CSC309 *Programming on the Web*

week 11: cryptography

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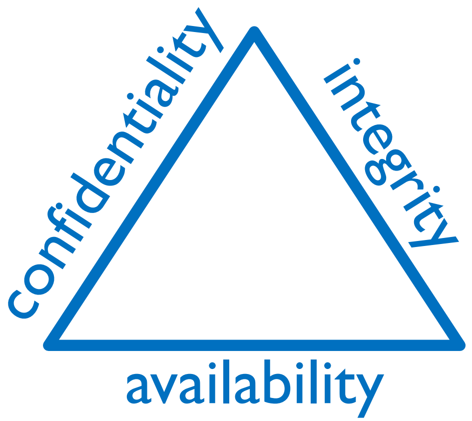
some contents are from:

- Computer networking: a top-down approach, Ross

review

- security requirements

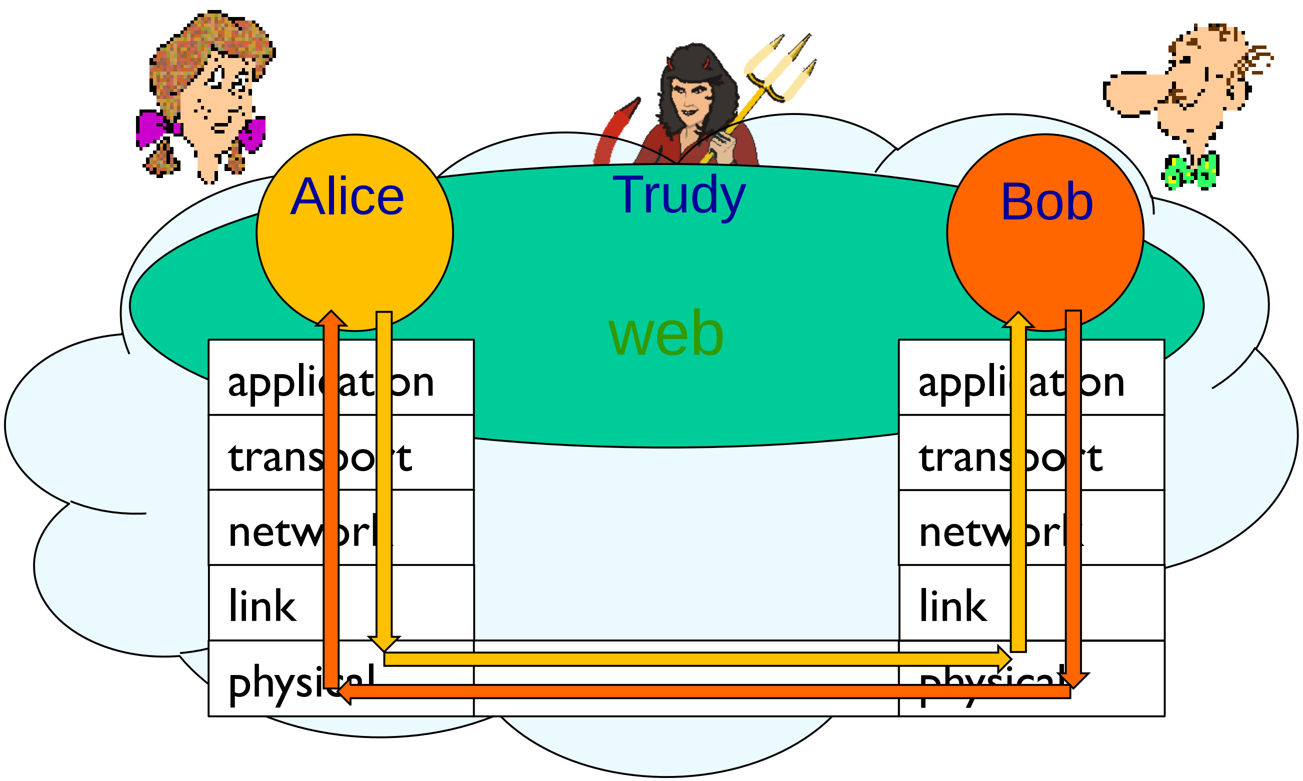


- attack vectors

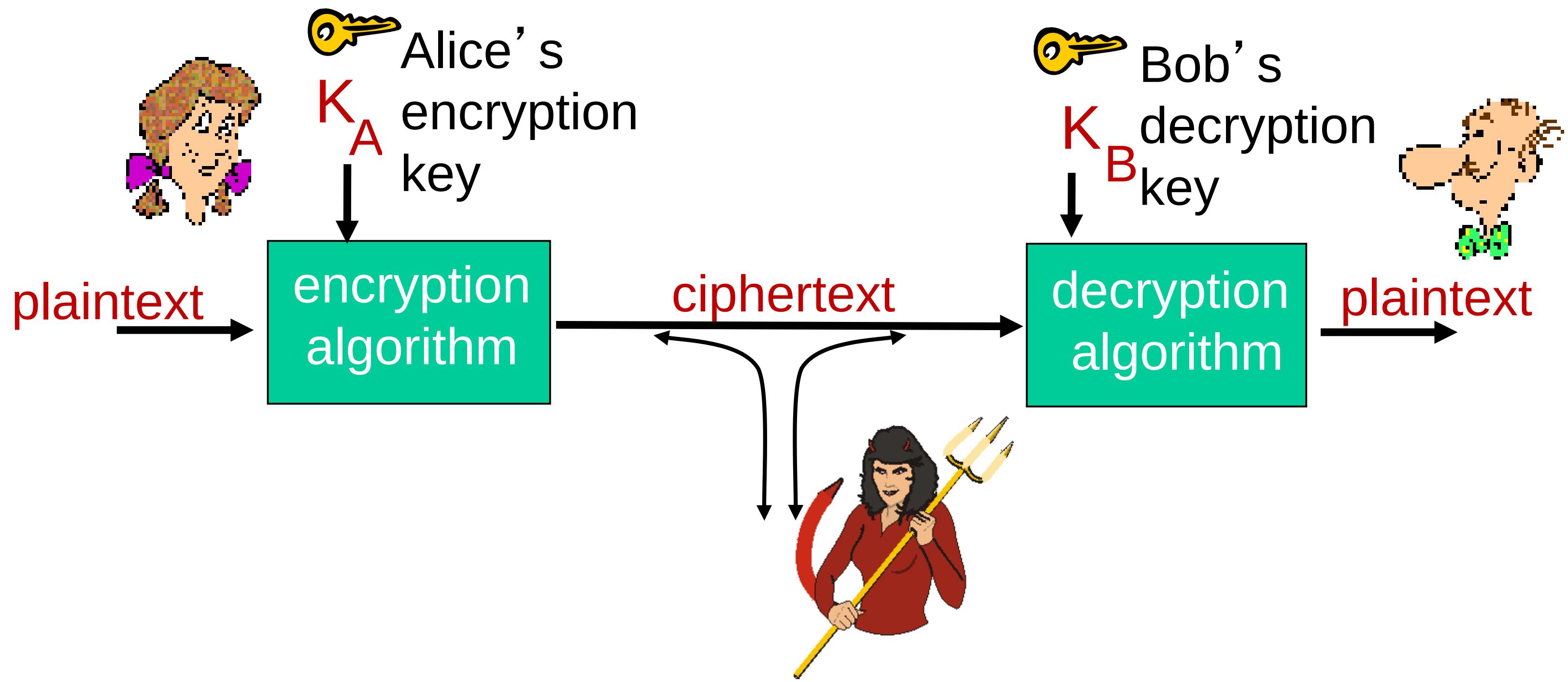
- **this week**
  - **cryptography**
    - to preserve confidentiality and integrity

friends and enemies: Alice, Bob, Trudy

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



the language of cryptography



m plaintext message

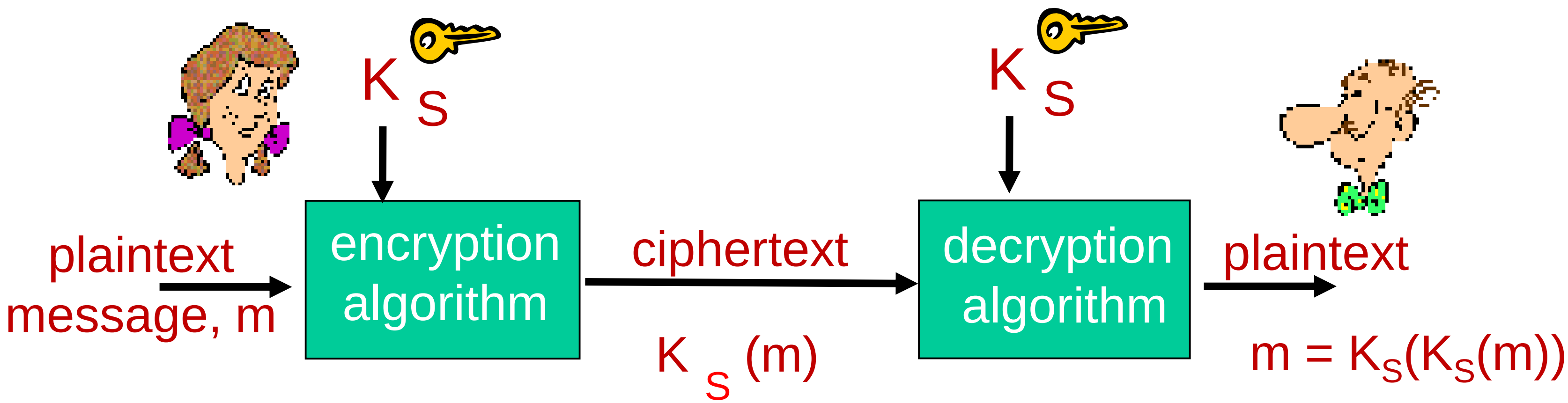
$K_A(m)$ ciphertext, encrypted with key K_A

$m = K_B(K_A(m))$

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 cryptography



symmetric key crypto: Bob and Alice share same (symmetric) key: K_S

- e.g., key is knowing substitution pattern in mono alphabetic substitution cipher

Q: 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

```
 plaintext:   abcdefghijklmnopqrstuvwxyz

ciphertext:   mnbvcxzasdfghjklpoiuytrewq
```

e.g.:

```
Plaintext: bob. i love you. alice
ciphertext: nkn. s gktc wky. mgsbc
```

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

a more sophisticated encryption approach

- `n` substitution ciphers, $M_1, M_2, \ldots, M_n$
- cycling pattern:
  - e.g., `n`=4: M_1,M_3,M_4,M_3,M_2; M_1,M_3,M_4,M_3,M_2; ..
- for each new plaintext symbol, use subsequent substitution pattern in cyclic pattern
  - dog: d from M_1, o from M_3, g from M_4

Encryption key: `n` substitution ciphers, and cyclic pattern

- key need not be just n-bit pattern

symmetric key crypto: des

des: data encryption standard

- US encryption standard [NIST 1993]
- 56-bit symmetric key, 64-bit plaintext input
- block cipher with cipher block chaining
- how secure is **des**?
  - **des** challenge: 56-bit-key-encrypted phrase decrypted (brute force) in less than a day
  - no known good analytic attack
- making **des** more secure:
  - **3des**: encrypt 3 times with 3 different keys

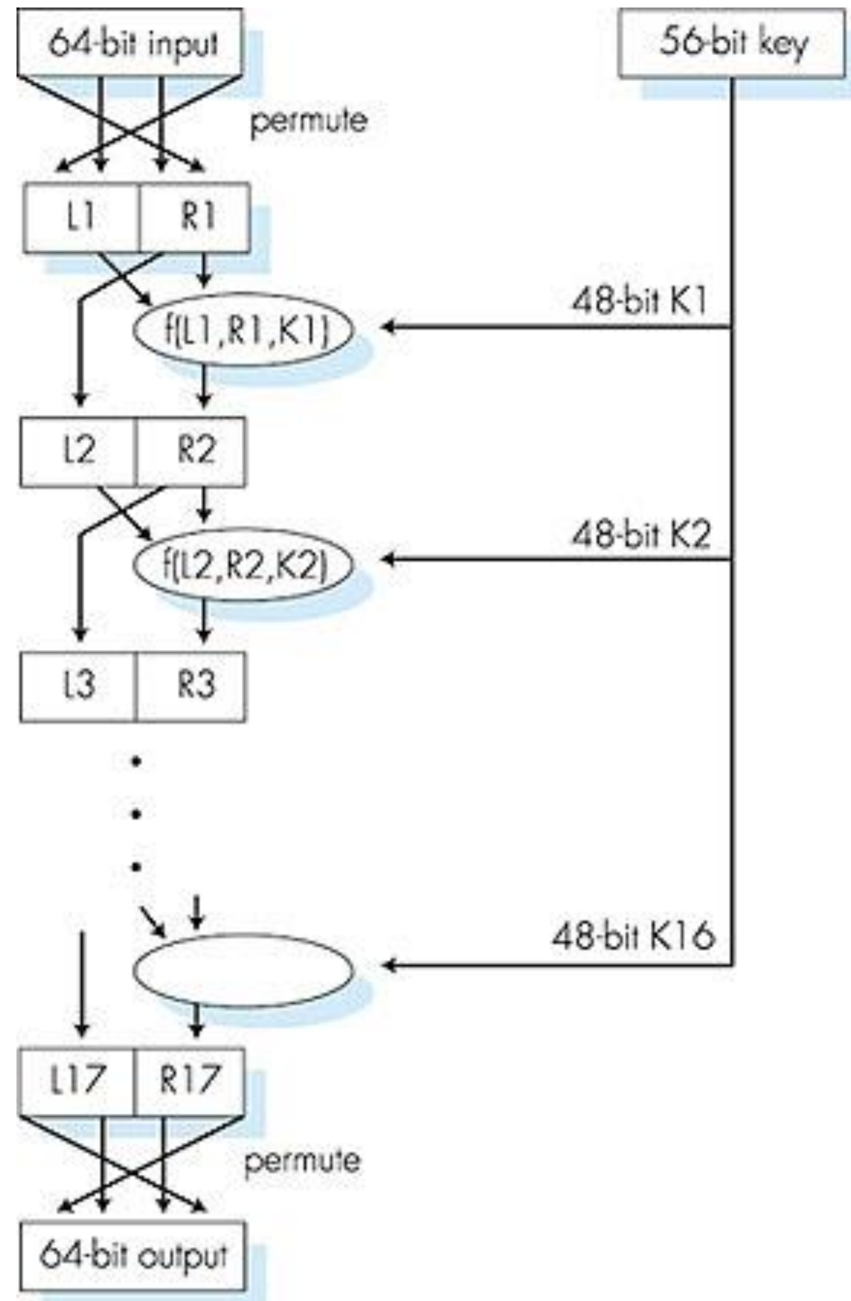
symmetric key crypto: **des**

***des** operation*

initial permutation

16 identical "rounds" of function application, each using different 48 bits of key

final permutation



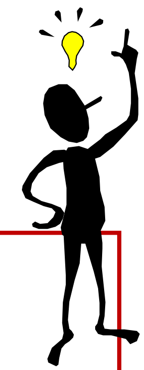
aes: advanced encryption standard

- symmetric-key NIST 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 crypto

symmetric key crypto

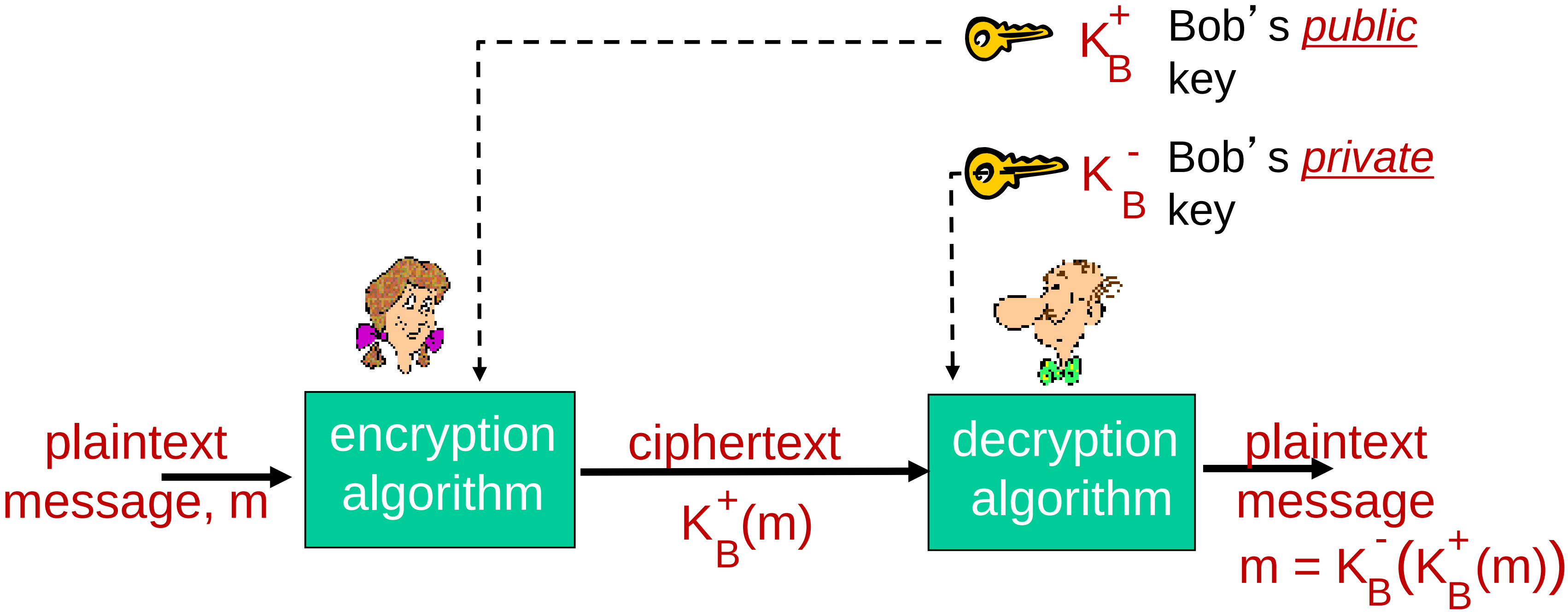
- requires client & server know shared secret key
- Q: how to agree on key in first place (particularly if never “met”)?



public key crypto

- radically different approach [Diffie-Hellman76, RSA78]
- client & server do *not* share secret key
- *public* encryption key known to *all*
- *private* decryption key known only to server

public key crypto



public key encryption algorithms

requirements:

1. need $K_B^+(\cdot)$ and $K_B^-(\cdot)$ such that

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

2. given public key K_B^+, it should be impossible to compute private key K_B^-

RSA: Rivest, Shamir, Adelson algorithm

prerequisite: modular arithmetic

- $x \bmod n$ = remainder of x when divide by n
- facts:

  $(a+b) \bmod n = [(a \bmod n) + (b \bmod n)] \bmod n$

  $(a-b) \bmod n = [(a \bmod n) - (b \bmod n)] \bmod n$

  $(a*b) \bmod n = [(a \bmod n) * (b \bmod n)] \bmod n$

- thus

  $a^d \bmod n = (a \bmod n)^d \bmod n$

- example: $x=14$, $n=10$, $d=2$:
  $(x \bmod n)^d \bmod n = 4^2 \bmod 10 = 6$
  $x^d = 14^2 = 196 \quad x^d \bmod 10 = 6$

rsa: getting ready

- message: just a bit pattern
- bit pattern can be 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 $n = pq$, $z = (p-1)(q-1)$
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: $ed \bmod z = 1$).
5. *public* key is $\underbrace{(n,e)}_{K_B^+}$. *private* key is $\underbrace{(n,d)}_{K_B^-}$.

rsa: encryption, decryption

0. given (n,e) and (n,d) as computed above

1. to encrypt message m $(<n)$, compute

   $c = m^e \bmod n$

2. to decrypt received bit pattern, c, compute

   $m = c^d \bmod n$

magic happens!

$$m = (\underbrace{m^e \bmod n}_{c})^d \bmod n$$

rsa example:

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).

encrypting 8-bit messages.

encrypt: $\underbrace{\text{bit pattern}}_{00001100}$ $\underbrace{m}_{12}$ $\underbrace{m^e}_{24832}$ $\underbrace{c = m^e \bmod n}_{17}$

decrypt: $\underbrace{c}_{17}$ $\underbrace{c^d}_{481968572106750915091411825223071697}$ $\underbrace{m = c^d \bmod n}_{12}$

rsa: another important property

The following property will be *very* useful 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!

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

follows directly from modular arithmetic:

$$(m^e \bmod n)^d \bmod n = m^{ed} \bmod n$$
$$= m^{de} \bmod n$$
$$= (m^d \bmod n)^e \bmod n$$

why is rsa secure?

- suppose you know Bob's public key (n,e). How hard is it to determine d?
- essentially need to find factors of n without knowing the two factors p and q
  - fact: factoring a big number is hard
  - e.g., 2 years to factor a 232-digit number

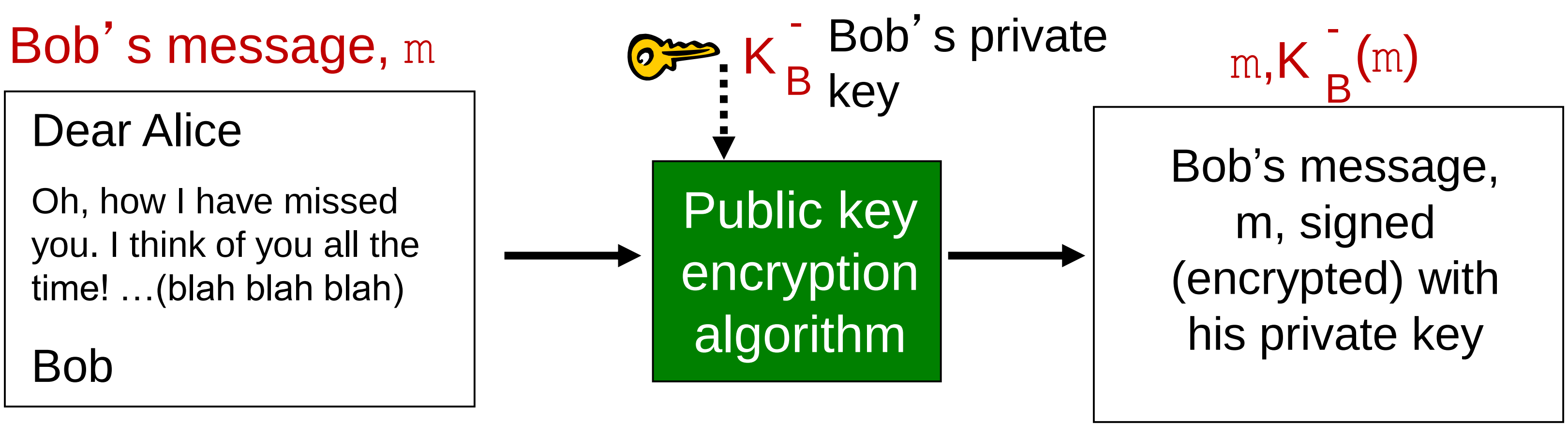
pk crypto in practice: **digital signatures**

- cryptographic technique analogous to hand-written signatures:
- sender (Bob) digitally signs document, establishing he is document owner/creator
- *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, $K_B^-(m)$



digital signatures

- suppose Alice receives msg m, with signature: m, $K_B^-(m)$
- Alice verifies m signed by Bob by applying Bob's public key K_B^+ to $K_B^-(m)$ then checks $K_B^+(K_B^-(m)) = m$
- If $K_B^+(K_B^-(m)) = m$, 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'

non-repudiation:

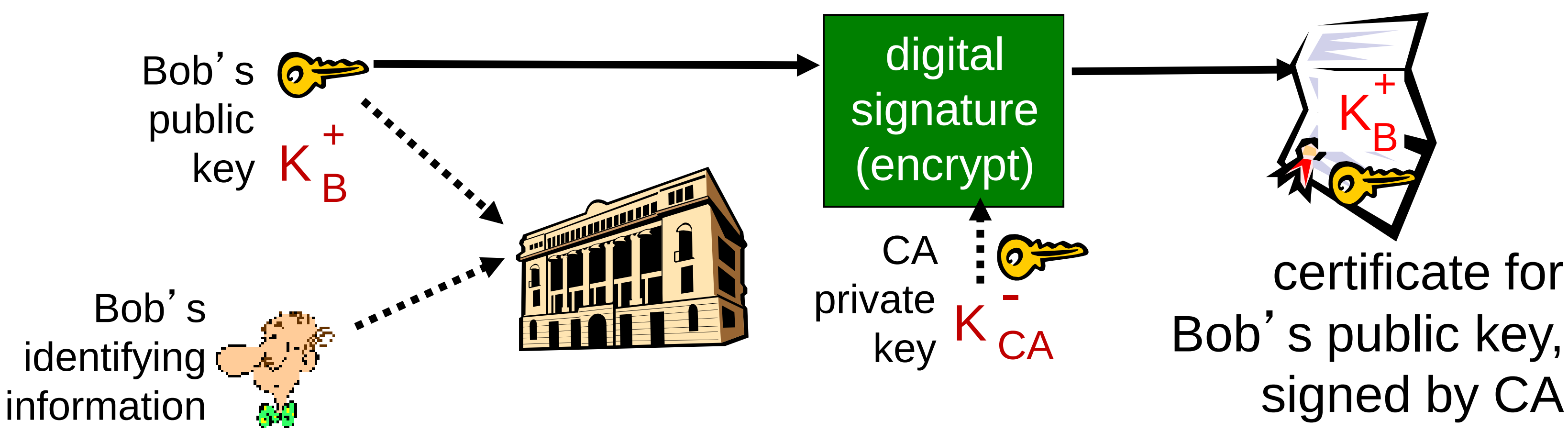
- ✓ Alice can take m, and signature $K_B^-(m)$ to court and prove that Bob signed m

pk crypto in practice: **pk 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 pepperoni pizzas to Bob
  - Bob doesn't even like pepperoni

public-key certification

- *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"



pk crypto in practice: **session keys**

- exponentiation in **rsa** is computationally intensive
- **des** is at least 100 times faster than **rsa**
- idea:
  - public key crypto is used to establish secure connection, then second key (e.g. symmetric session key) is exchanged 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

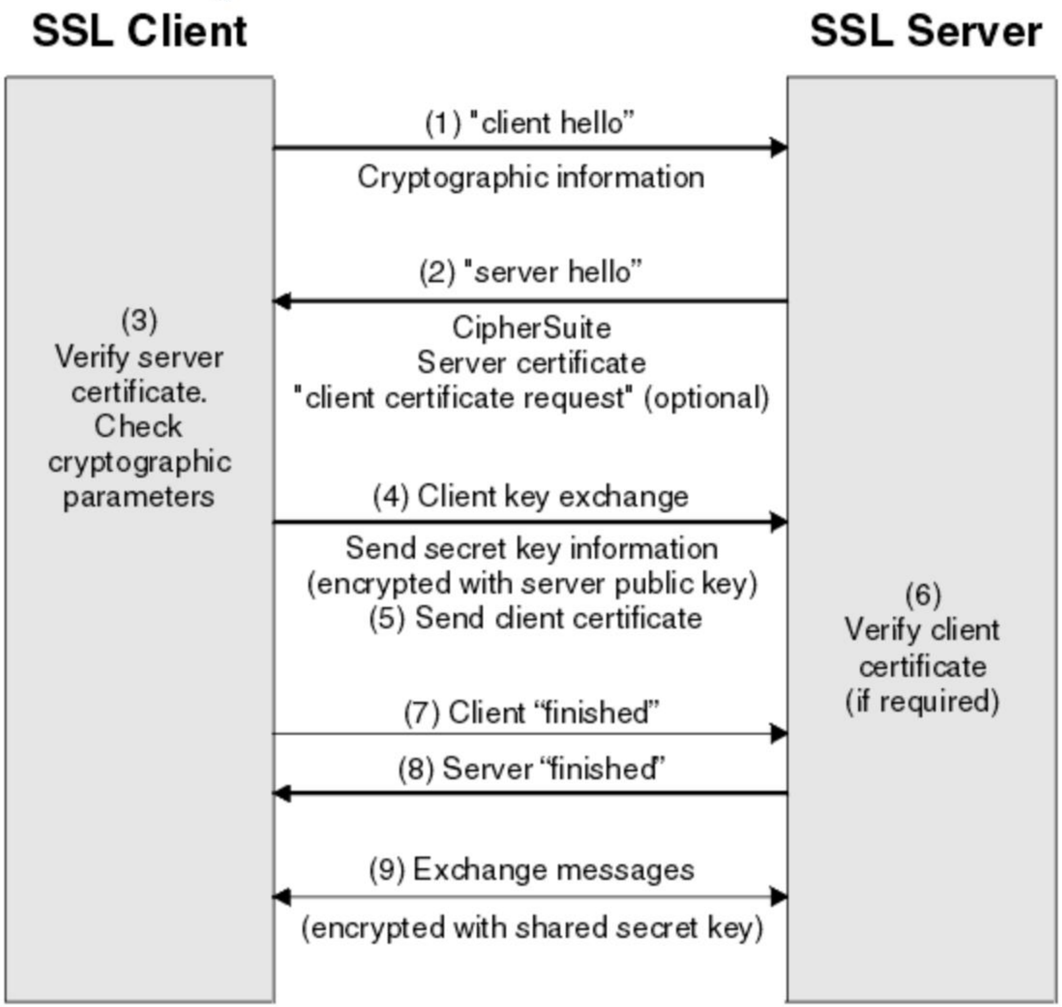
concept underlying SSL/TLS

- Secure Socket Layer/Transport Layer Security

pk crypto in practice:

- you get a ssl certificate for your server
  - this includes, a pair of public and private keys
- once the certificate is installed on your server
- clients' browsers can verify it, via the trusted CA's they know
- before sending you a secret key and exchanging messages with your server

Figure 1. Overview of the SSL or TLS handshake



http://www.ibm.com/support/knowledgecenter/SSFKSJ_7.1.0/com.ibm.mq.doc/sy10660.htm

final exam: cover page

CSC309H1S
Duration – 3 hours

No Aids Allowed

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In the meantime, please fill out the identification section above,
and read the instructions below carefully.

This exam consists of 7 questions on 32 pages (including this one). Pages 10 to 31 consist of code snippets from projects.

Please answer questions in the space provided. You will earn 20% for any question you leave blank or write "I cannot answer this question," on. We think we have provided a lot of space for your work, but please do not feel you need to fill all available space.

You must achieve at least 40% of this exam to pass the course.

Write neatly and concisely. If we cannot read it, we cannot grade it.

GOOD LUCK!

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Initial								
Mark	/16	/15	/12	/12	/10	/15	/20	/100

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