CSE 484: Computer Security and Privacy

Cryptography
Hashing + Integrity + Asymmetric

Fall 2021

David Kohlbrenner
dkohlbre@cs

Thanks to Franzi Roesner, Dan Boneh, Dieter Gollmann, Dan Halperin, David Kohlbrenner, Yoshi Kohno, Ada Lerner, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...
Administrivia

• Lab 1 due on Wednesday
• HW2 is out
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...
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.
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 $\text{hash(password)}$

• When user enters a password, compute its hash and compare with the entry in the password file

• Why is hashing better than encryption here?
  • Breakout
Application: Password Hashing

• Instead of user password, store $\text{hash(password)}$
• 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
Hash Functions Review

• 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: 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
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

• Commitments (e.g. auctions)
  • Alice wants to bid B, sends H(B), later reveals B
  • One-wayness: rival bidders should not recover B (this may mean that they need to hash some randomness with B too)
  • Collision resistance: Alice should not be able to change their mind to bid B’ such that H(B)=H(B’)

10/21/2021
Commitments
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!
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
Aside: 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 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
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 $sk$. 

Alice
(pkA, skA)

Bob
(pkB, skB)

Adversary
(pkA, skB)

Encapsulate: $pk_B, sk_A$

Decapsulate: $pk_A, sk_B$
Public Key Crypto: Basic Problem

**Given:** Everybody knows Bob’s **public key**
Only Bob knows the corresponding **private key**

**Goals:** 1. Alice wants to send a secret message to Bob
2. Bob wants to authenticate themself

Ignore for now: How do we know it’s REALLY Bob’s??
Applications of Public Key Crypto

• Encryption for confidentiality
  • Anyone can encrypt a message
    • With symmetric crypto, must know secret key to encrypt
  • Only someone who knows private key can decrypt
  • Key management is simpler (or at least different)
    • Secret is stored only at one site: good for open environments

• Digital signatures for authentication
  • Can “sign” a message with your private key

• Session key establishment
  • Exchange messages to create a secret session key
  • Then switch to symmetric cryptography (why?)
Session Key Establishment
Modular Arithmetic

• Given $g$ and prime $p$, compute: $g^1 \mod p$, $g^2 \mod p$, ... $g^{100} \mod p$
  • For $p=11$, $g=10$
    • $10^1 \mod 11 = 10$, $10^2 \mod 11 = 1$, $10^3 \mod 11 = 10$, ...
    • Produces cyclic group $\{10, 1\}$ (order=2)
  • For $p=11$, $g=7$
    • $7^1 \mod 11 = 7$, $7^2 \mod 11 = 5$, $7^3 \mod 11 = 2$, ...
    • Produces cyclic group $\{7,5,2,3,10,4,6,9,8,1\}$ (order = 10)
    • $g=7$ is a “generator” of $\mathbb{Z}_{11}^*$
Diffie-Hellman Protocol (1976)
Diffie-Hellman Protocol (1976)

- Alice and Bob never met and share no secrets
- **Public info:** $p$ and $g$
  - $p$ is a large prime, $g$ is a **generator** of $\mathbb{Z}_p^*$
    - $\mathbb{Z}_p^* = \{1, 2 \ldots p-1\}$; $a \in \mathbb{Z}_p^*$ such that $a = g^i \mod p$
    - **Modular arithmetic:** numbers “wrap around” after they reach $p$

Alice

**Pick secret, random $x$**

Bob

**Pick secret, random $y$**

Compute $k = (g^y)^x \equiv g^{xy} \mod p$

Compute $k = (g^x)^y \equiv g^{xy} \mod p$