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

Client connects to server on port 25
- Connection Accepted
- 220 pony-express.cs.rit.edu
- HELO macalester.edu
- 250 pony-express.cs.rit.edu
- MAIL FROM: schneider@macalester.edu
- 250 ok
- RCPT TO: ptt@cs.rit.edu
- 250 ok
- DATA
- 354 go ahead
- Hello Paul!!!
- .
- 250 ok 1023450966 qp 26984

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)

![Diagram of network layers]

- Physical
- Data-link
- Network
- Transport
- Application

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
- 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)
  - 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

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

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](chart)

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<tr>
<th>OSI Model</th>
<th>Internet Model</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPLICATION</td>
<td>APPLICATION</td>
<td>Telnet, FTP, etc.</td>
</tr>
<tr>
<td>PRESENTATION</td>
<td>TRANSPORT</td>
<td>TCP &amp; UDP</td>
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<td>SESSION</td>
<td>INTERNET</td>
<td>IP</td>
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<td>TRANSPORT</td>
<td>HOST</td>
<td>Device Driver &amp; Card</td>
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<td>NETWORK</td>
<td>TO NETWORK</td>
<td></td>
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<tr>
<td>DATA-LINK</td>
<td></td>
<td></td>
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<tr>
<td>PHYSICAL</td>
<td></td>
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</tbody>
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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