# CS 33

## More Network Programming

# Client-Server Interaction

- Client sends requests to server
- Server responds
- Server may deal with multiple clients at once
- Client may contact multiple servers

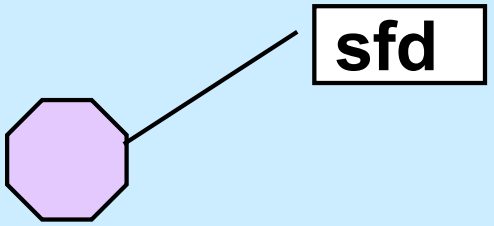
# Reliable Communication

- The promise …
  - what is sent is received
  - order is preserved
- Set-up is required
  - two parties agree to communicate
  - within the implementation of the protocol:
    - » each side keeps track of what is sent, what is received
    - » received data is acknowledged
    - » unack'd data is re-sent
- The standard scenario
  - server receives connection requests
  - client makes connection requests

# Streams in the Inet Domain (1)

- **Server steps**
  - **1) create socket**

```
sfd = socket(AF_INET, SOCK_STREAM, 0);
```

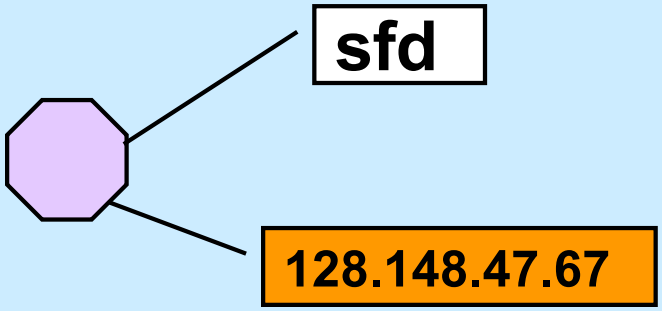


# Streams in the Inet Domain (2)

- **Server steps**
  - **2) bind name to socket**

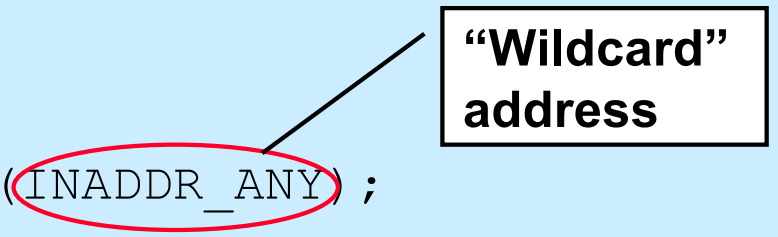
```
bind(sfd,
   (struct sockaddr *)&my_addr, sizeof(my_addr));
```



# Some Details …

- **Server may have multiple interfaces; we want to be able to receive on all of them**

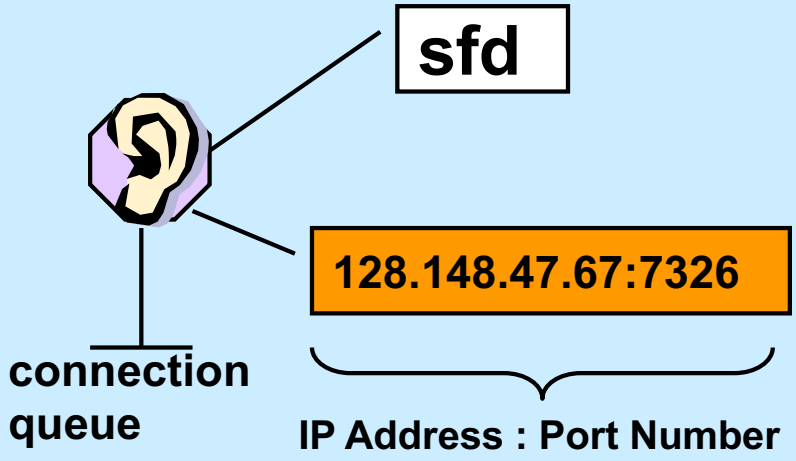
```
struct sockaddr_in {
   sa_family_t sin_family;
   in_port_t sin_port;
   struct in_addr sin_addr;
} my_addr;

my_addr.sin_family = AF_INET;
my_addr.sin_addr.s_addr = htonl(INADDR_ANY);
my_addr.sin_port = htons(port);
```



# Streams in the Inet Domain (3)

- **Server steps**
  - **3) put socket in "listening mode"**

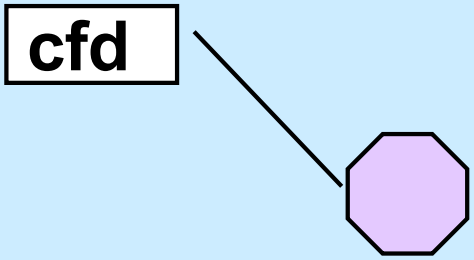
```
int listen(int sfd, int MaxQueueLength);
```



# Streams in the Inet Domain (4)

- **Cient steps**
  - **1) create socket**

```
cfd = socket(AF_INET, SOCK_STREAM, 0);
```

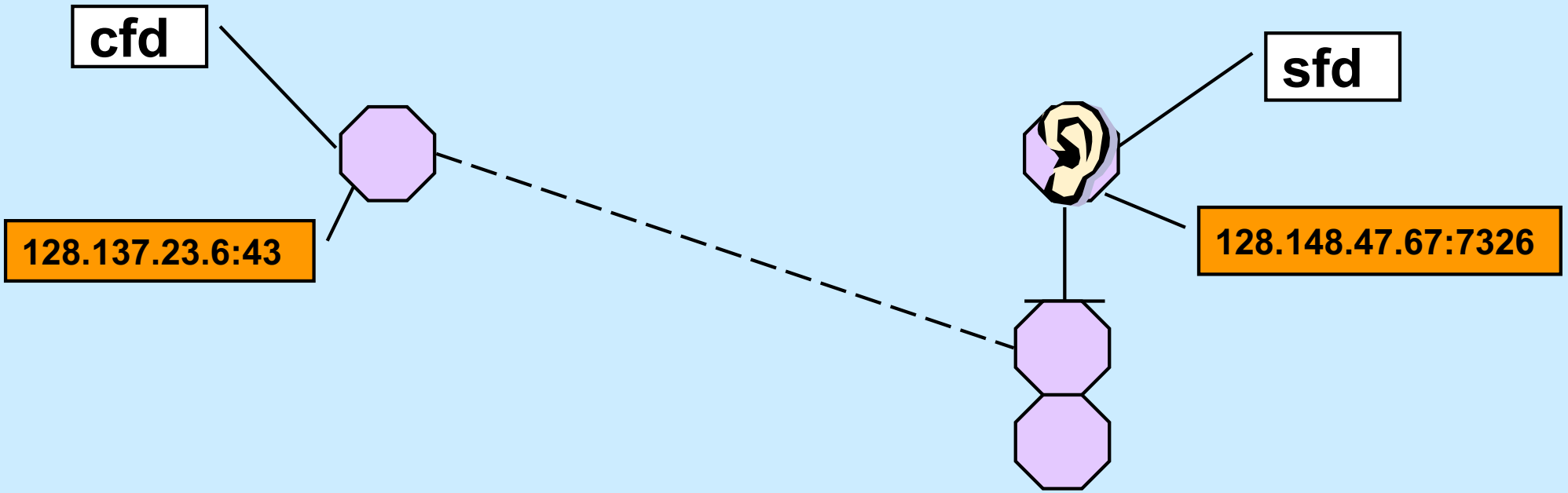


# Streams in the Inet Domain (5)

- **Client steps**
  - **2) connect to server**

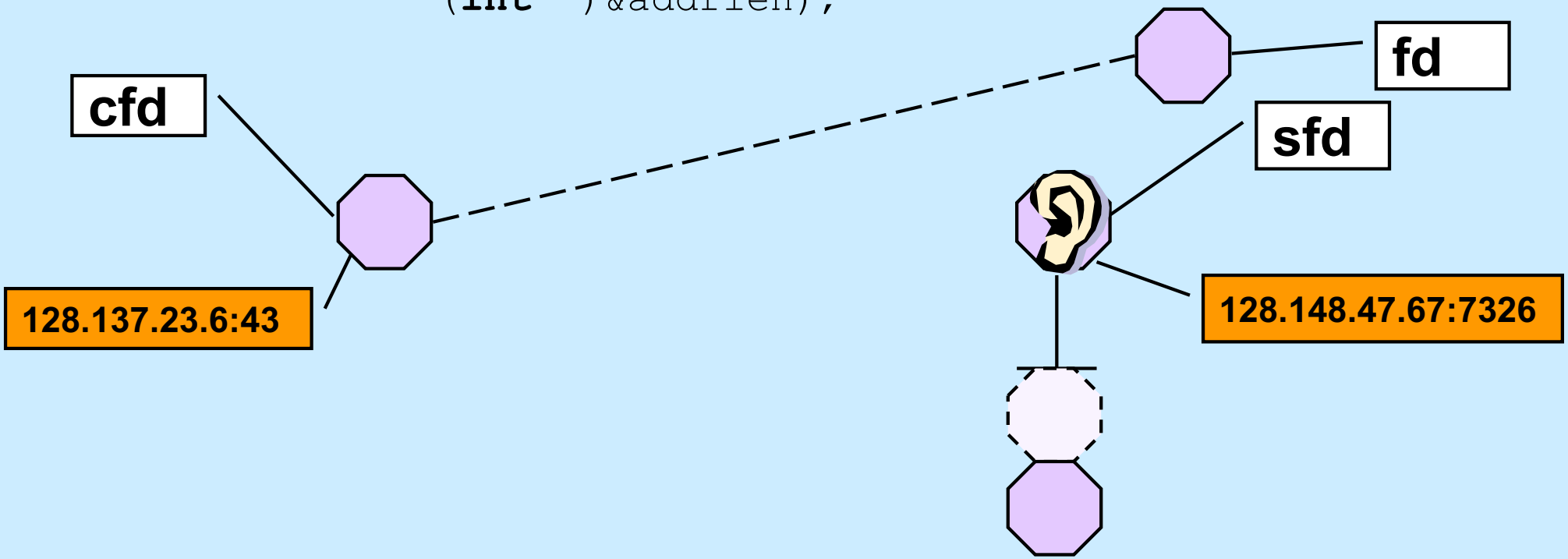
```
connect(cfd, (struct sockaddr *)&server_addr,
    sizeof(server_addr));
```



# Streams in the Inet Domain (6)

- **Server steps**
  - **3) accept connection**

```
fd = accept((int)sfd, (struct sockaddr *)addr,
     (int *)&addrlen);
```



# Inet Stream Example (1)

- **Server side**

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

int main(int argc, char *argv[ ]) {
  struct sockaddr_in my_addr;
  int lsock;
  void serve(int);
  if (argc != 2) {
    fprintf(stderr, "Usage: tcpServer port\n");
    exit(1);
  }
```

# Inet Stream Example (2)

```
// Step 1: establish a socket for TCP
if ((lsock = socket(AF_INET, SOCK_STREAM, 0)) < 0) {
  perror("socket");
  exit(1);
}
```

# Inet Stream Example (3)

```
/* Step 2: set up our address */
memset(&my_addr, 0, sizeof(my_addr));
my_addr.sin_family = AF_INET;
my_addr.sin_addr.s_addr = htonl(INADDR_ANY);
my_addr.sin_port = htons(atoi(argv[1]));

/* Step 3: bind the address to our socket */
if (bind(lsock, (struct sockaddr *)&my_addr,
    sizeof(my_addr)) < 0) {
  perror("bind");
  exit(1);
}
```

# Inet Stream Example (4)

```
/* Step 4: put socket into "listening mode" */
if (listen(lsock, 100) < 0) {
  perror("listen");
  exit(1);
}
while (1) {
  int csock;
  struct sockaddr_in client_addr;
  int client_len = sizeof(client_addr);

  /* Step 5: receive a connection */
  csock = accept(lsock,
      (struct sockaddr *)&client_addr, &client_len);
  printf("Received connection from %s#%hu\n",
      inet_ntoa(client_addr.sin_addr), client_addr.sin_port);
```

# Inet Stream Example (5)

```
    switch (fork( )) {
    case -1:
      perror("fork");
      exit(1);
    case 0:
      // Step 6: create a new process to handle connection
      serve(csock);
      exit(0);
    default:
      close(csock);
      break;
    }
  }
}
```

# Inet Stream Example (6)

```
void serve(int fd) {
  char buf[1024];
  int count;

  // Step 7: read incoming data from connection
  while ((count = read(fd, buf, 1024)) > 0) {
    write(1, buf, count);
  }
  if (count == -1) {
    perror("read");
    exit(1);
  }
  printf("connection terminated\n");
}
```

# Inet Stream Example (7)

- **Client side**

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>
// + more includes ...

int main(int argc, char *argv[]) {
  int s, sock;
  struct addrinfo hints, *result, *rp;

  char buf[1024];
  if (argc != 3) {
       fprintf(stderr, "Usage: tcpClient host port\n");
       exit(1);
  }
```

# Inet Stream Example (8)

```
// Step 1: find the internet address of the server
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_UNSPEC;
hints.ai_socktype = SOCK_STREAM;

if ((s=getaddrinfo(argv[1], argv[2], &hints, &result)) != 0) {
     fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(s));
     exit(1);
}
```

# Inet Stream Example (9)

```
// Step 2: set up socket for TCP and connect to server
for (rp = result; rp != NULL; rp = rp->ai_next) {
     // try each interface till we find one that works
     if ((sock = socket(rp->ai_family, rp->ai_socktype,
          rp->ai_protocol)) < 0) {
               continue;
     }
     if (connect(sock, rp->ai_addr, rp->ai_addrlen) >= 0) {
               break;
     }
     close(sock);
}
if (rp == NULL) {
     fprintf(stderr, "Could not connect to %s\n", argv[1]);
     exit(1);
}
freeaddrinfo(result);
```

# Inet Stream Example (10)

```
    // Step 3: send data to the server
    while(fgets(buf, 1024, stdin) != 0) {
        if (write(sock, buf, strlen(buf)) < 0) {
            perror("write");
            exit(1);
        }
    }
    return 0;
}
```

# Quiz 1

**The previous slide contains**

```
write(sock, buf, strlen(buf))
```

**If data is lost and must be retransmitted**

**a) write returns an error so the caller can retransmit the data.**

**b) nothing happens as far as the application code is concerned, the data is retransmitted automatically.**

# Quiz 2

**A previous slide contains**

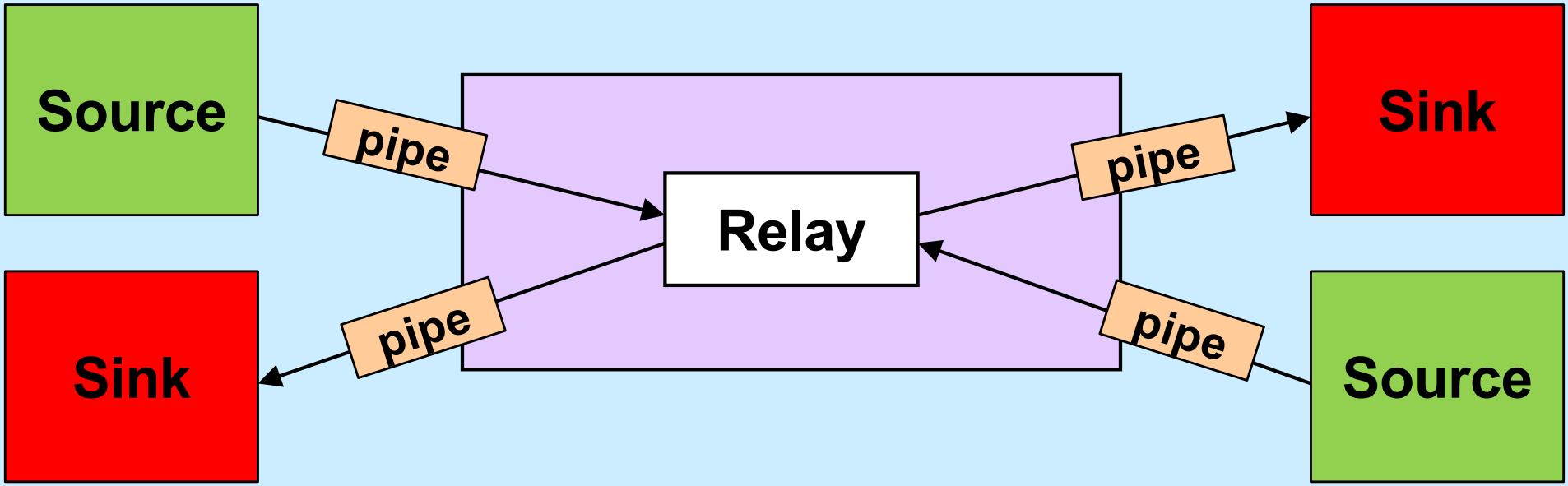
```
write(sock, buf, strlen(buf))
```

**We lose the connection to the other party (perhaps a network cable is cut).**

**a) write returns an error so the caller can reconnect, if desired.**

**b) nothing happens as far as the application code is concerned, the connection is reestablished automatically.**

# Stream Relay



# Solution?

```
while(…) {
    size = read(left, buf, sizeof(buf));
    write(right, buf, size);
    size = read(right, buf, sizeof(buf));
    write(left, buf, size);
}
```

# Select System Call

```
int select(
  int nfds,           // size of fd_sets
  fd_set *readfds,    // descriptors of interest
                      // for reading
  fd_set *writefds,   // descriptors of interest
                      // for writing
  fd_set *excpfds,    // descriptors of interest
                      // for exceptional events
  struct timeval *timeout
                      // max time to wait
);
```

# Relay Sketch

```
void relay(int left, int right) {
    fd_set rd, wr;
    int maxFD = max(left, right) + 1;
    FD_ZERO(&rd); FD_SET(left, &rd); FD_SET(right, &rd);
    FD_ZERO(&wr); FD_SET(left, &wr); FD_SET(right, &wr);
    while (1) {
        select(maxFD, &rd, &wr, 0, 0);
        if (FD_ISSET(left, &rd))
            read(left, bufLR, BSIZE);
        if (FD_ISSET(right, &rd))
            read(right, bufRL, BSIZE);
        if (FD_ISSET(right, &wr))
            write(right, bufLR, BSIZE);
        if (FD_ISSET(left, &rd))
            write(left, bufRL, BSIZE);
    }
}
```

# Quiz 3

**40 bytes have been read from the left-hand source. Select reports that it is ok to write to the right-hand sink.**

a) **You're guaranteed you can immediately write all 40 bytes to the right-hand sink**

b) **All that's guaranteed is that you can immediately write at least one byte to the right-hand sink**

c) **Nothing is guaranteed**

# Relay (1)

```
void relay(int left, int right) {
  fd_set rd, wr;
  int left_read = 1, right_write = 0;
  int right_read = 1, left_write = 0;
  int sizeLR, sizeRL, wret;
  char bufLR[BSIZE], bufRL[BSIZE];
  char *bufpR, *bufpL;
  int maxFD = max(left, right) + 1;
```

# Relay (2)

```
while(1) {
  FD_ZERO(&rd);
  FD_ZERO(&wr);
  if (left_read)
    FD_SET(left, &rd);
  if (right_read)
    FD_SET(right, &rd);
  if (left_write)
    FD_SET(left, &wr);
  if (right_write)
    FD_SET(right, &wr);

  select(maxFD, &rd, &wr, 0, 0);
```

# Relay (3)

```
if (FD_ISSET(left, &rd)) {
  sizeLR = read(left, bufLR, BSIZE);
  left_read = 0;
  right_write = 1;
  bufpR = bufLR;
}
if (FD_ISSET(right, &rd)) {
  sizeRL = read(right, bufRL, BSIZE);
  right_read = 0;
  left_write = 1;
  bufpL = bufRL;
}
```

# Relay (4)

```
      if (FD_ISSET(right, &wr)) {
        if ((wret = write(right, bufpR, sizeLR)) == sizeLR) {
          left_read = 1; right_write = 0;
        } else {
          sizeLR -= wret; bufpR += wret;
        }
      }
      if (FD_ISSET(left, &wr)) {
        if ((wret = write(left, bufpL, sizeRL)) == sizeRL) {
          right_read = 1; left_write = 0;
        } else {
          sizeRL -= wret; bufpL += wret;
        }
      }
    }
    return 0;
}
```

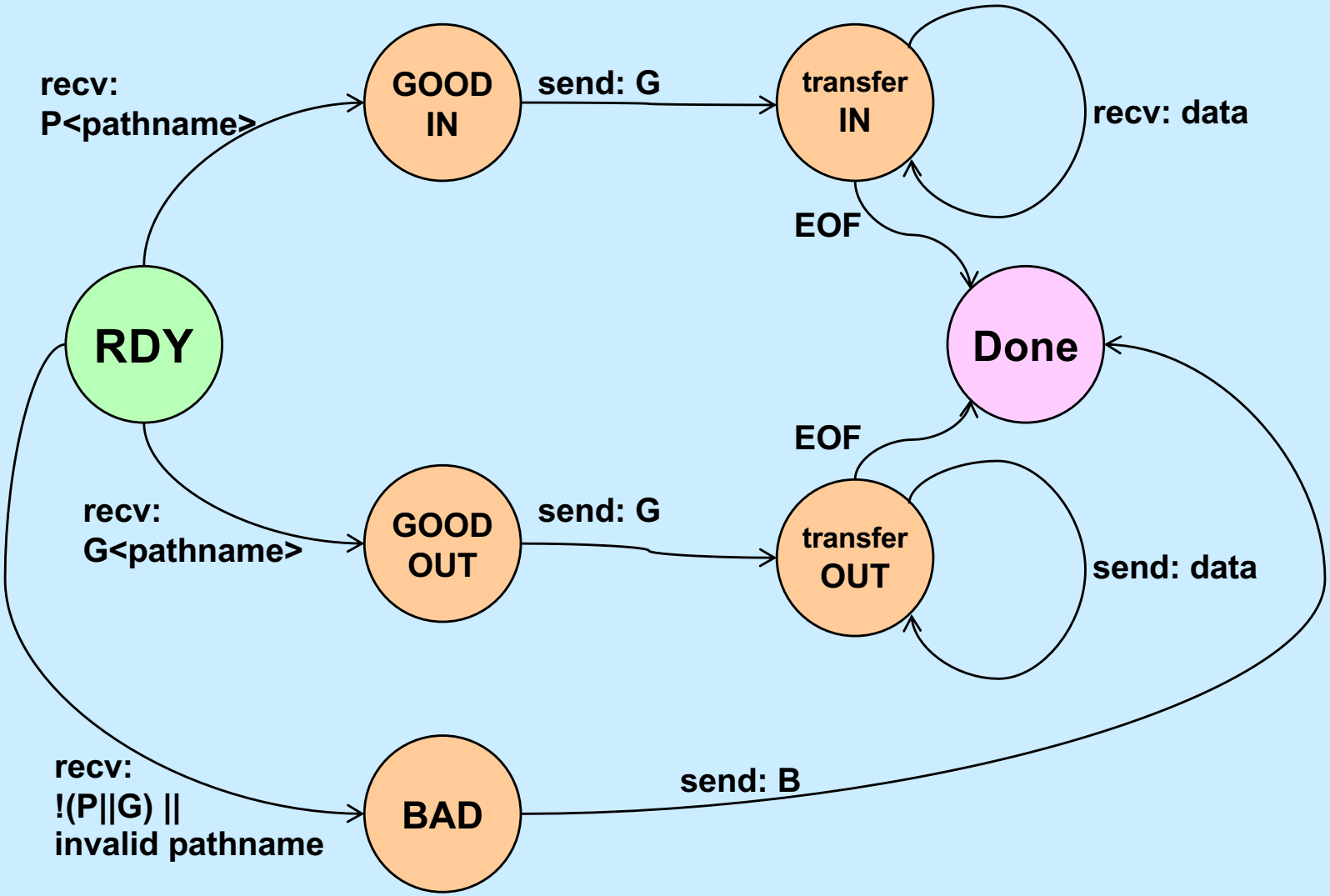
# A Really Simple Protocol

- Transfer a file
  - layered on top of TCP
    - » reliable
    - » indicates if connection is closed
- To send a file

  P<null-terminated pathname><contents of file>
- To retrieve a file

  G<null-terminated pathname>

# Server State Machine



# Keeping Track of State

```
typedef struct client {
  int fd;      // file descriptor of local file being transferred
  int size;    // size of out-going data in buffer
  char buf[BSIZE];
  enum state {RDY, BAD, GOOD, TRANSFER} state;
  /*
     states:
        RDY: ready to receive client's command (P or G)
        BAD: client's command was bad, sending B response + error msg
        GOOD: client's command was good, sending G response
        TRANSFER: transferring data
    */
  enum dir {IN, OUT} dir;
  /*
     IN: client has issued P command
     OUT: client has issued G command
   */
} client_t;
```

# Keeping Track of Clients

```
client_t clients[MAX_CLIENTS];
for (i=0; i < MAX_CLIENTS; i++)
  clients[i].fd = -1; // illegal value
```

# Main Server Loop

```
while(1) {
  select(maxfd, &trd, &twr, 0, 0);
  if (FD_ISSET(lsock, &trd)) {
    // a new connection
    new_client(lsock);
  }
  for (i=lsock+1; i<maxfd; i++) {
    if (FD_ISSET(i, &trd)) {
      // ready to read
      read_event(i);
    }
    if (FD_ISSET(i, &twr)) {
      // ready to write
      write_event(i);
    }
  }
  trd = rd; twr = wr;
}
```

# New Client

```
// Accept a new connection on listening socket
// fd. Return the connected file descriptor

int new_client(int fd) {
  int cfd = accept(fd, 0, 0);
  clients[cfd].state = RDY;
  FD_SET(cfd, &rd);
  return cfd;
}
```

# Read Event (1)

```
// File descriptor fd is ready to be read. Read it, then handle
// the input
void read_event(int fd) {
  client_t *c = &clients[fd];
  int ret = read(fd, c->buf, BSIZE);
  switch (c->state) {
  case RDY:
    if (c->buf[0] == 'G') {
      // GET request (to fetch a file)
      c->dir = OUT;
      if ((c->fd = open(&c->buf[1], O_RDONLY)) == -1) {
        // open failed; send negative response and error message
        c->state = BAD;
        c->buf[0] = 'B';
        strncpy(&c->buf[1], strerror(errno), BSIZE-2);
        c->buf[BSIZE-1] = 0;
        c->size = strlen(c->buf)+1;
      }
```

# Read Event (2)

```
    else {
      // open succeeded; send positive response
      c->state = GOOD;
      c->size = 1;
      c->buf[0] = 'G';
    }
    // prepare to send response to client
    FD_SET(fd, &wr);
    FD_CLR(fd, &rd);
    break;
  }
```

# Read Event (3)

```
if (c->buf[0] == 'P') {
  // PUT request (to create a file)
  c->dir = IN;
  if ((c->fd = open(&c->buf[1],
      O_RDWR|O_CREAT|O_TRUNC, 0666)) == -1) {
      // open failed; send negative response and error message
      ...
  } else {
    // open succeeded; send positive response
    ...
  }
  // prepare to send response to client
  FD_SET(fd, &wr);
  FD_CLR(fd, &rd);
  break;
}
```

# Read Event (4)

```
case TRANSFER:
  // should be in midst of receiving file contents from client
  if (ret == 0) {
    // eof: all done
    close(c->fd);
    close(fd);
    FD_CLR(fd, &rd);
    break;
  }
  if (write(c->fd, c->buf, ret) == -1) {
    // write to file failed: terminate connection to client
    ...
    break;
  }
  // continue to read more data from client
  break;
}
```

# Write Event (1)

```
// File descriptor fd is ready to be written to. Write to it, then,
// depending on current state, prepare for the next action.
void write_event(int fd) {
  client_t *c = &clients[fd];
  int ret = write(fd, c->buf, c->size);
  if (ret == -1) {
    // couldn't write to client; terminate connection
    close(c->fd);
    close(fd);
    FD_CLR(fd, &wr);
    c->fd = -1;
    perror("write to client");
    return;
  }
  switch (c->state) {
```

# Write Event (2)

```
case BAD:
  // finished sending error message; now terminate client connection
  close(c->fd);
  close(fd);
  FD_CLR(fd, &wr);
  c->fd = -1;
  break;
```

# Write Event (3)

```
case GOOD:
  c->state = TRANSFER;
  if (c->dir == IN) {
    // finished response to PUT request
    FD_SET(fd, &rd);
    FD_CLR(fd, &wr);
    break;
  }
  // otherwise finished response to GET request, so proceed
```

# Write Event (4)

```
  case TRANSFER:
    // should be in midst of transferring file contents to client
    if ((c->size = read(c->fd, c->buf, BSIZE)) == -1) {
      ...
      break;
    } else if (c->size == 0) {
      // no more file to transfer; terminate client connection
      close(c->fd);
      close(fd);
      FD_CLR(fd, &wr);
      c->fd = -1;
      break;
    }
    // continue to write more data to client
    break;
  }
}
```

# Problems

- Works fine as long as the protocol is followed correctly
  - can client (malicious or incompetent) cause server to misbehave?
- How can the server limit the number of clients?
- How does server limit file access?