CS4254

Computer Network Architecture and Programming

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Sockets Programming Introduction

Outline

- Sockets API and abstraction
- Simple Daytime client
- Wrapper functions
- Simple Daytime Server

Sockets API

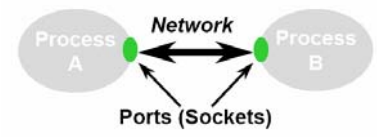
API is Application Programming Interface

- Sockets API defines interface between application and
- transport layer
  - ➢ two processes communicate by sending data into socket, reading data out of socket
- Socket interface gives a file system like abstraction to the capabilities of the network
- Each transport protocol offers a set of services
  - ➢ The socket API provides the abstraction to access these services
- The API defines function calls to create, close, read and write to/from a socket

Sockets Abstraction

The *socket* is the basic abstraction for network communication in the socket API

- ➢ Defines an endpoint of communication for a process
- ➢ Operating system maintains information about the socket and its connection
- ➢ Application references the socket for sends, receives, etc



Simple Daytime Client 1/5

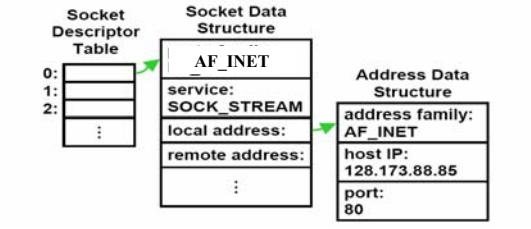
- Source code available from http://www.unpbook.com
- Read README file first!
- Source file is daytimetcpcli.c

- Include "unp.h"
  - Textbook's header file
  - Includes system headers needed by most network programs
  - Defines various constants such as MAXLINE
- Create TCP Socket
  - **sockfd = socket (AF_INET, SOCK_STREAM, 0)**
  - Returns a small integer descriptor used to identify socket
  - If returned value < 0 then error

Simple Daytime Client 2/5

Socket Descriptors

- Operating system maintains a set of socket descriptors for each process → Note that socket descriptors are shared by threads
- Three data structures
  - Socket descriptor table → Socket data structure → Address data structure



Simple Daytime Client 3/5

- Specify Server IP Address and Port
  - Fill an *Internet socket address structure* with server's IP address and port
  - Set entire structure to zero first using **bzero**
  - Set address family to AF_INET
  - Set port number to 13 (well-known port for daytime server on host supporting this service)
  - Set IP address to value specified as command line argument (argv[1])
  - IP address and port number must be in specific format
  - **htons** → host to network short
  - **inet_pton** → *presentation to numeric*, converts ASCII dotted-decimal command line argument (128.82.4.66) to proper format

Simple Daytime Client 4/5

- Establish connection with server
  - **Connect (sockfd, (SA *) &servaddr, sizeof(servaddr))**
  - Establish a TCP connection with server specified by socket address structure pointed to by second argument
  - Specify length of socket address structure as third argument
  - **SA** is #defined to be **struct sockaddr** in **unp.h**
- Read and Display server reply
  - Server reply normally a 26-byte string of the form

    Mon May 26 20:58:40 2003\r\n
  - TCP a *byte-stream* protocol, always code the **read** in a loop and terminate loop when **read** returns 0 (other end closed connection) or value less than 0 (error)

Simple Daytime Client 5/5

- Terminate program
  - Exit terminates the program **exit (0)**
  - Unix closes all open descriptors when a process terminates
  - TCP socket closed
- Program protocol dependent on IPv4, will see later how to change to IPv6 and even make it protocol independent

Error Handling: Wrapper Functions

- Check every function call for error return
- In previous example, check for errors from **socket**, **inet_pton**, **connect**, **read**, and **fputs**
- When error occurs, call textbook functions **err_quit** and **err_sys** to print an error message and terminate the program
- Define wrapper functions in lib/wrapsock.c
- Unix **errno** value
  - When an error occurs in a Unix function, global variable **errno** is set to a positive value indicating the type of error and the function normally returns -1
  - **err_sys** function looks at **errno** and prints corresponding error message (e.g., connection timed out)

Simple Daytime Server 1/2

- Source code in daytimetcpsrv.c
- Create a TCP Socket
  - Identical to client code
- Bind server well-known port to socket
  - Fill an Internet socket address structure
  - Call **Bind** (wrapper function) → local protocol address bound to socket
  - Specify IP address as **INADDR_ANY**: accept client connection on any interface (if server has multiple interfaces)
- Convert socket to listening socket
  - Socket becomes a listening socket on which incoming connections from clients will be accepted by the kernel
  - **LISTENQ** (defined in unp.h) specifies the maximum number of client connections the kernel will queue for this listening descriptor

Simple Daytime Server 2/2

- Accept client connection, send reply
  - Server is put to sleep (blocks) in the call to **accept**
  - After connection accepted, the call returns and the return value is a new descriptor called the *connected descriptor*
  - New descriptor used for communication with the new client
- Terminate connection
  - Initiate a TCP connection termination sequence
- Some Comments
  - Server handles one client at a time
  - If multiple client connections arrive at about the same time, kernel queues them up, up to some limit, and returns them to accept one at a time (An example of an iterative server, other options?)

IPv4 Socket Address Structure

```
struct  in_addr {
  in_addr_t   s_addr ;   // 32-bit, IPv4 network byte order (unsigned)
}

struct sockaddr_in {
    uint8_t          sin_len;   /*unsigned 8 bit integer*/
    sa_family_t      sin_family; /*AF_INET*/
    in_port_t        sin_ port ; /* 16 bit TCP or UDP port number */
    struct   in_addr   sin_addr; /* 32 bit IPv4 address */
    char               sin _zero[8];  /*unused*/
}
struct  sockaddr_in   servaddr;
servaddr.sin_addr.s_addr = htonl(INADDR_ANY);
```


Generic Socket Address Structure

- *A socket address structure always passed by reference when passed as an argument to any socket function*
- How to declare the pointer that is passed?
- Define a generic socket address structure

```
struct sockaddr {
    uint8_t        sa_len;   /*unsigned 8 bit integer*/
    sa_family_t    sa_family; /*AF_INET*/
    char           sa_data[14] ; /* protocol specific address*/
}
Prototype for bind
int bind (int, struct sockaddr * socklen_t)

struct sockaddr_in serv;
bind (sockfd, (struct sockaddr *) &serv,sizeof(serv));
Or #define SA struct sockaddr → bind (sockfd, (SA *) &serv, sizeof(serv));
```


Value-Result Arguments

- Length of socket passed as an argument
- Method by which length is passed depends on which direction the structure is being passed (from process to kernel, or vice versa)

- Value-only: ***bind***, ***connect***, ***sendto*** (from process to kernel)
- Value-Result: ***accept***, ***recvfrom***, ***getsockname***, ***getpeername*** (from kernel to process, pass a pointer to an integer containing size)
  - *Tells process how much information kernel actually stored*

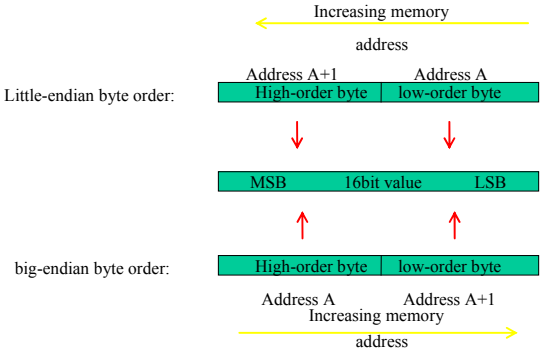
```
struct sockaddr_in    clientaddr ;
socklen_t             len;
int                   listenfd, connectfd;

len = sizeof (clientaddr);
connectfd = accept (listenfd,  (SA *) &clientaddr,  &len);
```


Byte Ordering Functions 1/4

- Two ways to store 2 bytes (16-bit integer) in memory
  - Low-order byte at starting address → little-endian byte order
  - High-order byte at starting address → big-endian byte order
- *in a big-endian computer* → store 4F52
  - Stored as 4F52 → 4F is stored at storage address 1000, 52 will be at address 1001, for example
- *In a little-endian system* → store 4F52
  - it would be stored as 524F (52 at address 1000, 4F at 1001)
- Byte order used by a given system known as *host byte order*
- Network programmers use *network byte order*
- Internet protocol uses big-endian byte ordering for integers (port number and IP address)

Byte Ordering Functions 2/4



Byte Ordering Functions 3/4

```
#include     "unp.h"
int main(int argc, char **argv)
{
        union {
          short  s;
          char   c[sizeof(short)];
        } un;

        un.s = 0x0102;
        printf("%s: ", CPU_VENDOR_OS);
        if (sizeof(short) == 2) {
                if (un.c[0] == 1 && un.c[1] == 2)
                        printf("big-endian\n");
                else if (un.c[0] == 2 && un.c[1] == 1)
                        printf("little-endian\n");
                else
                        printf("unknown\n");
        } else
                printf("sizeof(short) = %d\n", sizeof(short));

        exit(0);
}
```

- Sample program to figure out little-endian or big-endian machine
- Source code in byteorder.c

Byte Ordering Functions 4/4

- To convert between byte orders
  - Return value in network byte order
    - ✓htons (s for short word 2 bytes)
    - ✓htonl (l for long word 4 bytes)
  - Return value in host byte order
    - ✓ntohs
    - ✓ntohl
- Must call appropriate function to convert between host and network byte order
- On systems that have the same ordering as the Internet protocols, four functions usually defined as null macros

servaddr.sin_addr.s_addr = htonl(INADDR_ANY);
servaddr.sin_port = htons(13);

Byte Manipulation Functions

#include <strings.h>

void bzero (void *dest, size_t nbytes);
// sets specified number of bytes to 0 in the destination

void bcopy (const void *src,void * dest, size_t nbytes);
// moves specified number of bytes from source to destination

void bcmp (const void *ptr1, const void *ptr2,size_t nbytes)
//compares two arbitrary byte strings, return value is zero if two byte strings are identical, otherwise, nonzero

Address Conversion Functions 1/2

Convert an IPv4 address from a dotted-decimal string "206.168.112.96" to a 32-bit network byte order binary value

#include <arpa/inet.h>
int inet_aton (const char* strptr, struct in_addr *addrptr);
// return 1 if string was valid, 0 on error. Address stored in *addrptr

in_addr_t inet_addr (const char * strptr);
// returns 32 bit binary network byte order IPv4 address, currently deprecated

char * inet_nota (struct in_addr inaddr);
//returns pointer to dotted-decimal string

Address Conversion Functions 2/2

To handle both IPv4 and IPv6 addresses
#include <arpa/inet.h>
int inet_pton (int family, const char* strptr, void *addrptr);
// return 1 if OK, 0 on error. 0 if not a valid presentation, -1 on error, Address stored in *addrptr

Const char * inet_ntop (int family, const void* addrptr, char *strptr, size_t len);
// return pointer to result if OK, NULL on error

```
if (inet_pton(AF_INET, argv[1], &servaddr.sin_addr) <= 0)
                err_quit("inet_pton error for %s", argv[1]);

ptr = inet_ntop (AF_INET,&addr.sin_addr,str,sizeof(str));
```


Reading and Writing Functions 1/2

- int send (int socket, char *message, int msg_len, int flags) (TCP)
- int sendto (int socket, void *msg, int len, int flags, struct sockaddr * *to*, int *tolen*); (UDP)
- int write(int socket, void *msg, int len); /* TCP */
- int recv (int socket, char *buffer, int buf_len, int flags) (TCP)
- int recvfrom(int socket, void *msg, int len, int flags, struct sockaddr *from, int *fromlen); (UDP)
- int read(int socket, void *msg, int len); (TCP)

Reading and Writing Functions 2/2

- Stream sockets (TCP sockets) exhibit a behavior with read and write that differs from normal file I/O
- A read or write on a stream socket might input or output fewer bytes than requested (not an error)