CMSC 132:
Object-Oriented Programming II

Networking

Department of Computer Science
University of Maryland, College Park

Advanced Programming Concepts

- Objected-oriented support in Java for
  - Exception handling
  - Streams
  - Threads
  - Graphics user interfaces (GUIs)
  - Networking

- Look at networking as example of OO design

Overview

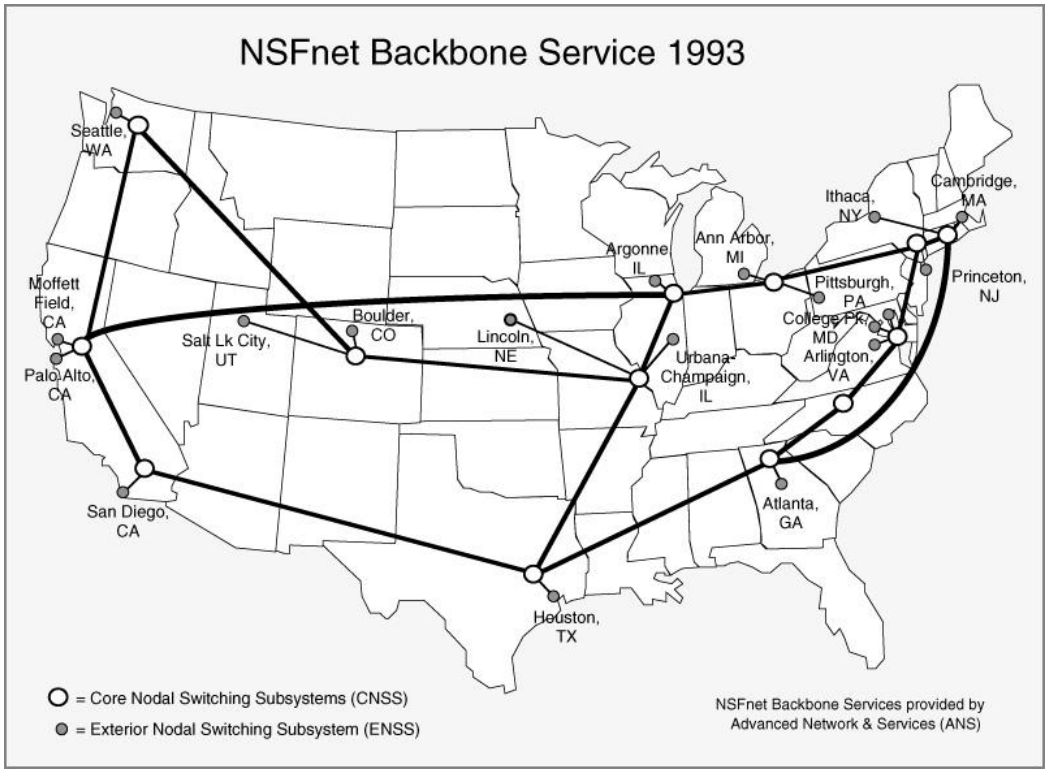
- Networking
  - Background
  - Concepts & terms
  - Java's objected-oriented view
  - Java's networking API
    (Application Program Interface)
  - Network applications

This lecture

Next lecture

Networking Background

- **Definition**
  - **Set of computers using common protocols to communicate over connecting media**
- **History**
  - **1969 ARPANET**
  - **1986 NSFnet**
  - **1995 Internet**



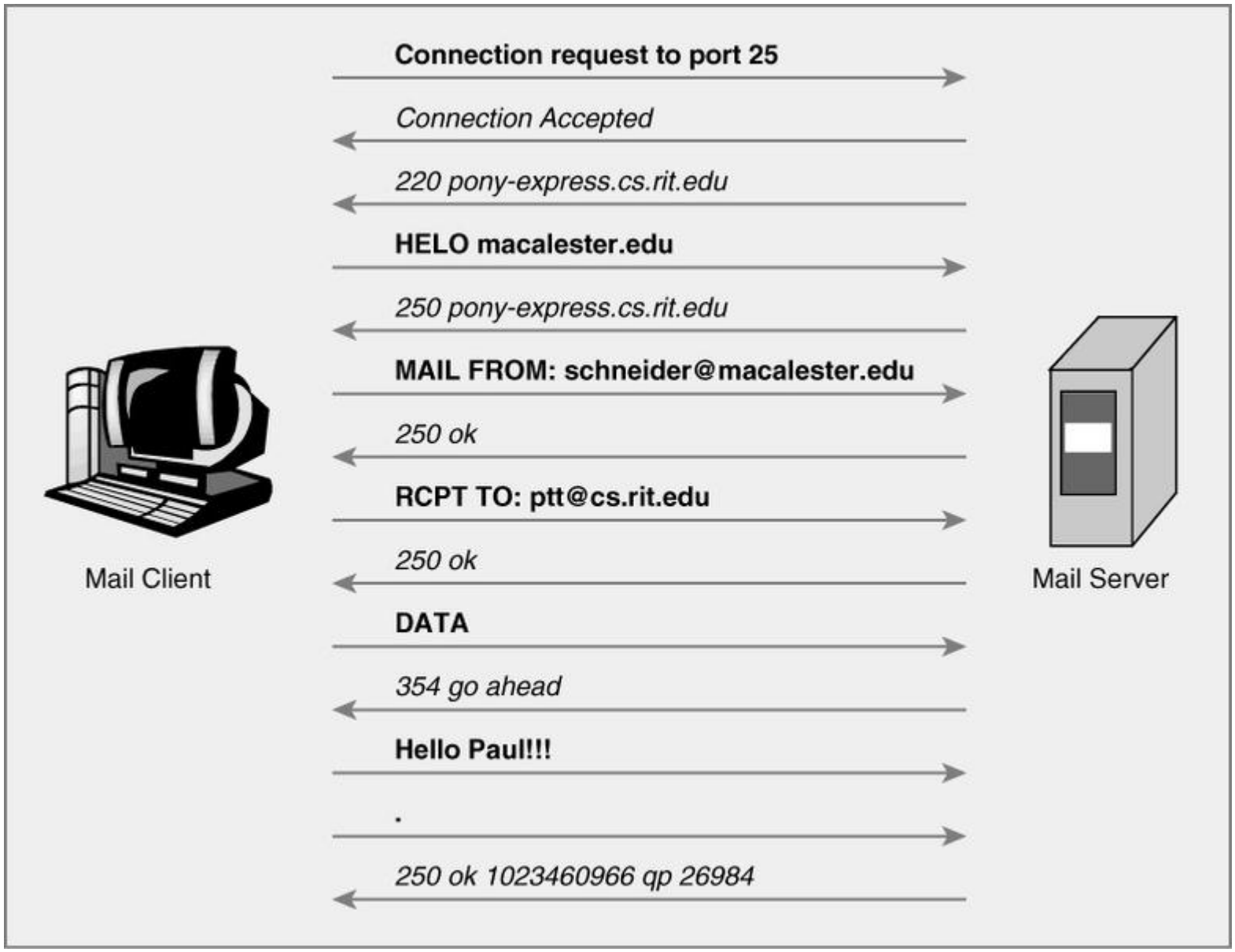
Networking Concepts

- Protocols
- Network model
- Internet addresses
- Ports
- Sockets
- URLs
- Connection (TCP) vs. packet oriented (UDP)
- Reliability

Protocols

- Definition
  - Formal description of formats and rules
- Used for
  - Message formats
  - Sequence & order of actions
- Needed by computers to exchange information
- Vital for networking

Protocols – Email Delivery



Protocol – HTTP GET (Web Page)

- **Client connects to server on port 80**

  GET /~pugh/index.html HTTP/1.0

  <blank line>

- **Server responses with HTTP headers**

  HTTP/1.1 200 OK

  Date: Mon, 20 Feb 2006 03:47:44 GMT

  Server: Apache

  Last-Modified: Wed, 15 Feb 2006 01:17:09 GMT

  ETag: "9b2b1c-948-1222af40"

  Accept-Ranges: bytes

  Content-Length: 2376

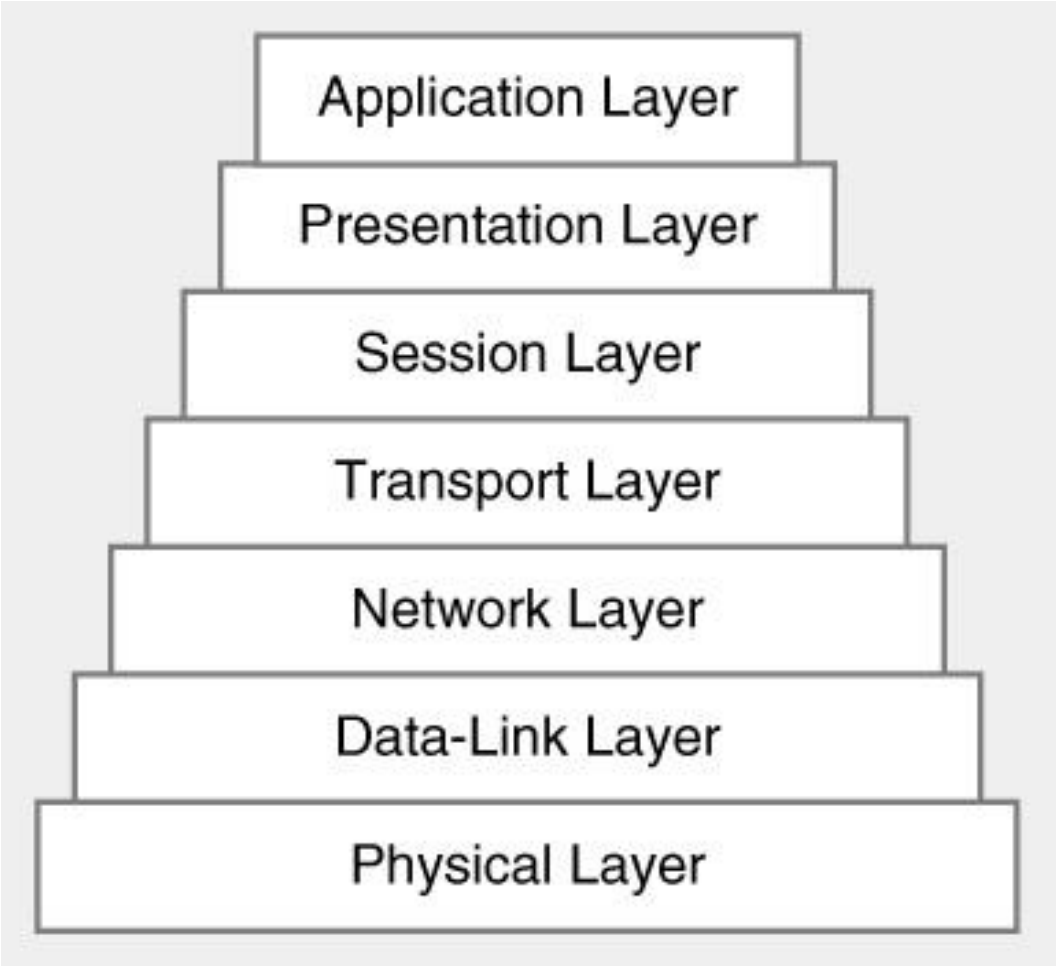
  Connection: close

  Content-Type: text/html; charset=ISO-8859-1

- **Followed by blank line, then contents of response**

Network Model

- Open Systems Interconnection (OSI) model
  - Multiple layers (7)
  - One function each
  - Each layer relies on previous layer
- Designed to reduce complexity using abstraction

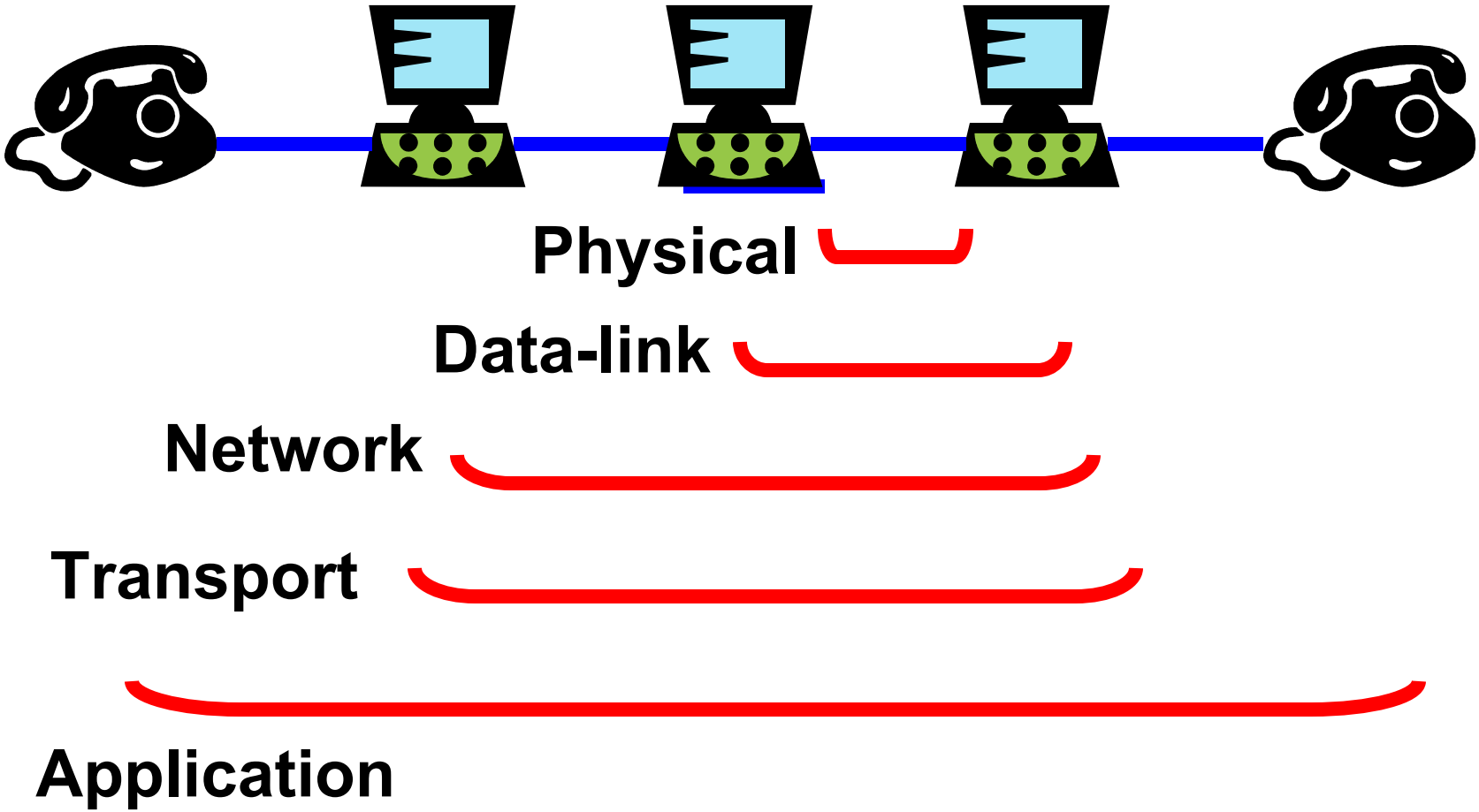


Network Model – Layers

- **Physical layer**
  - Transmit data as 0's and 1's over connection
- **Data-link layer**
  - Between two physically connected computers
- **Network layer**
  - Between any two computers connected to network
- **Transport layer**
  - Deliver network data to application
- **Application layer**
  - Between two applications using network

Network Model – VOIP Example

- Voice over IP (VOIP)



Internet (IP) Address

- Unique address for machine on internet
  - Get from ISP when connecting to internet
  - Allows network to find your machine
- Format
  - 32-bit unsigned integer ⇒ 128.8.128.8
  - Domain name ⇒ cs.umd.edu
- Name and address for local machine
  - Localhost
  - 127.0.0.1
- Machine can have multiple IP addresses
  - Virtual machines

Internet (IP) Address

- **Problem**
  - Running out of 32-bit IP addresses
  - Caused by initial address allocation
    - Stanford & MIT given more IP addresses than China
- **Switching to 128-bit IP addresses in IPv6**
  - 1+ million addresses per square meter on Earth

IP Address – DNS

- Domain Name System (DNS)
  - Protocol for translating domain names to IP addresses
    - Example: cs.umd.edu → 128.8.128.44
  - Multiple DNS servers on internet
  - DNS server may need to query other DNS servers
    - edu DNS server queries umd.edu server to find cs.umd.edu

IP Address – DHCP

- Dynamic Host Configuration Protocol (DHCP)
  - Protocol used by networked computers to obtain
    - Unique IP addresses
    - Default router, subnet mask
    - IP addresses for DNS servers
  - DHCP server on local network
  - Used when computers first connect to network
  - Settings (leases) periodically refreshed

IP Address – NAT

- **Network Address Translation (NAT)**
  - **Rewriting source / destination IP addresses**
    - **As data passes through router**
  - **Permits sharing of single IP address among multiple computers**
  - **Used in home networking (NAT box)**

IP Address – NAT

- NAT approach
  - NAT box connects to both internet & private network
    - Obtains single public IP address from ISP
    - Assigns local IP address to computers on private network
  - For data traveling to / from internet
    - NAT box merges and translates IP addresses
      - Local IP addresses ↔ public IP address
  - From Internet
    - All private computers appear to have same IP address

Ports

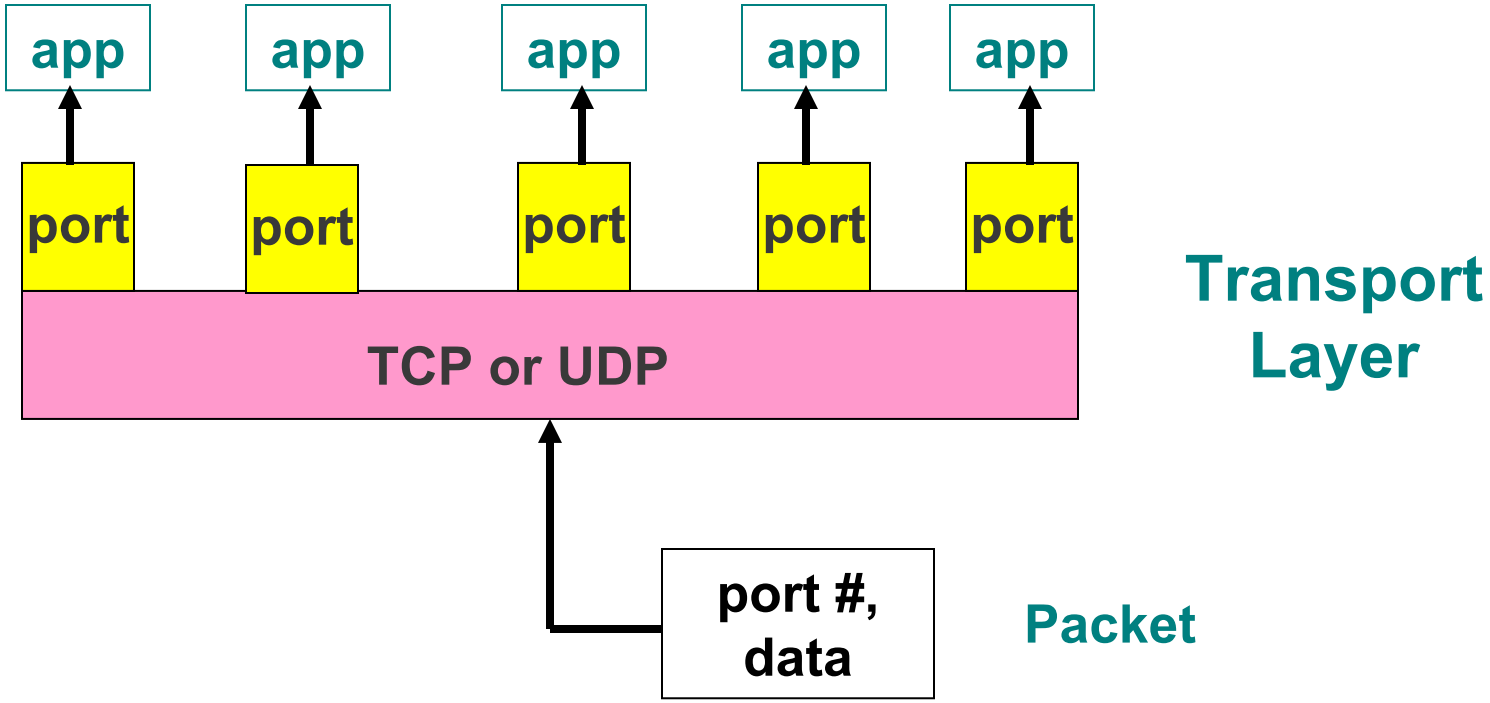
- Abstraction to identify (refine) destination
  - Provide multiple destinations at single IP address
- Format
  - Unsigned 16-bit integer (0 to 65,535)
  - Ports 0 to 4096 often reserved & restricted
- Many ports pre-assigned to important services
  - 21 ftp (file transfer)
  - 23 telnet (remote terminal)
  - 25 SMTP (email)
  - 80 http (web)
  - …

Sockets

- Application-level abstraction
  - Represents network connection
  - Implemented in software
  - Supports both UDP and TCP protocols
- History
  - Introduced in Berkley UNIX in 1980s
  - Networking API

Sockets

- Socket is bound to port number
  - Receives data packet
  - Relays to specific port



Uniform Resource Locators (URLs)

- **Represent web resources**
  - **Web pages**
  - **Arbitrary files**
  - **…**
- **Examples**
  - **http://www.cs.umd.edu/index.html**
  - **ftp://www.cs.umd.edu/pub/doc/csd_policies.pdf**
  - **https://login.yahoo.com/**
  - **file://dir/my.txt**

Uniform Resource Locators (URLs)

- Consists of
  - Protocol
    - http
    - ftp
    - https (secure http)
    - file
    - …
  - IP address (or domain name)
  - Port (optional)
    - http://www.cs.umd.edu:80/
  - Reference to anchor (optional)

Internet Connections

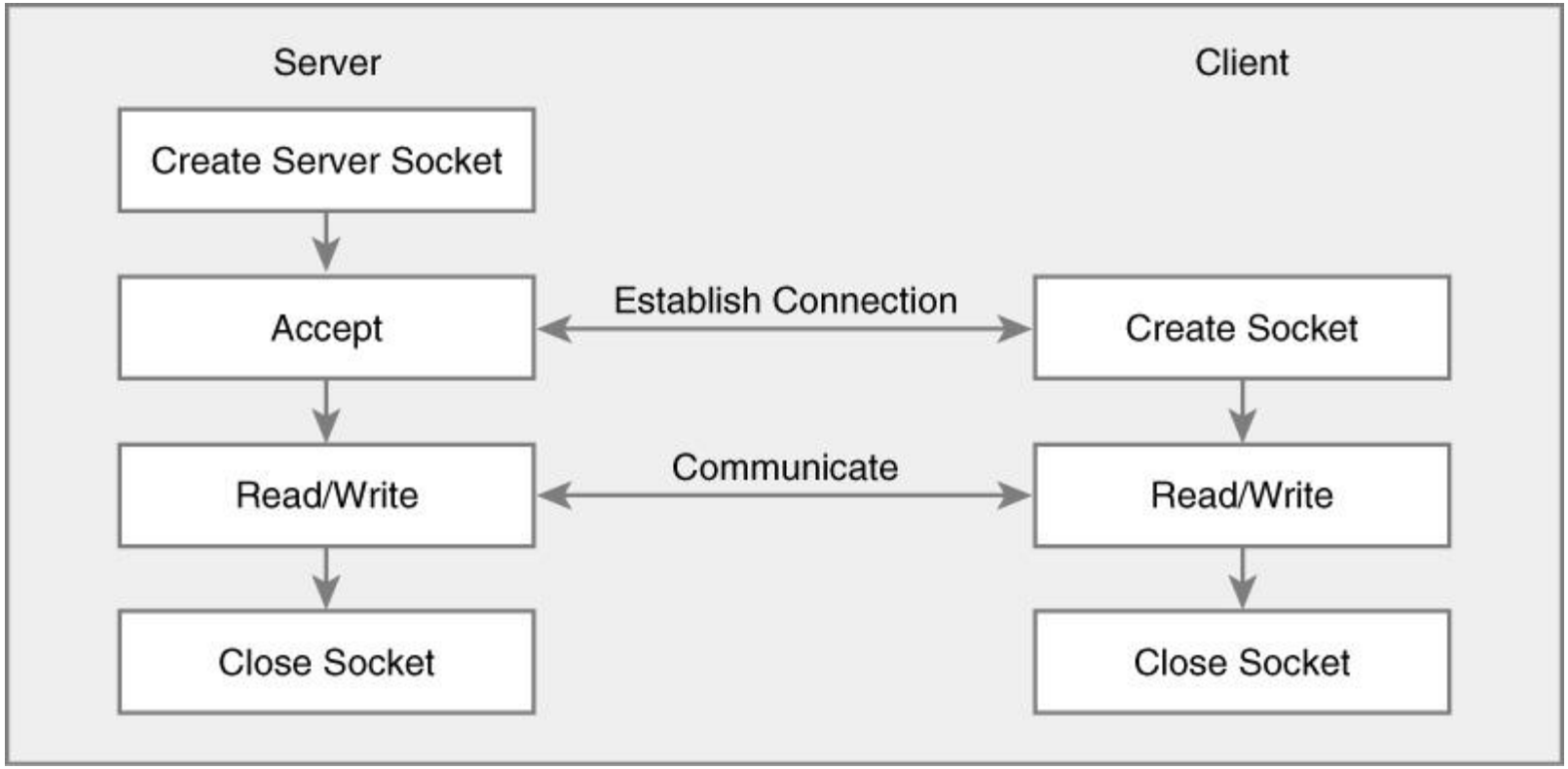
- **Two types of connections**
  1. **Connection-oriented (TCP)**
  2. **Packet-oriented (UDP)**

Connection Oriented

- Approach
  - Reserve (single) communication channel
  - Send stream of data along channel
- Also called
  - Circuit switching
  - Stream oriented
- Example
  - Telephone call (current)

Connection Oriented

- **Protocol**



Connection Oriented

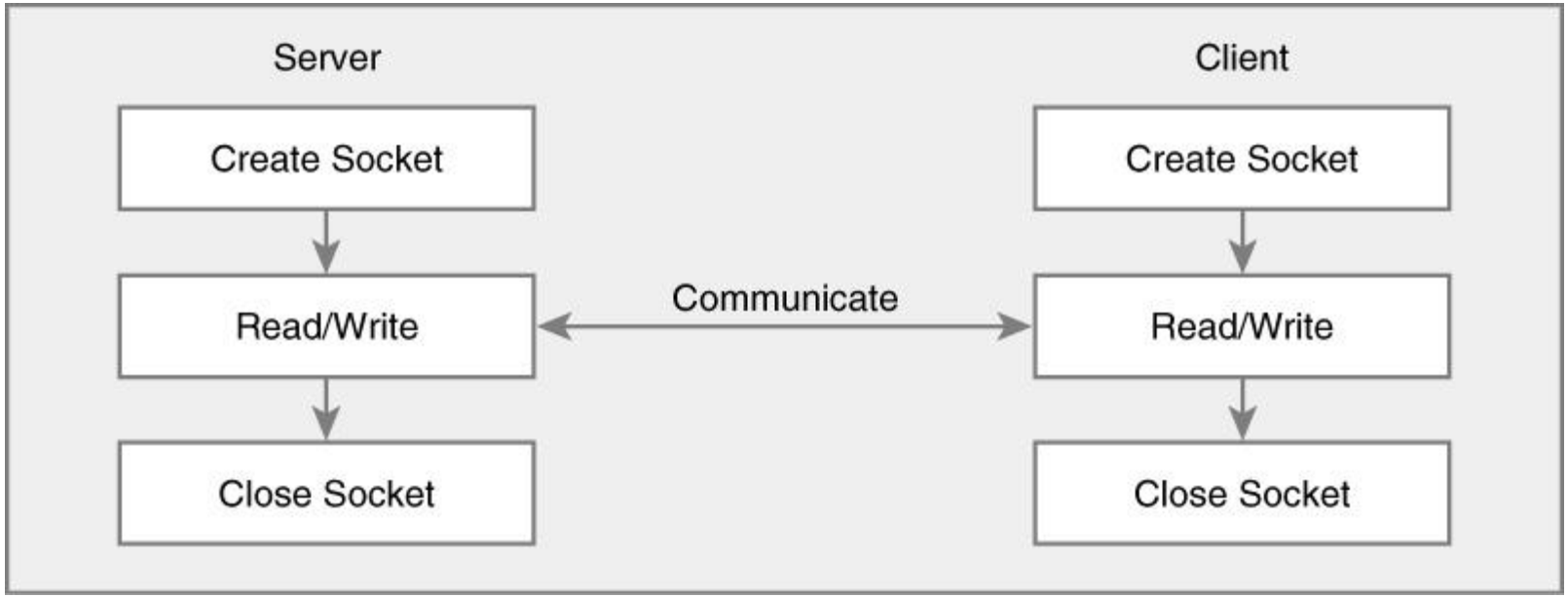
- **Advantages**
  - **Simpler scheme**
  - **Easier to use**
  - **Higher quality communication**
    - **Less likely to lose data (at network layer)**

Packet Oriented

- Approach
  - Break message up into packets
  - Transmit packets separately
  - Assemble packets at destination
- Also called
  - Packet switching
  - Connectionless
- Example
  - US Mail
  - VOIP (Voice over IP)

Packet Oriented

- **Protocol**



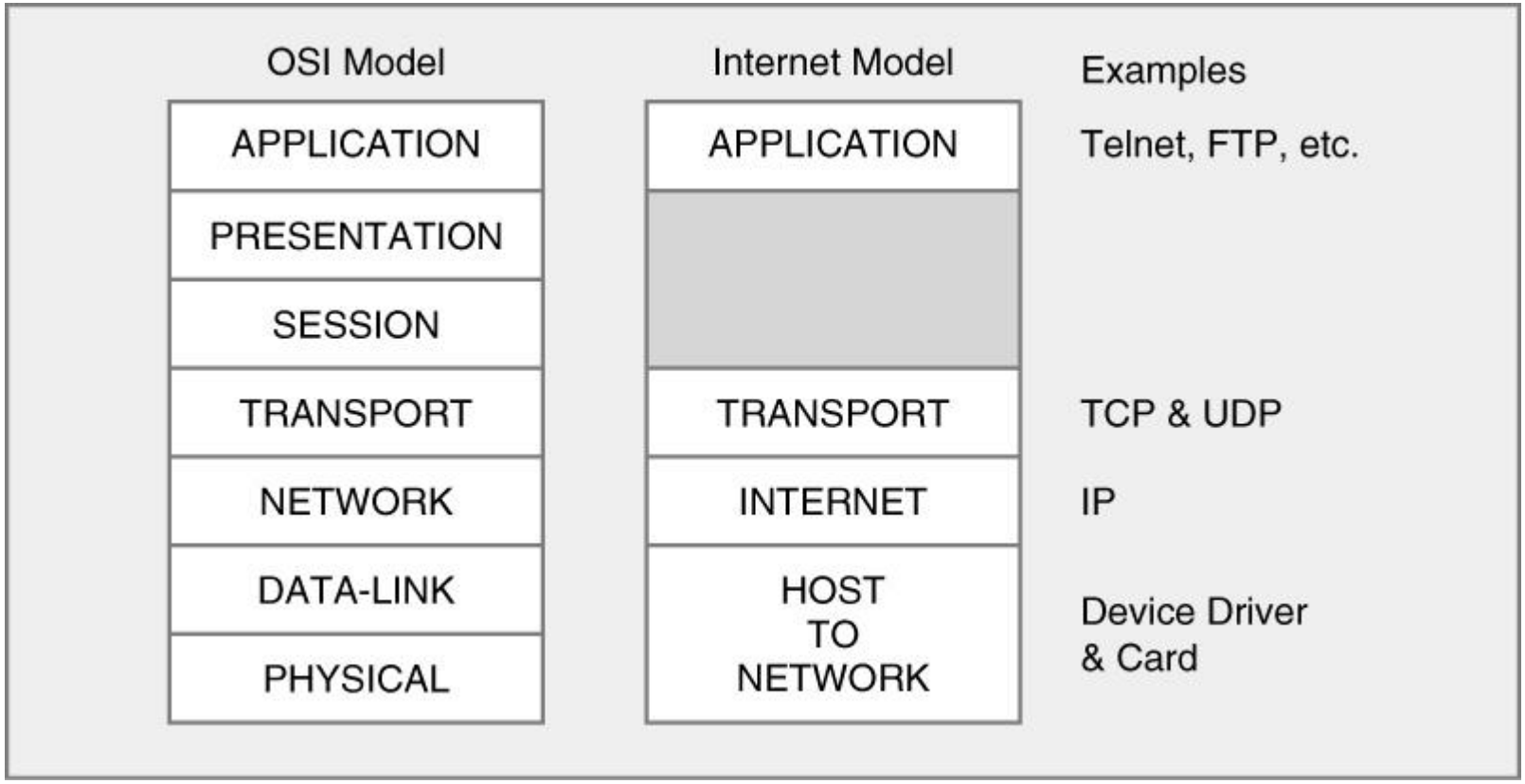
Packet Oriented

- Advantages
  - Higher utilization of channels
    - Can share communication channel
    - Can utilize multiple channels at once
  - Can reroute around failed channels

Internet

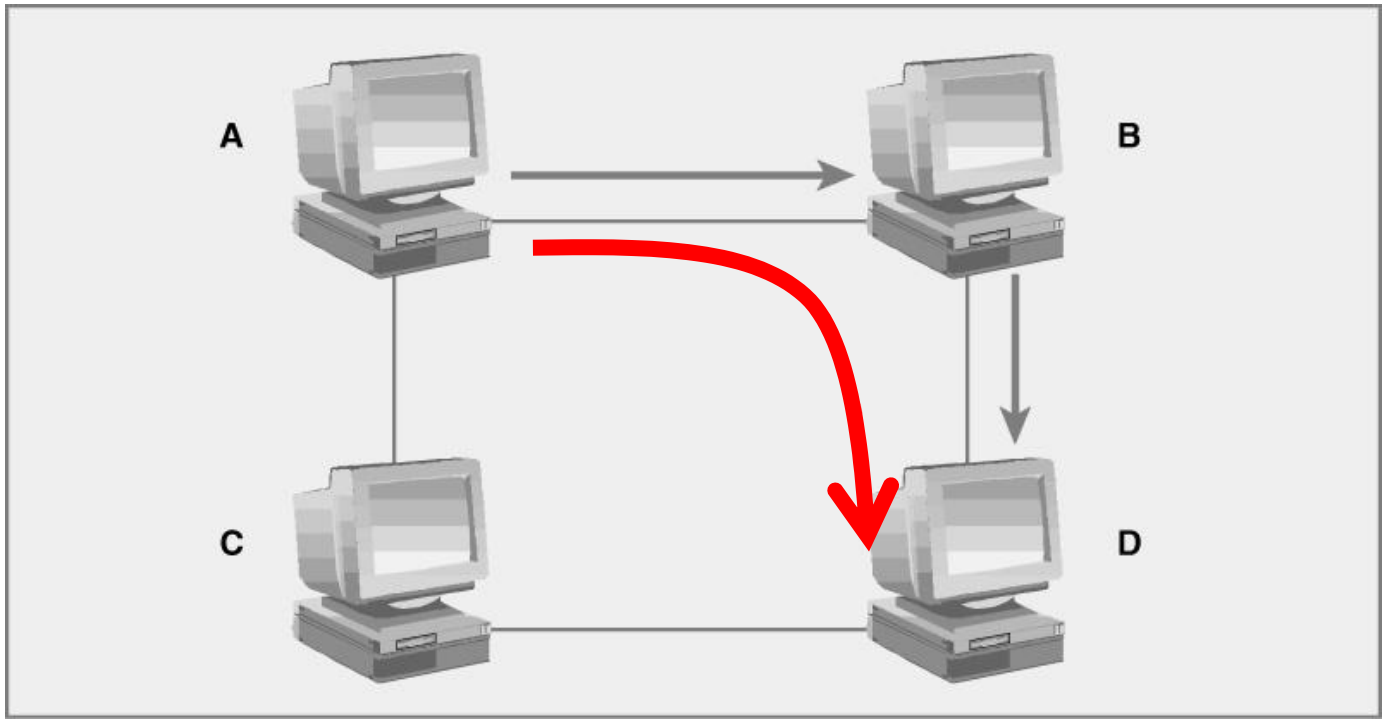
- Network layer
  - Internet Protocol (IP)
- Transport layer
  - User Datagram Protocol (UDP)
  - Transmission Control Protocol (TCP)

Internet


OSI Model
Internet Model
Examples
APPLICATION
APPLICATION
Telnet, FTP, etc.
PRESENTATION
SESSION
TRANSPORT
TRANSPORT
TCP & UDP
NETWORK
INTERNET
IP
DATA-LINK
HOST TO NETWORK
Device Driver & Card
PHYSICAL

Internet Protocol (IP)

- Packet oriented
- Packets routed between computers
- Unreliable



User Datagram Protocol (UDP)

- Packet oriented
- Message split into datagrams
- Send datagrams as packets on network layer
- Unreliable but fast
- Application must deal with lost packets
- Examples
  - Ping
  - Streaming multimedia
  - Online games

Transmission Control Protocol (TCP)

- Connection oriented
- Message split into datagrams
- Send datagrams as packets on network layer
- Provides illusion of reliable connection
  - Extra messages between sender / recipient
  - Resend packets if necessary
  - Ensure all packets eventually arrive
  - Store packets and process in order
  - Provides warning if packets are lost

Transmission Control Protocol (TCP)

- Reliable but slower
- Application can treat as reliable connection
  - Despite unreliability of underlying IP (network)
- Examples
  - ftp (file transfer)
  - telnet (remote terminal)
  - http (web)

Reliability – Reliable

- What is reliability?
- Reliable
  - Data guaranteed to
    - Arrive in order (if it arrives)
  - More overhead
  - Slower
- Reliability does not guarantee arrival
  - But will provide warning if data does not arrive

Reliability – Unreliable

- **Unreliable**
  - **Data not guaranteed to**
    - **Arrive ⇒ lost data**
    - **Arrive in order ⇒ out of order data**
  - **Less overhead**
  - **Faster!**
  - **Transfers responsibility to higher layer**
    - **Extra work for higher layer**
    - **Compensate with timeouts**
      - **Estimate packet lost if longer than average round trip**

Reliability

- Reliable layers
  - Data-link
- Unreliable layers
  - Physical
  - Network
- Can be either
  - Transport
    - Reliable ⇒ TCP
    - Unreliable ⇒ UDP
  - Application