Lecture 15: networking overview

CS 3281

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Sockets introduction

- Sockets: method for IPC between applications
  - Can be on the same host
  - Can be on a different host connected by a network
- Typical organization: client-server
  - The client makes requests
    - Example: a web browser
  - The server responds to requests
    - Example: an Apache web server
- Communication involves a network protocol
  - Usually multiple layers of network protocols
- We'll cover TCP/IP
  - Also called the Internet protocol suite

Big picture: the Internet

- Began in 1960s: as network that could connect computers that were far away
  - Funding came from DARPA, and first ARPANET message was sent from UCLA to Stanford (350 miles) in 1969
- Originally linked research operations and CS departments
  - Spread to the commercial world in the 1990s and become “the Internet”
- Today: the Internet links millions of loosely connected, independent networks
- Data is through the networks in “packets” called IP (Internet Protocol) packets
  - Transported in one or more physical packets, like Ethernet or WiFi
  - Each IP packet passes through multiple gateways
    - Each gateway passes the packet to a gateway closer to the ultimate destination
- An internet (lowercase i) connects different computer networks
  - The Internet (capital I) refers to the TCP/IP internet that connects millions of computers
  - Some modern style guides do not capitalize “Internet.” We do here for conceptual clarity.

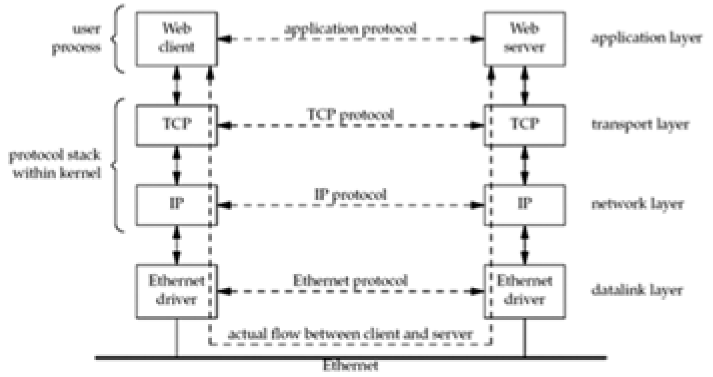
https://en.wikipedia.org/wiki/Capitalization_of_Internet

The Internet (cont'd)

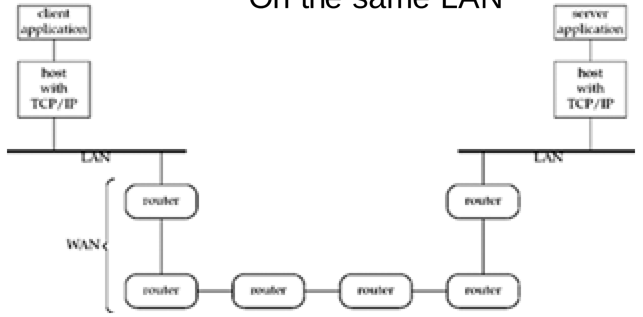
- The core protocol is the Internet Protocol
  - Defines a uniform transport mechanism and a common format for information in transit
  - IP packets are carried by different kinds of hardware using their own protocols
- The Transmission Control Protocol (TCP) sits on top of IP
  - TCP provides a reliable mechanism for sending arbitrarily long sequences of bytes
- Above TCP, higher-level protocols use TCP to provide services that we think of as “the Internet”
  - Examples: browsing, e-mail, file sharing
- All of these protocols taken together define the Internet

Protocol layers

- Example on the right:
  - Web servers and web clients communicate using TCP
  - TCP uses the Internet Protocol (IP)
  - IP uses a data link protocol (like Ethernet)
- The client and server use an application protocol
  - The transport layers use the TCP protocol
- Information flows down the protocol stack on one side, back up on the other
- Client and server are in user space
  - TCP, IP, data link in kernel space (usually)



On the same LAN



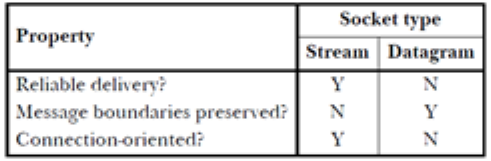
On different LANs

Sockets and client/server communication

- Each application creates a socket
- The server binds its socket to a well-known address so clients can locate it

```
fd = socket(domain, type, protocol);
```

- Domain determines:
  - Format of address, and range of communication (same or different hosts)
    - AF_UNIX, AF_INET, AF_INET6
- Type: stream or datagram
- Protocol: generally 0
  - Nonzero for some types like raw sockets (passes directly from data link to application)



Property	Socket type	
	Stream	Datagram
Reliable delivery?	Y	N
Message boundaries preserved?	N	Y
Connection-oriented?	Y	N

Stream sockets

- Stream sockets provide reliable, bidirectional, byte-stream communication
  - Reliable: Either the transmitted data arrives intact at the receiving end, or we receive notification of a probable failure in transmission
  - Bidirectional: data may be transmitted in either direction
  - Byte-stream: no message boundaries
    - Example: receiver doesn't know if the sender originally sent two 1-byte messages or one 2-byte message
- Operate in connected pairs (aka connection oriented)
  - *Peer* socket: socket at the other end of a connection
  - *Peer* address: address of that socket
  - *Peer* application: application using the peer socket
    - *Peer* is equivalent to *remote* or *foreign*

Datagram sockets

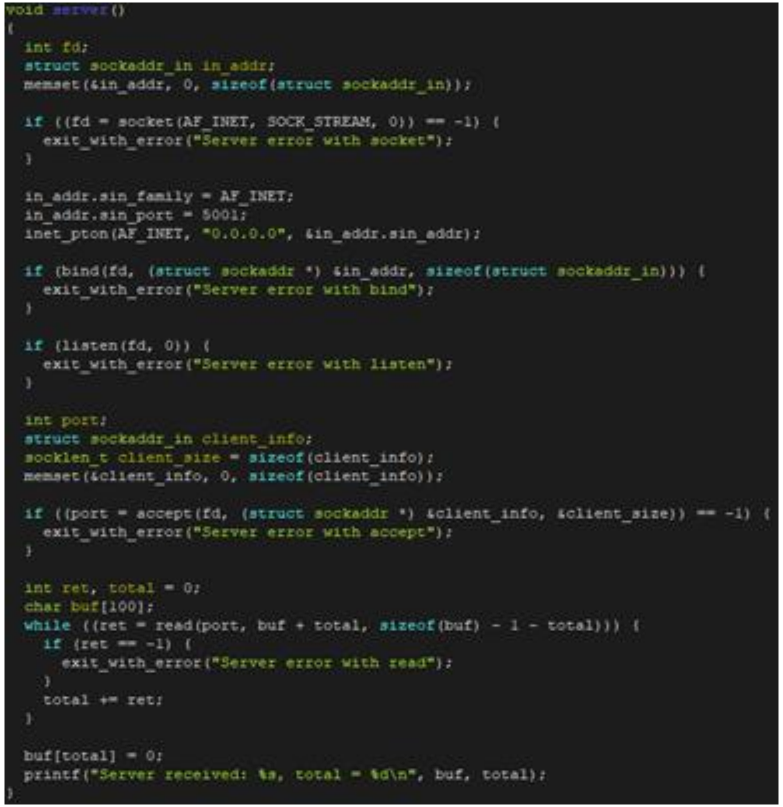
- Allow data to be exchanged in the form of messages called *datagrams*
  - Message boundaries are preserved
  - Data transmission is not reliable
    - Data may arrive out of order, be duplicated, or not arrive at all
  - Example of a connectionless socket
    - Doesn't need to be connected to another socket in order to be used
- In the Internet domain:
  - Datagram sockets use UDP
  - Stream sockets use* TCP

**Almost always*

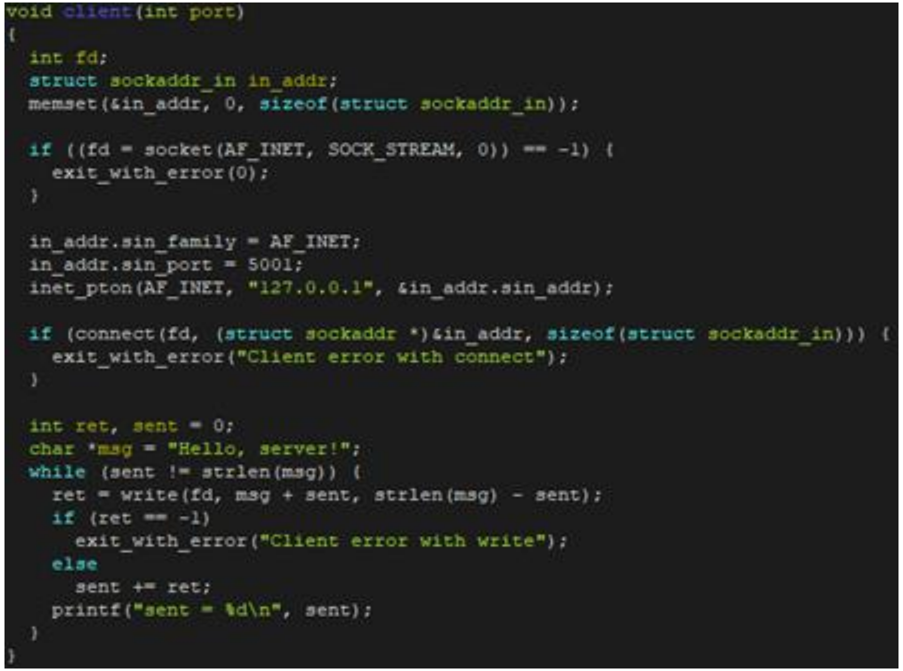
Key socket calls

- socket() creates a new socket
- bind() binds a socket to an address
- listen() lets a TCP socket to accept incoming connections from other sockets
- accept() accepts a connection from a peer application
- connect() establishes a connection with another socket
- Socket I/O can be done using
  - read() and write(), or
  - send(), recv(), sendto(), recvfrom()

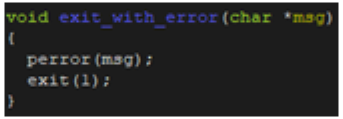
Server-client example



```
void server()
{
  int fd;
  struct sockaddr_in in_addr;
  memset(&in_addr, 0, sizeof(struct sockaddr_in));

  if ((fd = socket(AF_INET, SOCK_STREAM, 0)) == -1) {
    exit_with_error("Server error with socket");
  }

  in_addr.sin_family = AF_INET;
  in_addr.sin_port = 5001;
  inet_pton(AF_INET, "0.0.0.0", &in_addr.sin_addr);

  if (bind(fd, (struct sockaddr *) &in_addr, sizeof(struct sockaddr_in))) {
    exit_with_error("Server error with bind");
  }

  if (listen(fd, 0)) {
    exit_with_error("Server error with listen");
  }

  int port;
  struct sockaddr_in client_info;
  socklen_t client_size = sizeof(client_info);
  memset(&client_info, 0, sizeof(client_info));

  if ((port = accept(fd, (struct sockaddr *) &client_info, &client_size)) == -1) {
    exit_with_error("Server error with accept");
  }

  int ret, total = 0;
  char buf[100];
  while ((ret = read(port, buf + total, sizeof(buf) - 1 - total))) {
    if (ret == -1) {
      exit_with_error("Server error with read");
    }
    total += ret;
  }

  buf[total] = 0;
  printf("Server received: %s, total = %d\n", buf, total);
}
```

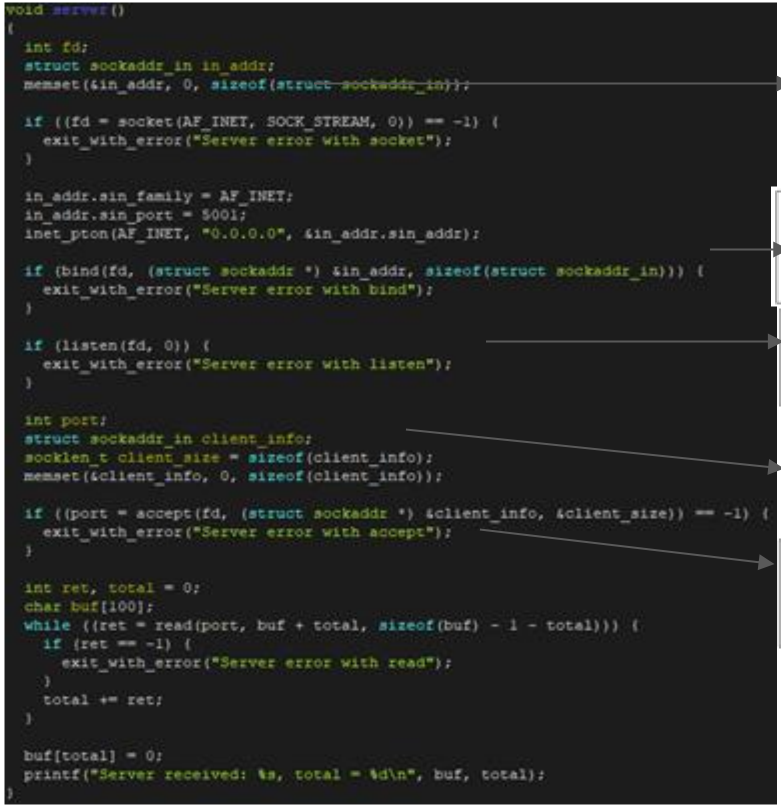


```
void client(int port)
{
  int fd;
  struct sockaddr_in in_addr;
  memset(&in_addr, 0, sizeof(struct sockaddr_in));

  if ((fd = socket(AF_INET, SOCK_STREAM, 0)) == -1) {
    exit_with_error(0);
  }

  in_addr.sin_family = AF_INET;
  in_addr.sin_port = 5001;
  inet_pton(AF_INET, "127.0.0.1", &in_addr.sin_addr);

  if (connect(fd, (struct sockaddr *)&in_addr, sizeof(struct sockaddr_in))) {
    exit_with_error("Client error with connect");
  }

  int ret, sent = 0;
  char *msg = "Hello, server!";
  while (sent != strlen(msg)) {
    ret = write(fd, msg + sent, strlen(msg) - sent);
    if (ret == -1)
      exit_with_error("Client error with write");
    else
      sent += ret;
    printf("sent = %d\n", sent);
  }
}
```



```
void exit_with_error(char *msg)
{
  perror(msg);
  exit(1);
}
```

Server-client example



```c
void server()
{
  int fd;
  struct sockaddr_in in_addr;
  memset(&in_addr, 0, sizeof(struct sockaddr_in));

  if ((fd = socket(AF_INET, SOCK_STREAM, 0)) == -1) {
    exit_with_error("Server error with socket");
  }

  in_addr.sin_family = AF_INET;
  in_addr.sin_port = 5001;
  inet_pton(AF_INET, "0.0.0.0", &in_addr.sin_addr);

  if (bind(fd, (struct sockaddr *) &in_addr, sizeof(struct sockaddr_in))) {
    exit_with_error("Server error with bind");
  }

  if (listen(fd, 0)) {
    exit_with_error("Server error with listen");
  }

  int port;
  struct sockaddr_in client_info;
  socklen_t client_size = sizeof(client_info);
  memset(&client_info, 0, sizeof(client_info));

  if ((port = accept(fd, (struct sockaddr *) &client_info, &client_size)) == -1) {
    exit_with_error("Server error with accept");
  }

  int ret, total = 0;
  char buf[100];
  while ((ret = read(port, buf + total, sizeof(buf) - 1 - total))) {
    if (ret == -1) {
      exit_with_error("Server error with read");
    }
    total += ret;
  }

  buf[total] = 0;
  printf("Server received: %s, total = %d\n", buf, total);
}
```

<u>IPv4 socket address structure</u>

```c
struct in_addr {                  /* IPv4 4-byte address */
    in_addr_t s_addr;             /* Unsigned 32-bit integer */
};

struct sockaddr_in {              /* IPv4 socket address */
    sa_family_t    sin_family;    /* Address family (AF_INET) */
    in_port_t      sin_port;      /* Port number */
    struct in_addr sin_addr;      /* IPv4 address */
    unsigned char  __pad[X];      /* Pad to size of 'sockaddr'
                                     structure (16 bytes) */
};
```

<u>Generic socket address structure</u>

```c
struct sockaddr {
    sa_family_t sa_family;        /* Address family (AF_* constant) */
    char        sa_data[14];      /* Socket address (size varies
                                     according to socket domain) */
};
```

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

int bind(int sockfd, const struct sockaddr *addr, socklen_t addrlen);
```

Returns 0 on success, or –1 on error

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

int listen(int sockfd, int backlog);
```

Returns 0 on success, or –1 on error

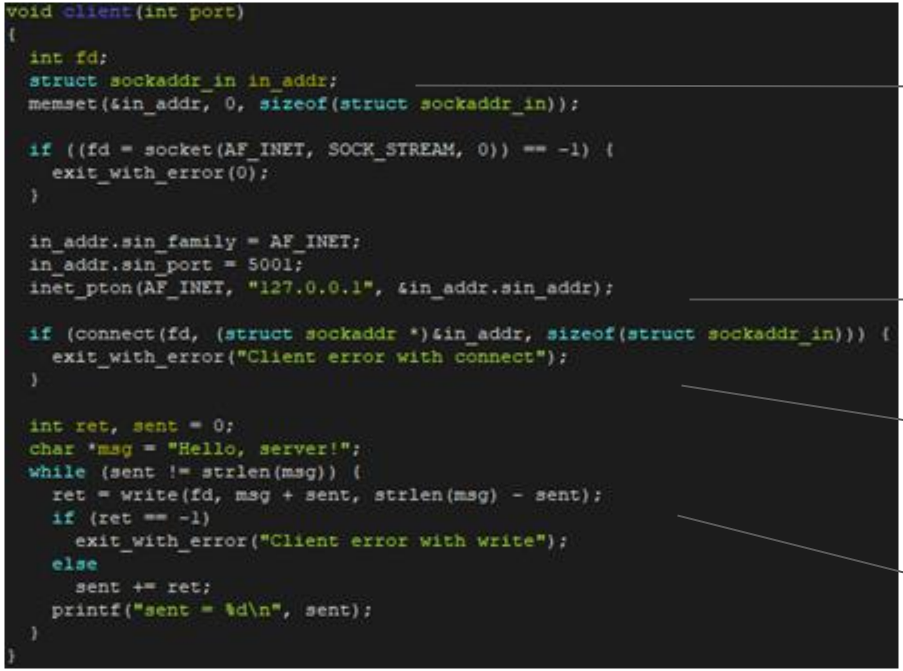
```c
#define __ss_aligntype uint32_t        /* On 32-bit architectures */
struct sockaddr_storage {
    sa_family_t ss_family;
    __ss_aligntype __ss_align;         /* Force alignment */
    char __ss_padding[SS_PADSIZE];     /* Pad to 128 bytes */
};
```

<u>Large enough for IPv4 or IPv6</u>

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

int accept(int sockfd, struct sockaddr *addr, socklen_t *addrlen);
```

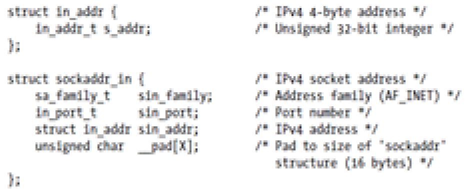
Returns file descriptor on success, or –1 on error

Server-client example

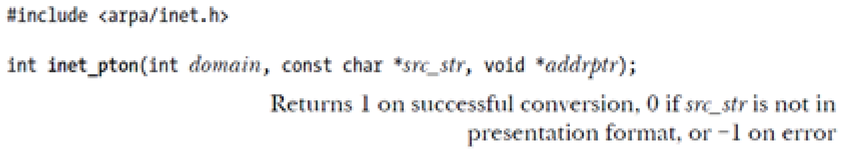


```c
void client(int port)
{
  int fd;
  struct sockaddr_in in_addr;
  memset(&in_addr, 0, sizeof(struct sockaddr_in));

  if ((fd = socket(AF_INET, SOCK_STREAM, 0)) == -1) {
    exit_with_error(0);
  }

  in_addr.sin_family = AF_INET;
  in_addr.sin_port = 5001;
  inet_pton(AF_INET, "127.0.0.1", &in_addr.sin_addr);

  if (connect(fd, (struct sockaddr *)&in_addr, sizeof(struct sockaddr_in))) {
    exit_with_error("Client error with connect");
  }

  int ret, sent = 0;
  char *msg = "Hello, server!";
  while (sent != strlen(msg)) {
    ret = write(fd, msg + sent, strlen(msg) - sent);
    if (ret == -1)
      exit_with_error("Client error with write");
    else
      sent += ret;
    printf("sent = %d\n", sent);
  }
}
```

IPv4 socket address structure

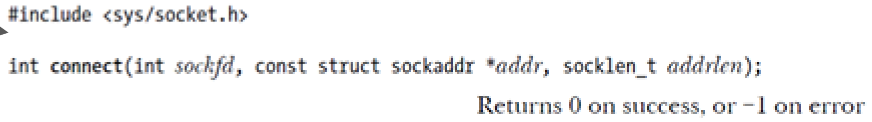


```c
struct in_addr {                    /* IPv4 4-byte address */
    in_addr_t s_addr;               /* Unsigned 32-bit integer */
};

struct sockaddr_in {                /* IPv4 socket address */
    sa_family_t    sin_family;      /* Address family (AF_INET) */
    in_port_t      sin_port;        /* Port number */
    struct in_addr sin_addr;        /* IPv4 address */
    unsigned char  __pad[X];        /* Pad to size of 'sockaddr'
                                       structure (16 bytes) */
};
```



```c
#include <arpa/inet.h>

int inet_pton(int domain, const char *src_str, void *addrptr);
```

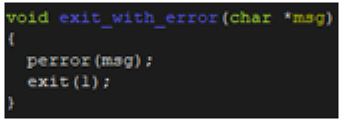
Returns 1 on successful conversion, 0 if *src_str* is not in presentation format, or −1 on error



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

int connect(int sockfd, const struct sockaddr *addr, socklen_t addrlen);
```

Returns 0 on success, or −1 on error

Basic write() library call uses a generic file descriptor



```c
void exit_with_error(char *msg)
{
  perror(msg);
  exit(1);
}
```

Print the last error encountered during a system call or library function

Protocols and communication

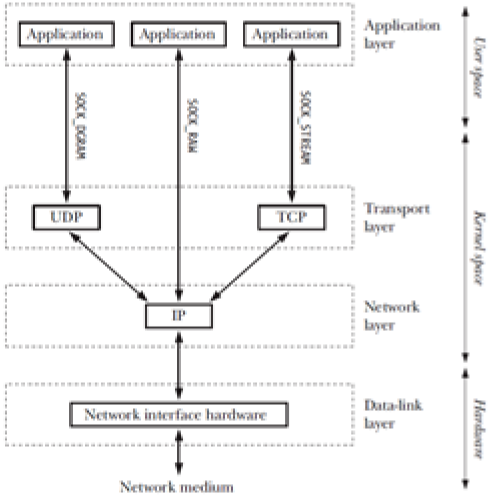
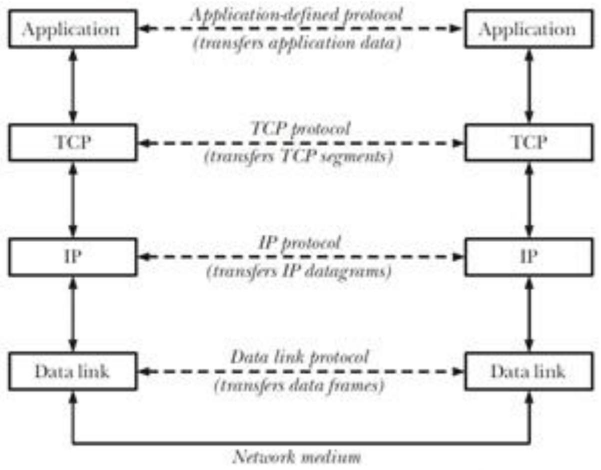
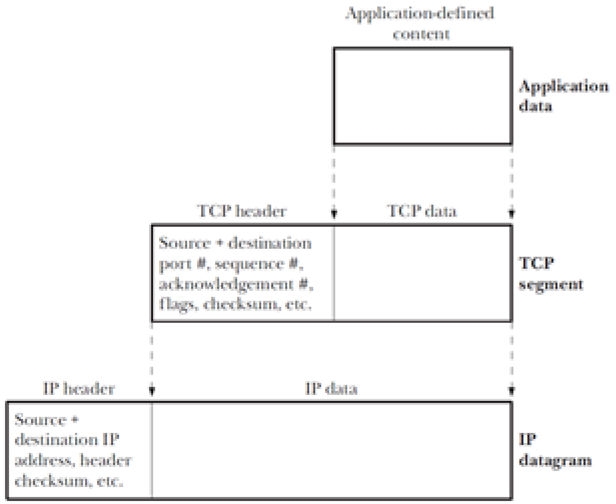


Figure 58-2: Protocols in the TCP/IP suite



Application
Application-defined protocol (transfers application data)
Application
TCP
TCP protocol (transfers TCP segments)
TCP
IP
IP protocol (transfers IP datagrams)
IP
Data link
Data link protocol (transfers data frames)
Data link
Network medium

Figure 58-3: Layered communication via the TCP/IP protocols



Application-defined content
Application data
TCP header
TCP data
Source + destination port #, sequence #, acknowledgement #, flags, checksum, etc.
TCP segment
IP header
IP data
Source + destination IP address, header checksum, etc.
IP datagram

Figure 58-4: Encapsulation within the TCP/IP protocol layers