Distributed Systems

Giuseppe Anastasi
g.anastasi@iet.unipi.it
Pervasive Computing & Networking Lab. (PerLab)
Dept. of Information Engineering, University of Pisa

Overview

- Introduction
- Communication Networks
- Communication Protocols
- Distributed Programming

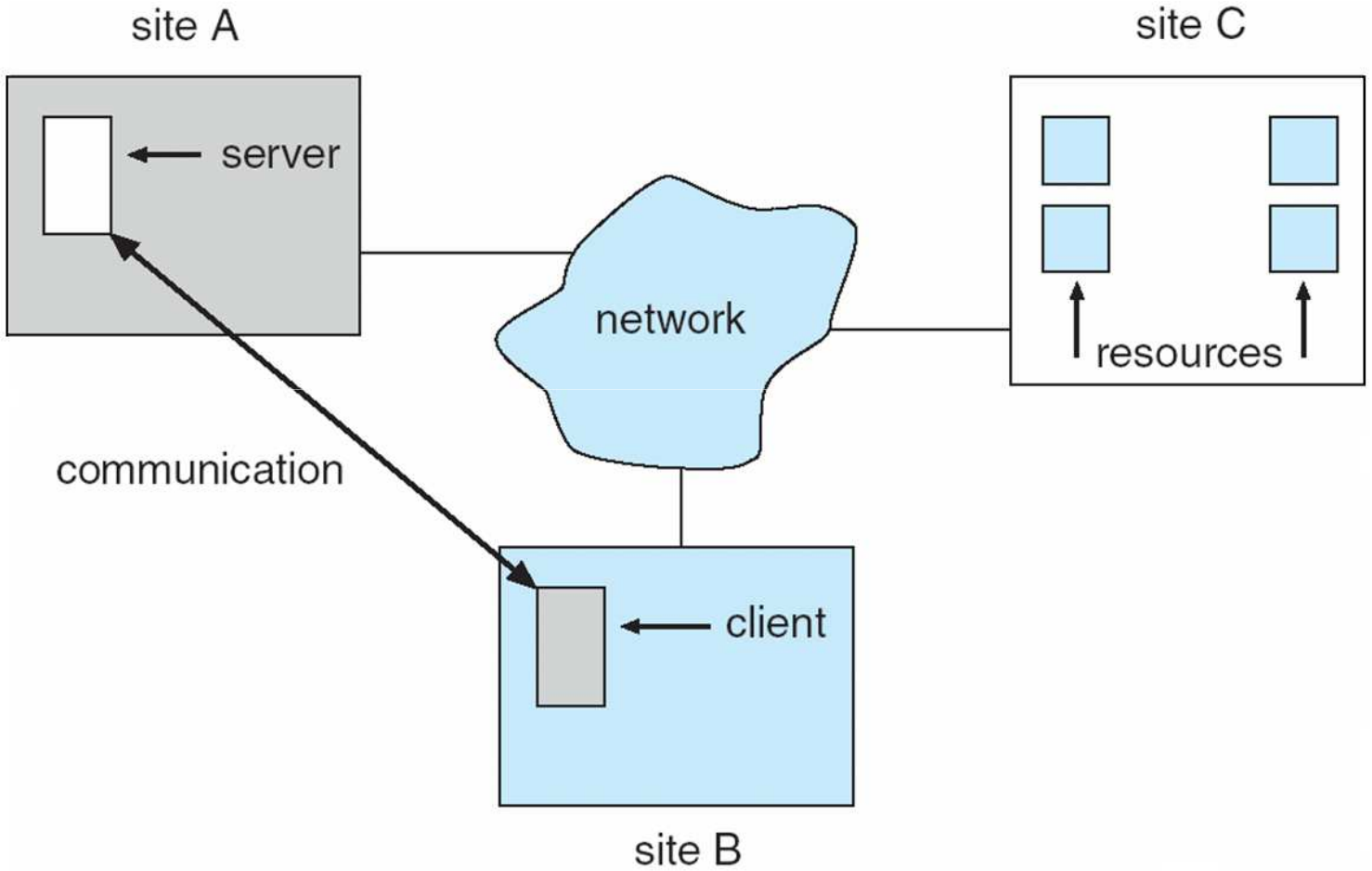
Objectives

- Provide a high-level overview of distributed systems and underlying communications networks
- Introduce different types of communication networks
- Discuss networking protocols that allow communication in a distributed environment
- Introduce principles of distributed programming

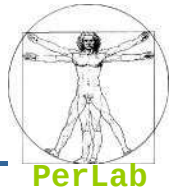
Motivation

- Distributed system is collection of loosely coupled processors interconnected by a communications network
- Processors variously called *nodes, computers, machines, hosts*
  - *Site* is location of the processor
- Reasons for distributed systems
  - Resource sharing
    - sharing and printing files at remote sites
    - processing information in a distributed database
    - using remote specialized hardware devices
  - Computation speedup – load sharing
  - Reliability – detect and recover from site failure, function transfer, reintegrate failed site
  - Communication – message passing

A Distributed System



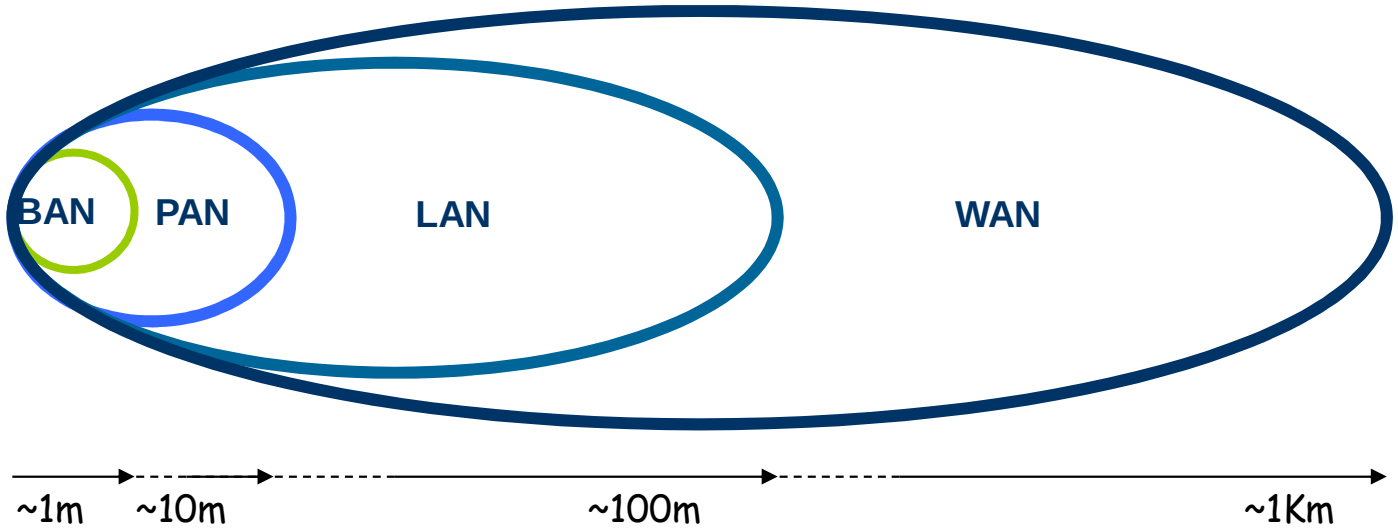
Overview



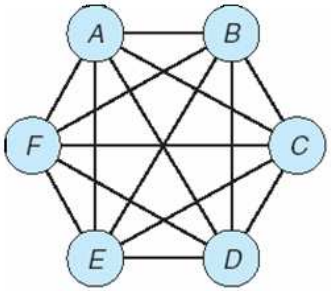
- Introduction
- Communication Networks
  - LAN
  - WAN
  - Internet
- Communication Protocols
- Distributed Programming

Classification of Communication Networks

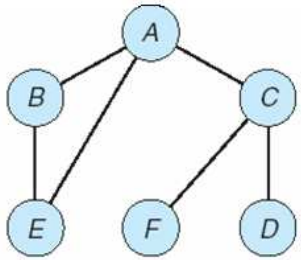
- Wide Area Networks (WAN)
- Metropolitan Area Networks (MAN)
- Local Area Networks (LAN)
- Personal Area Networks (PAN)
- Body Area Networks (BAN)



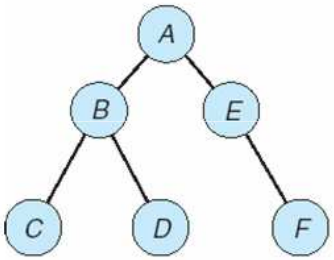
Network Topologies



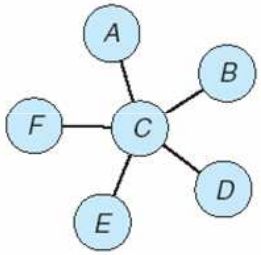
fully connected network



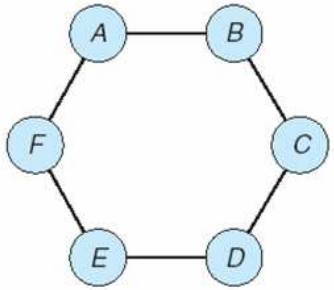
partially connected network



tree-structured network



star network



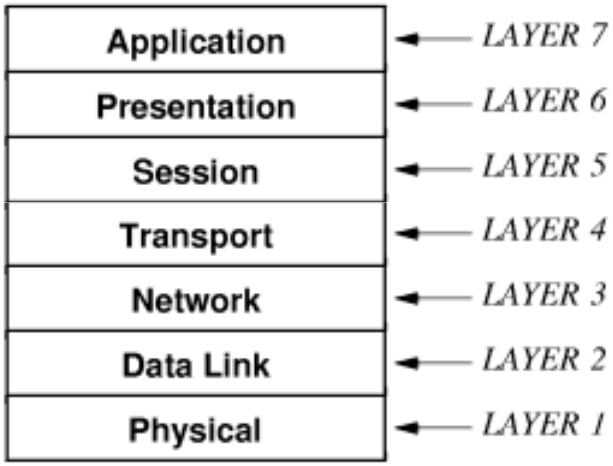
ring network

Service Types

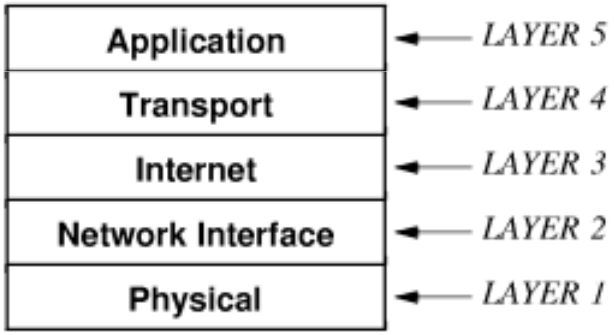
- Connection Oriented (Stream)
  - Inspired from the telephone system
  - Connection Setup, Data Transfer, Connection Tear down
  - Messages tend to follow the same path from source to destination
- Connectionless (Datagram)
  - Inspired from the mail system
  - Each message includes the destination address
  - Different messages follows different paths
  - No guarantee on message ordering

Layered Architecture

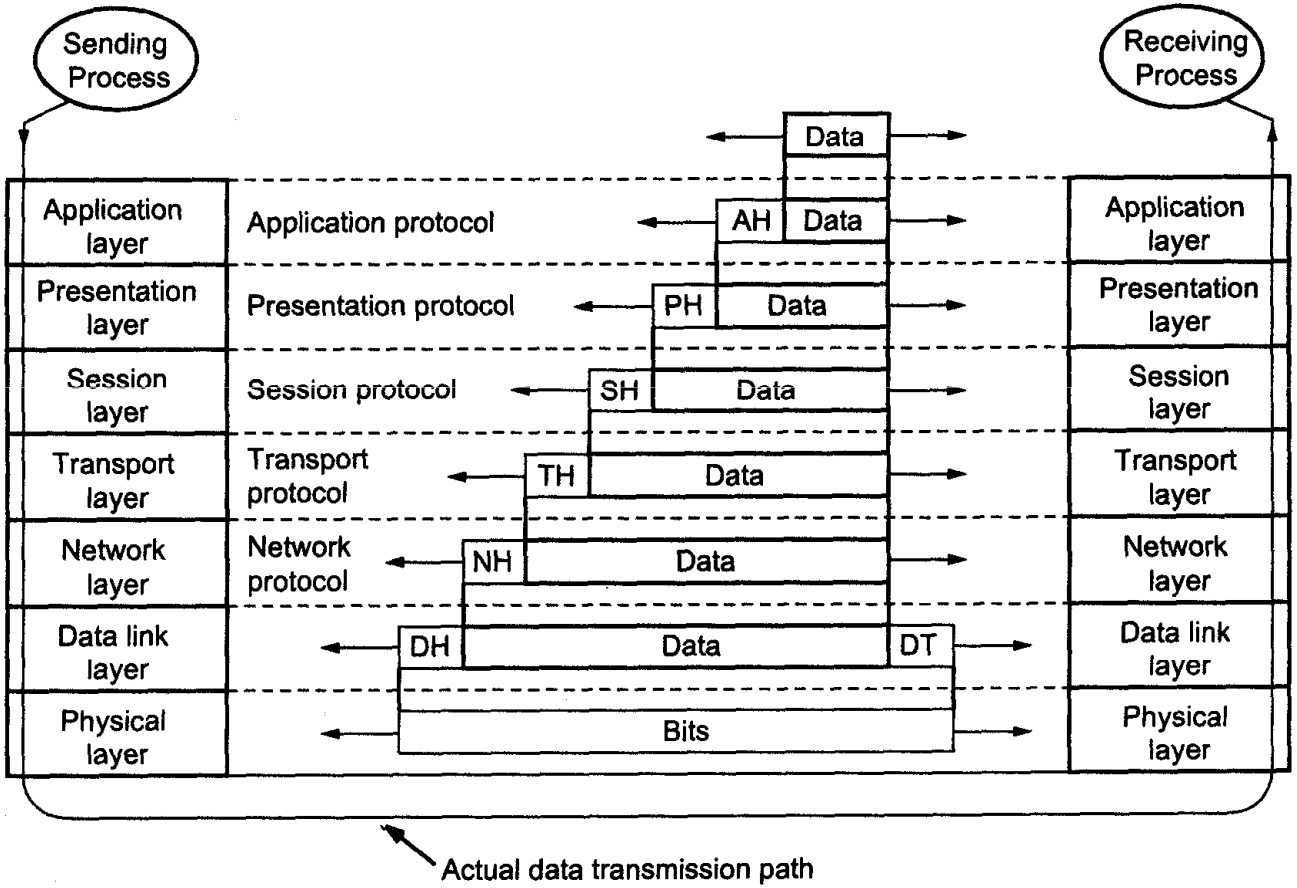
OSI



TCP/IP

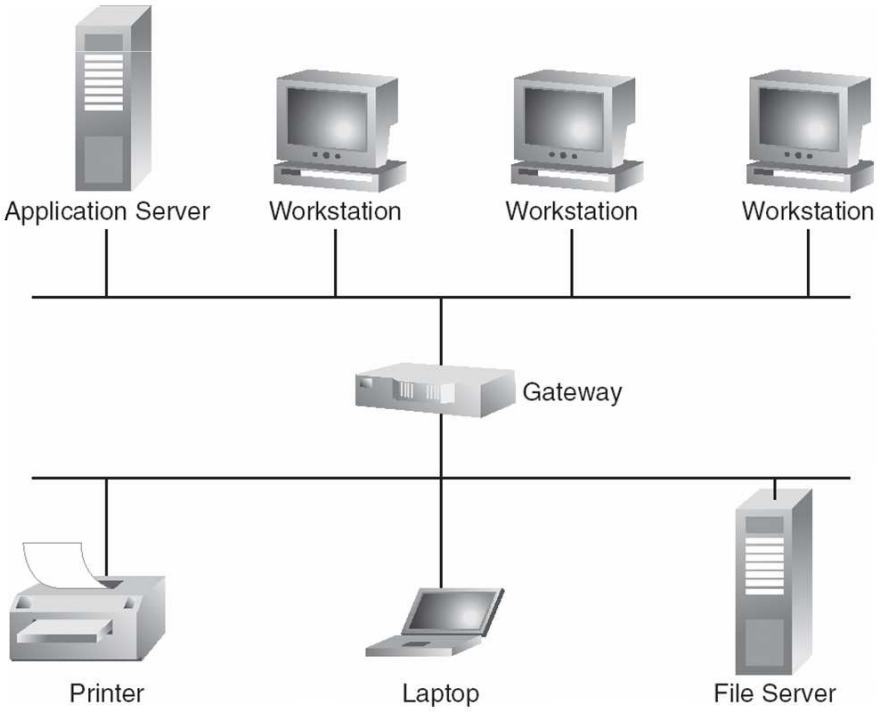


Actual Data Path



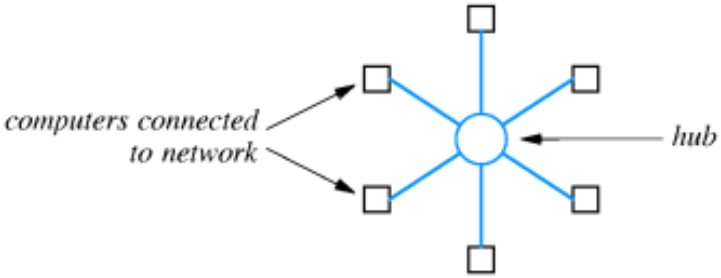
Local Area Networks (LANs)

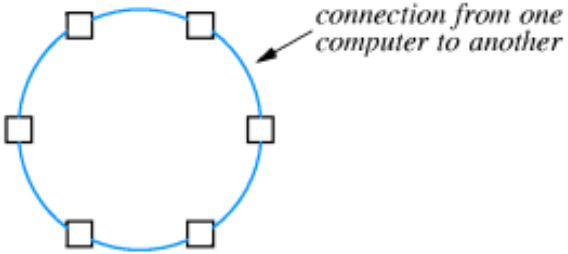
- Cover small geographical area.
- Speed ≈ 10 – 100 Mbps
- Nodes:
  - usually workstations and/or personal computers
  - a few (usually one or two) mainframes
- Shared Communication Medium
- Broadcast communication

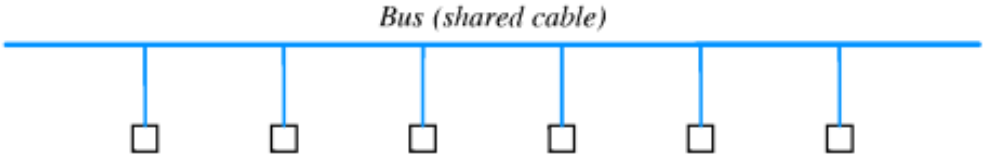


LAN Topologies

Shared Communication Medium







Node use a MAC (Medium Access Protocol) to regulate the access to the communication medium

Physical Addressing Scheme

How to implement unicast communication?

Each node in the LAN is assigned with a unique address (physical address or hw address o MAC address)

The sending node inserts the destination address in each packet it sends

The destination node accepts the received packet *only if* the destination address corresponds to its own address.

Ethernet LANs

- Ethernet a 10 Mbps
  - 10BaseT
  - 10Base5
  - 10Base2
- Fast Ethernet (100 BaseT, 100 Mbps)
- Gigabit Ethernet (1, 10 Gbps)
  - IEEE 802.3z (1 Gbps)
  - IEEE 802.3ae (10 Gbps)

An Example of Ethernet LAN

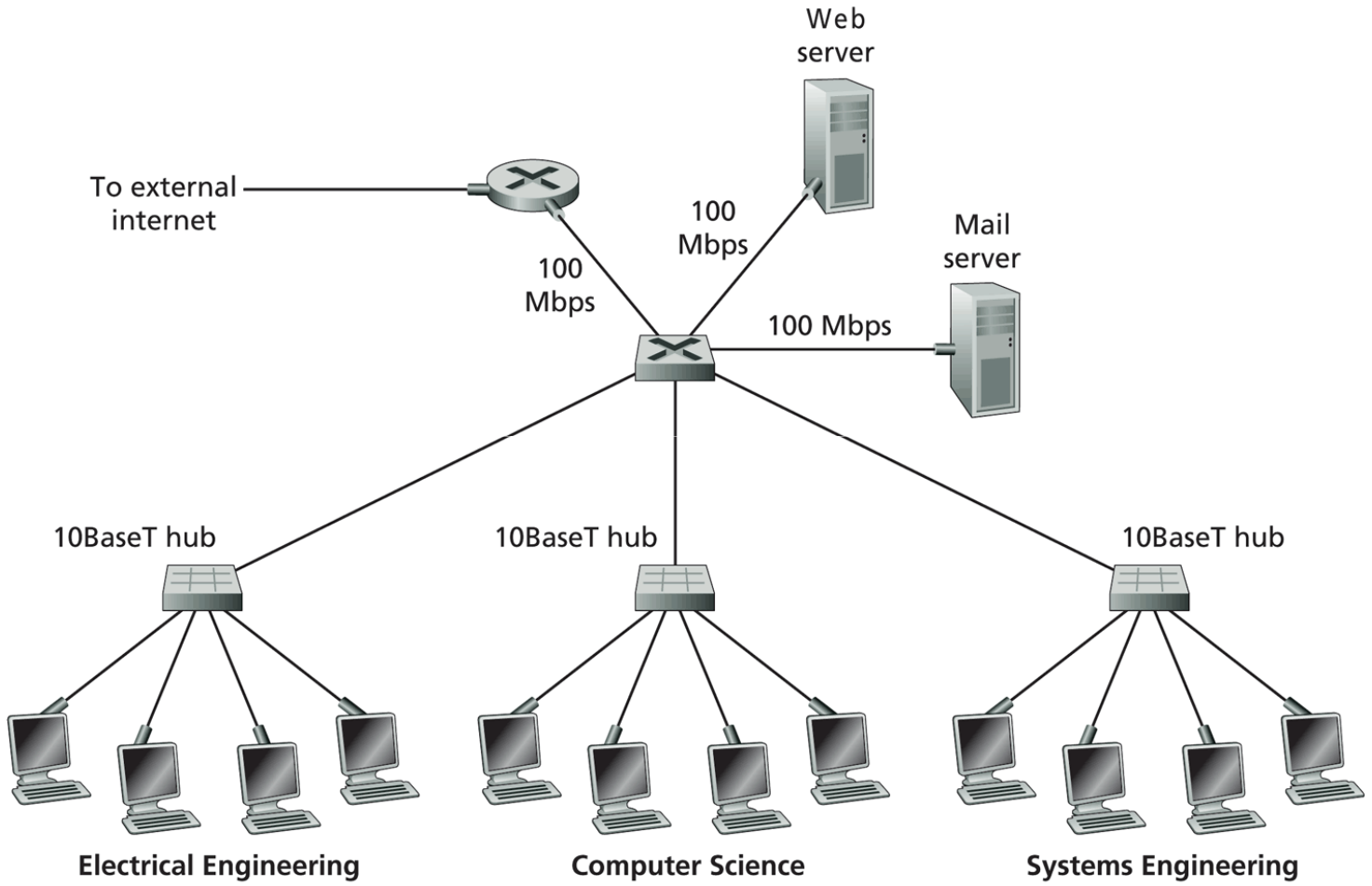
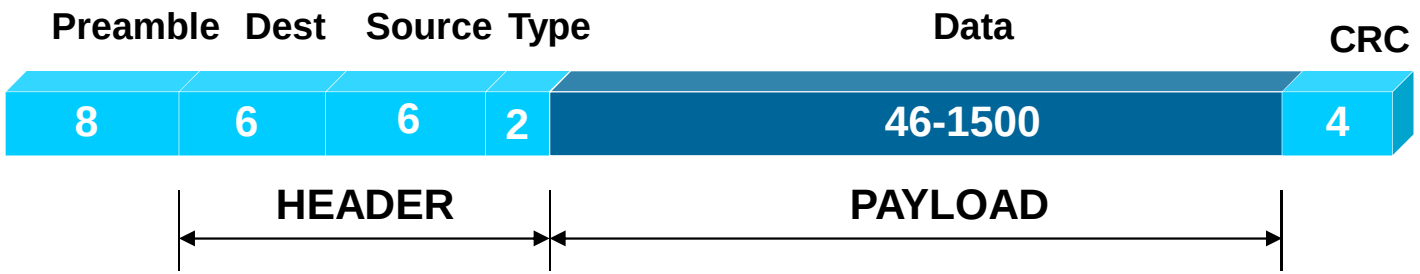


Figure 5.29 ♦ An institutional network using a combination of hubs, Ethernet switches, and a router

Frame Ethernet



- Preamble
  - 64-bit string used for clock synchronization
- Destination Address
  - Broadcast address: 11111……1
- Source Address
- Type
  - Specify the data type (e.g., 0800: IPv4)
- Payload
- CRC (Cyclic Redundancy Check)
  - Error detection

Ethernet MAC Protocol

- **CSMA/CD** - Carrier sense with multiple access (CSMA); collision detection (CD)
  - A node determines whether another packet is currently being transmitted over that link (carrier sense).
  - If the link is sensed as free the packet transmission is started. The node continues listening while transmitting
  - If two or more nodes begin transmitting at exactly the same time, then they will register a collision and will stop transmitting
  - A collided packet is re-tried after a random backoff interval

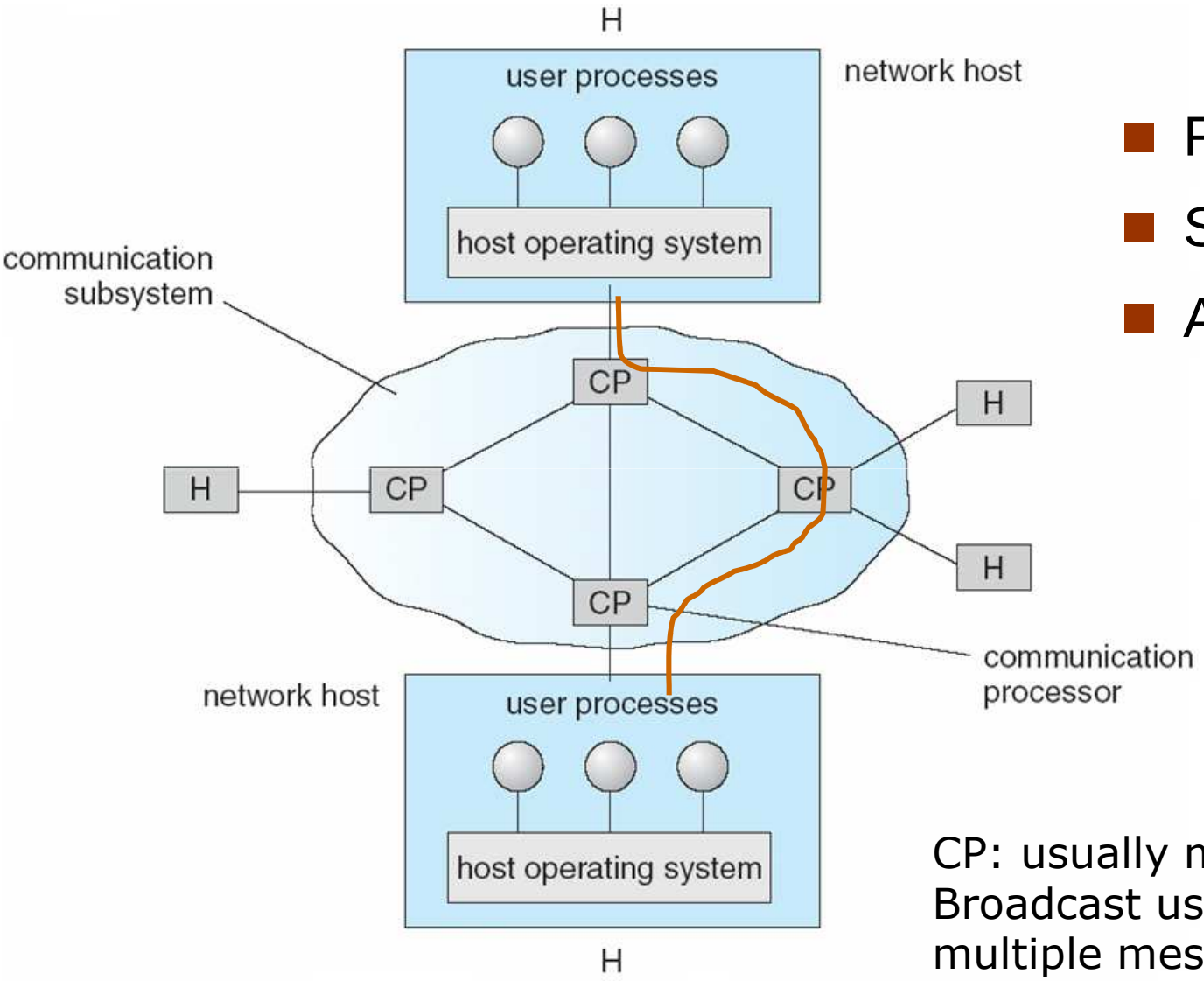
Wide Area Networks (WANs)

- Links geographically separated sites
- Point-to-point connections over long-haul lines (often leased from a phone company)
- Speed ≈ 1.544 – 45 Mbps

Point-to-Point Physical Links

- Collegamenti via modem
- Linee dedicate
- Linee ISDN
- Linee DSL
  - ADSL (Asynchronous Digital Subscriber Line)
  - SDSL (Synchronous Digital Subscriber Line)
  - HDSL (High-Rate Digital Subscriber Line)
  - VDSL (Very high-rate Digital Subscriber Line)

Point-to-Point Virtual Links

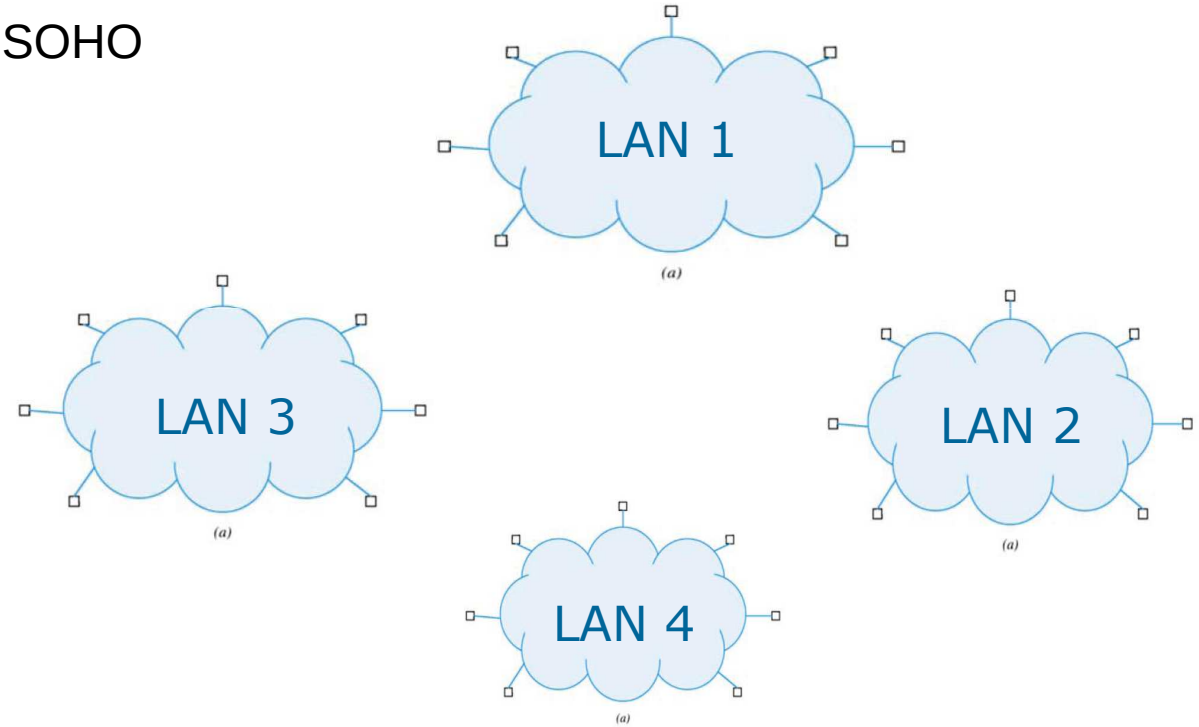


- Frame Relay
- SMDS
- ATM

CP: usually mainframes
Broadcast usually requires multiple messages

Limitazioni delle LAN

- Le LAN permettono di interconnettere calcolatori in ambito locale
  - Ambienti SOHO
  - Edifici
  - Campus

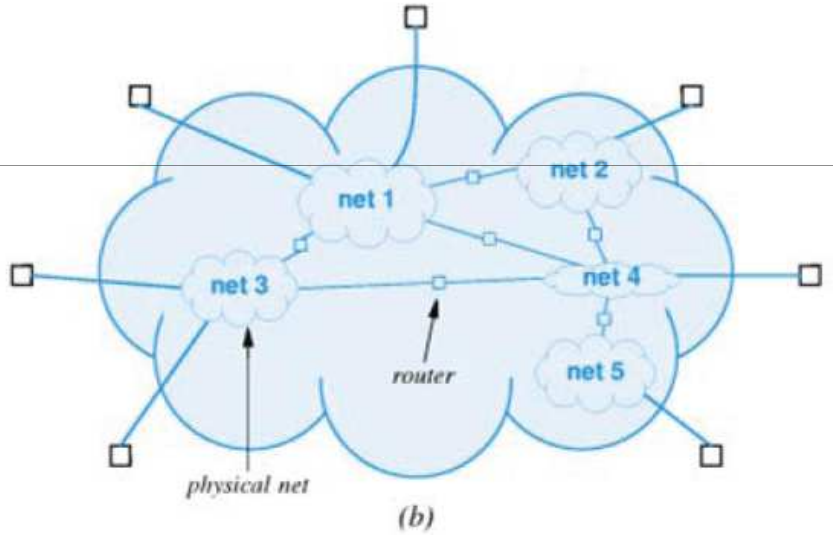


Come far comunicare fra loro calcolatori collegati a reti di tipo diverso e in posti diversi?

Quello che vorremmo …

Due calcolatori devono poter comunicare indipendentemente dalla rete fisica a cui sono collegati

- Aumento di produttività
- Problemi da risolvere
  - Diversi segnali elettrici,
  - Diverso formato dei pacchetti
  - Diverso schema di indirizzamento

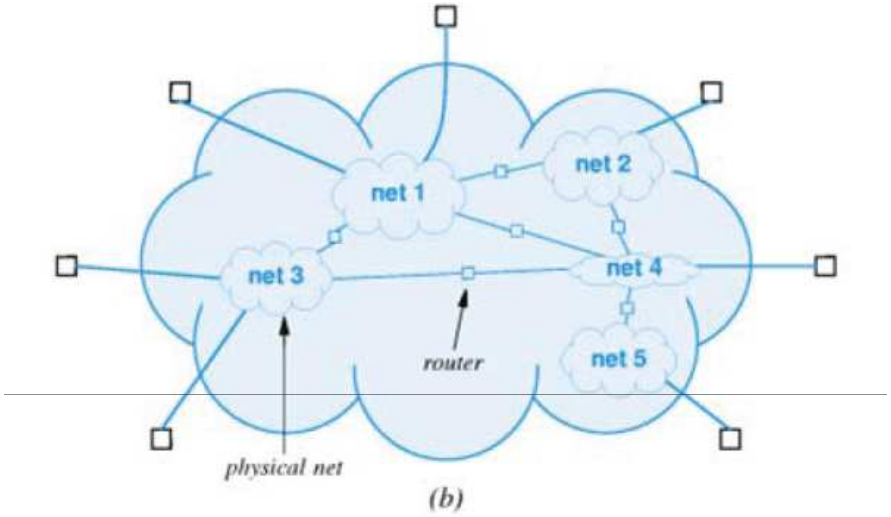


(b)

Inter-rete

Occorre

- Raccordare fisicamente le reti fisiche mediante opportuni dispositivi fisici (router)
- Aggiungere uno strato software sopra l'hardware di rete
  - Fa apparire l' insieme di reti eterogenee come un unico sistema

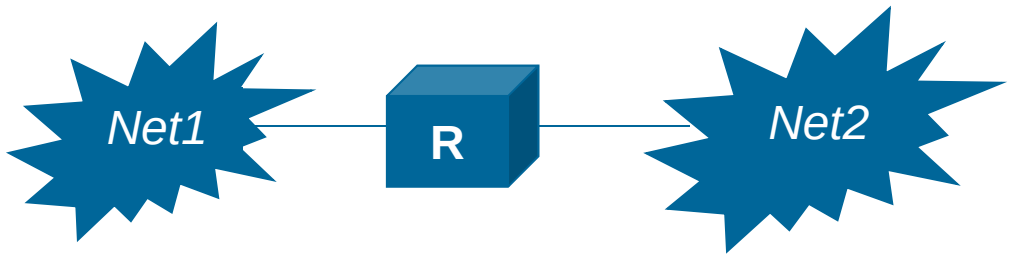


Il sistema che si realizza è detto inter-rete o internet

Router

- Calcolatore specializzato dedicato alla interconnessione
  - CPU, memoria, ...
  - una interfaccia per ciascuna rete a cui è collegato
- Si collega come un qualsiasi altro calcolatore
  - Collegato contemporaneamente a (almeno) due reti fisiche
- Può interconnettere reti di tipo qualsiasi

Inter-rete = reti di calcolatori collegate da router



Protocolli software

- Simulano una rete virtuale
  - si può collegare un calcolatore come si farebbe con una rete singola
- Nascondono i dettagli delle reti fisiche sottostanti
  - L'utenti si può disinteressare del tipo di reti fisiche sottostanti, della presenza o meno di router, ecc.
- Realizzano un servizio universale
  - Ogni calcolatore è individuato tramite un **indirizzo software**
  - Ogni calcolatore può scambiare messaggi con altri calcolatori collegati alla inter-rete

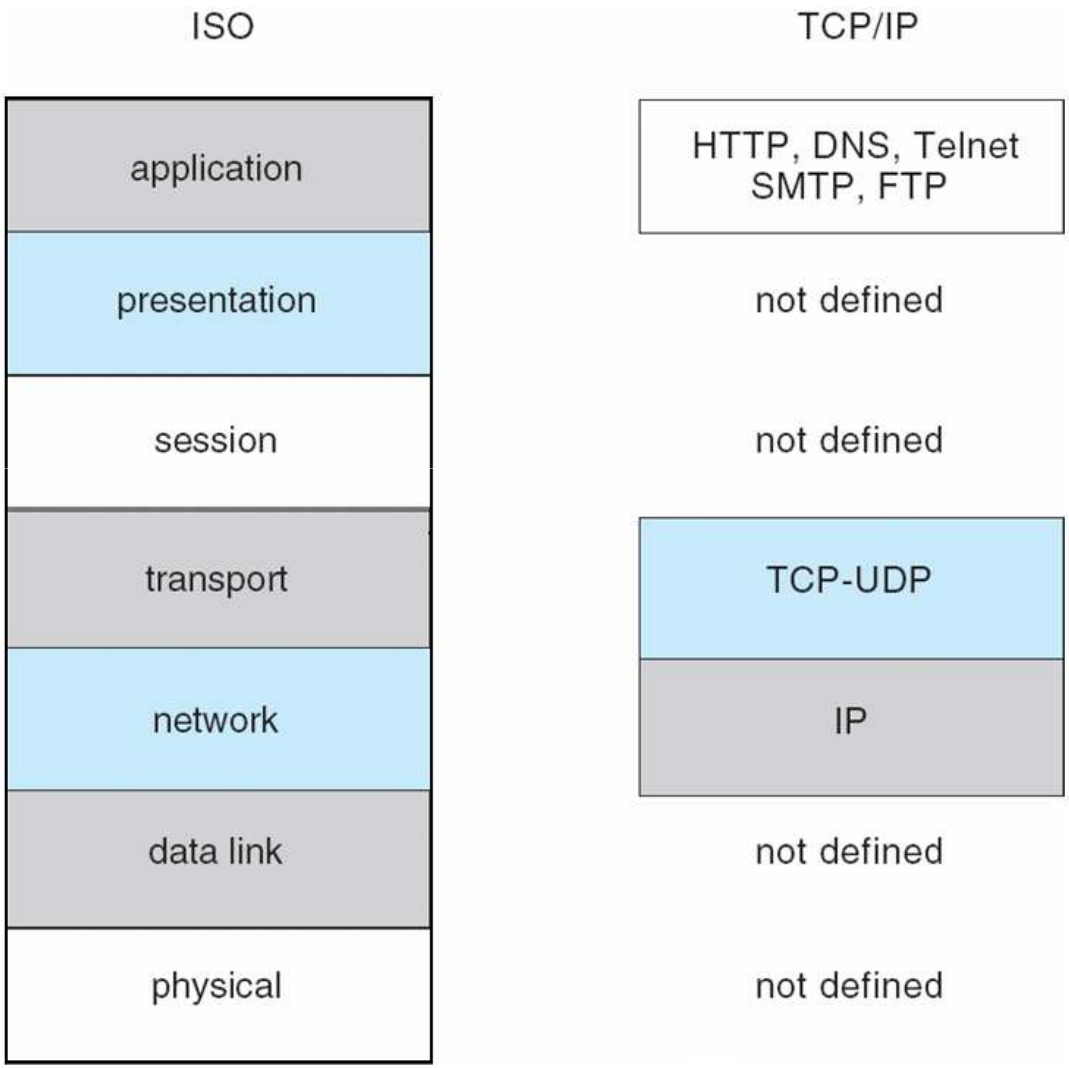
Protocolli TCP/IP

TCP = Transmission Control Protocol

IP = Internet Protocol

- Famiglia di protocolli usati in **Internet**
- Usati anche per la realizzazione di inter-reti private (Intranet)
- Progettati verso gli inizi degli anni ‘70 su iniziativa del Pentagono
  - Agenzia ARPA ➔ Arpanet
  - Arpanet ➔ Internet

The TCP/IP Protocol Layers



Overview

- Introduction
- Network-Based Operating Systems
- Communication Networks
- Communication Protocols
  - TCP/UDP
  - IP
- Distributed Programming

Internet Layer (Protocollo IP)

- Formato dei pacchetti (datagram)
- Formato degli indirizzi software (indirizzi IP)
- Instradamento dei datagrammi
- Servizio best-effort
  - Connectionless
    - Possibili fuori sequenza
  - Non affidabile
    - Perdite e/o alterazioni dei datagram
    - Nessuna garanzia di QoS (ritardo, jitter, throughput)

Transport Layer (Protocollo UDP)

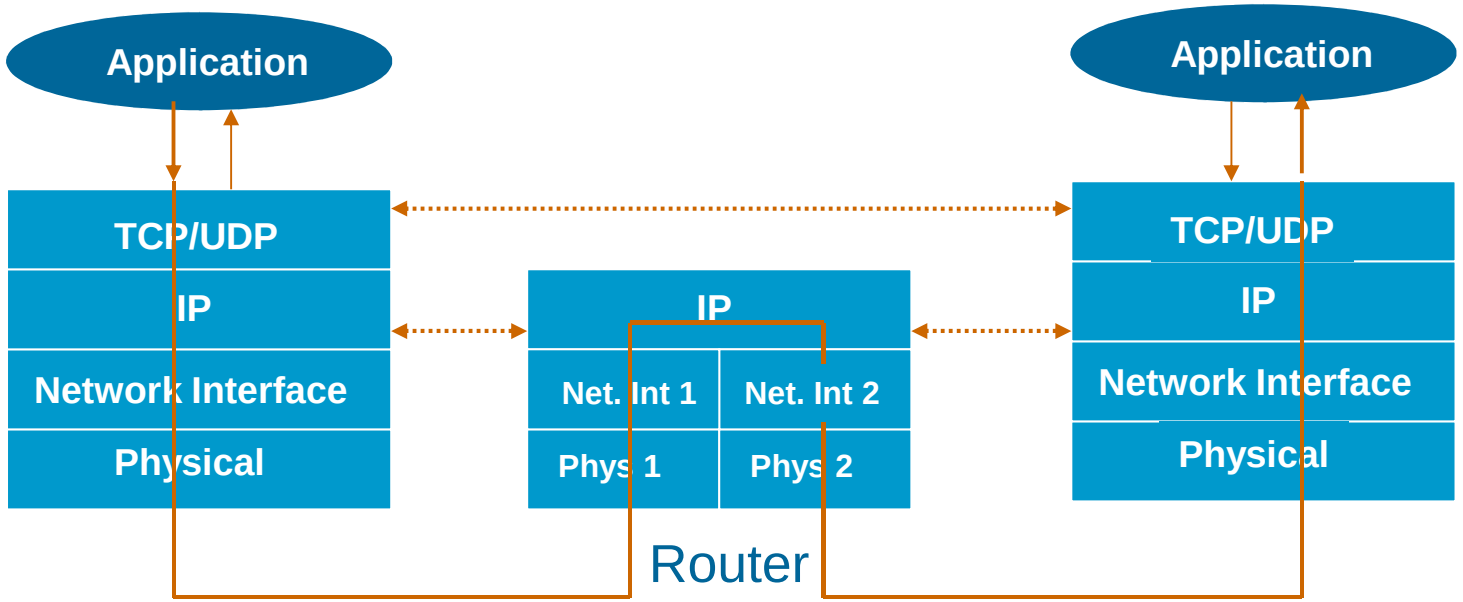
- Demultiplexing dei datagram
  - Riceve un flusso indistinto di datagrammi IP
  - Recapita i datagram ai processi applicativi a cui sono destinati
- Nessun incremento al servizio offerto da IP
  - Servizio connectionless e non affidabile

Transport Layer (Protocollo TCP)

- Flusso di byte (stream)
  - ma la comunicazione è sempre a pacchetti (segmenti)
- Trattamento di fuori-sequenza e duplicati
- Rilevazione dei segmenti alterati o persi
- Recupero dei segmenti alterati, persi, ritardati
- Controllo del flusso
- Controllo della congestione
- Servizio Connection-oriented e affidabile
  - **Tutti** i segmenti vengono consegnati in sequenza
  - Assenza di duplicati
  - Nessuna garanzia sul ritardo, sul jitter e sul throughput

Host, Router e Protocolli

Host = qualsiasi calcolatore collegato alla inter-rete



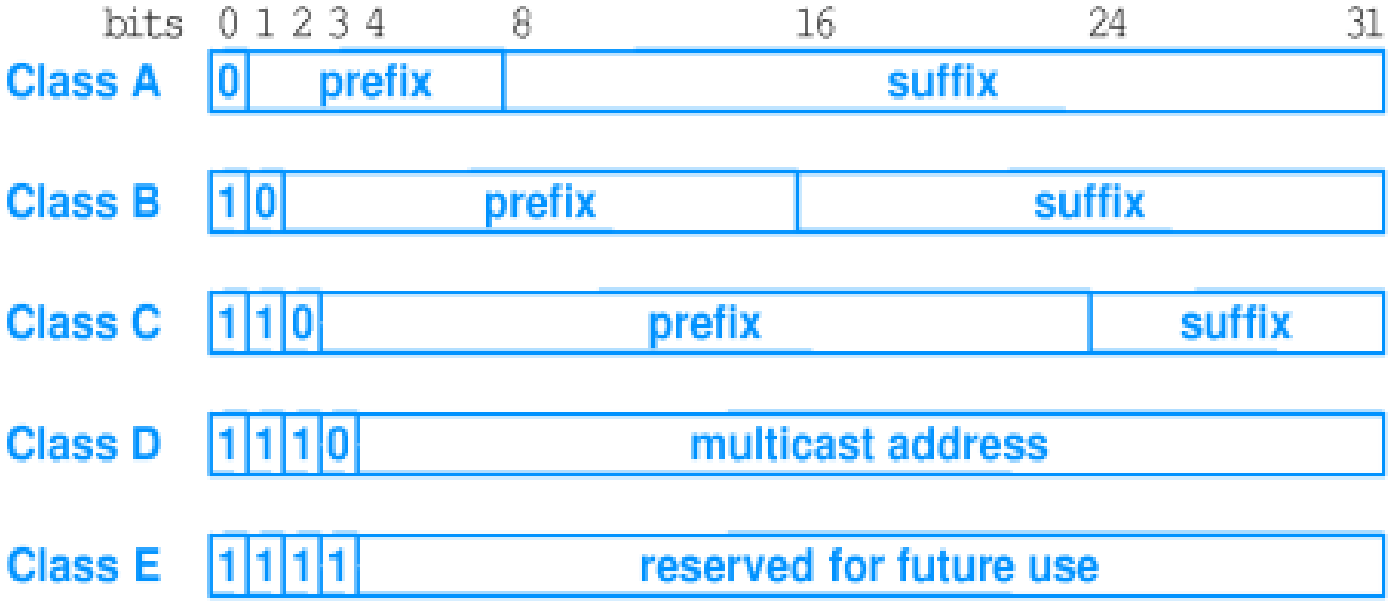
Indirizzi IP

- Indirizzo a 32 bit assegnato a ogni host
- Struttura Gerarchica
  - Indirizzo di rete (prefisso) + Indirizzo di host (suffisso)
- Indirizzo di rete (network number)
  - Identifica una rete fisica
  - Assegnato da una autorità centrale che garantisce l'univocità

Indirizzo di host (host number)

- Identifica un particolare host all'interno della rete fisica
- Assegnato localmente dall'amministratore

Classi di indirizzi IP



Notazione decimale puntata

- I 4 byte sono interpretati come numeri decimali
  - compresi fra 0 e 255
- Indirizzo letto come 4 numeri decimali separati da punti

32-bit Binary Number	Equivalent Dotted Decimal
10000001 00110100 00000110 00000000	129 . 52 . 6 . 0
11000000 00000101 00110000 00000011	192 . 5 . 48 . 3
00001010 00000010 00000000 00100101	10 . 2 . 0 . 37
10000000 00001010 00000010 00000011	128 . 10 . 2 . 3
10000000 10000000 11111111 00000000	128 . 128 . 255 . 0

Indirizzi IP riservati

- Indirizzo per l'intera sottorete
  - Suffisso di tutti zeri (131.114.0.0)
- Indirizzo di trasmissione brodcast orientata
  - Suffisso di tutti 1 (131.114.255.255)
- Indirizzo di trasmissione brodcast ristretta
  - Costituito da tutti 1 (255.255.255.255)
- Indirizzo di "questo calcolatore"
  - Indirizzi di tutti 0
  - Usato all'avvio
- Indirizzo loopback
  - 127.0.0.1
  - Usato nello fase di sviluppo di applicazione di rete

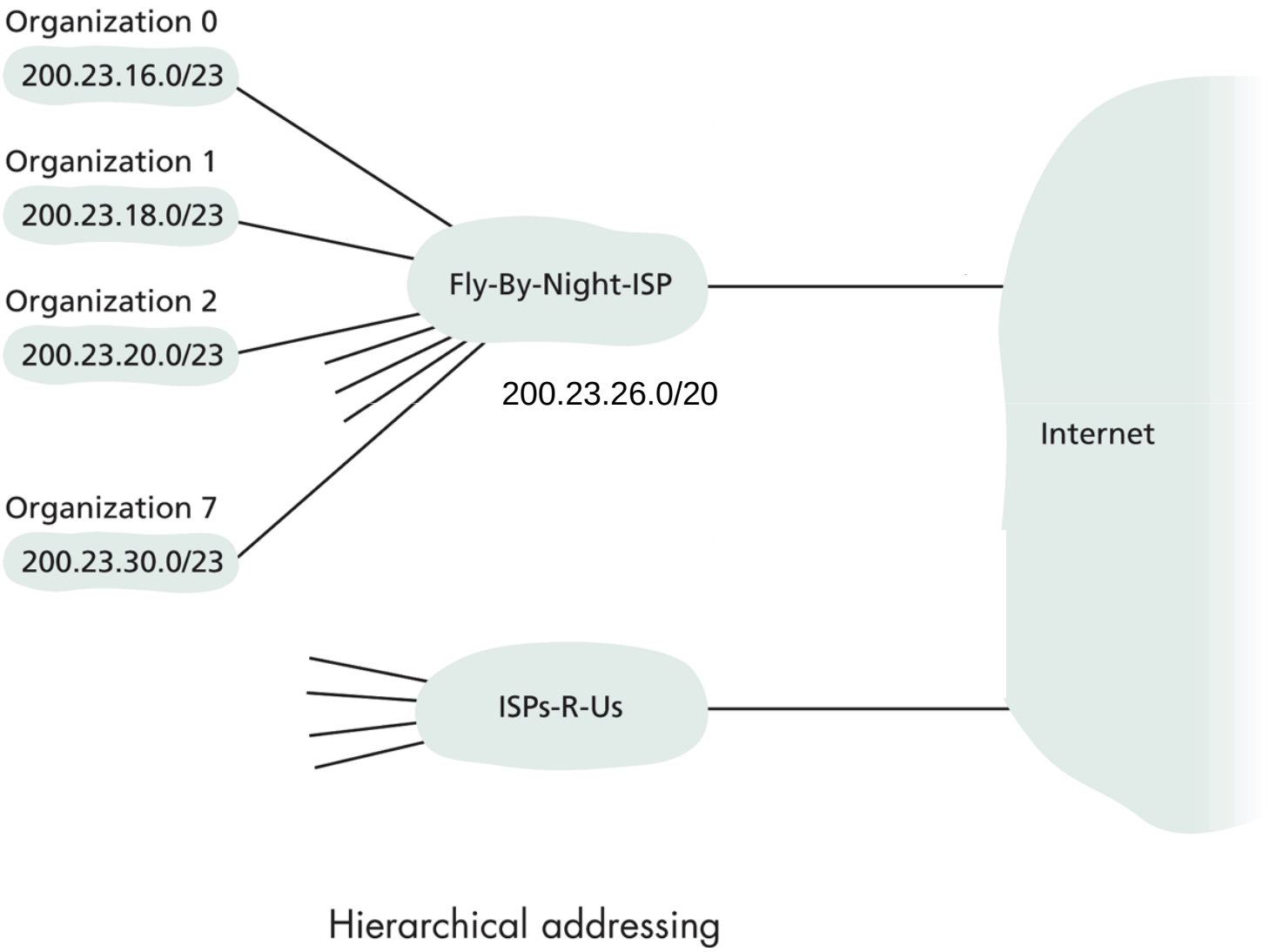
IP addressing: CIDR

CIDR: Classless InterDomain Routing

- subnet portion of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in subnet portion of address

200.23.16.0/23

Hierarchical Addressing



Hierarchical addressing

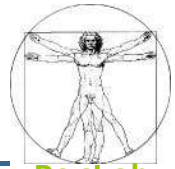
IP Addresses: how to get one?

Q: How does *network* get subnet part of IP addr?

A: gets allocated portion of its provider ISP's address space

ISP's block	11001000 00010111 00010000	00000000	200.23.16.0/20
Organization 0	11001000 00010111 00010000	00000000	200.23.16.0/23
Organization 1	11001000 00010111 00010010	00000000	200.23.18.0/23
Organization 2	11001000 00010111 00010100	00000000	200.23.20.0/23
...	.....	....	....
Organization 7	11001000 00010111 00011110	00000000	200.23.30.0/23

IP addressing: the last word...



Q: How does an ISP get block of addresses?

A: ICANN: Internet Corporation for Assigned Names and Numbers

- allocates addresses
- manages DNS
- assigns domain names, resolves disputes

IP addresses: how to get one?

Q: How does a *host* get IP address?

- Permanent Address
  - hard-coded by system admin in a file
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- Temporary Address
  - DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
  - “plug-and-play”

DHCP: Dynamic Host Configuration Protocol

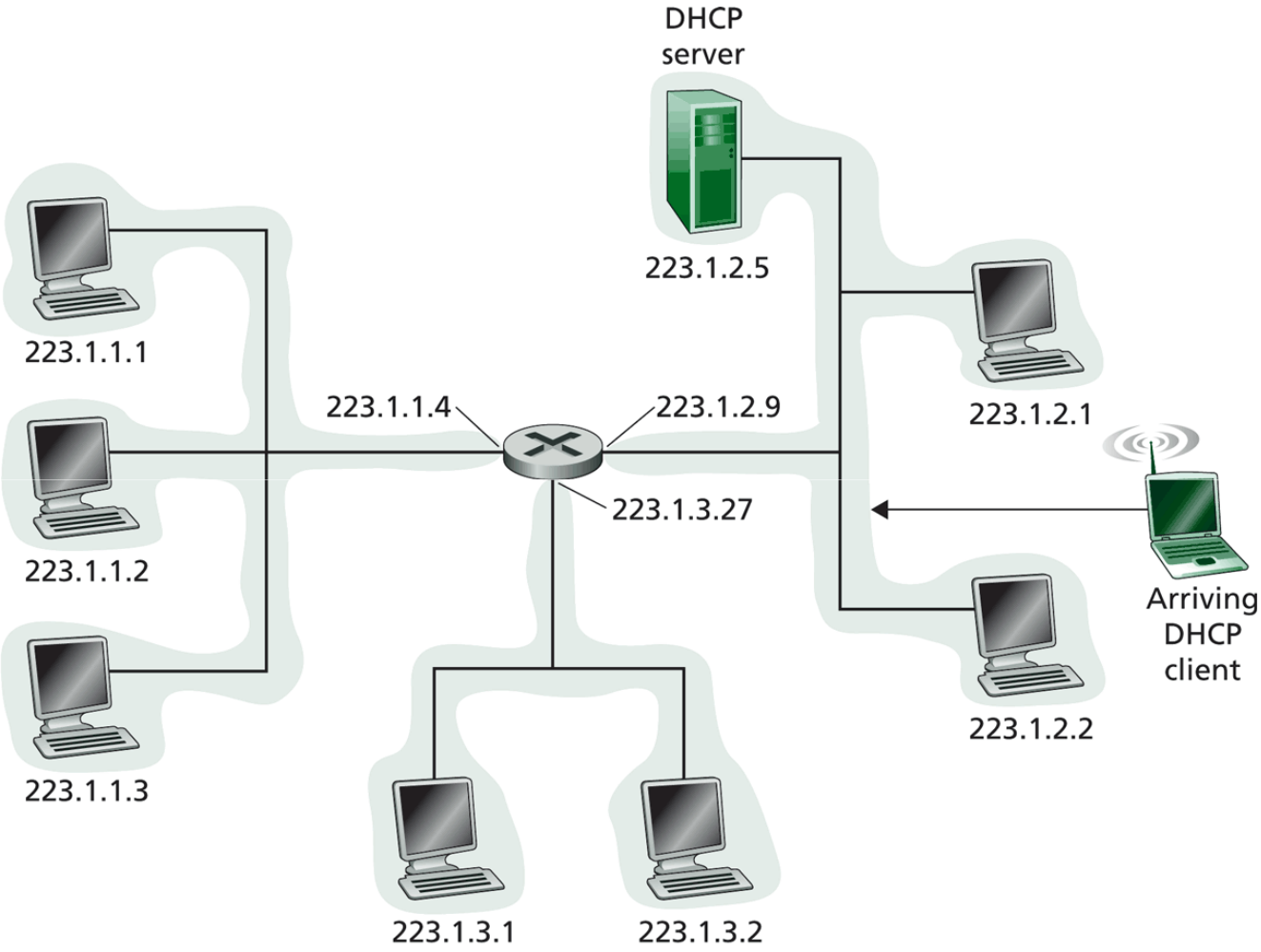
Goal: allow host to *dynamically* obtain its IP address from network server when it joins network

- Allows reuse of addresses (only hold address while connected “on”)
- Support for mobile users who want to join network (more shortly)

DHCP overview:

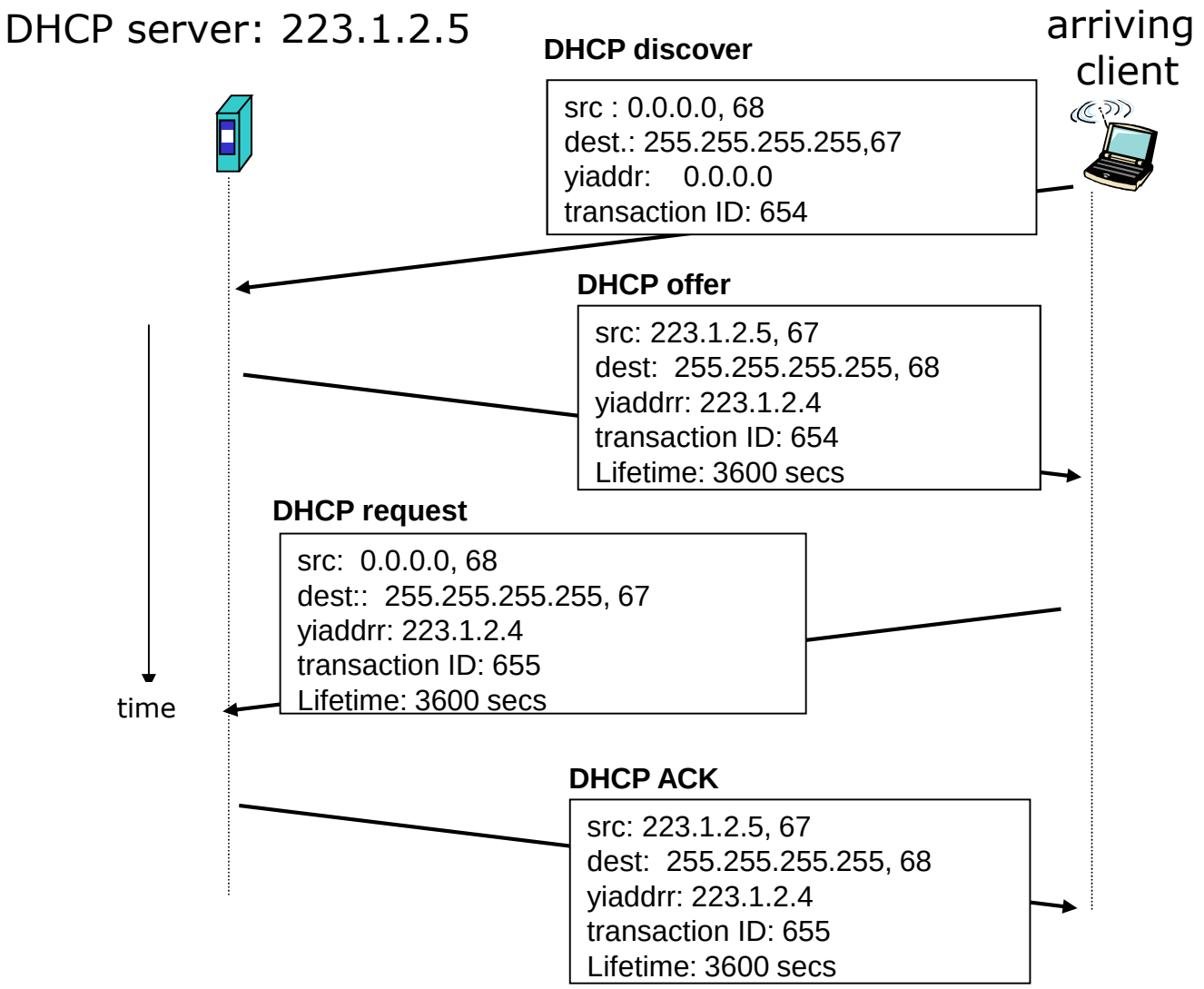
- host broadcasts “DHCP discover” msg
- DHCP server responds with “DHCP offer” msg
- host requests IP address: “DHCP request” msg
- DHCP server sends address: “DHCP ack” msg

DHCP client-server scenario



DHCP client-server scenario

DHCP client-server scenario



DHCP: more than IP address

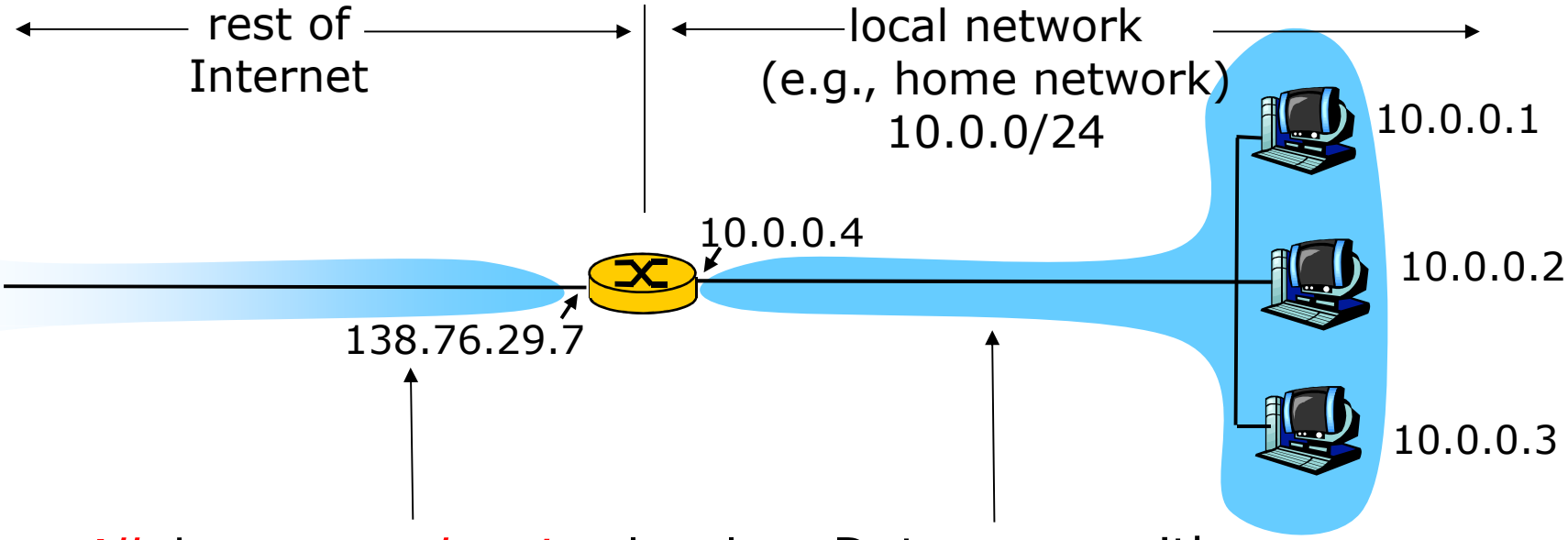
DHCP can return more than just allocated IP address on subnet:

- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

NAT: Network Address Translation

- Motivation: local network uses just one IP address as far as outside world is concerned:
  - range of addresses not needed from ISP: just one IP address for all devices
  - can change addresses of devices in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - devices inside local net not explicitly addressable, visible by outside world (a security plus).

NAT: Network Address Translation



All datagrams *leaving* local network have same single source NAT IP address: 138.76.29.7, different source port numbers

Datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: Network Address Translation

Implementation: NAT router must:

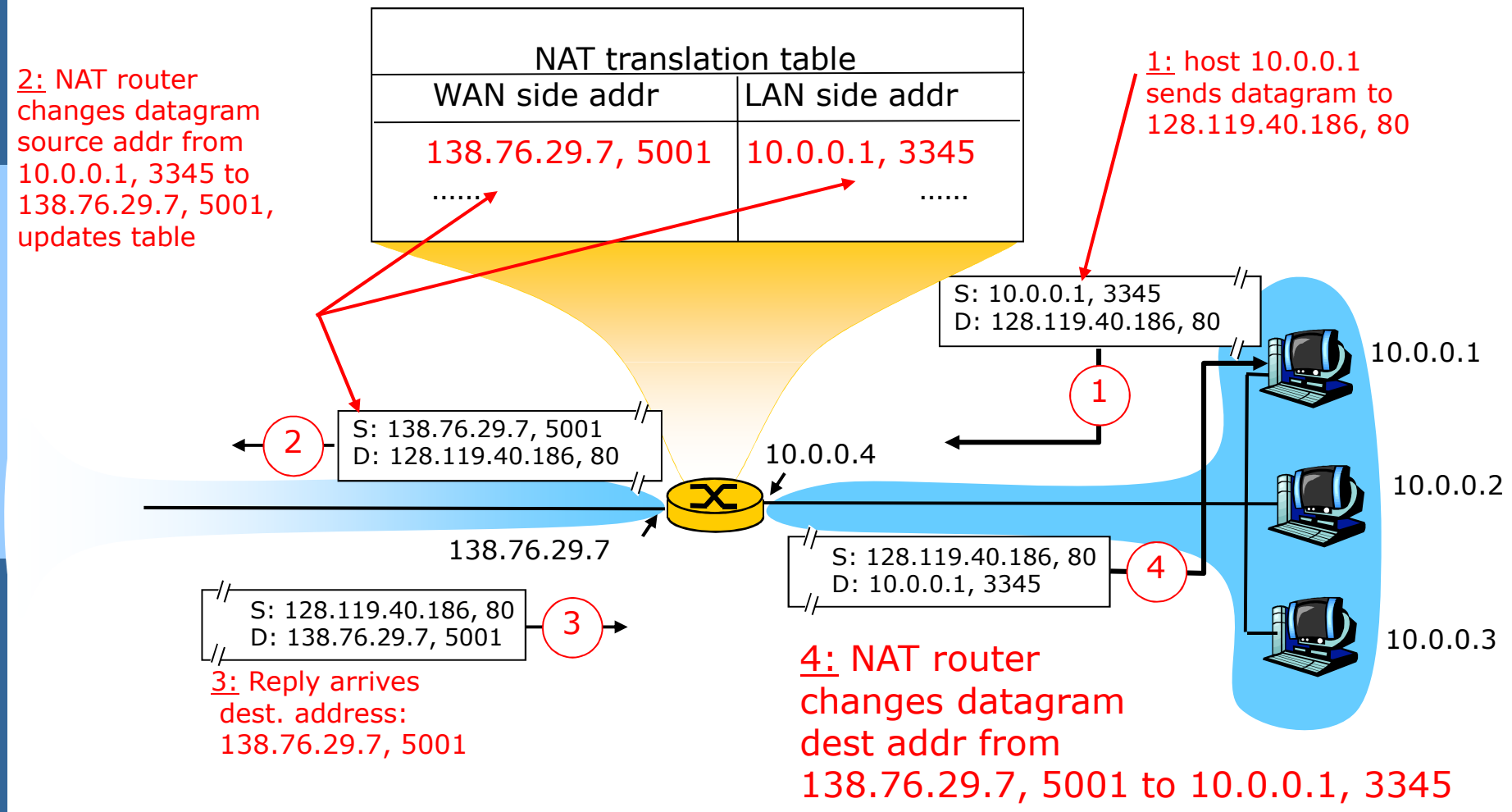
- *outgoing datagrams: replace* (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)

  . . . remote clients/servers will respond using (NAT IP address, new port #) as destination addr.

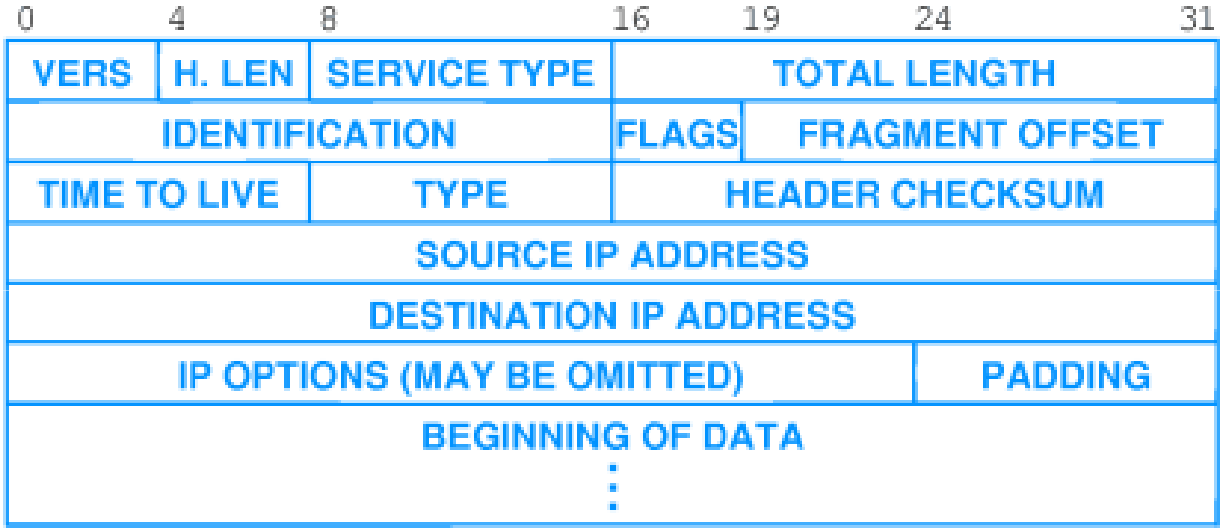
- *remember (in NAT translation table)* every (source IP address, port #) to (NAT IP address, new port #) translation pair

- *incoming datagrams: replace* (NAT IP address, new port #) in dest fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

NAT: Network Address Translation



Datagram IP

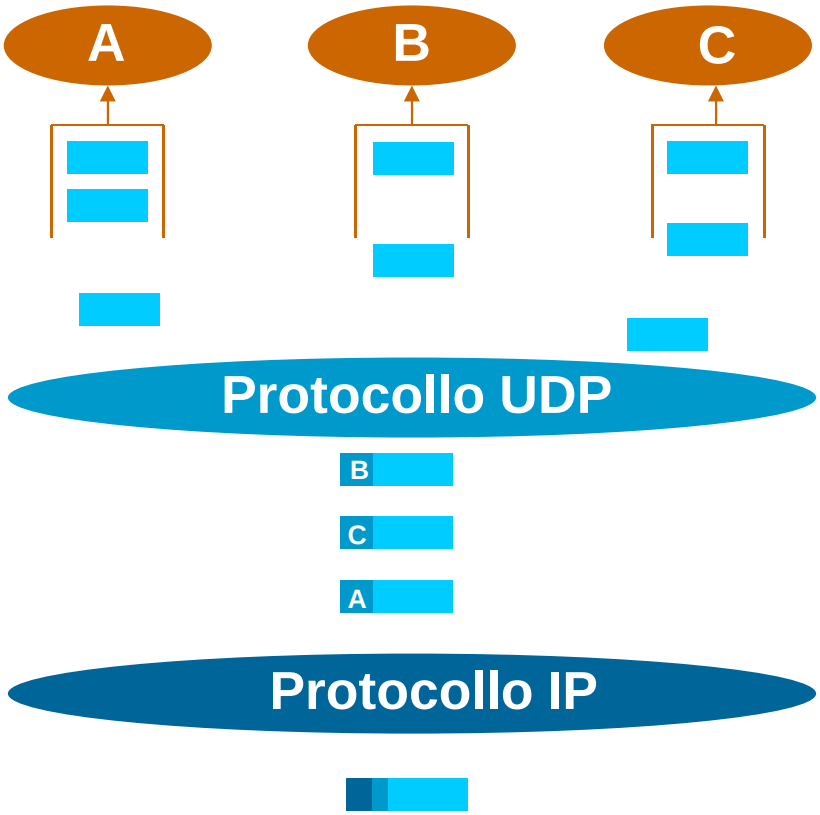

0
4
8
16
19
24
31
VERS
H. LEN
SERVICE TYPE
TOTAL LENGTH
IDENTIFICATION
FLAGS
FRAGMENT OFFSET
TIME TO LIVE
TYPE
HEADER CHECKSUM
SOURCE IP ADDRESS
DESTINATION IP ADDRESS
IP OPTIONS (MAY BE OMITTED)
PADDING
BEGINNING OF DATA

Livello di trasporto

- Estende il servizio di trasporto host-to-host in un servizio di comunicazione fra processi
  - Esegue il demultiplexing delle informazioni
  - Basato sul concetto di porta
- I processi vengono individuati mediante la coppia

  <Host IP Address, Port Number>
- Il processo mittente deve specificare sia l'indirizzo IP che il numero di porta
- Il SO realizza la porta come coda di messaggi

Protocollo UDP



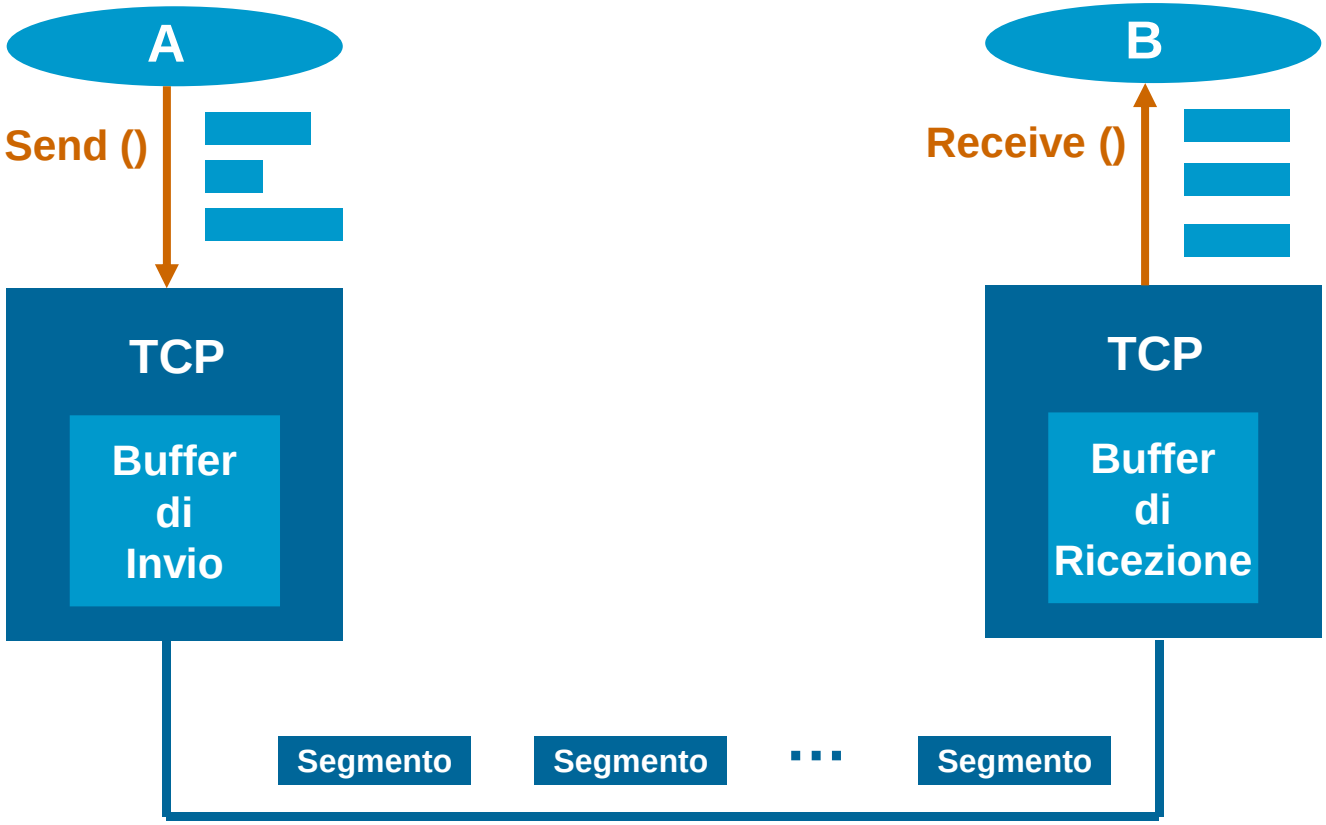
Introduzione al TCP

- Servizio di comunicazione fra processi orientato alla connessione
  - Meccanismo di de-multiplexing basato sulle porte
  - Apertura connessione, trasferimento dati, chiusura connessione
- Punto-Punto
  - Ogni connessione TCP collega esattamente due processi
- Affidabile
  - Consegna affidabile, senza duplicati e in sequenza di un flusso di byte
- Full duplex
  - Un flusso di byte in ciascuna direzione

Introduzione al TCP

- Controllo e gestione degli errori
  - Checksum e ACK
  - Timeout e ritrasmissione
- Controllo del flusso
  - Evita che il mittente invii più dati di quanti il ricevitore possa gestire
- Controllo della congestione
  - Evita che il mittente invii più dati di quanti la rete sia in grado di trasportare

Flusso di byte

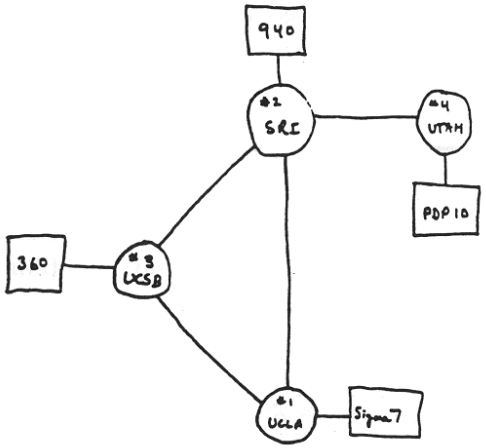


Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet public demonstration
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- ate70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

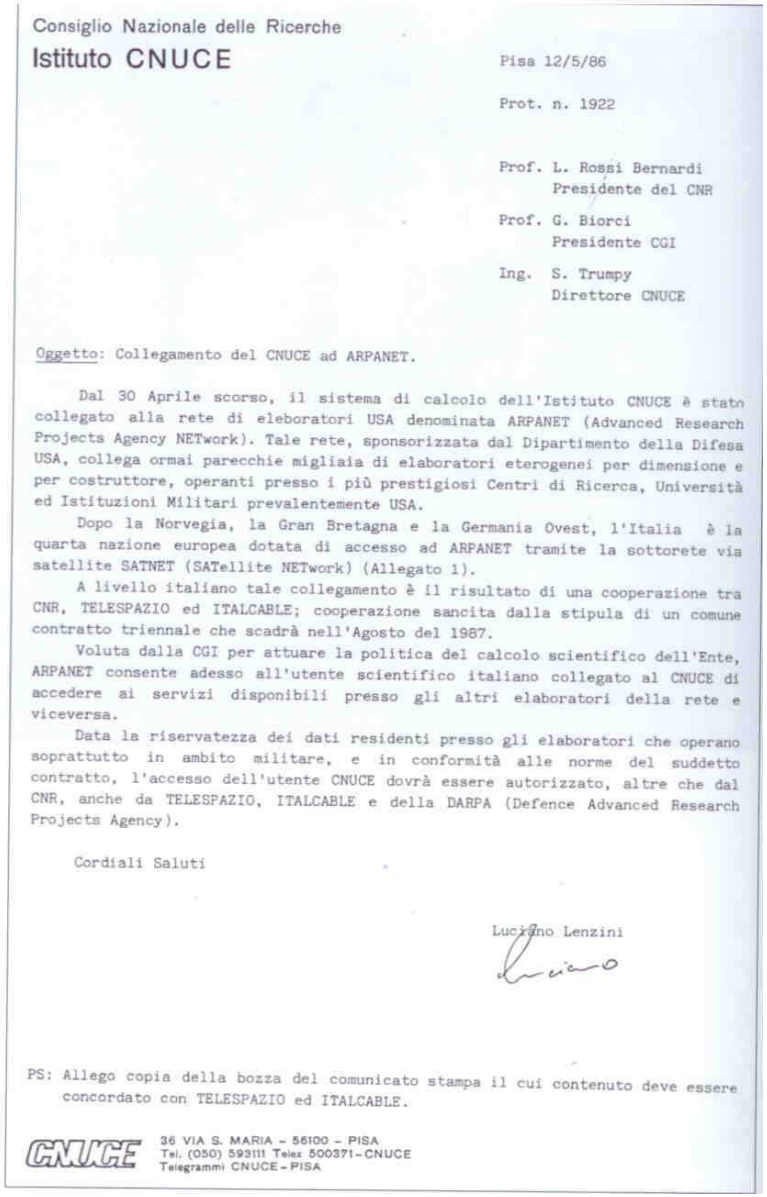
Internet History

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1986: first Italian node connected to the Internet (Pisa)
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History

- First Italian node connected to the Internet
  - 30 Aprile 1986
  - Nodo CNUCE, Pisa



Consiglio Nazionale delle Ricerche
Istituto CNUCE

Pisa 12/5/86

Prot. n. 1922

Prof. L. Rossi Bernardi
Presidente del CNR

Prof. G. Biorci
Presidente CGI

Ing. S. Trumpy
Direttore CNUCE

Oggetto: Collegamento del CNUCE ad ARPANET.

Dal 30 Aprile scorso, il sistema di calcolo dell'Istituto CNUCE è stato collegato alla rete di eleboratori USA denominata ARPANET (Advanced Research Projects Agency NETwork). Tale rete, sponsorizzata dal Dipartimento della Difesa USA, collega ormai parecchie migliaia di elaboratori eterogenei per dimensione e per costruttore, operanti presso i più prestigiosi Centri di Ricerca, Università ed Istituzioni Militari prevalentemente USA.

Dopo la Norvegia, la Gran Bretagna e la Germania Ovest, l'Italia è la quarta nazione europea dotata di accesso ad ARPANET tramite la sottorete via satellite SATNET (SATellite NETwork) (Allegato 1).

A livello italiano tale collegamento è il risultato di una cooperazione tra CNR, TELESPAZIO ed ITALCABLE; cooperazione sancita dalla stipula di un comune contratto triennale che scadrà nell'Agosto del 1987.

Voluta dalla CGI per attuare la politica del calcolo scientifico dell'Ente, ARPANET consente adesso all'utente scientifico italiano collegato al CNUCE di accedere ai servizi disponibili presso gli altri elaboratori della rete e viceversa.

Data la riservatezza dei dati residenti presso gli elaboratori che operano soprattutto in ambito militare, e in conformità alle norme del suddetto contratto, l'accesso dell'utente CNUCE dovrà essere autorizzato, altre che dal CNR, anche da TELESPAZIO, ITALCABLE e della DARPA (Defence Advanced Research Projects Agency).

Cordiali Saluti

Luciano Lenzini

PS: Allego copia della bozza del comunicato stampa il cui contenuto deve essere concordato con TELESPAZIO ed ITALCABLE.

CNUCE 36 VIA S. MARIA - 56100 - PISA
Tel. (050) 593111 Telex 500371-CNUCE
Telegrammi CNUCE-PISA

Internet History

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

Late 1990's – 2000's:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet History

2007:

- ~500 million hosts
- Voice, Video over IP
- P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- more applications: YouTube, gaming
- wireless, mobility

Overview

- Introduction
- Network-Based Operating Systems
- Communication Networks
- Communication Protocols
- Distributed Programming
  - Socket interface
  - Client-server Model
  - Peer-to-Peer Model

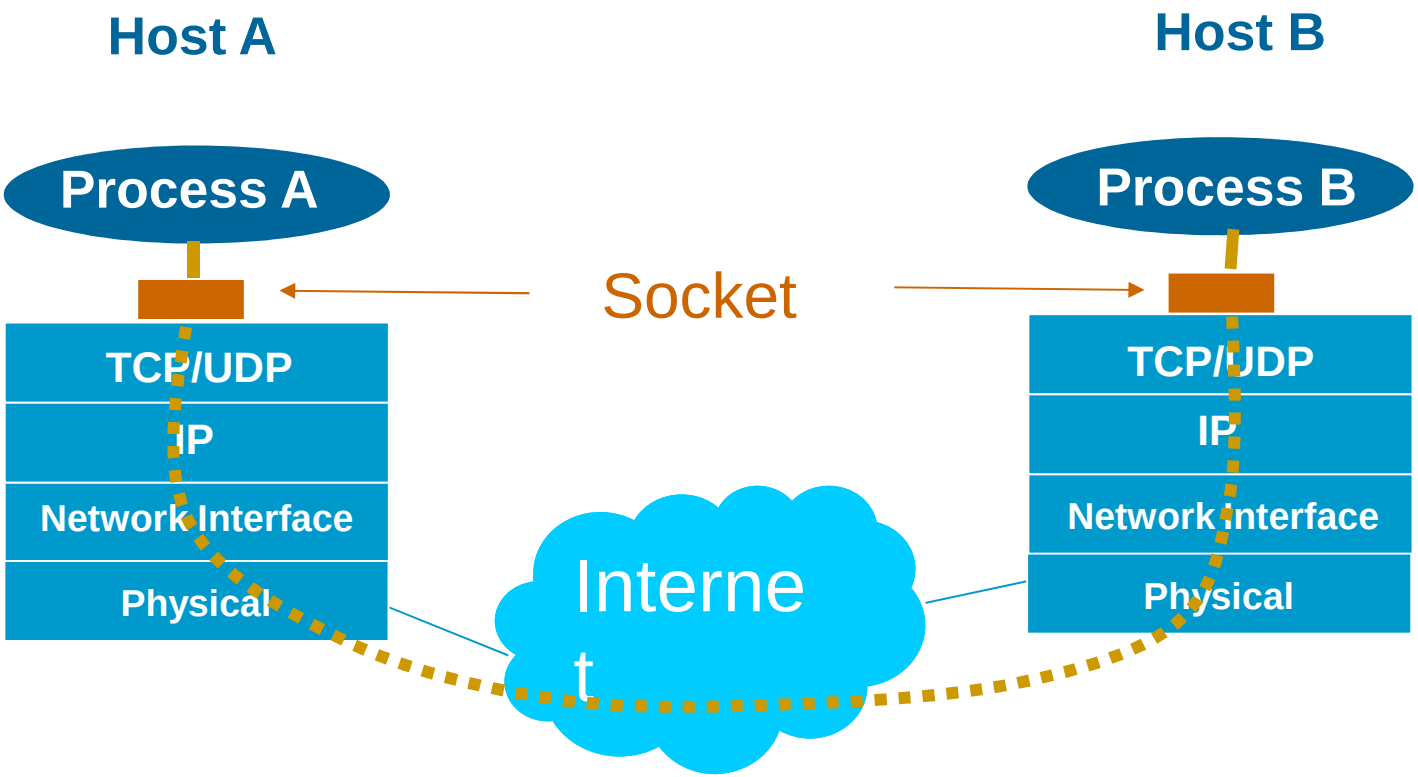
Interfaccia Socket

- Standard *de facto* per la comunicazione fra processi in ambiente distribuito
  - Si può usare anche per la comunicazione fra processi sulla stessa macchina
- Interfaccia unica per operare con i vari protocolli di rete a disposizione
- Nasconde tutti i meccanismi di comunicazione di livello inferiore (TCP/UDP, IP, …)

Socket

- Estremità di canale di comunicazione identificata da un indirizzo
  - Socket: presa telefonica
  - Indirizzo: numero di telefono
- Indirizzo
  - Indirizzo dell'Host (Indirizzo IP)
  - Indirizzo del processo (Port Number)
- La comunicazione avviene tramite una coppia di socket

Comunicazione mediante socket

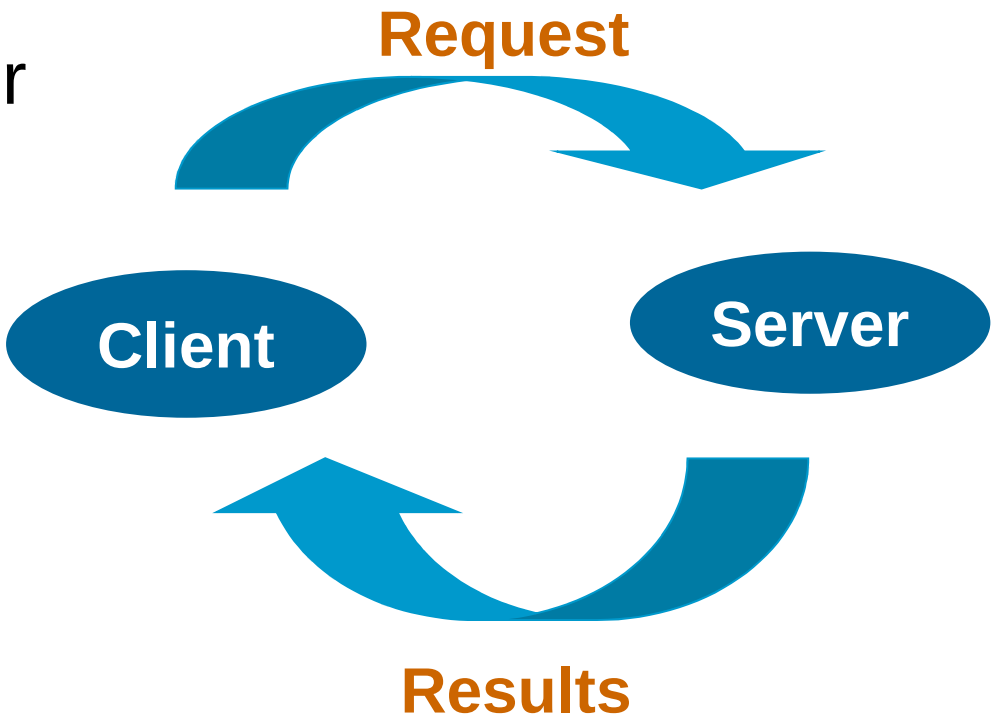


Supporto del SO

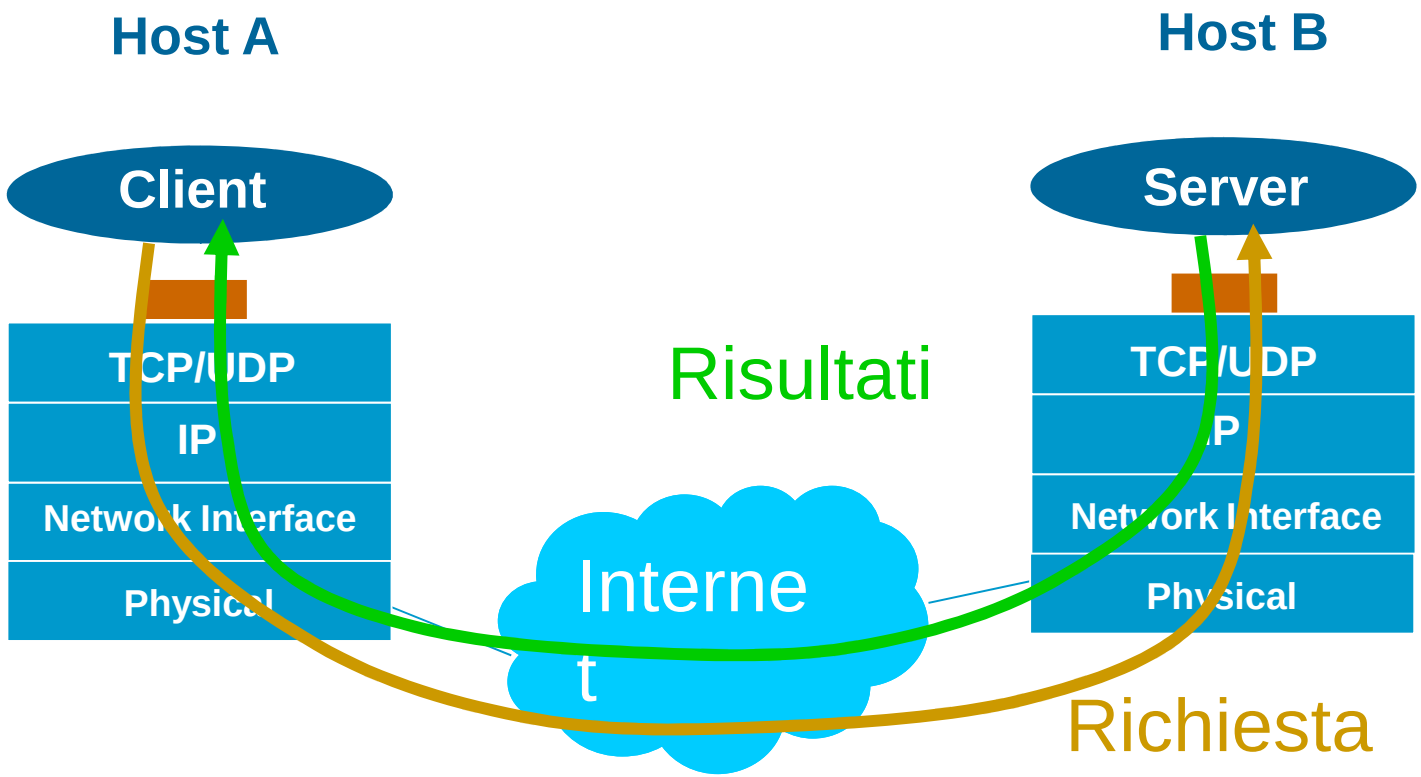
- Il SO implementa l'astrazione di socket
- System call per
  - Creare un socket
  - Associare indirizzo IP e porta al socket
  - Mettere in ascolto un processo su un socket (server)
  - Accettare una richiesta di servizio su un socket (server)
  - Aprire una connessione verso un socket remoto (client)
  - Inviare un messagio verso un socket remoto
  - Ricevere un messaggio da un socket
  - ....

Modello Client-Server

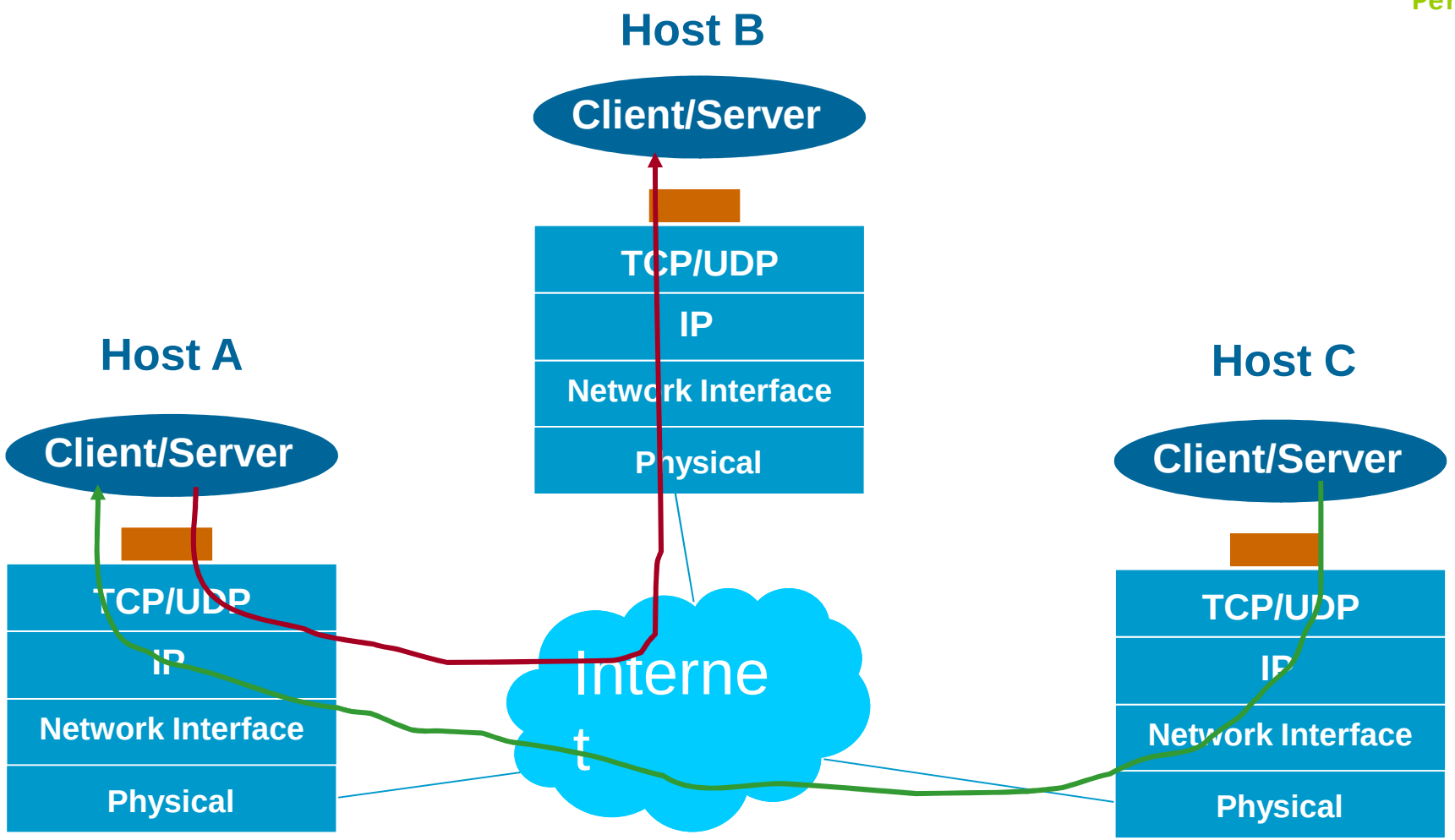
- Paradigma basato su scambio di messaggi
  - Paradigma generale
  - Ma usato principalmente in ambito distribuito
- Scambio di msg per
  - Richiesta di servizio
  - Invio dei risultati



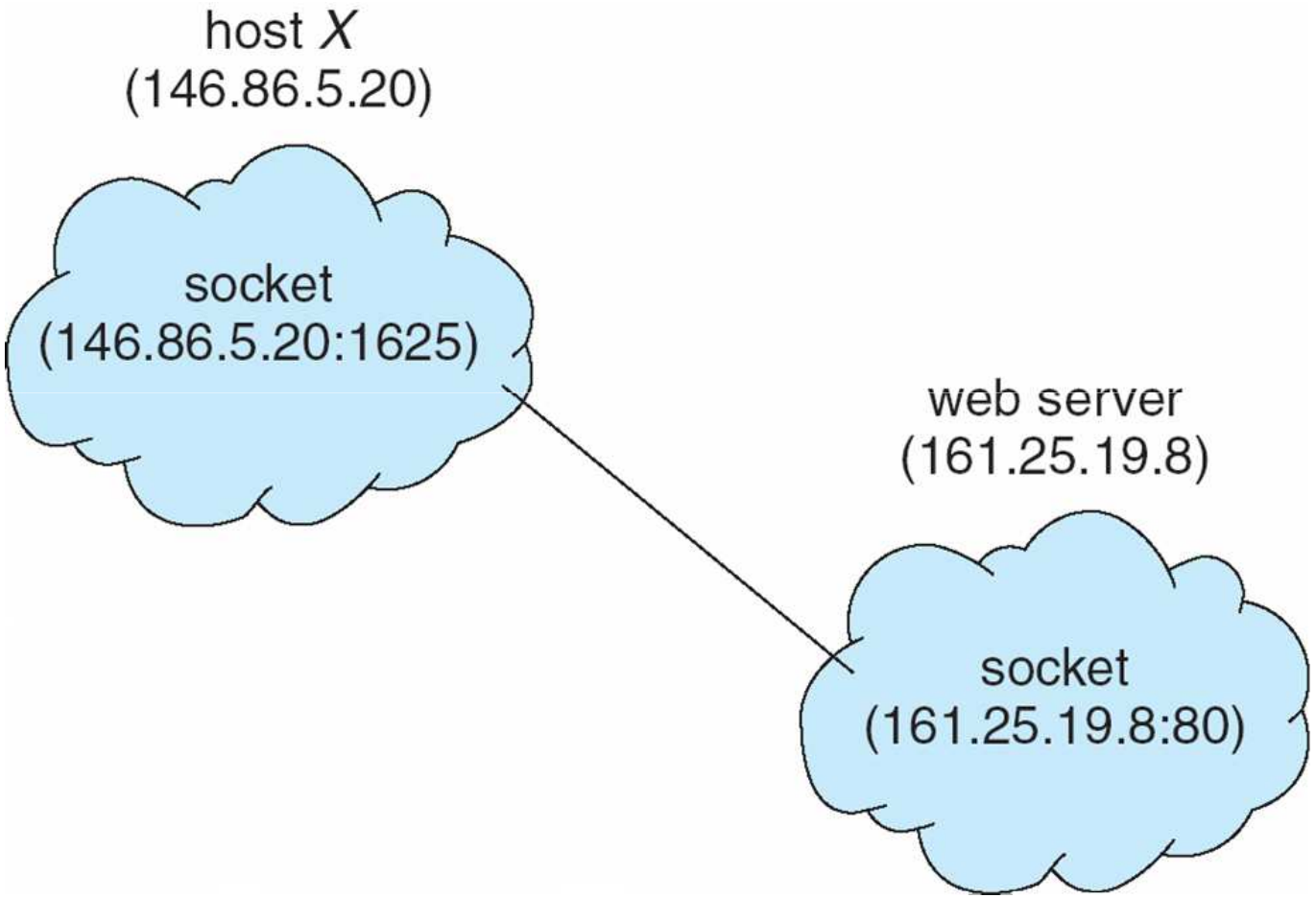
Client-Server in Sistemi Distribuiti



Modello P2P


Host B
Client/Server
TCP/UDP
IP
Network Interface
Physical
Host A
Client/Server
TCP/UDP
IP
Network Interface
Physical
Interne
t
Host C
Client/Server
TCP/UDP
IP
Network Interface
Physical

Client-Server Communication



Remote Procedure Calls

- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
- **Stubs** – client-side proxy for the actual procedure on the server
- The client-side stub locates the server and *marshalls* the parameters
- The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server

RPC: general issues

- Data Representation
  - Little endian vs. big endian
  - A system-independent representation is used (e.g., XDR: eXternal Data Representation)
- Exactly-once semantic
  - Acks and retransmissions for avoid message losses (at least once
  - Timestamps for avoiding multiple execution (at most once)

RPC: general issues

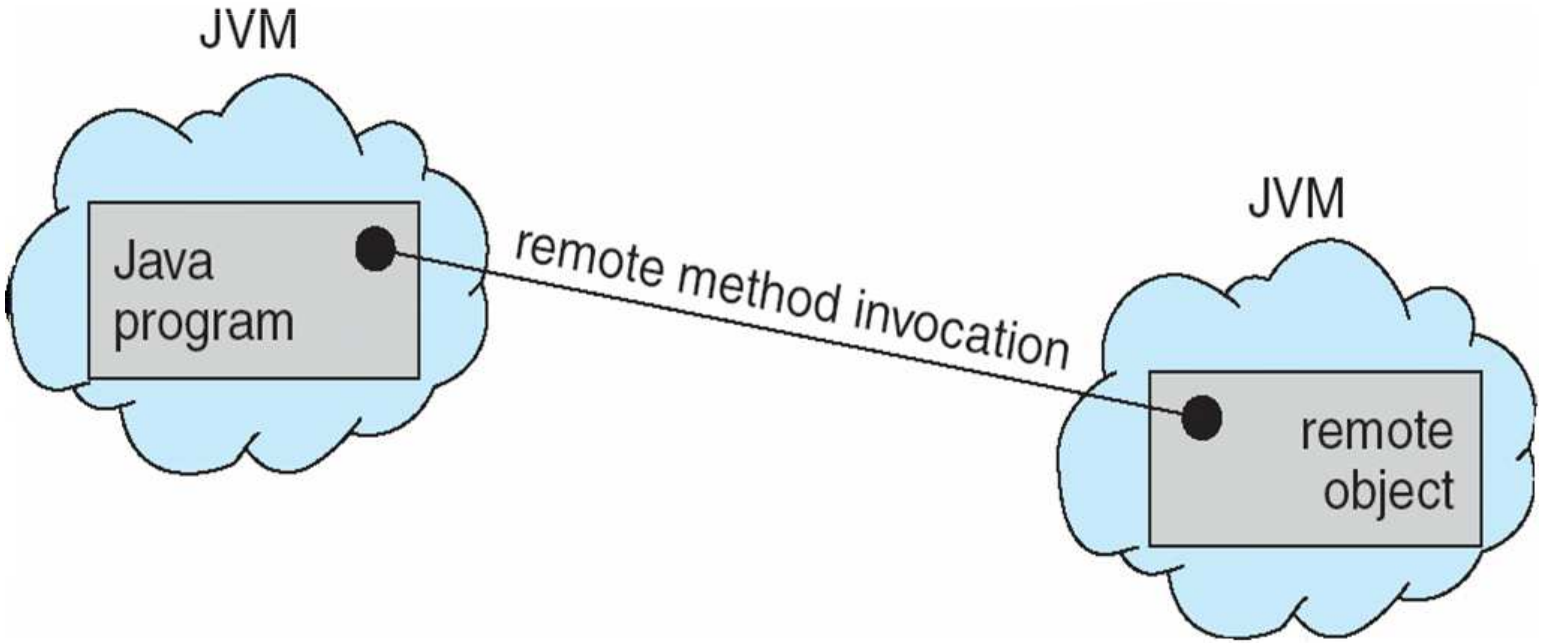
- Client-server communication
  - How to locate the RPC port on the server?
- Predefined ports
  - RPC are associated at compile time with fixed port numbers
  - The server cannot change the port number of the required service
- Rendez-Vous
  - The server-side OS provides a rendez-vous daemon (*matchmaker*)
  - The client requires the port number to the matchmaker
  - The daemon replies with the port number
  - The client send the RPC request to the appropriate port number

An RPC Application

- Distributed File System (DFS)
  - Set of daemons and RPC clients
  - Messages containing file-system operations
    - read, write, rename, delete, status
  - The client sends a message to the server
  - The command is executed on the server
  - A reply message is sent to the client

Remote Method Invocation

- Remote Method Invocation (RMI) is a Java mechanism similar to RPCs
- RMI allows a Java program on one machine to invoke a method on a remote object



Questions?