Week 10

Network Programming

School of Information Technology and Electrical Engineering
The University of Queensland

CSSE2310 7231

Outline

- TCP/IP
- Sockets
- Typical TCP client
- Typical TCP server

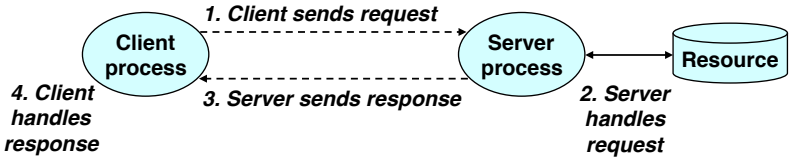
- Credits:
  - Glass and Ables, "UNIX for Programmers and Users"
  - Bryant and O'Halloran, "Computer Systems: A Programmer's Perspective"
  - Rochkind, "Advanced UNIX Programming"
  - Tanenbaum, "Computer Networks"

2

CSSE2310 7231

Client-Server Model

- Most network applications are based on the **client-server model**:
  - A *server* process and one or more *client* processes
  - Server manages some *resource*
  - Server provides *service* by manipulating resource for clients



Note: clients and servers are processes running on hosts (can be the same or different hosts).

3

CSSE2310 7231

TCP/IP

- Protocol = Rules for communication
- **TCP** = Transmission Control Protocol
  - Provides communication between ports on two computers (hosts)
    - Bidirectional
    - Point-to-point
    - Reliable
    - Byte stream
  - Uses **IP** (Internet Protocol) to transmit small packets of data between two IP addresses
- Joel will return to these protocols next week
- Today – how to write programs using TCP/IP

4

CSSE2310 7231

TCP Connections

- Identified by
  - Source IP address
  - Source port number
  - Destination IP address
  - Destination port number

5

CSSE2310 7231

IP Addresses (v4)

- 32-bit numbers
- Often written in **dotted-decimal** notation for human consumption
  - each of the 4 bytes written in decimal
    - e.g. 130.102.2.15
- Some addresses have special meanings

6

CSSE2310 7231

Port Numbers

- 16 bits: 0 – 65535
- Below 1024
  - Well known ports
  - Reserved for standard services, e.g.
    - 23 - Telnet
    - 21 – FTP
    - 80 – HTTP
  - Look in /etc/services on a UNIX box

7

CSSE2310 7231

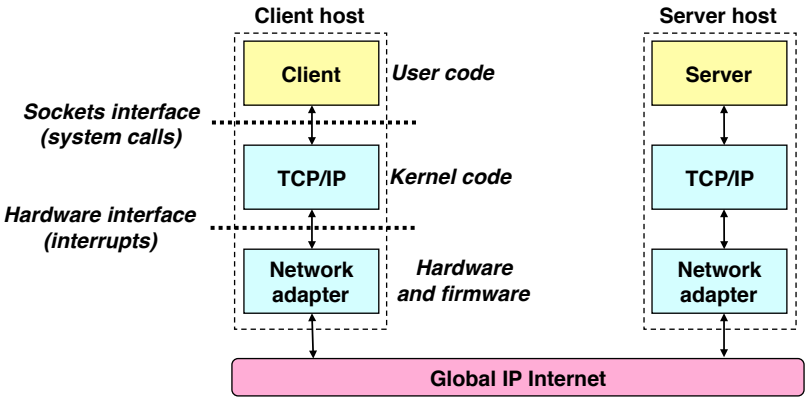
Sockets

- Introduced in Berkeley UNIX
- Sometimes called UNIX sockets
- Originally C based
  - Many other languages now
- A socket is a **communication endpoint**
  - Associated with a file descriptor in UNIX – can do file I/O on socket
  - Main distinction between regular file I/O and socket I/O is how the application "opens" the socket descriptors
- Many types of sockets
  - We'll look at stream sockets (TCP)

8

CSSE2310 / CSSE7231

Hardware and Software Organisation of a TCP/IP Application



9

CSSE2310 / CSSE7231

Socket System Calls

- **`socket(…)`**
  - Create new communication end-point
- **`bind(…)`**
  - Attach a local address to a socket
- **`listen(…)`**
  - Willing to accept connections, give queue size
- **`accept(…)`**
  - Wait for a connection attempt to arrive
- **`connect(…)`**
  - Attempt to establish a connection

10

CSSE2310 7231

Socket System Calls (cont.)

- **`send(…)`** or **`write(…)`**
  - Send data over the connection
- **`recv(…)`** or **`read(…)`**
  - Receive data over the connection
- **`sendto(…)`**
  - Send datagram
- **`recvfrom(…)`**
  - Receive datagram
- **`close(…)`**
  - Release the connection
- **`shutdown(…)`**
  - Close down one side of connection (or both sides)

- Not all are applicable in all circumstances!

11

CSSE2310 7231

Typical TCP Server

- Create socket — `socket(…)`
- Bind to address/port — `bind(…)`
- Specify willingness to accept connections — `listen(…)`
- Block waiting for connection — `accept(…)`
  - `accept(…)` returns a new socket
  - Original socket continues to listen
- Deal with request
  - e.g. spawn process or thread — `send(…)` or `write(…)` / `recv(…)` or `read(…)`
- Continue

12

CSSE2310 7231

Typical TCP Client

- Create socket — `socket(…)`
- Connect to server (at a particular address) — `connect(…)`
- Send/receive data as necessary — `send(…)` or `write(…)`, `recv(…)` or `read(…)`
- Close connection — `close(…)`

- Clients don't normally use `bind(…)`
  - don't care what the outgoing port is

13

CSSE2310 7231

Other Programming Languages

- Sockets interface is available in many programming languages
  - Interface is similar (but not identical) across all of them
- We'll be concentrating on the C sockets interface

14

CSSE2310 7231

IP Addresses in C

- 32-bit IP addresses are stored in an *IP address struct*
  - IP addresses are always stored in memory in network byte order (big-endian byte order)
  - True in general for any integer transferred in a packet header from one machine to another
    - E.g., the port number used to identify an Internet connection

```
typedef uint32_t in_addr_t;
/* Internet address structure */
struct in_addr {
    in_addr_t  s_addr; /* network byte order (big-endian) */
};
```

- Handy network byte-order conversion functions:
  - **`htonl()`**: convert uint32_t from host to network byte order.
  - **`htons()`**: convert uint16_t from host to network byte order.
  - **`ntohl()`**: convert uint32_t from network to host byte order.
  - **`ntohs()`**: convert uint16_t from network to host byte order.

16

CSSE2310 7231

IP Addresses in C (cont.)

- Users (applications) often write IP addresses using dotted decimal notation
  - e.g. IP address `0x8002C2F2 = 128.2.194.242`
- Functions for converting between binary IP addresses and dotted decimal strings:
  - `inet_aton(…)`: converts a dotted decimal string to an IP address in network byte order
  - `inet_ntoa(…)`: converts an IP address in network byte order to its corresponding dotted decimal string
  - "n" denotes network representation. "a" denotes application representation

17

CSSE2310 7231

Address Handling Code Examples

- *To be discussed/commented in class*

18

CSSE2310 7231

Creating a Socket

- `socket(…)` creates a socket descriptor
  - `AF_INET`: indicates that the socket is associated with Internet protocols
  - `SOCK_STREAM`: selects a reliable byte stream connection (TCP)

```
int fd; /* socket descriptor */

/* Create a TCP socket descriptor */
fd = socket(AF_INET, SOCK_STREAM, 0)
if (fd < 0) {
    perror("Socket creation failed");
    exit(1);
}
```

19

CSSE2310 7231

Socket Address Structures

- Generic socket address:
  - For address arguments to `connect`, `bind`, and `accept`.
  - Necessary only because C did not have generic (`void *`) pointers when the sockets interface was designed

```
struct sockaddr {
  sa_family_t     sa_family;    /* protocol family */
  char            sa_data[14];  /* address data.  */
};
```

- Internet-specific socket address:
  - Must cast (`struct sockaddr_in *`) to (`struct sockaddr *`) for `connect`, `bind`, and `accept`

```
struct sockaddr_in  {
  sa_family_t     sin_family;  /* address family (always AF_INET) */
  in_port_t       sin_port;    /* port num in network byte order */
  struct in_addr  sin_addr;    /* IP addr in network byte order */
  unsigned char   sin_zero[8]; /* pad to sizeof(struct sockaddr) */
};
```

CSSE2310 7231

Socket Address Structures

```
struct sockaddr {
  sa_family_t     sa_family;    /* protocol family */
  char            sa_data[14];  /* address data.  */
};
```

```
struct sockaddr_in  {
  sa_family_t     sin_family;  /* address family (always AF_INET) */
  in_port_t       sin_port;    /* port num in network byte order */
  struct in_addr  sin_addr;    /* IP addr in network byte order */
  unsigned char   sin_zero[8]; /* pad to sizeof(struct sockaddr) */
};
```

CSSE2310 7231

Typical Client (Stream based)

- Create socket — `socket(…)`
- Connect to server (at a particular address) — `connect(…)`
- Send/receive data as necessary — `send(…)` or `write(…)` / `recv(…)` or `read(…)`
- Close connection — `close(…)`

23

CSSE2310 7231

Sample Client Code

- *To be discussed/commented in class*

24

CSSE2310 7231

Typical Server (Stream based)

- Create socket — `socket(…)`
- Bind to address/port — `bind(…)`
- Specify willingness to accept connections — `listen(…)`
- Block waiting for connection — `accept(…)`
  - `accept(…)` returns a new socket
  - Original socket continues to listen
- Deal with request
  - e.g. spawn process/thread & communicate — `send(…)` or `write(…)` / `recv(…)` or `read(…)`
- Continue

25

CSSE2310 7231

accept()

- `accept(…)` blocks waiting for a connection request

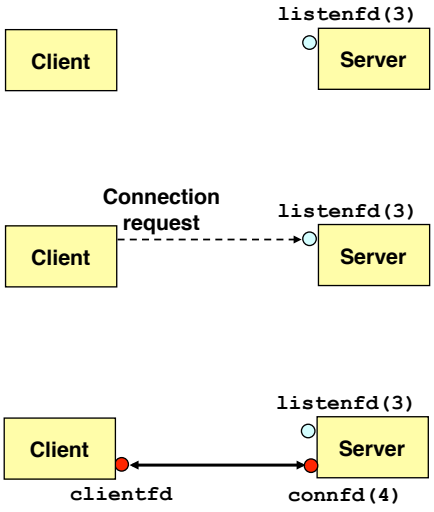
```
int listenfd; /* listening descriptor */
int connfd;   /* connected descriptor */
struct sockaddr_in clientaddr;
int clientlen;

clientlen = sizeof(clientaddr);
connfd = accept(listenfd, (struct sockaddr*)&clientaddr, &clientlen);
```

- `accept(…)` returns a *connected descriptor* (`connfd`) with the same properties as the *listening descriptor* (`listenfd`)
  - Returns when the connection between client and server is created and ready for I/O transfers
  - All I/O with the client will be done via the connected socket
- `accept(…)` also fills in client's IP address.

26

CSSE2310 7231

`accept()` Illustrated



1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`.

2. Client makes connection request by calling and blocking in `connect`.

3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`.

27

CSSE2310 7231

Connected vs. Listening Descriptors

- **Listening** descriptor
  - End point for client connection requests
  - Created once and exists for lifetime of the server
- **Connected** descriptor
  - End point of the connection between client and server
  - A new descriptor is created each time the server accepts a connection request from a client
  - Exists only as long as it takes to service client
- Why the distinction?
  - Allows for *concurrent* servers that can communicate over many client connections simultaneously
    - e.g., each time we receive a new request, we fork a child process to handle the request

28

CSSE2310 7231

Socket Options: `setsockopt`

- The socket can be given some attributes
  - Many are integers

```
int optval = 1;
…
/* Eliminates "Address already in use" error from bind(). */
if (setsockopt(fd, SOL_SOCKET, SO_REUSEADDR,
               (const void *)&optval , sizeof(int)) < 0)
{
    perror("Unable to set socket option");
    exit(1);
}
```

- Handy trick that allows us to rerun a server immediately after we kill it
  - Otherwise we may have to wait about 30 secs+
  - Eliminates "Address already in use" error from `bind()`
  - Useful when debugging

29

CSSE2310 7231

Identifying the Client

- The server can determine the domain name and IP address of the client

```
int error;
char hostname[128];       /* Space to hold hostname */

/* After accept() has populated clientaddr, clientlen */

error = getnameinfo((struct sockaddr*)&clientaddr, clientlen,
        hostname, 128, NULL, 0, 0);
if(!error) {
    printf("Connection from %s (%s)\n", hostname,
            inet_ntoa(clientaddr.sin_addr));
}
```

30

CSSE2310 7231

Testing Servers Using `netcat`

- The `netcat (nc)` program is invaluable for testing servers that transmit over Internet connections
  - Our simple server
  - Web servers
  - Mail servers
- Usage:
  - `unix> nc <host> <portnumber>`
  - Creates a connection with a server running on `<host>` and listening on port `<portnumber>`
- `netcat` can also pretend to be a server
  - `unix> nc -l -p <portnumber>`

32

CSSE2310 7231

Sample Server Code

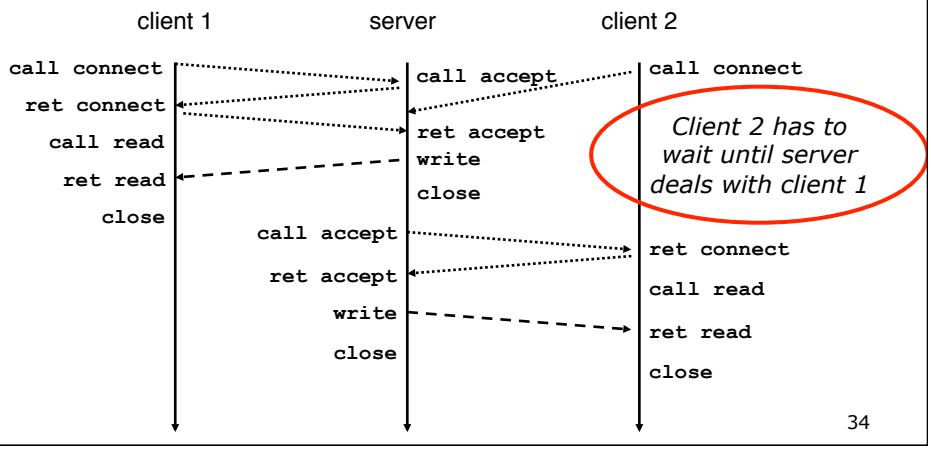
- *To be discussed/commented in class*

33

CSSE2310 7231

Iterative Servers

- Iterative servers process one request at a time



34

CSSE2310 7231

3 Basic Mechanisms for Creating Concurrent Flows

1. Processes
   - Kernel automatically interleaves multiple logical flows
   - Each flow has its own private address space
2. Threads
   - Kernel automatically interleaves multiple logical flows
   - Each flow shares the same address space
3. I/O multiplexing with `select()`
   - User manually interleaves multiple logical flows
   - Each flow shares the same address space
   - Popular for high-performance server designs

35

CSSE2310 7231

Resources

- Beej's Guide to Network Programming
  - http://beej.us/guide/bgnet/
- Manual pages
  - On moss: `man <name>` or `man -s 2 <name>`
  - where `<name>` is socket, bind, connect, listen, accept, recv, send, …
- Glass & Ables, "UNIX for Programmers and Users"
- Rochkind, "Advanced UNIX Programming"
- Bryant and O'Halloran, "Computer Systems: A Programmer's Perspective"
- Other UNIX Programming books…
  - See Reference text list in course profile

36