THE UNIVERSITY OF MELBOURNE

COMP30023 – Computer Systems

2022 – Semester 1 - Week 4 – Lecture 2

Secure communication

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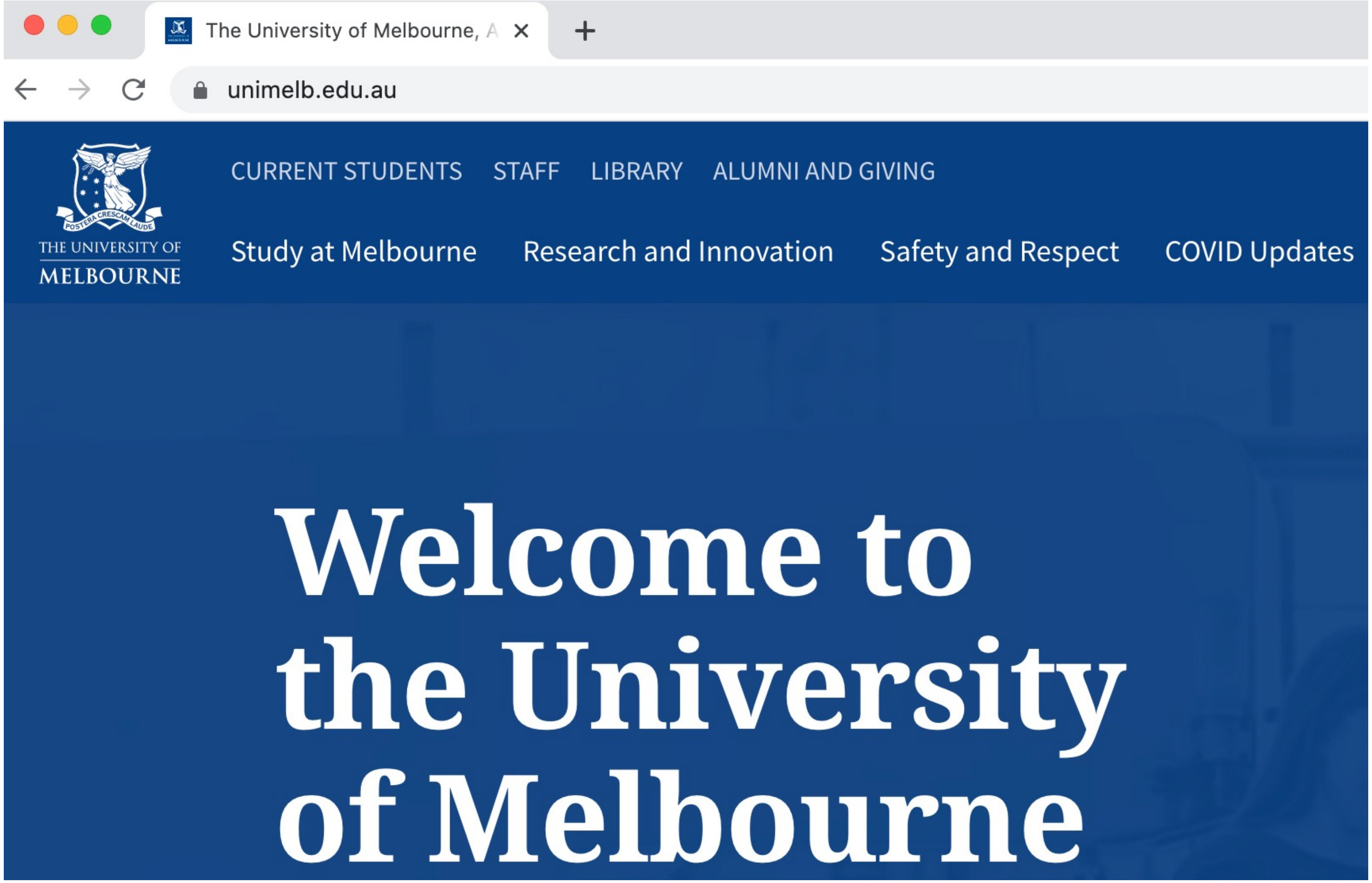
Project 1

- Announcement on LMS
- Spec is available via LMS
- Extra consultation hours
- Participation in Ed discussions

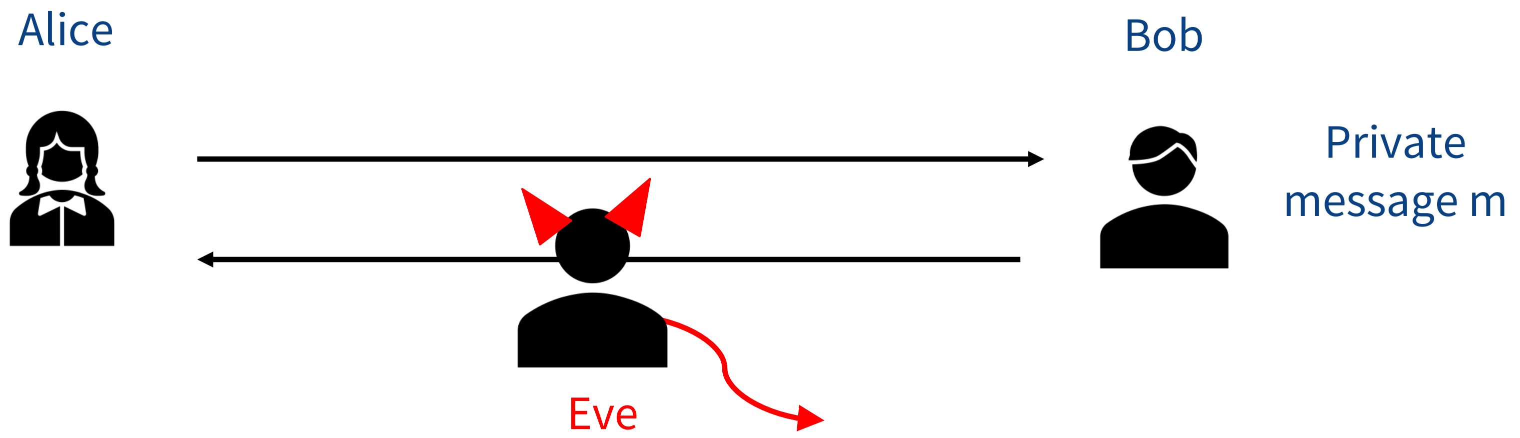
Recap

- Symmetric vs. asymmetric cryptography
- Encryption
- Signatures
- Hashing

What does the lock mean?

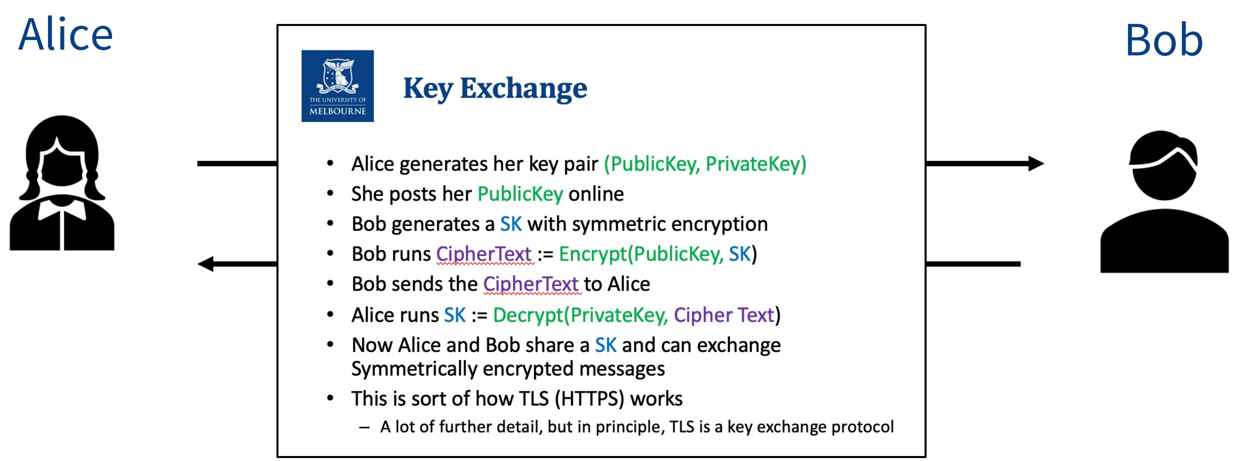


Goal: Secure Communication



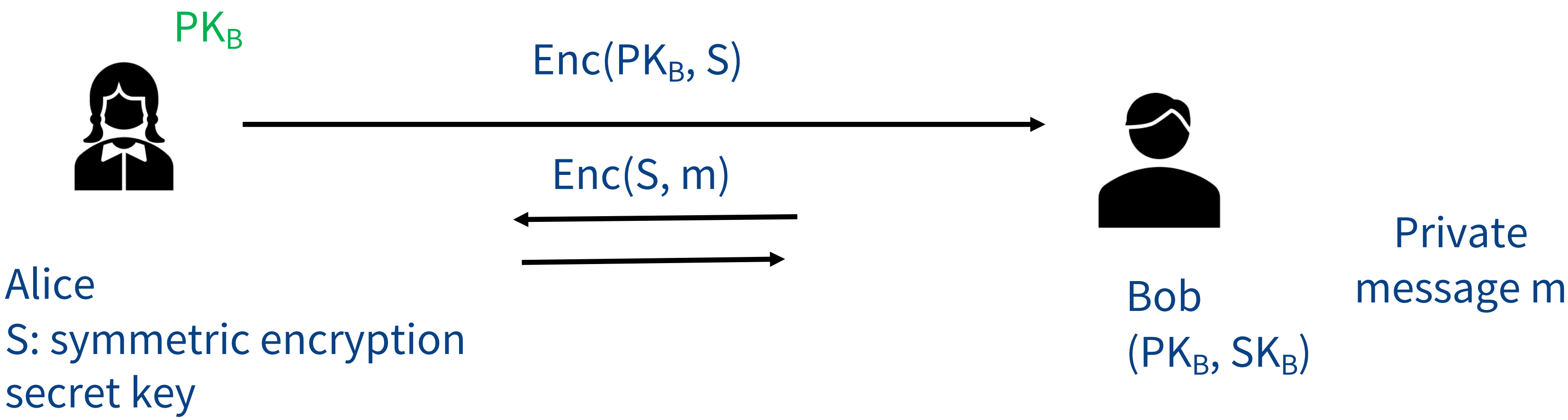
Adversary controls Wi-Fi, DNS, routers, can create its own websites, can listen to any packet, modify packets in transit, inject its own packets into the network

Goal: Secure Communication



Goal: Secure Communication

Why



PK_B
$Enc(PK_B, S)$
$Enc(S, m)$
Alice
S: symmetric encryption secret key
Bob
(PK_B, SK_B)
Private message m

Secure Communication

WHEN I SEND A MESSAGE TO SOMEONE, HOW DO I KNOW THEY ARE PPL I TRUST.

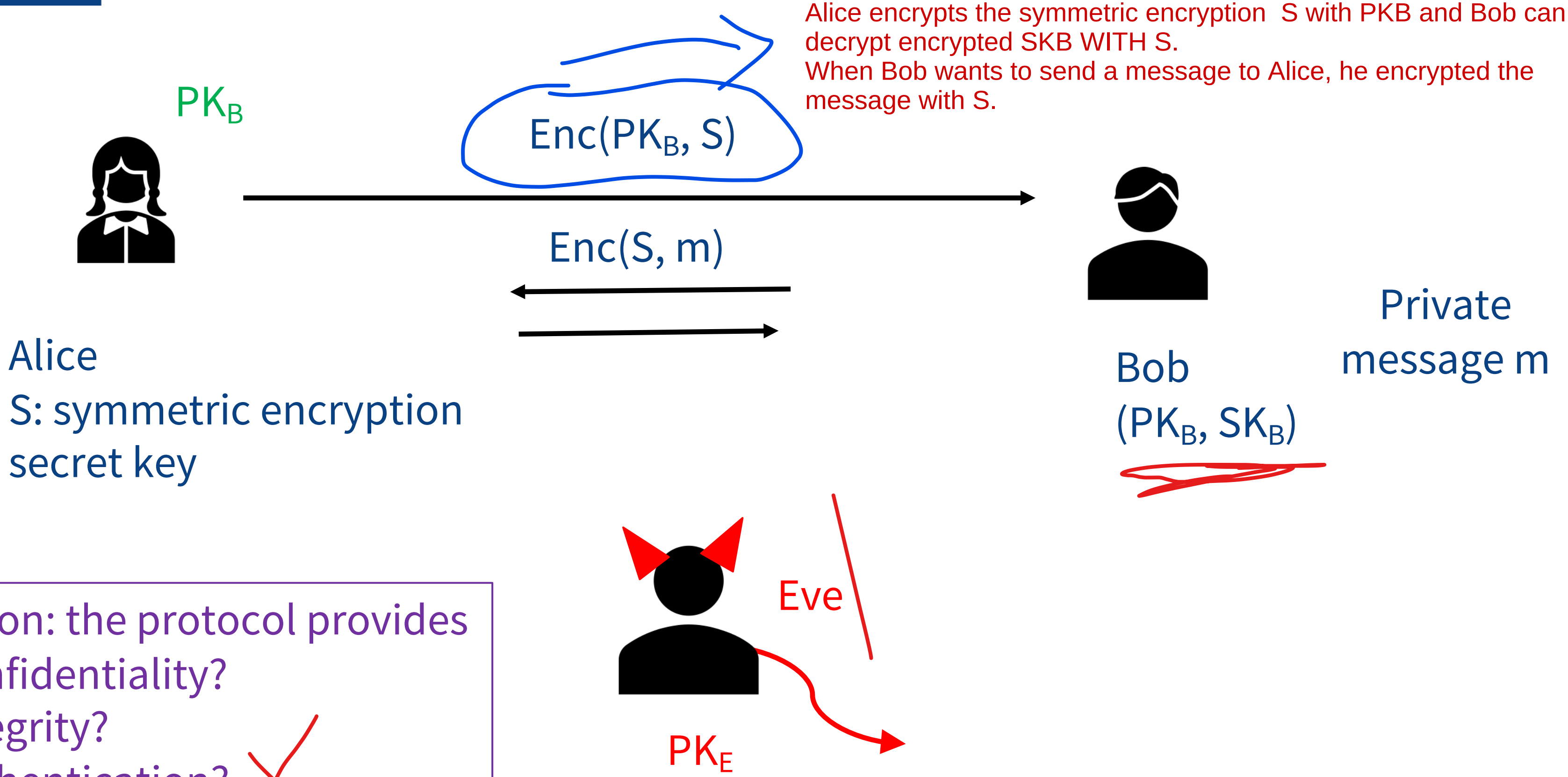
how do i know my message is not modified

Confidentiality – Authentication – Integrity

Objective is to provide **secure private** communication between two end-points, with **integrity checks** to ensure data does not change in transit, and **authentication** to establish identities of one or both of the end-points.

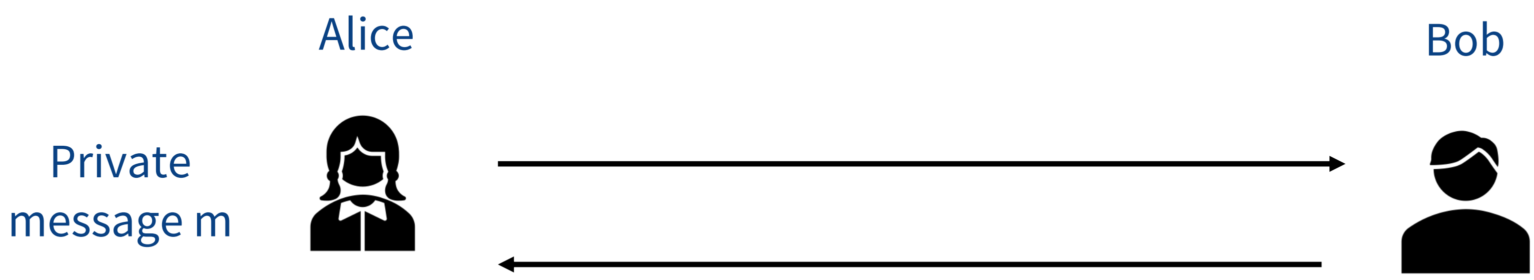
Why

Alice encrypts the symmetric encryption S with PKB and Bob can decrypt encrypted SKB WITH S.
When Bob wants to send a message to Alice, he encrypted the message with S.



Question: the protocol provides
- Confidentiality?
- Integrity?
- Authentication?

Goal: Secure Communication



2 problems:

1. How does Alice know ciphertext has not been modified?
2. How does Alice know PK_B is Bob's public key?

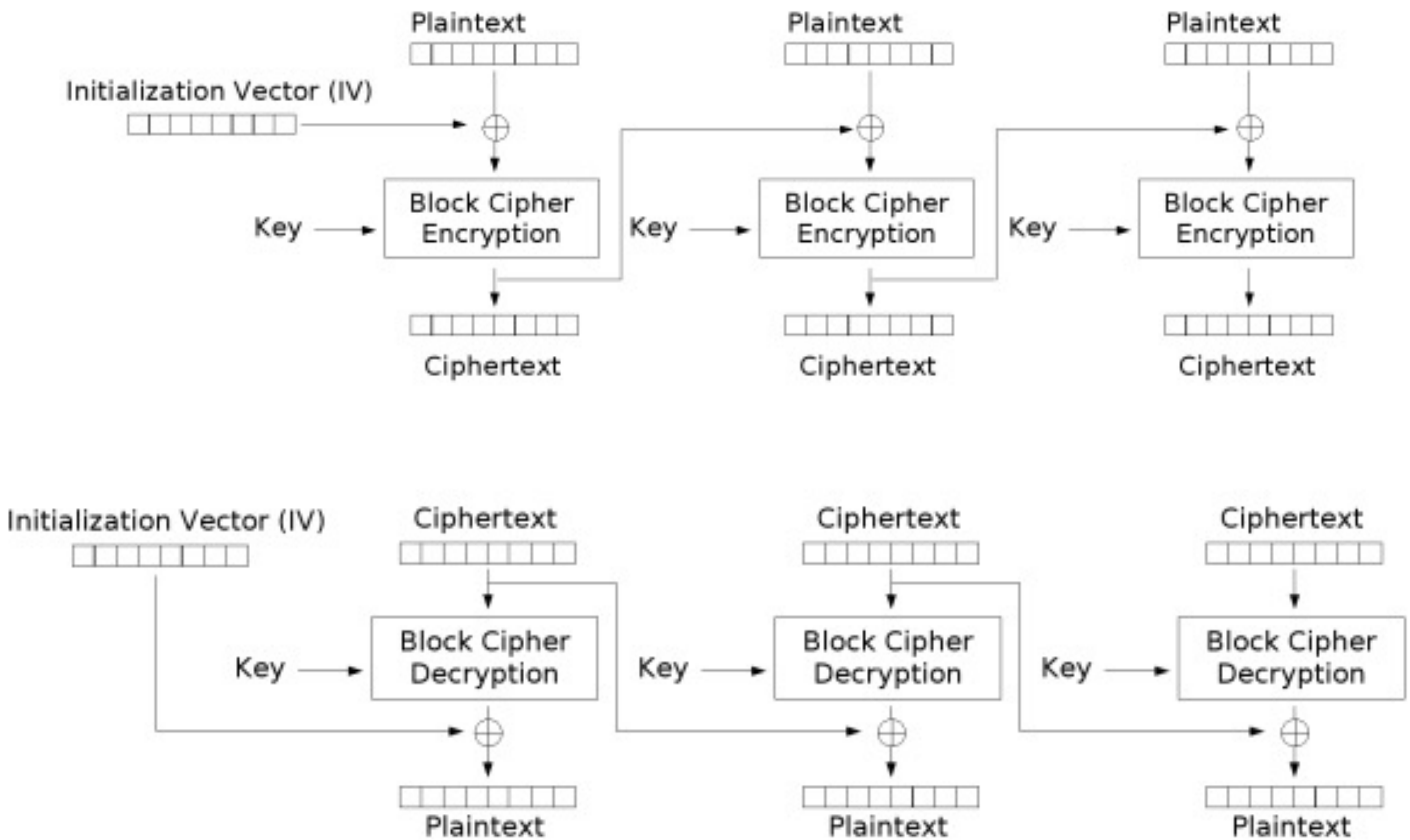
Today:
Towards Secure Communication

- Message authentication code
- Authenticated encryption

Properties we want: confidentiality and integrity

- Diffie Hellman Key Exchange
- Public Key Infrastructure (Certificates)

CBC – Cipher Block Chaining Tampering I (previous lecture)



Encryption

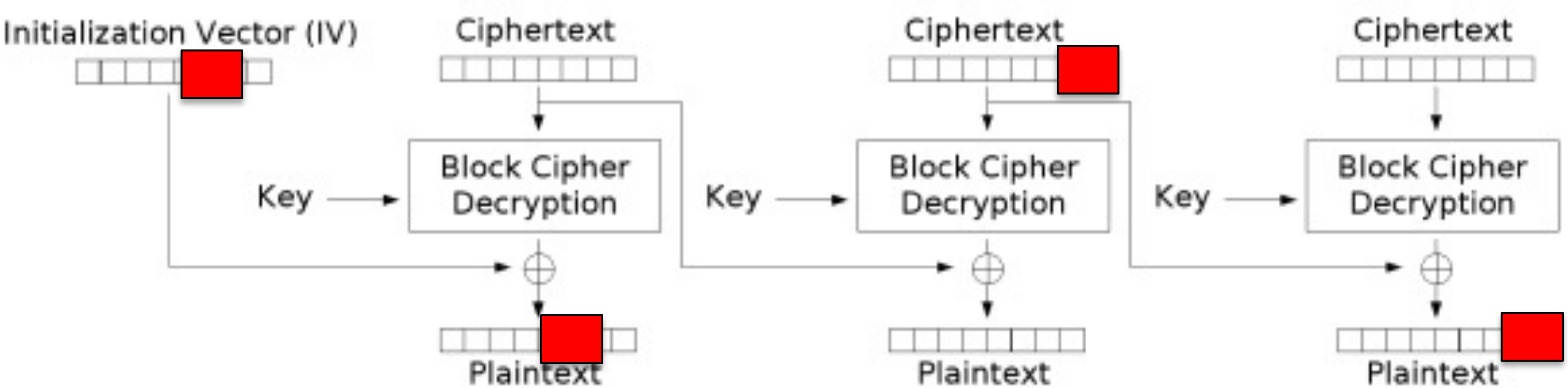
Decryption

Cipher Block Chaining (CBC) mode decryption

CBC – Cipher Block Chaining Tampering I (previous lecture)

Attacker can:
- reorder ciphertext
- flip bits

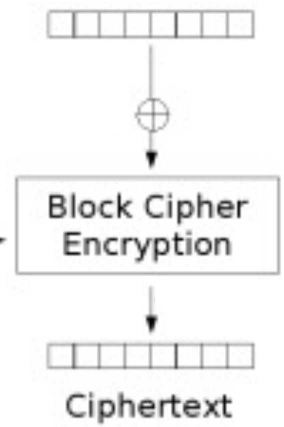
Every possible ciphertext corresponds to some valid plaintext



Cipher Block Chaining (CBC) mode decryption

Towards Authenticated Encryption

m: message



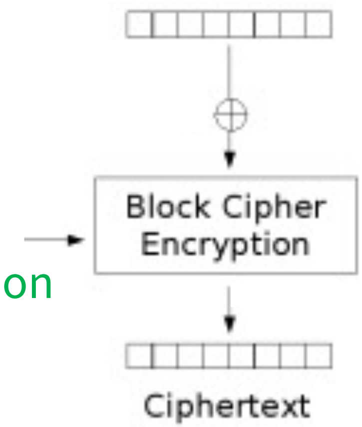
Secret key SK of symmetric encryption

c: ciphertext

Properties we want: confidentiality and integrity

Potential solutions for message authentication

m: message



Secret key SK of symmetric encryption

c: ciphertext

t := Authenticate (, m/c,)

Verify(…, ~~m/c, t,…)~~ ??

Hash: collision resistant hash function

- Hashing? (Is Hash(m) a good authentication method? Is Hash(c)?)
- Digital signatures? (Is Sign(SigningKey, m)? Is Sign(SigningKey, c)?)

we can only sign one of them (leave as a homework to figure out which one we should sign)

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Message Authentication Code (MAC)

Like we mac the original message to create a tag (this secret key (s1) used for the Mac function and and when receiver has the message + tag, they can put them as inputs for the Verify function. b = 0 => message was tampered. b = 1 => message was not tampered.

Message Authentication Code ensures integrity but not confidentiality because we dont encrypt the message.

- Detect if message has been tampered with
- s: MAC's secret key; m: message
- t := Mac(s,m); b := Verify(s,m,t)
  - b is 0/1 indicating successful verification
- Verifies integrity of a message using a secret key
- Security: Adversary cannot create (m', t') such that Verify(s,m',t') returns b = 1 for m' it has not seen

CBC-MAC and HMAC

CBC-MAC based on encryption (careful with variable length messages)

HMAC: Industry standard and used widely in practice

HMAC: Generate a MAC tag t:

$$t := \text{Hash}\ (\ (s \oplus \text{opad})\ \|\ \text{Hash}\ ((s \oplus \text{ipad})\ \|\ m))$$

ipad and opad are fixed constants used for padding

Authenticated Encryption

- Confidentiality and integrity of messages exchanged between Alice and Bob

- General construction: Encrypt-then-Mac:
  - c :=Encrypt(SK, m)
  - t := Mac(s, c)

- Encrypt -> Mac is more secure than Mac and Encrypt.
- If we use Digital Signature instead of Mac , it is not secure (figure out)

Message m
Secret key SK of symmetric encryption

- Verify: if Verify(s,t,c) returns 0, ~~do not decrypt~~

- Examples: AES-GCM, AES-OCB, AES-CCM

Today:
Towards Secure Communication

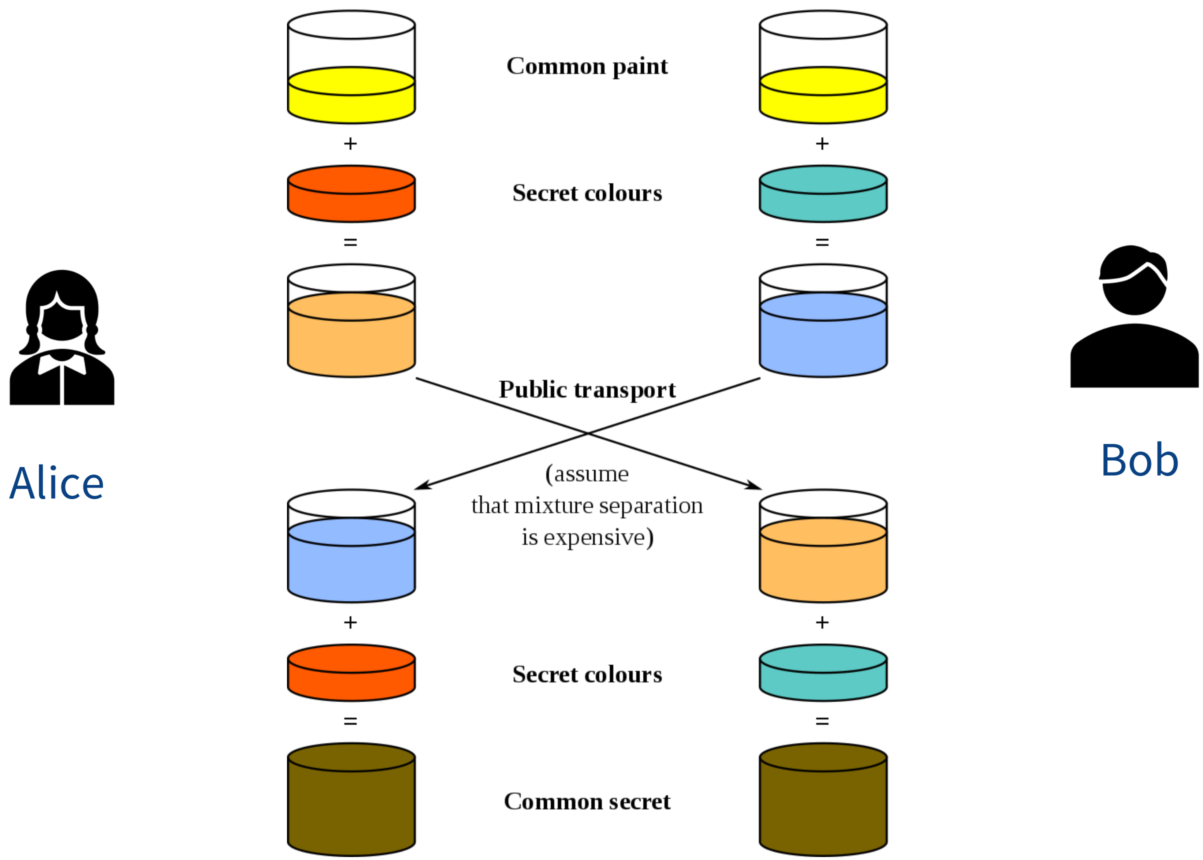
- Message authentication code
- Authenticated encryption
- Diffie Hellman Key Exchange
- Public Key Infrastructure

Diffie-Hellman Key Exchange

Turing award 2015

- Fundamental to protocols such as HTTPS, Secure Shell (SSH), Internet Protocol Security (IPsec), Simple Mail Transfer Protocol Secure (SMTPS), and other protocols that rely on Transport Layer Security (TLS).
- Agree on a shared key
- Provides perfect forward secrecy: exposure of long term keys does not compromise security of past sessions
- Sends information in a way that allows both parties to calculate a shared key without having to ever explicitly communicate the shared key

Diffie-Hellman Key Exchange



Diffie-Hellman Key Exchange

- Generate some public information:
  - A large prime p
  - A generator g (primitive root modulo p)
- Alice picks a random value x and computes $X=g^x \bmod p$
  - Sends X to Bob
- Bob picks a random value y and computes $Y=g^y \bmod p$
  - Send Y to Alice
- Alice calculates the secret $s=Y^x \bmod p = g^{yx} \bmod p$
- Bob calculates the secret $s=X^y \bmod p = g^{xy} \bmod p$
- $g^{yx} \bmod p = g^{xy} \bmod p$

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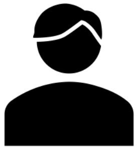
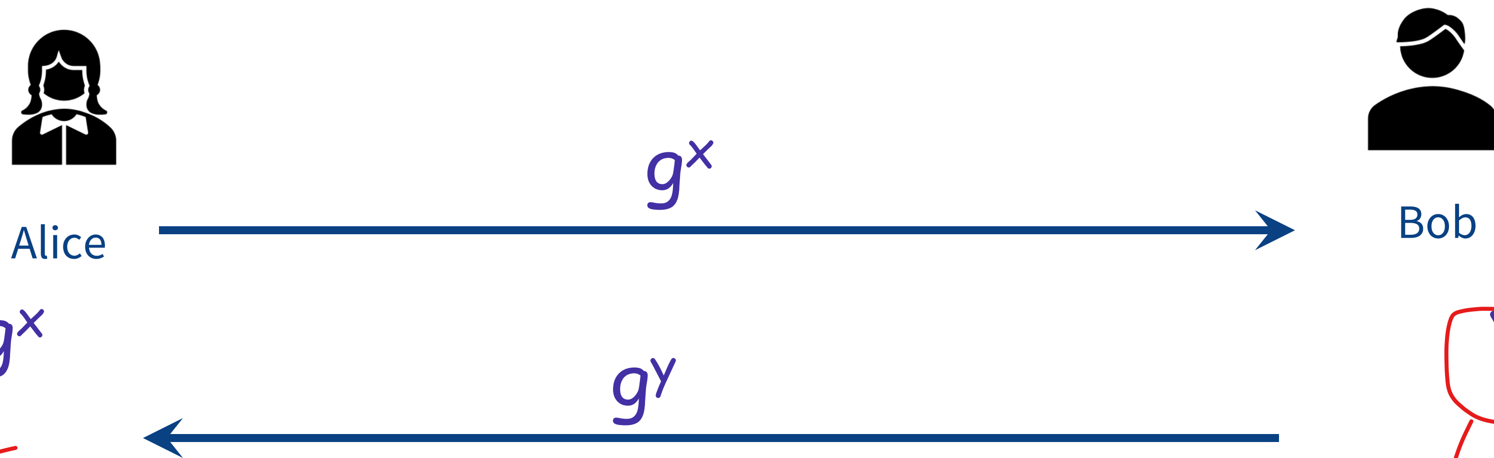
Diffie-Hellman Exchange [DH'76]

Alice



Bob

Diffie-Hellman Exchange [DH'76]



x, g^x

y, g^y

secret key of Alice

secret key of Bob

both parties compute the secret key $s=g^{xy}$

shared secret key.

Diffie-Hellman Key Exchange

- At the end of the process we have a shared secret, the component parts of which we have never openly communicated
- Solving the discrete log (in the particular group we operate) is considered a hard problem
- As such, it is considered infeasible to recover the x from g^x
- Provided the two parties discard their secrets, even if one of them loses their private key, it will not allow past communication to be decrypted

What does it mean secure

- Secret key should look indistinguishable from random
- DH key exchange relies on Decisional DH

Assumptions based on Hard Problems

Problem	Given	Figure out
Discrete logarithm (DL)	g^x	x
Computational Diffie-Hellman (CDH)	g^x, g^y	g^{xy}
Decisional Diffie-Hellman (DDH)	g^x, g^y, g^z	Is $z \equiv xy \pmod{\lvert G \rvert}$?

Figure 10.1: An informal description of three discrete logarithm related problems over a cyclic group G with generator g. For each problem we indicate the input to the attacker, and what the attacker must figure out to "win." The formal definitions are in the text.

https://web.cs.ucdavis.edu/~rogaway/classes/227/spring05/book/main.pdf

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Bonus Question:

- If you can solve DL, can you solve CDH?
- If you can solve CDH, can you solve DDH?

https://web.cs.ucdavis.edu/~rogaway/classes/227/spring05/book/main.pdf

Summary

- Message authentication code
- Authenticated encryption
- Diffie Hellman Key Exchange

Acknowledgement

- The slides were prepared by Olya Ohrimenko based on some material developed previously by Chris Culnane
- Reference: KR 8.3, 8.3.1, 8.3.2 and references from Week 4 Lecture 1
- Some of the images included in the notes were supplied as part of the teaching resources accompanying the text books listed in lecture 1.
  - (And also) Wikimedia Commons