University of Glasgow

Network Programming in C

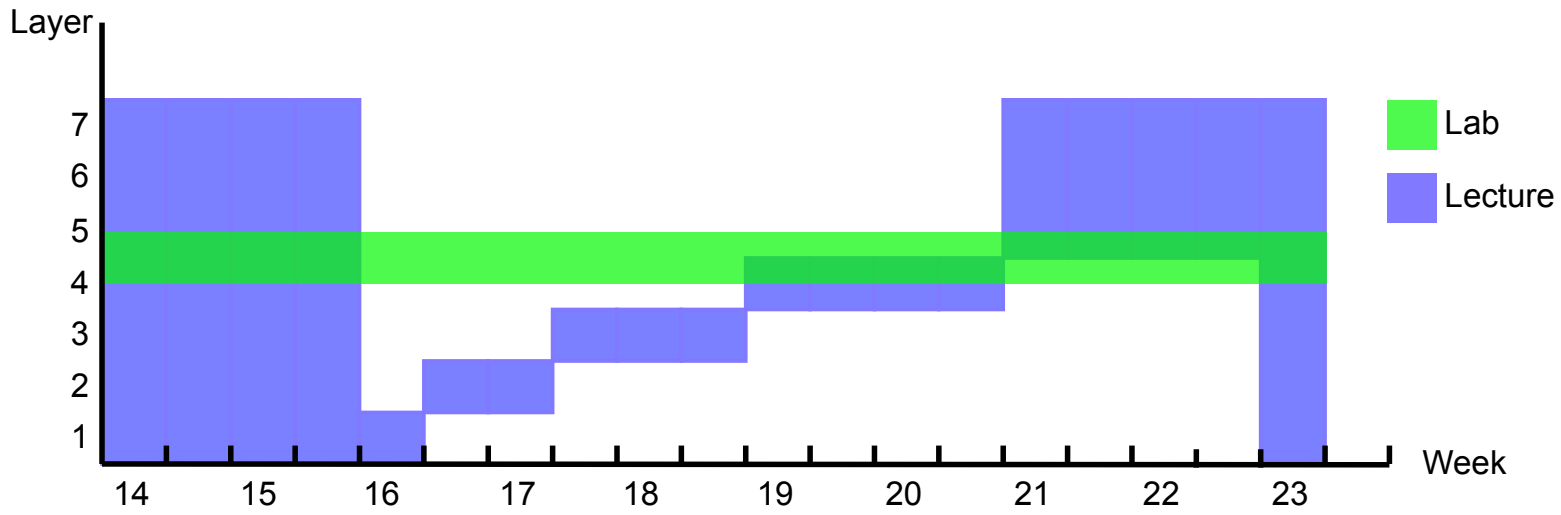
Networked Systems 3
Laboratory Sessions and Problem Sets

Lab Timetable, Aims, and Objectives

Teaching Week	Activity
14	Introduction
15	Warm-up exercise
16	Web client
17	
18	
19	Web server
20	
21	
22	
23	-

- Aims and objectives
  - To demonstrate how the world-wide web works, at a protocol level
  - To teach concurrent network programming in C

Relation Between Labs and Lectures

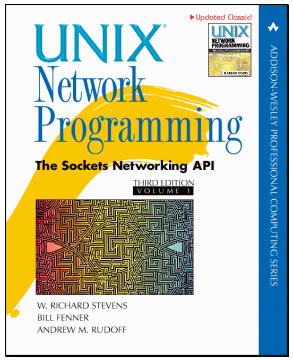


Network Programming in C: The Berkeley Sockets API

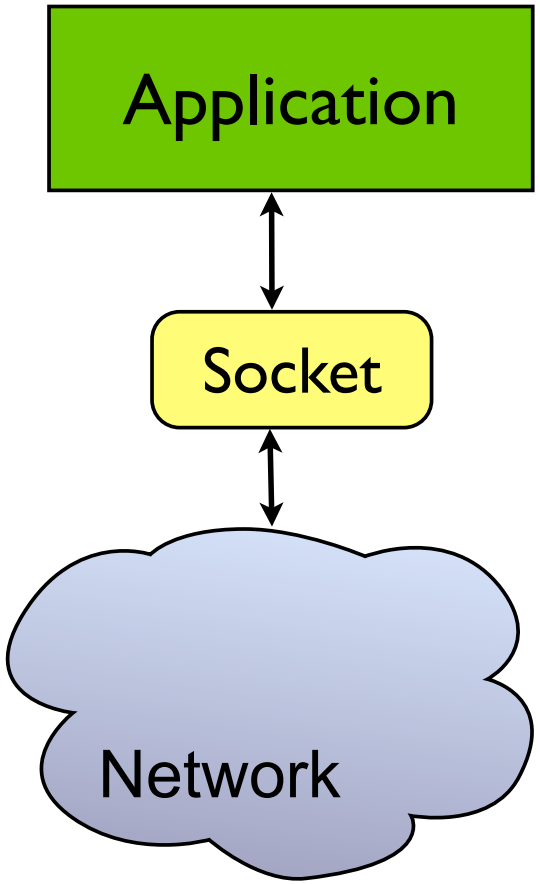
The Berkeley Sockets API

- Widely used low-level C networking API
- First introduced in 4.3BSD Unix
  - Now available on most platforms: Linux, MacOS X, Windows, FreeBSD, Solaris, etc.
  - Largely compatible cross-platform

- Recommended reading:
  - Stevens, Fenner, and Rudoff, “Unix Network Programming volume 1: The Sockets Networking API”, 3rd Edition, Addison-Wesley, 2003.



Concepts

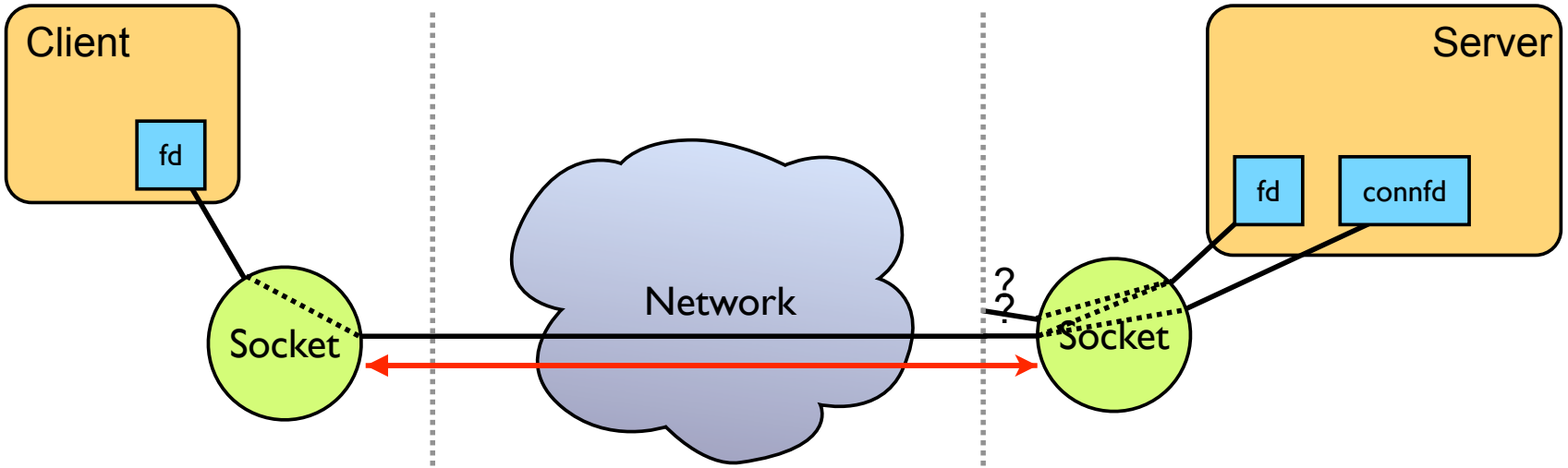


- Sockets provide a standard interface between network and application
- Two types of socket:
  - Stream – provides a virtual circuit service
  - Datagram – delivers individual packets
- Independent of network type:
  - Commonly used with TCP/IP and UDP/IP, but not specific to the Internet protocols
  - Only discuss TCP/IP sockets today

What is a TCP/IP Connection?

- A reliable byte-stream connection between two computers
  - Most commonly used in a client-server fashion:
    - The server listens on a well-known *port*
      - The *port* is a 16-bit number used to distinguish servers
      - E.g. web server listens on port 80, email server on port 25
    - The client connects to that port
  - Once connection is established, either side can write data into the connection, where it becomes available for the other side to read
- The Sockets API represents the connection using a *file descriptor*

TCP/IP Connection

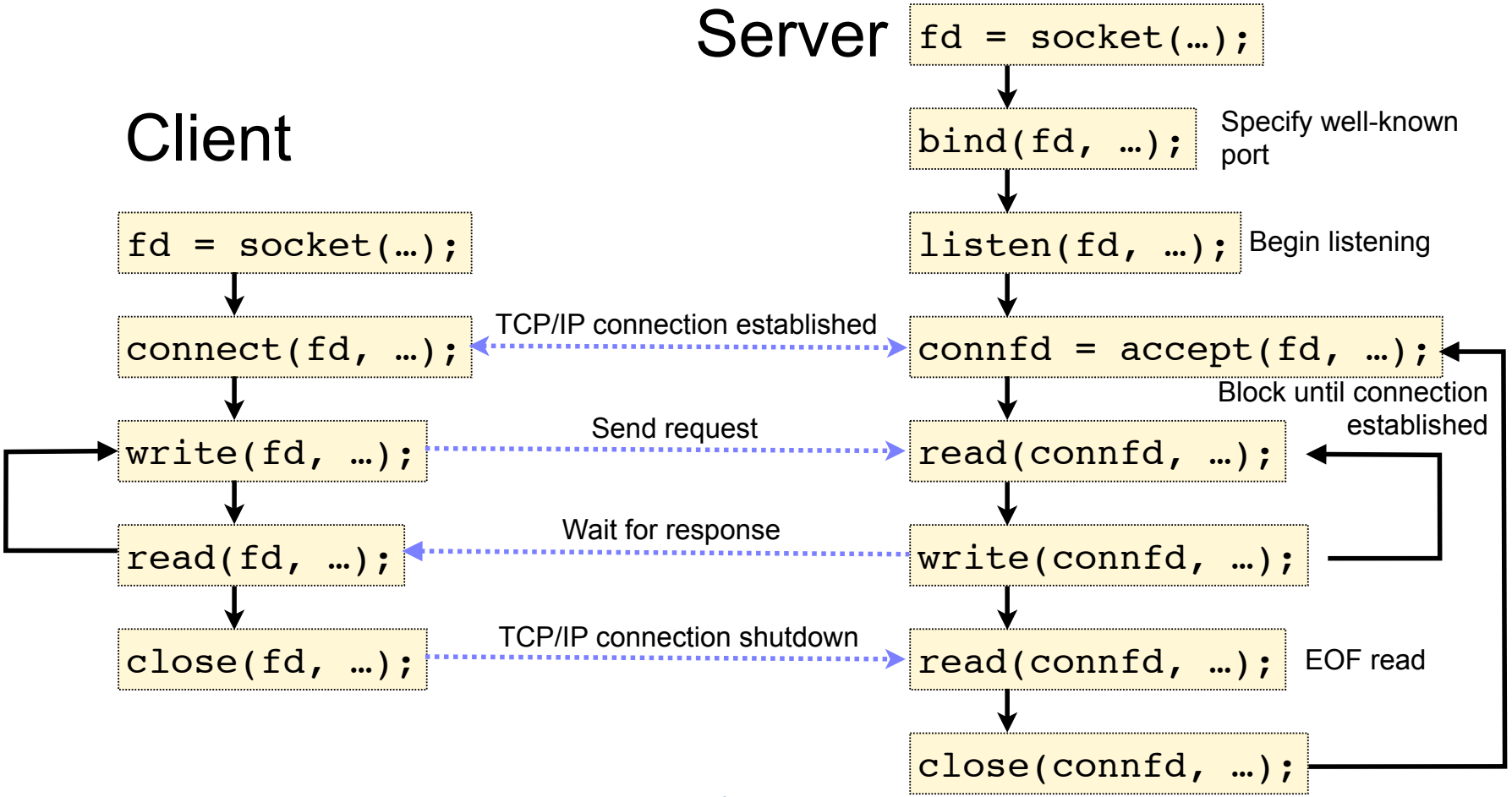



```
int fd = socket(...)

connect(fd, ..., ...)
write(fd, data, datalen)
read(fd, buffer, buflen)
close(fd)
```

```
int fd = socket(...)
bind(fd, ..., ...)
listen(fd, ...)
connfd = accept(fd, ...)
read(connfd, buffer, buflen)
write(connfd, data, datalen)
close(connfd)
```

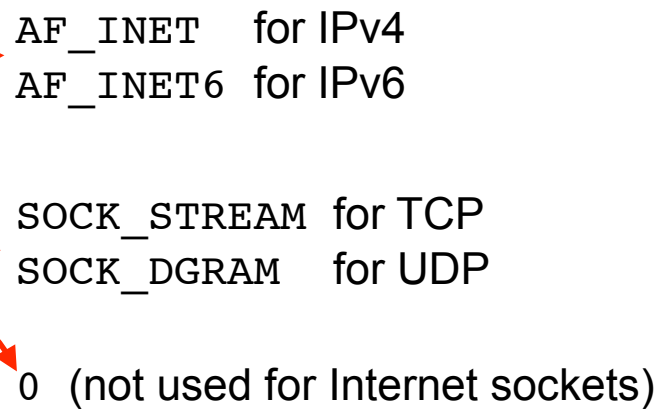
TCP/IP Connection



Creating a socket

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

int fd;
...
fd = socket(family, type, protocol);
if (fd == -1) {
    // Error: unable to create socket
    ...
}
...
```



Create an unbound socket, not connected to network; can be used as either a client or a server

Handling Errors

Socket functions return `-1` and set the global variable `errno` on failure

```
fd = socket(family, type, protocol);
if (fd == -1) {
    switch (errno) {
    case EPROTONOSUPPORT :
        // Protocol not supported
        ...
    case EACCES:
        // Permission denied
        ...
    case ...
    default:
        // Other error...
        ...
    }
```

The Unix man pages list possible errors that can occur for each function

E.g. do "`man 2 socket`" in a terminal, and read the ERRORS section

Binding a Server Socket

- Bind a socket to a port on a network interface
  - Needed to run servers on a well-known port - with *addr* specified as INADDR_ANY
  - Not generally used on clients, since typically don't care which port used

```
#include <sys/types.h>
#include <sys/socket.h>
...
if (bind(fd, addr, addrlen) == -1) {
    // Error: unable to bind
    ...
}
...
```

Listening for Connections

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

```
if (listen(fd, backlog) == -1) {
    // Error
    ...
}
...
```

Tell the socket to listen for new connections

The *backlog* is the maximum number of connections the socket will queue up, each waiting to be `accept()`'ed

Connecting to a Server

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

```
if (connect(fd, addr, addrlen) == -1) {
    // Error: unable to open connection
    ...
}
...
```

Pointer to a `struct sockaddr`

Size of the struct in bytes

Tries to open a connection to the server
Times out after 75 seconds if no response

Specifying Addresses & Ports

- Must specify the address and port when calling `bind()` or `connect()`
  - The address can be either IPv4 or IPv6
  - Could be modelled in C as a union, but the designers of the sockets API chose to use a number of structs, and abuse casting instead

`struct sockaddr`

- Addresses specified via `struct sockaddr`
  - Has a data field big enough to hold the largest address of any family
  - Plus `sa_len` and `sa_family` to specify the length and type of the address
  - Treats the address as an opaque binary string

```
struct sockaddr {
    uint8_t         sa_len;
    sa_family_t     sa_family;
    char            sa_data[22];
};
```

struct sockaddr_in

- Two variations exist for IPv4 and IPv6 addresses
  - Use `struct sockaddr_in` to hold an IPv4 address
  - Has the same size and memory layout as `struct sockaddr`, but interprets the bits differently to give structure to the address

```
struct in_addr {
    in_addr_t       s_addr;
};

struct sockaddr_in {
    uint8_t         sin_len;
    sa_family_t     sin_family;
    in_port_t       sin_port;
    struct in_addr  sin_addr;
    char            sin_pad[16];
};
```

struct sockaddr_in6

- Two variations exist for IPv4 and IPv6 addresses
  - Use `struct sockaddr_in6` to hold an IPv6 address
  - Has the same size and memory layout as `struct sockaddr`, but interprets the bits differently to give structure to the address

```
struct in6_addr {
    uint8_t          s6_addr[16];
};

struct sockaddr_in6 {
    uint8_t          sin6_len;
    sa_family_t      sin6_family;
    in_port_t        sin6_port;
    uint32_t         sin6_flowinfo;
    struct in6_addr  sin6_addr;
};
```

Working with Addresses

- Work with either `struct sockaddr_in` or `struct sockaddr_in6`
- Cast it to a `struct sockaddr` before calling the socket routines

```
struct sockaddr_in  addr;
...
// Fill in addr here
...
if (bind(fd, (struct sockaddr *) &addr, sizeof(addr)) == -1) {
    ...
```

Creating an Address: Manually (Client)

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

`inet_pton()` to convert address
`htons()` to convert port

```
struct sockaddr_in  addr;
...
inet_pton(AF_INET, “130.209.240.1”, &addr.sin_addr);
addr.sin_family = AF_INET;
addr.sin_port   = htons(80);

if (connect(fd, (struct sockaddr *)&addr, sizeof(addr)) == -1) {
    ...
```

Creating an Address: Manually (Server)

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

Usually specify INADDR_ANY

`htons()` to convert port

```
struct sockaddr_in  addr;
...
addr.sin_addr.s_addr = INADDR_ANY;
addr.sin_family      = AF_INET;
addr.sin_port        = htons(80);

if (bind(fd, (struct sockaddr *)&addr, sizeof(addr)) == -1) {
    ...
```

Creating an Address: DNS

- Prefer using DNS names to raw IP addresses
  - Use `getaddrinfo()` to look-up name in DNS
  - Returns a linked list of `struct addrinfo` values, representing addresses of the host

```
struct addrinfo {
    int              ai_flags;     // input flags
    int              ai_family;    // AF_INET, AF_INET6, ...
    int              ai_socktype;  // IPPROTO_TCP, IPPROTO_UDP
    int              ai_protocol;  // SOCK_STREAM, SOCK_DRAM, ...
    socklen_t        ai_addrlen;   // length of socket-address
    struct sockaddr *ai_addr;      // socket-address for socket
    char            *ai_canonname; // canonical name of host
    struct addrinfo *ai_next;      // pointer to next in list
};
```

Connecting via a DNS Query

```
struct addrinfo   hints, *ai, *ai0;
int i;

memset(&hints, 0, sizeof(hints));
hints.ai_family    = PF_UNSPEC;
hints.ai_socktype  = SOCK_STREAM;
if ((i = getaddrinfo(“www.google.com”, "80", &hints, &ai0)) != 0) {
    printf("Unable to look up IP address: %s", gai_strerror(i));
    ...
}

for (ai = ai0; ai != NULL; ai = ai->ai_next) {
    fd = socket(ai->ai_family, ai->ai_socktype, ai->ai_protocol);
    if (fd == -1) {
        perror("Unable to create socket");
        continue;
    }

    if (connect(fd, ai->ai_addr, ai->ai_addrlen) == -1) {
        perror("Unable to connect");
        close(fd);
        continue;
    }
    ...
}
```

Accepting Connections

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

```
int                 connfd;
struct sockaddr_in  cliaddr;
socklen_t           cliaddrlen = sizeof(cliaddr);
...
connfd = accept(fd, (struct sockaddr *) &cliaddr, &cliaddrlen);
if (connfd == -1) {
    // Error
    ...
}
...
```

Accepts a connection, returns *new* file descriptor for the connection (`connfd`) and client address (`cliaddr`)

Accepting Connections

- A TCP/IP server may have multiple connections outstanding
  - Can `accept()` connections one at a time, handling each request in series
  - Can `accept()` connections and start a new thread for each, allowing it to process several in parallel
- Each call to `accept()` returns a new file descriptor

Reading and Writing Data

```
#define BUFLEN 1500
...
ssize_t i;
ssize_t rcount;
char    buf[BUFLEN];
...
rcount = read(fd, buf, BUFLEN);
if (rcount == -1) {
    // Error has occurred
    ...
}
...
for (i = 0; i < rcount; i++) {
    printf("%c", buf[i]);
}
```

Read up to BUFLEN bytes of data from connection; blocks until data available

Returns actual number of bytes read, or –1 on error

Data is *not* null terminated

Reading and Writing Data

```
char data[] = “Hello, world!”;
int  datalen = strlen(data);
...
if (write(fd, data, datalen) == -1) {
    // Error has occurred
    ...
}
...
```

Send data on a TCP/IP connection; blocks until all data can be written

Returns actual number of bytes written, or `-1` on error

Reading and Writing Data

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

int main()
{
        char     x[] = "Hello, world!";
        char    *y   = malloc(14);

        sprintf(y, "Hello, world!");

        printf("x = %s\n", x);
        printf("y = %s\n", y);

        printf("sizeof(x) = %d\n", sizeof(x));
        printf("sizeof(y) = %d\n", sizeof(y));

        printf("strlen(x) = %d\n", strlen(x));
        printf("strlen(y) = %d\n", strlen(y));

        return 0;
}
```

What gets printed?

Why?

Closing a Socket

```
#include <unistd.h>
```

```
close(fd);
```

Close and destroy a socket

Close the file descriptor for each connection, then the file descriptor for the underlying socket

Programming Exercises

Assessment

- Laboratory work is assessed, total weighting 20%

Exercise	Date set	Date due*	Weighting
Warm-up	13 January	26 January, 12:00pm	4%
Web client	27 January	16 February, 12:00pm	6%
Web server	17 February	12 March, 12:00pm	10%

* Note: these are hard deadlines; late submissions will receive a mark of zero unless accompanied by a valid special circumstances form.

- All students are required to attend Wednesday labs

Warm-up Exercise

- Write two programs in C: `hello_client` and `hello_server`
  - The server listens for, and accepts, a single TCP connection; it reads all the data it can from that connection, and prints it to the screen; then it closes the connection
  - The client connects to the server, sends the string “Hello, world!”, then closes the connection
- Details on the handout…

Questions?