Web Essentials: Clients, Servers, and Communication
The Internet

- Technical origin: ARPANET (late 1960’s)
  - One of earliest attempts to network heterogeneous, geographically dispersed computers
  - Email first available on ARPANET in 1972 (and quickly very popular!)
- ARPANET access was limited to select DoD-funded organizations
The Internet

- Open-access networks
  - Regional university networks (e.g., SURAnet)
  - CSNET for CS departments not on ARPANET

- NSFNET (1985-1995)
  - Primary purpose: connect supercomputer centers
  - Secondary purpose: provide backbone to connect regional networks
The Internet

The 6 supercomputer centers connected by the early NSFNET backbone
The Internet

- Original NSFNET backbone speed: 56 kbit/s
- Upgraded to 1.5 Mbit/s (T1) in 1988
- Upgraded to 45 Mbit/s (T3) in 1991

- In 1988, networks in Canada and France connected to NSFNET
- In 1990, ARPANET is decommissioned, NSFNET the center of the internet
The Internet

- Internet: the network of networks connected via the public backbone and communicating using TCP/IP communication protocol
  - Backbone initially supplied by NSFNET, privately funded (ISP fees) beginning in 1995
Internet Protocols

- Communication protocol: how computers talk
  - Cf. telephone “protocol”: how you answer and end call, what language you speak, etc.
- Internet protocols developed as part of ARPANET research
  - ARPANET began using TCP/IP in 1982
- Designed for use both within local area networks (LAN’s) and between networks
Internet Protocol (IP)

- IP is the fundamental protocol defining the Internet (as the name implies!)

- IP address:
  - 32-bit number (in IPv4)
  - Associated with at most one device at a time (although device may have more than one)
  - Written as four dot-separated bytes, e.g. 192.0.34.166
IP

- IP function: transfer data from source device to destination device
- IP source software creates a packet representing the data
  - Header: source and destination IP addresses, length of data, etc.
  - Data itself
- If destination is on another LAN, packet is sent to a gateway that connects to more than one network
IP

Source

Gateway

Network 1

Gateway

Gateway

Network 2

Network 3

Destination
IP

Source

LAN 1

Gateway

Internet Backbone

Gateway

Gateway

LAN 2

Destination
Transmission Control Protocol (TCP)

- Limitations of IP:
  - No guarantee of packet delivery (packets can be dropped)
  - Communication is one-way (source to destination)

- TCP adds concept of a connection on top of IP
  - Provides guarantee that packets delivered
  - Provide two-way (full duplex) communication
TCP

Establish connection.

Send packet with acknowledgment.

Resend packet if no (or delayed) acknowledgment.

Source

Can I talk to you?

OK. Can I talk to you?

OK.

Here’s a packet.

Got it.

Destination

Here’s a resent packet.

Got it.
TCP

- TCP also adds concept of a port
  - TCP header contains port number representing an application program on the destination computer
  - Some port numbers have **standard meanings**
    - Example: port 25 is normally used for email transmitted using the Simple Mail Transfer Protocol (SMTP)
  - Other port numbers are available first-come-first served to any application
TCP
User Datagram Protocol (UDP)

- Like TCP in that:
  - Builds on IP
  - Provides port concept

- Unlike TCP in that:
  - No connection concept
  - No transmission guarantee

- Advantage of UDP vs. TCP:
  - Lightweight, so faster for one-time messages
Domain Name Service (DNS)

- DNS is the “phone book” for the Internet
  - Map between host names and IP addresses
  - DNS often uses UDP for communication
- Host names
  - Labels separated by dots, e.g., www.example.org
  - Final label is top-level domain
    - Generic: .com, .org, etc.
    - Country-code: .us, .il, etc.
DNS

- Domains are divided into second-level domains, which can be further divided into subdomains, etc.
  - E.g., in www.example.com, example is a second-level domain

- A host name plus domain name information is called the fully qualified domain name of the computer
  - Above, www is the host name, www.example.com is the FQDN
nslookup program provides command-line access to DNS (on most systems)

looking up a host name given an IP address is known as a reverse lookup

- Recall that single host may have multiple IP addresses.
- Address returned is the canonical IP address specified in the DNS system.
DNS

- `ipconfig` (on windows) can be used to find the IP address (addresses) of your machine
- `ipconfig /displaydns` displays the contents of the DNS Resolver Cache (`ipconfig /flushdns` to flush it)
Analogy to Telephone Network

- IP ~ the telephone network
- TCP ~ calling someone who answers, having a conversation, and hanging up
- UDP ~ calling someone and leaving a message
- DNS ~ directory assistance
Higher-level Protocols

- Many protocols build on TCP
  - Telephone analogy: TCP specifies how we initiate and terminate the phone call, but some other protocol specifies how we carry on the actual conversation

- Some examples:
  - SMTP (email) (25)
  - FTP (file transfer) (21)
  - HTTP (transfer of Web documents) (80)
World Wide Web

- Originally, one of several systems for organizing Internet-based information
  - Competitors: WAIS, Gopher, ARCHIE
- Distinctive feature of Web: support for hypertext (text containing links)
  - Communication via Hypertext Transport Protocol (HTTP)
  - Document representation using Hypertext Markup Language (HTML)
World Wide Web

- The Web is the collection of machines (Web servers) on the Internet that provide information, particularly HTML documents, via HTTP.
- Machines that access information on the Web are known as Web clients. A Web browser is software used by an end user to access the Web.
Hypertext Transport Protocol (HTTP)

- **HTTP** is based on the request-response communication model:
  - Client sends a request
  - Server sends a response

- **HTTP** is a stateless protocol:
  - The protocol does not require the server to remember anything about the client between requests.
HTTP

- Normally implemented over a TCP connection (80 is standard port number for HTTP)
- Typical browser-server interaction:
  - User enters Web address in browser
  - Browser uses DNS to locate IP address
  - Browser opens TCP connection to server
  - Browser sends HTTP request over connection
  - Server sends HTTP response to browser over connection
  - Browser displays body of response in the client area of the browser window
HTTP

- The information transmitted using HTTP is often entirely text
- Can use the Internet’s Telnet protocol to simulate browser request and view server response
Connect

{ $ telnet www.example.org 80
  Trying 192.0.34.166...
  Connected to www.example.com
  (192.0.34.166).
  Escape character is ’^]’.

Send Request

{ GET / HTTP/1.1
  Host: www.example.org

Receive Response

{ HTTP/1.1 200 OK
  Date: Thu, 09 Oct 2003 20:30:49 GMT
  ...

HTTP
HTTP Request

- Structure of the request:
  - start line
  - header field(s)
  - blank line
  - optional body
HTTP Request

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HTTP Request

- Start line
  - Example: GET / HTTP/1.1

- Three space-separated parts:
  - HTTP request method
  - Request-URI (Uniform Resource Identifier)
  - HTTP version
HTTP Request

- Start line
  - Example: GET / HTTP/1.1

- Three space-separated parts:
  - HTTP request method
  - Request-URI
  - HTTP version
    - We will cover 1.1, in which version part of start line must be exactly as shown
HTTP Request

- Start line
  - Example: `GET / HTTP/1.1`

- Three space-separated parts:
  - HTTP request method
  - Request-URI
  - HTTP version
HTTP Request

- Uniform Resource Identifier (URI)
  - Syntax: `scheme : scheme-depend-part`
    - Ex: In `http://www.example.com/`, the scheme is `http`
  - Request-URI is the portion of the requested URI that follows the host name (which is supplied by the required Host header field)
    - Ex: `/` is Request-URI portion of `http://www.example.com/`
URI

- URI’s are of two types:
  - Uniform Resource Name (URN)
    - Can be used to identify resources with unique names, such as books (which have unique ISBN’s)
    - Scheme is urn
  - Uniform Resource Locator (URL)
    - Specifies location at which a resource can be found
    - In addition to http, some other URL schemes are https, ftp, mailto, and file
HTTP Request

- **Start line**
  - Example: `GET / HTTP/1.1`

- **Three space-separated parts:**
  - HTTP request method
  - Request-URI
  - HTTP version
HTTP Request

- Common request methods:
  - **GET**
    - Used if link is clicked or address typed in browser
    - No body in request with GET method
  - **POST**
    - Used when submit button is clicked on a form
    - Form information contained in body of request
  - **HEAD**
    - Requests that only header fields (no body) be returned in the response
HTTP Request

Structure of the request:
- start line
- header field(s)
- blank line
- optional body
HTTP Request

- Header field structure:
  - field name : field value

- Syntax
  - Field name is not case sensitive
  - Field value may continue on multiple lines by starting continuation lines with white space
  - Field values may contain MIME types, quality values, and wildcard characters (‘*’s)
Multipurpose Internet Mail Extensions (MIME)

- Convention for specifying content type of a message
  - In HTTP, typically used to specify content type of the body of the response
- MIME content type syntax:
  - top-level type / subtype
- Examples: text/html, image/jpeg
HTTP Quality Values and Wildcards

- Example header field with quality values:
  ```
  accept:
  text/xml,text/html;q=0.9, text/plain;q=0.8, image/jpeg, image/gif;q=0.2,*/*;q=0.1
  ```
- Quality value applies to all preceding items
- Higher the value, higher the preference
- Note use of wildcards to specify quality 0.1 for any MIME type not specified earlier
HTTP Request

- Common header fields:
  - Host: host name from URL (required)
  - User-Agent: type of browser sending request
  - Accept: MIME types of acceptable documents
  - Connection: value close tells server to close connection after single request/response
  - Content-Type: MIME type of (POST) body, normally application/x-www-form-urlencoded
  - Content-Length: bytes in body
  - Referer: URL of document containing link that supplied URI for this HTTP request
HTTP Response

- Structure of the response:
  - status line
  - header field(s)
  - blank line
  - optional body
HTTP Response

- Structure of the response:
  - status line
  - header field(s)
  - blank line
  - optional body
HTTP Response

- Status line
  - Example: HTTP/1.1 200 OK

- Three space-separated parts:
  - HTTP version
  - status code
  - reason phrase (intended for human use)
HTTP Response

- Status code
  - Three-digit number
  - First digit is class of the status code:
    - 1=Informational
    - 2=Success
    - 3=Redirection (alternate URL is supplied)
    - 4=Client Error
    - 5=Server Error
  - Other two digits provide additional information
  - See http://www.w3.org/Protocols/rfc2616/rfc2616-sec10.html
HTTP Response

Structure of the response:

- status line
- header field(s)
- blank line
- optional body
HTTP Response

- **Common header fields:**
  - **Connection, Content-Type, Content-Length**
  - **Date:** date and time at which response was generated (required)
  - **Location:** alternate URI if status is redirection
  - **Last-Modified:** date and time the requested resource was last modified on the server
  - **Expires:** date and time after which the client’s copy of the resource will be out-of-date
  - **ETag:** a unique identifier for this version of the requested resource (changes if resource changes)
Client Caching

- A cache is a local copy of information obtained from some other source.
- Most web browsers use cache to store requested resources so that subsequent requests to the same resource will not necessarily require an HTTP request/response.
  - Ex: icon appearing multiple times in a Web page.
Client Caching

1. HTTP request for image
2. HTTP response containing image
3. Store image
Client Caching

Client

Browser

I need that image again...

Cache

Web Server

Server
Client Caching

Browser
I need that image again...

Web Server

HTTP request for image

HTTP response containing image

This…
Client Caching

Browser
I need that image again...

Get image

... or this

Web Server

Server

Client
Client Caching

- Cache advantages
  - (Much) faster than HTTP request/response
  - Less network traffic
  - Less load on server

- Cache disadvantage
  - Cached copy of resource may be invalid (inconsistent with remote version)
Client Caching

- Validating cached resource:
  - Send HTTP HEAD request and check Last-Modified or ETag header in response
  - Compare current date/time with Expires header sent in response containing resource
  - If no Expires header was sent, use heuristic algorithm to estimate value for Expires
    - Ex: Expires = 0.01 * (Date – Last-Modified) + Date
Character Sets

- Every document is represented by a string of integer values (code points)
- The mapping from code points to characters is defined by a character set
- Some header fields have character set values:
  - Accept-Charset: request header listing character sets that the client can recognize
    - Ex: accept-charset: ISO-8859-1,utf-8;q=0.7,*;q=0.5
  - Content-Type: can include character set used to represent the body of the HTTP message
    - Ex: Content-Type: text/html; charset=UTF-8
Character Sets

- Technically, many “character sets” are actually character encodings
  - An encoding represents code points using variable-length byte strings
  - Most common examples are Unicode-based encodings UTF-8 and UTF-16
- IANA maintains complete list of Internet-recognized character sets/encodings
Character Sets

- Typical US PC produces ASCII documents
- US-ASCII character set can be used for such documents, but is not recommended
- UTF-8 and ISO-8859-1 are supersets of US-ASCII and provide international compatibility
  - UTF-8 can represent all ASCII characters using a single byte each and arbitrary Unicode characters using up to 4 bytes each
  - ISO-8859-1 is 1-byte code that has many characters common in Western European languages, such as é
Web Clients

- Many possible web clients:
  - Text-only “browser” (lynx)
  - Mobile phones
  - Robots (software-only clients, e.g., search engine “crawlers”)
  - etc.

- We will focus on traditional web browsers
Web Browsers

- First graphical browser running on general-purpose platforms: Mosaic (1993)
Web Browsers

You have reached this web page by typing "example.com", "example.net", or "example.org" into your web browser.

These domain names are reserved for use in documentation and are not available for registration. See [RFC 2606](http://www.example.org), Section 3.
Web Browsers

- **Primary tasks:**
  - Convert web addresses (URL’s) to HTTP requests
  - Communicate with web servers via HTTP
  - Render (appropriately display) documents returned by a server
HTTP URL’s

- Browser uses authority to connect via TCP
- Request-URI included in start line (/ used for path if none supplied)
- Fragment identifier not sent to server (used to scroll browser client area)
Web Browsers

- Standard features
  - Save web page to disk
  - Find string in page
  - Fill forms automatically (passwords, CC numbers, …)
  - Set preferences (language, character set, cache and HTTP parameters)
  - Modify display style (e.g., increase font sizes)
  - Display raw HTML and HTTP header info (e.g., Last-Modified)
  - Choose browser themes (skins)
  - View history of web addresses visited
  - Bookmark favorite pages for easy return
Web Browsers

- Additional functionality:
  - Execution of scripts (e.g., drop-down menus)
  - Event handling (e.g., mouse clicks)
  - GUI for controls (e.g., buttons)
  - Secure communication with servers
  - Display of non-HTML documents (e.g., PDF) via plug-ins
Web Servers

- Basic functionality:
  - Receive HTTP request via TCP
  - Map Host header to specific virtual host (one of many host names sharing an IP address)
  - Map Request-URI to specific resource associated with the virtual host
    - File: Return file in HTTP response
    - Program: Run program and return output in HTTP response
  - Map type of resource to appropriate MIME type and use to set Content-Type header in HTTP response
  - Log information about the request and response
Web Servers

- httpd: UIUC, primary Web server c. 1995
- Apache: “A patchy” version of httpd, now the most popular server (esp. on Linux platforms)
- IIS: Microsoft Internet Information Server
- **Tomcat:**
  - Java-based
  - Provides container (Catalina) for running Java servlets (HTML-generating programs) as back-end to Apache or IIS
  - Can run stand-alone using Coyote HTTP front-end
Web Servers

- Some Coyote communication parameters:
  - Allowed/blocked IP addresses
  - Max. simultaneous active TCP connections
  - Max. queued TCP connection requests
  - “Keep-alive” time for inactive TCP connections
- Modify parameters to tune server performance
Web Servers

- Some Catalina container parameters:
  - Virtual host names and associated ports
  - Logging preferences
  - Mapping from Request-URI’s to server resources
  - Password protection of resources
  - Use of server-side caching
Tomcat Web Server

- HTML-based server administration
- Browse to http://localhost:8080 and click on Server Administration link
  - localhost is a special host name that means “this machine”
Tomcat Web Server
Tomcat Web Server
Tomcat Web Server
Tomcat Web Server

- Some Connector fields:
  - Port Number: port “owned” by this connector
  - Max Threads: max connections processed simultaneously
  - Connection Timeout: keep-alive time
Tomcat Web Server
Tomcat Web Server

- Each Host is a virtual host (can have multiple per Connector)
- Some fields:
  - Host: localhost or a fully qualified domain name
  - Application Base: directory (may be path relative to JWSDP installation directory) containing resources associated with this Host
Tomcat Web Server
Tomcat Web Server

- Context provides mapping from Request-URI path to a web application
- Document Base field is directory (possibly relative to Application Base) that contains resources for this web application
- For this example, browsing to http://localhost:8080/ returns resource from c:\jwsdp-1.3\webapps\ROOT
  - Returns index.html (standard welcome file)
Tomcat Web Server

- Access log records HTTP requests
- Parameters set using AccessLogValve
- Default location: \texttt{logs/access\_log.*} under JWSDP installation directory
- Example “common” log format entry (one line):
  \texttt{www.example.org - admin [20/Jul/2005:08:03:22 -0500] "GET /admin/frameset.jsp HTTP/1.1" 200 920}
Tomcat Web Server

- Other logs provided by default in JWSDP:
  - Message log messages sent to log service by web applications or Tomcat itself
    - logs/jwsdp_log.*: default message log
    - logs/localhost_admin_log.*: message log for web apps within /admin context
  - System.out and System.err output (exception traces often found here):
    - logs/launcher.server.log
Tomcat Web Server

Access control:

- Password protection (e.g., admin pages)
  - Users and roles defined in `conf/tomcat-users.xml`

- Deny access to machines
  - Useful for denying access to certain users by denying access from the machines they use
  - List of denied machines maintained in `RemoteHostValve` (deny by host name) or `RemoteAddressValve` (deny by IP address)
Secure Servers

- Since HTTP messages typically travel over a public network, private information (such as credit card numbers) should be encrypted to prevent eavesdropping
- https URL scheme tells browser to use encryption
- Common encryption standards:
  - Secure Socket Layer (SSL)
  - Transport Layer Security (TLS)
Secure Servers

I’d like to talk securely to you (over port 443)

Here’s my certificate and encryption data

Here’s an encrypted HTTP request

Here’s an encrypted HTTP response

Here’s an encrypted HTTP request

Here’s an encrypted HTTP response

Here’s an encrypted HTTP response
Secure Servers
Man-in-the-Middle Attack

What's IP address for www.example.org?

Fake DNS Server
What's IP address for www.example.org?

100.1.1.1

Fake www.example.org 100.1.1.1

My credit card number is...

Real www.example.org

Browser
Secure Servers
Preventing Man-in-the-Middle

What’s IP address for www.example.org?

100.1.1.1

Send me a certificate of identity

100.1.1.1