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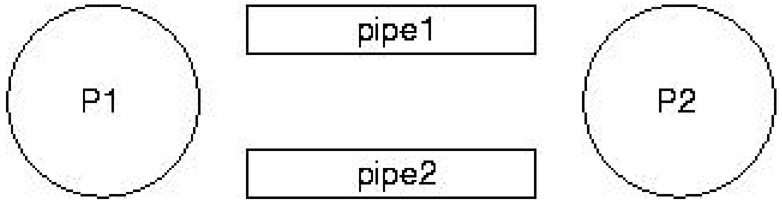
- 

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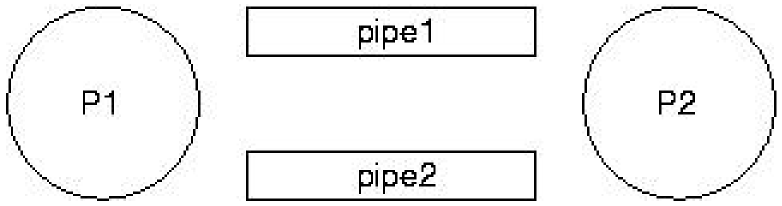
- 

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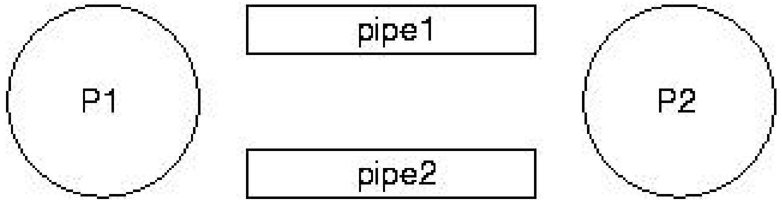
- 

- Totally reliable *byte stream* between producer and consumer.
- Tie-in to conventional Unix semantics of process creation and termination.

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

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

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Once a domain is specified, know the semantics of supported IPC mechanisms

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        unsigned short sun_family;      /* AF_UNIX */
        char sun_path[UNIX_PATH_MAX];   /* pathname */
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`/dev/printer` is a Unix domain socket used by the printer spooler subsystem.

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Choose socket type in accordance with needs of application. Program in accordance with well-specified delivery semantics of chosen type.

Operations on sockets:

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The programs `unix_wdgram.c` and `unix_rdgram.c` illustrate the use of these constructs to build a simple client/server system based on Unix domain datagrams. (Warning ... error checking deleted from the code to make smaller slides.)

unix_rdgram.c: Server

```
#include <errno.h>
#include <strings.h>
#include <stdio.h>
#include <unistd.h>
#include <sys/socket.h>
#include <sys/un.h>

main()
{
  short p_len;
  int socket_fd, cc, h_len, fsize, namelen;
  void printsun();
  struct sockaddr_un s_un, from;
  size_t addrlength;

  struct {
    char head;
    u_long body;
    char tail;
  } msg;

  socket_fd = socket (AF_UNIX, SOCK_DGRAM, 0);

  s_un.sun_family = AF_UNIX;
  strcpy(s_un.sun_path, "udgram");
  addrlength = sizeof(s_un.sun_family) + sizeof(s_un.sun_path); /* Note! */

  unlink("udgram");  /* Just in case ... */

  bind(socket_fd, (struct sockaddr *)&s_un, addrlength)

  for(;;) {
   fsize = sizeof(from);
   cc = recvfrom(socket_fd,&msg,sizeof(msg),0,(struct sockaddr *)&from,
                 &fsize);
   printsun( &from, "unix_rdgram: ", "Packet from:");
   printf("Got data ::%c%ld%c\n",msg.head,msg.body,msg.tail);fflush(stdout);
  }
}
```

```
void printsun(Sun, s1, s2)
struct sockaddr_un *Sun; char *s1, *s2;
{
 printf ("%s %s:\n", s1, s2);
 printf ("    family <%d> addr <%s>\n", Sun->sun_family, Sun->sun_path);
}
```

unix_wdgram.c: Client

```
#include <errno.h>
#include <strings.h>
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>

main()
{
  int socket_fd, cc;
  long getpid();
  struct sockaddr_un dest;

  struct {
    char head;
    u_long body;
    char tail;
  } msgbuf;

  socket_fd = socket (AF_UNIX, SOCK_DGRAM, 0);

  dest.sun_family = AF_UNIX;
  strcpy(dest.sun_path, "udgram");
  msgbuf.head = '<';
  msgbuf.body = (u_long) getpid();
  msgbuf.tail = '>';

  cc = sendto(socket_fd,&msgbuf,sizeof(msgbuf),0,
                   (struct sockaddr *)&dest,sizeof(dest));
}
```

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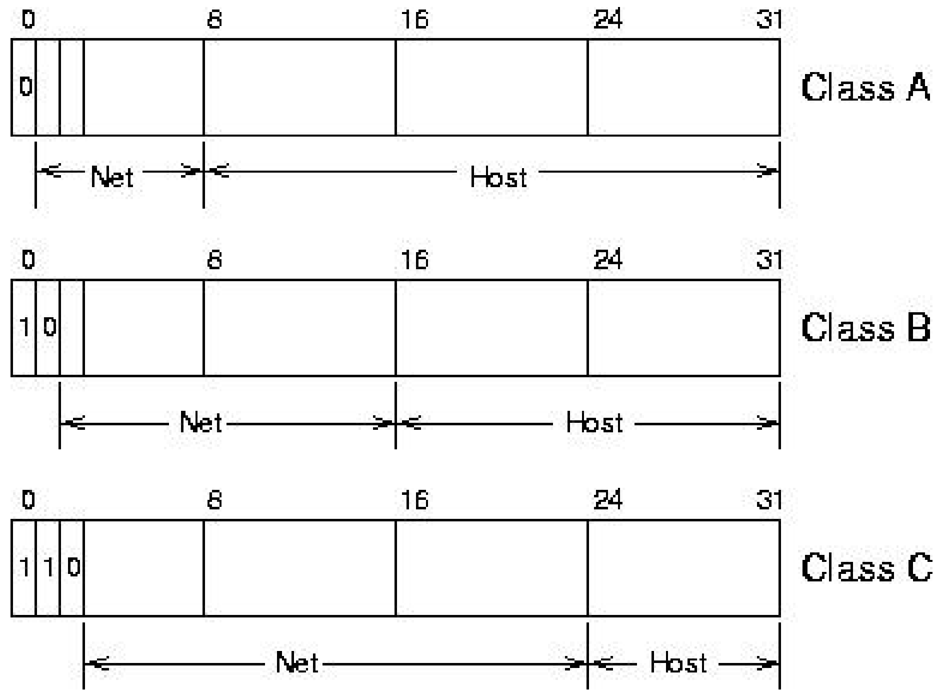
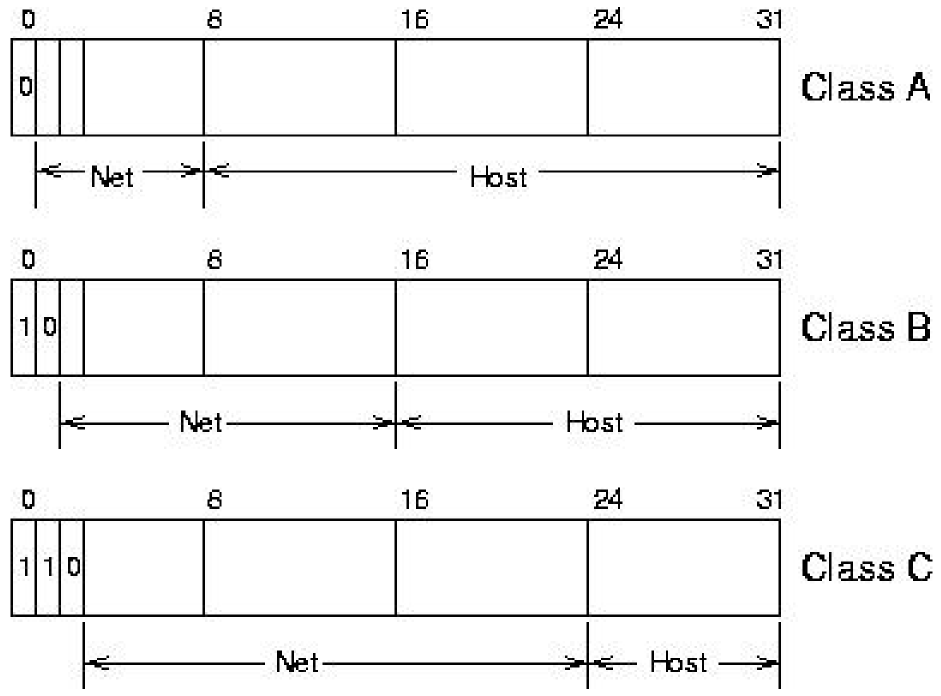
Header file `<netinet/in.h>` defines a 32-bit address for an Internet host. Actually identifies a specific network interface on a specific system on the Internet. 32-bit number.

```
struct in_addr {
        __u32   s_addr;
};
```



- Class D for multicast; Class E is reserved; Classless.



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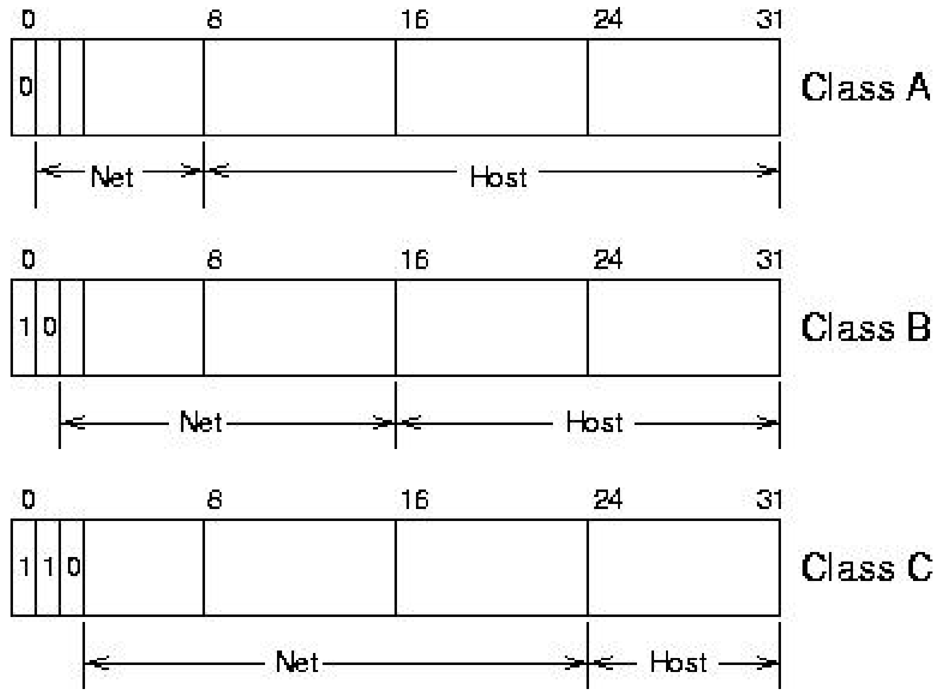

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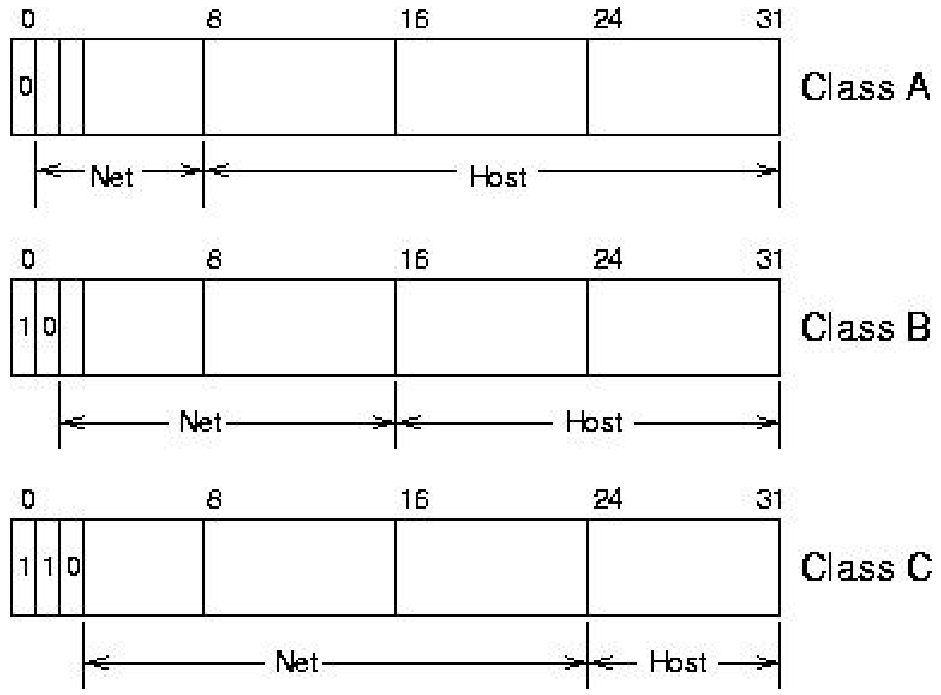

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- Localhost—127.0.0.1

- In header file `<netinet/in.h>`:

```
#define __SOCK_SIZE__   16          /* sizeof(struct sockaddr)      */

struct sockaddr_in {
 short int          sin_family;     /* Address family               */
 unsigned short int sin_port;       /* Port number                  */
 struct in_addr     sin_addr;       /* Internet address             */

 /* Pad to size of ‘struct sockaddr’. */
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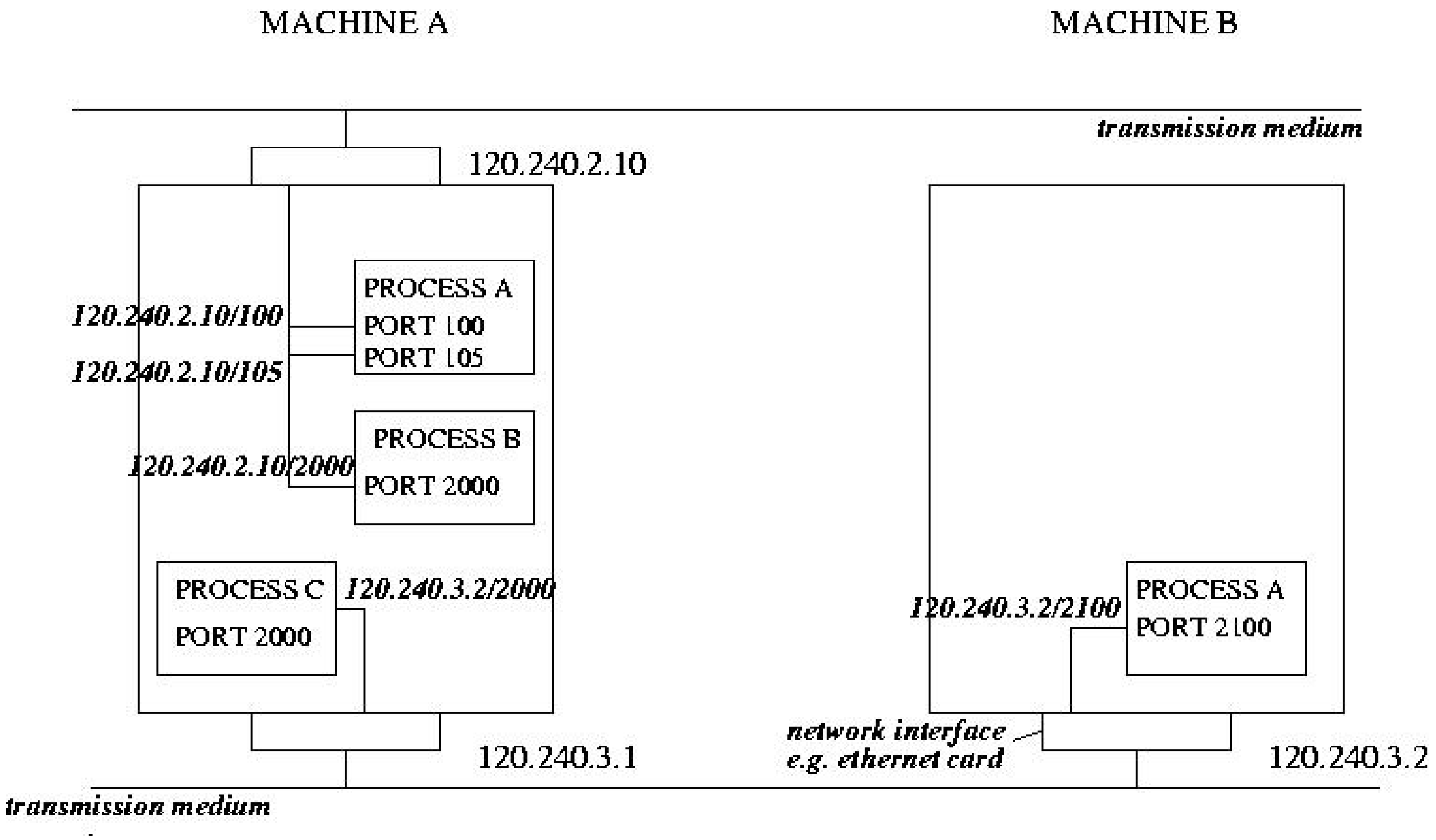
- ftp uses 20 & 21; telnet uses 23; finger uses 79; rlogin uses 513; talk uses 517 . . . see `/etc/services` ("well-known" ports).



MACHINE A
MACHINE B
transmission medium
120.240.2.10
PROCESS A
PORT 100
PORT 105
120.240.2.10/100
120.240.2.10/105
PROCESS B
PORT 2000
120.240.2.10/2000
PROCESS C
PORT 2000
120.240.3.2/2000
120.240.3.2/2100
PROCESS A
PORT 2100
network interface
e.g. ethernet card
120.240.3.1
120.240.3.2
transmission medium

Library function to map symbolic host name into IP address(es):

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#include <netdb.h>

struct hostent *gethostbyname(const char *name)

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Hostent data structure:

```
struct hostent {
  char    *h_name;        /* official name of host */
  char    **h_aliases;    /* alias list */
  int     h_addrtype;     /* host address type */
  int     h_length;       /* length of address */
  char    **h_addr_list;  /* list of addresses */
}
#define h_addr  h_addr_list[0]
```

Useful for printing IP addresses and turning “dotted decimal” strings into IP addresses (see UPM inet(3) for more info):

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```
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>

char *inet_ntoa(struct in_addr in);

int inet_aton(const char *cp, struct in_addr *inp);
```

getaddrs.c: Get Host Info From Symbolic Name

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```
#include <netdb.h>
#include <sys/socket.h>
#include <arpa/inet.h>
#include <netinet/in.h>
main(argc,argv)
int argc; char **argv;

  struct hostent *entry; char **next; struct in_addr address, **addrptr;
  entry = gethostbyname(argv[1]);
  if (!entry) { herror("lookup error"); exit(1);}
  printf("Official name -> %s\n", entry->h_name);
  if (entry->h_aliases[0]) {
    printf("Aliases ->\n");
    for (next = entry->h_aliases; *next; next++)
      printf("     %s\n", *next);
  }
  printf("IP Addresses:\n");
  for (addrptr=(struct in_addr **) entry->h_addr_list; *addrptr; addrptr++)
    printf("     %s\n", inet_ntoa(**addrptr));
}
```

```
anthony.csl% ./getaddrs anthony
Official name -> anthony.csl.mtu.edu
Aliases:
     anthony.csl
     anthony
     cslab21
IP Addresses:
     141.219.150.190
```

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anthony.csl% ./getaddrs www.linux.org
Official name -> www.linux.org
IP Addresses:
     198.182.196.56
```

Inverse function (know IP adress, want symbolic name):

```
#include <netdb.h>

struct hostent *gethostbyaddr(const char *addr, int len, int type);
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```

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#include <netdb.h>
#include <sys/socket.h>
#include <arpa/inet.h>
#include <netinet/in.h>
main(argc,argv)
int argc; char **argv;
{
  struct hostent *entry; struct in_addr address; char **next;
  inet_aton(argv[1], &address);
    entry = gethostbyaddr((char *)&address,sizeof(address),AF_INET);
  if (!entry) { herror("lookup error"); exit(1);}

  . . . like getaddrs.c . . .
```

```
anthony.csl% ./gethost 141.219.150.190
Official name -> anthony.csl.mtu.edu
Aliases:
     anthony.csl
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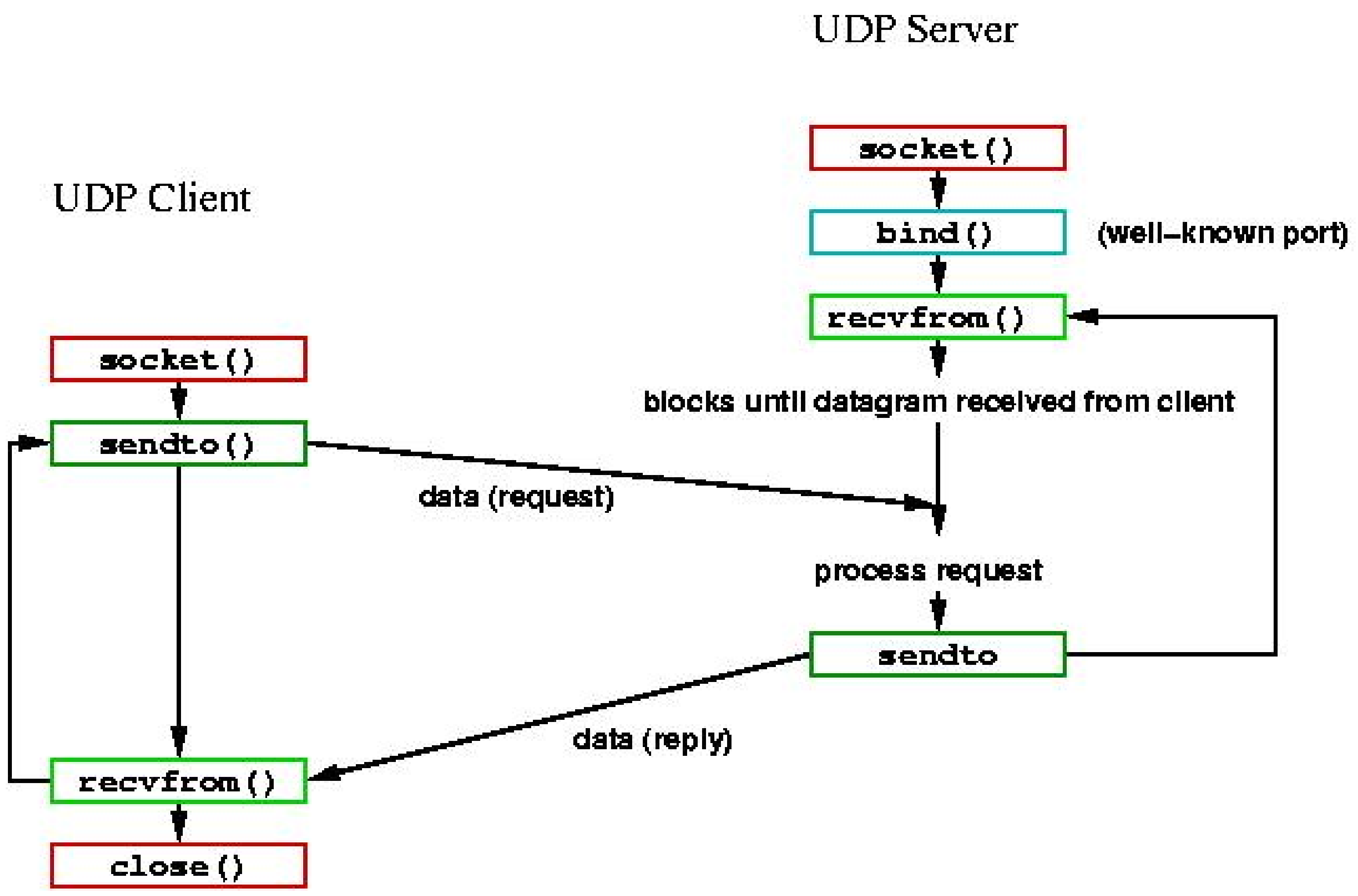
     141.219.150.190
```


UDP Server
UDP Client
socket()
bind()
(well-known port)
recvfrom()
blocks until datagram received from client
socket()
sendto()
data (request)
process request
sendto
data (reply)
recvfrom()
close()

recv_udp.c: UDP/IP Server

recv_udp.c: UDP/IP Server

```
main()
{
  short p_len;
  int socket_fd, cc, h_len, fsize, namelen;
  struct sockaddr_in  s_in, from;
  struct { char head; u_long  body; char tail;} msg;

  socket_fd = socket (AF_INET, SOCK_DGRAM, 0);

  bzero((char *) &s_in, sizeof(s_in));  /* They say you must do this    */
  s_in.sin_family = (short)AF_INET;
  s_in.sin_addr.s_addr = htonl(INADDR_ANY);    /* WILDCARD */
  s_in.sin_port = htons((u_short)0x3333);
  printsin( &s_in, "RECV_UDP", "Local socket is:"); fflush(stdout);
  bind(socket_fd, (struct sockaddr *)&s_in, sizeof(s_in));
  for(;;) {
    fsize = sizeof(from);
    cc = recvfrom(socket_fd,&msg,sizeof(msg),0,(struct sockaddr *)&from,&fsize);
    printsin( &from, "recv_udp: ", "Packet from:");
    printf("Got data ::%c%ld%c\n",msg.head,ntohl(msg.body),msg.tail); fflush(stdout);
  }
}
```

send_udp.c: UDP/IP Client

send_udp.c: UDP/IP Client

```
main(argc,argv)
int argc; char **argv;
{
  int socket_fd;
  struct sockaddr_in  dest;
  struct hostent *hostptr;

  struct { char head; u_long body; char tail; } msgbuf;

  socket_fd = socket (AF_INET, SOCK_DGRAM, 0);

  bzero((char *) &dest, sizeof(dest)); /* They say you must do this */
  hostptr = gethostbyname(argv[1]);
  dest.sin_family = (short) AF_INET;
  bcopy(hostptr->h_addr, (char *)&dest.sin_addr,hostptr->h_length);
  dest.sin_port = htons((u_short)0x3333);

  msgbuf.head = '<';
  msgbuf.body = htonl(getpid());    /* IMPORTANT! */
  msgbuf.tail = '>';

  sendto(socket_fd,&msgbuf,sizeof(msgbuf),0,(struct sockaddr *)&dest,
                  sizeof(dest));
}
```

Note striking similarities and simple differences between Unix datagram programs and Internet datagram programs. (Extends local IPC into networked IPC relatively seamlessly).

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Different socket creation parameters (trivial).

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Of course, underlying implementation is completely different (but generally hidden from programmer).

Impt. practical note: can always open up Internet ports on “localhost” (127.0.0.1) to test/develop network software. Implementation should be smart enough not to put packets on wire (move from output buffer to input buffer).

Want a much fancier application. Namely:

- Receiver will shut down cleanly if no datagram received after a 1 minute interval. Will also shut down cleanly if receives anything on stdin.

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- Basic problem . . . hanging a read/recv from several descriptors at once.
- Solution thru kernel call:

```
#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);
```

fancy_recv_udp.c: Fancy UDP Server

fancy_recv_udp.c: Fancy UDP Server

```
main()
{
  int socket_fd, cc, h_len, fsize, namelen, hits;
  fd_set mask;
  struct timeval timeout;
  struct sockaddr_in  s_in, from;

  struct { char head; u_long body; char tail; } msg;

  socket_fd = socket (AF_INET, SOCK_DGRAM, 0);

  bzero((char *) &s_in, sizeof(s_in));  /* They say you must do this    */
  s_in.sin_family = (short) AF_INET;
  s_in.sin_addr.s_addr = htons(INADDR_ANY);    /* WILDCARD */
  s_in.sin_port = htonl((u_short)0x3333);
  bind(socket_fd, (struct sockaddr *)&s_in, sizeof(s_in));
  for(;;) {
    fsize = sizeof(from);
    FD_ZERO(&mask); FD_SET(0,&mask); FD_SET(socket_fd,&mask);
    timeout.tv_sec = 60; timeout.tv_usec = 0;

    if ((hits = select(socket_fd+1, &mask, (fd_set *)0, (fd_set *)0,
                       &timeout)) < 0) {
      perror("recv_udp:select"); exit(1);
    }


    if ( (hits==0) || ((hits>0) && (FD_ISSET(0,&mask))) ) {
      printf("Shutting down\n"); exit(0);
    }
    cc = recvfrom(socket_fd,&msg,sizeof(msg),0,
                          (struct sockaddr *)&from,&fsize);
    printsin(&from, "recv_udp: ", "Packet from:");
    printf("Got data ::%c%ld%c\n",msg.head,ntohl(msg.body),msg.tail);
    fflush(stdout);
  }
}
```

Internet Virtual Circuits (TCP/IP)

Want to extend pipe abstraction into the Internet. This means a *reliable* byte stream with no visible packets/messages.

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Client-server model implicit.

New kernel calls:

To mark socket as being capable of accepting TCP/IP connections, server does:

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#include <sys/socket.h>

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#include <sys/socket.h>

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```

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To accept a TCP/IP connection on a listening socket, server can then do:

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

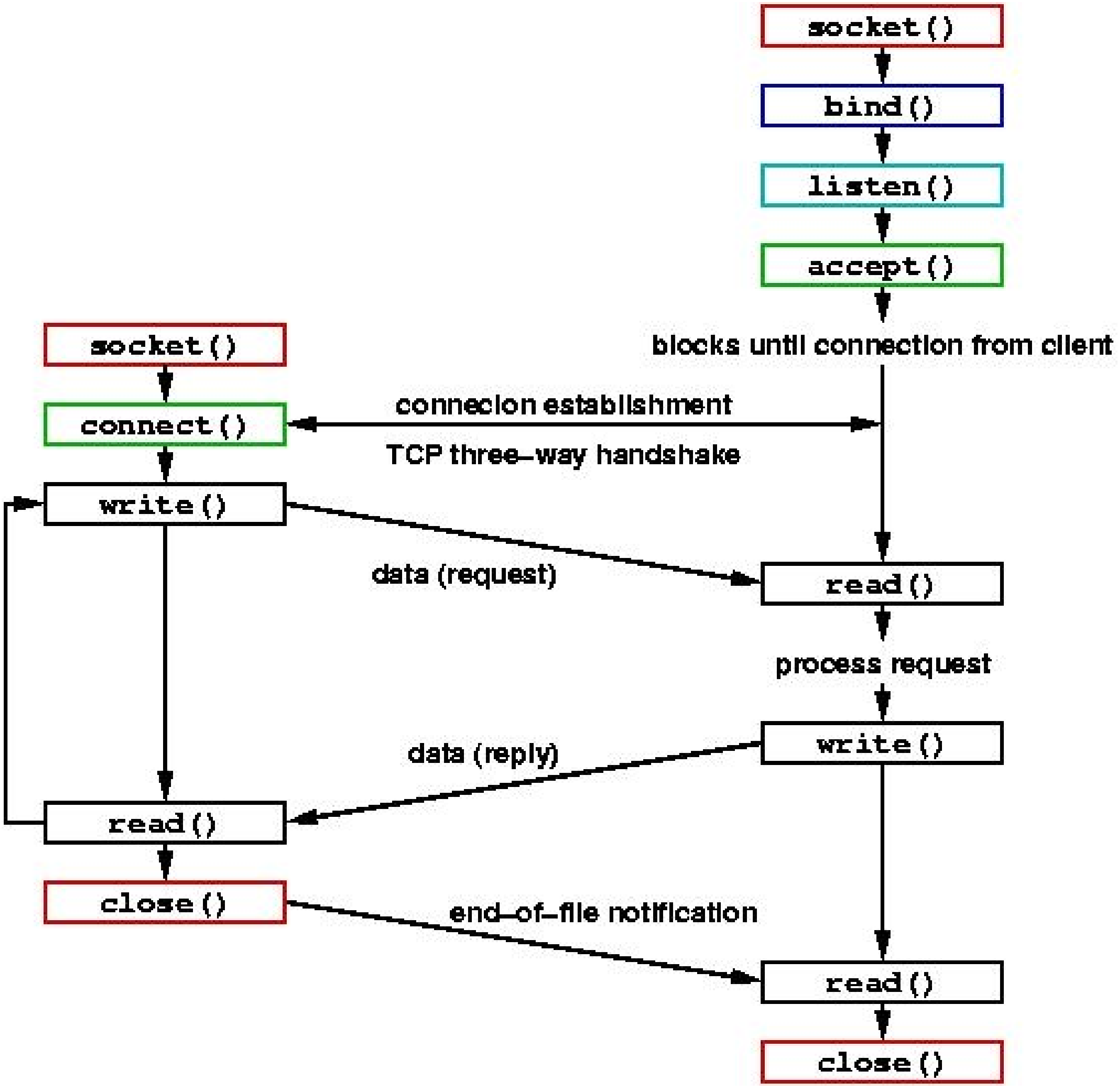
int accept(int s, struct sockaddr *addr, int *addrlen);
```

To initiate a connection to a server, client does:

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

int connect(int sockfd, struct sockaddr *serv_addr, int  addrlen );
```

Can then use `read` and `write` to pass data on the virtual circuit.


socket()
bind()
listen()
accept()
blocks until connection from client
socket()
connect()
connecion establishment
TCP three–way handshake
write()
data (request)
read()
process request
write()
data (reply)
read()
close()
end–of–file notification
read()
close()

inet_wstream.c TCP/IP Client

inet_wstream.c TCP/IP Client

```
char msg[] = { "false pearls before real swine" };
main(argc, argv)
int argc; char **argv;
{
  char *remhost; u_short remport;
  int sock, left, num, put;
  struct sockaddr_in remote;
  struct hostent *h;

  remhost = argv[1];  remport = atoi(argv[2]);

  sock = socket( AF_INET, SOCK_STREAM, 0 );

  bzero((char *) &remote, sizeof(remote));
  remote.sin_family = AF_INET;
  h = gethostbyname(remhost);
  bcopy((char *)h->h_addr, (char *)&remote.sin_addr, h->h_length);
  remote.sin_port = htons(remport);
  connect(sock, (struct sockaddr *)&remote, sizeof(remote));

/* can’t guarantee socket will accept all we try to write, cope */

  left = sizeof(msg); put=0;
  while (left > 0){
    if((num = write(sock, msg+put , left)) < 0) {
      perror("inet_wstream:write");
      exit(1);
    }
    else {
      left -= num;
      put += num;
    }
  }
}
```

inet_rstream.c TCP/IP Server

inet_rstream.c TCP/IP Server

```
main()
{
  int listener, conn, length; char ch;
  struct sockaddr_in s1, s2;

  listener = socket( AF_INET, SOCK_STREAM, 0 );

  bzero((char *) &s1, sizeof(s1));
  s1.sin_family = AF_INET;
  s1.sin_addr.s_addr = htonl(INADDR_ANY);  /* Any of this host’s interfaces is OK. */
  s1.sin_port = htons(0);                  /* bind() will gimme unique port. */
  bind(listener, (struct sockaddr *)&s1, sizeof(s1));
  length = sizeof(s1);
  getsockname(listener, (struct sockaddr *)&s1, &length); /* Find out port number */
  printf("RSTREAM:: assigned port number %d\n", s1.sin_port);

  listen(listener,1);
  length = sizeof(s2);
  conn=accept(listener, (struct sockaddr *)&s2, &length);
  printsin(&s2,"RSTREAM::", "accepted connection from");

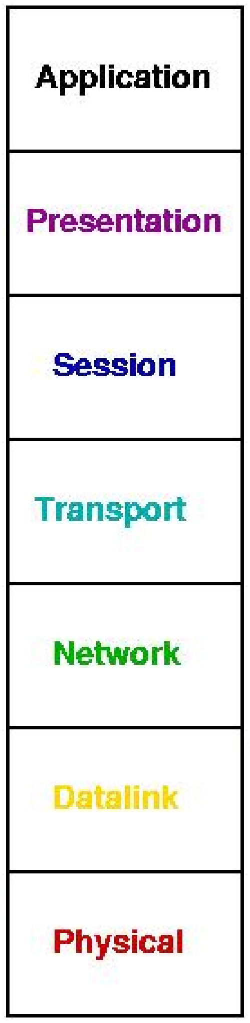
  printf("\n\nRSTREAM:: data from stream:\n");
  while ( read(conn, &ch, 1) == 1) putchar(ch);
  putchar(’\n’);
}
```

Typical TCP/IP Client/Server Server

Typical TCP/IP Client/Server Server

```
. . .
listener = socket(...);
. . .
bind(listener, ...);
listen(listener, ...);
...
while (1) {
    new = accept(listener, ...);
    if (fork() == 0) {
        close(listener);
        /* read lots of stuff from new */
    }
    close(new);
    while(wait3(status, WNOHANG, NULL)); /* Can also handle
                                            SIGCHLD */
}
```

OSI Reference Model



Application related protocols

e.g., FTP: handle file naming
convention differences

Services requested frequently

Concerned with syntax and semantics of information
transmission
e.g., data encoding, data compression

Allow users to establish session

Dialogue control
Token management
Synchronization

End–to–end layer

Ensure data from session layer arrives
in order, error free
Data broken into smaller units

Control operation of subnet

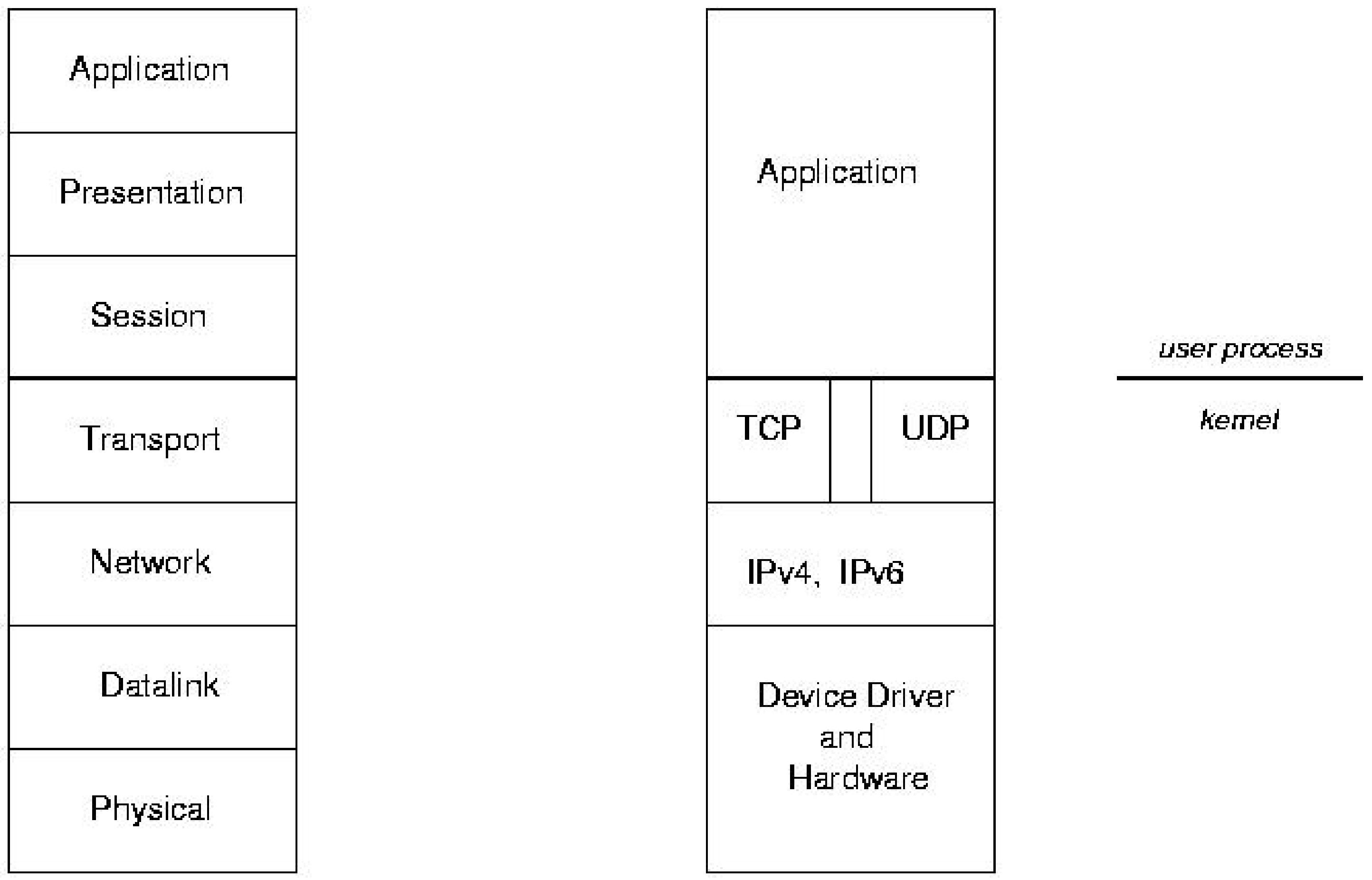
Routing
Congestion control
Accounting

Turn raw transmission into apparently error–free line

Data broken into frames
Create and recognize frame boundaries
Handle lost or duplicated frames

Transmission of raw bits over wire

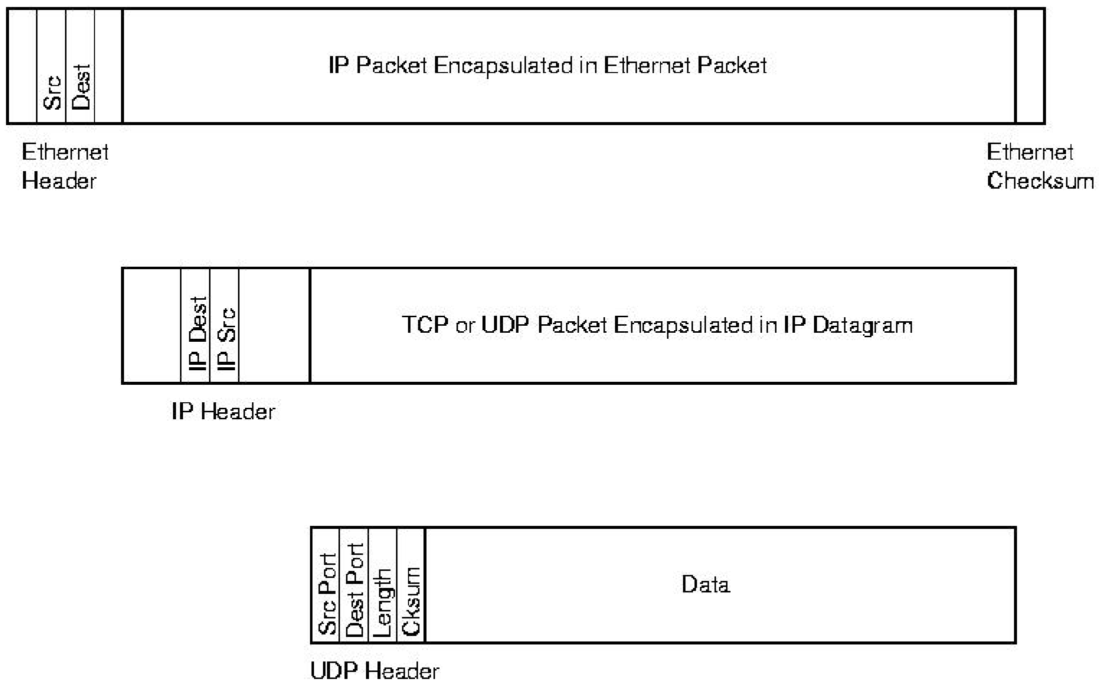
How many volts represent a 1, a 0?
Is transmission bidirectional?



OSI REFERENCE MODEL

INTERNET PROTOCOL SUITE

Packet Encapsulation



Ethernet

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jmayo: arp -a

```
cec.mtu.edu (141.219.151.196) at 08:00:20:1D:16:13 [ether] on eth0
kurosawa.hu.mtu.edu (141.219.148.44) at 00:50:04:A1:D4:C2 [ether] on eth0
cslserver.csl.mtu.edu (141.219.150.71) at 08:00:20:77:32:D6 [ether] on eth0
cs.mtu.edu (141.219.150.12) at 08:00:20:21:A5:D3 [ether] on eth0
brtr11.tc.mtu.edu (141.219.148.1) at 00:00:EF:06:76:30 [ether] on
eth0
```

```
jmayo> ping rainbow.cs.mtu.edu
PING rainbow.cs.mtu.edu (141.219.150.6) from 141.219.150.16 : 56(84) bytes of data.
64 bytes from rainbow.cs.mtu.edu (141.219.150.6): icmp_seq=0 ttl=255 time=1.2 ms64 bytes from rainbo
--- rainbow.cs.mtu.edu ping statistics ---
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round-trip min/avg/max = 0.5/0.8/1.2 ms
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rainbow.cs.mtu.edu (141.219.150.6) at 08:00:20:9C:2F:97 [ether] on eth0
```

jmayo: ping ftp.x.org

```
PING ftp.x.org (198.4.202.8) from 141.219.150.16 : 56(84) bytes of data.
64 bytes from ftp.x.org (198.4.202.8): icmp_seq=0 ttl=51 time=81.0 ms
64 bytes from ftp.x.org (198.4.202.8): icmp_seq=1 ttl=51 time=79.0 ms

--- ftp.x.org ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max = 79.0/80.0/81.0 ms
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  - ⋆ Network Information System (NIS)
- Access DNS via library routines

  resolver library; `gethostbyname`,`gethostbyaddr`,etc.

jmayo: traceroute www.sydney.com.au

```
traceroute to www.sydney.com.au (209.66.116.64), 30 hops max, 38 byte packets
 1  brtr11.tc.mtu.edu (141.219.148.1)  0.791 ms  0.585 ms  0.587 ms
 2  bfs001-backbone.tc.mtu.edu (141.219.72.6)  2.321 ms  1.086 ms  1.101 ms
 3  fe1-0-0.mtu2.mich.net (198.110.131.61)  1.600 ms  1.790 ms  1.590 ms
 4  198.108.23.141 (198.108.23.141)  13.184 ms  11.848 ms  11.948 ms
 5  aads.above.net (206.220.243.71)  74.809 ms  75.470 ms  74.266 ms
 6  core1-chicago-2.ord.above.net (216.200.254.89)  76.393 ms  73.363 ms  74.317 ms
 7  sjc-ord-oc12.sjc2.above.net (207.126.96.118)  73.871 ms  72.713 ms  73.291 ms
 8  core5-core1-oc48.sjc.above.net (216.200.0.177)  73.828 ms  72.795 ms  72.903 ms
 9  main2-core5-oc3.sjc.above.net (216.200.0.206)  77.723 ms  75.180 ms  73.493 ms
10  sydney.com.au (209.66.116.64)  77.176 ms  75.010 ms  75.228 ms
```

jmayo: traceroute cs.wm.edu

```
traceroute to cs.wm.edu (128.239.2.31), 30 hops max, 38 byte packets
 1  brtr11.tc.mtu.edu (141.219.148.1)  14.237 ms  0.713 ms  0.765 ms
 2  bfs001-backbone.tc.mtu.edu (141.219.72.6)  1.955 ms  1.127 ms  0.920 ms
 3  fe1-0-0.mtu2.mich.net (198.110.131.61)  2.114 ms  1.755 ms  1.609 ms
 4  198.108.23.141 (198.108.23.141)  12.832 ms  12.052 ms  12.678 ms
 5  192.122.182.18 (192.122.182.18)  16.851 ms  16.688 ms  16.350 ms
 6  clev-ipls.abilene.ucaid.edu (198.32.8.26)  22.950 ms  23.675 ms  23.446 ms
 7  nycm-clev.abilene.ucaid.edu (198.32.8.30)  34.659 ms  35.171 ms  34.652 ms
 8  cisco7200-at-wm-to-noc-at-abilene.wm.edu (128.239.12.1)  46.280 ms  45.460 ms  46.232 ms
 9  128.239.14.6 (128.239.14.6)  46.616 ms  45.396 ms  45.868 ms
10  va.cs.wm.edu (128.239.2.31)  47.630 ms  46.582 ms  47.162 ms
```