

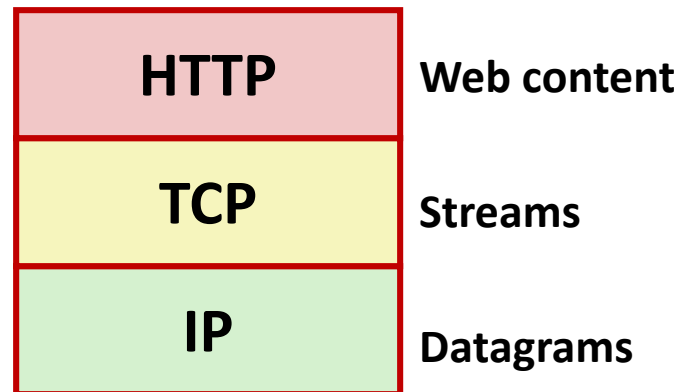
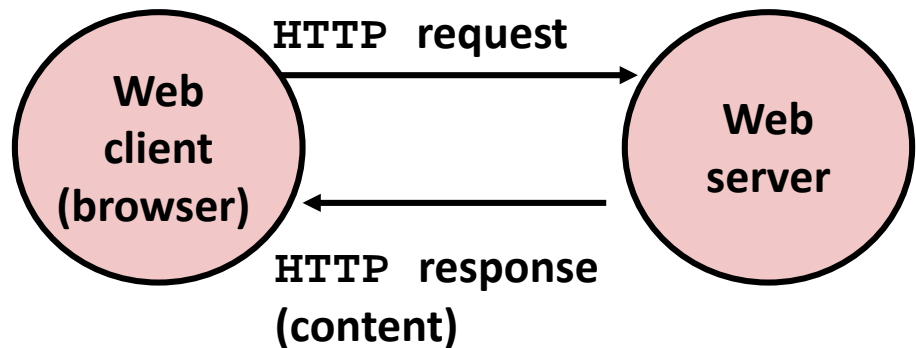
# Network Programming: Part II

**CS230 System Programming**  
**16<sup>th</sup> Lecture**

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# 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

- |                           |                                     |
|---------------------------|-------------------------------------|
| ■ <code>text/html</code>  | HTML document                       |
| ■ <code>text/plain</code> | Unformatted text                    |
| ■ <code>image/gif</code>  | Binary image encoded in GIF format  |
| ■ <code>image/png</code>  | Binary image encoded in PNG format  |
| ■ <code>image/jpeg</code> | 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)
    - See <http://www.ietf.org/rfc/rfc2396.txt>
  - `<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

# Example HTTP Transaction

whaleshark> telnet www.cmu.edu 80	Client: open connection to server
Trying 128.2.42.52...	Telnet prints 3 lines to terminal
Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.	
Escape character is '^['.	
GET / HTTP/1.1	Client: request line
Host: www.cmu.edu	Client: required HTTP/1.1 header
	Client: empty line terminates headers
HTTP/1.1 301 Moved Permanently	Server: response line
Date: Wed, 05 Nov 2014 17:05:11 GMT	Server: followed by 5 response headers
Server: Apache/1.3.42 (Unix)	Server: this is an Apache server
Location: http://www.cmu.edu/index.shtml	Server: page has moved here
Transfer-Encoding: chunked	Server: response body will be chunked
Content-Type: text/html; charset=...	Server: expect HTML in response body
	Server: empty line terminates headers
15c	Server: first line in response body
<HTML><HEAD>	Server: start of HTML content
...	
</BODY></HTML>	Server: end of HTML content
0	Server: last line in response body
Connection closed by foreign host.	Server: closes connection

- 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	Client: open connection to server
Trying 128.2.42.52...	Telnet prints 3 lines to terminal
Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.	
Escape character is '^['.	
GET /index.shtml HTTP/1.1	Client: request line
Host: www.cmu.edu	Client: required HTTP/1.1 header
	Client: empty line terminates headers
HTTP/1.1 200 OK	Server: response line
Date: Wed, 05 Nov 2014 17:37:26 GMT	Server: followed by 4 response headers
Server: Apache/1.3.42 (Unix)	
Transfer-Encoding: chunked	
Content-Type: text/html; charset=...	
	Server: empty line terminates headers
1000	Server: begin response body
<html ..>	Server: first line of HTML content
...	
</html>	
0	Server: end response body
Connection closed by foreign host.	Server: close connection

# 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

# Tiny Serving Static Content

```
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));

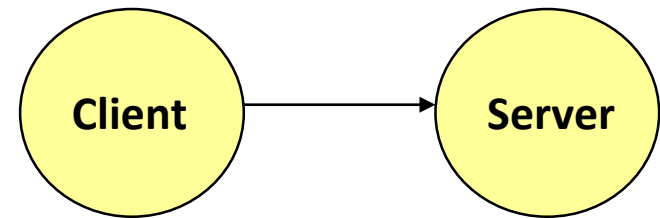
    /* Send response body to client */
    srcfd = Open(filename, O_RDONLY, 0);
    srcp = Mmap(0, filesize, PROT_READ, MAP_PRIVATE, srcfd, 0);
    Close(srcfd);
    Rio_writen(fd, srcp, filesize);
    Munmap(srcp, filesize);
}
```

tiny.c

# Serving Dynamic Content

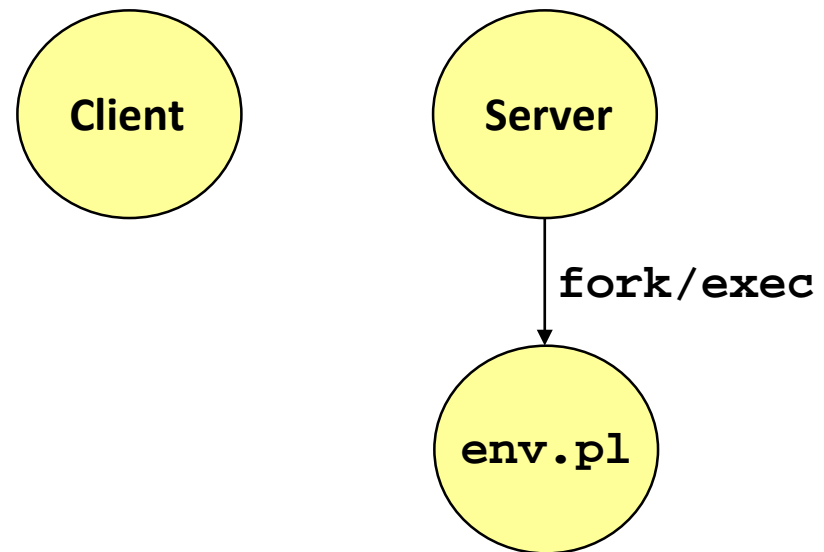
- Client sends request to server
- If request URI contains the string `/cgi-bin`, the Tiny server assumes that the request is for dynamic content

`GET /cgi-bin/env.pl HTTP/1.1`



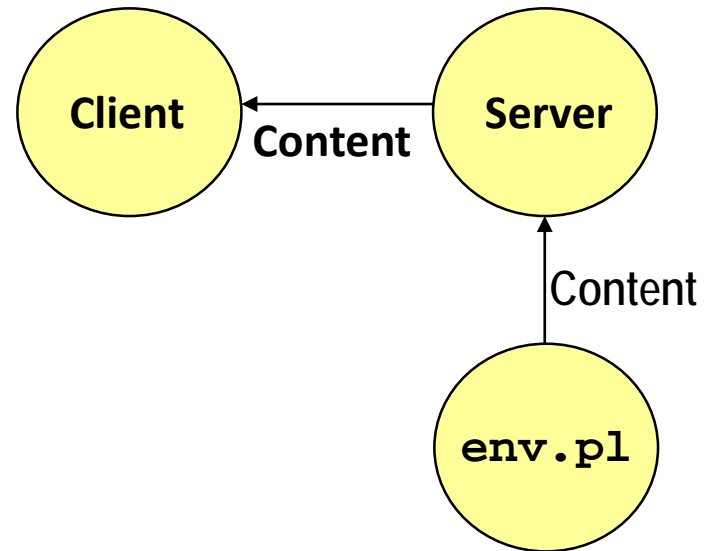
# Serving Dynamic Content (cont)

- The server creates a child process and runs the program identified by the URI in that process



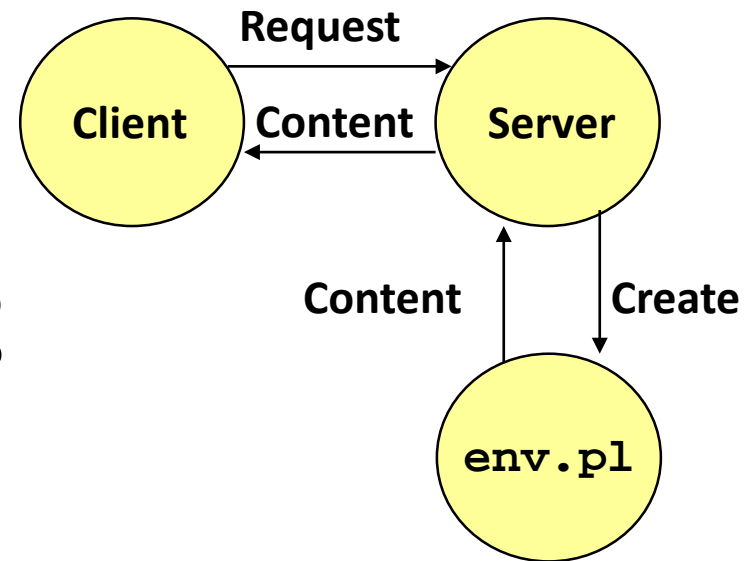
# Serving Dynamic Content (cont)

- 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.

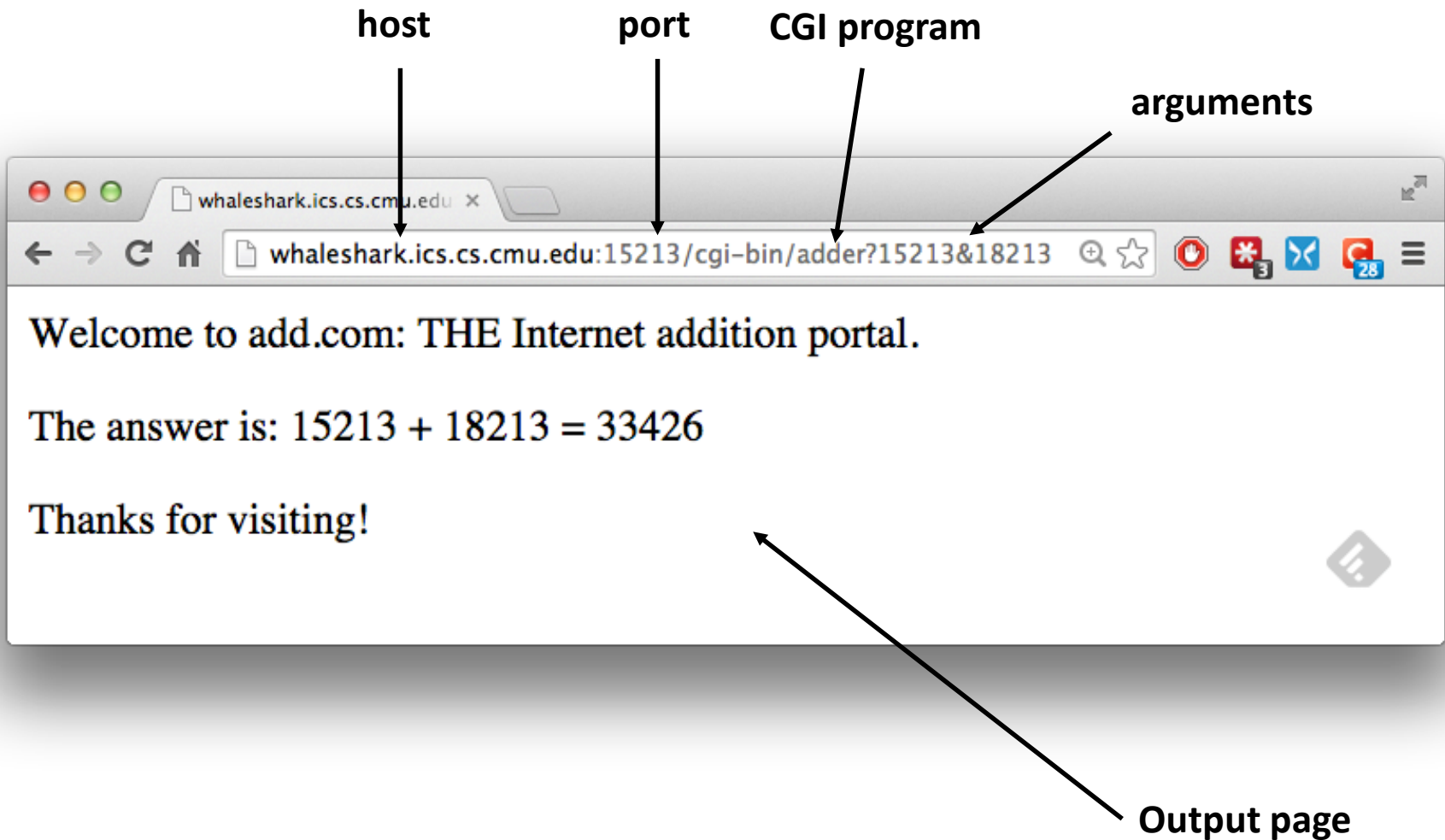




# CGI

- 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



# 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”

```
/* 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);  
}
```

adder.c

# 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.

```
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 */
}
```

# Serving Dynamic Content with GET

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

```
/* 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);
```

adder.c

# Serving Dynamic Content With GET

```
bash:makoshark> telnet whaleshark.ics.cs.cmu.edu 15213
Trying 128.2.210.175...
Connected to whaleshark.ics.cs.cmu.edu (128.2.210.175).
Escape character is '^]'.
GET /cgi-bin/adder?15213&18213 HTTP/1.0
```

*HTTP request sent by client*

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

*HTTP response generated  
by the server*

```
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>
```

*HTTP response generated  
by the CGI program*



# For More Information

- **W. Richard Stevens et. al. “Unix Network Programming: The Sockets Networking API”, Volume 1, Third Edition, Prentice Hall, 2003**
  - THE network programming bible.
- **Michael Kerrisk, “The Linux Programming Interface”, No Starch Press, 2010**
  - 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`
  - `csapp.{c,h}`, `hostinfo.c`, `echoclient.c`, `echoserveri.c`, `tiny.c`, `adder.c`
  - You can use any of this code in your assignments.

# Additional slides

# 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\n
Date: Sun, 31 Oct 2010 20:47:48 GMT\n
Server: Apache/1.3.41 (Unix)\n
Keep-Alive: timeout=15, max=100\n
Connection: Keep-Alive\n
Transfer-Encoding: chunked\n
Content-Type: text/html\n
\r\n
```

```
d75\r\n
```

**First Chunk: 0xd75 = 3445 bytes**

```
<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
```

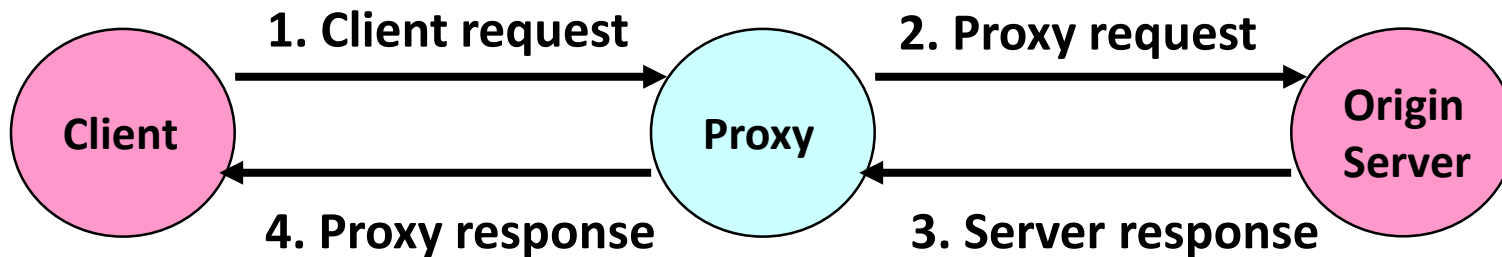
```
0\r\n
```

**Second Chunk: 0 bytes (indicates last chunk)**

```
\r\n
```

# 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

