Network Applications and Network Programming: Web

9/23/2009

Outline

- Recap
- FTP
- Web

Recap: Connectionless: Big Picture (Java version)

Server (running on hostid) — Client

Server:
- create socket, port=x, for incoming request: serverSocket = DatagramSocket(x)
- read request from serverSocket
- write reply to serverSocket specifying client host address, port number

Client:
- create socket, clientSocket = DatagramSocket()
- Create, address (hostid, port=x, send datagram request using clientSocket
- read reply from clientSocket
- close clientSocket

Recap: Client/Server Socket Interaction: (Java version)

Server (running on hostid) — Client

Server:
- create socket, port=x, for incoming request: welcomeSocket = ServerSocket(x)
- wait for incoming connection request connectionSocket = welcomeSocket.accept()
- read request from connectionSocket
- write reply to connectionSocket
- close connectionSocket

TCP connection setup

Client:
- create socket, connect to hostid, port=x clientSocket = Socket(hostid, x)
- send request using clientSocket
- read reply from clientSocket
- close clientSocket

Recap: Some Issues to Consider

- Pay attention to encoding of data: what transport layer handles only a sequence of bytes, the meaning of the bytes is by app.
  - String/char <-> bytes depends on charset
  - DataOutputStream writeBytes(String)
  - Please read chapter 4 of Java Network Programming for more details
  - Typically network protocols are using big-endian order: int x = 0x0A0B0C0D
  - Use programming assignment 0 as a good practice: try ByteBuffer

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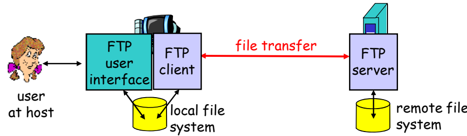
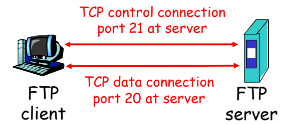
FTP: the File Transfer Protocol



- Transfer files to/from remote host
- Client/server model
  - *client:* side that initiates transfer (either to/from remote)
  - *server:* remote host
- ftp: RFC 959
- ftp server: port 21 (smtp 25, http 80)

FTP: A Client-Server Application with Separate Control, Data Connections

- Two parallel TCP connections opened:
  - control: exchange commands, responses between client, server.
    "out of band control"
    - port 21 at server
  - data: file data to/from server
    - port 20 at server
- ftp server maintains "state", e.g.,
  - current directory,
  - earlier authentication



FTP Commands, Responses

- Is the application extensible, scalable, robust, secure?

Sample commands:
- sent as ASCII text over control channel
- **USER** ***username***
- **PASS** ***password***
- **PORT h1,h2,h3,h4,p1,p2** specifies the IP address and port the client receives its data
- **LIST** return list of file in current directory
- **RETR filename** retrieves (gets) file
- **STOR filename** stores file

Sample return codes
- status code and phrase (as in http)
- **331 Username OK, password required**
- **125 data connection already open; transfer starting**
- **425 Can't open data connection**
- **452 Error writing file**

Discussion: why separate control/data connections?

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The Web: Some Jargon

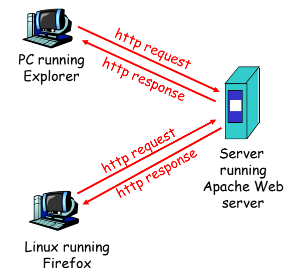
- Web page:
  - consists of "objects"
  - addressed by a URL
- Most Web pages consist of:
  - base HTML page, and
  - several referenced objects
- URL has two components: host name, port number and path name:

- User agent for Web is called a browser, e.g.
  - Mozilla Firefox
  - MS Internet Explorer
- Server for Web is called Web server:
  - Apache
  - MS Internet Information Server

http://www.cs.yale.edu:80/index.html

The Web: the HTTP Protocol

HTTP: hypertext transfer protocol
- Web's application layer protocol
- HTTP uses TCP as transport service
- client/server model
  - *client:* browser that requests, receives, "displays" Web objects
  - *server:* Web server sends objects in response to requests
- http1.0: RFC 1945
- http1.1: RFC 2068



HTTP 1.0 Message Flow

- Client initiates TCP connection (creates socket) to server, port 80
- Server waits for requests from clients
- Client sends request for a document
- Web server sends back the document
- TCP connection closed

- Client parses the document to find embedded objects (images)
  - repeat above for each image

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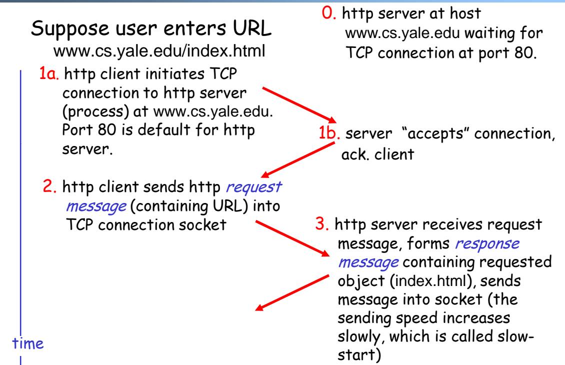
HTTP 1.0 Message Flow (more detail)

Suppose user enters URL www.cs.yale.edu/index.html



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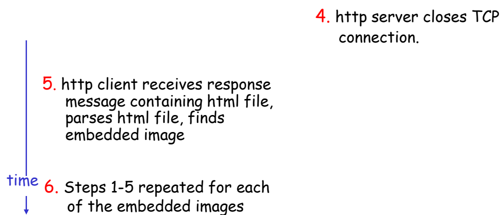
HTTP 1.0 Message Flow (cont.)



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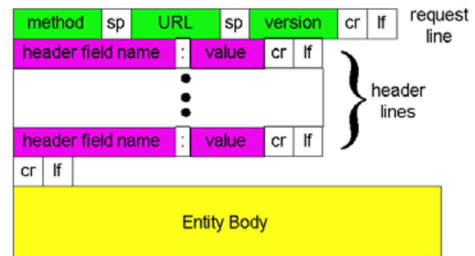
HTTP Request Message: General Format

- ASCII (human-readable format)



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HTTP Request Message Example: GET

request line (GET, POST, HEAD commands)

```
GET /somedir/page.html HTTP/1.0
Host: www.somechool.edu
Connection: close
User-agent: Mozilla/4.0
Accept: text/html, image/gif, image/jpeg
Accept-language: en
```

header lines

Carriage return, line feed indicates end of message

(extra carriage return, line feed)

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HTTP Response Message

status line (protocol status code status phrase)

```
HTTP/1.0 200 OK
Date: Wed, 23 Jan 2008 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 1998 …...
Content-Length: 6821
Content-Type: text/html

data data data data data ...
```

header lines

data, e.g., requested html file

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HTTP Response Status Codes

In the first line of the server->client response message. A few sample codes:

`200 OK`
- request succeeded, requested object later in this message

`301 Moved Permanently`
- requested object moved, new location specified later in this message (Location:)

`400 Bad Request`
- request message not understood by server

`404 Not Found`
- requested document not found on this server

`505 HTTP Version Not Supported`

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Trying out HTTP (client side) for yourself

1. Telnet to your favorite Web server:

`telnet www.yale.edu 80`

Opens TCP connection to port 80 (default http server port) at www.yale.edu. Anything typed in sent to port 80 at www.yale.edu

2. Type in a GET http request:

`GET /index.html HTTP/1.0`

By typing this in (hit carriage return twice), you send this minimal (but complete) GET request to http server

3. Look at response message sent by the http server.

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HTTP/1.0 Delay

- For each object:
  - TCP handshake --- 1 RTT
  - client request and server responds --- at least 1 RTT (if object can be contained in one packet)
- Discussion: how to reduce delay?

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HTTP Message Flow: Persistent HTTP

- Default for HTTP/1.1
- On same TCP connection: server parses request, responds, parses new request, ...
- Client sends requests for all referenced objects as soon as it receives base HTML
- Fewer RTTs

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Browser Cache and Conditional GET

- Goal: don't send object if client has up-to-date stored (cached) version
- client: specify date of cached copy in http request
  `If-modified-since: <date>`
- server: response contains no object if cached copy up-to-date:
  `HTTP/1.0 304 Not Modified`

client | server

http request msg
`If-modified-since: <date>`
→ object not modified
http response
`HTTP/1.0 304 Not Modified`

http request msg
`If-modified-since: <date>`
→ object modified
http response
`HTTP/1.1 200 OK ... <data>`

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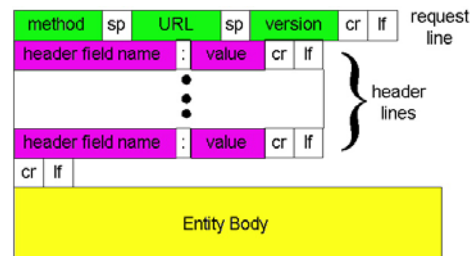
HTTP Message Extension: Form

- if an HTML page contains forms, they are encoded in message body



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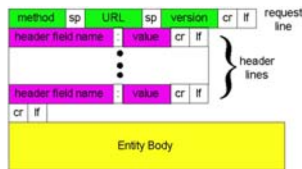
HTTP Message Flow Extensions: Keeping State

- Why do we need to keep state?
- How does FTP keep state (e.g., current dir) and why does HTTP not use it?



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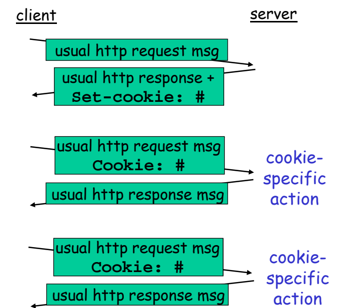
User-server Interaction: Cookies

Goal: no explicit application level session

- Server sends "cookie" to client in response msg
  `Set-cookie: 1678453`
- Client presents cookie in later requests
  `Cookie: 1678453`
- Server matches presented-cookie with server-stored info
  - authentication
  - remembering user preferences, previous choices



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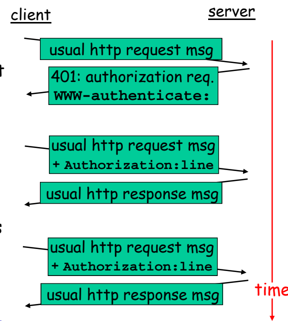
User-Server Interaction: Authentication

Authentication goal: control access to server documents

- stateless: client must present authorization in each request
- authorization: typically name, password
  - `Authorization:` header line in request
  - if no authorization presented, server refuses access, sends
    `WWW-authenticate:`
    header line in response



Browser caches name & password so that user does not have to repeatedly enter it.

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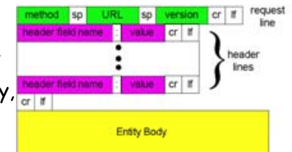
Summary: HTTP

- Is the application extensible, scalable, robust, secure?

- HTTP message format
  - ASCII (human-readable format) requests, header lines, entity body, and responses line



- HTTP message flow
  - stateless server
    - each request is self-contained; thus cookie and authentication, are needed in each message
  - reducing latency
    - persistent HTTP
      - the problem is introduced by layering !
    - conditional GET reduces server/network workload and latency
    - cache and proxy reduce traffic and latency

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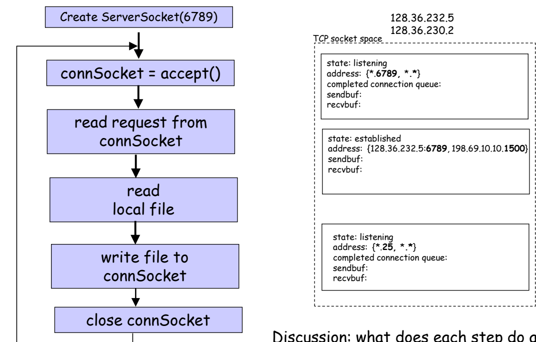
Example: WebServer

- A simple web server which supports only simple HTTP/1.0

http://zoo.cs.yale.edu/classes/cs433/programming/examples-java-socket/WebServer/

WebServer Flow



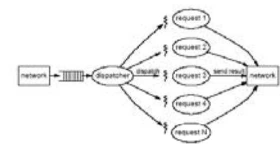
Discussion: what does each step do and how long does it take?

Writing High Performance Servers: Major Issues

- Many socket/IO operations can cause a process to block, e.g.,
  - `accept`: waiting for new connection;
  - `read` a socket waiting for data or close;
  - `write` a socket waiting for buffer space;
  - I/O `read/write` for disk to finish
- Thus a crucial perspective of network server design is the concurrency design (non-blocking)
  - for high performance
  - to avoid denial of service
- Concurrency is also important for clients!

Writing High Performance Servers: Using Multi-Threads

- Using multiple threads
  - so that only the flow processing a particular request is blocked
  - A thread is a sequence of instructions which may execute in parallel with other threads



Java Thread

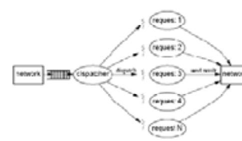
- Two ways to implement Java thread
  - Extend the Thread class, or
  - Implement the Runnable interface

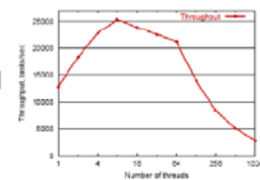
```
class RequestHandler
        extends Thread {
   public void run() { }
   …
}

Thread t =
   new RequestHandler(requestInfo);
t.start();
```

```
class RequestHandler
        implements Runnable {
   public void run() { }
   …
}
RequestHandler rh =
   new RequestHandler(requestInfo);
Thread t = new Thread(rh);
t.start();
```

Example: a Multi-threaded WebServer, which creates a thread for each request

Problems of Multi-Thread Server

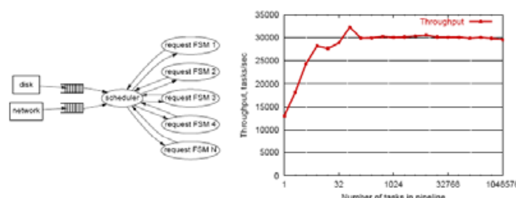


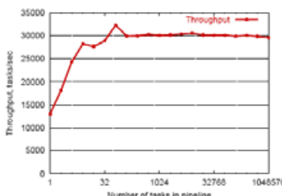


(937 MHz x86, Linux 2.2.14, each thread reading 8KB file)

- High resource usage, context switch overhead, contended locks
- Too many threads → throughput meltdown, response time explosion
- In practice: bound total number of threads

Event-Driven Programming





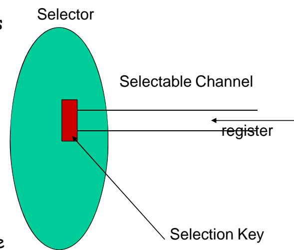
- Event-driven programming, also called asynchronous i/o
- Using Finite State Machines (FSM) to monitor the progress of requests
- Yields efficient and scalable concurrency
- Many examples: Click router, Flash web server, TP Monitors, etc.
- Java: asynchronous i/o
  - for an example see: http://www.cafeaulait.org/books/jnp3/examples/12/

Async I/O in Java

- An important class is the class `Selector`, which is a multiplexer of selectable channel objects
  - example channels: `DatagramChannel`, `ServerSocketChannel`, `SocketChannel`
  - use `configureBlocking(false)` to make a channel non-blocking
- A selector may be created by invoking the `open` method of this class

Async I/O in Java

- A selectable channel registers events (called a `SelectionKey`) with a selector with the `register` method
- A `SelectionKey` object contains two *operation sets*
  - interest Set
  - ready Set
- A `SelectionKey` object has an attachment which can store data
  - often the attachment is a buffer



Async I/O in Java

- Call `select` (or `selectNow()`, or `select(int timeout)`) to check for ready events, called the selected key set
- Iterate over the set to process all ready events

Problems of Event-Driven Server

- Difficult to engineer, modularize, and tune
- Little OS and tool support: "roll your own"
- No performance/failure isolation between FSMs
- FSM code can never block (but page faults, garbage collection may still force a block)
  - thus still need multiple threads

Optional Slides

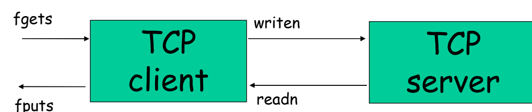
Asynchronous Network Programming

(C/C++)

A Relay TCP Client: telnet-like Program

fgets

fputs



http://zoo.cs.yale.edu/classes/cs433/programming/examples-c-socket/tcpclient

Method 1: Process and Thread

- process
  - fork()
  - waitpid()
- Thread: light weight process
  - pthread_create()
  - pthread_exit()

pthread

```
Void main() {
 char  recvline[MAXLINE + 1];
  ss = new socketstream(sockfd);

  pthread_t  tid;
  if (pthread_create(&tid, NULL, copy_to, NULL)) {
    err_quit("pthread_creat()");
  }

  while  (ss->read_line(recvline, MAXLINE) > 0) {
    fprintf(stdout, "%s\n", recvline);
  }
}

void *copy_to(void *arg) {
  char sendline[MAXLINE];

  if (debug) cout << "Thread create()!" << endl;
  while (fgets(sendline, sizeof(sendline), stdin))
    ss->writen_socket(sendline, strlen(sendline));

  shutdown(sockfd, SHUT_WR);
  if (debug) cout << "Thread done!" << endl;

  pthread_exit(0);
}
```


Method 2: Asynchronous I/O (Select)

- select: deal with blocking system call

  int select(int n, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, struct timeval *timeout);

  FD_CLR(int fd, fd_set *set);
  FD_ZERO(fd_set *set);
  FD_ISSET(int fd, fd_set *set);
  FD_SET(int fd, fd_set *set);

Method 3: Signal and Select

- signal: events such as timeout

Examples of Network Programming

- Library to make life easier
- Four design examples
  - TCP Client
  - TCP server using select
  - TCP server using process and thread
  - Reliable UDP
- Warning: It will be hard to listen to me reading through the code. Read the code.

Example 2: A Concurrent TCP Server Using Process or Thread

- Get a line, and echo it back
- Use select()
- For how to use process or thread, see later
- Check the code at:
  http://zoo.cs.yale.edu/classes/cs433/programming/examples-c-socket/tcpserver

- Are there potential denial of service problems with the code?

Example 3: A Concurrent HTTP TCP Server Using Process/Thread

- Use process-per-request or thread-per-request
- Check the code at:

http://zoo.cs.yale.edu/classes/cs433/programming/examples-c-socket/simple_httpd