Network Programming: Part II

15-213: Introduction to Computer Systems
“22nd” Lecture, July 19, 2018

Instructor:
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Client

- socket
- inet_pton
- connect
- rio_readlineb
- rio_writen
- close

Server

- socket
- bind
- listen
- accept
- inet_ntop
- rio_readlineb
- rio_writen
- close

Connection request

Client / Server Session

Await connection request from next client
**Client**

- socket
- inet_pton
- connect
- close

**Server**

- socket
- bind
- listen
- accept
- close

**Client / Server Session**

1. **Client**
   - `socket`
   - `inet_pton`
   - `connect`
   - `rio_readlineb`
   - `rio_writen`
   - `close`

2. **Server**
   - `socket`
   - `bind`
   - `listen`
   - `accept`
   - `inet_ntop`
   - `rio_readlineb`
   - `close`

**Await connection request from next client**
**Sockets Interface**

**Client**
- `socket`
- `inet_pton`
- `connect`
- `rio_readlineb`
- `rio_writen`
- `close`

**Server**
- `socket`
- `bind`
- `listen`
- `accept`
- `inet_ntop`
- `close`

---

Connection request from next client

---

**Client / Server Session**

Bryant and O'Hallaron, Computer Systems: A Programmer's Perspective, Third Edition
Sockets Interface

Client

socket

inet_pton

connect

Connection request

Socket

inet_ntop

rio_readlineb

rio_writen

close

Server

socket

bind

listen

connect

accept

Await connection request from next client

Client / Server Session

Await connection request from next client

Bryant and O'Hallaron, Computer Systems: A Programmer's Perspective, Third Edition
Sockets Interface

**Client**

- `socket`
- `inet_pton`
- `connect`
- `rio_readlineb`
- `rio_written`
- `close`

**Server**

- `socket`
- `bind`
- `listen`
- `accept`
- `inet_ntop`
- `rio_readlineb`
- `rio_written`
- `close`

**Connection Request**

- `Await connection request from next client`
Sockets Interface

Client

- socket
  - inet_pton
  - connect
  - rio_readlineb
  - rio_written
  - close

Server

- socket
  - bind
  - listen
  - accept
  - rio_readlineb
  - inet_ntop
  - rio_written
  - close

Connection request from next client
**Sockets Interface**

**Client**
- `socket`
- `inet_pton`
- `connect`
- `rio_readlineb`
- `rio_write`
- `close`

**Server**
- `socket`
- `bind`
- `listen`
- `accept`
- `inet_ntop`
- ` rio_readlineb`
- `close`

Connection request from next client.
Client / Server Session

1. Start server
   - Server
   - socket
   - bind
   - listen
   - accept

2. Start client
   - Client
   - socket
   - inet_pton
   - connect

3. Exchange data
   - Await connection request from next client
   - rio_readlineb
   - inet_ntop
   - rio_readlineb
   - rio_writen
   - rio_readlineb

4. Disconnect client
   - close

5. Drop client
   - close

Connection request
Internet Domain Names

Top-level domain names (TLDs)

Second-level domain names

Third-level domain names

\[\text{unnamed root}\]

\[.\text{net} \quad .\text{edu} \quad .\text{gov} \quad .\text{com}\]

\[\text{mit} \quad \text{cmu} \quad \text{berkeley} \quad \text{amazon}\]

\[\text{cs} \quad \text{ece} \quad \text{www}\]

\[\text{ics} \quad \text{pdl}\]

\[\text{whaleshark} \quad \text{www}\]

\[128.2.210.175 \quad 128.2.131.66 \quad 54.239.25.208\]
Domain Name System (DNS)

- The Internet maintains a mapping between IP addresses and domain names in a huge worldwide distributed database called DNS.

- Conceptually, programmers can view the DNS database as a collection of millions of host entries.
  - Each host entry defines the mapping between a set of domain names and IP addresses.
  - In a mathematical sense, a host entry is an equivalence class of domain names and IP addresses.
Properties of DNS Mappings

- Can explore properties of DNS mappings using `nslookup`
  - Output edited for brevity

- Each host has a locally defined domain name `localhost` which always maps to the *loopback address* `127.0.0.1`

  ```
  linux> nslookup localhost
  Address: 127.0.0.1
  ```

- Use `hostname` to determine real domain name of local host:

  ```
  linux> hostname
  whaleshark.ics.cs.cmu.edu
  ```
Properties of DNS Mappings (cont)

- Simple case: one-to-one mapping between domain name and IP address:

  ```
  linux> nslookup whaleshark.ics.cs.cmu.edu
  Address: 128.2.210.175
  ```

- Multiple domain names mapped to the same IP address:

  ```
  linux> nslookup cs.mit.edu
  Address: 18.62.1.6
  ```
  ```
  linux> nslookup eecs.mit.edu
  Address: 18.62.1.6
  ```
Properties of DNS Mappings (cont)

- Multiple domain names mapped to multiple IP addresses:

```
linux> nslookup www.twitter.com
Address: 104.244.42.65
Address: 104.244.42.129
Address: 104.244.42.193
Address: 104.244.42.1
```

```
linux> nslookup www.twitter.com
Address: 104.244.42.129
Address: 104.244.42.65
Address: 104.244.42.193
Address: 104.244.42.1
```

- Some valid domain names don’t map to any IP address:

```
linux> nslookup ics.cs.cmu.edu
*** Can't find ics.cs.cmu.edu: No answer
```
Sockets Interface

Client

socket

inet_pton

connect

Server

socket

bind

listen

accept

Connection request

Await connection request from next client

Client / Server Session

rio_readlineb

rio_written

close

inet_ntop

rio_readlineb

close

close
Sockets Interface

Client

- `socket`
- `getaddrinfo`
- `connect`
- `rio_readlineb`
- `rio_written`
- `close`

Server

- `socket`
- `bind`
- `listen`
- `accept`
- `inet_ntop`
- `rio_readlineb`
- `rio_written`
- `close`

Connection request: `listen` to incoming connections, `accept` the connection, `connect` to the server, `rio_readlineb` to read data, `rio_written` to write data, `close` to terminate the connection.

Await connection request from next client.
Given host and service, `getaddrinfo` returns result that points to a linked list of `addrinfo` structs, each of which points to a corresponding socket address struct, and which contains arguments for the sockets interface functions.

**Helper functions:**
- `freeaddrinfo` frees the entire linked list.
- `gai_strerror` converts error code to an error message.
Linked List Returned by getaddrinfo

Clients: walk this list, trying each socket address in turn, until the calls to socket and connect succeed.

Servers: walk the list until calls to socket and bind succeed.
Client

socket

getaddrinfo

connect

Server

socket

bind

listen

accept

Connection request

Client / Server Session

rio_readlineb

rio_writen

close

inet_ntop

rio_readlineb

close

close

Await connection request from next client
Client

- socket
- getaddrinfo
- connect

Server

- socket
- bind
- listen
- accept

CS:APP Helpers

Open_clientfd

- Open_listenfd

Client / Server Session

- rio_readlineb
- rio_writen
- close

Await connection request from next client
CS:APP Helpers

Client

open_clientfd

Connection request

rio_readlineb

rio_written

close

Server

open_listenfd

accept

inet_ntop

rio_readlineb

close

close

close

Await connection request from next client
Web Server Basics

- Clients and servers communicate using the HyperText Transfer Protocol (HTTP)
  - Client and server establish TCP connection
  - Client requests content
  - Server responds with requested content
  - Client and server close connection (eventually)

- Current version is HTTP/1.1
  - RFC 2616, June, 1999.

http://www.w3.org/Protocols/rfc2616/rfc2616.html
Web Content

- Web servers return content to clients
  - content: a sequence of bytes with an associated MIME (Multipurpose Internet Mail Extensions) type

- Example MIME types
  - text/html: HTML document
  - text/plain: Unformatted text
  - image/gif: Binary image encoded in GIF format
  - image/png: Binary image encoded in PNG format
  - image/jpeg: Binary image encoded in JPEG format

You can find the complete list of MIME types at:
http://www.iana.org/assignments/media-types/media-types.xhtml
Static and Dynamic Content

The content returned in HTTP responses can be either static or dynamic:

- **Static content**: content stored in files and retrieved in response to an HTTP request
  - Examples: HTML files, images, audio clips
  - Request identifies which content file

- **Dynamic content**: content produced on-the-fly in response to an HTTP request
  - Example: content produced by a program executed by the server on behalf of the client
  - Request identifies file containing executable code

**Bottom line:** Web content is associated with a file that is managed by the server
URLs and how clients and servers use them

- **Unique name for a file: URL (Universal Resource Locator)**
- **Example URL:** `http://www.cmu.edu:80/index.html`
- **Clients use prefix** (`http://www.cmu.edu:80`) to infer:
  - What kind (protocol) of server to contact (HTTP)
  - Where the server is (`www.cmu.edu`)
  - What port it is listening on (80)

- **Servers use suffix** (`/index.html`) to:
  - Determine if request is for static or dynamic content.
    - No hard and fast rules for this
    - One convention: executables reside in `cgi-bin` directory
  - Find file on file system
    - Initial “/” in suffix denotes home directory for requested content.
    - Minimal suffix is “/”, which server expands to configured default filename (usually, `index.html`)
HTTP Requests

- HTTP request is a *request line*, followed by zero or more *request headers*

### Request line: `<method> <uri> <version>`
- `<method>` is one of GET, POST, OPTIONS, HEAD, PUT, DELETE, or TRACE
- `<uri>` is typically URL for proxies, URL suffix for servers
  - A URL is a type of URI (Uniform Resource Identifier)
- `<version>` is HTTP version of request (HTTP/1.0 or HTTP/1.1)

### Request headers: `<header name>: <header data>`
- Provide additional information to the server
HTTP Responses

- HTTP response is a *response line* followed by zero or more *response headers*, possibly followed by *content*, with blank line ("\r\n") separating headers from content.

- Response line:

  `<version>  <status code>  <status msg>`
  - `<version>` is HTTP version of the response
  - `<status code>` is numeric status
  - `<status msg>` is corresponding English text

  - **200  OK** Request was handled without error
  - **301  Moved** Provide alternate URL
  - **404  Not found** Server couldn’t find the file

- Response headers: `<header name>`: `<header data>`
  - Provide additional information about response
  - **Content-Type**: MIME type of content in response body
  - **Content-Length**: Length of content in response body
Aside: Testing Servers Using `telnet`

- The `telnet` program is invaluable for testing servers that transmit ASCII strings over Internet connections
  - Our simple echo server
  - Web servers
  - Mail servers

- **Usage:**
  - `linux> telnet <host> <portnumber>`
  - Creates a connection with a server running on `<host>` and listening on port `<portnumber>`
Example HTTP Transaction

whaleshark> telnet www.cmu.edu 80
Trying 128.2.42.52...
Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.
Escape character is '^[']'.
GET / HTTP/1.1
Host: www.cmu.edu

HTTP/1.1 301 Moved Permanently
Date: Wed, 05 Nov 2014 17:05:11 GMT
Server: Apache/1.3.42 (Unix)
Location: http://www.cmu.edu/index.shtml
Transfer-Encoding: chunked
Content-Type: text/html; charset=... 

15c
<HTML><HEAD>
...
</BODY></HTML>
0
Connection closed by foreign host.

- HTTP standard requires that each text line end with “\r\n”
- Blank line (“\r\n”) terminates request and response headers
Example HTTP Transaction, Take 2

whaleshark> telnet www.cmu.edu 80
Trying 128.2.42.52...
Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.
Escape character is '^]'.
GET /index.shtml HTTP/1.1
Host: www.cmu.edu

HTTP/1.1 200 OK
Date: Wed, 05 Nov 2014 17:37:26 GMT
Server: Apache/1.3.42 (Unix)
Transfer-Encoding: chunked
Content-Type: text/html; charset=...  
1000
<html ..>
...
</html>
0
Connection closed by foreign host.
Tiny Web Server

- Tiny Web server described in text
  - Tiny is a sequential Web server
  - Serves static and dynamic content to real browsers
    - text files, HTML files, GIF, PNG, and JPEG images
  - 239 lines of commented C code
  - Not as complete or robust as a real Web server
    - You can break it with poorly-formed HTTP requests (e.g., terminate lines with “\n” instead of “\r\n”)

Tiny Operation

- Accept connection from client
- Read request from client (via connected socket)
- Split into `<method>  <uri> <version>`
  - If method not GET, then return error
- If URI contains “cgi-bin” then serve dynamic content
  - (Would do wrong thing if had file “abcgi-bingo.html”)
  - Fork process to execute program
- Otherwise serve static content
  - Copy file to output
void serve_static(int fd, char *filename, int filesize)
{
    int srcfd;
    char *srcp, filetype[MAXLINE], buf[MAXBUF];

    /* Send response headers to client */
    get_filetype(filename, filetype);
    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\r\n", buf, filesize);
    sprintf(buf, "%sContent-type: %s\r\n\r\n", buf, filetype);
    Rio_writen(fd, buf, strlen(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);
}
Additional slides
Review: C Standard I/O, Unix I/O and RIO

- Robust I/O (RIO): 15-213 special wrappers
  - good coding practice: handles error checking, signals, and “short counts”
Socket Address Structures & getaddrinfo

- **Generic socket address:**
  - For address arguments to `connect`, `bind`, and `accept`
  - Necessary only because C did not have generic (`void *`) pointers when the sockets interface was designed
  - For casting convenience, we adopt the Stevens convention:
    ```c
    typedef struct sockaddr SA;
    ```

    ```c
    struct sockaddr {
    uint16_t sa_family;   /* Protocol family */
    char sa_data[14];     /* Address data. */
    };
    ```

- **getaddrinfo** converts string representations of hostnames, host addresses, ports, service names to socket address structures
Socket Address Structures

- Internet (IPv4) specific socket address:
  - Must cast `(struct sockaddr_in *)` to `(struct sockaddr *)` for functions that take socket address arguments.

```c
struct sockaddr_in {
    uint16_t sin_family; /* Protocol family (always AF_INET) */
    uint16_t sin_port;  /* Port num in network byte order */
    struct in_addr sin_addr; /* IP addr in network byte order */
    unsigned char sin_zero[8]; /* Pad to sizeof(struct sockaddr) */
};
```

<table>
<thead>
<tr>
<th>sin_port</th>
<th>sin_addr</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

**Family Specific**

Bryant and O'Hallaron, Computer Systems: A Programmer's Perspective, Third Edition
Sockets Interface: socket

- Clients and servers use the `socket` function to create a socket descriptor:

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

- Example:

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

  - Indicates that we are using 32-bit IPV4 addresses
  - Indicates that the socket will be the end point of a connection

Protocol specific! Best practice is to use `getaddrinfo` to generate the parameters automatically, so that code is protocol independent.
Sockets Interface: \texttt{bind}

- A server uses \texttt{bind} to ask the kernel to associate the
server’s socket address with a socket descriptor:

\begin{verbatim}
int bind(int sockfd, SA *addr, socklen_t addrlen);
\end{verbatim}

Recall: typedef struct sockaddr SA;

- Process can read bytes that arrive on the connection whose
endpoint is \texttt{addr} by reading from descriptor \texttt{sockfd}

- Similarly, writes to \texttt{sockfd} are transferred along
connection whose endpoint is \texttt{addr}

Best practice is to use \texttt{getaddrinfo} to supply the arguments
\texttt{addr} and \texttt{addrlen}. 
Sockets Interface: \texttt{listen}

- By default, kernel assumes that descriptor from socket function is an \textit{active socket} that will be on the client end of a connection.

- A server calls the \texttt{listen} function to tell the kernel that a descriptor will be used by a server rather than a client:

  \begin{verbatim}
  int listen(int sockfd, int backlog);
  \end{verbatim}

- Converts \texttt{sockfd} from an active socket to a \textit{listening socket} that can accept connection requests from clients.

- \texttt{backlog} is a hint about the number of outstanding connection requests that the kernel should queue up before starting to refuse requests.
Sockets Interface: accept

- Servers wait for connection requests from clients by calling `accept`:
  
  ```c
  int accept(int listenfd, SA *addr, int *addrlen);
  ```

- Waits for connection request to arrive on the connection bound to `listenfd`, then fills in client’s socket address in `addr` and size of the socket address in `addrlen`.

- Returns a *connected descriptor* that can be used to communicate with the client via Unix I/O routines.
Sockets Interface: `connect`

- A client establishes a connection with a server by calling `connect`:
  ```c
  int connect(int clientfd, SA *addr, socklen_t addrlen);
  ```
- Attempts to establish a connection with server at socket address `addr`
  - If successful, then `clientfd` is now ready for reading and writing.
  - Resulting connection is characterized by socket pair
    `(x:y, addr.sin_addr:addr.sin_port)`
    - `x` is client address
    - `y` is ephemeral port that uniquely identifies client process on client host

Best practice is to use `getaddrinfo` to supply the arguments `addr` and `addrlen`.
accept Illustrated

1. Server blocks in accept, waiting for connection request on listening descriptor `listenfd`

2. Client makes connection request by calling and blocking in `connect`

3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`
Connected vs. Listening Descriptors

- **Listening descriptor**
  - End point for client connection requests
  - Created once and exists for lifetime of the server

- **Connected descriptor**
  - End point of the connection between client and server
  - A new descriptor is created each time the server accepts a connection request from a client
  - Exists only as long as it takes to service client

- **Why the distinction?**
  - Allows for concurrent servers that can communicate over many client connections simultaneously
    - E.g., Each time we receive a new request, we fork a child to handle the request
Sockets Helper: open_clientfd

- Establish a connection with a server

```c
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; /* ...using numeric port arg. */
    hints.ai_flags |= AI_ADDRCONFIG; /* Recommended for connections */
    Getaddrinfo(hostname, port, &hints, &listp);
}
```
Clients: walk this list, trying each socket address in turn, until the calls to socket and connect succeed.

Servers: walk the list until calls to socket and bind succeed.
/* 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;
}
Sockets Helper: open_listenfd

- Create a listening descriptor that can be used to accept connection requests from clients.

```c
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 connect. */
    hints.ai_flags = AI_PASSIVE | AI_ADDRCONFIG; /* ...on any IP addr */
    hints.ai_flags |= AI_NUMERICSERV; /* ...using port no. */
    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 conn. requests */
if (listen(listenfd, LISTENQ) < 0) {
    Close(listenfd);
    return -1;
}
return listenfd;

Key point: open_clientfd and open_listenfd are both independent of any particular version of IP.
Testing the Echo Server With `telnet`

whaleshark> ./echoserveri 15213  
Connected to (MAKOSHARK.ICS.CS.CMU.EDU, 50280)  
server received 11 bytes  
server received 8 bytes

makoshark> telnet whaleshark.ics.cs.cmu.edu 15213  
Trying 128.2.210.175...  
Escape character is '^[]'.  
Hi there!  
Hi there!  
Howdy!  
Howdy!  
^[]  
telnet> quit  
Connection closed.  
makoshark>
Serving Dynamic Content

- Client sends request to server

- If request URI contains the string `/cgi-bin`, the Tiny server assumes that the request is for dynamic content

GET /cgi-bin/env.pl HTTP/1.1
The server creates a child process and runs the program identified by the URI in that process.
Serving Dynamic Content (cont)

- The child runs and generates the dynamic content

- The server captures the content of the child and forwards it without modification to the client
Issues in Serving Dynamic Content

- How does the client pass program arguments to the server?
- How does the server pass these arguments to the child?
- How does the server pass other info relevant to the request to the child?
- How does the server capture the content produced by the child?
- These issues are addressed by the **Common Gateway Interface (CGI)** specification.
Because the children are written according to the CGI spec, they are often called *CGI programs*.

However, CGI really defines a simple standard for transferring information between the client (browser), the server, and the child process.

CGI is the original standard for generating dynamic content. Has been largely replaced by other, faster techniques:

- E.g., fastCGI, Apache modules, Java servlets, Rails controllers
- Avoid having to create process on the fly (expensive and slow).
The add.com Experience

Welcome to add.com: THE Internet addition portal.

The answer is: 15213 + 18213 = 33426

Thanks for visiting!
Serving Dynamic Content With GET

- **Question:** How does the client pass arguments to the server?
- **Answer:** The arguments are appended to the URI

- Can be encoded directly in a URL typed to a browser or a URL in an HTML link
  - `http://add.com/cgi-bin/adder?15213&18213`
  - **adder** is the CGI program on the server that will do the addition.
  - argument list starts with “?”
  - arguments separated by “&”
  - spaces represented by “+” or “%20”
Serving Dynamic Content With GET

- URL suffix:
  - cgi-bin/adder?15213&18213

- Result displayed on browser:

```
Welcome to add.com: THE Internet addition portal.

The answer is: 15213 + 18213 = 33426

Thanks for visiting!
```
**Serving Dynamic Content With GET**

- **Question**: How does the server pass these arguments to the child?

- **Answer**: In environment variable QUERY_STRING
  - A single string containing everything after the “?”
  - For add: `QUERY_STRING = “15213&18213”`

```c
/* Extract the two arguments */
if ((buf = getenv("QUERY_STRING")) != NULL) {
    p = strchr(buf, '&');
    *p = '\0';
    strcpy(arg1, buf);
    strcpy(arg2, p+1);
    n1 = atoi(arg1);
    n2 = atoi(arg2);
}
```
Serving Dynamic Content with GET

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

Answer: The child generates its output on stdout. Server uses dup2 to redirect stdout to its connected socket.

```c
void serve_dynamic(int fd, char *filename, char *cgiargs)
{
    char buf[MAXLINE], *emptylist[] = { NULL };

    /* 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");
    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 stdout to client */
        Execve(filename, emptylist, environ); /* Run CGI program */
    }

    Wait(NULL); /* Parent waits for and reaps child */
} tiny.c
```
Serving Dynamic Content with GET

Notice that only the CGI child process knows the content type and length, so it must generate those headers.

```c
/* Make the response body */
sprintf(content, "Welcome to add.com: ");
sprintf(content, "%sTHE Internet addition portal.\r\n<p>", content);
sprintf(content, "%sThe answer is: %d + %d = %d\r\n<p>",
        content, n1, n2, n1 + n2);
sprintf(content, "%sThanks for visiting!\r\n", content);

/* Generate the HTTP response */
printf("Content-length: %d\r\n", (int)strlen(content));
printf("Content-type: text/html\r\n\r\n"); printf("%s", content);
fflush(stdout);
exit(0);
```
bash:makoshark> telnet whaleshark.ics.cs.cmu.edu 15213
Trying 128.2.210.175...
Escape character is '\]'.
GET /cgi-bin/adder?15213&18213 HTTP/1.0

HTTP/1.0 200 OK
Server: Tiny Web Server
Connection: close
Content-length: 117
Content-type: text/html

Welcome to add.com: THE Internet addition portal.
<p>The answer is: 15213 + 18213 = 33426
<p>Thanks for visiting!
Connection closed by foreign host.
bash:makoshark>
For More Information

  - THE network programming bible.
  - THE Linux programming bible.
- Complete versions of all code in this lecture is available from the 213 schedule page.
  - [http://www.cs.cmu.edu/~213/schedule.html](http://www.cs.cmu.edu/~213/schedule.html)
  - csapp.{.c,.h}, hostinfo.c, echoclient.c, echoserveri.c, tiny.c, adder.c
  - You can use any of this code in your assignments.
Web History

- **1989:**
  - Tim Berners-Lee (CERN) writes internal proposal to develop a distributed hypertext system
    - Connects “a web of notes with links”
    - Intended to help CERN physicists in large projects share and manage information

- **1990:**
  - Tim BL writes a graphical browser for Next machines
Web History (cont)

- **1992**
  - NCSA server released
  - 26 WWW servers worldwide

- **1993**
  - Marc Andreessen releases first version of NCSA Mosaic browser
  - Mosaic version released for (Windows, Mac, Unix)
  - Web (port 80) traffic at 1% of NSFNET backbone traffic
  - Over 200 WWW servers worldwide

- **1994**
  - Andreessen and colleagues leave NCSA to form “Mosaic Communications Corp” (predecessor to Netscape)
HTTP Versions

Major differences between HTTP/1.1 and HTTP/1.0

- HTTP/1.0 uses a new connection for each transaction
- HTTP/1.1 also supports *persistent connections*
  - multiple transactions over the same connection
  - `Connection: Keep-Alive`
- HTTP/1.1 requires HOST header
  - `Host: www.cmu.edu`
  - Makes it possible to host multiple websites at single Internet host
- HTTP/1.1 supports *chunked encoding*
  - `Transfer-Encoding: chunked`
- HTTP/1.1 adds additional support for caching
GET Request to Apache Server
From Firefox Browser

URI is just the suffix, not the entire URL

GET /~bryant/test.html HTTP/1.1
Host: www.cs.cmu.edu
User-Agent: Mozilla/5.0 (Windows; U; Windows NT 6.0; en-US; rv:1.9.2.11) Gecko/20101012 Firefox/3.6.11
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,/*;q=0.8
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 115
Connection: keep-alive
CRLF (\r\n)
**GET Response From Apache Server**

HTTP/1.1 200 OK
Date: Fri, 29 Oct 2010 19:48:32 GMT
Server: Apache/2.2.14 (Unix) mod_ssl/2.2.14 OpenSSL/0.9.7m mod_pubcookie/3.3.2b PHP/5.3.1
Accept-Ranges: bytes
Content-Length: 479
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
Content-Type: text/html

<html>
<head><title>Some Tests</title></head>

<body>
<h1>Some Tests</h1>
...
</body>
</html>
Data Transfer Mechanisms

- **Standard**
  - Specify total length with content-length
  - Requires that program buffer entire message

- **Chunked**
  - Break into blocks
  - Prefix each block with number of bytes (Hex coded)
Chunked Encoding Example

HTTP/1.1 200 OK
Date: Sun, 31 Oct 2010 20:47:48 GMT
Server: Apache/1.3.41 (Unix)
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
Transfer-Encoding: chunked
Content-Type: text/html

\r\n\r\nd75\r\n<html>
<head>
<link href="http://www.cs.cmu.edu/style/calendar.css" rel="stylesheet" type="text/css">
</head>
<body id="calendar_body">

<div id='calendar'><table width='100%' border='0' cellpadding='0' cellspacing='1' id='cal'>
  ...
</body>
</html>
\r\n\r\n0\r\n\r
First Chunk: 0xd75 = 3445 bytes

Second Chunk: 0 bytes (indicates last chunk)
Proxies

- A **proxy** is an intermediary between a client and an **origin server**
  - To the client, the proxy acts like a server
  - To the server, the proxy acts like a client
Why Proxies?

- Can perform useful functions as requests and responses pass by
  - Examples: Caching, logging, anonymization, filtering, transcoding

![Diagram showing a client making a request for foo.html to a proxy cache, which then sends the response back to the client. The proxy cache is located between the client and the origin server, facilitating faster and more efficient network communication.]