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)  
7. Source repudiation  [Digital Signatures]
8. Destination repudiation  [Message Authentication]
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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

<table>
<thead>
<tr>
<th>Message</th>
<th>Authenticator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send the army to ... leaving at 10:30am.</td>
<td>7c91ad850b513</td>
</tr>
</tbody>
</table>

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?
**Authenticator: Concept**

**Message**

Send the army to ... leaving at 10:30am.

**Authenticator**

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**Question:** Will a cryptographic hash function work?
Specifically: How is this related to second preimage resistance?

- 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.

**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 $T = E(K, S)$ using a non-malleable cipher

**Question 1:** Can you find any other message with same tag?
Message Authentication Codes

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

**Question 1**: Can you find any other message with the same tag?

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?

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

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

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

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Message Authentication Codes

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

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 $|K|^2/2$ 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 $K$:

\[
\{ (M_1, \text{MAC}(K, M_1)), (M_2, \text{MAC}(K, M_2)), \ldots, (M_n, \text{MAC}(K, M_n)) \}
\]

**Security challenge:** Find a pair $(M, T)$ where

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

$(M, T)$ 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

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 $M_1, M_2, \ldots, M_n$ then gets all tags
- Attacker picks $M_i$ and gets $T_i$, then picks $M_j$ and gets $T_j$, 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: existentially 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.))

![Diagram of hash structure]

\[ f \]

Output (T)

Initial State

\[ K \]

\[ M_1 \]

\[ M_2 \]

\[ M_3 \]

\[ M_4 \]

Then add a 4th block!

So: Given \( M_1, M_2, M_3 \) and \( T = \text{MAC}(K, M_1 || M_2 || M_3) \)

\[ \Rightarrow \text{Can pick } M_4 \text{ and compute } T' = f(T, M_4) = \text{MAC}(K, M_1 || M_2 || M_3 || M_4) - \text{forgery!} \]

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

Key point:
Don’t know H(\text{K} \oplus 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.