Chapter 9: Application Development

Database System Concepts, 7th Ed.

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

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>
```

Embedded Javascript for Node.js (EJS)

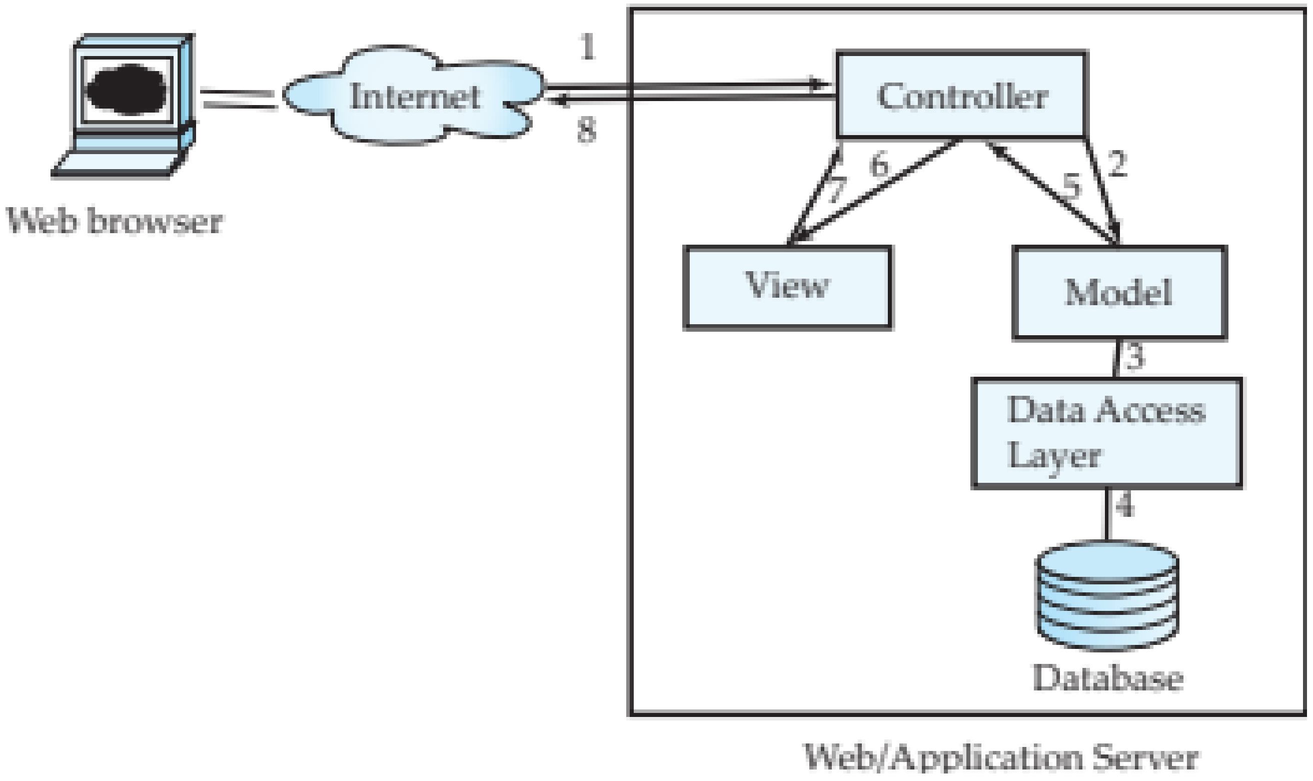
https://www.geeksforgeeks.org/use-ejs-as-template-engine-in-node-js/

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

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

Encryption

Encryption

- Data may be *encrypted* when database authorization provisions do not offer sufficient protection.
- Properties of good encryption technique:
  - Relatively simple for authorized users to encrypt and decrypt data.
  - Encryption scheme depends not on the secrecy of the algorithm but on the secrecy of a parameter of the algorithm called the encryption key.
  - Extremely difficult for an intruder to determine the encryption key.
- **Symmetric-key encryption**: same key used for encryption and for decryption
- **Public-key encryption** (a.k.a. **asymmentric-key encryption**): use different keys for encryption and decryption
  - Encryption key can be public, decryption key secret

Encryption (Cont.)

- ***Data Encryption Standard* (DES)** substitutes characters and rearranges their order on the basis of an encryption key which is provided to authorized users via a secure mechanism. Scheme is no more secure than the key transmission mechanism since the key has to be shared.
- **Advanced Encryption Standard (AES)** is a new standard replacing DES, and is based on the Rijndael algorithm, but is also dependent on shared secret keys.
- ***Public-key encryption*** is based on each user having two keys:
  - *Public key* – publicly published key used to encrypt data, but cannot be used to decrypt data
  - *Private key* -- key known only to individual user, and used to decrypt data. Need not be transmitted to the site doing encryption.

  Encryption scheme is such that it is impossible or extremely hard to decrypt data given only the public key.
- The RSA public-key encryption scheme is based on the hardness of factoring a very large number (100's of digits) into its prime components

Encryption (Cont.)

- **Hybrid schemes** combining public key and private key encryption for efficient encryption of large amounts of data
- Encryption of small values such as identifiers or names vulnerable to **dictionary attacks**
  - Especially if encryption key is publicly available
  - But even otherwise, statistical information such as frequency of occurrence can be used to reveal content of encrypted data
  - Can be deterred by adding extra random bits to the end of the value, before encryption, and removing them after decryption
    - Same value will have different encrypted forms each time it is encrypted, preventing both above attacks
    - Extra bits are called **salt bits**

Encryption in Databases

- Database widely support encryption
- Different levels of encryption:
  - **disk block**
    - Every disk block encrypted using key available in database-system software.
    - Even if attacker gets access to database data, decryption cannot be done without access to the key.
  - **Entire relations, or specific attributes of relations**
    - Non-sensitive relations, or non-sensitive attributes of relations need not be encrypted
    - However, attributes involved in primary/foreign key constraints cannot be encrypted.
- Storage of encryption or decryption keys
  - Typically, single master key used to protect multiple encryption/decryption keys stored in database
- Alternative: encryption/decryption is done in application, before sending values to the database

Encryption and Authentication

- Password based authentication is widely used, but is susceptible to sniffing on a network.
- **Challenge-response** systems avoid transmission of passwords
  - DB sends a (randomly generated) challenge string to user.
  - User encrypts string and returns result.
  - DB verifies identity by decrypting result
  - Can use public-key encryption system by DB sending a message encrypted using user's public key, and user decrypting and sending the message back.
- **Digital signatures** are used to verify authenticity of data
  - E.g., use private key (in reverse) to encrypt data, and anyone can verify authenticity by using public key (in reverse) to decrypt data. Only holder of private key could have created the encrypted data.
  - Digital signatures also help ensure **nonrepudiation**: sender cannot later claim to have not created the data

End of Chapter 9