CMSC 132:
Object-Oriented Programming II

Networking

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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

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Overview

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

This lecture

Next lecture

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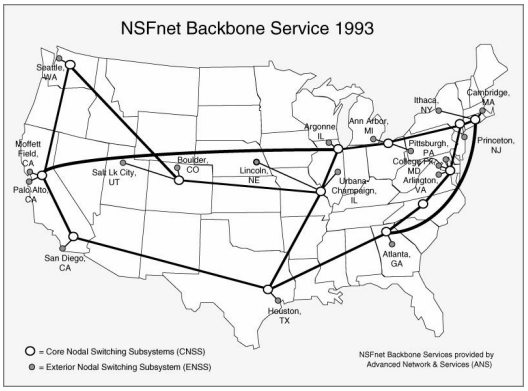
Networking Background

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



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Networking Concepts

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

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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

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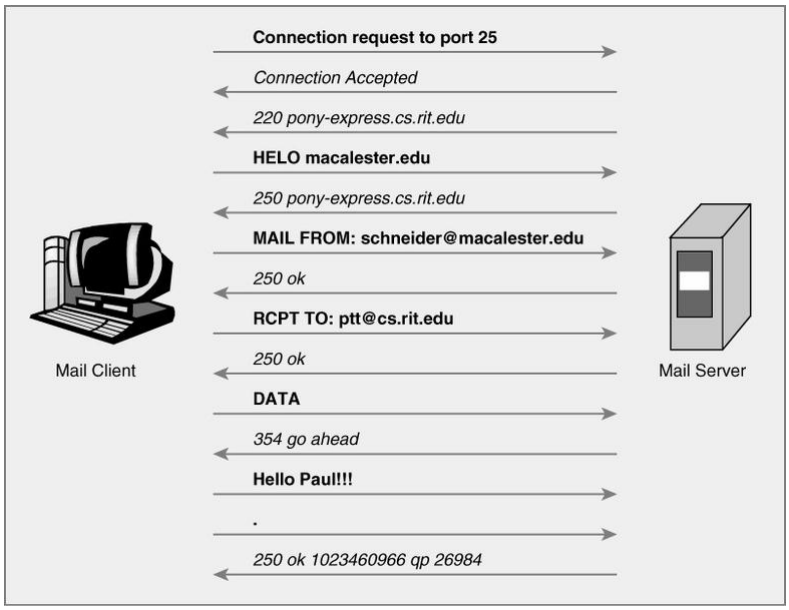
Protocols – Email Delivery



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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**

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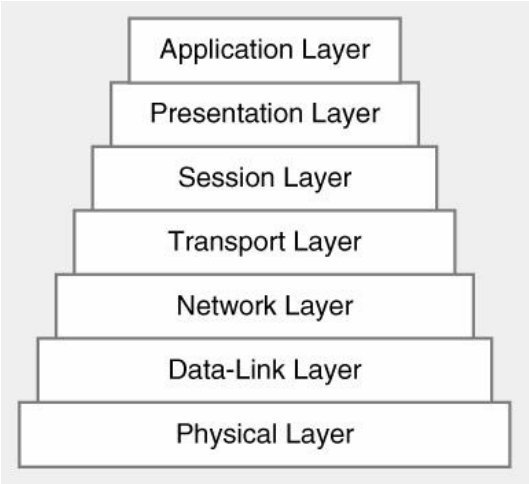
Network Model

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



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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

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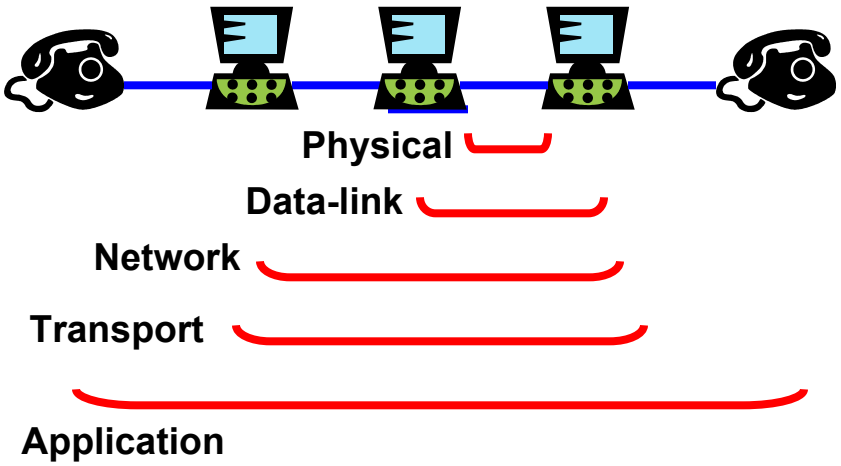
Network Model – VOIP Example

- Voice over IP (VOIP)



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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

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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

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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

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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

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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)

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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

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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)
  - …

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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

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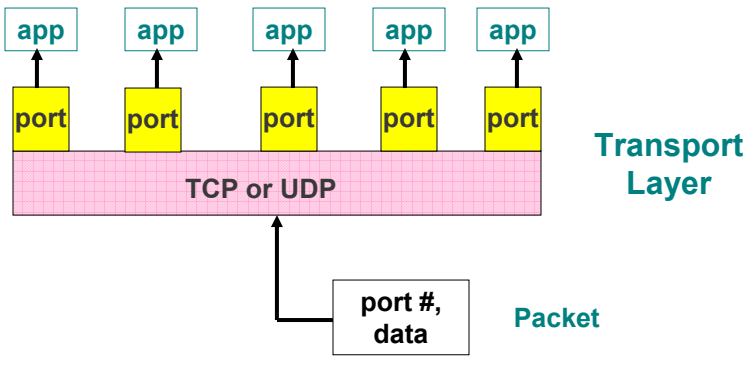
Sockets

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



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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

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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)

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Internet Connections

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

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Connection Oriented

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

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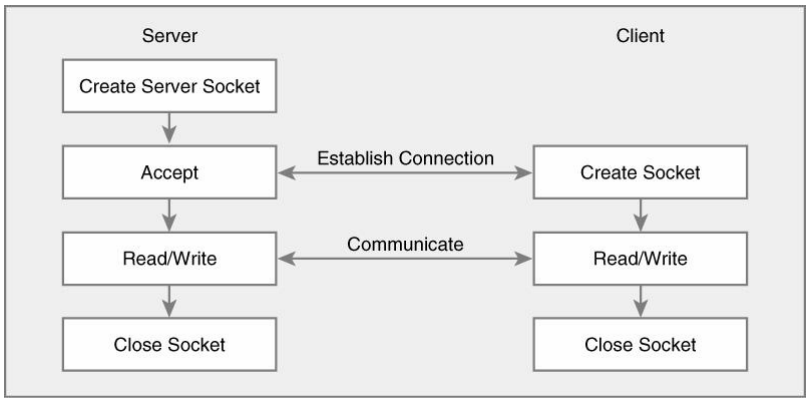
Connection Oriented

- Protocol



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Connection Oriented

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

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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)

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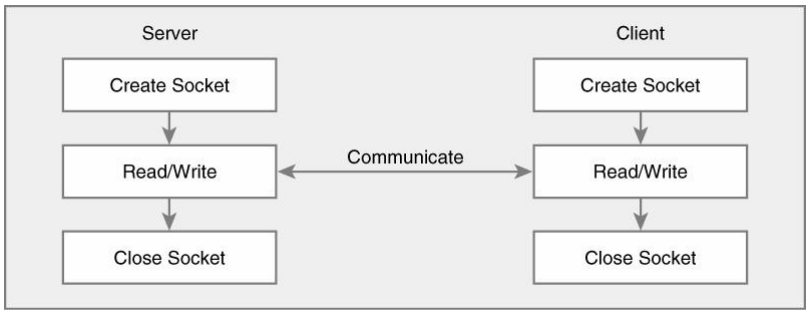
Packet Oriented

- Protocol



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Packet Oriented

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

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Internet

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

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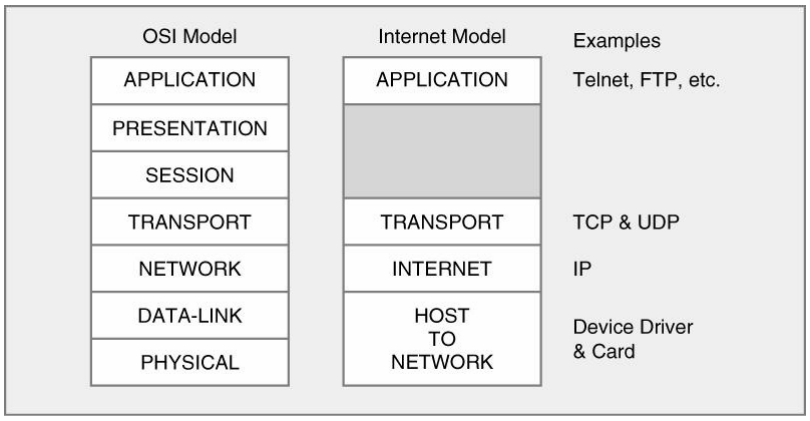
Internet



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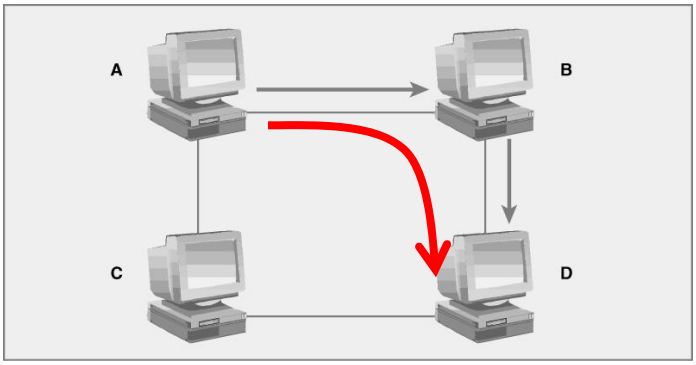
Internet Protocol (IP)

- Packet oriented
- Packets routed between computers
- Unreliable



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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

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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

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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)

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Reliability

- 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

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Reliability

- 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

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Reliability

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

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