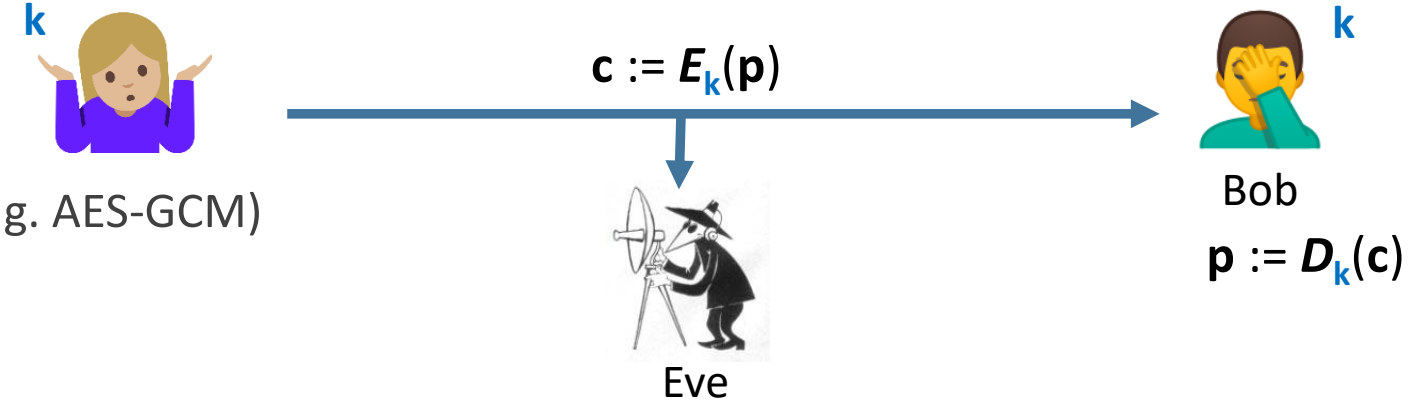
Cryptography Basics – Key exchange

Review

Integrity: prevent Mallory from tampering
- Message Authentication Code
- Hashes -> HMAC
  - Use: SHA2, SHA3

Confidentiality: prevent eavesdropper (Eve) from learning the (plaintext) message
- Stream ciphers
  - **AES-CTR, ChaCha20**
- Block ciphers
  - **AES-CBC** (caution: padding oracles!)

Best practice: Authenticated ciphers (e.g. AES-GCM)
- **Encrypt, then MAC**



Sharing k

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)

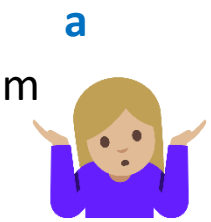
Relies on a mathematical hardness assumption called *discrete log problem*
(a problem believed to be hard)

Diffie-Hellman protocol

D-H protocol

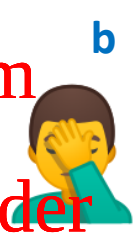
1. Alice and Bob agree on public parameters (maybe in standards doc*, or pick them)
   p: a large "safe prime" s.t. (**p**-1)/2 is also prime
   g: a square mod **p** (but not 1)

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



$g^a \bmod p$ →

← $g^b \bmod p$



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

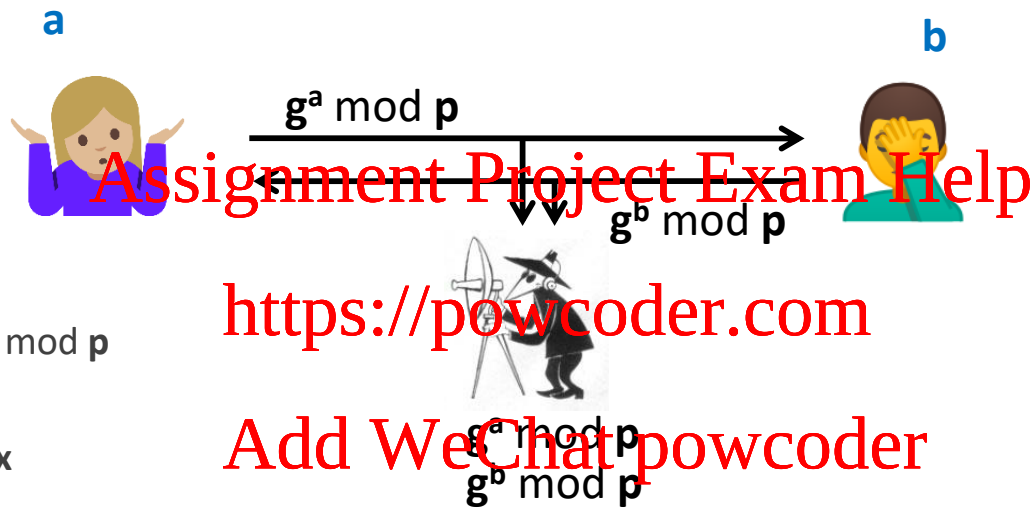
3.

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.

DH passive eavesdropping attack



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*

Best practice: Use large DH group size (e.g. 2048-bit primes)
or a more secure group (Elliptic curve cryptography)

[Breakout exercise: what about Mallory (active attacks)?]

Man-in-the-middle (MITM) attack

Alice does D-H exchange,
really with Mallory

Bob does D-H exchange,
really with Mallory

$k_{Alice} = g^{ab'} \bmod p$

$k_{Bob} = g^{a'b} \bmod p$

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.]

Public key encryption

Can Alice share a “public key” ($\mathbf{g}^{\mathbf{a}}$ mod $\mathbf{p}$) and have anyone encrypt a message only she can read?

Public key encryption

Can Alice share a "public key" (g^a mod **p**) and have anyone encrypt a message only she can read?

Diffie-Hellman doesn't allow this directly, but with some math:

Alice's **public key** is A= g^a mod **p** and her **private key** is **a**

Bob has Alice's public key, and a message **m** he wants to send her:

- Pick a random value **r** [0,p-2]
- Compute R= g^r mod **p**
- Compute S=m*A^r mod **p**
- Send Alice (R,S)

To decrypt:

- Alice computes S*R^{-a} mod **p** = m*A^r *$g^{r(-a)}$ mod **p** = m*$g^{ar}g^{r(-a)}$ mod **p** = m*g^{ar-ar} mod **p** = m*g^0 mod **p** = m