Introduction to Cryptography and Security

Message Integerity

Slides are taken from Dan Boneh's Course

Outline

1. Message Authentication Codes
2. MACs based on Pseudo Random Functions
3. MAC padding

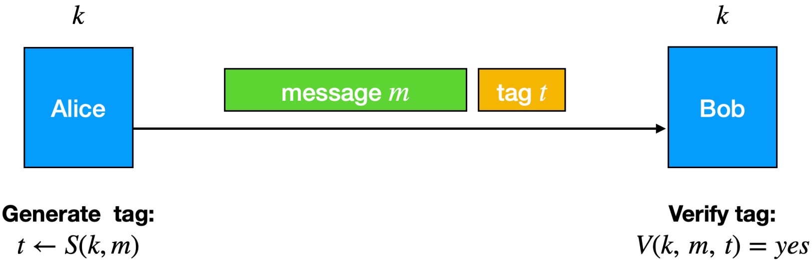
Message Integrity

Goal: **integrity**, no confidentiality.

Examples:

- Protecting public binaries on disk.
- Protecting banner ads on web pages.

Message integrity: MACs



Definition

A **MAC** system $\mathcal{I} = (S, V)$ is a pair of efficient algorithms, S and V,

- where S is called a **signing algorithm** and V is called a **verification algorithm**.
- Algorithm S is used to generate tags and algorithm V is used to verify tags.

Integrity requires a secret key

Generate tag:
$t \leftarrow CRC(m)$

Verify tag:
$V(m, t) = yes$

- Attacker can easily modify message m and re-compute CRC.
- CRC designed to detect random, not malicious errors.

Secure MACs

- Attacker's power: **chosen message attack**

  for $m_1, m_2, \ldots, m_q$ attacker is given $t_i \leftarrow S(k, m_i)$

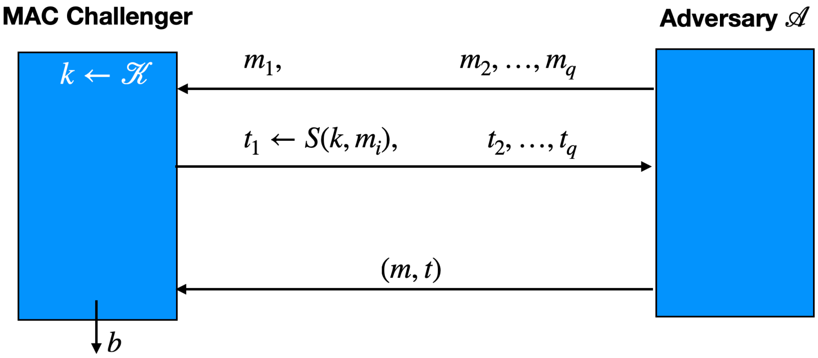
- Attacker's goal: **existential forgery**

  produce some new valid message/tag pair (m, t)

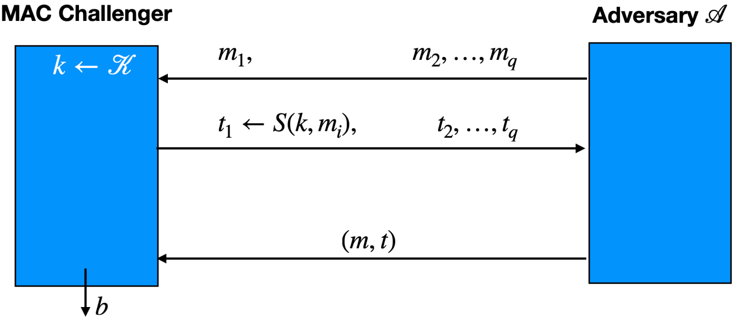
$$(m, t) \notin \{(m_1, t_1), \cdots, (m_q, t_q)\}$$

- Thus, attacker cannot produce some new valid message/tag pair (m, t).
- Given (m, t) attacker cannot even produce (m, t') for $t' \neq t$

MAC-game



$$\begin{cases} b = 1 & \textbf{if } V(k, m, t) = yes \quad \textbf{and} \quad (m, t) \notin \{(m_1, t_1), \ldots, (m_q, t_q)\} \\ b = 0 & \textbf{otherwise} \end{cases}$$



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Definition

$I = (S, V)$ is a **secure** MAC if for all "efficient" $\mathcal{A}$:

$$\text{Adv}(I, \mathcal{A}) = \Pr[\text{Challenger outputs } 1] \text{ is "negligible."}$$

Question

Let $I = (S, V)$ be a MAC. Suppose an attacker is able to find $m_0 \neq m_1$ such that

$$S(k, m_0) = S(k, m_1) \qquad \text{for } 1/2 \text{ of the keys } k \in \mathcal{K}.$$

Can this MAC be secure?

1. Yes, the attacker cannot generate a valid tag for m_0 or m_1
2. No, this MAC can be broken using a chosen msg attack
3. It depends on the details of the MAC

Question

Let $I = (S, V)$ be a MAC. Suppose $S(k, m)$ is always 5 bits long.

Can this MAC be secure?

1. No, an attacker can simply guess the tag for messages
2. It depends on the details of the MAC
3. Yes, the attacker cannot generate a valid tag for any message

Example: protecting system files

- Suppose at install time the system computes:

Filename F_1	Filename F_2	...	Filename F_n
$t_1 = S(k, F_1)$	$t_2 = S(k, F_2)$		$t_n = S(k, F_n)$

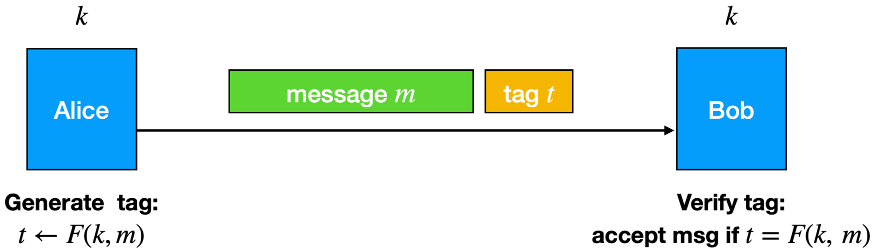
- Later a virus infects system and modifies system files
- User reboots into clean OS and supplies his password
- Then: secure MAC $\Rightarrow$ all modified files will be detected

Outline

Secure PRF $\Rightarrow$ Secure MAC

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

- $S(k, m) := F(k, m)$
- $V(k, m, t)$: output 'yes' if $t = F(k, m)$ and 'no' otherwise.



A bad example

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

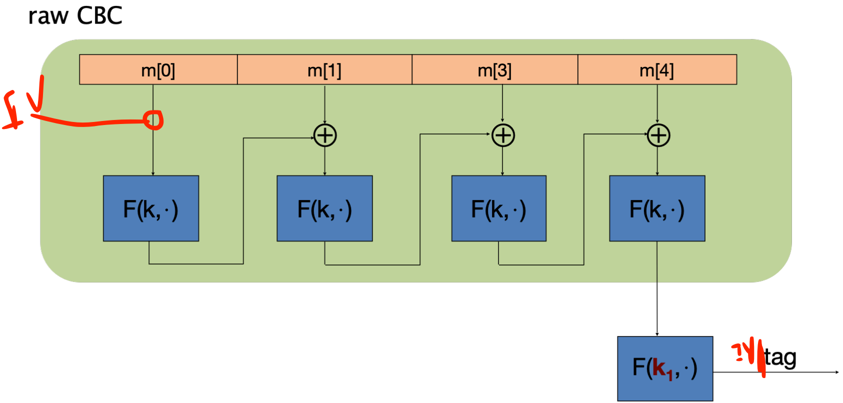
Is the derived MAC I_F a secure MAC system?

- Yes, the MAC is secure because the PRF is secure
- No tags are too short: anyone can guess the tag for any msg
- It depends on the function F

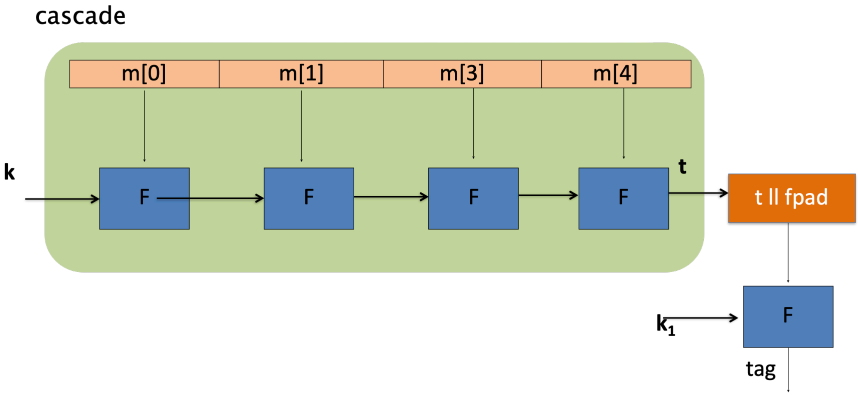
Examples

- AES: a MAC for 16-byte messages.
- Main question: how to convert Small-MAC into a Big-MAC?
- Two main constructions used in practice:
  - CBC-MAC (banking – ANSI X9.9, X9.19, FIPS 186-3)
  - HMAC (Internet protocols: SSL, IPsec, SSH,...)
  - Both convert a small-PRF into a big-PRF.

Construction 1: encrypted CBC-MAC



Construction 2: NMAC



Question

Why the last encryption step in NMAC?

NMAC: suppose we define a MAC $I = (S, V)$ where

$$S(k, m) = \text{cascade}(k, m)$$

1. This MAC is secure
2. This MAC can be forged without any chosen msg queries
3. This MAC can be forged with one chosen msg query
4. This MAC can be forged, but only with two msg queries

Question

Why the last encryption step in ECBC-MAC?

Suppose we define a MAC $I_{\text{RAW}} = (S, V)$ where

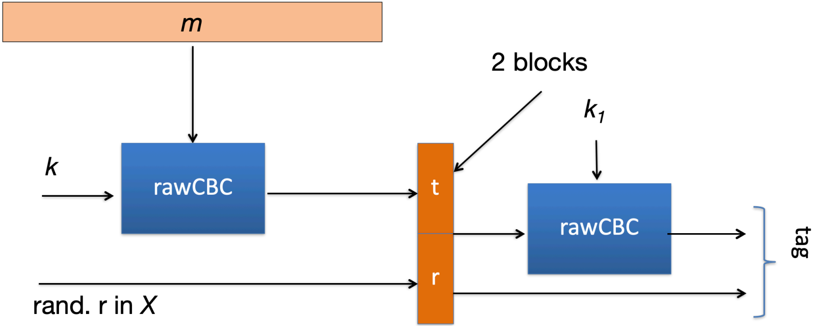
$$S(k, m) = \text{rawCBC}(k, m)$$

Then I_{RAW} is easily broken using a 1-chosen msg attack.

Adversary works as follows:

- Choose an arbitrary one-block message $m \in X$
- Request tag for m. Get $t = F(k, m)$
- Output t as MAC forgery for the 2-block message $(m, t \oplus m)$

Better security: a randomized construction



Comparison

ECBC-MAC is commonly used as an AES-based MAC

- CCM encryption mode (used in 802.11i)
- NIST standard called CMAC

NMAC not usually used with AES or 3DES

- Main reason: need to change AES key on every block
  requires re-computing AES key expansion
- But NMAC is the basis for a popular MAC called HMAC

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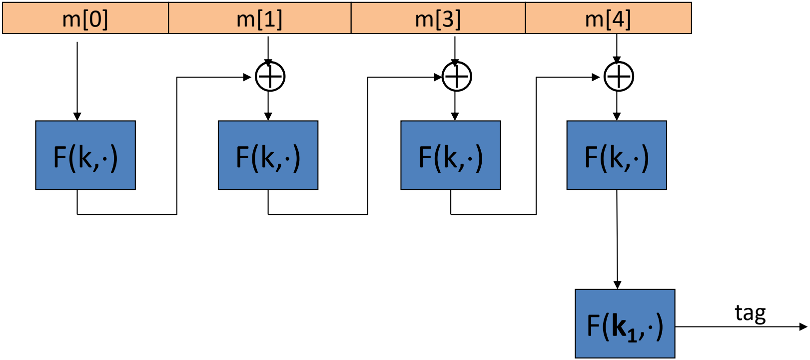
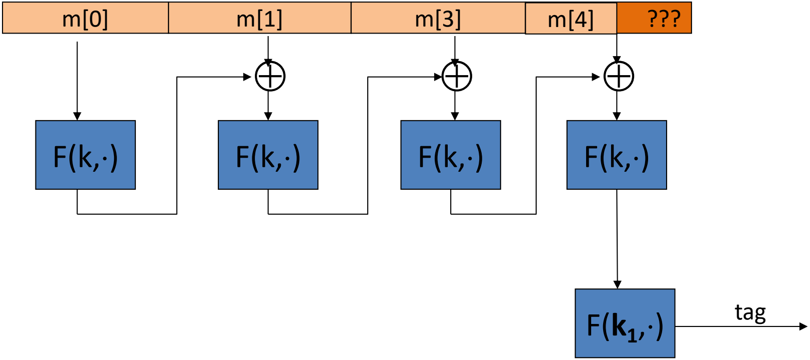
Recall: ECBC-MAC



What if message length is not multiple of block-size?



CBC MAC padding

Bad idea: pad m with 0's

$$\boxed{m[0] \mid m[1]} \quad \Rightarrow \quad \boxed{m[0] \mid m[1] \mid 000\cdots}$$

Is the resulting MAC secure?

1. Yes, the MAC is secure
2. It depends on the underlying MAC
3. No, given tag on msg m attacker obtains tag on $m \| 0$

CBC MAC padding

For security, padding must be invertible !

$$m_0 \neq m_1 \qquad \Rightarrow \qquad \text{pad}(m_0) \neq \text{pad}(m_1)$$

ISO: pad with $1000\cdots0$. Add new dummy block if needed.

- The '1' indicates beginning of pad.

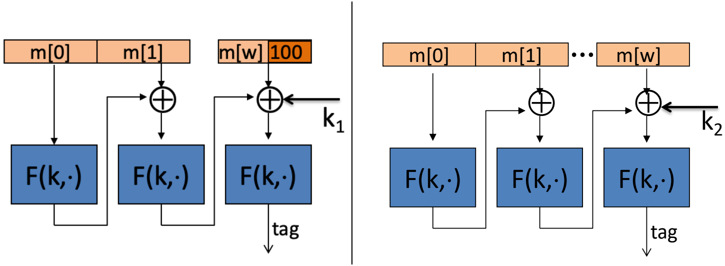
$m[0]$	$m[1]$

$\Rightarrow$

$m[0]$	$m[1]$	$1000\cdots$

Variant of CBC-MAC where key $= (k, k_1, k_2)$

- No final encryption step (extension attack thwarted by last keyed xor)
- No dummy block (ambiguity resolved by use of k_1 or k_2)



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Thank you!

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