CSE 484 / CSE M 584: Cryptography

Winter 2022

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Announcements

- Feb 14: Alex Gantman (Qualcomm) – entirely virtual lecture
- Feb 16: Lucy Simko (UW) – entirely virtual lecture
- Feb 17: Final Project Part #1 deadline
  - https://courses.cs.washington.edu/courses/cse484/22wi/assignments/final_project.html
  - Groups strongly encouraged; groups of up to 3 people
  - 12–15-minute video, at non-accelerated or non-slowed timing (this is a security class, after all :P)
  - Use guest lectures, homework 1, **homework 2**, reading of news, personal interests, and any other resource you wish for inspiration

Announcements (continued)

- HW2: Online now (or soon)
- HW3: Cryptography (also online soon)
- Structurally, I moved the crypto homework (usually HW2) to HW3 because more compatible with where we are at
  - Usually, we announce HW2 before we are finished with the crypto discussions
  - Given timing for this quarter, better for the crypto homework to be due toward the end of the quarter
  - For HW3, I will tell you as we go which parts you should already be able to do now, in case you would like to get a head start

Announcements (continued)

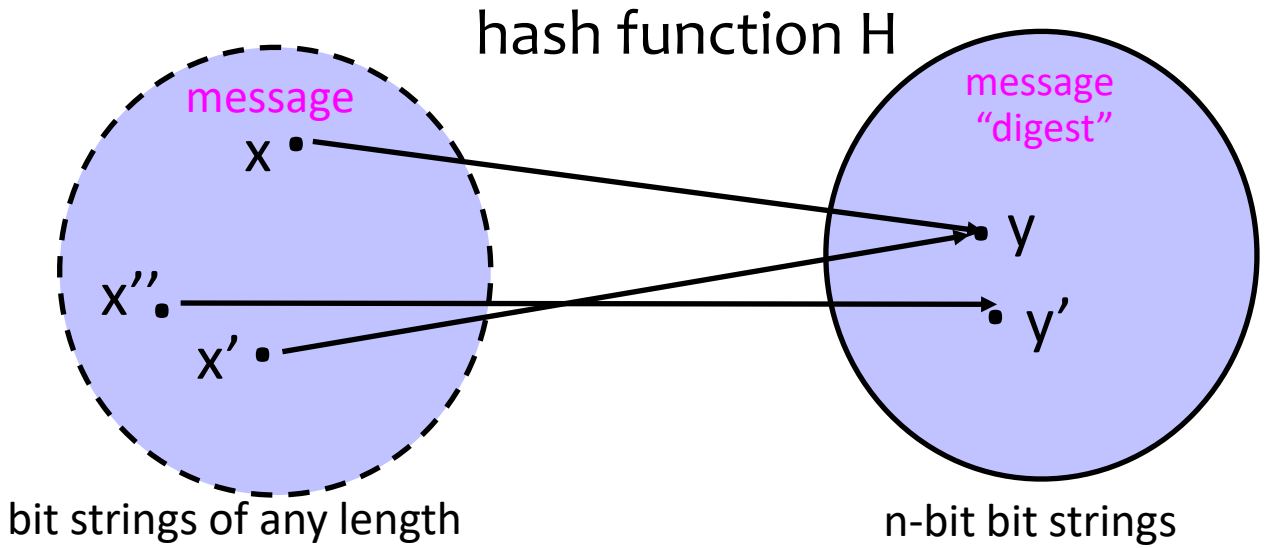
- Homework 2
  - More on security mindset
  - Relationship between people+society and technology
- From HW2 preamble:
  - Technologies do not exist in isolation. Technologies exist in the context of people and society. Societies have policies and laws and norms. The people might be the direct users of a technology, or they might be impacted by a technology even if they are not the direct users.
  - Computer security offers one vantage point to thinking about the relationship between technologies and people + society. The reason: in computer security and privacy, we consider adversaries. There are other vantages points, like considering algorithmic bias, but for the purposes of this course we will focus on computer security and privacy.
  - Homework 2, like Homework 1, is (1) an opportunity to revisit the security mindset, this time with the context of the first portion of the course and with a renewed focus on the relationship between technology and people+society. Additionally, Homework 2 (2) provides an opportunity to spend some time thinking about a technology that might be relevant to your final project (if you wish).

Announcements (continued)

- Physical security lecture

Begin: Review Slides

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 page of people on Zoom (depending on the size of your window) or first few rows of class 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 **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.

Collision resistance does **not** imply one-wayness.

You can prove this by constructing a function that has one property but not the other.

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.

End: Review

Hash Functions Summary (Thus Far)

- Map large domain to small range (e.g., range of all 160- or 256-bit values)
- Properties:
  - Collision Resistance: Hard to find two distinct inputs that map to same output
  - One-wayness: Given a point in the range (that was computed as the hash of a random domain element), hard to find a preimage
  - Weak Collision Resistance: Given a point in the domain and its hash in the range, hard to find a new domain element that maps to the same range element

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
- Don’t need to worry about where to store the key
- Cannot go from hash to password

Application: Password Hashing

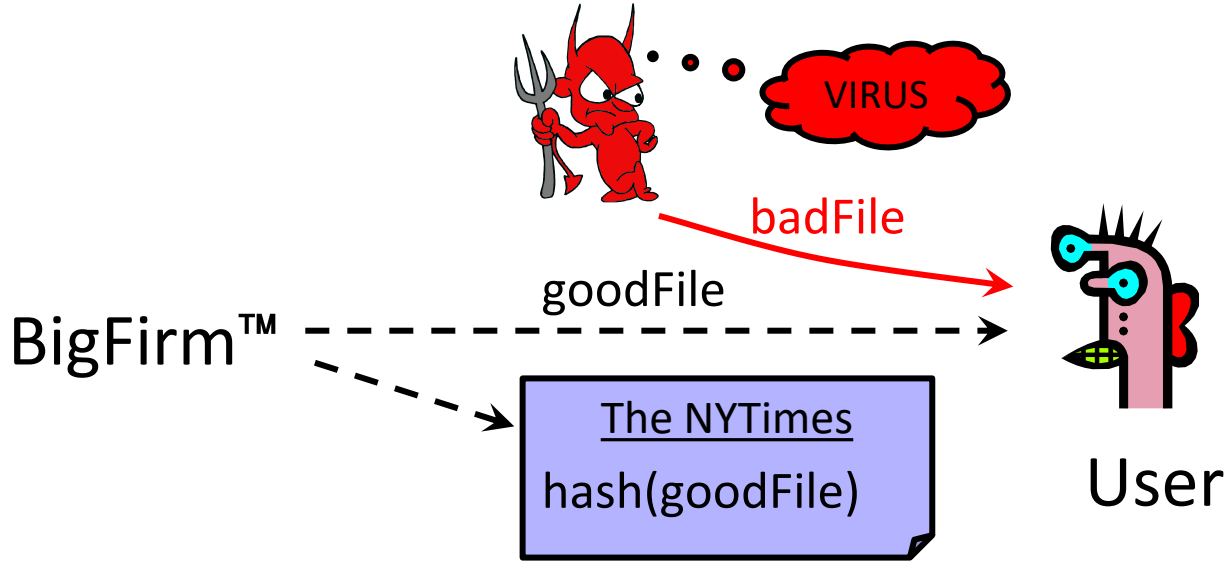
- Which property do we need?
  - One-wayness?
  - (At least weak) Collision resistance?
  - Both?

Application: Password Hashing + Salting

- Salting
  - We ‘salt’ hashes for password by adding a randomized suffix to the password
    - E.g. Hash(“coolpassword”+”35B67C2A”)
  - We then store the salt with the hashed password!
  - Server generates the salt

- The goal is to prevent *precomputation attacks*
  - If the adversary doesn’t know the salt, they can’t *precompute* common passwords

Application: Software Integrity



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

Idea: given goodFile and hash(goodFile), very hard to find badFile such that hash(goodFile)=hash(badFile)

Application: Software Integrity

- Which property do we need?
  - One-wayness?
  - (At least weak) Collision resistance?
  - Both?

Which Property Do We Need?

One-wayness, Collision Resistance, Weak CR?

- 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

Common Hash Functions

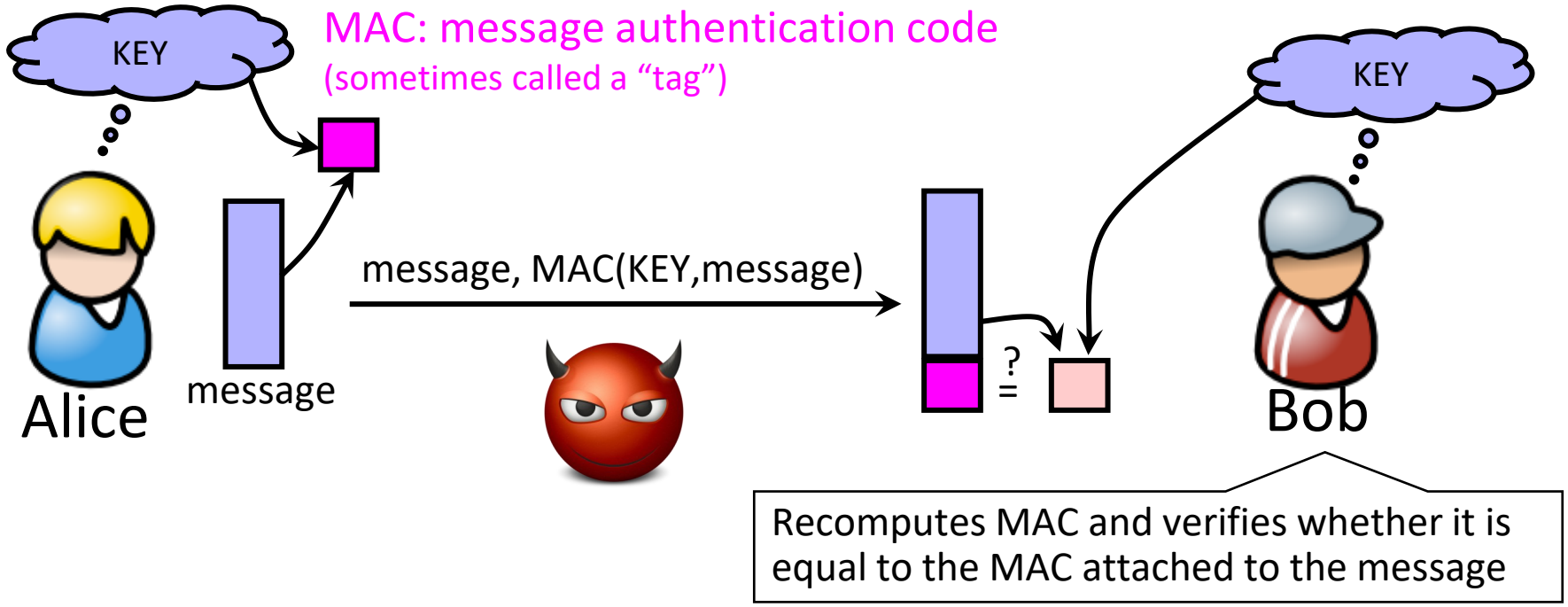
- **SHA-2: SHA-256, SHA-512, SHA-224, SHA-384**
- **SHA-3: standard released by NIST in August 2015**
- MD5 – Don't Use!
  - 128-bit output
  - Designed by Ron Rivest, used very widely
  - Collision-resistance broken (summer of 2004)
- RIPEMD
  - 160-bit version is OK
  - 128-bit version is *not* good
- 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!

How we evaluate hash functions

- Speed
  - Is it amenable to hardware implementations?
- Diffusion
  - Does changing 1 bit in the input affect all output bits?
- Resistance to attack approaches
  - Collisions?
  - Length extensions?
  - etc

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? (Historical reasons)
  - 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

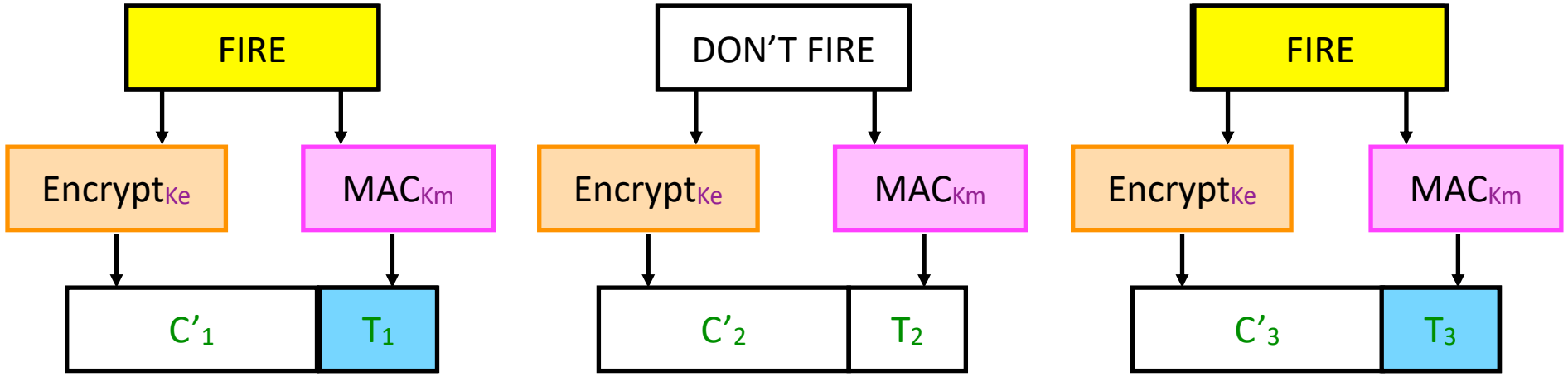
MAC with SHA3

- SHA3(Key || Message)

- SHA3 has some nice features that prevent the class of attacks HMAC prevents

Authenticated Encryption

- What if we want <u>both</u> 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 → same MAC

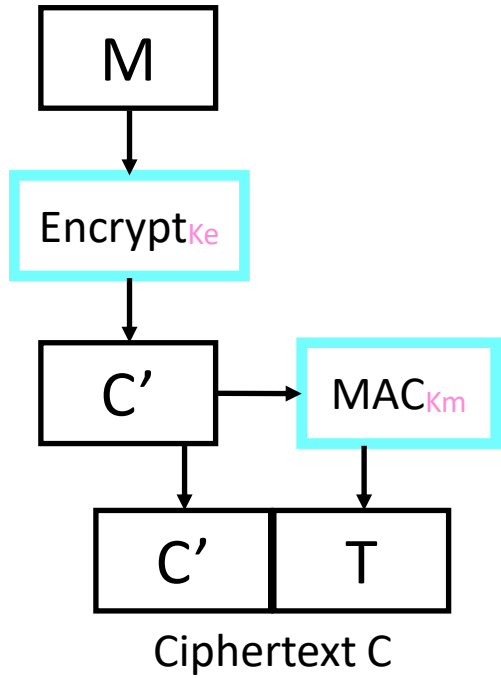


Authenticated Encryption

- Instead:

  Encrypt *then* MAC.

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



Encrypt-then-MAC

Back to cryptography land

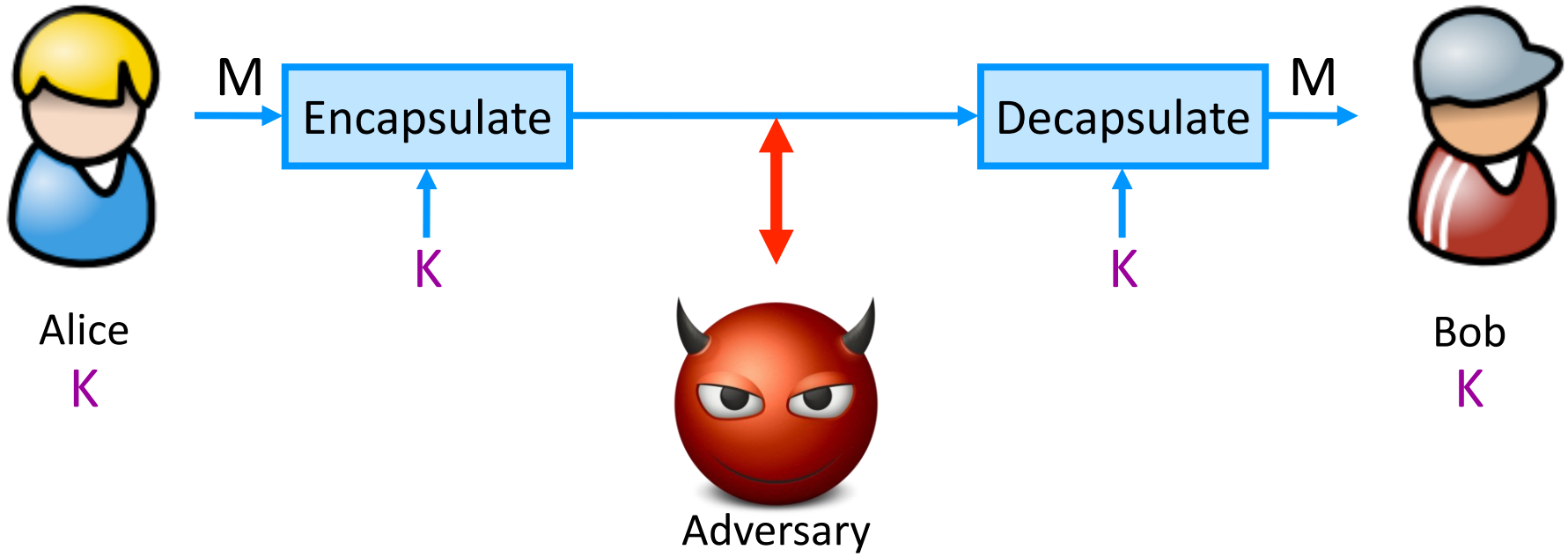
Stepping Back: Flavors of Cryptography

- Symmetric cryptography
  - Both communicating parties have access to a shared random string K, called the key.

- Asymmetric cryptography
  - Each party creates a public key pk and a secret key sk.

Symmetric Setting

Both communicating parties have access to a shared random string K, called the key.



Asymmetric Setting

Each party creates a public key pk and a secret key sk.