How to Install Apache Tomcat 8 (on Windows, Mac OS, Ubuntu) and Get Started with Java Servlet Programming

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This practical can be completed in a 3-hour session.

This installation and configuration guide is applicable to Tomcat 7 and 8, and possibly the earlier versions.

Take note that Tomcat 8 requires JDK 1.7. It will NOT work with JDK 1.6. If your JDK is below 1.7, upgrade it (See JDK How-To). You can check your JDK version via command "`javac -version`".

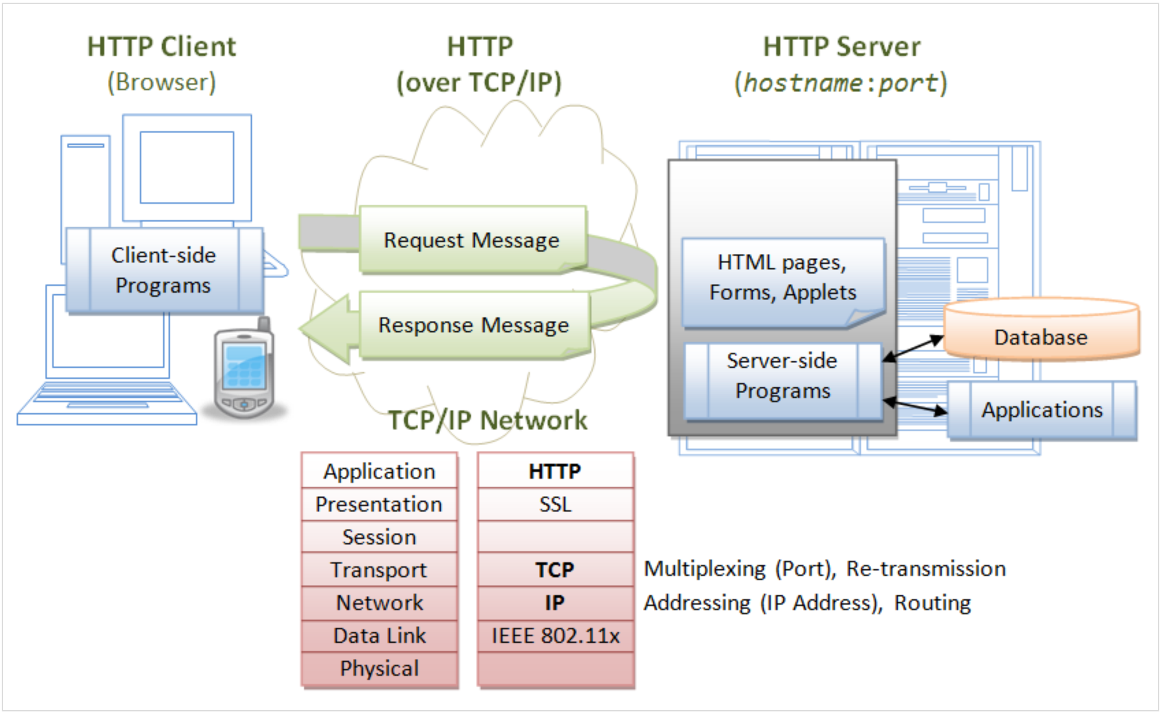
1. Introduction

1.1 Web Application (Webapp)

A *web application* (or webapp), unlike standalone application, runs over the Internet. Examples of webapps are google, amazon, ebay, facebook and twitter.

A webapp is typically a *3-tier* (or *multi-tier*) *client-server database application* run over the Internet as illustrated in the diagram below. It comprises five components:

1. **HTTP Server**: E.g., Apache HTTP Server, Apache Tomcat Server, Microsoft Internet Information Server (IIS), nginx, Google Web Server (GWS), and others.
2. **HTTP Client (or Web Browser)**: E.g., Internet Explorer (MSIE), FireFox, Chrome, Safari, and others.
3. **Database**: E.g., Open-source MySQL, Apache Derby, mSQL, SQLite, PostgreSQL, OpenOffice's Base; Commercial Oracle, IBM DB2, SAP SyBase, MS SQL Server, MS Access; and others.
4. **Client-Side Programs**: could be written in HTML Form, JavaScript, VBScript, Flash, and others.
5. **Server-Side Programs**: could be written in Java Servlet/JSP, ASP, PHP, Perl, Python, CGI, and others.



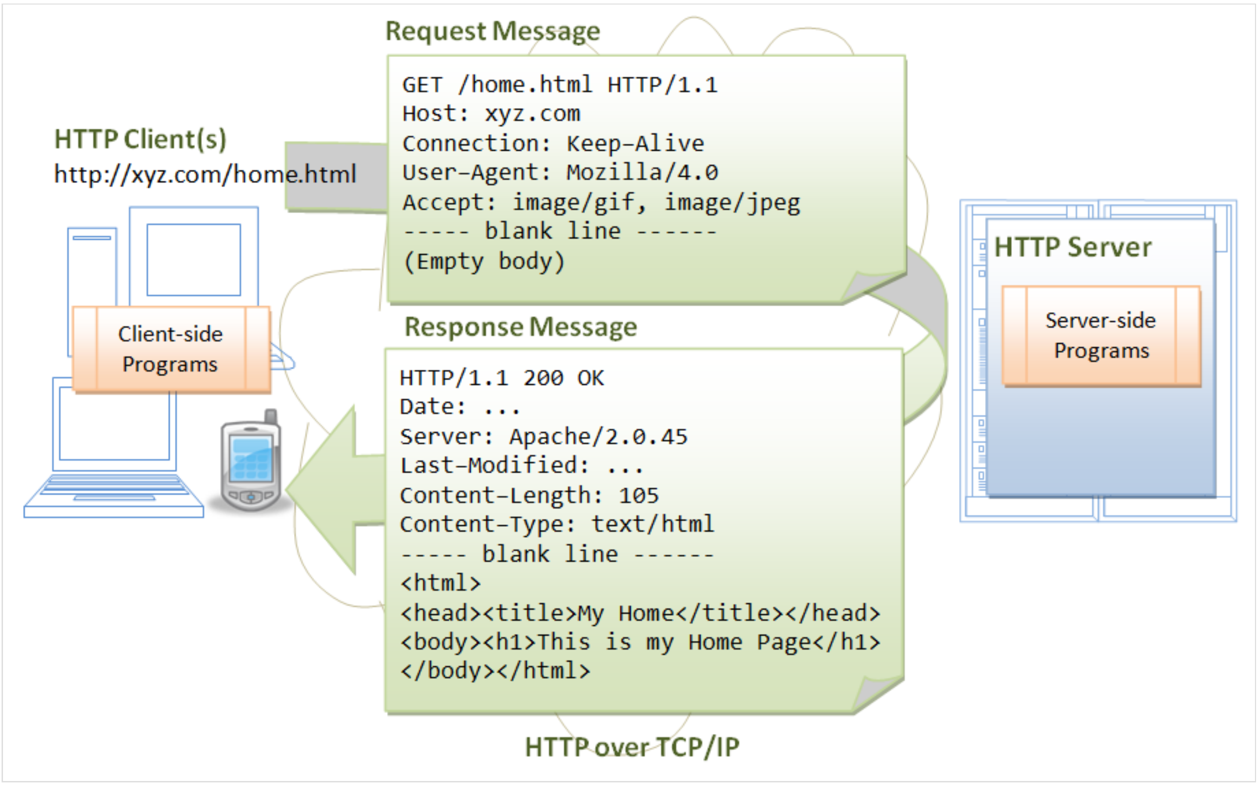
The typical use-case is:

1. A user, via a web browser (HTTP client), issues a URL request to an HTTP server to start a webapp.

2. The HTTP server returns an HTML form (client-side program), which is loaded into the client's browser.
3. The user fills up the query criteria inside the form and submits the form.
4. The client-side program sends the query parameters to a server-side program.
5. The server-side program receives the query parameters, queries the database based on these parameters, and returns the query result to the client-side program.
6. The client-side program displays the query result on the browser.
7. The process repeats for the next request.

1.2 Hypertext Transfer Protocol (HTTP)

- HTTP is an *application layer* protocol runs over TCP/IP. The IP provides support for routing and addressing (via an unique IP address for machines on the Internet); while TCP supports multiplexing via 64K ports from port number 0 to 65535. The default port number assigned to HTTP is TCP port 80.
- HTTP is an *asynchronous request-response application-layer protocol*. A client sends a request message to the server. The server then returns a response message to the client. In other words, HTTP is a *pull* protocol, a client pulls a page from the server (instead of server pushes pages to the clients).
- The syntax of the message is defined in the HTTP specification.



```
GET /home.html HTTP/1.1
Host: xyz.com
Connection: Keep-Alive
User-Agent: Mozilla/4.0
Accept: image/gif, image/jpeg
----- blank line ------
(Empty body)
```

```
HTTP/1.1 200 OK
Date: ...
Server: Apache/2.0.45
Last-Modified: ...
Content-Length: 105
Content-Type: text/html
----- blank line ------
<html>
<head><title>My Home</title></head>
<body><h1>This is my Home Page</h1>
</body></html>
```

1.3 Apache Tomcat HTTP Server

Apache Tomcat is a Java-capable HTTP server, which could execute special Java programs known as "Java Servlet" and "Java Server Pages (JSP)". Tomcat is an *open-source* project, under the "Apache Software Foundation" (which also provides the most use, open-source, industrial-strength Apache HTTP Server). The mother site for Tomcat is http://tomcat.apache.org. Alternatively, you can find tomcat via the Apache mother site @ http://www.apache.org.

Tomcat was originally written by James Duncan Davison (then working in Sun), in 1998, based on an earlier Sun's server called Java Web Server (JWS). It began at version 3.0 after JSWDK 2.1 it replaced. Sun subsequently made Tomcat open-source and gave it to Apache.

The various Tomcat releases are:

1. Tomcat 3.x (1999): RI for Servlet 2.2 and JSP 1.1.
2. Tomcat 4.x (2001): RI for Servlet 2.3 and JSP 1.2.
3. Tomcat 5.x (2002): RI for Servlet 2.4 and JSP 2.0.
4. Tomcat 6.x (2006): RI for Servlet 2.5 and JSP 2.1.
5. Tomcat 7.x (2010): RI for Servlet 3.0, JSP 2.2 and EL 2.2.
6. Tomcat 8.x (2013): RI for Servlet 3.1, JSP 2.3, EL 3.0 and Java WebSocket 1.0.

Tomcat is an HTTP application runs over TCP/IP. In other words, the Tomcat server runs on a specific TCP port from a specific IP address. The default TCP port number for HTTP protocol is 80, which is used for the *production* HTTP server. For *test* HTTP server, you can choose any unused port number between 1024 and 65535.

2. How to Install Tomcat 8 and Get Started with Java Servlet Programming

2.1 STEP 1: Download and Install Tomcat

NOTE: At the time of writing, Tomcat 9 is at the alpha stage, not stable release. We shall install Tomcat 8.5.11.

For Windows

1. Goto http://tomcat.apache.org ⇒ Under "Tomcat 8.5.{xx} Released" (where *{xx}* is the latest upgrade number) ⇒ Downloads ⇒ Under "8.5.{xx}" ⇒ Binary Distributions ⇒ Core ⇒ "**ZIP**" package (e.g., "`apache-tomcat-8.5.{xx}.zip`", about 9 MB).
2. Create your project directory, say "`d:\myProject`" or "`c:\myProject`". UNZIP the downloaded file into your project directory. Tomcat will be unzipped into directory "`d:\myProject\apache-tomcat-8.0.{xx}`".
3. For **ease of use**, we shall shorten and rename this directory to "`d:\myProject\tomcat`".

Take note of Your Tomcat Installed Directory. Hereafter, I shall refer to the Tomcat installed directory as `<TOMCAT_HOME>`.

For Mac OS

1. Goto http://tomcat.apache.org ⇒ Under "Tomcat 8.5.{xx} Released" (where *{xx}* is the latest upgrade number) ⇒ Downloads ⇒ Under "8.5.{xx}"⇒ Binary distribution ⇒ Core ⇒ "**tar.gz**" package (e.g., "`apache-tomcat-8.0.{xx}.tar.gz`", about 9 MB).
2. To install Tomcat:
   a. Goto "`~/Downloads`", double-click the downloaded tarball (e.g., "`apache-tomcat-8.0.{xx}.tar.gz`") to expand it into a folder (e.g., "`apache-tomcat-8.0.{xx}`").
   b. Move the extracted folder (e.g., "`apache-tomcat-8.0.{xx}`") to "`/Applications`".
   c. For **ease of use**, we shall shorten and rename this folder to "tomcat".

Take note of Your Tomcat Installed Directory. Hereafter, I shall refer to the Tomcat installed directory as `<TOMCAT_HOME>`.

For Ubuntu

Read "How to Install Tomcat 8 on Ubuntu". You need to switch between these two articles.

For academic learning, I recommend "`zip`" (or "`tar.gz`") version, as you could simply delete the entire directory when Tomcat is no longer needed (without running any un-installer). You are free to move or rename the Tomcat's installed directory. You can install (unzip) multiple copies of Tomcat in the same machine. For production, it is easier to use the installer to properly configure the Tomcat.

Tomcat's Directories

Take a quick look at the Tomcat installed directory. It contains the following sub-directories:

- **`bin`**: contains the binaries; and startup script (`startup.bat` for Windows and `startup.sh` for Unixes and Mac OS), shutdown script (`shutdown.bat` for Windows and `shutdown.sh` for Unix and Mac OS), and other binaries and scripts.
- **`conf`**: contains the system-wide configuration files, such as `server.xml`, `web.xml`, `context.xml`, and `tomcat-users.xml`.
- **`lib`**: contains the Tomcat's system-wide JAR files, accessible by all webapps. You could also place external JAR file (such as MySQL JDBC Driver) here.
- **`logs`**: contains Tomcat's log files. You may need to check for error messages here.
- **`webapps`**: contains the webapps to be deployed. You can also place the WAR (Webapp Archive) file for deployment here.
- **`work`**: Tomcat's working directory used by JSP, for JSP-to-Servlet conversion.
- **`temp`**: Temporary files.

2.2 STEP 2: Create an Environment Variable `JAVA_HOME`

(For Windows)

You need to create an *environment variable* called "`JAVA_HOME`" and set it to your JDK installed directory.

1. First, find your JDK installed directory. The default is "`c:\Program Files\Java\jdk1.8.0_{xx}`", where *{xx}* is the upgrade number. Take note of your JDK installed directory.
2. To set the environment variable `JAVA_HOME` in Windows 7/8/10: Start "Control Panel" ⇒ System and Security (Optional) ⇒ System ⇒ Advanced system settings ⇒ Switch to "Advanced" tab ⇒ Environment Variables ⇒ System Variables ⇒ "New" ⇒ In "Variable Name", enter "`JAVA_HOME`" ⇒ In "Variable Value", enter your JDK installed directory as noted in Step 1.
3. To verify, **RE-START** a CMD shell (restart needed to refresh the environment) and issue:

```
SET JAVA_HOME
JAVA_HOME=c:\Program Files\Java\jdk1.8.0_{xx}   <== Verify that this is YOUR JDK installed directory
```

(For Mac OS)

Skip this step. No need to do anything.

2.3 STEP 3: Configure Tomcat Server

The Tomcat configuration files are located in the "`conf`" sub-directory of your Tomcat installed directory, e.g. "`d:\myProject\tomcat\conf`" (for Windows) or "`/Applications/tomcat/conf`" (for Mac OS). There are 4 configuration XML files:

1. `server.xml`
2. `web.xml`

3. context.xml
4. tomcat-users.xml

Make a BACKUP of the configuration files before you proceed!!!

Step 3(a) "conf\server.xml" - Set the TCP Port Number

Use a programming text editor (e.g., NotePad++, TextPad, Sublime, Atom for Windows; or gEdit, jEdit, Sublime, Atom for Mac OS) to open the configuration file "server.xml", under the "conf" sub-directory of Tomcat installed directory.

The default TCP port number configured in Tomcat is 8080, you may choose any number between 1024 and 65535, which is not used by an existing application. We shall choose 9999 in this article. (For production server, you should use port 80, which is pre-assigned to HTTP server as the default port number.)

Locate the following lines (around Line 69) that define the HTTP connector, and change port="8080" to port="9999".

```
<!-- A "Connector" represents an endpoint by which requests are received
      and responses are returned. Documentation at :
      Java HTTP Connector: /docs/config/http.html (blocking & non-blocking)
      Java AJP  Connector: /docs/config/ajp.html
      APR (HTTP/AJP) Connector: /docs/apr.html
      Define a non-SSL HTTP/1.1 Connector on port 8080
-->
<Connector port="9999" protocol="HTTP/1.1"
           connectionTimeout="20000"
           redirectPort="8443" />
```

Step 3(b) "conf\web.xml" - Enabling Directory Listing

Again, use a programming text editor to open the configuration file "web.xml", under the "conf" sub-directory of Tomcat installed directory.

We shall enable directory listing by changing "listings" from "false" to "true" for the "default" servlet. This is handy for test system, but not for production system for security reasons.

Locate the following lines (around Line 103) that define the "default" servlet; and change the "listings" from "false" to "true".

```
<!-- The default servlet for all web applications, that serves static     -->
<!-- resources.  It processes all requests that are not mapped to other   -->
<!-- servlets with servlet mappings.                                      -->
<servlet>
  <servlet-name>default</servlet-name>
  <servlet-class>org.apache.catalina.servlets.DefaultServlet</servlet-class>
  <init-param>
    <param-name>debug</param-name>
    <param-value>0</param-value>
  </init-param>
  <init-param>
    <param-name>listings</param-name>
    <param-value>true</param-value>
  </init-param>
  <load-on-startup>1</load-on-startup>
</servlet>
```

Step 3(c) "conf\context.xml" - Enabling Automatic Reload

We shall add the attribute reloadable="true" to the <Context> element to enable automatic reload after code changes. Again, this is handy for test system but not for production, due to the overhead of detecting changes.

Locate the <Context> start element (around Line 19), and change it to <Context reloadable="true">.

```
<Context reloadable="true">
   ......
   ......
</Context>
```

Step 3(d) (Optional) "conf\tomcat-users.xml"

Enable the Tomcat's manager by adding the highlighted lines, inside the <tomcat-users> elements:

```
<tomcat-users>
  <role rolename="manager-gui"/>
  <user username="manager" password="xxxx" roles="manager-gui"/>
</tomcat-users>
```

This enables the manager GUI app for managing Tomcat server.

2.4 STEP 4: Start Tomcat Server

The Tomcat's executable programs and scripts are kept in the "bin" sub-directory of the Tomcat installed directory, e.g., "d:\myProject\tomcat\bin" (for Windows) or "/Applications/tomcat/bin" (for Mac OS).

Step 4(a) Start Server

For Windows

Launch a CMD shell. Set the current directory to "`<TOMCAT_HOME>\bin`", and run "`startup.bat`" as follows:

```
// Change the current directory to Tomcat's "bin"
// Assume that Tomcat is installed in "d:\myProject\tomcat"
d:                             // Change the current drive
cd \myProject\tomcat\bin  // Change Directory to YOUR Tomcat's "bin" directory

// Start Tomcat Server
startup
```

For Mac OS

I assume that Tomcat is installed in "`/Applications/tomcat`". To start the Tomcat server, open a new "Terminal" and issue:

```
// Change current directory to Tomcat's binary directory
cd /Applications/tomcat/bin

// Start tomcat server
./catalina.sh run
```

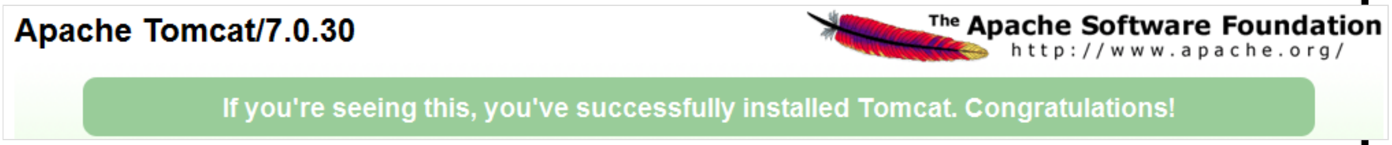
A *new* Tomcat console window appears. Study the messages on the console. Look out for the Tomcat's port number (double check that Tomcat is running on port 9999). Future error messages will be send to this console. `System.out.println()` issued by your Java servlets will also be sent to this console.

```
......
......
xxx xx, xxxx x:xx:xx xx org.apache.coyote.AbstractProtocol start
INFO: Starting ProtocolHandler ["http-bio-9999"]
xxx xx, xxxx x:xx:xx xx org.apache.coyote.AbstractProtocol start
INFO: Starting ProtocolHandler ["ajp-bio-8009"]
xxx xx, xxxx x:xx:xx xx org.apache.catalina.startup.Catalina start
INFO: Server startup in 2477 ms
```

(Skip Unless ...) Cannot Start Tomcat: Read "How to Debug".

Step 4(b) Start a Client to Access the Server

Start a browser (as HTTP client). Issue URL "`http://localhost:9999`" to access the Tomcat server's welcome page. The hostname "`localhost`" (with IP address of `127.0.0.1`) is meant for local loop-back testing inside the same machine. For users on the other machines over the net, they have to use the server's IP address or DNS domain name or hostname in the format of "`http://`*`serverHostnameOrIPAddress`*`:9999`".


Apache Tomcat/7.0.30

The Apache Software Foundation http://www.apache.org/

If you're seeing this, you've successfully installed Tomcat. Congratulations!

Try issuing URL `http://localhost:9999/examples` to view the servlet and JSP examples. Try running some of the servlet examples.

(Optional) Try issuing URL `http://localhost:9999/manager/html` to run the Tomcat Web Manager. Enter the username and password configured earlier in `tomcat-users.xml`.

Step 4(c) Shutdown Server

For Windows

You can shutdown the tomcat server by either:

1. Press Ctrl-C on the Tomcat console; OR
2. Run "`<TOMCAT_HOME>\bin\`**`shutdown.bat`**" script. Open a new "cmd" and issue:

```
// Change the current directory to Tomcat's "bin"
d:                             // Change the current drive
cd \myProject\tomcat\bin  // Change Directory to YOUR Tomcat's "bin" directory

// Shutdown the server
shutdown
```

For Mac OS

To shutdown the Tomcat server:

1. Press Control-C (NOT Command-C) on the Tomcat console; OR
2. Run the "`<TOMCAT_HOME>/bin/shutdown.sh`" script. Open a new "Terminal" and issue:

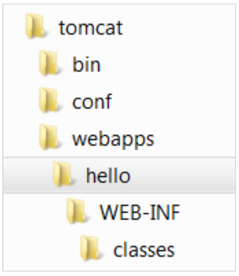
```
// Change current directory to Tomcat's bin directory
cd /Applications/tomcat/bin

// Shutdown the server
./shutdown.sh
```

WARNING: You MUST properly shutdown the Tomcat. DO NOT kill the cat by pushing the window's "CLOSE" button.

2.5 STEP 5: Develop and Deploy a WebApp

Step 5(a) Create the Directory Structure for your WebApp



First of all, choose a *name* for your webapp. Let's call it "`hello`". Goto Tomcat's "`webapps`" sub-directory. Create the following directory structure for you webapp "`hello`" (as illustrated):

1. Under Tomcat's "`webapps`", create your webapp *root* directory "`hello`" (i.e., "`<TOMCAT_HOME>\webapps\hello`").
2. Under "`hello`", create a sub-directory "`WEB-INF`" (case sensitive, a "dash" not an underscore) (i.e., "`<TOMCAT_HOME>\webapps\hello\WEB-INF`").
3. Under "`WEB-INF`", create a sub-sub-directory "`classes`" (case sensitive, plural) (i.e., "`<TOMCAT_HOME>\webapps\hello\WEB-INF\classes`").

You need to keep your web resources (e.g., HTMLs, CSSs, images, scripts, servlets, JSPs) in the proper directories:

- "`hello`": The is called the *context root* (or *document base directory*) of your webapp. You should keep all your HTML files and resources visible to the web users (e.g., HTMLs, CSSs, images, scripts, JSPs) under this *context root*.
- "`hello/WEB-INF`": This directory, although under the context root, is *not visible* to the web users. This is where you keep your application's web descriptor file "`web.xml`".
- "`hello/WEB-INF/classes`": This is where you keep all the Java classes such as servlet class-files.

You should RE-START your Tomcat server to pick up the `hello` webapp. Check the Tomcat's console to confirm that "`hello`" application has been properly deployed:

```
......
INFO: Deploying web application directory D:\myProject\tomcat\webapps\hello
......
```

You can issue the following URL to access the web application "`hello`":

```
http://localhost:9999/hello
```

You should see the directory listing of the directory "`<TOMCAT_HOME>\webapps\hello`", which shall be empty (provided you have enabled directory listing in `web.xml` earlier).

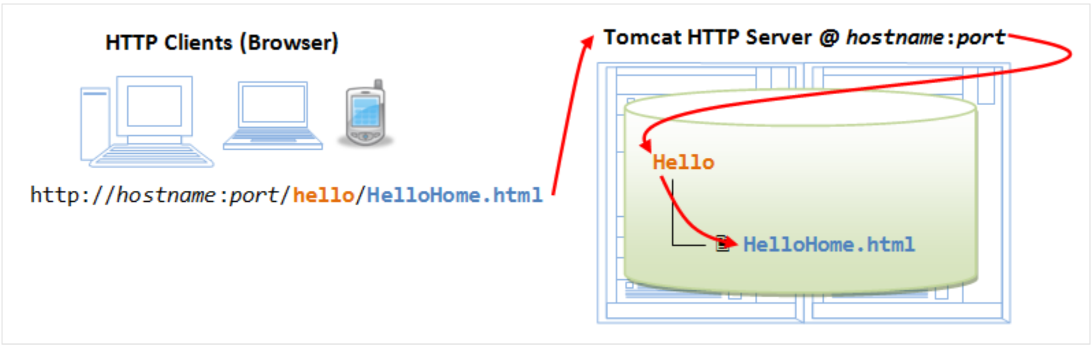
Step 5(b) Write a Welcome Page

Create the following HTML page and save as "`HelloHome.html`" in your application's root directory "`hello`".

```
<html>
  <head><title>My Home Page</title></head>
  <body>
    <h1>My Name is so and so. This is my HOME.</h1>
  </body>
</html>
```

You can browse this page by issuing this URL:

```
http://localhost:9999/hello/HelloHome.html
```


HTTP Clients (Browser)
http://hostname:port/hello/HelloHome.html
Tomcat HTTP Server @ hostname:port
Hello
HelloHome.html

Alternatively, you can issue an URL to your web application root "`hello`":

```
http://localhost:9999/hello
```

The server will return the directory listing of your base directory. You can then click on "`HelloHome.html`".

Rename "`HelloHome.html`" to "`index.html`", and issue a directory request again:

```
http://localhost:9999/hello
```

Now, the server will redirect the directory request to "`index.html`", if the root directory contains an "`index.html`", instead of serving the directory listing.

You can check out the home page of your peers by issuing:

```
http://YourPeerHostnameOrIPAddress:9999/hello
http://YourPeerHostnameOrIPAddress:9999/hello/HelloHome.html
http://YourPeerHostnameOrIPAddress:9999/hello/index.html
```

with a valid "*YourPeerHostnameOrIPAddress*", provided that your peer has started his tomcat server and his firewall does not block your access. You can use command such as "`ipconfig`" (Windows), "`ifconfig`" (Mac OS and Unix) to find your IP address.

(Skip Unless...) The likely errors are "Unable to Connect", "Internet Explorer cannot display the web page", and "404 File Not Found". Read "How to Debug" section.

2.6 STEP 6: Write a "Hello-world" Java Servlet

A *servlet* is Java program that runs inside a Java-capable HTTP Server, such as Apache Tomcat. A web user invokes a servlet by issuing an appropriate URL from a web browser (HTTP client).

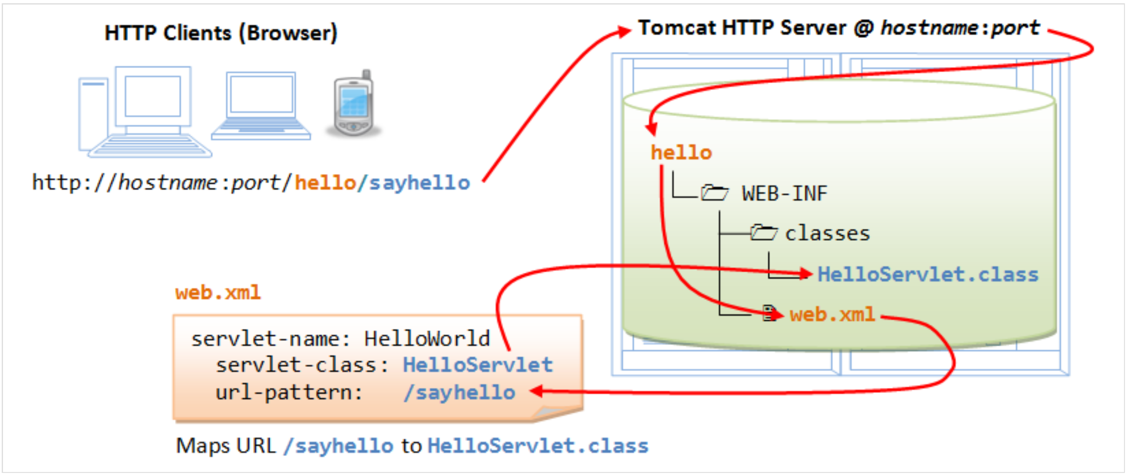
Before you proceed, I shall assume that you are familiar with Java Programming and have installed the followings:

1. JDK (Read "How to install JDK and Get Started").
2. A programming text editor, such as TextPad or Notepad++ (for Windows); jEdit or gEdit (for Mac OS) (Read "Programming Text Editor").

Step 6(a) Write a "Hello-world" Java Servlet

A Java servlet is a Java program that runs inside a HTTP server. A web user invokes a servlet by issuing a URL from a browser (or HTTP client).

In this example, we are going to write a Java servlet called `HelloServlet`, which says "Hello, world!". We will then write a configuration such that web users can invoke this servlet by issuing URL `http://`*`hostname`*`:`*`port`*`/hello/sayhello` from their browser, as illustrated:



HTTP Clients (Browser)
http://hostname:port/hello/sayhello
Tomcat HTTP Server @ hostname:port
hello
WEB-INF
classes
HelloServlet.class
web.xml
web.xml
servlet-name: HelloWorld
servlet-class: HelloServlet
url-pattern: /sayhello
Maps URL /sayhello to HelloServlet.class

Write the following source codes called "HelloServlet.java" and save it under your application "classes" directory (i.e., "`<TOMCAT_HOME>\webapps\hello\`**`WEB-INF\classes`**`\HelloServlet.java`"). This servlet says "Hello", echoes some request information, and prints a random number upon each request.

```java
// To save as "<TOMCAT_HOME>\webapps\hello\WEB-INF\classes\HelloServlet.java"
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class HelloServlet extends HttpServlet {
   @Override
   public void doGet(HttpServletRequest request, HttpServletResponse response)
         throws IOException, ServletException {

      // Set the response MIME type of the response message
      response.setContentType("text/html");
      // Allocate a output writer to write the response message into the network socket
      PrintWriter out = response.getWriter();

      // Write the response message, in an HTML page
      try {
         out.println("<html>");
         out.println("<head><title>Hello, World</title></head>");
         out.println("<body>");
         out.println("<h1>Hello, world!</h1>");  // says Hello
         // Echo client's request information
         out.println("<p>Request URI: " + request.getRequestURI() + "</p>");
         out.println("<p>Protocol: " + request.getProtocol() + "</p>");
         out.println("<p>PathInfo: " + request.getPathInfo() + "</p>");
         out.println("<p>Remote Address: " + request.getRemoteAddr() + "</p>");
         // Generate a random number upon each request
         out.println("<p>A Random Number: <strong>" + Math.random() + "</strong></p>");
         out.println("</body></html>");
      } finally {
         out.close();  // Always close the output writer
      }
   }
}
```

Step 6(b) Compiling the Servlet (DIFFICULT)

We need the Servlet API to compile the servlet. Servlet API is NOT part of JDK. Nonetheless, Tomcat provides a copy in `<TOMCAT_HOME>/lib/servlet-api.jar`. We need to include this JAR file in the compilation via the `-cp` (classpath) option.

(For Windows)

```
// Assume that Tomcat is installed in d:\myProject\tomcat
// Change directory to the source file
d:
cd \myProject\tomcat\webapps\hello\WEB-INF\classes

// Compile
javac -cp .;d:\myProject\tomcat\lib\servlet-api.jar HelloServlet.java
    // Note: You need to enclose the jar file in double quotes if the path contains blank
    //       e.g., javac -cp .;"d:\Path To\tomcat\lib\servlet-api.jar" HelloServlet.java
```

(For Mac OS)

```
// Assume that Tomcat is installed in /Applications/tomcat
// Change directory to the source file
cd /Applications/tomcat/webapps/hello/WEB-INF/classes

// Compile
javac -cp .:/Applications/tomcat/lib/servlet-api.jar HelloServlet.java
```

The output of the compilation is "`HelloServlet.class`". Browse the "`classes`" folder to make sure that it is created.

(Skip Unless...) Read "Common Errors in Compiling Java Servlet".

Step 6(c) Configure Servlet's Request URL in "`webapps\hello\WEB-INF\web.xml`"

A web user invokes a servlet, which is kept in the web server, by issuing *a request URL* from the browser. We need to configure this request URL for our `HelloServlet`.

Create the following configuration file called "**`web.xml`**", and save it under "**`webapps\hello\WEB-INF`**" (i.e., "`<TOMCAT_HOME>\webapps\hello\WEB-INF\web.xml`").

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<web-app version="3.0"
  xmlns="http://java.sun.com/xml/ns/javaee"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://java.sun.com/xml/ns/javaee http://java.sun.com/xml/ns/javaee/web-app_3_0.xsd">

   <!-- To save as "hello\WEB-INF\web.xml" -->

   <servlet>
      <servlet-name>HelloWorld</servlet-name>
      <servlet-class>HelloServlet</servlet-class>
   </servlet>

   <!-- Note: All <servlet> elements MUST be grouped together and
         placed IN FRONT of the <servlet-mapping> elements -->

   <servlet-mapping>
      <servlet-name>HelloWorld</servlet-name>
      <url-pattern>/sayhello</url-pattern>
   </servlet-mapping>
</web-app>
```

In the above configuration, a servlet having a class file "`HelloServlet.class`" is mapped to request URL "`/sayhello`" (via an *arbitrary* `servlet-name` "`HelloWorld`"), under this web application "`hello`". In other words, the complete request URL for this servlet is "`http://`*`hostname`*`:`*`port`***`/hello/sayhello`**".

This configuration file, saved under your webapp "`hello`", is applicable only to this particular webapp "`hello`".

RESTART your Tomcat server to refresh the "`web.xml`" file.

IMPORTANT: For EACH servlet, you need to write a pair of `<servlet>` and `<servlet-mapping>` elements with a common but arbitrary `<servlet-name>`. Take note that all the `<servlet>` elements MUST be grouped together and placed IN FRONT of the `<servlet-mapping>` elements.

Step 6(d) Invoke the Servlet

To run this servlet, start a browser, and issue the request URL configured earlier:

```
http://localhost:9999/hello/sayhello
```

You shall see the output of the servlet displayed in your web browser.

Refresh the browser, you shall see a new random number upon each refresh. In other word, the `doGet()` method of the servlet runs once per request.

View Page Source

(For Firefox and Chrome) Right-click the page ⇒ "View Page Source" to look at the output received by the web browser (returned by the server). Take note that the web browser receives only the output of the servlet (generated via the `out.println()` statements). The client has no access to the servlet source codes (which may contain confidential information).

(For Mac OS's Safari browser) You need to enable "Developer Menu" under the "Preferences" to enable the "View Source" menu.

```
<html>
<head><title>Hello, World</title></head>
<body>
<h1>Hello, world!</h1>
<p>Request URI: /hello/sayhello</p>
<p>Protocol: HTTP/1.1</p>
<p>PathInfo: null</p>
<p>Remote Address: 127.0.0.1</p>
<p>A Random Number: <strong>0.3523682325749493</strong></p>
</body>
</html>
```

(Skip Unless...) The likely errors are "404 File Not Found" and "500 Internal Server Error". Read "How to debug" Section.

(Optional) Inspecting HTTP Request and Response Messages

When you enter a URL (e.g., `http://localhost:9999/hello/sayhello`) on a web browser, an HTTP GET *request message* is sent to the server; and the server returns a *response message* for display on the web browser. You can inspect the request and response messages via Web browser's Developer Tool.

For **Firefox**, press F12 to enable "web console". Choose "Console" pane. Enter URL `http://localhost:9999/hello/sayhello` (or refresh). Enable "Net" (not in Gray). Expand the link `http://localhost:9999/hello/sayhello`. A HTTP message consists of a header and a body. Inspect the request header and body; as well as the response header and body.

For **Chrome**, press F12 to enable "developer tool". Choose "Network" pane. Enter URL `http://localhost:9999/hello/sayhello` (or refresh). Selet the link `http://localhost:9999/hello/sayhello`.Inspect the request header and body; as well as the response header and body.

The request message *header* is as follows:

```
GET http://localhost:9999/hello/sayhello HTTP/1.1
Host: localhost:9999
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Encoding: gzip, deflate
Accept-Language: en-US,en;q=0.5
Cache-Control:max-age=0
Connection: keep-alive
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Windows NT 10.0; WOW64; rv:52.0) Gecko/20100101 Firefox/52.0
```

For this request, there is no request message body.

The response message *header* is as follows:

```
HTTP/1.1 200 OK
Date: Wed, 22 Mar 2017 09:30:23 GMT
Content-Length: 286
Content-Type: text/html;charset=ISO-8859-1
```

The response message *body* is as follows:

```
<html>
<head><title>Hello, World</title></head>
<body>
<h1>Hello, world!</h1>
<p>Request URI: /hello/sayhello</p>
<p>Protocol: HTTP/1.1</p>
<p>PathInfo: null</p>
<p>Remote Address: 0:0:0:0:0:0:0:1</p>
<p>A Random Number: <strong>0.4480280769255568</strong></p>
</body></html>
```

2.7 STEP 7: Write a Database Servlet

This section assumes that you are familiar with "Java database programming" and "MySQL database server". Otherwise, read "Java Database Program" and "How to Install MySQL 5 and Get Started".

Step 7(a) Setup a Database on MySQL (Already done in the MySQL exercises)

Start your MySQL server. Take note of the server's port number. I shall assume that the MySQL server is running on port `3306` (whereas the Tomcat is running on port 9999).

```
// For Windows
cd {path-to-mysql-bin}   // Check your MySQL installed directory
mysqld --console

// For Mac OS
// Use graphical control at "System Preferences" -> MySQL
```

Start a MySQL client. I shall assume that there is a user called "`myuser`" with password "`xxxx`".

```
// For Windows
cd {path-to-mysql-bin}   // Check your MySQL installed directory
mysql -u myuser -p
```

```
// For Mac OS
cd /usr/local/mysql/bin
./mysql -u myuser -p
```

Run the following SQL statements to create a database called "ebookshop", with a table called "books" with 5 columns: `id`, `title`, `author`, `price`, `qty`.

```
create database if not exists ebookshop;

use ebookshop;

drop table if exists books;
create table books (
   id     int,
   title  varchar(50),
   author varchar(50),
   price  float,
   qty    int,
   primary key (id));

insert into books values (1001, 'Java for dummies', 'Tan Ah Teck', 11.11, 11);
insert into books values (1002, 'More Java for dummies', 'Tan Ah Teck', 22.22, 22);
insert into books values (1003, 'More Java for more dummies', 'Mohammad Ali', 33.33, 33);
insert into books values (1004, 'A Cup of Java', 'Kumar', 55.55, 55);
insert into books values (1005, 'A Teaspoon of Java', 'Kevin Jones', 66.66, 66);

select * from books;
```

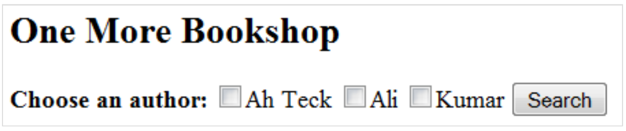
Step 7(b) Install MySQL JDBC Driver (Already done in the previous JDBC exercises)

You need to download MySQL JDBC driver if you have not done so. Read "Installing the MySQL JDBC Driver".

> **(For Advanced Users Only)** You could also place the MySQL driver jar-file "`mysql-connector-java-5.1.{xx}-bin.jar`" in Tomcat's "`lib`" directory.

Step 7(c) Write a Client-side HTML Form

Let's write an HTML script to create a *query form* with 3 checkboxes and a submit button, as illustrated below. Save the HTML file as "`querybook.html`" in your application root directory "`<TOMCAT_HOME>\webapps\hello`".



```
<html>
<head>
  <title>Yet Another Bookshop</title>
</head>
<body>
  <h2>Yet Another Bookshop</h2>
  <form method="get" action="http://localhost:9999/hello/query">
    <b>Choose an author:</b>
    <input type="checkbox" name="author" value="Tan Ah Teck">Ah Teck
    <input type="checkbox" name="author" value="Mohammad Ali">Ali
    <input type="checkbox" name="author" value="Kumar">Kumar
    <input type="submit" value="Search">
  </form>
</body>
</html>
```

You can browse the HTML page by issuing the following URL:

```
http://localhost:9999/hello/querybook.html
```

Check a box (e.g., "Tan Ah Teck") and click the "Search" button. An HTTP GET request will be issued to the URL specified in the `<form>`'s "`action`" attribute. Observe the URL of the HTTP GET request:

```
http://localhost:9999/hello/query?author=Tan+Ah+Teck
```

The request consists of two part: a URL corresponding to the "`action`" attribute of the `<form>` tag, and the "name=value" pair extracted from the `<input>` tag, separated by a `'?'`. Take note that blanks are replaced by `'+'` (or `%20`), because blanks are not allowed in the URL.

If you check two boxes (e.g., "Tan Ah Teck" and "Mohammad Ali"), you will get this URL, which has two "name=value" pairs separated by an `'&'`.

```
http://localhost:9999/hello/query?author=Tan+Ah+Teck&author=Mohammad+Ali
```

You are expected to get an error "404 File Not Found", as you have yet to write the server-side program.

Step 7(d) Write the Server-side Database Query Servlet

The next step is to write a Java servlet, which responses to the client's request by querying the database and returns the query results.

```
// To save as "<TOMCAT_HOME>\webapps\hello\WEB-INF\classes\QueryServlet.java".
```

```java
import java.io.*;
import java.sql.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class QueryServlet extends HttpServlet {  // JDK 1.6 and above only

   // The doGet() runs once per HTTP GET request to this servlet.
   @Override
   public void doGet(HttpServletRequest request, HttpServletResponse response)
               throws ServletException, IOException {
      // Set the MIME type for the response message
      response.setContentType("text/html");
      // Get a output writer to write the response message into the network socket
      PrintWriter out = response.getWriter();

      Connection conn = null;
      Statement stmt = null;
      try {
         // Step 1: Allocate a database Connection object
         conn = DriverManager.getConnection(
            "jdbc:mysql://localhost:3306/ebookshop?useSSL=false", "myuser", "xxxx"); // <== Check!
            // database-URL(hostname, port, default database), username, password

         // Step 2: Allocate a Statement object within the Connection
         stmt = conn.createStatement();

         // Step 3: Execute a SQL SELECT query
         String sqlStr = "select * from books where author = "
              + "'" + request.getParameter("author") + "'"
              + " and qty > 0 order by price desc";

         // Print an HTML page as the output of the query
         out.println("<html><head><title>Query Response</title></head><body>");
         out.println("<h3>Thank you for your query.</h3>");
         out.println("<p>You query is: " + sqlStr + "</p>"); // Echo for debugging
         ResultSet rset = stmt.executeQuery(sqlStr);  // Send the query to the server

         // Step 4: Process the query result set
         int count = 0;
         while(rset.next()) {
            // Print a paragraph <p>...</p> for each record
            out.println("<p>" + rset.getString("author")
                 + ", " + rset.getString("title")
                 + ", $" + rset.getDouble("price") + "</p>");
            count++;
         }
         out.println("<p>==== " + count + " records found =====</p>");
         out.println("</body></html>");
     } catch (SQLException ex) {
        ex.printStackTrace();
     } finally {
        out.close();  // Close the output writer
        try {
           // Step 5: Close the resources
           if (stmt != null) stmt.close();
           if (conn != null) conn.close();
        } catch (SQLException ex) {
           ex.printStackTrace();
        }
     }
   }
}
```

Compile the source "QueryServlet.java" into "QueryServlet.class". See the previous example in Step 6(b) on how to compile a servlet.

Step 7(e) Configure the Request URL for the Servlet

Open the configuration file "web.xml" of your application "hello" that you have created earlier for the HelloServlet, i.e., "<TOMCAT_HOME>\webapps\hello\WEB-INF\web.xml". Add the lines that are shown in red at the LOCATIONS INDICATED.

```xml
<?xml version="1.0" encoding="ISO-8859-1"?>
<web-app version="3.0"
  xmlns="http://java.sun.com/xml/ns/javaee"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://java.sun.com/xml/ns/javaee http://java.sun.com/xml/ns/javaee/web-app_3_0.xsd">

   <!-- To save as "hello\WEB-INF\web.xml" -->

   <servlet>
      <servlet-name>HelloWorld</servlet-name>
      <servlet-class>HelloServlet</servlet-class>
   </servlet>

   <servlet>
      <servlet-name>UserQuery</servlet-name>
      <servlet-class>QueryServlet</servlet-class>
   </servlet>

   <!-- Note: All <servlet> elements MUST be grouped together and
         placed IN FRONT of the <servlet-mapping> elements -->

   <servlet-mapping>
      <servlet-name>HelloWorld</servlet-name>
      <url-pattern>/sayhello</url-pattern>
   </servlet-mapping>

   <servlet-mapping>
      <servlet-name>UserQuery</servlet-name>
      <url-pattern>/query</url-pattern>
   </servlet-mapping>
</web-app>
```

The above lines configure the following URL to invoke `QueryServlet`:

```
http://localhost:9999/hello/query
```

Step 7(f) Invoke the Servlet from the Client-Side Form

Issue the following URL to browse the HMTL form "`querybook.html`" that you have created earlier:

```
http://localhost:9999/hello/querybook.html
```

Select an author (e.g., "Tan Ah Teck") and click the submit button, which activates the following URL coded in the `<form>`'s "`action`" attribute, together with the name=value pair:

```
http://localhost:9999/hello/query?author=Tan+Ah+Teck
```

This URL "/query" triggers `QueryServlet`. The `QueryServlet` retrieves the name=value pair of "`author=Tan+Ah+Teck`". Inside the `QueryServlet`, the method `request.getParameter("author")` returns "`Tan Ah Teck`", which is inserted into the SQL `SELECT` command to query the database. The processed query result is then written to the client as an HTML document.

(Skip Unless...) The likely errors are "404 File Not Found" and "500 Internal Server Error". Read "How to debug" Section.

2.8 (Advanced) Deploying Servlet using `@WebServlet` (Servlet 3.0 on Tomcat 7)

Servlet 3.0, which is supported by Tomcat 7, introduces the `@WebServlet` annotation, which greatly simplifies the deployment of servlets. You no longer need to write the deployment descriptor in "`web.xml`". Instead, you can use the `@WebServlet` annotation to specify the URL mapping.

For example, let us write a new servlet called `AnotherHelloServlet.java`, by modifying the `HelloServlet.java` written earlier, with URL mapping of "`sayhi`".

```
// To save as "<TOMCAT_HOME>\webapps\hello\WEB-INF\classes\AnotherHelloServlet.java"
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;
import javax.servlet.annotation.*;

@WebServlet("/sayhi")
public class AnotherHelloServlet extends HttpServlet {
   @Override
   public void doGet(HttpServletRequest request, HttpServletResponse response)
         throws IOException, ServletException {

      // Set the response MIME type
      response.setContentType("text/html;charset=UTF-8");
      // Allocate a output writer to write the response message into the network socket
      PrintWriter out = response.getWriter();

      // Write the response message, in an HTML page
      try {
         out.println("<html>");
         out.println("<head><title>Hello, World</title></head>");
         out.println("<body>");
         out.println("<h1>Hello world, again!</h1>");  // says Hello
         // Echo client's request information
         out.println("<p>Request URI: " + request.getRequestURI() + "</p>");
         out.println("<p>Protocol: " + request.getProtocol() + "</p>");
         out.println("<p>PathInfo: " + request.getPathInfo() + "</p>");
         out.println("<p>Remote Address: " + request.getRemoteAddr() + "</p>");
         // Generate a random number upon each request
         out.println("<p>A Random Number: <strong>" + Math.random() + "</strong></p>");
         out.println("</body></html>");
      } finally {
         out.close();  // Always close the output writer
      }
```

```
    }
}
```

In Line 7, the annotation `@WebServlet("/sayhi")` is used to declare the URL mapping for this servlet, i.e., `http://localhost:9999/hello/sayhi`. There is no need to provide any more configuration in "`web.xml`"!

3. How to Debug?

"Everything that can possibly go wrong will go wrong." The most important thing to do is to find the **ERROR MESSAGE**!!!

Always...

1. Refresh your browser using **Cntl-F5** (instead of refresh button or simply F5) to get a fresh copy, instead of from the cache.
2. You may re-start your Tomcat server. You may also re-start your browser to clear the cache.
3. Check your spelling! Always assume that all programs are case-sensitive. Don't type, copy and paste if possible!
4. and MOST IMPORTANTLY - Find the **ERROR MESSAGE**!!!
    a. Check the Error Messages on Tomcat's Console. Most of the error messages have a few screens of lines. You need to scroll up slowly from the last line to **look for the FIRST LINE of the error messages**.
    b. Check the Tomcat's log files, located at "`<TOMCAT_HOME>\logs`". The "`catalina.yyyy-mm-dd.log`" shows the Tomcat's startup messages. Also check the "`localhost.yyyy-mm-dd.log`".
5. If things were running fine until the lightning strikes, ask yourself "What have I changed?"

Cannot Start Tomcat - Tomcat's Console Flashes and Disappears

1. Try running the script "`configtest.bat`" (for Windows) or "`./configtest.sh`" (for Mac OS/Linux) to check your configuration files.
2. Check the Tomcat's log files for error messages. The log files are located at "`<TOMCAT_HOME>\logs`". The "`catalina.{yyyy-mm-dd}.log`" shows the Tomcat's startup messages. Also check the "`localhost.{yyyy-mm-dd}.log`".
3. If the error messages indicate that another Tomcat instance is running (`java.net.BindException: Address already in use: JVM_Bind`), kill the Tomcat process (see below); or try running the "`shutdown`" script at Tomcat's `bin` (For Windows, simply double-click the "`shutdown.bat`" or issue "`shutdown`" from CMD. For Mac OS, issue "`./shutdown.sh`" from Terminal.)
4. If the error messages indicate that another application is running on the Tomcat's port numbers, then you need to change the Tomcat's port number in `server.xml`. You can issue command "`netstat -an`" to check the status of all the ports.
5. Start the tomcat in the debugging mode by running "`catalina debug`" (or `./catalina.sh debug`) and type "`run`" in the "`jdb`" prompt. Look for the error messages.

Locating/Killing Tomcat's Process

- In windows, start "Task Manager", Tomcat run as a "process" named "`java.exe`". You may need to kill the process.
- In Mac OS, start "Activity Monitor". Select "All Processes" and look for "`java.exe`".
- In Linux/Mac OS, you may issue "`ps aux | grep tomcat`" to locate the Tomcat process. Note down the process ID (pid). You can kill the Tomcat process via "`kill -9 pid`".

(Firefox) Unable to Connect
(IE) Internet Explorer cannot display the webpage
(Chrome) Oops! Google Chrome could not connect to ...
(Safari) Safari can't connect to the server

Cause: You are simply not connecting to your Tomcat.

Solution:

1. Check if your Tomcat server has been started?
2. Check the hostname and port number, separated by a colon '`:`', of your URL (`http://localhost:9999/...`).

Error 404 File Not Found

Cause: You have connected to your Tomcat. But Tomcat server cannot find the HTML file or Servlet that your requested.

Solution:

1. Check your spelling! The path is case-sensitive!
2. For HTML file with URL `http://localhost:9999/xxxx/filename.html`:
    a. Open Tomcat's "`webapps`" directory, check if sub-directory "*xxxx*" exists. It is case-sensitive.
    b. Open the "*xxxx*" directory, check if "*filename*`.html`" exists.
3. For Servlet with URL `http://localhost:9999/xxxx/servletURL`:
    a. Check the Tomcat's console for error message. Your application cannot be deployed if you make a mistake in editing "`web.xml`", which triggered many error messages.
    b. Check the Tomcat console to make sure that your application has been deployed.
    c. Open Tomcat's "`webapps`" directory, check if sub-directory "*xxxx*" exists.
    d. Open the "*xxxx*" directory, check if sub-sub-directory "`WEB-INF`" (uppercase with a dash) exists.
    e. Open the "`WEB-INF`", check if sub-sub-sub directory "classes" (lowercase, plural) exists.

f. Open the configuration file "`WEB-INF\web.xml`":
  a. Check that *`servletURL`* is defined in a `<servlet-mapping>` tag. Take note of the *name* in `<servlet-name>` tag.
  b. Based on the *name* noted, look for the matching `<servlet-class>` tag. Take note of the *`ServletClassname`*.
  c. Open "`WEB-INF\classes`", check if "*`ServletClassname`*`.class`" that you noted exists (Note: It is "`.class`", and NOT "`.java`". You need to compile the "`.java`" to get the "`.class`".)

Error 500 Internal Server Error

Error 500 should have triggered many error message in the Tomcat's console. Go to the Tomcat's console, find the error message. The error message spans tens of lines. You need to scroll up slowly to look for the *first line* of the error message. The error message should tell you the cuase of this error, e.g. SQL syntax error, wrong user/password, etc.

For database servlet, you may check the error messages at "Common Errors in JDBC Programming".

- For "No suitable driver found" (Windows) or `NullPointerException` (Mac OS and Linux): Read Step 7(b) again, again, and again.

More Errors

Try searching "Common Error Messages".

REFERENCES & RESOURCES

1. Apache Tomcat mother site @ http://tomcat.apache.org.
2. Apache Tomcat Documentation @ "`<TOMCAT_HOME>\webapps\docs`".
3. "How to install MySQL and Get Started".
4. "Introduction to Java Database (JDBC) Programming".
5. Jason Brittain, Ian F. Darwin, "*Tomcat The Definitive Guide*", 2nd eds, OReilly, 2007.

Latest version tested: Tomcat 8.5.11, MySQL 5.7.17, JDK 1.8.0_112, Windows 10, Mac OS 10.10, Ubuntu 16.04LTS
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