Topic 5: Sockets*

Cross-host Interprocess Communication (IPC)

- We've seen (or will see) IPC on the same machine via
  - files
  - signals
  - pipes,
  - shared memory
  - ...
- What happens if a computer network lies between the processes?

Cross-host Interprocess Communication (IPC)

- Typically client-server model over network
- Server – provides a service
- Server – waits for client to connect
- Clients – connect to utilize the service
- Clients – possibly more than one at a time

Some networked applications/services

- E-mail
- Web
- Instant messaging
- Remote login
- P2P file sharing
- Multi-user network games
- Streaming stored video clips
- Internet telephone
- Real-time video conference
- Massive parallel computing
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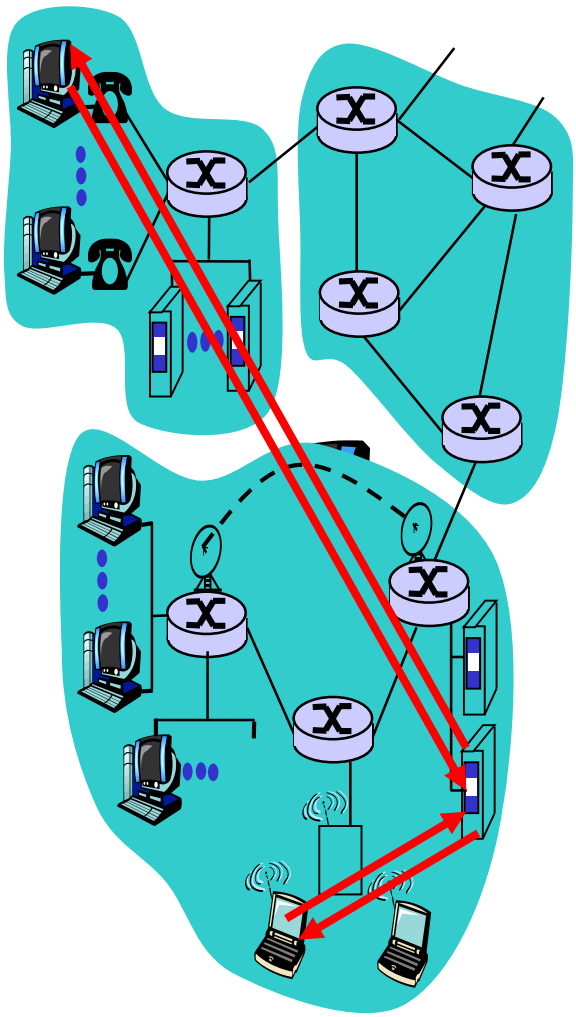
Communication Models

- Client-server
- Peer-to-peer (P2P)
- Hybrid of client-server and P2P

Client-server architecture



server:

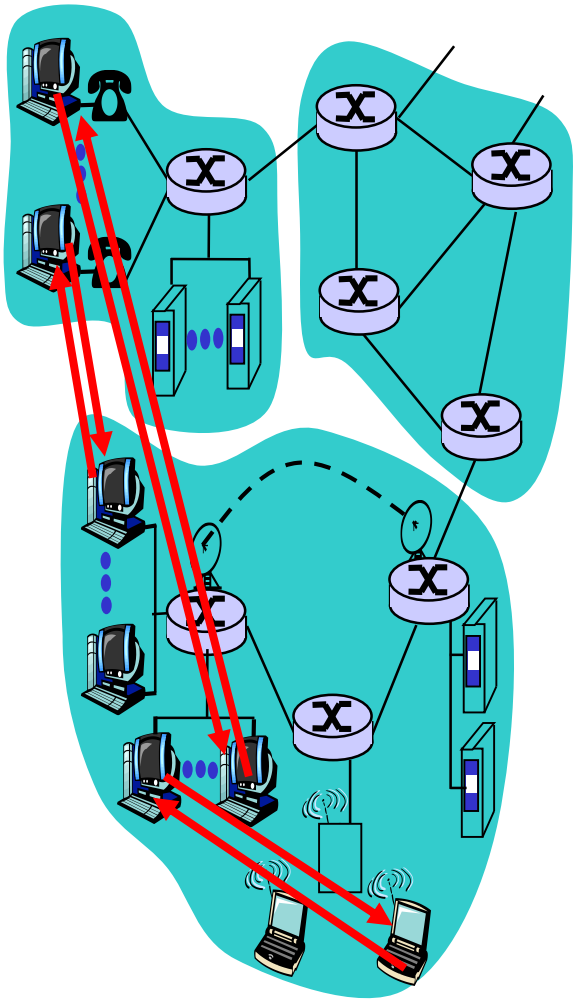
- always-on host
- permanent IP address
- server farms for scaling

clients:

- communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do not communicate directly with each other

Pure P2P architecture

- no always-on server
- arbitrary end systems directly communicate
- each node (peer) acts as both a server and a client
- peers are intermittently connected and change IP addresses
- example: Gnutella



Highly scalable but difficult to manage

Hybrid of client-server and P2P

Skype

- Internet telephony app
- Finding address of remote party: centralized server(s)
- Client-client connection is direct (not through server)

Instant messaging

- Chatting between two users is P2P
- Presence detection/location centralized:
  - User registers IP address with central server when she goes online
  - User contacts central server to find IP addresses of buddies

The Internet Protocol

- Each device in a network is assigned an IP address
- IPv4 32 bit, IPv6 128 bit
  - IPv4 (in decimal)

    69.89.31.226 ← 4 octets
  - IPv6 (in hex)

    2001:0db8:0a0b:12f0:0000:0000:0000:0001
    ← 8 16 bit blocks
- Each device may host many services
- Accessing a service requires an (IP, port) pair
- Services you know of: ssh (port 22), http (port 80), DNS (port 53), DHCP (ports 67,68)

Common service use cases

- Browse the World Wide Web
  - Each web server has a static IP
  - DNS used to translate www.google.com to 216.58.213.4
  - Contact service at 216.58.213.4 and port 80 (http)

Common service use cases

- Your home network
  - You turn on your modem. It gets a public IP address from your ISP (e.g., 79.166.80.131)
  - Your modem runs a DHCP server giving IPs in 192.168.x.y
  - Your modem acts as an Internet gateway. Translates IPs from 192.168.x.y to 79.166.80.131. (NAT box, IP Masquerade)
  - What if you need to set up a service running inside your 192.168.x.y network available to the internet? Do port forwarding.

Processes communicating

Process: program running within a host.

- within same host, two processes communicate using inter-process communication (defined by OS).
- processes in different hosts communicate by exchanging messages

Client process: process that initiates communication

Server process: process that waits to be contacted

- Note: applications with P2P architectures have client processes & server processes

Application protocol defines

- Types of messages exchanged,
  - e.g., request, response
- Message syntax:
  - what fields in messages & how fields are delineated
- Message semantics
  - meaning of information in fields
- Rules for when and how processes send & respond to messages

Public-domain protocols:

- defined in RFCs
- allows for interoperability
- e.g., HTTP, SMTP

Proprietary protocols:

- e.g., Skype, KaZaA, etc.

Transport Services Offered by OS

- OS deals with host to host data transfer
  - Did the data get there?
  - What to do when the data gets there?
- Supplies the application layer with a socket API (connect, send, receive)
- When data arrives at a host from the net, OS determines which application process is to receive the data (via socket)
- Applications typically use one of
  - Transmission Control Protocol (TCP)
  - User Datagram Protocol (UDP)

What transport service does an application need?

Data loss

- some apps (e.g., audio) can tolerate some loss
- other apps (e.g., file transfer, telnet) require 100% reliable data transfer

Timing

- some apps (e.g., Internet telephony, interactive games) require low delay to be "effective"

Bandwidth

- some apps (e.g., multimedia) require minimum amount of bandwidth to be "effective"
- other apps ("elastic apps") make use of whatever bandwidth they get

OS Transport Services (TCP and UDP)

TCP service:

- *connection-oriented:* setup required between client and server processes
- *reliable transport* between sending and receiving process
- *flow control:* sender won't overwhelm receiver
- *congestion control:* throttle sender when network overloaded
- *does not provide:* timing, minimum bandwidth guarantees

UDP service:

- unreliable data transfer between sending and receiving process
- does not provide: connection setup, reliability, flow control, congestion control, timing, or bandwidth guarantee

Q: why bother? Why is there a UDP?

TCP versus UDP

Applications using TCP:

- HTTP (WWW), FTP (file transfer), Telnet/SSH (remote login), SMTP (email)

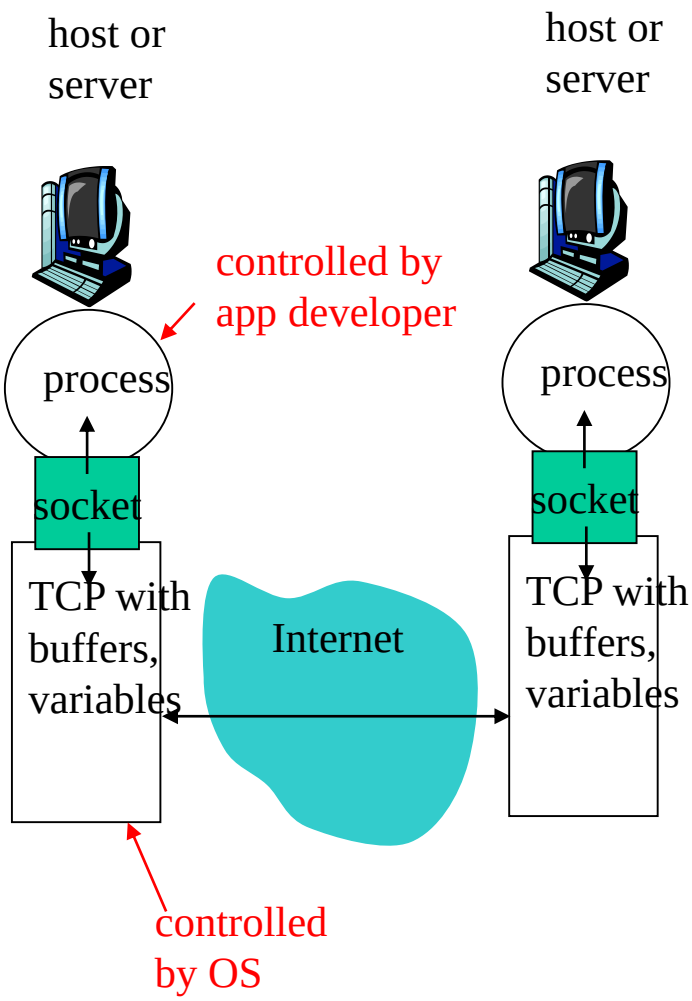
Applications using UDP:

- streaming media, teleconferencing, DNS, Internet telephony

How would you choose between TCP and UDP?

Sockets (Υποδοχές)

- process sends/receives messages to/from its socket
- socket analogous to door
  - sending process shoves message out door
  - sending process relies on transport infrastructure on other side of door which brings message to socket at receiving process



- API: (1) choice of transport service OS will use; (2) ability to fix a few parameters

Addressing processes

- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- Q: does IP address of host on which process runs suffice for identifying the process?

Addressing processes

- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- Q: does IP address of host on which process runs suffice for identifying the process?
  - Answer: NO, many processes can be running on same host

- *identifier* includes both IP address and port numbers associated with process on host.
- Example port numbers:
  - HTTP server: 80
  - Mail server: 25
- to send HTTP message to www.di.uoa.gr web server:
  - IP address: 147.52.17.2
  - Port number: 80

Socket programming

Goal: learn how to build client/server application programs that communicate using sockets

Socket API

- introduced in BSD4.1 UNIX, 1981
- explicitly created, used, released by applications
- client/server paradigm
- two types of transport service via socket API:
  - unreliable datagram (UDP)
  - reliable, byte stream-oriented (TCP)

socket

a *host-local*, *application-created*, *OS-controlled* interface (a "door") into which application process can both send and receive messages to/from another application process

More on sockets

- A socket is a communication endpoint
- Processes refer to a socket using an integer (file) descriptor
- Communication domain
  - Internet domain (over internet)
  - Unix domain (same host)
- Communication type
  - Stream (usually TCP)
  - Datagram (usually UDP)

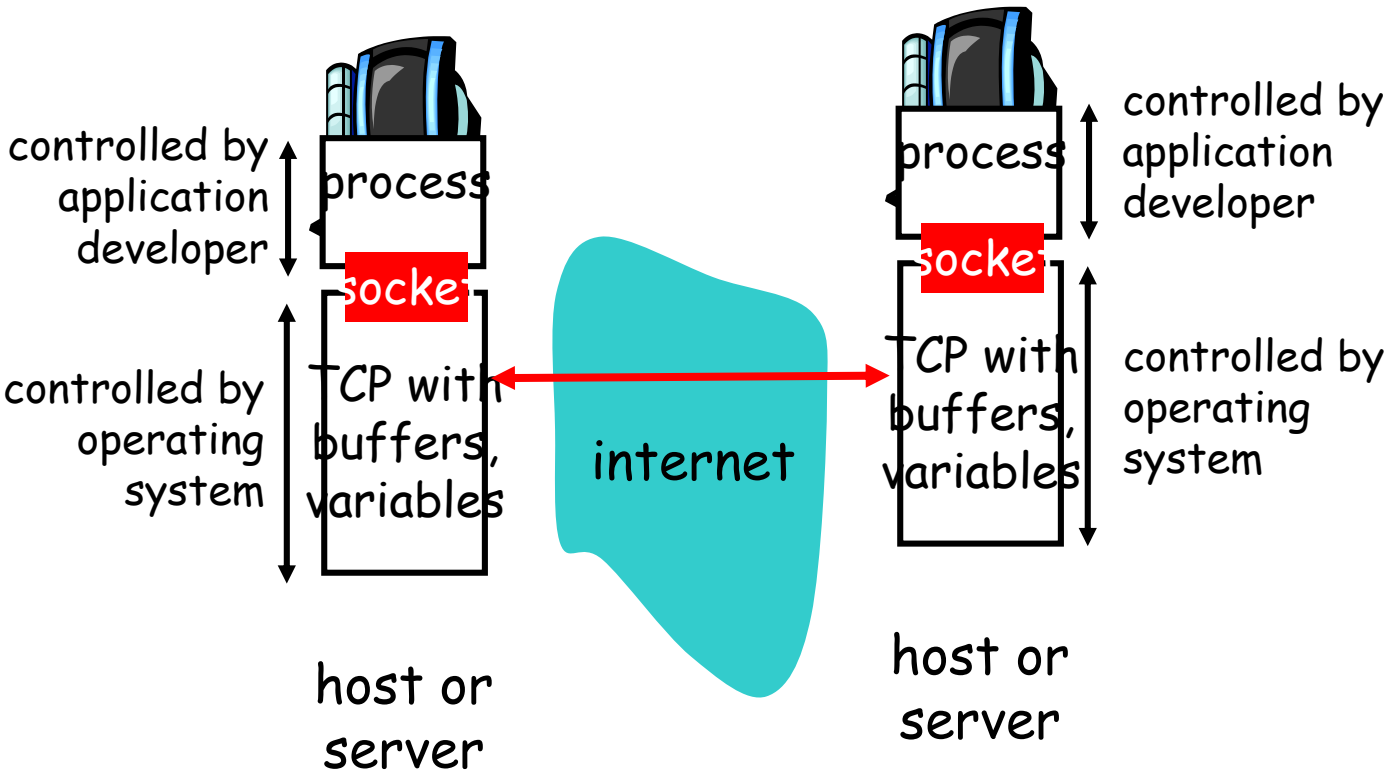
TCP versus UDP

	TCP	UDP
CONNECTION REQUIRED	YES	NO
RELIABILITY	YES	NO
MESSAGE BOUNDARIES	NO	YES
IN-ORDER DATA DELIVERY	YES	NO
SOCKET TYPE	SOCK_STREAM	SOCK_DGRAM

Socket-programming using TCP

Socket: a door between application process and end-end-transport protocol (UDP or TCP)

TCP service: reliable transfer of **bytes** from one process to another



Socket programming with TCP

Client must contact server

- server process must first be running
- server must have created socket (door) that welcomes client's contact

Client contacts server by:

- creating client-local TCP socket
- specifying IP address, port number of server process
- When client creates socket: client TCP establishes connection to server TCP

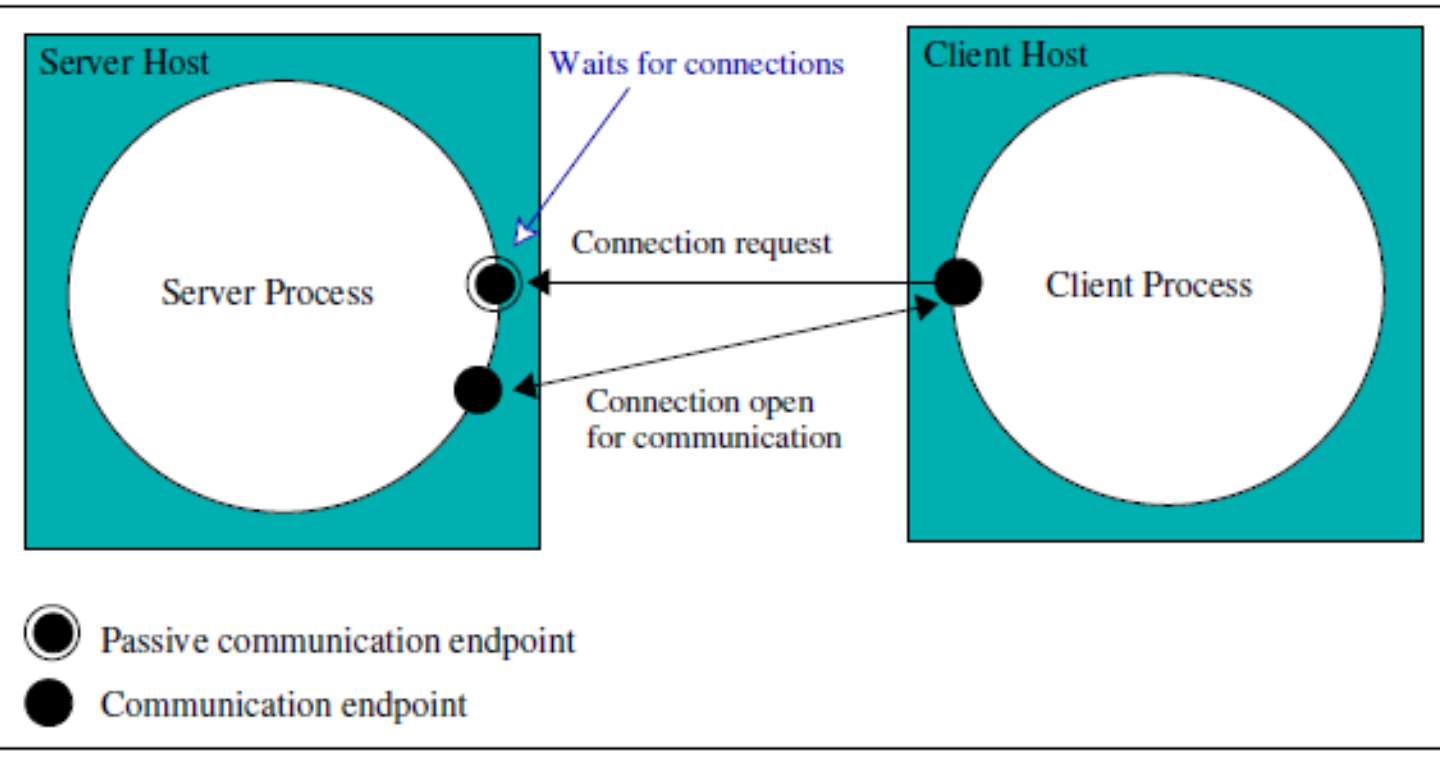
- When contacted by client, server TCP creates new socket for server process to communicate with client
  - allows server to talk with multiple clients
  - source port numbers used to distinguish clients

application viewpoint

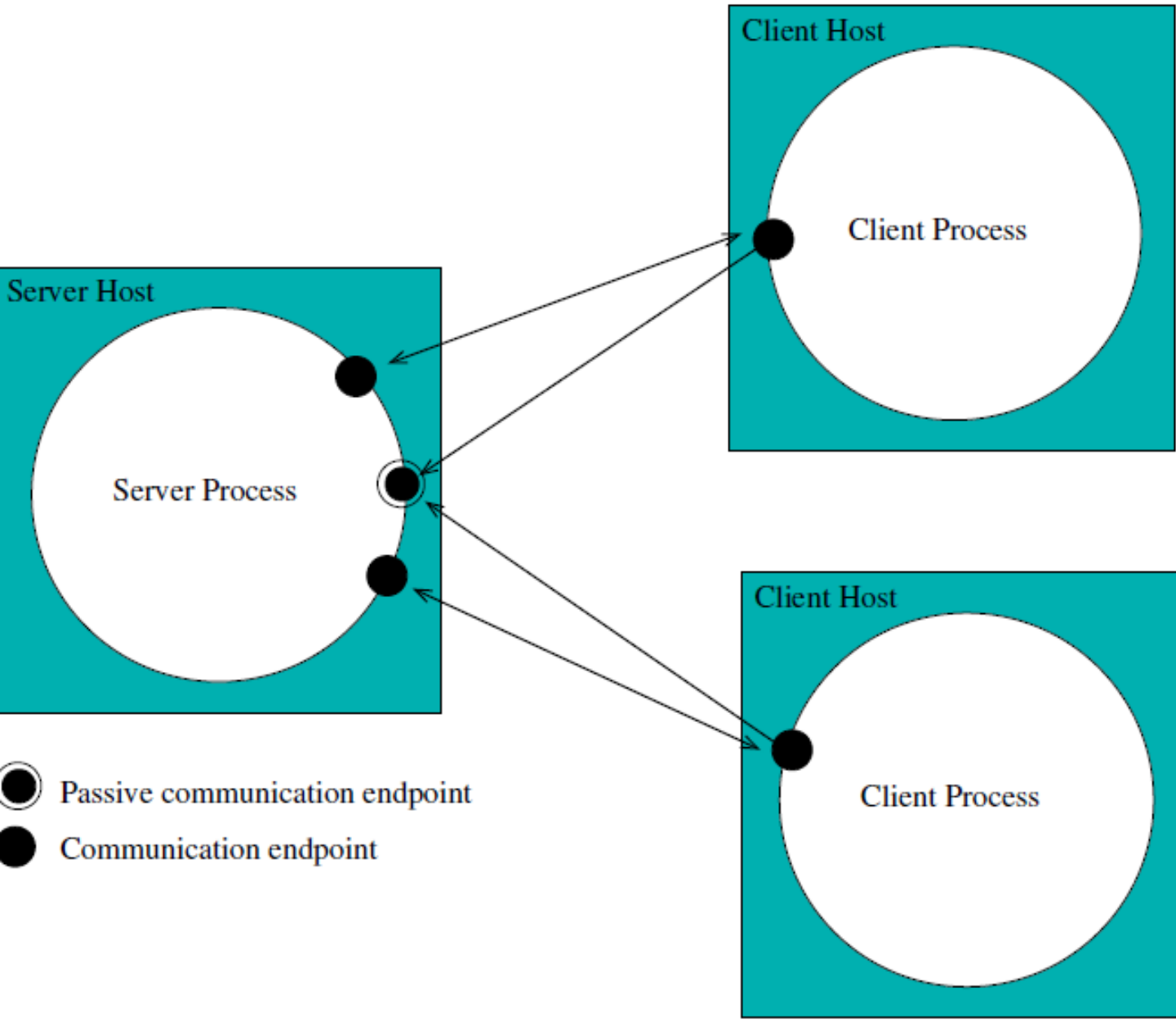
TCP provides reliable, in-order transfer of bytes ("pipe") between client and server

More on TCP

- TCP uses acknowledgements
- Non-acknowledged messages are retransmitted
- Messages re-ordered by the receiver's OS network stack
- Application thus sees a properly ordered *data stream*



TCP – multiple clients



Serial server (TCP)

```
for (;;) {
  wait for a client request on the listening file descriptor
  create a private two-way communication channel to the clie
  while (no error on the private communication channel)
        read from the client
        process the request
        respond to the client
   close the file descriptor for the private communication channel
}
```

ALWAYS

DRAWBACKS?

Serial server (TCP)

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for (;;) {
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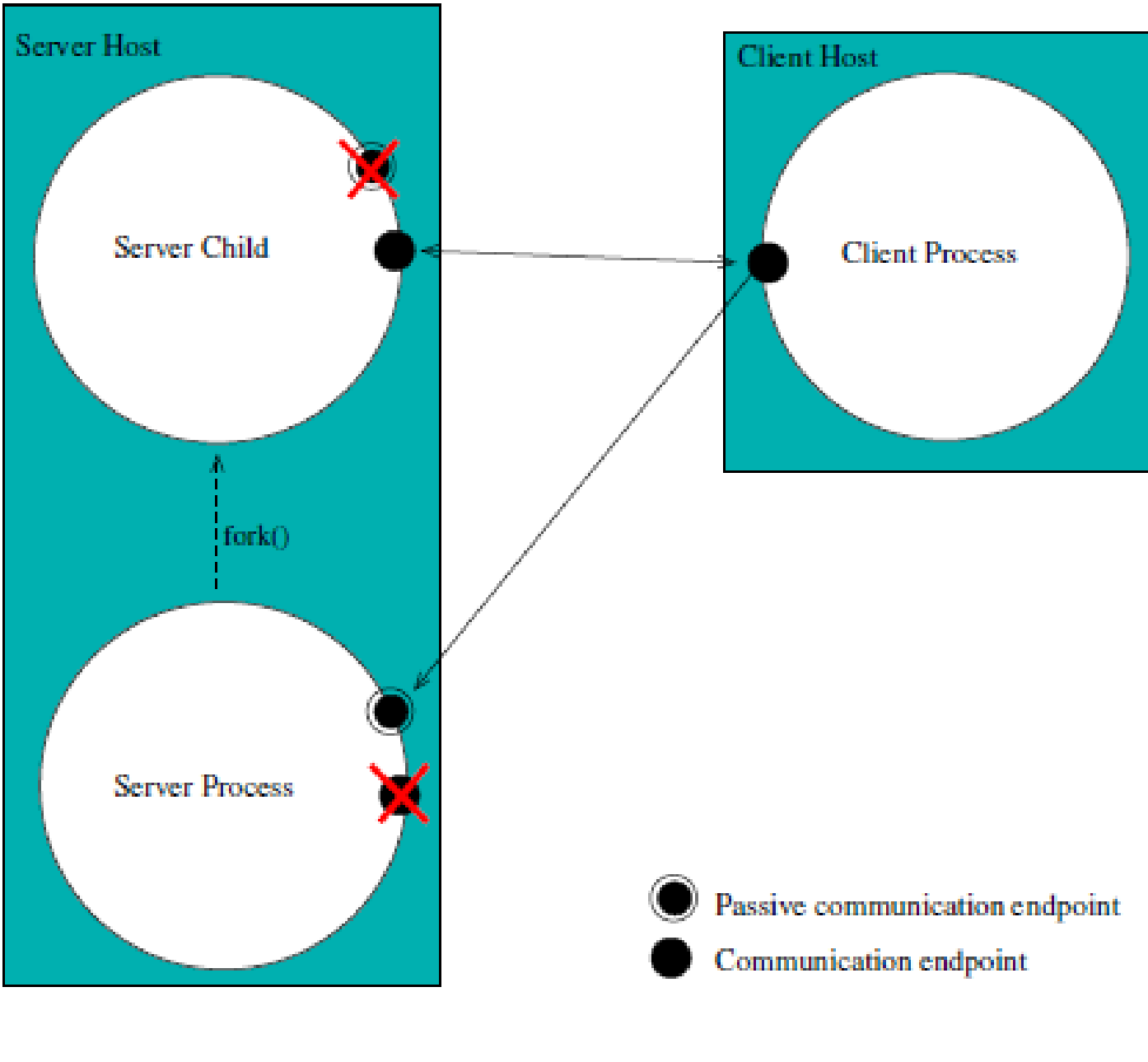
        read from the client
        process the request
        respond to the client
   close the file descriptor for the private communication channel
}
```

ALWAYS

DRAWBACKS

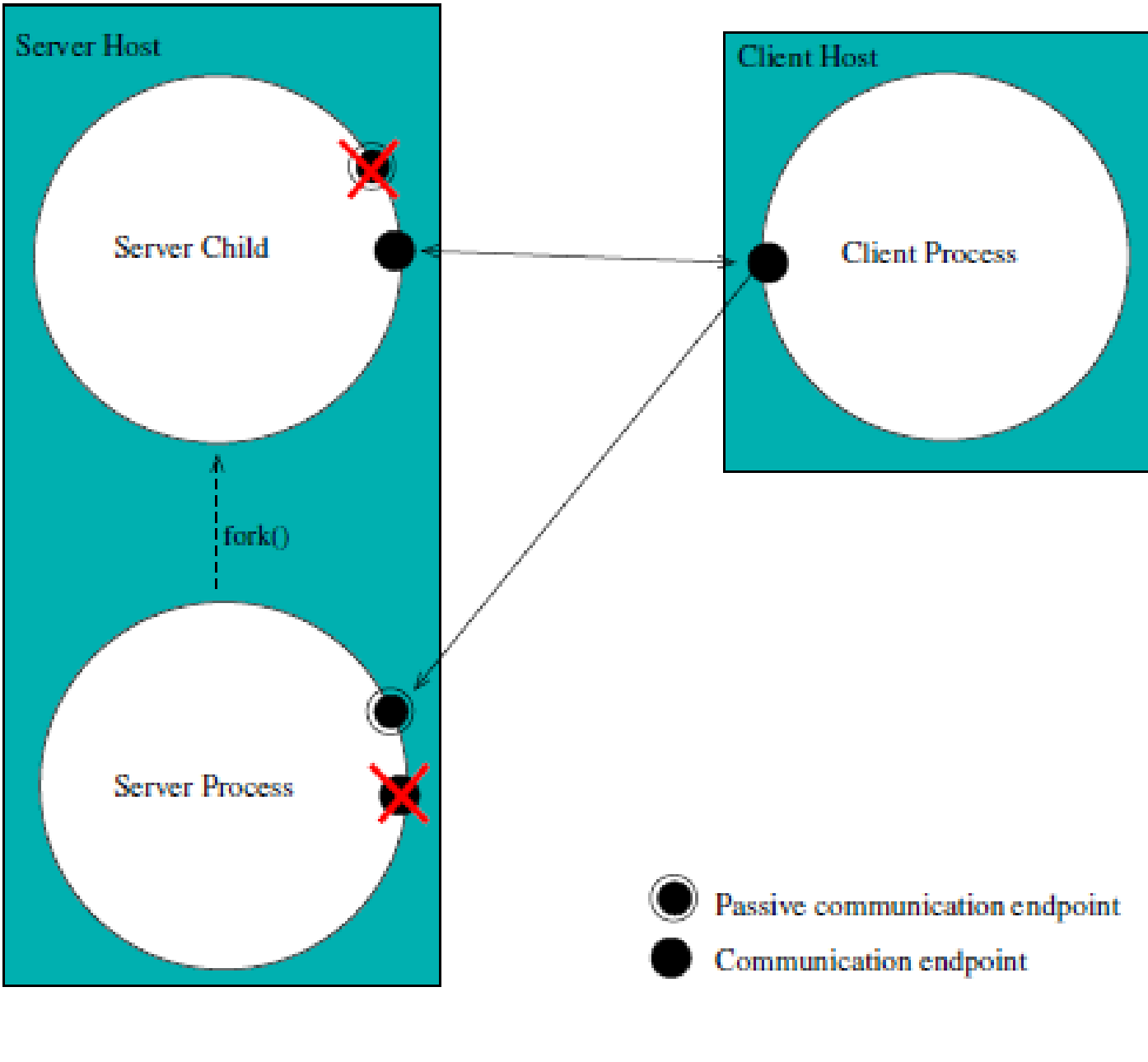
1) Serves only one client at a time
2) Other clients are forced to wait or even fail

1 process per client model



- New process forked for each client
- Multiple clients served at the same time
- Drawbacks?

1 process per client model



- New process forked for each client
- Multiple clients served at the same time
- Inefficient, too many clients → too many processes

1 process per client model

Parent process

for (;;) {
  wait for a client request on the listening file descriptor
  create a private two-way communication channel to the client
  fork a child to handle the client
  close the file descriptor for the private communication channel
  clean up zombie children
}

ALWAYS

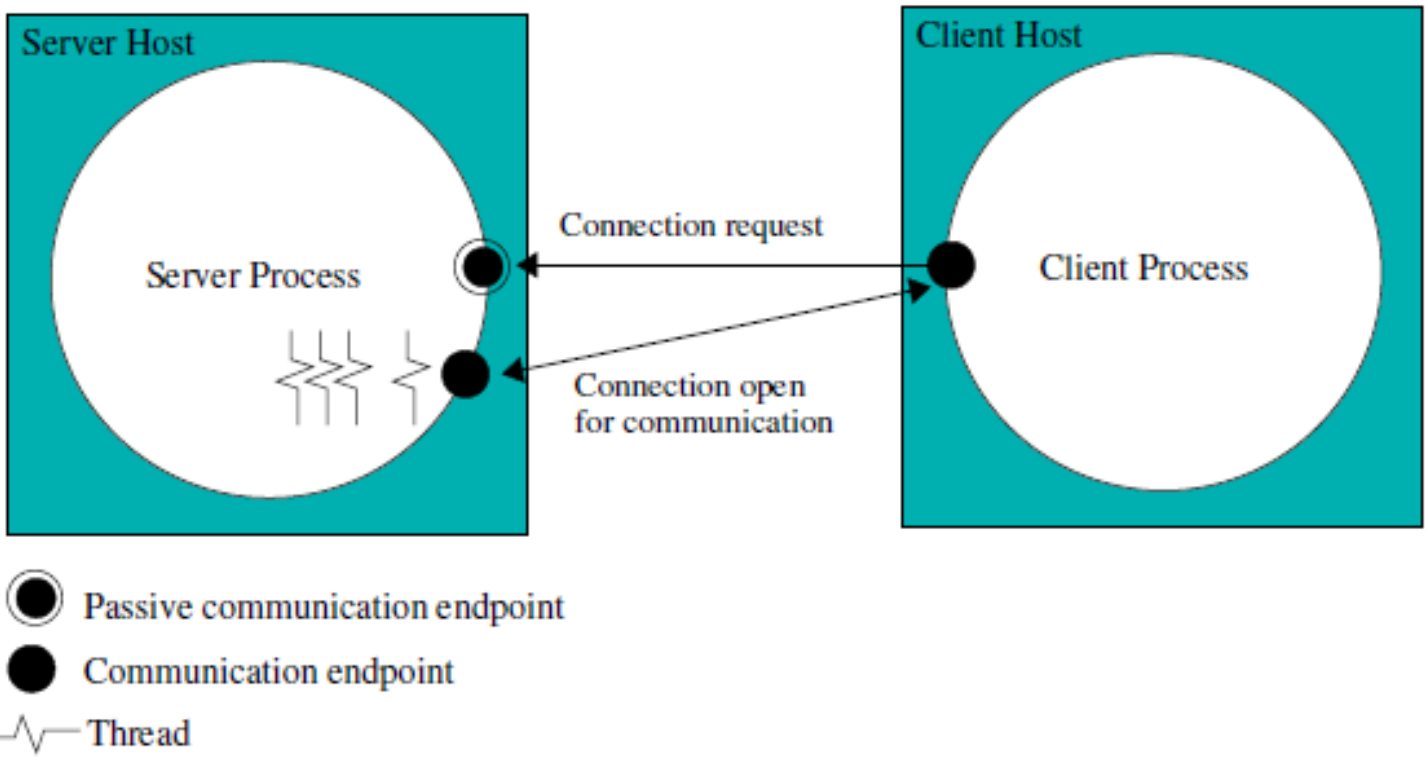
Child process

close the listening file descriptor
handle the client
close the communication for the private channel
exit

Why should parent process close file descriptor for the private channel?

- Avoids risk of running about of file descriptors
- Enables the destruction of the channel once the other two parties (child & client) close their file descriptors
- Enables the child process to receive EOF after the client closes its end of the channel (and vice versa)

Multithreaded server model



- Create a new thread for each client
- Multiple threads handle multiple clients concurrently
- Drawback: requires thread synchronization for access to shared resources

Dealing with byte order

•Ένας ακέραιος με δεκαεξαδική αναπαράσταση 0xD04C σε little-endian αρχιτεκτονική θα ερμηνευτεί ως 0x4CD0 σε big-endian host.
(π.χ., SUN (big-endian) vs Intel (little-endian))

•Η αποστολή δυαδικών αριθμών πρέπει να γίνεται με κάποια προσυμφωνημένη δικτυακή διάταξη (Network Byte Order)

•Συναρτήσεις βιβλιοθήκης htons, htonl, ntohs, και ntohl
unsigned short htons(unsigned short hostshort)
unsigned long htonl(unsigned long hostlong)
unsigned short ntohs(unsigned short netshort)
unsigned long ntohl(unsigned long netlong)

•Μετατροπή ακολουθίας bytes από διάταξη «μηχανής» σε διάταξη «δικτύου» και αντίστροφα για short και long ακεραίους

•Απαιτήσεις
#include <sys/types.h>
#include <netinet/in.h>

Example (ByteOrder)

```
# include <stdio.h>
# include <arpa/inet.h>
int main() {
uint16_t nhost = 0xD04C, nnetwork;
unsigned char *p;
p =(unsigned char *) &nhost;
printf( "%x %x \n", *p , *( p +1) ) ;
/* 16 - bit number from host to network
byte order */
nnetwork = htons(nhost);
p =(unsigned char *) &nnetwork ;
printf (" %x %x \n " , *p , *(p +1) ) ;
exit (1) ;
}
```

- **Output on an Intel-based (Little-Endian) machine:**

```
mema@bowser>  ./ByteOrder
4c d0
d0 4c
mema@bowser>
```

- **Output on a Sparc (Big-Endian/Network Byte Order) machine:**

```
mema@pubsrv1> . /ByteOrder
d0 4c
d0 4c
mema@pubsrv1>
```

From *Domain Names* to *Addresses* and back

- Συναρτήσεις βιβλιοθήκης gethostbyname και gethostbyaddr

```
struct hostent *gethostbyname(char *name)
struct hostent *gethostbyaddr(char *addr,
                              int len, int type)
```

- Η gethostbyname βρίσκει τη διεύθυνση IP που αντιστοιχεί στο όνομα name.
- Η gethostbyaddr μετατρέπει μια διεύθυνση IP addr, με μέγεθος len, και τύπου type (πάντα **AF_INET**), σε όνομα.
- Και οι δυο συναρτήσεις επιστρέφουν έναν δείκτη σε δομή struct hostent ή NULL σε περίπτωση σφάλματος (ορίζει το σφάλμα το h_errno)
- For error reporting, use h_error(char *s) and hstrerror(int err)

- Απαίτηση: #include <netdb.h>

From *Domain Names* to *Addresses* and back

```
struct hostent {
char    *h_name;            /* official name of host */
char    **h_aliases;        /* aliases ( alt . names ) */
int     h_addrtype          /* usually AF_INET */
int     h_length;           /* length of address in bytes*/
char    **h_addr_list ;     /* pointer to array of
                               network addresses */
char   *h_addr             /* first address in h_addr_list
                              for backward compatibility */
};
```

Example: GetHostByName

```
# include < netdb .h >
# include < stdio .h >
# include < stdlib .h >
# include < string .h >
# include < sys / socket .h >
# include < netinet / in .h >
# include < arpa / inet .h >
void main ( int argc , char ** argv ) {
int i =0;
char hostname[50] , symbolicip[50];
struct hostent *mymachine ;
struct in_addr **addr_list ;
if (argc !=2) {printf( "Usage: GetHostByName hostname \n");
                exit (0) ;}
if ( (mymachine = gethostbyname(argv[1])) == NULL)
    printf ("Could not resolve Name : %s \n " , argv[1]) ;
else {
   printf ("Name To Be Resolved : %s \n", mymachine->h_name)
   printf “Name Length in Bytes : %d \n ",
               mymachine->h_length);
    addr_list = (struct in_addr **) mymachine ->h_addr_list;
    for (i = 0; addr_list[ i ] != NULL ; i ++) {
          strcpy ( symbolicip , inet_ntoa (*addr_list [ i ]) ) ;
           printf ( "  %s resolved to %s \n ", mymachine->h_name
                       symbolicip ) ;
           }
     }
}
```

Example: GetHostByName

```
mema@bowser>  ./GetHostByName di.uoa.gr
Name To Be  Resolved: di.uoa.gr
Name Length in Bytes: 4
di.uoa.gr resolved to 195.134.65.123
mema@bowser> ./GetHostByName netflix.com
Name To Be  Resolved: netflix.com
Name Length in Bytes: 4
netflix.com resolved to 54.155.246.232
netflix.com resolved to 54.73.148.110
netflix.com resolved to 18.200.8.190
mema@bowser> ./GetHostByName amazon.com
Name To Be  Resolved: amazon.com
Name Length in Bytes: 4
amazon.com resolved to 205.251.242.103
amazon.com resolved to 54.239.28.85
amazon.com resolved to 52.94.236.248
mema@bowser> ./GetHostByName www.nytimes.com
Name To Be Resolved : www.nytimes.com
Name Length in Bytes : 4
www.nytimes.com resolved to 170.149.161.130
```

Resolving IP addresses

```
# include <netdb .h>
# include <stdio .h>
# include <stdlib .h>
# include <string .h>
# include <sys / socket .h>
# include <netinet /in.h>
# include <arpa / inet .h>
int main(int argc , char * argv []) {
    struct hostent *foundhost ;
    struct in_addr myaddress ;
/*IPv4 dot - number into binary form (network byte order)*/
inet_aton(argv[1], &myaddress);
foundhost = gethostbyaddr((const char *) &myaddress
                                    sizeof(myaddress), AF_INET);
if (foundhost != NULL){
      printf ("IP - address :%s Resolved to: %s\n",
                argv[1], foundhost->h_name );
      exit(0) ;
}
else {
      printf ("IP - address :%s could not be resolved \n",
                 argv[1]) ;
       exit(1) ;
}
}
```

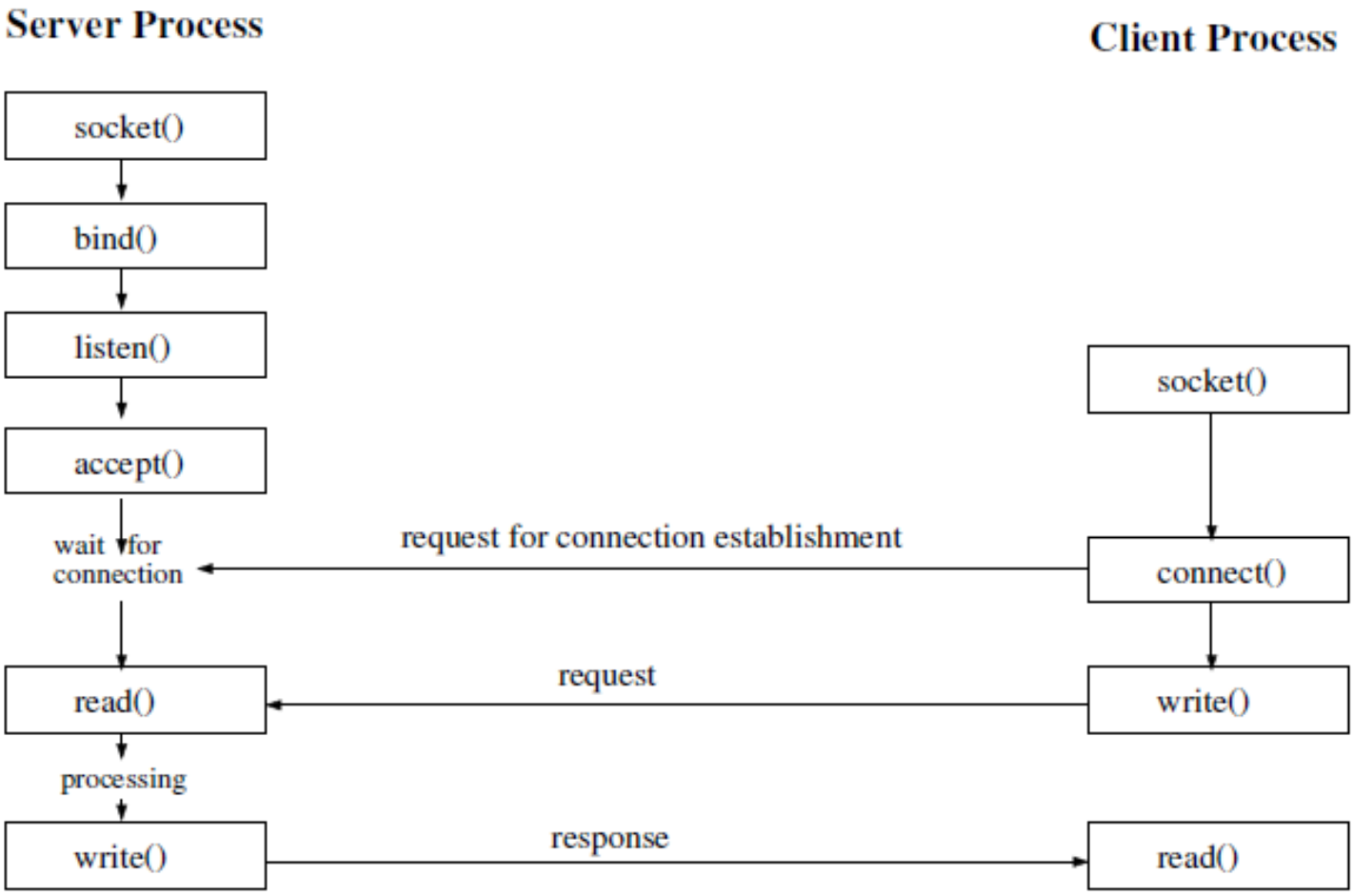
Outcome

```
mema@bowser> ./GetHostByAddress  195.134.65.123
IP-address:195.134.65.123 Resolved to: www.di.uoa.gr
mema@bowser> ./GetHostByAddress 128.10.2.166
IP-address:128.10.2.166 Resolved to: merlin.cs.purdue.ed
mema@bowser>
mema@bowser>./GetHostByAddress 195.134.67.183
IP-address:195.134.67.183 Resolved to: sydney.di.uoa.gr
mema@bowser>
```

- gethostbyname() and gethostbyaddr() are in use in legacy systems
- POSIX.1-2001 suggests instead the use of getnameinfo() and getaddrinfo() respectively

TCP Communication

Create the communication endpoint. Use it as a file descriptor.



socket()

•Όλες οι κλήσεις συστήματος που ακολουθούν και χρησιμοποιούνται για διαχείριση υποδοχών απαιτούν

```
#include <sys/types.h>
#include <sys/socket.h>
```

και επιστρέφουν -1 σε περίπτωση αποτυχίας

•Κλήση συστήματος socket

```
int socket(int domain, int type, int protocol)
```

Δημιουργεί μια υποδοχή και επιστρέφει ένα περιγραφέα αρχείου που αντιστοιχεί σ'αυτην

Το domain πρέπει να είναι AF_INET (παλιά PF_INET)
Το type πρέπει να είναι SOCK_STREAM ή SOCK_DGRAM
Σαν protocol, πάντα δίνουμε το default (0)

```
int sock;
if ((sock = socket(AF_INET, SOCK_STREAM,0)) == -1)
    perror("Failed to create socket");
```

Address Format for Sockets

- An address identifies a socket in a specific communication domain.
  - Internet domain (over internet)
  - Unix domain (same host)
- Addresses with different formats can be passed to the socket programming functions – all casted to the generic sockaddr structure.
- Internet addresses are defined in <netinet/in.h>.

Address Format for Sockets

- In IPv4 Internet domain (AF_INET), a socket address is represented by the sockaddr_in as:

```
#include <netinet/in.h>
struct sockaddr_in {
    sa_family_t sin_family;      /* AF_INET */
    in_port_t sin_port;           /* port number  */
    struct in_addr sin_addr;     /* IPv4 address */
};

struct in_addr {
    in_addr_t s_addr;     /* IPv4 unsigned 32 bit int */
};
```

- in_port_t data type is uint16_t (defined in <stdint.h>)
- in_addr_t data type is uint32_t (defined in <stdint.h>)

Binding sockets to addresses with bind()

- bind requests for an address to be assigned to a socket
- You must bind a SOCK_STREAM socket to a local address before receiving TCP connections
- Need #include<netinet/in.h>
- int bind (int socket, const struct sockaddr *address, socklen_t address_len);
- We pass a sockaddr_in struct as the address that has at least the following members expressed in network byte-order:
  - sin_family: address family is AF_INET in the Internet domain
  - sin_addr.s_addr: address can be a specific IP or INADDR_ANY
  - sin_port: TCP or UDP port number

Socket binding example

```
#include <netinet/in.h> /* for sockaddr_in */
#include <sys/socket.h>
#include <sys/types.h>
#include <arpa/inet.h> /* for hton * */

int bind_on_port ( int sock, short port ) {
    struct sockaddr_in server;
    server.sin_family = AF_INET;
    server.sin_addr.s_addr = htonl (INADDR_ANY);
    server.sin_port = htons(port);
    return bind(sock, (struct sockaddr *) &server,
                    sizeof (server));
}
```

- INADDR ANY is a special address (0.0.0.0) meaning “any address”
- *sock* will receive connections from all addresses of the host machine

listen(), accept()

int listen(int socket, int backlog);

- Listen for connections on a socket
- At most backlog connections will be queued waiting to be accepted

int accept(int socket, struct sockaddr * address, socklen_t * address_len);

- Accepts a connection on a socket
- Blocks until a client connects/gets-interrupted by a signal
- Returns new socket descriptor to communicate with client
- Returns info on client's address through address. Pass NULL if you don't care.
- Value-result address len must be set to the amount of space pointed to by address (or NULL).

connect()

int connect(int socket, struct sockaddr *address, socklen_t address_len);

- When called by a client, a connection is attempted to a listening socket on the server in address. Normally, the server accepts the connection and a communication channel is established.
- If socket is of type SOCK_DGRAM, address specifies the peer with which the socket is to be associated (datagrams are sent/received only to/from this peer via the UDP protocol).

Library functions bzero() and bcopy()

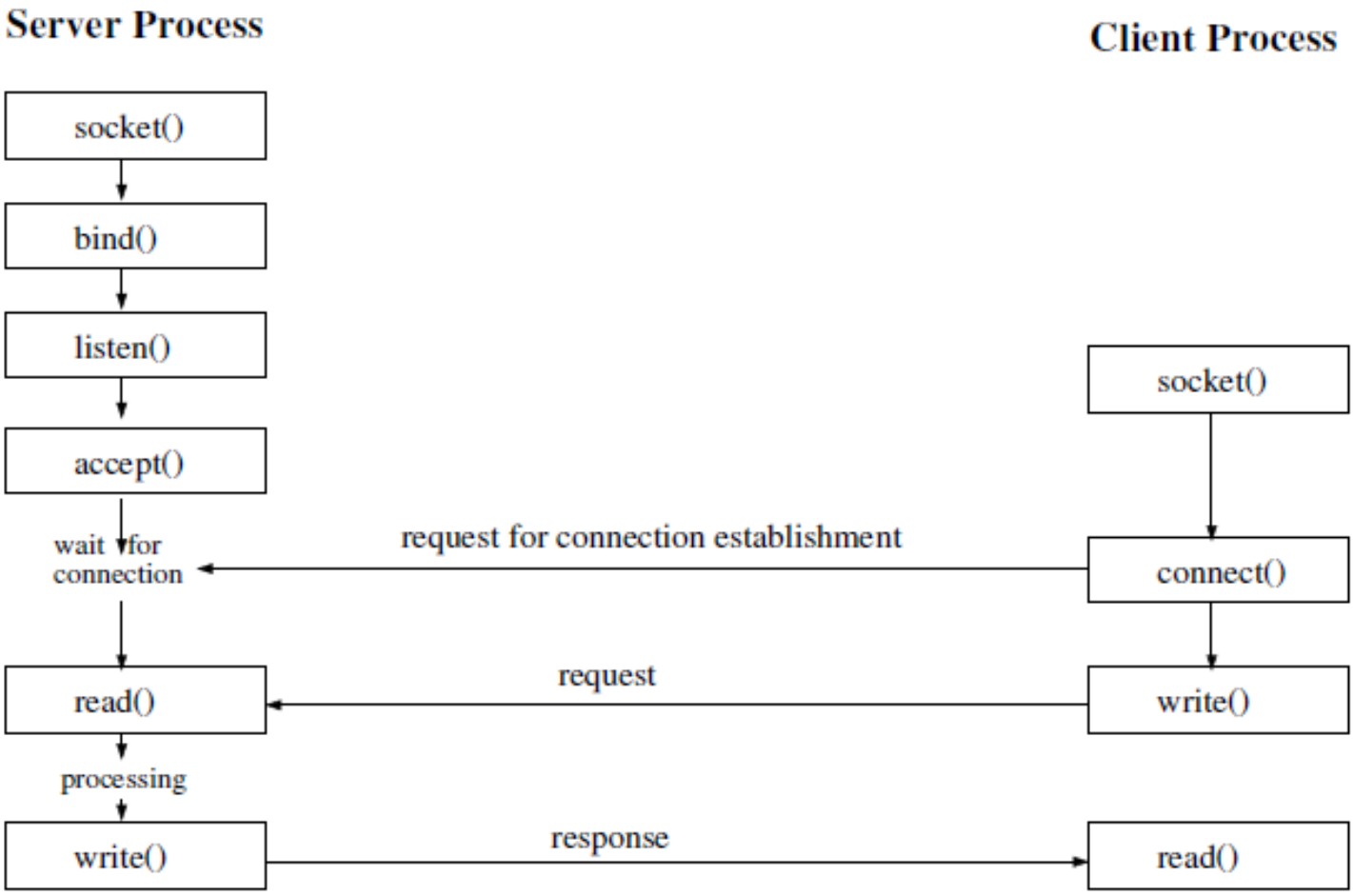
- void bzero(char *buf, int count)
  - Sets *count* bytes to 0 starting at address *buf*
  - Can now use memset instead
- void bcopy(char *buf1, char *buf2, int count)
  - Copies *count* bytes starting from address *buf1* to address *buf2*
  - Opposite of memcpy
- Need #include<string.h>
- In Solaris compile with “-lsocket -lnsl”

Tips and warnings

- If a process attempts to write through a socket that has been closed by the other peer, a SIGPIPE signal is received.
- Since SIGPIPE is by default fatal, install a signal handler to override this.
- When a server quits, the listening port remains busy (state TIME WAIT) for a while
- Restarting the server *fails in bind* with "Bind: Address Already in Use"
  - To override this, use setsockopt() to enable SO_REUSEADDR flag before you call bind().

TCP Communication

Create the communication endpoint. Use it as a file descriptor.



Example (inet_str_server)

- TCP server receives a string and replies with the string capitalized

```
/*inet_str_server.c: Internet stream sockets server */
#include <stdio.h>
#include <sys/wait.h>          /* sockets */
#include <sys/types.h>         /* sockets */
#include <sys/socket.h>        /* sockets */
#include <netinet/in.h>        /* internet sockets */
#include <netdb.h>            /* gethostbyaddr */
#include <unistd.h>           /* fork */
#include <stdlib.h>           /* exit */
#include <ctype.h>            /* toupper */
#include <signal.h>          /* signal */
void child_server(int newsock);
void perror_exit(char *message);
void sigchld_handler (int sig);

void main(int argc, char *argv[]) {
   int              port, sock, newsock;
   struct sockaddr_in server, client;
   socklen_t clientlen;
   struct sockaddr *serverptr=(struct sockaddr *)&server;
   struct sockaddr *clientptr=(struct sockaddr *)&client;
   struct hostent *rem;
   if (argc != 2) {
      printf("Please give port number\n");exit(1);}
   port = atoi(argv[1]);
   /* Reap dead children asynchronously */
   signal(SIGCHLD, sigchld_handler);
```

```
/* Create socket */
  if ((sock = socket(AF_INET, SOCK_STREAM, 0)) < 0)
     perror_exit("socket");
  server.sin_family = AF_INET;  /* Internet domain */
  server.sin_addr.s_addr = htonl(INADDR_ANY);
  server.sin_port = htons(port);      /* The given port */
  /* Bind socket to address */
  if (bind(sock, serverptr, sizeof(server)) < 0)
     perror_exit("bind");
  /* Listen for connections */
  if (listen(sock, 5) < 0) perror_exit("listen");
  printf("Listening for connections to port %d\n", port);
  while (1) {  clientlen = sizeof(client);
     /* accept connection */
    if ((newsock = accept(sock, clientptr, &clientlen))
          < 0) perror_exit("accept");
    /* Find client's name  */
    if ((rem = gethostbyaddr((char *) &client.sin_addr.s_addr,
         sizeof(client.sin_addr.s_addr), client.sin_family))
          == NULL) {
       herror("gethostbyaddr"); exit(1);}
    printf("Accepted connection from %s\n", rem->h_name);
    switch (fork()) {    /* Create child for serving client */
    case -1:     /* Error */
       perror("fork"); break;
    case 0:       /* Child process */
       close(sock); child_server(newsock);
       exit(0);
     }
```

```
close(newsock); /* parent closes socket to client */
    }
}

void child_server(int newsock) {
    char buf[1];
    while(read(newsock, buf, 1) > 0) {  /* Receive 1 char */
        putchar(buf[0]);          /* Print received char */
        /* Capitalize character */
        buf[0] = toupper(buf[0]);
        /* Reply */
        if (write(newsock, buf, 1) < 0)
            perror_exit("write");
    }
    printf("Closing connection.\n");
    close(newsock);       /* Close socket */
}

/* Wait for all dead child processes */
void sigchld_handler(int sig) {
        while (waitpid(-1, NULL, WNOHANG) > 0);
}

void perror_exit(char *message) {
    perror(message);
    exit(EXIT_FAILURE);
}
```

And now the client…

```
/* inet_str_client.c: Internet stream sockets client */
#include <stdio.h>
#include <sys/types.h>        /* sockets */
#include <sys/socket.h>       /* sockets */
#include <netinet/in.h>       /* internet sockets */
#include <unistd.h>          /* read, write, close */
#include <netdb.h>            /* gethostbyaddr */
#include <stdlib.h>           /* exit */
#include <string.h>           /* strlen */

void perror_exit(char *message);

void main(int argc, char *argv[]) {
   int             port, sock, i;
   char            buf[256];
   struct sockaddr_in server;
   struct sockaddr *serverptr = (struct sockaddr*)&server;
   struct hostent *rem;
   if (argc != 3) {
      printf("Please give host name and port number\n");
      exit(1);}
      /* Create socket */
   if ((sock = socket(AF_INET, SOCK_STREAM, 0)) < 0)
      perror_exit("socket");
      /* Find server address */
   if ((rem = gethostbyname(argv[1])) == NULL) {
        herror("gethostbyname"); exit(1);
   }
```

```
port = atoi(argv[2]);    /*Convert port number to integer*/
   server.sin_family = AF_INET;       /* Internet domain */
   memcpy(&server.sin_addr, rem->h_addr, rem->h_length);
   server.sin_port = htons(port);        /* Server port */
   /* Initiate connection */
   if (connect(sock, serverptr, sizeof(server)) < 0)
         perror_exit("connect");
   printf("Connecting to %s port %d\n", argv[1], port);
   do {
     printf("Give input string: ");
     fgets(buf, sizeof(buf), stdin);  /* Read from stdin*/
     for(i=0; buf[i] != '\0'; i++) { /* For every char */
        /* Send i-th character */
          if (write(sock, buf + i, 1) < 0)
            perror_exit("write");
        /* receive i-th character transformed */
          if (read(sock, buf + i, 1) < 0)
             perror_exit("read");
     }
     printf("Received string: %s", buf);
   } while (strcmp(buf, "END\n") != 0); /* Finish on "end" */
   close(sock);                /* Close socket and exit */
}

void perror_exit(char *message)
{
   perror(message);
   exit(EXIT_FAILURE);
}
```

Server on linux02:

```
mema@linux02> ./server 9002
Listening for connections to port 9002
Accepted connection from linux03.di.uoa.gr
Hello world
EnD
Closing connection .
```

Client on linux03:

```
mema@linux03> ./client linux02.di.uoa.gr 9002
Connecting to linux02.di.uoa.gr port 9002
Give input string : Hello world
Received string : HELLO WORLD
Give input string : EnD
Received string : END
mema@bowser>
```

More useful tips

- INADDR_ANY (0.0.0.0)
  - Means “listen on all network interfaces” on this host
- port = 0
  - Lets the OS choose a port
  - Use getsockname() after bind to find which port was given to you
- int setsockopt()
  - Sets certain properties of a socket
  - We’ll see example use later
- int shutdown(int socket_fd, int how)
  - Shuts down part of a full-duplex connection
  - Can be used to tell server that we have sent the whole request
  - how = SHUT_RD, SHUT_WR, or SHUT_RDWR
  - Example: HTTP client sends request, then shutdown(fd, SHUT_WR) to tell server “I am done sending the whole request, but can still receive.” Server detects EOF by receive of 0 bytes and can assume it has complete request.
  - At end, we close the socket with close() call

More useful functions

- int getsockname(int sock_fd, struct sockaddr *address, int *address_len)
  - Returns the current address to which the socket is bound with using the buffer pointed to by address

- int getpeername(int sock_fd, struct sockaddr *address, int *address_len)
  - Get the name (address) of the (remote) peer connected to a socket; useful if a server has called a fork/exec combination and only the socket is known
  - On return, address points to struct sockaddr with fields filled in

The netstat command

- Use system program netstat to view the status of sockets
- E.g., netstat –n –l –p
  - Show in numerical form (-n)
  - the LISTEN-ing sockets (-l)
  - And the processes that own them (-p)
- Also...
  - -t / -u TCP/UDP
  - -a show sockets in all the states
- TCP states
  - LISTEN, ESTABLISHED, TIME_WAIT…

Parsing and Printing Addresses

Old:

inet_ntoa **Convert struct in_addr to printable form ‘a.b.c.d’**

inet_aton **Convert IP address string in ‘.’ notation to 32bit network address**

New (these work with IPv6 as well as IPv4):

inet_ntop **Convert address from network format to printable presentation format**

inet_pton **Convert presentation format address to network format**

Review

- A traditional way to write network servers:
  - the main server process (or thread) blocks on accept(), waiting for a connection.
  - once a connection comes in, the server forks new process (thread), the child process (thread) handles the connection
  - the main server process is able to accept new incoming requests.

Alternative server structure with select ()

- A single process multiplexes all sockets via *select()* call
  - Adv: no need for separate child process/thread per request
- Select() blocks until an "event" occurs on a file descriptor (socket)
  - Data comes in off the net for a socket
  - File descriptor ready for writing
  - Describe events (file descriptors) of interest by filling a *fd_set* structure using macros

Alternative server structure with select () *

- Fill up a fd_set structure with the fds you want to know when data comes in on
- Fill up a fd_set structure with the fds you want to know when you can write on
- Call select(), block until event occurs
- When select returns, check if any fds was the reason process woke up and service relevant fd
- Repeat forever
- * See code samples at:

http://www.gnu.org/software/libc/manual/html_node/Server-Example.html#Server-Example

http://www.lowtek.com/sockets/select.html

```
#include "sockhelp.h"
#include <ctype.h>
#include <sys/time.h>
#include <fcntl.h>

int sock;       /* The socket file descriptor for our "listening"
                   socket */
int connectlist[5];  /* Array of connected sockets so we know
                        who we are talking to */
fd_set socks;        /* Socket file descriptors we want to wake
                        up for, using select() */
int highsock;    /* Highest #'d file desc, needed for select() */

void setnonblocking(sock)
int sock;
{
        int opts;

        opts = fcntl(sock,F_GETFL);
        if (opts < 0) {
                perror("fcntl(F_GETFL)");
                exit(EXIT_FAILURE);
        }
        opts = (opts | O_NONBLOCK);
        if (fcntl(sock,F_SETFL,opts) < 0) {
                perror("fcntl(F_SETFL)");
                exit(EXIT_FAILURE);
        }
        return;
}
```

```
void build_select_list() {
    int listnum;    /* Current item in connectlist for for loops */

    /* First put together fd_set for select(), which will
       consist of the sock variable in case a new connection
       is coming in, plus all the sockets we have already
       accepted. */
    /* FD_ZERO() clears out the fd_set called socks, so that
           it doesn't contain any file descriptors. */

    FD_ZERO(&socks);

    /* FD_SET() adds the file descriptor "sock" to the fd_set,
           so that select() will return if a connection comes in on
           that socket (which means you have to accept(), etc. */

    FD_SET(sock,&socks);

    /* Loops through all the possible connections and adds
           those sockets to the fd_set */

    for (listnum = 0; listnum < 5; listnum++) {
           if (connectlist[listnum] != 0) {
                  FD_SET(connectlist[listnum],&socks);
                  if (connectlist[listnum] > highsock)
                         highsock = connectlist[listnum];
           }
    }
```

```
void handle_new_connection() {
    int listnum;   /* Current item in connectlist for for loops */
    int connection; /* Socket file descriptor for incoming
                       connections */

    /* We have a new connection coming in!  We'll
    try to find a spot for it in connectlist. */
    connection = accept(sock, NULL, NULL);
    if (connection < 0) {
        perror("accept");
        exit(EXIT_FAILURE);
    }
    setnonblocking(connection);
  for (listnum = 0; (listnum < 5) && (connection != -1); listnum ++)
      if (connectlist[listnum] == 0) {
        printf("\nConnection accepted:   FD=%d; Slot=%d\n"
                    connection,listnum);
        connectlist[listnum] = connection;
        connection = -1;
      }
    if (connection != -1) {
        /* No room left in the queue! */
        printf("\nNo room left for new client.\n");
        sock_puts(connection,"Sorry, this server is too busy.  "
                        Try again later!\r\n");
        close(connection);
    }
}
```

```
void deal_with_data(
        int listnum   /* Current item in connectlist for for loops */
        ) {
        char buffer[80];     /* Buffer for socket reads */
        char *cur_char;      /* Used in processing buffer */

        if (sock_gets(connectlist[listnum],buffer,80) < 0) {
                /* Connection closed, close this end
                   and free up entry in connectlist */
                printf("\nConnection lost: FD=%d;  Slot=%d\n",
                        connectlist[listnum],listnum);
                close(connectlist[listnum]);
                connectlist[listnum] = 0;
        } else {
                /* We got some data, so upper case it
                   and send it back. */
                printf("\nReceived: %s; ",buffer);
                cur_char = buffer;
                while (cur_char[0] != 0) {
                        cur_char[0] = toupper(cur_char[0]);
                        cur_char++;
                }
                sock_puts(connectlist[listnum],buffer);
                sock_puts(connectlist[listnum],"\n");
                printf("responded: %s\n",buffer);
        }
}
```

```
void read_socks() {
      int listnum; /* Current item in connectlist for for loops */

      /* OK, now socks will be set with whatever socket(s)
         are ready for reading.  Lets first check our
         "listening" socket, and then check the sockets
         in connectlist. */

      /* If a client is trying to connect() to our listening
            socket, select() will consider that as the socket
            being 'readable'. Thus, if the listening socket is
            part of the fd_set, we need to accept a new connectio

      if (FD_ISSET(sock,&socks))
            handle_new_connection();
      /* Now check connectlist for available data */

      /* Run through our sockets and check to see if anything
            happened with them, if so 'service' them. */

      for (listnum = 0; listnum < 5; listnum++) {
            if (FD_ISSET(connectlist[listnum],&socks))
                  deal_with_data(listnum);
      } /* for (all entries in queue) */
}
```

```
int main (argc, argv)
int argc;
char *argv[];
{
    char *ascport;  /* ASCII version of the server port */
    int port;  /* Port number after conversion from ascport */
    struct sockaddr_in server_address; /* bind info structure *
    int reuse_addr = 1;  /* Used so we can re-bind to our port
                            while a previous connection is still
                            in TIME_WAIT state. */
    struct timeval timeout;  /* Timeout for select */
    int readsocks;  /* Number of sockets ready for reading */

    /* Make sure we got a port number as a parameter */
    if (argc < 2) {
        printf("Usage: %s PORT\r\n",argv[0]);
        exit(EXIT_FAILURE);
    }

    /* Obtain a file descriptor for our "listening" socket */
    sock = socket(AF_INET, SOCK_STREAM, 0);
    if (sock < 0) {
        perror("socket");
        exit(EXIT_FAILURE);
    }
    /* So that we can re-bind to it without TIME_WAIT
       problems */
    setsockopt(sock, SOL_SOCKET, SO_REUSEADDR,
                    &reuse_addr, sizeof(reuse_addr));
```

```
/* Set socket to non-blocking with setnonblocking routine */
    setnonblocking(sock);

    /* Get the address information, and bind it to the socket */
    ascport = argv[1]; /* Read what the user gave us */
    port = atoport(ascport); /* Use function from sockhelp to
                                convert to an int */
    memset((char *) &server_address, 0,
                sizeof(server_address));
    server_address.sin_family = AF_INET;
    server_address.sin_addr.s_addr = htonl(INADDR_ANY);
    server_address.sin_port = port;
    if (bind(sock, (struct sockaddr *) &server_address,
      sizeof(server_address)) < 0 ) {
          perror("bind");
          close(sock);
          exit(EXIT_FAILURE);
    }

    /* Set up queue for incoming connections. */
    listen(sock,5);

    /* Since we start with only one socket, the listening socket,
       it is the highest socket so far. */
    highsock = sock;
    memset((char *) &connectlist, 0, sizeof(connectlist));
```

```
while (1) { /* Main server loop - forever */
    build_select_list();
    timeout.tv_sec = 1;
    timeout.tv_usec = 0;

     /* The first argument to select is the highest file
        descriptor value plus 1. In most cases, you can
        just pass FD_SETSIZE and you'll be fine. */

     /* The second argument to select() is the address of
        the fd_set that contains sockets we're waiting
        to be readable (including the listening socket). */

     /* The third parameter is an fd_set that you want to
        know if you can write on -- this example doesn't
        use it, so it passes 0, or NULL. The fourth parameter
        is sockets you're waiting for out-of-band data for,
        which usually, you're not. */

     /* The last parameter to select() is a time-out of how
        long select() should block. If you want to wait forever
        until something happens on a socket, you'll probably
        want to pass NULL. */

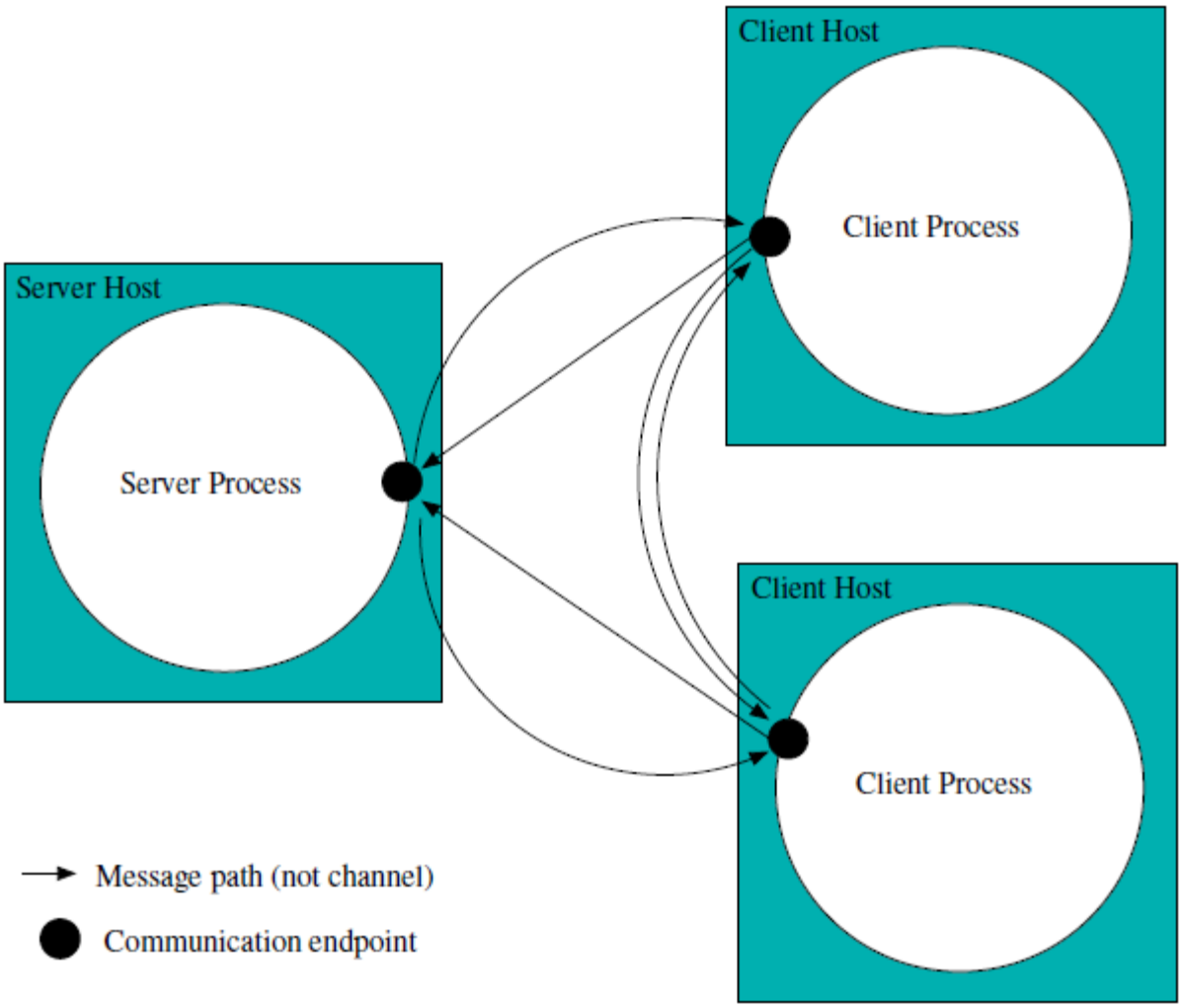
     readsocks = select(highsock+1, &socks, (fd_set *) 0,
                        (fd_set *) 0, &timeout);
```

```
/* select() returns the number of sockets that had
      things going on with them -- i.e. they're readable. */

      /* Once select() returns, the original fd_set has been
            modified so it now reflects the state of why select()
            woke up. i.e. If file descriptor 4 was originally in
            the fd_set, and then it became readable, the fd_set
            contains file descriptor 4 in it. */

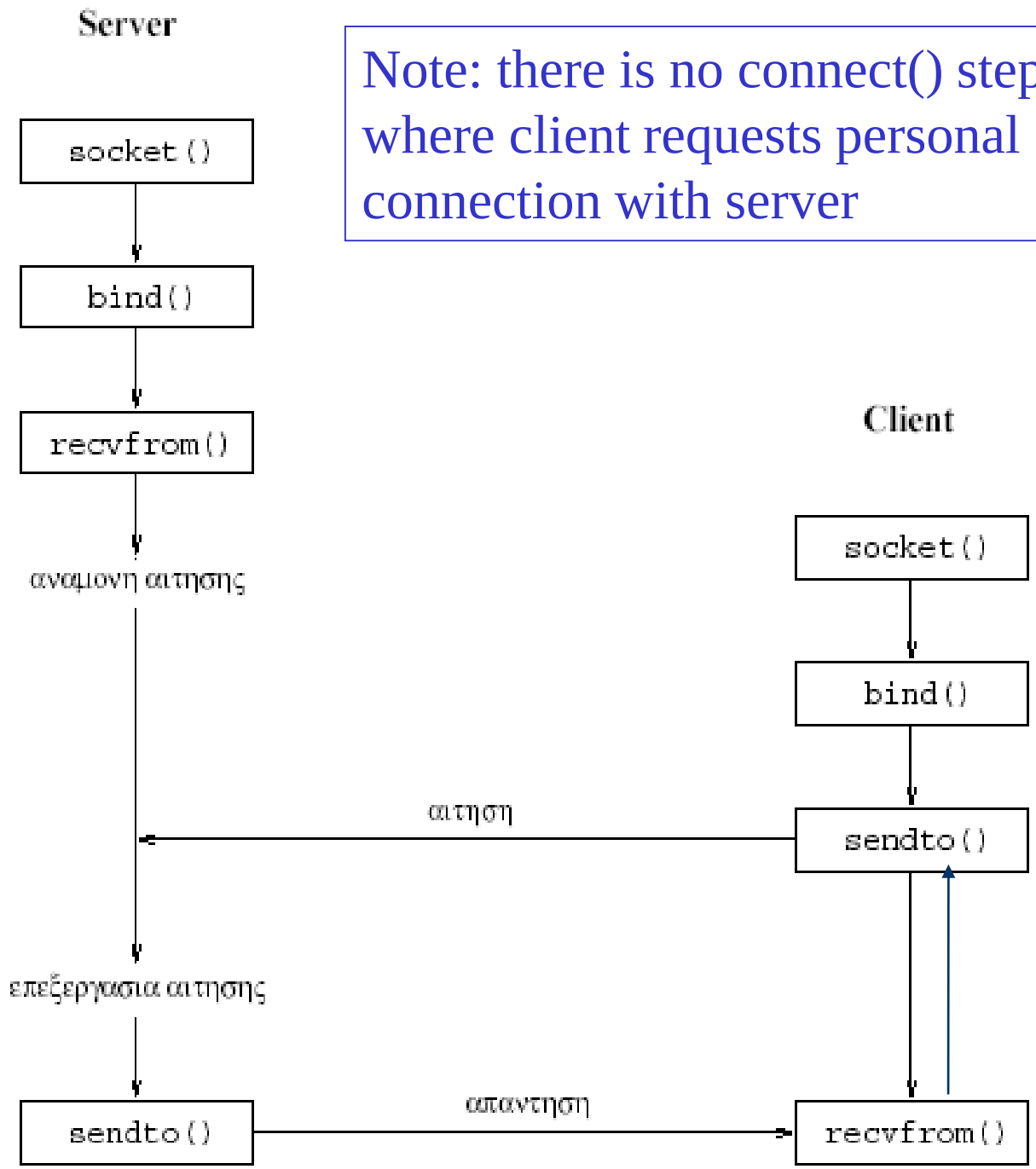
      if (readsocks < 0) {
            perror("select");
            exit(EXIT_FAILURE);
      }
      if (readsocks == 0) {
            /* Nothing ready to read, just show that
               we're alive */
            printf(".");
            fflush(stdout);
      } else
            read_socks();
      } /* while(1) */
} /* main */
```

User Datagram Protocol (UDP)



- No Connections: Think postcards, not telephone.
- Datagrams (messages) exchanged.
- Datagrams either arrive (possibly out of order) or get lost!

UDP Communication



Note: there is no connect() step where client requests personal connection with server

sendto(), recvfrom()

- ssize_t sendto (int sock , void *buff, int count, int flags , struct sockaddr *dest_addr, socklen_t dest_len);
  - Send a message to a socket
  - Similar to write() & send() but designates destination
- ssize_t recvfrom (int socket, void *buf, int count, int flags, struct sockaddr *address, socklen_t *address_len);
  - **Receive a message** from a socket
  - Similar to read() & recv() but on return, fills in source address in *address
  - address len is value-result and must be initialized to the size of the buffer pointed to by the address pointer
  - last two arguments can be NULL
- Usually flags = 0; rarely used (ex. out of band data)

A simple echoing UDP server

Client on linux03:
mema@linux03> ./inet_dgr_client linux02 49024
Unix is cool
Unix is cool
Tax evasion SUCKS
Tax evasion SUCKS
Can I go back?
Can I go back?
mema@linux03>

Server on linux02:
mema@linux02> ./inet_dgr_server
Socket port : 49024
Received from linux03 : Unix is cool
Received from linux03 : Tax evasion SUCKS
Received from linux03 : Can I go back?

```
/* inet_dgr_server.c: Internet datagram sockets server */
#include <sys/types.h>                  /* sockets */
#include <sys/socket.h>                 /* sockets */
#include <netinet/in.h>             /* Internet sockets */
#include <netdb.h>                  /* gethostbyaddr */
#include <arpa/inet.h>                  /* inet_ntoa */
#include <stdio.h>
#include <stdlib.h>
void perror_exit(char *message);
char *name_from_address(struct in_addr addr) {
   struct hostent *rem; int asize = sizeof(addr.s_addr);
   if ((rem = gethostbyaddr(&addr.s_addr, asize, AF_INET)))
      return rem->h_name;  /* reverse lookup success */
   return inet_ntoa(addr);  /* fallback to a.b.c.d form */
}
void main() {
   int n, sock; unsigned int serverlen, clientlen;
   char buf[256], *clientname;
   struct sockaddr_in server, client;
   struct sockaddr *serverptr = (struct sockaddr*) &server;
   struct sockaddr *clientptr = (struct sockaddr*) &client;
   /* Create datagram socket */
   if ((sock = socket(AF_INET, SOCK_DGRAM, 0)) < 0)
      perror_exit("socket");
   /* Bind socket to address */
   server.sin_family = AF_INET;       /* Internet domain */
   server.sin_addr.s_addr = htonl(INADDR_ANY);
   server.sin_port = htons(0);      /* Autoselect a port */
   serverlen = sizeof(server);
```

```
if (bind(sock, serverptr, serverlen) < 0)
    perror_exit("bind");
  /* Discover selected port */
  if (getsockname(sock, serverptr, &serverlen) < 0)
    perror_exit("getsockname");
  printf("Socket port: %d\n", ntohs(server.sin_port));
  while(1) { clientlen = sizeof(client);
    /* Receive message */
    if ((n = recvfrom(sock, buf, sizeof(buf), 0, clientptr,
                      &clientlen)) < 0)
      perror("recvfrom");
    buf[sizeof(buf)-1]='\0';    /* force str termination */
    /* Try to discover client's name */
    clientname = name_from_address(client.sin_addr);
    printf("Received from %s: %s\n", clientname, buf);
    /* Send message */
    if (sendto(sock, buf, n, 0, clientptr, clientlen)<0)
      perror_exit("sendto");
  }}

void perror_exit(char *message)
{
  perror(message);
  exit(EXIT_FAILURE);
}
```

```
/* inet_dgr_client.c: Internet datagram sockets client    */
#include <sys/types.h>                  /* sockets */
#include <sys/socket.h>                 /* sockets */
#include <netinet/in.h>             /* Internet sockets */
#include <netdb.h>                  /* gethostbyname */
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

void main(int argc, char *argv[]) {
   int sock; char buf[256]; struct hostent *rem;
   struct sockaddr_in server, client;
   unsigned int serverlen = sizeof(server);
   struct sockaddr *serverptr = (struct sockaddr *) &server;
   struct sockaddr *clientptr = (struct sockaddr *) &client;
   if (argc < 3) {
      printf("Please give host name and port\n"); exit(1);}
   /* Create socket */
   if ((sock = socket(AF_INET, SOCK_DGRAM, 0)) < 0) {
      perror("socket"); exit(1); }
   /* Find server's IP address */
   if ((rem = gethostbyname(argv[1])) == NULL) {
      herror("gethostbyname"); exit(1); }
   /* Setup server's IP address and port */
   server.sin_family = AF_INET;        /* Internet domain */
   memcpy(&server.sin_addr, rem->h_addr, rem->h_length);
   server.sin_port = htons(atoi(argv[2]));
```

```
/* Setup my address */
   client.sin_family = AF_INET;       /* Internet domain */
   client.sin_addr.s_addr=htonl(INADDR_ANY); /*Any address*/
   client.sin_port = htons(0);        /* Autoselect port */
   /* Bind my socket to my address*/
   if (bind(sock, clientptr, sizeof(client)) < 0) {
      perror("bind"); exit(1); }
   /* Read continuously messages from stdin */
   while (fgets(buf, sizeof buf, stdin)) {
      buf[strlen(buf)-1] = '\0';          /* Remove '\n' */
      if (sendto(sock, buf, strlen(buf)+1, 0, serverptr,
                     serverlen) < 0) {
        perror("sendto"); exit(1); }     /* Send message */
      bzero(buf, sizeof buf);            /* Erase buffer */
      if (recvfrom(sock, buf, sizeof(buf), 0, NULL, NULL) < 0) {
        perror("recvfrom"); exit(1); }  /* Receive message */
      printf("%s\n", buf); }
}
```

Looks good but….

- Everything looks good and runs ok, but there is a BUG!
- UDP is *unreliable*

```
/* rlsd.c - a remote ls server - with paranoia */
#include  <stdio.h>
#include  <stdlib.h>
#include  <unistd.h>
#include  <sys/types.h>
#include  <sys/socket.h>
#include  <netinet/in.h>
#include  <netdb.h>
#include  <time.h>
#include  <string.h>
#include  <ctype.h>
#define PORTNUM  15000       /* rlsd listens on this port */

void perror_exit(char *msg);
void sanitize(char *str);

int main(int argc, char *argv[]) {
    struct sockaddr_in myaddr;  /* build our address here */
    int      c, lsock, csock;     /* listening and client sockets */
    FILE *sock_fp;            /* stream for socket IO */
    FILE *pipe_fp;              /* use popen to run ls */
    char    dirname[BUFSIZ];             /* from client */
    char    command[BUFSIZ];              /* for popen() */

    /** create a TCP a socket **/
    if ((lsock = socket( AF_INET, SOCK_STREAM, 0)) < 0)
       perror_exit( "socket" );
```

```
/** bind address to socket. **/
   myaddr.sin_addr.s_addr = htonl(INADDR_ANY);
   myaddr.sin_port = htons(PORTNUM); /*port to bind socket*/
   myaddr.sin_family = AF_INET;  /* internet addr family */
   if(bind(lsock,(struct sockaddr*)&myaddr,sizeof(myaddr)))
         perror_exit( "bind" );
   /** listen for connections with Qsize=5 **/
   if ( listen(lsock, 5) != 0 )
      perror_exit( "listen" );
   while ( 1 ){ /* main loop: accept - read - write */
         /* accept connection, ignore client address */
         if ( (csock = accept(lsock, NULL, NULL)) < 0 )
            perror_exit("accept");
         /* open socket as buffered stream */
         if ((sock_fp = fdopen(csock,"r+")) == NULL)
            perror_exit("fdopen");
        /* read dirname and build ls command line */
         if (fgets(dirname, BUFSIZ, sock_fp) == NULL)
            perror_exit("reading dirname");
         sanitize(dirname);
         snprintf(command, BUFSIZ, "ls %s", dirname);
         /* Invoke ls through popen */
         if ((pipe_fp = popen(command, "r")) == NULL )
            perror_exit("popen");
         /* transfer data from ls to socket */
         while( (c = getc(pipe_fp)) != EOF )
            putc(c, sock_fp);
         pclose(pipe_fp);
         fclose(sock_fp);
   }
```

(Fork+exec+pipe creation). Αντί για ανακατεύθυνση εντολής σε αρχείο, popen. Μπορώ να διαβάσω ή γράψω με popen. ΟΧΙ και τα 2 μαζί

```
return 0;
}

/* it would be very bad if someone passed us a dirname like
 * "; rm *"  and we naively created a command  "ls ; rm *".
 * So..we remove everything but slashes and alphanumerics.
 */
void sanitize(char *str)
{
        char *src, *dest;
        for ( src = dest = str ; *src ; src++ )
                if ( *src == '/' || isalnum(*src) )
                        *dest++ = *src;
        *dest = '\0';
}

/* Print error message and exit */
void perror_exit(char *message)
{
    perror(message);
    exit(EXIT_FAILURE);
}
```

```
/* rls.c - a client for a remote directory listing service
 *         usage: rls hostname directory */
#include <stdio.h>
#include <stdlib.h>                     /* exit */
#include <string.h>                     /* strlen */
#include <unistd.h>                     /* STDOUT_FILENO */
#include <sys/types.h>                  /* sockets */
#include <sys/socket.h>                 /* sockets */
#include <netinet/in.h>                 /* internet sockets */
#include <netdb.h>                      /* gethostbyname */
#define  PORTNUM 15000
#define  BUFFSIZE 256
void perror_exit(char *msg);

/* Write() repeatedly until 'size' bytes are written */
int write_all(int fd, void *buff, size_t size) {
    int sent, n;
    for(sent = 0; sent < size; sent+=n) {
        if ((n = write(fd, buff+sent, size-sent)) == -1)
            return -1; /* error */
    }
    return sent;
}

int main(int argc, char *argv[]) {
    struct sockaddr_in  servadd;   /* The address of server */
    struct hostent *hp;          /* to resolve server ip */
    int    sock, n_read;     /* socket and message length */
    char   buffer[BUFFSIZE];       /* to receive message */
```

```
if ( argc != 3 ) {
    puts("Usage: rls <hostname> <directory>");exit(1);}
  /* Step 1: Get a socket */
  if ((sock = socket(AF_INET, SOCK_STREAM, 0)) == -1 )
    perror_exit( "socket" );
  /* Step 2: lookup server's address and connect there */
  if ((hp = gethostbyname(argv[1])) == NULL) {
    herror("gethostbyname"); exit(1);}
  memcpy(&servadd.sin_addr, hp->h_addr, hp->h_length);
  servadd.sin_port = htons(PORTNUM);  /* set port number */
  servadd.sin_family = AF_INET ;     /* set socket type */
  if (connect(sock, (struct sockaddr*) &servadd,
          sizeof(servadd)) !=0)
    perror_exit( "connect" );
  /* Step 3: send directory name + newline */
  if ( write_all(sock, argv[2], strlen(argv[2])) == -1)
    perror_exit("write");
  if ( write_all(sock, "\n", 1) == -1 )
    perror_exit("write");
  /* Step 4: read back results and send them to stdout */
  while( (n_read = read(sock, buffer, BUFFSIZE)) > 0 )
    if (write_all(STDOUT_FILENO, buffer, n_read)<n_read)
        perror_exit("fwrite");
  close(sock);
  return 0;
}
```

Server on linux01

```
k24-syspro@linux01> ./rlsd
ls: cannot open directory /home/users/mema: Permission denied
```

Client on linux02

```
mema@linux02> . /rls linux01.di.uoa.gr /home/users/k24-syspro
project1
project2
project3
students.txt
mema@linux02> . /rls linux01.di.uoa.gr /home/users/mema/
mema@linux02>
```

One more example

The ROCK PAPER SCISSORS game

- One referee process.
- Two players: a local process, a remote process
- Referee talks to the local process through pipes
- Referee talks to the remote process through sockets

Referee (prsref) program

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <sys/wait.h>                   /* For wait */
#include <sys/types.h>                  /* For sockets */
#include <sys/socket.h>                 /* For sockets */
#include <netinet/in.h>                 /* For Internet sockets */
#include <netdb.h>                    /* For gethostbyname */

#define READ    0
#define WRITE  1

int read_data (int fd, char *buffer);
int write_data (int fd, char* message);
void prs (int *score1, int *score2, int len1, int len2);

int main(int argc, char *argv[])
{
      int n, port, sock, newsock;
      int i, pid, fd1[2], fd2[2], option, status;
      int  score1=0, score2=0;          /* Score variables */
      char buf[60], buf2[60], buf3[60];  /* Buffers */
        /* prs options */
      char *message[] = { "ROCK", "PAPER", "SCISSORS" };
      unsigned int serverlen, clientlen; /* Server- client variables */
      struct sockaddr_in server, client;
      struct sockaddr *serverptr, *clientptr;
      struct hostent *rem;
```

```
if ( argc < 3 ){                    /* At least 2 arguments */
        fprintf(stderr, "usage: %s <n> <port>\n", argv[0]);
        exit(0);
    }

    n = atoi(argv[1]);                  /* Number of games */
    port = atoi(argv[2]);               /* Port */
     /* Create socket */
    if ((sock = socket(AF_INET, SOCK_STREAM, 0)) == -1){

        perror("socket");
        exit(-1);
    }
    server.sin_family = AF_INET;      /* Internet domain */
    server.sin_addr.s_addr = htonl(INADDR_ANY);
    server.sin_port = htons(port);/* The given port */
    serverptr = (struct sockaddr *) &server;
    serverlen = sizeof server;
    if (bind(sock, serverptr, serverlen) < 0){
        perror("bind"); exit(-1);
    }
    if (listen(sock, 5) < 0){
        perror("listen");exit(-1);
    }

    printf("I am the referee with PID %d waiting for game
      request at port %d\n", (int) getpid(), port);

    if (pipe (fd1) == -1){  /* First pipe: parent -> child */
        perror("pipe");exit(-1);
```

```
}
if (pipe(fd2) == -1){   /* Second pipe: child -> parent */
        perror("pipe");exit(-1);
}

if ((pid = fork()) == -1)      /* Create child for player 1 */
{
        perror("fork");exit(-1);
}

if ( !pid ){            /* Child process */
        close(fd1[WRITE]);close(fd2[READ]);  /*Close unused*
        srand(getppid());
        printf("I am player 1 with PID %d\n", (int) getpid());
        for(;;)                 /* While read "READY" */
        {
             /* Read "READY" or "STOP" */
              read_data(fd1[READ], buf);
              option = rand()%3;
              if ( strcmp("STOP", buf)){     /* If != "STOP" */
                    /* Send random option */
                    write_data(fd2[WRITE], message[option]);
                    /* Read result of this game */
                    read_data(fd1[READ], buf);
                    printf("%s", buf);          /* Print result */
              }else
                    break;
        }
        read_data(fd1[READ], buf);     /* Read final result */
```

```
        printf("%s", buf);    /* Print final result */
        close(fd1[READ]); close(fd2[WRITE]);
}
else{           /* Parent process */
        clientptr = (struct sockaddr *) &client;
        clientlen = sizeof client;
        close(fd1[READ]); close(fd2[WRITE]);
        printf("Player 1 is child of the referee\n");
        if ((newsock = accept(sock, clientptr, &clientlen)) < 0){
                perror("accept"); exit(-1);
        }
        if ((rem = gethostbyaddr((char *) &client.sin_addr.s_addr,
                 sizeof client.sin_addr.s_addr, client.sin_family))
                 == NULL) {
                perror("gethostbyaddr");exit(-1);
        }

        printf("Player 2 connected %s\n",rem->h_name);
        write_data (newsock, "2");  /* Send player's ID (2) */
        for(i = 1; i <= n; i++){
                write_data(fd1[WRITE], "READY");
                write_data(newsock, "READY");
                read_data(fd2[READ], buf);
                read_data(newsock, buf2);
                /* Create result string */
                sprintf(buf3, "Player 1:%10s\tPlayer 2:%10s\n",
                        buf, buf2);
                write_data(fd1[WRITE], buf3);
                write_data(newsock, buf3);
                prs(&score1,&score2,strlen(buf),strlen(buf2));
```

```
        }

        /* Calculate final results for each player */
        if ( score1 == score2 ){
                sprintf(buf, "Score = %d - %d (draw)\n",
                        score1, score2);
                sprintf(buf2, "Score = %d - %d (draw)\n",
                        score1, score2);
        }else if (score1 > score2 ){
                sprintf(buf, "Score = %d - %d (you won)\n",
                         score1, score2);
                sprintf(buf2, "Score = %d - %d (player 1 won)\n"
                        score1, score2);
        }else{
                sprintf(buf, "Score = %d - %d (player 2 won)\n",
                        score1, score2);
                sprintf(buf2, "Score = %d - %d (you won)\n",
                        score1, score2);
        }
        write_data(fd1[WRITE], "STOP");
        write_data(fd1[WRITE], buf);
        close(fd1[WRITE]); close(fd2[READ]);
        wait(&status);    /* Wait child */
        write_data(newsock, "STOP");
        write_data(newsock, buf2);
        close(newsock);  /* Close socket */
    }
    return 0;
}
```

```
int read_data(int fd, char *buffer){ /* Read formated data*/
        char temp;int i = 0, length = 0;
        if ( read(fd, &temp, 1 ) < 0 )   /* Get length of string */
                exit (-3);
        length = temp;
        while ( i < length )     /* Read $length chars */
                if ( i < ( i+= read(fd, &buffer[i], length - i)))
                        exit (-3);
        return i;       /* Return size of string */
}

/*Write formated data*/
int write_data( int fd, char* message ){
        char temp; int length = 0;
        length = strlen(message) + 1;  /* Find length of string */
        temp = length;
        if( write(fd, &temp, 1) < 0 )    /* Send length first */
                exit(-2);
        if( write(fd, message, length) < 0 ) /* Send string */
                exit(-2);
        return length;          /* Return size of string */
}
```

```
/* void prs(int *score1, int *score2, int len1, int len2):
*  Each option (PAPER, ROCK, SCISSORS) has a number of letters (5, 4, 8).
*  PAPER wins ROCK, ROCK wins SCISSORS and SCISSORS win PAPER.
*  This means, for the 1st player to be the winner the difference in the
*   number of letters must be equal to 3 (SCISSORS-PAPER)
*   or 1 (PAPER-ROCK)
*   or -4 (ROCK-SCISSORS). If not, then the 2nd player wins!
*   (If we have a zero, then we call it a draw and nobody get points)
*/
void prs(int *score1, int *score2, int len1, int len2)
{
        /* len1 = buf1 length, len2 = buf2 length */
       int result = len1 - len2;
       if (result == 3 || result == 1 || result == -4) /* 1st player win
              (*score1)++;
       else if (result)       /* 2nd player wins */
              (*score2)++;
       return;
}
```

Remote player (prs)

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <strings.h>       /* For bcopy */
#include <unistd.h>
#include <sys/wait.h>          /* For wait */
#include <sys/types.h>         /* For sockets */
#include <sys/socket.h>        /* For sockets */
#include <netinet/in.h>        /* For Internet sockets */
#include <netdb.h>         /* For gethostbyname */

int read_data(int fd, char *buffer);
int write_data(int fd, char* message);

int main (int argc, char *argv[])
{
      int i, port, sock, option;
      char opt[3], buf[60], *message[] =
                  { "PAPER", "ROCK", "SCISSORS" };
      unsigned int serverlen;
      struct sockaddr_in server;
      struct sockaddr *serverptr;
      struct hostent *rem;
      if (argc < 3){  /* At least 2 arguments */
            fprintf(stderr, "usage: %s <domain> <port>\n",
                        argv[0]);
            exit(-1);
      }
```

```
if ((sock = socket(AF_INET, SOCK_STREAM, 0)) < 0){
        perror("socket");
        exit(-1);
}
 /* Find server address */
if ((rem = gethostbyname(argv[1])) == NULL){
        perror("gethostbyname");
        exit(-1);
}
port = atoi(argv[2]);
server.sin_family = AF_INET;
bcopy((char *) rem -> h_addr, (char *) &server.sin_addr,
            rem -> h_length);
server.sin_port = htons(port);
serverptr = (struct sockaddr *) &server;
serverlen = sizeof server;
if (connect(sock, serverptr, serverlen) < 0){
        perror("connect");exit(-1);
}

read_data(sock, buf); /* Read player's ID (1 or 2) */
printf("I am player %d with PID %d\n", buf[0]-'0',
            (int) getpid());
for ( i = 1; ; i++ ){    /* While read "READY" */
        read_data(sock, buf);/* Read "READY" or "STOP"*/
        if ( strcmp("STOP", buf) ){  /* If != "STOP" */
                printf("Give round %d play: ", i);
                scanf("%s", opt);
```

```
                switch (*opt){     /* First letter of opt */
                /* Note: The other 2 are \n and \0 */
                        case 'p':option = 0; break;
                        case 'r':option = 1; break;
                        case 's':option = 2; break;
                        default: fprintf(stderr, "Wrong
                                        option %c\n", *opt);
                                option = ((int)*opt)%3; break;
                }
                write_data (sock, message[option]);
                read_data (sock, buf);
                printf ("%s", buf);
        }else break;
    }
    read_data (sock, buf);      /* Read final score */
    printf("%s", buf);
    close(sock);
    return 0;
}

/* Read formated data */
int read_data (int fd, char *buffer){
    char temp; int i = 0, length = 0;
    if ( read ( fd, &temp, 1 ) < 0 )  /* Get length of string */
        exit (-3);
    length = temp;
    while ( i < length )      /* Read $length chars */
        if ( i < ( i+= read (fd, &buffer[i], length - i) ) )
            exit (-3);
```

```
    return i;       /* Return size of string */
}

/* Write formated data */
int write_data ( int fd, char* message ){
    char temp; int length = 0;
    length = strlen(message) + 1;  /* Find length of string */
    temp = length;
    if ( write (fd, &temp, 1) < 0 )  /* Send length first */
        exit (-2);
    if ( write (fd, message, length) < 0 )     /* Send string */
        exit (-2);
    return length;                  /* Return size of string */
}
```

Server

```
mema@bowser> ./prsref 3 2323
I am the referee with PID 25499 …
    waiting for game request at port 2323
I am player 1 with PID 25500
Player 1 is child of the referee
Player 2 connected localhost
Player 1:    PAPER    Player 2:    PAPER
Player 1:     ROCK    Player 2:  SCISSORS
Player 1:  SCISSORS    Player 2:  SCISSORS
Score = 1 - 0 (you won)
mema@bowser>
```

Client

```
mema@bowser> ./prs localhost 2323
I am player 2 with PID 25519
Give round 1 play: p
Player 1:    PAPER    Player 2:    PAPER
Give round 2 play: s
Player 1:     ROCK    Player 2:  SCISSORS
Give round 3 play: s
Player 1:  SCISSORS    Player 2:  SCISSORS
Score = 1 - 0 (player 1 won)
mema@bowser>
```