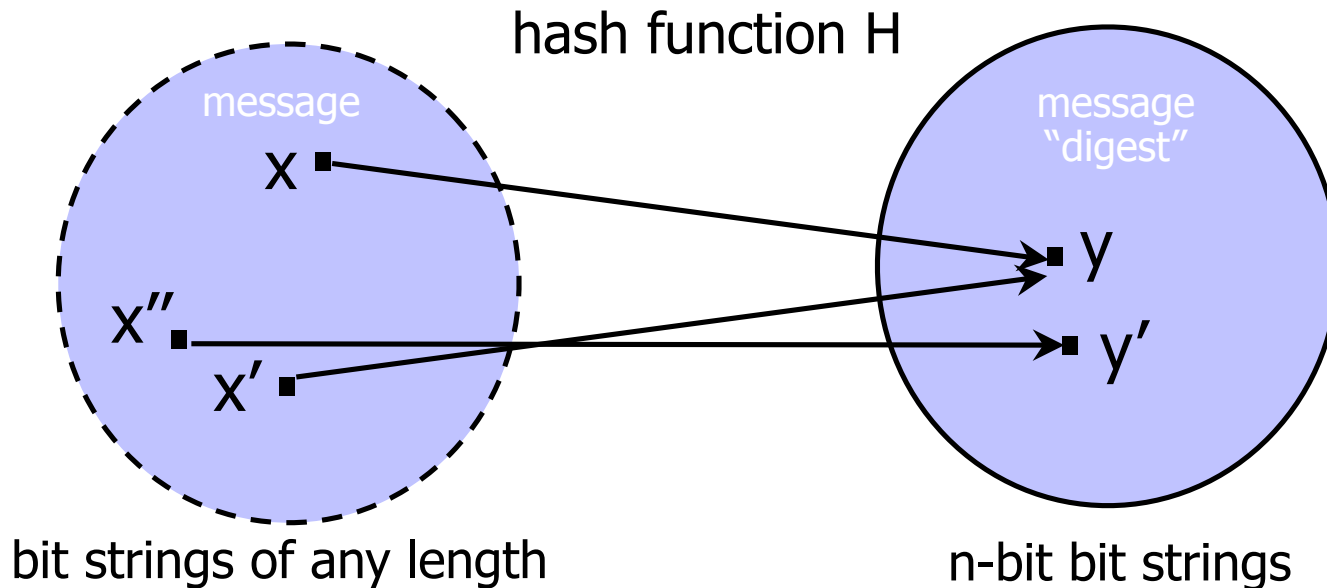
Thanks to Dan Boneh, Dieter Gollmann, Dan Halperin, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

Goals for Today

- ◆ Cryptography (Symmetric)
- ◆ Physical Security, Computer Security, and Cryptography

- ◆ Also
 - Lab due on Friday
 - 584 reading up, due next Tuesday
 - HW1 out Tues or Wed

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 $x, x', x'' \dots$ 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? $O(2^{n/2})$
 - How many pairs x, x' total? $\text{Choose}(t, 2) = t(t-1)/2 \sim O(t^2)$
 - What is t ? $2^{n/2}$

One-Way vs. Collision Resistance

◆ One-wayness does not 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 not 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 $\text{hash}(\text{password})$
 - Weak collision resistance: 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

- 128-bit output
- Designed by Ron Rivest, used very widely
- Collision-resistance broken (summer of 2004)

◆ RIPEMD-160

- 160-bit variant of MD5

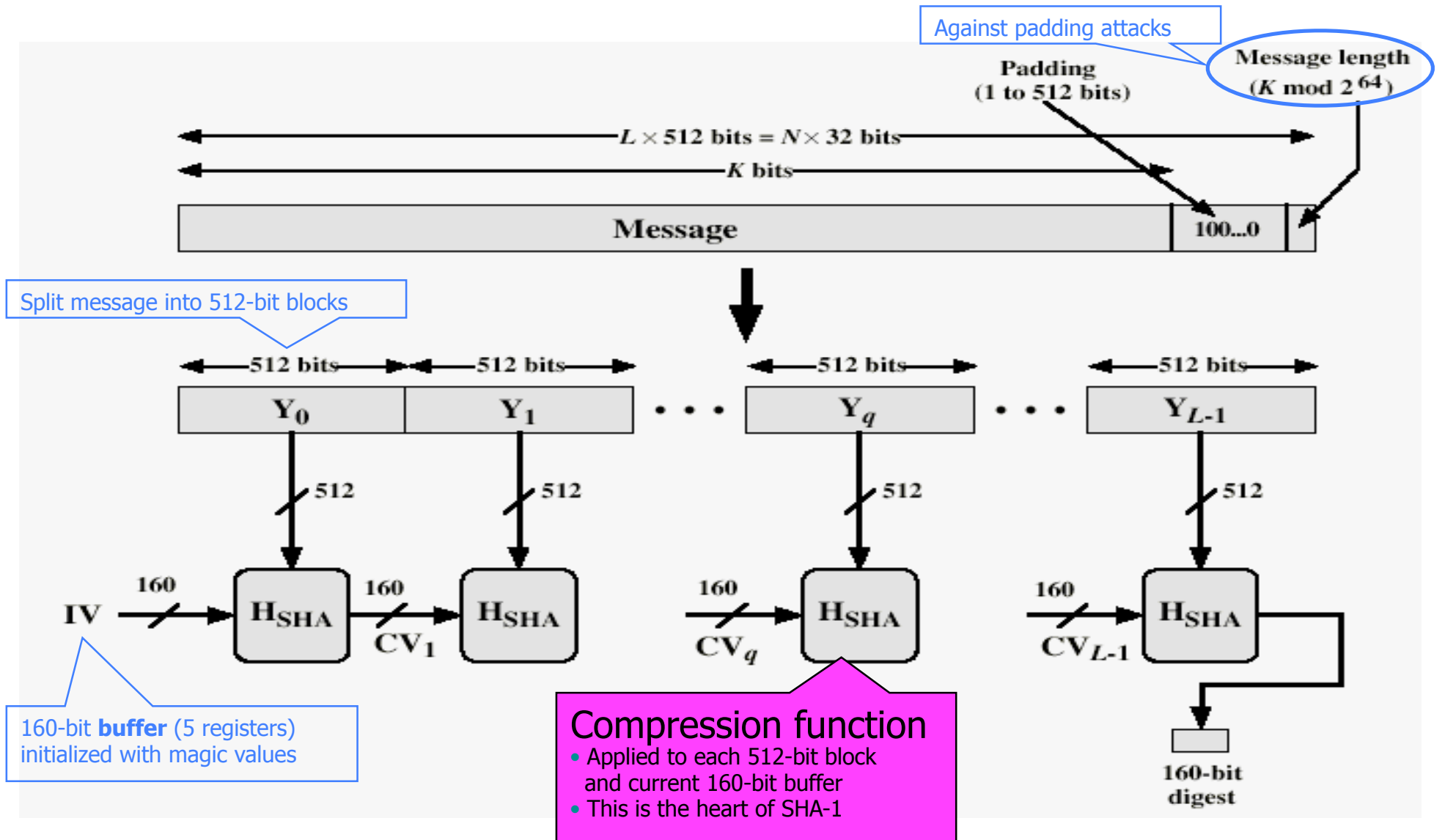
◆ SHA-1 (Secure Hash Algorithm)

- 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: Forthcoming.

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)

International Criminal Tribunal for Rwanda (Example Application)

- ◆ http://www.nytimes.com/2009/01/27/science/27arch.html?_r=1&ref=science



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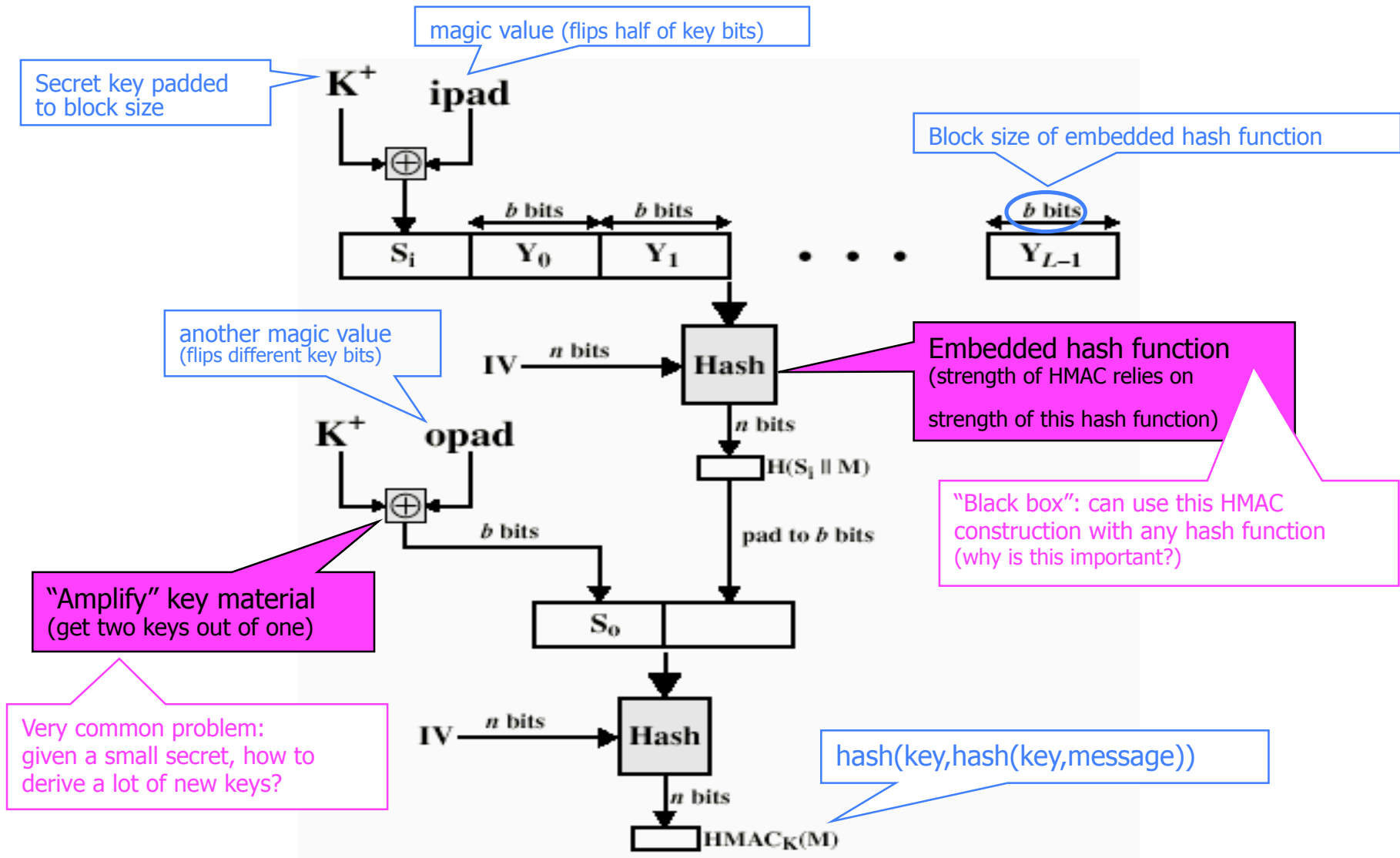
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- ◆ Credits: Alexei Czeskis, Karl Koscher, Batya Friedman

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

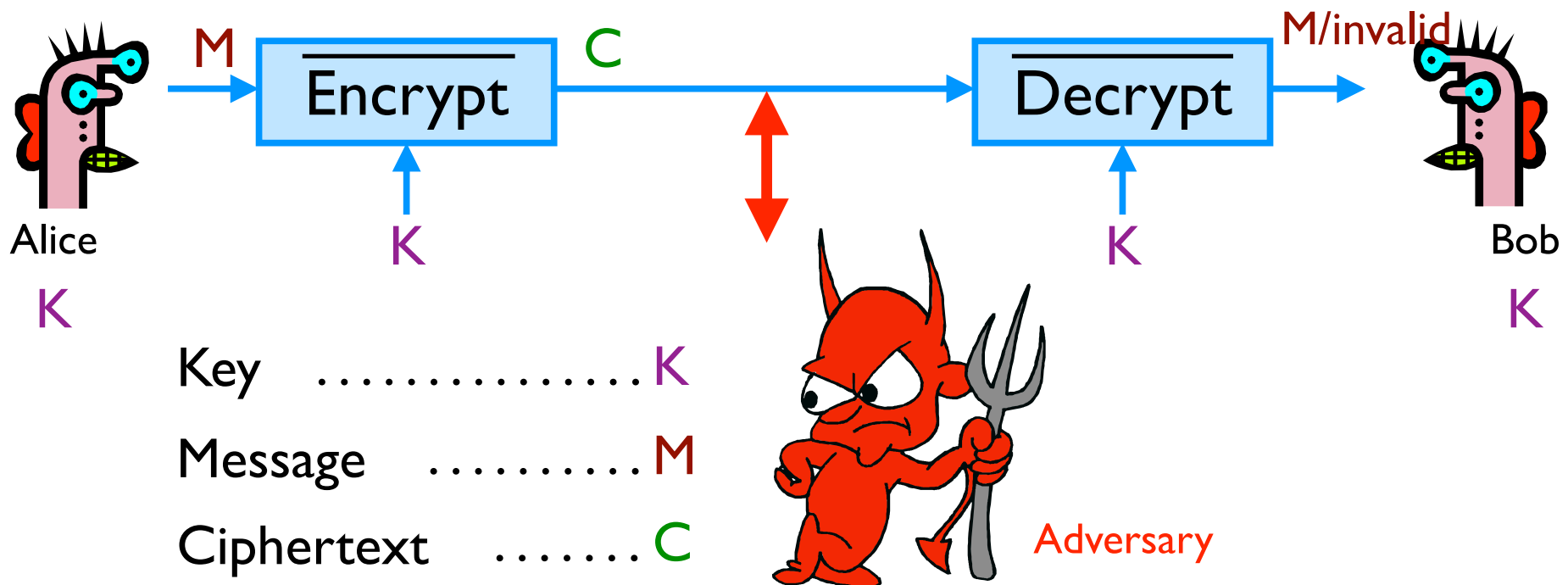
Structure of HMAC



Achieving Both Privacy and Integrity

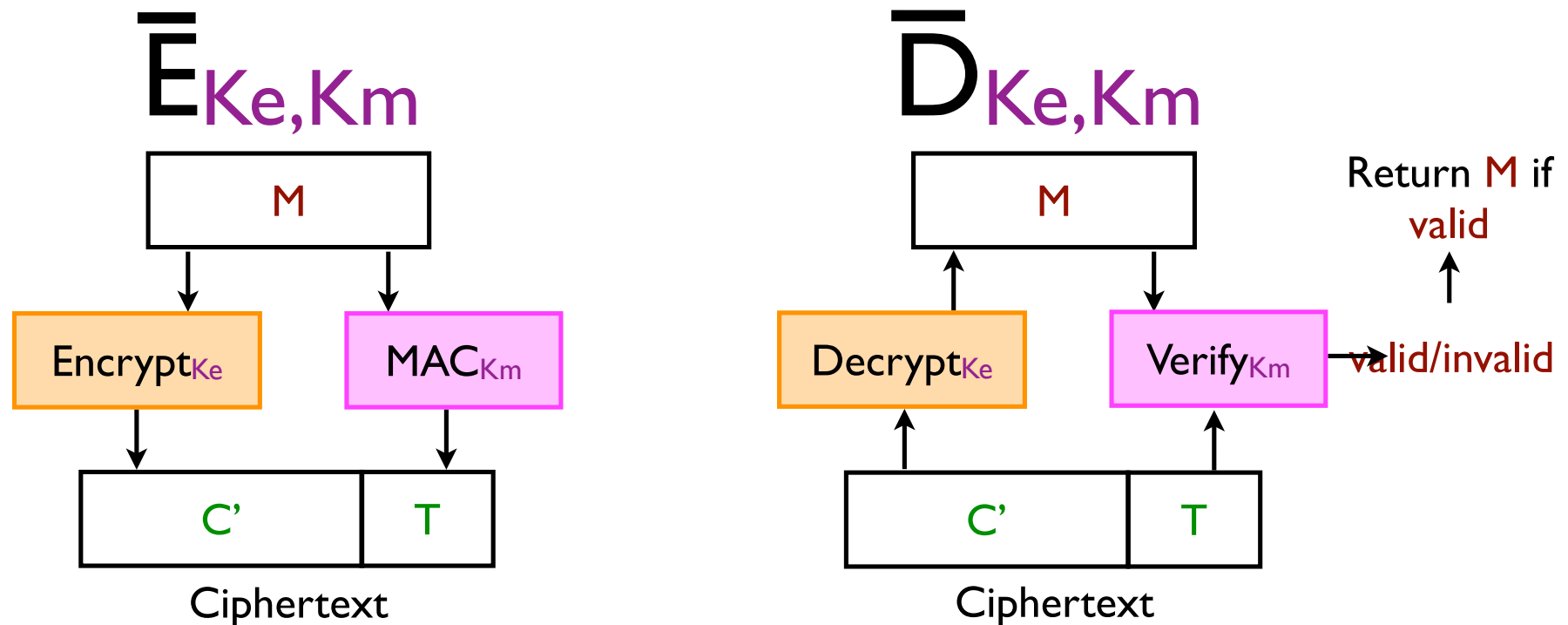
Authenticated encryption scheme

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



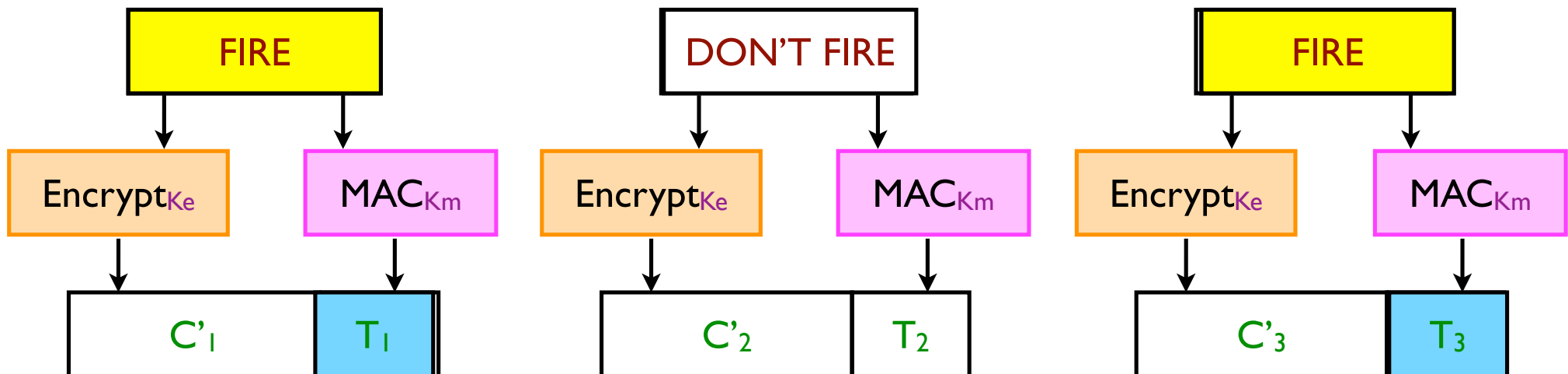
Some subtleties! Encrypt-and-MAC

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



But insecure! [BN, Kra]

Assume Alice sends messages:

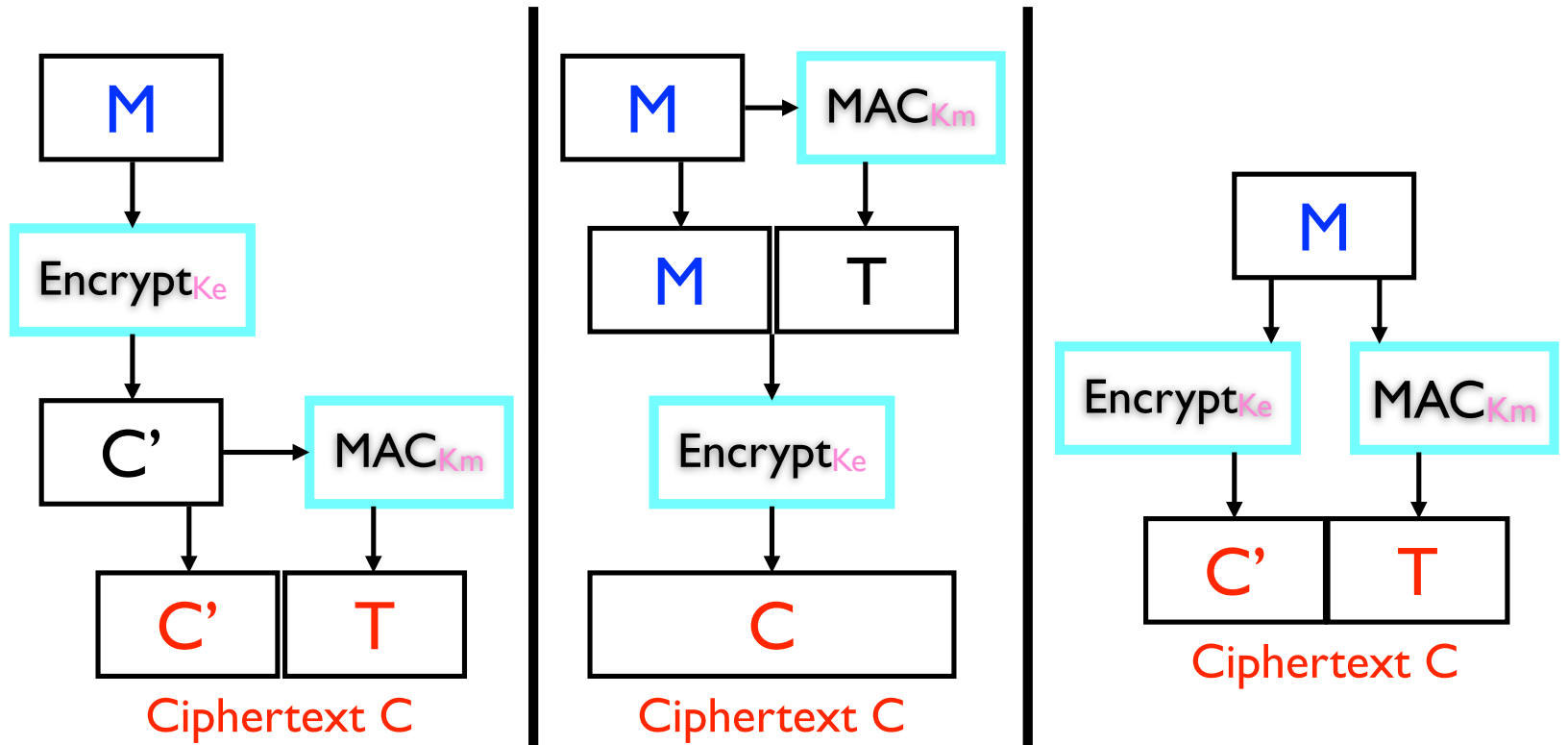


If $T_i = T_j$ then $M_i = M_j$

Adversary learns whether two plaintexts are equal.

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

Results of [BN00,Kra01]



Encrypt-then-MAC

MAC-then-Encrypt

Encrypt-and-MAC

Privacy

Strong (CCA)

Weak (CPA)

Insecure

Integrity

Strong (CTXT)

Weak (PTXT)

Weak (PTXT)