Lecture 3: Message Authentication Codes (MACs)

Logistics: Lab 1 is out, due Friday Sept. 30th.

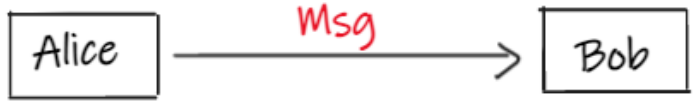
So far: Authentication people:

* something you know (password)
* something you have (device)
* something you are (biometrics)

Collision resistant hash functions

authenticating files, code, data ⟵ A user authenticating its own files

Today: Authenticate communication



Goal: Bob wants to know that the message indeed came from Alice

Example:

How does the server know the instruction came from Alice?

Message Authentication Code:

Assumes the communicating parties share a random secret key K.

Imossible unless Alice knows a secret that the adv doesn't know, and that Bob can somehow verify

It Consists of two function:

A signing function S(K,M) that produces a "tag" for the message M.

A verification function V(K,M,tag) and outputs 0/1.

Often V checks tag by recomputing S(K,M), in which case we can define a single alg, often referred to as MAC(K,M)

Correctness:

For every K in the key space, and every M in the message space:

V(K,M,S(K,M))=1.

Security: ??

Attacker Power:

Chosen message attack:

Attacker can obtain valid tags for any messages of his choice: M1, M2,...

A common real word attack: The attacker sends Alice emails of his choice. Alice will store these emails on her disc, but will tag them first. Then the attacker can steal her disc.

Attacker Goal:

Existential forgery:

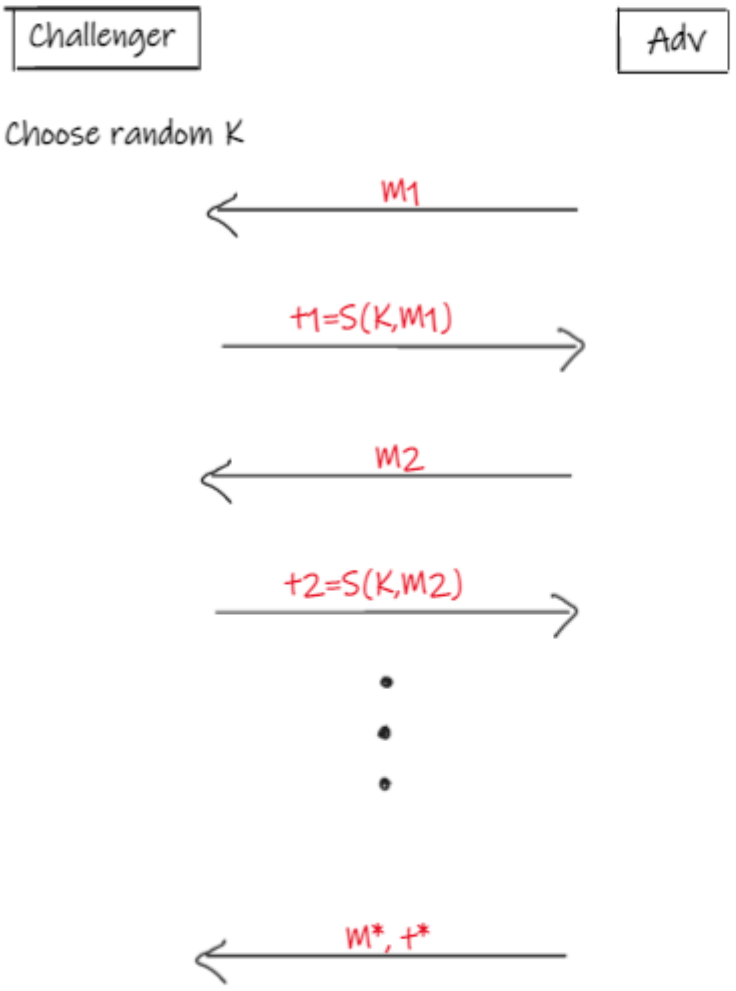
An attacker who is given tags t1=S(K,M1), t2=S(k,M2),...

for messages M1, M2,... of his choice cannot produce a valid tag for any new message M*.

Note: Adv wins even if M* is gibberish.

This can still be devastating, since sometimes parties MAC a secret key, which is gibberish.

Security as a game:



Adv wins if M* is different from M1,M2,... and V(K,M*,t*)=1

Strong security: Adv wins if (M*,t*) is different from (Mi,ti) for every i, and V(K,M*,t*)=1

(strong)

Def: The MAC is secure (existentially secure against adaptive chosen message attacks)

if any efficient adversary wins in this game with negligible probability

How do we construct a MAC??

May seem impossible!

How can we use a single fixed size secret K, to generate more and more unpredictible tags?

Moreover, the MACs used in practice generate random looking tags!

How can we take a fixed size random secret K, and deterministically generate more and more randomness???

Impossible!

We cannot generate randomness "out of thin air"!

Magically: We can generate "pseudo randomness" out of hardness!

Pseudo-Random Functions (PRF):

Informal Definition: A function F is pseudo-random if for a random secret K,

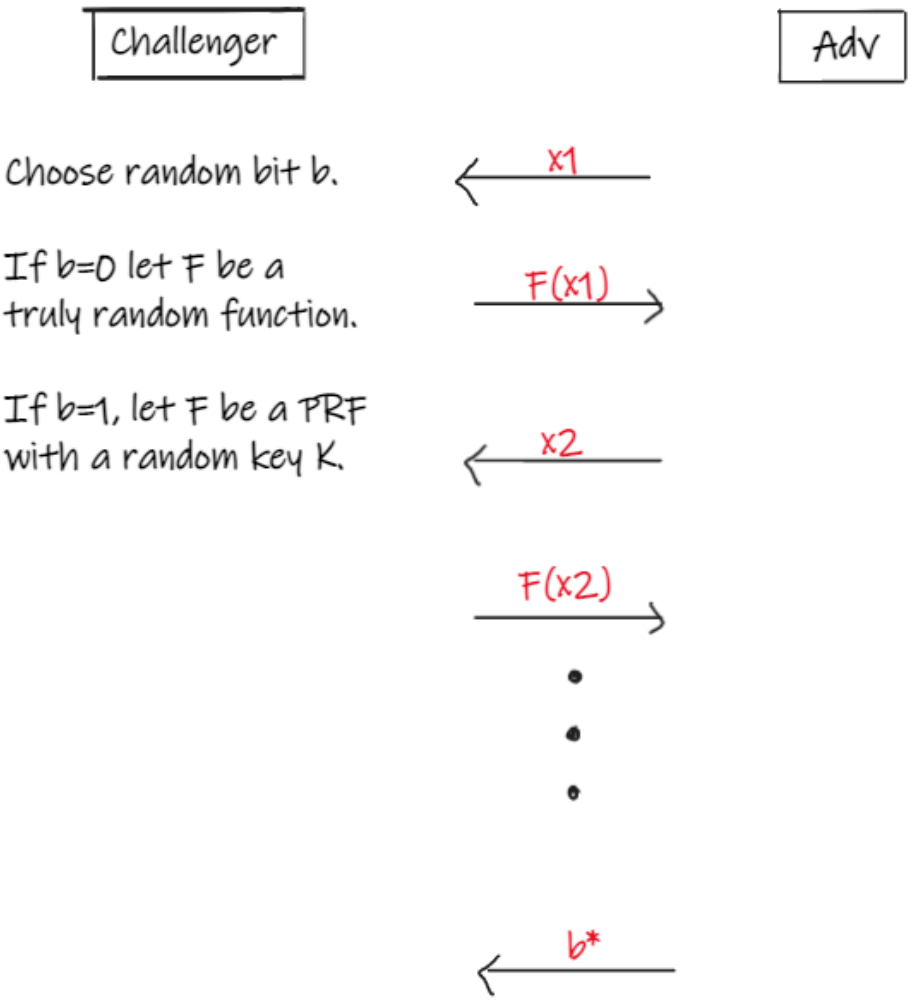
for any (adaptively chosen) inputs x1, x2,... F(K,x1), F(K,x2),... all "look random"

Formal Definition (using a security game):

A function F is a PRF if any efficient adversary A wins in the following game

with probability at most 1/2+negligible:

Security as a game:



Adv wins if b*=b

Theorem: There exists a PRF assuming one-way functions exist.

Definition: A one-way function (OWF) is a function that is easy to compute but hard to invert.

Go to 6.875 if you are interested in the (beautiful!) proof of this theorem

PRF in practice: AES

Advanced Encryption Standard. This is a block cipher (which we will talk about later in this course)

Go to 6.857 if you are interested in the details of the AES construction.

AES is a keyed function that takes 128 bit input to 128 bit output.

Key size has three options: 128, 192 or 256 bits.

AES is assumed to be a PRF.

Actually, as we will see later in this course, AES is a permutation, and hence assumed to be a pseudorandom permutation (PRP)

Question: Is every PRF F with domain D also a secure MAC for messages from D, where the tag of M is F(K,M)?

No!

Note: tag cannot be too small. If tag is only 4 bits, the MAC cannot be secure!

If we think of 2^{-128} as negligible, then tag needs to be at least 128 bits long.

Theorem: Every PRF with domain D and range R where 1/|R| is "negligible" is a MAC for messages from D.

Corollary: AES is a secure MAC for messages of length 128 bits.

Question: How can we MAC messages of arbitrary length?

Going from small MAC to big MAC:

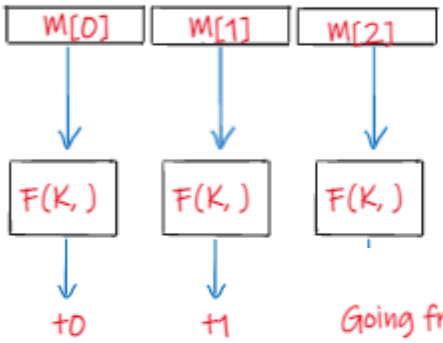
Two MAC constructions standardized by NIST: One based on AES (CMAC) and one based on SHA2 (HMAC).

Later in the course we will see a different construction of authenticated encryption AES-GCM

(Gallois Counter Mode)

AES-based MAC (There is also a hash-based MAC called HMAC)

Try 1:

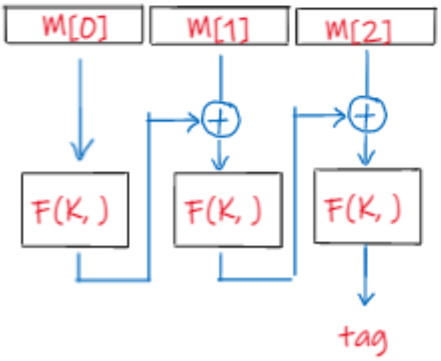


Going from small MAC to big MAC:

Insecure!

Adversary can use the tag for message (M[0],M[1]) to tag the message (M[1],M[0]).

Try 2:



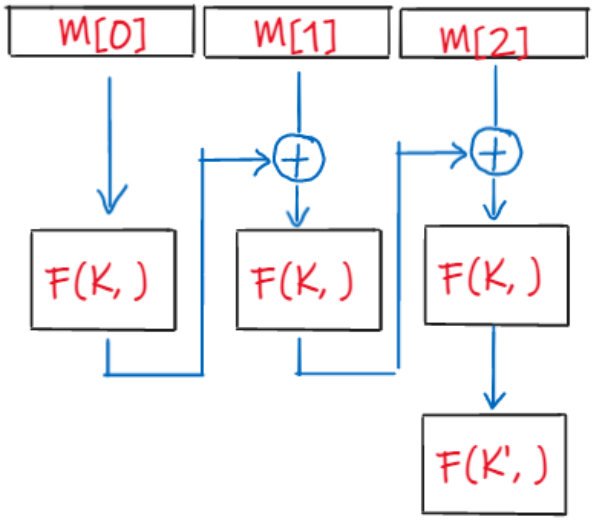
Insecure! Adversary can use the tag for message (M[0],M[1],m[2]) and tag' for message m'[0],

to tag the message (M[0].M[1],M[2],tag xor M'[0]).

Final try:

CBC MAC:

Cipher Block Chaning



The secret key is (K,K')

This additional secret key prohibits these "extension attacks"

Similar to why adding the message length in the construction of a collision resistant hash function is needed to make it secure.

Note: Need to pad the message so that its length will be a multiple of 128.

This is a HW problem (in Pset 1).

The standardized version of CBC MAC is called CMAC