THE SOCKETS API, PART I

Internet Protocols

CSC / ECE 573

Fall, 2005

N. C. State University

Today's Lecture

I. Clients and Servers

II. The Sockets API

III. Data Structures and Conversion Functions

IV. Using the Sockets API for UDP Applications

Announcements

After class today: persons seeking project partners please gather at the front of the room.

Negotiating TCP options:
"…both sides must send Window Scale options in their SYN segments to enable window scaling in either direction."

CLIENTS AND SERVERS

Clients and Servers

Clients	**Server**
Many	One
Initiate communication (active open)	Wait for communication request (listen)
Often make short request and then exit	Usually started at boot-up time, remain running for a long time
Use ephemeral ports, dynamically assignable	Use "well-known" (assigned) ports so it is easy to contact them
Implementation is usually simple	Implementation may be complex

Server Complexity

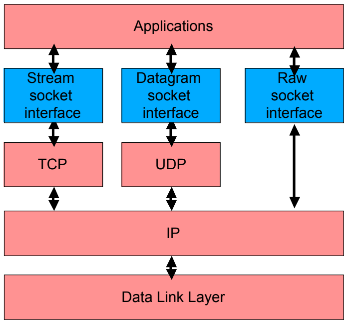
- Must be robust
- Must handle concurrent requests
- Must be secure (authenticate users and requests, etc.)

THE SOCKETS API

The Sockets Application Programming Interface (API)

- Goals: flexible / expressive, portable, easy to use
- Introduced in 1981 by Unix BSD 4.1
  - implemented as system calls
  - available on lots of platforms
- Types of service
  - datagram (UDP)
  - stream (TCP)
  - raw (plain IP, no transport layer)

Sockets API (cont'd)



Applications

Stream socket interface

Datagram socket interface

Raw socket interface

TCP

UDP

IP

Data Link Layer

For Full Documentation / Details

- See…
  - Comer, Volume III, Appendix I
  - Your OS's online documentation (e.g., `man connect`)
  - Other web resources (see Links web page)

System Calls and Errors

- In general, systems calls return a negative number to indicate an error
  - servers generally log errors
  - clients generally provide some feedback to the user
- Whenever an error occurs, the value of the global variable `errno` is set
  - you can check `errno` for specific errors
  - you can use support functions to print out a text error message: `perror()`, `strerror()`

```
extern int errno;
```

DATA STRUCTURES AND CONVERSION FUNCTIONS

Constant and Function Definitions

- You’ll need to include these definitions for your programs to compile

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <unistd.h>
#include <stdarg.h>
#include <errno.h>
#include <fcntl.h>
#include <sys/time.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <netdb.h>
```

Data Structure: Socket Addresses

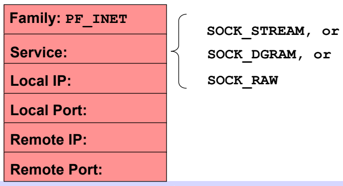
- IPv4 addresses = 32 bits
- Socket address = port + IP address

```
struct in_addr {
    u_long            s_addr;         /* 32-bit address*/
                                      /* for IPv4      */
};


struct sockaddr_in {
    u_char            sin_len;        /* total length   */
    short             sin_family;     /* AF_INET        */
    u_short           sin_port;       /* port number    */
    struct in_addr    sin_addr;       /* the IP address */
    char              sin_zero[8];    /* unused, padding*/
};
```

The Socket Abstraction

- Describes the state of a connection
  - also provides buffering
  - sockets are not bound to specific addresses at the time of creation
- Identified by small integer, the *socket descriptor*



Family: `PF_INET`

Service:

Local IP:

Local Port:

Remote IP:

Remote Port:

`SOCK_STREAM, or`

`SOCK_DGRAM, or`

`SOCK_RAW`

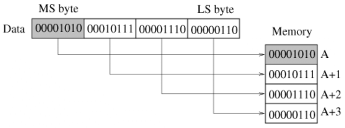
Socket Abstraction (cont’d)

- **`Service`**: filled by `socket()` (also creates the socket data structure)

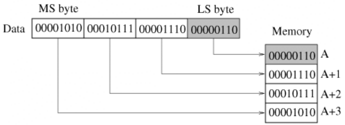
```
s = socket(PF_INET, type, ppe->p_proto);
```

- **`Local Address, Port`**: filled by `bind()`
- **`Remote Address, Port`**: filled by `connect(), send(), recv()`

Byte Ordering Definitions



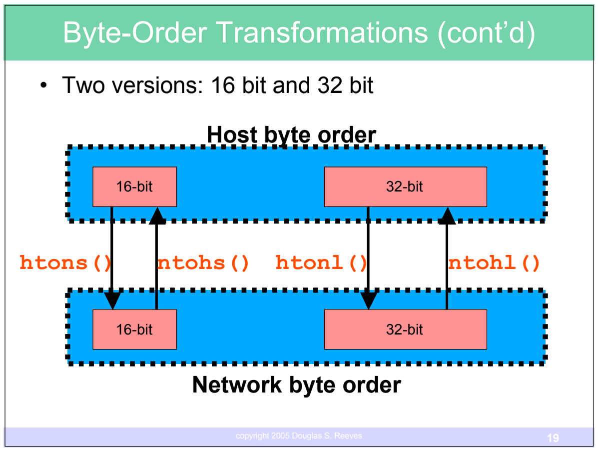
(a) Big-endian byte order



(b) Little-endian byte order

Byte-Order Transformations

- Byte ordering is a function of machine architecture
  - Intel: little-endian
  - Sparc, PowerPC: big-endian
  - Network order: big-endian
- With little-endian, you must do byte ordering conversions before writing / reading header fields
  - it never hurts to use, and it improves portability
  - how about the payload?
  - only necessary for multiple-byte words (16 bits, 32 bits)



Byte-Order Transformations (cont'd)

- Two versions: 16 bit and 32 bit

Host byte order

16-bit

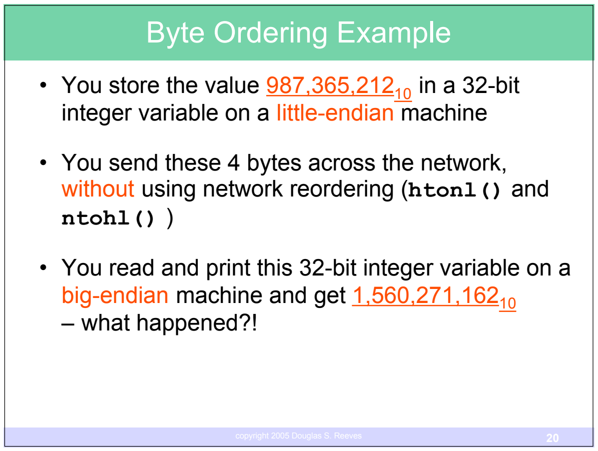
32-bit

`htons()` `ntohs()` `htonl()` `ntohl()`

16-bit

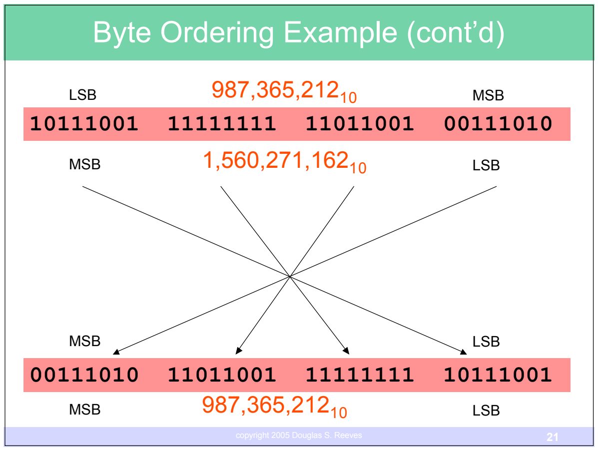
32-bit

Network byte order



Byte Ordering Example

- You store the value $987{,}365{,}212_{10}$ in a 32-bit integer variable on a little-endian machine
- You send these 4 bytes across the network, without using network reordering (`htonl()` and `ntohl()`)
- You read and print this 32-bit integer variable on a big-endian machine and get $1{,}560{,}271{,}162_{10}$ – what happened?!



Byte Ordering Example (cont'd)

LSB $987{,}365{,}212_{10}$ MSB

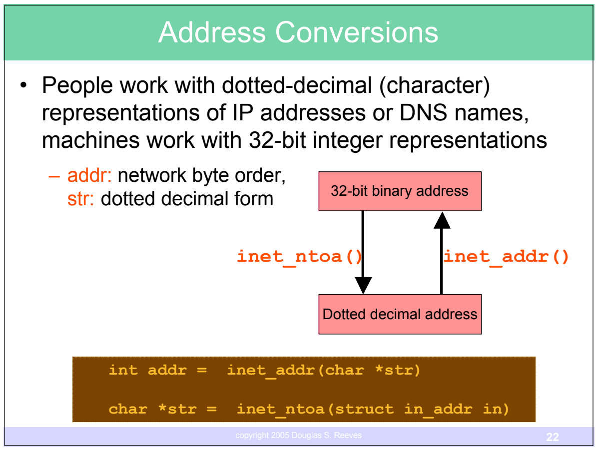
`10111001 11111111 11011001 00111010`

MSB $1{,}560{,}271{,}162_{10}$ LSB

MSB LSB

`00111010 11011001 11111111 10111001`

MSB $987{,}365{,}212_{10}$ LSB



Address Conversions

- People work with dotted-decimal (character) representations of IP addresses or DNS names, machines work with 32-bit integer representations
  - addr: network byte order, str: dotted decimal form

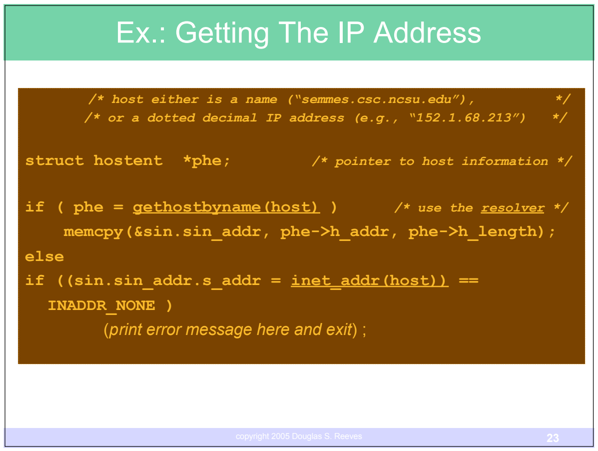
32-bit binary address

`inet_ntoa()` `inet_addr()`

Dotted decimal address

```
int addr =  inet_addr(char *str)

char *str =  inet_ntoa(struct in_addr in)
```

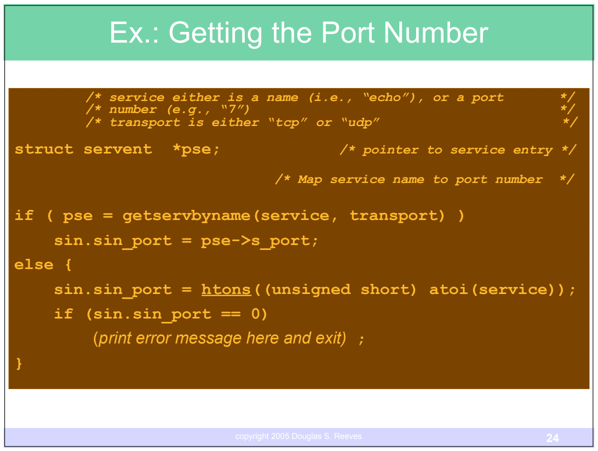


Ex.: Getting The IP Address

```
        /* host either is a name ("semmes.csc.ncsu.edu"),          */
        /* or a dotted decimal IP address (e.g., "152.1.68.213")   */

struct hostent  *phe;          /* pointer to host information */

if ( phe = gethostbyname(host) )        /* use the resolver */
    memcpy(&sin.sin_addr, phe->h_addr, phe->h_length);
else
if ((sin.sin_addr.s_addr = inet_addr(host)) ==
   INADDR_NONE )
        (print error message here and exit) ;
```



Ex.: Getting the Port Number

```
        /* service either is a name (i.e., "echo"), or a port      */
        /* number (e.g., "7")                                      */
        /* transport is either "tcp" or "udp"                      */

struct servent  *pse;              /* pointer to service entry */

                              /* Map service name to port number  */

if ( pse = getservbyname(service, transport) )
    sin.sin_port = pse->s_port;
else {
    sin.sin_port = htons((unsigned short) atoi(service));
    if (sin.sin_port == 0)
        (print error message here and exit)  ;
}
```

Ex.: Getting the Transport Protocol Type

```
                                /* transport is either "udp" or "tcp" */
int      type;                                /* socket type          */
struct   protoent *ppe;            /* pointer to protocol entry */


                /* Map transport protocol name to protocol number    */
if ( (ppe = getprotobyname(transport)) == 0)
    (print error message here and exit)  ;


                            /* Use protocol to choose a socket type */
if (strcmp(transport, "udp") == 0)
    type = SOCK_DGRAM;
else
    type = SOCK_STREAM;
```

Obtaining Socket Addresses

- Newly created process may need to determine the addresses (local and remote) associated with a socket
  - only works with connected sockets
- Get the remote IP address and port number

```
getpeername(int s, struct sockaddr *peeraddr,
                int *peerlen)
```

- Get the local IP address and port number

```
getsockname(int s, struct sockaddr *localaddr,
                int *locallen)
```

USING THE SOCKETS API FOR UDP APPLICATIONS

Types of Servers

	Concurrent connections	One connection at a time
Connection-oriented: TCP	**Normal TCP**	A few simple TCP applications
Connectionless: UDP	A few high-volume or long-duration UDP applications	**Normal UDP**

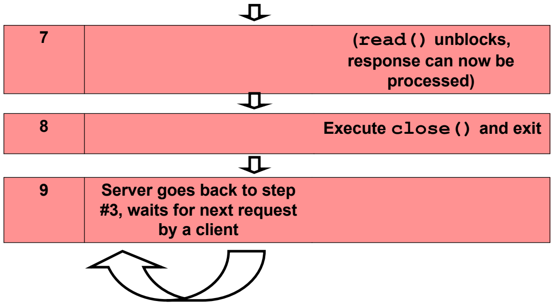
Client-Server Interaction: UDP

Step #	Server	Client
1	Create socket with `socket()`	Create socket with `socket()`
2a	Bind socket to <u>local</u> port and IP address with `bind()`	
2b		Bind socket to <u>remote</u> IP address and port with `connect()`; (also chooses <u>local</u> port and binds socket to it)

Client-Server Interaction (cont'd)

3	Execute `recvfrom()`; block until data (a request) is received from a remote client, and record <u>remote</u> address	
4		Send a request to the server with `write()`
5	(`recvfrom()` unblocks, request can now be processed by the server)	execute `read()` and block until response is sent by server
6	Send response to the client using `sendto()` and <u>remote</u> address	

Client-Server Interaction (cont'd)



7 **(`read()` unblocks, response can now be processed)**

8 **Execute `close()` and exit**

9 **Server goes back to step #3, waits for next request by a client**

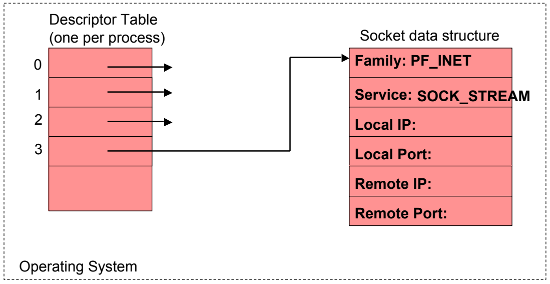
Creating A Socket with `socket()`

- Parameters
  - domain: `PF_INET`
  - type: `SOCK_DGRAM, SOCK_STREAM, SOCK_RAW`
  - protocol: usually = 0 (i.e., default for type)
- Example

```
s = socket(PF_INET, SOCK_STREAM, 0);
```

Result of `socket()`

Server and Client sockets



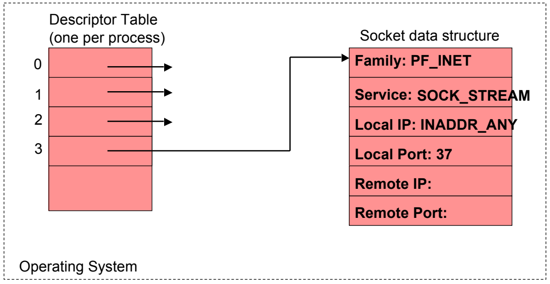
Binding to a Socket with `bind()`

- Used by servers to specify the well-known local port to use
- Optional for clients; system usually chooses an "available" local port
- Use INADDR_ANY to bind the socket to all of the machine's interfaces (if multi-homed)

```
sin.sin_addr.s_addr = INADDR_ANY;
if ( bind(s, (struct sockaddr *) &sin, sizeof(sin)) < 0)
    (print error message here)  ;
```

Result: `bind()`

Server socket



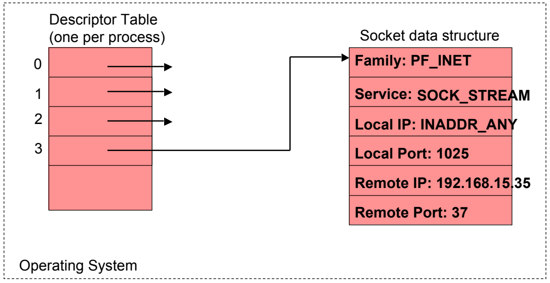
Connecting to Remote Endpoint with `connect()`

- Clients use `connect()` to specify a remote endpoint so other calls don't have to
  - no packet exchange or connection establishment!
- Also binds to an available local port

```
if (connect(s, (struct sockaddr *) &sin, sizeof(sin)) < 0)
        (print error message here)    ;
```

Result: `connect()`

Client socket



Descriptor Table
(one per process)

0
1
2
3

Socket data structure

Family: PF_INET
Service: SOCK_STREAM
Local IP: INADDR_ANY
Local Port: 1025
Remote IP: 192.168.15.35
Remote Port: 37

Operating System

Steps #3-7: Sending and Receiving Datagrams

- Each function call sends or receives one complete message (datagram)
- “Flags” parameter can modify action of the call
  - `recv()`, `send()`, `recvfrom()`, and `sendto()` can specify flags
  - `read()` and `write()` cannot

Receiving UDP Datagrams

```
int  read(int s, char *buf, int buflen);
```

```
int  recv(int s, char *buf, int buflen, int flags);
```

```
int  recvfrom(int s, char *buf, int buflen, int flags,
              struct sockaddr *from, int fromlen);
```

- Receives up to `len` bytes into buffer
  - returns number of bytes received
  - if `buf` is not large enough, any additional bytes in the datagram are discarded
- `recvfrom()` records the remote endpoint address that sent the datagram if not connected

---

Sending UDP Datagrams

```
int  write(int s, char* buf, int buflen);
```

```
int  send(int s, char* buf, int buflen, int flags);
```

```
int  sendto(int s, char *buf, int buflen, int flags,
            struct sockaddr *to, int tolen);
```

- Sends up to `buflen` bytes
- The return value indicates how much data was accepted by the O.S. for sending as a datagram
  - not how much data made it to the destination
  - there is no return code indicating destination got the data

---

Sending UDP Datagrams (cont’d)

- `sendto()` specifies the remote IP address / port number to which the data should be sent (if not connected)

Step #8: Closing UDP Sockets

```
int  close(int s);
```

- Releases the resources associated with a socket
- Does not inform the remote endpoint that the socket is closed
  - i.e., there is no connection to terminate

Summary

1. The Sockets API is pretty much universal for network programming
2. Best advice
   1. learn the functions
   2. then develop and use a standard “template” for writing networked applications

`socket(), bind(),` and `listen()` create a passive (unconnected) socket

UDP applications relatively easy to write: send a datagram, wait for a response

Next Lecture

- Sockets Programming Part II, and Server Design