The Berkeley Sockets API

Networked Systems Architecture 3
Lecture 4

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of
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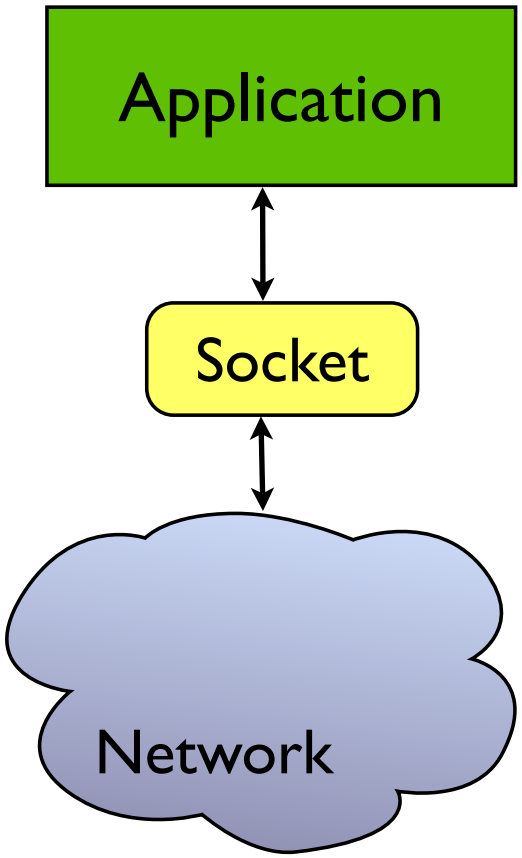
The Berkeley Sockets API

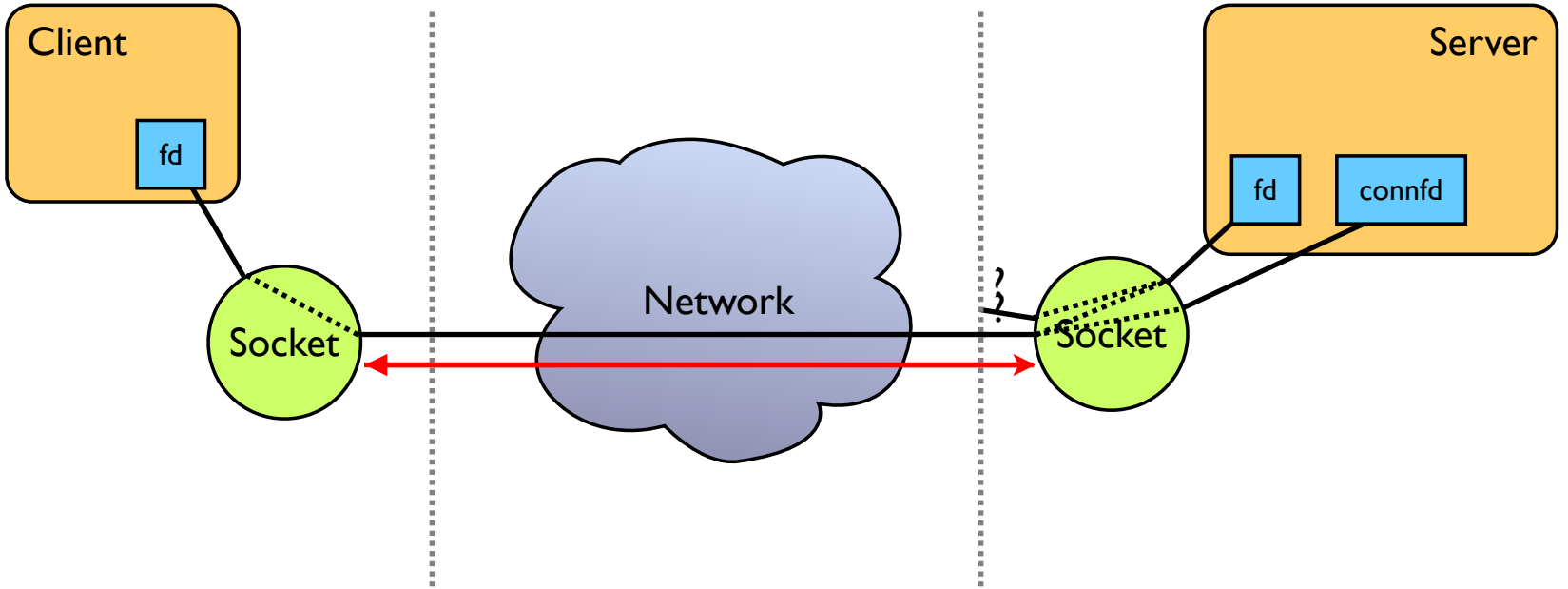
- Widely used low-level C networking API
- First introduced in 4.3BSD Unix
  - Now available on most platforms: Linux, MacOS X, Windows, FreeBSD, Solaris, etc.
  - Largely compatible cross-platform

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

TCP/IP Connection

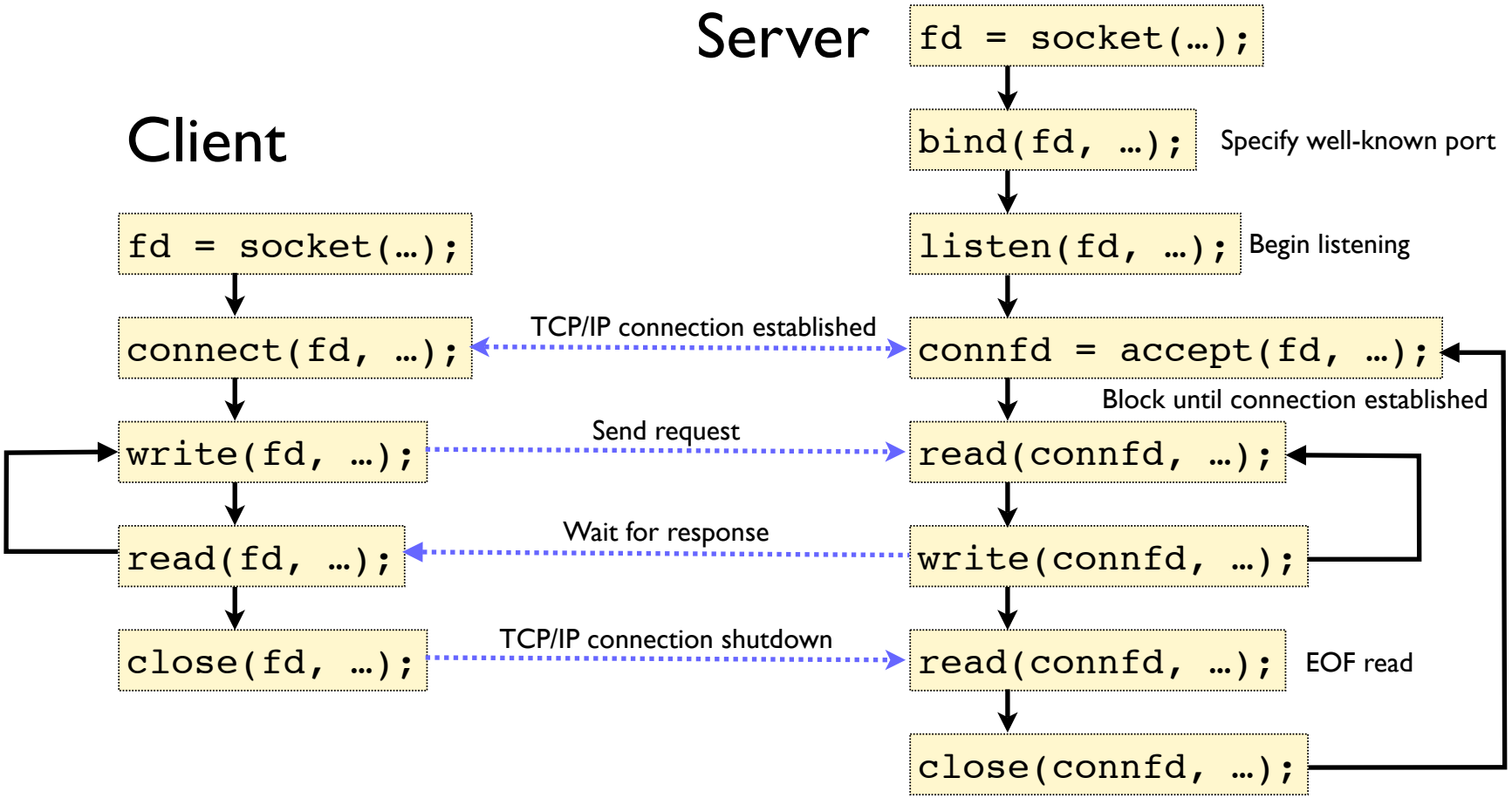



```
int fd = socket(...)

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)
```

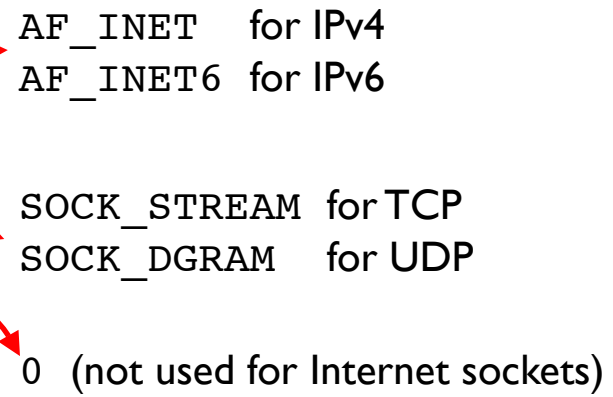
TCP/IP Connection



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 EPROTONOTSUPPORT :
        // Protocol not supported
        ...
    case EACCESS:
        // Permission denied
        ...
    default:
        // Other error...
        ...
    }
```

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

E.g. do "`man socket`" and see 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
  - 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 using `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

```
#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: DNS

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

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, &cliaddr, &cliaddrlen);
if (connfd == -1) {
    // Error
    ...
}
...
```

Accept a connection, returning a new file descriptor for that connection (`connfd`) and the client's 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 for the new connection

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 to read.

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

Data read from the connection is *not* null terminated.

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?

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.

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

Questions?