

A Quick Guide to Networking Software
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Mission Briefing

Welcome to this quick guide in networking programming.

You will be given a username and password to access any of the RC lab computers. They are connected to Internet and running Linux.

Your mission, should you decide to accept it, is to complete the tasks that will be presented as you move along the guide. They involve the development of programs that communicate through the Internet.

The tools that you will be using are the basis for the development of network applications over the Internet (web browsers and servers, email, peer-to-peer, remote logins, file transfers ...).

The kind of network applications you will be able to develop, on your own, at the end of this guide, will only be bounded by your imagination.

As always, should you or any team member be caught in thrall of network programming, the author would disavow any knowledge of your actions.



Login:

alunos

Password:

alunos

Good! Move on!
2nd Task: Now that you have a name, get the IP address.
15 minutes.

getaddrinfo

```
// test.c
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <arpa/inet.h>
#include <string.h>

int main(void)
{
    struct addrinfo hints,*res,*p;
    int errcode;
    char buffer[INET_ADDRSTRLEN];
    struct in_addr *addr;

    memset(&hints,0,sizeof hints);
    hints.ai_family=AF_INET;//IPv4
    hints.ai_socktype=SOCK_DGRAM;
    hints.ai_flags=AI_CANONNAME;

    if((errcode=getaddrinfo("tejo.tecnico.ulisboa.pt",NULL,&hints,&res))!=0)
        fprintf(stderr,"error: getaddrinfo: %s\n",gai_strerror(errcode));
    else{
        printf("canonical hostname: %s\n",res->ai_canonname);
        for(p=res;p!=NULL;p=p->ai_next){
            struct sockaddr_in *ip = (struct sockaddr_in *)p->ai_addr;
            addr = &(ip->sin_addr);
            printf("internet address: %s (%08lx)\n",
                inet_ntop(p->ai_family, addr, buffer, sizeof(buffer)),
                (long unsigned int)ntohl(addr->s_addr));
        }
        freeaddrinfo(res);
    }
    exit(0);
}
```

```
#include <arpa/inet.h>

const char *inet_ntop(int af,
    const void *src,char *dst,
    socklen_t size);

#include <string.h>
void *memset(void *s,int c,size_t n);
```

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

int getaddrinfo(const char *node, const char *service,
    const struct addrinfo *hints,
    struct addrinfo **res);
void freeaddrinfo(struct addrinfo *res);
const char *gai_strerror(int errcode);
```

```
struct addrinfo {
    // (item in a linked list)
    int ai_flags; // additional options
    int ai_family; // address family
    int ai_socktype; // socket type
    int ai_protocol; // protocol
    socklen_t ai_addrlen; // address length (bytes)
    struct sockaddr *ai_addr; // socket address
    char *ai_canonname; // canonical hostname
    struct addrinfo *ai_next; // next item
};
```

```
struct sockaddr_in {
    sa_family_t sin_family; // address family: AF_INET
    u_int16_t sin_port; // port in (16 bits)
    struct in_addr sin_addr; // internet address
};
```

network byte order

```
struct in_addr{
    uint32_t s_addr; // 32 bits
};
```

0xC1==193
0x88==136
0x8A==138
0x8E==142

```
#include <arpa/inet.h>
uint32_t ntohl(uint32_t netlong);
// (network to host long)
```

Long (32 bits) 0x76543210

	Little endian system	Network byte order
ADDR	0x10	0x76
ADDR+1	0x32	0x54
ADDR+2	0x54	0x32
ADDR+3	0x76	0x10

Big Endian

```
$ make
gcc test.c -o test
$ ./test
canonical hostname: tejo.tecnico.ulisboa.pt
internet address: 193.136.138.142 (C1888A8E)
$
```

```
More?
$
$ man getaddrinfo inet_ntop memset ntohl 7 ip$
```

OK!
3rd Task: Try to send some text to the
UDP echo server on tejo.tecnico.ulisboa.pt:58001.
15 minutes.



UDP, socket and sendto

```
#include <sys/types.h>
#include <sys/socket.h>
int socket(int domain,int type,int protocol);
ssize_t sendto(int s,const void *buf,size_t len,int flags,
               const struct sockaddr *dest_addr,socklen_t addrlen);
```

```
//test.c
#include <stdlib.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>
```

```
int main(void)
{
    struct addrinfo hints,*res;
    int fd,errcode;
    ssize_t n;
```

```
fd=socket(AF_INET,SOCK_DGRAM,0); //UDP socket
if(fd==-1)/*error*/exit(1);

memset(&hints,0,sizeof hints);
hints.ai_family=AF_INET; //IPv4
hints.ai_socktype=SOCK_DGRAM; //UDP socket
```

```
errcode=getaddrinfo("tejo.tecnico.ulisboa.pt","58001",&hints,&res);
if(errcode!=0)/*error*/exit(1);

n=sendto(fd,"Hello!\n",7,0,res->ai_addr,res->ai_addrlen);
if(n==-1)/*error*/exit(1);
/*...*/
freeaddrinfo(res);
exit(0);
}
```

```
struct addrinfo{
    int          ai_flags;           // (item in a linked list)
    int          ai_family;         // additional options
    int          ai_socktype;       // address family
    int          ai_protocol;       // socket type
    socklen_t    ai_addrlen;        // protocol
    struct sockaddr *ai_addr;       // address length (bytes)
    char         *ai_canonname;     // socket address
    struct addrinfo *ai_next;      // canonical hostname
};
```

```
struct sockaddr {
    unsigned short  sa_family; // address family
    char            sa_data[14]; // protocol specific address
};
```

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

int getaddrinfo(const char *node, const char *service,
               const struct addrinfo *hints,
               struct addrinfo **res);
```



```
More?
$
$ man socket sendto getaddrinfo memset htons 7 ip
```

UDP and recvfrom

```
//test.c
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>
#include <unistd.h>
```

```
int main(void)
{
    int fd;
    struct sockaddr addr;
    socklen_t addrlen;
    ssize_t n;
    char buffer[128+1];
```

```
/*...*/see previous task code
```

```
addrlen=sizeof(addr);
n=recvfrom(fd,buffer,128,0,&addr,&addrlen);
if(n==-1)/*error*/exit(1);
buffer[n] = '\0';
printf("echo: %s\n", buffer);

close(fd);
exit(0);
}
```

```
#include <sys/types.h>
#include <sys/socket.h>
ssize_t  recvfrom(int s,void *buf,size_t len,int flags,
                  struct sockaddr *from,socklen_t *fromlen);
```

```
$ make
gcc test.c -o test
$ ./test
echo: Hello!
$
```

input/output
argument

Question 2: How do you know the message you received came from the UDP echo server on tejo:58001.

Question 3: Which port number is your UDP client listening to when it is waiting for the echo reply?

Question 4: How many bytes do you expect to receive from `recvfrom`?

Question 5: Do you expect buffer content to be a NULL terminated string?

Question 1: What happens if the messages do not arrive at the destination? Try specifying a wrong port number for the destination echo server. Did you get an error message?

More?

```
$
$ man recvfrom
```

Answers

Answer to question 1: No message will be received back at the client and it will block in `recvfrom`. No error will be detected unless timeouts are used.

You are using UDP. There are no guarantees that the messages will be delivered at the destination, and the order by which they are delivered may not be the same as that in which they were transmitted.

Answer to question 2: You have to check the `recvfrom` `addr` output argument. See, in the next slide, how to use `getnameinfo` for that purpose.

If you only want to receive messages from a specific address, then use `send` and `recv`. Find out more on manual page 2 (`man 2 send recv`).

Question 1: What happens if the messages do not arrive at the destination? Try specifying a wrong port number for the destination echo server. Did you get an error message?

Answer to question 3: The system assigned some unused port in the range when you first called `sendto` and this is the port `recvfrom` is listening to. If you want to use a specific port number you have to use `bind`. More on that later.

Answer to question 4: In this particular case, you should expect to receive 7 bytes (see `sendto` in previous slide).

Answer to question 5: In this particular case, you should not expect `buffer` to be `NULL` terminated. See `sendto` in previous slide and notice that the `'\0'` was not sent.

Question 2: How do you know the message you received came from the UDP echo server on `tejo:58001`.

Question 3: Which port number is your UDP client listening to when it is waiting for the echo reply?

Question 4: How many bytes do you expect to receive from `recvfrom`?

Question 5: Do you expect `buffer` content to be a `NULL` terminated string?

OK. Now let's move from UDP to TCP.
TCP is connection-oriented.
6th Task: Connect to the TCP echo server on [tejo.tecnico.ulisboa:58001](http://tejo.tecnico.ulisboa.pt:58001).
10 minutes.

TCP, socket and connect

```
//test.c
#include <stdlib.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>

int main(void)
{
    struct addrinfo hints,*res;
    int fd,n;

    fd=socket(AF_INET,SOCK_STREAM,0); //TCP socket
    if(fd==-1) exit(1); //error

    memset(&hints,0,sizeof hints);
    hints.ai_family=AF_INET; //IPv4
    hints.ai_socktype=SOCK_STREAM; //TCP socket

    n=getaddrinfo("tejo.tecnico.ulisboa.pt", "58001",&hints,&res);
    if(n!=0) /*error*/ exit(1);

    n=connect(fd,res->ai_addr,res->ai_addrlen);
    if(n==-1) /*error*/ exit(1);

    /*...*/
}
```

```
#include <sys/types.h>
#include <sys/socket.h>
int connect(int sockfd,const struct sockaddr *serv_addr,
            socklen_t addrlen);
```

Question 6: Did you notice that the host name and port number are the same as before?

Question 7: What do you expect to happen if you type the wrong host name or port number?

Alternative:

```
errcode=getaddrinfo("193.136.138.142", "58001",&hints,&res);
```

More?

```
$
$ man connect
```


Answers

Answer to question 6: There is no problem in having two servers on the same port number as long as they are using different protocols. In this case, one is using UDP and the other TCP.

Answer to question 7: If you type the wrong host name, `getaddrinfo` would give you an error, unless you type a name that also exists. If you type the wrong port number, `connect` would give you an error, unless there is a TCP server listening on that port.

Question 6: Did you notice that the host name and port number are the same as before?

Question 7: What do you expect to happen if you type the wrong host name or port number?

7th Task: Send some text over the connection you have just established and read the response.
10 minutes.

TCP, write and read

```
//test.c
#include <stdio.h>
#include <unistd.h>
#include <string.h>
/* ... */
int main(void)
{
    int fd;
    ssize_t nbytes,nleft,nwritten,nread;
    char *ptr,buffer[128+1];
    /*...*///see previous task code
    ptr=strcpy(buffer,"Hello!\n");
    nbytes=7;
    nleft=nbytes;
    while(nleft>0){nwritten=write(fd,ptr,nleft);
                    if(nwritten<=0)/*error*/exit(1);
                    nleft-=nwritten;
                    ptr+=nwritten;}
    nleft=nbytes; ptr=buffer;
    while(nleft>0){nread=read(fd,ptr,nleft);
                    if(nread==-1)/*error*/exit(1);
                    else if(nread==0)break;/**closed by peer
                    nleft-=nread;
                    ptr+=nread;}
    nread=nbytes-nleft;

    buffer[nread] = '\0';
    printf("echo: %s\n", buffer);
    close(fd);
    exit(0);
}
```

```
#include <unistd.h>
ssize_t write(int fd,const void *buf,size_t count);
ssize_t read(int fd,void *buf,size_t count);
```

also used to write and
read to/from files

```
$ make
gcc test.c -o test
$ ./test
echo: Hello!
$
```

Question 8: Did you notice that you may have to call `write` and `read` more than once?

Question 9: What do you expect to happen if your messages do not arrive at the destination?

More?

```
$
$ man 2 write read
```

Answers

Answer to question 8: There is no guarantee that `write` would send all the bytes you requested when you called it. Transport layer buffers may be full. However, `write` returns the number of bytes that were sent (accepted by the transport layer). So, you just have to use this information to make sure everything is sent.

You may also have to call `read` more than once, since `read` would return as soon as data is available at the socket. It may happen that, when `read` returns, there was still data to arrive. Since `read` returns the number of bytes read from the socket, you just have to use this information to make sure nothing is missing.

Answer to question 9: If the transport layer can not deliver your messages to the destination, the connection will be lost. In some circumstances, this may take a few minutes due to timeouts. If your process is blocked in a `read` when the connection is lost, then `read` would return `-1` and `errno` would be set to the appropriate error.

If you call `write` on a lost connection, `write` would return `-1`, `errno` will be set to `EPIPE`, but the system would raise a `SIGPIPE` signal and, by default, that would kill your process. See the next slide for a way to deal with the `SIGPIPE` signal.

Note however that, if the connection is closed, by the peer process, in an orderly fashion, while `read` is blocking your process, then `read` would return `0`, as a sign of EOF(end-of-file).

Question 8: Did you notice that you may have to call `write` and `read` more than once?

Question 9: What do you expect to happen if your messages do not arrive at the destination?

Be careful. If the connection is lost and you write to the socket, the system will raise a SIGPIPE signal and, by default, this will kill your process.

8th Task: Protect the application against SIGPIPE signals.

5 minutes.

TCP and the SIGPIPE signal

```
//test.c
#include <signal.h>

/*...*/

int main(void)
{
    /*...*/
    struct sigaction act;

    memset(&act,0,sizeof act);
    act.sa_handler=SIG_IGN;

    if(sigaction(SIGPIPE,&act,NULL)==-1)/*error*/exit(1);

    /*...*/
}
```

```
#include <signal.h>
int sigaction(int signum, const struct sigaction *act,
              struct sigaction *oldact);
```

More?

```
$
$ man sigaction 7 signal
```

From now on, the SIGPIPE signal will be ignored.

Now, if the connection is lost and you write to the socket, the write will return -1 and errno will be set to EPIPE.

Let's move from clients to servers.
Servers have well-known ports.
9th Task: Write a UDP echo server and run it on port 58001.
15 minutes.

UDP server and bind

```
#include <stdlib.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>
```

well-known
port number

```
#include <sys/types.h>
#include <sys/socket.h>
int bind(int sockfd, const struct sockaddr *my_addr,
         socklen_t addrlen);
```

```
int main(void)
{
    struct addrinfo hints,*res;
    int fd,errcode;
    struct sockaddr addr;
    socklen_t addrlen;
    ssize_t n,nread;
    char buffer[128];

    if((fd=socket(AF_INET,SOCK_DGRAM,0))==-1)exit(1);//error

    memset(&hints,0,sizeof hints);
    hints.ai_family=AF_INET;//IPv4
    hints.ai_socktype=SOCK_DGRAM;//UDP socket
    hints.ai_flags=AI_PASSIVE;
    if((errcode=getaddrinfo(NULL,"58001",&hints,&res))!=0)/*error*/exit(1);

    if(bind(fd,res->ai_addr,res->ai_addrlen)==-1)/*error*/exit(1);

    while(1){addrlen=sizeof(addr);
        nread=recvfrom(fd,buffer,128,0, &addr,&addrlen);
        if(nread==-1)/*error*/exit(1);
        n=sendto(fd,buffer,nread,0,&addr,addrlen);
        if(n==-1)/*error*/exit(1);
    }
    //freeaddrinfo(res);
    //close(fd);
    //exit(0);
}
```

Use bind to register the server well known address (and port) with the system.

More?

\$
\$ man 2 bind

Question 10: What do you expect to happen if there is already a UDP server on port 58001?

Note: You can also use bind to register the address (and port) in clients. In that case, if you set the port number to 0, the system assigns some unused port in the range 1024 through 5000.

Send only the bytes you read.

Answers

Question 10: What do you expect to happen if there is already a UDP server on port 58001?

Answer to question 10: You would get an error on `bind`.

Now, do the same, but with TCP.
10th Task: Write a TCP echo server and run it also on port 58001.
20 minutes.

TCP server, bind, listen and accept

```
#include <stdlib.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>
#include <unistd.h>

int main(void)
{
    struct addrinfo hints,*res;
    int fd,newfd,errcode;          ssize_t n,nw;
    struct sockaddr addr;          socklen_t addrlen;
    char *ptr,buffer[128];

    if((fd=socket(AF_INET,SOCK_STREAM,0))==-1)exit(1);//error

    memset(&hints,0,sizeof hints);
    hints.ai_family=AF_INET;//IPv4
    hints.ai_socktype=SOCK_STREAM;//TCP socket
    hints.ai_flags=AI_PASSIVE;
    if((errcode=getaddrinfo(NULL,"58001",&hints,&res))!=0)/*error*/exit(1);

    if(bind(fd,res->ai_addr,res->ai_addrlen)==-1)/*error*/exit(1);
    if(listen(fd,5)==-1)/*error*/exit(1);

    while(1){addrlen=sizeof(addr);
        if((newfd=accept(fd,&addr,&addrlen))==-1)
            /*error*/exit(1);
        while((n=read(newfd,buffer,128))!=0){if(n==-1)/*error*/exit(1);
            ptr=&buffer[0];
            while(n>0){if((nw=write(newfd,ptr,n))<=0)/*error*/exit(1);
                n-=nw; ptr+=nw;}
            }
        close(newfd);
    }
    //freeaddrinfo(res);close(fd);exit(0);
}
```

Use `bind` to register the server well known address (and port) with the system.

Use `listen` to instruct the kernel to accept incoming connection requests for this socket. The `backlog` argument defines the maximum length the queue of pending connections may grow to.

Use `accept` to extract the first connection request on the queue of pending connections. Returns a socket associated with the new connection.

address of the connected peer process

Question 11: Where do you expect the program to block?

Question 12: What happens if more than one client try to connect with the server?

Note: Do not forget to protect your application against the SIGPIPE signal.

More?

```
$
$ man 2 bind listen accept 7 tcp
```

Answers

Answer to question 11: This particular program is going to block in the `accept` call, until an incoming connection arrives. Then, it would block in the `read` call, until data is available at the `newfd` socket. Only after this connection is finished, the program would return to the `accept` call, where it would block if there are no pending connections waiting.

Answer to question 12: As it was written, this program can only serve a client at a time. In the meantime, connections from other clients would become pending or would be rejected. The number of pending connections depends on the `listen backlog` argument.

Question 11: Where do you expect the program to block?

Question 12: What happens if more than one client try to connect with the server?

If you are already serving a client, send “busy\n” to new incoming clients.

11th Task: Change the previous code to do that.

15 minutes.

select

```
#include <sys/time.h>
#include <sys/types.h>
#include <unistd.h>
/* ... */
#define max(A,B) ((A)>=(B)?(A):(B))

int main(void)
{
    int fd,newfd,afd=0;
    fd_set rfds;
    enum {idle,busy} state;
    int maxfd,counter;
    /*...*/
    /*fd=socket(...);bind(fd,...);listen(fd,...);*/
    state=idle;
    while(1){FD_ZERO(&rfds);
        switch(state){
            case idle: FD_SET(fd,&rfds);maxfd=fd; break;
            case busy: FD_SET(fd,&rfds);FD_SET(afd,&rfds);maxfd=max(fd,afd); break;
        }//switch(state)
```

Returns the number of file descriptors ready.

```
        counter=select(maxfd+1,&rfds,(fd_set*)NULL,(fd_set*)NULL,(struct timeval *)NULL);
        if(counter<=0)/*error*/exit(1);
```

```
        for(;counter;--counter)
```

```
            switch(state){
```

```
                case idle: if(FD_ISSET(fd,&rfds)){FD_CLR(fd,&rfds);
```

```
                    addrlen=sizeof(addr);
```

```
                    if((newfd=accept(fd,&addr,&addrlen))==1)/*error*/exit(1);
```

```
                    afd=newfd;state=busy;}
```

```
                break;
```

```
                case busy: if(FD_ISSET(fd,&rfds)){FD_CLR(fd,&rfds);
```

```
                    addrlen=sizeof(addr);
```

```
                    if((newfd=accept(fd,&addr,&addrlen))==1)/*error*/exit(1);
```

```
                    /* ... write “busy\n” in newfd */
```

```
                    close(newfd);}
```

```
                else if(FD_ISSET(afd,&rfds)){FD_CLR(afd,&rfds);
```

```
                    if((n=read(afd,buffer,128))!=0)
```

```
                        {if(n==1)/*error*/exit(1);
```

```
                            /* ... write buffer in afd */}
```

```
                    else{close(afd);state=idle;}//connection closed by peer
```

```
                }
```

```
            break;
```

```
        }//switch(state)
```

```
    }//while(1)
```

```
    /*close(fd);exit(0);*/
```

```
}//main
```

```
#include <sys/time.h>
#include <sys/types.h>
#include <unistd.h>
int select(int n,fd_set *readfds,fd_set *writefds,
            fd_set *exceptfds,struct timeval *timeout);
FD_CLR(int fd,fd_set *set);
FD_ISSET(int fd,fd_set *set);
FD_SET(int fd,fd_set *set);
FD_ZERO(fd_set *set);
```

fd is ready

fd is ready

afd is ready

Blocks until one of the file descriptors, previously set in rfds, are ready to be read.

Question 13: And now, where do you expect the program to block?

More?

```
$
$ man 2 select
```

Answers

Answer to question 13: This program is only going to block in the `select` call. It would not block neither in the `accept` call, neither in the `read` call, since those are only executed when their sockets are ready to be read (and so they have no reason to block).

Question 13: And now, where do you expect the program to block?

Further Reading

Unix Network Programming: Networking APIs: Sockets and XTI (Volume 1), 2nd ed., W. Richard Stevens, 1998, Prentice-Hall PTR, ISBN 013490012X.

Unix Network Programming: Networking APIs: The Sockets Networking API (Volume 1), 3rd ed., W. Richard Stevens, Bill Fenner, Andrew M. Rudoff, 2003, Addison-Wesley Professional, ISBN 0131411551.