05 Hash, MAC, Signature

2021 Spring
Information Security

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What We Have Learned?

- **Confidentiality**.
- **Integrity**.
- Availability.
- Authenticity.
- Accountability.

Now we will introduce some techniques about other factors.

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- **Confidentiality**.
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Wait a moment! I think public key system can be treated as an authentication way!

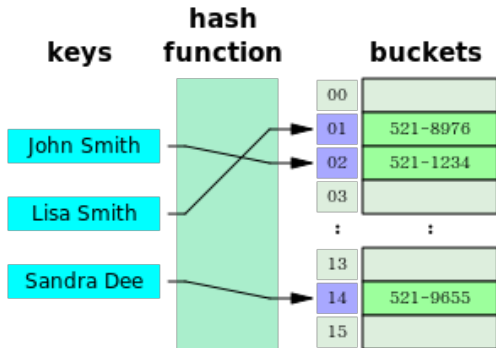Not good enough. Where do you get other's public key?

- Goal: **Integrity**, not confidentiality.

So in practice, all techniques you learned here should be used combined with what you learned before.
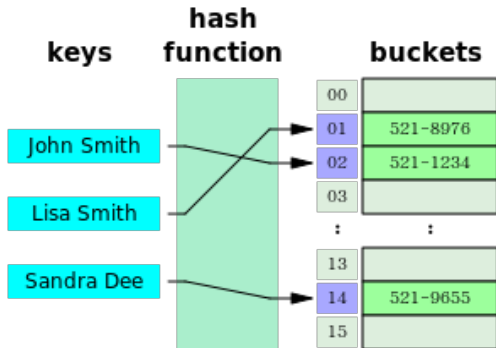
Cryptographic Hash

What is Hash?

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- Undoubtedly, you have learned it from Data Structure.
- Why do you need hash functions?

Cryptographic Hash Requirement

1. Variable input size.

2. Fixed output size.

3. Efficiency.

4. One-way property.

5. **Collision resistant**.
   - **Weak**: For any given x, it is computationally infeasible to find $y \neq x$ with $H(y) = H(x)$.
   - **Strong**: It is computationally infeasible to find any pair (x, y) that $y \neq x$ and $H(y) = H(x)$.

6. Pseudorandomness.

Collision is inevitable.

Why?

In this class, are there any two who have the same birthday?

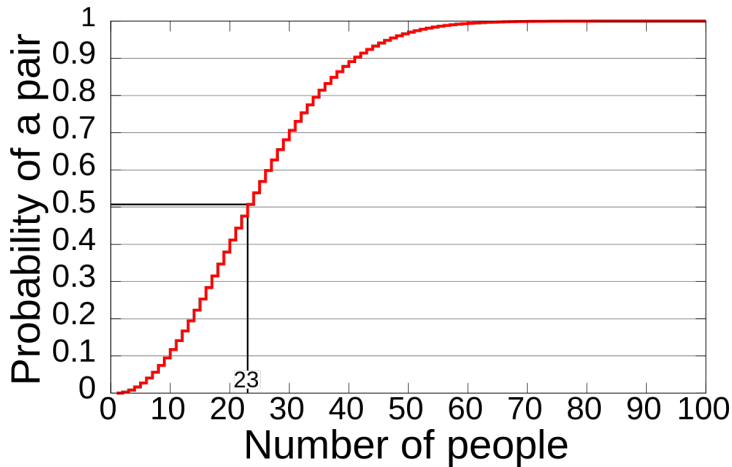In this class, are there any two who have the same birthday?

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Suppose there are n students here. The probability that every has an unique birthday is

$$P = 1 - \bar{P} = 1 - \prod_{i=0}^{n-1} \frac{365 - i}{365}$$

- This implies to find a Hash collision, you do not need to do 2^n searches. For most cases, $2^{\frac{n}{2}}$ searches are enough for you to find a collision.
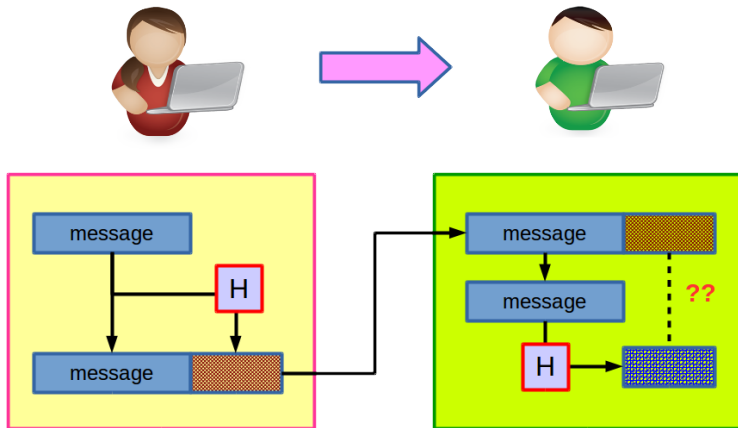
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- How to solve this problem?

- This implies to find a Hash collision, you do not need to do 2^n searches. For most cases, $2^{\frac{n}{2}}$ searches are enough for you to find a collision.
- How to solve this problem?
- Make n larger!

Integrity Check in the Real World

	Name	Last modified	Size	Description
	Parent Directory		-	
	MD5SUMS	2019-02-14 22:53	138	
	MD5SUMS-metalink	2019-02-14 22:53	148	
	MD5SUMS-metalink.gpg	2019-02-14 22:53	916	
	MD5SUMS.gpg	2019-02-14 22:53	916	
	SHA1SUMS	2019-02-14 22:53	154	
	SHA1SUMS.gpg	2019-02-14 22:53	916	
	SHA256SUMS	2019-02-14 22:53	202	
	SHA256SUMS.gpg	2019-02-14 22:53	916	
	ubuntu-18.04.2-desktop-amd64.iso	2019-02-10 00:27	1.9G	Desktop image for 64-bit PC (AMD64) computers (standard download)
	ubuntu-18.04.2-desktop-amd64.iso.torrent	2019-02-14 22:51	75K	Desktop image for 64-bit PC (AMD64) computers (BitTorrent download)
	ubuntu-18.04.2-desktop-amd64.iso.zsync	2019-02-14 22:51	3.7M	Desktop image for 64-bit PC (AMD64) computers (zsync metafile)
	ubuntu-18.04.2-desktop-amd64.list	2019-02-10 00:27	7.8K	Desktop image for 64-bit PC (AMD64) computers (file listing)
	ubuntu-18.04.2-desktop-amd64.manifest	2019-02-10 00:25	57K	Desktop image for 64-bit PC (AMD64) computers (contents of live filesystem)
	ubuntu-18.04.2-desktop-amd64.metalink	2019-02-14 22:53	47K	Ubuntu 18.04.2 LTS (Bionic Beaver)

What is the difference between /etc/passwd and /etc/shadow in Linux?

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Never store the passwords in the plaintext way.
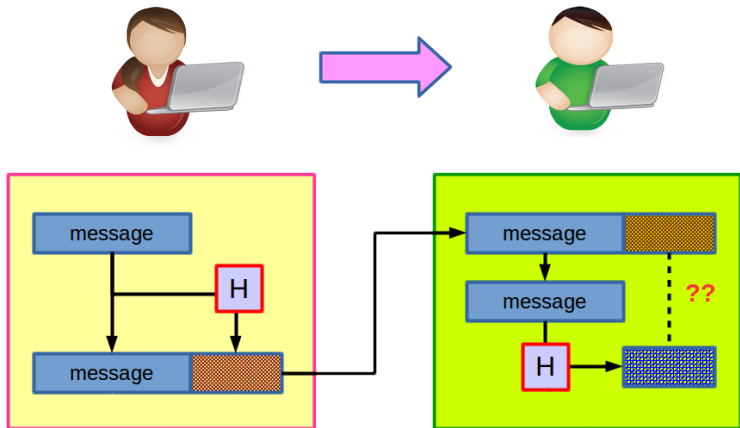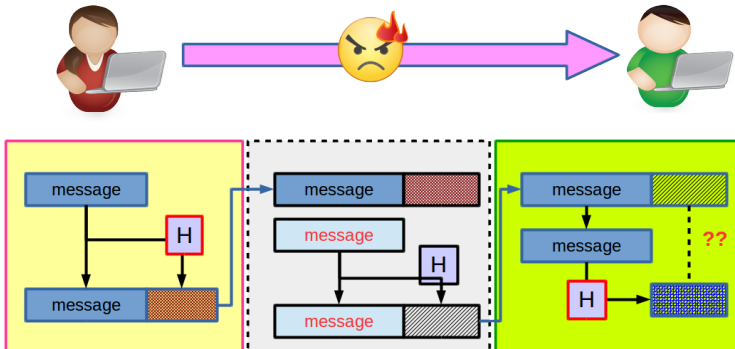
- So in most cases, we will not use the hash function in that way.
- Wait! You just show some real cases, right?
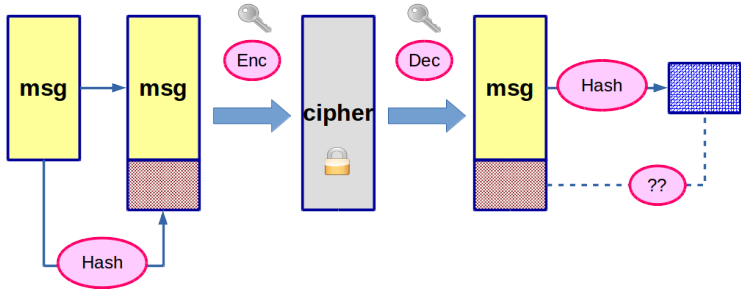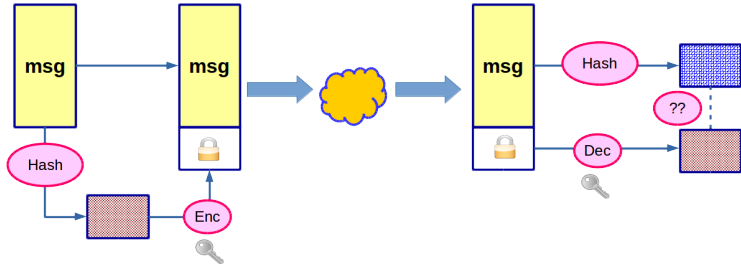
$$E(K, M || H(M))$$

$$M||E(K, H(M))$$
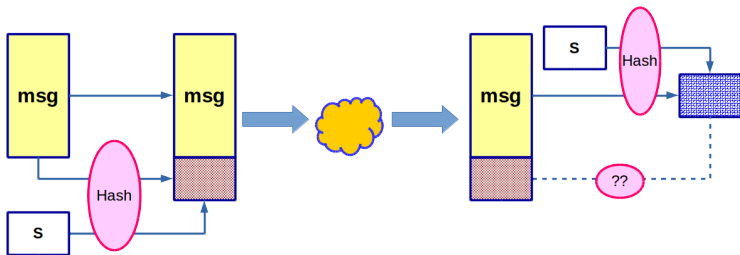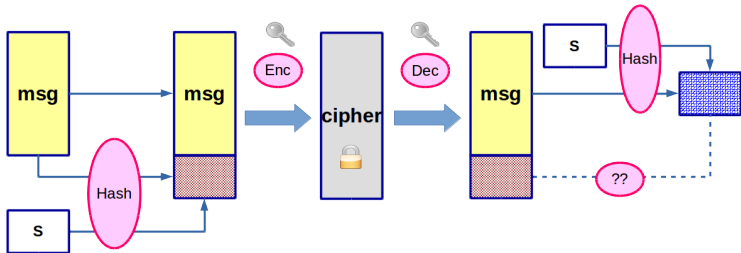
$M||H(M||S)$

$$E(K, M\|H(M\|S))$$

How to Make a Cryptographic HASH Function?
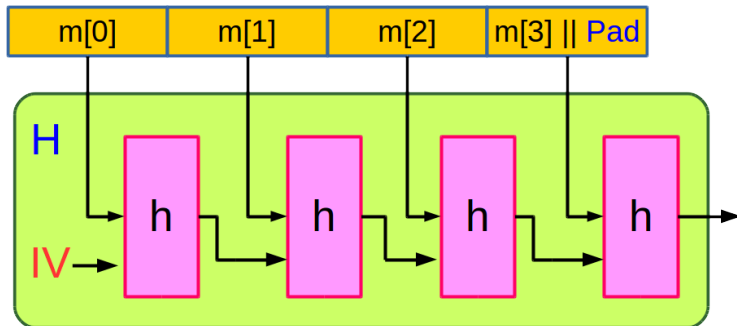
Given $h : T \times X \to T$(compression function), we obtain
$H : X^L \to T$.

Theorem

If h is collision resistant, H is also collision resistant.

How to prove?

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How to prove?

- Suppose $H(M) = H(M')$ and $M \neq M'$, we can find a collision pair for h.

- We can build h by a block cipher.
- The Davies-Meyer compression function:

$$h(m, H) = E(m, H) \oplus H.$$
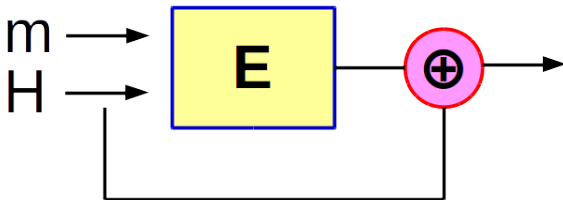
How to prove its collision resistance?

If we define $h(m, H) = E(m, H)$, is h collision resistant?

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No! Why?

Given $H, m, m', H' = D(m', E(m, H))$.

- Miyaguchi-Preneel:

$$h(m, H) = E(m, H) \oplus H \oplus m$$

- Actually, there are 12 styles of this.

Common Hash Functions

Common Hash Functions

- MD5.
- SHA1.
- SHA256.
- SHA512.

MD5

- Output: 128 bits.
- Widely used before.
- Collisions for the full MD5 were announced by Xiaoyun Wang, Dengguo Feng, Xuejia Lai, and Hongbo Yu.
- It can still be used as a checksum to verify data integrity, but only against unintentional corruption.
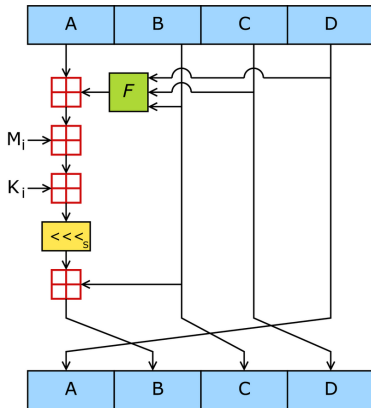
- Output 160 bits.
- On 23 February 2017, the CWI (Centrum Wiskunde & Informatica) and Google announced the SHAttered attack, in which they generated two different PDF files with the same SHA-1 hash in roughly 263.1 SHA-1 evaluations.
- `https://shattered.io/` .
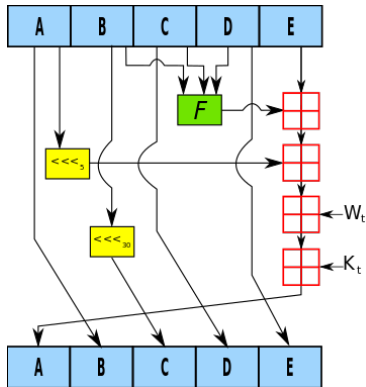
- Output: 256bits.
- Merkle-Damgard function.
- Davies-Meyer compression function.
- Block cipher: SHACAL-2.
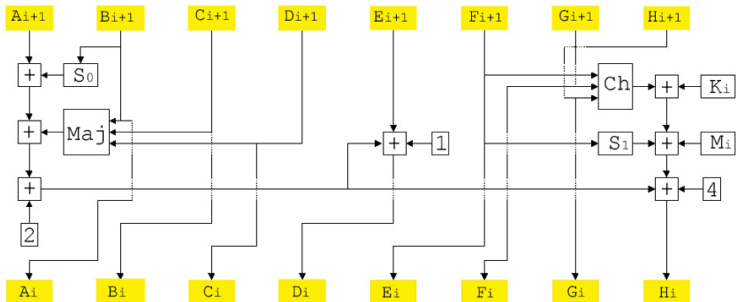
Have you noticed that I do not introduce the compression function in detail?

Provable Compression Function

- The compression function above can be replaced with some other provable compression functions.
- Example:
$$h(m, H) = u^H v^m \bmod p.$$

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- Example:

$$h(m, H) = u^H v^m \bmod p.$$

  - How to prove this is a secure compression function?
  - In fact, we do not use this. Why?

MAC: Message Authentication Code

- Message authentication is a procedure to verify that received messages come from the **alleged source** and have not been modified.
- We also called MAC is a **key-ed hash**.

For a MAC $I = (S, V)$ where S is **Sign** algorithm and V is **Verify** algorithm, the security model is
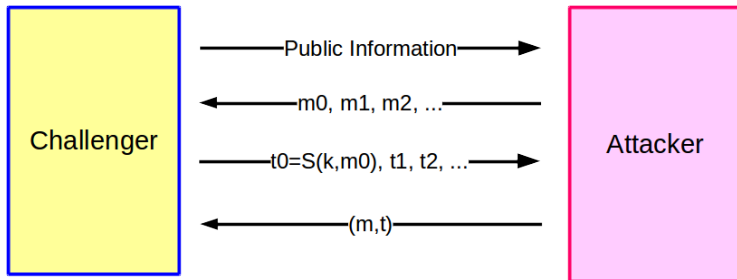
The attacker wins the game if (m, t) is valid and $m \neq m_0, m_1, m_2, \ldots$

A MAC $I = (S, V)$ is called secure if for all efficient A, $\text{Adv}_{\text{MAC}}[A, I]$ is negligible.

Let $I = (S, V)$ be a MAC.

Suppose an attacker can find $m_0 \neq m_1$ such that $S(k, m_0) = S(k, m_1)$ for $\frac{1}{2}$ of the keys.

Is $I = (S, V)$ a secure MAC?

Let $I = (S, V)$ be a MAC.

Suppose $S(k, m)$ is always 5-bits long.

Is $I = (S, V)$ a secure MAC?

How can they catch the cheating event?
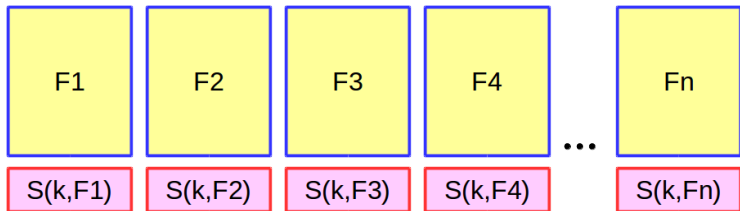
How to Build a MAC

- Based on PRF.
- CBC-MAC.
- NMAC.
- PMAC.
- HMAC (Hash-based MAC).

For a PRF $F : K \times X \to Y$, define a MAC $I = (S, V)$ as follows:

$$S(k, m) = F(k, m),$$

$$V(k, m, t) = \begin{cases} 1, & \text{if } t = F(k, m) \\ 0, & \text{otherwise} \end{cases} .$$

Is this a secure MAC?

Suppose $F : K \times X \to Y$ is a secure PRF with $Y = \{0, 1\}^{10}$.

Is the derived MAC a secure MAC?

Theorem

If $F \colon K \times X \to Y$ is a secure PRF and $\frac{1}{|Y|}$ is negligible, then I_F is a secure MAC.

$$\mathsf{Adv}_{\mathsf{MAC}}[A, I_F] \leq \mathsf{Adv}_{\mathsf{PRF}}[B, F] + \frac{1}{|Y|}.$$

$$F_{\text{CMAC}} : K^2 \times X^L \to X.$$
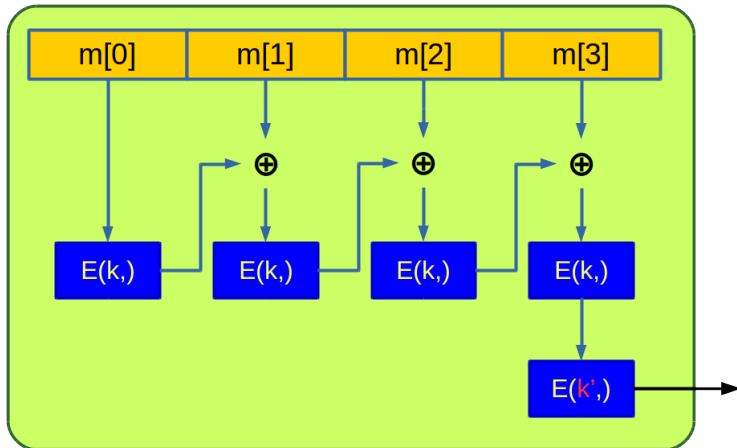
$$F_{\text{NMAC}} : K^2 \times X^L \to K.$$
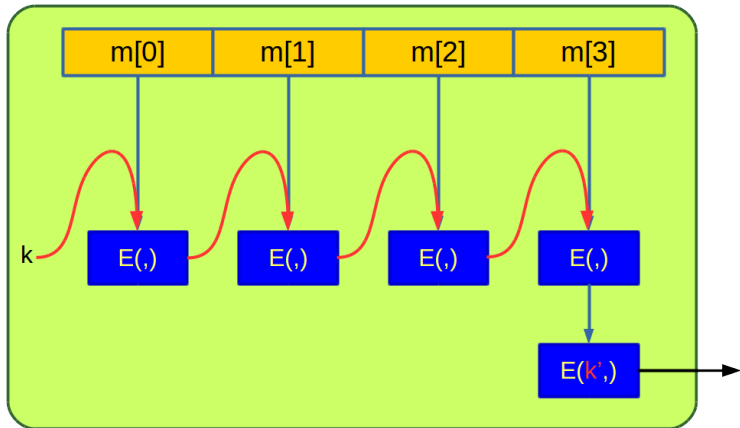
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Wait a moment! I know that NMAC has the cascade problem.
How about CMAC?? The attacker do not have k, right?

Good question! But that will be your homework.

- **ECBC**-**MAC** is commonly used as an AES-based MAC.
  - CCM encryption mode (used in 802.11i).
  - NIST standard called CMAC.

- **NMAC** is not usually used with AES or 3DES.
  - Why?
  - But NMAC is the basis for a popular MAC called **HMAC**.

- Both of them are sequential, is there any parallel one?

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  - CCM encryption mode (used in 802.11i).
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- **NMAC** is not usually used with AES or 3DES.
  - Why? Need to change AES key on every block.
  - But NMAC is the basis for a popular MAC called **HMAC**.

- Both of them are sequential, is there any parallel one?
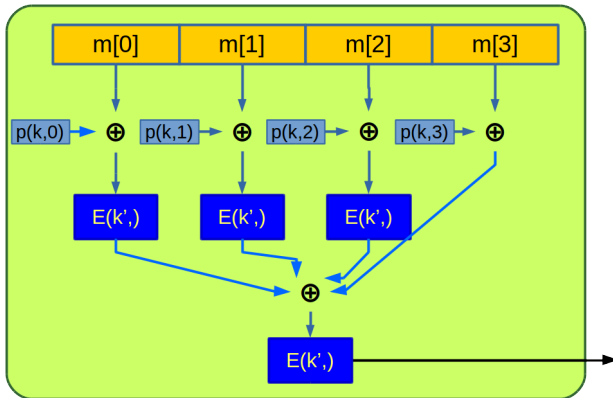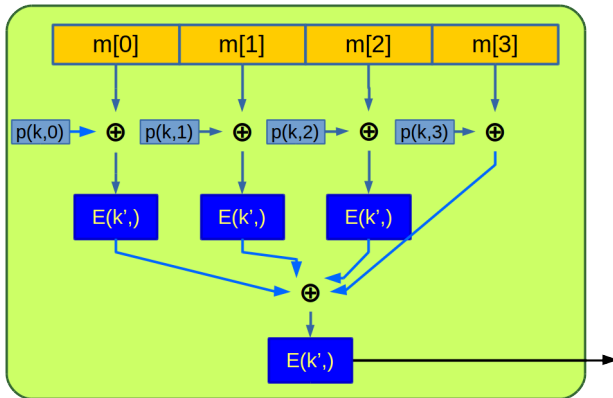
$$F_{\text{CMAC}} : K^2 \times X^L \to X.$$

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If we modify m[1] to m[1]', how can we update the MAC value?

- We can also use hash functions to build MAC.
- Of course, you should not use MD5 or SHA-1.

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- **Quiz**:

  - How about the following construction?

 $$S(k, m) = H(k||m).$$

  - Is this secure or not?

- We can also use hash functions to build MAC.

- Of course, you should not use MD5 or SHA-1.

- **Quiz**:
  - How about the following construction?

  $$S(k, m) = H(k\|m).$$

  - Is this secure or not?
  - No. Because of Merkle-Damgard iterated construction.

- Build from a black-box Hash function.
  - This implies that you can replace the black-box with what you want.
- HMAC$(K, M) : H(H(K \oplus \text{opad})||H((K \oplus \text{ipad})||M))$.
  - opad: 0x5c5c5c...5c5c
  - ipad: 0x363636...3636
- TLS must supports HMAC-SHA1-96.
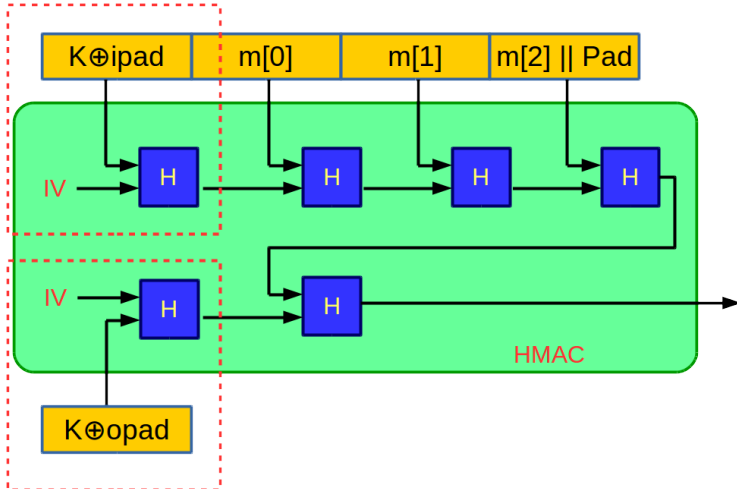
The red blocks can be pre-computed.

- How about padding all zeros?
  - Bad idea, why?

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    - Bad idea, why?
- ISO: Pad with "100...0", add a dummy block if necessary.

Digital Signature

Digital Signature = HASH + Authentication

- **Hash**: Msg content is correct, which means it is the same with the one when the sender send it.
- **Authentication**: The message is really from the one who claims that he/she sends it.

- Digital Signature has nothing to do with confidentiality.
- So in most case, we will use it with encryption.
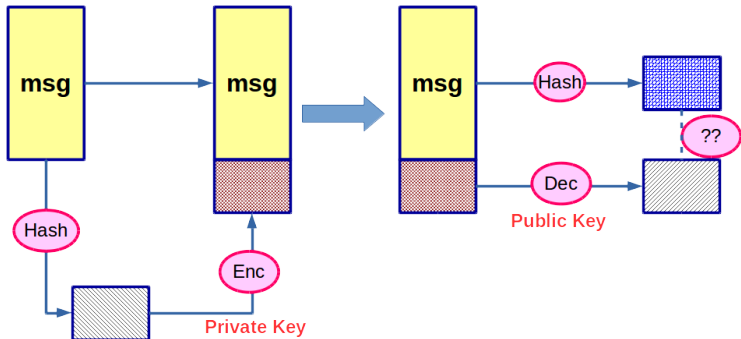
- Can you sign a document when you do not know its content?
- Why do I need this feature?
  - Think about **eVoting**.
- Blind RSA Signature:
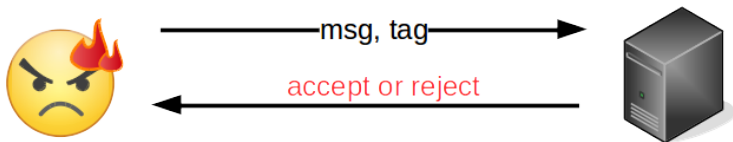 - Given a message m and you want to ask others to sign this message without knowing its content, how to do this?

- I will not cover this topic here.
- To introduce DSA, I will introduce another technique first ⋯ So please wait.

Appendix

Generally speaking, Hash is faster than Symmetric Key Encryption and Symmetric Key Encryption is faster than Asymmetric Key Encryption.

To compute a tag for a target message:

1. Query the server with random tag.

2. Loop over all possible first bytes and query the server. Stop when verification takes a little longer.

3. Repeat until all bytes are found.

Make the string comparator always takes the same time.

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Unfortunately, sometimes compiler may optimize this part.

Do Not Implement Crypto Yourself!