# Need For Protocols (continued)

- Need mechanisms to distinguish among
  - Multiple computers on a network
  - Multiple applications on a computer
  - Multiple copies of a single application on a computer

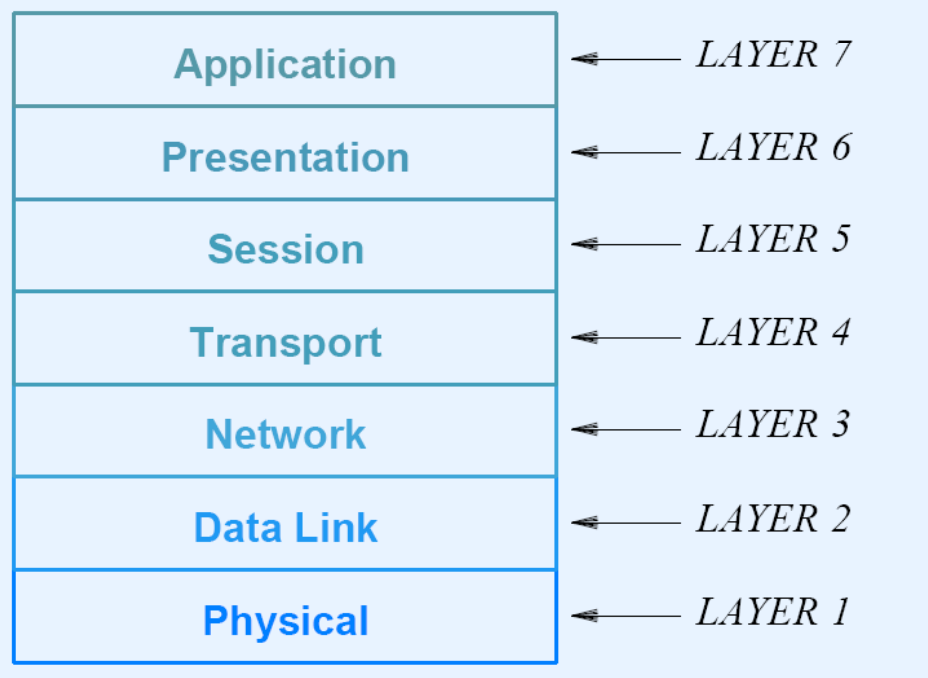
# Set Of Protocols

- Work together
- Each protocol solves part of communication problem
- Known as
  - Protocol suite
  - Protocol family
- Designed in layers

# Plan For Protocol Design

- Intended for protocol designers
- Divides protocols into layers
- Each layer devoted to one subproblem
- Example: ISO 7-layer reference model

# Illustration Of The 7-Layer Model




- Defined early (by ISO (International Organization for Standardization)
- Now somewhat dated
- Does not include Internet layer!

# ISO Layers

- Layer 1: Physical
  - Underlying hardware ( e.g. RS232 )
- Layer 2: Data Link (media access)
  - Hardware frame definitions (testing) + (transmission)

  (e.g. frame format, byte stuffing, checksum)
- Layer 3: Network
  - Packet forwarding (e.g. IP addressing)
- Layer 4: Transport
  - Reliability (e.g. UDP/TCP)

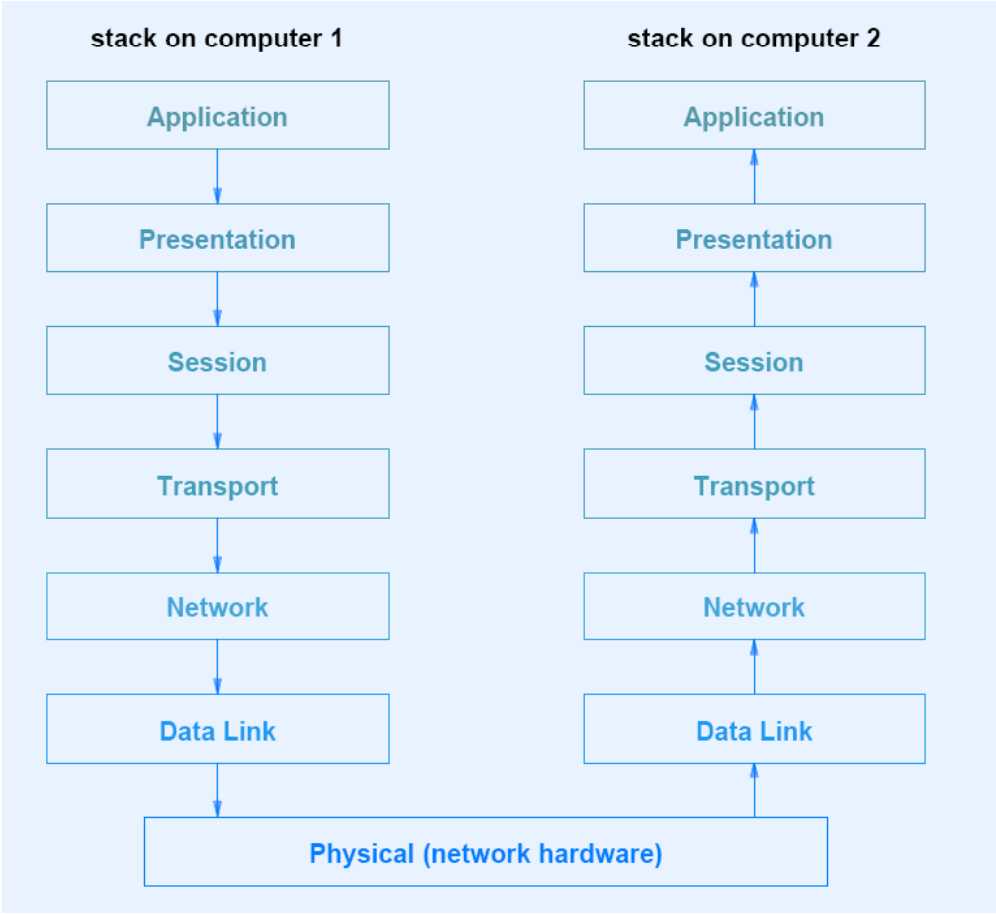
# ISO Layers (continued)

- Layer 5: Session
  - How to establish a communication session (e.g. Login and passwords, authentication)
- Layer 6: Presentation
  - Data representation (differing brands uses differing representations of integers and characters)
- Layer 7: Application
  - Individual application program

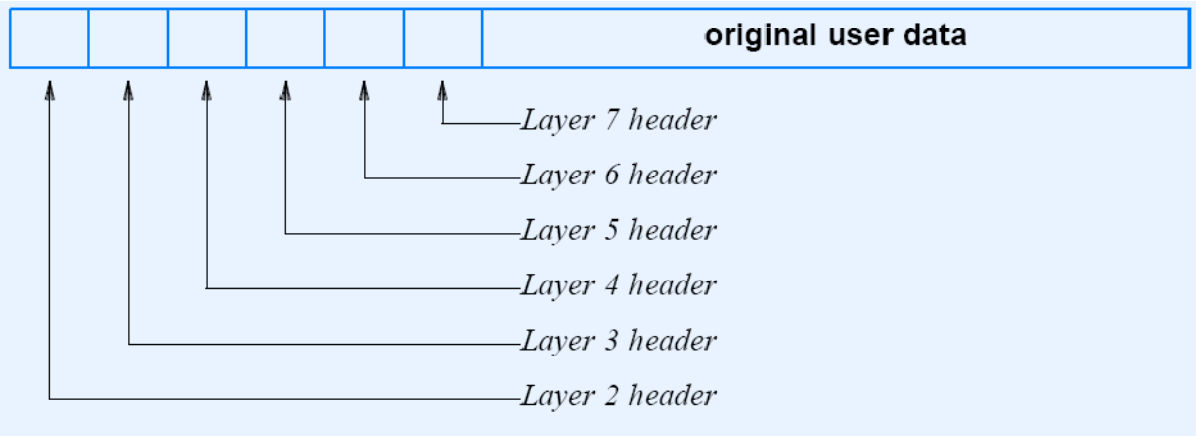
# Layers And Protocol Software

- Protocol software follows layering model
  - One software module per layer
  - Modules cooperate
  - Incoming or outgoing data passes from one module to another
- Entire set of modules known as stack

# Illustration Of Stacks



# Layers And Packet Headers




- Each layer
  - Prepends header to outgoing packet
    (some protocols appends trailer, too)
  - Removes header from incoming packet

• Lower level protocol header first

• No Header for layer 1

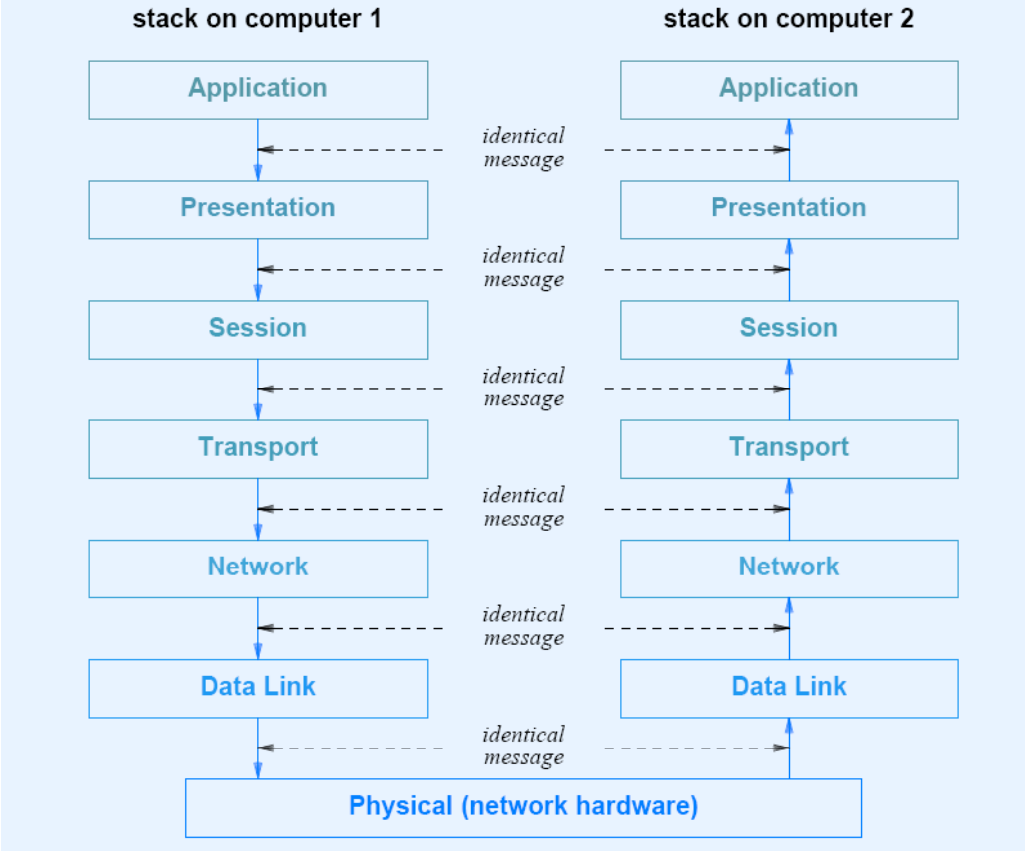
# Scientific Layering Principle

Software implementing layer N at the destination receives exactly the message sent by software implementing layer N at the source.

Change in a layer is invisible to other layers,

Can be designed, implemented, tested independently w.r.t other layers

# Illustration Of Layering Principle



# Protocol Techniques
## (Various techniques for all the layers)

- For bit corruption
  - Parity
  - Checksum
  - CRC
- For out-of-order delivery
  (usually connectionless network
  -(i+1)th by shorter path compared to ith packet
  - Sequence numbers
- Duplication
  (e.g. sender transmits twice during collision in CSMA/CD)
  - Sequence numbers

# Protocol Techniques (continued)

- For lost packets
  - Positive acknowledge and retransmission
  (Set a timer to measure ACK response)
  (Should handle duplicate packet by retransmitting lost packets
  - but too early decision causes the duplication)
- For replay (excessive queuing delay)
  - Unique message ID (for each session)
  - (Previous session terminated if new session starts for replay.)
  (e.g.: time the session is established)
- For data overrun
  - Flow control
  (e.g.: stop-and-go (single packet basis) → inefficient)
  sliding window (window size basis))

# Flow Control

- Needed because
  - Sending computer faster than receiving computer
  - Sending application faster than receiving application
- Related to buffering
- Two forms
  - Stop-and-go
  - Sliding window

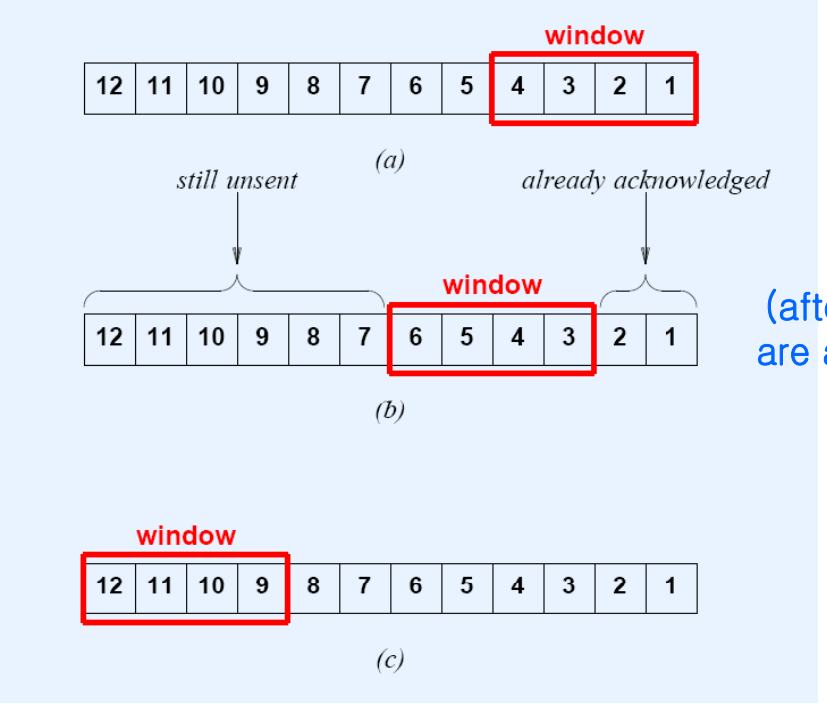
# Stop-And-Go Flow Control

- Sending side
  - Transmits one packet
  - Waits for signal from receiver
- Receiving side
  - Receives and consumes packet
  - Transmits signal to sender
- Inefficient

# Sliding Window Flow Control

- Receiving side
  - Establishes multiple buffers and informs sender
- Sending side
  - Transmits packets for all available buffers (@receiver)
  - Only waits if no signal arrives before transmission completes
- Receiving side
  - Sends signals as packets arrive

# Illustration Of Sliding Window On Sending Side



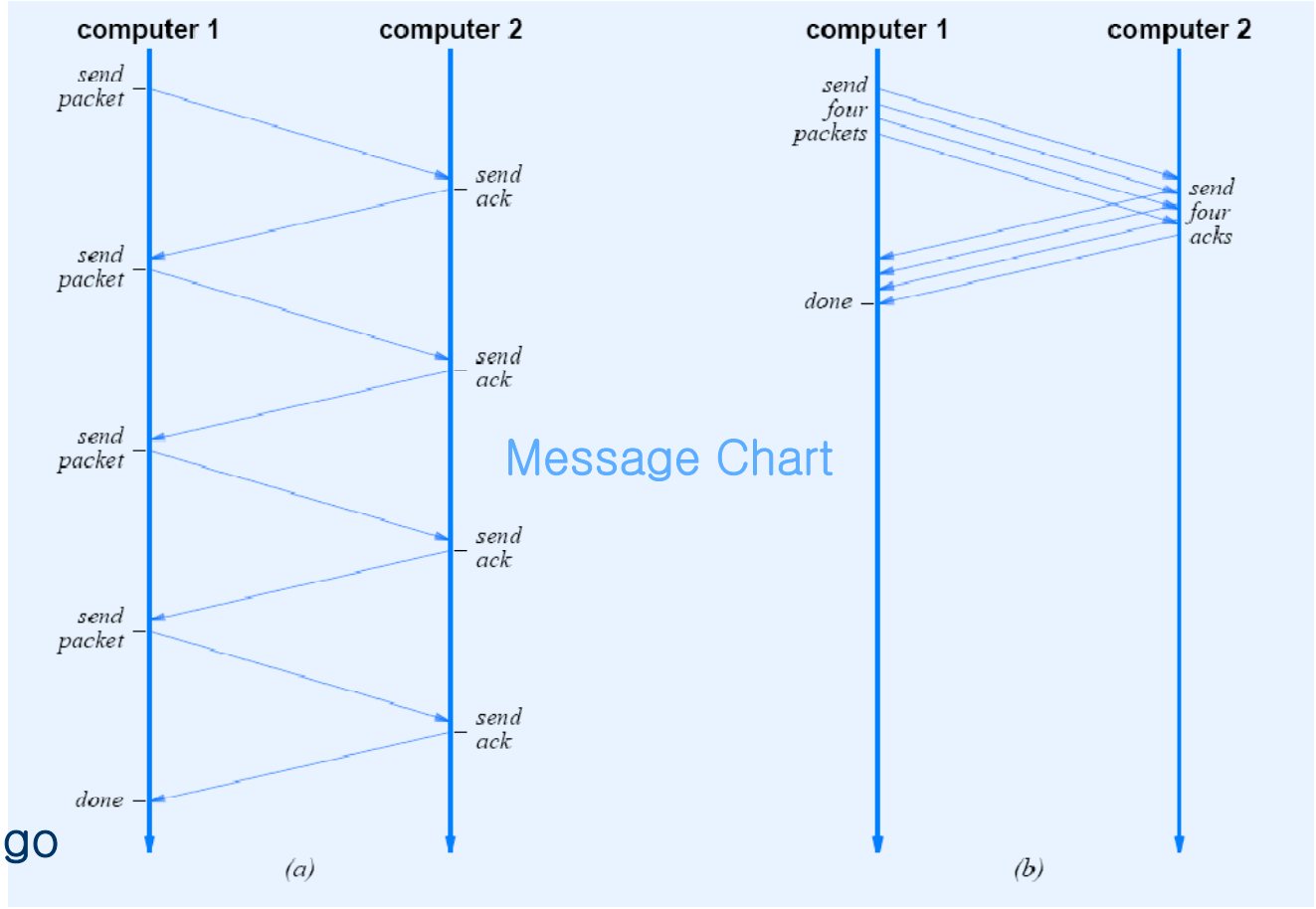

(after two packets are acknowledged.)

- Window tells how many packets can be sent
- Window moves as acknowledgements arrive

# Performance

- Stop-and-go
  - Slow
  - Useful only in special cases
- Sliding window
  - Fast
  - Needed in high-speed network

# Comparison Of Flow Control




Stop and go

Sliding Window

# Why Sliding Window?

- Simultaneously
  - Increase throughput
  - Control flow
- Speedup

$$T_w = \min (B, T_g \times W)$$

where

* Tw is sliding window throughput
* B is underlying hardware bandwidth
* Tg is stop-and-go throughput
* W is window size.

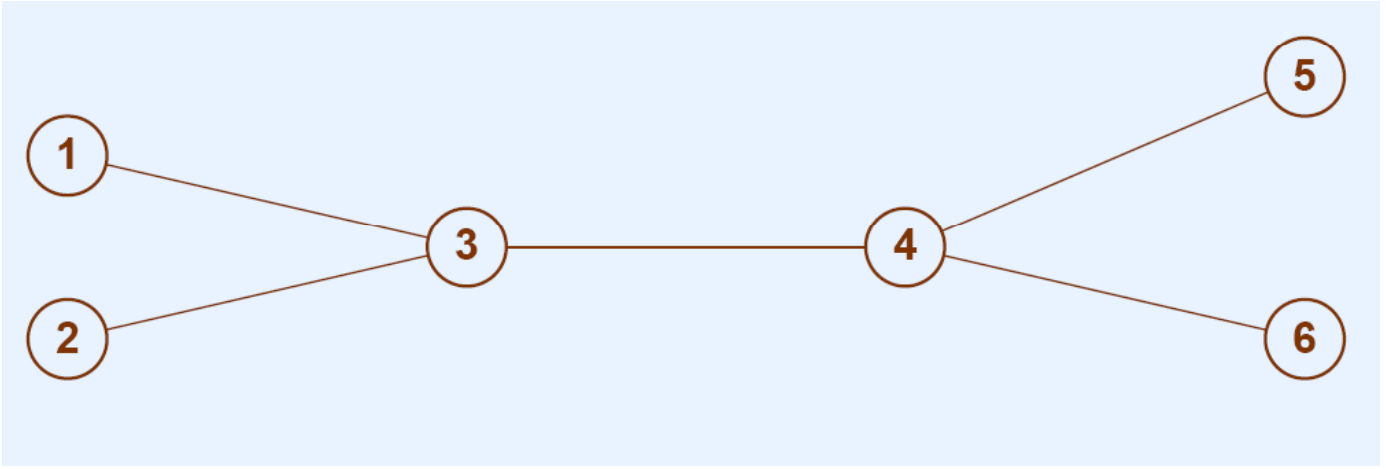
(Window size can't exceed the B)

# Congestion

- Fundamental problem in networks
- Caused by traffic, not hardware failure
- Analogous to congestion on a highway
- Principle cause of delay

→ (Bottleneck)

# Illustration Of Architecture That Can Experience Congestion




- Multiple sources
- Bottleneck

# Congestion And Loss

Modern network hardware works well; most packet loss results from congestion, not from hardware failure.

If entire network becomes unusable → congestion collapse → packet switch (on the way) sets a bit in header → destination acknowledge the sender informing congestion occurred.

# Avoiding Congestion

- Rate control
  - Limit rate of data transmission
  - Performed by sending computer
    (reducing sliding window size etc.) → balancing needed
  - Performed by network
- Network rate control
  - Monitor incoming traffic
  - Drop or reject packets over rate
  - Called traffic shaping

# Summary

- Protocols
  - Rules for communication
  - Specify syntax (forms) and semantics (meanings)
  - Complex
- Protocol layering
  - Intended for protocol designers
  - Helps organize set of protocols
  - Each layer handles one problem

# Summary (continued)

- Problems and techniques
  - Corruption: parity, checksums, CRCs
  - Duplication, out-of-order delivery: sequence numbers
  - Loss: acknowledgement and retransmission
  - Replay: unique ID
  - Congestion: rate control
  - Data overrun: flow control

# Summary (continued)

- Two types of flow control
  - Stop-and-go
  - Sliding window
- Sliding window
  - Receiver advertises buffer
  - Sender can fill entire buffer
  - Produces higher performance

# PART X

## Internetworking Part 1
## (Concept, IP Addressing, IP Routing,
## IP Datagrams, Address Resolution)

# Motivation For Internetworking

- LANs
  - Low cost
  - Limited distance
- WANs
  - High cost
  - Unlimited distance

# Heterogeneity Is Inevitable

No single networking technology best for all needs.

# Universal Service

- Fundamental concept in networking
- Pioneered by telephone system
- Arbitrary pair of computers can communicate
- Desirable
- Difficult in a heterogeneous world

# Heterogeneity And Universal Service

- Incompatibilities among networks
  - Electrical properties
  - Signaling and data encoding
  - Packet formats
  - Addresses

# The Bottom Line

Although universal service is highly desirable, incompatibilities among network hardware and physical addressing prevent an organization from building a bridged network that includes arbitrary technologies.

# An Internetworking (= Internet)

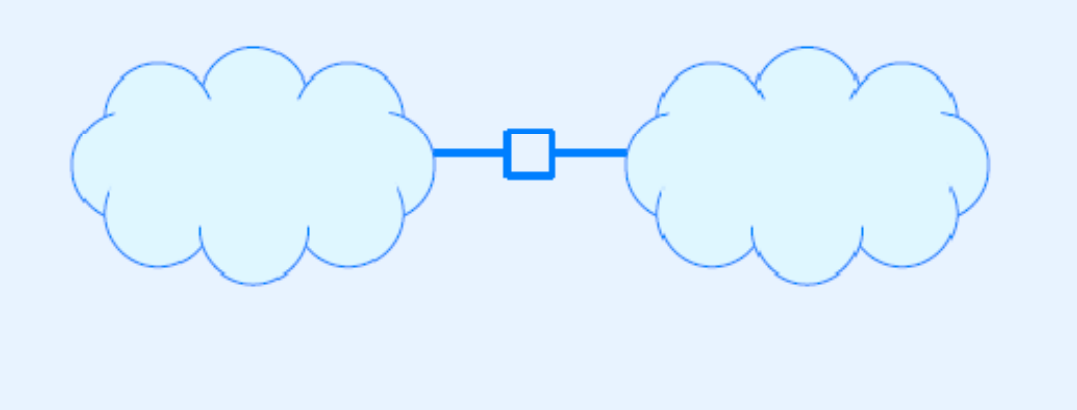
- Begin with heterogeneous network technologies
- Connect the physical networks
- Create software to make resulting system appear homogeneous
- Called an internetwork or internet

# Connecting Heterogeneous Networks

- Computer system used
  - Special-purpose
  - Dedicated
  - Works with LAN or WAN technologies
  - Known as
    - * Internet router
    - * Internet gateway

In modern networking parlance, "gateway" and "router" are usually interchangeable and refer to devices with the same purpose. For a network administrator running a large company network, there can be a difference between a router and a gateway. The company may have several subnets connected together via routers, and all of the routers are connected to a gateway device that allows the computers on the subnets to access the Internet. In this case, at a technical level the gateway and the routers perform the same networking functions, but the gateway is an actual "gateway" to the Internet and the routers allow inter-subnet communication – the real difference lies in a device's role in the network structure.

# Illustration Of An Internet Router



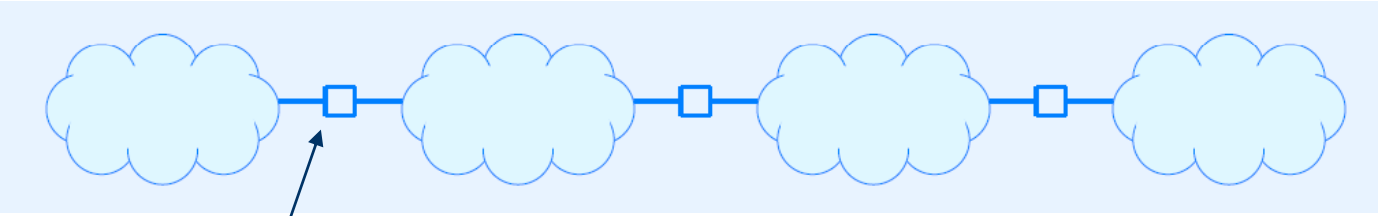
- Cloud denotes arbitrary network technology
- One interface per network

  (Router is treated as a computer)

# Important Idea

A router can interconnect networks that use different technologies, including different media and media access techniques, physical addressing schemes, or frame formats.

# Internet Architecture

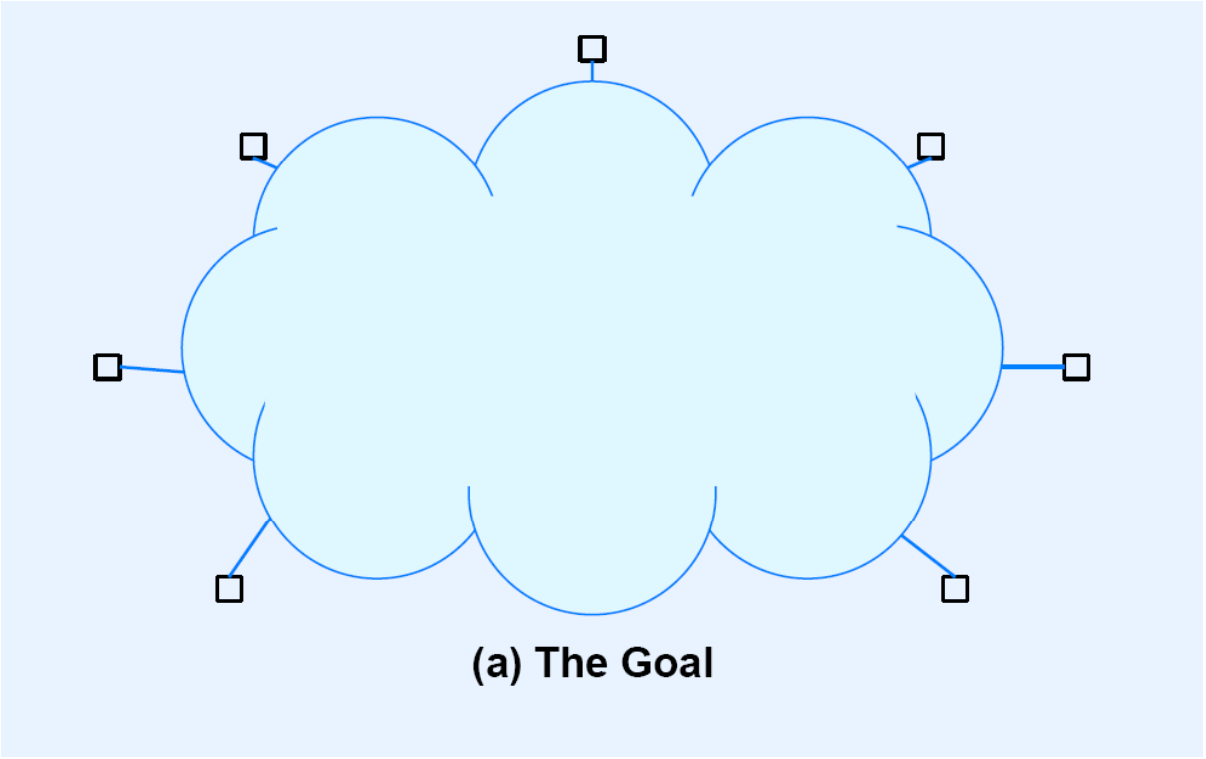


- Multiple
  - Networks
  - Routers interconnecting networks
- Host computer connects to a network
- Single router has insufficient
  (to connect all the networks)
  - CPU power and memory
  - I/O capability

# Internetworking

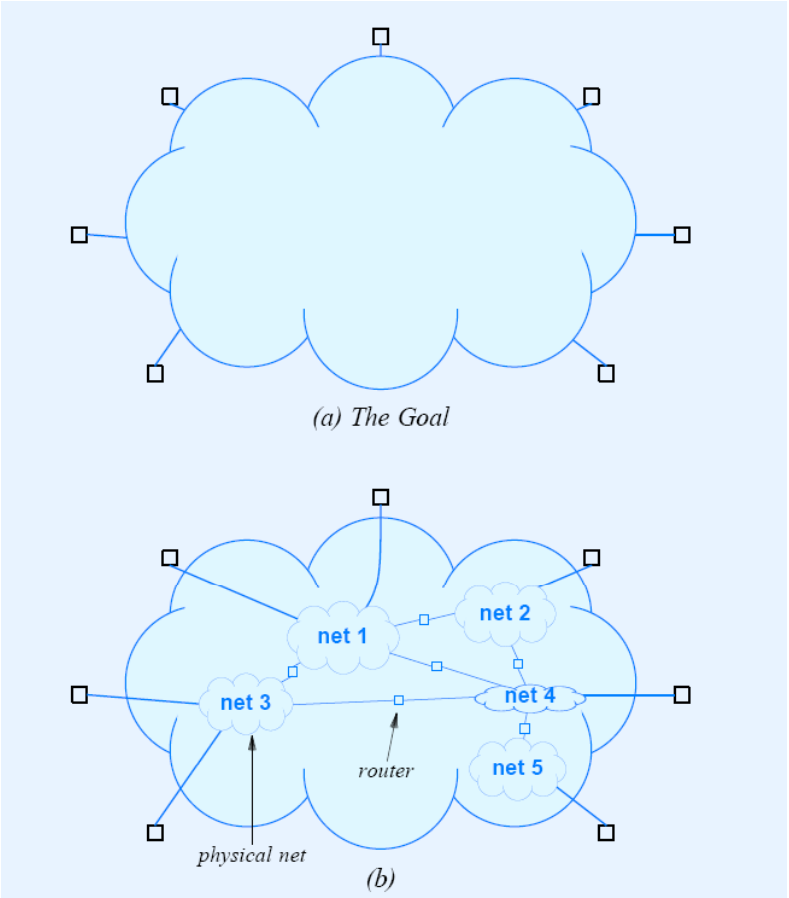
- Goal: communication system
  - Seamless
  - Uniform
  - General-purpose
  - Universal
  - Hides heterogeneity from user

# The Internet Concept



(a) The Goal

# The Internet Concept




Virtual Network

Heterogeneous network connected through routers in reality

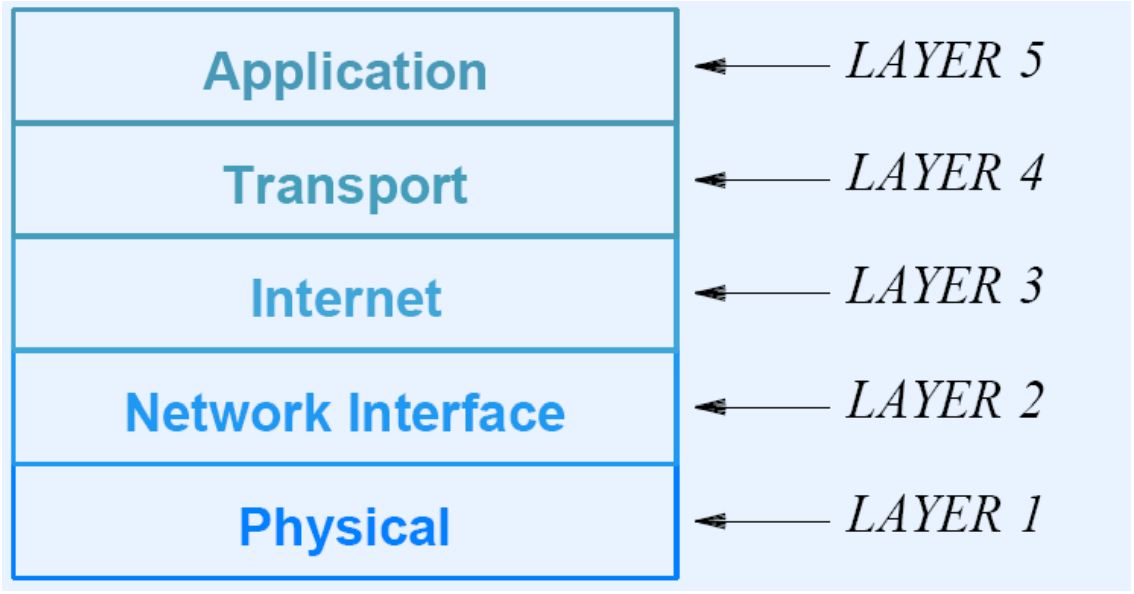
# To Hide Heterogeneity

- Create “virtual” network
- Invent
  - Addressing scheme
  - Naming scheme
- Implement with
  - Protocol software
- Note: protocol software needed on both hosts and routers

# Internet Protocols

- Known as TCP/IP
- Many protocols comprise suite
- Designed to work together
- Divided into five conceptual layers

# Layering Used With TCP/IP




Note: TCP/IP layering model replaces the old ISO model

# TCP/IP Layers

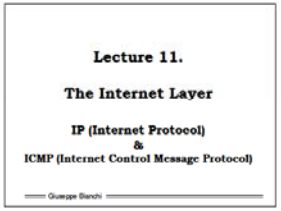
- Layer 1: Physical
  - Basic network hardware
- Layer 2: Network Interface (→ like Data Link layer)
  - MAC frame format
  - MAC addressing
  - Interface between computer and network (NIC)
- Layer 3: Internet
  - Facilities to send packets across internet composed of multiple routers
    - Specify the format of packets
    - How to forward packets through routers

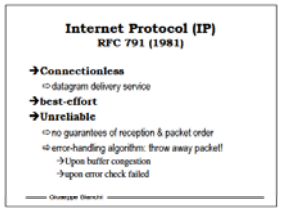
# TCP/IP Layers (continued)

- Layer 4: Transport
  - Transport from an application on one computer to application on another → (Reliability)
- Layer 5: Application
  - Everything else

# Internet Protocol (IP)

- Only protocol at Layer 3
- Fundamental in suite
- Defines
  - Internet addressing
  - Internet packet format
  - Internet routing



# IP Addressing

- Abstraction
- Independent of hardware addressing

  (Since Multiple network technologies use different address formats)
- Used by
  - Higher-layer protocols
  - Applications

# IP Address

- Virtual
  - Only understood by software
- Used for all communication
- 32-bit integer
- Unique value for each host