COMP 3704 Computer Security

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Design Criteria for Hash Functions

- $H : \{0,1\}^n \rightarrow \{0,1\}^m$ for fixed $m \in \mathbb{N}$ and any $n \in \mathbb{N}$
- Given M, it is easy to compute $h = H(M)$
- Given h, it is hard to find an M such that $H(M) = h$
- Given M, it is hard to find an $M' \neq M$ such that $H(M) = H(M')$
- It is hard to find random messages M and $M' \neq M$ such that $H(M) = H(M')$

Birthday Attack!

Probability of not finding a n-bit collision after generating $2^{n/2}$ messages is less than 50%:

$$p(k) = \prod_{i=0}^{k} \left(1 - \frac{i}{2^n}\right) \quad (1)$$

$$\approx \prod_{i=0}^{k} e^{\frac{-i}{2^n}} \quad (2)$$

$$= e^{-\frac{(k(k-1))}{2^{n+1}}} \quad (3)$$

General Construction

Difficult to define function $H : \{0,1\}^n \rightarrow \{0,1\}^m$. Instead use:

$$h_i = f(M_i, h_{i-1}) \tag{4}$$

$f : \{0,1\}^b \times \{0,1\}^m \rightarrow \{0,1\}^m$ for a fixed b is called a **compression function**.

General Implementation

```
struct hash_context;
void hash_init_context(struct hash_context * ctx);
void hash_process_bytes(const void * buf,
                        size_t len,
                        struct hash_context * ctx);
void hash_finish(struct hash_context * ctx,
                 void * result);
```

Example: MD5

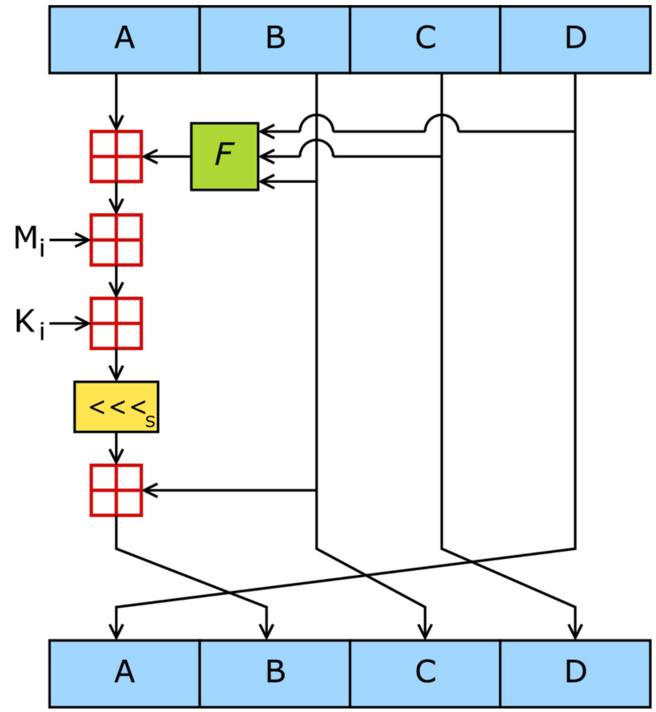


Figure 1: MD5 consists of four rounds of 16 operations.

MD5 Functions

$$F(X, Y, Z) = (X \wedge Y) \vee (\neg X \wedge Z) \tag{5}$$

$$G(X, Y, Z) = (X \wedge Y) \vee (Y \wedge \neg Z) \tag{6}$$

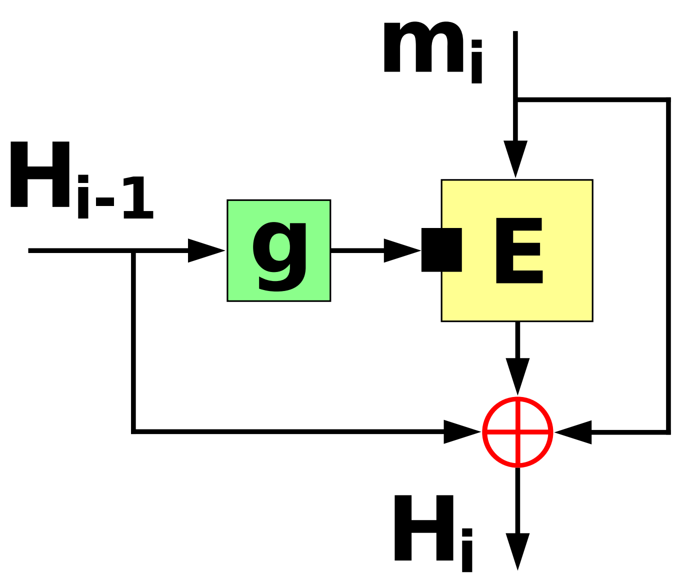
$$H(X, Y, Z) = X \oplus Y \oplus Z \tag{7}$$

$$I(X, Y, Z) = Y \oplus (X \vee \neg Z) \tag{8}$$

Common Hash Functions

- MD5 – 128 bits
- RIPE160MD – 160 bits
- SHA1 – 160 bits
- SHA-2 – 256-512 bits
- WHIRLPOOL – 512 bits

Miyaguchi-Preneel Constructions



Example: WHIRLPOOL = Miyaguchi-Preneel + AES

Successful Attacks

- SHA-1: collisions found in 2005
- MD4, MD5 and RIPEMD-128: collisions found in 2004

$\Rightarrow$ Use 256 or more bits

Password Crackers

- Passwords do not usually have 128-bits of entropy

- We could actually compute hash codes for all 2^{64} "realistic" passwords (8 ASCII characters)

- However, we could not store all 2^{64} values

$\Rightarrow$ Precompute and use space-computation trade-off when cracking!

Precomputed Hash Chains

- Have set P of realistic passwords and domain D of H
- Define **reduction** function $F : D \rightarrow P$
- Pre-compute chains $X(I) = H(F(H(F(H(F(H(I)))))))$ for many I
- When cracking C, check if $C = X(I)$ or $H(F(C)) = X(I)$ or $H(F(...(H(F(C)))))) = X(I)$.

$\Rightarrow$ reduce storage space by chain length L at the expense of $O(L)$ more computation during cracking.

Problems with Hash Chains

- F can cause collisions in two chains, merging the chains
- Collisions reduce effectiveness of table construction (to often less than 70%) and bound chain length

⇒ Tables are much too big!

⇒ Some chains are discarded as ineffective

⇒ Wasted time during construction!

⇒ Possibility of "false alarms"

Rainbow Tables

- Key idea: use different functions F_i in chain
- Pre-compute chains $X(I) = H(F_3(H(F_2(H(F_1(H(I)))))))$

⇒ Collisions only merge chains if they also happen at same position

⇒ Can achieve 99% effectiveness

⇒ Cracking overhead increases from $O(L)$ to $O(L^2)$ for chain traversal

⇒ Cracking overhead decreases from $O(L)$ to $O(1)$ due to fewer chains

Defense: Salt!

- $hash = H(password + salt)$
- Extends length of the password
- Rainbow tables commonly only support 8 characters

$\Rightarrow$ Add 16 characters (or more) of salt

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Reality

- UNIX NIS/YP/shadow: salted for a long time
- Windows NT/2000 LAN Manager: unsalted, easily cracked

Questions

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Exercise

Generate a rainbow table (and password cracker) for SHA1 that can invert passwords of up to 5 characters (A-Za-z).

You may link against `libgcrypt` or OpenSSL for hashing.