Sockets

- Based on
  - Section 17.3 of Computer Networking with Internet Protocols and Technology, by William Stallings, Prentice Hall.
  - book chapter 12.6.2

Sockets

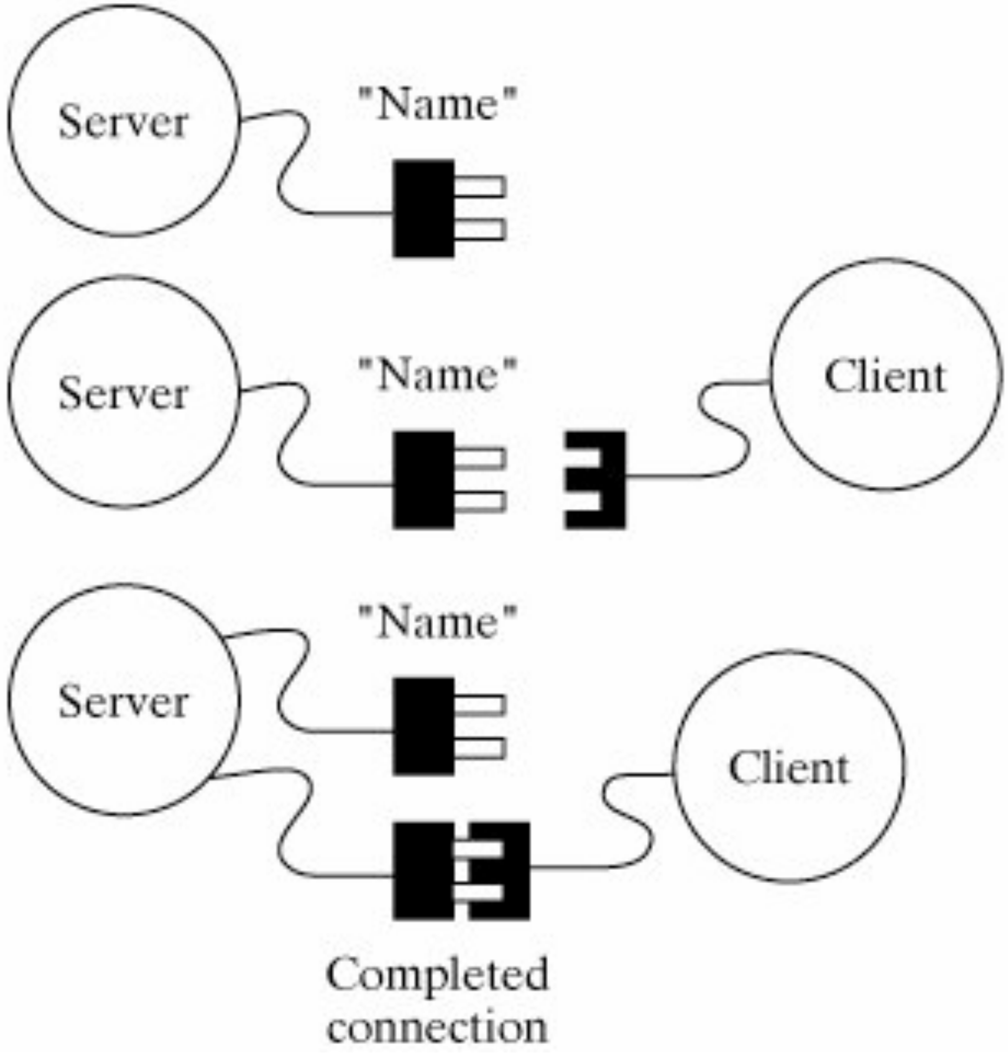
- The concept of sockets and sockets programming was developed in the 1980s in the UNIX environment as the Berkeley Sockets Interface.
    - a socket enables communication between a client and server process and may be connection-oriented or connectionless.
    - The Berkeley Sockets Interface is the de facto standard application programming interface (API) for developing networking applications
    - Windows Sockets (WinSock) is based on the Berkeley specification.
    - The sockets API provides generic access to interprocess communications services.

Sockets

1. Server creates a named socket.

2. Client creates an unnamed socket and requests a connection.

3. Client makes a connection. Server retains original named socket.



Sockets

- TCP and UDP header includes source port and destination port fields, IP header includes IP address
  - TCP/UDP: The port values identify the respective users (applications) of the two TCP entities.
  - IP (IPv4 and IPv6): header includes source address and destination address fields
    - these IP addresses identify the respective host systems.
- Definition of a Socket
  - The concatenation of a port value and an IP address forms a socket, which is unique throughout the Internet.

Sockets

- The socket is used to define an API, which is a generic communication interface for writing programs that use TCP or UDP.

- In practice, when used as an API, a socket is identified by the triple (protocol, local address, local process).

- The local address is an IP address and the local process is a port number. Because port numbers are unique within a system, the port number implies the protocol (TCP or UDP).

Sockets

- The Sockets API recognizes two types of sockets:
  - Stream sockets (SOCK_STREAM)
    - make use of TCP, which provides a connection-oriented reliable data transfer.
    - with stream sockets, all blocks of data sent between a pair of sockets are guaranteed for delivery and arrive in the order that they were sent.

Sockets

- The Sockets API recognizes two types of sockets:
  - Datagram sockets, (SOCK_DGRAM)
    - make use of UDP, which does not provide the connection-oriented features of TCP.
    - with datagram sockets, delivery is not guaranteed, nor is order necessarily preserved.
- There is a third type of socket provided by the Sockets API: raw sockets, (SOCK_RAW)
  - Raw sockets
    - allow direct access to lower layer protocols, such as IP.

Sockets

- Socket Interface Calls

- To use sockets, it is a three-step process:
  - 1. Socket Setup
  - 2. Socket Connection
  - 3. Socket Communication

- Any program that uses sockets must include
  - /usr/include/sys/types.h
  - /usr/include/sys/socket.h

Sockets

- The typical TCP client's communication involves four basic steps:
  - 1. Create a TCP socket using **socket**().
  - 2. Establish a connection to the server using **connect**().
  - 3. Communicate using **send**() and **recv**().
  - 4. Close the connection with **close**().

Sockets

- Socket Setup
  - The first step in using Sockets is to create a new socket using the socket() command. There are three parameters:

1. the *protocol family* is always PF INET for the TCP/IP protocol suite.

2. the *type* specifies whether this is a stream or datagram socket

3. the *protocol* specifies either TCP or UDP.

- The reason that both type and protocol need to be specified is to allow additional transport-level protocols to be included in a future implementation.

Sockets

- After socket is created, it must have an address to listen to.
    - The **bind**() function binds a socket to a socket address. The address has the structure:

```
struct sockaddr_in {
   short int sin_family;           // Address family (TCP/IP)
   unsigned short int sin_port;    // Port number
   struct in_addr sin_addr;        // Internet address
   unsigned char sin_zero[8];      // Same size as struct sockaddr
};
```

Sockets

- Socket Connection
  - Stream socket
    - once the socket is created, a connection must be set up to a remote socket.
    - one side functions as a client, and requests a connection to the other side, which acts as a server.

Sockets

- The server side of a connection setup requires two steps:

  1. a server application issues a **listen**(),

  - indicates that socket is ready to accept incoming connections.
  - parameter *backlog* is the number of connections allowed on the incoming queue.
  - Each incoming connections is placed in this queue until a matching accept() is issued by the server side.

Sockets

- The server side of a connection setup requires two steps:

  2. the **accept**() call is used to remove one request from the queue.

  - If the queue is empty, the accept() blocks the process until a connection request arrives.
  - If there is a waiting call, then accept() returns a new file descriptor for the connection.
  - This creates a new socket, which has the IP address and port number of the remote party, the IP address of this system, and a new port number.

Sockets

- A client application issues a **connect**()
  - that specifies both a local socket and the address of a remote socket.
  - If the connection attempt is unsuccessful connect() returns the value 1.
  - If the attempt is successful, connect() returns a 0 and fills in the file descriptor parameter to include the IP address and port number of the local and foreign sockets.
  - Recall that the remote port number may differ from that specified in the foreignAddress parameter because the port number is changed on the remote host.

Sockets

- Socket Communication
  - For stream communication, the functions **send**() and **recv**() are used to send or receive data over the connection identified by the sockfd parameter.
  - In the send() call, the **msg* parameter points to the block of data to be sent and the *len* parameter specifies the number of bytes to be sent.
  - The *flags* parameter contains control flags, typically set to 0.
  - The send() call returns the number of bytes sent, which may be less than the number specified in the *len* parameter.

Sockets

- Socket Communication cont.
  - In the recv() call, the **buf* parameter points to the buffer for storing incoming data, with an upper limit on the number of bytes set by the *len* parameter.
  - At any time, either side can close the connection with the close() call, which prevents further sends and receives. The **shutdown**() call allows the caller to terminate sending or receiving or both.

Socket System Calls

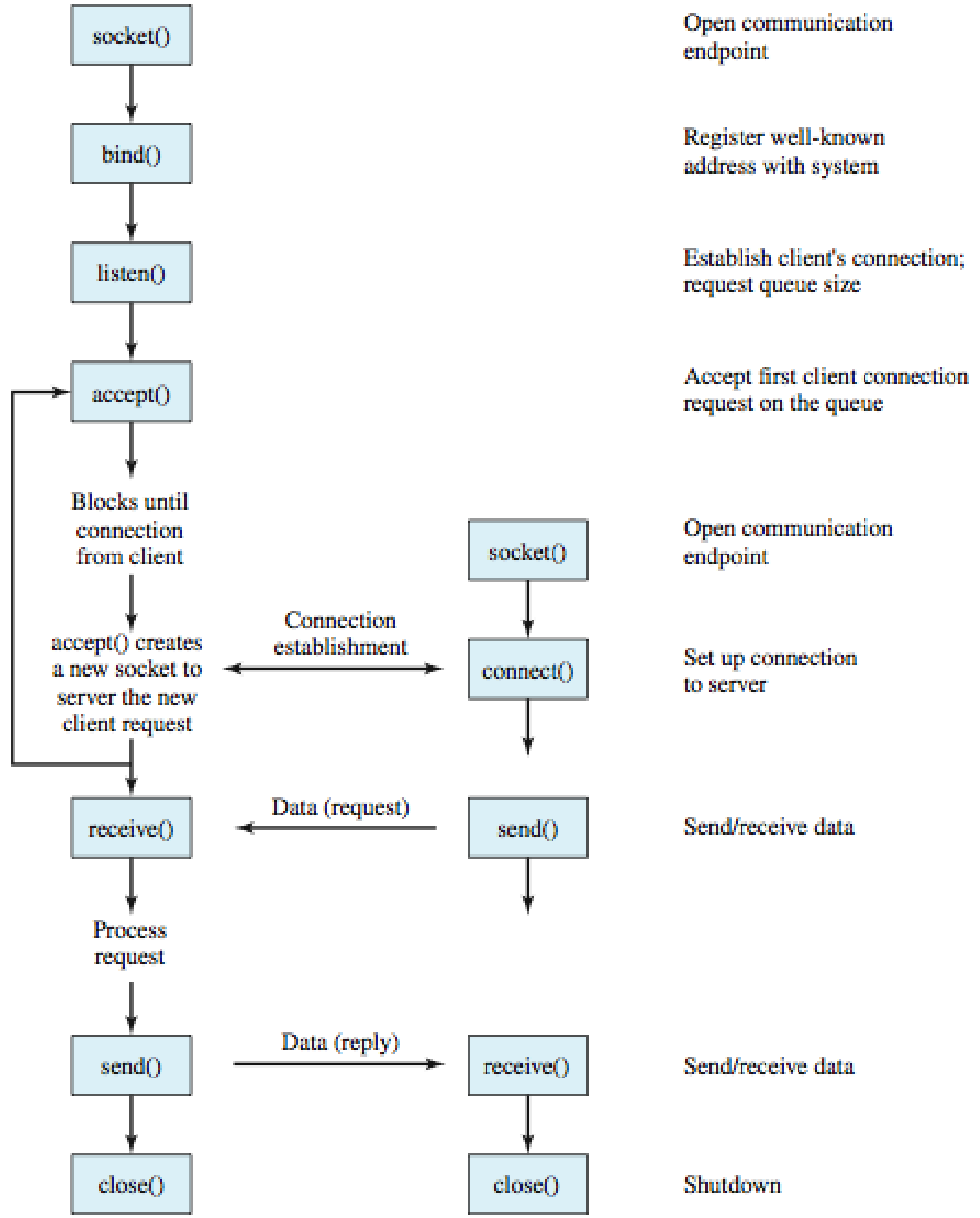

socket()
bind()
listen()
accept()
Blocks until connection from client
accept() creates a new socket to server the new client request
receive()
Process request
send()
close()
socket()
connect()
send()
receive()
close()
Connection establishment
Data (request)
Data (reply)
Open communication endpoint
Register well-known address with system
Establish client's connection; request queue size
Accept first client connection request on the queue
Open communication endpoint
Set up connection to server
Send/receive data
Send/receive data
Shutdown

Figure 17.6 **Socket System Calls for Connection-Oriented Protocol**

Sockets

- Datagram Communication
  - For datagram communication, the functions **sendto**() and **recvfrom**() are used.
    - The sendto() call includes all the parameters of the send() call plus a specification of the destination address (IP address and port).
    - Similarly, the recvfrom() call includes an address parameter, which is filled in when data are received.

Sockets

- Example from socket tutorial at
  - http://www.linuxhowtos.org/C_C++/socket.htm
  - the server and client code for this site are shown below

server code

```
/* A simple server in the internet domain using TCP
   The port number is passed as an argument */
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>

void error(char *msg)
{
    perror(msg);
    exit(1);
}
```

```
int main(int argc, char *argv[])
{
     int sockfd, newsockfd, portno, clilen;
     char buffer[256];
     struct sockaddr_in serv_addr, cli_addr;
     int n;
     if (argc < 2) {
         fprintf(stderr,"ERROR, no port provided\n");
         exit(1);
     }
     sockfd = socket(AF_INET, SOCK_STREAM, 0);
     if (sockfd < 0)
        error("ERROR opening socket");
     bzero((char *) &serv_addr, sizeof(serv_addr));
     portno = atoi(argv[1]);
     serv_addr.sin_family = AF_INET;
     serv_addr.sin_addr.s_addr = INADDR_ANY;
     serv_addr.sin_port = htons(portno);
     if (bind(sockfd, (struct sockaddr *) &serv_addr,
              sizeof(serv_addr)) < 0)
              error("ERROR on binding");
     listen(sockfd,5);
     clilen = sizeof(cli_addr);
     newsockfd = accept(sockfd,
                 (struct sockaddr *) &cli_addr,
                 &clilen);
     if (newsockfd < 0)
          error("ERROR on accept");
     bzero(buffer,256);
     n = read(newsockfd,buffer,255);
     if (n < 0) error("ERROR reading from socket");
     printf("Here is the message: %s\n",buffer);
     n = write(newsockfd,"I got your message",18);
     if (n < 0) error("ERROR writing to socket");
     return 0;
}
```

client code

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>

void error(char *msg)
{
    perror(msg);
    exit(0);
}
```

```
int main(int argc, char *argv[])
{
    int sockfd, portno, n;
    struct sockaddr_in serv_addr;
    struct hostent *server;

    char buffer[256];
    if (argc < 3) {
       fprintf(stderr,"usage %s hostname port\n", argv[0]);
       exit(0);
    }
    portno = atoi(argv[2]);
    sockfd = socket(AF_INET, SOCK_STREAM, 0);
    if (sockfd < 0)
        error("ERROR opening socket");
    server = gethostbyname(argv[1]);
    if (server == NULL) {
        fprintf(stderr,"ERROR, no such host\n");
        exit(0);
    }
    bzero((char *) &serv_addr, sizeof(serv_addr));
    serv_addr.sin_family = AF_INET;
    bcopy((char *)server->h_addr,
         (char *)&serv_addr.sin_addr.s_addr,
         server->h_length);
    serv_addr.sin_port = htons(portno);
    if (connect(sockfd,&serv_addr,sizeof(serv_addr)) < 0)
        error("ERROR connecting");
    printf("Please enter the message: ");
    bzero(buffer,256);
    fgets(buffer,255,stdin);
    n = write(sockfd,buffer,strlen(buffer));
    if (n < 0)
         error("ERROR writing to socket");
    bzero(buffer,256);
    n = read(sockfd,buffer,255);
    if (n < 0)
         error("ERROR reading from socket");
    printf("%s\n",buffer);
    return 0;
}
```

Sockets

- Another example

Sample Application

```
/* TCPEchoClient4.c
 */

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>

#include "Practical.h"

int main(int argc, char *argv[])
{
  if (argc < 3 || argc > 4) // Test for correct number of arguments
     DieWithUserMessage("Parameter(s)",
        "<Server Address> <Echo Word> [<Server Port>]");

   char *servIP = argv[1]; // First arg: server IP address (dotted quad)
   char *echoString = argv[2]; // Second arg: string to echo

   // Third arg (optional): server port (numeric). 7 is well-known echo port
   in_port_t servPort = (argc == 4) ? atoi(argv[3]) : 7;

   // Create a reliable, stream socket using TCP
   int sock = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
   if (sock < 0)
      DieWithSystemMessage("socket() failed");
```

```
// Construct the server address structure
struct sockaddr_in servAddr; // Server address
memset(&servAddr, 0, sizeof(servAddr)); // Zero out structure
servAddr.sin_family = AF_INET; // IPv4 address family
// Convert address
int rtnVal = inet_pton(AF_INET, servIP, &servAddr.sin_addr.s_addr);
if (rtnVal == 0)
   DieWithUserMessage("inet_pton() failed", "invalid address string");
else if (rtnVal < 0)
   DieWithSystemMessage("inet_pton() failed");
servAddr.sin_port = htons(servPort); // Server port

// Establish the connection to the echo server
if (connect(sock, (struct sockaddr *) &servAddr, sizeof(servAddr)) < 0)
  DieWithSystemMessage("connect() failed");

size_t echoStringLen = strlen(echoString); // Determine input length

// Send the string to the server
ssize_t numBytes = send(sock, echoString, echoStringLen, 0);
if (numBytes < 0)
   DieWithSystemMessage("send() failed");
else if (numBytes != echoStringLen)
   DieWithUserMessage("send()", "sent unexpected number of bytes");
   // Receive the same string back from the server
   unsigned int totalBytesRcvd = 0; // Count of total bytes received
   fputs("Received: ", stdout); // Setup to print the echoed string

   while (totalBytesRcvd < echoStringLen)
   {
      char buffer[BUFSIZE]; // I/O buffer
      /* Receive up to the buffer size (minus 1 to leave space for
         a null terminator) bytes from the sender */
      numBytes = recv(sock, buffer, BUFSIZE - 1, 0);
      if (numBytes < 0)
         DieWithSystemMessage("recv() failed");
      else if (numBytes == 0)
         DieWithUserMessage("recv()", "connection closed prematurely");

      totalBytesRcvd += numBytes; // Keep tally of total bytes
      buffer[numBytes] = '\0'; // Terminate the string!
      fputs(buffer, stdout); // Print the echo buffer
  }

  fputc('\n', stdout); // Print a final linefeed

  close(sock);

  exit(0);
}
```