CSC 580
Cryptography and Computer Security

Message Authentication Codes
(Sections 12.1-12.5)

March 29, 2018

Overview

Today:

- Quiz over HW7 material
- Discuss message authentication codes

Next:

- Complete ungraded HW 8
- Read Chapter 12.7-12.9
- ***Project Progress Report due Tuesday!***

Message Authentication Requirements
From Textbook, Section 12.1

Attacks on network communication include

1. Disclosure
2. Traffic analysis

Confidentiality issues

3. Masquerade
4. Content modification
5. Sequence modification
6. Timing modification (incl replay)

Message Authentication

7. Source repudiation
8. Destination repudiation

Digital Signatures

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Digital Signatures

Basics: Message authentication is a procedure to verify that received messages come from the alleged source and have not been altered. (By including tamper-proof sequence numbers and timestamps, can protect other properties.)

Using Symmetric Encryption

Consider using a non-malleable cipher

If decryption is "sensible" then most likely:

- Message wasn't tampered with (non-malleable)
- Source was desired sender (only they know the key)

Problem: What does "sensible" decryption mean?

And what if message can be arbitrary binary data?

Can add some structure or redundancy and look for on decryption

But -- is there a more direct solution?

Authenticator: Concept

Message	*Authenticator*
Send the army to … leaving at 10:30am.	7c91ad850b513

Authenticator computed from message
Message and authenticator both transmitted
Receiver recomputes from message - must match!

Question: Will a cryptographic hash function work?

Specifically: How is this related to second preimage resistance?

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Attacker can't replace message, using *same* authenticator

But: if authenticator is a known hash function, can compute a new authenticator and replace the original.

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But: if authenticator is a known hash function, can compute a new authenticator and replace the original.

Sender and receiver share secret → Then attacker can't compute!

If only sender and receiver know secret, authenticates source too

Message Authentication Codes

A first, naive attempt:

For message made of up n blocks $M_1, M_2, \ldots, M_n$:

1. Calculate $S = M_1 \oplus M_2 \oplus \ldots \oplus M_n$
2. Calculate tag $T = \mathrm{E}(K,S)$ using a non-malleable cipher

__Question 1__: Can you find *any* other message with same tag?

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XOR is commutative and associative, so just rearrange blocks

Question 2: Can you construct a message mostly of your own choosing with the same tag?

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<u>*Question 1*</u>: Can you find *any* other message with same tag?

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<u>*Question 2*</u>: Can you construct a message mostly of your own choosing with the same tag?

For any n-1 block forgery F_1, F_2, …, $F_{n\text{-}1}$, compute

$F_n = F_1 \oplus F_2 \oplus \ldots \oplus F_{n-1} \oplus S$,

so $F_1 \oplus F_2 \oplus \ldots \oplus F_{n-1} \oplus F_n = S$

Message Authentication Codes

Function MAC: $\mathcal{K} \times \mathcal{M} \rightarrow \{0,1\}^h$

Keyspace *Message space* *Authenticator (or "tag")*

Important properties:

- Given M and T = MAC(K,M), can't find M' with MAC(K,M') = MAC(K,M)
  - *Like second preimage resistance*
- Given M and MAC(K,M), can't calculate K
  - *Similar to preimage resistance (one-way)*
  - *Brute force attack takes time $|\mathcal{K}|/2$ on average*
- Given M and T = MAC(K,M), can't find M' and T' s.t. T'=MAC(K,M')

So… was sent by someone who knows K, and M hasn't been tampered with

Formal Security of MACs

Consider: What is best algorithm to take a set of message/tag pairs, generated with an unknown key K:

$$\{ (M_1, \mathrm{MAC}(K,M_1)) , (M_2, \mathrm{MAC}(K,M_2)), \dots , (M_n, \mathrm{MAC}(K,M_n)) \}$$

__Security challenge__: Find a pair (M, T) where

1. $M \notin \{M_1, M_2, \dots, M_n\}$ (i.e., M hasn't been seen before)
2. $T = \mathrm{MAC}(K, M)$

(M,T) is called a forgery

In a real attack, probably want M to be chosen or at least meaningful

In formal model, tilt advantage toward attacker: M can be anything

- This is called an *__existential forgery__*
- A MAC that is secure against this is called *__existentially unforgeable__*

Formal Security of MACs

Next: Where does the set of known message/tag pairs come from?

Some options:

- Provided or random messages (think: captured communications)
- Attacker picks all n messages M_1, M_2, …, M_n then gets all tags
- Attacker picks M_1 and gets T_1, then picks M_2 and gets T_2, etc.

Each option gives attacker more power than previous option.

Design against strongest possible adversary - the last option

- This is called an *adaptive chosen message attack*
- So best possible goal: *existential unforgeability against adaptive chosen message attack* (*EUF-CMA*)
- Note: More commonly used as security goal for signatures, but same idea

Making a MAC from a Hash Function

Insecure first attempt

Idea: Need a hash function with a secret key, so start with a standard hash function

Attempt 1 - Insecure

(but a lot of people do this anyway - don't be one of those people)

Idea: Concatenate key and message, and hash: $T = H(K \| M)$

Can't figure out key if H is preimage resistant. Can't pick different M (for same T) if H is collision resistant.

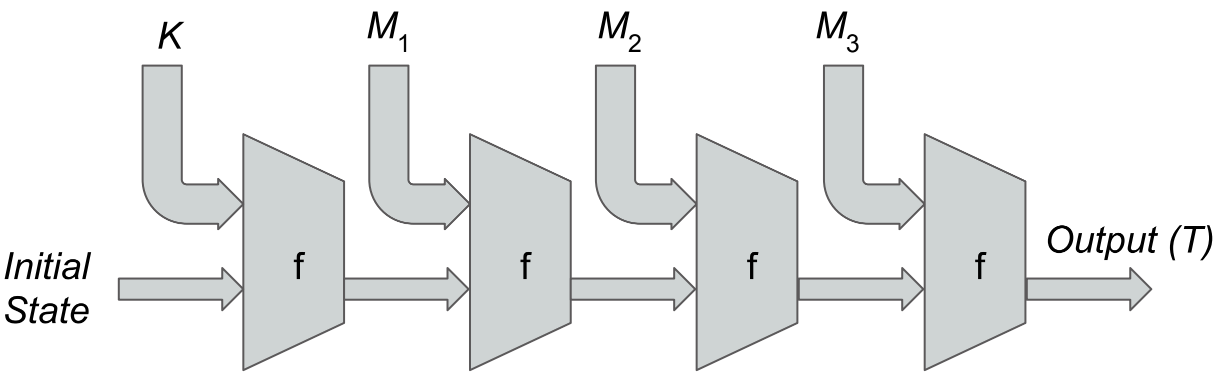
So… what's the problem?

Making a MAC from a Hash Function

Insecure first attempt

Recall Merkle-Damgard hash structure - 3 block example

(used by SHA1, SHA2 family (SHA256, SHA512, etc.)



Making a MAC from a Hash Function
Insecure first attempt

Recall Merkle-Damgard hash structure - 3 block example

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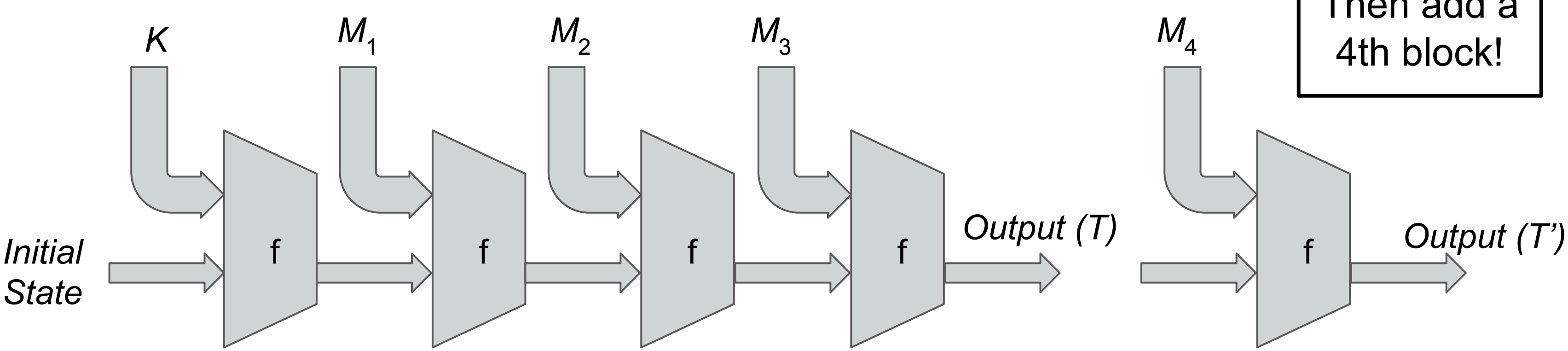
Then add a 4th block!



Making a MAC from a Hash Function

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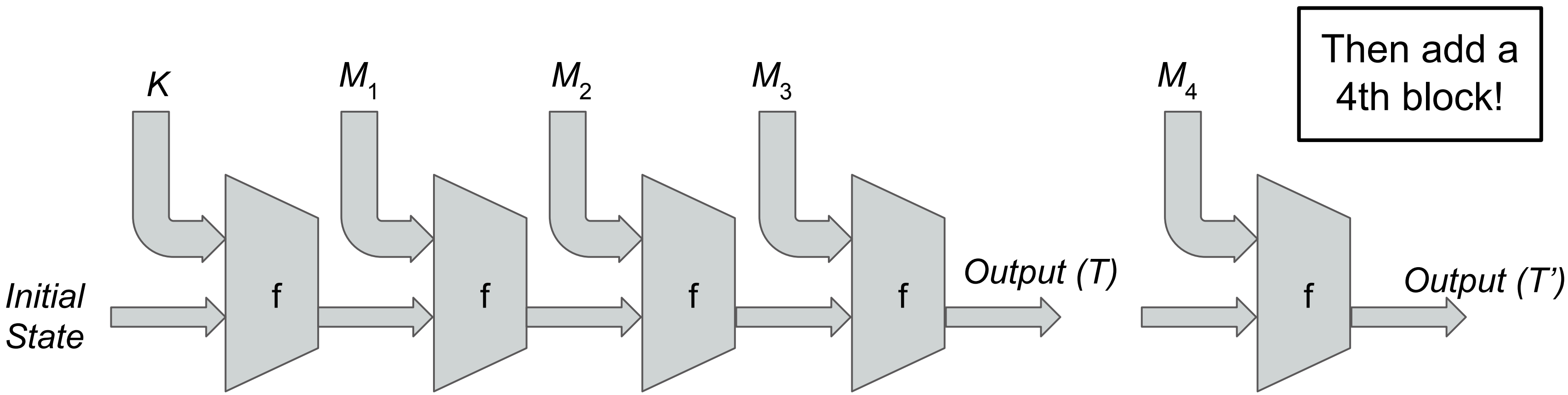

So: Given M_1, M_2, M_3, and T = MAC(K,$M_1||M_2||M_3$)

➔ Can pick M_4 and compute $T' = f(T, M_4)$ = MAC(K,$M_1||M_2||M_3||M_4$) - forgery!

This is called an *extension attack*

- Problem with any Merkle-Damgard hash function used this way
- Is not problem with SHA3!

HMAC - The Right Way

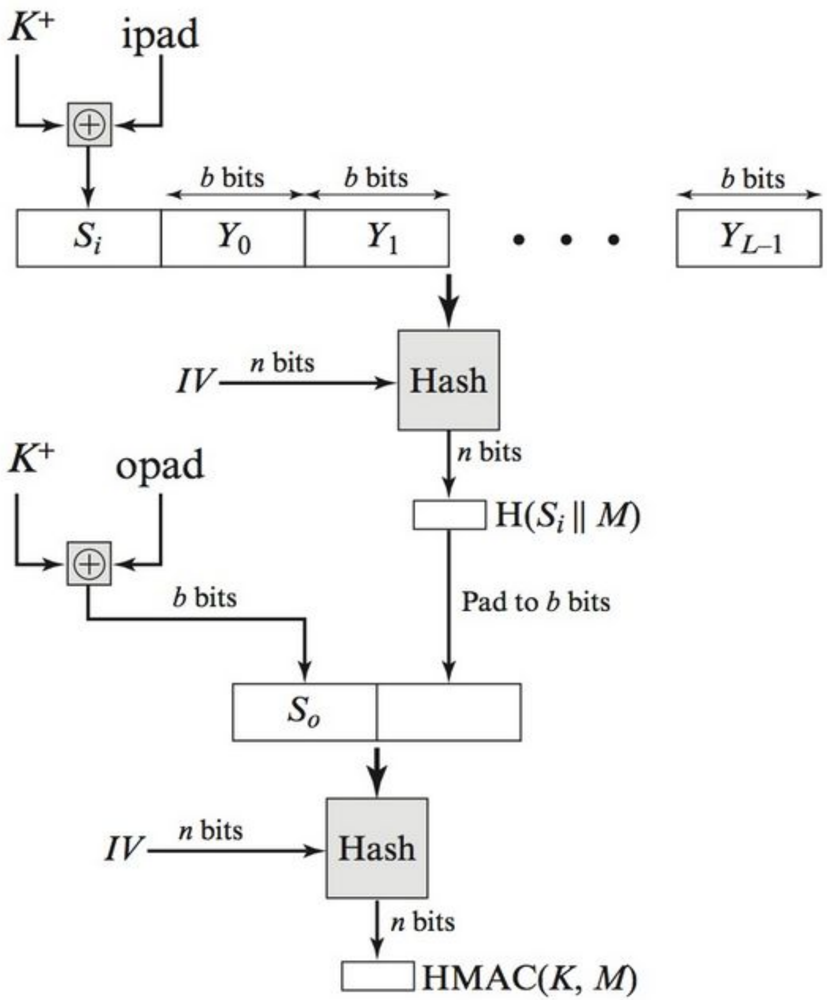

Figure 12.5 HMAC Structure

Key point:

Don't know $H(S_i \| M)$ so can't extend message!

HMAC - Proven Security!

Theorem (informally stated): If H is a Merkle-Damgard style hash function in which the compression function is a pseudorandom function (PRF), then HMAC using H is a pseudorandom function.

Proved in: Mihir Bellare. “New Proofs for NMAC and HMAC: Security without Collision-Resistance,” *2006 Conference on Advances in Cryptology* (*CRYPTO ‘06*).