the three-way handshake (the acknowledgment) into the TCP connection. Once the request message arrives at the server, the server sends the HTML file into the TCP connection. This HTTP request/response eats up another RTT. Thus, roughly, the total response time is two RTTs plus the transmission time at the server of the HTML file.

HTTP with Persistent Connections

Non-persistent connections have some shortcomings. First, a brand-new connection must be established and maintained for *each requested object*. For each of these connections, TCP buffers must be allocated and TCP variables must be kept in both the client and server. This can place a significant burden on the Web server, which may be serving requests from hundreds of different clients simultaneously. Second, as we just described, each object suffers a delivery delay of two RTTs—one RTT to establish the TCP connection and one RTT to request and receive an object.

With persistent connections, the server leaves the TCP connection open after sending a response. Subsequent requests and responses between the same client and server can be sent over the same connection. In particular, an entire Web page (in the example above, the base HTML file and the 10 images) can be sent over a single persistent TCP connection. Moreover, multiple Web pages residing on the same server can be sent from the server to the same client over a single persistent TCP connection. These requests for objects can be made back-to-back, without waiting for replies to pending requests (pipelining). Typically, the HTTP server closes a connection when it isn't used for a certain time (a configurable timeout interval). When the server receives the back-to-back requests, it sends the objects back-to-back. The default mode of HTTP uses persistent connections with pipelining. We'll quantitatively compare the performance of non-persistent and persistent connections in the homework problems of Chapters 2 and 3. You are also encouraged to see [Heidemann 1997; Nielsen 1997].

2.2.3 HTTP Message Format

The HTTP specifications [RFC 1945; RFC 2616] include the definitions of the HTTP message formats. There are two types of HTTP messages, request messages and response messages, both of which are discussed below.

HTTP Request Message

Below we provide a typical HTTP request message:

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
```

```
Connection: close
User-agent: Mozilla/5.0
Accept-language: fr
```

We can learn a lot by taking a close look at this simple request message. First of all, we see that the message is written in ordinary ASCII text, so that your ordinary computer-literate human being can read it. Second, we see that the message consists of five lines, each followed by a carriage return and a line feed. The last line is followed by an additional carriage return and line feed. Although this particular request message has five lines, a request message can have many more lines or as few as one line. The first line of an HTTP request message is called the **request line**; the subsequent lines are called the **header lines**. The request line has three fields: the method field, the URL field, and the HTTP version field. The method field can take on several different values, including `GET`, `POST`, `HEAD`, `PUT`, and `DELETE`. The great majority of HTTP request messages use the `GET` method. The `GET` method is used when the browser requests an object, with the requested object identified in the URL field. In this example, the browser is requesting the object `/somedir/page.html`. The version is self-explanatory; in this example, the browser implements version HTTP/1.1.

Now let's look at the header lines in the example. The header line `Host: www.someschool.edu` specifies the host on which the object resides. You might think that this header line is unnecessary, as there is already a TCP connection in place to the host. But, as we'll see in Section 2.2.5, the information provided by the host header line is required by Web proxy caches. By including the `Connection: close` header line, the browser is telling the server that it doesn't want to bother with persistent connections; it wants the server to close the connection after sending the requested object. The `User-agent:` header line specifies the user agent, that is, the browser type that is making the request to the server. Here the user agent is Mozilla/5.0, a Firefox browser. This header line is useful because the server can actually send different versions of the same object to different types of user agents. (Each of the versions is addressed by the same URL.) Finally, the `Accept-language:` header indicates that the user prefers to receive a French version of the object, if such an object exists on the server; otherwise, the server should send its default version. The `Accept-language:` header is just one of many content negotiation headers available in HTTP.

Having looked at an example, let's now look at the general format of a request message, as shown in Figure 2.8. We see that the general format closely follows our earlier example. You may have noticed, however, that after the header lines (and the additional carriage return and line feed) there is an "entity body." The entity body is empty with the `GET` method, but is used with the `POST` method. An HTTP client often uses the `POST` method when the user fills out a form—for example, when a user provides search words to a search engine. With a `POST` message, the user is still requesting a Web page from the server, but the specific contents of the Web page

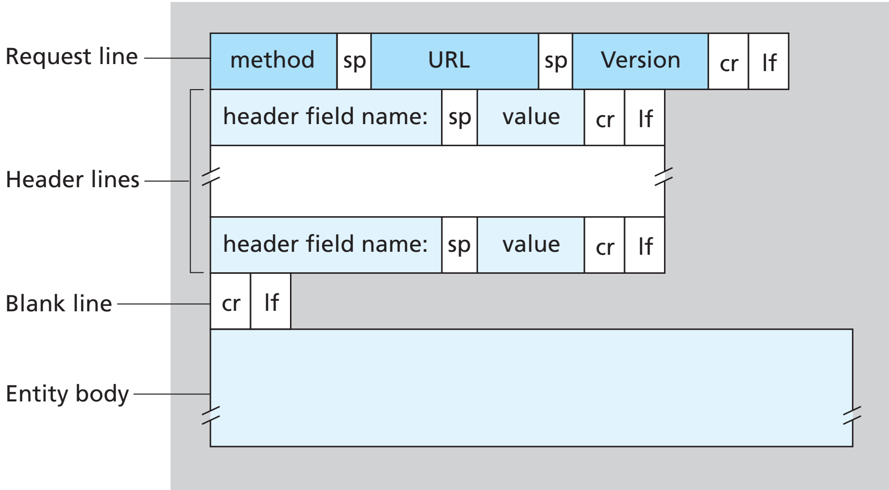

Figure 2.8 ♦ General format of an HTTP request message

depend on what the user entered into the form fields. If the value of the method field is `POST`, then the entity body contains what the user entered into the form fields.

We would be remiss if we didn't mention that a request generated with a form does not necessarily use the `POST` method. Instead, HTML forms often use the `GET` method and include the inputted data (in the form fields) in the requested URL. For example, if a form uses the `GET` method, has two fields, and the inputs to the two fields are `monkeys` and `bananas`, then the URL will have the structure `www.somesite.com/animalsearch?monkeys&bananas`. In your day-to-day Web surfing, you have probably noticed extended URLs of this sort.

The `HEAD` method is similar to the `GET` method. When a server receives a request with the `HEAD` method, it responds with an HTTP message but it leaves out the requested object. Application developers often use the `HEAD` method for debugging. The `PUT` method is often used in conjunction with Web publishing tools. It allows a user to upload an object to a specific path (directory) on a specific Web server. The `PUT` method is also used by applications that need to upload objects to Web servers. The `DELETE` method allows a user, or an application, to delete an object on a Web server.

HTTP Response Message

Below we provide a typical HTTP response message. This response message could be the response to the example request message just discussed.

```
HTTP/1.1 200 OK
Connection: close
```

```
Date: Tue, 09 Aug 2011 15:44:04 GMT
Server: Apache/2.2.3 (CentOS)
Last-Modified: Tue, 09 Aug 2011 15:11:03 GMT
Content-Length: 6821
Content-Type: text/html

(data data data data data ...)
```

Let's take a careful look at this response message. It has three sections: an initial **status line**, six **header lines**, and then the **entity body**. The entity body is the meat of the message—it contains the requested object itself (represented by `data data data data data ...`). The status line has three fields: the protocol version field, a status code, and a corresponding status message. In this example, the status line indicates that the server is using HTTP/1.1 and that everything is OK (that is, the server has found, and is sending, the requested object).

Now let's look at the header lines. The server uses the `Connection: close` header line to tell the client that it is going to close the TCP connection after sending the message. The `Date:` header line indicates the time and date when the HTTP response was created and sent by the server. Note that this is not the time when the object was created or last modified; it is the time when the server retrieves the object from its file system, inserts the object into the response message, and sends the response message. The `Server:` header line indicates that the message was generated by an Apache Web server; it is analogous to the `User-agent:` header line in the HTTP request message. The `Last-Modified:` header line indicates the time and date when the object was created or last modified. The `Last-Modified:` header, which we will soon cover in more detail, is critical for object caching, both in the local client and in network cache servers (also known as proxy servers). The `Content-Length:` header line indicates the number of bytes in the object being sent. The `Content-Type:` header line indicates that the object in the entity body is HTML text. (The object type is officially indicated by the `Content-Type:` header and not by the file extension.)

Having looked at an example, let's now examine the general format of a response message, which is shown in Figure 2.9. This general format of the response message matches the previous example of a response message. Let's say a few additional words about status codes and their phrases. The status code and associated phrase indicate the result of the request. Some common status codes and associated phrases include:

- `200 OK`: Request succeeded and the information is returned in the response.
- `301 Moved Permanently`: Requested object has been permanently moved; the new URL is specified in `Location:` header of the response message. The client software will automatically retrieve the new URL.

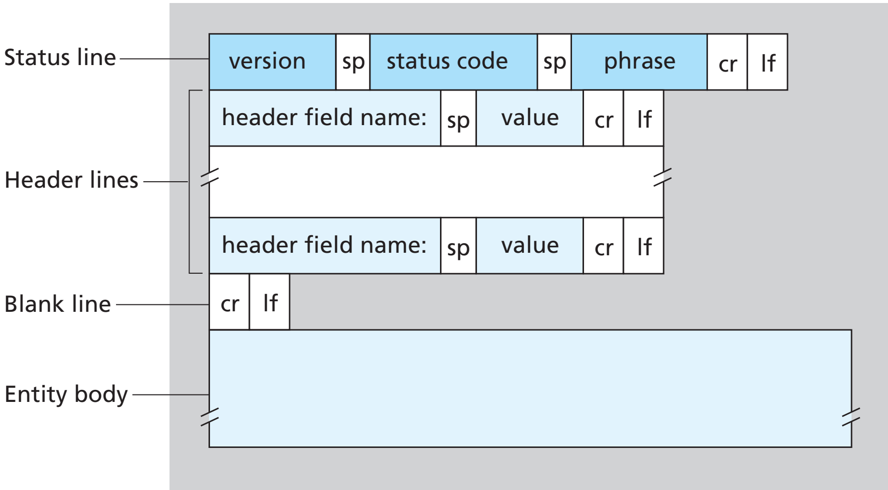

Figure 2.9 ♦ General format of an HTTP response message

- `400 Bad Request`: This is a generic error code indicating that the request could not be understood by the server.
- `404 Not Found`: The requested document does not exist on this server.
- `505 HTTP Version Not Supported`: The requested HTTP protocol version is not supported by the server.

How would you like to see a real HTTP response message? This is highly recommended and very easy to do! First Telnet into your favorite Web server. Then type in a one-line request message for some object that is housed on the server. For example, if you have access to a command prompt, type:

VideoNote
Using Wireshark to investigate the HTTP protocol

```
telnet cis.poly.edu 80

GET /~ross/ HTTP/1.1
Host: cis.poly.edu
```

(Press the carriage return twice after typing the last line.) This opens a TCP connection to port 80 of the host `cis.poly.edu` and then sends the HTTP request message. You should see a response message that includes the base HTML file of Professor Ross's homepage. If you'd rather just see the HTTP message lines and not receive the object itself, replace `GET` with `HEAD`. Finally, replace `/~ross/` with `/~banana/` and see what kind of response message you get.

In this section we discussed a number of header lines that can be used within HTTP request and response messages. The HTTP specification defines many, many more header lines that can be inserted by browsers, Web servers, and network cache servers. We have covered only a small number of the totality of header lines. We'll cover a few more below and another small number when we discuss network Web caching in Section 2.2.5. A highly readable and comprehensive discussion of the HTTP protocol, including its headers and status codes, is given in [Krishnamurthy 2001].

How does a browser decide which header lines to include in a request message? How does a Web server decide which header lines to include in a response message? A browser will generate header lines as a function of the browser type and version (for example, an HTTP/1.0 browser will not generate any 1.1 header lines), the user configuration of the browser (for example, preferred language), and whether the browser currently has a cached, but possibly out-of-date, version of the object. Web servers behave similarly: There are different products, versions, and configurations, all of which influence which header lines are included in response messages.

2.2.4 User-Server Interaction: Cookies

We mentioned above that an HTTP server is stateless. This simplifies server design and has permitted engineers to develop high-performance Web servers that can handle thousands of simultaneous TCP connections. However, it is often desirable for a Web site to identify users, either because the server wishes to restrict user access or because it wants to serve content as a function of the user identity. For these purposes, HTTP uses cookies. Cookies, defined in [RFC 6265], allow sites to keep track of users. Most major commercial Web sites use cookies today.

As shown in Figure 2.10, cookie technology has four components: (1) a cookie header line in the HTTP response message; (2) a cookie header line in the HTTP request message; (3) a cookie file kept on the user's end system and managed by the user's browser; and (4) a back-end database at the Web site. Using Figure 2.10, let's walk through an example of how cookies work. Suppose Susan, who always accesses the Web using Internet Explorer from her home PC, contacts Amazon.com for the first time. Let us suppose that in the past she has already visited the eBay site. When the request comes into the Amazon Web server, the server creates a unique identification number and creates an entry in its back-end database that is indexed by the identification number. The Amazon Web server then responds to Susan's browser, including in the HTTP response a `Set-cookie:` header, which contains the identification number. For example, the header line might be:

```
Set-cookie: 1678
```

When Susan's browser receives the HTTP response message, it sees the `Set-cookie:` header. The browser then appends a line to the special cookie file that it manages. This line includes the hostname of the server and the identification number in the `Set-cookie:` header. Note that the cookie file already has an entry for