

**CSE 484 / CSE M 584: Computer Security and
Privacy**

Cryptography

Autumn 2018

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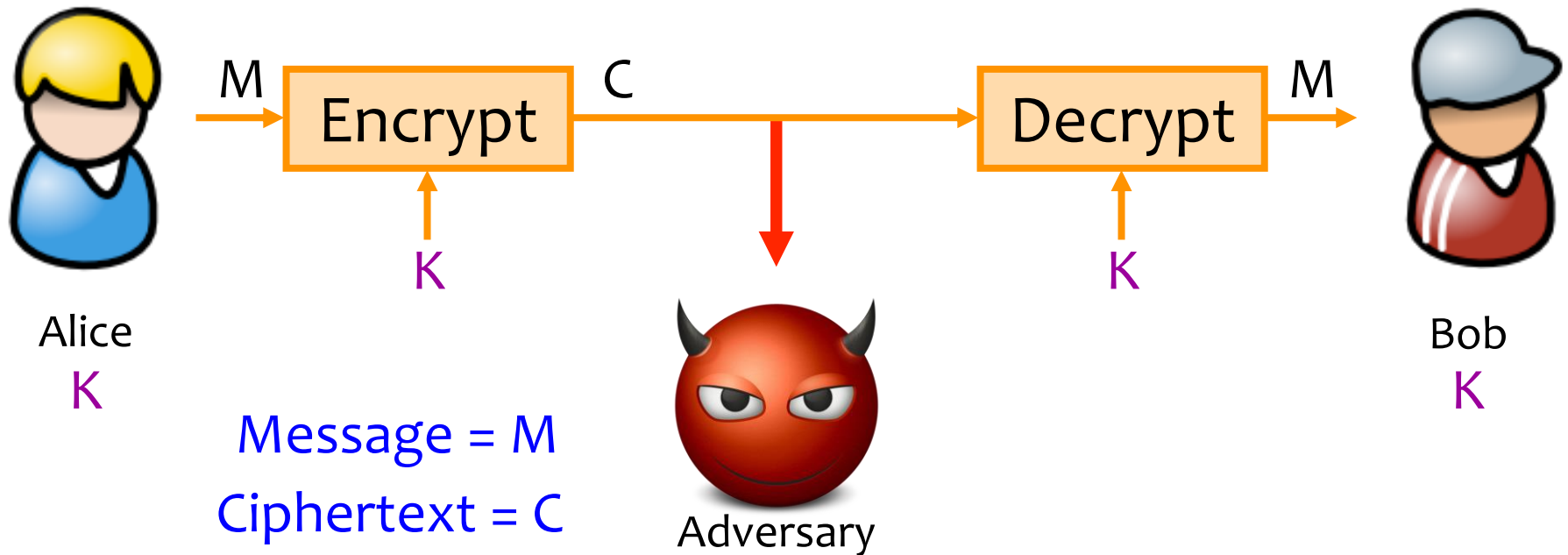
Thanks to Dan Boneh, Dieter Gollmann, Dan Halperin, Ada Lerner, John Manferdelli, John Mitchell, Franziska Roesner, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

Admin

- Lab 1:
 - Due Oct 24, 4:30pm
- Quiz sections (especially for Lab 1): M 2:30, W 1:30, F 12
- My office hours (especially for crypto, research readings, administrivia, worksheet pick up): M 11:30

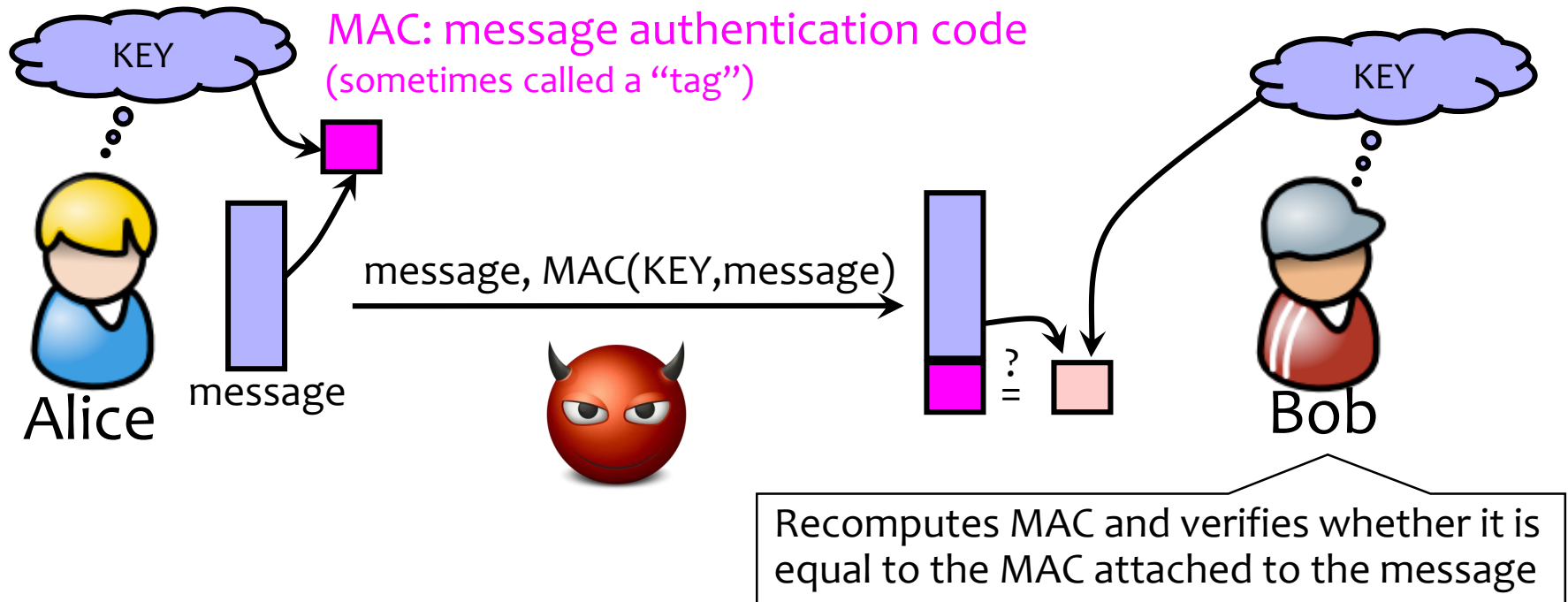
So Far: Achieving Privacy

Encryption schemes: A tool for protecting **privacy**.



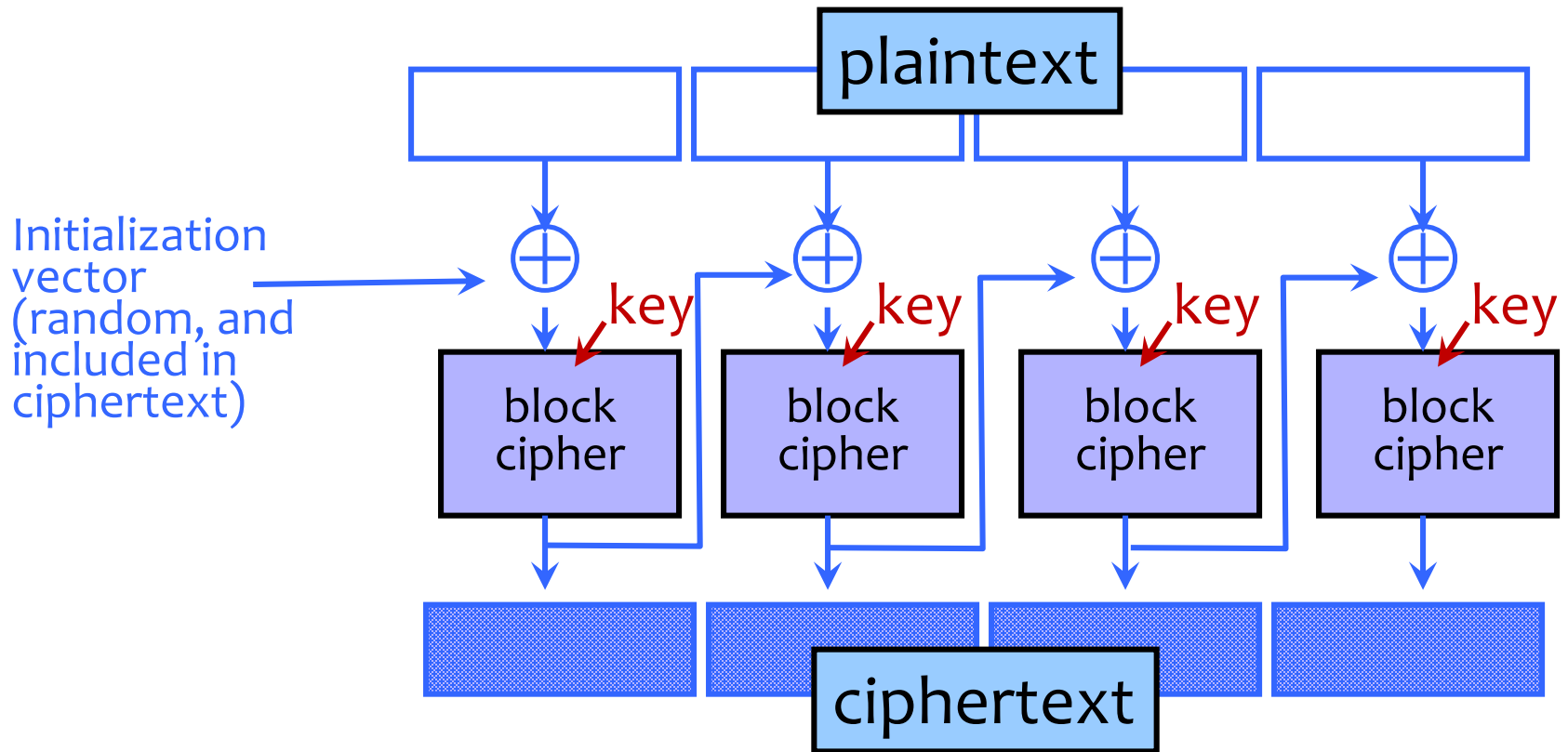
Now: Achieving Integrity

Message authentication schemes: A tool for protecting integrity.



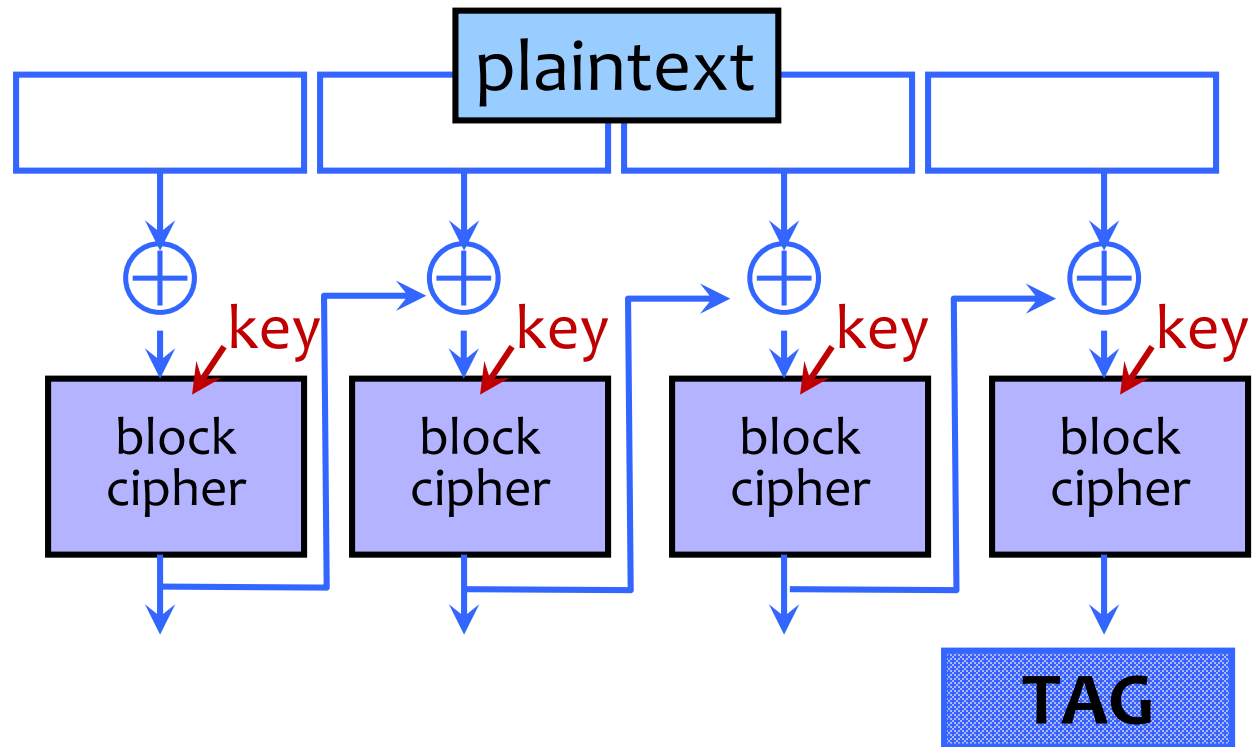
Integrity and authentication: only someone who knows KEY can compute correct MAC for a given message.

Reminder: CBC Mode Encryption



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

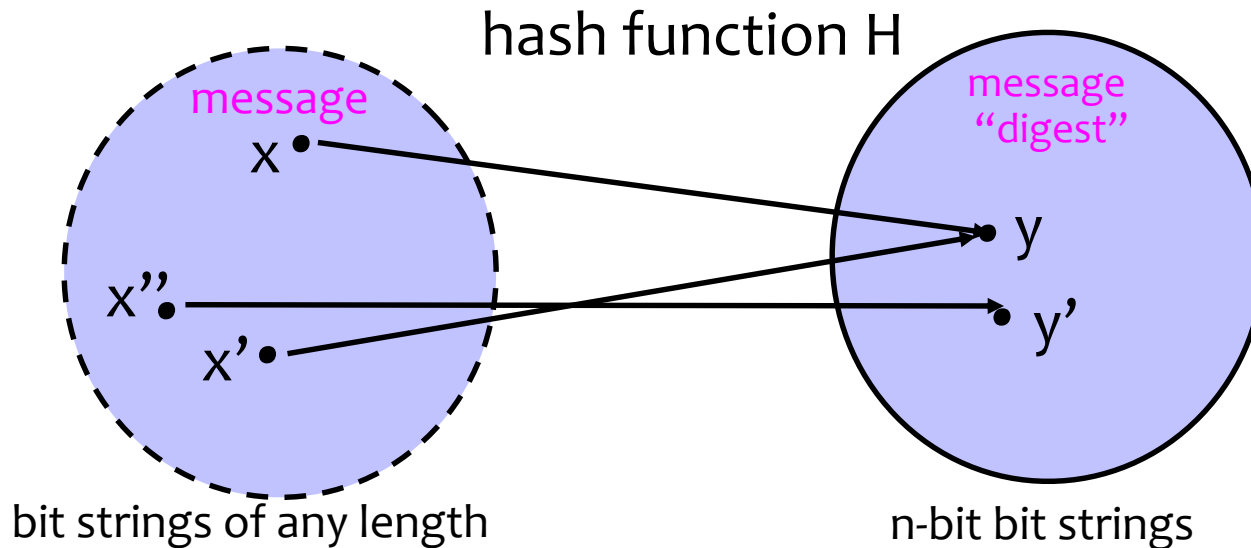
CBC-MAC



- Not secure when system may MAC messages of different lengths.
- NIST recommends a derivative called CMAC [FYI only]
- Other MACs exist, e.g., GMAC, UMAC, HMAC (next section)

Another Tool: Hash Functions

Hash Functions: Main Idea



- Hash function H is a lossy compression function
 - Collision: $h(x)=h(x')$ for distinct inputs x, x'
- $H(x)$ should look “random”
 - Every bit (almost) equally likely to be 0 or 1
- Cryptographic hash function needs a few properties...

Property 1: 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 .

Property 2: Collision Resistance

- Should be hard to find $x \neq x'$ such that $h(x) = h(x')$

Birthday Paradox

- Are there two people in the first few rows of this classroom that have the same birthday?
 - 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 birthday “collision” with a room of only 23 people.
 - For simplicity, approximate when we expect a collision as $\text{sqrt}(365)$.
- Why is this important for cryptography?
 - 2^{128} different 128-bit values
 - Pick one value at random. To exhaustively search for this value requires trying on average 2^{127} values.
 - Expect “collision” after selecting approximately 2^{64} random values.
 - 64 bits of security against collision attacks, not 128 bits.

Property 2: Collision Resistance

- Should be hard to find $x \neq x'$ such that $h(x) = h(x')$
- Birthday paradox means that brute-force collision search is **only $O(2^{n/2})$, not $O(2^n)$**
 - For SHA-1, this means $O(2^{80})$ vs. $O(2^{160})$

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 , $h(x_0)=h(x_1)$
- Collision resistance does not imply one-wayness
 - Suppose g is collision-resistant
 - Define $y=h(x)$ 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. $\frac{1}{2}$

Property 3: 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
- Weak collision resistance does not imply collision resistance.

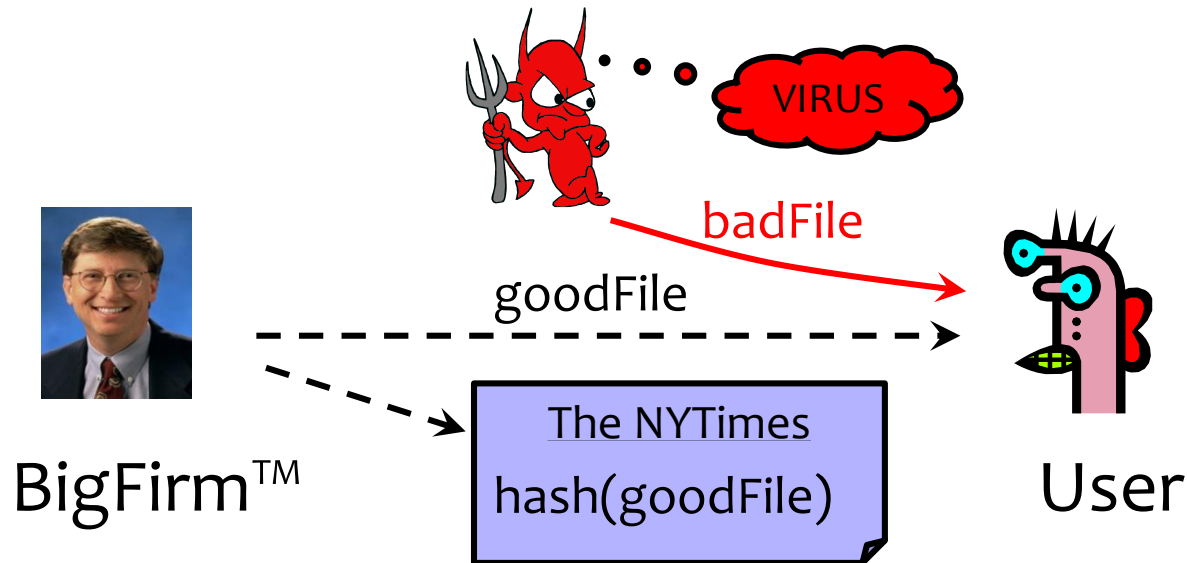
Hashing vs. Encryption

- Hashing is one-way. There is no “un-hashing”
 - A ciphertext can be decrypted with a decryption key... hashes have no equivalent of “decryption”
- Hash(x) looks “random” but can be compared for equality with Hash(x’)
 - Hash the same input twice → same hash value
 - Encrypt the same input twice → different ciphertexts
- Cryptographic hashes are also known as “cryptographic checksums” or “message digests”

Application: Password Hashing

- Instead of user password, store `hash(password)`
- When user enters a password, compute its hash and compare with the entry in the password file
- Why is hashing better than encryption here?
- System does not store actual passwords!
- Cannot go from hash to password!

Application: Software Integrity



Goal: Software manufacturer wants to ensure file is received by users without modification.

Idea: given goodFile and $\text{hash}(\text{goodFile})$, very hard to find badFile such that $\text{hash}(\text{goodFile}) = \text{hash}(\text{badFile})$

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**
 - But software images are not really random... may need **full collision resistance** if considering malicious developers

Which Property Do We Need?

- UNIX passwords stored as $\text{hash}(\text{password})$
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 - **Weak collision resistance**
 - But software images are not really random... may need **full 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 – Don't use!
 - 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) – Don't use!
 - 160-bit output
 - US government (NIST) standard as of 1993-95
 - Theoretically broken 2005; practical attack 2017!
- SHA-256, SHA-512, SHA-224, SHA-384
- SHA-3: standard released by NIST in August 2015

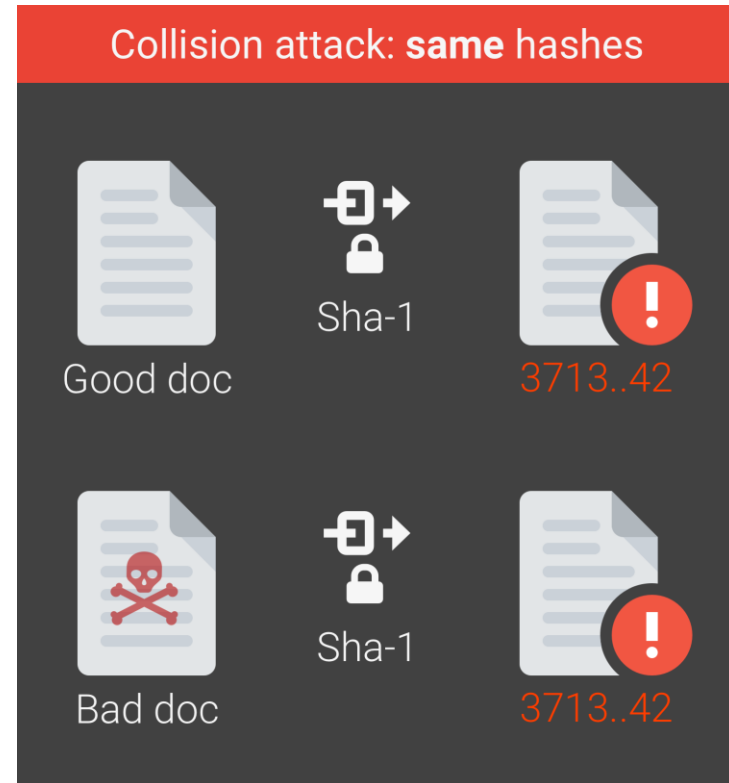
SHA-1 Broken in Practice (2017)

Google just cracked one of the building blocks of web encryption (but don't worry)

It's all over for SHA-1

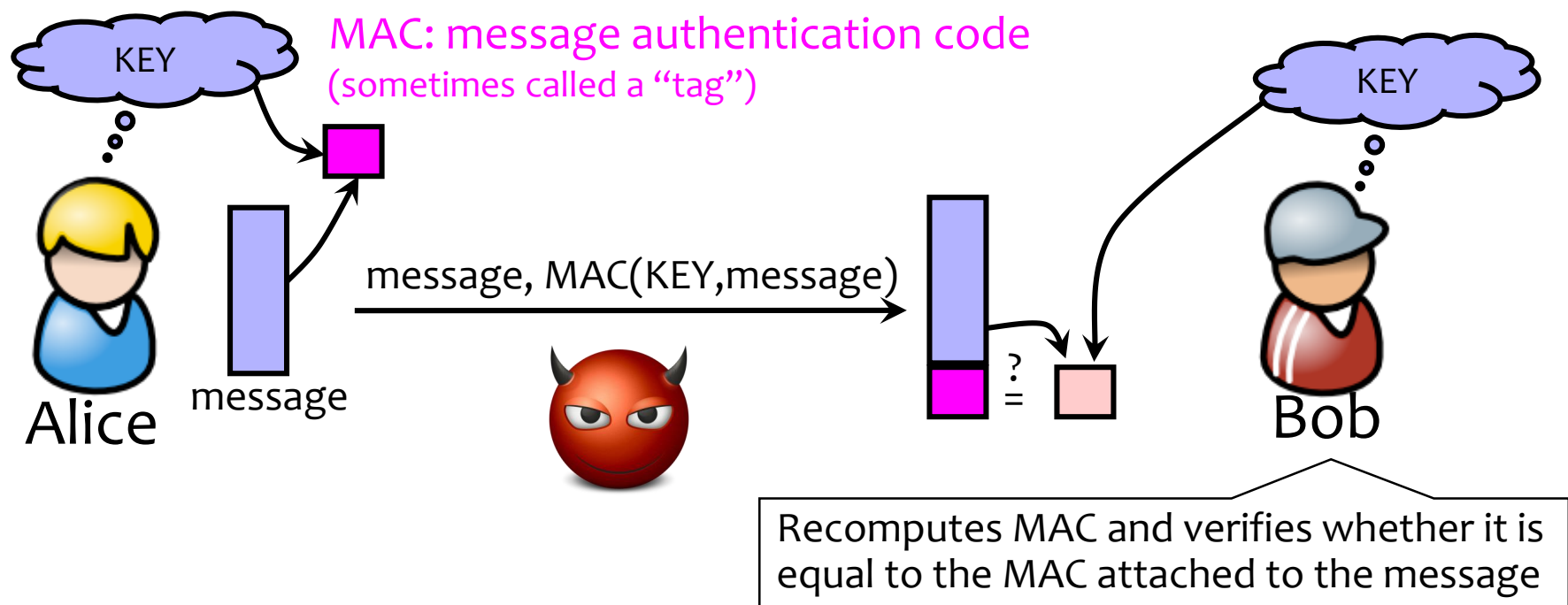
by Russell Brandom | @russellbrandom | Feb 23, 2017, 11:49am EST

<https://shattered.io>



Recall: Achieving Integrity

Message authentication schemes: A tool for protecting integrity.



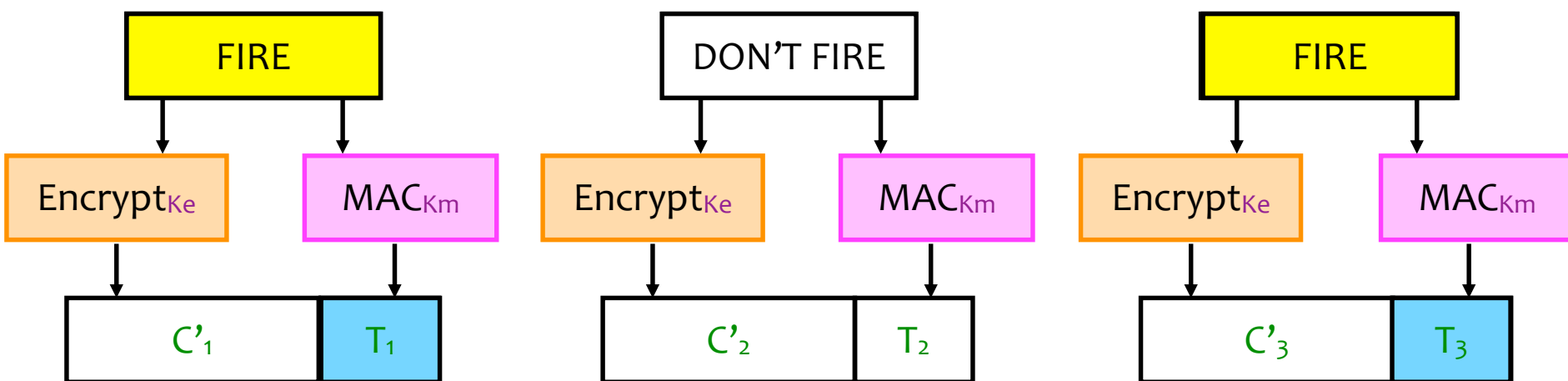
Integrity and authentication: only someone who knows KEY can compute correct MAC for a given message.

HMAC

- Construct MAC from a cryptographic hash function
 - Invented by Bellare, Canetti, and Krawczyk (1996)
 - Used in SSL/TLS, mandatory for IPsec
- Why not encryption?
 - Hashing is faster than block ciphers in software
 - Can easily replace one hash function with another
 - There used to be US export restrictions on encryption

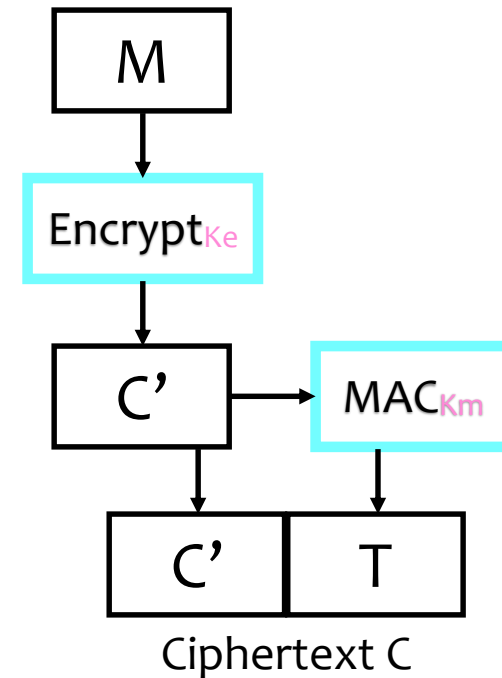
Authenticated Encryption

- What if we want both privacy and integrity?
- Natural approach: combine **encryption scheme** and a **MAC**.
- **But be careful!**
 - Obvious approach: Encrypt-and-MAC
 - Problem: MAC is deterministic! same plaintext \rightarrow same MAC



Authenticated Encryption

- Instead:
Encrypt then MAC.
- (Not as good:
MAC-then-Encrypt)



Encrypt-then-MAC