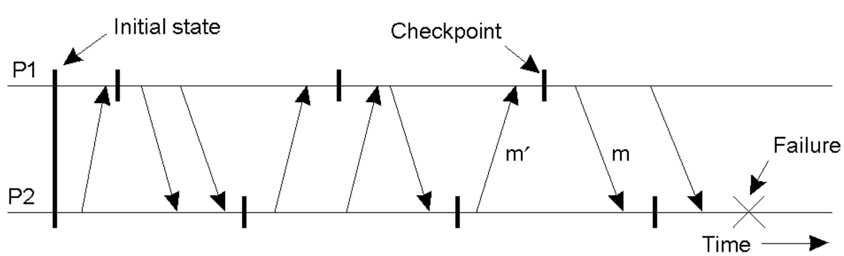
Recovery

- Techniques thus far allow failure handling
- Recovery: operations that must be performed after a failure to recover to a correct state
- Techniques:
  - Checkpointing:
    - Periodically checkpoint state
    - Upon a crash roll back to a previous checkpoint with a *consistent state*

Independent Checkpointing



- Each processes periodically checkpoints independently of other processes
- Upon a failure, work backwards to locate a consistent cut
- Problem: if most recent checkpoints form inconsistent cut, will need to keep rolling back until a consistent cut is found
- Cascading rollbacks can lead to a domino effect.

Coordinated Checkpointing

- Take a distributed snapshot [discussed in Lec 11]
- Upon a failure, roll back to the latest snapshot
  - All process restart from the latest snapshot

Message Logging

- Checkpointing is expensive
  - All processes restart from previous consistent cut
  - Taking a snapshot is expensive
  - Infrequent snapshots => all computations after previous snapshot will need to be redone [wasteful]
- Combine checkpointing (expensive) with message logging (cheap)
  - Take infrequent checkpoints
  - Log all messages between checkpoints to local stable storage
  - To recover: simply replay messages from previous checkpoint
    - Avoids recomputations from previous checkpoint

Recovery Oriented Computing

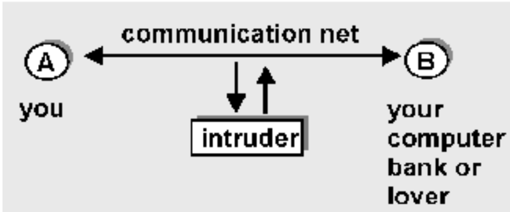
- Cheaper to optimize for recover than to design the system to prevent faults
- Need to restart the system upon failure

- Naïve case: reboot
- Reboot part of the system: modular system, where components can be restarted independently
  - Unix /etc/rc service
- Stateful recovery
  - Database recovery
  - Use of checpointing

Security in Distributed Systems

- Introduction
- Cryptography
- Authentication
- Key exchange
- Readings: Tannenbaum, chapter 9
  Ross/Kurose, Ch 7

Network Security



Intruder may

- eavesdrop
- remove, modify, and/or insert messages
- read and playback messages
- Security threats
  - Interception, Interruption, Modification, Fabrication

Issues

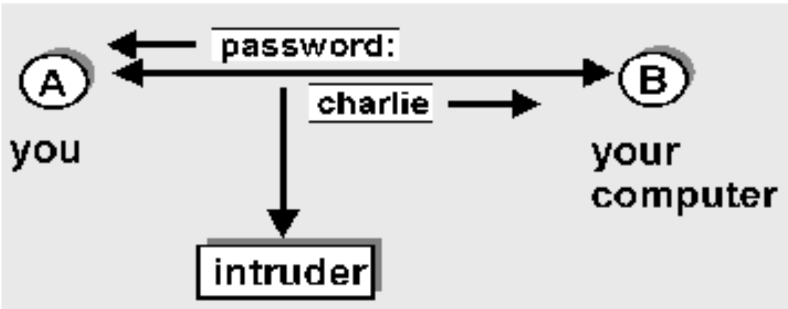
Important issues:

- *Encryption/ cryptography:* secrecy of info being transmitted
- *authentication:* proving who you are and having correspondent prove his/her/its identity
- *Authorization:* verify you have rights to perform requested action
- *Auditing:* log actions and do post-facto analysis (forensics)

Security in Computer Networks

User resources:

- login passwords often transmitted unencrypted in TCP packets between applications (e.g., telnet, ftp)



Security Issues

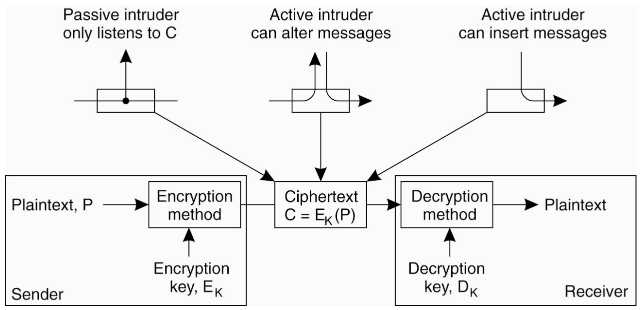
Network resources:

- often completely unprotected from intruder eavesdropping, injection of false messages
- mail spoofs, router updates, ICMP messages, network management messages

Bottom line:

- intruder attaching his/her machine (access to OS code, root privileges) onto network can override many system-provided security measures
- users must take a more active role

Encryption



plaintext: unencrypted message

ciphertext: encrypted form of message

Intruder may

- intercept ciphertext transmission
- intercept plaintext/ciphertext pairs
- obtain encryption decryption algorithms

A simple encryption algorithm

Substitution cipher:

`abcdefghijklmnopqrstuvwxyz`

`poiuytrewqasdfghjklmnbvczx`

- replace each plaintext character in message with matching ciphertext character:

plaintext: `Charlotte, my dear`

ciphertext: `iepksgmmy, dz uypk`

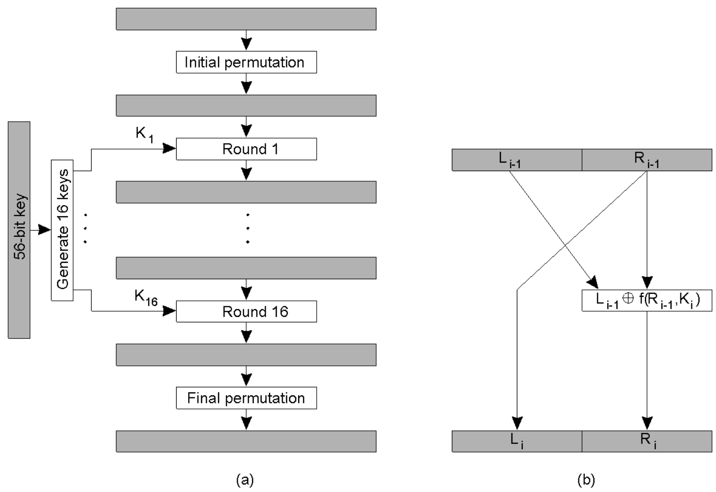
Encryption Algo (contd)

- key is pairing between plaintext characters and ciphertext characters
- **symmetric key:** sender and receiver use same key
- 26! (approx 10^26) different possible keys: unlikely to be broken by random trials
- substitution cipher subject to decryption using observed frequency of letters
  - 'e' most common letter, 'the' most common word

DES: Data Encryption Standard

- encrypts data in 64-bit chunks
- encryption/decryption algorithm is a published standard
  - everyone knows how to do it
- substitution cipher over 64-bit chunks: 56-bit key determines which of 56! substitution ciphers used
  - substitution: 19 stages of transformations, 16 involving functions of key
- Replacements: DES3 and now AES

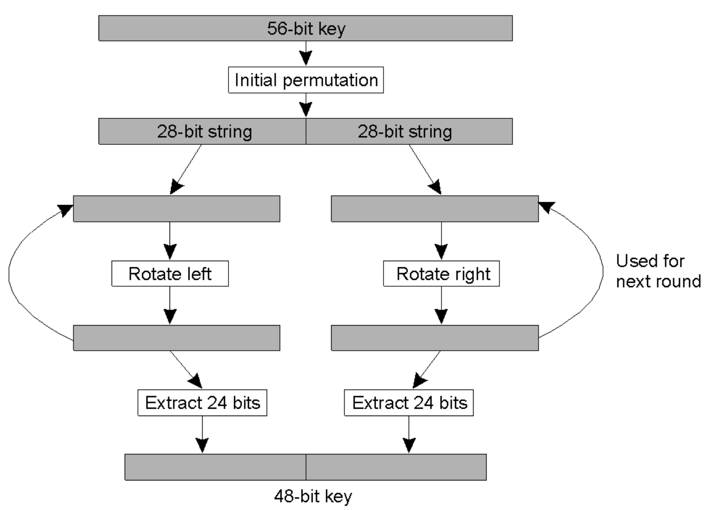
Symmetric Cryptosystems: DES (1)



a) The principle of DES

b) Outline of one encryption round

Symmetric Cryptosystems: DES (2)



- Details of per-round key generation in DES.

Key Distribution Problem

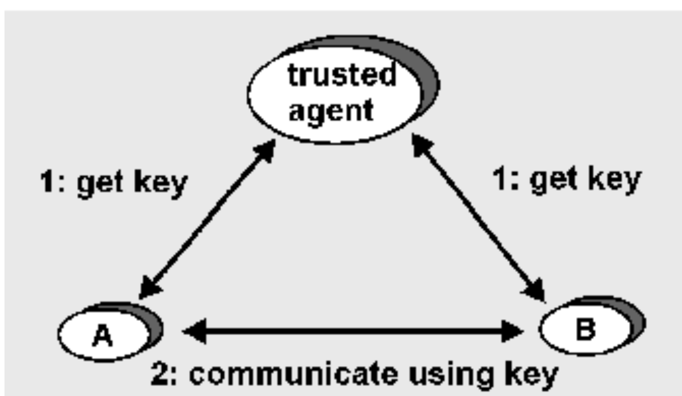
Problem: how do communicant agree on symmetric key?

- N communicants implies N keys

Trusted agent distribution:

- keys distributed by centralized trusted agent
- any communicant need only know key to communicate with trusted agent
- for communication between i and j, trusted agent will provide a key

Key Distribution

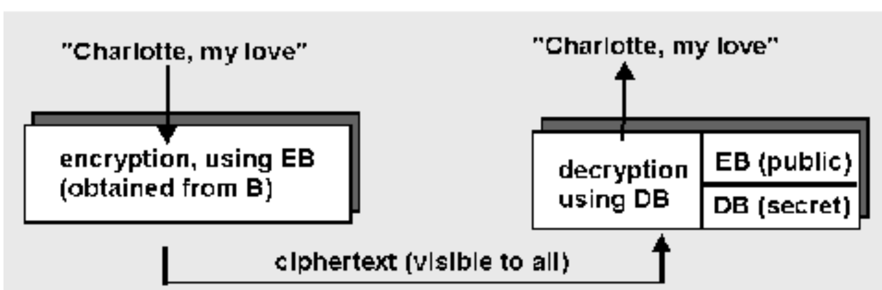


We will cover in more detail shortly

Public Key Cryptography

- separate encryption/decryption keys
  - receiver makes *known* (!) its encryption key
  - receiver keeps its decryption key secret
- to send to receiver B, encrypt message M using B's publicly available key, EB
  - send EB(M)
- to decrypt, B applies its private decrypt key DB to receiver message:
  - computing DB(EB(M)) gives M

Public Key Cryptography



- knowing encryption key does not help with decryption; decryption is a non-trivial inverse of encryption
- only receiver can decrypt message

Question: good encryption/decryption algorithms

RSA: public key encryption/ decryption

RSA: a public key algorithm for encrypting/decrypting

Entity wanting to receive encrypted messages:

- choose two prime numbers, p, q greater than 10^100
- compute $n=pq$ and $z = (p-1)(q-1)$
- choose number d which has no common factors with z
- compute e such that $ed = 1$ mod z, i.e.,

  integer-remainder((ed) / ((p-1)(q-1))) = 1, i.e.,

  $ed = k(p-1)(q-1) + 1$
- three numbers:
  - e, n made public
  - d kept secret

RSA (continued)

to encrypt:

- divide message into blocks, $\{b\_i\}$ of size j: $2^j < n$
- encrypt: $encrypt(b\_i) = b\_I^e \bmod n$

to decrypt:

- $b\_i = encrypt(b\_i)^d$

to break RSA:

- need to know p, q, given $pq=n$, n known
- factoring 200 digit n into primes takes 4 billion years using known methods

RSA example

- choose $p=3$, $q=11$, gives $n=33$, $(p-1)(q-1)=z=20$
- choose $d = 7$ since 7 and 20 have no common factors
- compute $e = 3$, so that $ed = k(p-1)(q-1)+1$ (note: $k=1$ here)

Further notes on RSA

why does RSA work?

- crucial number theory result: if p, q prime then
  b_i^((p-1)(q-1)) mod $pq = 1$
- using mod pq arithmetic:

$(b$^e)^d = b^{ed}

= b^{k(p-1)(q-1)+1} for some k

= b b^(p-1)(q-1) b^(p-1)(q-1) ... b^(p-1)(q-1)

= b 1 1 ... 1

= b

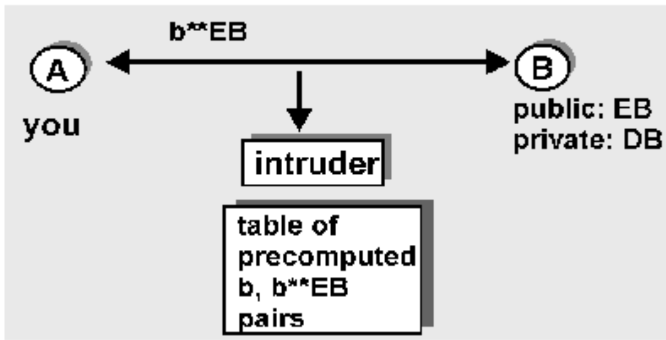
Note: we can also encrypt with d and encrypt with e.

- this will be useful shortly

How to break RSA?

Brute force: get B's public key

- for each possible *b_i* in plaintext, compute *b_i^e*
- for each observed *b_i^e*, we then know *b_i*
- moral: choose size of *b_i* "big enough"



Breaking RSA

man-in-the-middle: intercept keys, spoof identity: