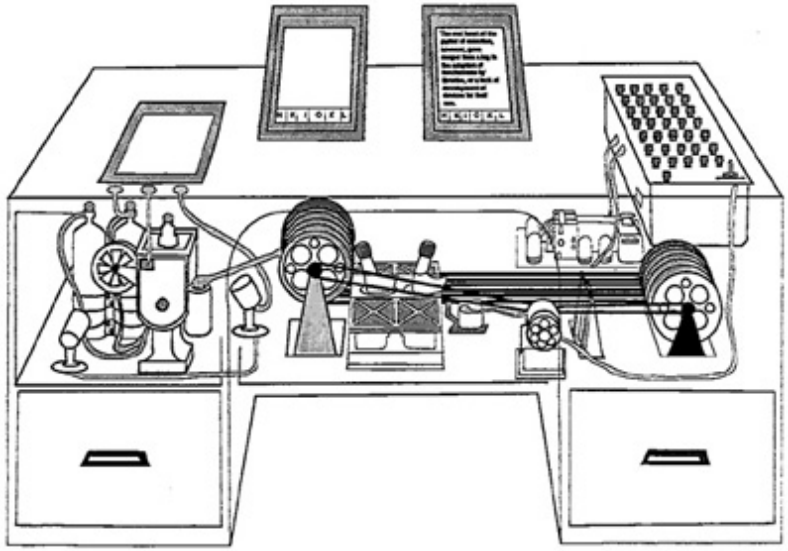
Web Services

15-213: Introduction to Computer Systems
21st Lecture, Nov. 4, 2010

Instructors:

Randy Bryant and Dave O'Hallaron

Web History



"Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and to coin one at random, "memex" will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory."

- **1945:**
  - Vannevar Bush, "As we may think", Atlantic Monthly, July, 1945.
    - Describes the idea of a distributed hypertext system.
    - A "memex" that mimics the "web of trails" in our minds.

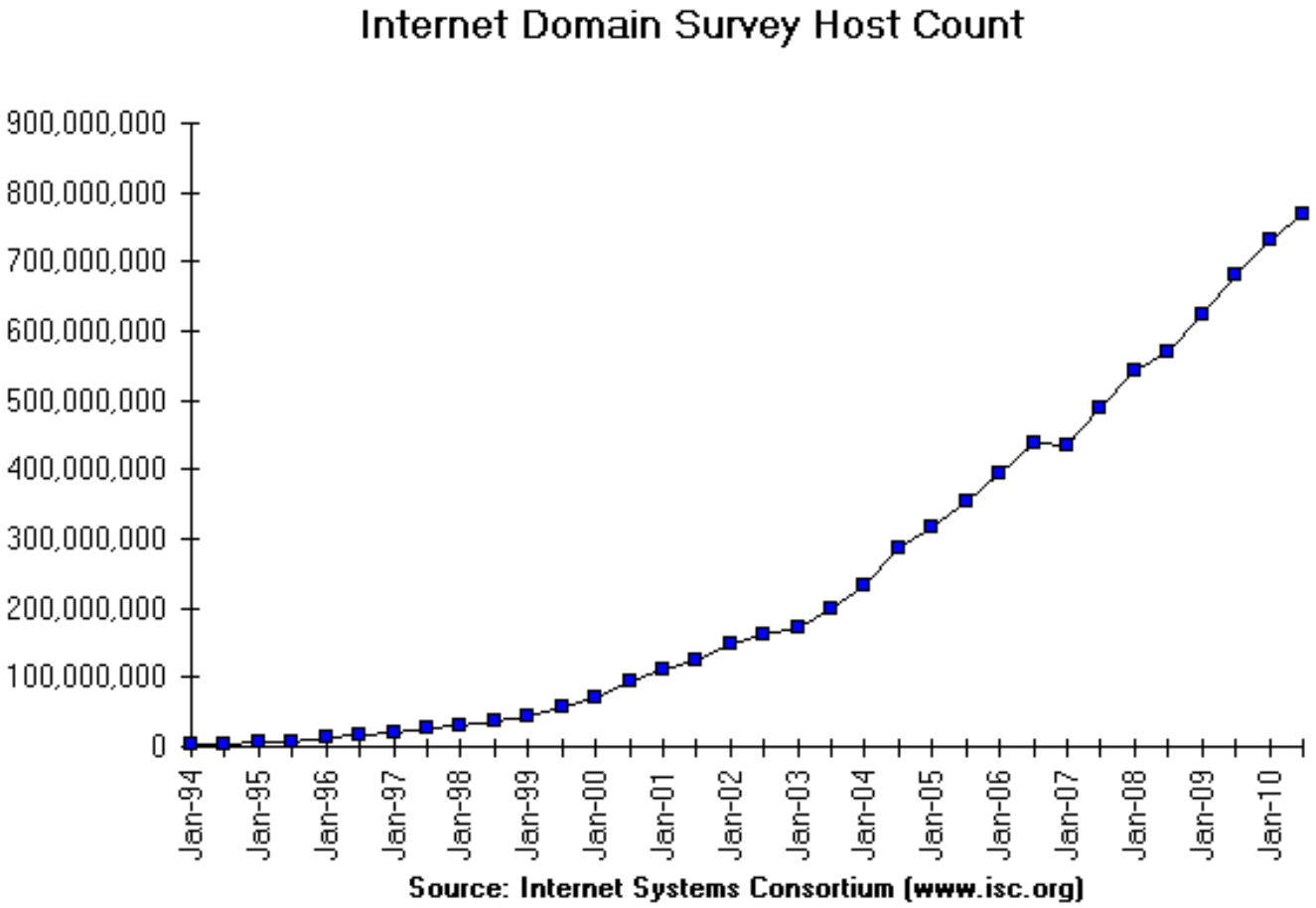
Web History

- **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).

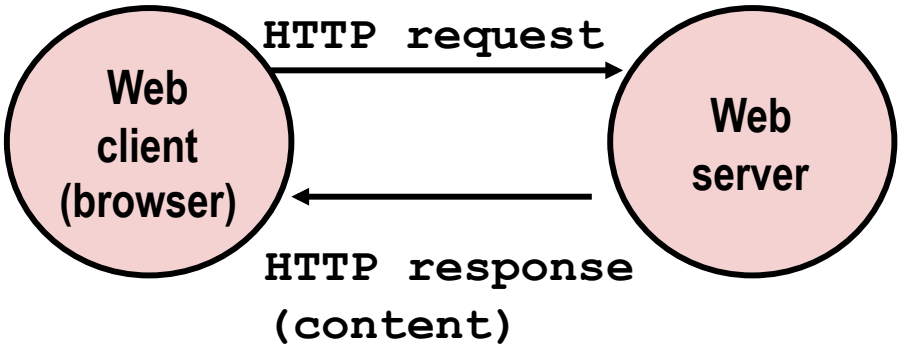
Internet Hosts

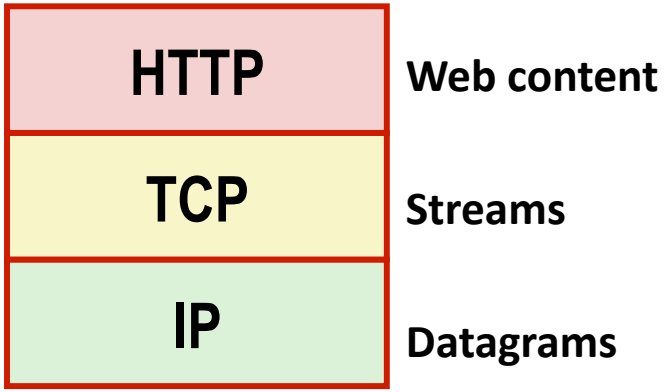


- How many of the 2^{32} IP addresses have registered domain names?

Web Servers

- **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
  - `application/postscript` Postcript document
  - `image/gif` Binary image encoded in GIF format
  - `image/jpeg` Binary image encoded in JPEG format

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 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: *All Web content is associated with a file that is managed by the server.***

URLs

- **Each file managed by a server has a unique name called a URL (Universal Resource Locator)**
- **URLs for static content:**
  - `http://www.cs.cmu.edu:80/index.html`
  - `http://www.cs.cmu.edu/index.html`
  - `http://www.cs.cmu.edu`
    - Identifies a file called `index.html`, managed by a Web server at `www.cs.cmu.edu` that is listening on port 80.
- **URLs for dynamic content:**
  - `http://www.cs.cmu.edu:8000/cgi-bin/proc?15000&213`
    - Identifies an executable file called `proc`, managed by a Web server at `www.cs.cmu.edu` that is listening on port 8000, that should be called with two argument strings: `15000` and `213`.

How Clients and Servers Use URLs

- **Example URL: `http://www.cmu.edu:80/index.html`**
- **Clients use *prefix* (`http://www.cmu.edu:80`) to infer:**
  - What kind of server to contact (Web server)
  - 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.
    - 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 all servers expand to some default home page (e.g., `index.html`).

Anatomy of an HTTP Transaction

```
unix> telnet www.cmu.edu 80
Trying 128.2.10.162...
Connected to www.cmu.edu.
Escape character is '^]'.
GET / HTTP/1.1
host: www.cmu.edu

HTTP/1.1 301 Moved Permanently
Location: http://www.cmu.edu/index.shtml

Connection closed by foreign host.
unix>
```

Client: open connection to server
Telnet prints 3 lines to the terminal

Client: request line
Client: required HTTP/1.1 HOST header
Client: empty line terminates headers .
Server: response line
Client should try again

Server: closes connection
Client: closes connection and terminates

Anatomy of an HTTP Transaction, Take 2

```
unix> telnet www.cmu.edu 80
Trying 128.2.10.162...
Connected to www.cmu.edu.
Escape character is '^]'.
GET /index.shtml HTTP/1.1
host: www.cmu.edu

HTTP/1.1 200 OK
Date: Fri, 29 Oct 2010 19:41:08 GMT
Server: Apache/1.3.39 (Unix) mod_pubcookie/3.3.3 ...
Transfer-Encoding: chunked
Content-Type: text/html
...
Connection closed by foreign host.
unix>
```

Client: open connection to server
Telnet prints 3 lines to the terminal

Client: request line
Client: required HTTP/1.1 HOST header
Client: empty line terminates headers .
Server: responds with web page

Lots of stuff
Server: closes connection
Client: closes connection and terminates

HTTP Requests

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

- **Request line: `<method> <uri> <version>`**
  - `<version>` is HTTP version of request (`HTTP/1.0` or `HTTP/1.1`)
  - `<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
  - `<method>` is either `GET`, `POST`, `OPTIONS`, `HEAD`, `PUT`, `DELETE`, or `TRACE`.

HTTP Requests (cont)

- **HTTP methods:**
  - `GET`: Retrieve static or dynamic content
    - Arguments for dynamic content are in URI
    - Workhorse method (99% of requests)
  - `POST`: Retrieve dynamic content
    - Arguments for dynamic content are in the request body
  - `OPTIONS`: Get server or file attributes
  - `HEAD`: Like `GET` but no data in response body
  - `PUT`: Write a file to the server!
  - `DELETE`: Delete a file on the server!
  - `TRACE`: Echo request in response body
    - Useful for debugging.
- **Request headers: `<header name>: <header data>`**
  - Provide additional information to the server.

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* (described later)
    - Transfer-Encoding: chunked
  - HTTP/1.1 adds additional support for caching

HTTP Responses

- **HTTP response is a *response line* followed by zero or more *response headers*.**
- **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
    - 403 Forbidden Server lacks permission to access file
    - 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.

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>
```

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 and JPEG images.
  - 226 lines of commented C code.
  - Not as complete or robust as a real web server

Tiny Operation

- **Read request from client**
- **Split into method / uri / version**
  - If 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

From `tiny.c`

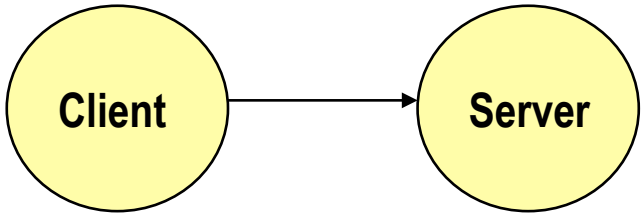
```
/* Send response headers to client */
    get_filetype(filename, filetype);
    sprintf(buf, "HTTP/1.0 200 OK\r\n");
    sprintf(buf, "%sServer: Tiny Web Server\r\n", buf);
    sprintf(buf, "%sContent-length: %d\r\n", buf, filesize);
    sprintf(buf, "%sContent-type: %s\r\n\r\n",
            buf, 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);
```

- Serve file specified by `filename`
- Use file metadata to compose header
- “Read” file via mmap
- Write to output

Serving Dynamic Content

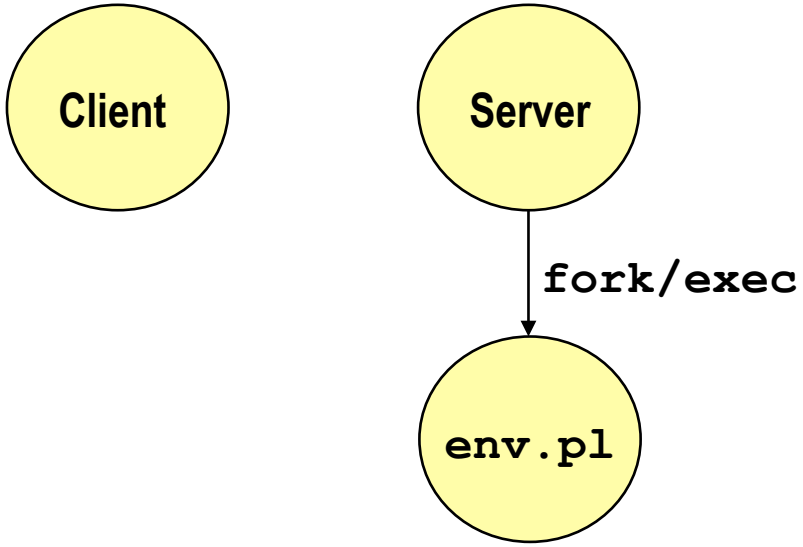
- Client sends request to server.
- If request URI contains the string "`/cgi-bin`", then the server assumes that the request is for dynamic content.

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



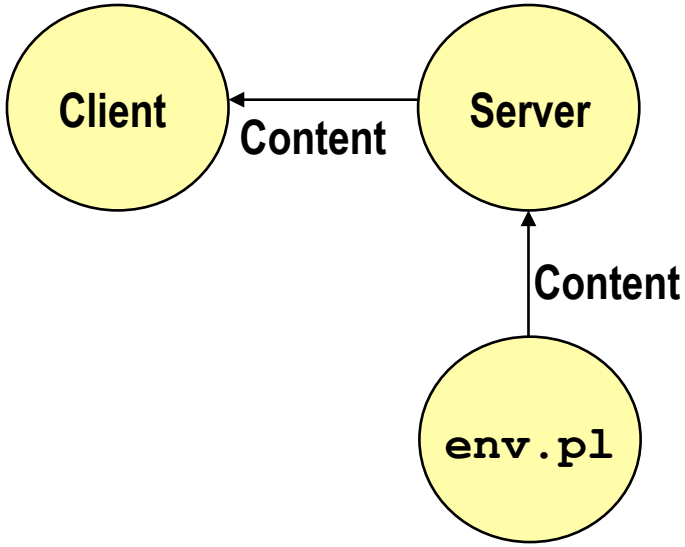
Serving Dynamic Content (cont)

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



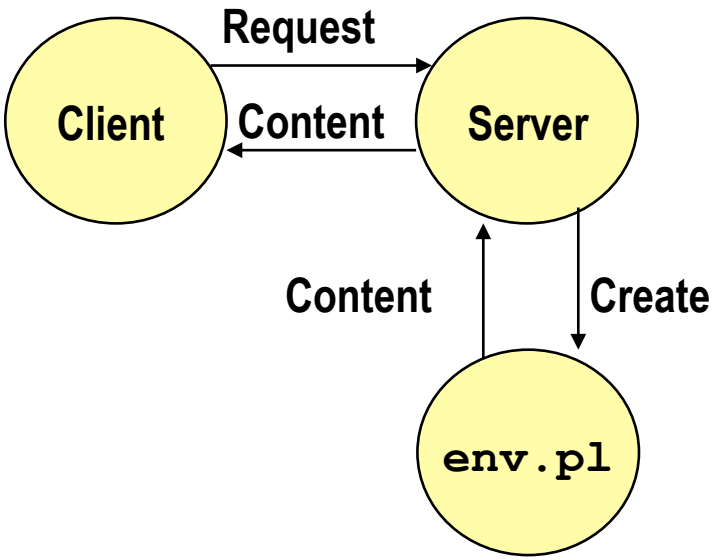
Serving Dynamic Content (cont)

- 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

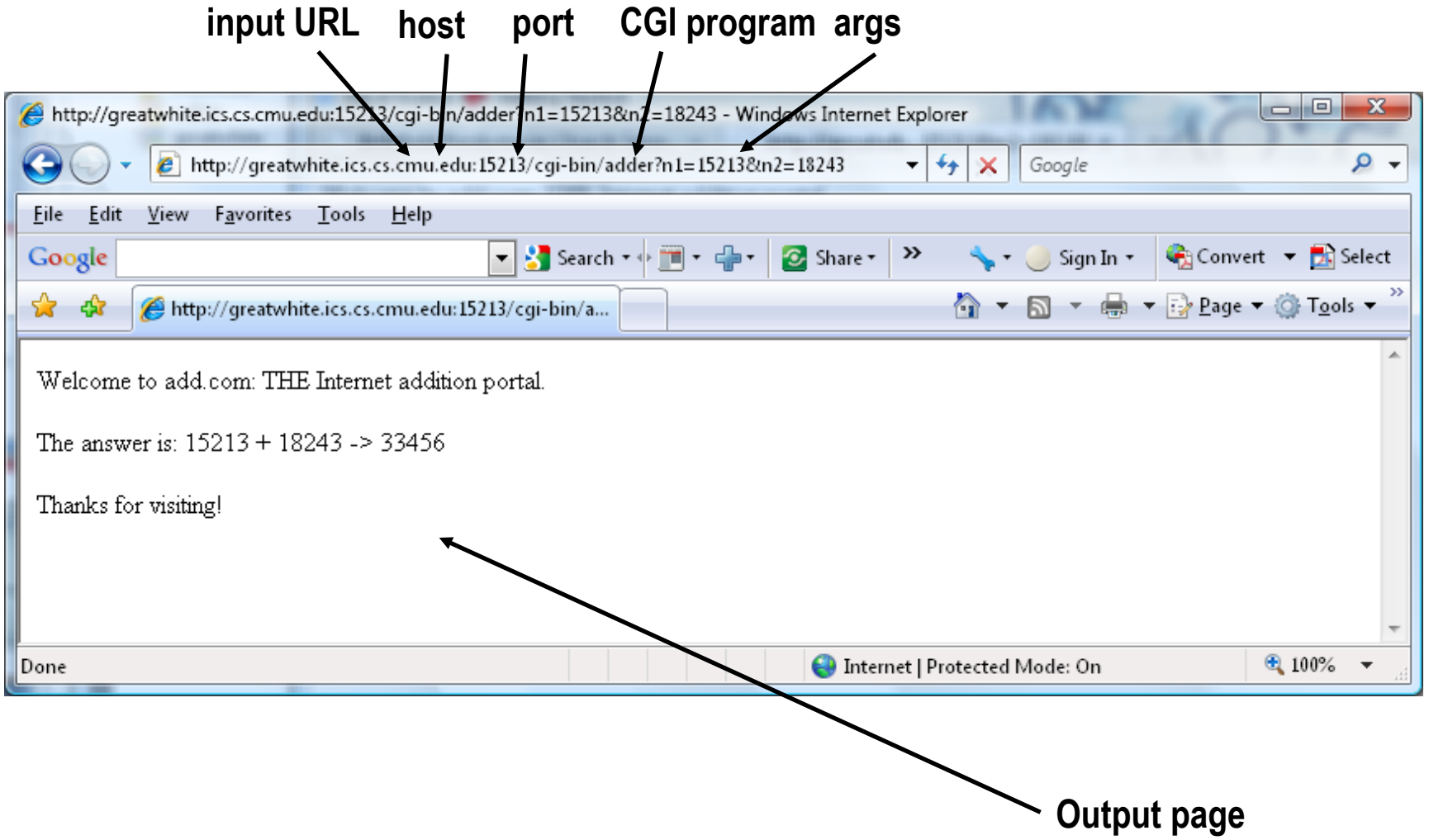
- How does the client pass program arguments to the server?
- How does the server pass these arguments to the child?
- How does the server pass other info relevant to the request to the child?
- How does the server capture the content produced by the child?
- These issues are addressed by the Common Gateway Interface (CGI) specification.



CGI

- Because the children are written according to the CGI spec, they are often called *CGI programs*.
- Because many CGI programs are written in Perl, they are often called *CGI scripts*.
- However, CGI really defines a simple standard for transferring information between the client (browser), the server, and the child process.

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?n1=15213&n2=18243`
  - `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`"
- **URI often generated by an HTML form**

```
<FORM METHOD=GET ACTION="cgi-bin/adder">
<p>X <INPUT NAME="n1">
<p>Y <INPUT NAME="n2">
<p><INPUT TYPE=submit>
</FORM>
```

Serving Dynamic Content With GET

- **URL:**
  - `cgi-bin/adder?n1=15213&n2=18243`

- **Result displayed on browser:**

Welcome to add.com: THE Internet addition portal. The answer is: 15213 + 18243 -> 33456
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` = "`n1=15213&n2=18243`"

From `adder.c`

```
if ((buf = getenv("QUERY_STRING")) != NULL) {
   if (sscanf(buf, "n1=%d&n2=%d\n", &n1, &n2) == 2)
     sprintf(msg, "%d + %d -> %d\n", n1, n2, n1+n2);
   else
     sprintf(msg, "Can't parse buffer '%s'\n", buf);
 }
```

Additional CGI Environment Variables

- **General**
  - `SERVER_SOFTWARE`
  - `SERVER_NAME`
  - `GATEWAY_INTERFACE` (CGI version)
- **Request-specific**
  - `SERVER_PORT`
  - `REQUEST_METHOD` (`GET`, `POST`, etc)
  - `QUERY_STRING` (contains `GET` args)
  - `REMOTE_HOST` (domain name of client)
  - `REMOTE_ADDR` (IP address of client)
  - `CONTENT_TYPE` (for `POST`, type of data in message body, e.g., `text/html`)
  - `CONTENT_LENGTH` (length in bytes)

Even More CGI Environment Variables

- **In addition, the value of each header of type *type* received from the client is placed in environment variable `HTTP_`*type***
  - Examples (any "-" is changed to "_") :
    - `HTTP_ACCEPT`
    - `HTTP_HOST`
    - `HTTP_USER_AGENT`

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.
  - Notice that only the child knows the type and size of the content. Thus the child (not the server) must generate the corresponding headers.

From `adder.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: %s\r\n<p>",
            content, msg);
    sprintf(content, "%sThanks for visiting!\r\n", content);

    /* Generate the HTTP response */
    printf("Content-length: %u\r\n", (unsigned) strlen(content));
    printf("Content-type: text/html\r\n\r\n");
    printf("%s", content);
```

Serving Dynamic Content With GET

```
linux> telnet greatwhite.ics.cs.cmu.edu 15213
Trying 128.2.220.10...
Connected to greatwhite.ics.cs.cmu.edu (128.2.220.10).
Escape character is '^]'.
GET /cgi-bin/adder?n1=5&n2=27 HTTP/1.1
host: greatwhite.ics.cs.cmu.edu
<CRLF>
HTTP/1.0 200 OK
Server: Tiny Web Server
Content-length: 109
Content-type: text/html

Welcome to add.com: THE Internet addition portal.
<p>The answer is: 5 + 27 -> 32

<p>Thanks for visiting!
Connection closed by foreign host.
```

HTTP request sent by client

HTTP response generated by the server

HTTP response generated by the CGI program

Tiny Serving Dynamic Content

From `tiny.c`

```
/* 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 prog  */
    }
    Wait(NULL); /* Parent waits for and reaps child */
```

- Fork child to execute CGI program
- Change stdout to be connection to client
- Execute CGI program with execve

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

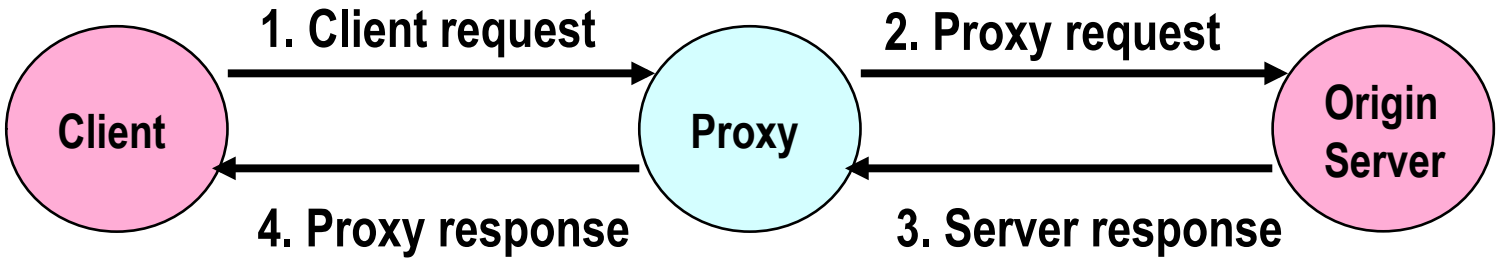
```
HTTP/1.1 200 OK\n
Date: Sun, 31 Oct 2010 20:47:48 GMT\n
Server: Apache/1.3.41 (Unix)\n
Keep-Alive: timeout=15, max=100\n
Connection: Keep-Alive\n
Transfer-Encoding: chunked\n
Content-Type: text/html\n
\r\n
d75\r\n
<html>
<head>
.<link href="http://www.cs.cmu.edu/style/calendar.css" rel="stylesheet"
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
\r\n
```

First Chunk: 0xd75 = 3445 bytes

Second Chunk: 0 bytes (indicates last chunk)

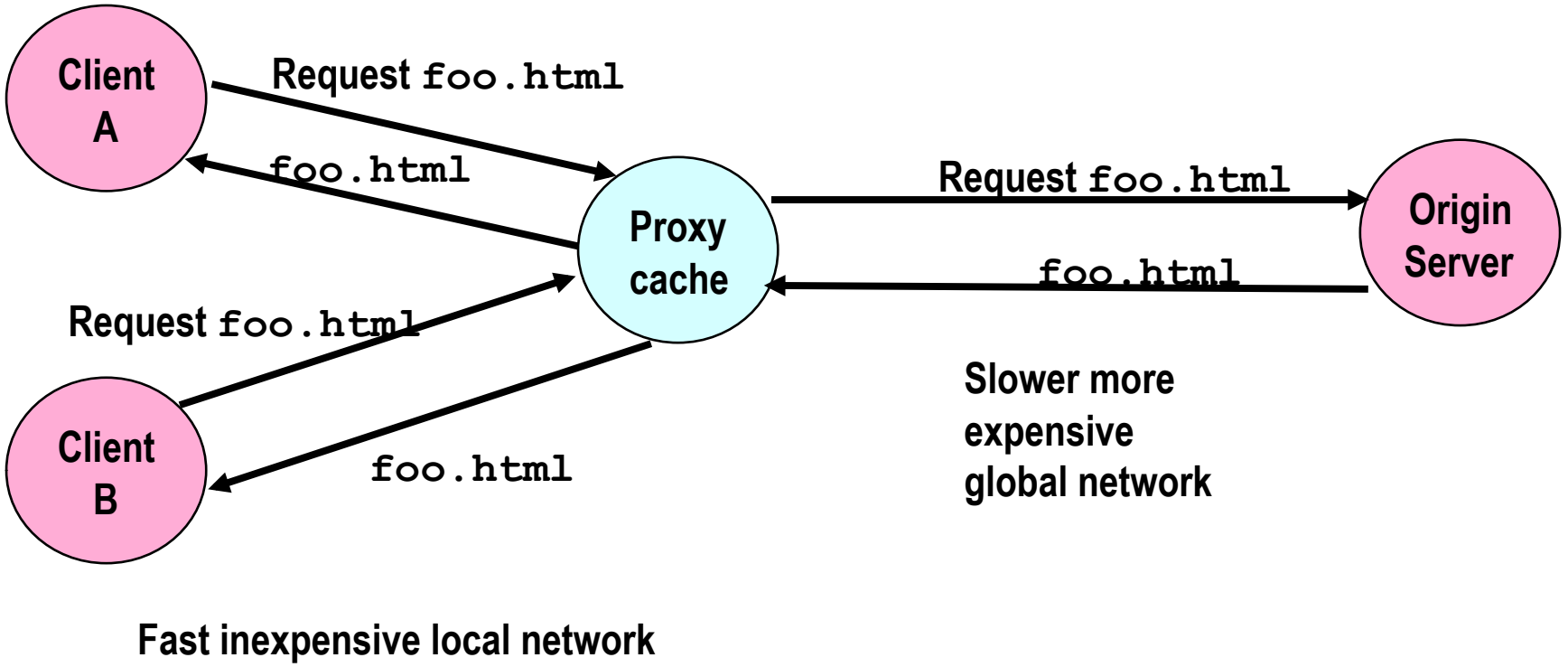
Proxies

- **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



For More Information

- **Study the Tiny Web server described in your text**
  - Tiny is a sequential Web server.
  - Serves static and dynamic content to real browsers.
    - text files, HTML files, GIF and JPEG images.
  - 220 lines of commented C code.
  - Also comes with an implementation of the CGI script for the add.com addition portal.

- **See the HTTP/1.1 standard:**
  - `http://www.w3.org/Protocols/rfc2616/rfc2616.html`