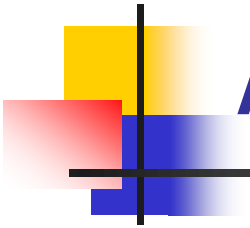
Network Socket Programming - 3

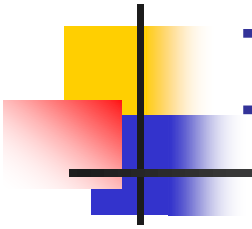
BUPT/QMUL

2019-03-25



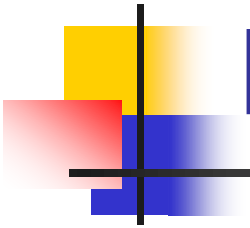
Agenda

- Basic concepts in NP
- Introduction to IP & TCP/UDP
- *Introduction to Sockets*



Introduction to Sockets

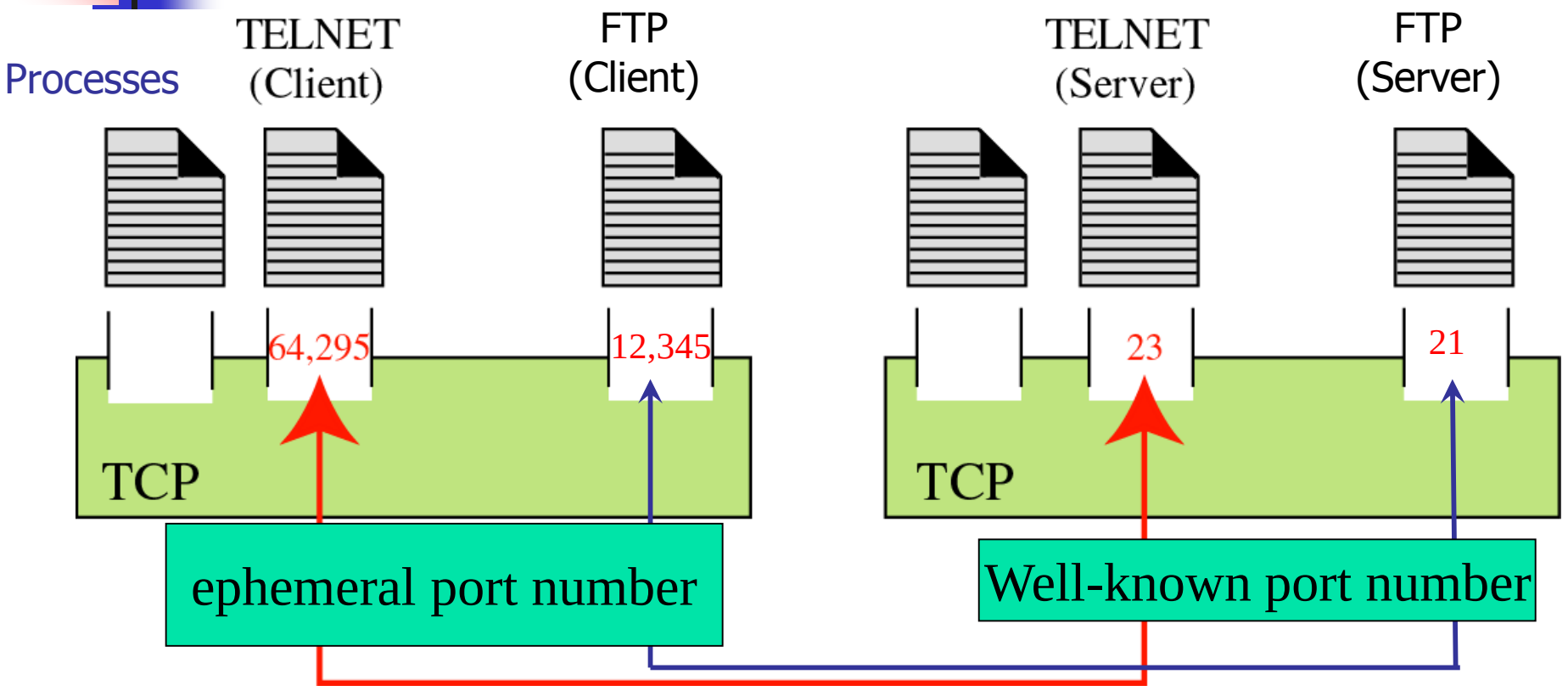
- *Reviews of some helpful points*
- *Sockets interface*
- Major system calls
- Sample programs



Review

- Introduction to Sockets
  - Some Helpful Points
    - Client-Server Model
    - Data Structure of IP Address
      - Host Byte Order vs. Network Byte Order
    - Host Entry Structure of DNS
    - Connections
  - Socket Interface
    - What is **Socket**?
    - Types of Sockets
      - **SOCK_STREAM** (TCP) and **SOCK_DGRAM** (UDP)

Connection and Port Number



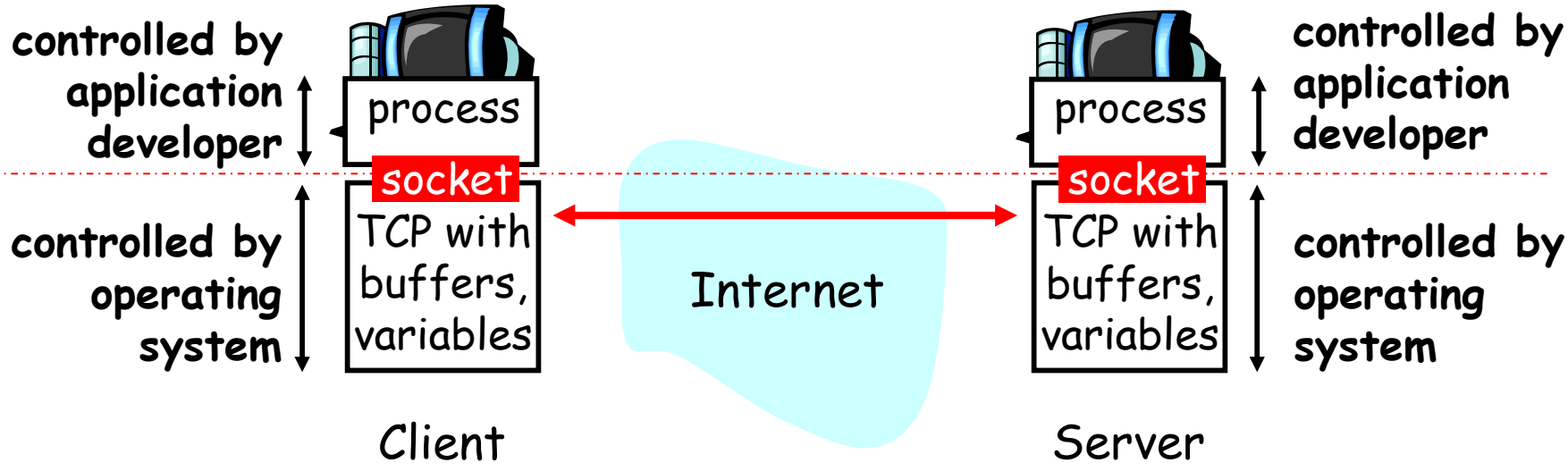
A connection is identified by (Source IP address, Source Port Number, Destination IP address, Destination Port Number), i.e. a pair of socket address

Understanding Socket

- An extension to OS's I/O system, enabling communication between processes and machines
- A host-local, application-created/owned, OS-controlled interface (a "door") into which application process can both send and receive messages to/from another (remote or local) application process
- A socket can be treated the same as a standard file descriptor except that
  - It is created with the socket()
  - Additional system calls are needed to connect and activate it
  - recv() and send() are also used as counterparts to read() and write()

Socket Programming using TCP

- Socket: a door between application process and end-end-transport protocol (UDP or TCP)
- TCP service: reliable transfer of bytes from one process to another



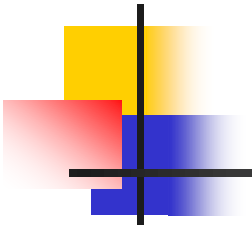
Socket Address

Generic socket address

```
struct sockaddr {
    unsigned short sa_family;      /* PF_INET for IPv4 */
    char sa_data[14];              /* protocol-specific address,
                                      up to 14 bytes. */
};
```

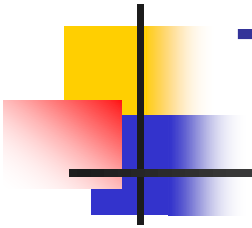
Internet-specific socket address

```
struct sockaddr_in{
    unsigned short  sin_family;   /* AF_INET */
    unsigned short  sin_port;     /* 16-bit port number */
                                  /* Network Byte Order*/
    struct in_addr sin_addr;      /* 32-bit IP Address */
                                  /* Network Byte Order */
    char            sin_zero[8];  /* unused */
}
```

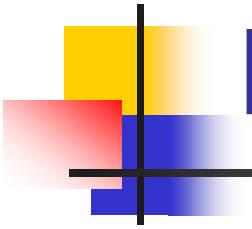


Introduction to Sockets
Part III: major system calls

Socket Programming: Telephone Analogy

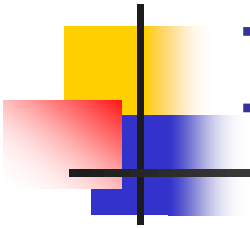


- A telephone call over a “telephony network” works as follows:
  - Both parties have a telephone installed.
  - A phone number is assigned to each telephone.
  - Turn on ringer to listen for a caller.
  - Caller lifts telephone and dials a number.
  - Telephone rings and the receiver of the call picks it up.
  - Both Parties talk and exchange data.
  - After conversation is over they hang up the phone.



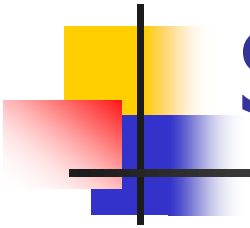
Dissecting the Analogy

- A network application works as follows:
  - An endpoint (telephone) for communication is created on both ends.
  - An address (phone no) is assigned to both ends to distinguish them from the rest of the network.
  - One of the endpoint(receiver) waits for the communication to start.
  - The other endpoints (caller) initiate a connection.
  - Once the call has been accepted, a connection is made and data is exchanged (talk).
  - Once data has been exchanged the endpoints are closed (hang up).



In the world of sockets……

- socket() – Create endpoint for communication
- bind() - Assign a unique telephone number
- listen() – Wait for a caller
- connect() - Dial a number
- accept() – Receive a call
- send(), recv() – Talk
- close() – Hang up

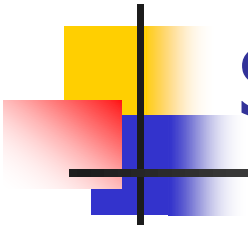


System Calls

- Socket operation
- Byte order operation
- Address formats conversion
- Socket option
- Name and address operation

System Calls – Socket Operation

- socket()
  - returns a socket descriptor
- bind()
  - What address I am on / what port to attach to
- connect()
  - Connect to a remote host
- listen()
  - Waiting for someone to connect to my port
- accept()
  - Get a socket descriptor for an incoming connection
- send() and recv()
  - Send and receive data over a connection
- read(), write()
  - Read from / Write to a particular socket, similar to recv()/ send()
- sendto() and recvfrom()
  - Send and receive data without connection
- close() and shutdown()
  - Close a connection Two way / One way

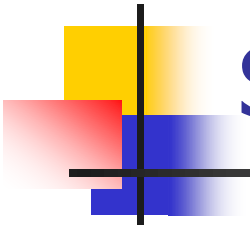


System Calls – Byte Order Conversion

- htonl()
  - host byte order → network byte order for ***long int***
- htons()
  - host byte order → network byte order for ***short int***
- ntohl()
  - network byte order → host byte order for ***long int***
- ntohs()
  - network byte order → host byte order for ***short int***

System Calls – Address Formats Conversion

- **inet_aton()**
  - IP address in numbers-and-dots notation (ASCII string) → IP address structure in network byte order
- **inet_addr()**
  - same function with inet_aton()
- **inet_ntoa()**
  - IP address structure in network byte order → IP address in numbers-and-dots notation (ASCII string)
- **inet_pton()**
  - Similar to inet_aton() but working with IPv4 and IPv6
- **inet_ntop()**
  - Similar to inet_ntoa() but working with IPv4 and IPv6



System Calls – Socket Option

- getsockopt()
  - Allow an application to require information about the socket
- setsockopt()
  - Allow an application to set a socket option

- eg. get/set sending/receiving buffer size of a socket

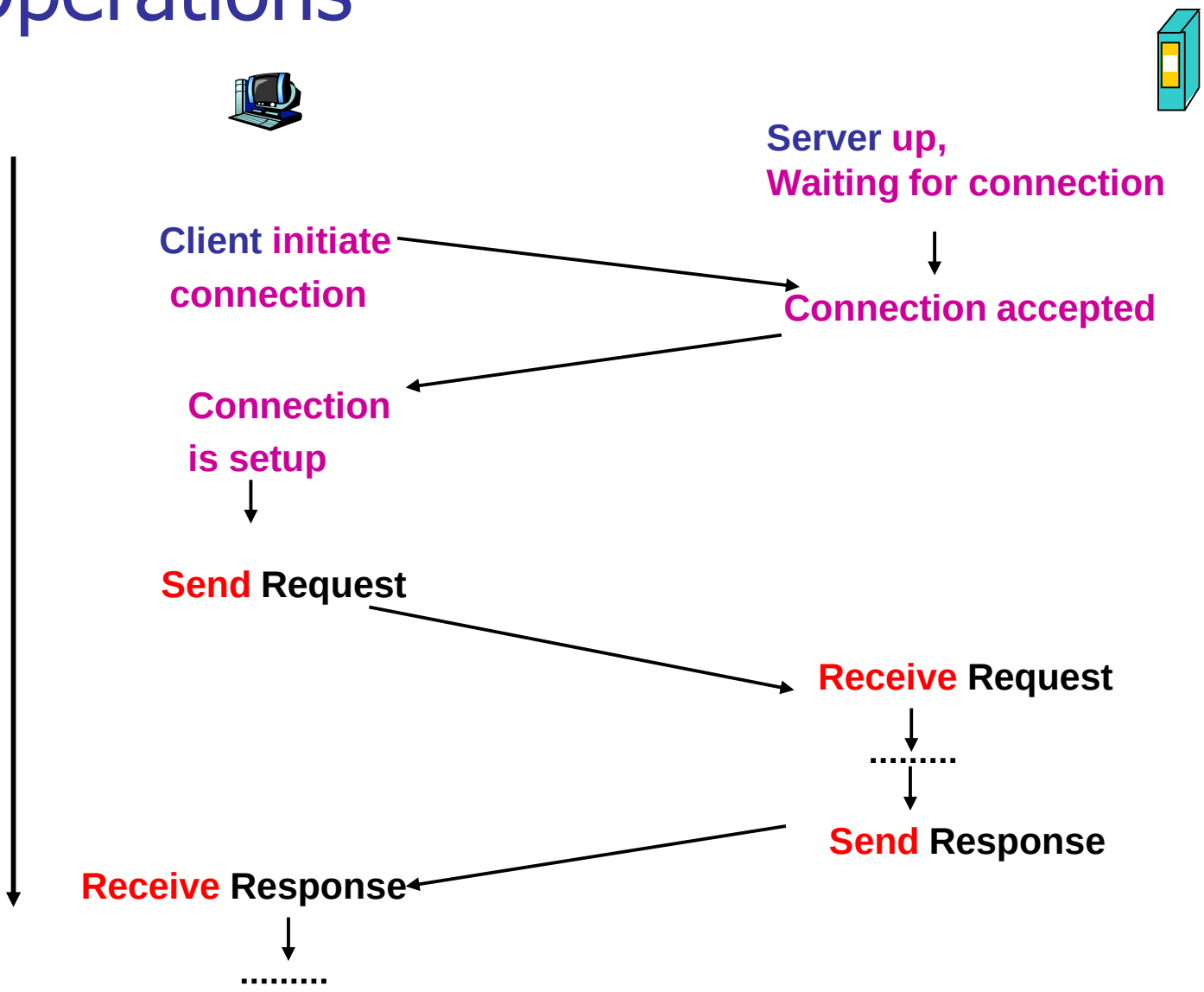
System Calls – Name and Address Operation

- **gethostbyname()**
  - retrieving host entries from DNS and the query key is a DNS domain name
- **gethostbyaddr()**
  - retrieving host entries from DNS and the query key is an IP address
- gethostname()
  - Obtaining the name of a host
- getservbyname()
  - Mapping a named service onto a port number
- getservbyport()
  - Obtaining an entry from the services database given the port number assigned to it

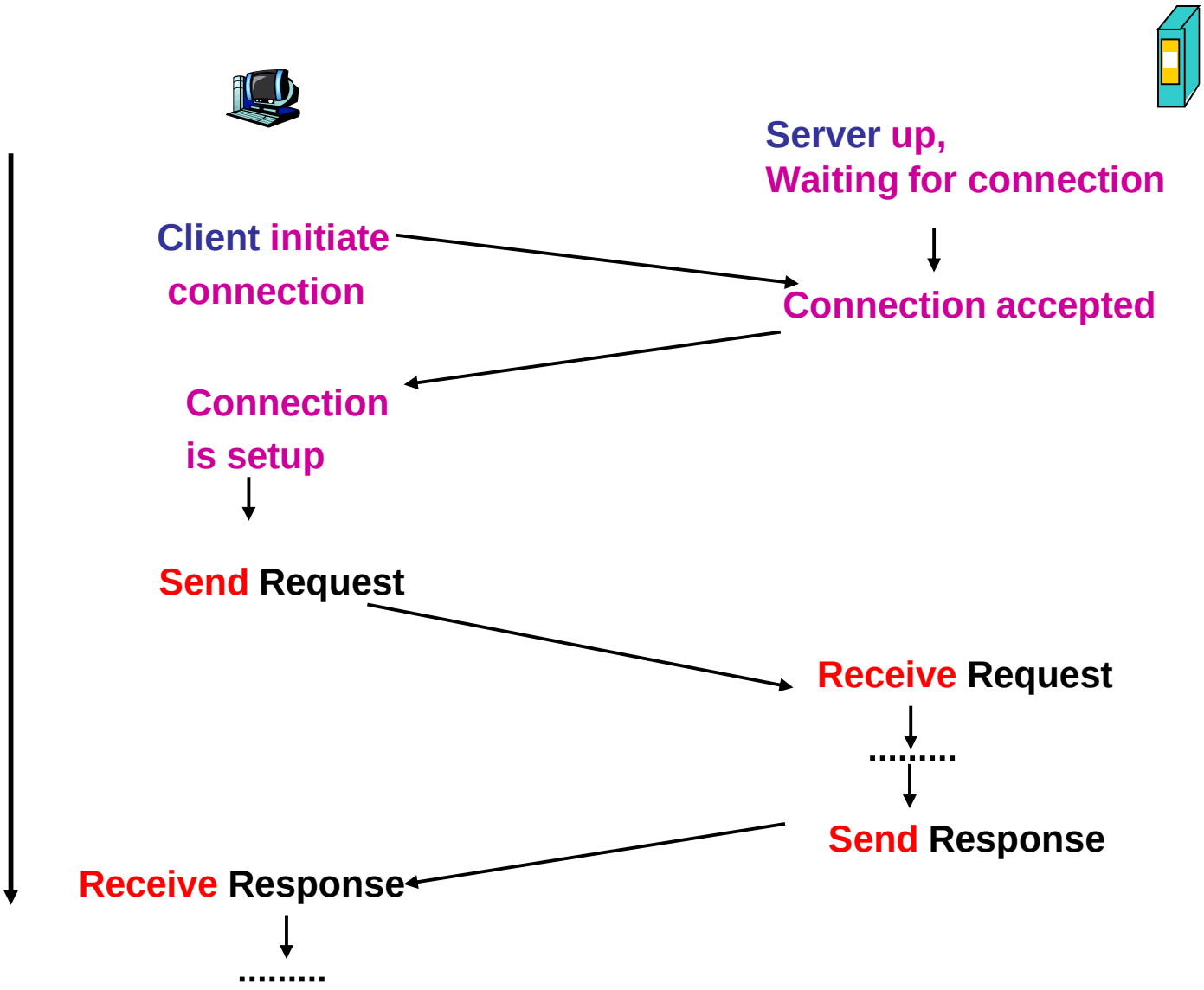
Using UDP to query Local DNS Server

Returns a pointer to struct hostent (host entry structure) on success

Process of Socket Operation: TCP Operations



Map to TCP socket programming



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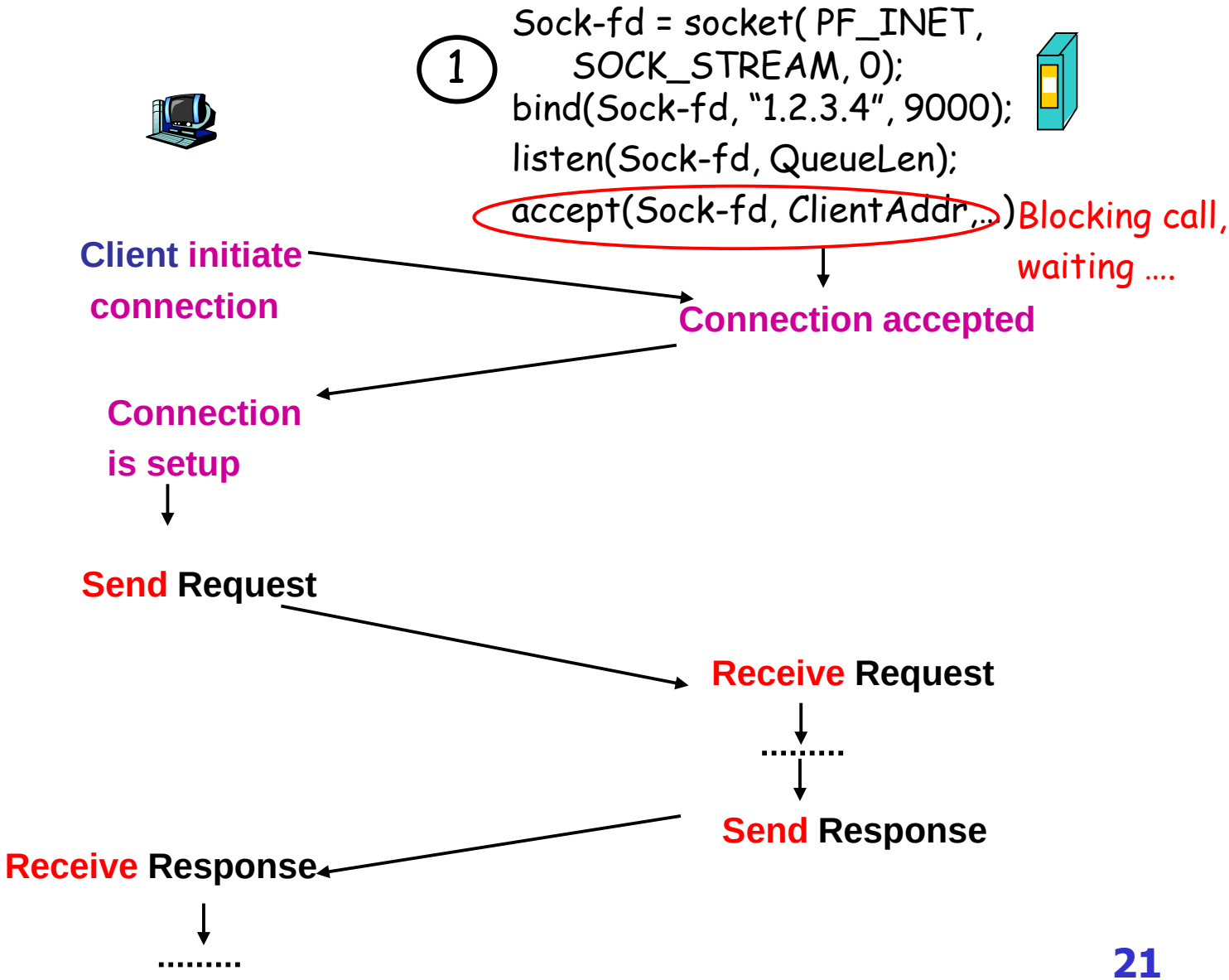

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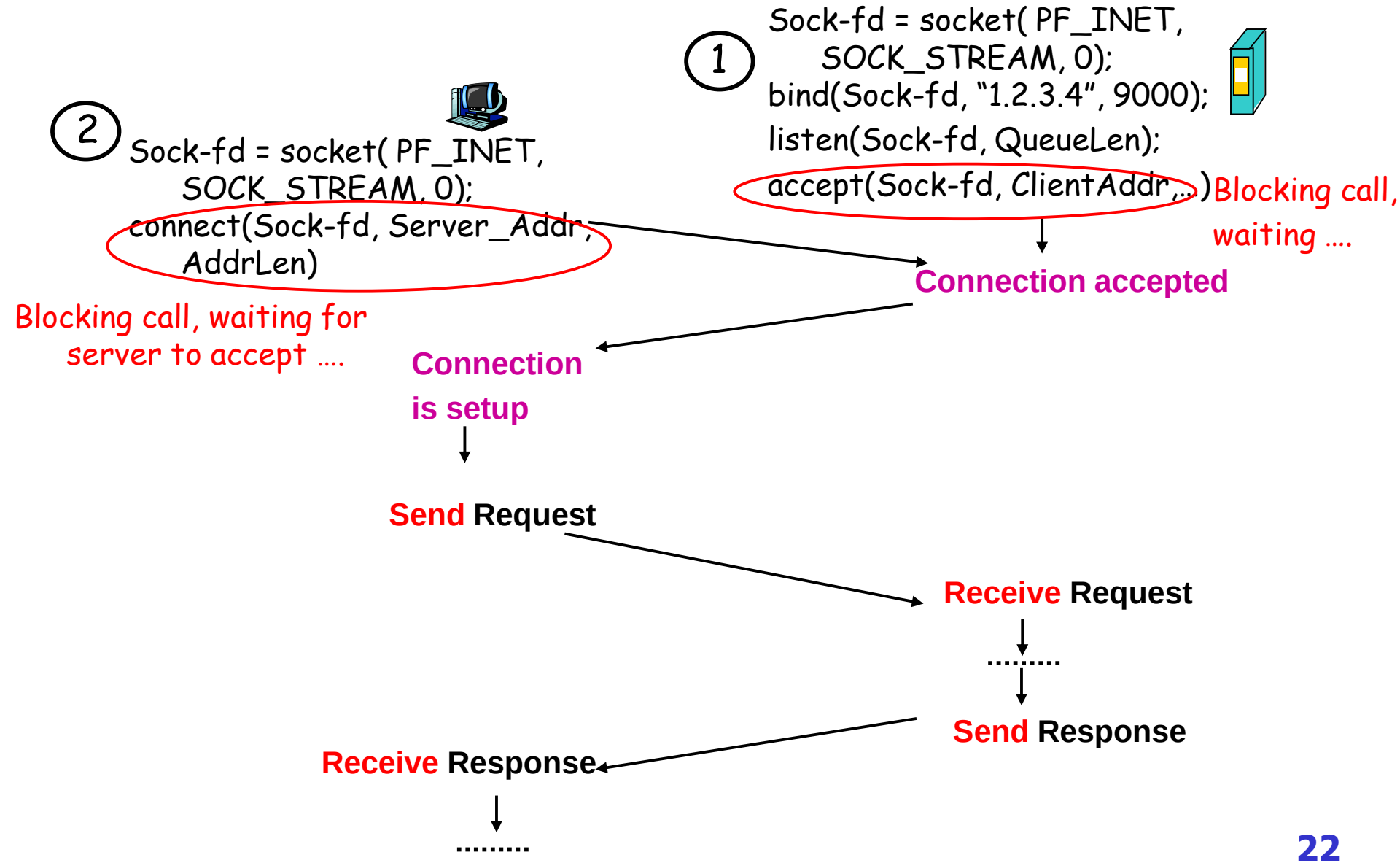

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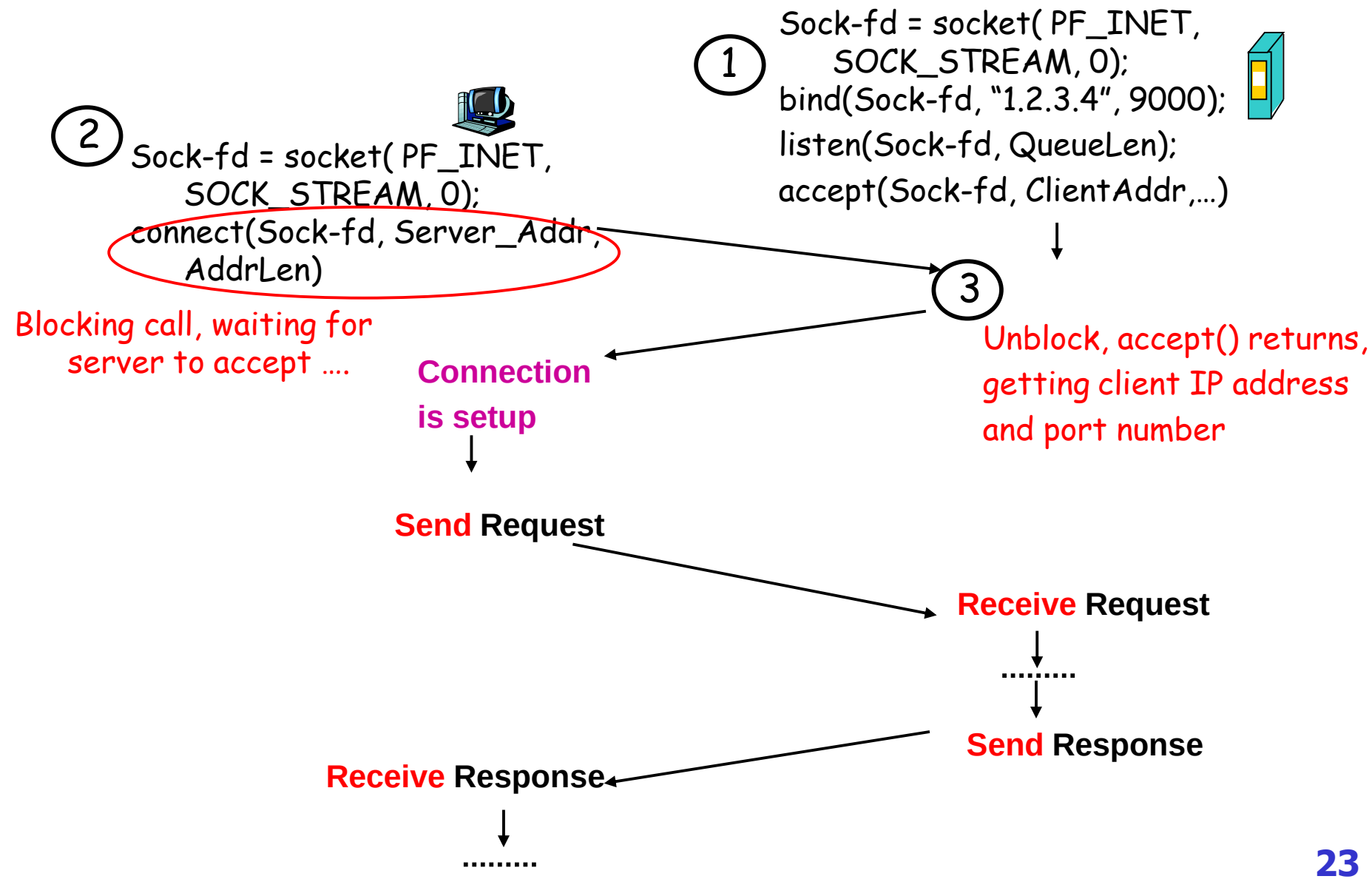

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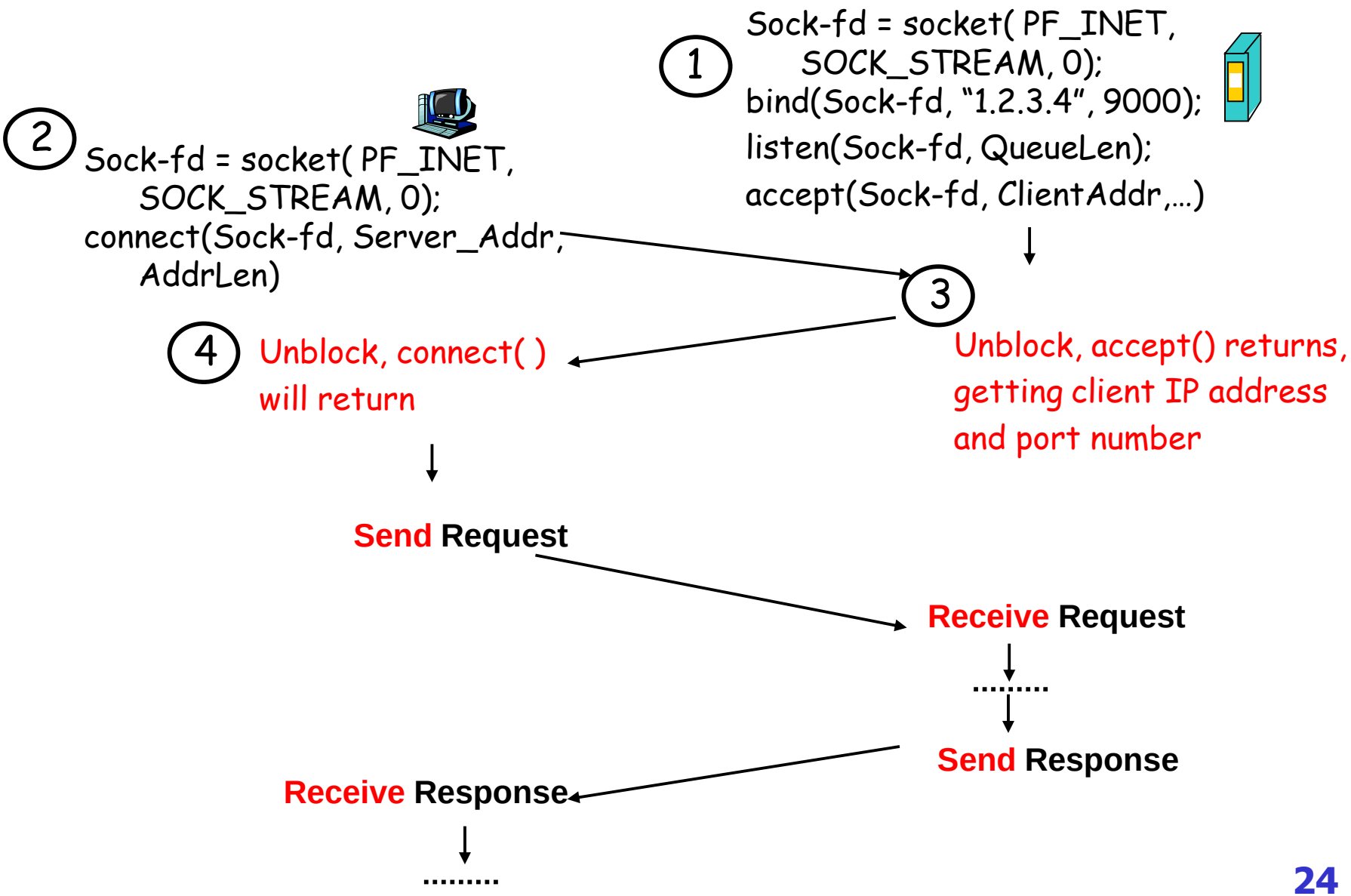

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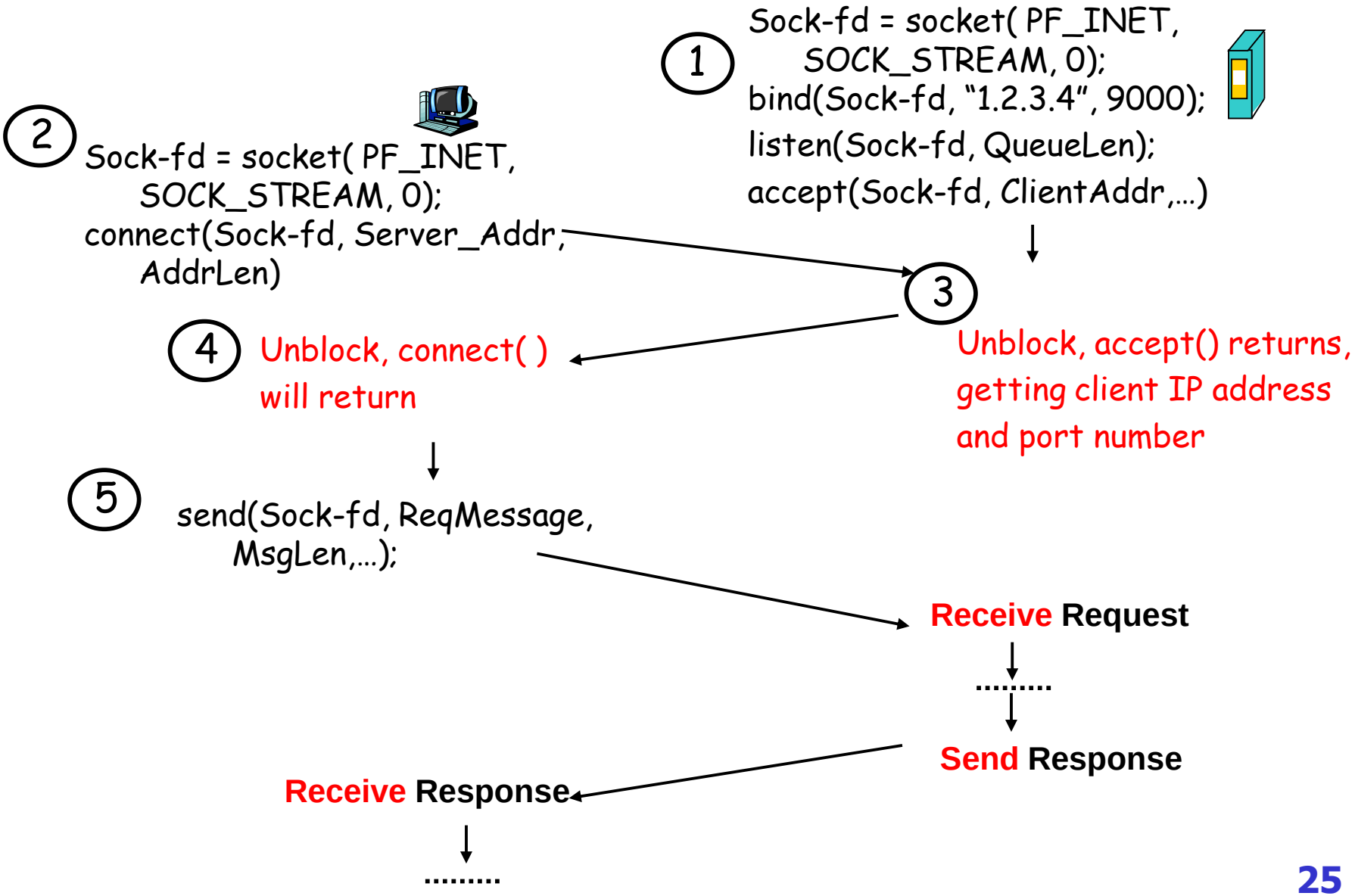

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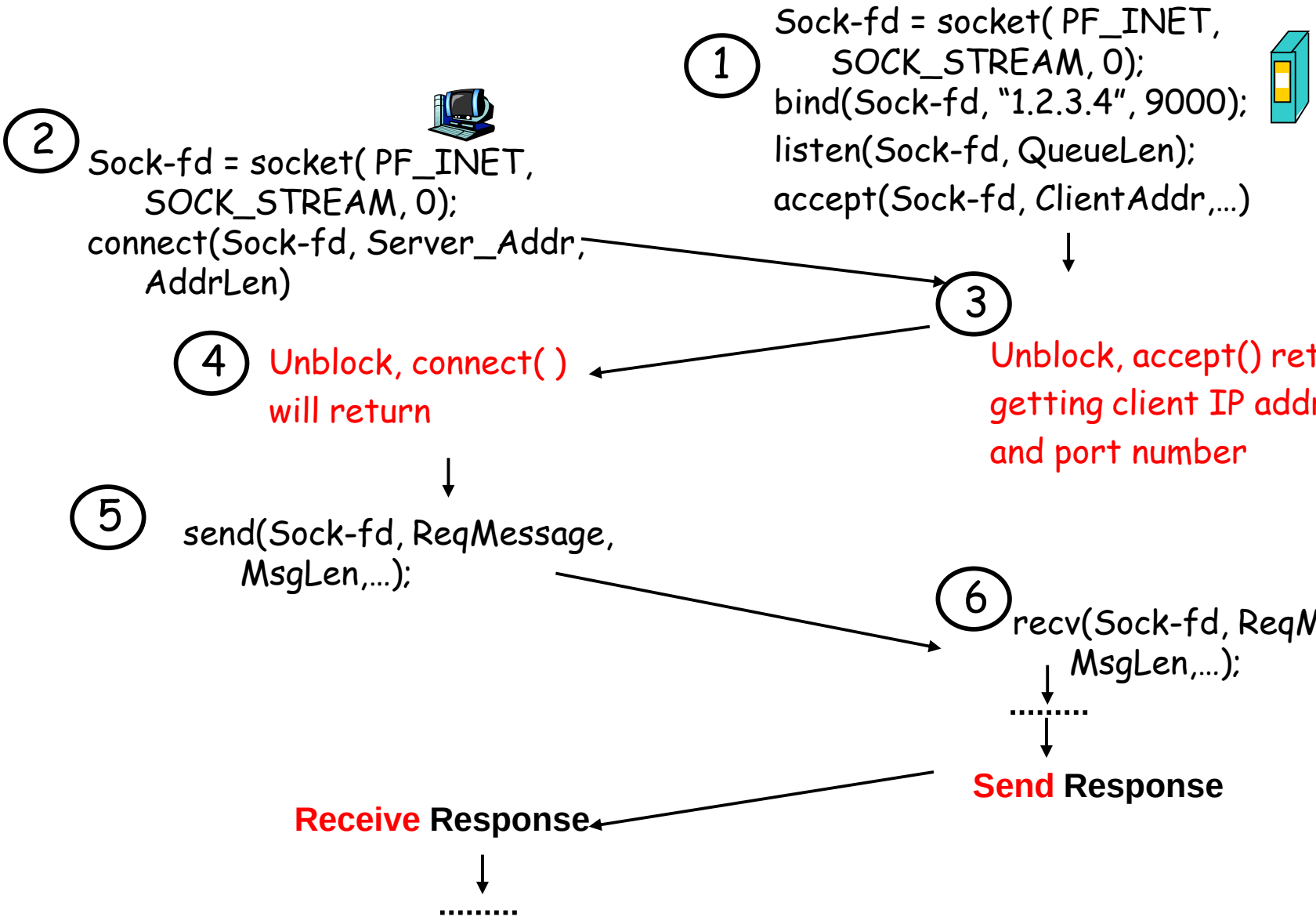

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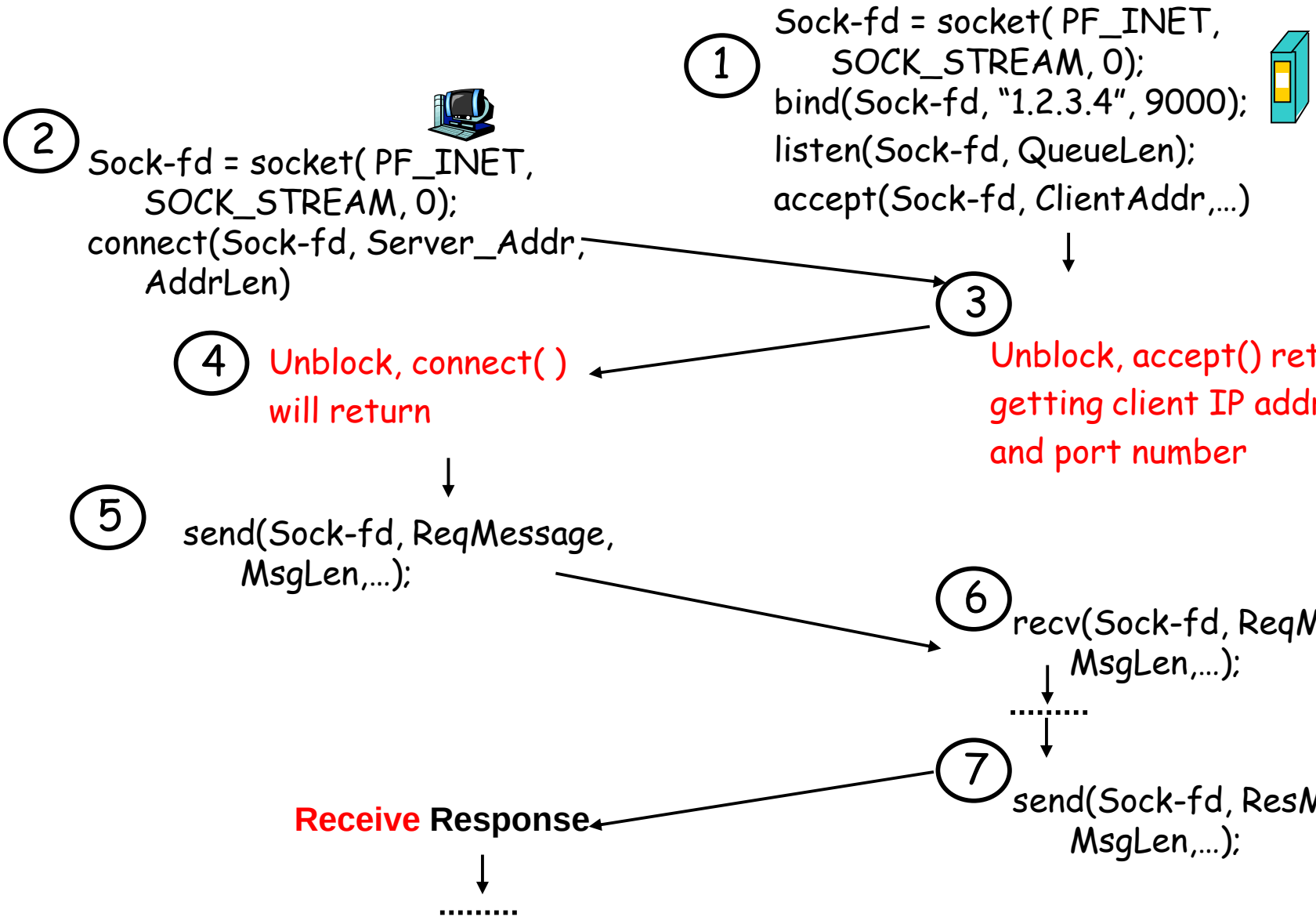
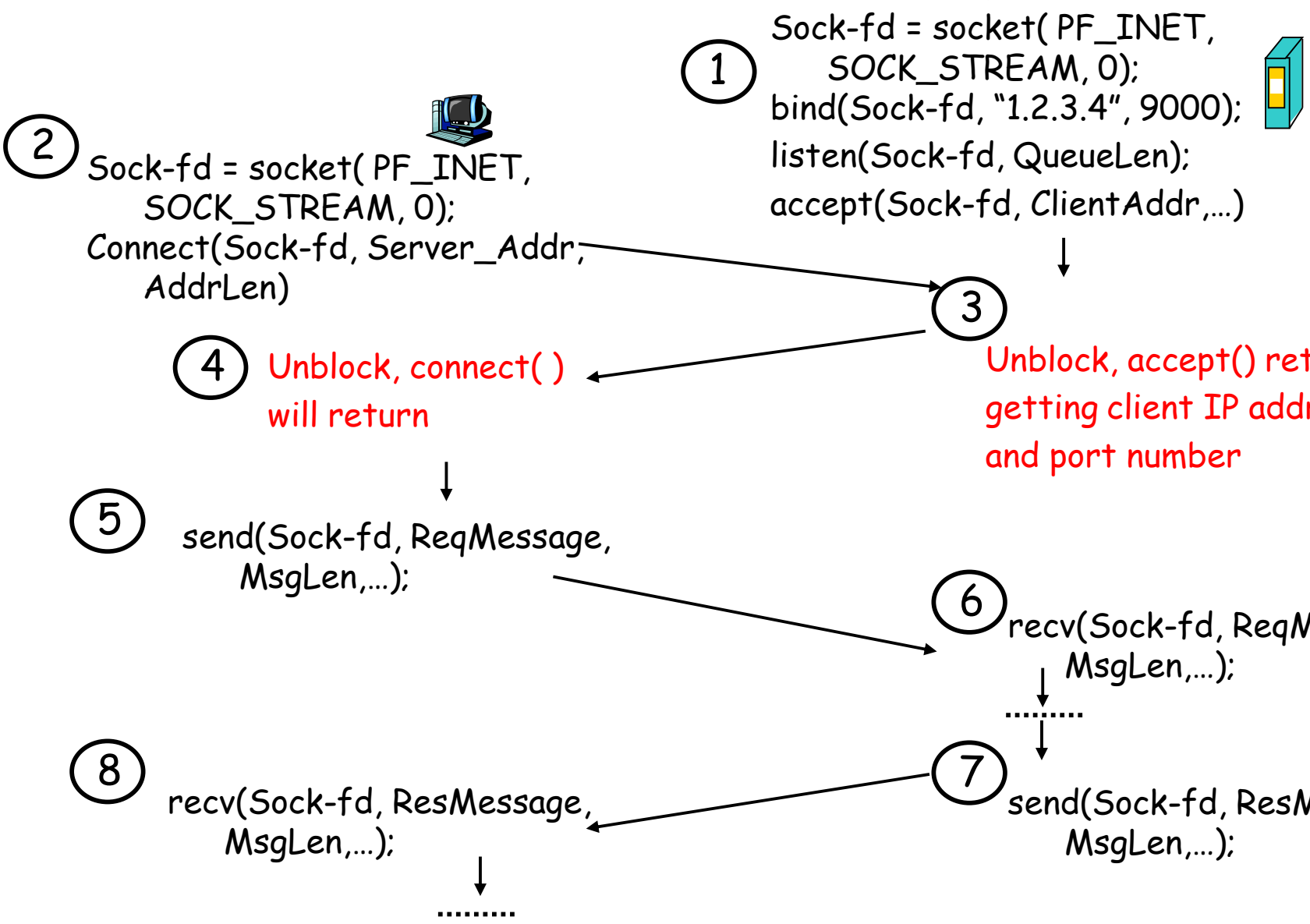
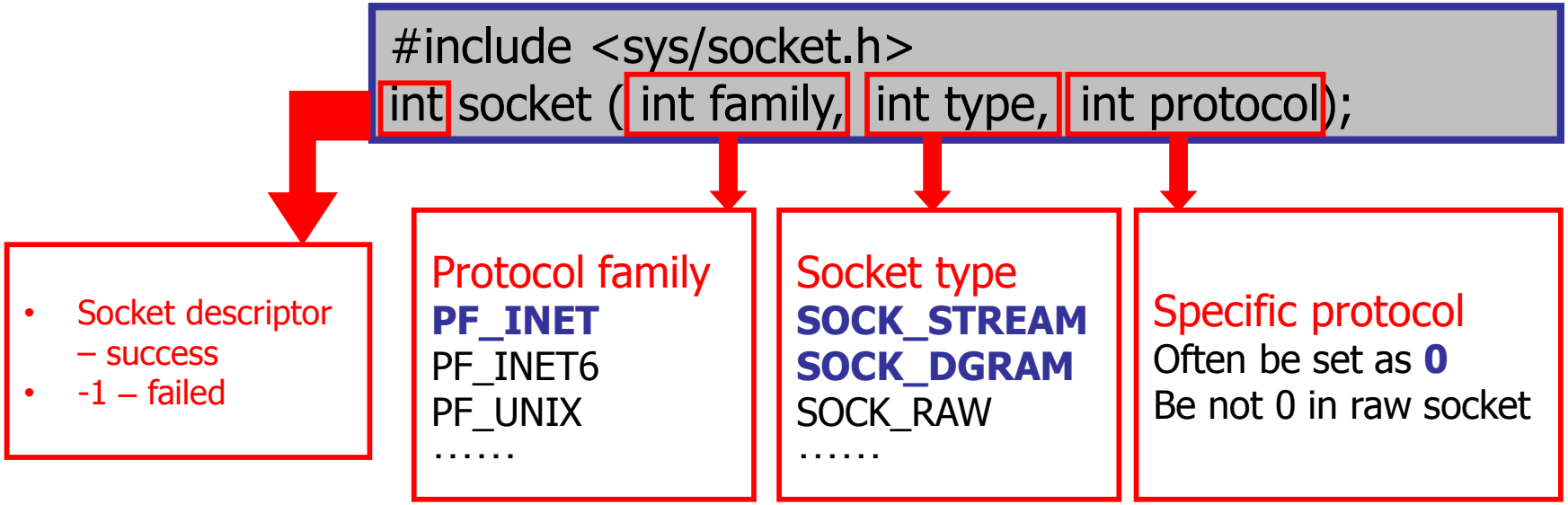


Map to TCP socket programming



System Calls – socket()

- An application calls *socket()* to create a new socket that can be used for network communication
- The call returns a descriptor for the newly created socket



System Calls – bind()

- An application calls bind() to specify the local endpoint address (a **local IP address and protocol port number**) for a socket
- For TCP/IP, the endpoint address uses the ***sockaddr_in*** structure.
- Must cast Internet-specific socket address (`struct sockaddr_in *`) to generic socket address (`struct sockaddr *`) for bind
- **Servers** use *bind* to specify the well-known port at which they will await connections

```
#include <sys/socket.h>
int bind (int sockfd, const struct sockaddr *myaddr, socklen_t addrlen);
```

- 0 – success, -1 – failed
- Socket descriptor to be bound
- The local address to which the socket should be bound
- The length of the structure (bytes)

System Calls – listen()

- Connection-oriented **servers** call *listen()* to place a socket in *passive mode* and make it ready to accept incoming connections
- *listen()* also sets the number of incoming connection requests that the protocol software should enqueue for a given socket while the server handles another request
- It only applies to socket used with **TCP**

```
#include <sys/socket.h>
int listen (int sockfd,        int qlength);
```

0 – success
-1 – failed

Socket that should be prepared for use by a server

The length of the request queue for that socket

System Calls – accept()

- The **server** calls accept() to extract the next incoming request
- *accept()* creates a new socket for each new connection request, and returns the descriptor of the new socket to its caller
- *accept()* fills in the structure (*sockaddr*) with the IP address and protocol port number of the remote machine
- Must cast Internet-specific socket address (`struct sockaddr_in *`) to generic socket address (`struct sockaddr *`) for accept()

```
#include <sys/socket.h>
int accept (int sockfd, struct sockaddr *cliaddr, socklen_t *addrlen);
```

Socket Descriptor (non-zero) – success
-1 – failed

Socket on which to wait

The address of the client that placed the request

The length of the client address

System Calls – connect()

- After creating a socket, a **client** calls *connect()* to establish an active connection to a remote server
- Must cast Internet-specific socket address (`struct sockaddr_in *`) to generic socket address (`struct sockaddr *`) for connect

```
#include <sys/socket.h>
int connect (int sockfd, const struct sockaddr *servaddr, socklen_t addrlen);
```

- 0 – success
  -1 – failed
- Socket to connect
- The server's address to which the socket should connect
- The length of the server's address (bytes)

System Calls – send()

- Both clients (to transmit request) and servers (to transmit replies) used *send()* to transfer data across a **TCP connection**
- The application passes the descriptor of a socket to which the data should be sent, the address of the data to be sent, and the length of the data
- Usually, send copies outgoing data into buffers in the OS kernel

```
#include <sys/socket.h>
ssize_t send (int sockfd, const void *buff, size_t nbytes, int flags);
```

- Number of bytes that are sent successfully

  -1 – failed
- socket descriptor you want to send data to
- The address of the data to be sent
- The number of bytes to be sent
- The flag controlling the connection, usually 0

System Calls – recv()

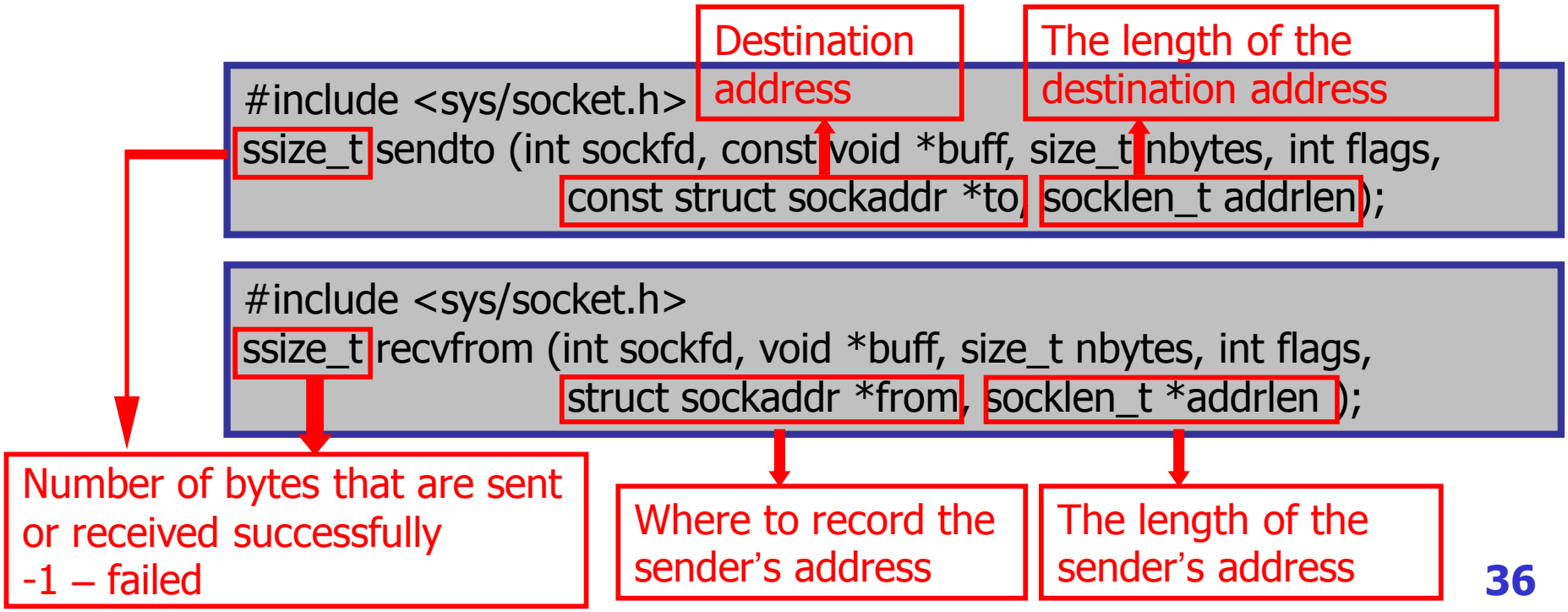
- Both clients (to receive a reply) and servers (to receive a request) use *recv* to receive data from a **TCP connection**
- If the buffer cannot hold an incoming user datagram, *recv* fills the buffer and discards the remainder

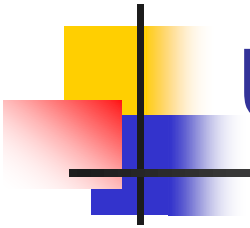
```
#include <sys/socket.h>
ssize_t recv (int sockfd, void *buff, size_t nbytes, int flags);
```

- Number of bytes that are received successfully
  -1 – failed
- socket descriptor to read from
- The address in memory into which the data to be placed
- The length of the buffer area
- The flag controlling the reception, usually 0

System Calls – sendto() & recvfrom()

- Allow the caller to send or receive a message over **UDP**
- sendto() requires the caller to specify a destination
- recvfrom() uses an argument to specify where to record the sender's address





Using Read and Write with sockets

- In Linux, as in most other UNIX systems, programmers can use *read* instead of *recv*, and *write* instead of *send*
  - *int read (sockfd, bptr, buflen)*
  - *int write (sockfd, bptr, buflen)*
- The chief advantage of *send* and *recv* is that they are easier to spot in the code

System Calls – close()

- Once a client or server finishes using a socket, it calls *close* to deallocate it
- Any unread data waiting at the socket will be discarded

```
#include <unistd.h>
int close ( int sockfd);
```

0 – success
-1 – failed

Socket to be closed

System Calls – inet_aton() & inet_addr()

- Converts an IP address in numbers-and-dots notation into unsigned long in network byte order

```
#include <arpa/inet.h>
int inet_aton (const char *string, struct in_addr *address);
```

- 1 – success
  0 – error
- Pointer to the string that contains the numbers-and-dots notation
- Pointer to IP address structure

```
#include <arpa/inet.h>
in_addr_t inet_addr (const char *string);
```

- When success: return the 32-bit address in network byte order
  When failed: return INADDR_NONE
- Pointer to the string that contains the numbers-and-dots notation

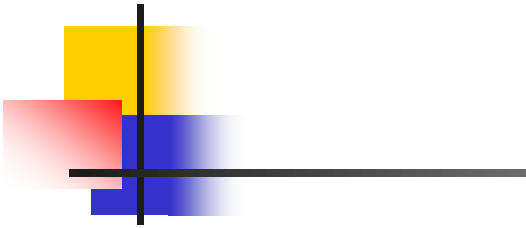
System Calls – inet_ntoa()

- Mapping a 32-bit integer (an IP address in network byte order) to an ASCII string in dotted decimal format

```
#include <arpa/inet.h>
char * inet_ntoa ( struct in_addr inaddr );
```

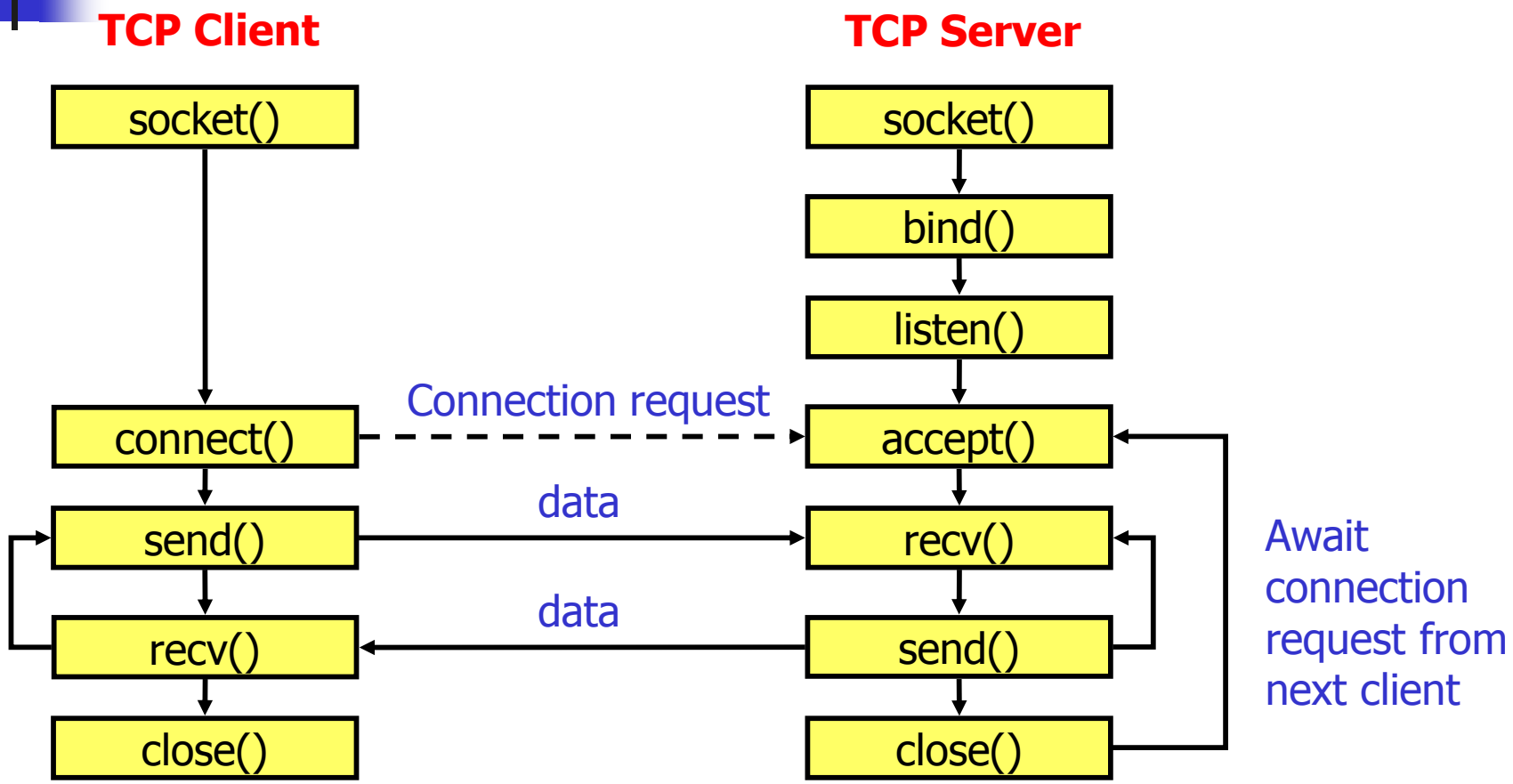
Pointer to the string contains the numbers-and-dots notation

IP address structure in network byte order

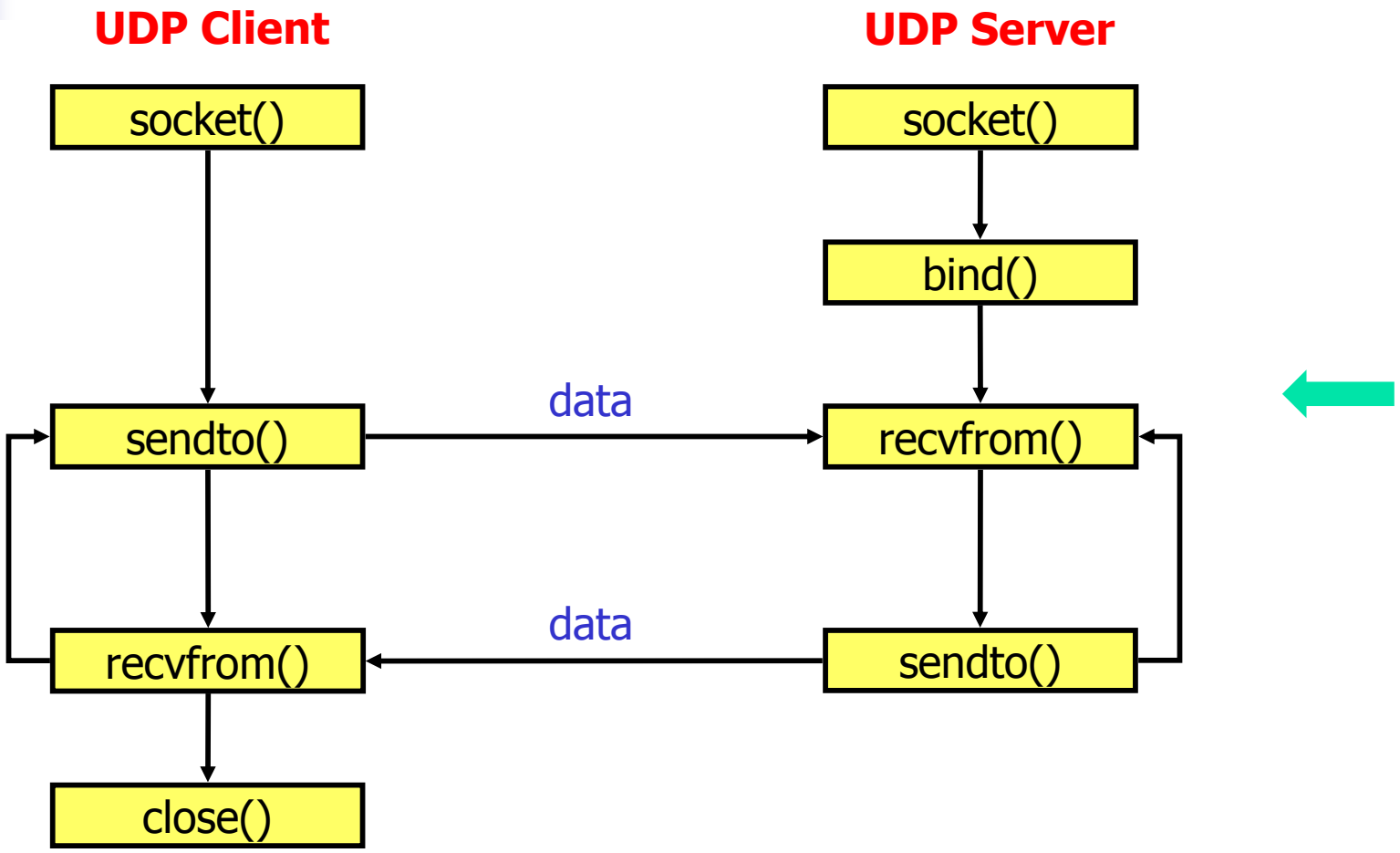


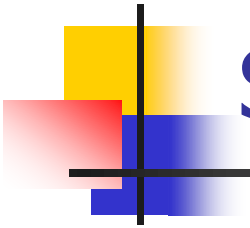
Introduction to Sockets
Part IV: sample programs

Overview of TCP-based sockets API



Overview of UDP-based sockets API

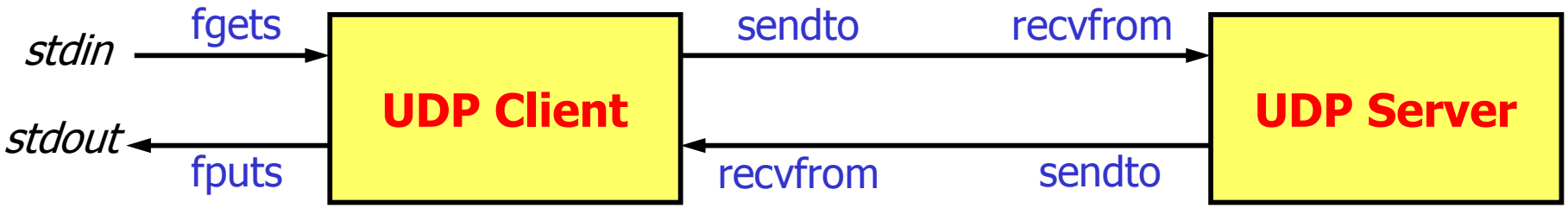




Sample programs

- UDP-based echo service
  - An echo service simply sends back to the originating source any data it receives
  - A very useful debugging and measurement tool
  - UDP Based Echo Service：be defined as a datagram based application on UDP. A server listens for UDP datagrams on UDP port 7. When a datagram is received, the data from it is sent back in an answering datagram.
- Sample programs
  - udpechoclt.c
  - udpechosvr.c

Basic flow of UDP-based echo service



Head part of UDP EchoClient

```
#include <stdio.h> /* for printf() and fprintf() */
#include <sys/socket.h> /* for socket(), sendto() and
                           recvfrom() */
#include <arpa/inet.h> /* for sockaddr_in and inet_addr() */
#include <stdlib.h> /* for atoi() and exit() */
#include <string.h> /* for memset() */
#include <unistd.h> /* for close() */
```

Initial part of UDP EchoClient

```
#define ECHOMAX 255 /* Longest string to echo */

int main(int argc, char *argv[])
{
    int sock; /* Socket descriptor */
    struct sockaddr_in echoServAddr; /* Echo server address */
    struct sockaddr_in fromAddr; /* Source address of echo */
    unsigned short echoServPort; /* Echo server port */
    unsigned int fromSize; /* In-out of address size
                              for recvfrom() */
    char *servIP; /* IP address of server */
    char *echoString; /* String to send to echo server */
    char echoBuffer[ECHOMAX+1]; /* Buffer for receiving
                                   echoed string */
    int echoStringLen; /* Length of string to echo */
    int respStringLen; /* Length of received response */
```

Argument check part of UDP EchoClient

```
if ((argc < 3) || (argc > 4)) /* Test for correct number of
 arguments */
{
    printf("Usage: %s <Server IP> <Echo Word> [<Echo Port>]\n",
                argv[0]);
    exit(1);
 }

servIP = argv[1]; /* First arg: server IP address (dotted quad) */
echoString = argv[2]; /* Second arg: string to echo */
if ((echoStringLen = strlen(echoString)) > ECHOMAX) /* Check input
                                                       length */
    printf("Echo word too long.\n");
if (argc == 4)
    echoServPort = atoi(argv[3]); /* Use given port, if any */
else
    echoServPort = 7; /* 7 is the well-known port for echo service */
```

ASCII to integer

I/O part of UDP EchoClient

```
/* Create a datagram/UDP socket */
if ((sock = socket(PF_INET, SOCK_DGRAM, IPPROTO_UDP)) < 0)
    printf("socket() failed.\n");
/* Construct the server address structure */
memset(&echoServAddr, 0, sizeof(echoServAddr));/*Zero out structure*/
echoServAddr.sin_family = AF_INET; /* Internet addr family */
echoServAddr.sin_addr.s_addr = inet_addr(servIP);/*Server IP address*/
echoServAddr.sin_port = htons(echoServPort); /* Server port */
/* Send the string to the server */
if ((sendto(sock, echoString, echoStringLen, 0,
        (struct sockaddr *) &echoServAddr, sizeof(echoServAddr)))
        != echoStringLen)
    printf("sendto() sent a different number of bytes than expected.\n");
/* Recv a response */
fromSize = sizeof(fromAddr);
if ((respStringLen = recvfrom(sock, echoBuffer, ECHOMAX, 0,
        (struct sockaddr *) &fromAddr, &fromSize)) != echoStringLen)
    printf("recvfrom() failed\n");
```

Generic socket address

Last part of UDP EchoClient

```
if (echoServAddr.sin_addr.s_addr != fromAddr.sin_addr.s_addr)
{
     printf("Error: received a packet from unknown source.\n");
     exit(1);
 }

/* null-terminate the received data */
echoBuffer[respStringLen] = '\0';
printf("Received: %s\n", echoBuffer);/*Print the echoed message*/
close(sock);
exit(0);
}
```

Head part of UDP EchoServer

```
#include <stdio.h> /* for printf() and fprintf() */
#include <sys/socket.h> /* for socket(), bind(), sendto()
                           and recvfrom() */
#include <arpa/inet.h> /* for sockaddr_in and inet_ntoa() */
#include <stdlib.h> /* for atoi() and exit() */
#include <string.h> /* for memset() */
#include <unistd.h> /* for close() */
```

Initial part of UDP EchoServer

```
#define ECHOMAX 255 /* Longest string to echo */

int main(int argc, char *argv[])
{
    int sock; /* Socket */
    struct sockaddr_in echoServAddr; /* Local address */
    struct sockaddr_in echoClntAddr; /* Client address */
    unsigned int cliAddrLen; /* Length of client address */
    char echoBuffer[ECHOMAX]; /* Buffer for echo string */
    unsigned short echoServPort; /* Server port */
    int recvMsgSize; /* Size of received message */
```

Argument check part of UDP EchoServer

```
if (argc != 2)
{
    printf("Usage: %s <UDP SERVER PORT>\n", argv[0]);
    exit(1);
 }
```

Socket part of UDP EchoServer

```
echoServPort = atoi(argv[1]); /* First arg: local port */

/* Create socket for sending/receiving datagrams */
if ((sock = socket(PF_INET, SOCK_DGRAM, 0)) < 0)
    printf("socket() failed.\n");
/* Construct local address structure */
memset(&echoServAddr, 0, sizeof(echoServAddr));
echoServAddr.sin_family = AF_INET;
echoServAddr.sin_addr.s_addr = htonl(INADDR_ANY);
echoServAddr.sin_port =htons(echoServPort);
/* Bind to the local address */
if ((bind(sock, (struct sockaddr *) &echoServAddr,
       sizeof(echoServAddr))) < 0)
    printf("bind() failed.\n");
```

Main loop of UDP EchoServer

```
for (;;) /* Run forever */
{
    /* Set the size of the in-out parameter */
    cliAddrLen = sizeof(echoClntAddr);
    /* Block until receive message from a client */
    if ((recvMsgSize = recvfrom(sock, echoBuffer, ECHOMAX,
          0,(struct sockaddr *) &echoClntAddr, &cliAddrLen)) < 0)
        printf("recvfrom() failed.\n");
    printf("Handling client %s\n",inet_ntoa(echoClntAddr.sin_addr));
    /* Send received datagram back to the client */
    if ((sendto(sock, echoBuffer, recvMsgSize, 0,
          (struct sockaddr *) &echoClntAddr,
          sizeof(echoClntAddr))) != recvMsgSize)
        printf("sendto() sent a different number of bytes
                than expected.\n");
 }

}
```

Run the Sample Programs (1)

- Give correct arguments

Server process window

```
[shiyan@localhost 20071022]$ ./udpechosvr
Usage: ./udpechosvr <UDP SERVER PORT>
```

Client process window

```
[shiyan@localhost 20071022]$ ./udpechoclt
Usage: ./udpechoclt <Server IP> <Echo Word> [<Echo Port>]
```

Run the Sample Programs (2)

- Use correct username

Server process window

```
[shiyan@localhost 20071022]$ ./udpechosvr 7
bind() failed.
```

Note: binding the port number less than 1024 requires root authority

Client process window

```
[shiyan@localhost 20071022]$ ./udpechoclt 192.168.1.253 hello
```

Run the Sample Programs (3)

- Successful running using root

Server process window

```
[root@localhost 20071022]# ./udpechosvr 7
Handling client 192.168.1.253
```

Client process window

```
[root@localhost 20071022]# ./udpechoclt 192.168.1.253 hello
Received: hello
[root@localhost 20071022]#
```

Run the Sample Programs (4)

- Successful running using other username

Server process window

```
[shiyan@localhost 20071022]$ ./udpechosvr 1500
Handling client 192.168.1.253
```

Client process window

```
[shiyan@localhost 20071022]$ ./udpechoclt 192.168.1.253 hello 1500
Received: hello
[shiyan@localhost 20071022]$
```

Summary: Conceptual View of Socket