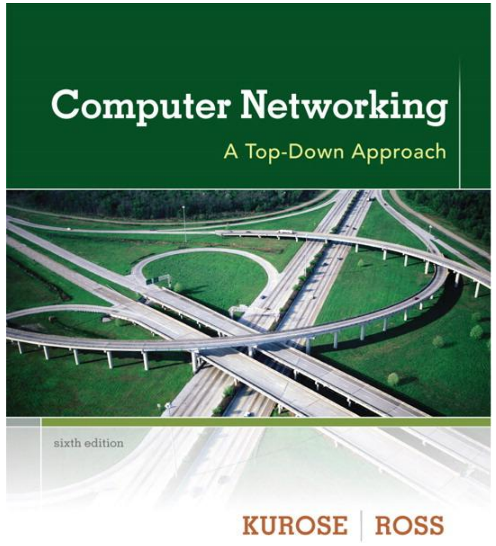
Chapter 8
Security



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Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
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- These slides are adapted from the slides provided by Kurose-Ross Book

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


NATIONAL SECURITY AGENCY
UNITED STATES OF AMERICA

What is network security?

confidentiality: only sender, intended receiver should "understand" message contents

- sender encrypts message
- receiver decrypts message

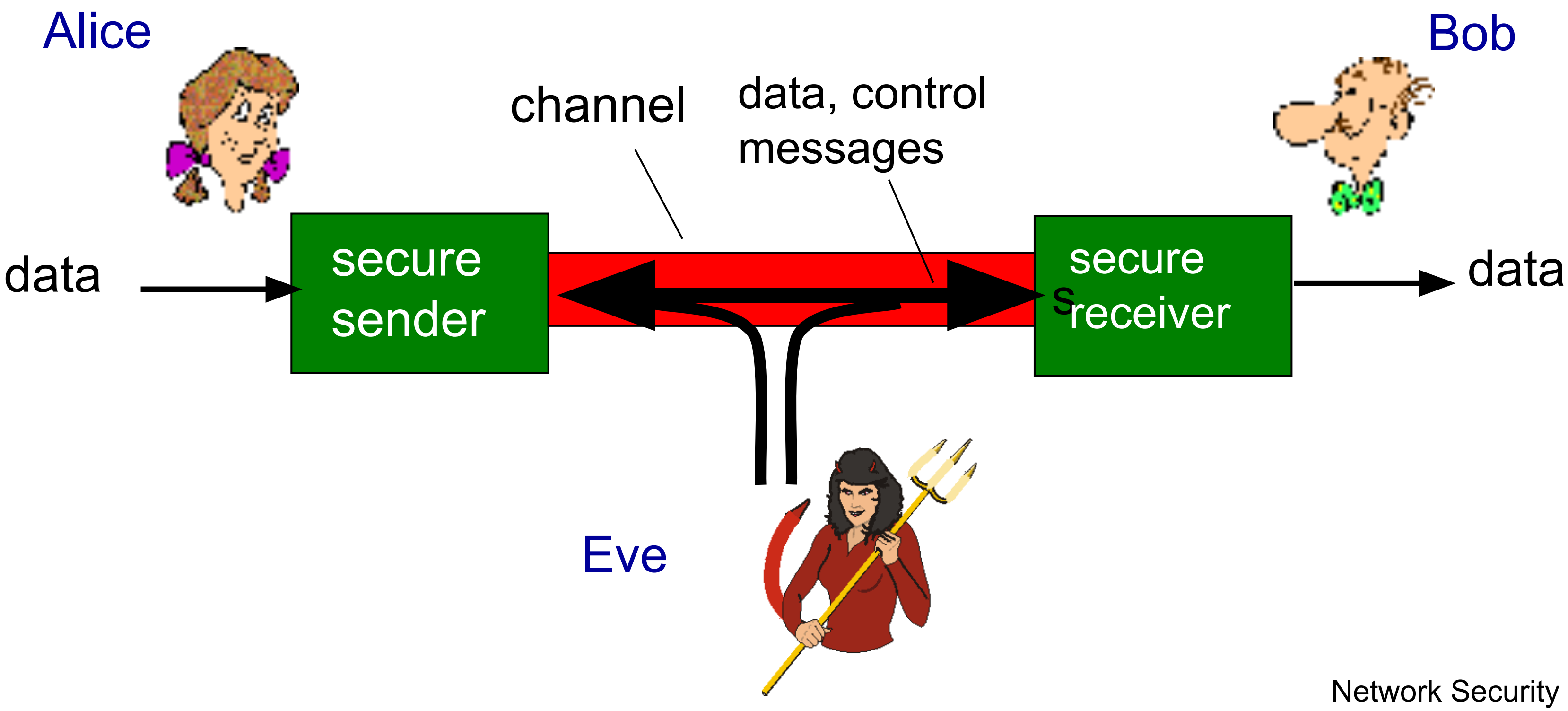
authentication: sender, receiver want to confirm identity of each other

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, Eve

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



Who might Bob, 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!

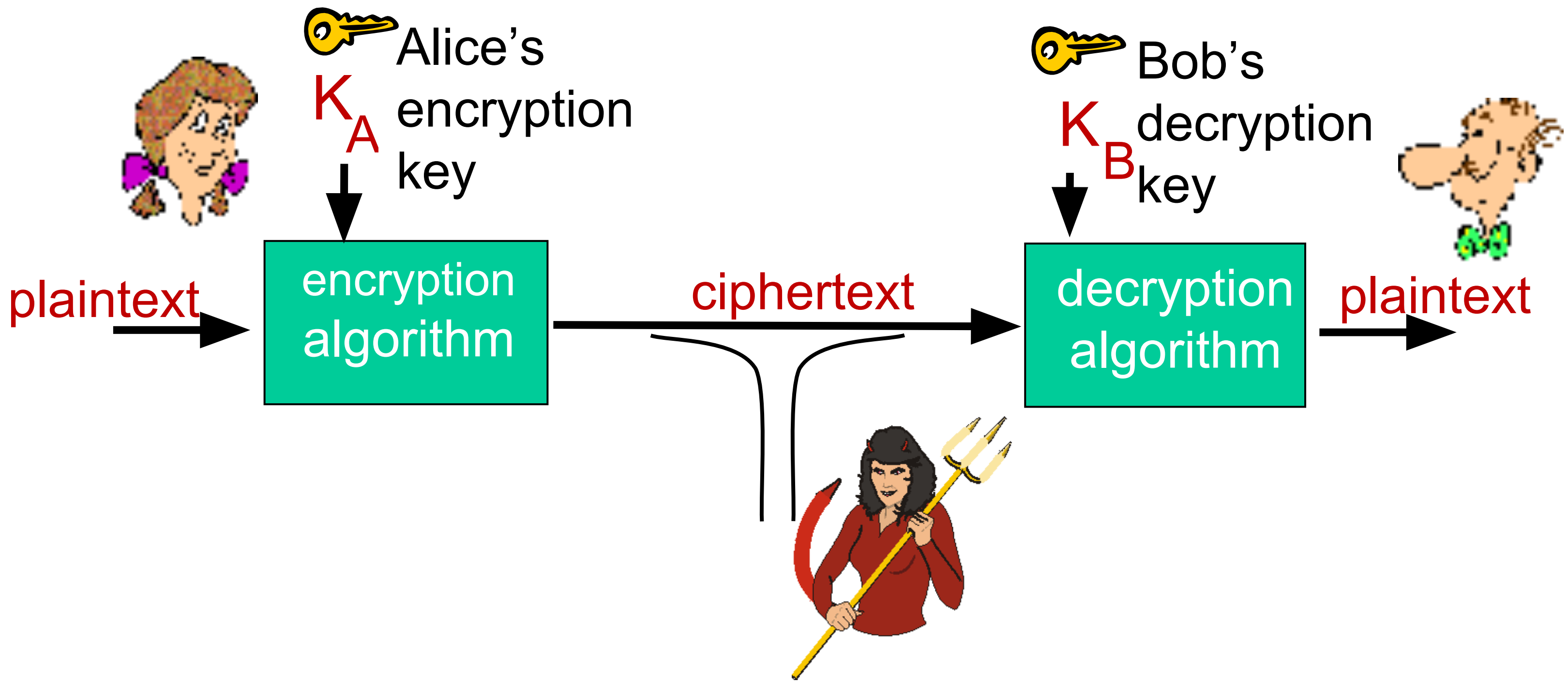
Q: What can a "bad guy" do?

A: A lot!

- *eavesdrop:* intercept messages
- actively *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)

Chapter 8 roadmap

The language of cryptography



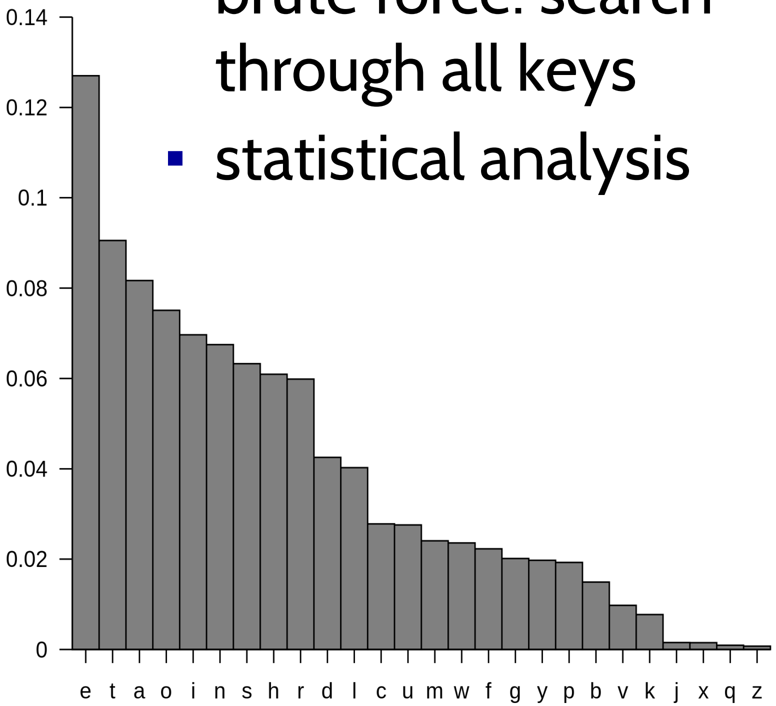
m plaintext message

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

$m = K_B(K_A(m))$

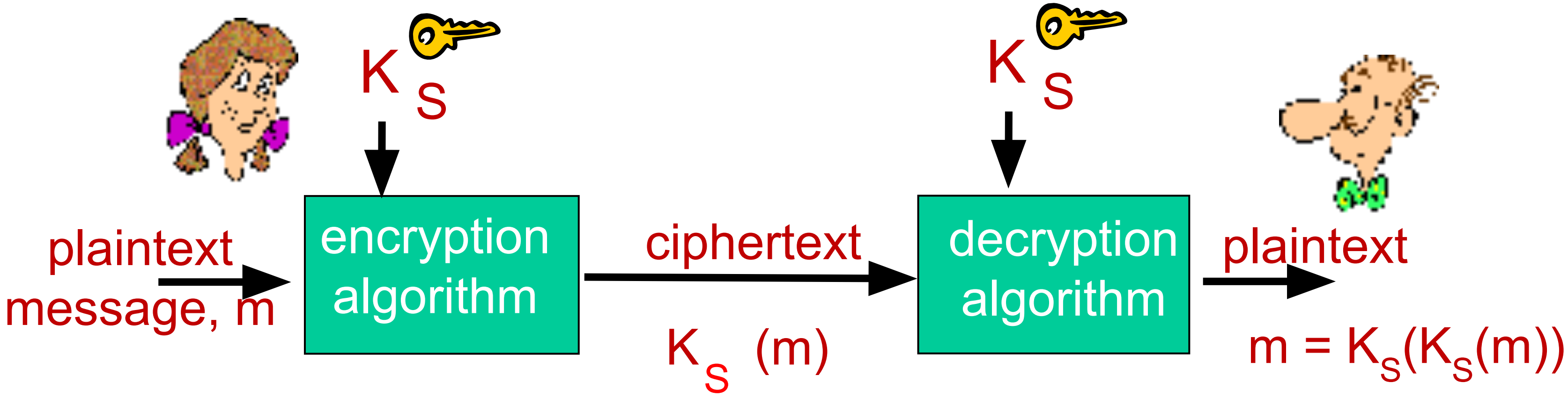
Breaking an encryption scheme

- cipher-text only attack: Eve has ciphertext she can analyze
- two approaches:
  - brute force: search through all keys
  - statistical analysis



- known-plaintext attack: Eve has plaintext corresponding to ciphertext
  - e.g., in monoalphabetic cipher, Eve determines pairings for a,l,i,c,e,b,o,
- chosen-plaintext attack: Eve can get ciphertext for chosen plaintext

Symmetric key cryptography

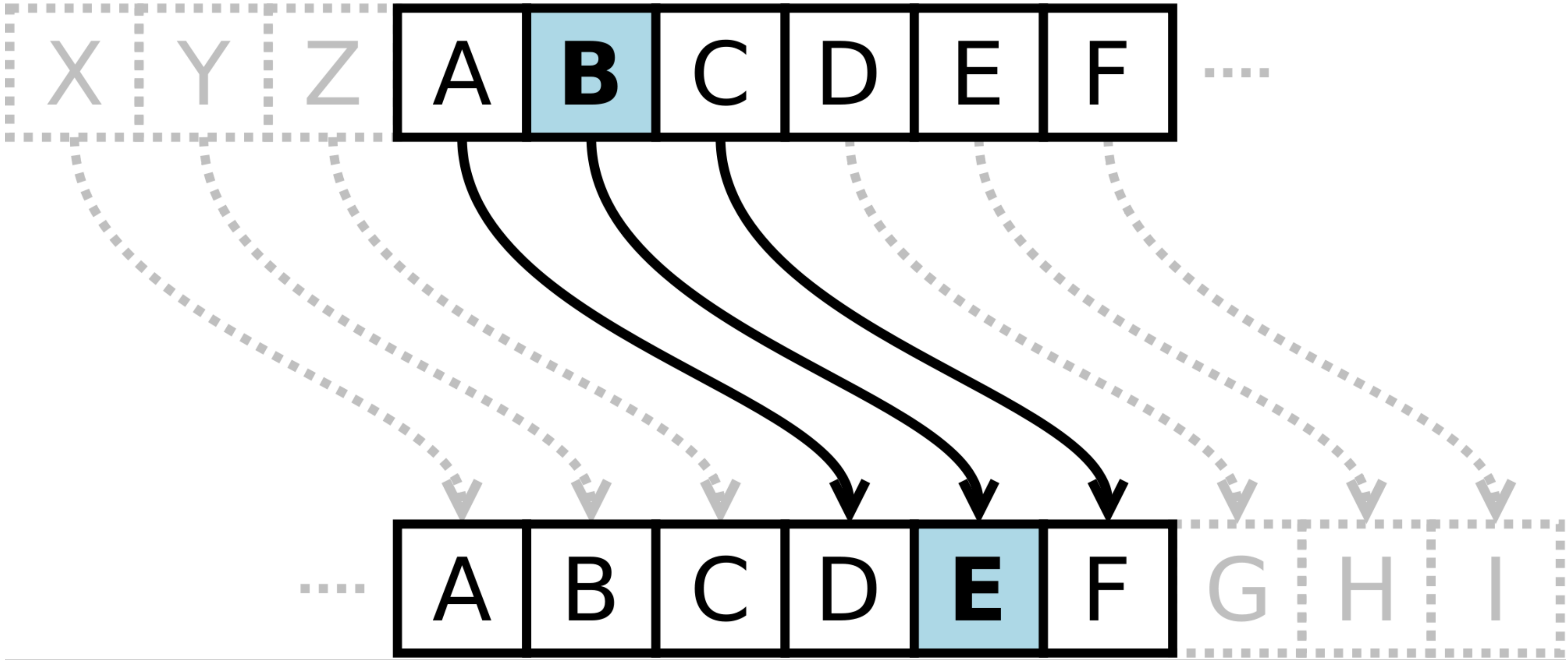


symmetric key crypto: Bob and Alice share same (symmetric) key: K_S

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

Q: how do Bob and Alice agree on key value?

Caesar cipher scheme



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

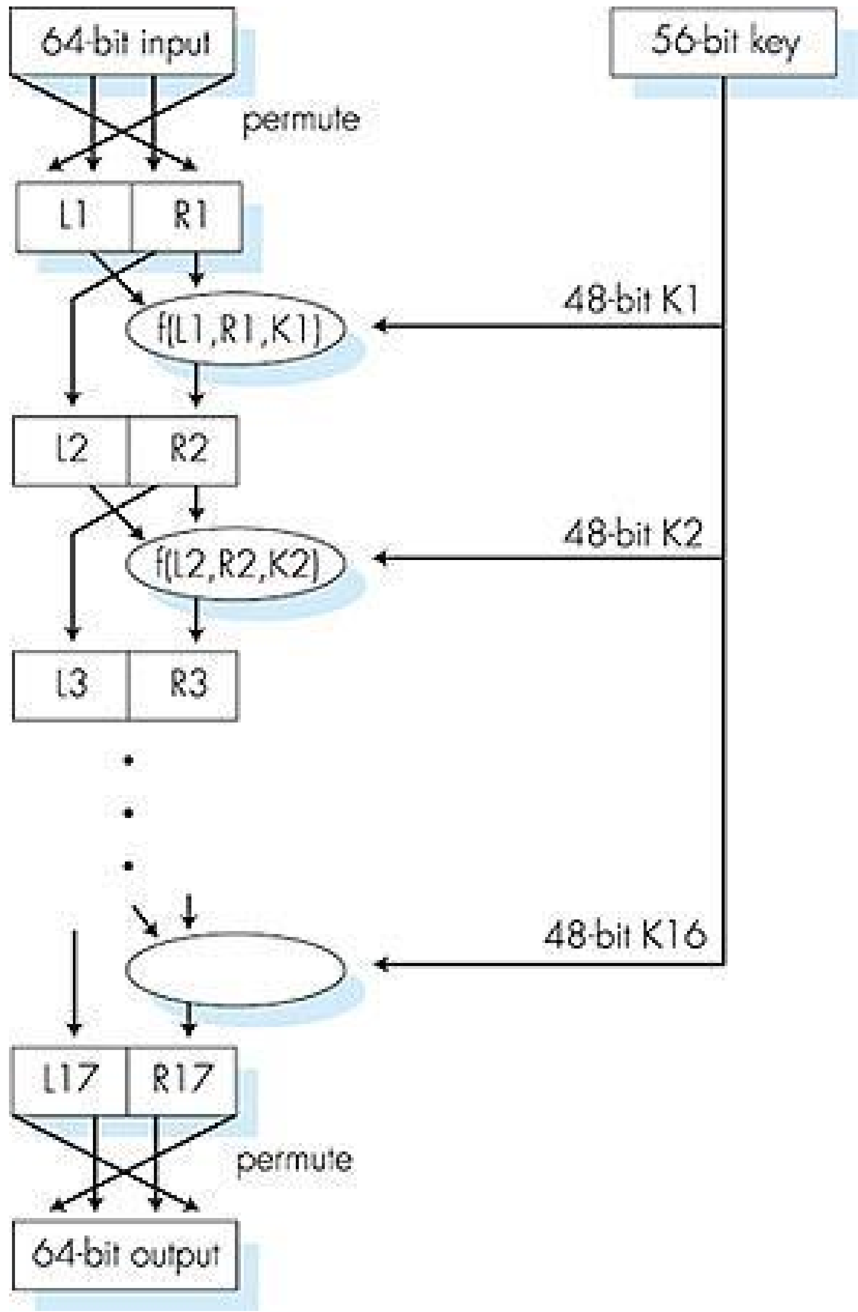
DES: Data Encryption Standard

- 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

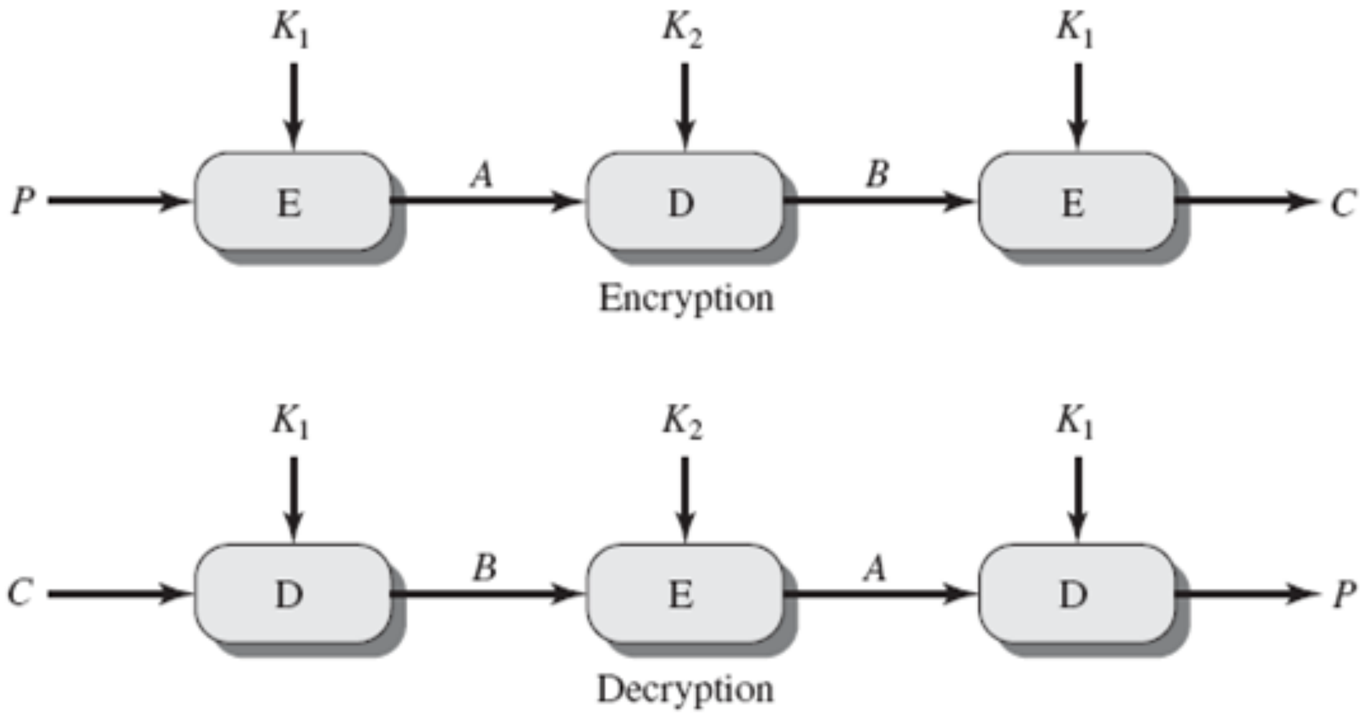
Symmetric key crypto: DES

DES operation

- initial permutation
- 16 identical "rounds" of function application, each using different 48 bits of key
- final permutation



3DES



(b) Triple encryption

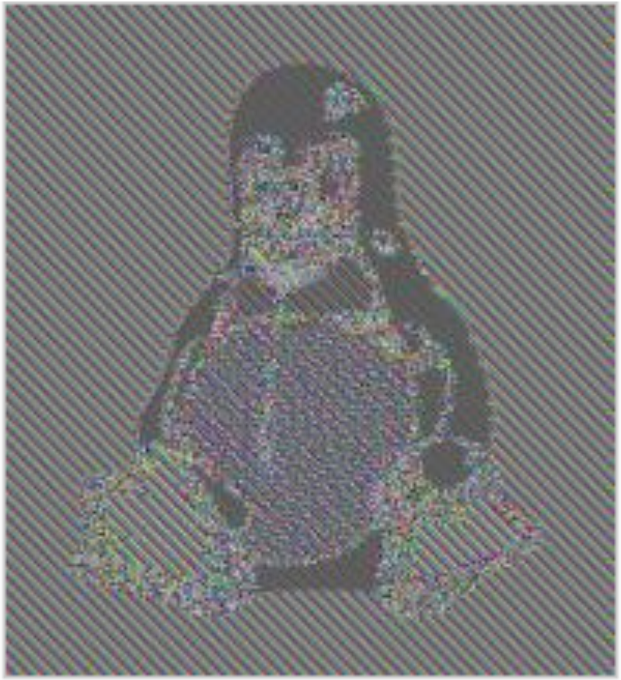
Figure 6.1 Multiple Encryption

AES: Advanced Encryption Standard

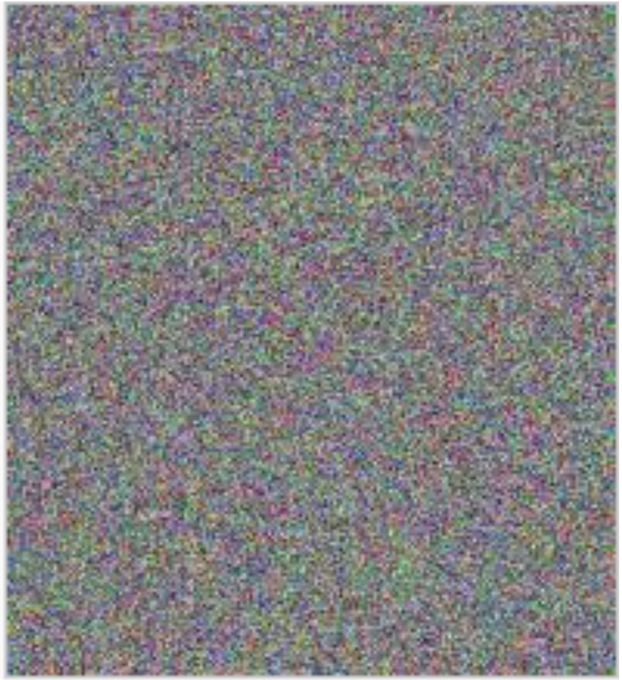
- symmetric-key NIST standard, replaced DES (Nov 2001)
- processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for AES

Same Plaintext same Ciphertext?

Original image

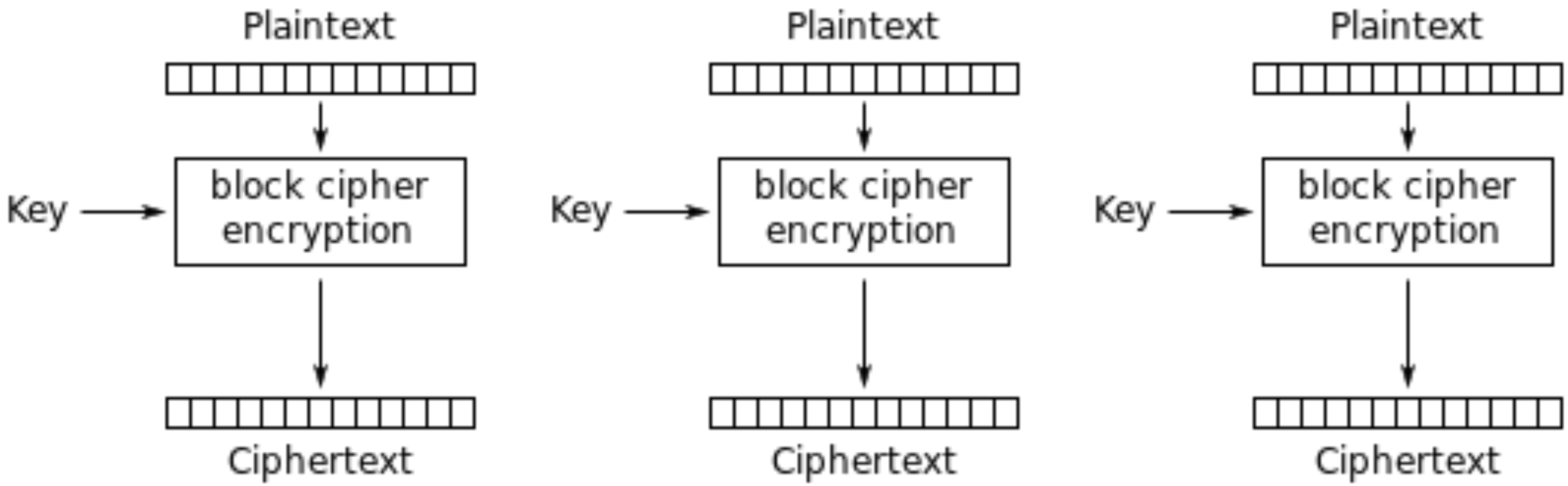


Encrypted using ECB mode



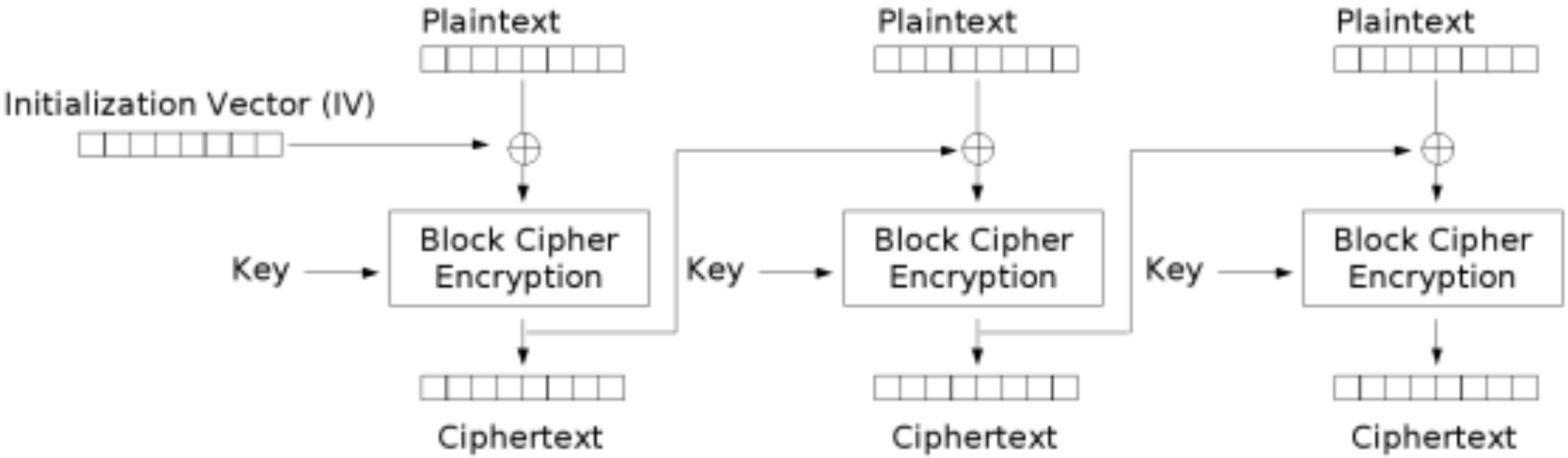
Modes other than ECB result in pseudo-randomness

Mode of operation: ECB



Electronic Codebook (ECB) mode encryption

Mode of operation: CBC



Cipher Block Chaining (CBC) mode encryption

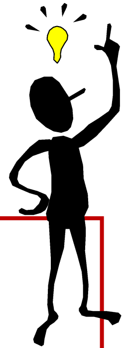
Let's try to decrypt

DGHVVR IDFFNDPR AQD SDAVD

Public Key Cryptography

symmetric key crypto

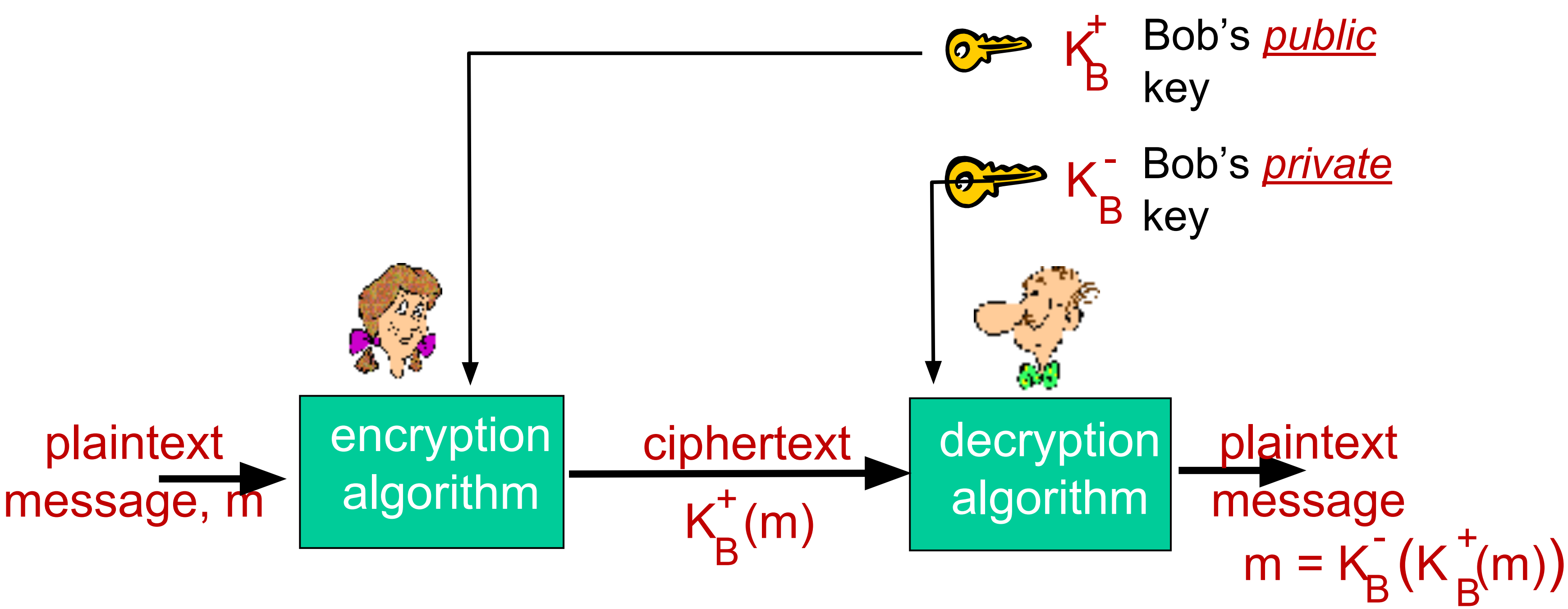
- requires sender, receiver know shared secret key
- Q: how to agree on key in first place (particularly if never "met")?



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 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

Prerequisite: modular arithmetic

- 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

  $(a \bmod n)^d \bmod n = a^d \bmod n$
- 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 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 $n = pq$, $z = (p-1)(q-1)$

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 (n,e). *private* key is (n,d).

$\underbrace{(n,e)}_{K_B^+}$ $\underbrace{(n,d)}_{K_B^-}$

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.

	bit pattern	m	m^e	$c = m^e \bmod n$
encrypt:	00001000	12	24832	17

	c	c^d	$m = c^d \bmod n$
decrypt:	17	481968572106750915091411825223071697	12

Why does RSA work?

- must show that $c^d \bmod n = m$
  where $c = m^e \bmod n$
- fact: for any x and y: $x^y \bmod n = x^{(y \bmod z)} \bmod n$
  - where n= pq and z = (p-1)(q-1)
- thus,
  $c^d \bmod n = (m^e \bmod n)^d \bmod n$
  $= m^{ed} \bmod n$
  $= m^{(ed \bmod z)} \bmod n$
  $= m^1 \bmod n$
  $= m$

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

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

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

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

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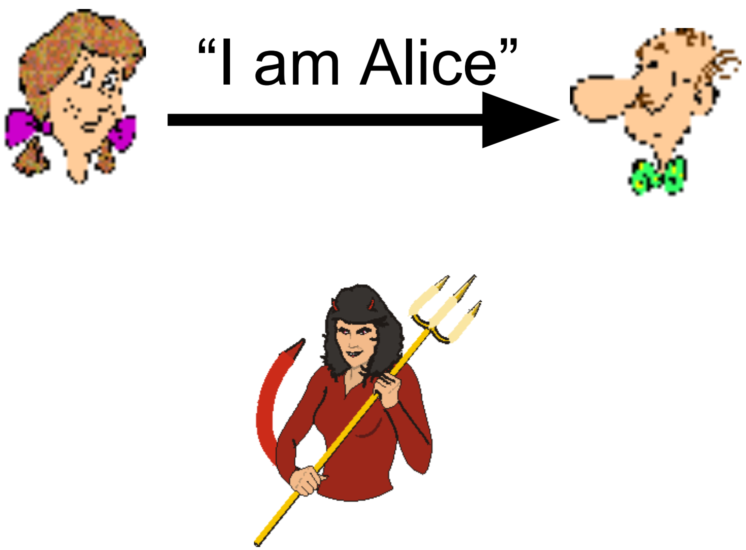
Authentication

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

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

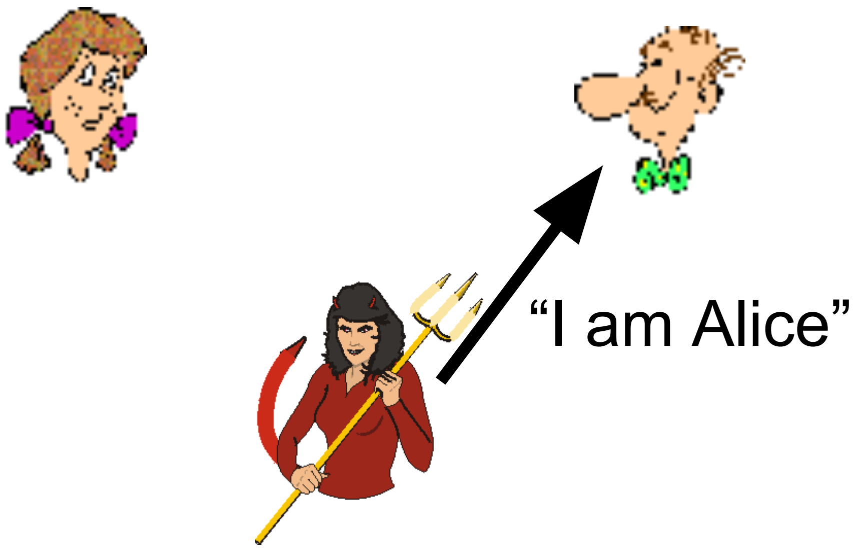


Failure scenario??

Authentication

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

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



in a network,
Bob can not "see" Alice,
so Eve simply declares
herself to be Alice

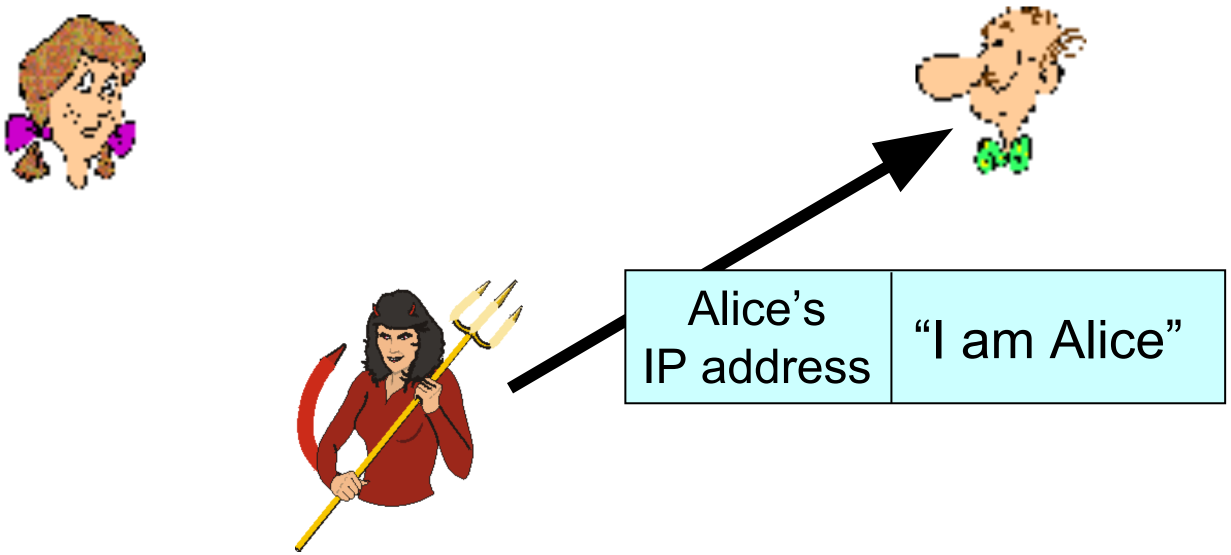
Authentication: another try

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

Failure scenario??

Authentication: another try

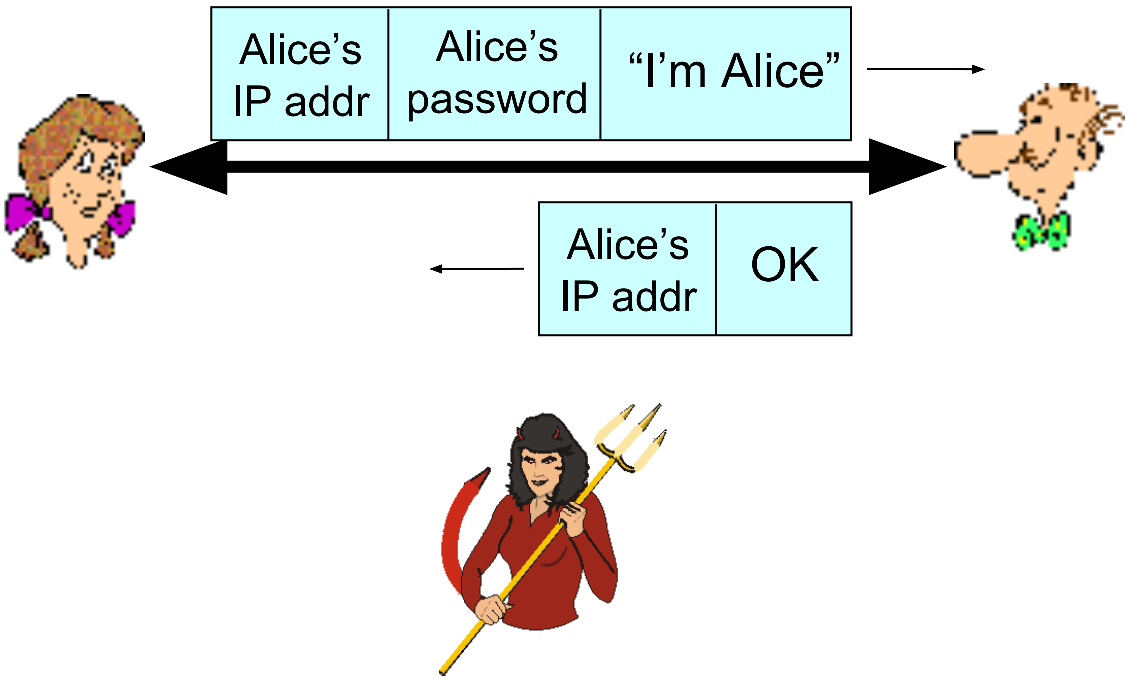
Protocol ap2.0: Alice says "I am Alice" in an IP packet containing her source IP address



Eve 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.



Failure scenario??

Authentication: another try

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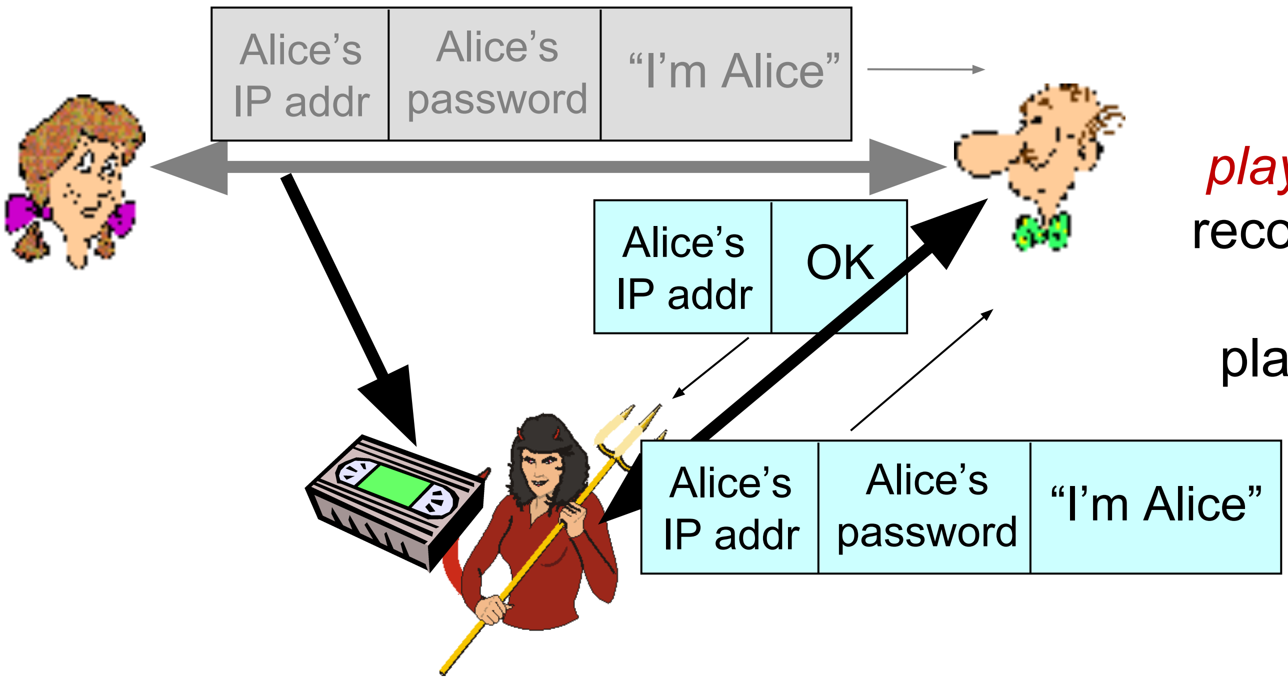
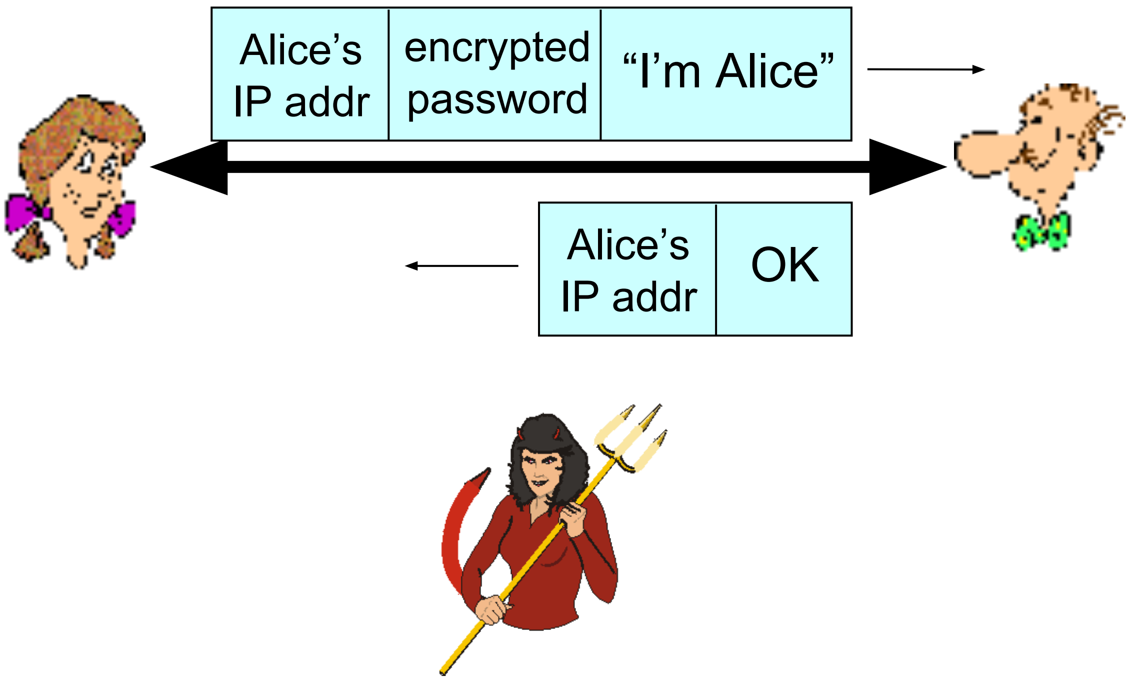


playback attack: Eve records Alice's packet and later plays it back to Bob

Authentication: yet another try

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



Failure scenario??

Authentication: yet another try

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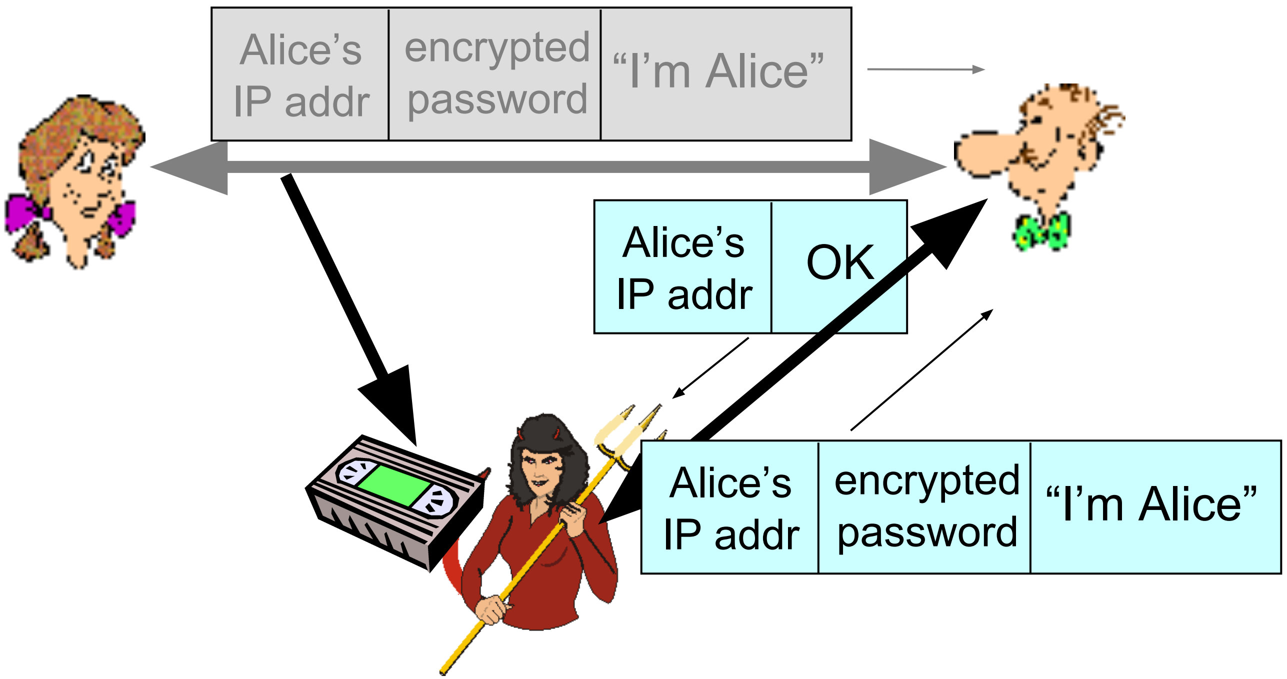


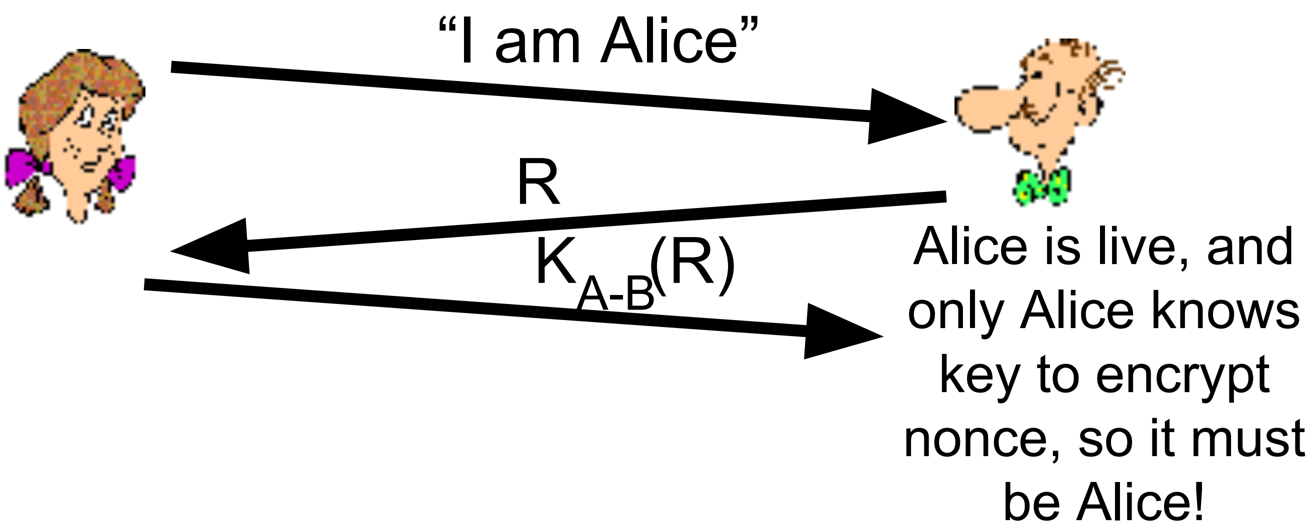
record and playback *still* works!

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



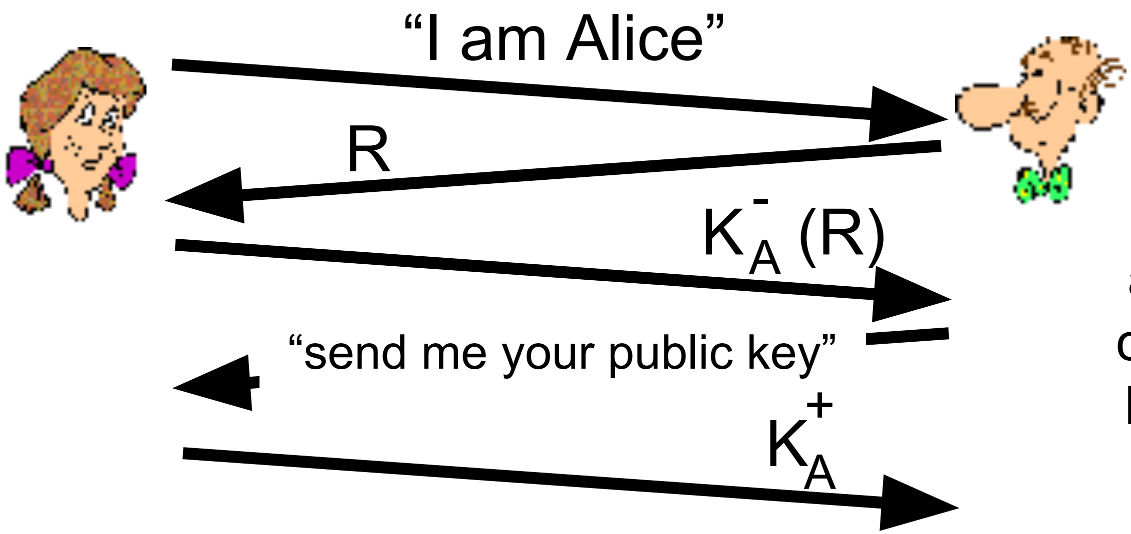
Failures, drawbacks?

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

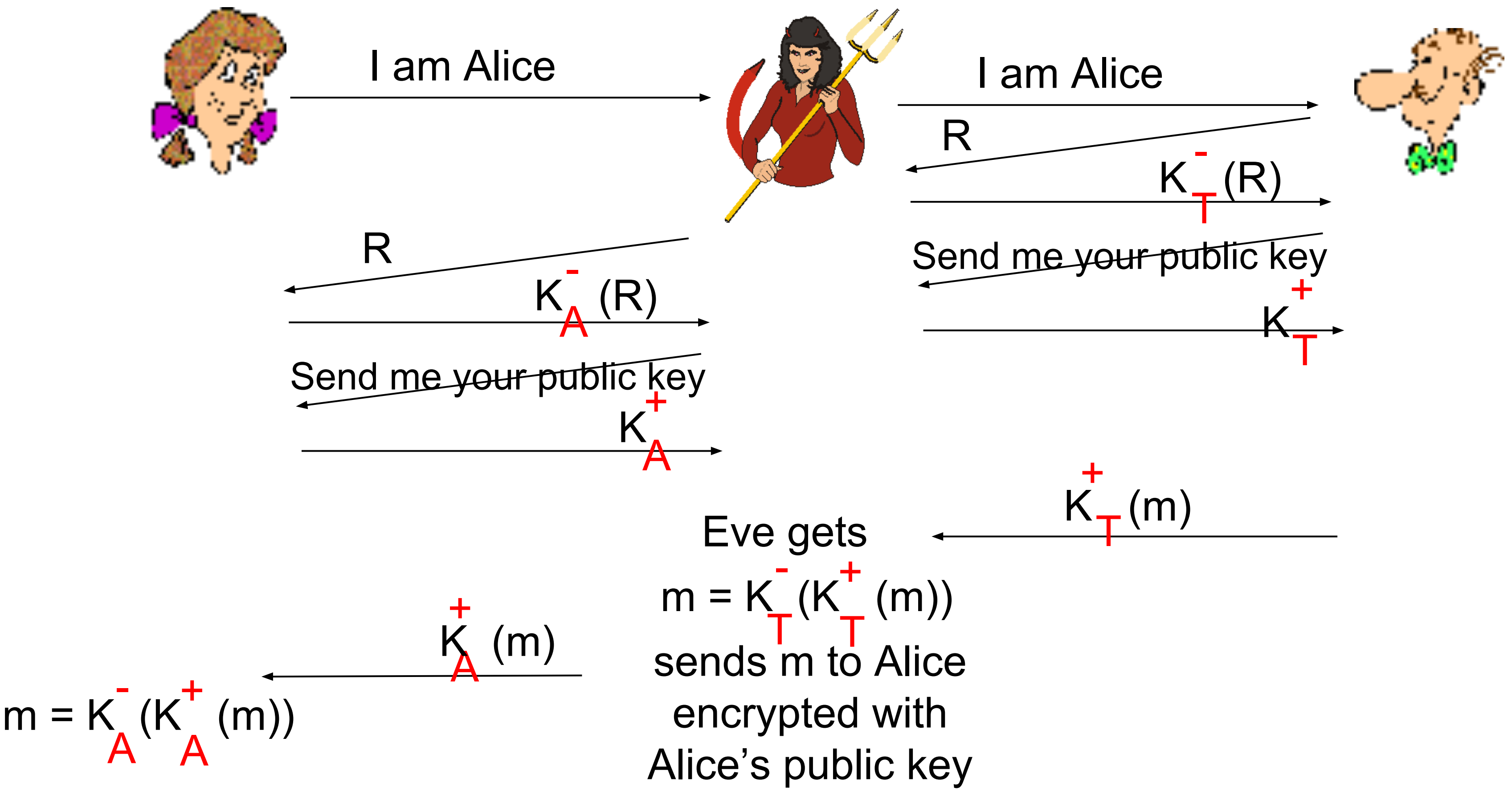
$K_A^+(K_A^-(R)) = R$

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 (or woman) in the middle attack: Eve poses as Alice (to Bob) and as Bob (to Alice)



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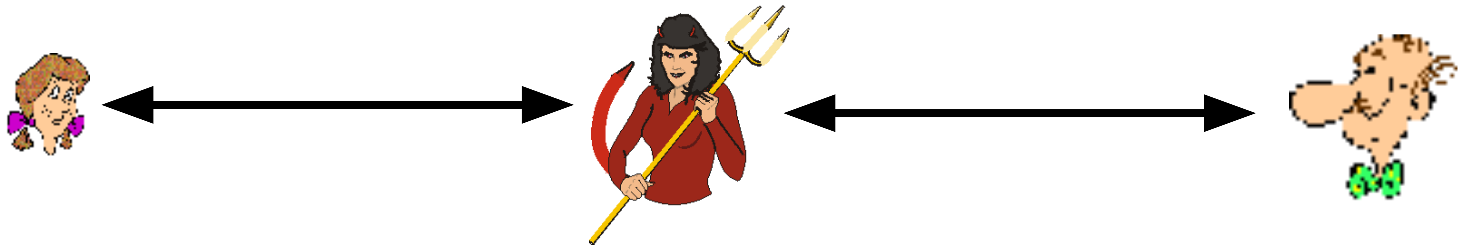

difficult to detect:

- Bob receives everything that Alice sends, and vice versa. (e.g., so Bob, Alice can meet one week later and recall conversation!)
- problem is that Eve receives all messages as well!