Client Server Programming

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Network Applications

- There are many network applications
  - Network applications involve the cooperation of processes running on different hosts connected by a network
- Applications may be “standard” or custom applications
  - Internet applications are typically defined in one or more Request for Comments (RFCs)
    - HTTP defined in RFC 1945
  - May be standard, drafts, or informational

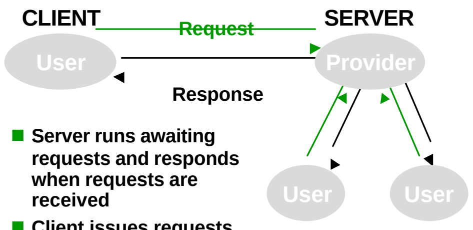
Port Assignment

- UDP and TCP ports are used to distinguish between multiple applications on one host
- Standard numbering for “well-known port numbers”
  - Defined in RFC 1700 for “standard” Internet applications
  - Configured in various places specific to the operating system and in the application itself
    - Windows 95/98: \Windows\services
    - NT: Systemroot\System32\Drivers\Etc\services
    - UNIX: /etc/services

Sample From /etc/services

```
echo            7/tcp
echo            7/udp
discard         9/tcp    sink null
discard         9/udp    sink null
systat         11/tcp
systat         11/tcp    users
daytime        13/tcp
daytime        13/udp
netstat        15/tcp
qotd           17/tcp    quote
qotd           17/udp    quote
chargen        19/tcp    ttytst source
chargen        19/udp    ttytst source
```

Service User Versus Service Provider



- Server runs awaiting requests and responds when requests are received
- Client issues requests to server and accepts response

There may be multiple users of one provider

Concurrency at the Server

- Many servers provide concurrent operation
  - Apparent concurrency using asynchronous socket I/O
  - True (program-level) concurrency using multithreaded design
- Concurrency adds complexity!
- When is concurrency justified?
  - Need to simultaneously handle multiple requests
  - Need to increase performance

Example Standard Service: TELNET

- TELNET is a standard application protocol for remote login
  - Defines format of data sent by application program to remote machine and by remote machine to the application
  - Defines character encoding
  - Defines special messages to control the session
- telnetd is server running on the remote host (at port 23)
- Client is the application program on the local host, e.g. CRT or other TELNET client

TELNET to Access Alternative Services

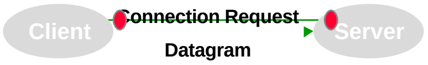
- A TELNET client can be used to access alternative servers
  - Simple text transfer -- so can access general text based services
  - Typical TELNET clients can be configured to access different remote ports
  - Of course, other clients are designed to provide a better user interface

Peer-to-Peer Communication Model

- TCP/IP suite supports *peer-to-peer* communication
- Peer-to-peer communication is *symmetric*
  - Any node can initiate or terminate communication
  - Communication can occur in either direction
- There are no implications of …
  - When applications should interact
  - Meaning of data -- they’re just bytes
  - Structure of a networked application

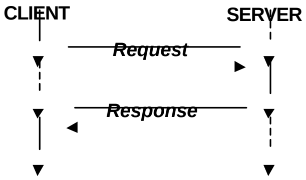
Application-Level Model

- Higher level model needed to implement networked applications
- TCP and UDP require that a program be available to accept a connection request (TCP) or a datagram (UDP)
- *Client-server model* is widely used to provide a workable structure



Client-Server Model

- Client initiates peer-to-peer communication (at TCP- or UDP-level)
- Server waits for incoming request



Clients Versus Servers

- Clients
  - Relatively simple (with respect to network communication)
  - User-level programs that require no special privileges
- Servers
  - More complex than servers due to performance and security requirements
  - Often require special system privileges
  - May run all the time or be started on-demand by operating system mechanisms, e.g. inetd in UNIX

Privilege

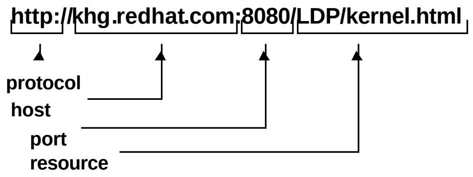
- Server often runs in a privileged mode, so must protect improper use of privileges by a client
  - *Authentication*: verify identity of the client
  - *Authorization*: verify permission to access service
  - *Data security and privacy*: prevent unauthorized viewing or altering of data
  - *Protection*: protect system resources from misuse

Client Parameterization

- Parameterized clients lead to generality, e.g. as in TELNET client being able to access other services
- Parameters
  - Destination host
    - Host name: vtopus.cs.vt.edu
    - IP address: 128.173.40.24
  - Port number (not just default)
  - Protocol- or application-specific information, e.g. block size
  - Protocol itself, e.g. FTP, HTTP, or Gopher

Universal Resource Locators (1)

- URLs integrate many parameters



http://khg.redhat.com:8080/LDP/kernel.html

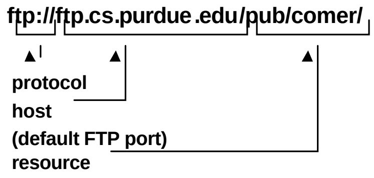
protocol

host

port

resource

Universal Resource Locators (2)



ftp://ftp.cs.purdue.edu/pub/comer/

protocol

host

(default FTP port)

resource

Connectionless/Connection-oriented (1)

- ***Connection-oriented*** **servers**
  - Client must first connect to the server prior to any data transfer
  - Based on TCP (usually) -- reliable at the expense of connection overhead
    - Data arrives correctly
    - Data ordering is maintained
    - Data is not duplicated

Connectionless/Connection-oriented (2)

- ***Connectionless*** **servers**
  - Data can be sent by clients immediately
  - Based on UDP (usually) -- no connection overhead, but no benefits
    - Data may not arrive
    - Data may be incorrect, although unlikely
    - Duplicates may arrive, although unlikely
    - May arrive out of order, although unlikely

Connectionless/Connection-oriented (3)

- Connectionless vs. connection-oriented design issues
  - Inherent reliability?
  - Reliability needed?
  - Reliability is already very high (LAN vs. WAN)?
  - Real-time operation gives no time for error correction (retransmission)?
  - Need for broadcast or multicast?
- Need to test in a variety of environments
  - Packet delay
  - Packet loss

Stateless/Stateful

- State information is any information about ongoing interactions
- *Stateful servers* maintain state information
- *Stateless servers* keep no state information
- Examples -- stateful or stateless?
  - Finger?
  - TELNET?
  - HTTP?
  - FTP?
  - NFS?

File Server Example

- Consider a file server that supports four operations
  - OPEN -- identify file and operation, e.g. read or write
  - READ -- identify file, location in file, number of bytes to read
  - WRITE -- identify file, location in file, number of bytes, data to write
  - CLOSE -- identify file

File Server Example: Stateless

- Stateless version -- identify all information with each request
- Example
  - OPEN(/tmp/test.txt, “r”)
  - READ(/tmp/test.txt, 0, 200)
  - READ(/tmp/test.txt, 200, 200)
- Redundant information is provided with subsequent requests
  - Inefficient with respect to information transfer
  - Server operation is simplified

File Server Example: Stateful (1)

- Stateful version -- server provides *handle* to access state at the server
- File open
  - Request: OPEN(/tmp/test.txt, “r”)
  - Reply: OPEN(ok, 32) -- handle = 32
  - State: 32: /tmp/test.txt, 0, read
- File read
  - Request: READ(32, 200)
  - Reply: READ(ok, data)
  - State: 32: /tmp/test.txt, 200, read

File Server Example: Stateful (2)

- What if there is a duplicate request?
  - READ(32, 200) sent once, but received twice
  - Client and server lose synchronization -- server thinks that 400 bytes have been read, client thinks it has read just 200 bytes
- Stateful servers are more complex than stateless servers since they must deal with synchronization
- State is implied by the protocol, not the implementation
  - TCP is a stateful protocol
  - Synchronization required with byte numbers

Stateful Protocol Design Issues

- Time-outs
- Duplicate requests and replies
- System crashes (at one end)
- Multiple clients
- File locking

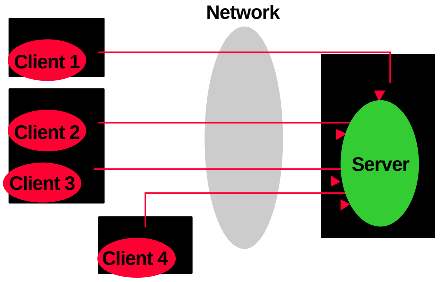
Concurrency in Network Applications

- *Concurrency* is real or apparent simultaneous computing
  - Real in a multiprocessor
  - Apparent in a time-shared uniprocessor (apparent concurrency provided by OS)
- Networks are inherently concurrent -- multiple hosts have the appearance of simultaneously transferring data
  - Real, to some extent, in switched networks
  - Apparent in shared media networks (apparent concurrency provided by MAC protocol)

Client Concurrency

- Clients usually make use of concurrency in a trivial way
  - Multiple clients can run on a single processor
- Such concurrency is provided by the operating system, not by any programmed features of the client
- Note that complex clients can use concurrency, e.g. modern Web browser
  - Simultaneous requests and receipt of multiple files
  - Overlapping communication with graphical rendering or other processing

Server Concurrency (1)



Server Concurrency (2)

- Servers use concurrency to achieve functionality and performance
- Concurrency is inherent in the server -- must be explicitly considered in server design
- Exact design and mechanisms depend on support provided by the underlying operating system
- Achieved through
  - Concurrent processes
  - Concurrent threads

Processes

- *Process*: fundamental unit of computation
  - Per process information:
    - Owner of process
    - Program being executed
    - Program and data memory areas
    - Run-time stack for procedure activation
    - Instruction pointer
    - Allocated resources, e.g. file and socket descriptors
- A *program* implies just the code, a *process* includes the concept of the active execution of the code

Concurrent Execution

- *Concurrent execution*: executing a piece of code more than once at apparently the same time
- If a program is executed multiple times at apparently the same time
  - Each invocation is a unique process
  - Each invocation has its own unique per process information, such as distinct instruction pointer, program and data memory, resources, etc.

Threads

- Threads are another form of concurrent execution *within* a process
  - Each thread has its own:
    - Instruction pointer
    - Copy of *local* variables
    - Run-time stack for procedure activation
  - Multiple threads can be associated with a single process
  - All threads within a process share:
    - Process owner
    - Program being executed
    - Program and *global* data memory
    - Allocated resources

Processes Versus Threads

- Both provide mechanisms for concurrent execution
- Advantages of threads
  - Allocated resources and global data are easily shared
  - Typically lower overhead for creation and switching (but not zero overhead)
- Advantages of multiple processes
  - Inherent separation (isolation) makes interaction clearer
  - More widely supported on different operating systems; common mechanisms

Context Switching

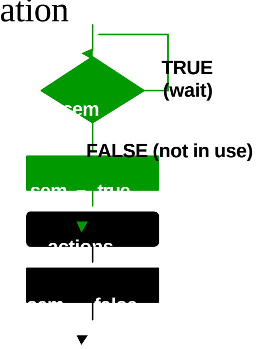
- *Context switching* is the operation of changing from the execution of one process or thread to another
  - Overhead incurred with each context switch
  - Context switch for threads requires less overhead than for processes
    - Threads are "lightweight processes"

Mutual Exclusion

- Threads do share allocated resources (files, sockets, etc.) and global memory
- So, some form of *mutual exclusion* is needed to ensure that only a single thread has use of a particular resource at any given time
- Mutual exclusion can be implemented using a "test and set" operation on a true-false value

Semaphore Operation

- Semaphore is variable *sem*
  - TRUE Þ in use
  - FALSE Þ not in use
- Semaphore (sem) is first initialized to FALSE
- Test-and-set must be an "indivisible" or "atomic" operation



Apparent Concurrency (1)

- Threads allow concurrency to be implemented at the application level
- Apparent concurrency is also possible where server appears to be simultaneously serving requests, but is doing this with a single thread
- Based on asynchronous I/O
  - *Synchronous I/O* is blocking -- a call blocks until the source is ready
  - *Asynchronous I/O* is non-blocking

Apparent Concurrency (2)

- select() call
  - Allows a program to select between multiple services and returns when one becomes active
  - Basis for apparent concurrency

You should now be able to … (1)

- Specify general design requirements for clients and servers
- Characterize application protocols with respect to
  - Connection versus connection-less
  - Stateful versus stateless
- Identify design issues related to use of stateful and stateless protocols
- Identify the need for concurrent execution

You should now be able to … (2)

- Identify the properties of threads and processes
- Identify design issues related to the use of threads versus processes
- Identify the difference between concurrent execution with threads and apparent concurrency