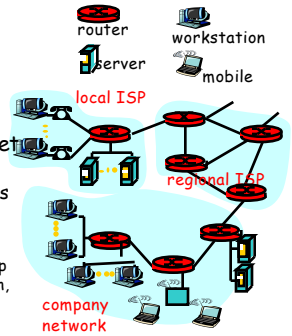
CS458/CS558
Introduction to Computer Security

Introduction to Network

What's the Internet

What's the Internet

- A network that interconnects millions of computing devices (end systems) throughout the world.
- End systems access internet through Internet Service Providers (ISPs), companies that provide access to the Internet.
  - AT&T, Sprint, 56kbps dial-up modern access, cable modern, DSL, etc.



What's a protocol?…

- All communication activity in Internet governed by protocols
- A network protocol defines a language of rules and conventions for communication between network devices.
- Protocols define format, order of messages sent and received among network entities, and actions taken on message transmission

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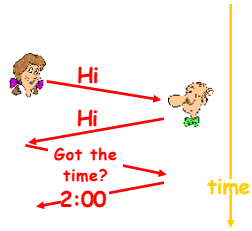
- A network protocol defines a language of rules and conventions for communication between network devices.
- Protocols define format, order of messages sent and received among network entities, and actions taken on message transmission
  - E.g. Transmission Control Protocol (TCP), Hypertext Transfer Protocol (HTTP), File Transfer Protocol (FTP)

What's a protocol?

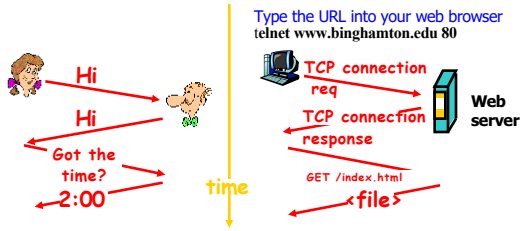
A human protocol and a computer network protocol



A network protocol is similar to a human protocol except that the entities sending and receiving mesgs are hardware/software components of some device.

What's a protocol?

A human protocol and a computer network protocol:



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Protocol Layers

Protocol Layers

- Dealing with complex systems:
  - Provide a structural way to discuss system components.
  - Modularization eases maintenance, updating of system
    - Change of implementation of layer's service transparent to rest of system

Protocol Layers (Cont.)

- TCP/IP model: 5 layers

application
Transport
network
link
physical

- OSI reference model: 7 layers

application
presentation
session
transport
network
link
physical

Internet protocol stack (TCP/IP Model)

- Application
  - Provides a means for the user to access information on the network through an application.
  - Supports network applications and application-layer protocols such as FTP, HTTP, SMTP.
  - Data sent over the network is passed into the application layer where it is encapsulated into the application layer protocol. The data is passed down into the transport layer.

application
transport
network
link
physical

Internet protocol stack (TCP/IP Model)

- Transport
  - Provides transparent transfer of data between end users
  - Controls the reliability of a given link through flow control, segmentation/ desegmentation, and error control

application
transport
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Internet protocol stack (TCP/IP Model)

- Transport
  - Provides transparent transfer of data between end users
  - Controls the reliability of a given link through flow control, segmentation/ desegmentation, and error control
  - Converts messages into TCP segments or User Datagram Protocol (UDP), etc.
    - TCP: a reliable connection-oriented protocol
    - UDP: an unreliable, connectionless protocol. e.g. streaming media (audio, video, etc).

application
transport
network
link
physical

Internet protocol stack (TCP/IP Model)

- Network: routes datagrams from source to destination
  - Routers operate at this layer
  - IP, routing protocols
- Link: provides the functional and procedural means to transfer data between network entities
  - Bridges and link-layer switches operate.

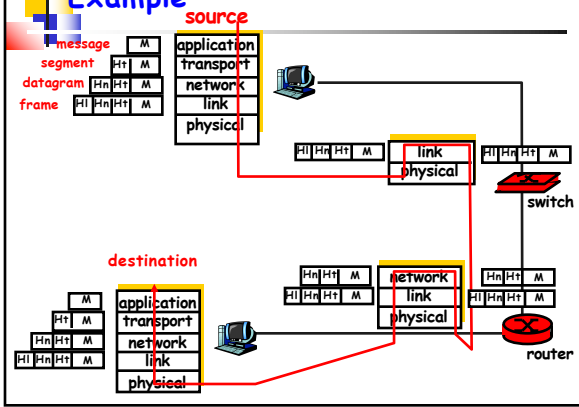
application
transport
network
link
physical

Internet protocol stack (TCP/IP Model)

- Physical: encodes and transmits raw data over network communications media (e.g. optical fiber).
  - Make sure that when one side sends a 1 bit, it is received by the other side as 1 bit.

application
transport
network
link
physical

Example



Reference

- TCP/IP model:
  http://en.wikipedia.org/wiki/TCP/IP_model

Socket Programming

Client-Server Model

- Most network applications use the client-server model.

  - Client: requests, receives service from an always-on server
    - Needs to know of the existence of and the address of the server.
  - Server does not need to know the address of the client prior to the connection being established.
  - Once a connection is established, both sides can send and receive information.
  - A good analogy is a person who makes a phone call to another person.
  - e.g. Web browser/server; email client/server

Client-Server Model

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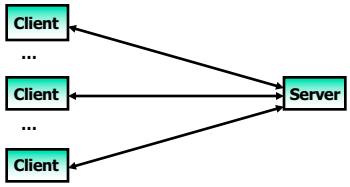


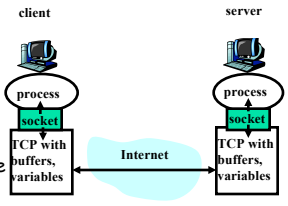
  - Clients usually communicate with one server a time
  - It is not unusual for a server to be communicating with multiple clients

Socket

- The system calls for establishing a connection are different for the client and the server
- But both involve the basic construct of a socket.

Sockets

- Process sends/receives messages to/from its socket
- Socket analogous to door
  - Sending process shoves message out door
  - Transport infrastructure brings message to the door at receiving process



Addressing Processes

- For a process to receive messages, it must have an identifier.

Addressing Processes

- For a process to receive messages, it must have an identifier.
- Identifier includes both the IP address and port number associated with the process on the host.
  - A host has an IP address
  - Does the IP address of the host on which the process runs suffice for identifying the process?
    - Answer: no, many processes can be running on same host
  - Port: A 16-bit number to identify the application process that is a network endpoint.

IP Address (IPv4)

- An identifier for each machine connected to an IP network.
  - 32 bit binary number
  - Represented as dotted decimal notation:
    - 4 decimal values, each representing 8 bits (octet), in the range 0 to 255.
- Example:
  - Dotted Decimal: 140.179.220.200
  - Binary: 10001100.10110011.11011100.11001000

Ports

- A 16-bit number to identify the application process that is a network endpoint.
- Reserved ports or well-known ports (0 to 1023)
- Standard TCP ports for well-known applications: Telnet (23), ftp(21), http (80).
- Ephemeral ports (1024-65535) : for ordinary user-developed programs.

Establish A TCP Socket on the Client Side

- Create a socket with the socket() system call
- Specify server's IP address and port
- Establish connection with server using the connect() system call
- Send and receive data, e.g., use the read() and write() system calls.

Socket()

- Create a socket with the socket() system call

```
//Contains data definitions and socket structures.
#include <sys/socket.h>
int socket(int family, int type, int protocol)
```

Returns: non-negative descriptor if OK, -1 on error

- Integer descriptor: identify the socket in all future function calls
- Protocol family constants
  - e.g. AF_INET: IPv4, AF_INET1: IPv6.
- Type of socket
  - SOCK_STREAM: stream socket, SOCK_DGRAM: datagram socket
- Protocol: normally 0 except for raw socket

Specify Server's IP Address and Port

- Specify server's IP address and port
- E.g. for TCP connection:

```
struct sockaddr_in servaddr;
//set the socket address structure 0
bzero(&servaddr, sizeof(servaddr));
//set the address family to AF_INET
servaddr.sin_family = AF_INET;
//set the port number.
servaddr.sin_port = htons(<port number>);
//set the ip address.
if (inet_pton(AF_INET, <ip addr>, &servaddr.sin_addr) <= 0)
```

Network-Byte Ordering

Two ways to store 16-bit/32-bit integers

- Little-endian byte order (e.g. Intel)

Low-order byte	High-order byte
Address A	Address A+1

- Big-endian byte order (E.g. Sparc)

High-order byte	Low-order byte
AddressA	Address A+1

Network-Byte Ordering (cont.)

- How do two machines with different byte-orders communicate?
  - Using network byte-order
  - Network byte-order = big-endian order
- Converting between the host byte order and the network byte order (<netinet/in.h>)
  - h: host: s: short, l: long
    - uint16_t htons(uint16_t n)
    - uint32_t htonl(uint32_t n)
    - uint16_t ntohs(uint16_t n)
    - uint32_t ntohl(uint32_t n)

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if (inet_pton(AF_INET, <ip addr>, &servaddr.sin_addr) <= 0)
```

Inet_pton, inet_ntop

```
<arpa/inet.h>
//Returns 1 if OK, 0 if input is not a valid format, -1 on error
int inet_pton(int family, const char *strptr, void *addrptr);
//Returns the pointer to result if OK, NULL on errors
const char *inet_ntop(int family, const void *addrptr, size_t
  len);
```

- p: presentation
  - Usually an ASCII string
- n: network
  - Binary value that goes into a socket address structure

Connect()

- Establish a connection with the TCP server using the connect() system call

```
#include <sys/socket.h>
int connect(int sockfd,  const struct sockaddr *servaddr,
socklen_t addrlen);
```

Return 0 if OK, -1 on error

read(), write()

- Send and receive data, e.g., use the write() and read() system calls.

```
//Read up to count bytes from the socket into the buffer
// Return the number of bytes read
int read(int sockfd, void *buf, int count);

// Write data to a TCP connection
int write(int sockfd, void *buf, int count)
```

Establish A Socket on the Server Side

1. Create a socket with the socket() system call
2. Bind the socket to an address using the bind() system call.
3. Listen for connections with the listen() system call
4. Accept a connection with the accept() system call.
5. Send and receive data

bind(), listen()

- The server specifies the IP address and port number associated with a socket using bind().

  int bind(int sockfd, const struct sockaddr *myaddr, socklen_t addrlen)

- Listen for connections with the listen() system call.

  int listen(int sockfd, int backlog)

  backlog: the number of maximum pending clients

Accept()

- Accept a connection with the accept() system call.

  int accept(int sockfd, struct sockaddr *client_addr, socklen_t *addrlen)

- accept() returns a new descriptor that is automatically created by the kernel. This descriptor refers to the TCP connection with the client.

Example of Client-Server Operation

A Simple Daytime
Client and Server

Daytime client

- Connects to a daytime server
- Retrieves the current date and time

```
% cli 128.226.6.39
Wed Feb 05 18:10:00 2014
```

Daytime client

```
int main(int argc, char **argv) {
    int  sockfd, n;
    char recvline[MAX + 1];
    struct sockaddr_in servaddr;
    if( argc != 2 ) {
        printf("Usage: cli <IP address>");
                                        exit(1); }

    /* Create a TCP socket */
      if((sockfd=socket(AF_INET,SOCK_STREAM, 0)) < 0){
                perror("socket"); exit(2);}

    /* Specify server's IP address and port */
    bzero(&servaddr, sizeof(servaddr));
    servaddr.sin_family = AF_INET;
    servaddr.sin_port = htons(10000); /* daytime server port */

    if (inet_pton(AF_INET, argv[1], &servaddr.sin_addr) <= 0) {
                perror("inet_pton"); exit(3);}
```

```
    /* Connect to the server */
    if (connect(sockfd,  (struct sockaddr *) &servaddr, sizeof(servaddr)) < 0 ) {
            perror("connect"); exit(4); }

     /* Read  from socket */
     while ( (n = read(sockfd, recvline, MAX)) > 0) {
            recvline[n] = '\0';        /* null terminate */
            printf("%s", recvline);
     }

      if (n < 0) { perror("read"); exit(5); }
      close(sockfd);
}
```

Daytime Server

1. Waits for requests from Client
2. Accepts client connections
3. Sends the current time
4. Terminates connection and goes back waiting for more connections.

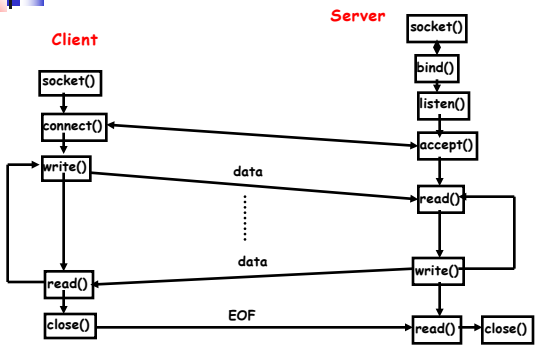
```
int main(int argc, char **argv) {
        int   listenfd, connfd;
        struct sockaddr_in servaddr, cliaddr;
        char buff[MAX];
        time_t ticks;
        /* Create a TCP socket */
        listenfd = socket(AF_INET, SOCK_STREAM, 0);
        /* Initialize server's address and well-known port */
        bzero(&servaddr, sizeof(servaddr));
        servaddr.sin_family  = AF_INET;
        /* allowed your program to work without knowing the IP address of
       the machine it was running on  */
        servaddr.sin_addr.s_addr = htonl(INADDR_ANY);
        servaddr.sin_port  = htons(10000);   /* daytime server */
        /* Bind server's address and port to the socket */
        bind(listenfd, (struct sockaddr *) &servaddr, sizeof(servaddr));
```

```
    /* Convert socket to a listening socket – max 100 pending clients*/
    listen(listenfd, 100);
    for ( ; ; ) {
      /* Wait for client connections and accept them */
      clilen = sizeof(cliaddr);
       connfd = accept(listenfd, (struct sockaddr *)&cliaddr, &clilen);
      /* Retrieve system time */
      ticks = time(NULL);
      snprintf(buff, sizeof(buff), "%s\r\n", ctime(&ticks));
      /* Write to socket */
      write(connfd, buff, strlen(buff));
      /* Close the connection */
      close(connfd);
    }
}
```

Run Daytime Client-Server

- Compiling the code on bingsuns
  gcc cli.c -o cli -lresolv -lsocket -lnsl
  gcc ser.c -o ser -lresolv -lsocket -lnsl
- Executing the code on bingsuns
  ./ser
  ./cli 128.226.6.39

TCP Connection Sequence



Summary: Socket API

- **int socket(int family, int type, int protocol):** Creates a socket
- **int connect(int sockfd, const struct sockaddr *servaddr, socklen_t addrlen)**
  - Enables a client to connect to a server.
- **int bind(int sockfd, const struct sockaddr *myaddr, socklen_t addrlen)**
  - Allows a server to specify the IP address/port_number associated with a socket
- **int listen(int sockfd, int backlog)**
  - Allows the server to specify a socket that can be used to accept connections.
- **int accept(int sockfd, struct sockaddr *client_addr, socklen_t *addrlen)**
  - Allows a server to wait till a new connection request arrives.
- **int close(int sockfd):** Terminates any connection associated with a socket and releases the socket descriptor.

Concurrent Servers

- Daytime client-server: iterative servers
- Concurrent Servers: handle multiple clients simultaneously
  - Fork
  - Threads

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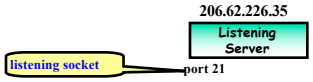
Forking Concurrent Servers



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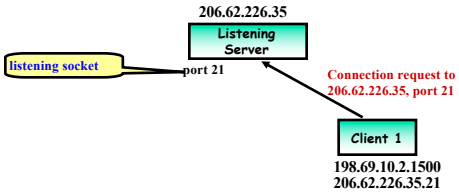

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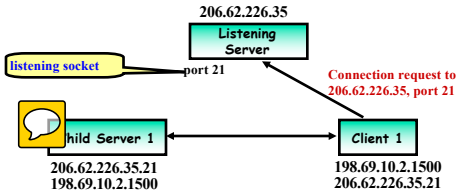

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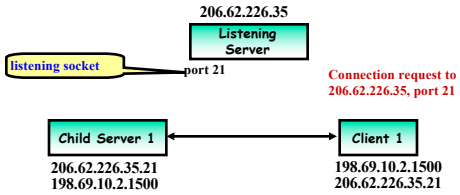

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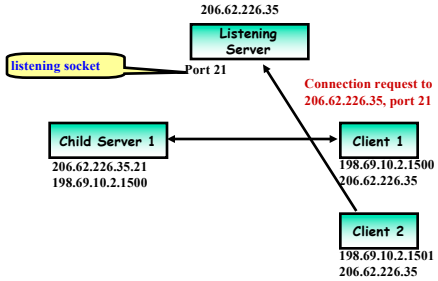

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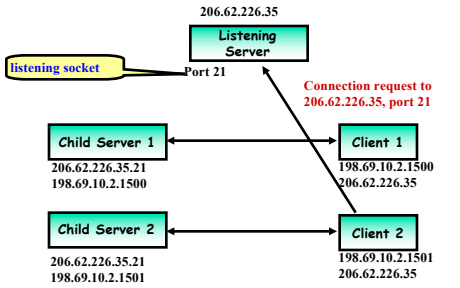

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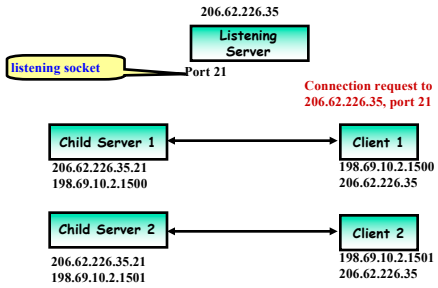

Forking Server Example

```
listenfd = socket( … )
bind( listenfd, … )
listen(listenfd,…);
for ( ;; ) {
    /* wait for client connection */
    connfd = accept(listenfd,…);
    if( (pid = fork() ) == 0) {
        /* Child Server */
        close(listenfd);          //child closes listening socket
        service_client(connfd);   //process the request
        close(connfd);            //done with this client
        exit(0);                  //child terminates
    }
    /* Parent */
    close(connfd);}               //parent closes connected socket
```

Java Socket Programming: An Example

Client

```
import java.io.*;
import java.net.*;
class TCPClient {
   public static void main(String argv[]) throws Exception {
      String modifiedSentence;
      Socket sock = new Socket("bingsuns.binghamton.edu",
    6789);
     /*Open an input and output stream to the socket. */
      PrintWriter out =
            new PrintWriter(sock.getOutputStream(),true);
      BufferedReader in =
            new BufferedReader(
           new InputStreamReader(sock.getInputStream()));
```

Client

```
     /*Writes out the string to the underlying output stream. */
      out.println("hello");
       /*Read a line of text*/
      modifiedSentence = in.readLine();
      System.out.println("FROM SERVER: " +
  modifiedSentence);
      sock.close();
}}
```

Server

```
import java.io.*;
import java.net.*;
class TCPServer {
      public static void main(String argv[]) throws Exception{
            String clientSentence, capitalizedSentence;
            ServerSocket listen = new ServerSocket(6789);
            while(true) {
               Socket conn = listen.accept();
               BufferedReader in = new BufferedReader(
                     new InputStreamReader(conn.getInputStream()));
               PrintWriter out =
                      new PrintWriter(conn.getOutputStream(),true);
               clientSentence = in.readLine();
               System.out.println("FROM CLIENT:" + clientSentence);
               capitalizedSentence = clientSentence.toUpperCase();
               out.println(capitalizedSentence);
               conn.close();
            }}}
```

Compilation & Execution

- Compiling the code on bingsuns
  - javac TCPServer.java
  - javac TCPClient.java
- Executing the code on bingsuns
  - java TCPServer
  - java TCPClient

References

- Package java.io
  - http://java.sun.com/j2se/1.4.2/docs/api/java/io/package-summary.html
- Tutorials and examples
  - http://www.javaworld.com/javaworld/jw-12-1996/jw-12-sockets.html
  - http://java.sun.com/docs/books/tutorial/networking/sockets/
  - http://www.prasannatech.net/2008/07/socket-programming-tutorial.html
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  - http://java.sun.com/docs/books/tutorial/essential/io/