Key Exchange
and
Key Management

Review: Integrity

Problem: Sending a message over an **untrusted channel** without being changed

Provably-secure solution: **Random function**

Practical solution:

e.g. "Attack at dawn", 628369867…

Pseudorandom function (**PRF**)

Input: arbitrary-length **k**
Output: fixed-length value

Secure if practically indistinguishable from a random function, unless know **k**

Real-world use:

Message authentication codes (**MACs**) built on cryptographic hash functions

Popular example: **HMAC-SHA256$_k$(m)**

[Cautions?!]

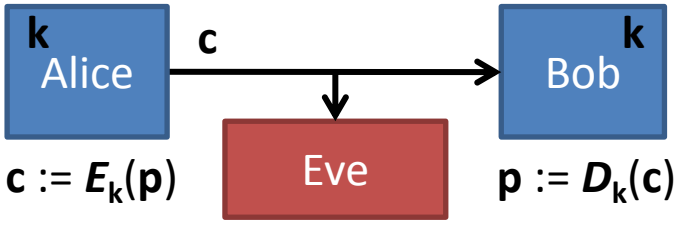
Review: Confidentiality

Problem: Sending message in the presence of an **eavesdropper** without revealing it

Provably-secure solution: **One-time pad**

Practical solution:

Pseudorandom generator (PRG)



Input: fixed-length **k**
Output: arbitrary-length stream

Secure if practically indistinguishable from a random stream, unless know **k**

Real-world use:

Stream ciphers (can't reuse **k**)
Popular example: **AES-128** + **CTR mode**

Block ciphers (need **padding/IV**)
Popular example: **AES-128** + **CBC mode**

[Cautions?!]

Building a secure channel

What if you want confidentiality and integrity at the same time?

Encrypt, then add integrity,
not the other way around.
(some reasons are subtle)

Use separate keys for
confidentiality and integrity.

Need two shared keys,
but only have one?
That's what PRGs are for!

If there's a reverse (Bob to Alice)
channel, use separate keys for that too

Modern encryption modes

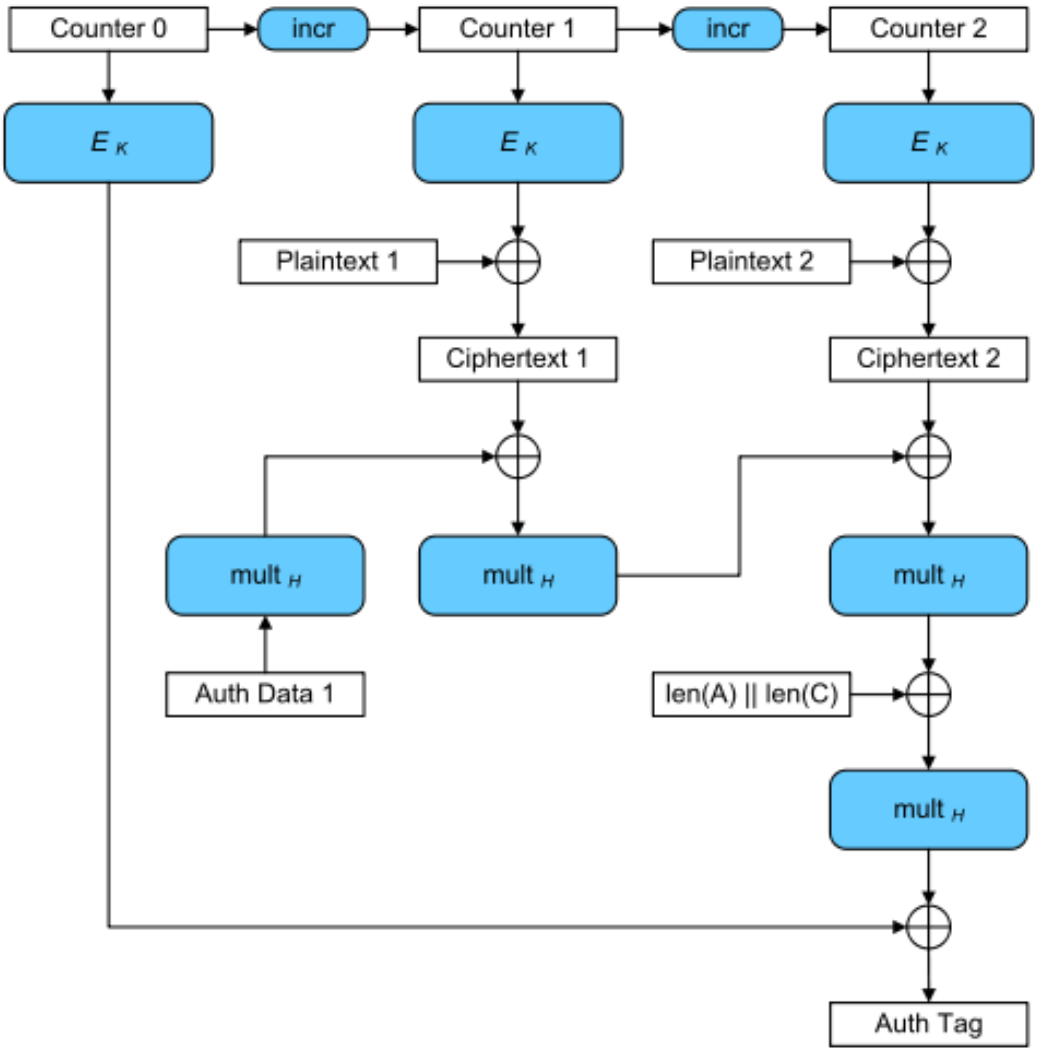
Authenticated Encryption

Encrypt and Authenticate the data

AES-GCM – Galois/Counter Mode

AES in CTR Mode for encryption

Galois Hashing for authentication



Issue: How big should keys be?

Want prob. of guessing to be infinitesimal… but watch out for Moore's law – safe size gets 1 bit larger every 18 months

128 bits usually safe for ciphers/PRGs

Need larger values for MACs/PRFs due to **birthday attack**

Often trouble if adversary can find any two messages with same MAC

Attack: Generate random values, look for coincidence.

Requires $O(2^{|k|/2})$ time, $O(2^{|k|/2})$ space.

For 128-bit output, takes 2^{64} steps: doable!

[Puzzle: Do it in constant space?]

Upshot: Want output of MACs/PRFs to be twice as big as cipher keys

e.g. use HMAC-SHA256 along side AES-128

Exercise:

100 people all communicating with each other, how many keys are needed? (using symmetric key crypto)

Issue: How do we get a shared key?

Amazing fact:

Alice and Bob can have a public conversation to derive a shared key!

Diffie-Hellman (D-H) key exchange

1976: Whit Diffie, Marty Hellman
with ideas from Ralph Merkle
(earlier, in secret, by Malcolm Williamson
of British intelligence agency)

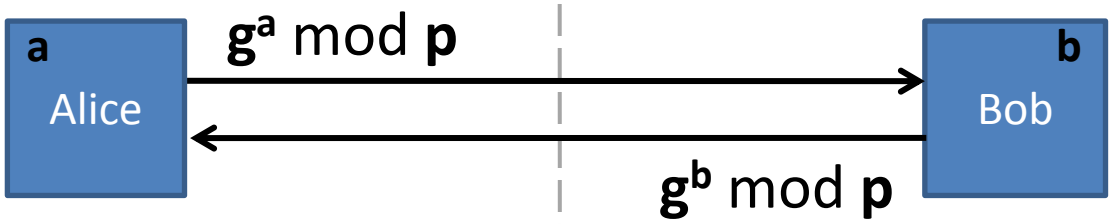
Relies on a mathematical hardness
assumption called *discrete log problem*
(a problem believed to be hard)

D-H protocol

1. Alice and Bob agree on public parameters (maybe in standards doc*, or pick them)
   p: a large "safe prime" s.t. (**p**-1)/2 is also prime
   g: a square mod **p** (but not 1)

2. **Alice**
   Generates random secret value **a**.
   (0 < **a** < **p**)

   Bob
   Generates random secret value **b**.
   (0 < **b** < **p**)



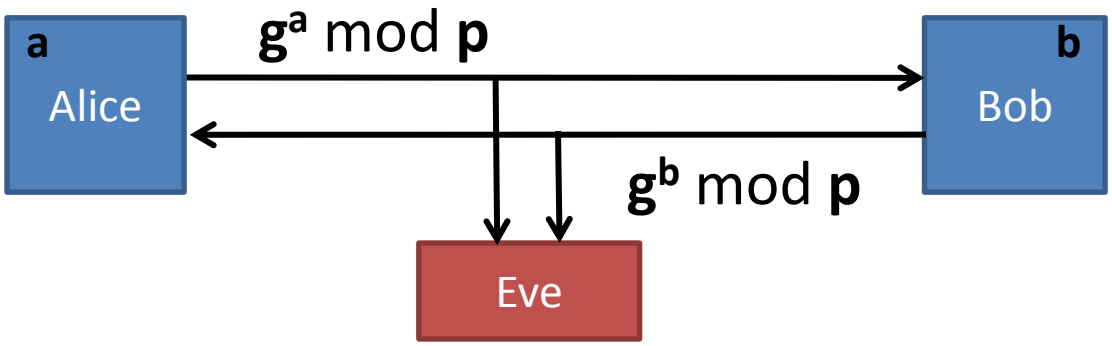
3. Computes **x**
   = $(g^b \bmod p)^a \bmod p$
   = $g^{ba} \bmod p$

   Computes **x'**
   = $(g^a \bmod p)^b \bmod p$
   = $g^{ab} \bmod p$

(Notice that **x** == **x'**)

Can use **k** := $HMAC_0(x)$ as a shared key.

Passive eavesdropping attack



Eve knows: **p**, **g**, g^a mod **p**, g^b mod **p**

Eve wants to compute $x = g^{ab}$ mod **p**

Best known approach:

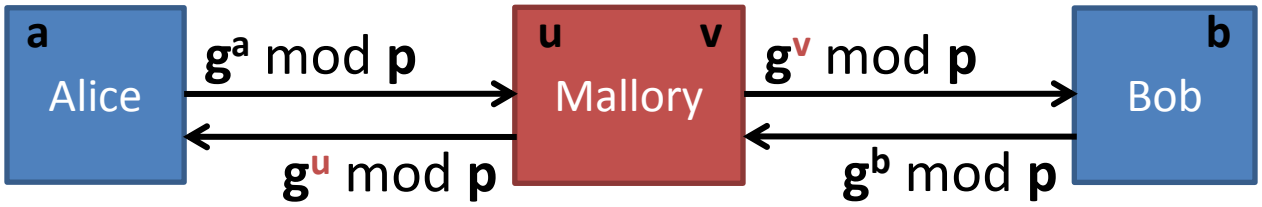
Find **a** or **b**, then compute **x**

Finding **y** given g^y mod **p** is an instance of the **discrete log problem**:

No known efficient algorithm.

[What's D-H's big weakness?]

Man-in-the-middle (MITM) attack



Alice does D-H exchange, *really with Mallory*, ends up with $g^{au} \bmod p$

Bob does D-H exchange, *really with Mallory*, ends up with $g^{bv} \bmod p$

Alice and Bob each think they are talking with the other, but really Mallory is between them and knows both secrets

Bottom line:

D-H gives you secure connection, but you don't know who's on the other end!

Defending D-H against MITM attacks:

- Cross your fingers and hope there isn't an active adversary.
- Rely on out-of-band communication between users. [Examples?]
- Rely on physical contact to make sure there's no MITM. [Examples?]
- Integrate D-H with user authentication.

  If Alice is using a password to log in to Bob, leverage the password:

  Instead of a fixed **g**, derive **g** from the password – Mallory can't participate w/o knowing password.
- Use digital signatures. [More next week.]

Exercise:

What happens if Alice uses the same **a** and $\mathbf{g^a}$ for all her communication with Bob?

The hard part of crypto

Key-management

Principles:

0. Always remember,
   key management is the hard part!
1. Each key should have only one purpose.
2. Vulnerability of a key increases:
   a. The more you use it.
   b. The more places you store it.
   c. The longer you have it.
3. Keep your keys far from the attacker.
4. Protect yourself against compromise of old keys.

   Goal: **forward secrecy** — learning old key shouldn't help adversary learn new key.

   [How can we get this?]

D-H doesn't quite deliver public-key encryption:

Alice and Bob agree on a secret key

El Gamal encryption directly supports encryption:

Bob's public key is $B=\mathbf{g}^{b} \bmod \mathbf{p}$,

private key is b.

Alice picks a random value r [0,p-2], forms ciphertext for message m:

$(\mathbf{g}^{r} \bmod \mathbf{p}, m \times B^{r} \bmod \mathbf{p})$ or (R,S)

Bob computes $R^{-b} \times S \bmod \mathbf{p}$

which is m mod p!

So Far: Foundations

The Security Mindset

Message Integrity

Confidentiality

Key Exchange

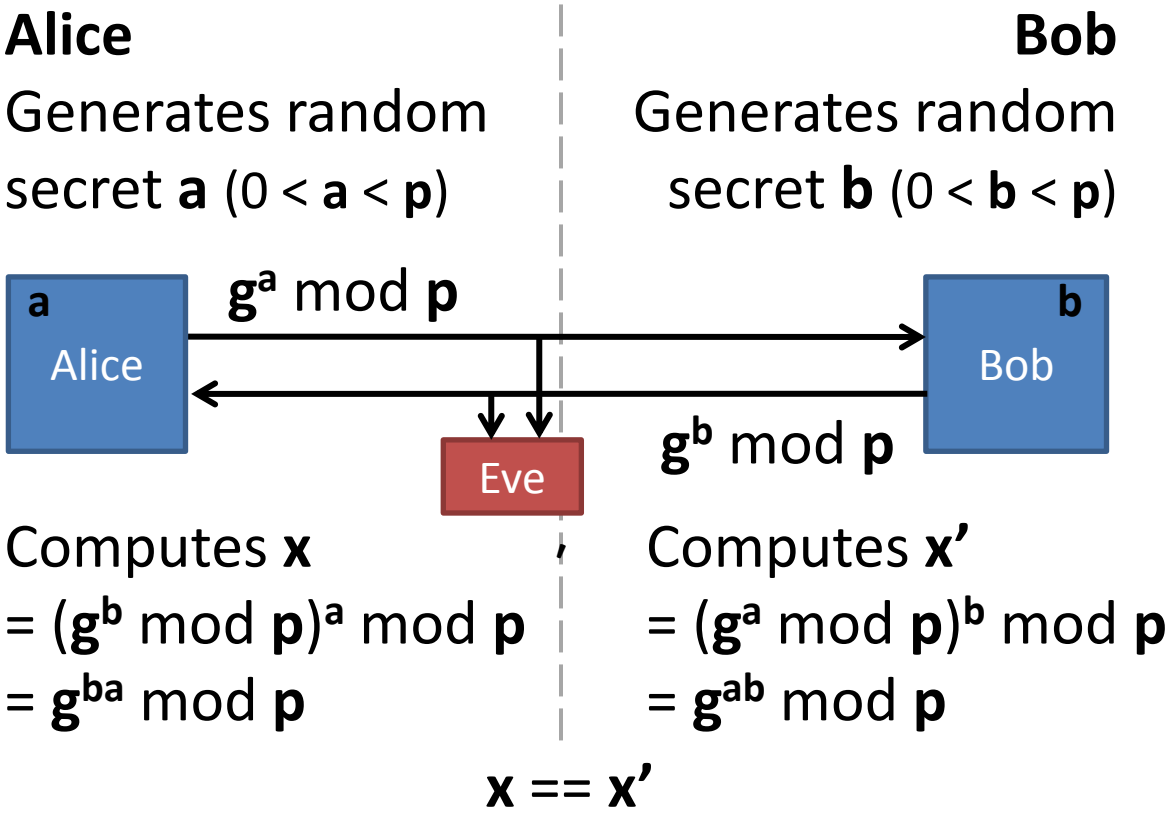
Building a Secure Channel

Thursday:

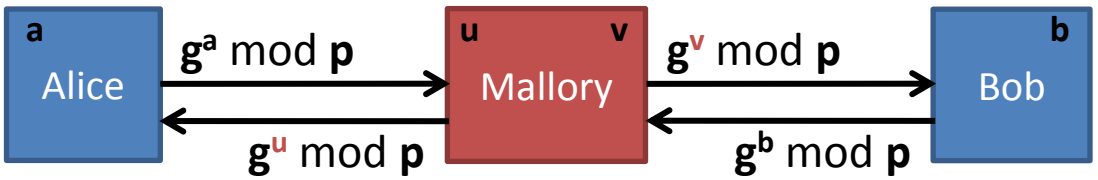
Public Key Crypto

Review: Diffie-Hellman Key Exchange

Lets Alice and Bob **agree on a shared secret** value by having a public conversation



Problem: **Man-in-the-middle attacks**



Caution: D-H gives you a shared secret, but don't know who's on the other end!