CS118 Discussion 1C, Week 1

Zhehui Zhang

Outline

- Logistics
- Intro to network programming
- Clarification of lecture materials

TA

- Zhehui Zhang, PhD in Computer Networking
- Office hours:
  - Monday 12:30-2:30 pm by Qianqu Li
  - **Tuesday 9-11 am by Zhehui Zhang**
  - Thursday 12-2 pm by Zhiyi Zhang
- Emails: zhehui@cs.ucla.edu
  - If you did not get reply in 24 hrs, please send it again.
  - Please use [CS118] in subject or may be flagged as spam
  - Please include your name, UID in email.

Logistics

- Submit your signed Academic Integrity Agreement
- Grading breakdown
  - Homework 20% (Weekly homework)
  - Projects 20% (Project 1: 8%; Project 2: 12%)
  - Quizzes 60%
- no late turn-in will be accepted for credit
- no make-up exams

Logistics: Homework

- Online submission to Gradescope only (course entry code: 932KV3). DEMO
  - Fill in your UCLA ID so that we can submit your score to CCLE
- Submission guidelines:
  - 1. **Hard deadline** on submission, so submit early! You can **resubmit** multiple times before the deadline, but the system will not accept submissions after the deadline.
  - 2. Each homework problem will have a dedicated **answering box** immediately below. Do **NOT** write your answers outside the box. Any answer outside the dedicated area may not get graded.
  - 3. You are encouraged to work out the problem on the PDF file directly **without altering the page layout in any way.**
  - 4. If you prefer handwriting or have to draw diagrams, you may scan the paper copy (e.g., using a smartphone app), convert it to a PDF file and then upload. It is **your** responsibility to upload a high-quality copy in black and white. Inaccessible answers will get low scores.

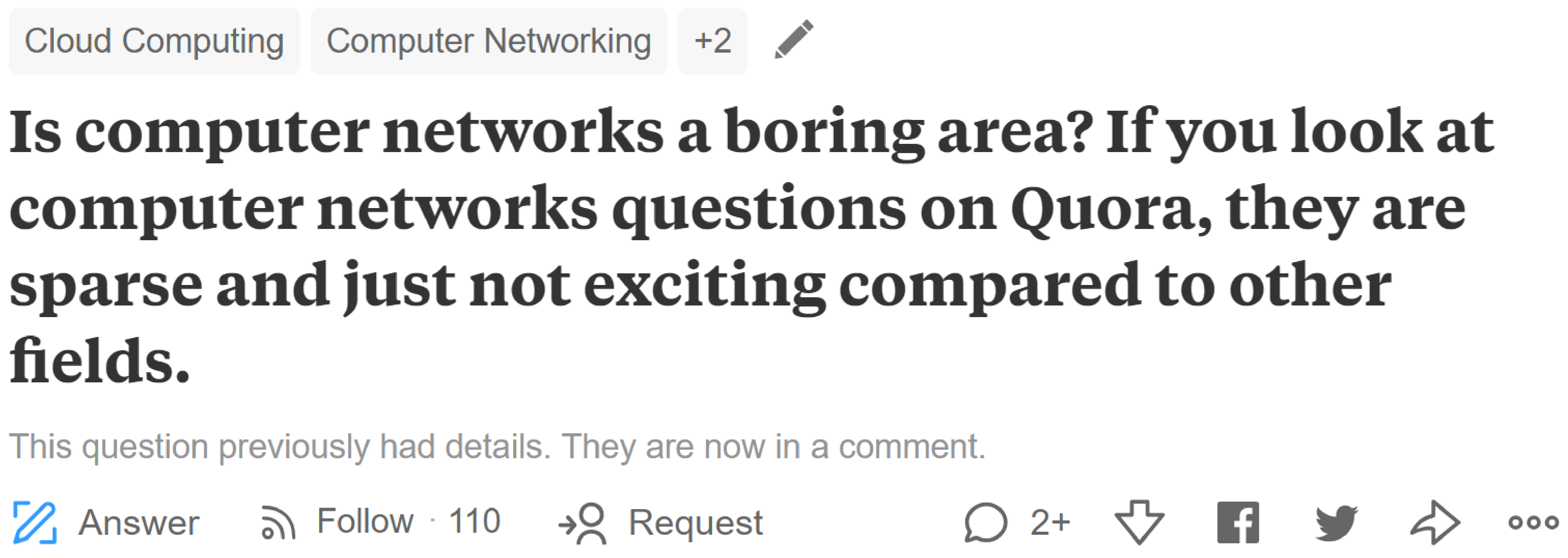
Logistics: Project

- Two projects (in C/C++):
  - A simple web server — get familiar with network programming;
  - Reliable data transfer — implement a simple user-level TCP-like transport protocol
- Test environment:
  - Ubuntu virtual machine

Computer Networks: A Top-Down approach

- Why computer networks may interest you?
- What are we learning in this course?

Why computer networks may interest you?

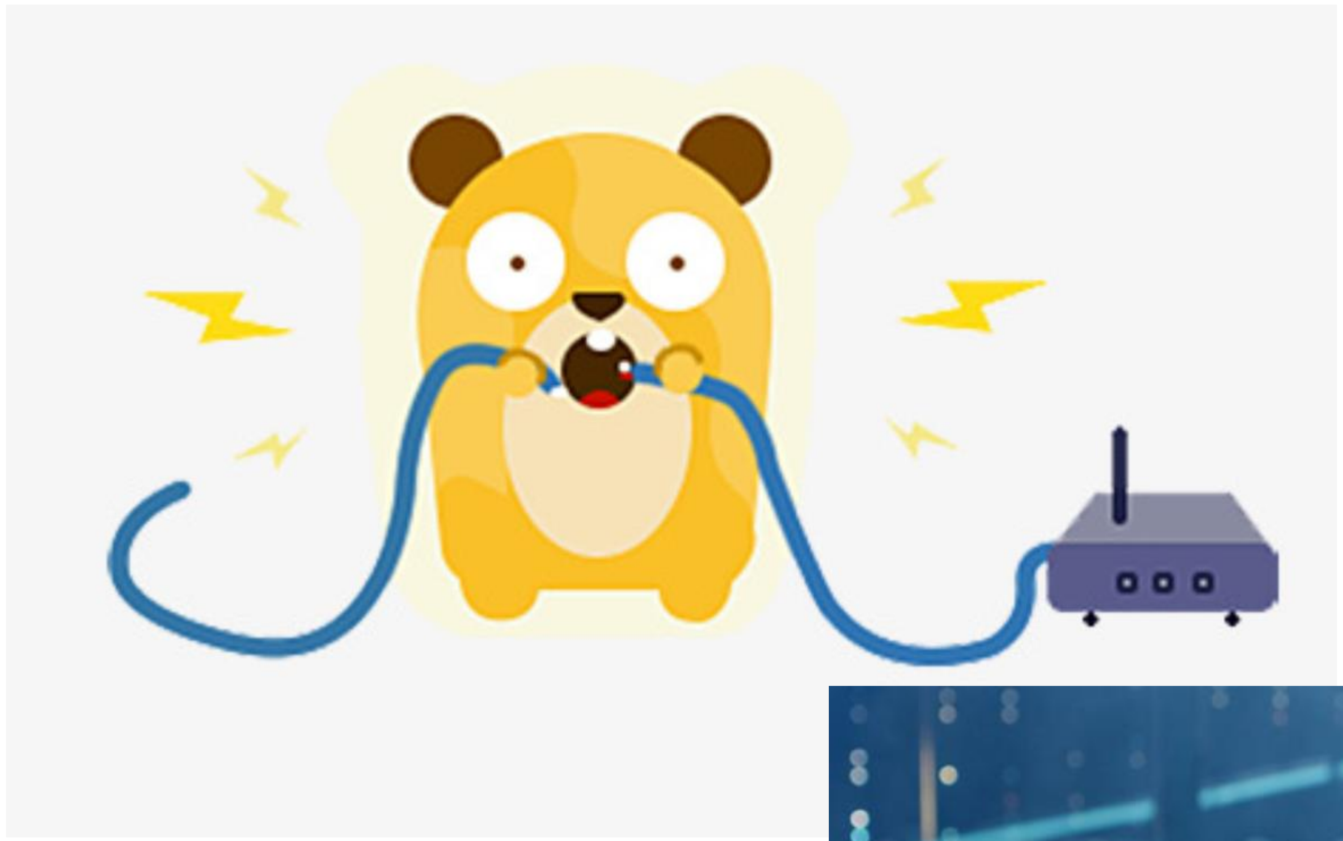

Cloud Computing Computer Networking +2

Is computer networks a boring area? If you look at computer networks questions on Quora, they are sparse and just not exciting compared to other fields.

This question previously had details. They are now in a comment.

"I can't think of ANY area of computer science that has produced more tangible changes for the average person over the last 20 years than networking and communications." -- Keith Winstein

What are we learning in this course



What are we learning in this course

Lectures:

Part 1: Introduction *(2 lectures, text: Chapter 1)*

Part 2: Application Layer *(2 lectures, text: Ch.2)*

-- introduction to socket programming is provided on Friday recitations

***Quiz 1 to cover Parts 1 &2**

Part 3: Transport Layer *(4.5 lectures, text Ch. 3)*

**Project 1: April 24, Friday*

***Quiz 2 to cover Part 3**

Part 4: Network Layer *(4 lectures, text: Ch. 4 and 5)*

***Quiz 3 to cover Part 4**

Part 5: Link Layer, LANs *(3.5 lectures, text: Ch. 6)*

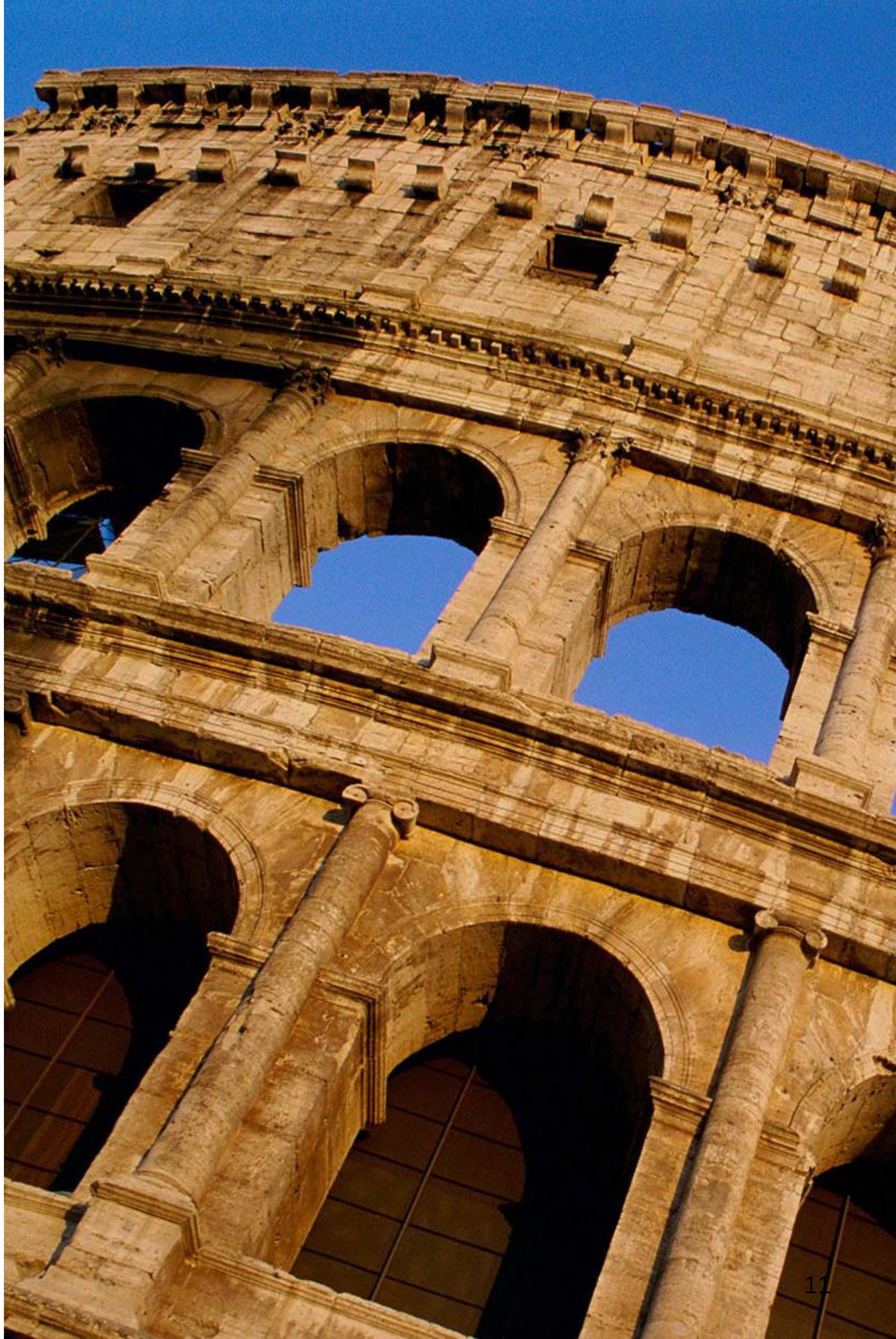
Part 6: Wireless and Mobile Networks *(1.5 lectures, text: Ch. 7)*

Part 8: Network Security (0.5 lecture: Ch. 8)

*Project 2: June 5, Friday

***Quiz 4 to cover Parts 5, 6 & 8 (using final exam slot)**.

Network Programming



Network programming

- **What is the model for network programming?**
- Where are we programming?
- Which APIs can we use? How to use them?

Client-server model

- Asymmetric communication
    - Client — requests data:
        - Initiates communication
        - Waits for server’s response
    - Server (Daemon) — responds data requests:
        - Discoverable by clients (e.g. IP address + port)
        - Waits for clients connection
        - Processes requests, sends replies

Demo: telnet

```
 ~ 耷 telnet google.com 80
Trying 216.58.217.206...
Connected to google.com.
Escape character is '^]'.
GET / HTTP/1.1

HTTP/1.1 200 OK
Date: Fri, 12 Jan 2018 21:44:31 GMT
Expires: -1
Cache-Control: private, max-age=0
Content-Type: text/html; charset=ISO-8859-1
P3P: CP="This is not a P3P policy! See g.co/p3phelp for more info."
Server: gws
X-XSS-Protection: 1; mode=block
X-Frame-Options: SAMEORIGIN
Set-Cookie: 1P_JAR=2018-01-12-21; expires=Sun, 11-Feb-2018 21:44:31 GMT; path=/; domain=.google.com
Set-Cookie: NID=12…J; expires=Sat, 14-Jul-2018 21:44:31 GMT; path=/; domain=.google.com; HttpOnly
Accept-Ranges: none
Vary: Accept-Encoding
Transfer-Encoding: chunked

754a
<!doctype html><html itemscope="" itemtype="http://schema.org/WebPage" lang="en"><head><meta content="Search the world's
information, including webpages, images, videos and more. Google has many special features to help you find exactly what you're looking for."
name="description">
```

Client-server model

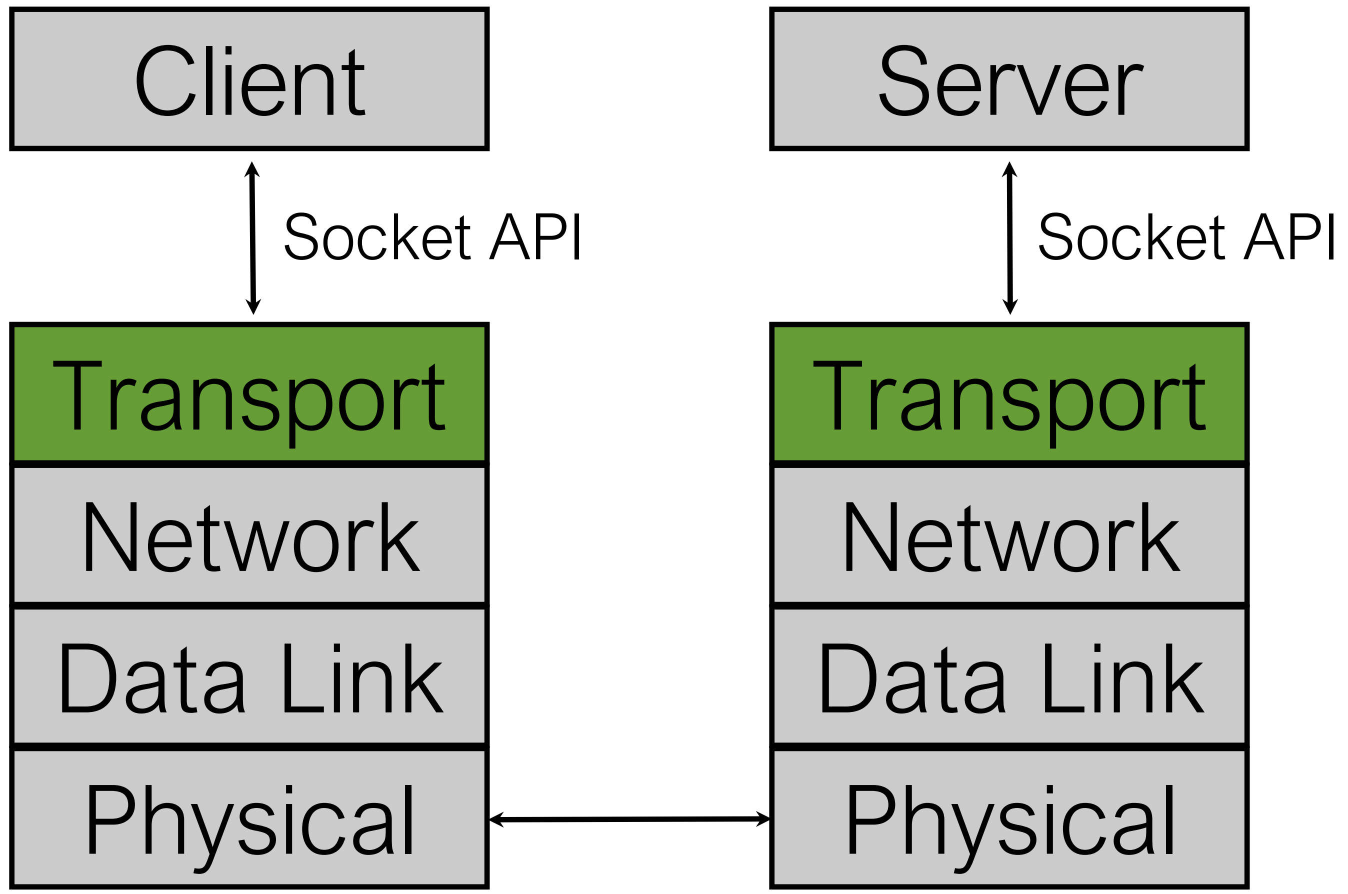
- Client and server are not disjoint
  - A client can be a server of another client
  - A server can be a client of another server
  - Example?
- Server’s service model
  - Concurrent: server processes multiple clients’ requests simultaneously
  - Sequential: server processes clients’ requests one by one
  - Hybrid: server maintains multiple connections, but responses sequentially

Network programming

- What is the model for network programming?
- **Where are we programming?**
- Which APIs can we use? How to use them?

Which layer are we at?

- "Clients" and "servers" are programs at application layer
- Transport layer is responsible for providing communication services for application layer
- Basic transport layer protocols:
  - TCP
  - UDP



TCP: Transmission Control Protocol

- A connection is set up between client and server
- Reliable data transfer
  - Guarantee deliveries of all data
  - No duplicate data would be delivered to application
- Ordered data transfer
  - If A sends data D1 followed by D2 to B, B will also receive D1 before D2
- Data transmission: full-duplex byte stream (in two directions simultaneously)
- Regulated data flow: flow control and congestion control

UDP: User Data Protocol

- Basic data transmission service
  - Unit of data transfer: datagram (in variable length)
- No reliability guarantee
- No ordered delivery guarantee
- No flow control / congestion control

Network programming

- What is the model for network programming?
- Where are we programming?
- **Which APIs can we use? How to use them?**

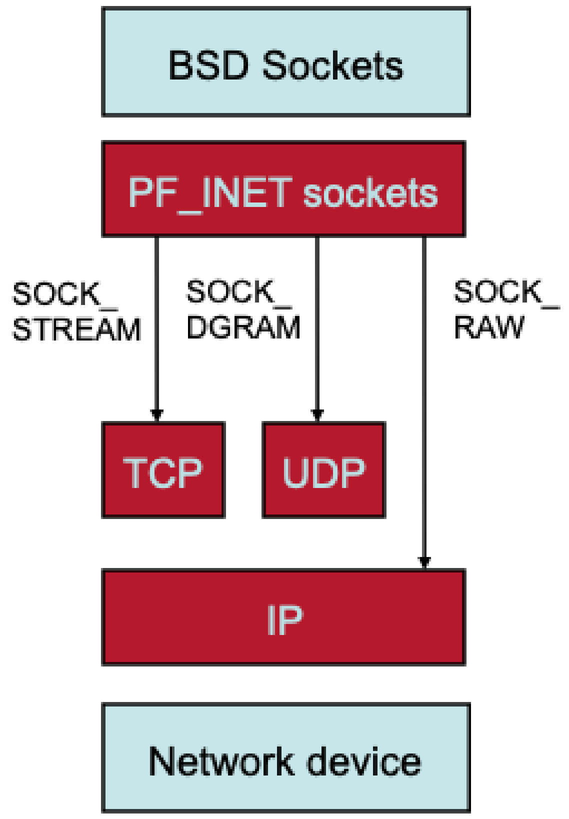
Our secret weapon: socket programming APIs

- From Wikipedia: “A network socket is an endpoint of an inter-process communication flow across a computer network”

- A socket is a tuple of <ip_addr:port>

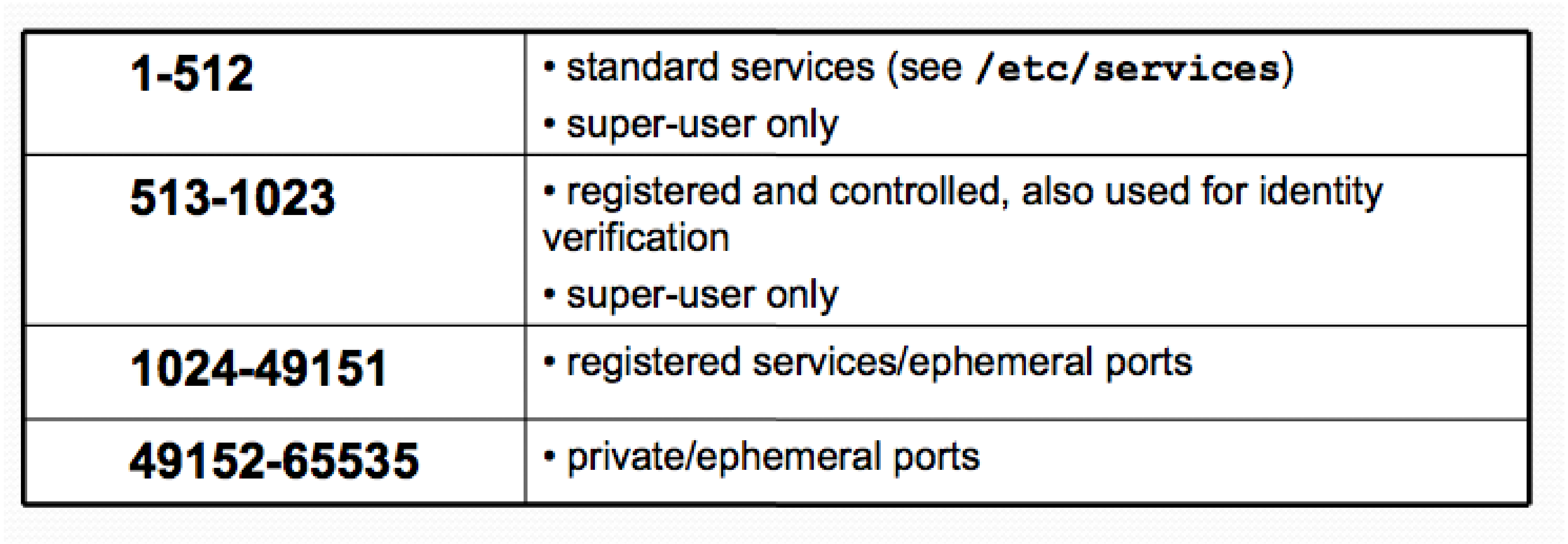
- Socket programming APIs help build the communication tunnel between applications and transport/network service

- We use TCP socket in this project



Socket: port number

- Port numbers are allocated and assigned by the IANA (Internet Assigned Numbers Authority)
- See RFC 1700 or https://www.ietf.org/rfc/rfc1700.txt



1-512	• standard services (see **`/etc/services`**) • super-user only
513-1023	• registered and controlled, also used for identity verification • super-user only
1024-49151	• registered services/ephemeral ports
49152-65535	• private/ephemeral ports

TCP socket: basic steps

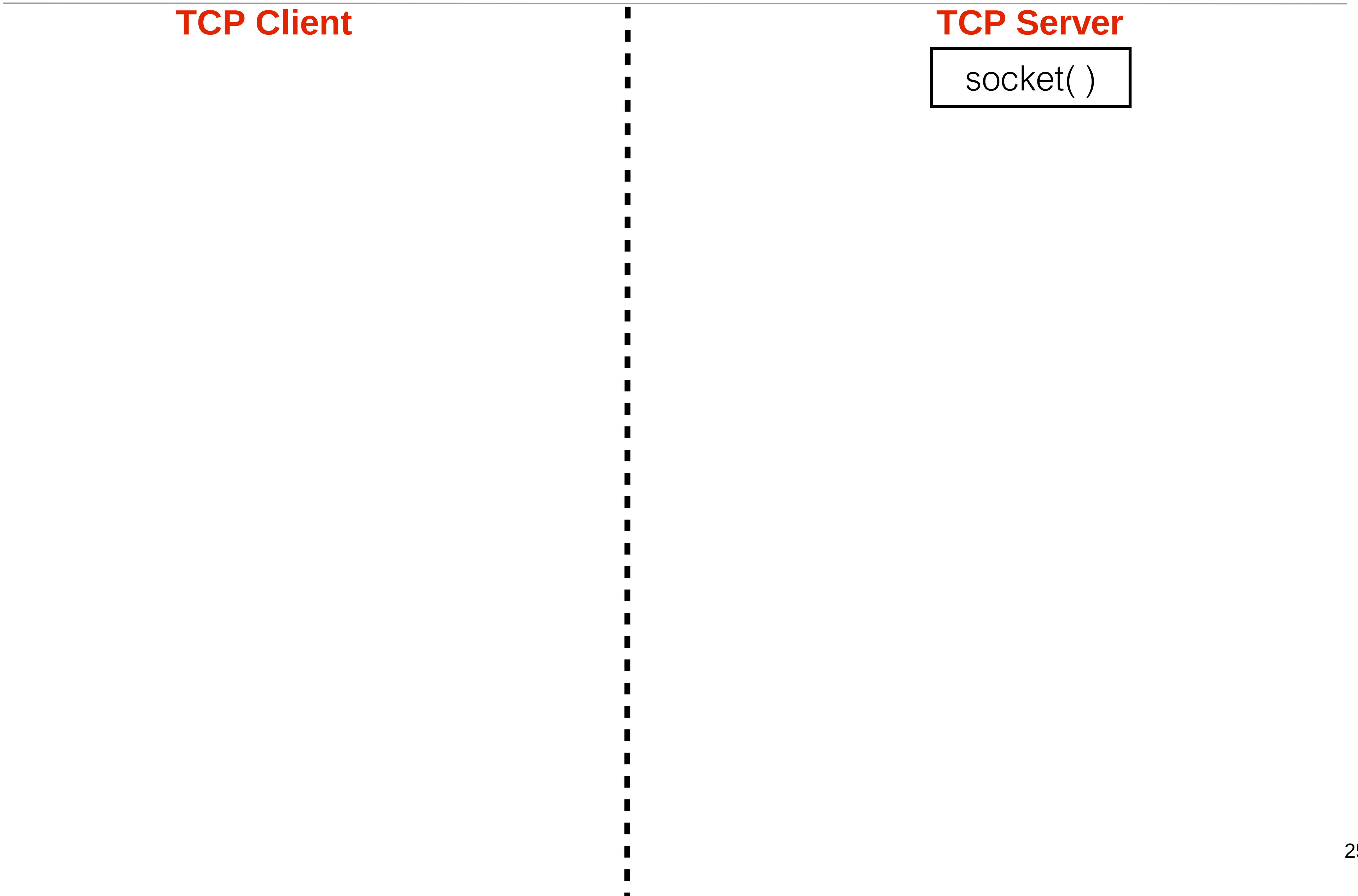
- Create service
- Establish a TCP connection
- Send and receive data
- Close the TCP connection

TCP socket: service setup

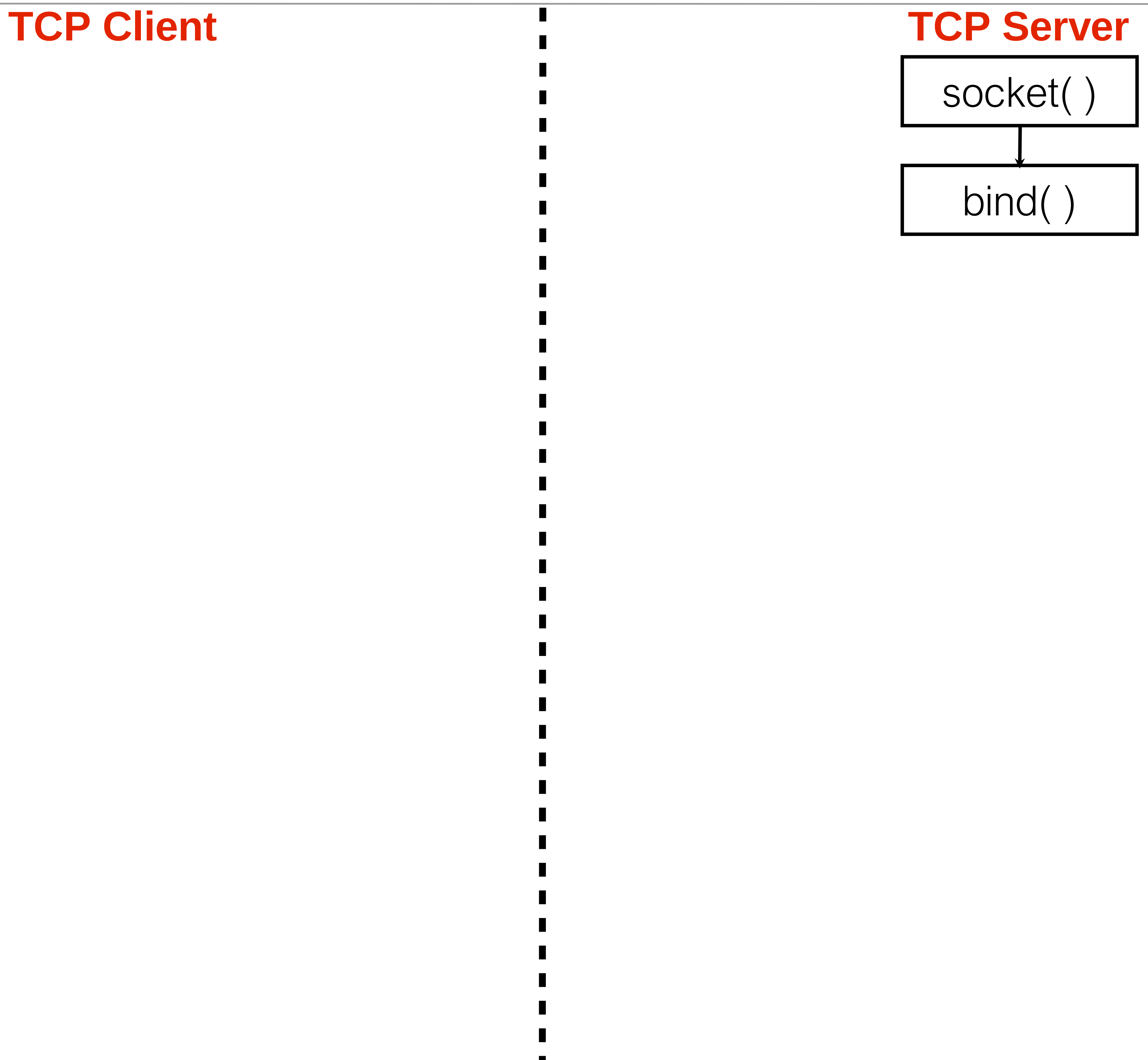
TCP Client

TCP Server

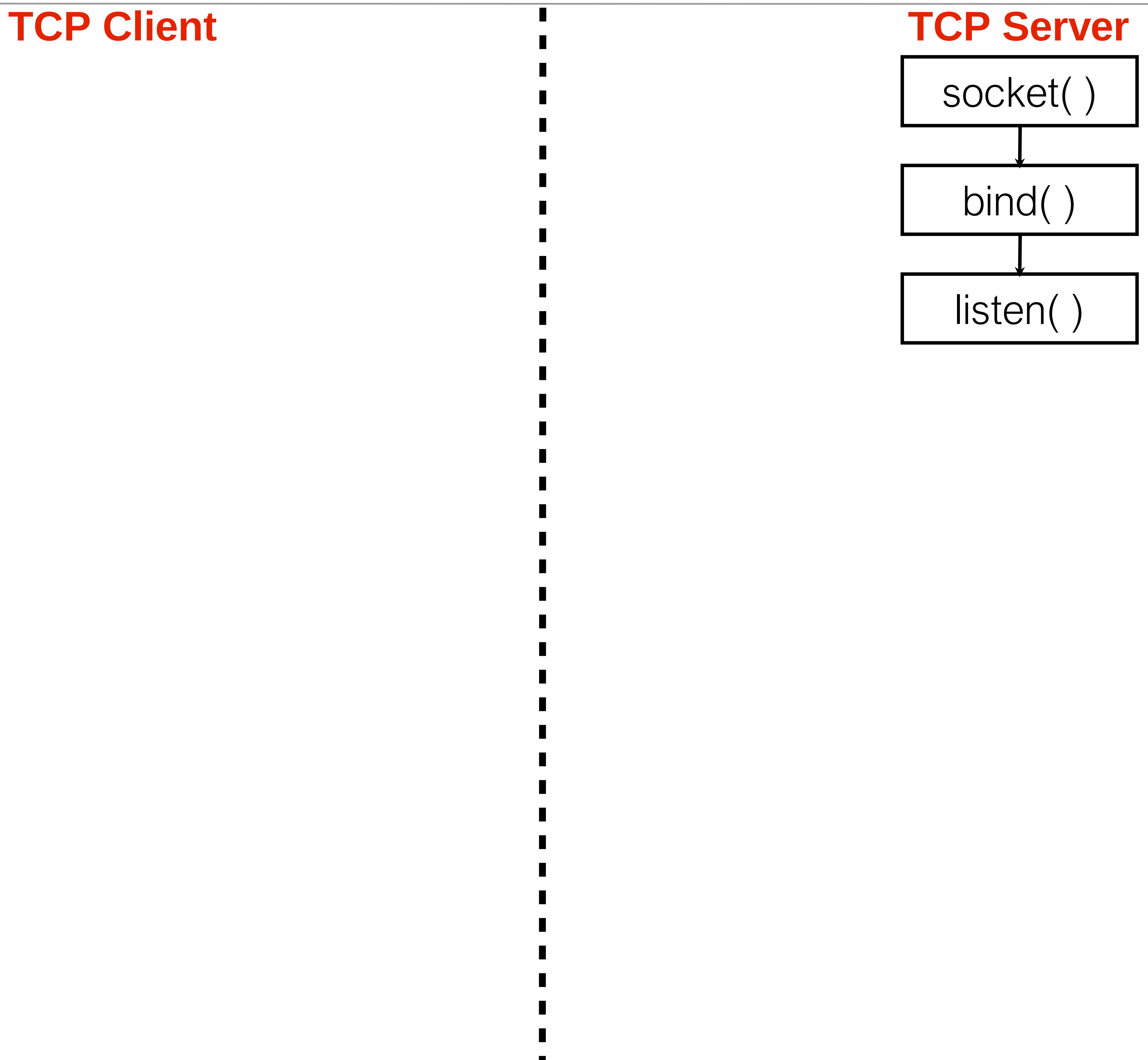
TCP socket: service setup



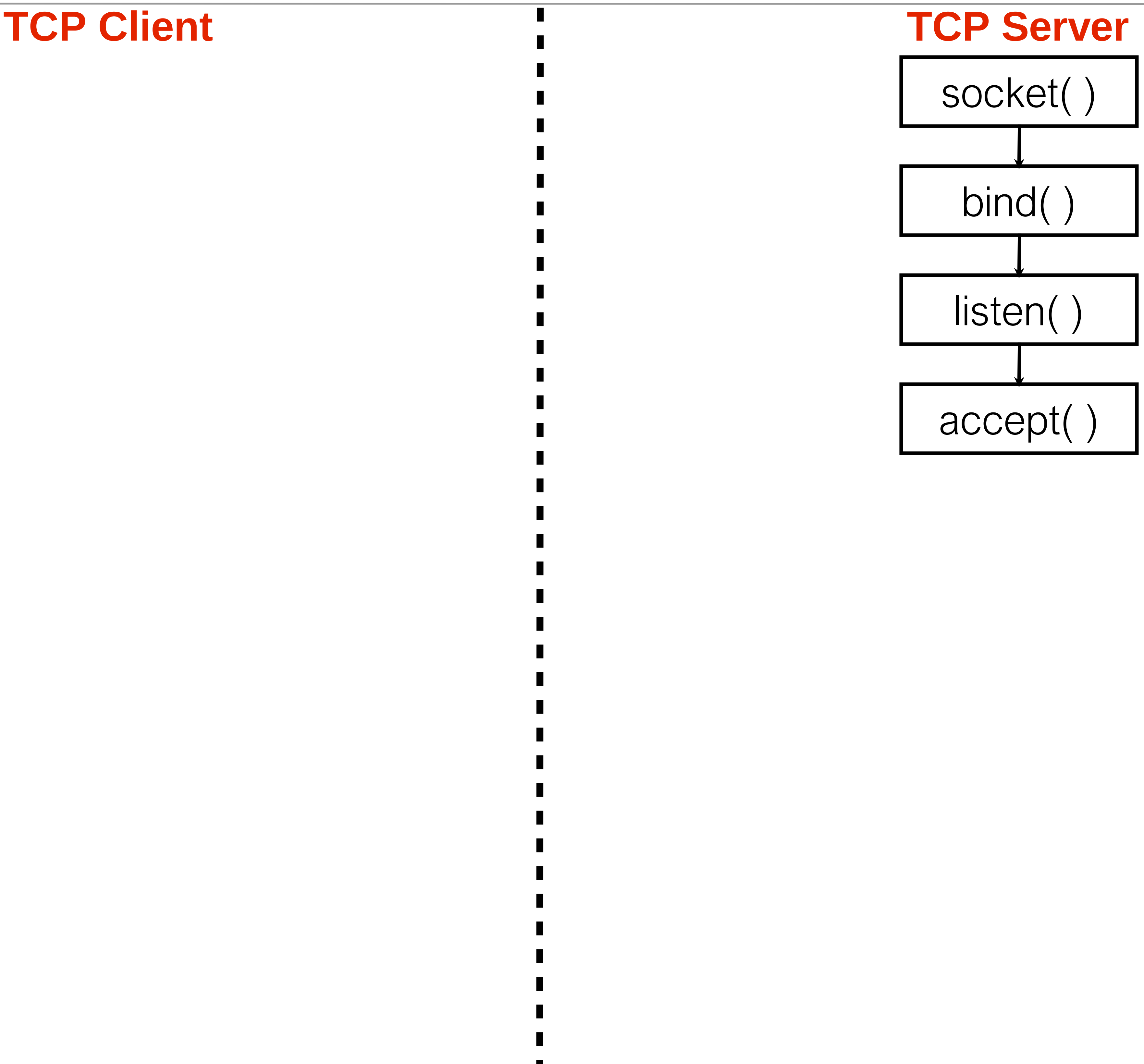
TCP socket: service setup



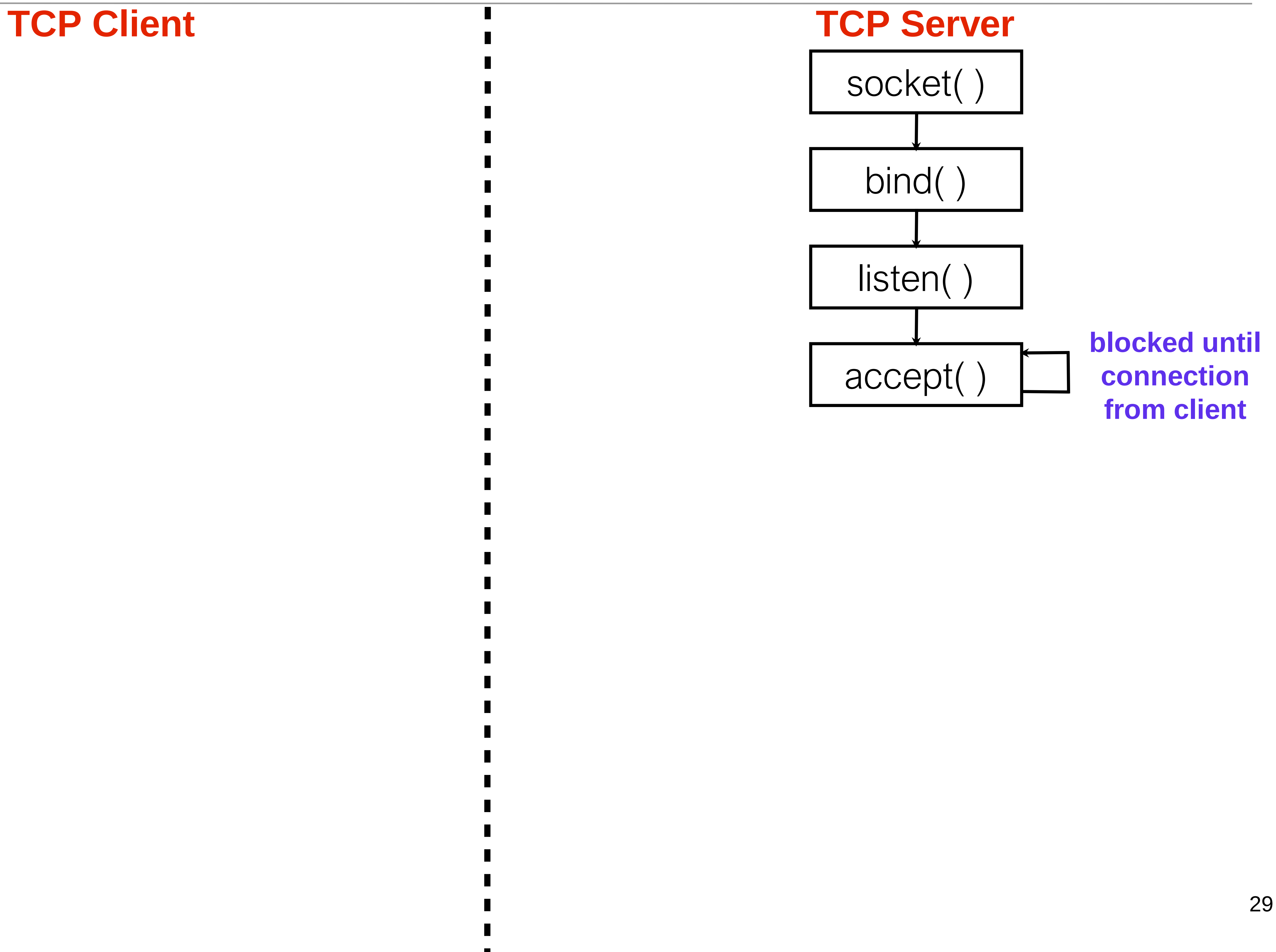
TCP socket: service setup



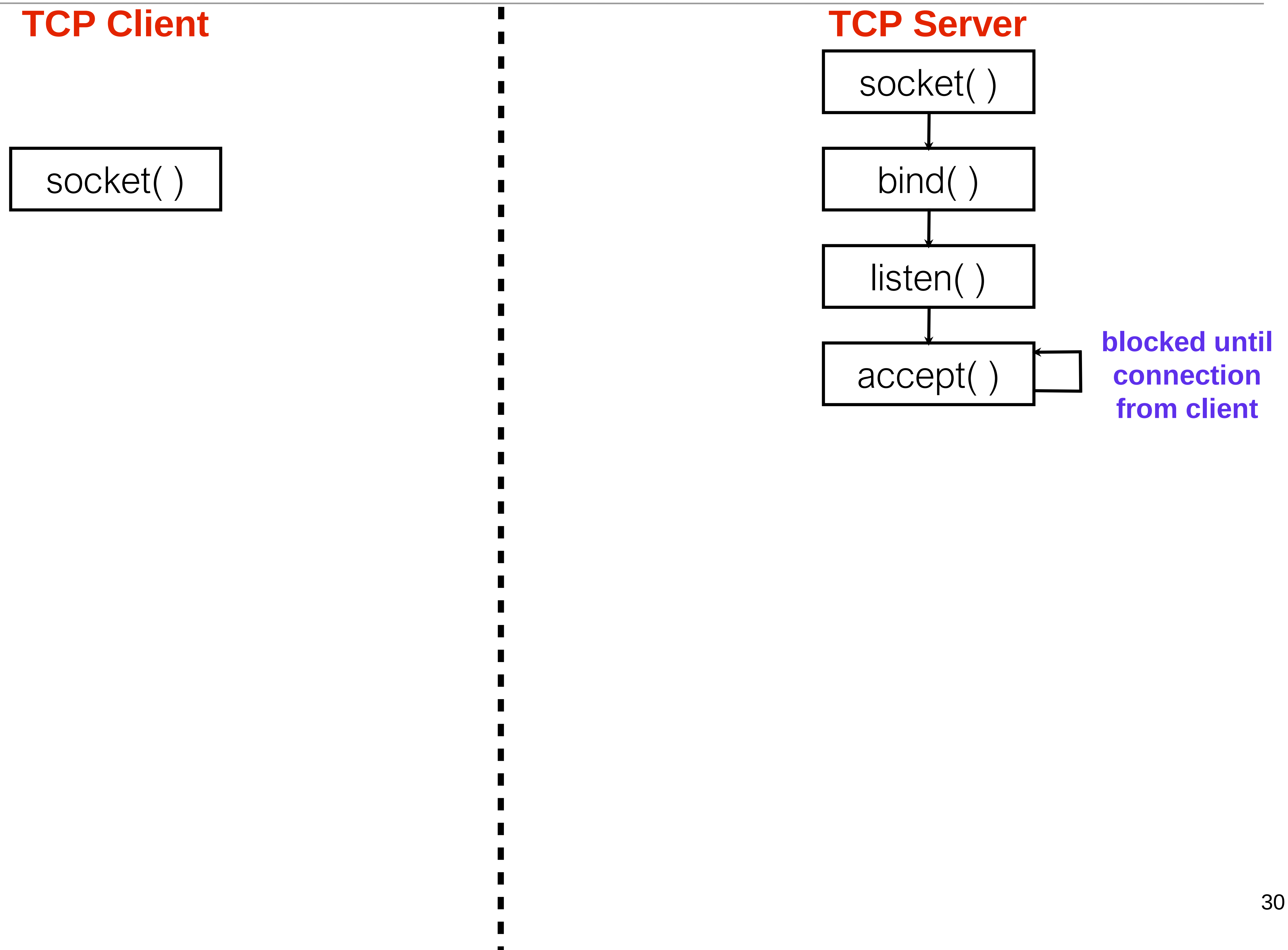
TCP socket: service setup



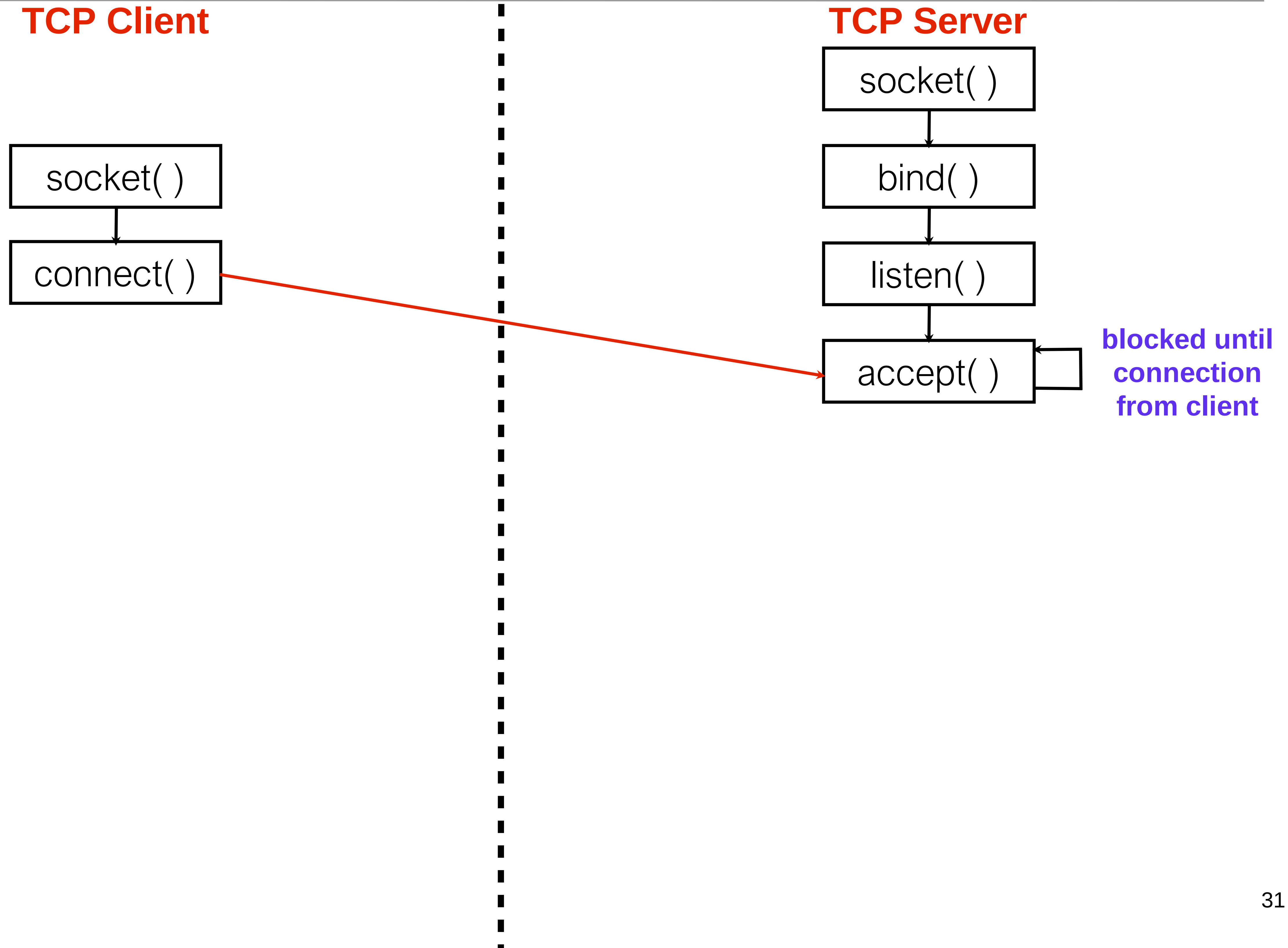
TCP socket: service setup



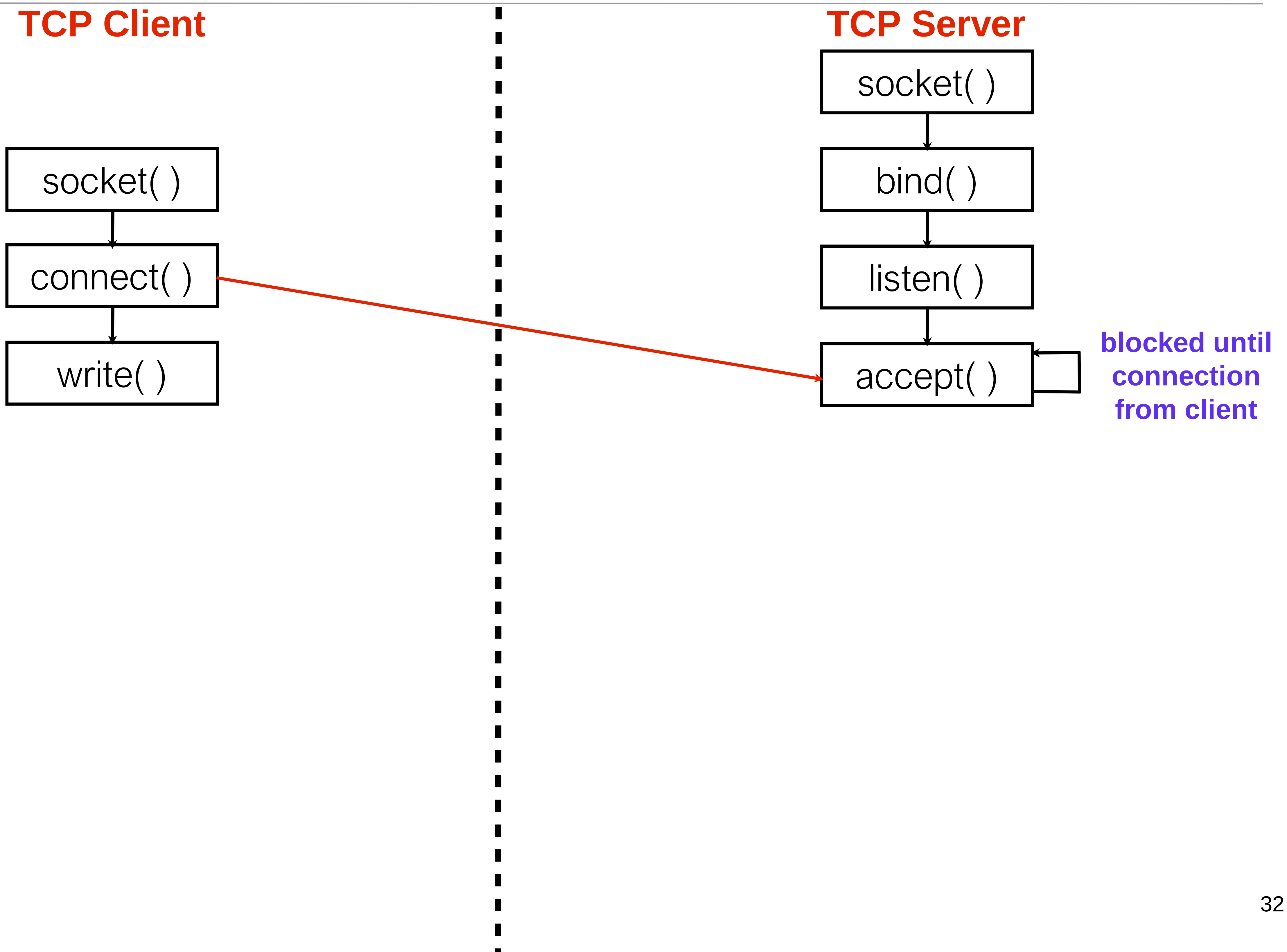
TCP socket: service setup



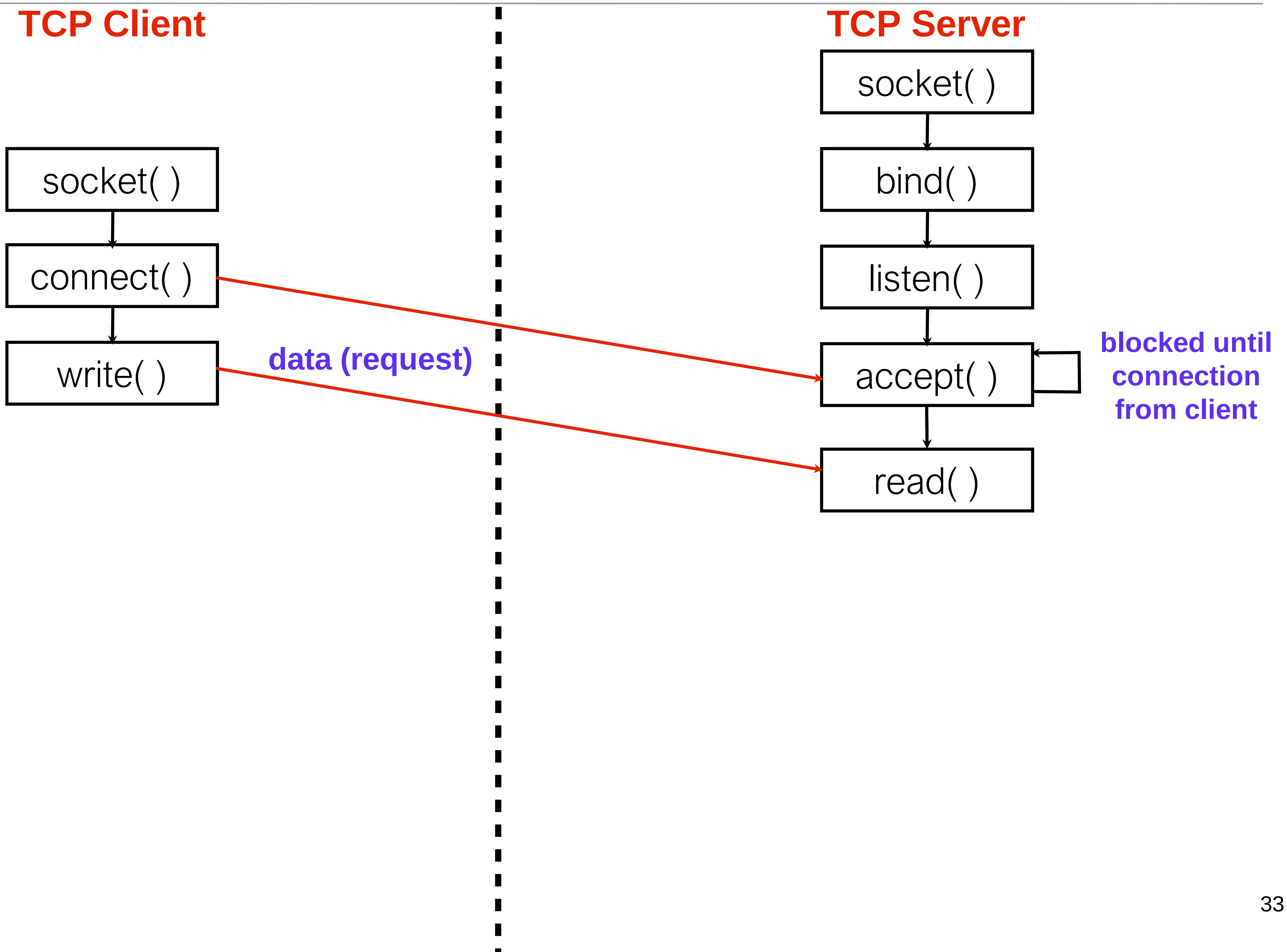
TCP socket: establish connection



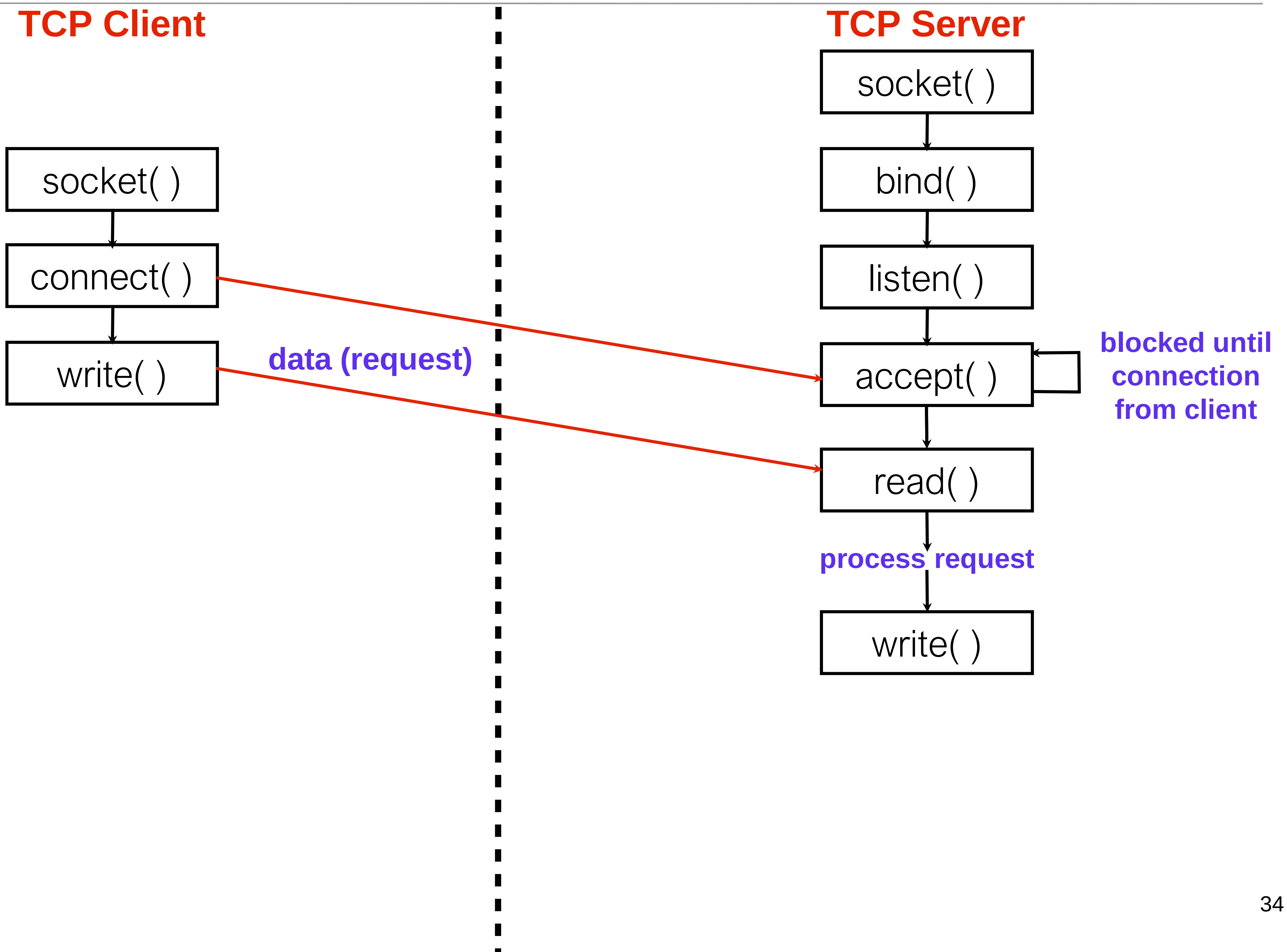
TCP socket: send and receive data



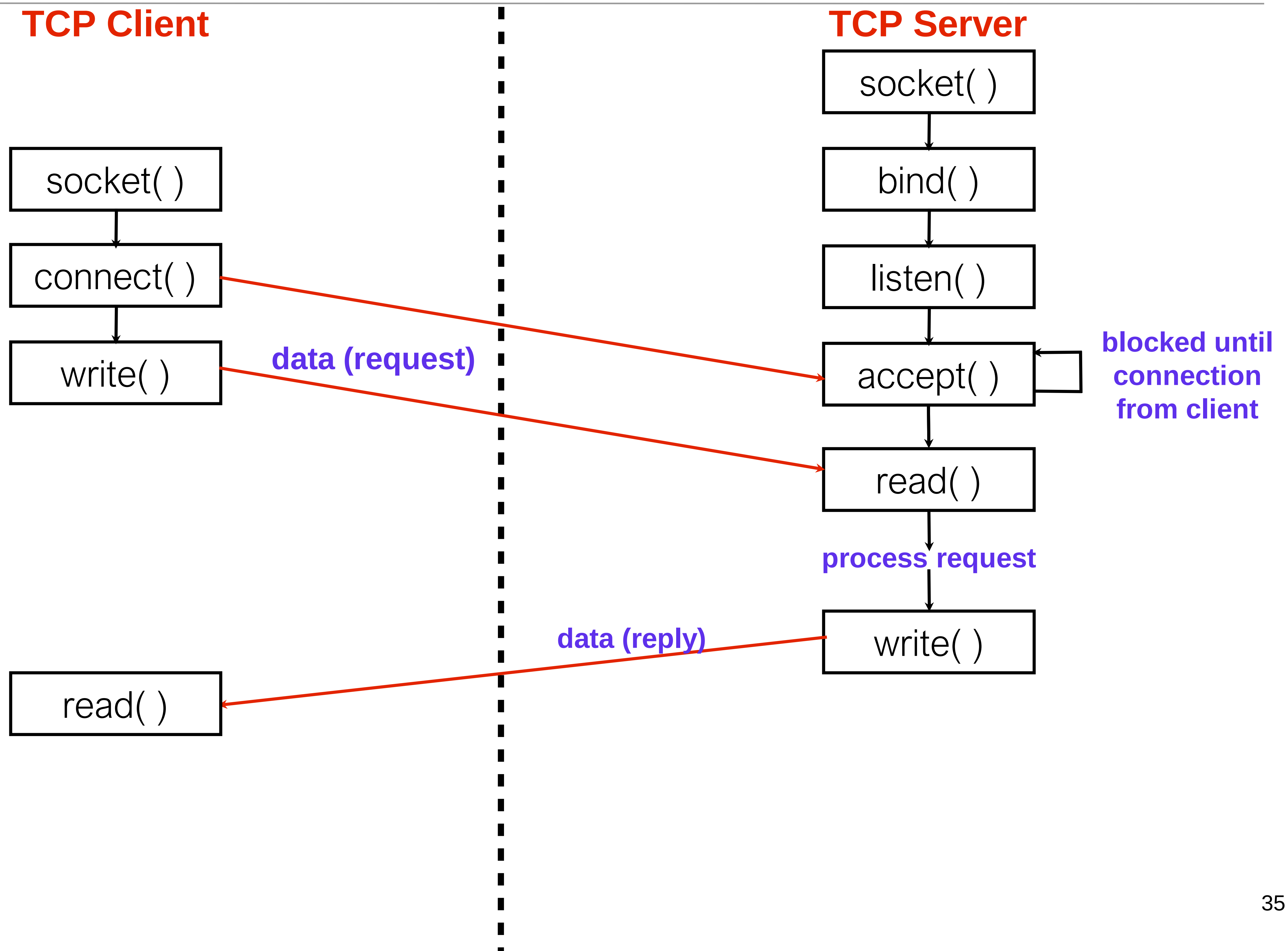
TCP socket: send and receive data



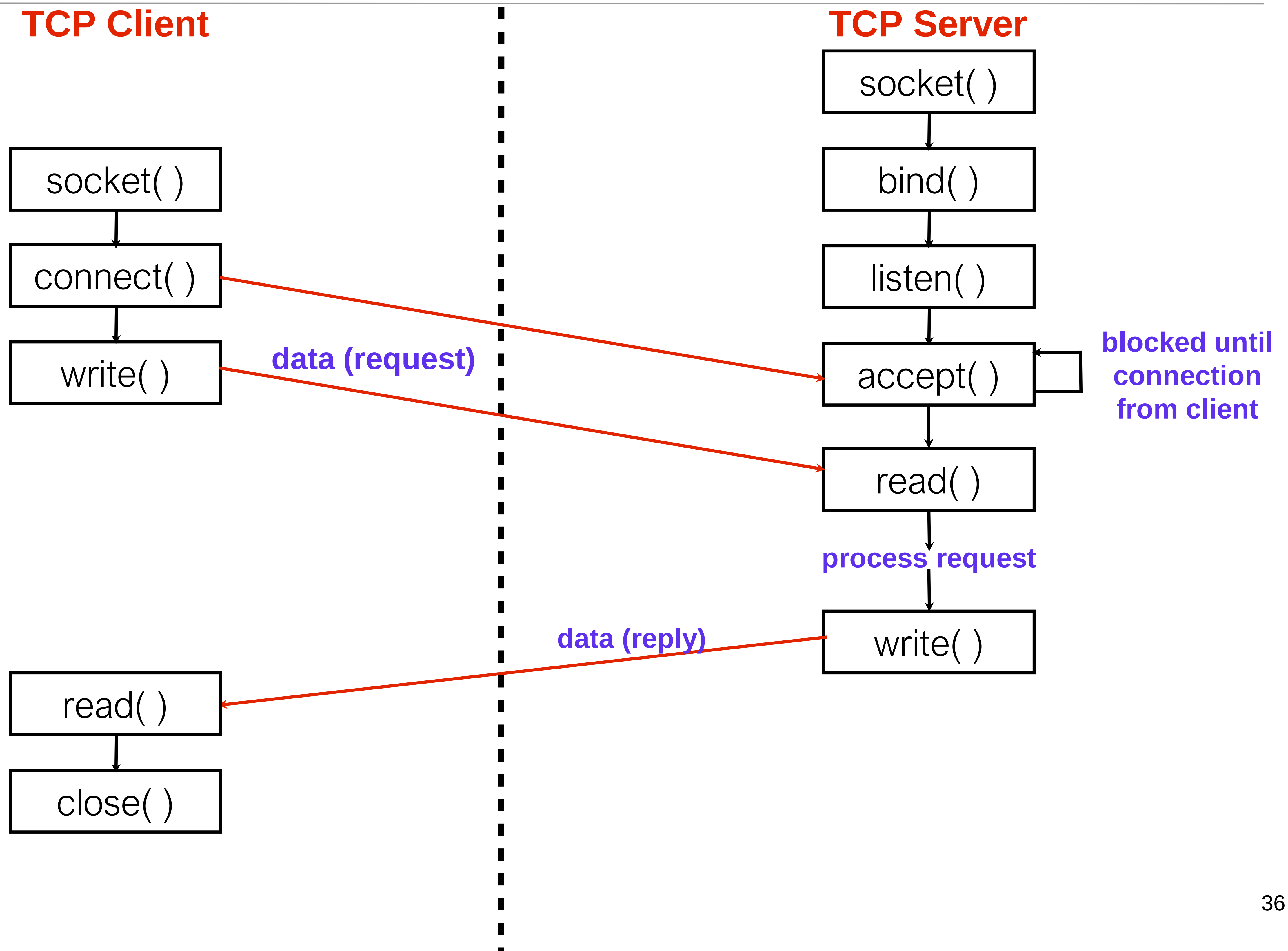
TCP socket: send and receive data



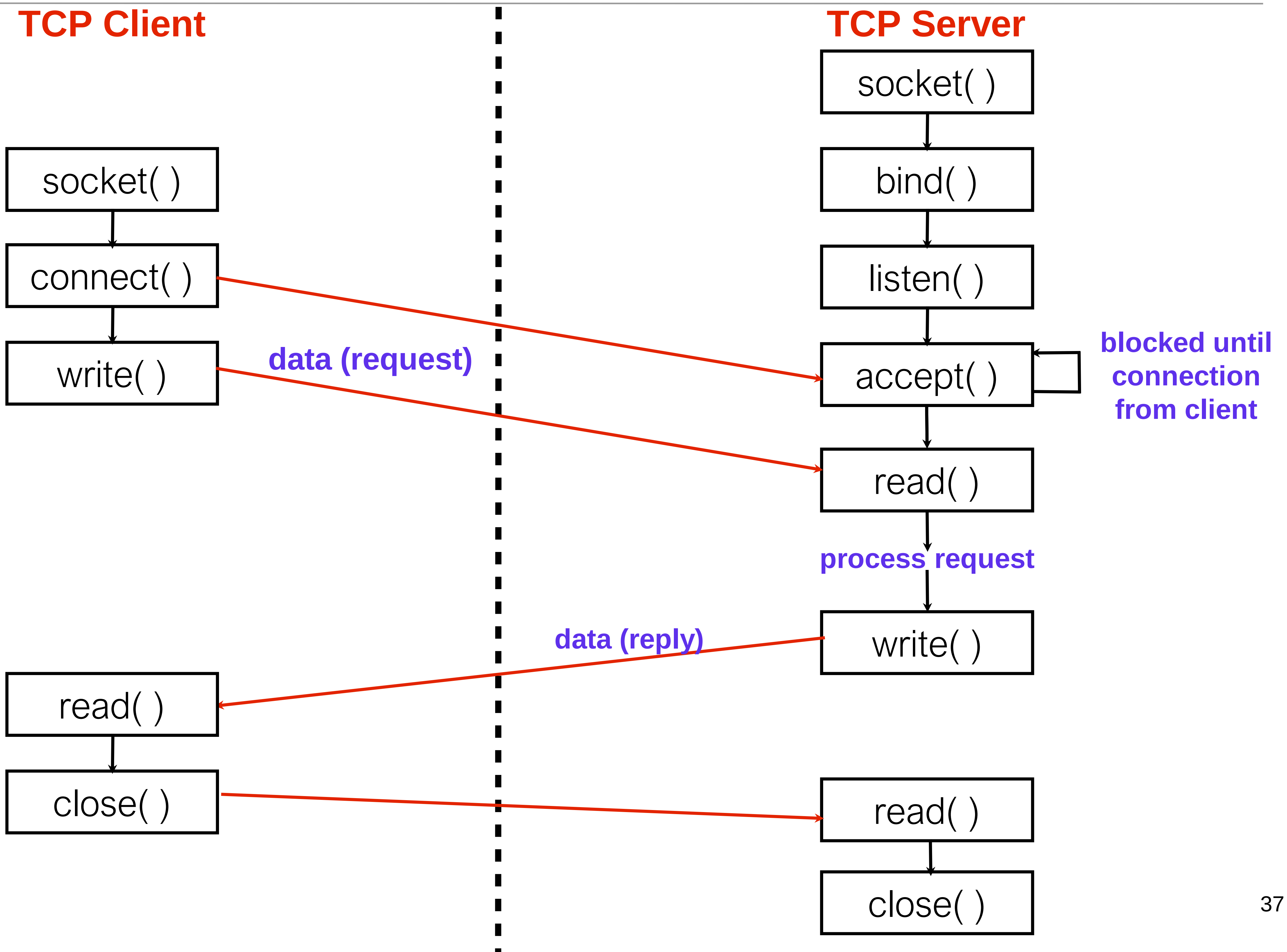
TCP socket: send and receive data



TCP socket: close connection



TCP socket: close connection



Socket programming API: syscalls

- **int socket(int domain, int type, int protocol);**
  - Create a socket
  - returns the socket descriptor or -1(failure). Also sets errno upon failure
  - **domain**: protocol family
    - **PF_INET** for IPv4, **PF_INET6** for IPv6, **PF_UNIX** or **PF_LOCAL** for Unix socket, **PF_ROUTE** for routing
  - **type**: communication style
    - **SOCK_STREAM** for TCP (with **PF_INET**)
    - **SOCK_DGRAM** for UDP (with **PF_INET**)
  - **protocol**: protocol within family, which is typically set to 0

Socket programming API: essential structs

- sockfd — socket descriptor. Just a regular `int`.
- sockaddr — socket address info
- sockaddr_in — yet another struct for the ‘internet’

```
struct sockaddr {
   unsigned short sa_family;   // addr family, AF_xxx
   char           sa_data[14]; // 14 bytes of proto addr
};
struct sockaddr_in { // used for IPv4 only
   short          sin_family;  // addr family, AF_INET
   unsigned short sin_port;    // port number
   struct in_addr sin_addr;    // internet address
   unsigned char  sin_zero[8]; // zeros, same size as sockaddr
};
struct in_addr { // used for IPv4 only
   uint32_t       sin_port;    // 32-bit IPv4 address
};
```

Socket programming API: syscalls

- **int bind(int sockfd, struct sockaddr* myaddr, int addrlen);**
  - Bind a socket to a local IP address and port number
  - returns 0 on success, -1 and sets errno on failure
  - **sockfd**: socket file descriptor returned by socket ( )
  - **myaddr**: includes IP address and port number
    - **NOTE**: sockaddr and sockaddr_in are of same size, use sockaddr_in and convert it to socketaddr
    - **sin_family**: protocol family, e.g. AF_INET
    - **sin_port**: port number assigned by caller
    - **sin_addr**: IP address
    - **sin_zero**: used for keeping same size as sockaddr
  - **addrlen**: sizeof(struct sockaddr_in)

```
struct sockaddr {
   short sa_family;
   char sa_data[14];
};

struct sockaddr_in {
   short sin_family;
   ushort sin_port;
   struct in_addr sin_addr;
   unsigned char  sin_zero[8];
};
```

a pointer to a struct sockaddr_in **can be cast to a pointer to a struct** sockaddr **and vice-versa**

What's the difference between PF_INET and AF_INET???

Socket programming API: syscalls

- **int listen(int sockfd, int backlog);**
  - Put socket into passive state (wait for connections rather than initiating a connection)
  - returns 0 on success, -1 and sets errno on failure
  - **sockfd**: socket file descriptor returned by socket( )
  - **backlog**: the maximum number of connections this program can serve simultaneously

Socket programming API: syscalls

- **int accept(int sockfd, struct sockaddr* client_addr, int* addrlen);**
  - Accept a new connection
  - Return client’s socket file descriptor or -1. Also sets errno on failure
  - **sockfd**: socket file descriptor for server, returned by socket( )
  - **client_addr**: IP address and port number of a client (returned from call)
  - **addrlen**: length of address structure = pointer to **int** set to **sizeof(struct sockaddr_in)**
  - **NOTE: client_addr and addrlen are result arguments**
    - i.e. The program passes empty client_addr and addrlen into the function, and the kernel will fill in these arguments with client’s information **(why do we need them?)**

Socket programming API: syscalls

- **int connect (int sockfd, struct sockaddr* server_addr, int addrlen);**
  - Connecter to another socket (server)
  - Return 0 on success, -1 and sets errno on failure
  - **sockfd**: socket file descriptor (returned from socket)
  - **server_addr**: IP address and port number of the server
    - server's IP address and port number should be known in advance
  - **addrlen**: sizeof(struct sockaddr_in)

Socket programming API: syscalls

- **int write(int sockfd, char* buf, size_t nbytes);**
  - Write data to a TCP stream
  - Return the number of sent bytes or -1 on failures
  - **sockfd**: socket file descriptor from socket ( )
  - **buf**: data buffer
  - **nbytes**: the number of bytes that caller wants to send

Socket programming API: syscalls

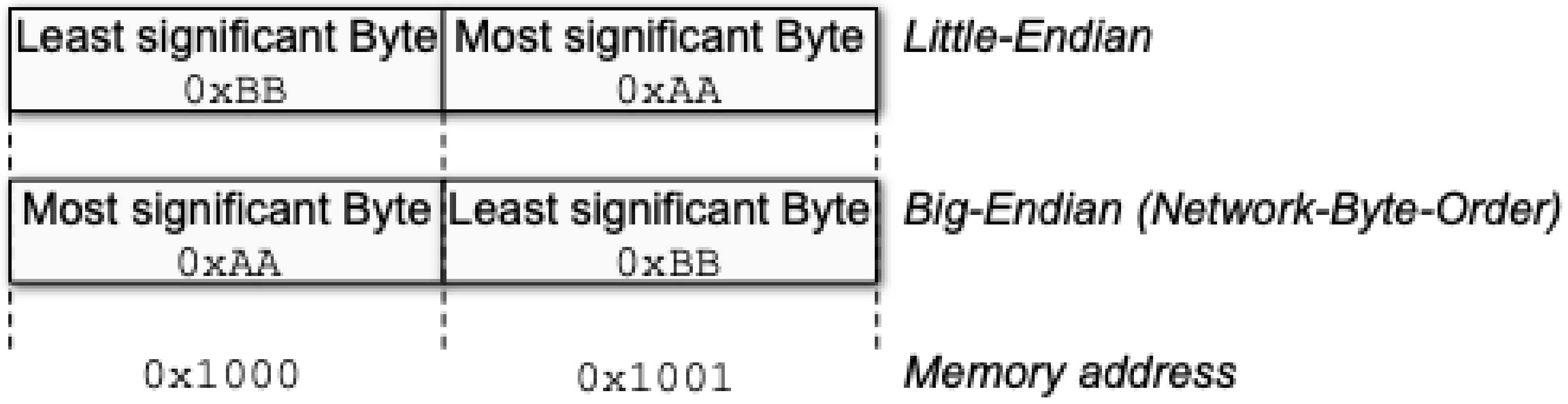
- **int read(int sockfd, char* buf, size_t nbytes);**
    - Read data from TCP stream
    - Return the number of bytes read or -1 on failures
    - Return 0 if socket is closed
    - **sockfd**: socket file descriptor returned from socket ( )
    - **buf**: data buffer
    - **nbytes**: the number of bytes that caller can read (usually set as buffer size)

Socket programming API: syscalls

- **int close(int sockfd);**
    - close a socket
    - return 0 on success, or -1 on failure
    - After close, sockfd is no longer valid

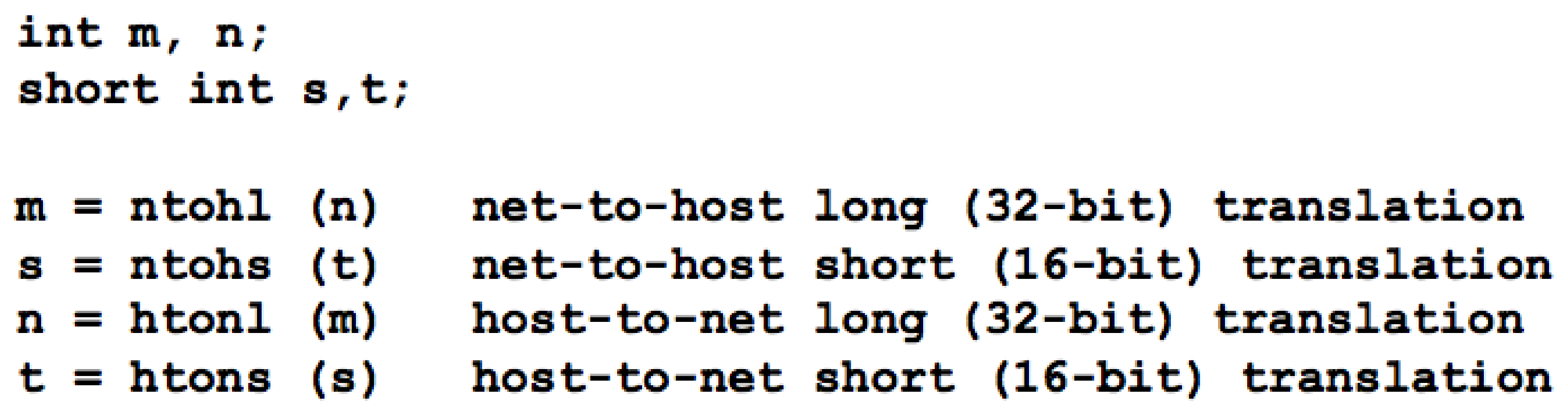
Caveat: byte ordering matters

- Little Endian: least significant byte of word is stored in the lowest address
- Big Endian: most significant byte of word is stored in the lowest address
- Hosts may use different orderings, so we need byte ordering conversion
- **Network Byte Order = Big Endian**



Caveat: byte ordering matters

- Byte ordering functions: used for converting byte ordering
- Example:



```
int m, n;
short int s,t;

m = ntohl (n)   net-to-host long (32-bit) translation
s = ntohs (t)   net-to-host short (16-bit) translation
n = htonl (m)   host-to-net long (32-bit) translation
t = htons (s)   host-to-net short (16-bit) translation
```

- Rule: for every int or short int
- Call htonl( ) or htons( ) before sending data
- Call ntohl( ) or ntohs( ) before reading received data

Address util functions

- All binary values are network byte ordered
- **struct hostent* gethostbyname (const char* hostname);**
  - Translate host name (e.g. “localhost”) to IP address (with DNS working)
- **struct hostent* gethostbyaddr (const char* addr, size_t len, int family);**
  - Translate IP address to host name
- **char* inet_ntoa (struct in_addr inaddr);**
  - Translate IP address to ASCII dotted-decimal notation (e.g. “192.168.0.1”)
- **int gethostname (char* name, size_namelen);**
  - Read local host’s name

FYI: `struct hostent`

`char *h_name`	The real canonical host name.
`char **h_aliases`	A list of aliases that can be accessed with arrays—the last element is `NULL`
`int h_addrtype`	The result's address type, which really should be `AF_INET` for our purposes.
`int length`	The length of the addresses in bytes, which is 4 for IP (version 4) addresses.
`char **h_addr_list`	A list of IP addresses for this host. Although this is a `char**`, it's really an array of `struct in_addr*`s in disguise. The last element is `NULL`.
`h_addr`	A commonly defined alias for `h_addr_list[0]`. If you just want any old IP address for this host (they can have more than one) just use this field.

Address util functions (cont’d)

- **in_addr_t inet_addr (const char* strptr);**
  - Translate dotted-decimal notation to IP address (network byte order)

```
struct sockaddr_in ina;
ina.sin_addr.s_addr = inet_addr("10.12.110.57");
```

- **int inet_aton (const char* strptr, struct in_addr *inaddr);**
  - Translate dotted-decimal notation to IP address

```
struct sockaddr_in my_addr;
my_addr.sin_family = AF_INET;          // host byte order
my_addr.sin_port = htons(MYPORT);      // short, network byte order
inet_aton("10.12.110.57",&(my_addr.sin_addr));
memset(&(my_addr.sin_zero), '\0', 8); // zero the rest of the struct
```

How to write a server: headers

```c
/* PLEASE include these headers */
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <errno.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/wait.h>
#include <netinet/in.h>
#define MYPORT 5000   /* Avoid reserved ports */
#define BACKLOG 10     /* pending connections queue size */
```

How to write a server: body (I)

```
int main()
{
   int sockfd, new_fd; /* listen on sock_fd, new connection on new_fd */
   struct sockaddr_in my_addr;       /* my address */
   struct sockaddr_in their_addr; /* connector addr */
   int sin_size;

   /* create a socket */
   if ((sockfd = socket(PF_INET, SOCK_STREAM, 0)) == -1) {
      perror("socket");
      exit(1);
   }
```

How to write a server: body (II)

```
// ...
/* set the address info */
my_addr.sin_family = AF_INET;
my_addr.sin_port = htons(MYPORT); /* short, network byte order */
my_addr.sin_addr.s_addr = htonl(INADDR_ANY);
/* INADDR_ANY allows clients to connect to any one of the host’s IP address. Optionally, use this line if you
know the IP to use:
   my_addr.sin_addr.s_addr = inet_addr(“127.0.0.1”);
 */
memset(my_addr.sin_zero, '\0', sizeof(my_addr.sin_zero));

/* bind the socket */
if (bind(sockfd, (struct sockaddr *) &my_addr,
         sizeof(struct sockaddr)) == -1) {
  perror("bind");
  exit(1);
}
```

How to write a server: body (III)

```
  // ...
    if (listen(sockfd, BACKLOG) == -1) {
    perror("listen");
    exit(1);
  }

  while (1) { /* main accept() loop */
    sin_size = sizeof(struct sockaddr_in);
    if ((new_fd = accept(sockfd, (struct sockaddr*)
                     &their_addr, &sin_size)) == -1) {
      perror("accept");
      continue;
    }
    printf("server: got connection from %s\n",
         inet_ntoa(their_addr.sin_addr));
    close(new_fd);
  }
}
```

How to write a client?

```
/* include all the headers */
int main() {
   int sockfd, new_fd;      /* listen on sock_fd, new connection on new_fd */
   struct sockaddr_in my_addr;      /* my address */
   struct sockaddr_in their_addr; /* connector addr */
   struct hostent* he;
   int sin_size;

   if ((sockfd = socket(PF_INET, SOCK_STREAM, 0)) == -1) {
      perror (“socket”);
      exit (1);
   }

   their_addr.sin_family = AF_INET; /* interp’d by host */
   their_addr.sin_port = htons (PORT);
   their_addr.sin_addr = *((struct in_addr*) he->h_addr);
   memset(their_addr.sin_zero, '\0', sizeof their_addr.sin_zero);

   if(connect(sockfd, (struct sockaddr*) &their_addr, sizeof(struct sockaddr)) == -1) {
      perror (“connect”);
      exit (1);
   }
   return 0;
}
```

Summary: what we have learned today

- What is the model for network programming?
  - **Client-Server model**
- Where are we programming?
  - **TCP and UDP in a nutshell**
- Which APIs can we use? How to use them?
  - **Socket programming**

Further Reading

- Stevens, W. Richard, Bill Fenner, and Andrew M. Rudoff. *UNIX Network Programming: The Sockets Networking API*. Vol. 1. Addison-Wesley Professional, 2004.

- Beej's Guide to Network Programming (http://beej.us/guide/bgnet)

- Socket Programming from Dartmouth, http://www.cs.dartmouth.edu/~campbell/cs60/socketprogramming.html

- C/C++ reference: http://en.cppreference.com

Q&A on lectures