EE 367L Lab Client-Server

Due date: See laulima

This is part 2 of the lab's documentation. Here is a list of topics:

The objective of this assignment is to gain experience with

- Client server paradigm
- Processes
- System calls (calls to functions in the operating system, which is assumed to be Linux)
- How data is transported over the Internet
- Communication between processes
    - pipes: communication between processes in a single machine
    - sockets: communication between processes over the Internet

The assignment is to write a simple client server system.

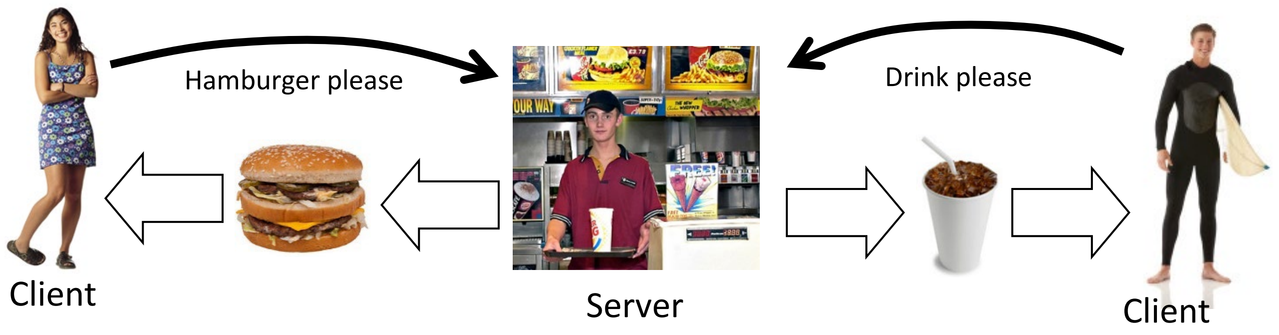
There are two parts to this lab:

- Part 1, Processes
    - What is a process
    - Managing processes
    - Launching programs from a process
    - Communicating processes: pipes
    - I/O redirection: dup2
    - More about processes
- Part 2, Internet – Reading, a few exercises in this document, and the Assignment
    - Client server
    - Internet
    - Sockets
    - Simple client-server example
    - Zombie processes
    - TCP port assignments
    - Simple exercises
    - Assignment

This document is Part 2.

Client-Server

In this project, you will implement a client and server. A *server* is an entity that waits for requests (or commands). When a request arrives, it processes the request and sends back a reply. The entity that sends requests is a *client*.



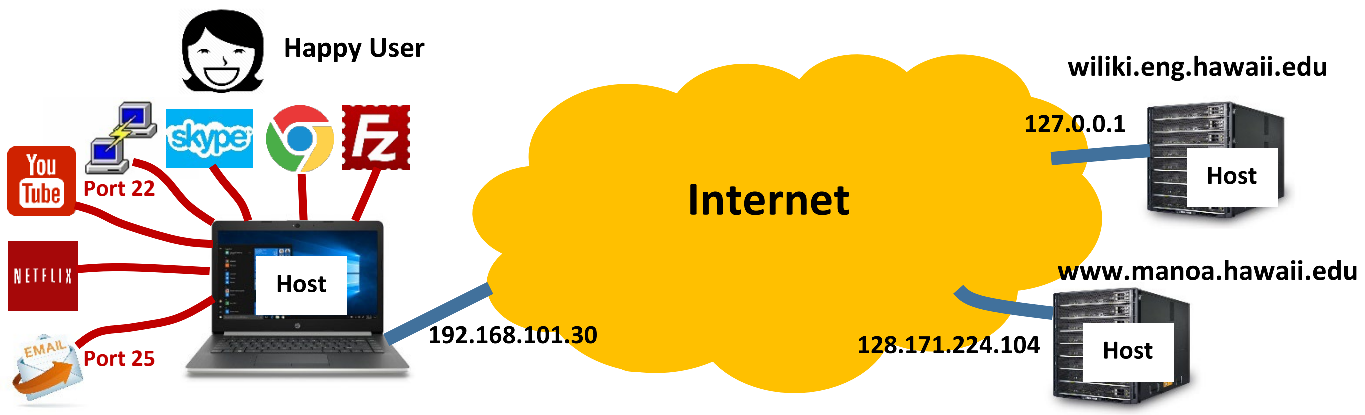
Attached are two programs: a client program client.c, and a server program server.c. This is from Beej's guide to network programming: http://beej.us/guide/bgnet/ More specifically it comes from the following which explains client, server, and sockets:
http://beej.us/guide/bgnet/output/html/multipage/clientserver.html

We will first describe the Internet, and then the code for the client.c and server.c.

Internet

Clients send and receive data to and from the server. Previously, we used pipes to connect processes, but pipes only work for programs in a single machine. An Internet server and its clients must communicate through the Internet which can be done using a *socket*. We will discuss the Internet, and then describe sockets.

The Internet is basically a big switch, as shown below. It is able to transport files to end nodes, which are referred as *hosts*. Hosts connected to the Internet must have Internet addresses (or IP addresses), which are 32-bit numbers (or four bytes). As an example, wiliki has the IP address 127.0.0.1. This address is in the *decimal dot format*, where the four bytes are represented by decimal values separated by dots. The IP address is the Internet's ID for the host.



Usually there are multiple software applications running on a host that are accessing the Internet. For example, we could have the following applications running simultaneously: Chrome Internet browser, Netflix video player, Mpg audio player, Skype, Putty, Filezilla, and so on. The applications must share the IP address of the host. In order to multiplex the software applications through the single IP address, there are *port numbers*. These port numbers are part of network transport protocols called TCP and UDP. Application software use ports to connect with other application software in the Internet. The port numbers are 16 bits, so they range from 0 to around 64K. Some of the port numbers are reserved, such as port 80 is used for the Internet server for the host, port 22 (basically SSH) is used in Filezilla, port 25 is used in Simple Mail Transfer protocol for email.

Notice that each Internet domain name corresponds to an IP address. For example, wiliki.eng.hawaii.edu is a domain name which corresponds to the IP address 127.0.0.1. The IP address is used by the machines, but it's too difficult to remember, so we have domain names. There is a directory service that translates the domain names to IP addresses and vice versa. This is called the Domain Name System (DNS). There are Linux system calls that use the DNS to translate a domain name to an IP address.

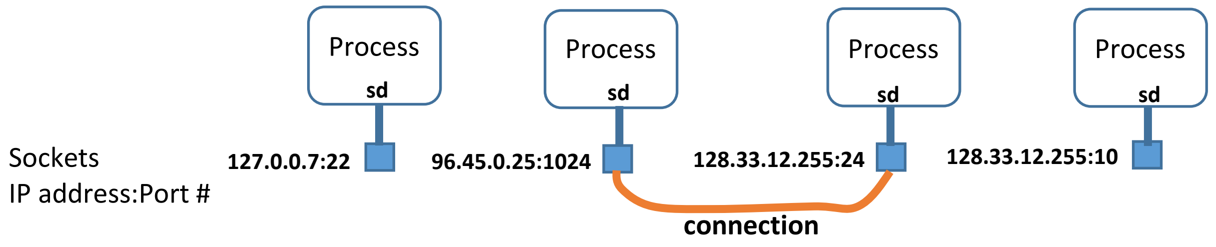
As mentioned earlier, there are two network transport protocols: TCP and UDP. TCP is used to transport a stream of bytes, while UDP is used to transport a single file of limited size, at most around 64KB. TCP is known as *stream* service, and UDP is known as *datagram* service. TCP is the most popular since it can transport an unlimited amount of bytes. For the rest of discussion, we will assume TCP rather than UDP, though keep in mind UDP is available. Also, there are two Internet protocols (IP), which is IPv4 (version 4) and IPv6 (version 6). We'll work with IPv4, which is the traditional version.

Sockets

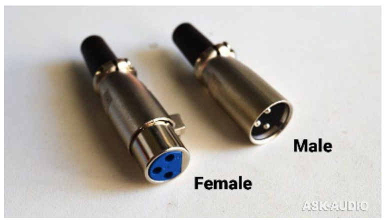
Network sockets are communication end points that can be used by processes to set up network connections between them. The connections can be on different computers. The connections can be realized by a TCP or UDP connection. But the details of running a connection are taken care of by the operating system. A *socket* is a nice interface for application software.

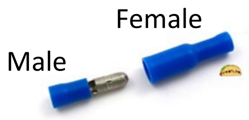
A socket is identified by its address, which is composed of an IP address and a TCP port number. It is often written as IPAddress:TCPportNumber, e.g., 127.0.0.2:22. When a process sets up a socket, it's ready to make a TCP connection using its socket address. The IP address is already determined because it corresponds to the machine that the process is running on. For example, if the process is running on wiliki, then the IP address is for wiliki. The TCP port number may be fixed for particular applications. For example, if the process is an Internet server, the port number may have to be 80. However, for many applications, there is no particular port number, so a process can choose one that is available.

The figure below shows four processes, each with a socket (shown are the sockets' addresses). The processes reference sockets through socket file descriptors (sd), which are analogous to ordinary file descriptors for files. Two of the sockets have a connection between them, allowing transfer of data. Two of the sockets have the same IP address indicating they are in the same computer.



Network sockets and connections are analogous to physical connectors. Note that in physical connections, there are "connectors" and cables (or wires). Example male and female connectors are shown below

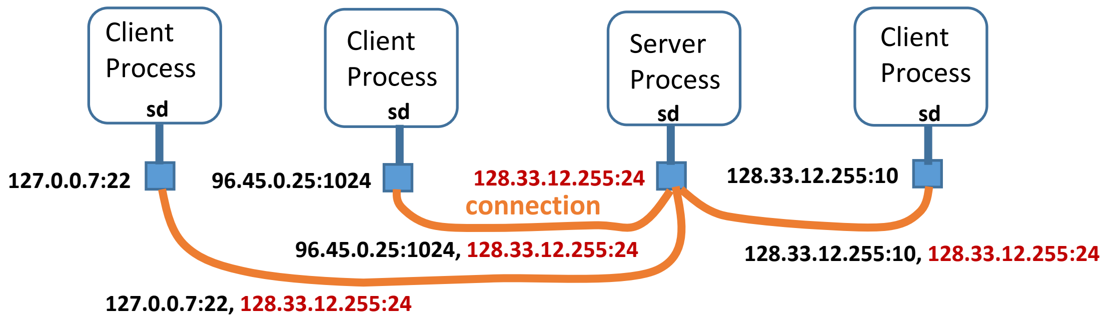




Sockets are analogous to female connectors. A network connection is analogous to having a cable, with male connectors at its ends, attached to two female connectors. A network connection can connect two sockets, just as a cable can connect two female connectors.

A *socket pair* is a communication connection between two sockets. It is described by a unique pair of (IPAddress:TCPPortNumber). For example, (127.0.0.1:3410, 96.255.56.12:22) is a socket pair. A socket communication connection is bidirectional, so its end points can send and receive data bytes.

A server will use a socket by putting it into the *listening* state. Then the server is waiting for requests from clients to establish a connection. These requests are queued at the server's socket. A request can be *accepted* by the server, which creates a connection. The connection corresponds to the socket pair (ClientIPAddress:ClientPortNumber), (ServerIPAddress:ServerPortNumber). The following figure shows a server process connected to three client processes. It also shows the socket addresses of the socket pairs.



The following system calls are used to establish and manage network connections and sockets

getaddrinfo:

```
int getaddrinfo(        char *node,  /* domain name or IP address */
                        char *service,  /* Port number or well known name of port number, e.g., "http" */
                        struct addrinfo * hints,  /* Parameters of the connection set by caller */
                        struct addrinfo ** res /* Information used by the operating system software */
):
```

getaddrinfo converts connection information readable by humans into connection information understandable by the operating system software.   Here is the struct addrinfo:

```
struct addrinfo {
        int                 ai_flags;
        int                 ai_family; /* Type of network; in our case it's IPv4 (AF_INET) */
        int                 ai_socktype; /* Type of socket; in our case it's SOCK_STREAM (= 1) */
        int                 ai_protocol;  /* Protocol type; in our case it's TCP (=6) */
        socklen_t           ai_addrlen;  /* Length of IP address; in the case of IPv4, it's 4 bytes */
        struct sockaddr     *ai_addr;  /* IP address and other address information */
        char                *ai_canonname; /* Cannonical name of host, which may be different from */
                                                 /* host domain name */
        struct addrinfo     *ai_next;  /* Next node in the linked list */
};
```

In getaddrinfo, "hints" is used by the calling function to specify the parameters. "res" is the output of getaddrinfo. It is actually a pointer to a linked list, where each node is a structure. The reason why "res' is a linked list is that a host can have multiple address configurations, e.g., IPv4 or IPv6 address and configurations. Each node in the linked list corresponds to an address configurations. To free the linked list, call freeaddrinfo( ).

Examples:

```
getaddrinfo("127.0.0.1", 3490, &hints, &res);  /* res = addrinfo for 127.0.0.1:3490*/
getaddrinfo("wiliki.eng.hawaii.edu", "http", &hints, &res);
```

In the first example, the system will look up the socket addresses of 127.0.0.1:3490. In the second example, the socket address corresponds to "wiliki.eng.hawaii.edu":"http". "wiliki.eng.hawaii.edu" is converted to its IP address using the DNS service, and "http" is converted to port number 80.

In ‘struct addrinfo’, there is a member ‘struct sockaddr’, which is the structure for the socket address. This can be for an IPv4 or IPv6 address, which are structured differently. The definition of struct addr is as follows:

```
struct sockaddr {
        unsigned short        sa_family;      // address family, AF_xxx
        char                  sa_data[14];    // 14 bytes of protocol address
};
```

The following socket structures are specific to IPv4 and IPv6 protocols.

```
struct sockaddr_in {   /* Socket address structure for IPv4 AF_INET sockets */
        short                 sin_family;     // e.g., AF_INET, AF_INET6
        unsigned short        sin_port;       // e.g., TCP port number – htons(3490), 2 bytes
                                              //    Here htons() converts the bytes of the value into the proper
                                              //    order for use in the network; think big and little endian
        struct in_addr        sin_addr;       // This is unsigned long, so it’s 4 bytes
        char                  sin_zero[8];    // Padding, and you can zero this
};
```

```
struct sockaddr_in6 {  /* Socket address structure for IPv6  AF_INET6 sockets */
        u_int16_t             sin6_family;            // address family, AF_INET6
        u_int16_t             sin6_port;              // port number, Network Byte Order
        u_int32_t             sin6_flowinfo;          // IPv6 flow information
        struct in6_addr       sin6_addr;              // IPv6 address, 16 bytes
        u_int32_t             sin6_scope_id;          // Scope ID
};
```

Note that sockaddr, sockaddr_in and sockaddr_in6 have the same beginning structure. So you can freely cast a pointer of one structure to another without problems. Thus, a pointer variable for struct socketaddr can be used to point to struct socketaddr_in or struct socketaddr_in6. Then getaddrinfo can be used for IPv4 or IPv6. See the following for more information: https://beej.us/guide/bgnet/html/multi/sockaddr_inman.html

Now suppose you want to create a sockaddr variable that can be used to carry either sockaddr_in or sockaddr_in6 data. Note that a struct sockaddr variable won’t work since it’s too small for data in struct ssockaddr_in6. Instead you can use the following which has enough space for sockaddr_in or sockaddr_in6:

```
struct sockaddr_storage{
        sa_family_t           ss_family;              // address family

        // all this is padding, implementation specific, ignore it:
        char                  __ss_pad1[_SS_PAD1SIZE];
        int64_t               __ss_align;
        char                  __ss_pad2[_SS_PAD2SIZE];
};
```

So use struct sockaddr if you want a generic form for a pointer to either struct sockaddr_in or struct sockaddr_in6, but if you want to allocate memory space that will work for either sockaddr_in or sockaddr_in6 use sockaddr_storage.

References:
Full description of getaddrinfo(): https://linux.die.net/man/3/getaddrinfo
Description from wikipedia: https://en.wikipedia.org/wiki/Getaddrinfo
Description of struct addrinfo: https://msdn.microsoft.com/en-us/library/windows/desktop/ms737530(v=vs.85).aspx

socket:

```
sockfd = socket(        int socket_family,   /* Type of network, e.g., IPv4 or IPv6 */
                        int socket_type,     /* Socket type, e.g., TCP stream socket (SOCK_STREAM) */
                        int protocol         /* Network protocol type, e.g., TCP (=6) */
);
```

Creates a socket according to the input parameters and returns a socket file descriptor.

References:
Full description of socket(): https://linux.die.net/man/7/socket

connect:

```
int connect(            int                 sockfd,
                        struct sockaddr     * addr,
                        socklen             addrlen        /* Address length */
);
```

Creates a connection between the socket referenced by 'sockfd' with the (possibly remote) socket specified by 'addr'. The connection for the resulting socket pair can be accessed by referencing sockfd. Note that the connection requires a local socket address, which is the IP address of the local machine and, by default, an unused TCP port chosen by the operating system. A particular TCP port can be specified by using the "bind()" system call.

In a client-server system, connect() is used by a client to connect to a server.

References:
Full description of connect(): https://linux.die.net/man/2/connect

bind:

int **bind**(int sockfd, struct sockaddr *addr, socklen_t addrlen);

bind() assigns an address specified in 'addr' to the socket corresponding to 'sockfd'. This is used by a server to specify a socket address to its local socket.

Reference:
Full description of bind(): https://linux.die.net/man/2/bind

listen:

int **listen**(int sockfd, int backlog);

listen() marks the socket specified by 'sockfd' as a passive socket, waiting for incoming connection requests. The requests arrive in a queue, which has a maximum size equal to 'backlog'. Incoming requests that find a full queue are dropped. listen() is used by servers, who are waiting for requests from clients.

Note that a connection request is just request, and a connection has not been established yet.

Reference:
Full description of listen(): https://linux.die.net/man/2/listen

accept:

int **accept**(int sockfd, struct sockaddr *addr, socklen_t addrlen);

Socket 'sockfd' must be a listening socket. accept() will accept a connection request in the queue of requests for 'sockfd'. Then a connection is established and the socket file descriptor is returned.

The returned socket file descriptor will be different from 'sockfd'. In this way, the new connection will not interfere with the listening socket 'sockfd'. If the queue of requests for 'sockfd' is empty then accept() is blocking until a request arrives. Also the address of connection requester is put in 'addr'.

Full description of accept(): https://linux.die.net/man/2/accept

send:

ssize_t **send**(int sockfd, const void *buf, size_t len, int flags);

Sends data in the buffer 'buf' into the socket 'sockfd' for a maximum of 'len' bytes. The return value is the actual number of bytes sent, which will be at most 'len'. If flags = 0 then send() is equivalent to write().

Full description of send(): https://linux.die.net/man/2/send

recv:

ssize_t **recv**(int sockfd, const void *buf, size_t len, int flags);

Receives data in the buffer ‘buf’ from the socket ‘sockfd’ for a maximum of ‘len’ bytes. The returned value is the actual number of bytes received, which will be at most ‘len’. If flags = 0 then recv() is equivalent to read(). By default, recv() is blocking until there is data to receive. You can change the connection to be nonblocking using fcntl() – in particular: fcntl(sockfd, F_SETFL, O_NONBLOCK); which sets flags of sockfd to nonblocking.

Full description of recv(): https://linux.die.net/man/2/recv

setsockopt:

int setsockopt(int sockfd, int level, int optname, void *optval, socklen_t *optionlen);

This will configure a socket sockfd. Configuration can be done at different levels, but for our purposes, the level will be the socket level, specified by SOL_SOCKET. *optname* is the option to set. In our case, we want it equal to SO_REUSEADDR which allows the socket’s port number to be reused. *optval* are the parameters needed to set the option. *optionlen* is a length of optval.

This option solves a problem in the event that a server terminates and is restarted right away, e.g., server crashes and then restarts quickly. Then sockets using the server port may not have terminated yet, so when the server restarts and tries to bind() to the port, it gets an “Address already in use” error message. By allowing the port to be reused, the restarting server can reuse the busy port.

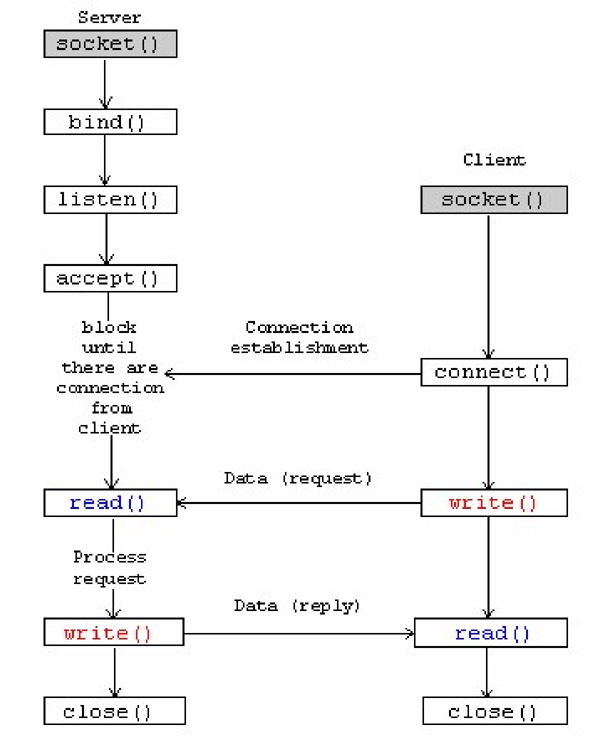
Description of setsockopt() from Beej’s guide: https://beej.us/guide/bgnet/html/multi/setsockoptman.html
Here’s an explanation of SO_REUSEADDR: http://www.unixguide.net/network/socketfaq/4.5.shtml

Simple Client-Server Example

We will go over a simple client-server example given in https://beej.us/guide/bgnet/html/multi/index.html
The web site explains socket programming. The important sections for this lab are Section 5 on System Calls, and Section 6 on Client-Server Background:

- Section 5: https://beej.us/guide/bgnet/html/multi/syscalls.html
- Section 6: https://beej.us/guide/bgnet/html/multi/clientserver.html

In Section 6, there is a client program client.c and server program server.c. Both of them are attached to this document. We will go over them. First note that in the simplest form, a client-server follows the figure below.



client.c:

```
/*
** client.c -- a stream socket client demo
*/

#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <errno.h>
#include <string.h>
#include <netdb.h>
#include <sys/types.h>
#include <netinet/in.h>
#include <sys/socket.h>
#include <arpa/inet.h>
```

```
#define PORT "3490" // the port client will be connecting to – port of the server

#define MAXDATASIZE 100 // max number of bytes we can get at once

// get sockaddr, IPv4 or IPv6 depending on the protocol
void *get_in_addr(struct sockaddr *sa)
{
      if (sa->sa_family == AF_INET) { // Return IPv4 address
            return &(((struct sockaddr_in*)sa)->sin_addr);
      }
      return &(((struct sockaddr_in6*)sa)->sin6_addr); // Return IPv6 address
}

int main(int argc, char *argv[])
{
      if (argc != 2) {
          fprintf(stderr,"usage: client hostname\n");
          exit(1);
      }
      // Get address information of server with IP address (or domain name) ‘arg[1]’
      //    and TCP port number PORT = “3490”.  It’s a stream connection which can be
      //    IPv4 or IPv6
      struct addrinfo hints; // hints used in getaddrinfo()
      memset(&hints, 0, sizeof hints); // Initialize hints to 0 to avoid problems
                                       //   from spurious leftover data in memory
      hints.ai_family = AF_UNSPEC;     // Can be either IPv4 or IPv6
      hints.ai_socktype = SOCK_STREAM;   // TCP stream socket

      struct addrinfo *servinfo; // It will point to the results from getaddrinfo()
      int rv;
      if ((rv = getaddrinfo(argv[1], PORT, &hints, &servinfo)) != 0) {
            fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(rv));
            return 1;
      }
      // Connect to the server:
      //    loop through all the results and connect to the first we can
      int sockfd;
      struct addrinfo *p;
      for(p = servinfo; p != NULL; p = p->ai_next) {
            // Create a socket, if possible
            if ((sockfd = socket(p->ai_family, p->ai_socktype,
                        p->ai_protocol)) == -1) {
                  perror("client: socket");
                  continue; // If it doesn’t work then skip the rest of this pass
                              //  and continue with loop
            }
            // We created a socket, now let’s establish a connection to the server
            //      with the socket address for ‘p’.
            if (connect(sockfd, p->ai_addr, p->ai_addrlen) == -1) {
                  close(sockfd);
                  perror("client: connect");
                  continue; // If we can’t establish a connection then skip
                              // the rest of this pass and continue with loop
            }
            // We created a socket and established a connection so we’re done
            //    with the loop
            break;
      }
      if (p == NULL) { // We failed to connect after going through
                        //  the linked list servinfo
            fprintf(stderr, "client: failed to connect\n");
            return 2;
      }

      // We established a connection with the server
      //    Notify the user that we made the connection
      char s[INET6_ADDRSTRLEN];  // Buffer to store char string
      inet_ntop(p->ai_family, get_in_addr((struct sockaddr *)p->ai_addr),
                  s, sizeof s);
      printf("client: connecting to %s\n", s);

      freeaddrinfo(servinfo); // all done with this structure

      // Display what's received from server
      int numbytes;
      char buf[MAXDATASIZE];
      if ((numbytes = recv(sockfd, buf, MAXDATASIZE-1, 0)) == -1) {
            // Note that recv() can be replaced by read() since flags = 0
          perror("recv");
          exit(1);
      }
      buf[numbytes] = '\0';
      printf("client: received '%s'\n",buf);

      close(sockfd);

      return 0;
}
```

server.c:

```
/*
** server.c -- a stream socket server demo
*/
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <errno.h>
#include <string.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <arpa/inet.h>
#include <sys/wait.h>
#include <signal.h>

#define PORT "3490"  // Port used by server.  Clients need to know this port number
#define BACKLOG 10       // how many pending connections queue will hold

// sigchld_handler is used to clean up zombie processes
//    This will be explained later
void sigchld_handler(int s)
{
      while(waitpid(-1, NULL, WNOHANG) > 0);
}
```

```
// the following is the same as in client.c, so we just have the prototype.
void *get_in_addr(struct sockaddr *sa);


int main(void)
{
      // Get address information for this server which includes the IP address of
      //    the local machine, and the TCP port number of the server, in this
      //    case PORT = “3490”.  It’s a stream connection which can be
      //    IPv4 or IPv6.  This is similar to client.c but we want the
      //    IP address of the local machine
      struct addrinfo hints;
      memset(&hints, 0, sizeof hints);
      hints.ai_family = AF_UNSPEC;
      hints.ai_socktype = SOCK_STREAM;
      hints.ai_flags = AI_PASSIVE; // use the IP of the local machine
                                   // AI_PASSIVE indicates that the resulting
                                   // socket will be used for listening by a server
      struct addrinfo *servinfo;    // The address results which is a linked list
      int rv;
      if ((rv = getaddrinfo(NULL, PORT, &hints, &servinfo)) != 0) {
            fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(rv));
            return 1;
      }
      // Loop through all the linked list of addressinfo results
      //    and create a socket and bind it to the addressinfo.
      //    Stop when the bind is successful.
      int sockfd;
      struct addrinfo *p;
      for(p = servinfo; p != NULL; p = p->ai_next) {
            // Create a socket, if possible
            if ((sockfd = socket(p->ai_family, p->ai_socktype,
                        p->ai_protocol)) == -1) {
                  perror("server: socket");
                  continue; // If it doesn’t work then skip the rest of this pass
                              //  and continue with loop
            }
            // setsockopt sets the socket so that it can rebind to its port after crash
            int yes=1;
            if (setsockopt(sockfd, SOL_SOCKET, SO_REUSEADDR, &yes,
                        sizeof(int)) == -1) {
                  perror("setsockopt");
                  exit(1);
            }
            // Let’s bind the socket with the socket address for ‘p’.
            if (bind(sockfd, p->ai_addr, p->ai_addrlen) == -1) {
                  close(sockfd);
                  perror("server: bind");
                  continue; // If we can’t bind then skip the rest of this pass
                              //  and continue with the loop
            }
            // We created a socket and it’s bound to a socket address with
            //   the IP address of the local machine and TCP port number PORT
            //   We’re done so we can break out of the loop
            break;
      }
```

```
	if (p == NULL)  { // We failed to create a socket for the server
		fprintf(stderr, "server: failed to bind\n");
		return 2;
	}
	// We now have a socket for the server for listening
	freeaddrinfo(servinfo); // all done with this structure

	// Server starts to listen for connection requests from clients.
	if (listen(sockfd, BACKLOG) == -1) {
		perror("listen");
		exit(1);
	}

	// In what follows, the server will create child processes.  It turns out that
	//    the child processes can become zombie processes.  What immediately follows
	//    is a method to get rid of zombie processes.  This will be explained later.
	struct sigaction sa;
	sa.sa_handler = sigchld_handler; // reap all dead processes
	sigemptyset(&sa.sa_mask);
	sa.sa_flags = SA_RESTART;
	if (sigaction(SIGCHLD, &sa, NULL) == -1) {
		perror("sigaction");
		exit(1);
	}

	printf("server: waiting for connections...\n");
	// The server runs forever in a while-loop
	//    In each pass of the loop, the server will accept() a connection
	//    request from a client.  accept() will return the socket fd for
	//    the connection.
	//
	//    After creating the connection, the server will create a child process
	//    to reply to the client.  In this case, the reply is to simply
	//    send the message "hello world".
	while(1) {  // main accept() loop
		struct sockaddr_storage their_addr; // connector's addr information
		socklen_t sin_size = sizeof their_addr;
		int new_fd = accept(sockfd, (struct sockaddr *)&their_addr, &sin_size);
		if (new_fd == -1) {
			perror("accept");
			continue;
		}
		// Display who the client is
		char s[INET6_ADDRSTRLEN];
		inet_ntop(their_addr.ss_family,
			get_in_addr((struct sockaddr *)&their_addr),
			s, sizeof s);
		printf("server: got connection from %s\n", s);
		if (!fork()) { // this is the child process
			close(sockfd); // child doesn't need the listener
			if (send(new_fd, "Hello, world!", 13, 0) == -1)
				perror("send");
			close(new_fd);
			exit(0);
		}
		close(new_fd);  // parent doesn't need this
	}
	return 0;
}
```

Zombie Processes

When a Linux process is created, it is recorded in a table in the operating system called the *process table*, which has all the active processes. The table can be used by a parent process to check the state of its child. For example, if the parent is executing a wait() for a child, it can check the table.

When a child process exits, it terminates, and all its memory and other resources are deallocated. However, it still has an entry in the process table because it's needed when the parent calls a wait() for the child. Now the child is a *zombie process* -- there's nothing left for the child except its entry in the process table.

Here is a description of zombie processes:
https://en.wikipedia.org/wiki/Zombie_process

The child's entry in the process table can be removed when a wait( ) is called by the parent process for the child. So the trick to completely delete a zombie process is to force its parent to call a wait() for it. However, forcing a parent to call wait() may be awkward for the parent, since this may interfere with the parent completing its own task. The solution is to create a *signal handler* to do the waiting.

A *signal* is a way for a process to be notified of an event, and a *signal handler* is code that is run when the signal occurs. When a signal occurs, the process suspends whatever it is running, and goes to the signal handler. When the signal handling is completed, the process resumes running at the point where it was interrupted by the signal. A signal is analogous to an interrupt, and a signal handler is analogous to an interrupt handler.

An example of a signal is when you type Control-C while a process is running in foreground. This signal is known as SIGINT. Its default signal handler will terminate the process.

Now when a child process terminates, it sends a signal called SIGCHLD to its parent process. Suppose the signal handler will wait() for the child process. This will remove the child from the process table, and the child will end being a zombie process.

Let's look at the signal handler for server.c:

```
void sigchld_handler(int s)
{
      while(waitpid(-1, NULL, WNOHANG) > 0);
}
```

This handler calls waitpid() with the WNOHANG option. This means waitpid() won't wait if there are no terminated processes. Thus, the while-loop will call waitpid() as long as there are zombie processes. This will clean up all the zombie processes. When there are no zombie processes, the while-loop will not wait and the signal handler is done.

The following is how the signal handler sigchld_handler is registered to SIGCHLD in main():

```
struct sigaction sa;
sa.sa_handler = sigchld_handler; // reap all dead processes
sigemptyset(&sa.sa_mask);
sa.sa_flags = SA_RESTART;
if (sigaction(SIGCHLD, &sa, NULL) == -1) {
      perror("sigaction");
      exit(1);
}
```

The registration is done using the system call sigaction().

The following is the definition of struct sigaction:

```
struct sigaction {
        void            (*sa_handler)(int);
        void            (*sa_sigaction)(int, siginfo_t *, void *);
        sigset_t        sa_mask;
        int             sa_flags;
        void            (*sa_restorer)(void);
};
```

sa_handler and sa_sigaction are function pointers to the signal handler. Either can be used but not both. Note that sa_handler has one input parameter (int), which will be the signal value. sa_restorer is not intended for application use, so it ignored in our case.

TCP Port Assignments To Students

You will need a port number for your server. The usable ports, called the ephemeral ports, are from 2000 to 5000. Each student, TA, and grader will be assigned two port numbers according to the table below:

Name	Port #	Name	Port #	Name	Port#
Achiu, Amanda	3500 3600	Lafradez, Harvey	3514 3614	Takeda, Kyle	3529 3629
Akemoto, Ashten	3501 3601	Liang, Leo	3515 3615	Tapper, Liam	3530 3630
Brewer, Joshua	3502 3602	Lorica, Joshua	3516 3616	Uyeda, Kobe	3531 3631
Chang Jaeden	3503 3603	Lum, Reid	3517 3617	Wan, Andrew	3532 3632
D'Sanson, Albert	3504 3604	Manuel, Patrick	3518 3618	Zhang, Yixin (TA)	3533 3633
Davis, Elijah	3505 3605	Matar, Ibrihim	3519 3619	Kam, Shannon (grader)	3534 3634
Diep, Elis	3506 3606	Matsuo, Matthew	3520 3620	Pauly, Maxwell	3535 3635
Domingo, Carl	3507 3607	Matsusaka, Kai	3521 3621		3536 3636
Enojardo, Jason	3508 3608	Mueller, Caleb	3522 3622		3537 3637
Galeria, Joshua	3509 3609	Murray, Nathaniel	3523 3623		3538 3638
Galway-Severtson, James	3510 3610	Ng, Gavin	3524 3624		3539 3639
Kaaihili, Victoria	3511 3611	Nguyen, Khanh	3525 3625		3540 3640
Komeya, Kade	3512 3612	Peng, Adrian	3527 3627		
Kouchi, Matthew	3513 3613	Soriano, Byron	3528 3628		

Use these ports for this lab and subsequent labs.

Simple Exercises

Do the following simple exercises.

Exercise 1: Attached is the client-server code client.c and server.c. Change the PORT numbers to one of your own. Then run the server in background, and then run the client. Afterwards, kill the server and make sure there are no leftover processes.

Exercise 2: Modify the client.c and server.c code to do the following. The client will send a text word string to the server. This text word will come from the command line.

The server will receive the string and display it on the terminal using something like

```
        printf("Server: received '%s'\n", string);
```

Then it will convert all lower-case alphabets to upper-case alphabets, and send the word back to the client. The client will receive the converted word and display it on the terminal using something like

```
        printf("Client: received '%s'\n", string);
```

Then the client terminates. You can now kill the server.

Here's an example run of the client:

```
./client   aloha
Server: received 'aloha'
Client: received 'ALOHA'
```

Hint: Recall that the letters 'a' through 'z' in ASCII is 0x61 through 0x7a in hexadecimal or 97 through 122 in decimal. The letters 'A' through 'Z' in ASCII is 0x41 through 0x5A in hexadecimal or 65 through 90 in decimal. See http://www.asciitable.com/ So the conversion for each char is to subtract 32 if the char is within 97 and 122.

If you're unfamiliar with inline arguments for main(), here's some information:
Function prototypes of the main function have the following forms (main can also return void)

```
int main(void);
int main();   // This is the same as the line above
void main();  // If nothing is returned by main
void main(void);

int main(int argc, char **argv); // You can replace 'int' with 'void' as a return data type
int main(int argc, char *argv[]);  // This is the same as the line above
```

The following is an example:

```
void main(int argc, char *argv[])
{
int k;

printf("Number of arguments = %d\n");
for (k=0; k,argc; k++) {
    printf("argv[%d] -> %s\n", k, argv[k]);
}
}
```

argc is the number of arguments in the command line when the program was launched.
argv[ ] is known as the argument vector. Suppose you compiled the program and then launched it as follows:

```
./a.out   -a  this   is  an  example
```

There are number of arguments is 6: './a.out', '-a', 'this', 'is', 'an', and 'example'. So argc will be 6.   argv[0] is a pointer to a char string of the first argument './a.out' which is terminated by NULL, arg[1] is a pointer to the second argument, and so on.

What will appear on the console is

```
Number of arguments = 6
argv[0] -> ./a.out
argv[1] -> -a
argv[2] -> this
argv[3] -> is
argv[4] -> an
argv[5] -> example
```

Assignment

For this lab assignment, you will work in groups of two, with the exception that there may be one group of three. As a group, you will develop two programs, server367 and client367, which are described later in this section. Your programs should run on wiliki. The most straightforward way to do this is to modify server.c and client.c. Note that attached to this assignment there are three files: file1, file2, and file3. These are arbitrary text files that you can use to test your code.

You are to work with your partner by doing "pair programming":
https://en.wikipedia.org/wiki/Pair_programming
https://www.youtube.com/watch?v=YhV4TaZaB84

Remember to switch roles frequently, e.g., every 30 minutes with a short break of a few minutes.

Here is show the client and server will work. Suppose server367 is running. A user should be able to use client367 to do the following. The client will continually accept commands until the user quits. The user interface is

```
Command (type 'h' for help):
```

The commands are single text characters. Here are the commands:

- **l: List**: List the contents of the directory of the server.

- **c: Check <file name>:** Check if the server has the file named <file name>.
    - If it exists then the client will output "File '<file name>' exists" on the console.
    - Otherwise, the client will output "File '<file name>' not found".

- **p: Display <file name>:** Check if the server has the file named <file name>.
    - If it exists then the client will display the contents of the file on the client's console.
    - Otherwise, the client will output "File '<file name>' not found".

- **d: Download <file name>:**
    - Check if the client has a file in its directory with the same file name
        - If it does then it will query the user if it would like to overwrite it
        - If the user does not want to overwrite then the client will discontinue processing this command
    - Check if the server has the file.
        - If it does then the client will download the file using the same file name.
        - Otherwise, the client will output "File '<file name>' not found"

- **q: Quit:** This is to terminate the client program. Otherwise the client continues.

- **h: Help:** Lists all the commands, e.g.,
    - **l: List**
    - **c: Check <file name>**
    - **p: Display <file name>**
    - **d: Download <file name>**
    - **q: Quit**
    - **h: Help**

The user starts client367 by typing: ./client367 <host name>

For example: ./client367 wiliki.eng.hawaii.edu

Here's a suggestion of what the client and server should do

- Client
    - The client is basically a loop that does the following
    - The client gets a command from the user through its user interface
        - "Command (enter 'h' for help): "
    - It responds to the command. For commands that require connecting to the server, it does the following
        - It encodes the command. For example, it could encode a command into single text character: "C" = check, "D" = download, "L" = list, and "P" = display.
        - It sets up a socket to the server, and then sends the command to the server using 'send' or 'write'. It may include additional parameters, e.g., in the case of Download, it may include the file name to download:
            - check = "C <file name>"
            - download = D <file name>"
            - list = "L"
            - display = "P <file name>"
        - It waits for a reply from the server by using "recv" or "read"
        - After completing the command, it terminates the socket
- Server
    - The server listens to its socket for any request for connections from client
    - If there is a request, it accepts it and establishes a connection
    - The server creates a child to handle the client
    - The child receives a message (text string) from the client using 'recv' or 'read'
    - It parses the message to determine the command
        - If the command is "C", "D", or "P" it further parses the message to find the file name
        - If the command is "C" then it checks if the file exists and sends a response back to the client. One way to do a check is to use Linux's access()
        - If the command is "D" or "P" then the file is opened and the contents are sent to the client
        - If the command is "L" then the child will create its own child, which executes "ls" using execl( ). The output is sent to the client.

- After the command is completed, the child closes the socket and terminates.

Hints:
Build the client and server in stages, each stage is an improvement over the previous stage. Here is a suggestion for a sequence of stages.

Stage 0: **Grade 0%**
Run client.c and server.c using your own port numbers. This is basically Exercise 1.

Stage 1: **Grade 30%**
Have the server execute "ls" whenever a client tries to connect to it. The "ls" should output to the console, i.e., the default output.

Stage 2: **Grade 40%**
This is the same as Stage 1 but have the output of "ls" is sent back to the client, where it is displayed.

Stage 3: **Grade 50%**
Design command messages that a client can send to the server
Modify client so it sends a command message for the server to execute 'ls'
Modify server so that it parses the command messages
    Then it runs 'ls'
    The output is sent back to the client
Modify the client so that it displays what's received from the server

Stage 4: **Grade 60%**
Modify client and server so that
    Client prompts user for command
    Client sends command messages
    Server parses and acts on command message
    Server sends output back to client
    Client displays results from server
The client should have a user interface that accepts the commands to "list" or "quit".

Stage 5: **Grade 70%**
The client and server should include the command "check". Hint: see the Linux function "access"

Stage 6: **Grade 80%**
The client and server should include the command "display". To implement "display", first have the server display the file directly to the console. Then have the server send the file back to the client. Hint: see the Linux function "cat"

Stage 7: **Grade 90%**
The client and server should include the command "download". Note that "download" is different from "display" because the client will store the file rather than display it on the console.

Stage 8: **Grade 100%**
Complete the assignment.

You can break these stages down even further. It is important to split up your progress so that it can be debugged. As much as possible, deal with one bug at a time.

Allow late submissions until end of February with a deduction of 15%.