ECE 463
Introduction to Computer Networks
Lecture: Socket Programming

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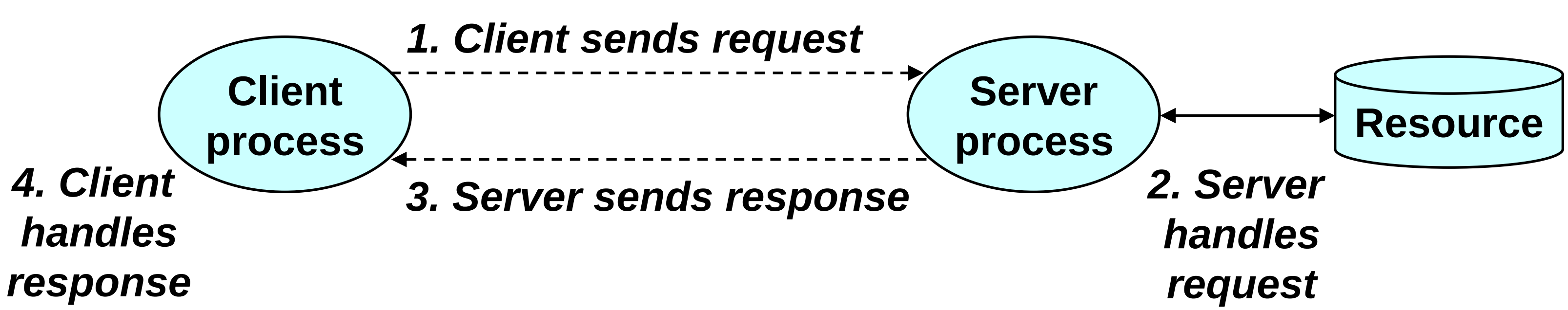
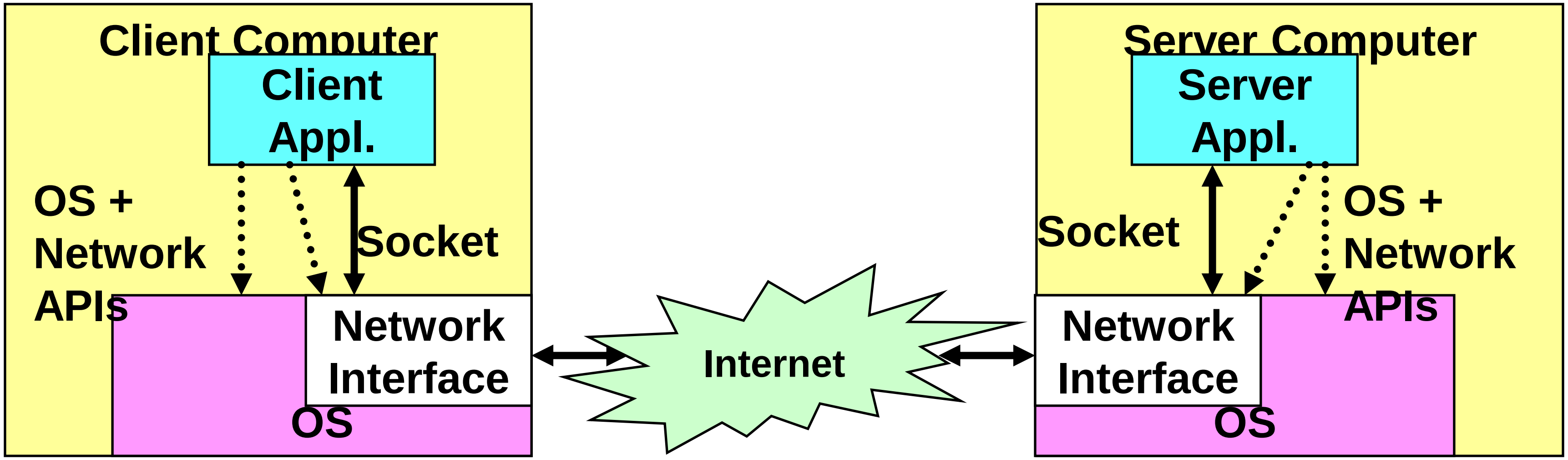
A Client-Server Transaction

- Every network application is based on the client-server model:
  - A *server* process and one or more *client* processes
  - Server manages some *resource*.
  - Server provides *service* by manipulating resource for clients.



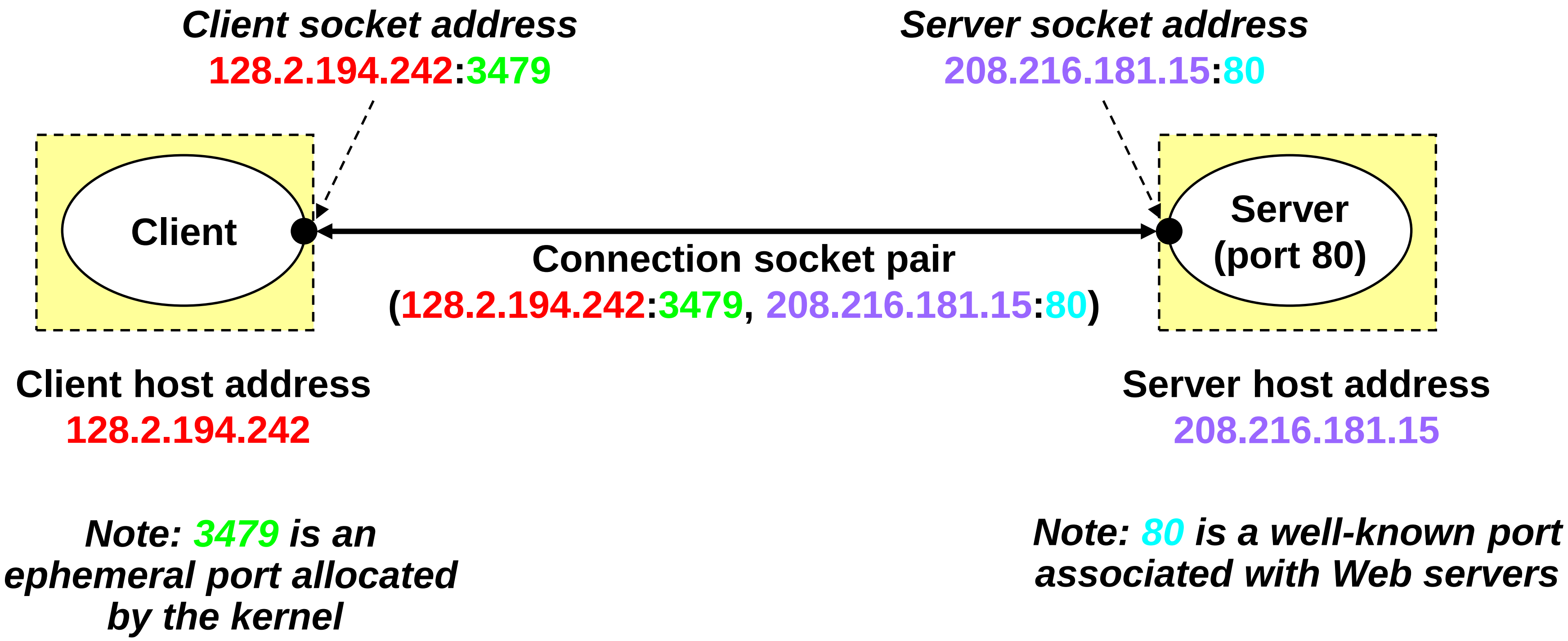
Network Applications



- Access to Network via Program Interface
  - Sockets make network I/O look like files
  - Call system functions to control and communicate
  - Network code handles issues of routing, reliability, ordering, etc.

Internet Connections (TCP/IP)

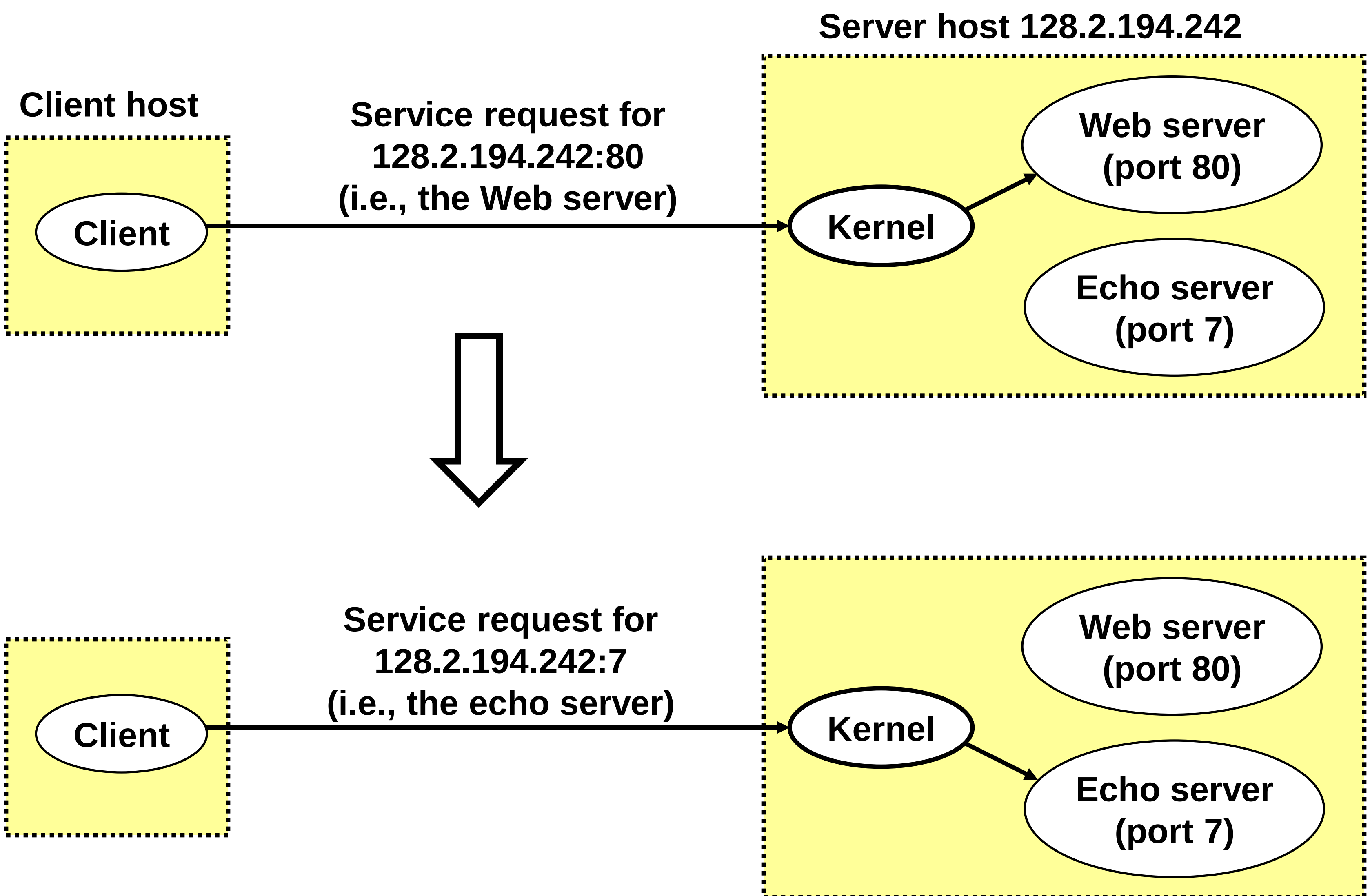
- Clients and servers communicate by sending streams of bytes over *connections*.
- Connections are point-to-point, full-duplex (2-way communication), and reliable.



Clients

- Examples of client programs
  - Web browsers, `ftp`, `telnet`, `ssh`
- How does a client find the server?
  - The IP address in the server socket address identifies the host
  - The (well-known) port in the server socket address identifies the service, and thus implicitly identifies the server process that performs that service.
  - Examples of well known ports
    - Port 7: Echo server
    - Port 23: Telnet server
    - Port 25: Mail server
    - Port 80: Web server

Using Ports to Identify Services

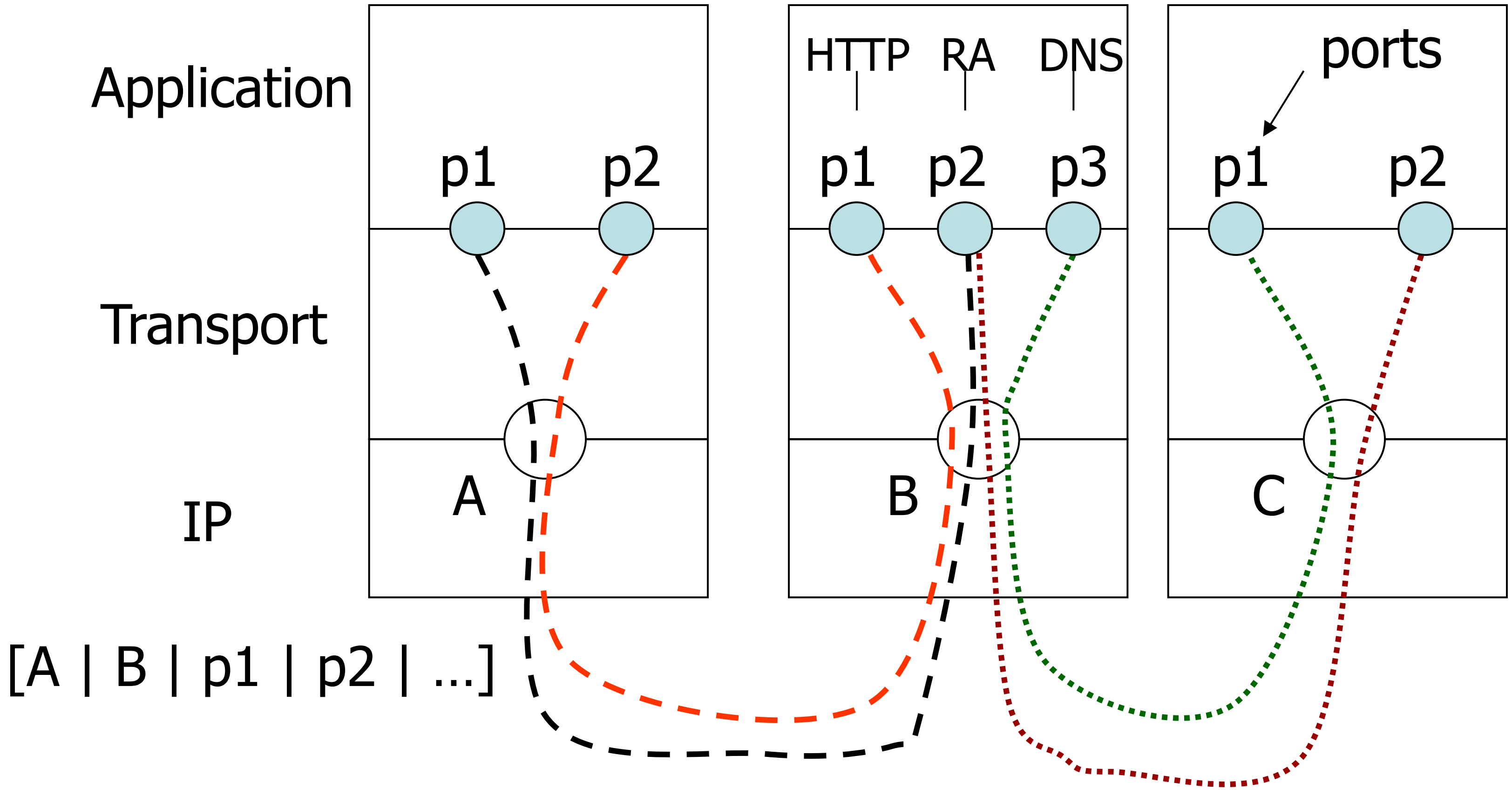


Servers

- Servers are long-running processes (daemons).
  - Created at boot-time (typically) by the init process
  - Run continuously until the machine is turned off.
- Each server waits for requests to arrive on a well-known port associated with a particular service.
  - Port 7: echo server
  - Port 23: telnet server
  - Port 25: mail server
  - Port 80: HTTP server
- A machine that runs a server process is also often referred to as a "server."

See `/etc/services` for a comprehensive list of the services available on a Linux machine.

Transport Layer



Multiplexing using Ports

- Well-known Vs. Ephemeral Ports
  - 0-1023 “well-known” port numbers
  - Typically used by servers of well-known apps
  - Higher numbers: “ephemeral”

Socket Programming using TCP

- TCP: “Byte Stream” Abstraction
  - Sender sends a stream of bytes
  - Receiver gets a stream of bytes

- Guarantees:
  - Reliability
  - In-Order Delivery

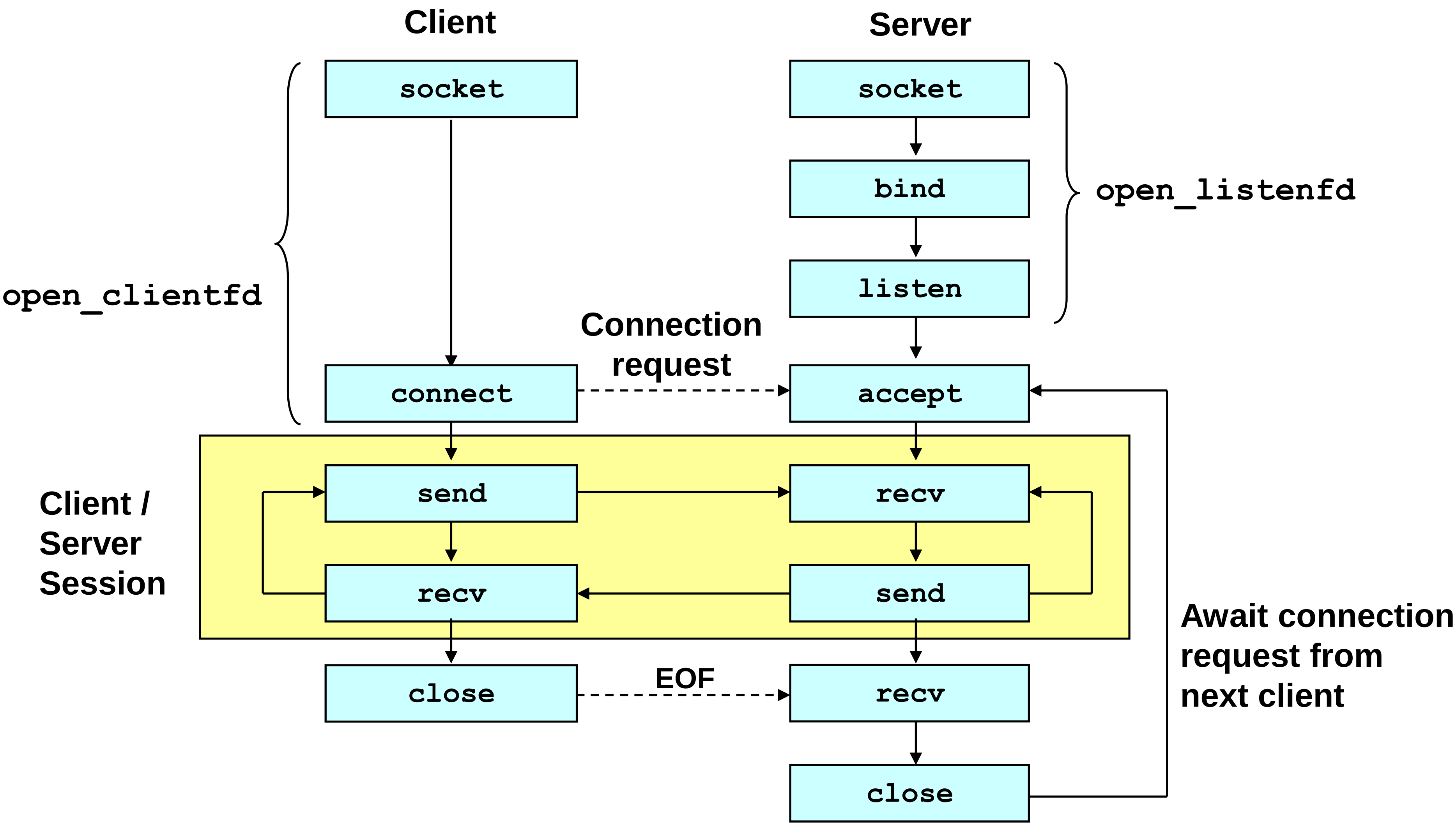
Sockets Interface

- Created in the early 80’s
  - Part of the original Berkeley distribution of Unix
  - Contained an early version of the Internet protocols.
- Provides a user-level interface to the network.
- Underlying basis for all Internet applications.
- Based on client/server programming model.

Sockets

- What is a socket?
  - To the kernel: endpoint of communication.
  - To an application: a file descriptor that lets the application read/write from/to the network.
  - All Unix I/O devices are modeled as files.
- Clients and servers communicate with each by reading from and writing to socket descriptors.
- The main distinction between regular file I/O and socket I/O is how the application "opens" the socket descriptors.

Overview of the Sockets Interface



Echo Client Main Routine

```
/* usage: ./echoclient host port */
int main(int argc, char **argv)
{
    int clientfd, port;
    char *host, buf[MAXLINE];


    host = argv[1];
    port = atoi(argv[2]);

    clientfd = Open_clientfd(host, port);

   while (fgets(buf, MAXLINE, stdin) != NULL) {
        write(clientfd, buf, strlen(buf));
        read(clientfd, buf, MAXLINE,);
        fputs(buf, stdout);
    }
    close(clientfd);
    exit(0);
}
```

Send line to server

Receive line from server

Echo Client: `open_clientfd`

```
int open_clientfd(char *hostname, int port)
{
  int clientfd;
  struct hostent *hp;
  struct sockaddr_in serveraddr;

  if ((clientfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1; /* check errno for cause of error */

  /* Fill in the server's IP address and port */
  if ((hp = gethostbyname(hostname)) == NULL)
    return -2; /* check h_errno for cause of error */
  bzero((char *) &serveraddr, sizeof(serveraddr));
  serveraddr.sin_family = AF_INET;
  bcopy((char *)hp->h_addr,
        (char *)&serveraddr.sin_addr.s_addr, hp->h_length);
  serveraddr.sin_port = htons(port);

  /* Establish a connection with the server */
  if (connect(clientfd, (SA *) &serveraddr, sizeof(serveraddr)) < 0)
    return -1;
  return clientfd;
}
```

This function opens a connection from the client to the server at `hostname:port`

Echo Client: `open_clientfd` (`socket`)

- `socket` creates a socket descriptor on the client.
  - `AF_INET`: indicates that the socket is associated with Internet protocols.
  - `SOCK_STREAM`: selects a reliable byte stream connection.

```
int clientfd;  /* socket descriptor */

if ((clientfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1; /* check errno for cause of error */

... (more)
```

Echo Client: `open_clientfd` (`gethostbyname`)

- Convert server name to an Internet address (IP address)

```
int clientfd;                    /* socket descriptor */
struct hostent *hp;              /* DNS host entry */
struct sockaddr_in serveraddr; /* server's IP address */

...

/* fill in the server's IP address and port */
if ((hp = gethostbyname(hostname)) == NULL)
    return -2; /* check h_errno for cause of error */
…..
```

Socket Address Structures

- Generic socket address:
  - Address arguments to `connect`, `bind`, and `accept`.

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

- Internet-specific socket address:

```
struct sockaddr_in  {
  unsigned short  sin_family;  /* address family (always AF_INET) */
  unsigned short  sin_port;    /* port num in network byte order */
  struct in_addr  sin_addr;    /* IP addr in network byte order */
  unsigned char   sin_zero[8]; /* pad to sizeof(struct sockaddr) */
};
```

Echo Client: `open_clientfd`

- The client then builds the server's Internet address.

```
int clientfd;                  /* socket descriptor */
struct hostent *hp;            /* DNS host entry */
struct sockaddr_in serveraddr; /* server’s IP address */

...

/* fill in the server's IP address and port */
if ((hp = gethostbyname(hostname)) == NULL)
    return -2; /* check h_errno for cause of error */
bzero((char *) &serveraddr, sizeof(serveraddr));
serveraddr.sin_family = AF_INET;
bcopy((char *)hp->h_addr,
      (char *)&serveraddr.sin_addr.s_addr, hp->h_length);
serveraddr.sin_port = htons(port);
```

Endian Format

- Different architectures have different endian formats
- IP addr and port stored in network (big-endian) byte order
  - `htonl()` converts longs from host byte order to network byte order.
  - `htons()` converts shorts from host byte order to network byte order.
  - ntohl(), ntohs() respectively convert from network byte order to host byte order

Echo Client: `open_clientfd` (`connect`)

- The client creates a connection with the server.
  - Client process blocks until connection is created.
  - After resuming, the client is ready to begin exchanging messages with the server on descriptor `sockfd`.

```
  int clientfd;                         /* socket descriptor */
  struct sockaddr_in serveraddr;    /* server address */
  typedef struct sockaddr SA;       /* generic sockaddr */
...
  /* Establish a connection with the server */
  if (connect(clientfd, (SA *)&serveraddr, sizeof(serveraddr)) < 0)
    return -1;
  return clientfd;
}
```

Echo Server: Main Loop

- The server loops endlessly, waiting for connection requests, then reading input from the client, and echoing the input back to the client.

```
main() {

   /* create and configure the listening socket */

   while(1) {
      /* accept(): wait for a connection request */
      /* echo(): read and echo input lines from client til EOF */
      /* Close(): close the connection */
   }
}
```

Echo Server: Main Routine

```
int main(int argc, char **argv) {
    int listenfd, connfd, port, clientlen;
    struct sockaddr_in clientaddr;
    struct hostent *hp;
    char *haddrp;

    port = atoi(argv[1]); /* the server listens on a port passed
                             on the command line */
    listenfd = open_listenfd(port);

    while (1) {
        clientlen = sizeof(clientaddr);
        connfd = accept(listenfd, (SA *)&clientaddr, &clientlen);
        hp = gethostbyaddr((const char *)&clientaddr.sin_addr.s_addr,
                           sizeof(clientaddr.sin_addr.s_addr), AF_INET);
        haddrp = inet_ntoa(clientaddr.sin_addr);
        printf("Fd %d connected to %s (%s:%s)\n",
               connfd, hp->h_name, haddrp, ntohs(clientaddr.sin_port));
        echo(connfd);
        close(connfd);
    }
}
```

Echo Server: `open_listenfd`

```
int open_listenfd(int port)
{
    int listenfd, optval=1;
    struct sockaddr_in serveraddr;

    /* Create a socket descriptor */
    if ((listenfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
        return -1;

    /* Eliminates "Address already in use" error from bind. */
    if (setsockopt(listenfd, SOL_SOCKET, SO_REUSEADDR,
                   (const void *)&optval , sizeof(int)) < 0)
        return -1;

... (more)
```

Echo Server: `open_listenfd` (cont)

```
...

  /* Listenfd will be an endpoint for all requests to port
       on any IP address for this host */
    bzero((char *) &serveraddr, sizeof(serveraddr));
    serveraddr.sin_family = AF_INET;
    serveraddr.sin_addr.s_addr = htonl(INADDR_ANY);
    serveraddr.sin_port = htons((unsigned short)port);
    if (bind(listenfd, (SA *)&serveraddr, sizeof(serveraddr)) < 0)
        return -1;

    /* Make it a listening socket ready to accept
       connection requests */
    if (listen(listenfd, LISTENQ) < 0)
        return -1;

   return listenfd;
}
```

Echo Server: `open_listenfd` (`socket`)

- `socket` creates a socket descriptor on the server.
  - `AF_INET`: indicates that the socket is associated with Internet protocols.
  - `SOCK_STREAM`: selects a reliable byte stream connection.

```
int listenfd; /* listening socket descriptor */

/* Create a socket descriptor */
if ((listenfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1;
```

Echo Server: `open_listenfd` (initialize socket address)

- Next, we initialize the socket with the server's Internet address (IP address and port)

```
  struct sockaddr_in serveraddr; /* server's socket addr */
...
  /* listenfd will be an endpoint for all requests to port
     on any IP address for this host */
  bzero((char *) &serveraddr, sizeof(serveraddr));
  serveraddr.sin_family = AF_INET;
  serveraddr.sin_addr.s_addr = htonl(INADDR_ANY);
  serveraddr.sin_port = htons((unsigned short)port);
```

Echo Server: `open_listenfd` (`bind`)

- `bind` associates the socket with the socket address we just created.

```
int listenfd;                  /* listening socket */
struct sockaddr_in serveraddr; /* server's socket addr */

...
  /* listenfd will be an endpoint for all requests to port
     on any IP address for this host */
  if (bind(listenfd, (SA *)&serveraddr, sizeof(serveraddr)) < 0)
      return -1;
```

Echo Server: `open_listenfd` (`listen`)

- `listen` indicates that this socket will accept connection (`connect`) requests from clients.

```
int listenfd; /* listening socket */

...
 /* Make it a listening socket ready to accept connection requests */
    if (listen(listenfd, LISTENQ) < 0)
        return -1;
    return listenfd;
}
```

Echo Server: Main Routine

```
int main(int argc, char **argv) {
    int listenfd, connfd, port, clientlen;
    struct sockaddr_in clientaddr;
    struct hostent *hp;
    char *haddrp;

    port = atoi(argv[1]); /* the server listens on a port passed
                             on the command line */
    listenfd = open_listenfd(port);

    while (1) {
        clientlen = sizeof(clientaddr);
        connfd = accept(listenfd, (SA *)&clientaddr, &clientlen);
        hp = gethostbyaddr((const char *)&clientaddr.sin_addr.s_addr,
                           sizeof(clientaddr.sin_addr.s_addr), AF_INET);
        haddrp = inet_ntoa(clientaddr.sin_addr);
        printf("Fd %d connected to %s (%s:%s)\n",
               connfd, hp->h_name, haddrp, ntohs(clientaddr.sin_port));
        echo(connfd);
        close(connfd);
    }
}
```

Echo Server: `accept`

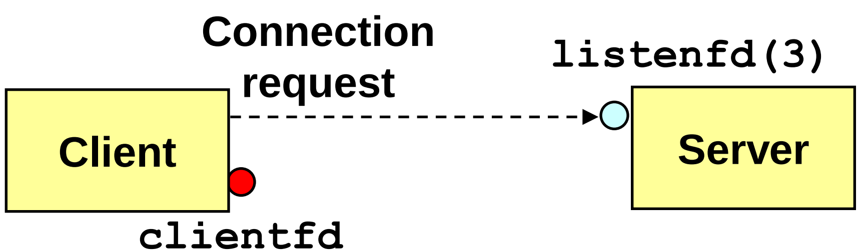
- `accept()` blocks waiting for a connection.

```
int listenfd; /* listening descriptor */
int connfd;   /* connected descriptor */
struct sockaddr_in clientaddr;
int clientlen;

clientlen = sizeof(clientaddr);
connfd = Accept(listenfd, (SA *)&clientaddr, &clientlen);
```

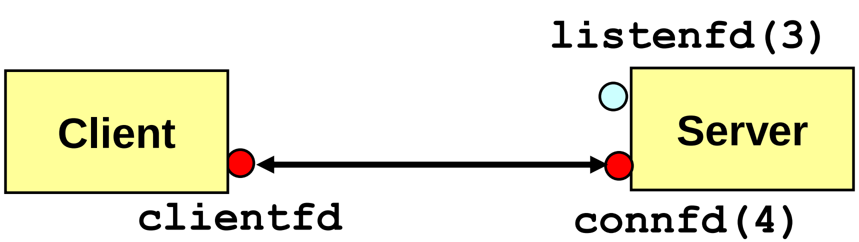
- `accept` returns a *connected descriptor* (`connfd`) with the same properties as the *listening descriptor* (`listenfd`)
  - Returns when the connection between client and server is created and ready for I/O transfers.
  - All I/O with the client will be done via the connected socket.
- `accept` also fills in client's IP address.

Echo Server: `accept` Illustrated

1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`.



2. Client makes connection request by calling and blocking in `connect`.



3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`.

Connected vs. Listening

- Listening descriptor
  - End point for client connection requests.
  - Created once and exists for lifetime of the server.
- Connected descriptor
  - End point of connection between client and server.
  - A new descriptor is created each time the server accepts a connection request from a client.
  - Exists only as long as it takes to service client.
- Why the distinction?
  - Allows for concurrent servers that can communicate over many client connections simultaneously.

Echo Server: Identifying Client

- The server can determine the domain name, IP address, and port of the client.

```
struct hostent *hp;  /* pointer to DNS host entry */
char *haddrp;        /* pointer to dotted decimal string */

hp = gethostbyaddr((const char *)&clientaddr.sin_addr.s_addr,
                   sizeof(clientaddr.sin_addr.s_addr), AF_INET);
haddrp = inet_ntoa(clientaddr.sin_addr);
printf("Fd %d connected to %s (%s:%s)\n",
       connfd, hp->h_name, haddrp, ntohs(clientaddr.sin_port));
```

Echo Server: `echo`

- The server reads and echoes text lines until EOF (end-of-file) is encountered.
  - EOF notification caused by client calling `close(clientfd)`.
  - IMPORTANT: EOF is a condition, not a particular data byte.

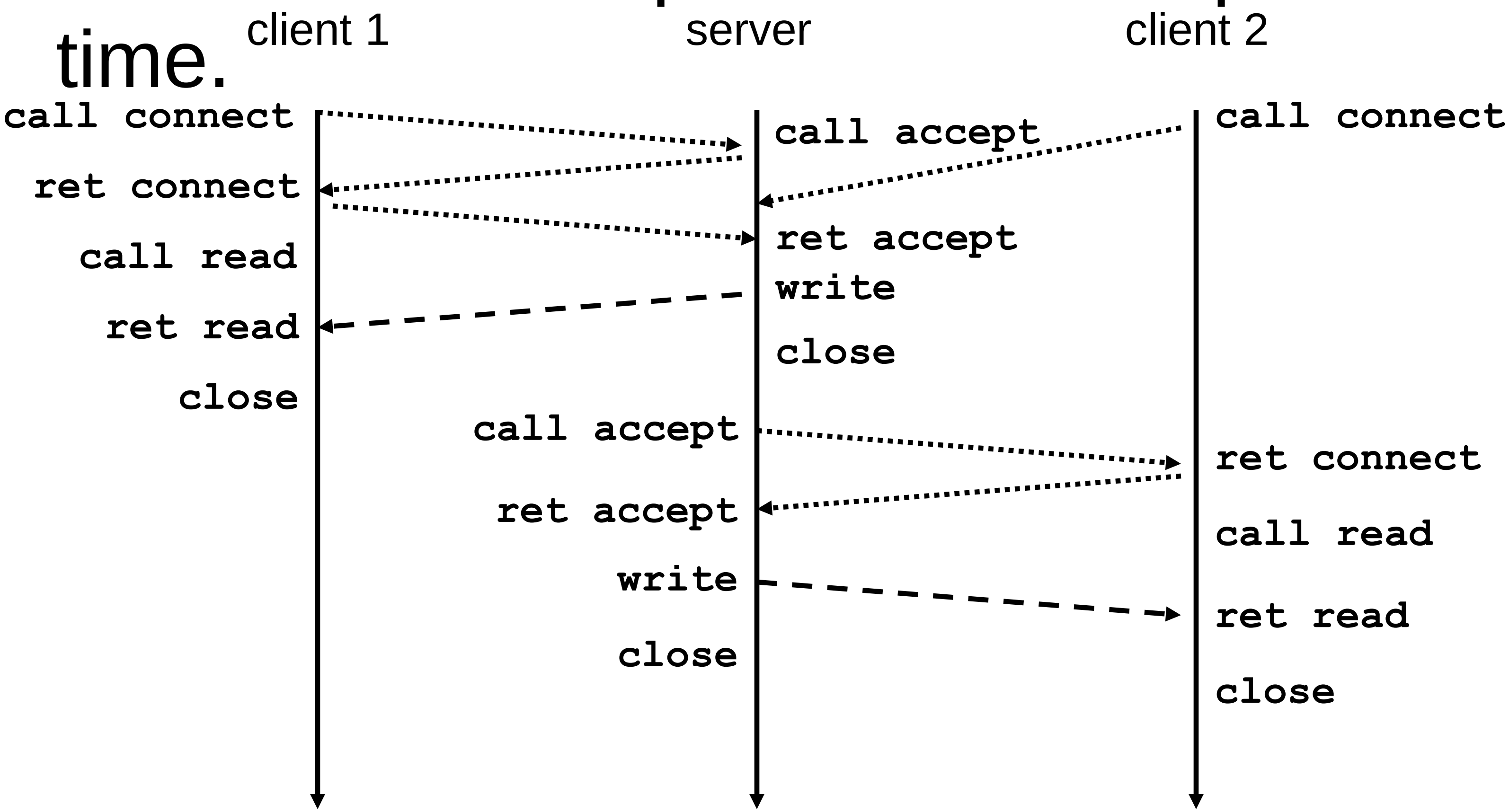
```
void echo(int connfd)
{
    size_t n;
    char buf[MAXLINE];



    while((n = read(connfd, buf, MAXLINE)) != 0) {
        printf("server received %d bytes\n", n);
         write(connfd, buf, n);
    }
}
```

Receive line from client

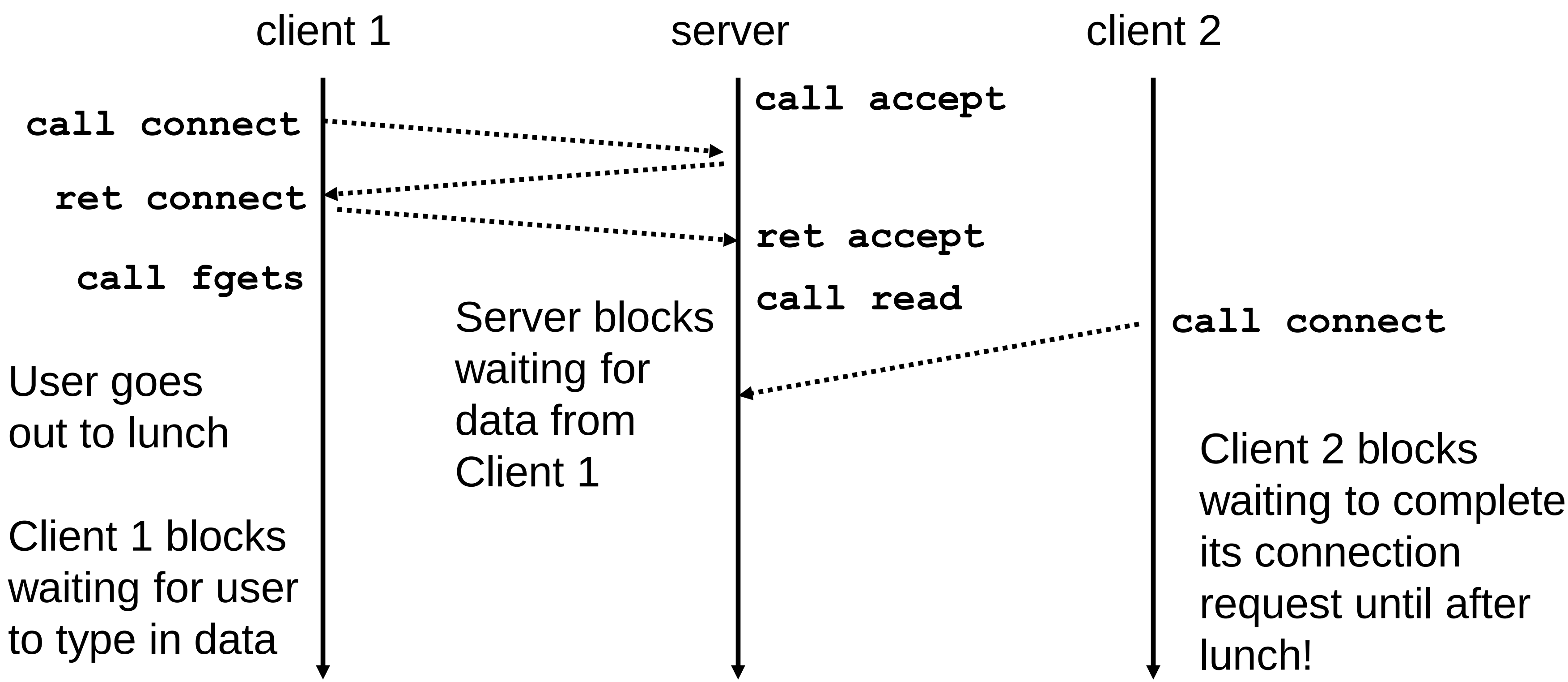
Send line to client

Iterative Servers

- Iterative servers process one request at a time.



Iterative Servers: "Blocking"

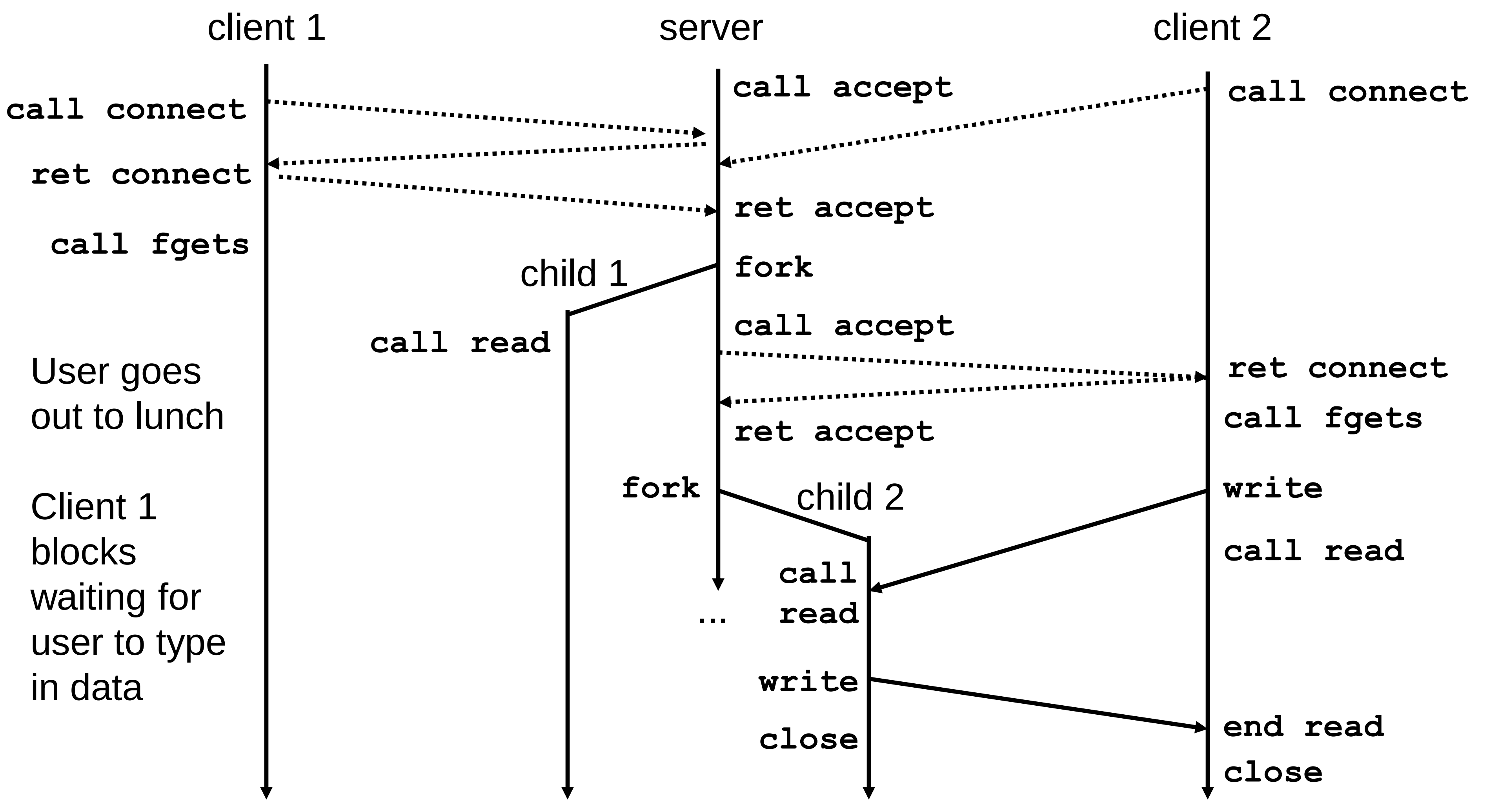


- Solution: use *concurrent servers* instead.
  - Concurrent servers use multiple concurrent flows to serve multiple clients at the same time.

Mechanisms for Concurrency

- 1. Processes
  - Each process has private address space.
- 2. I/O multiplexing with `select()`
  - User manually interleaves multiple flows.
  - Each flow shares the same address space.
- 3. Threads
  - Kernel interleaves multiple logical flows.
  - Each flow shares the same address space.

Concurrent Servers



Processes and Fork

- A **process** is an instance of a computer program that is being sequentially executed by a computer system that has the ability to run several computer programs concurrently.
- Fork:
  - Enables a process to make a copy of itself, so that one copy can handle one operation, while the other copy handles another task.

Fork() mechanics

- Calling fork()
  - Returns twice!
  - Once in parent process: ret value is childpid
  - Once in child process: ret value is 0
- All descriptors open in parent before the call to fork are shared with the child after fork returns.
  - Child and parent close descriptors not applicable to them.

Iterative Server

```
      ......

    while (1) {
        clientlen = sizeof(clientaddr);
        connfd = accept(listenfd, (SA *)&clientaddr, &clientlen);
        hp = gethostbyaddr((const char *)&clientaddr.sin_addr.s_addr,
                        sizeof(clientaddr.sin_addr.s_addr), AF_INET);
        haddrp = inet_ntoa(clientaddr.sin_addr);
        printf("Fd %d connected to %s (%s:%s)\n",
               connfd, hp->h_name, haddrp,ntohs(clientaddr.sin_port));
        echo(connfd);
        close(connfd);
    }
}
```

Concurrent Server

```
........

while (1) {
     clientlen = sizeof(clientaddr);
     connfd = accept(listenfd, (SA *)&clientaddr, &clientlen);

    if( (childpid = Fork()) == 0){
            /* child process */

      close(listenfd);
      processRequest(connfd);
      exit(0);
    }
     close(connfd);          /* parent process */
}
```

Mechanisms for Concurrency

- 1. Processes
  - Each process has private address space.
- 2. I/O multiplexing with `select()`
  - User manually interleaves multiple flows.
  - Each flow shares the same address space.
- 3. Threads
  - Kernel interleaves multiple logical flows.
  - Each flow shares the same address space.

I/O Multiplexing with Select

- Select allows the process to instruct the kernel to wait for one of multiple events to occur.
- Process to be waken up when one of the events occurs.
- Example events:
  - New data arrived on a connection
  - A timeout has expired.

Example: Quiz Program

- Design a “quiz” program
  - Ask user a question,
    - If user answers question within the time, process question
    - Else if user doesn’t respond within the time, he loses,

- How would we design this?

Example: Quiz program using select

```
#include <stdio.h>
#include <sys/select.h>

int main(void) {
  fd_set rfds;
  struct timeval tv;
  int retval;
  char ch1,ch2;

  while(1){
         tv.tv_sec = 5; tv.tv_usec = 0; /* Wait up to five seconds. */
         FD_ZERO(&rfds);
         FD_SET(0, &rfds);

         retval = select(1, &rfds, NULL, NULL, &tv);

         if (FD_ISSET(0, &rfds)){
               scanf("%c",&ch1);  scanf("%c",&ch2);
               printf("Data is available now: %c %c",ch1,ch2);
        }
        else{
           printf("No data within five seconds.\n");
        }
    }
  }
```

The `select` Function

```
int select(int maxfdp1,
           fd_set *readset,
            fd_set *writefds,
            fd_set *errorfds,
            struct timeval *timeout);
```

- readset: Specifies file descriptors to check for being ready to read
- writefds: Specifies the file descriptors to be checked for being ready to write
- errorfds: Specifies the file descriptors to be checked for error conditions pending, and on output indicates which file descriptors have error conditions pending.
- timeout: Specifies maximum time for which select must block.

The `select` Function

- Entries can be set to NULL if they are not relevant.

```
int select(int maxfdp1, fd_set *readset, NULL, NULL, NULL);
```

`readset`

- Opaque bit vector (max FD_SETSIZE bits) that indicates membership in a *descriptor set.*
  - On Linux machines, FD_SETSIZE = 1024
- If bit k is 1, then descriptor k is a member of the descriptor set.
- When call **`select`**, should have readset indicate which descriptors to test

`maxfdp1`

- Maximum descriptor in descriptor set plus 1.
- Tests descriptors 0, 1, 2, ..., maxfdp1 - 1 for set membership.

- `select()` returns the number of ready descriptors and keeps “on” each bit of `readset` for which corresponding descriptor is ready

Macros for Manipulating Set Descriptors

- `void FD_ZERO(fd_set *fdset);`
  - Turn off all bits in `fdset`.
- `void FD_SET(int fd, fd_set *fdset);`
  - Turn on bit `fd` in `fdset`.
- `void FD_CLR(int fd, fd_set *fdset);`
  - Turn off bit `fd` in `fdset`.
- `int FD_ISSET(int fd, *fdset);`
  - Is bit `fd` in `fdset` turned on?

Example: Waiting on 2 descriptors

```
 …..
while (1){
    FD_ZERO(&rfds);
    FD_SET(socketfd1, &rfds);
    FD_SET(socketfd2, &rfds);
    maxfd= max(socketfd1,socketfd2)+1  // max is a function that returns
                                         max of 2 numbers.
    retval = select(maxfd, &rfds, NULL, NULL, NULL);

    if (FD_ISSET(socketfd1, &rfds)){
           // read data from socketfd1
    }
    else if (FD_ISSET(socketfd2, &rfds)){
            // read data from socketfd2
    }
}
```

Example: Concurrent Server

- Maintain a pool of connected descriptors.
  - 1 listening descriptor, 1 connected descriptor for each connection
- Repeat the following forever:
  - Use the Unix `select` function to block until:
    - (a) New connection request arrives on the listening descriptor.
    - (b) New data arrives on an existing connected descriptor.
  - If (a), add the new connection to the pool of connections.
  - If (b), read any available data from the connection
    - Close connection on EOF and remove it from the pool.

Pro and Cons of Event-Based Designs

- Design of choice for high-performance Web servers and search engines.
  - One logical control flow.
  - Can single-step with a debugger.
  - No process or thread control overhead.
- Key issues with select:
  - More complex to code than process- or thread-based designs.

---UDP Sockets---

- Discussion so far focused on client/server programming with TCP.
- Programming with UDP similar, but a few key differences.

TCP Vs. UDP

- TCP: Reliable, in-order delivery
- UDP: Unreliable, possibly out-of-order delivery
- TCP:
  - Connection-Oriented, Stream Semantics
  - TCP: “connections”: state that captures a given pair of end-points are communicating.
  - Stream of bytes sent across end-points
- UDP:
  - Connectionless, datagram semantics
  - No “state” across a sequence of packets

UDP Vs. TCP Sockets

- Call to socket()
  - Use SOCK_DGRAM instead of SOCK_STREAM

UDP:

```
clientfd = socket(AF_INET, SOCK_DGRAM, 0)
```

TCP:

```
clientfd = socket(AF_INET, SOCK_STREAM, 0)
```

UDP Vs. TCP: Functions called

- TCP Client
  - Socket
  - Connect
- TCP Server
  - Socket
  - Bind
  - Listen
  - Accept
- UDP Client
  - Socket
  - sendto/recvfrom
- UDP Server
  - Socket
  - Bind
  - sendto/recvfrom

write/read Vs. sendto/recvfrom

- TCP uses connect()
  - Establishes communication with given server.
  - All further reads/writes refer to this server.
- UDP: typically don't use connect()
  - All further sendto must specify who the intended destination is.

  write(int fd, const void *buf, size_t count);

  sendto(int fd, const void *buf, size_t count, int flags, const struct sockaddr *dest_addr,socklen_t dest_len);
- Similar for read/recvfrom.

Stream Vs. Datagram Semantics

- TCP:
  - Assume application does:

    write(int fd, const void *buf, size_t count);
  - No relationship between buffer size and actual TCP packets sent.
  - In fact, must put “write” (or “read”) inside a loop.
- UDP:
  - Assume application does:

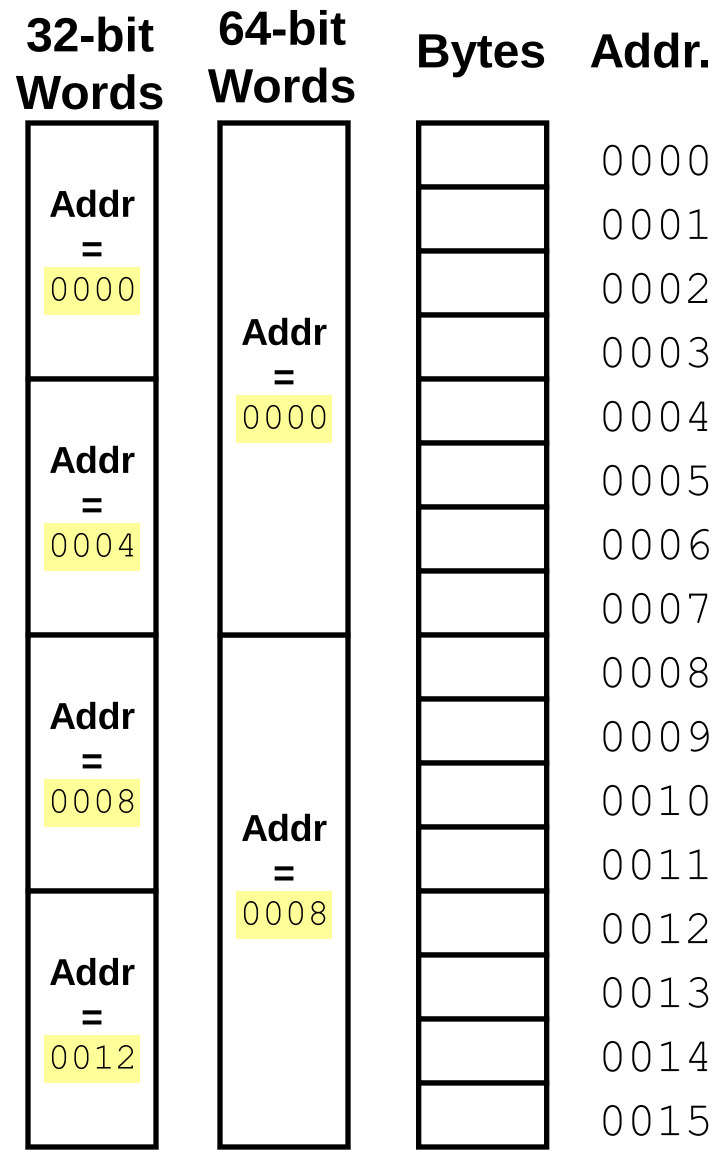
    sendto(int fd, const void *buf, size_t count,…);
  - buf corresponds to an actual UDP data packet sent
  - Each call to sendto() corresponds to one UDP packet.
  - Each call to recvfrom() reads entire UDP packet.

For More Information

- W. Richard Stevens, *Unix Network Programming: Networking APIs: Sockets and XTI*, Volume 1, Second Edition, Prentice Hall, 1998.
  - THE network programming bible.

C-programming Hints

- Addresses Specify Byte Locations
  - Address of first byte in word
  - Addresses of successive words differ by 4 (32-bit) or 8 (64-bit)



Simple Data Types

datatype	**size**	**values**
char	1	-128 to 127
short	2	-32,768 to 32,767
int	4	-2,147,483,648 to 2,147,483,647
long	4	-2,147,483,648 to 2,147,483,647
float	4	3.4E+/-38 (7 digits)
double	8	1.7E+/-308 (15 digits long)

Byte Ordering

- How should bytes within multi-byte word be ordered in memory?
- Conventions
  - Sun’s, Mac’s are “Big Endian” machines
    - Least significant byte has highest address
  - Alphas, PC’s are “Little Endian” machines
    - Least significant byte has lowest address

Byte Ordering Example

- Big Endian: LSB has highest address
- Little Endian: LSB has lowest address
- Example
  - Variable `x` has 4-byte representation `0x01234567`
  - Address given by `&x` is `0x100`

Big Endian

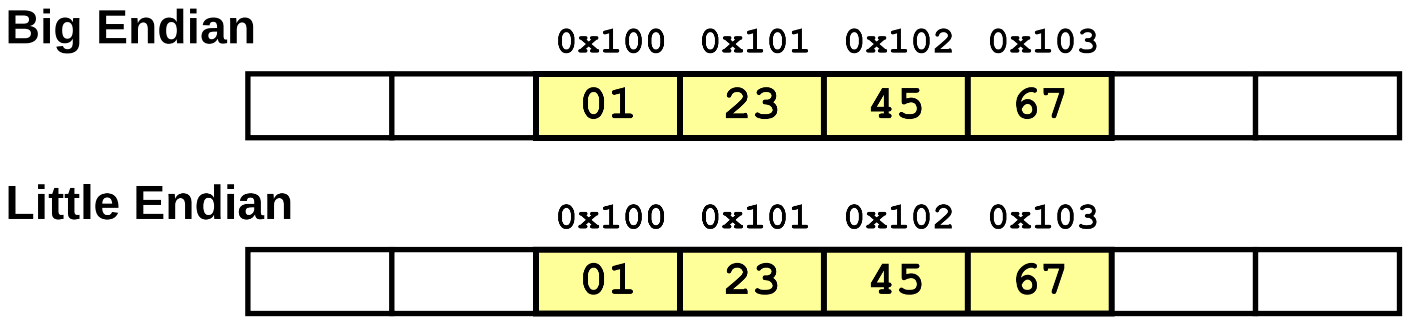
		0x100	0x101	0x102	0x103		
		01	23	45	67		

Little Endian

		0x100	0x101	0x102	0x103		
		67	45	23	01		

Byte Ordering Example

- What if character array?
  - 4 bytes `0x01 0x23 0x45 0x67`



C Test

```
void main(){
  int a= 0x01020304;

  int *ptr= &a;
  char *c = (char *)ptr;

  char x = (*c);
  printf ("%d \n",x);
}
```

What happens if we type cast a (char *) to a (long *)?

More C-stuff

- struct Pkt{

```
    int pktCode;
    char data[10];
  };

    Pkt pkt; … fill up stuff …

    PktPtr  *pktPtr=&pkt;
    char *dataPtr= (char *)pktPtr;

    char dataArr[10000];
    memcpy(dataArr, pktPtr, sizeof(Pkt))
```

Network Programming Tips

- Transfer data between machines

- Sender: struct -> char arr
- Receiver: char arr -> struct

- Need to be wary of big/little endian
- “Network” byte order:
  - ntohl, ntohs, htonl, htons

Arrays

- `char foo[80];`
  - An array of 80 characters
  - `sizeof(foo)`
    = 80 × `sizeof(char)`
    = 80 × 1 = 80 bytes
- `int bar[40];`
  - An array of 40 integers
  - `sizeof(bar)`
    = 40 × `sizeof(int)`
    = 40 × 4 = 160 bytes

Debuggers

- Gdb
  - gcc –g –o bin a.c
  - gdb bin <core>
  - gdb bin <processID>
  - Breakpoints etc.

- Valgrind/purify for memory errors