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2023 Fall Semester

Information Network Systems

Security, cryptography

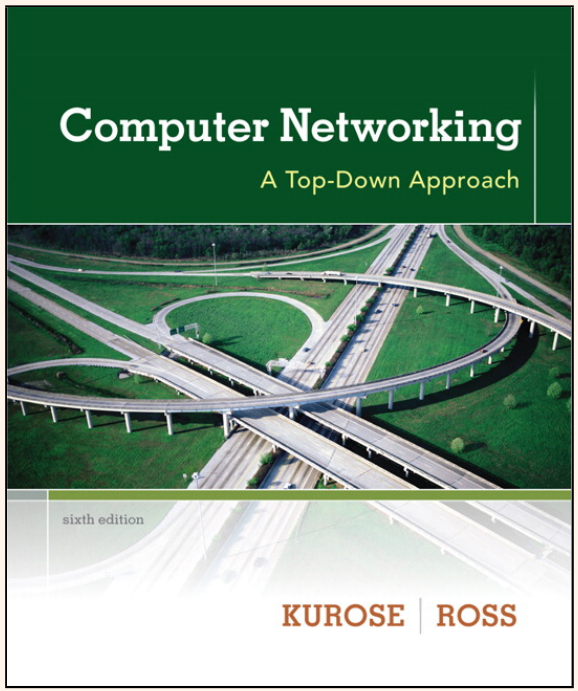
Last lecture

We've seen how to monitor traffic

- Tcpdump/Wireshark
  - Record/monitor traffic
  - Get a comprehensive view of network traffic
  - Detect anomalies

Today's Lecture: Security Cryptography

1. What is Network Security?
2. Symmetric Key Cryptography
3. Public Key Cryptography
4. Message Integrity
5. End-Point Authentication



- Chapter 8

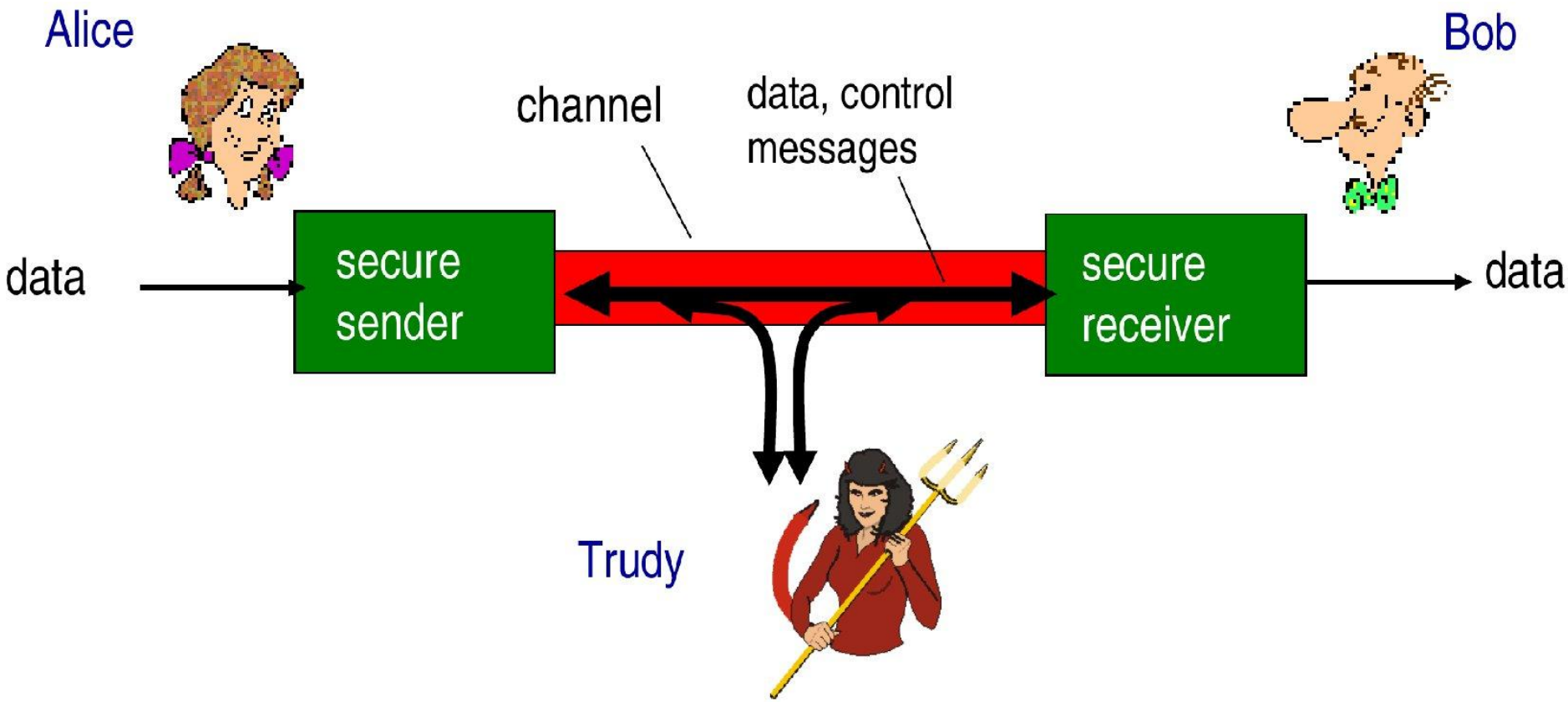
What is Network Security?

- Confidentiality: only sender, intended receiver should "understand" message contents
  - sender encrypts message
  - receiver decrypts message
- Authentication: sender, receiver want to confirm identity of each other
- Message integrity: sender, receiver want to ensure message not altered (in transit, or afterwards) without detection
- Access and availability: services must be accessible and available to users

Friends and enemies: Alice, Bob, Trudy

Example

- Well-known in network security world
- Bob, Alice (lovers!) want to communicate "securely"
- Trudy (intruder) may intercept, delete, add messages



Who might Bob and Alice be?

- ... well, real-life Bobs and Alices!
- Web browser/server for electronic transactions (e.g., on-line purchases)
- On-line banking client/server
- DNS servers
- Routers exchanging routing table updates
- Other examples?

There are bad guys (and girls) out there!

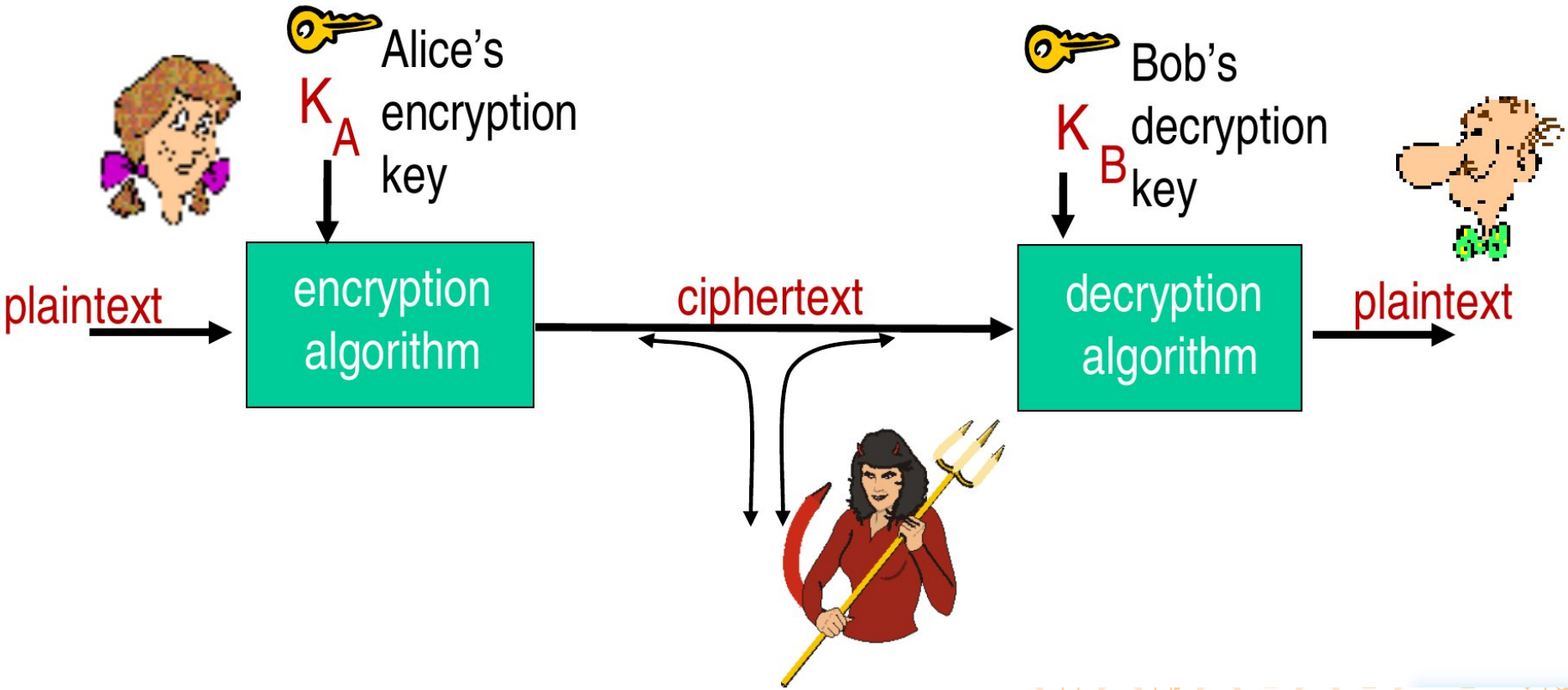
What can a "bad guy" do?

- Eavesdrop: intercept messages
- Actively modify/insert/delete messages into connection
- Impersonation: can fake (spoof) source address in packet (or any field in packet)
- Hijacking: "take over" ongoing connection by removing sender or receiver, inserting himself in place
- Denial of service (DoS): prevent service from being used by others (e.g., by overloading resources)

Principles of Cryptography

Example of encryption:

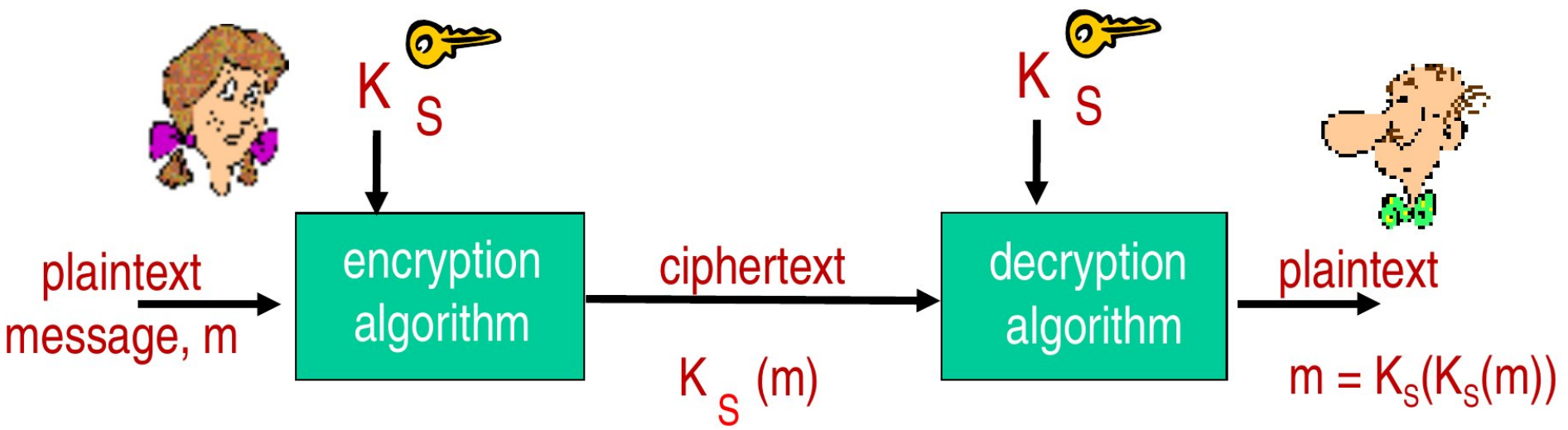
- m plaintext message
- $K_A(m)$ ciphertext, encrypted with key K_A
- $m = K_B(K_A(m))$



Symmetric key cryptography

Bob and Alice share same (symmetric) key: K

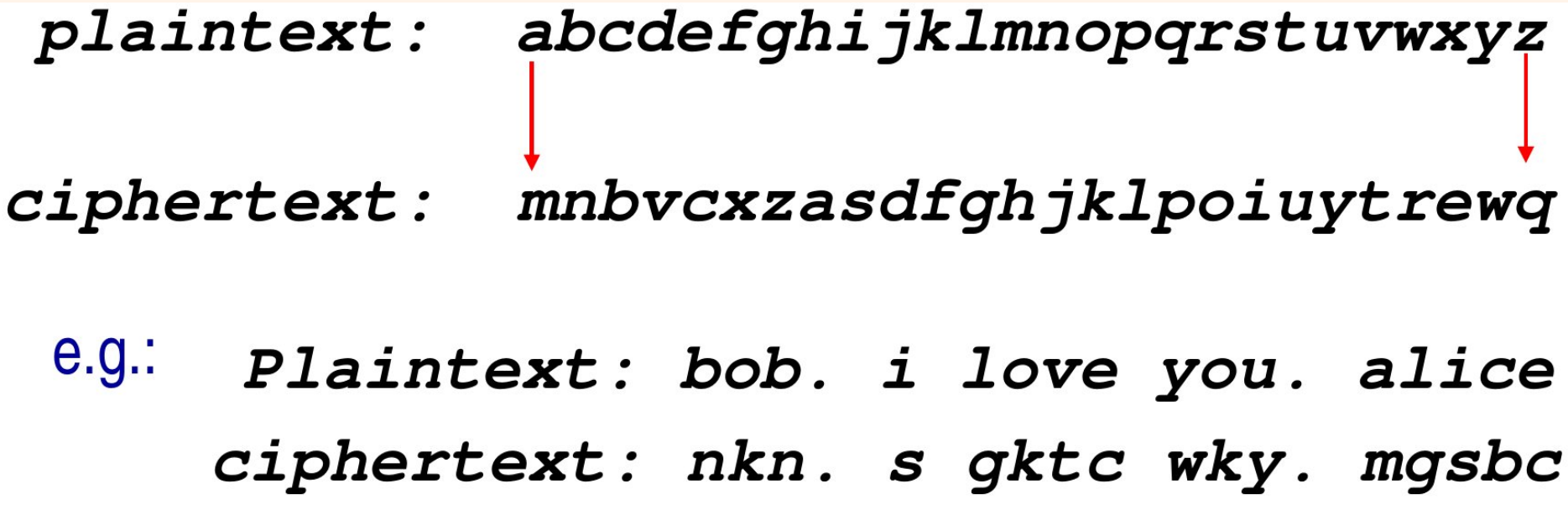
- e.g., key is knowing substitution pattern in mono alphabetic substitution cipher
- How do Bob and Alice agree on key value?



Simple encryption scheme

Substitution Cipher

- Substituting one thing for another
- Monoalphabetic cipher: substitute one letter for another



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

Breaking an Encryption Scheme

- Cipher-text only attack: Trudy has ciphertext she can analyze
  two approaches:
  - Brute force: search through all keys
  - Statistical analysis
- known-plaintext attack: Trudy has plaintext corresponding to ciphertext
  e.g., in monoalphabetic cipher, Trudy determines pairings for a,l,i,c,e,b,o,
- chosen-plaintext attack: Trudy can get ciphertext for chosen plaintext

Symmetric key crypto on Internet

DES: Data Encryption Standard

- Uses function instead of predetermined tables
- 56-bit symmetric key, 64-bit plaintext input
- 3DES: more secure, encrypt 3 times with 3 different keys

AES: Advanced Encryption Standard

- replaced DES (Nov 2001)
- processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for AES

Public Key Cryptography

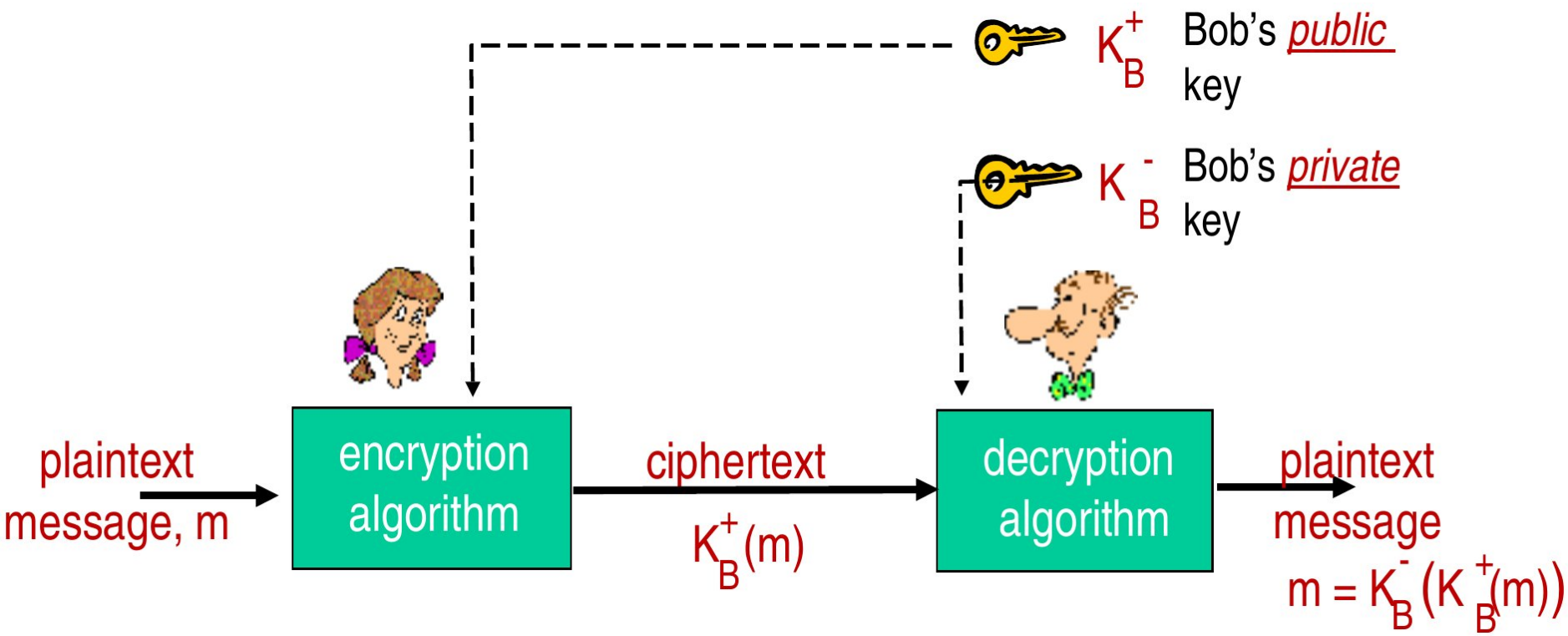
Symmetric key crypto

- requires sender, receiver know shared secret key
- Q: how to agree on key in first place (particularly if never "met")?

Public key crypto

- radically different approach
- sender, receiver do not share secret key
- public encryption key known to all
- private decryption key known only to receiver

Public Key cryptography



Public key encryption algorithms

Requirements:

1. Need K_B^+ and K_B^- such that $K_B^+(K_B^-(m)) = m$
2. Given public key K_B^+, it should be impossible to compute private key K_B^-

$\rightarrow$A good example: RSA (Rivest, Shamir, Adelson) algorithm

RSA: Getting Ready

- Message: just a bit pattern
- bit pattern can be uniquely represented by an integer number
- thus, encrypting a message is equivalent to encrypting a number.
- example:
  m= 10010001 . This message is uniquely represented by the decimal number 145.
- to encrypt m, we encrypt the corresponding number, which gives a new number (the ciphertext).

RSA: Creating public/private key pair

1. Choose two large prime numbers p, q. (e.g., 1024 bits each)
2. Compute $n = pq$ and $z = (p-1)(q-1)$
3. Choose e (with $e < n$) that has no common factors with z (e, z are "relatively prime").
4. Choose d such that $ed - 1$ is exactly divisible by z. (in other words: $ed \mod z = 1$).
5. Public key, K_B^+, is (n,e). Private key, K_B^-, is (n,d).

RSA: encryption, decryption

- Given (n,e) and (n,d) as computed above
- To encrypt message $m(< n)$, compute
  - $c = m^e \mod n$
- To decrypt received bit pattern, c, compute
  - $m = c^d \mod n$

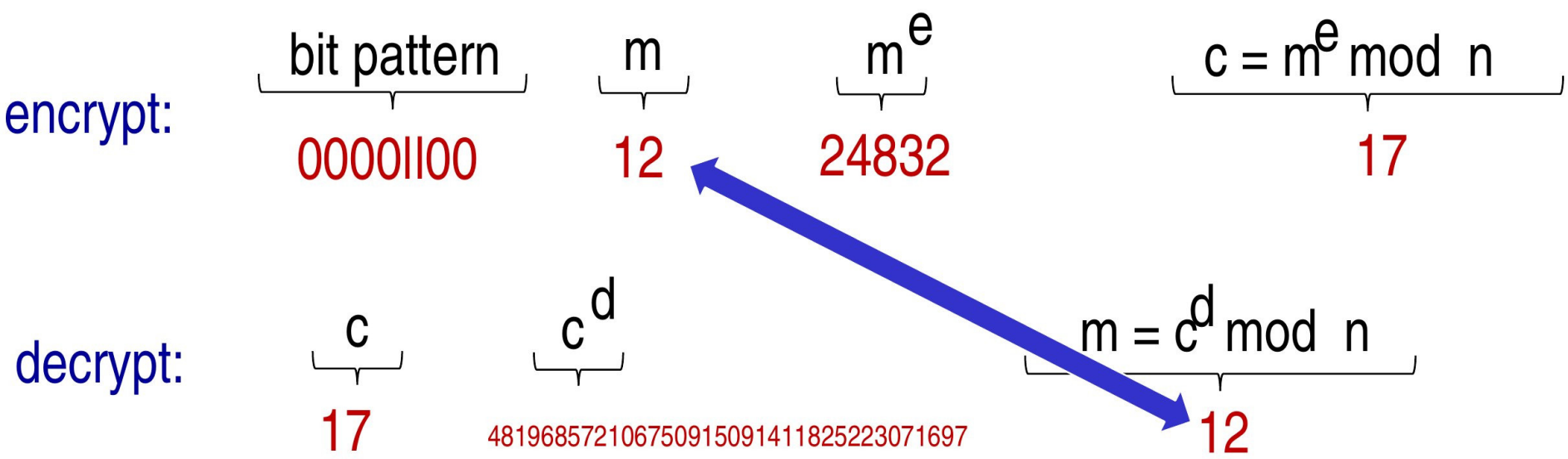
Magic happens!

$m = (m^e \mod n)^d \mod n$

RSA example

Encrypting 8-bit messages

- Bob chooses $p = 5$, $q = 7$. Then $n = 35$, $z = 24$
- $e = 5$ (so e, z relatively prime)
- $d = 29$ (so $ed - 1$ exactly divisible by z)



Why does RSA work? Prerequisite

$x \mod n$ = remainder of x when divide by n

- Facts:
  - $((a \mod n) + (b \mod n)) \mod n = (a + b) \mod n$
  - $((a \mod n) - (b \mod n)) \mod n = (a - b) \mod n$
  - $((a \mod n) * (b \mod n)) \mod n = (a * b) \mod n$
- thus $(a \mod n)^d \mod n = a^d \mod n$
- example, $a = 14, n = 10, d = 2$:
  - $(a \mod n)^d \mod n = 4^2 \mod 10 = 6$
  - $a^d = 14^2 = 196$ thus $a^d mod 10 = 6$

Why does RSA work?

Must show that $c^d \mod n = m$ where $c = m^e \mod n$

- Fact: for any x and y: $x^y \mod n = x^{(y \mod z)} \mod n$ where $n = pq$ and $z = (p-1)(q-1)$
- Thus,

$$\begin{aligned} c^d \mod n &= (m^e \mod n)^d \mod n \\ &= m^{ed} \mod n \\ &= m^{(ed \mod z)} \mod n \\ &= m^1 \mod n \\ &= m \end{aligned}$$

RSA: another important property

The following property will be very useful later:

$$K_B^+(K_B^-(m)) = m = K_B^-(K_B^+(m))$$

- Use public key first, followed by private key
- or, user private key first, followed by public key
- give the same result!

RSA: another important property

Why $K_B^+(K_B^-(m)) = m = K_B^-(K_B^+(m))$?

Follows directly from modular arithmetic:

$$\begin{aligned}(m^e \mod n)^d \mod n &= m^{ed} \mod n \\ &= m^{de} \mod n \\ &= (m^d \mod n)^e \mod n\end{aligned}$$

RSA in practice: session keys

Exponentiation in RSA is computationally intensive

- DES is at least 100 times faster than RSA
- Use public key cryto to establish secure connection, then establish second key = symmetric session key - for encrypting data
- Example, 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

Message Integrity

Allows communicating parties to verify that received messages are authentic.

- Content of message has not been altered
- Source of message is who/what you think it is
- Message has not been artificially delayed (playback attack)
- Sequence of messages is maintained

$\rightarrow$ Let's first talk about message digests

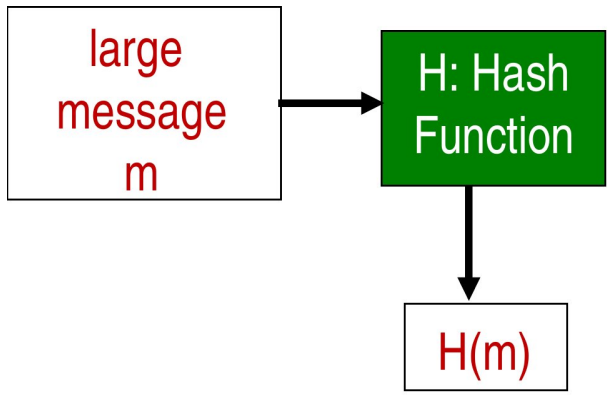
Message Digests

Hash function H()

- Function H() that takes as input an arbitrary length message and outputs a fixed-length string: "message signature"
- Note that H() is a many-to-1 function

Desirable properties:

- Easy to calculate
- Irreversibility: Can't determine m from H(m)
- Collision resistance: Computationally difficult to produce m and m' such that H(m) = H(m')
- Seemingly random output



Internet checksum: poor message digest

Internet checksum has some properties of hash function:

- produces fixed length digest (16-bit sum) of input
- is many-to-one

But...

- given message with given hash value, it is easy to find another message with same hash value.
- Example: Simplified checksum: add 4-byte chunks at a time:

message	ASCII format
I O U 1	49 4F 55 31
0 0 . 9	30 30 2E 39
9 B O B	39 42 D2 42
	B2 C1 D2 AC

different messages but identical checksums!

message	ASCII format
I O U 9	49 4F 55 39
0 0 . 1	30 30 2E 31
9 B O B	39 42 D2 42
	B2 C1 D2 AC

Hash Function Algorithms

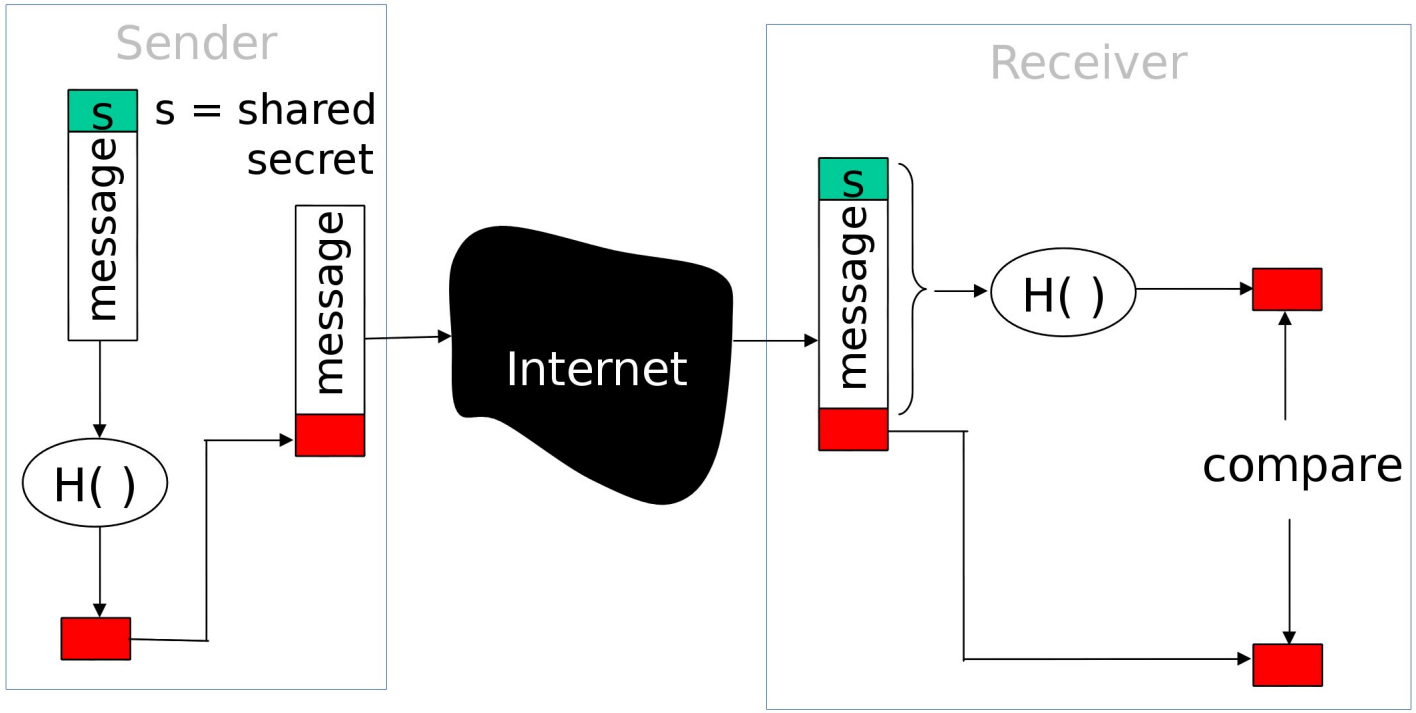
MD5 hash function widely used (RFC 1321)

- Computes 128-bit message digest in 4-step process.

SHA-1 is also used

- US standard
- 160-bit message digest

Message Authentication Code (MAC)



- Authenticates sender
- Verifies message integrity
- No encryption !
- Malicious guys cannot guess shared secret
- Also called “keyed hash”

HMAC: keyed-Hash Message Authentication Code

HMAC: Popular MAC standard

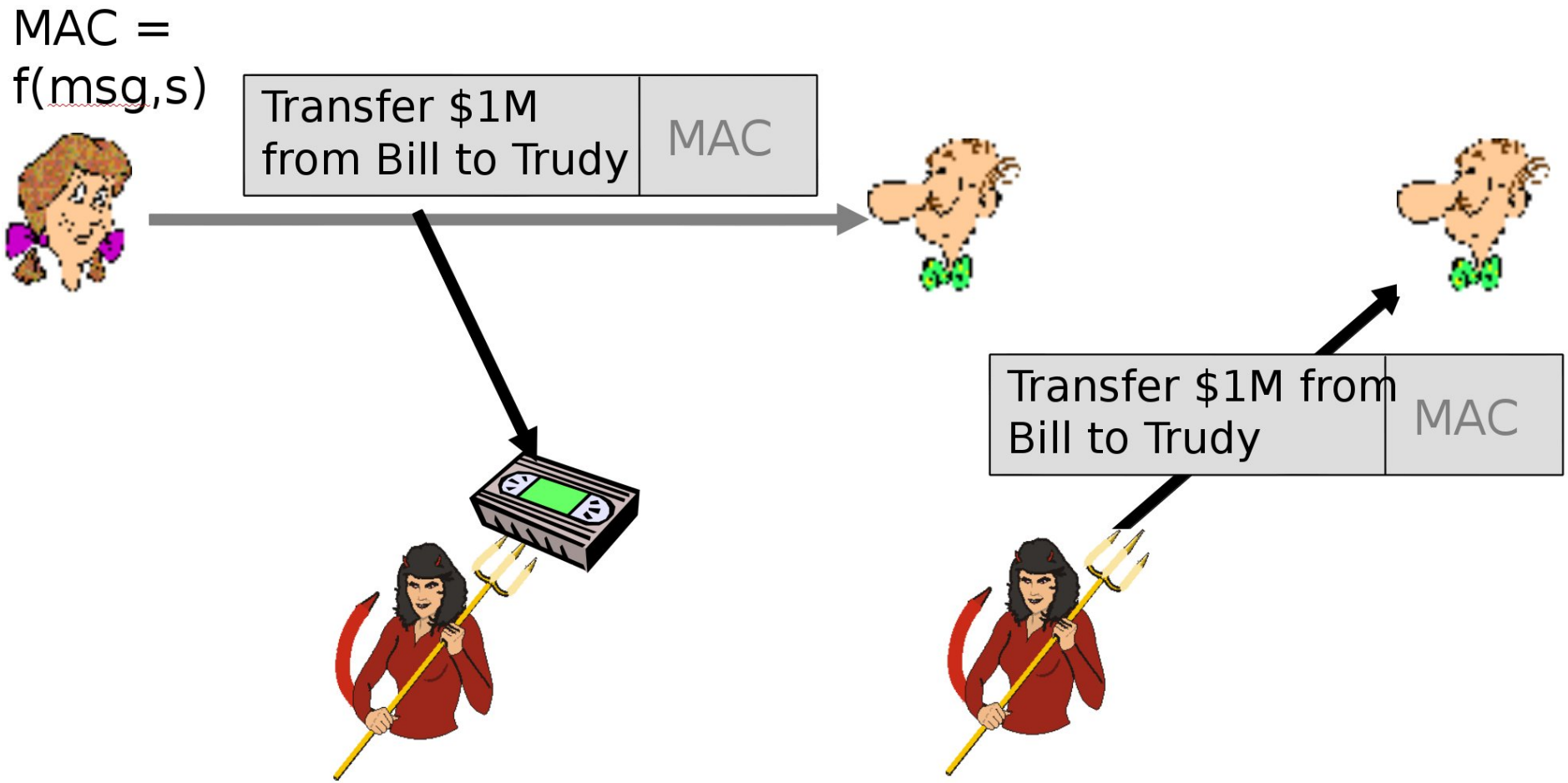
- Addresses some subtle security flaws
  1. Concatenates secret to front of message
  2. Hashes concatenated message
  3. Concatenates the secret to front of digest
  4. Hashes the combination again

End-point authentication

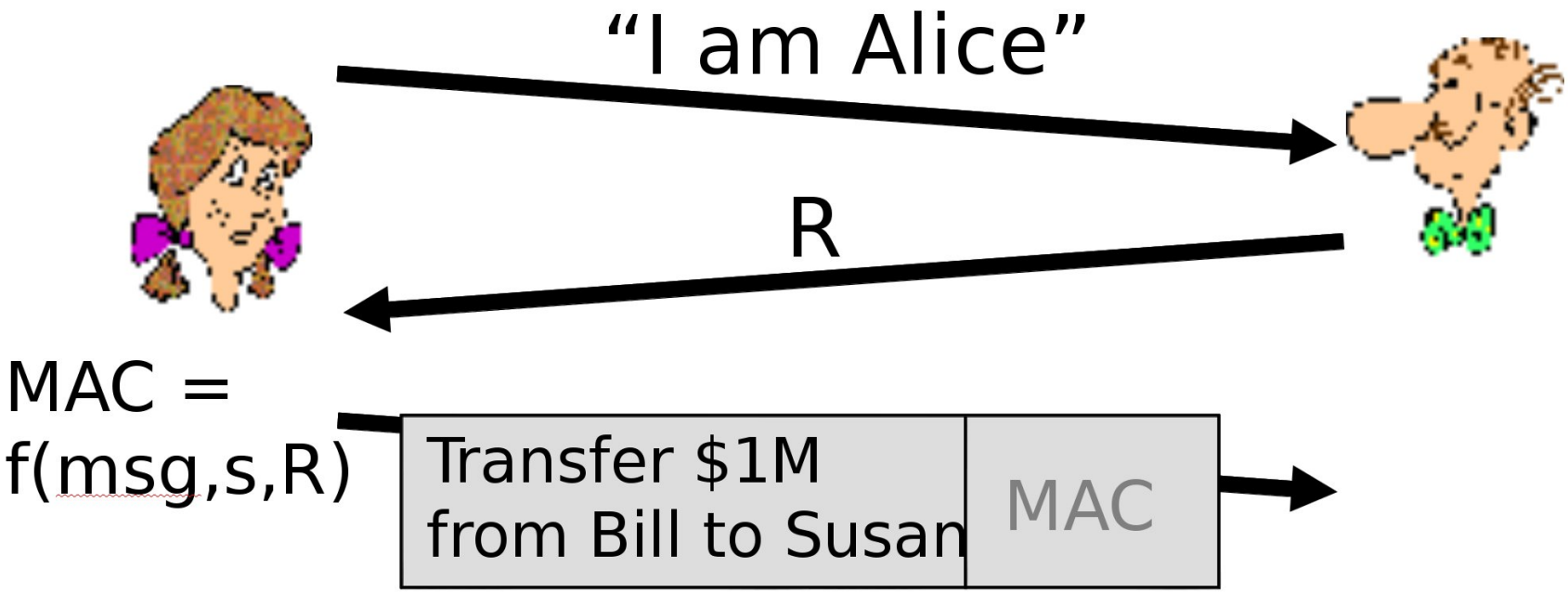
Is message authentication enough?

- Want to be sure of the originator of the message
- Assuming Alice and Bob have a shared secret, will MAC provide message authentication.
  - We do know that Alice created the message.
  - But did she send it?

Playback attack



Defending against playback attack: nonce



Nonce: R

- Number used only once in a lifetime
- Ensure that Alice is alive

Digital Signatures

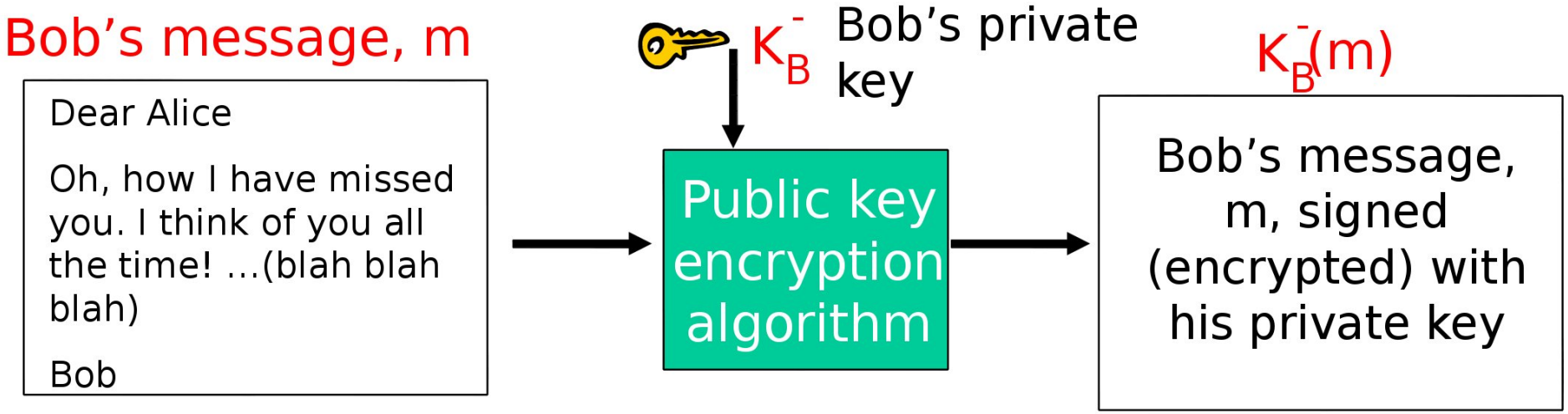
Cryptographic technique analogous to hand-written signatures.

- sender (Bob) digitally signs document, establishing he is document owner/creator.
- Goal is similar to that of a MAC, except now use public-key cryptography
- No need for the 2 peers to have a shared secret
- verifiable, nonforgeable: recipient (Alice) can prove to someone that Bob, and no one else (including Alice), must have signed document

Digital Signatures

Simple digital signature for message m:

- Bob signs m by encrypting with his private key K_B^-, creating "signed" message, $K_B^-(m)$



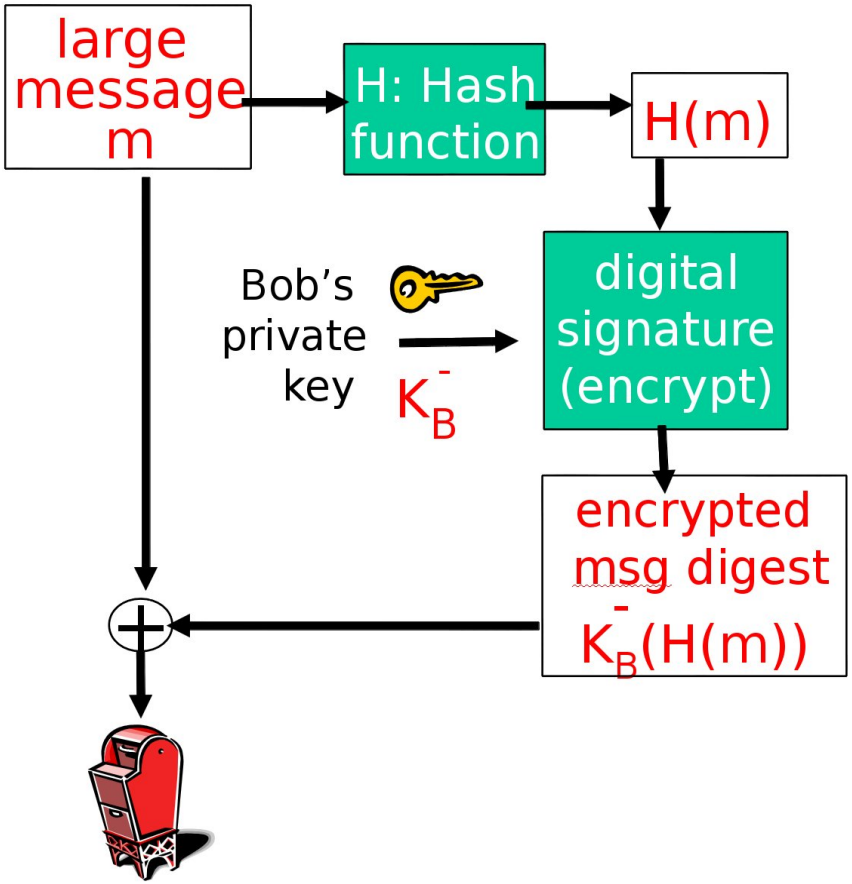
But..

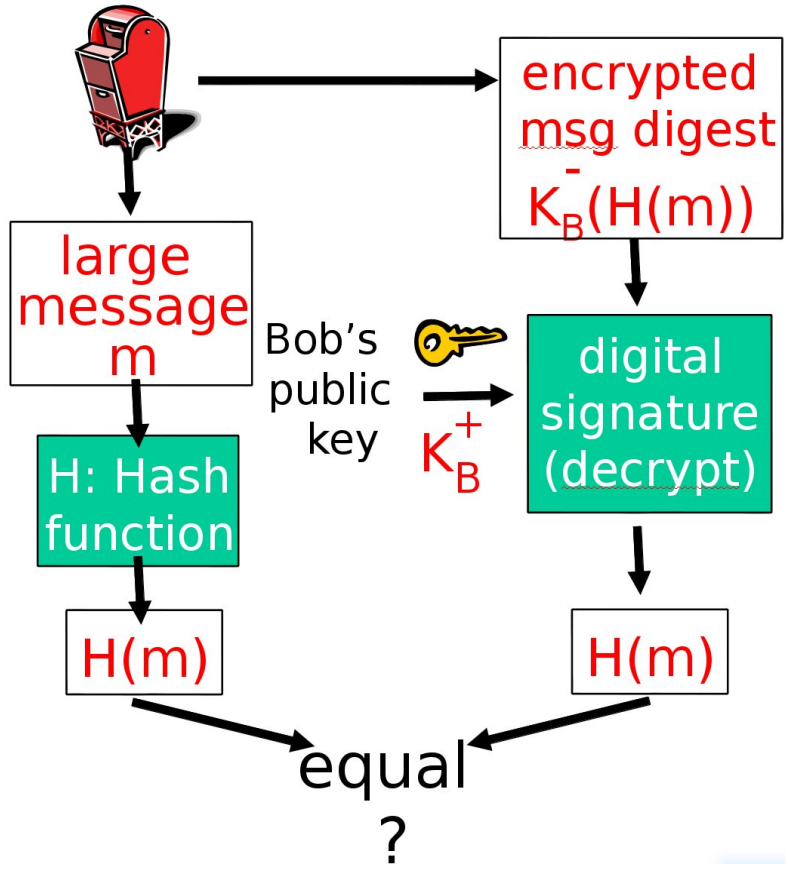
- this is computationally expensive for long messages
- more efficient approach with hash functions

Digital signature = signed message digest

- Bob sends message and the corresponding digital signature

- Alice verifies signature and integrity of digitally signed message





Digital signature

Suppose Alice receives msg m, digital signature $K_B^-(H(m))$

- Alice verifies m signed by Bob by applying Bob's public key K_B^+ to $K_B^-(H(m))$ then checks $K_B^+(K_B^-(H(m))) = H(m)$
- If $K_B^+(K_B^-(H(m))) = H(m)$, whoever signed m must have used Bob's private key

Alice thus verifies that:

- Bob signed m
- No one else signed m
- Bob signed m and not m'

Notes

- Bob is the only one to keep a secret (no secret shared key)
- Note: This time the private key is used to encrypt

Public-key certification

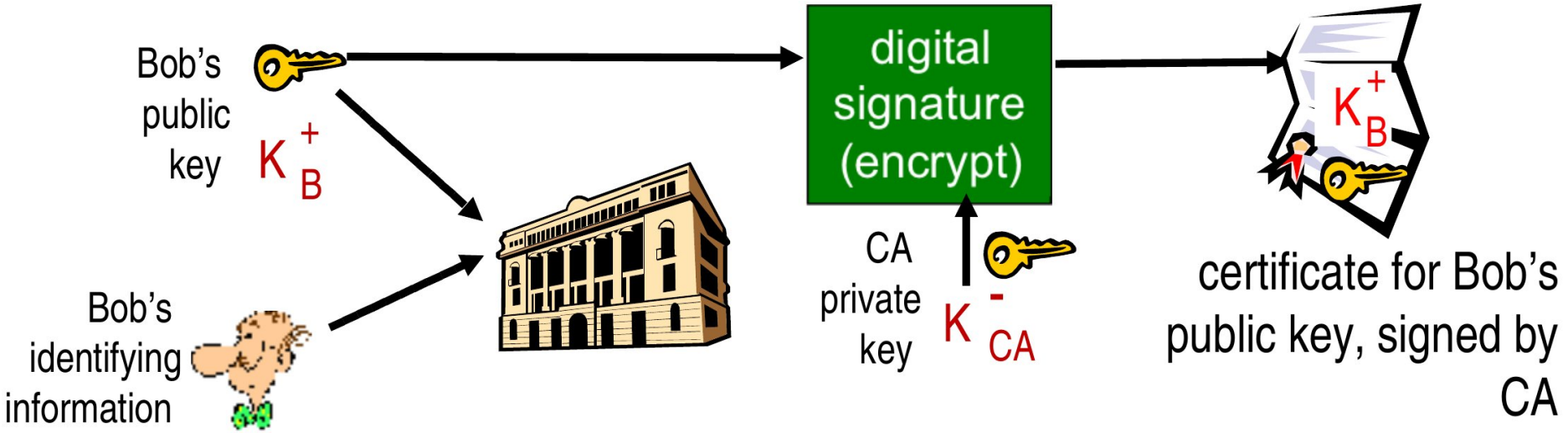
Motivation: Trudy plays pizza prank on Bob

- Trudy creates e-mail order:
  Dear Pizza Store, Please deliver to me four pepperoni pizzas. Thank you, Bob
- Trudy signs order with her private key
- Trudy sends order to Pizza Store
- Trudy sends to Pizza Store her public key, but says it's Bob's public key
- Pizza Store verifies signature; then delivers four pizzas to Bob
- Bob doesn't even like Pepperoni

Certification Authorities

Certification authority (CA): binds public key to particular entity, E.

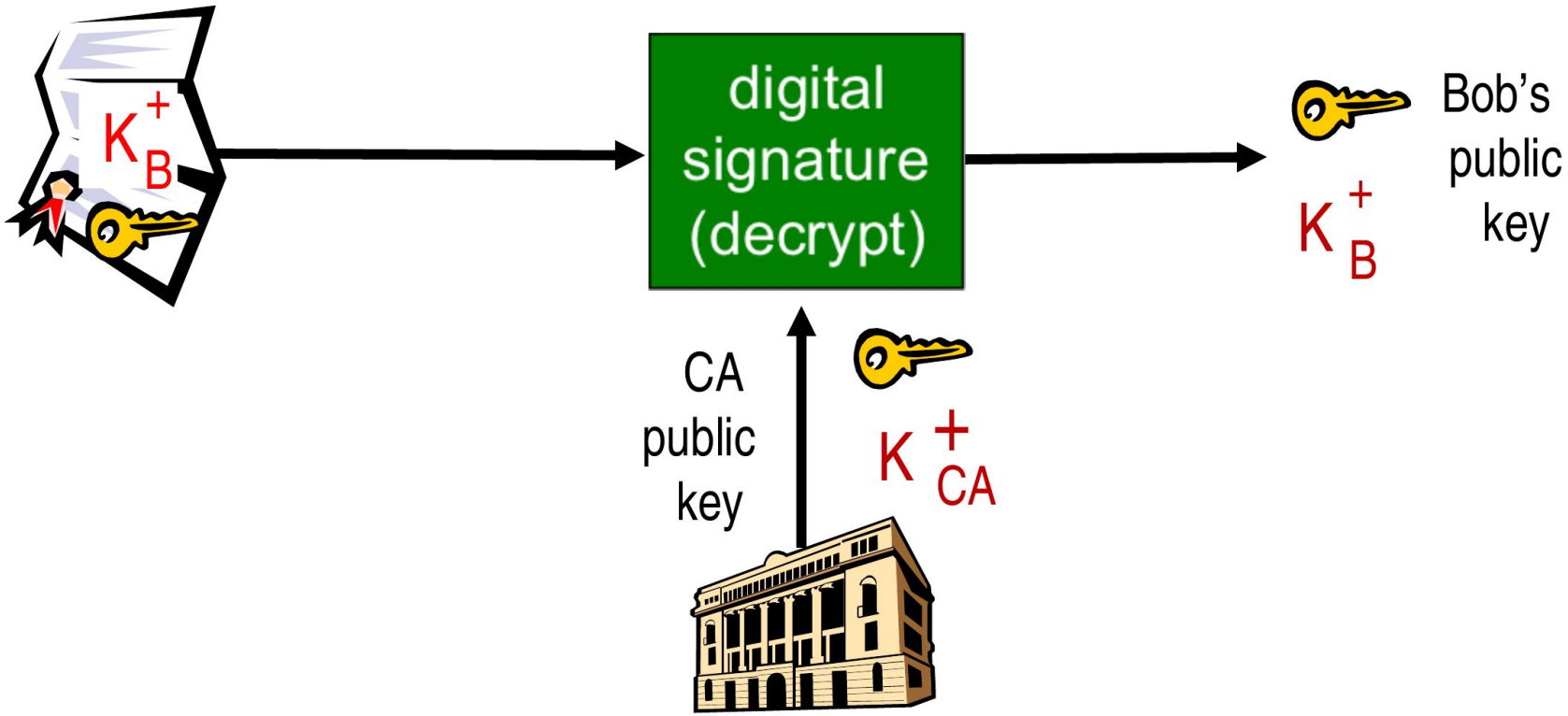
- E (person, router) registers its public key with CA
  - E provides "proof of identity" to CA
  - CA creates certificate binding E to its public key
  - Certificate containing E's public key digitally signed by CA - CA says "this is E's public key"



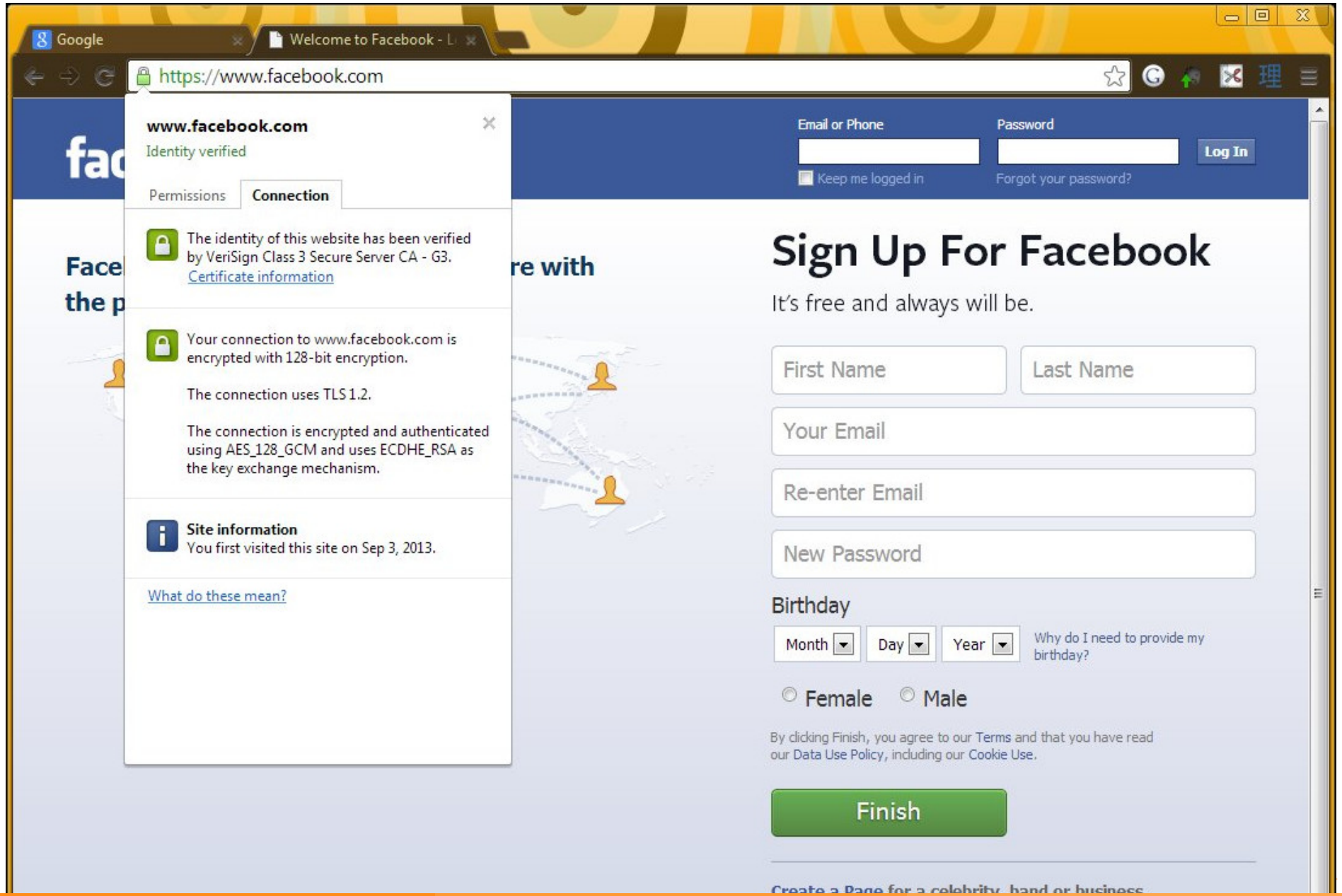
Certification Authorities

When Alice wants Bob's public key:

- gets Bob's certificate (from Bob or elsewhere).
- apply CA's public key to Bob's certificate, get Bob's public key



Example from everyday life



Cryptography: Summary

Today's lecture covered:

- Basic of cryptography
  - Symmetric key cryptography
  - Public key cryptography
  - Message integrity
  - End-Point Authentication

Next week: Secured Applications

- Securing email
- Securing TCP
- ...

Today's important points

- Public key
- Public key vs. Symmetric key
- Certificate