CH11-Network Programming

10.5 Robust & Standard I/O

回顾Unix I/O的读写文件函数

```
/*return:成功返回回读的字节数，已经EOP就为0，出错返回-1*/
ssize_t read(int fd, void *buf, size_t n);

/*return:成功返回回写的字节数，出错返回-1*/
ssize_t write(int fd, void *buf, size_t n);
```

Robust I/O

健壮的I/O包能够处理系统级函数read和write的不足值，提供两类函数：无缓冲和缓冲

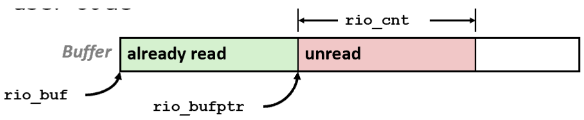
Unbuffered Input and Output

```
ssize_t rio_readn(int fd, void *buf, size_t count){
    size_t nleft = count;
    ssize_t nread;
    char *ptr = buf;
    while (nleft > 0) { /* 一次read可能不能读完所有需要的字节，所以使用while，保证读完字节 */
        if ((nread = read(fd, ptr, nleft)) < 0) {
            if (errno == EINTR) /* 只是被信号中断，只废弃本轮循环 */
                nread = 0; /* and call read() again */
            else
                return -1; /* errno set by read() */
        }
        else if (nread == 0)
            break; /* EOF */
        nleft -= nread;
        ptr += nread;
    }
    return (count - nleft); /* return >= 0 */
}
```

```
ssize_t rio_writen(int fd, const void *buf, size_t count){
    size_t nleft = count;
    ssize_t nwritten;
    const char *ptr = buf;
    while (nleft > 0) {
        if ((nwritten = write(fd, ptr, nleft)) <= 0) {
            if (errno == EINTR)
                nwritten = 0; /* and call write() again */
            else
                return -1; /* errorno set by write() */
        }
        nleft -= nwritten;
        ptr += nwritten;
    }
    return count;
}
```

Buffered I/O

提供应用级别的缓存，防止过多次发生系统调用(比如getline，不应当每读一个字节就发生一次系统调用)



```
#define RIO_BUFSIZE 8192
typedef struct {
    int rio_fd;                 /* descriptor for this internal buf */
    int rio_cnt;                /* unread bytes in internal buf */
    char *rio_bufptr;           /* next unread byte in internal buf */
    char rio_buf[RIO_BUFSIZE]; /* internal buffer */
} rio_t;

void rio_readinitb(rio_t *rp, int fd)
{
    rp->rio_fd = fd ;
    rp->rio_cnt = 0 ;
    rp->rio_bufptr = rp->rio_buf ;
}
```

```
static ssize_t rio_read(rio_t *rp, char *usrbuf, size_t n){
    int cnt = 0;
    while (rp->rio_cnt <= 0) { /* refill if buf is empty */
        rp->rio_cnt = read(rp->rio_fd, rp->rio_buf, sizeof(rp->rio_buf));
        if (rp->rio_cnt < 0) {
            if (errno != EINTR)
                return -1 ;
        }
        else if (rp->rio_cnt == 0) /* EOF */
            return 0;
        else
            rp->rio_bufptr = rp->rio_buf;/* reset buffer ptr */
    }
/* Copy min(n, rp->rio_cnt) bytes from internal buf to user buf */
    cnt = n ;
    if (rp->rio_cnt < n)
        cnt = rp->rio_cnt ;
    memcpy(usrbuf, rp->rio_bufptr, cnt) ;
    rp->rio_buffer += cnt ;
    rp->rio_cnt -= cnt ;
    return cnt ;
}
```

该函数能重新加载缓存，并读取小于buffer大小的字节数，如果大于缓存大小，就需要while包装一层

```c
ssize_t rio_readnb(rio_t *rp, void *usrbuf, size_t n){
    size_t nleft = n; ssize_t nread ;
    char *bufp = usrbuf;
    while (nleft > 0) {
        if ((nread = rio_read(rp, bufp, nleft)) < 0) {
            if (errno = EINTR) /* interrupted by sig handler return */
                nread = 0;
            else
                return -1;
        }
        else if (nread == 0)
            break;
        nleft -= nread;
        bufp += nread;
    }
    return (n – nleft);
}
```

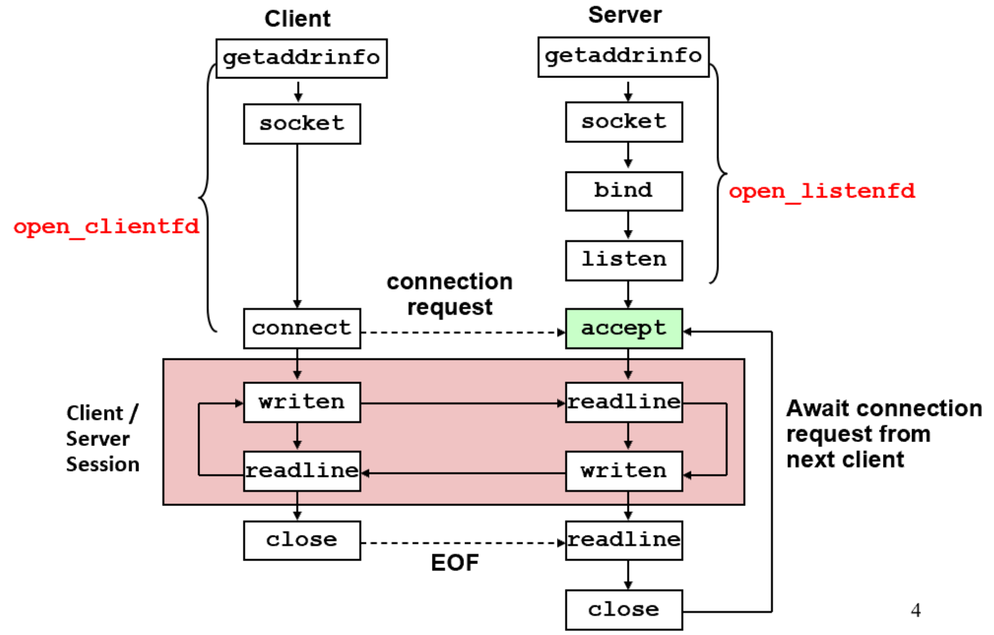
```c
ssize_t rio_readlineb(rio_t *rp, void *usrbuf, size_t maxlen){
    int n, rc;
    char c, *bufp = usrbuf;
    for (n = 1; n < maxlen; n++) { /* 应当从1开始循环，因为需要在字符串结尾放上'\0' */
        if ((rc = rio_read(rp, &c, 1)) == 1) {
            *bufp++ = c;
            if (c == ‘\n’)
                break;
        } else if (rc == 0) {
            if (n == 1)
                return 0; /* EOF, no data read */
            else
                break; /* EOF, some data was read */
        } else
            return -1; /* error */
    }
    *bufp = 0 ; /* Add terminal NULL to the text line */
    return n ;
}
```

Standard I/O

C语言封装并提供了std库的高级输入输出函数，也最常使用；当出现信号处理时，Unix I/O才能提供异步信号安全的函数；RIO则用于网络套接字

11.1 Introduction to Networks

11.4 Socket Interface



从Linux内核角度看，套接字就是通信的一个端点；从Linux程序角度看，套接字就是一个有相应描述符的打开文件
也就是将I/O设备都抽象成文件的读写

Key data structures

```
/* Internet address */
struct in_addr {
  uint32_t s_addr; /* 32-bit IP address */
};
```

为了适配各种类型的sockaddr，所以有struct sockaddr

```
/* IP socket address structure*/
struct sockaddr_in  {
  uint16_t sin_family; /*Address family (AF_INET) */
  uint16_t sin_port;   /*Port number*/
  struct in_addr  sin_addr;   /*IP address*/
  unsigned char sin_zero[8];   /*Pad to “sockaddr”*/
};
/* Generic socket address structure */
struct sockaddr {
  uint16_t sin_family;  /*Protocol family*/
  char     sa_data[14]; /*address data*/
};
typedef struct sockaddr SA;
```

Basic Function

- **socket**:创建套接字描述符，成功返回非负描述符，默认是主动套接字(即被客户端所有)

  ```
  int socket(int domain, int type, int protocol);
  ```

  使用如下方法使套接字成为连接的端点

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

- **connect**:客户端建立与服务器的连接

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

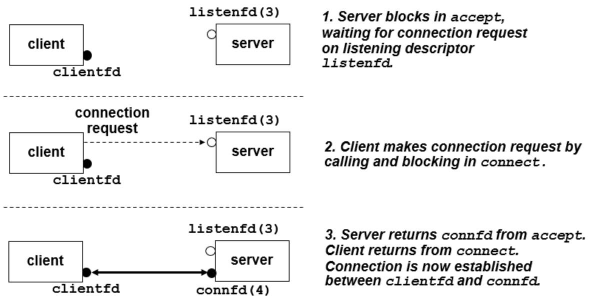
- **bind->listen->accept**:服务器与客户端连接
  - **bind**: 将套接字地址与套接字描述符连接在一起

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

  - **listen**: 让套接字描述符变成监听套接字，即成为可以接受客户端连接请求的服务端套接字，把backlog设得较大

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

  - **accept**: 等待客户端连接，其等待clientfd使用connect连接到listenfd，连接之后，设置addr为客户端套接字地址，并返回一个已连接描述符


client
clientfd
listenfd(3)
server
1. Server blocks in accept, waiting for connection request on listening descriptor listenfd.
connection request
client
clientfd
listenfd(3)
server
2. Client makes connection request by calling and blocking in connect.
client
clientfd
listenfd(3)
server
connfd(4)
3. Server returns connfd from accept. Client returns from connect. Connection is now established between clientfd and connfd.

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

Host and Service Conversion

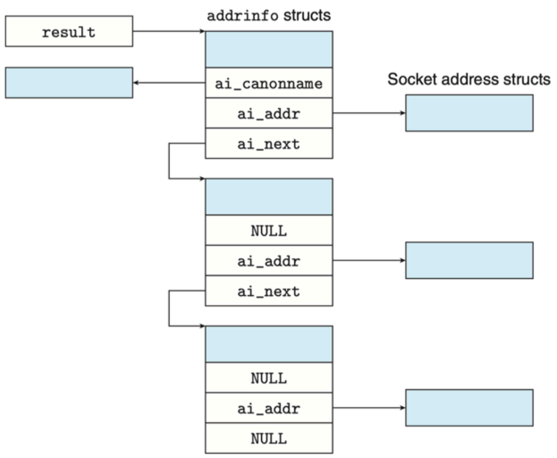
实现二进制套接字地址结构和主机名、主机地址、服务名、端口号组成的字符串的相互转换

```
struct addrinfo {
    int ai_flags;       /* Hints argument flags */
    int ai_family;      /* First arg to socket function */
    int ai_socktype;    /* Second arg to socket function */
    int ai_protocol;    /* Third arg to socket function */
    char *ai_canonname; /* Canonical hostname */
    size_t ai_addrlen;  /* Size of ai_addr struct */
    struct sockaddr *ai_addr;   /* Ptr to socket address structure */
    struct addrinfo *ai_next;   /* Ptr to next item in linked list */
};
```

对于前三个参数，有以下规定:

- **family: AF_INET,AF_INET6**(分别对应IPv4和IPv6)
- **socktype:SOCK_STREAM,SOCK_DGRAM,SOCK_RAW**
- **protocol:0**(指代套接字的协议，为0说明任意协议均可)

相关函数如下，使用getaddrinfo来实现字符串转结构体(返回一个链表)，getnameinfo实现结构体转字符串



```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
// 成功返回0；错误返回非零的错误代码
int getaddrinfo(const char *host, const char *service,
                const struct addrinfo *hints,
                struct addinfo **result);
// 释放链表中的结构体
void freeaddinfo(struct addinfo *result);
// 返回错误信息
Const char *gai_strerror(int errocde);
// 成功返回0；错误返回非零的错误代码
int getnameinfo(const struct sockaddr *sa, socklen_t salen,
                char *host, size_t hostlen,
                char *service, size_t servlen, int flags);
```

下面的例子展示了如何实现展示域名和它关联的IP地址的映射

```
#include <stdlib.h>
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>
#define MAXLINE 128
int main(int argc, char ** argv)
{
    struct addrinfo *p, *listp, hints;
    char buf[MAXLINE];
    int rc, flags;
    if(argc != 2) {
        fprintf(stderr, "usage: %s <domain name>\n", argv[0]);
        exit(0);
    }
    // 获取所有能对上的IP地址，将它们都压入链表
    memset(&hints, 0, sizeof(struct addrinfo));
    hints.ai_family = AF_INET; // 只限于IPv4
    hints.ai_socktype = SOCK_STREAM; // 只连接
    if((rc = getaddrinfo(argv[1], NULL, &hints, &listp)) != 0){
        fprintf(stderr,"getaddrinfo error: %s\n", gai_strerror(rc));
        exit(0);
    }
    // 遍历链表，并输出相应IP地址
    flags = NI_NUMERICHOST; // 字符串而非域名
    for(p = listp; p; p = p->ai_next){
        getnameinfo(p->ai_addr, p->ai_addrlen, buf, MAXLINE, NULL, 0, flags);
        printf("%s\n", buf);
    }
    // 释放
    freeaddrinfo(listp);
    exit(0);
}
```

Echo client

使用open_clientfd和open_listenfd分别创建客户端与服务端的描述符，从而使用Unix I/O进行输入输出

使用getaddrinfo获取链表，遍历链表获取套接字(socket)并连接(connect)

```
int open_clientfd(char *hostname, char *port) {
    int clientfd;
    struct addrinfo hints, *listp, *p;
    /* Get a list of potential server addresses */
    memset(&hints, 0, sizeof(struct addrinfo));
    hints.ai_socktype = SOCK_STREAM; /* Open a connection */
    hints.ai_flags = AI_NUMERICSERV;  /* Use a numeric port arg @port */
    hints.ai_flags |= AI_ADDRCONFIG;   /* Recommended for connections */
    getaddrinfo(hostname, port, &hints, &listp);
    /* Walk the list for one that we can successfully connect to */
    for (p = listp; p; p = p->ai_next) {
        /* Create a socket descriptor */
        if ((clientfd = socket(p->ai_family, p->ai_socktype, p->ai_protocol)) < 0)
            continue;   /* Socket failed, try the next */
        /* Connect to the server */
        if (connect(clientfd, p->ai_addr, p->ai_addrlen) != -1)
            break;      /* Success */
        Close(clientfd);    /* Connect failed, try another */
    }
    /* Clean up */
    Freeaddrinfo(listp);
    if (!p)     /* All connects failed */
        return -1;
    else    /* The last connect succeeded */
        return clientfd;
}
```

客户端在main函数中调用open_clientfd，并使用创建的描述符进行读写

```
int main(int argc, char **argv)
{
    int clientfd;
    char *host, *port, buf[MAXLINE];
    rio_t rio;

    if (argc != 3) {
       fprintf(stderr,"usage:%s <host> <port>\n",argv[0]);
       exit(0);
    }
    host = argv[1]; port = argv[2];
    clientfd = open_clientfd(host, port);
    Rio_readinitb(&rio, clientfd) ;

    while (Fgets(buf, MAXLINE, stdin) != NULL) {
        Rio_writen(clientfd, buf, strlen(buf));
        Rio_readline(&rio, buf, MAXLINE);
        Fputs(buf, stdout);
    }
    Close(clientfd);
}
```

Echo Server

open_listenfd同样使用getaddrinfo获取链表，遍历链表创建套接字(socket)，配置服务器(setsocketopt)并使用bind将服务器套接字地址与套接字描述符联系起来，最后使用listen让套接字可以监听客户端的连接请求

```
int open_listenfd(char *port)
{
    struct addrinfo hints, *listp, *p;
    int listenfd, optval=1;
    /* Get a list of potential server addresses */
    memset(&hints, 0, sizeof(struct addrinfo));
    hints.ai_socktype = SOCK_STREAM; /* Accept connections */
    hints.ai_flags = AI_PASSIVE | AI_ADDRCONFIG;
    hints.ai_flags |= AI_NUMERICSERV; /* using @port number */
    Getaddrinfo(NULL, port, &hints, &listp);
    /* Walk the list for one that we can bind to */
    for (p = listp; p; p = p->ai_next) {
        /* Create a socket descriptor */
        if ((listenfd = socket(p->ai_family, p->ai_socktype, p->ai_protocol)) < 0)
            continue;   /* Socket failed, try the next */
        /* Eliminates "Address already in use" error from bind */
        setsockopt(listenfd, SOL_SOCKET, SO_REUSEADDR,(const void *)&optval , sizeof(int));
        /* Bind the descriptor to the address */
        if (bind(listenfd, p->ai_addr, p->ai_addrlen) == 0)
            break;      /* Success */
        Close(listenfd);    /* Bind failed, try the next */
    }
    /* Clean up */
    freeaddrinfo(listp);
    if (!p)     /* No address worked */
        return -1;
    /* Make it a listening socket ready to accept connection requests */
    if (listen(listenfd, LISTENQ) < 0) {
        Close(listenfd);
        return -1;
    }
    return listenfd;
}
```

而服务端的main函数使用accept等待服务端的连接，连接成功后，使用echo函数进行读写，最后close已连接描述符

```
#include "csapp.h"

void echo(int connfd);

int main(int argc, char **argv)
{
    int listenfd, connfd;
    socklen_t clientlen;
    struct sockaddr_storage clientaddr; /* Enough space for any address */
    char client_hostname[MAXLINE], client_port[MAXLINE];
    if (argc != 2) {
        fprintf(stderr, "usage: %s <port>\n", argv[0]);
        exit(0);
    }
    listenfd = Open_listenfd(argv[1]);
    while (1) {
        clientlen = sizeof(struct sockaddr_storage);
        connfd = accept(listenfd, (SA *)&clientaddr, &clientlen);
        getnameinfo((SA *) &clientaddr, clientlen, client_hostname, MAXLINE, client_port, MAXLIN
        printf("Connected to (%s, %s)\n", client_hostname, client_port);
        echo(connfd);
        Close(connfd);
    }
    exit(0);
}
```

最后介绍echo函数

```
  void echo(int connfd)
  {
        size_t n;
        char buf[MAXLINE];
        rio_t rio

        Rio_readinitb(&rio, connfd)
        while((n = Rio_readlineb(&rio, buf, MAXLINE))!=0){
                  printf("server received %d bytes\n", n);
                  Rio_writen(connfd, buf, n);
        }
}
```

11.5 Web Server

Web content

内容是与一个MIME类型相关的字节序列，常见的如下

> **text/html** HTML page
>
> **text/plain** Unformatted text
>
> **application/postscript** Postcript document
>
> **image/gif** Binary image encoded in GIF format
>
> **image/jpg** Binary image encoded in JPG format

内容分为静态内容和动态内容

HTTP Transactions

使用linux的TELNET程序来和因特网上的web服务器执行事务，输入以下指令后会打印三行输出，接下来可以发送HTTP请求并获得HTTP响应

```
//Client: open connection to server
unix> telnet ipads.se.sjtu.edu.cn 80
//Telnet prints 3 lines to the terminal
Trying 202.120.40.85...
Connected to ipads.se.sjtu.edu.cn.
Escape character is '^]'.
//Client: request line
GET /courses/ics/index.shtml HTTP/1.1
//Client: required HTTP/1.1 HOST header
host: ipads.se.sjtu.edu.cn
//Client: empty line terminates headers
//Server: response line
HTTP/1.1 200 OK
//Server: followed by five response headers
Server: nginx/1.0.4
Date: Thu, 29 Nov 2012 10:15:38 GMT
//Server: expect HTML in the response body
Content-Type: text/html
//Server: expect 11,560 bytes in the response body
Content-Length: 11560
//Server: empty line ("\r\n") terminates hdrs
//Server: first HTML line in response body
<!DOCTYPE html PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN">
<html>
... //Server: 292 lines of HTML not shown.
</html>   //Server: last HTML line in response body
//Server: closes connection
Connection closed by foreign host.
Client: closes connection and terminates
unix>
```

HTTP Requests

request line格式为：

```
method URI version
```

method指定方法，如GET,POST,OPTIONS等等；URI是URL的后缀(而当使用proxy时必须是完整的URL)；version指定HTTP版本，如HTTP/1.1
request line会紧跟着零或更多的request headers，从而提供更多的信息，格式如下，注意一般来说使用Host报头

```
header-name: header-data
```

HTTP Responses

HTTP响应输出一个response line，紧跟着零或多个response headers，最后返回response body
response line格式如下：

```
version status-code status-msg
```

其中version还是描述HTTP版本；status-code是一个3位数字，后面会列出常见的状态码；status-msg给出与错误码等价的英文描述

> **200 OK** Request was handled without error
> **301 Moved** Provide alternate URL
> **403 Forbidden** Server lacks permission to access file
> **404 Not found** Server couldn’t find the file
> **501 Not Implemented** Server does not support the request method
> **505 HTTP version not supported** Server does not support version in request

response header格式与request header一致，注意两个最重要的报头：Content-Type告诉响应主体中的MIME内容类型；Content-Length指示响应主体字节大小

Serving dynamic content

How does the client pass program arguments to the server?

在URI中指定传递的参数，比如URI中包含"/cgi-bin"，认为是在请求一个动态内容

How does the server pass these arguments to the child?

服务端接受请求后，调用fork函数创建子进程，并使用execve在子进程上下文中执行/cgi-bin/adder程序(即CGI程序)，环境变量QUERY_STRING被设置为URI中'?'后的参数

How does the server pass other info relevant to the request to the child?

使用CGI定义的其他环境变量设置

> QUERY_STRING (contains GET args)
> SERVER_PORT
> REQUEST_METHOD (GET, POST, etc)
> REMOTE_HOST (domain name of client)

> REMOTE_ADDR (IP address of client)
> CONTENT_TYPE (for POST, MIME type of the request body)
> CONTENT_LENGTH (for POST, length in bytes)

How does the server capture the content produced by the child?

子进程将动态内容发送到stdout，在执行CGI程序之前，使用dup2函数将stdout重定向到已连接描述符，且子进程需要负责Content-type和Content-length响应报头，以及终止报头的空行

11.6 Tiny Web Server

待补充笔记

```c
/*
* tiny.c - A simple HTTP/1.0 Web server that uses the
* GET method to serve static and dynamic content.
*/
#include "csapp.h"

void doit(int fd);
void read_requesthdrs(int fd);
int parse_uri(char *uri, char *fname, char *cgiargs);
void serve_static(rio_t *rio, char *fname, int fsize);
void get_filetype(char *fname, char *ftype);
void serve_dynamic(rio_t *rio,char *fname,char*cgiargs);
void clienterror(rio_t *rio, char *cause, char *errnum, char *shortmsg, char *longmsg);
int main(int argc, char **argv)
{
    int listenfd, connfd;
    char hostname[MAXLINE], port[MAXLINE];
    socklen_t clientlen;
    struct sockaddr_storage clientaddr;
    /* check command line args */
    if (argc != 2) {
        fprintf(stderr,"usage: %s <port>\n", argv [0]);
        exit(1);
    }
    listenfd = open_listenfd(argv[1]);
    while (1) {
        clientlen = sizeof(clientaddr);
        connfd = Accept(listenfd, (SA *)&clientaddr, &clientlen);
        Getnameinfo((SA*)&clientaddr, clientlen, hostname, MAXLINE, port, MAXLINE, 0)
        printf(“Accepted Connection from (%s, %s)\n”, hostname, port);
        doit(connfd);
        Close(connfd);
    }
}
```

```
void doit(int fd)
{
    int is_static;
    struct stat sbuf;
    char buf[MAXLINE], method[MAXLINE], uri[MAXLINE], version[MAXLINE];
    char filename[MAXLINE], cgiargs[MAXLINE];
    rio_t rio;
    /* Read request line and headers */
    Rio_readinitb(&rio, fd);
    Rio_readlineb(&rio, buf, MAXLINE);
    printf("Request headers:\n");
    printf("%s", buf);
    sscanf(buf, "%s %s %s", method, uri, version);
    if (strcasecmp(method, "GET")) {
        clienterror(fd, method, "501", "Not implemented", "Tiny does not implement this method")
        return;
    }
    read_requesthdrs(&rio);
    /* Parse URI from GET request */
    is_static = parse_uri(uri, filename, cgiargs);
    if (stat(filename, &sbuf) < 0) {
        clienterror(fd, filename, "404", "Not found", "Tiny couldn’t find this file");
        return;
    }
    if (is_static) { /* Serve static content */
        if (!(S_ISREG(sbuf.st_mode)) || !(S_IRUSR & sbuf.st_mode)) {
            clienterror(fd, filename, "403", "Forbidden", "Tiny couldn’t read the file");
            return;
        }
        serve_static(fd, filename, sbuf.st_size);
    }
    else { /* Serve dynamic content */
        if (!(S_ISREG(sbuf.st_mode)) || !(S_IXUSR & sbuf.st_mode)) {
            clienterror(fd, filename, "403", "Forbidden", "Tiny couldn’t run the CGI program");
            return;
        }
        serve_dynamic(fd, filename, cgiargs);
    }
}
```

```
void clienterror(int fd, char *cause, char *errnum, char *shortmsg, char *longmsg)
{
    char buf[MAXLINE], body[MAXBUF];
    /* build the HTTP response body */
    sprintf(body, "<html><title>Tiny Error</title>");
    sprintf(body, "%s<body bgcolor=""ffffff"">\r\n", body);
    sprintf(body, "%s%s: %s\r\n", body, errnum, shortmsg);
    sprintf(body, "%s<p>%s: %s\r\n", body, longmsg, cause);
    sprintf(body, "%s<hr><em>Tiny Web server</em>\r\n",body);
    /* print the HTTP response */
    sprintf(buf, "HTTP/1.0 %s %s\r\n", errnum, shortmsg);
    Rio_writen(fd, buf, strlen(buf));
    sprintf(buf, "Content-type: text/html\r\n");
    Rio_writen(fd, buf, strlen(buf));
    sprintf(buf, "Content-length: %d\r\n\r\n", strlen(body));
    Rio_writen(fd, buf, strlen(buf));
    Rio_writen(fd, body, strlen(body));
}


void read_requesthdrs(rio_t *rp)
{
    char buf[MAXLINE];
    Rio_readline(rp, buf, MAXLINE);
    while(strcmp(buf, "\r\n")){
        Rio_readlineb(rp, buf, MAXLINE);
        printf(“%s”, buf);
    }
    return;
}
```

```c
int parse_uri(char *uri, char *filename, char *cgiargs)
{
    char *ptr;
    if (!strstr(uri, "cgi-bin")) { /* static content */
        strcpy(cgiargs, "");
        strcpy(filename, ".");
        strcat(filename, uri);
        if (uri[strlen(uri)-1] == ’/’)
            strcat(filename, "home.html");
        return 1;
    }
    else { /* dynamic content */
        ptr = index(uri, ’?’);
        if (ptr) {
            strcpy(cgiargs, ptr+1);
            *ptr = ’\0’;
        } else
            strcpy(cgiargs, "");
        strcpy(filename, ".");
        strcat(filename, uri);
        return 0;
    }
}
```

```
void serve_static(int fd, char *filename, int filesize)
{
    int srcfd;
    char *srcp, ftype[MAXLINE], buf[MAXBUF];
    /* send response headers to client */
    get_filetype(filename, ftype);
    sprintf(buf, "HTTP/1.0 200 OK\r\n");
    sprintf(buf, "%sServer: Tiny Web Server\r\n", buf);
    sprintf(buf, "%sConnection: close\r\n", buf);
    sprintf(buf, "%sContent-length: %d\n", buf, filesize);
    sprintf(buf, "%sContent-type: %s\r\n\r\n", buf, ftype);
    Rio_writen(fd, buf, strlen(buf));
    printf(“Response headers:\n”);
    printf(“%s”, buf);
    /* send response body to client */
    srcfd = Open(filename, O_RDONLY, 0);
    srcp = Mmap(0,filesize,PROT_READ,MAP_PRIVATE,srcfd,0);
    Close(srcfd);
    Rio_writen(fd, srcp, filesize);
    Munmap(srcp, filesize);
}


/*
* get_filetype - derive file type from file name
*/
void get_filetype(char *filename, char *filetype)
{
    if (strstr(filename, ".html"))
        strcpy(filetype, "text/html");
    else if (strstr(filename, ".gif"))
        strcpy(filetype, "image/gif");
    else if (strstr(filename, ".png"))
        strcpy(filetype, "image/png");
    else if (strstr(filename, ".jpg"))
        strcpy(filetype, "image/jpg");
    else
        strcpy(filetype, "text/plain");
}
```

```c
void serve_dynamic(int fd, char *filename, char *cgiargs)
{
    char buf[MAXLINE];
    /* return first part of HTTP response */
    sprintf(buf, "HTTP/1.0 200 OK\r\n");
    Rio_writen(fd, buf, strlen(buf));
    sprintf(buf, "Server: Tiny Web Server\r\n\r\n");
    Rio_writen(fd, buf, strlen(buf));
    if (Fork() == 0) { /* child */
        /* real server would set all CGI vars here */
        setenv("QUERY_STRING", cgiargs, 1);
        Dup2(fd, STDOUT_FILENO); /* redirect output to client*/
        Execve(filename, NULL, environ); /* run CGI program */
    }
    Wait(NULL); /* parent reaps child */
}
```