Chapter 9: Application Development

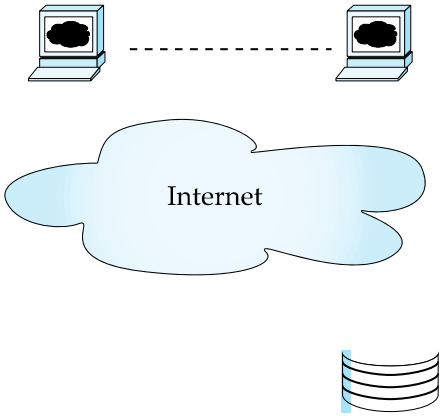
Database System Concepts, 7th Ed.

Application Programs and User Interfaces

- Most database users do *not* use a query language like SQL
- An application program acts as the intermediary between users and the database
  - Applications split into
    - front-end
    - middle layer
    - backend
- Front-end: user interface
  - Forms
  - Graphical user interfaces
  - Many interfaces are Web-based

Application Architecture Evolution

- Three distinct era's of application architecture
  - Mainframe (1960's and 70's)
  - Personal computer era (1980's)
  - Web era (mid 1990's onwards)
  - Web and Smartphone era (2010 onwards)



(a) Mainframe Era (b) Personal Computer Era (c) Web era

Web Interface

Web browsers have become the de-facto standard user interface to databases

- Enable large numbers of users to access databases from anywhere
- Avoid the need for downloading/installing specialized code, while providing a good graphical user interface
  - Javascript, Flash and other scripting languages run in browser, but are downloaded transparently
- Examples: banks, airline and rental car reservations, university course registration and grading, an so on.

Sample HTML Source Text

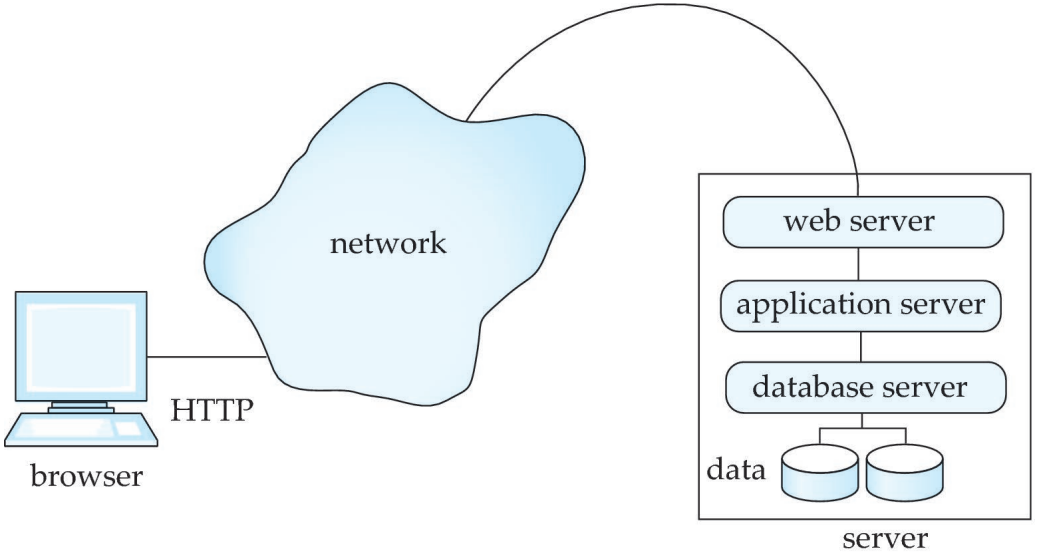
```
<html>
<body>
  <table border>
     <tr> <th>ID</th> <th>Name</th> <th>Department</th> </tr>
     <tr> <td>00128</td> <td>Zhang</td> <td>Comp. Sci.</td> </tr>
     ….
  </table>
  <form action="PersonQuery" method=get>
     Search for:
       <select name="persontype">
          <option value="student" selected>Student </option>
          <option value="instructor"> Instructor </option>
       </select> <br>
     Name: <input type=text size=20 name="name">
     <input type=submit value="submit">
  </form>
</body> </html>
```

Display of Sample HTML Source

ID	Name	Department
00128	Zhang	Comp. Sci.
12345	Shankar	Comp. Sci.
19991	Brandt	History

Search for: Student
Name:
submit

Three-Layer Web Architecture



HTTP and Sessions

- The HTTP protocol is **connectionless**
  - That is, once the server replies to a request, the server closes the connection with the client, and forgets all about the request
  - In contrast, Unix logins, and JDBC/ODBC connections stay connected until the client disconnects
    - retaining user authentication and other information
  - Motivation: reduces load on server
    - operating systems have tight limits on number of open connections on a machine
- Information services need session information
  - E.g., user authentication should be done only once per session
- Solution: use a **cookie**

Sessions and Cookies

- A **cookie** is a small piece of text containing identifying information
  - Sent by server to browser
    - Sent on first interaction, to identify session
  - Sent by browser to the server that created the cookie on further interactions
    - part of the HTTP protocol
  - Server saves information about cookies it issued, and can use it when serving a request
    - E.g., authentication information, and user preferences
- Cookies can be stored permanently or for a limited time

Servlets

- Java Servlet specification defines an API for communication between the Web/application server and application program running in the server
  - E.g., methods to get parameter values from Web forms, and to send HTML text back to client
- Application program (also called a servlet) is loaded into the server
  - Each request spawns a new thread in the server
    - thread is closed once the request is serviced
  - Programmer creates a class that inherits from HttpServlet
    - And overrides methods doGet, doPost, …
  - Mapping from servlet name (accessible via HTTP), to the servlet class is done in a file web.xml
    - Done automatically by most IDEs when you create a Servlet using the IDE

Example Servlet Code

```
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;
public class PersonQueryServlet extends HttpServlet {
   public void doGet (HttpServletRequest request, HttpServletResponse
     response)
                    throws ServletException, IOException
   {
     response.setContentType("text/html");
     PrintWriter out = response.getWriter();
     out.println("<HEAD><TITLE> Query Result</TITLE></HEAD>");
     out.println("<BODY>");
        ….. BODY OF SERVLET (next slide) …
     out.println("</BODY>");
     out.close();
   }
}
```

Example Servlet Code

```
String persontype = request.getParameter("persontype");
String number = request.getParameter("name");
if(persontype.equals("student")) {
    ... code to find students with the specified name ...
    ... using JDBC to communicate with the database ..
    out.println("<table BORDER COLS=3>");
    out.println(" <tr> <td>ID</td> <td>Name: </td>" + " <td>Department</td> </tr>");
    for(... each result ...){
        ... retrieve ID, name and dept name
        ... into variables ID, name and deptname
        out.println("<tr> <td>" + ID + "</td>" + "<td>" + name + "</td>" + "<td>" +
      deptname
                + "</td></tr>");
    };
    out.println("</table>");
}
else {
    ... as above, but for instructors ...
}
```

Servlet Sessions

- Servlet API supports handling of sessions
  - Sets a cookie on first interaction with browser, and uses it to identify session on further interactions
- To check if session is already active:
  - if (request.getSession(false) == true)
    - .. then existing session
    - else .. redirect to authentication page
  - authentication page
    - check login/password
    - Create new session
      - HttpSession session = request.getSession(true)
    - Store/retrieve attribute value pairs for a particular session
      - session.setAttribute("userid", userid)
  - If existing session:
    HttpSession = request.getSession(false);
    String userid = (String) session.getAttribute("userid")

Servlet Support

- Servlets run inside application servers such as
  - Apache Tomcat, Glassfish, JBoss
  - BEA Weblogic, IBM WebSphere and Oracle Application Servers
- Application servers support
  - Deployment and monitoring of servlets
  - Java 2 Enterprise Edition (J2EE) platform supporting objects, parallel processing across multiple application servers, etc

Server-Side Scripting

- Server-side scripting simplifies the task of connecting a database to the Web
  - Define an HTML document with embedded executable code/SQL queries.
  - Input values from HTML forms can be used directly in the embedded code/SQL queries.
  - When the document is requested, the Web server executes the embedded code/SQL queries to generate the actual HTML document.
- Numerous server-side scripting languages
  - JSP, PHP
  - General purpose scripting languages: VBScript, Perl, Python

Java Server Pages (JSP)

- A JSP page with embedded Java code

```
<html>
<head> <title> Hello </title> </head>
<body>
<% if (request.getParameter("name") == null)
{ out.println("Hello World"); }
else { out.println("Hello, " + request.getParameter("name")); }
%>
</body>
</html>
```

- JSP is compiled into Java + Servlets
- JSP allows new tags to be defined, in tag libraries
  - Such tags are like library functions, can are used for example to build rich user interfaces such as paginated display of large datasets

PHP

- PHP is widely used for Web server scripting
- Extensive libaries including for database access using ODBC

```
<html>
  <head> <title> Hello </title> </head>
  <body>
  <?php if (!isset($_REQUEST[ ‘name’ ]))
  { echo “Hello World”; }
  else { echo “Hello, ” + $_REQUEST[ ‘name’ ]; }
  ?>
  </body>
</html>
```

Javascript

- Javascript very widely used
  - Forms basis of new generation of Web applications (called Web 2.0 applications) offering rich user interfaces
- Javascript functions can
  - Check input for validity
  - Modify the displayed Web page, by altering the underling **document object model (DOM)** tree representation of the displayed HTML text
  - Communicate with a Web server to fetch data and modify the current page using fetched data, without needing to reload/refresh the page
    - Forms basis of AJAX technology used widely in Web 2.0 applications
    - E.g. on selecting a country in a drop-down menu, the list of states in that country is automatically populated in a linked drop-down menu

Javascript

- Example of Javascript used to validate form input

```
<html> <head>
    <script type="text/javascript">
        function validate() {
            var credits=document.getElementById("credits").value;
            if (isNaN(credits)|| credits<=0 || credits>=16) {
                alert("Credits must be a number greater than 0 and less than 16");
                return false
            }
        }
    </script>
</head> <body>
    <form action="createCourse" onsubmit="return validate()">
        Title: <input type="text" id="title" size="20"><br />
        Credits: <input type="text" id="credits" size="2"><br />
        <Input type="submit" value="Submit">
    </form>
</body> </html>
```

Application Architectures

Application Architectures

- Application layers
  - Presentation or user interface
    - **model-view-controller (MVC)** architecture
      - **model**: business logic
      - **view**: presentation of data, depends on display device
      - **controller**: receives events, executes actions, and returns a view to the user
  - **business-logic** layer
    - provides high level view of data and actions on data
      - often using an object data model
    - hides details of data storage schema
  - **data access** layer
    - interfaces between business logic layer and the underlying database
    - provides mapping from object model of business layer to relational model of database

Application Architecture

Business Logic Layer

- Provides abstractions of entities
  - E.g., students, instructors, courses, etc
- Enforces **business rules** for carrying out actions
  - E.g., student can enroll in a class only if she has completed prerequsites, and has paid her tuition fees
- Supports **workflows** which define how a task involving multiple participants is to be carried out
  - E.g., how to process application by a student applying to a university
  - Sequence of steps to carry out task
  - Error handling
    - E.g. what to do if recommendation letters not received on time
  - Workflows discussed in Section 26.2

Object-Relational Mapping

- Allows application code to be written on top of object-oriented data model, while storing data in a traditional relational database
  - Alternative: implement object-oriented or object-relational database to store object model
    - Has not been commercially successful
- Schema designer has to provide a mapping between object data and relational schema
  - E.g., Java class *Student* mapped to relation *student,* with corresponding mapping of attributes
  - An object can map to multiple tuples in multiple relations
- Application opens a session, which connects to the database
- Objects can be created and saved to the database using
  session.save(object)
  - Mapping used to create appropriate tuples in the database
- Query can be run to retrieve objects satisfying specified predicates

Object-Relational Mapping and Hibernate (Cont.)

- The **Hibernate** object-relational mapping system is widely used
  - Public domain system, runs on a variety of database systems
  - Supports a query language that can express complex queries involving joins
    - Translates queries into SQL queries
  - Allows relationships to be mapped to sets associated with objects
    - E.g., courses taken by a student can be a set in Student object
  - See book for Hibernate code example
- The **Entity Data Model** developed by Microsoft
  - Provides an entity-relationship model directly to application
  - Maps data between entity data model and underlying storage, which can be relational
  - Entity SQL language operates directly on Entity Data Model

Web Services

- Allow data on Web to be accessed using remote procedure call mechanism
- Two approaches are widely used
  - **Representation State Transfer (REST)**: allows use of standard HTTP request to a URL to execute a request and return data
    - Returned data is encoded either in XML, or in **JavaScript Object Notation (JSON)**
  - **Big Web Services**:
    - Uses XML representation for sending request data, as well as for returning results
    - Standard protocol layer built on top of HTTP
    - See Section 23.7.3

Disconnected Operations

- Tools for applications to use the Web when connected, but operate locally when disconnected from the Web
  - Make use of HTML5 local storage

Rapid Application Development

- A lot of effort is required to develop Web application interfaces
  - More so, to support rich interaction functionality associated with Web 2.0 applications
- Several approaches to speed up application development
  - Function library to generate user-interface elements
  - Drag-and-drop features in an IDE to create user-interface elements
  - Automatically generate code for user interface from a declarative specification
- Above features have been in used as part of **rapid application development (RAD)** tools even before advent of Web
- Web application development frameworks
  - Java Server Faces (JSF) includes JSP tag library
  - Ruby on Rails
    - Allows easy creation of simple **CRUD** (create, read, update and delete) interfaces by code generation from database schema or object model

Application Performance

Improving Web Server Performance

- Performance is an issue for popular Web sites
  - May be accessed by millions of users every day, thousands of requests per second at peak time
- Caching techniques used to reduce cost of serving pages by exploiting commonalities between requests
  - At the server site:
    - Caching of JDBC connections between servlet requests
      - a.k.a. **connection pooling**
    - Caching results of database queries
      - Cached results must be updated if underlying database changes
    - Caching of generated HTML
  - At the client's network
    - Caching of pages by Web proxy

Application Security

Cross Site Scripting

- HTML code on one page executes action on another page
  - E.g., <img src = http://mybank.com/transfermoney?amount=1000&toaccount=14523>
  - Risk: if user viewing page with above code is currently logged into mybank, the transfer may succeed
  - Above example simplistic, since GET method is normally not used for updates, but if the code were instead a script, it could execute POST methods
- Above vulnerability called **cross-site scripting (XSS)** or **cross-site request forgery (XSRF or CSRF)**
- **Prevent your web site from being used to launch XSS or XSRF attacks**
  - Disallow HTML tags in text input provided by users, using functions to detect and strip such tags
- **Protect your web site from XSS/XSRF attacks launched from other sites**
  - ..next slide

Cross Site Scripting

Protect your web site from XSS/XSRF attacks launched from other sites

- Use **referer** value (URL of page from where a link was clicked) provided by the HTTP protocol, to check that the link was followed from a valid page served from same site, not another site
- Ensure IP of request is same as IP from where the user was authenticated
  - Prevents hijacking of cookie by malicious user
- Never use a GET method to perform any updates
  - This is actually recommended by HTTP standard

Password Leakage

- Never store passwords, such as database passwords, in clear text in scripts that may be accessible to users
  - E.g., in files in a directory accessible to a web server
    - Normally, web server will execute, but not provide source of script files such as file.jsp or file.php, but source of editor backup files such as file.jsp~, or .file.jsp.swp may be served
- Restrict access to database server from IPs of machines running application servers
  - Most databases allow restriction of access by source IP address

Application Authentication

- Single factor authentication such as passwords too risky for critical applications
  - Guessing of passwords, sniffing of packets if passwords are not encrypted
  - Passwords reused by user across sites
  - Spyware which captures password
- Two-factor authentication
  - E.g., password plus one-time password sent by SMS
  - E.g., password plus one-time password devices
    - Device generates a new pseudo-random number every minute, and displays to user
    - User enters the current number as password
    - Application server generates same sequence of pseudo-random numbers to check that the number is correct.

Application Authentication

- **Man-in-the-middle** attack
  - E.g., web site that pretends to be mybank.com, and passes on requests from user to mybank.com, and passes results back to user
  - Even two-factor authentication cannot prevent such attacks
- Solution: authenticate Web site to user, using digital certificates, along with secure http protocol
- **Central authentication** within an organization
  - Application redirects to central authentication service for authentication
  - Avoids multiplicity of sites having access to user's password
  - LDAP or Active Directory used for authentication

Single Sign-On

- **Single sign-on** allows user to be authenticated once, and applications can communicate with authentication service to verify user's identity without repeatedly entering passwords
- **Security Assertion Markup Language (SAML)** standard for exchanging authentication and authorization information across security domains
  - E.g., user from Yale signs on to external application such as acm.org using userid joe@yale.edu
  - Application communicates with Web-based authentication service at Yale to authenticate user, and find what the user is authorized to do by Yale (e.g. access certain journals)
- **OpenID** standard allows sharing of authentication across organizations
  - E.g., application allows user to choose Yahoo! as OpenID authentication provider, and redirects user to Yahoo! for authentication

Application-Level Authorization

- Current SQL standard does not allow fine-grained authorization such as "students can see their own grades, but not other's grades"
  - Problem 1: Database has no idea who are application users
  - Problem 2: SQL authorization is at the level of tables, or columns of tables, but not to specific rows of a table
- One workaround: use views such as

  create view *studentTakes* **as**
  select *
  from *takes*
  where *takes.ID* = *syscontext.user_id*()

  - where syscontext.user_id() provides end user identity
    - End user identity must be provided to the database by the application
  - Having multiple such views is cumbersome

Application-Level Authorization (Cont.)

- Currently, authorization is done entirely in application
- Entire application code has access to entire database
  - Large surface area, making protection harder
- Alternative: **fine-grained (row-level) authorization** schemes
  - Extensions to SQL authorization proposed but not currently implemented
  - Oracle Virtual Private Database (VPD) allows predicates to be added transparently to all SQL queries, to enforce fine-grained authorization
    - E.g., add *ID= sys_context.user_id()* to all queries on student relation if user is a student

Audit Trails

- Applications must log actions to an audit trail, to detect who carried out an update, or accessed some sensitive data
- Audit trails used after-the-fact to
  - Detect security breaches
  - Repair damage caused by security breach
  - Trace who carried out the breach
- Audit trails needed at
  - Database level, and at
  - Application level

End of Chapter 9