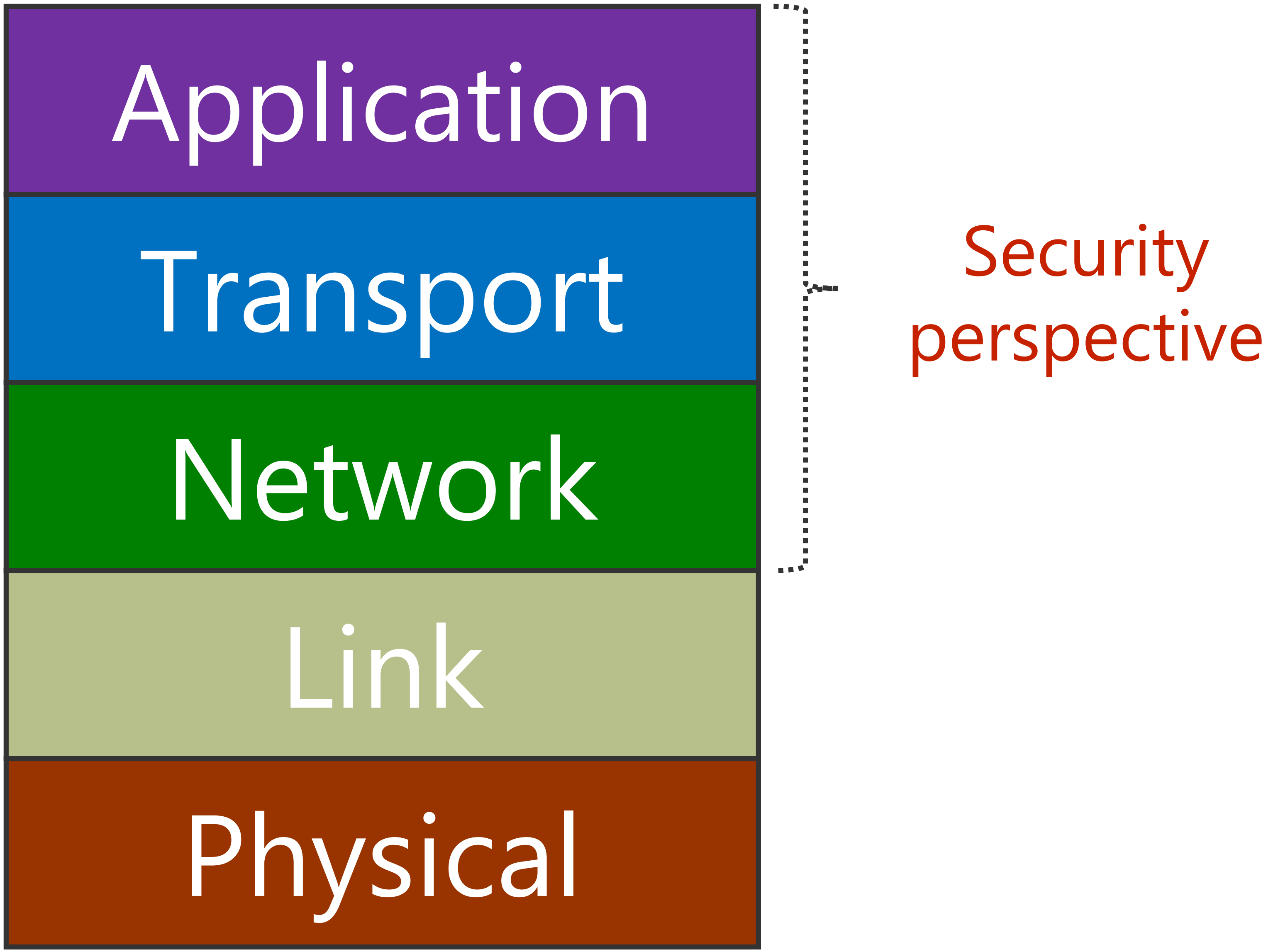
CS2105 Introduction to Computer Network

Lecture 8

Network Security

15 October 2018


Application
Transport
Network
Link
Physical
Security perspective

Lecture 8: Network Security

After this class, you are expected to understand:

- how *symmetric key* cryptography and *public key* cryptography can be used to ensure message confidentiality.
- how *message authentication code* and *digital signature* ensure message integrity and authenticity.

Lecture 8: Roadmap

8.1 What is Network Security?

8.2 Principles of Cryptography

8.3 Message Integrity and Digital Signatures

8.6 Securing TCP Connections: SSL

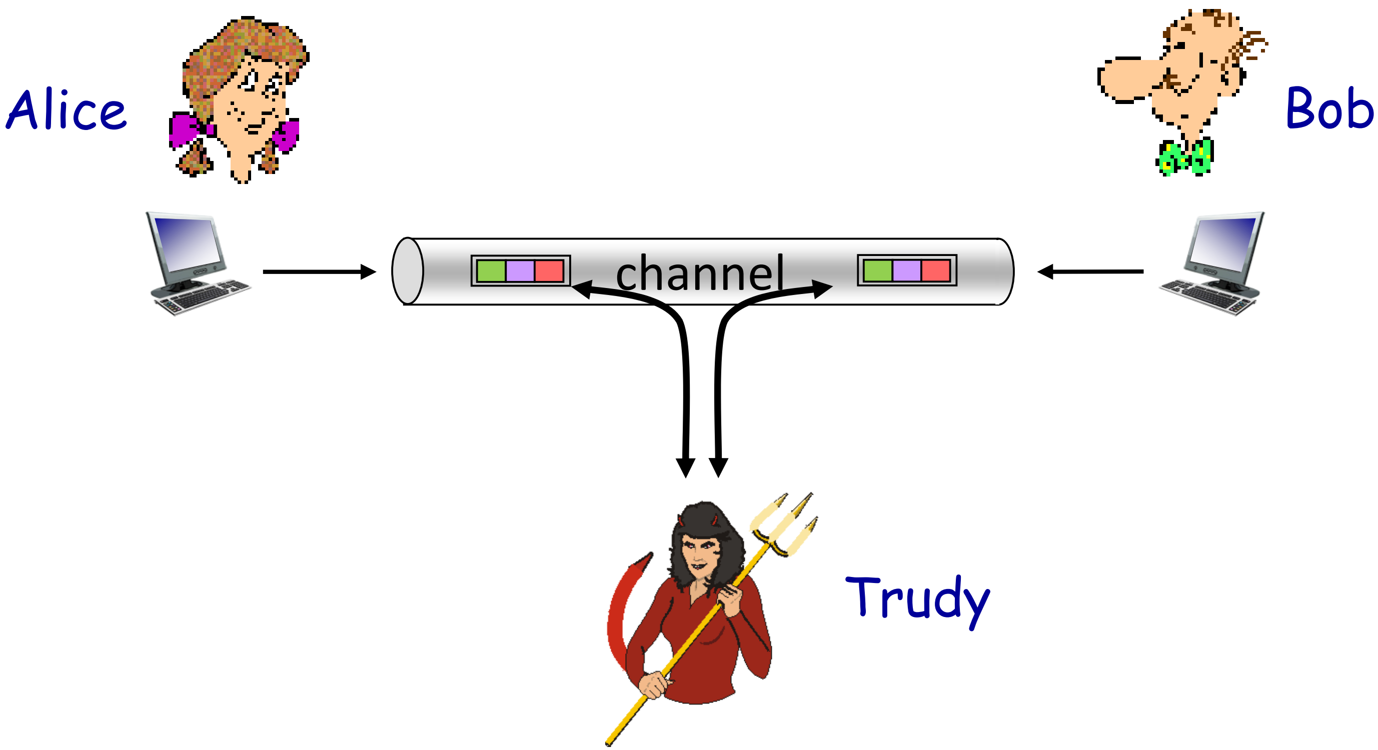
8.7 Network Layer Security: IPsec

Non-examinable

Kurose Textbook, Chapter 8
(Some slides are taken from the book)

Friends and Enemies: Alice, Bob, Trudy

- Alice and Bob (lovers!) want to communicate "secretly".
- Trudy (intruder) wants to interfere.



What Can Bad Guy Trudy Do?

Trudy may:

- intercept messages of Alice and Bob (*eavesdrop*).
  - Need to ensure message confidentiality.
- modify messages between Alice and Bob or forge messages and insert into communication
  - Need to ensure message integrity and message authenticity.
- attack the communication channel between Alice and Bob (e.g. denial-of-service attack).
  - Need to ensure service availability (not covered).

Network Security: Algorithms

- We will not discuss any security algorithms in great details.
- Interested students may read chapter 8 of the textbook or take security courses offered by SoC, e.g.
  - **CS2107** Introduction to Information Security
  - **CS3235** Computer Security
  - **CS4236** Cryptography Theory and Practice
  - **CS5321** Network Security

Lecture 8: Roadmap

8.1 What is Network Security?

8.2 Principles of Cryptography

- 8.2.1 Symmetric Key Cryptography
- 8.2.2 Public Key Encryption

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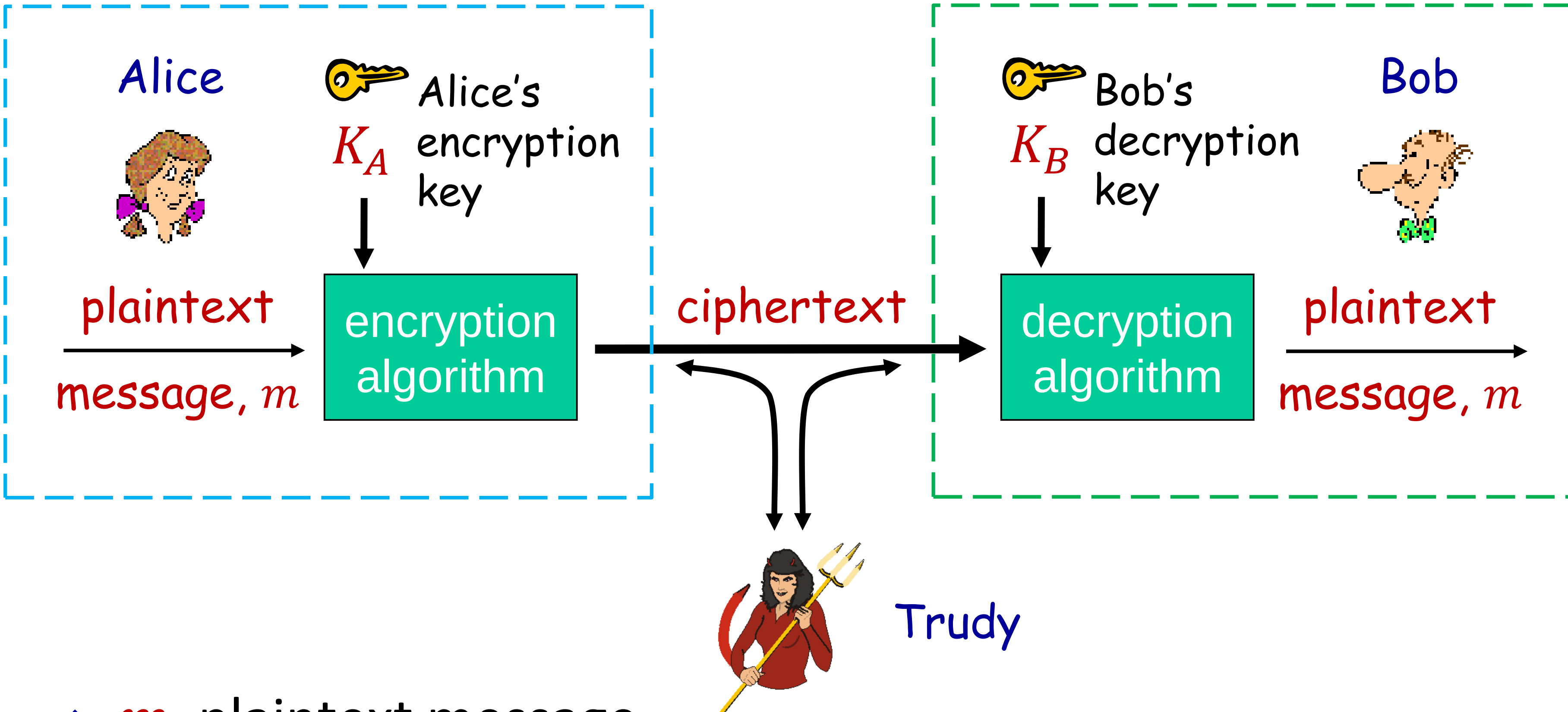
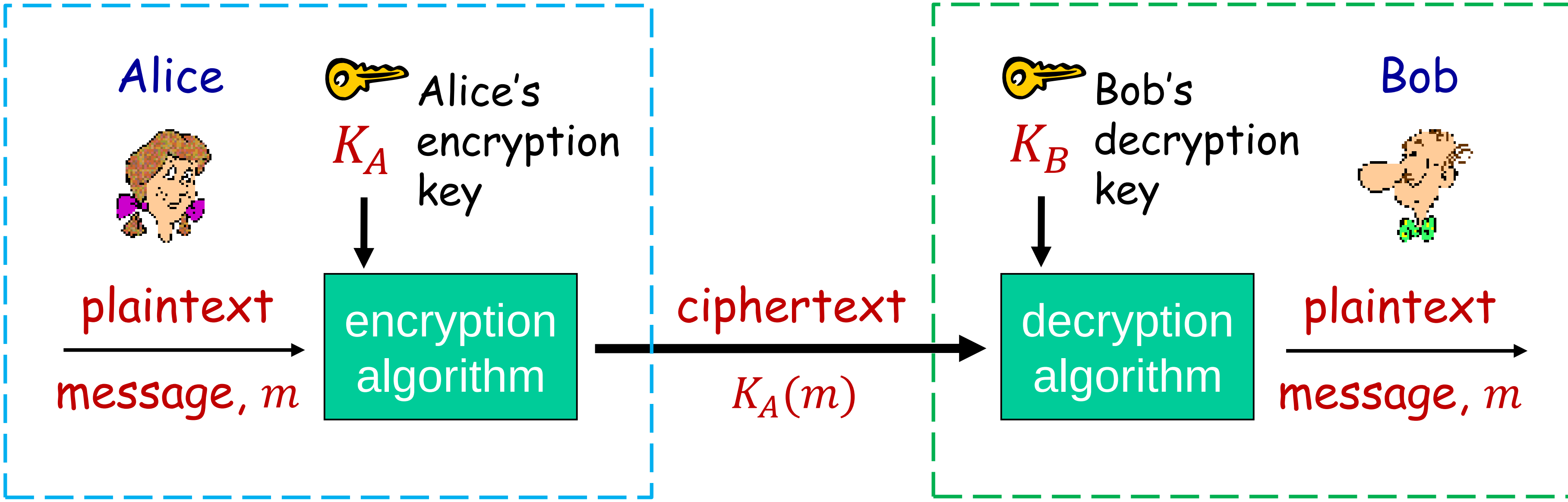
The Language of Cryptography



- m plaintext message
- $K_A(m)$ ciphertext, encrypted with key K_A
- $K_B(K_A(m)) = m$

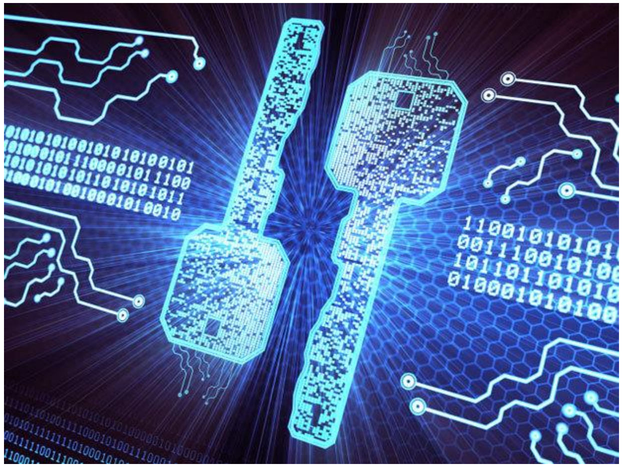
The Language of Cryptography



- Given ciphertext $K_A(m)$, it should be computationally hard to find plaintext m without knowing decryption key K_B.
- We will skip the mathematical details on how to derive K_A and K_B.

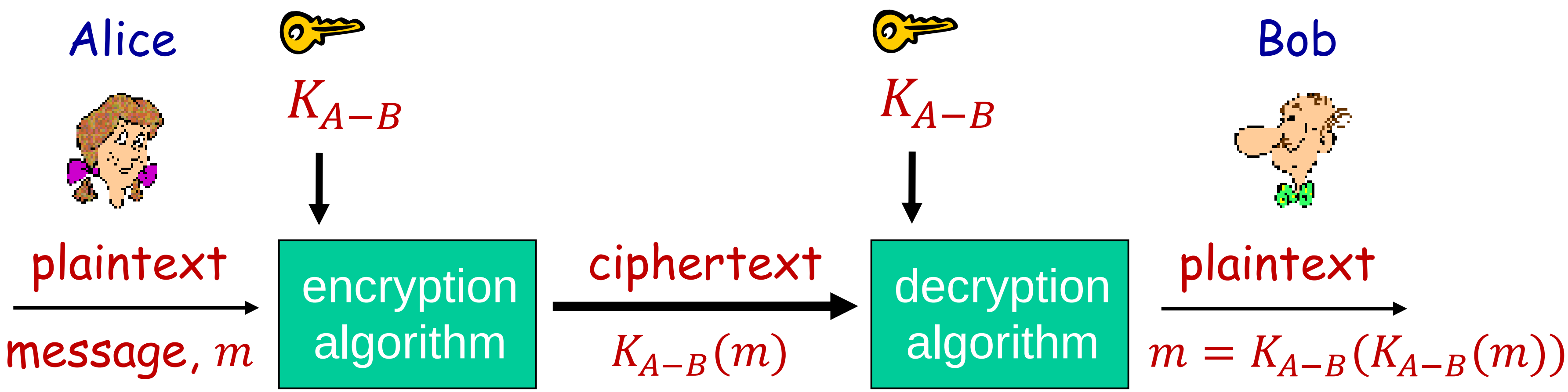
Types of Cryptography

- The purpose of cryptography is to make it difficult for an unauthorized third party to understand private communication between two parties.
- Cryptography often uses keys:
  - Algorithms are known to everyone
  - Only "keys" are secret
- Symmetric key cryptography
  - Involves the use of one key
- Public key cryptography
  - Involves the use of a pair of keys



Source: IEEE Spectrum

Symmetric Key Cryptography



- Symmetric key crypto: Bob and Alice share and use the same (symmetric) key: K_{A-B}
  - Popular algorithms: DES (Data Encryption Standard), AES (Advanced Encryption Standard)

Example Encryption Scheme

- Mono-alphabetic cipher: substituting one letter for another.

plaintext	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
ciphertext	m	n	b	v	c	x	z	a	s	d	f	g	h	j	k	l	p	o	i	u	y	t	r	e	w	q

Alice

Plaintext: bob, i love you. alice

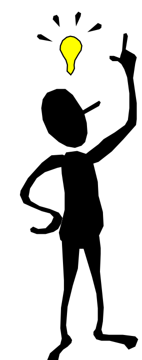
ciphertext: nkn, s gktc wky. mgsbc

Bob

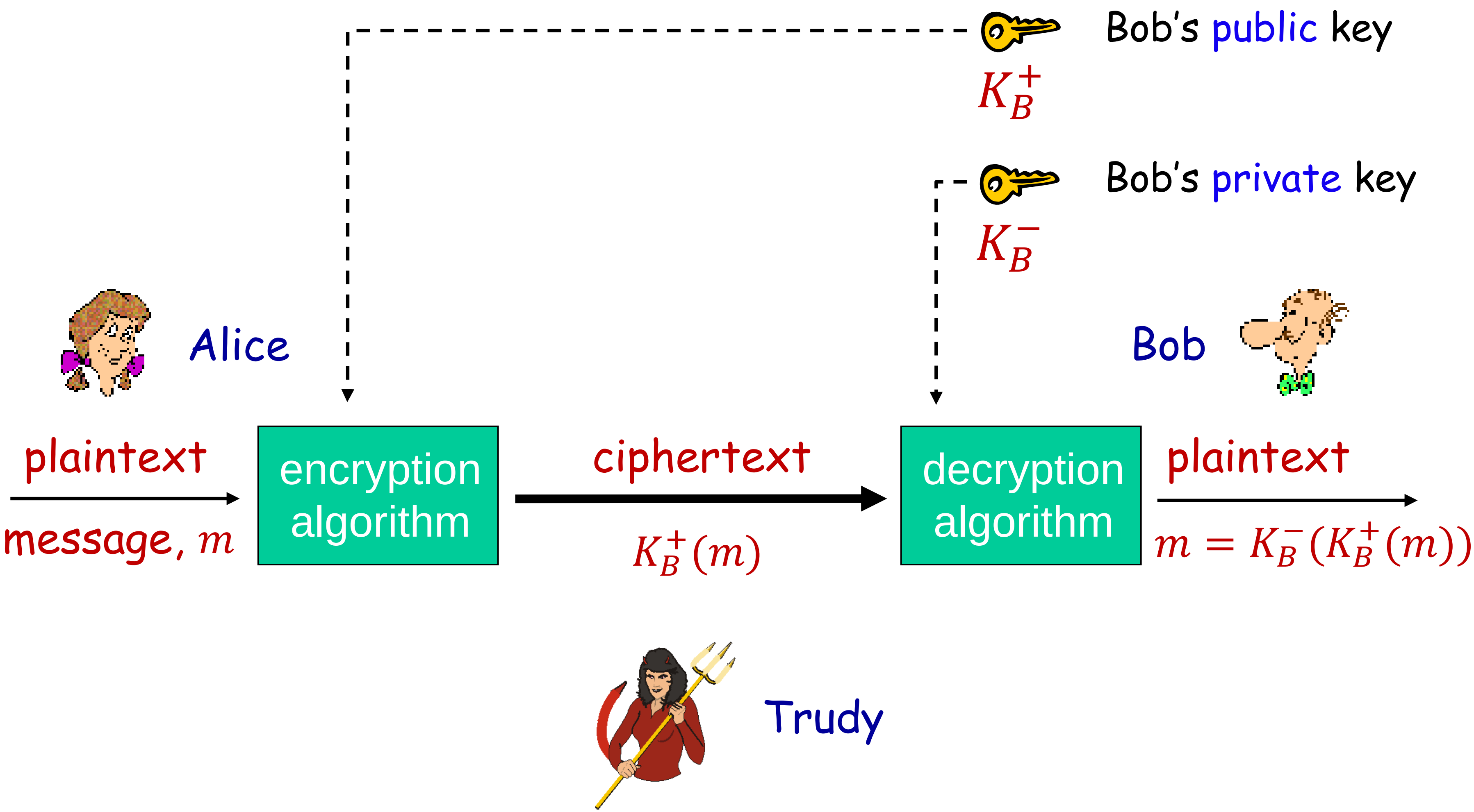
Encryption key: mapping from a set of 26 letters to another set of 26 letters

Public Key Cryptography

- Symmetric key crypto issues:
  - Require sender and receiver to share a secret key.
  - Use the same secret key to encrypt and decrypt data.
  - Question: how to agree on a key in the first place?
- Public key crypto:
  - Sender and receiver do not share secret key.
  - Use a pair of keys. One for encryption and the other for decryption.
  - Public encryption key: known to the world.
  - Private decryption key: known only to receiver.



Public Key Cryptography



Public Key Encryption Algorithms

- Key points of public key encryption:

  1. Need to find a pair of public/private keys such that

  $$K_B^-\left(K_B^+(m)\right) = m$$

  2. Given public key K_B^+, it should be very difficult to find private key K_B^-.

- Most popular algorithm: RSA (Rivest, Shamir, Adelson algorithm)

Public Key: RSA Algorithm

- In RSA
  - The public key is the product of two very large primes.
  - The private key is derived from these two large primes.
- The security of RSA relies on the difficulty of factoring a large composite number.
  - It would be too slow to “guess” the two large primes, given the current state of the art of number theory.
- We will skip the mathematical details.

An Important Property of RSA

- The following property of RSA will be *very* useful for our discussion later:

$$\underbrace{K_B^-(\,K_B^+(m)\,)}_{\text{use public key first, followed by private key}} = m = \underbrace{K_B^+(\,K_B^-(m)\,)}_{\text{use private key first, followed by public key}}$$

Result is the same!

RSA in Practice: Session Key

- RSA (public key encryption) is computationally intensive (but doesn't require key sharing).
- DES (symmetric key encryption) is at least 100 times faster than RSA.
- Question: how to take advantage of both?
  - use public key crypto to establish secure connection, then second key – symmetric key – for encrypting data.

Session key K_S:

- Bob and Alice use RSA to exchange a symmetric key K_S.
- Once both have K_S, they use symmetric key cryptography.
- No need to remember K_S, it's valid for one session only.

Lecture 8: Roadmap

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8.2 Principles of Cryptography

8.3 Message Integrity and Digital Signatures

- 8.3.1 Cryptographic Hash Functions
- 8.3.2 Message Authentication Code
- 8.3.3 Digital Signatures

8.6 Securing TCP Connections: SSL

8.7 Network Layer Security: IPsec

Non-examinable

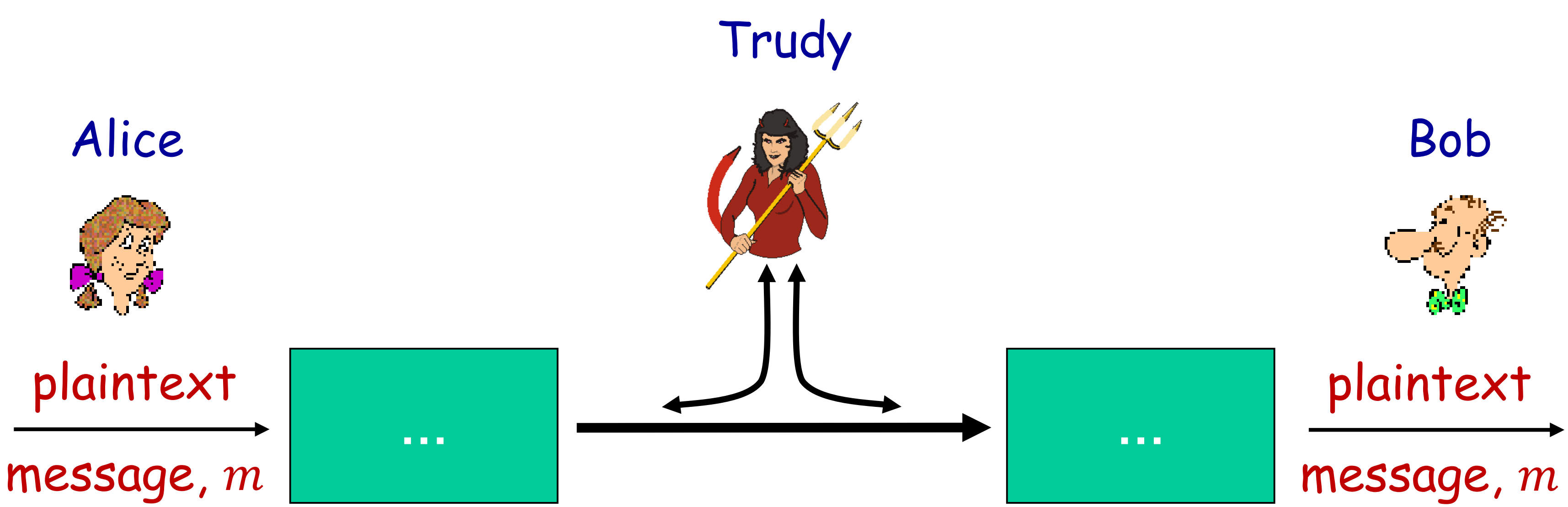
Message Integrity and Authentication

- We have seen how encryption can be used to provide confidentiality to two communicating entities.

- On the other hand, we often need to
  - ensure message has not been modified during transmission.
  - verify the creator of a message.

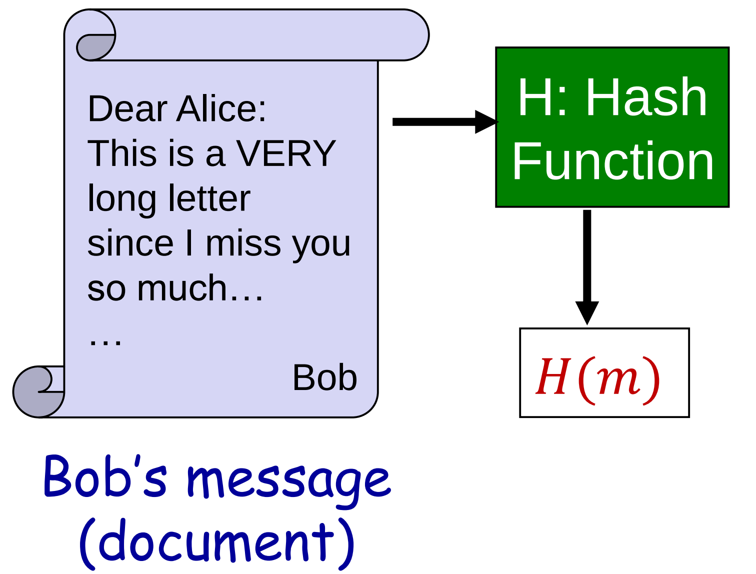
Message Integrity and Authentication

- We are going to study the following two topics:
  1. message authentication code (MAC)
  2. digital signature
- The basics of both is cryptographic hash function.



Cryptographic Hash Functions

- A hash function takes an input, m, and generates a fixed size string $H(m)$ known as message digest (hash or finger print).



- Popular algorithms: MD5 (Message Digest) and SHA-1 (Secure Hash Algorithm)
  - Example usage: both have been widely used to ensure a file downloaded from server has arrived intact.

Cryptographic Hash Functions

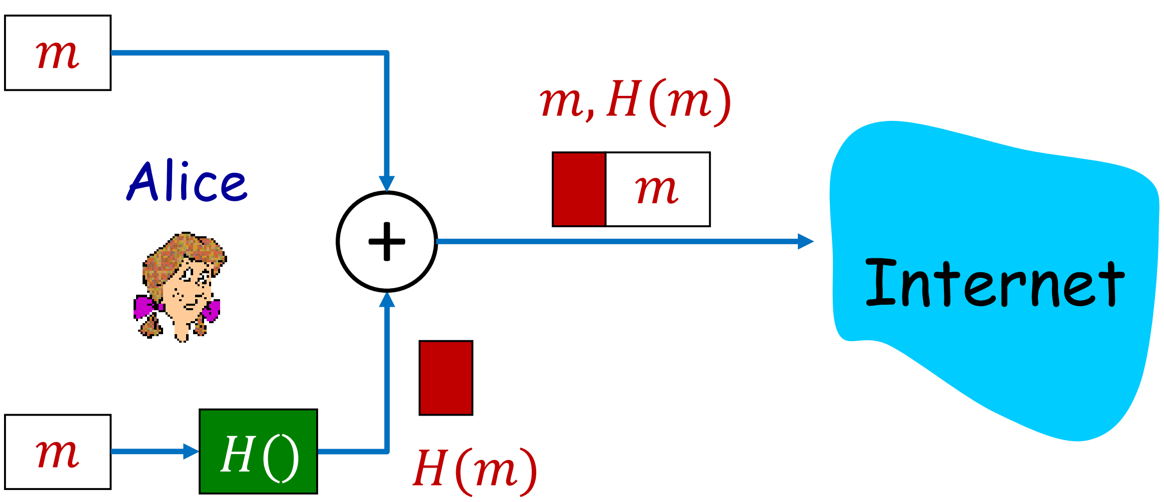
- Cryptographic hash functions are one-way functions:
  - It is computationally infeasible to find two different messages m and m' such that $H(m) = H(m')$.
  - Therefore impossible for Trudy to forge another message m' with the same message digest as m.

- When using cryptographic hash functions,
  - A small change in the message (say, by eavesdropper) will create a significant change in the message digest.

Example Usage (1/3)

For Alice:

1. Alice creates message m and calculates the hash $H(m)$.
2. Alice then appends $H(m)$ to the message m, creating an extended message $(m, H(m))$, and sends the extended message to Bob.



Example Usage (2/3)

For Bob:

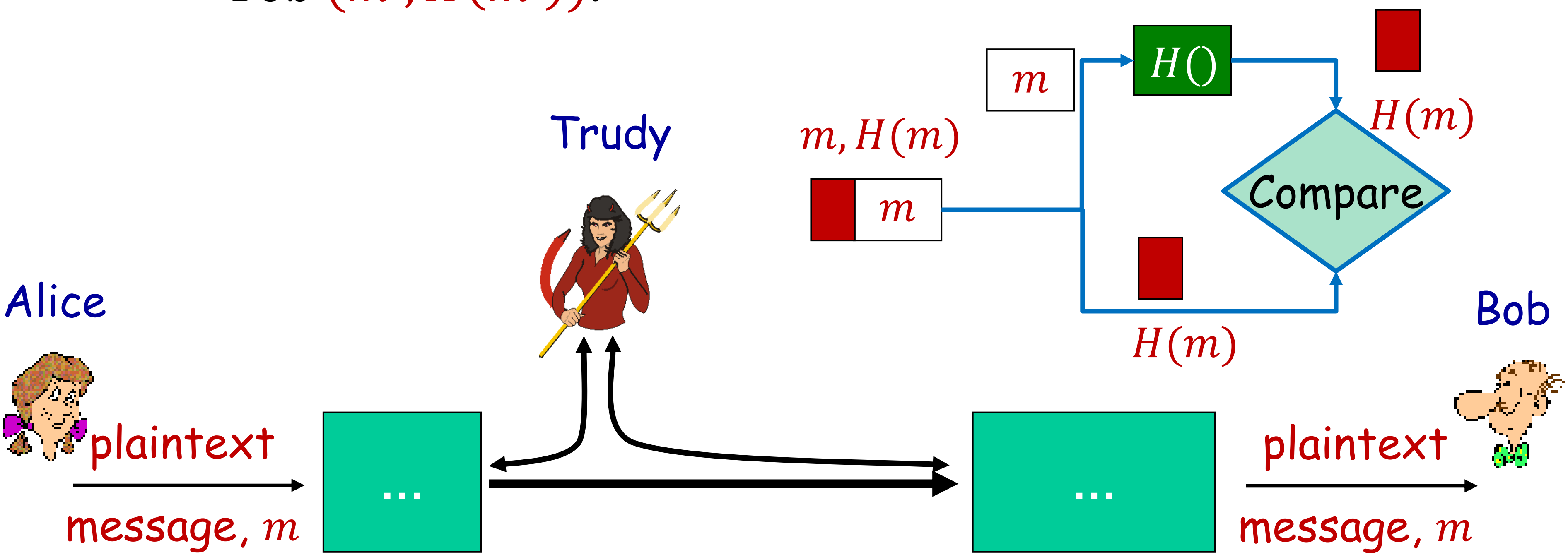
1. Bob receives an extended message (m', h') .
2. Bob calculates $H(m')$. If $H(m') = h'$, Bob conclude
s that everything is fine.

Recap: Lecture 5

❖ TCP/UDP Checksum

Example Usage (3/3)

- Q: Can Bob be sure the source of message is Alice?
  - No. Because Trudy can create a bogus message m' in which she says she is Alice, calculates $H(m')$, and sends Bob $(m', H(m'))$.

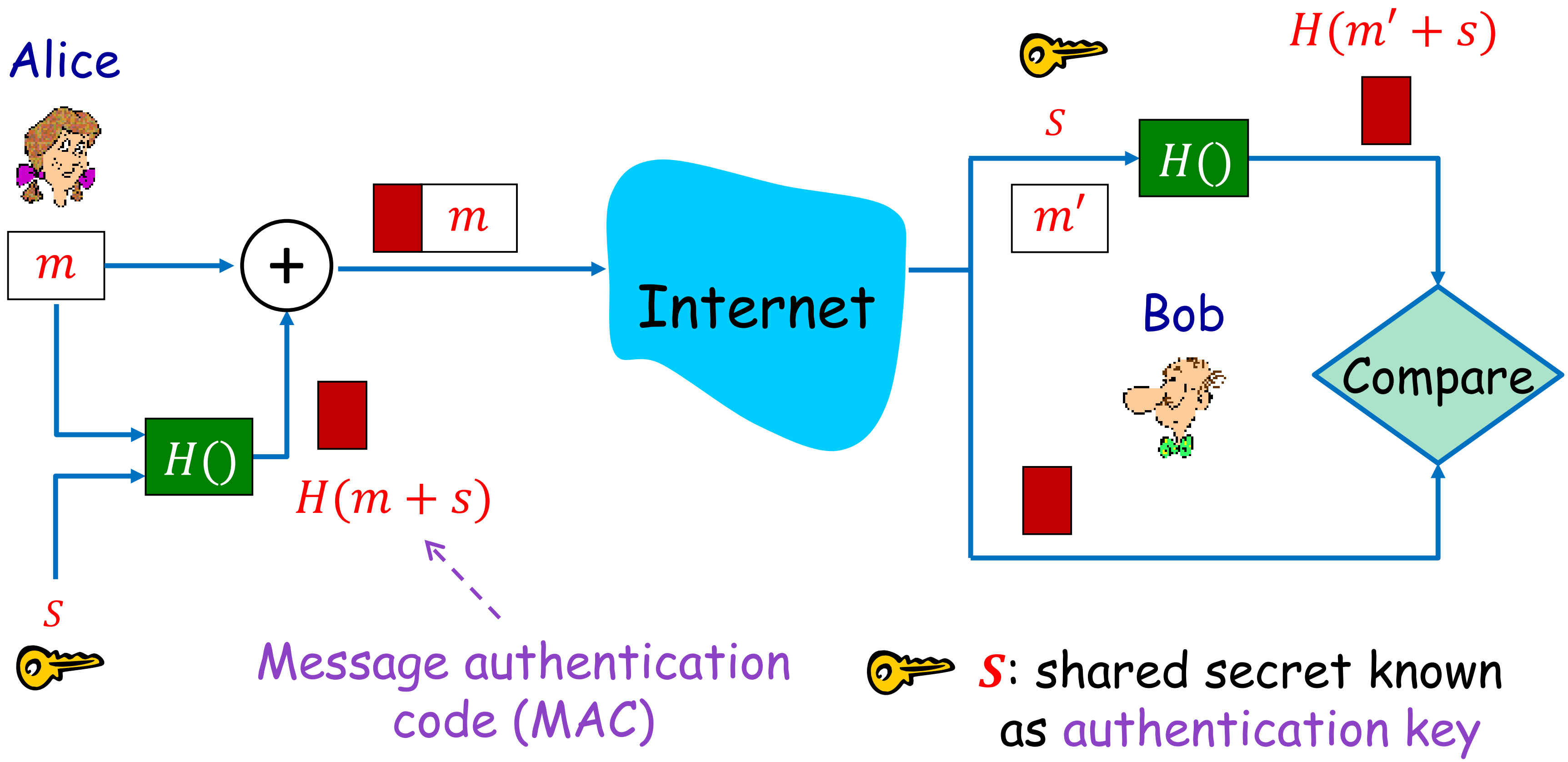


Message Authentication Code

- If a key is used as part of the message digest generation, such an algorithm is said to generate a message authentication code (MAC).
  - Can detect accidental and intentional changes to a message.
  - Can affirm to the receiver, the message's origin.

- Java supports the following standard MAC algorithms:
  - HmacMD5, HmacSHA1, HmacSHA256

Message Authentication Code



- MAC proves to Bob that the creator of the message is Alice and the message is not corrupted.

Digital Signature

Sender (Alice) signs a document digitally (analogous to hand-written signatures).

- *verifiable:* recipient (Bob) can verify that Alice, and no one else, has signed this document.
- *non-repudiation:* If Bob shows this document and digital signature to a third party (e.g. court), the third party is confident that this document is indeed signed by Alice (but no one else including Bob).

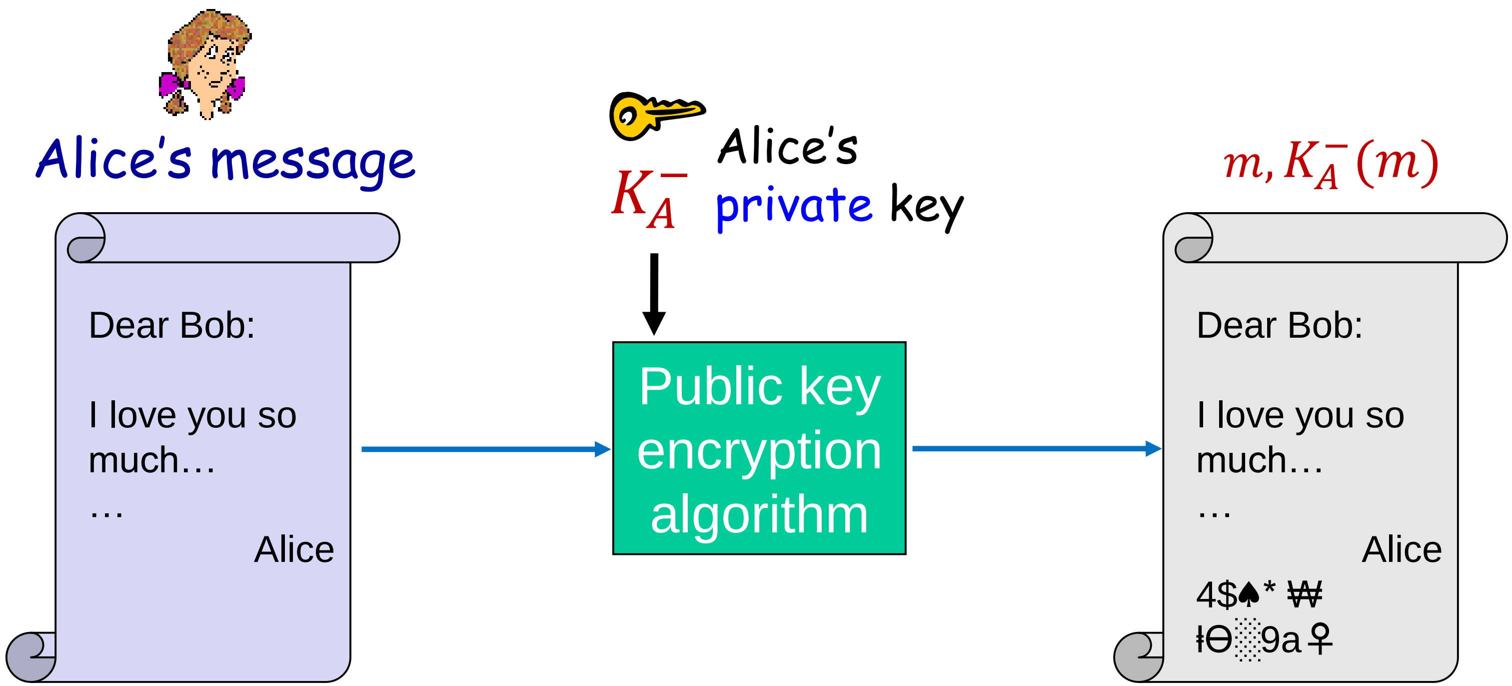
Digital Signature vs. MAC

- Message authentication code (MAC) uses an authentication key shared between sender (Alice) and receiver (Bob).
  - Either Alice or Bob can produce the same MAC on a document, using the shared key.
  - Cannot prove to a third party MAC is produced by Alice or Bob.

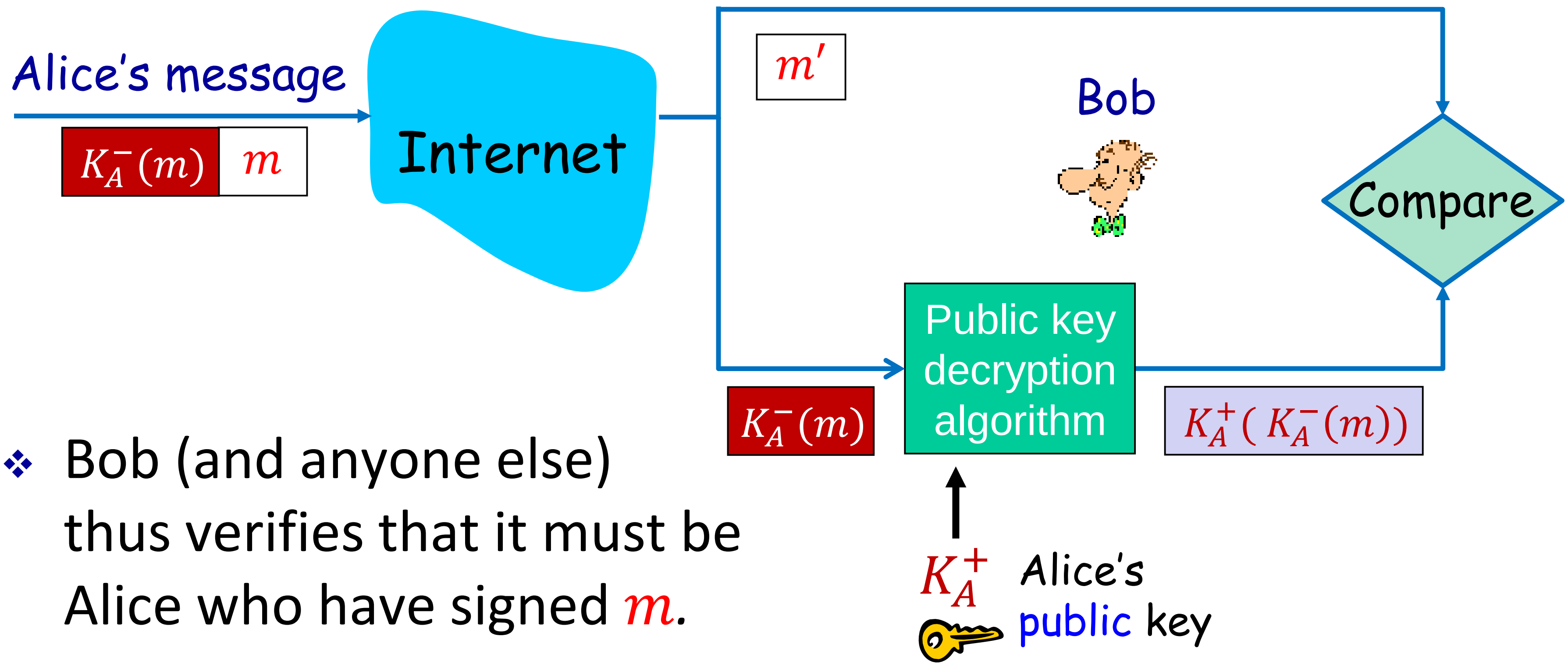
- When Alice signs document digitally, she must put something on the doc that is unique to her.
  - her private key 

Digital Signature Example (1/2)

- Alice signs m by encrypting it with her private key K_A^-, creating a "signed" message, $K_A^-(m)$.
  - Send both m and $K_A^-(m)$ to Bob.

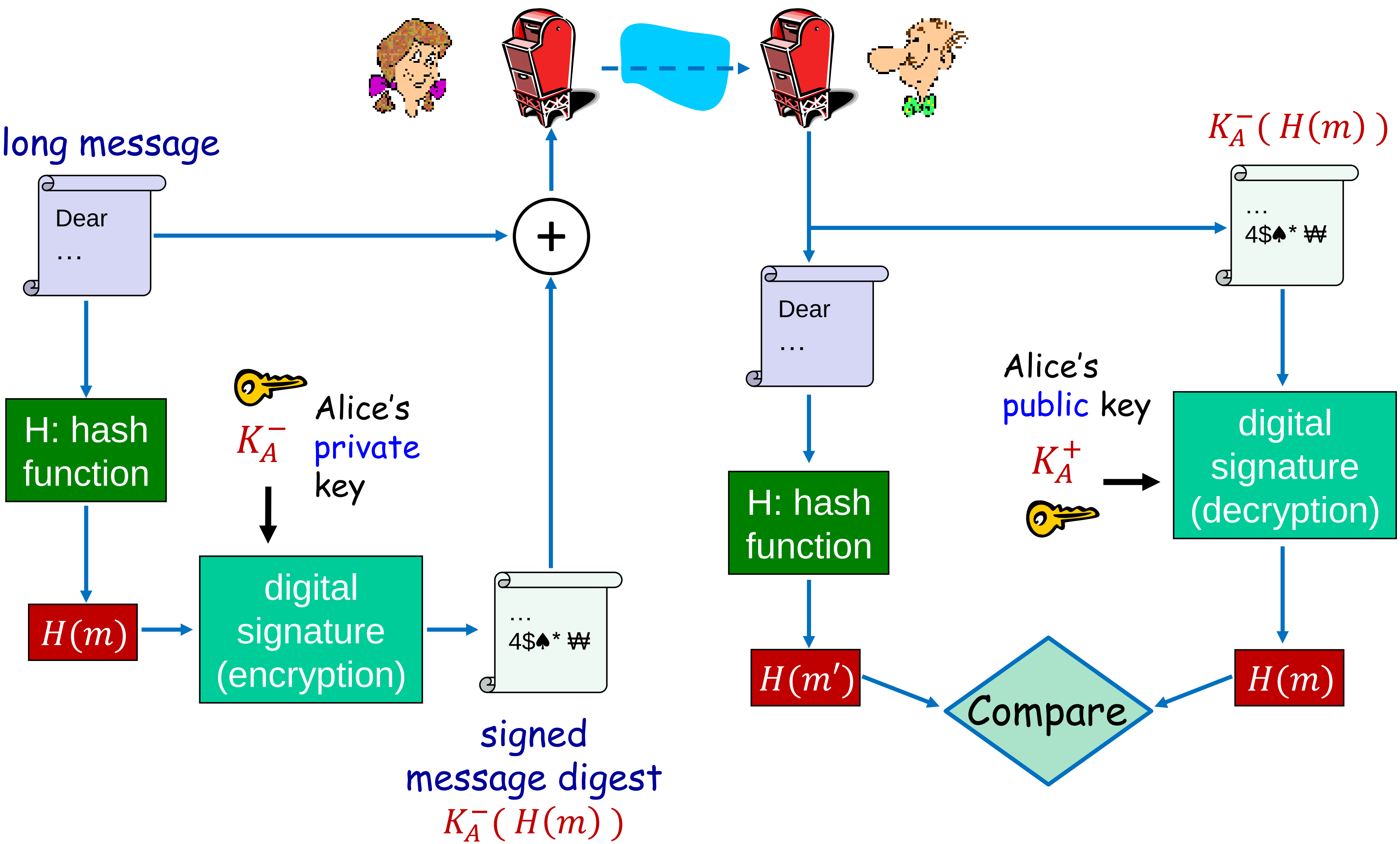


Digital Signature Example (2/2)



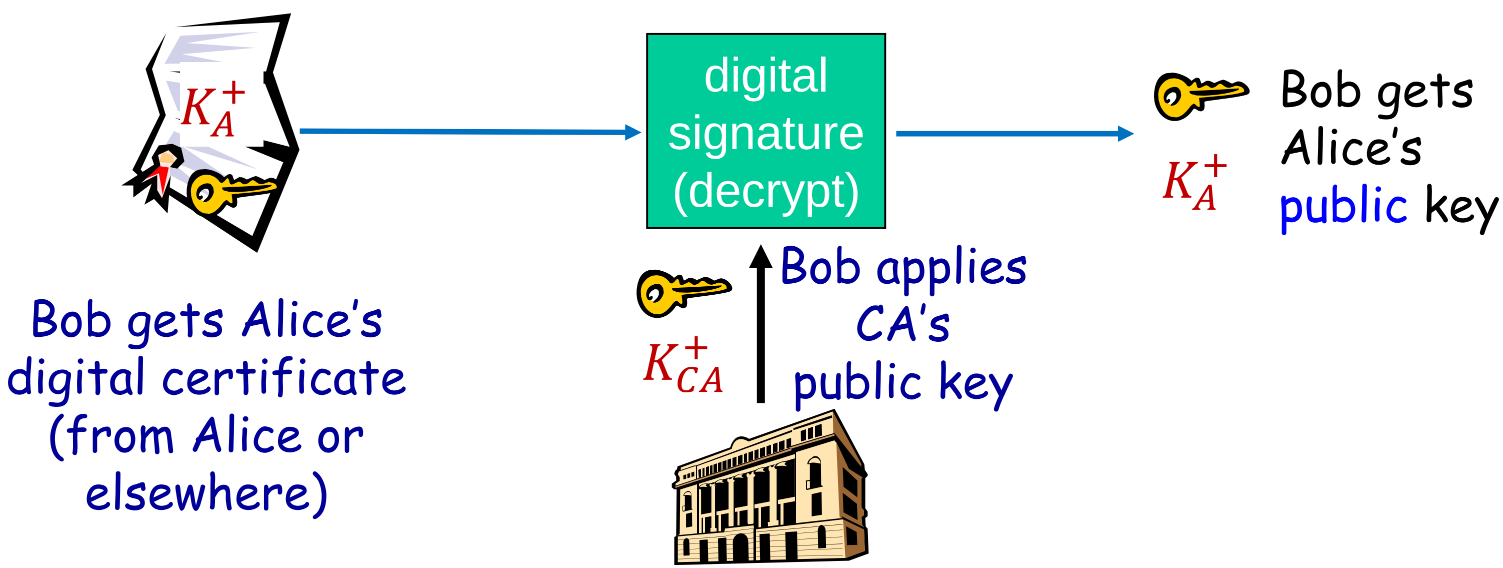
- Bob (and anyone else) thus verifies that it must be Alice who have signed m.
- Just one minor point:
  - Public key encryption is very slow.
  - Efficiency is a concern if m is long.

Digital Signature = Signed Message Digest



Digital Certificate

- Bob may wonder if the public key he uses is indeed Alice's.
- Certificate authority (CA) is an entity that issues digital certificates.
  - A digital certificate certifies the ownership of a public key by the named subject of the certificate.



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Non-examinable

SSL: Secure Sockets Layer

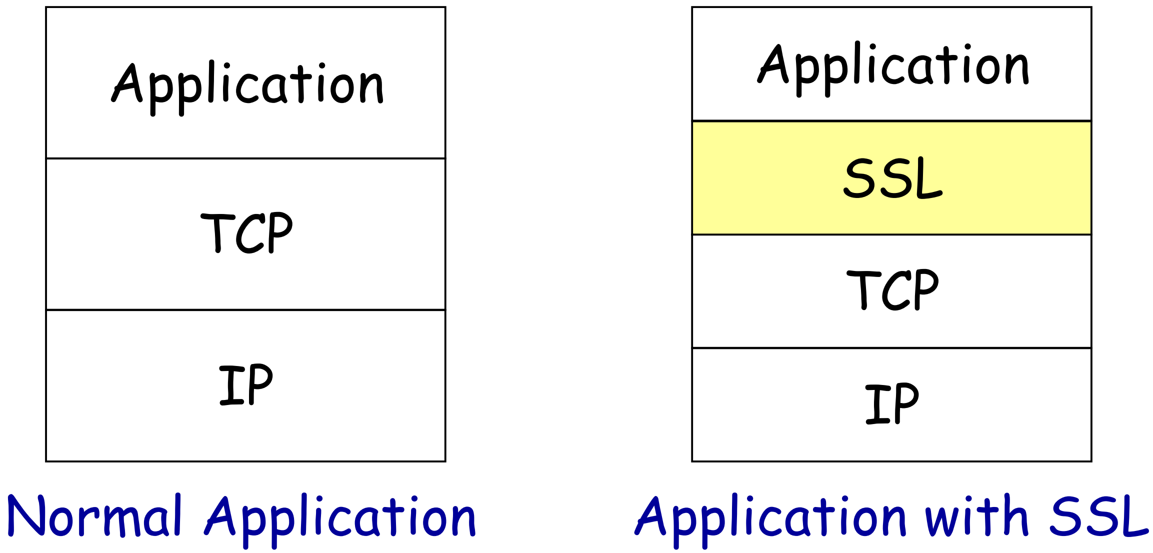
SSL is a widely deployed security protocol.

- Applicable to TCP applications
- A variation is TLS (Transport Layer Security) defined in RFC 2246.
- Supported by almost all modern browsers and web servers.
- For example, https = http + SSL/TLS
  - adding security capabilities of SSL/TLS to standard HTTP communications.

Common SSL symmetric ciphers
- DES – Data Encryption Standard: block
- 3DES – Triple strength: block
- RC2 – Rivest Cipher 2: block
- RC4 – Rivest Cipher 4: stream

SSL public key encryption
- RSA

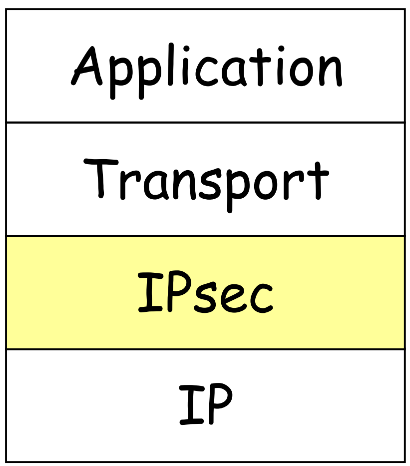
SSL: Secure Sockets Layer

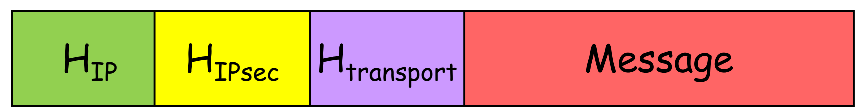


- SSL provides application programming interface (API) to applications.
  - Java SSL libraries/classes readily available.

Internet Protocol Security (IPsec)

- IPsec is a suite of protocols that secure communications by authenticating and encrypting each IP packet of a communication session.





Packet structure w/ IPsec

- Both SSL and IPsec can be used to build VPN.
  - SoC and NUS WebVPN run over SSL.

Lecture 8: Summary

basic techniques ….

- data confidentiality (symmetric and public keys)
- message digest
- message authentication code
- digital signature

…. used in many different security scenarios

- https
- secure transport (SSL)
- IPsec
- 802.11 WEP