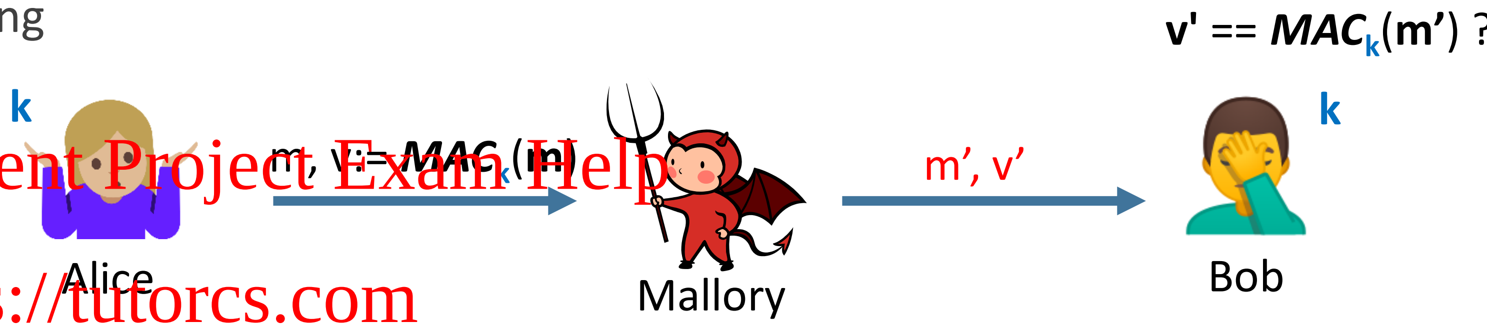
Cryptography Basics – Key exchange

Review

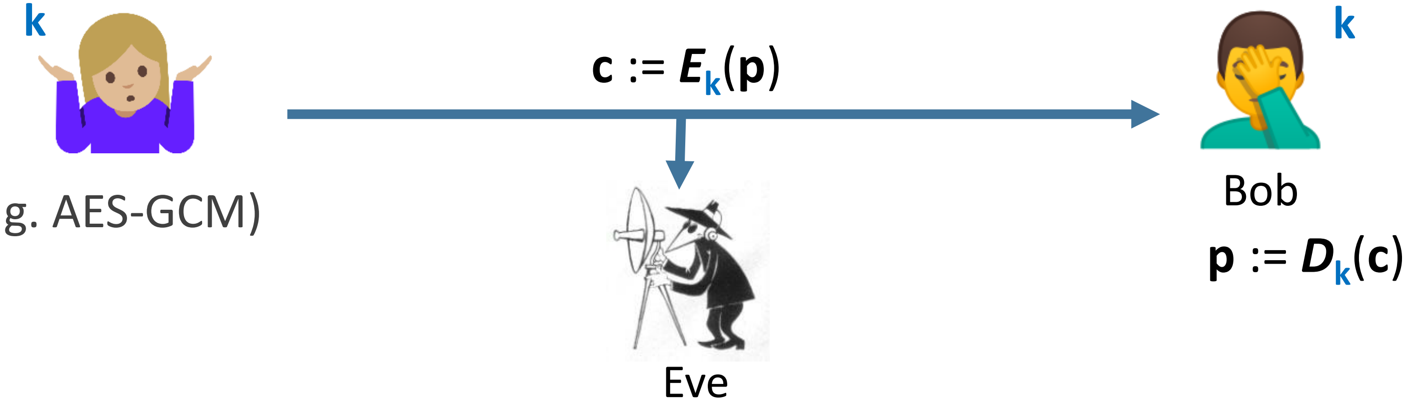
Integrity: prevent Mallory from tampering

- 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)

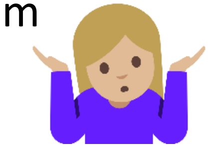
Diffie-Hellman protocol

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**)

   a



$\mathbf{g}^a$ mod **p** →

← $\mathbf{g}^b$ mod **p**

b

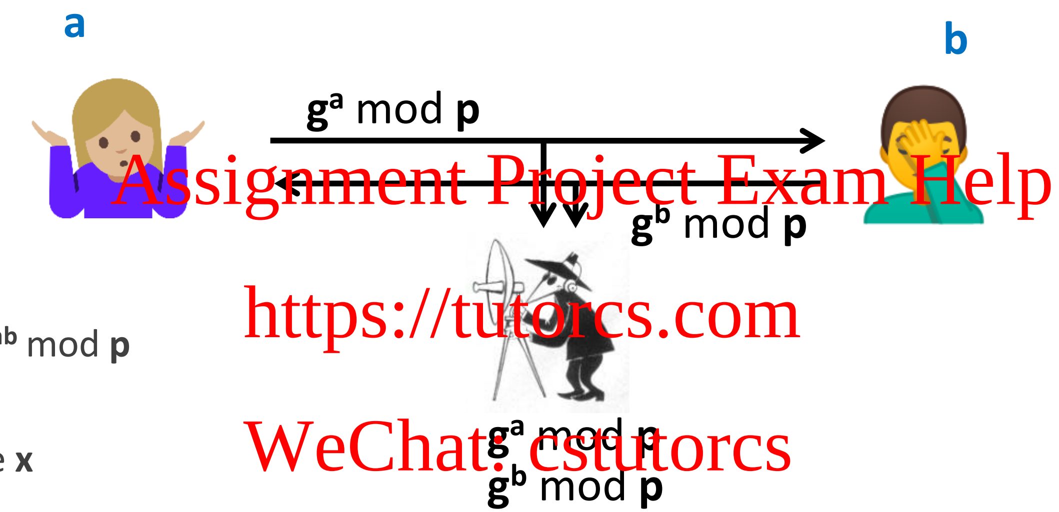
Bob
Generates random secret value **b**.
(0 < **b** < **p**)

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

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

(Notice that **x** == **x'**)
Can use **k** := HMAC_0(**x**) as a shared key.

DH passive eavesdropping attack



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

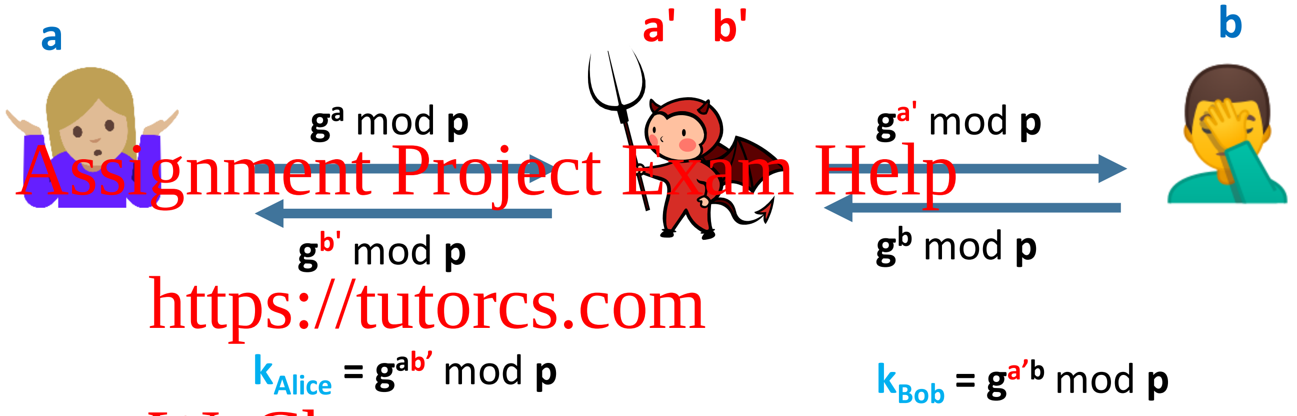
Best known approach:
Find **a** or **b**, then compute **x**

Finding **y** given $\mathbf{g}^{y}$ 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

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" ($\mathbf{g}^a$ 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