CS4220
Computer Networks

Lecture 6 Socket Programming

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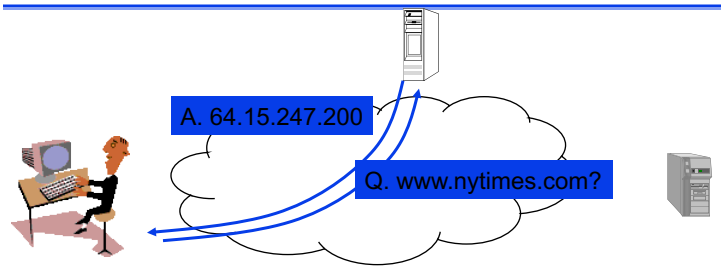
1. DNS



- User clicks on http://www.nytimes.com/
- URL contains Internet name of machine (www.nytimes.com), but not Internet address
- Internet needs Internet address to send information to a machine
- Browser software uses Domain Name System (DNS) protocol to send query for Internet address
- DNS system responds with Internet address

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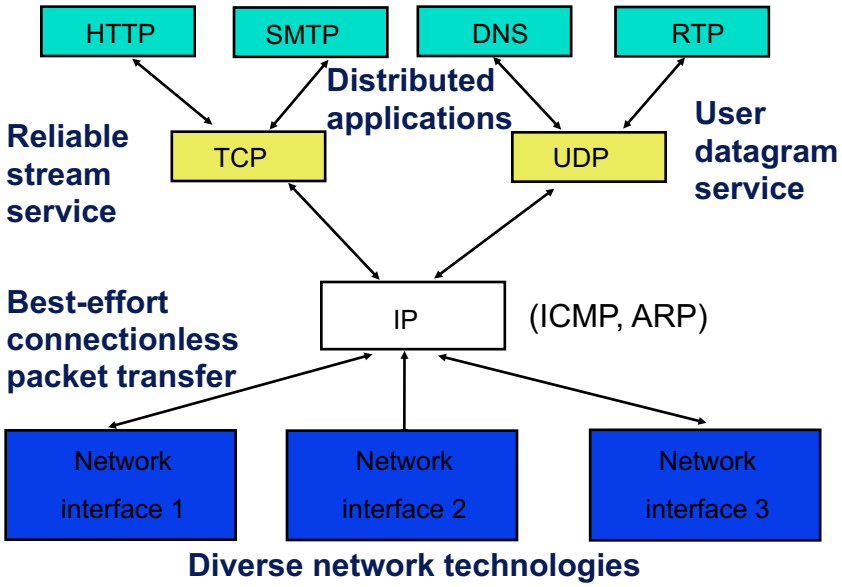
TCP/IP Protocol Suite



UDP (User Datagram Protocol)

- UDP is a transport layer protocol
- Provides *best-effort datagram service* between two processes in two computers across the Internet
- Port numbers distinguish various processes in the same machine
- UDP is *connectionless*
- Datagram is sent immediately
- Quick, simple, but not reliable

TCP (Transmission Control Protocol)

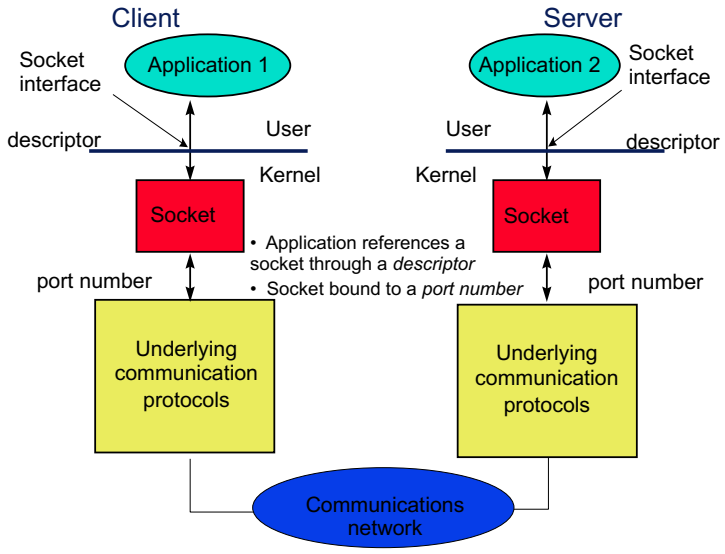
- TCP is a transport layer protocol
- Provides *reliable byte stream service* between two processes in two computers across the Internet
- Sequence numbers keep track of the bytes that have been transmitted and received
- Error detection and retransmission used to recover from transmission errors and losses
- TCP is *connection-oriented*: the sender and receiver must first establish an association and set initial sequence numbers before data is transferred
- Connection ID is specified uniquely by

(send port #, send IP address, receive port #, receiver IP address)

Socket API

- API (Application Programming Interface)
  - Provides a standard set of functions that can be called by applications
- Berkeley UNIX Sockets API
  - Abstraction for applications to send & receive data
  - Applications create sockets that "plug into" network
  - Applications write/read to/from sockets
  - Implemented in the kernel
  - Facilitates development of network applications
  - Hides details of underlying protocols & mechanisms
- Also in Windows, Linux, and other OS's

Communications through Socket Interface



Stream Mode of Service

Connection-oriented

- First, setup connection between two peer application processes
- Then, reliable bidirectional in-sequence transfer of *byte stream* (boundaries not preserved in transfer)
- Multiple write/read between peer processes
- Finally, connection release
- Uses TCP

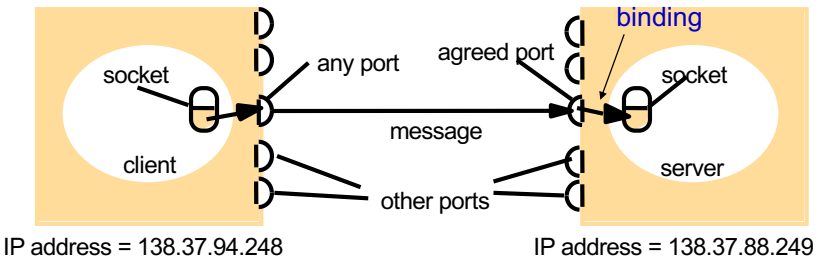
Connectionless

- Immediate transfer of one block of information (boundaries preserved)
- No setup overhead & delay
- Destination address with each block
- Send/receive to/from multiple peer processes
- Best-effort service only
  - Possible out-of-order
  - Possible loss
- Uses UDP

Client & Server Differences

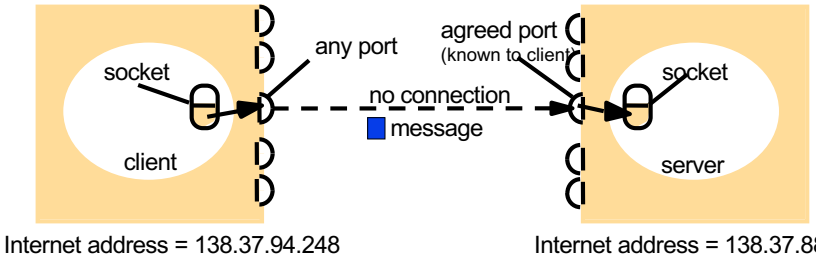
- **Server**
  - **Specifies well-known port # when creating socket**
  - **May have multiple IP addresses (net interfaces)**
  - **Waits passively for client requests**
- **Client**
  - **Assigned ephemeral port #**
  - **Initiates communications with server**
  - **Needs to know server's IP address & port #**
    - **DNS for URL & server well-known port #**
  - **Server learns client's address & port #**

Socket-based Network Programming



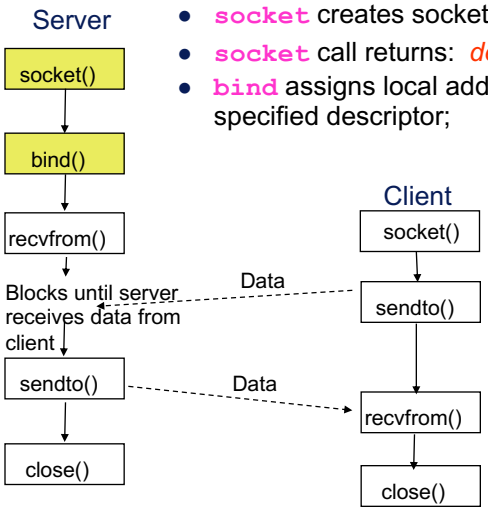
- Socket: provides an endpoint for communication between processes
  - Must be bound to a port # and an IP address at server side
  - Message destinations: (Internet address, local port)
  - Port: a message destination within a computer, an 16-bit integer
  - One port has one receiver (process), but can have many senders
  - One process can use multiple ports

UDP Datagram Communication



- UDP: The delivery of the message is not guaranteed
  - Message size: up to 2^16 B (usual restriction 8 KB)
  - Non-blocking *send* and blocking *receive*
  - Timeout: to avoid infinite wait of blocking *receive (setSoTimeout)*
  - Receive from any
  - Ordering: messages can be delivered out of sender order
  - Omission failures: send-omission, receive-omission, channel-omission

Socket Calls for Connection-less Mode (UDP)

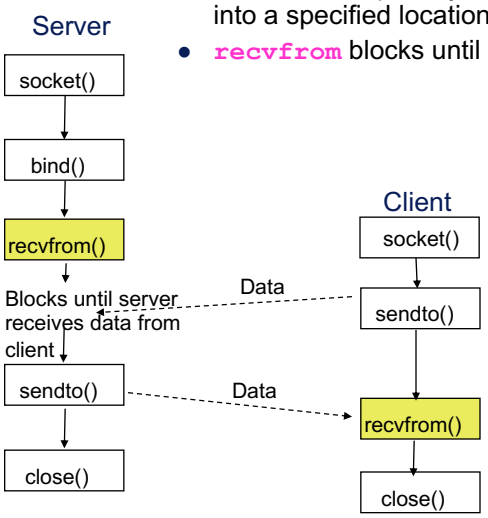


Server started

- `socket` creates socket of type UDP (datagram)
- `socket` call returns: *descriptor*; or -1 if unsuccessful
- `bind` assigns local address & port # to socket with specified descriptor;

Socket Calls for Connection-less Mode (UDP)

- `recvfrom` copies bytes received in specified socket into a specified location
- `recvfrom` blocks until data arrives



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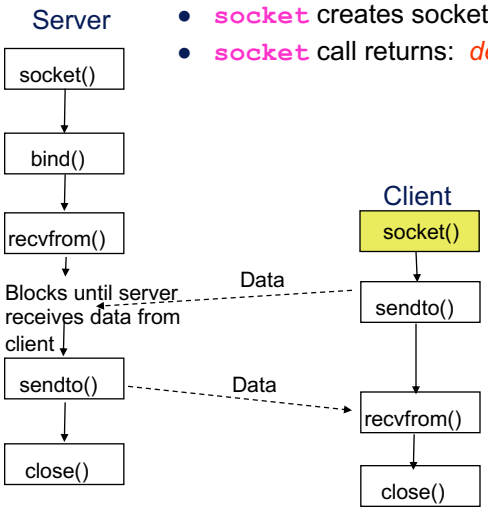
Socket Calls for Connection-less Mode (UDP)

Client started

- `socket` creates socket of type UDP (datagram)
- `socket` call returns: *descriptor*; or -1 if unsuccessful



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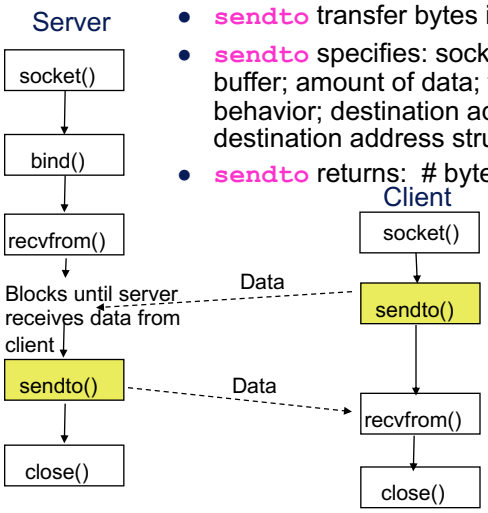
Socket Calls for Connection-less Mode (UDP)

Client started

- `sendto` transfer bytes in buffer to specified socket
- `sendto` specifies: socket descriptor; pointer to a buffer; amount of data; flags to control transmission behavior; destination address & port #; length of destination address structure
- `sendto` returns: # bytes sent; or -1 if unsuccessful



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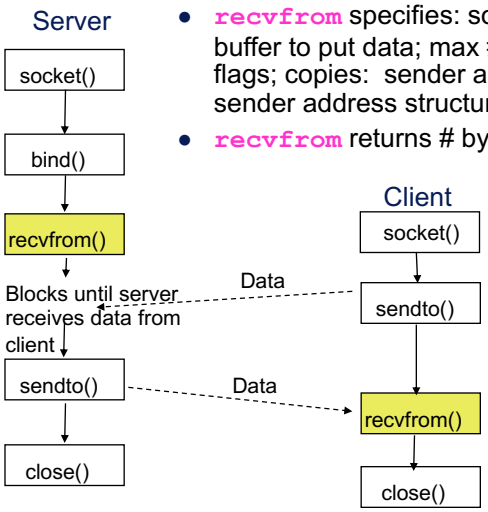
Socket Calls for Connection-less Mode (UDP)

- `recvfrom` wakes when data arrives
- `recvfrom` specifies: socket descriptor; pointer to a buffer to put data; max # bytes to put in buffer; control flags; copies: sender address & port #; length of sender address structure
- `recvfrom` returns # bytes received or -1 (failure)



Note: `receivefrom` returns data from at most one `send`, i.e. from one datagram

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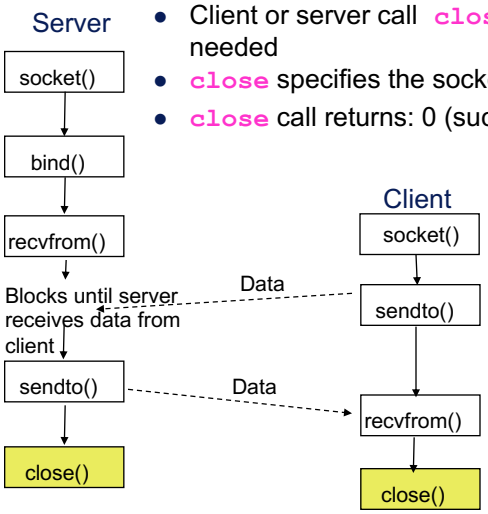
Socket Calls for Connection-less Mode (UDP)



Socket Close

- Client or server call `close` when socket is no longer needed
- `close` specifies the socket descriptor
- `close` call returns: 0 (success); or -1 (failure)

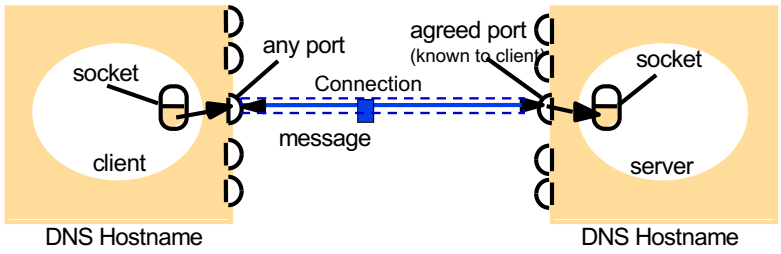
Example: UDP Echo Server

```
/* Echo server using UDP */
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>

#define SERVER_UDP_PORT             5000
#define MAXLEN                      4096

int main(int argc, char **argv)
{
      int   sd, client_len, port, n;
      char  buf[MAXLEN];
      struct            sockaddr_in
            server, client;

      switch(argc) {
      case 1:
            port = SERVER_UDP_PORT;
            break;
      case 2:
            port = atoi(argv[1]);
            break;
      default:
            fprintf(stderr, "Usage: %s [port]\n",
      argv[0]);
            exit(1);
      }

      /* Create a datagram socket */
      if ((sd = socket(AF_INET, SOCK_DGRAM, 0)) == -
      1) {
            fprintf(stderr, "Can't create a
      socket\n");
            exit(1);
      }

      /* Bind an address to the socket */
      bzero((char *)&server, sizeof(server));
      server.sin_family = AF_INET;
      server.sin_port = htons(port);
      server.sin_addr.s_addr = htonl(INADDR_ANY);
      if (bind(sd, (struct sockaddr *)&server,
      sizeof(server)) == -1) {
            fprintf(stderr, "Can't bind name to
      socket\n");
            exit(1);
      }

      while (1) {
            client_len = sizeof(client);
            if ((n = recvfrom(sd, buf, MAXLEN, 0,
            (struct sockaddr *)&client, &client_len))
      < 0) {
                  fprintf(stderr, "Can't receive
      datagram\n");
                  exit(1);
            }

            if (sendto(sd, buf, n, 0,
            (struct sockaddr *)&client, client_len)
      != n) {
                  fprintf(stderr, "Can't send
      datagram\n");
                  exit(1);
            }
      }
      close(sd);
      return(0);
}
```

Example: UDP Echo Client

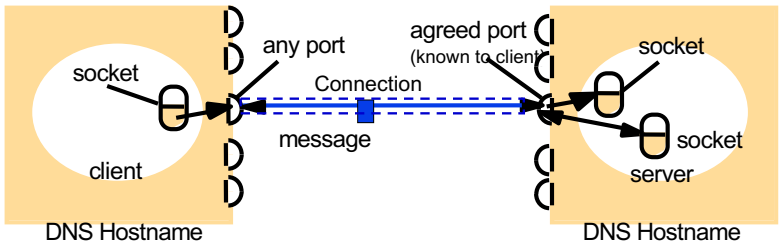
```
#include <stdio.h>
#include <string.h>
#include <sys/time.h>
#include <netdb.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#define SERVER_UDP_PORT         5000
#define MAXLEN                  4096
#define DEFLEN                  64

long delay(struct timeval t1, struct timeval t2)
{
        long d;
        d = (t2.tv_sec - t1.tv_sec) * 1000;
        d += ((t2.tv_usec - t1.tv_usec + 500) / 1000);
        return(d);
}
int main(int argc, char **argv)
{
        int     data_size = DEFLEN, port = SERVER_UDP_PORT;
        int     i, j, sd, server_len;
        char    *pname, *host, rbuf[MAXLEN], sbuf[MAXLEN];
        struct  hostent         *hp;
        struct  sockaddr_in     server;
        struct  timeval         start, end;
        unsigned long address;

        pname = argv[0];
        argc--;
        argv++;
        if (argc > 0 && (strcmp(*argv, "-s") == 0)) {
                if (--argc > 0 && (data_size = atoi(*++argv))) {
                        argc--;
                        argv++;
                }
                else {
                        fprintf(stderr,
                        "Usage: %s [-s data_size] host [port]\n", pname);
                        exit(1);
                }
        }
        if (argc > 0) {
                host = *argv;
                if (--argc > 0)
                        port = atoi(*++argv);
        }
        else {
                fprintf(stderr,
                "Usage: %s [-s data_size] host [port]\n", pname);
                exit(1);
        }

        if ((sd = socket(AF_INET, SOCK_DGRAM, 0)) == -1) {
                fprintf(stderr, "Can't create a socket\n");
                exit(1);
        }
        bzero((char *)&server, sizeof(server));
        server.sin_family = AF_INET;
        server.sin_port = htons(port);
        if ((hp = gethostbyname(host)) == NULL) {
                fprintf(stderr, "Can't get server's IP address\n");
                exit(1);
        }
        bcopy(hp->h_addr, (char *) &server.sin_addr, hp->h_length);

        if (data_size > MAXLEN) {
                fprintf(stderr, "Data is too big\n");
                exit(1);
        }
        for (i = 0; i < data_size; i++) {
                j = (i < 26) ? i : i % 26;
                sbuf[i] = 'a' + j;
        } // construct data to send to the server
        gettimeofday(&start, NULL); /* start delay measurement */
        server_len = sizeof(server);
        if (sendto(sd, sbuf, data_size, 0, (struct sockaddr *)
                &server, server_len) == -1) {
                fprintf(stderr, "sendto error\n");
                exit(1);
        }
        if (recvfrom(sd, rbuf, MAXLEN, 0, (struct sockaddr *)
                &server, &server_len) < 0) {
                fprintf(stderr, "recvfrom error\n");
                exit(1);
        }
        gettimeofday(&end, NULL); /* end delay measurement */
        if (strncmp(sbuf, rbuf, data_size) != 0)
                printf("Data is corrupted\n");
        close(sd);
        return(0);
}
```


TCP Stream Communication



- TCP: The delivery of the message is “guaranteed”
  - Message size: unlimited, handled by underlying TCP protocol
  - Loss: an acknowledgement scheme; timeout and retransmission
  - Flow control: to match the speeds of the processes that read and write to a stream; if writing too fast, blocked
  - Duplication and ordering: message identifiers associated with each packet; reordering provided
  - Message destinations: explicit after connection is built (*connect*, *accept*)

TCP Stream Communication Issues

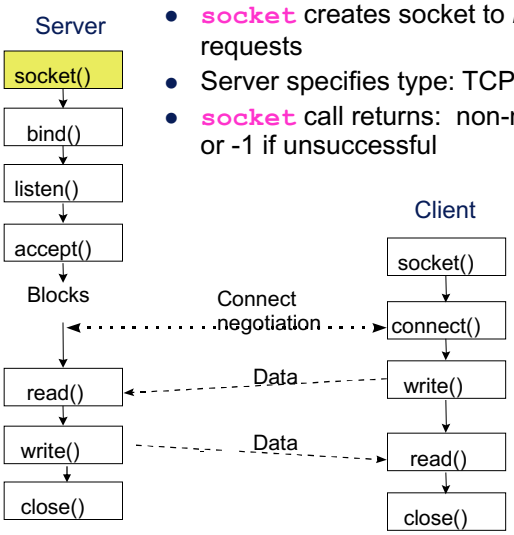


- Matching of data items: two ends agree on the contents (order) of the data; e.g., *int + double*
- Blocking: reading blocks until data becomes available; TCP *flow control protocol* will block a writing process if reading is too slow
- Threads: when accepting a connection, it generally creates a new thread with a socket to communicate to the new client for higher concurrency; no thread? *select()* in Unix

Socket Calls for Connection-Oriented Mode (TCP)

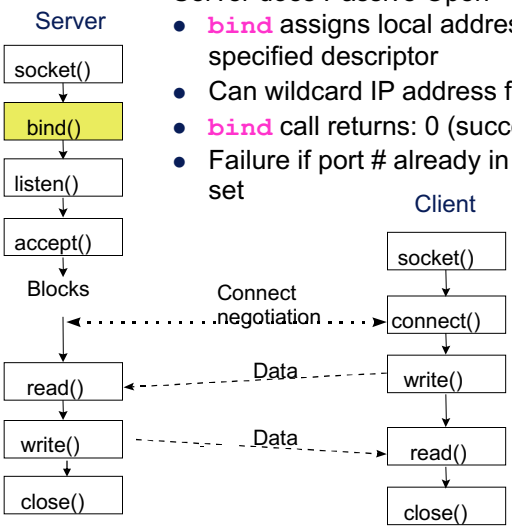
Server does Passive Open

- `socket` creates socket to *listen* for connection requests
- Server specifies type: TCP (stream)
- `socket` call returns: non-negative integer *descriptor*; or -1 if unsuccessful



Difference to UDP procedure?

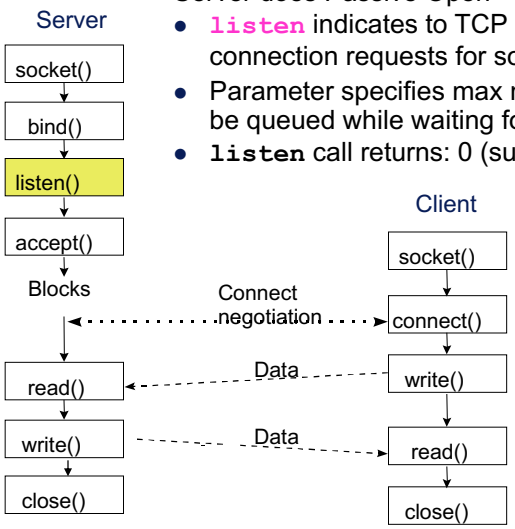
Socket Calls for Connection-Oriented Mode (TCP)



Server does Passive Open

- `bind` assigns local address & port # to socket with specified descriptor
- Can wildcard IP address for multiple net interfaces
- `bind` call returns: 0 (success); or -1 (failure)
- Failure if port # already in use or if reuse option not set

Socket Calls for Connection-Oriented Mode (TCP)



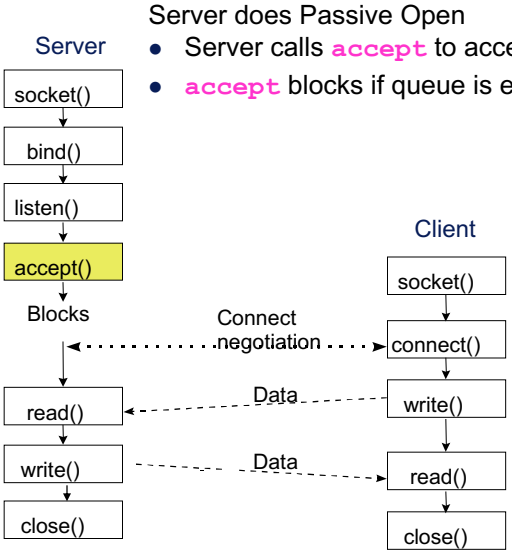
Server does Passive Open

- `listen` indicates to TCP readiness to receive connection requests for socket with given descriptor
- Parameter specifies max number of requests that may be queued while waiting for server to accept them
- `listen` call returns: 0 (success); or -1 (failure)

Socket Calls for Connection-Oriented Mode (TCP)

Server does Passive Open

- Server calls `accept` to accept incoming requests
- `accept` blocks if queue is empty



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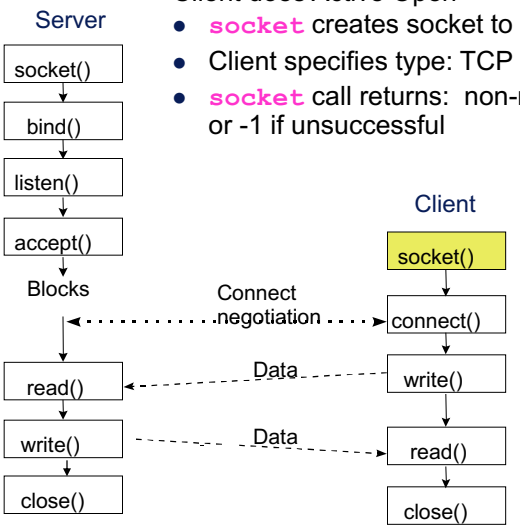
Socket Calls for Connection-Oriented Mode (TCP)

Client does Active Open

- `socket` creates socket to connect to server
- Client specifies type: TCP (stream)
- `socket` call returns: non-negative integer *descriptor*; or -1 if unsuccessful



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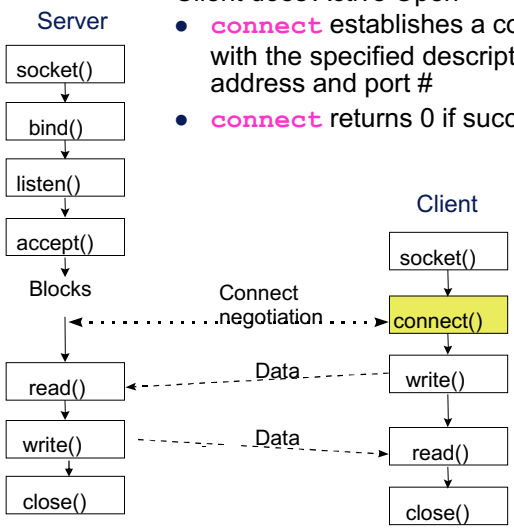
Socket Calls for Connection-Oriented Mode (TCP)



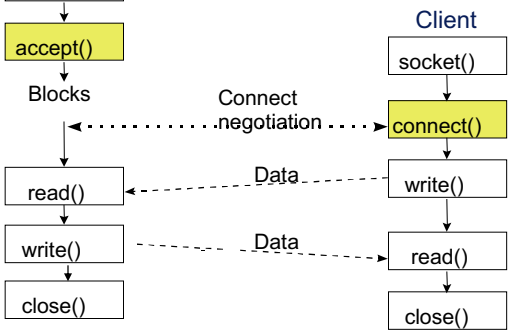
Client does Active Open

- `connect` establishes a connection on the local socket with the specified descriptor to the specified remote address and port #
- `connect` returns 0 if successful; -1 if unsuccessful

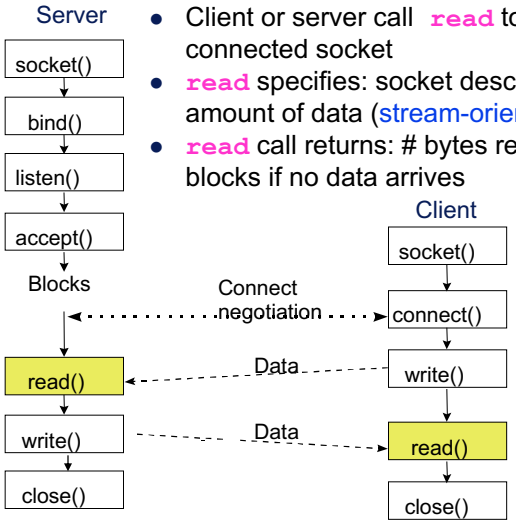
Note: `connect` initiates TCP three-way handshake

Socket Calls for Connection-Oriented Mode (TCP)

- `accept` wakes with incoming connection request
- `accept` fills client address & port # into address structure
- `accept` call returns: *descriptor of **new** connection socket* (success); or -1 (failure)
- Server uses new socket for data transfer from/to client
- Original socket continues to listen for new requests



Socket Calls for Connection-Oriented Mode (TCP)

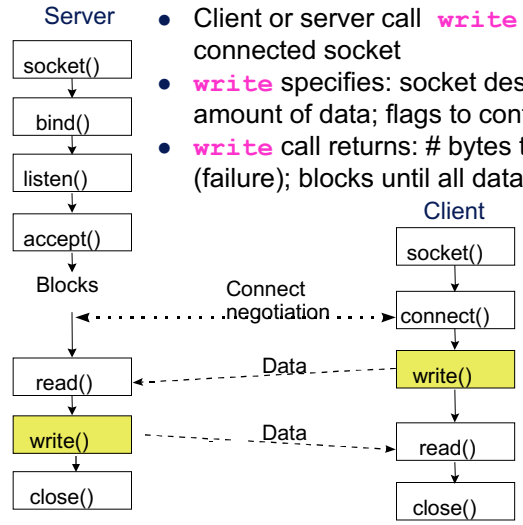


Data Transfer

- Client or server call `read` to receive data from a connected socket
- `read` specifies: socket descriptor; pointer to a buffer; amount of data (stream-oriented -> repeated reads)
- `read` call returns: # bytes read (success); or -1 (failure); blocks if no data arrives

Note: `write` and `read` can be called multiple times to transfer byte streams in both directions

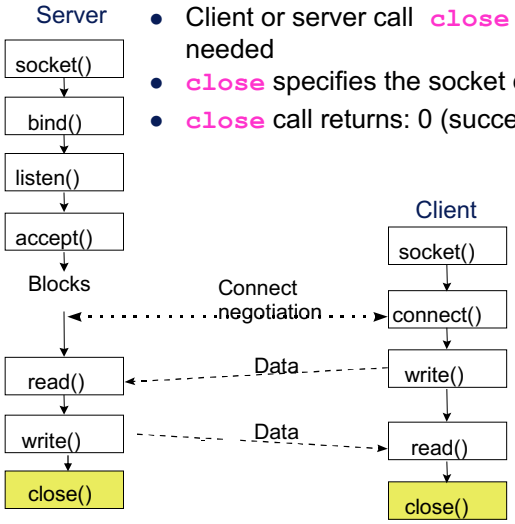
Socket Calls for Connection-Oriented Mode (TCP)



Data Transfer

- Client or server call `write` to transmit data into a connected socket
- `write` specifies: socket descriptor; pointer to a buffer; amount of data; flags to control transmission behavior
- `write` call returns: # bytes transferred (success); or -1 (failure); blocks until all data transferred

Socket Calls for Connection-Oriented Mode (TCP)



Connection Termination

- Client or server call `close` when socket is no longer needed
- `close` specifies the socket descriptor
- `close` call returns: 0 (success); or -1 (failure)

Note: `close` initiates TCP graceful close sequence

TCP Server: Socket Establishment

```
int establish (unsigned short portnum)
{ char   myname[MAXHOSTNAME+1];
  int   s;
  struct sockaddr_in sa;
  struct hostent *hp;

  memset (&sa, 0, sizeof(struct sockaddr_in));          /* clear our address */
  gethostname (myname, MAXHOSTNAME);                    /* who are we? */
  hp= gethostbyname (myname);                           /* get our address info */
  if (hp == NULL)                                       /* we don't exist !? */
            return(-1);
  sa.sin_family= hp->h_addrtype;                        /* this is our host address */
  sa.sin_port= htons (portnum);                         /* this is our port number */
  if ((s= socket (AF_INET, SOCK_STREAM, 0)) < 0) /* create socket */
            return(-1);
  if (bind (s, (struct sockaddr *)&sa,sizeof (struct sockaddr_in)) < 0) {
            close(s);
            return(-1);                                 /* bind address to socket */
  }
  listen (s, 3);                                /* max # of queued connects */
  return (s);
  }
```

TCP Server: Connection Accept

```
/* wait for a connection to occur on a socket created with establish() */
int get_connection (int s)
{
  int t; /* socket of connection */

  if ((t = accept (s,NULL,NULL)) < 0) /* accept connection if there is one */
        return(-1);
  return(t);
}
```


TCP Client: Socket Establishment and Connection

```
int call_socket (char *hostname, unsigned short portnum)          // how to call a server socket
{ struct sockaddr_in sa;
  struct hostent *hp;
  int a, s;

  if ((hp = gethostbyname (hostname)) == NULL) { /* do we know the host's */
        errno= ECONNREFUSED; /* address? */
        return(-1); /* no */
  }
  memset (&sa,0,sizeof(sa));                                      /* clear our address */
  memcpy ((char *)&sa.sin_addr, hp->h_addr, hp->h_length);        /* set address */
  sa.sin_family= hp->h_addrtype;
  sa.sin_port= htons ((u_short) portnum);                 // host byte order to network byte order
                                                                  // ntohl() vice versa; important!
  if ((s= socket(hp->h_addrtype,SOCK_STREAM,0)) < 0)              /* get socket */
        return(-1);
  if (connect (s, (struct sockaddr *)&sa, sizeof sa) < 0) {       /* connect (dialing) */
        close(s);
        return(-1);
  }
  return(s);
}
```

TCP Server: Multiple Connections

```
#include <errno.h>                  // you may still accept calls while processing previous connections.
#include <stdio.h>                  // For this reason you usually fork off child jobs to handle each connection.
#include <signal.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/wait.h>
#include <netinet/in.h>
#include <netdb.h>

PORTNUM 50000 /* random port number, we need something */
void fireman(void);
void do_something(int);

main()
{int s, t;
 if ((s= establish (PORTNUM)) < 0) { /* plug in the phone */
            perror("establish");
            exit(1);
 }
            /* as children die we should catch their returns or else we get zombies, A Bad Thing.
            fireman() catches falling children. */
signal (SIGCHLD, fireman);  /* this eliminates zombies */
```


TCP Server: Multiple Connections (cont.)

```
for (;;) { /* loop for phone calls */
            if ((t= get_connection (s)) < 0) {      /* get a connection */
                        if (errno == EINTR) /* EINTR might happen on accept(), */
                                    continue;       /* try again */
                        perror("accept");           /* bad */
                        exit(1);
            }
            switch (fork()) { /* try to handle connection */
                        case -1 : /* bad news. scream and die */
                                    perror("fork");
                                    close(s); close(t); exit(1);
                        case 0 : /* we're the child, do something */
                                    close(s);
                                    do_something(t);
                                    exit(0);
                        default : /* we're the parent so look for */
                                    close(t);       /* another connection */
                                    continue;
                        }
            }
 }          /* main() ends */
void fireman(void) { while (waitpid(-1, NULL, WNOHANG) > 0) ; }
/* this is the function that plays with the socket. it will be called after getting a connection. */
 void do_something(int s) { /* do your thing with the socket here : : */ }
```

How to Talk between Sockets

```
int read_data (int s,           /* connected socket */
               char *buf,       /* pointer to the buffer */
               int n)           /* number of characters (bytes) we want */

{ int bcount;          /* counts bytes read */
  int br;              /* bytes read this pass */

                       // you don't usually get back the same number of characters that you asked for,
                       // so you must loop until you have read the number of characters that you want.
  bcount= 0;
  br= 0;
  while (bcount < n) { /* loop until full buffer due to stream-oriented communication */
          if ((br = read (s, buf, n - bcount)) > 0) {
                  bcount += br;        /* increment byte counter */
                  buf += br;           /* move buffer ptr for next read */
          }
          else if (br < 0) /* signal an error to the caller */
                  return(-1);
 }
 return (bcount);
}
```


Socket Programming Example: Internet File Server (P.490-1)

Client code using sockets.

```
/* This page contains a client program that can request a file from the server program
 * on the next page. The server responds by sending the whole file.
 */

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

#define SERVER_PORT 12345               /* arbitrary, but client & server must agree */
#define BUF_SIZE 4096                   /* block transfer size */

int main(int argc, char *argv)
{
  int c, s, bytes;
  char buf[BUF_SIZE];                   /* buffer for incoming file */
  struct hostent *h;                    /* info about server */
  struct sockaddr_in channel;           /* holds IP address */

  if (argc != 3) fatal("Usage: client server-name file-name");
  h = gethostbyname(argv[1]);           /* look up host's IP address */
  if (!h) fatal("gethostbyname failed");

  s = socket(PF_INET, SOCK_STREAM, IPPROTO_TCP);
  if (s <0) fatal("socket");
  memset(&channel, 0, sizeof(channel));
  channel.sin_family= AF_INET;
  memcpy(&channel.sin_addr.s_addr, h->h_addr, h->h_length);
  channel.sin_port= htons(SERVER_PORT);

  c = connect(s, (struct sockaddr *) &channel, sizeof(channel));
  if (c < 0) fatal("connect failed");

  /* Connection is now established. Send file name including 0 byte at end. */
  write(s, argv[2], strlen(argv[2])+1);

  /* Go get the file and write it to standard output. */
  while (1) {
      bytes = read(s, buf, BUF_SIZE);   /* read from socket */
      if (bytes <= 0) exit(0);          /* check for end of file */
      write(1, buf, bytes);             /* write to standard output */
  }
}

fatal(char *string)
{
  printf("%s\n", string);
  exit(1);
}
```

Socket Programming Example: Internet File Server (2)

```
#include <sys/types.h>                  /* This is the server code */
#include <sys/fcntl.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#define SERVER_PORT 12345               /* arbitrary, but client & server must agree */
#define BUF_SIZE 4096                   /* block transfer size */
#define QUEUE_SIZE 10
int main(int argc, char *argv[])
{
  int s, b, l, fd, sa, bytes, on = 1;
  char buf[BUF_SIZE];                   /* buffer for outgoing file */
  struct sockaddr_in channel;           /* hold's IP address */

  /* Build address structure to bind to socket. */
  memset(&channel, 0, sizeof(channel));  /* zero channel */
  channel.sin_family = AF_INET;
  channel.sin_addr.s_addr = htonl(INADDR_ANY);
  channel.sin_port = htons(SERVER_PORT);

  /* Passive open. Wait for connection. */
  s = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);   /* create socket */
  if (s < 0) fatal("socket failed");
  setsockopt(s, SOL_SOCKET, SO_REUSEADDR, (char *) &on, sizeof(on));

  b = bind(s, (struct sockaddr *) &channel, sizeof(channel));
  if (b < 0) fatal("bind failed");

  l = listen(s, QUEUE_SIZE);            /* specify queue size */
  if (l < 0) fatal("listen failed");

  /* Socket is now set up and bound. Wait for connection and process it. */
  while (1) {
      sa = accept(s, 0, 0);             /* block for connection request */
      if (sa < 0) fatal("accept failed");

      read(sa, buf, BUF_SIZE);          /* read file name from socket */

      /* Get and return the file. */
      fd = open(buf, O_RDONLY);         /* open the file to be sent back */
      if (fd < 0) fatal("open failed");

      while (1) {
          bytes = read(fd, buf, BUF_SIZE); /* read from file */
          if (bytes <= 0) break;        /* check for end of file */
          write(sa, buf, bytes);        /* write bytes to socket */
      }
      close(fd);                        /* close file */
      close(sa);                        /* close connection */
  }
}
```

Server code using sockets.

Summary

- **Very widely used primitives started with TCP on UNIX**
  - **Notion of "sockets" as transport endpoints**
  - **Like simple set plus SOCKET, BIND, and ACCEPT**

Primitive	Meaning
SOCKET	Create a new communication end point
BIND	Associate a local address with a socket
LISTEN	Announce willingness to accept connections; give queue size
ACCEPT	Passively establish an incoming connection
CONNECT	Actively attempt to establish a connection
SEND	Send some data over the connection
RECEIVE	Receive some data from the connection
CLOSE	Release the connection

Where to get more information

- UNIX Network Programming, W. Richard Stevens, Prentice Hall.
- BSD manual: http://www.freebsd.org/
- http://java.sun.com