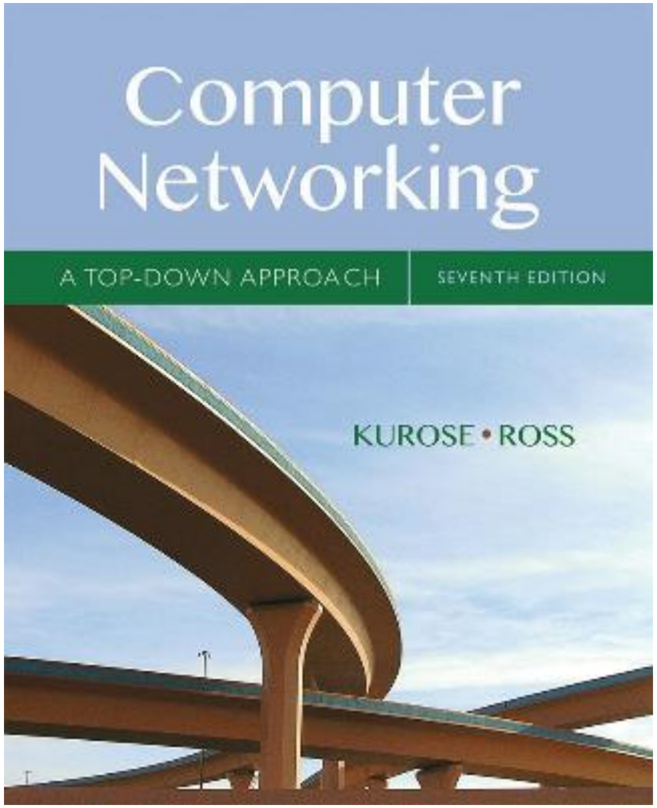
Chapter 6 The Link Layer and LANs



Computer Networking: A Top Down Approach

7th edition
Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Slides adopted from original ones provided by the textbook authors.

Link layer, LANs: outline

6.1 introduction, services

6.2 error detection, correction

6.3 multiple access protocols

6.4 LANs
- addressing, ARP
- Ethernet
- switches
- VLANS

6.5 link virtualization: MPLS

6.6 data center networking

6.7 a day in the life of a web request

Link layer services

- *framing*
- *link access*
- *error detection and correction*

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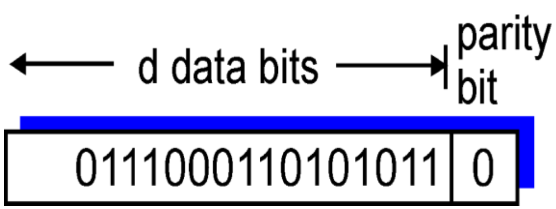
Parity checking

single bit parity:

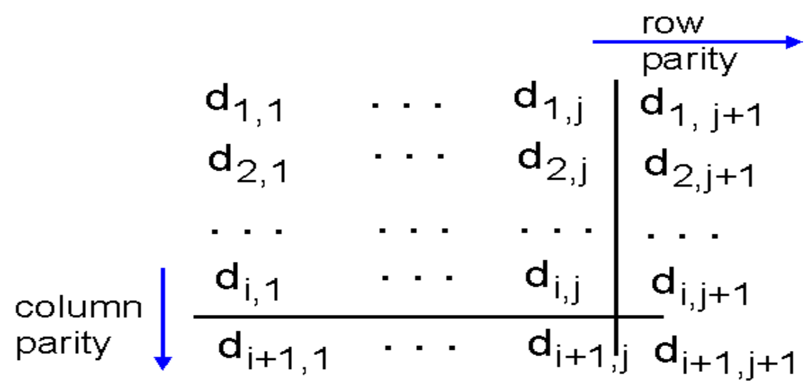
- detect single bit errors

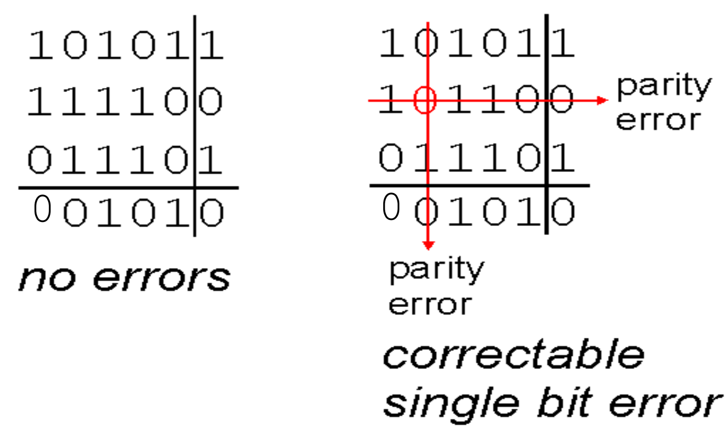


Even parity: parity bit chosen for even # of 1s
Odd parity: parity bit chose for odd # of 1s

two-dimensional bit parity:

- detect and correct single bit errors





CRC example

want:

$D \cdot 2^r$ XOR $R = nG$

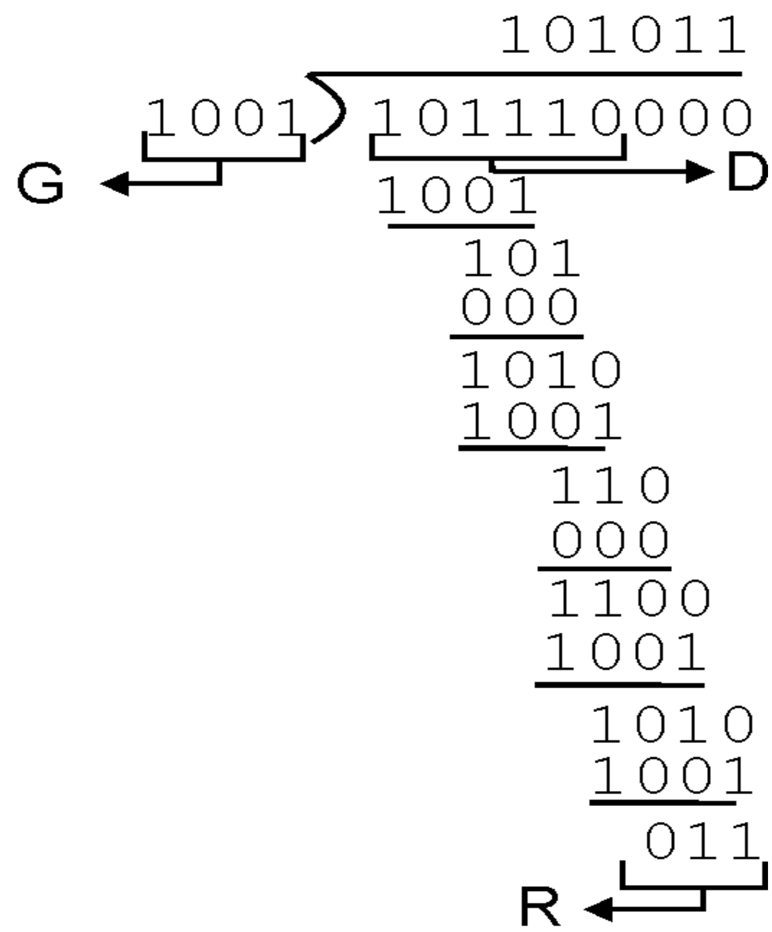
equivalently:

$D \cdot 2^r = nG$ XOR R

equivalently:

if we divide $D \cdot 2^r$ by G, want remainder R to satisfy:

$$\boxed{R = remainder\left[\frac{D \cdot 2^r}{G}\right]}$$



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Summary of MAC protocols

- *channel partitioning,* by time, frequency
  - Time Division Multiple Access
  - Frequency Division Multiple Access
- *random access* (dynamic),
  - ALOHA, S-ALOHA
  - carrier sensing: easy in some technologies (wire), hard in others (wireless)
  - CSMA/CD used in Ethernet
- *taking turns*
  - polling from central site used in Bluetooth
  - token passing used in fiber optical, token ring

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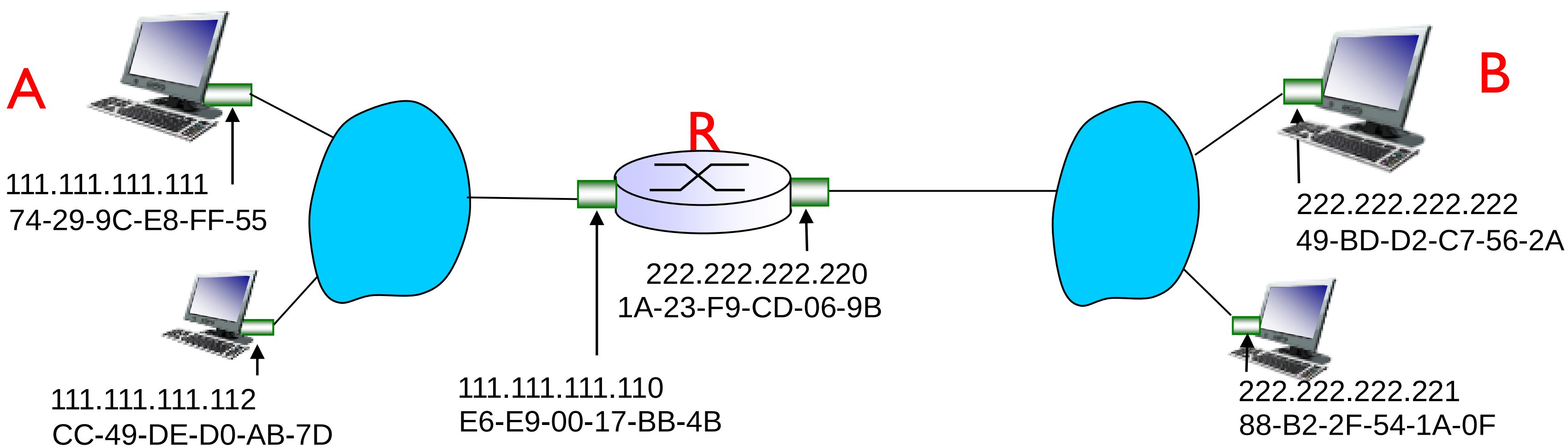
ARP: mapping IP to MAC

- A wants to send datagram to B
  - B's MAC address not in A's ARP table.
- A broadcasts ARP query packet, containing B's IP address
  - dest MAC address = FF-FF-FF-FF-FF-FF
  - all nodes on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A's MAC address (unicast)
- A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)
  - soft state: information that times out (goes away) unless refreshed
- ARP is "plug-and-play":
  - nodes create their ARP tables *without intervention from net administrator*

Addressing: routing to another LAN

- Destination IP in another LAN
  - Destination MAC is that of first hop router interface (aka default gateway)
- Destination IP in same LAN
  - Destination MAC is that of destination host



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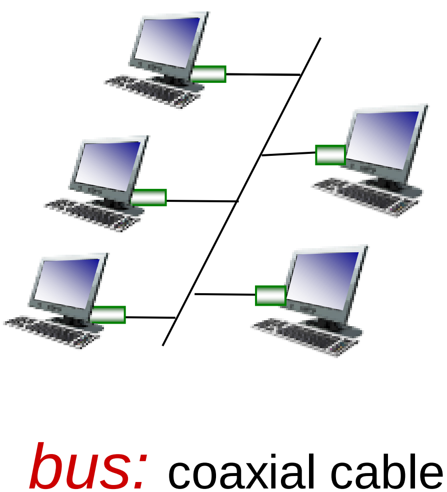
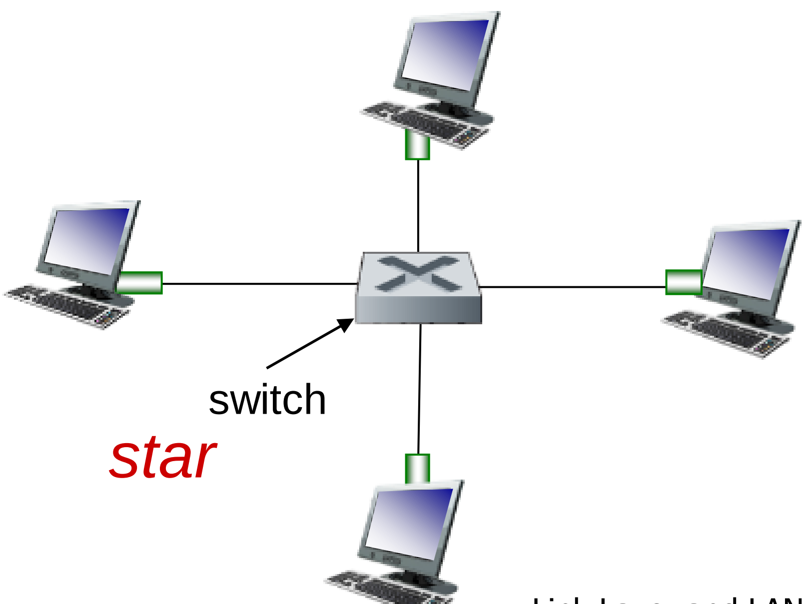
Ethernet: physical topology

- *bus:* popular through mid 90s
  - all nodes in same collision domain (can collide with each other)
- *star:* prevails today
  - active *switch* in center
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)





Ethernet

- frame structure: sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame

- features:
  - *Connectionless*
  - *Unreliable*
  - MAC protocol: unslotted *CSMA/CD wth binary backoff*

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Ethernet switch

- link-layer device: takes an *active* role
  - store, forward Ethernet frames
  - examine incoming frame's MAC address, selectively forward frame to one-or-more outgoing links when frame is to be forwarded on segment, uses CSMA/CD to access segment
- *transparent*
  - hosts are unaware of presence of switches
- *plug-and-play, self-learning*
  - switches do not need to be configured

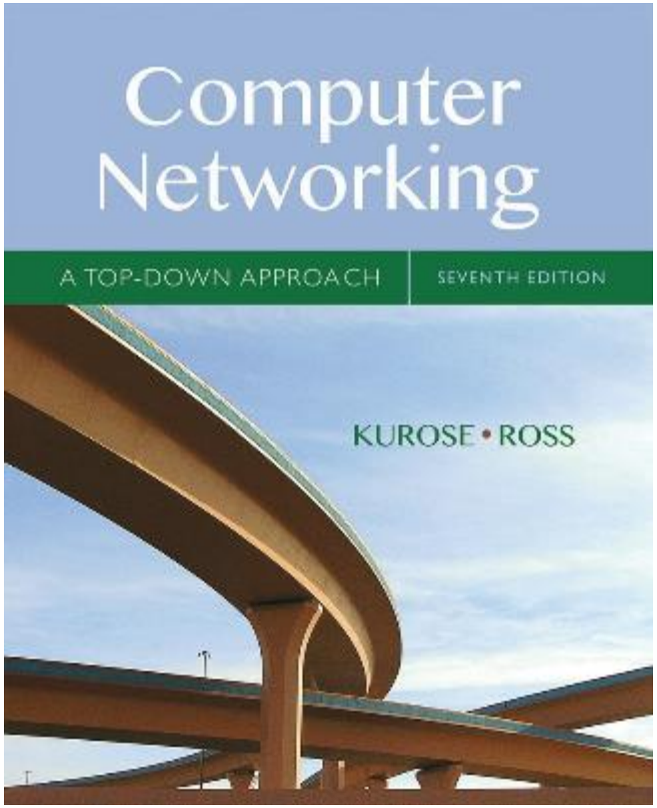
Switch: self-learning

- switch learns which hosts can be reached through which interfaces
  - when frame received, switch "learns" location of sender
  - records sender/location pair in switch table
- forwarding packet
  - frame destination unknown: flood
  - destination location known: selective send

VLANs: motivation

- Motivation
  - Lack of traffic isolation
  - Inefficient use of switches
  - Managing users
- Virtual Local Area
  - Switch(es) supporting VLAN capabilities can be configured to define multiple virtual LANS over single physical LAN infrastructure.
  - *trunk port:* carries frames between VLANS defined over multiple physical switches via the 802.1q protocol

Chapter 8
Security



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Chapter 8: Network Security

Chapter goals:

- understand principles of network security:
  - cryptography and its *many* uses beyond "confidentiality"
  - authentication
  - message integrity
- security in practice:
  - firewalls and intrusion detection systems
  - security in application, transport, network, link layers

Chapter 8 roadmap

8.1 What is network security?
8.2 Principles of cryptography
8.3 Message integrity, authentication
8.4 Securing e-mail
8.5 Securing TCP connections: SSL
8.6 Network layer security: IPsec
8.7 Securing wireless LANs
8.8 Operational security: firewalls and IDS

What is network security?

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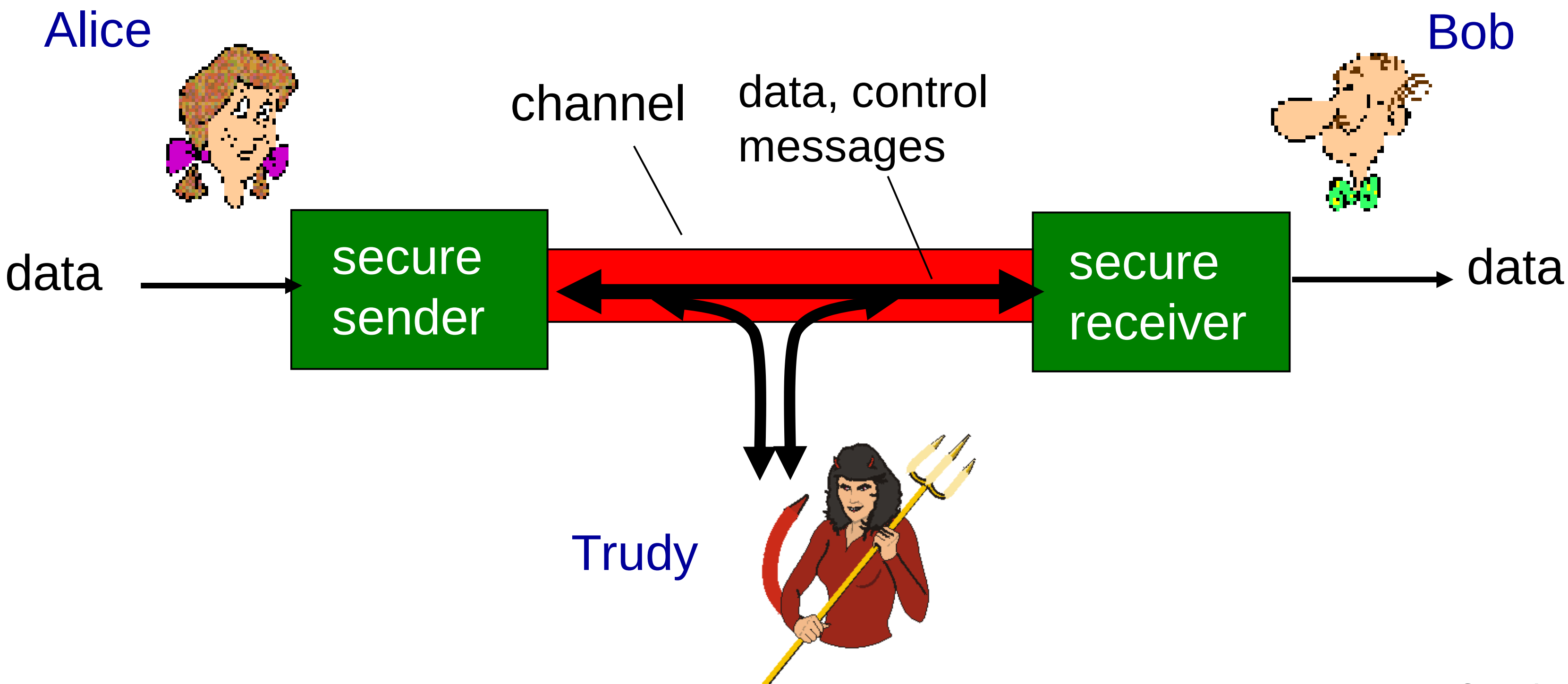
message integrity: sender, receiver want to ensure message not altered (in transit, or afterwards) without detection

access and availability: services must be accessible and available to users

Friends and enemies: Alice, Bob, Trudy

- Bob, Alice want to communicate "securely"
- Trudy (intruder) may intercept, delete, or add messages



Who might Bob, Alice be?

- Web browser/server for electronic transactions (e.g., on-line purchases)
- on-line banking client/server
- DNS clients/servers
- routers exchanging routing table updates
- other examples?

There are bad guys out there!

Q: What can a "bad guy" do?

A: A lot! See section 1.6

- *eavesdropping:* intercept messages
- *injection:* insert 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:* prevent service from being used by others (e.g., by overloading resources)

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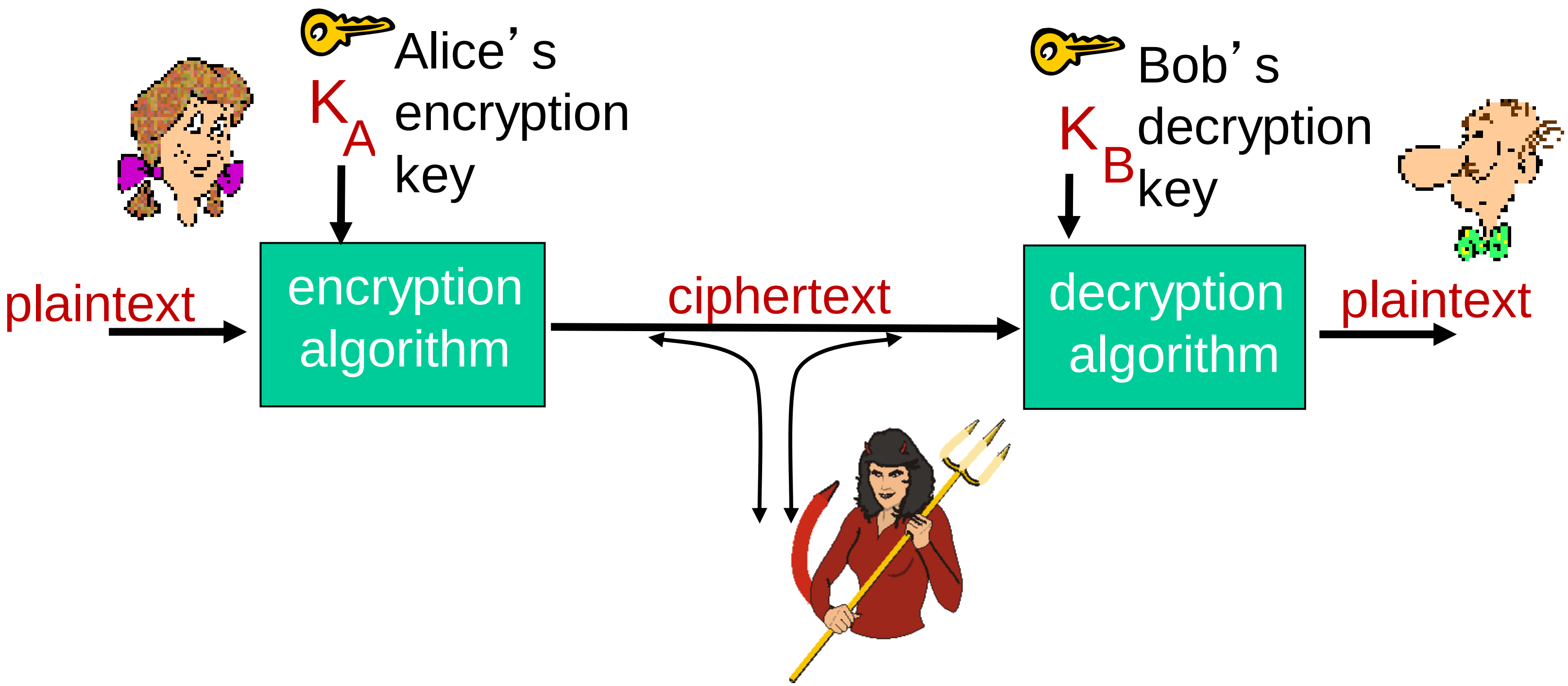
The language of cryptography



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

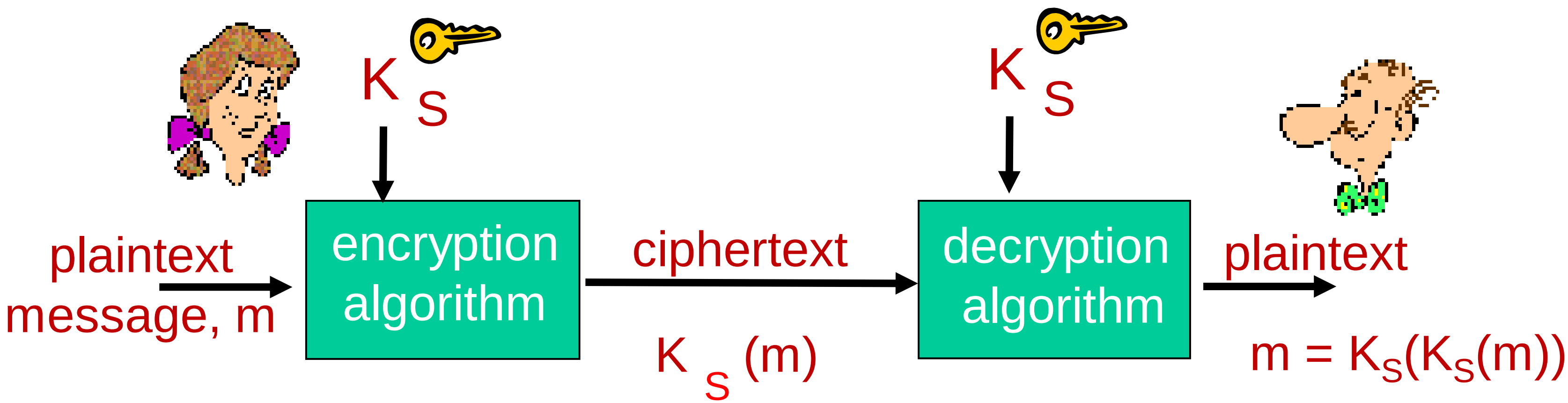
Key Size (bits)	Number of Alternative Keys	Time required at 1 decryption/µs	Time required at 10^6 decryptions/µs
32	$2^{32} = 4.3 \times 10^9$	2^{31} µs = 35.8 minutes	2.15 milliseconds
56	$2^{56} = 7.2 \times 10^{16}$	2^{55} µs = 1142 years	10.01 hours
128	$2^{128} = 3.4 \times 10^{38}$	2^{127} µs = 5.4×10^{24} years	5.4×10^{18} years
168	$2^{168} = 3.7 \times 10^{50}$	2^{167} µs = 5.9×10^{36} years	5.9×10^{30} years
26 characters (permutation)	$26! = 4 \times 10^{26}$	4×10^{26} µs = 6.4×10^{12} years	6.4×10^6 years

  - statistical analysis

Breaking an encryption scheme

- 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?

A: Initial key distribution

Caesar Cipher

- can define transformation as:

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
D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C

- mathematically give each letter a number

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
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

- then have Caesar cipher as:

  c = E(p) = (p + k) mod (26)

  p = D(c) = (c – k) mod (26)

Cryptanalysis of Caesar Cipher

- only have 26 possible ciphers
  - A maps to A,B,..Z
- could simply try each in turn
- a brute force search
- given ciphertext, just try all shifts of letters
- do need to recognize when have plaintext
- E.g. break ciphertext "GCUA VQ DTGCM"

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
```

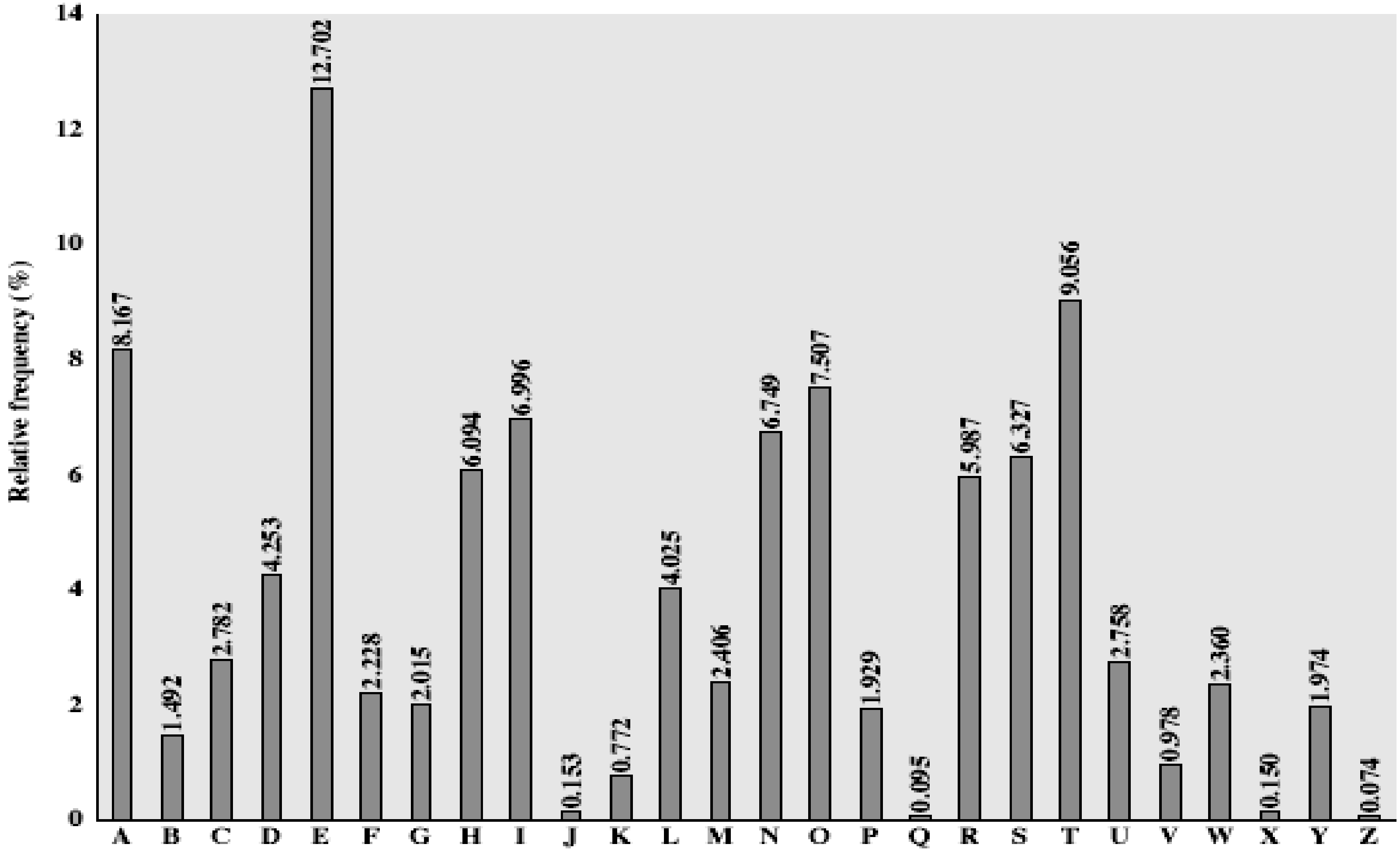
Encryption key: mapping from set of 26 letters to set of 26 letters

# of keys: $26! = 4 \times 10^{26}$

Language Redundancy and Cryptanalysis

- letters are not equally commonly used
- in English E is by far the most common letter
  - followed by T,R,N,I,O,A,S
- other letters like Z, J, K, Q, X are fairly rare
- have tables of single, double & triple letter frequencies for various languages

English Letter Frequencies



Use in Cryptanalysis

- key concept - monoalphabetic substitution ciphers do not change relative letter frequencies
- calculate letter frequencies for ciphertext
- compare counts/plots against known values
- look for common peaks/troughs
  - peaks at: A-E-I triple, NO pair, RST triple
  - troughs at: JK, X-Z

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

Transposition Ciphers

- now consider classical **transposition** or **permutation** ciphers
- these hide the message by rearranging the letter order, without altering the actual letters used
- can recognise these since have the same frequency distribution as the original text
- E.g. rail fence cipher, write message out as:

```
m e m a t r h t g p r y
 e t e f e t e o a a t
```

- giving ciphertext

```
MEMATRHTGPRYETEFETEOAAT
```

Product Ciphers

- ciphers using only substitutions or transpositions are not secure because of language characteristics
- hence consider using several ciphers in succession to make harder
- this is bridge from classical to modern ciphers

DES: Data Encryption Standard

- widely used symmetric key cipher
- US encryption standard [NIST 1993]
- 56-bit symmetric key, 64-bit plaintext input
- pros:
  - product cipher
  - block cipher with cipher block chaining
  - no known good analytic attack
- cons:
  - DES Challenge: 56-bit-key-encrypted phrase decrypted (brute force) in less than a day
  - inflexible

AES: Advanced Encryption Standard

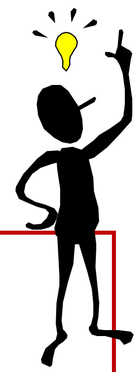
- symmetric-key NIST standard, replacing DES (Nov 2001)
- processes data in 128 bit blocks
- flexible key length:128, 192, or 256 bits
- brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for AES

Public Key Cryptography

symmetric key crypto

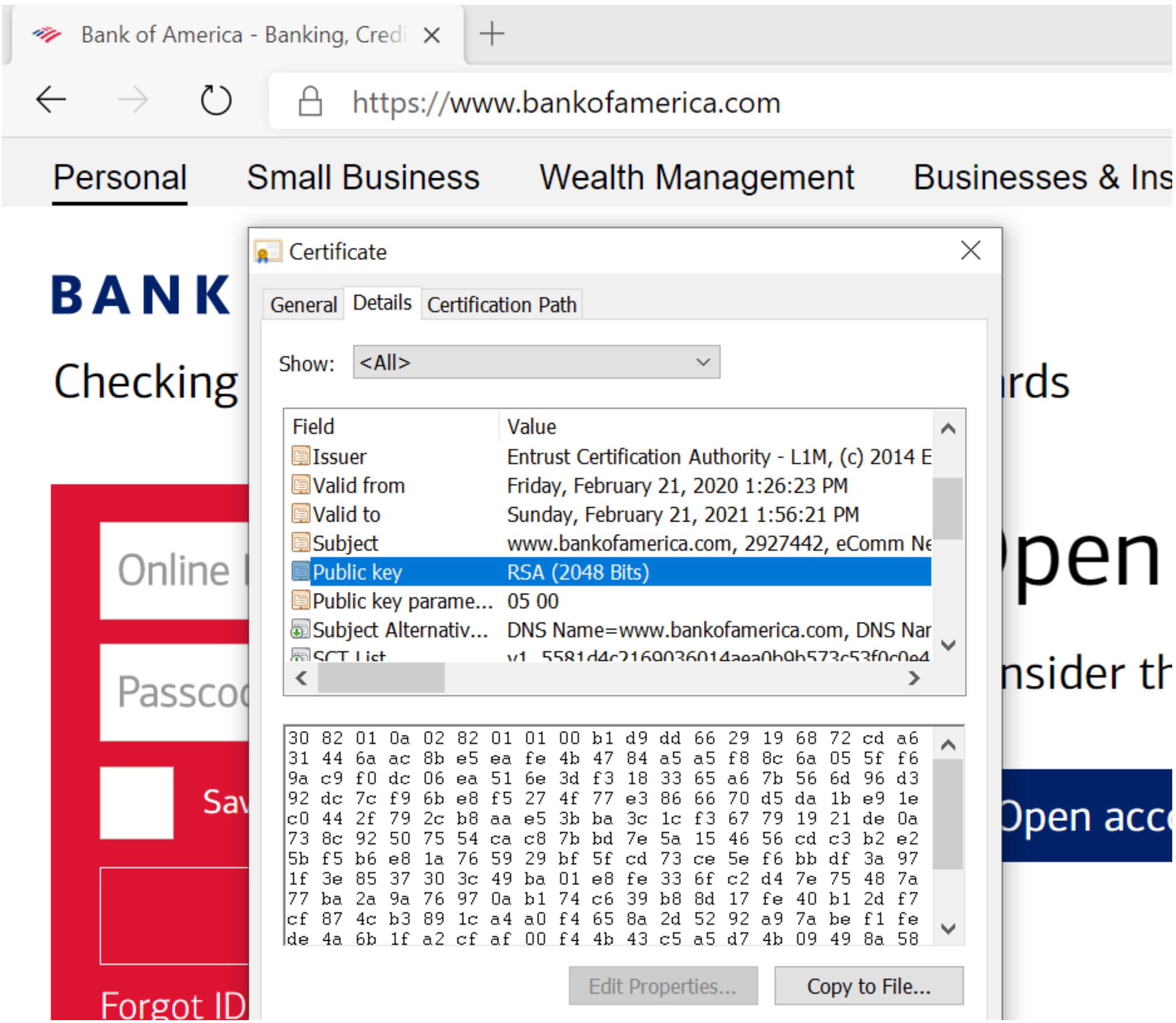
- requires sender, receiver know shared secret key
- Q: how to agree on key in first place (particularly if never "met")?

public key crypto

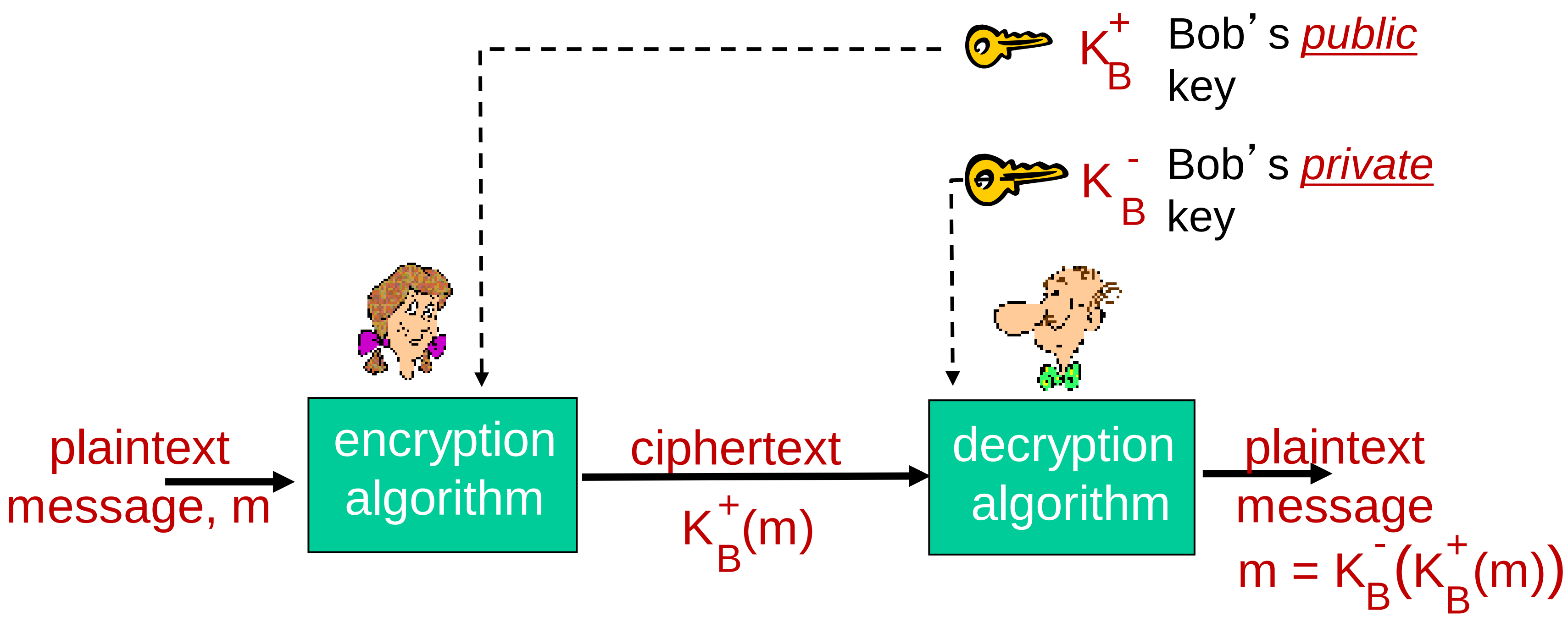


- radically different approach [Diffie-Hellman76, RSA78]
- sender, receiver do *not* share secret key
- *public* encryption key known to *all*
- *private* decryption key known only to receiver

Public Key Example



Public key cryptography



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

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!

RSA in practice: session keys

- exponentiation in RSA is computationally intensive
- DES is at least 100 times faster than RSA
- use public key crypto to establish secure connection, then establish second key – symmetric session 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

Chapter 8 roadmap

Authentication

Goal: Bob wants Alice to "prove" her identity to him

Protocol ap1.0: Alice says "I am Alice"

Failure scenario??

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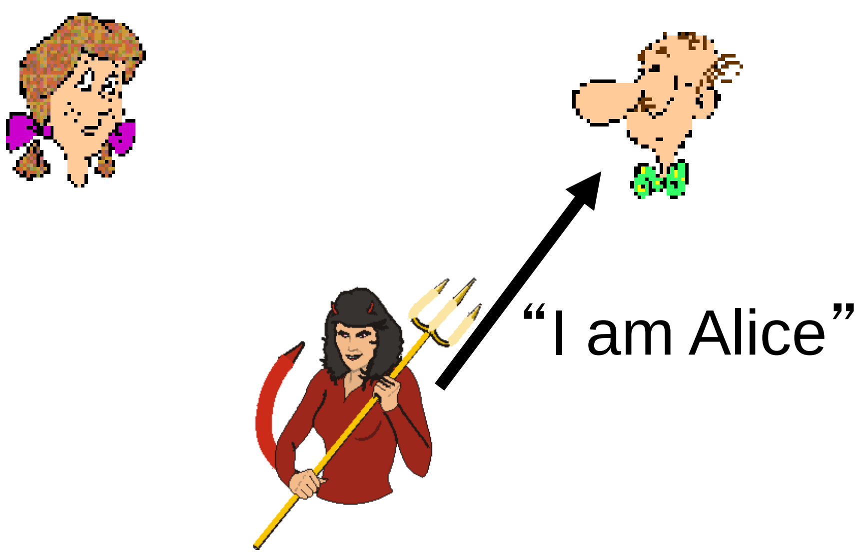
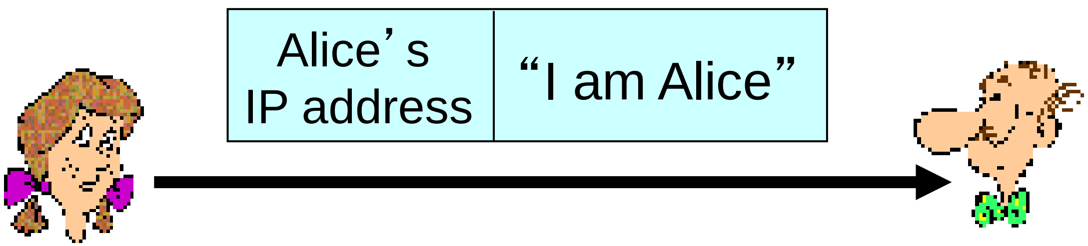


in a network,
Bob can not “see” Alice,
so Trudy simply declares
herself to be Alice

Authentication: another try

Protocol ap2.0: Alice says "I am Alice" in an IP packet containing her source IP address



Failure scenario??

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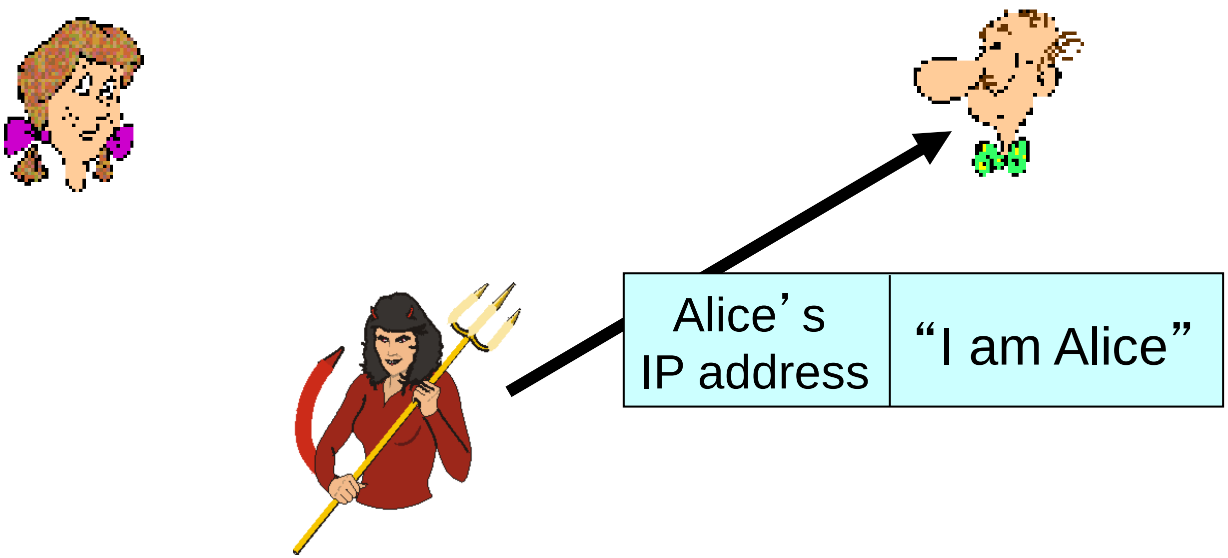
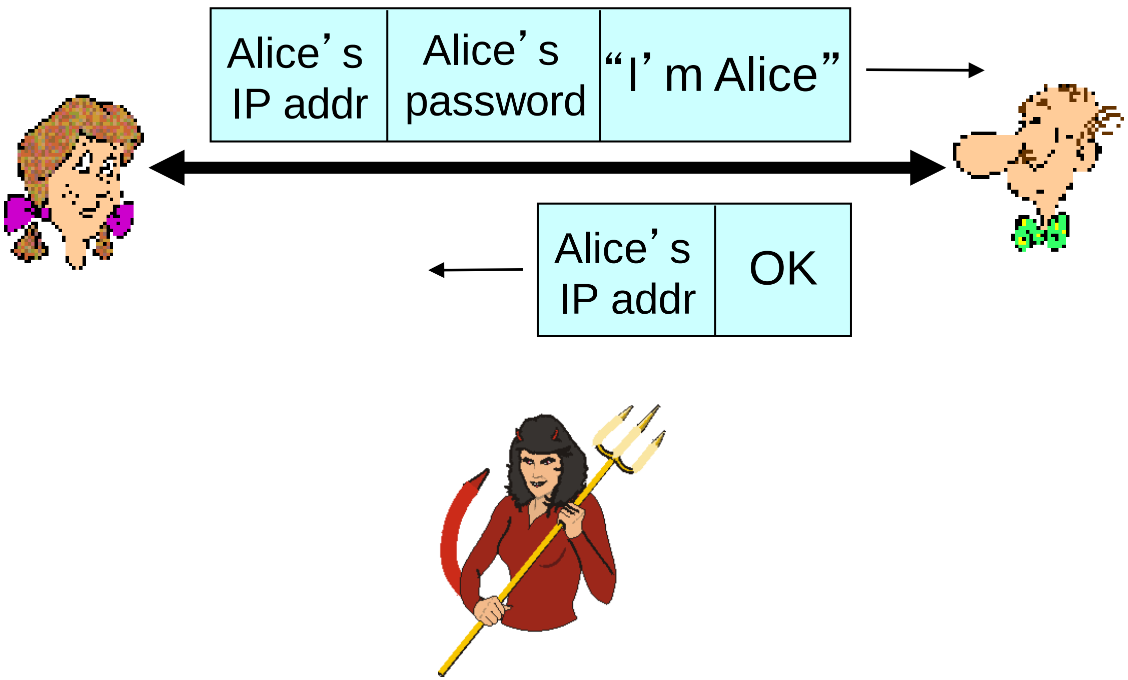


Trudy can create a packet "spoofing" Alice's address

Authentication: another try

Protocol ap3.0: Alice says "I am Alice" and sends her secret password to "prove" it.



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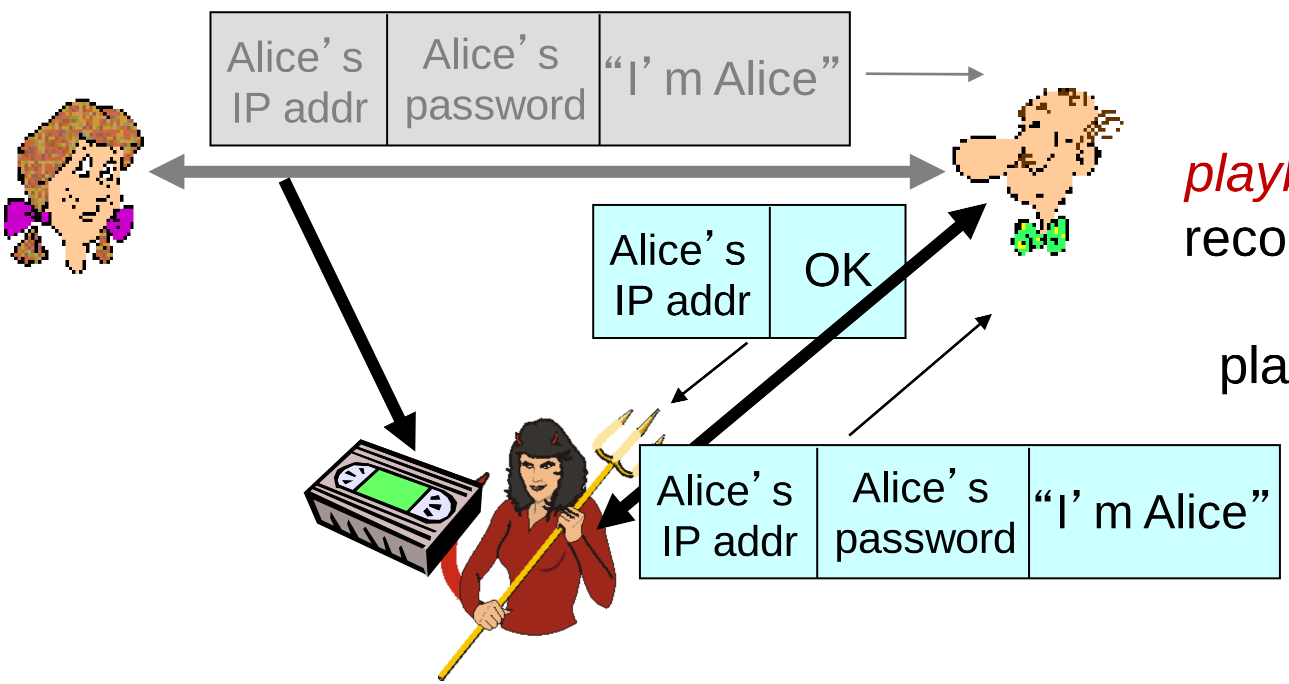
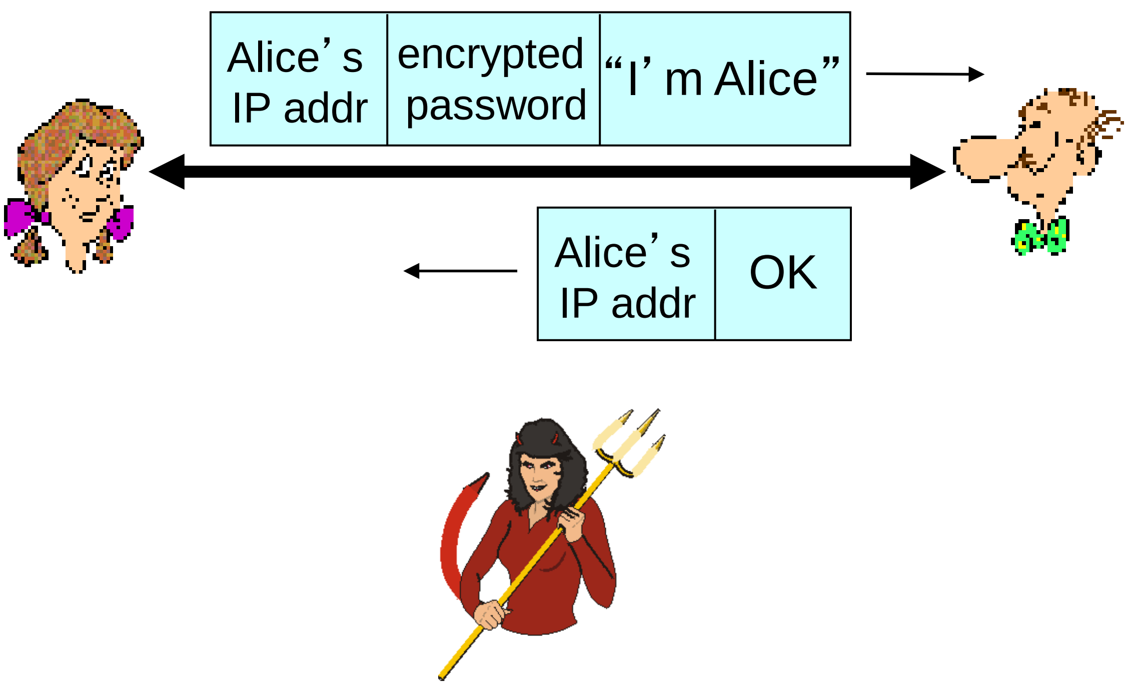


playback attack: Trudy records Alice's packet and later plays it back to Bob

Authentication: yet another try

Protocol ap3.1: Alice says “I am Alice” and sends her *encrypted* secret password to “prove” it.



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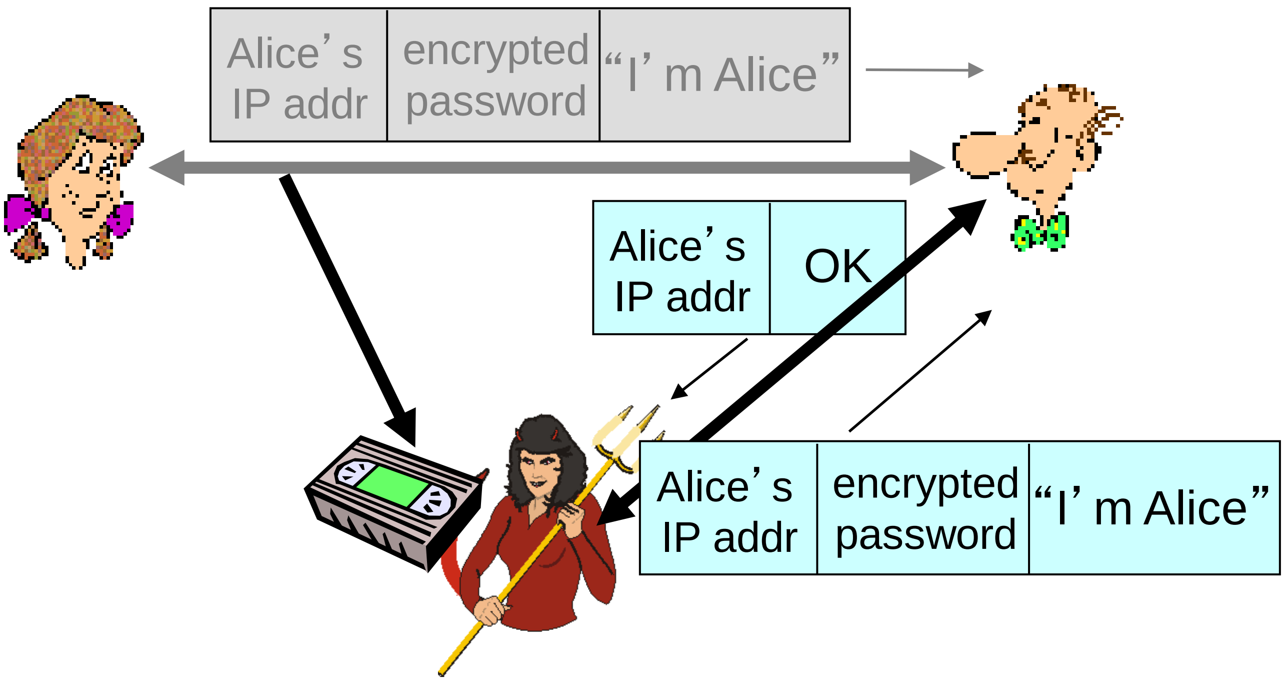


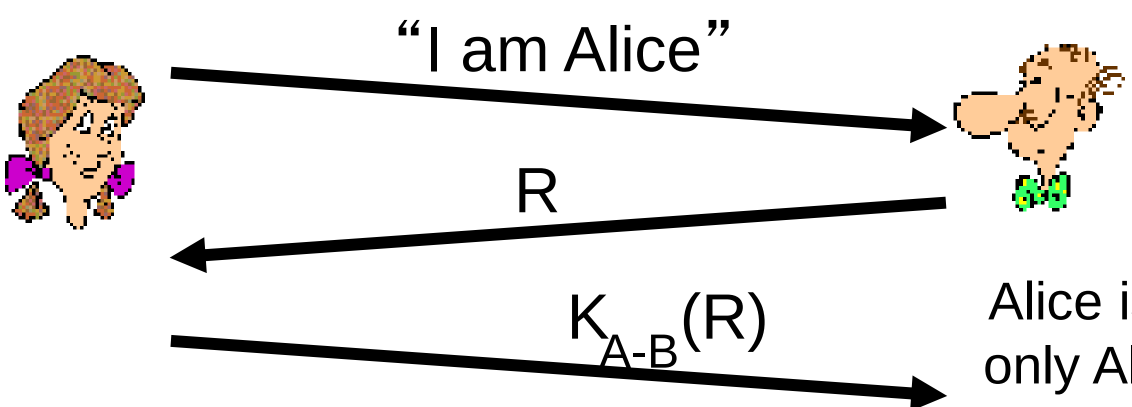
record and playback *still* works!

Authentication: yet another try

Goal: avoid playback attack

nonce: number (R) used only *once-in-a-lifetime*

ap4.0: to prove Alice "live", Bob sends Alice *nonce*, R. Alice must return R, encrypted with shared secret key



Alice is live, and only Alice knows key to encrypt nonce, so it must be Alice!

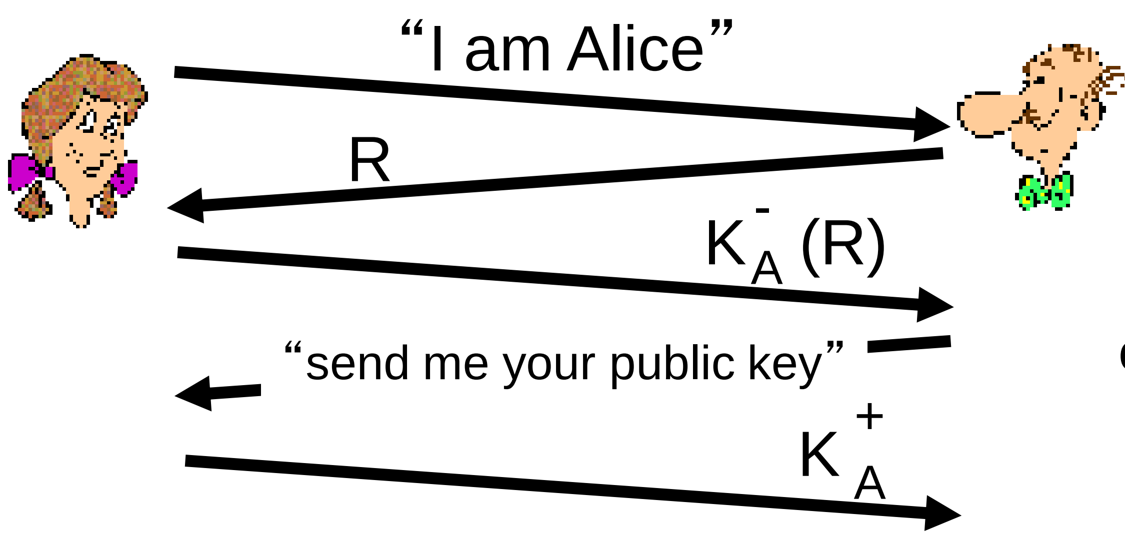
Failures, drawbacks?

Authentication: ap5.0

ap4.0 requires shared symmetric key

- can we authenticate using public key techniques?

ap5.0: use nonce, public key cryptography



Bob computes

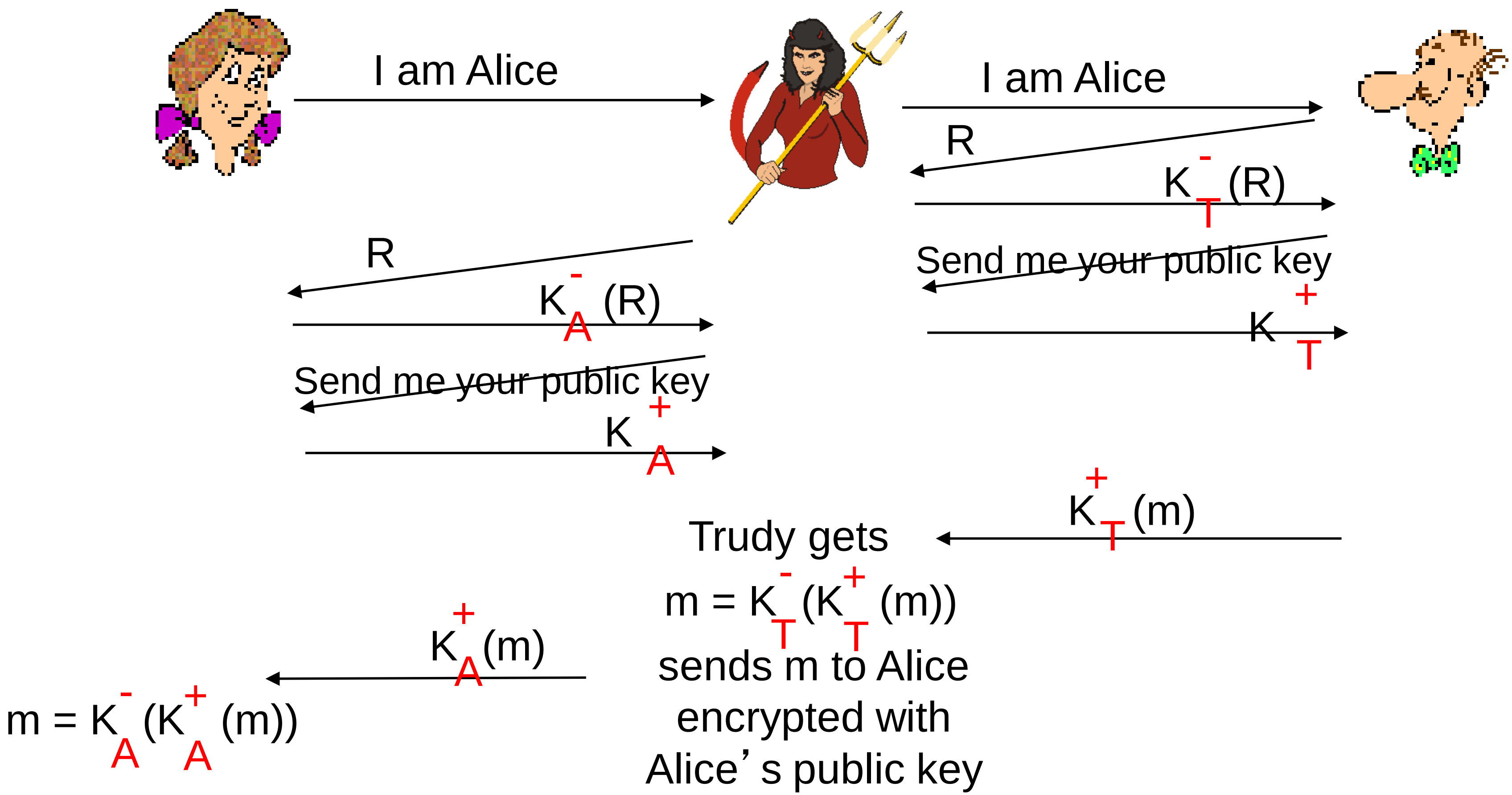
$$K_A^+(K_A^-(R)) = R$$

and knows only Alice could have the private key, that encrypted R such that

$$K_A^+(K_A^-(R)) = R$$

ap5.0: security hole

man in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)



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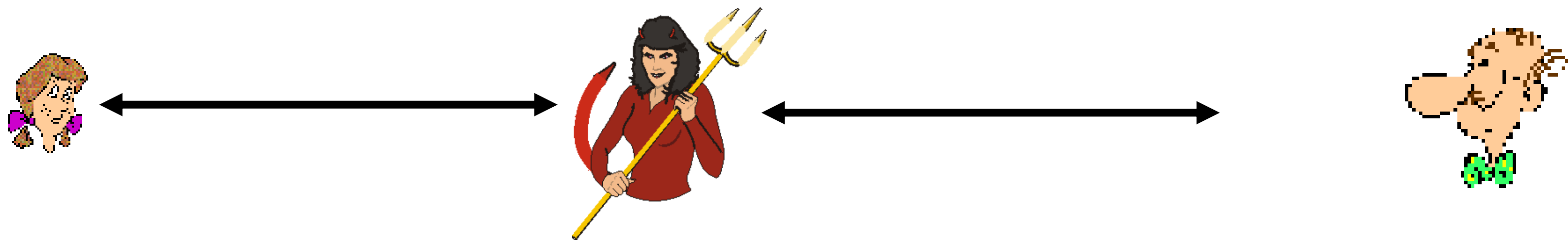
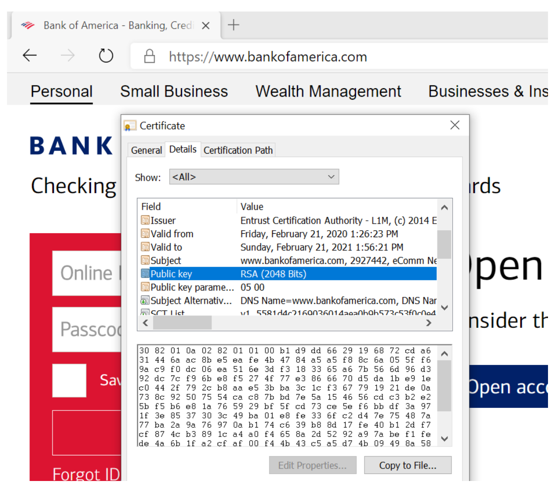


use digital certificate to assure identity

e.g. BoA's certificate proving website authenticity



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Digital signatures

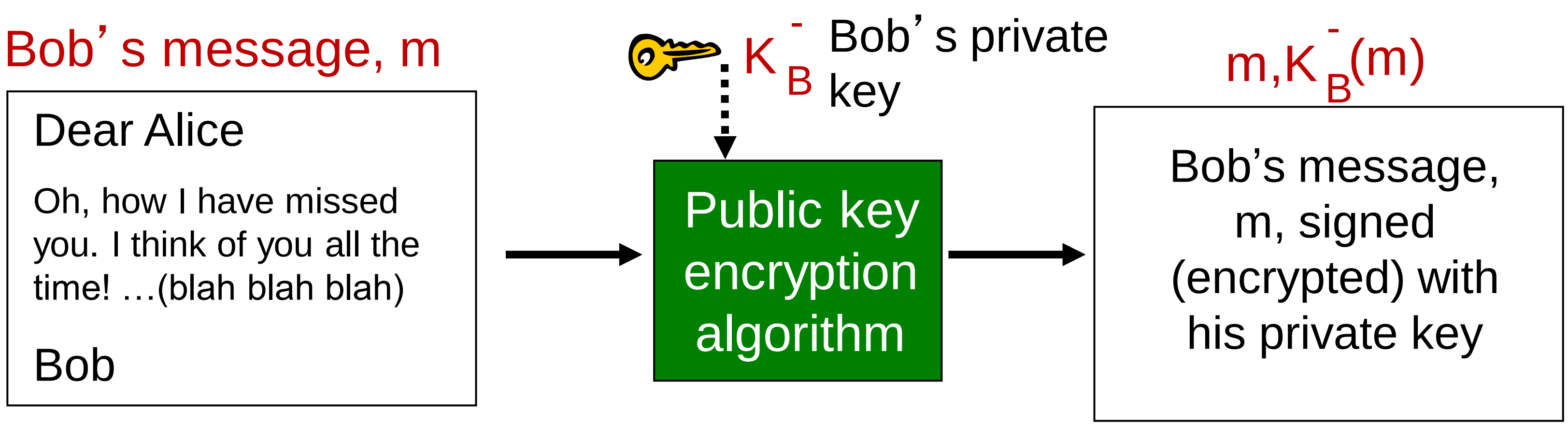
cryptographic technique analogous to hand-written signatures:

- 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.

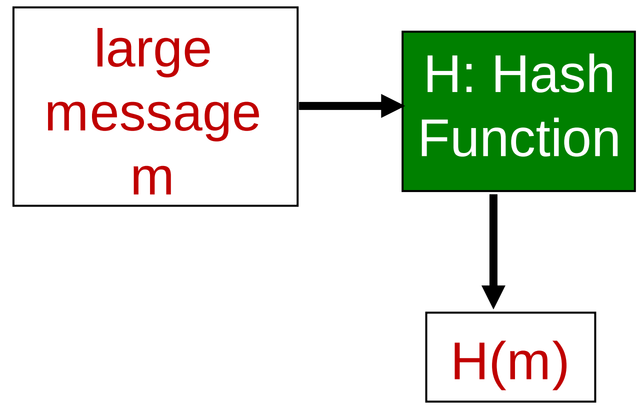
Alice thus verifies that:

- 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

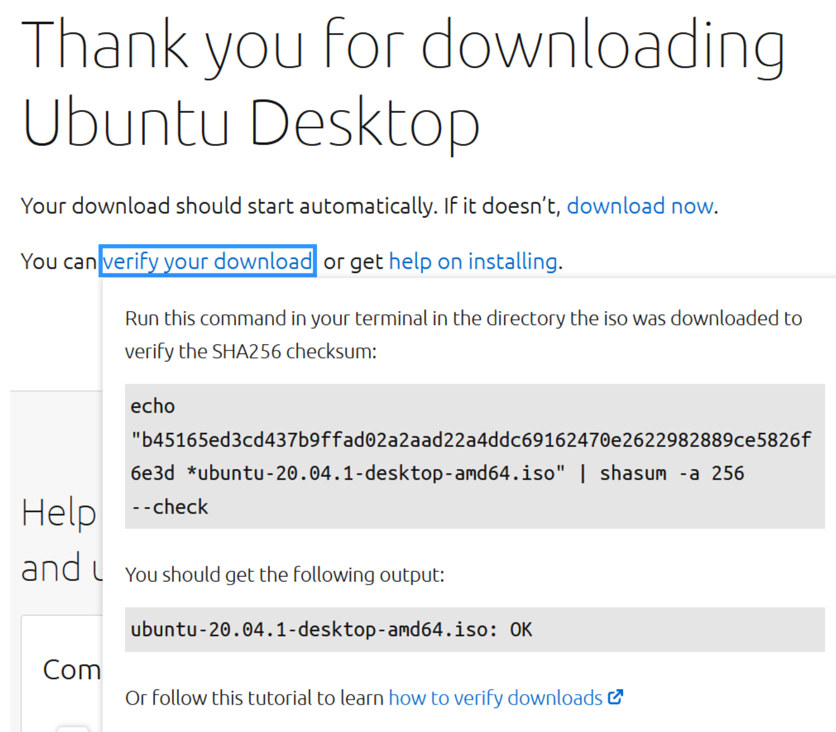
Message digests



computationally expensive to public-key-encrypt long messages

goal: fixed-length, easy-to-compute digital "fingerprint"

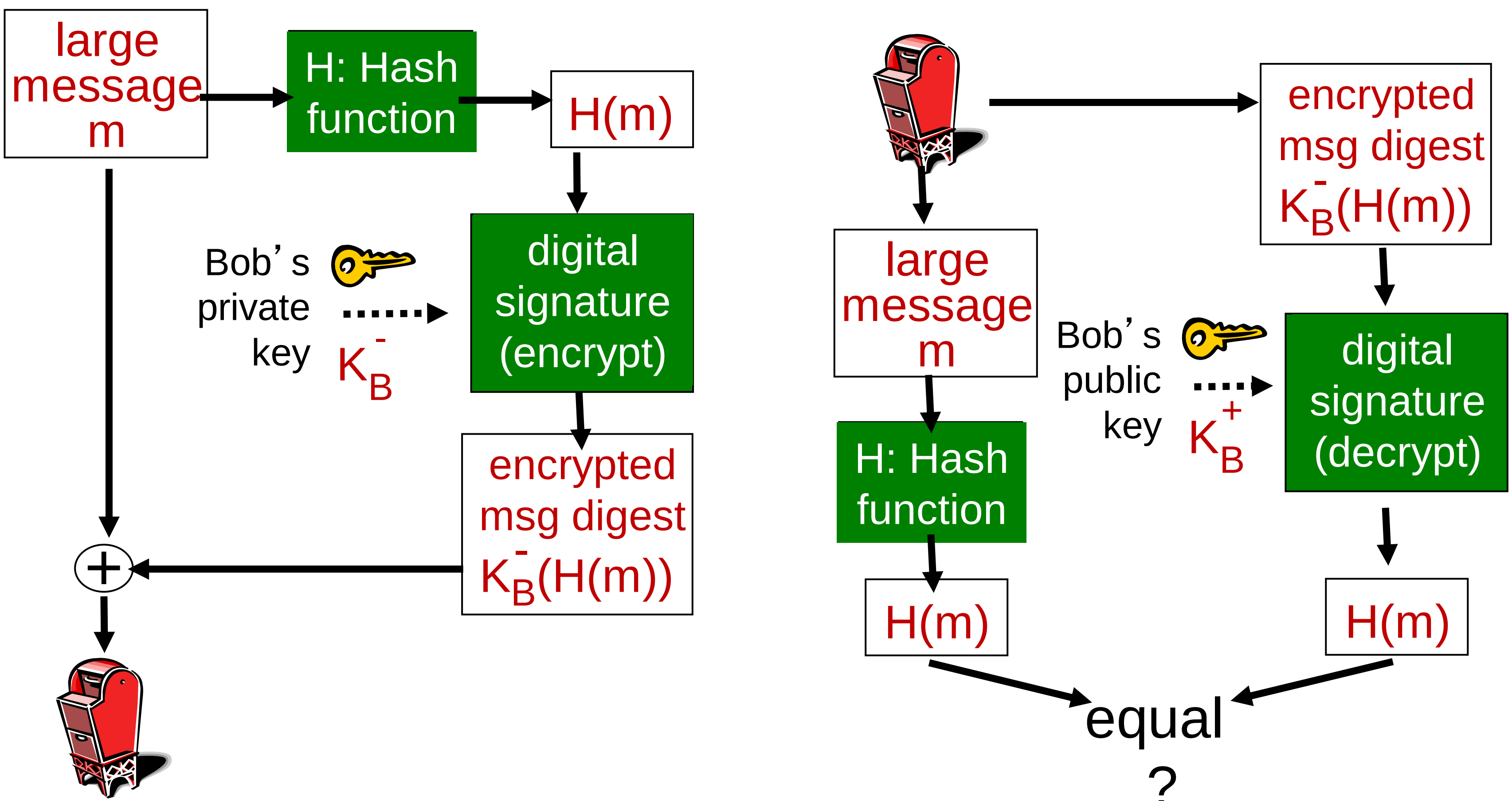
- apply hash function H to *m*, get fixed size message digest, *H(m)*.



Digital signature = signed message digest

Bob sends digitally signed message:

Alice verifies signature, integrity of digitally signed message:

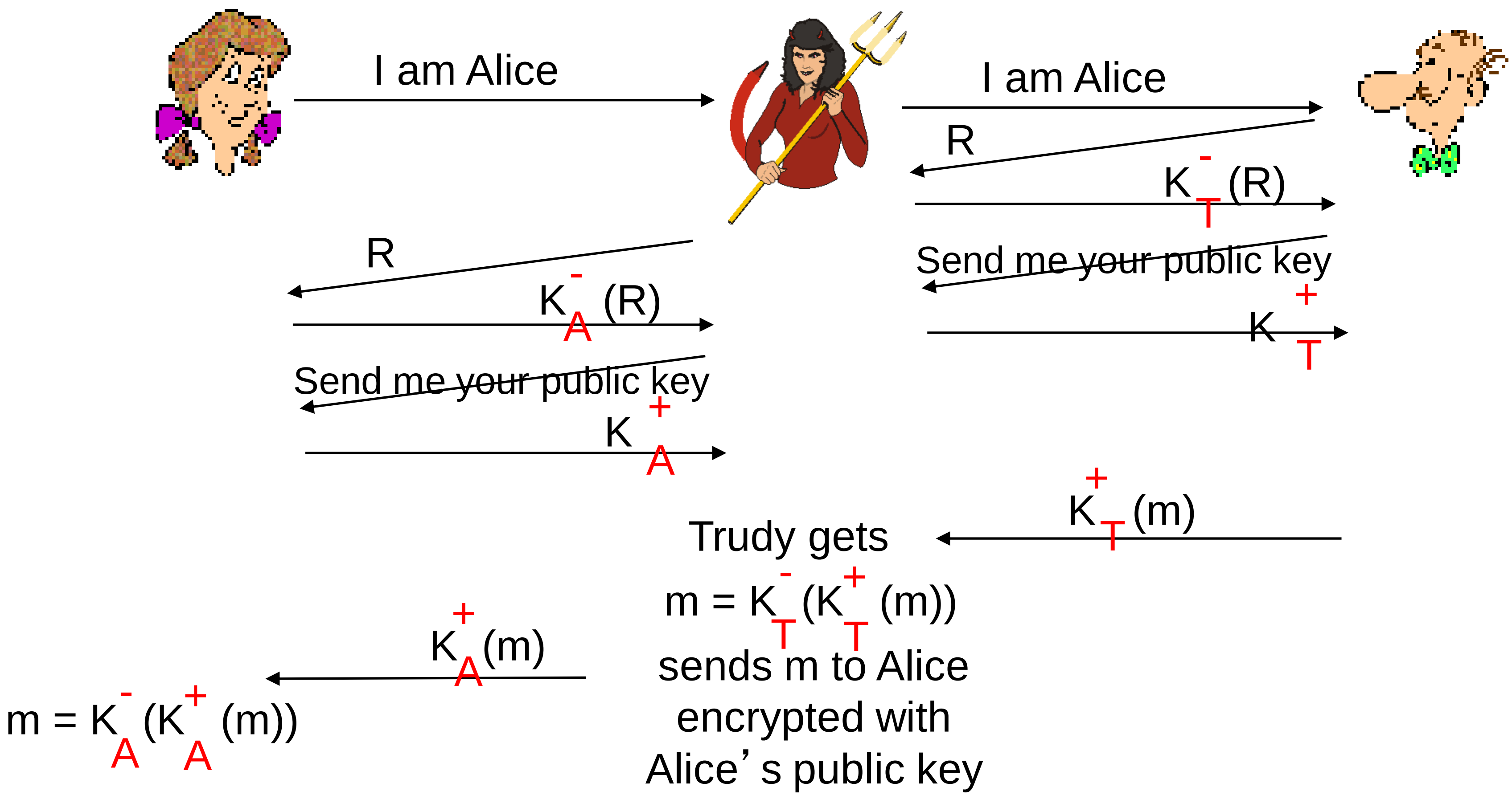


Hash function algorithms

- MD5 hash function widely used (RFC 1321)
  - computes 128-bit message digest in 4-step process.
  - arbitrary 128-bit string x, appears difficult to construct msg m whose MD5 hash is equal to x
- SHA-1 is also used
  - US standard [NIST, FIPS PUB 180-1]
  - 160-bit message digest

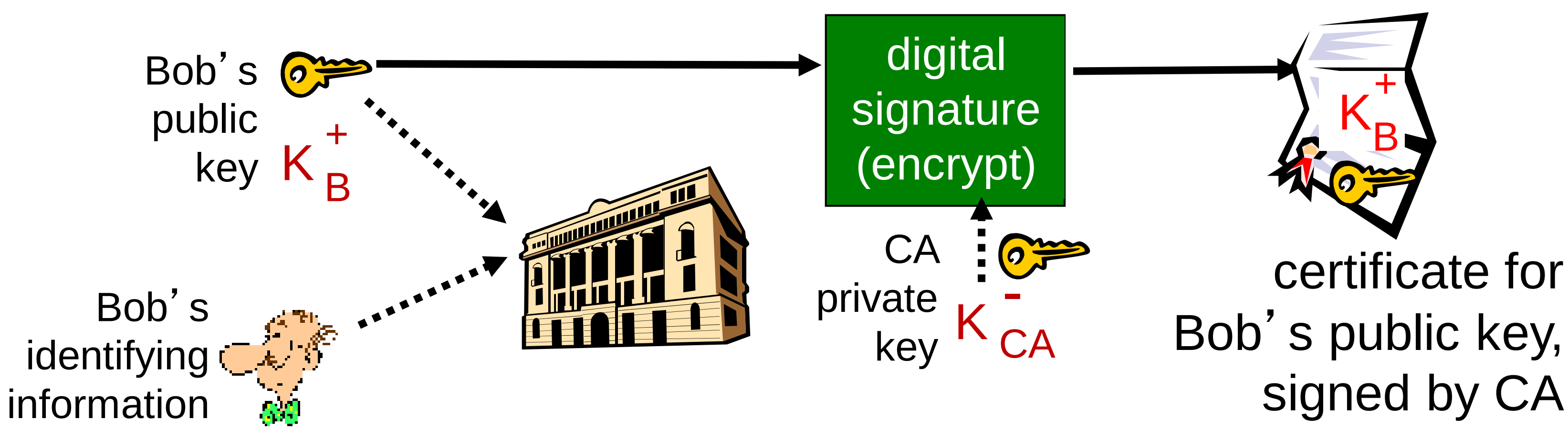
Recall: ap5.0 security hole

man in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)



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