UNIVERSITÄT MANNHEIM

Database Technology
Database Applications

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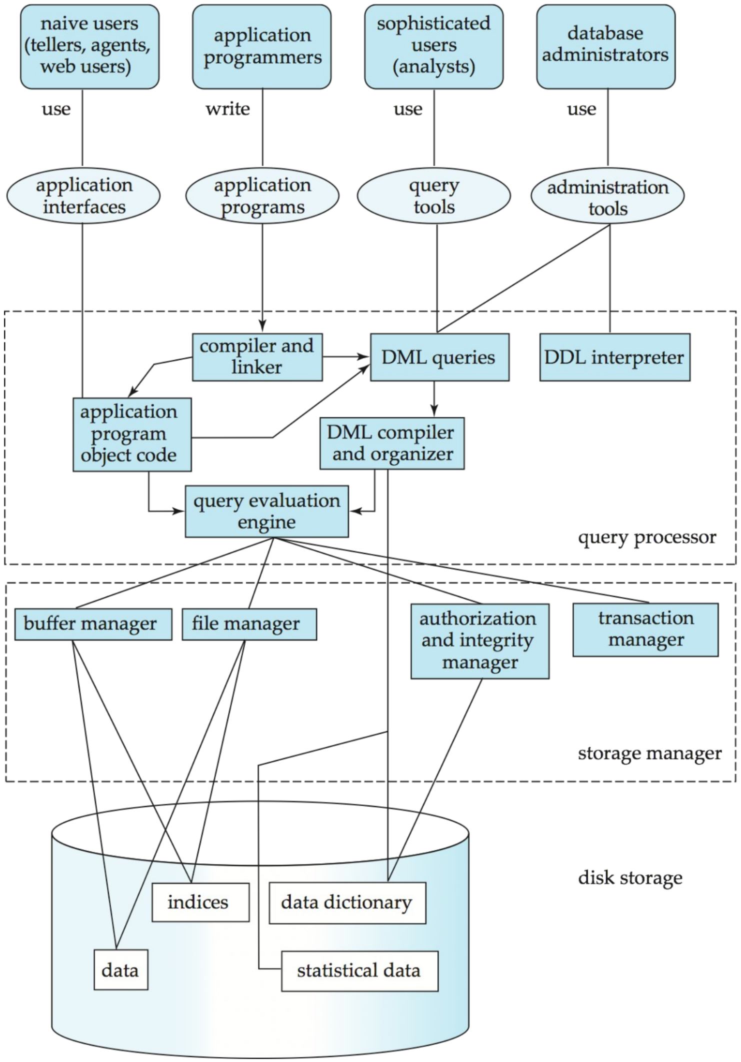
Recap: The Big Picture

- Users interact with databases *indirectly*
  - i.e., via *applications*
  - no direct usage of SQL
- Most applications today have a database under the hood, e.g.,
  - shopping portals
  - news web sites
  - games

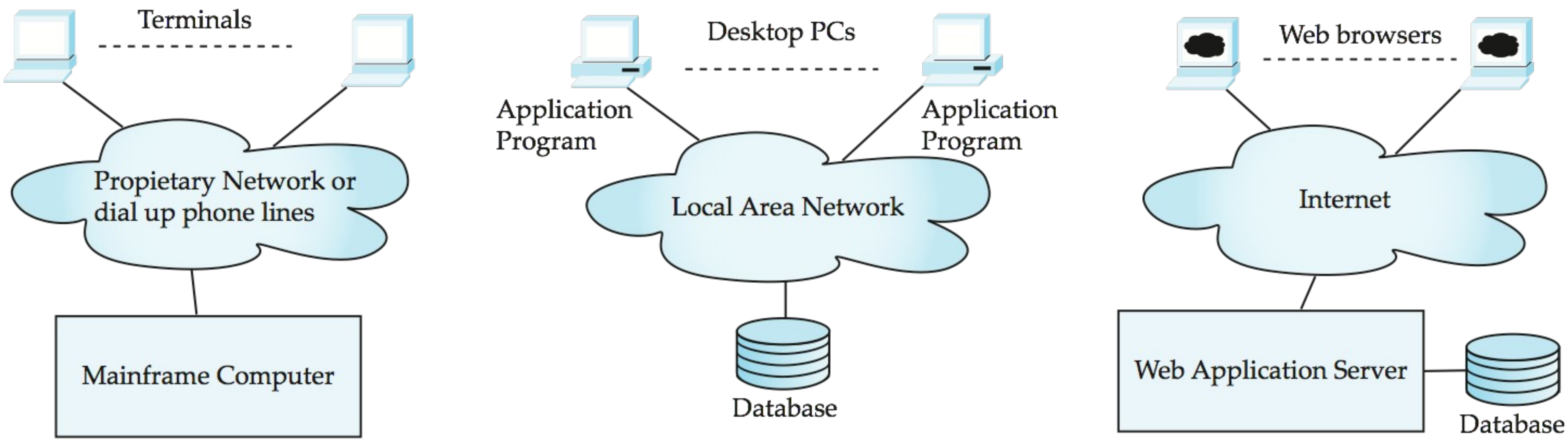


Today's Lecture

- Architectures for database centric applications
  - Three/Two-Layer Web Architecture
  - HTML/Session/Cookies
  - Server/Client Side Scripting
- Legacy Systems
- Performance Tuning
  - Bottlenecks
  - Database Design
- Security Issues
  - SQL Injection
  - Cross Site Scripting
  - Password Leakage
  - Application Authentication/Authorization

Application Architecture Evolution

- Three eras of application architecture
  - mainframe (1960’s and 70’s)
  - personal computer era (1980’s)
  - Web era (since 1990’s, nowadays mostly mobile Web)



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

Web Interface

- Web browsers
  - de-facto standard user interface to databases
  - multi-user, location agnostic interface
  - no 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, ...

Web based Applications in a Nutshell

- Web documents are *hypertext* documents formatted using HyperText Markup Language (HTML)
- HTML documents contain
  - text along with font specifications, and other formatting instructions
  - hypertext links to other documents
  - forms, enabling users to enter data which can then be sent back to the Web server
- HyperText Transfer Protocol (HTTP) used for communication with the Web server
- URL may identify a document or an executable program
  - executed by HTTP server
  - creates HTML documents, which is sent back to client
  - Web client can pass extra arguments with the name of the document

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

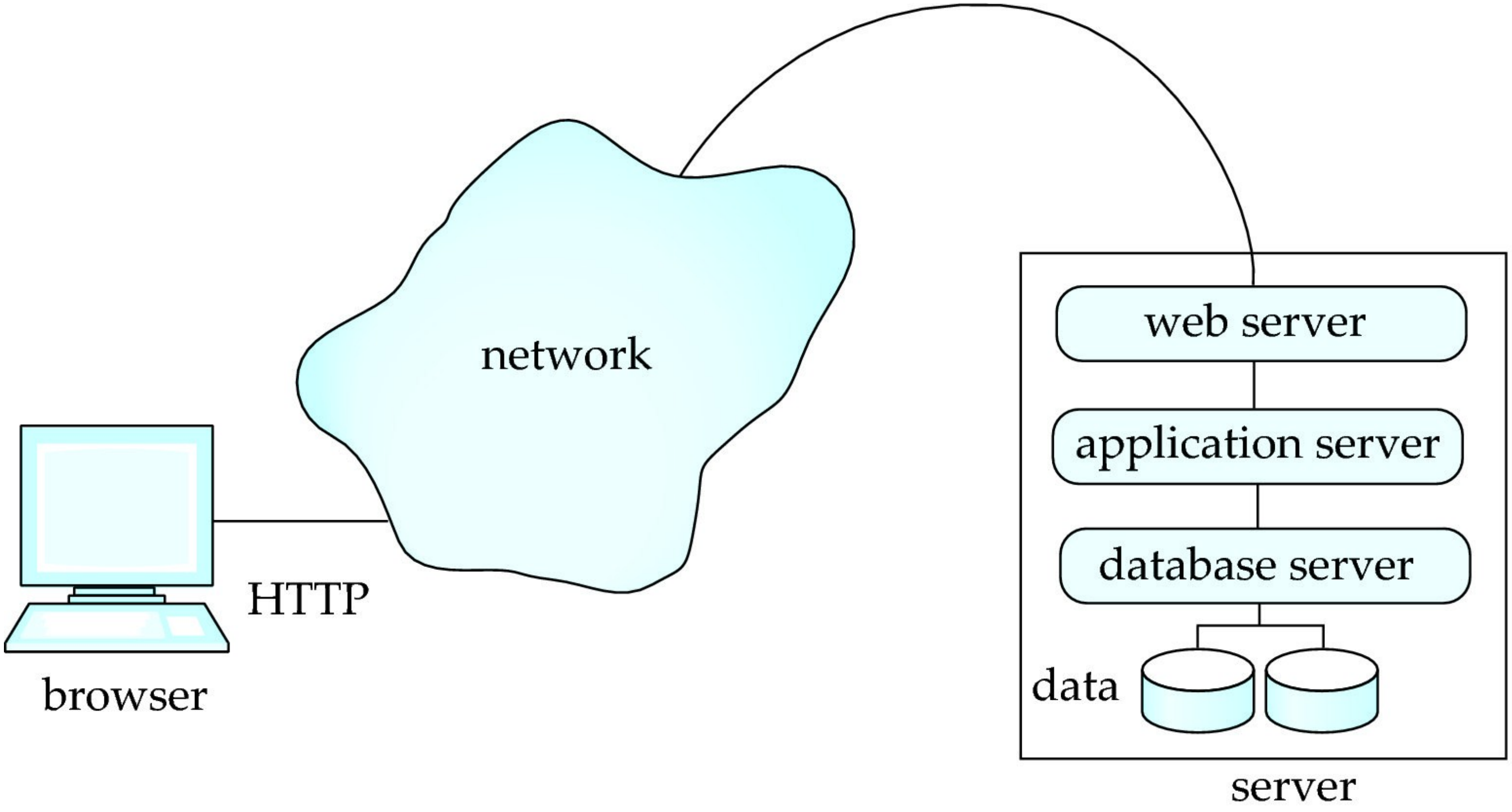
ID	Name	Department
00128	Zhang	Comp. Sci.
12345	Shankar	Comp. Sci.
19991	Brandt	History

Search for: Student

Name:

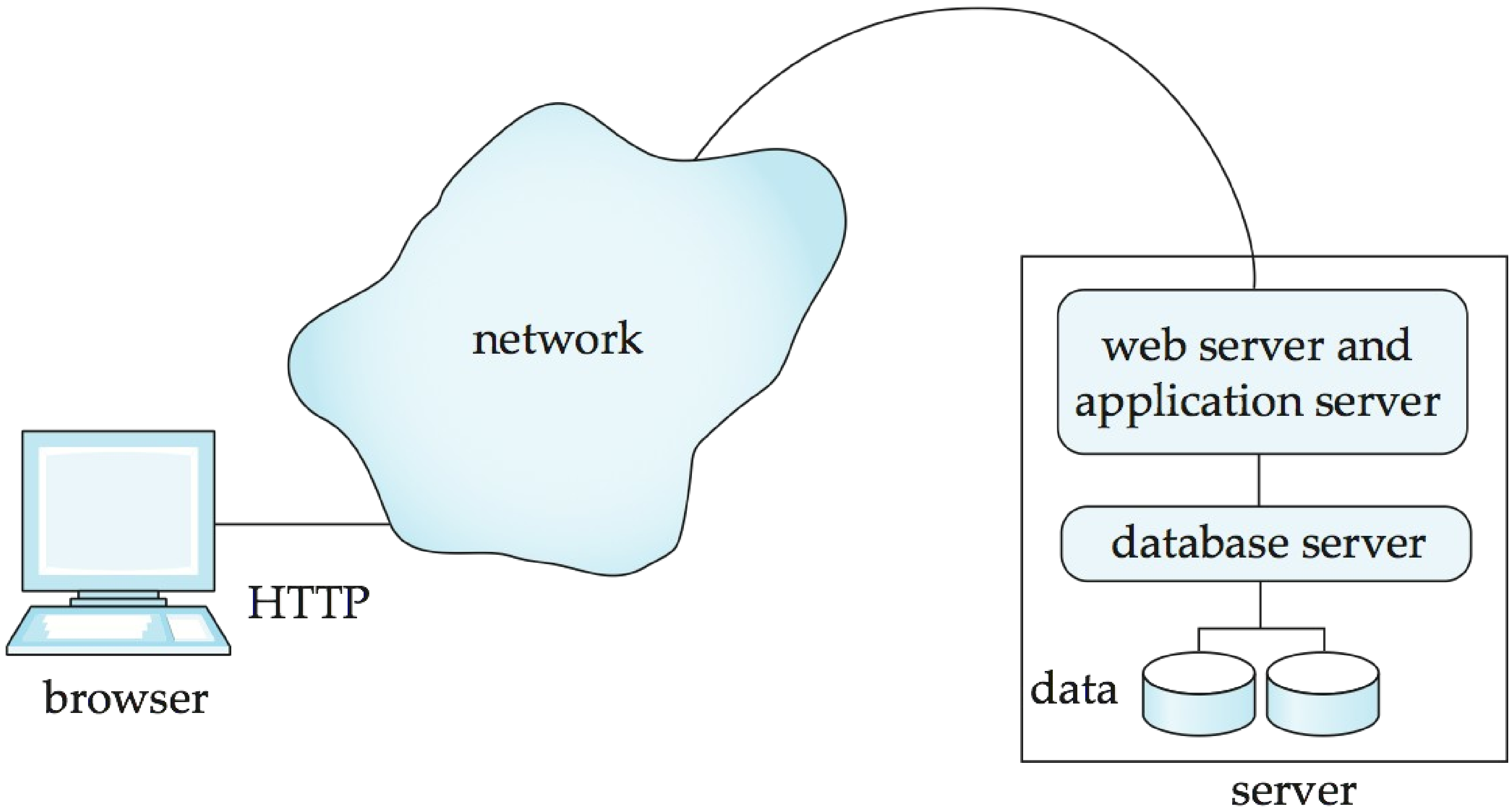
submit

Three-Layer Web Architecture



Two-Layer Web Architecture

- Multiple levels of indirection have overheads
  - Alternative: two-layer architecture



HTTP and Sessions

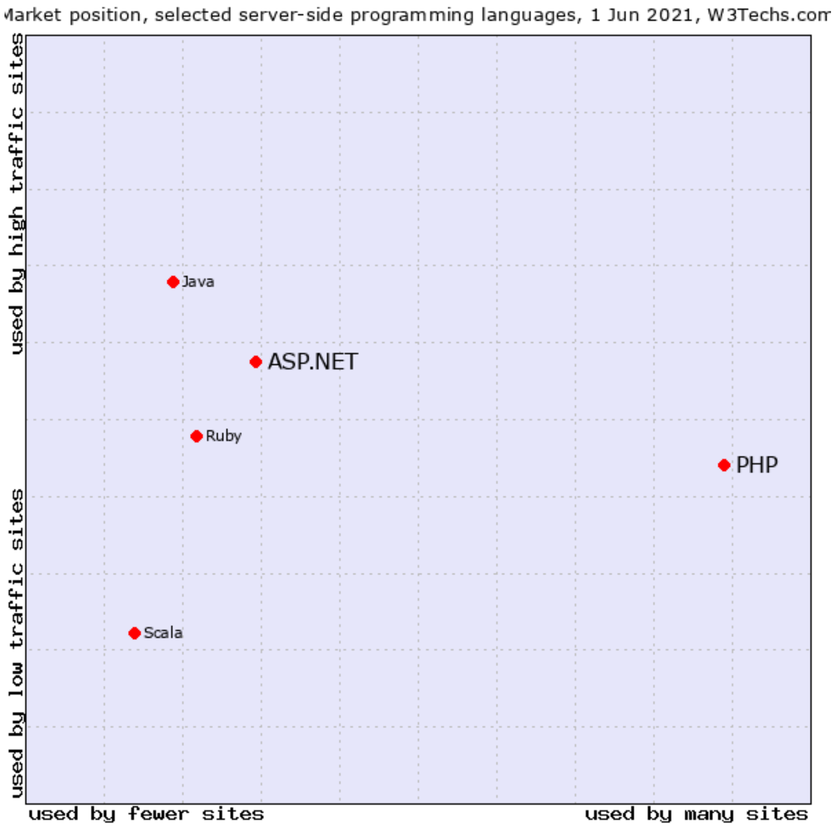
- The HTTP protocol is **connectionless**
  - Once the server replies to a request, the server closes the connection with the client, and forgets all about the request
  - In contrast, Unix logins, and JDBC/ODBC connections stay connected until the client disconnects
    - retaining user authentication and other information
  - Motivation: reduce 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: **cookies**

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 with each request
    - 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

Programming on the Server Side

- Paradigms
  - Programming (i.e., each document is assembled by a program)
  - Scripting (embedded in HTML)
- Different programming languages can be used, e.g.
  - PHP
  - ASP.NET
  - Java (JSP, Servlets)
  - ColdFusion
  - Perl
  - Python
  - ...



https://w3techs.com/technologies/comparison/pl-aspnet,pl-php

Servlets

- Java Servlet specification
  - defines an API for communication between the Web/application server and application program running in the server
    - methods to get parameter values from Web forms
    - methods 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

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
  - Set a cookie on first interaction with browser
  - use it to identify session on further interactions
- To check if session is already active:
  - if (request.getSession(false) == true)
    - .. then use existing session
    - else .. redirect to authentication page
  - authentication page
    - check login/password

we can also check the age of the cookie here for session timeout

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
  - HTML document with embedded executable code and/or SQL queries
  - Input values from HTML forms can be used directly
  - 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

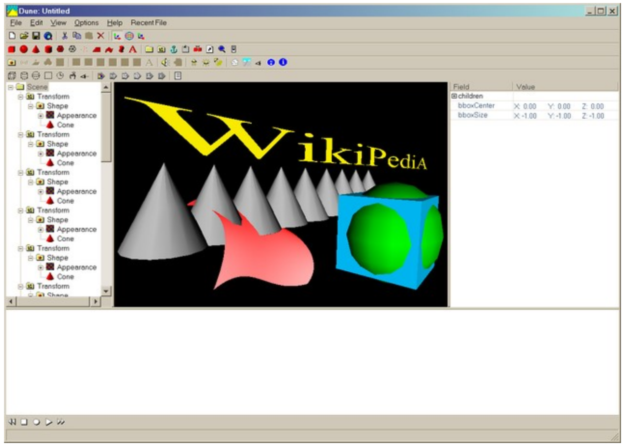
PHP

- 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>
```

Client Side Scripting

- Browsers can fetch certain scripts (client-side scripts) or programs along with documents, and execute them in “safe mode” at the client site
  - Javascript
  - Macromedia Flash and
    Shockwave for animation/games
  - VRML
  - Applets



- Client-side scripts/programs allow documents to be active
  - E.g., animation by executing programs at the local site
  - E.g., ensure that values entered by users satisfy some correctness checks
  - Permit flexible interaction with the user
    - Executing programs at the client site speeds up interaction by avoiding many round trips to server

https://de.wikipedia.org/wiki/Virtual_Reality_Modeling_Language

Client Side Scripting and Security

- Security mechanisms needed to ensure that malicious scripts do not cause damage to the client machine
  - easy for limited capability scripting languages
  - harder for general purpose programming languages like Java
- E.g., Java's security system ensures that the Java applet code does not make any system calls directly
  - Disallows dangerous actions such as file writes
  - Notifies the user about potentially dangerous actions
    - allow the option to abort the program or to continue execution

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 underlying **document object model (DOM)** tree
  - 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., loading further content upon scrolling down a Web page
    - 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

Legacy Systems

- Older-generation systems that are incompatible with current generation standards and systems but still in production use
  - E.g., applications written in COBOL that run on mainframes
    - Today's hot new system is tomorrows legacy system!
- Porting legacy system applications to a more modern environment is problematic
  - Legacy system may involve millions of LoC, written over decades
    - Original programmers usually no longer available
  - Switching over from old system to new system is a problem
    - more on this later
- One approach: build a **wrapper** layer on top of legacy application to allow interoperation between newer systems and legacy application
  - E.g., use ODBC or OLE-DB as wrapper

Legacy Systems (Cont.)

- Rewriting legacy application: understanding what it does (and how)
  - Legacy code often has no/little documentation documentation
  - **reverse engineering**: process of going over legacy code to
    - Come up with schema designs in ER or OO model
    - Get a high level view of system
- **Re-engineering**: reverse engineering followed by design of new system
  - Improvements are made on existing system design in this process

Legacy Systems (Cont.)

- Switching over from old to new system is a major problem
  - Production systems are in every day, generating new data
  - Stopping the system may bring all of a company's activities to a halt, causing enormous losses
- **Big-bang approach**:
  1. Implement complete new system
  2. Populate it with data from old system
     1. No transactions while this step is executed
     2. scripts are created to do this quickly
  3. Shut down old system and start using new system
  - Danger with this approach: what if new code has bugs or performance problems, or missing features
    - Company may be brought to a halt

Legacy Systems (Cont.)

- **Chicken-little approach**:
  - Replace legacy system one piece at a time
  - Use wrappers to interoperate between legacy and new code
    - E.g., replace front end first, with wrappers on legacy backend
      - Old front end can continue working in this phase in case of problems with new front end
    - Replace back end, one functional unit at a time
      - All parts that share a database may have to be replaced together, or wrapper is needed on database as well
  - Drawback: significant extra development effort to build wrappers and ensure smooth interoperation
    - Still worth it if company's life depends on system

Performance Tuning

- Adjusting various parameters and design choices
  - to improve system performance for a specific application
  - notion: continuous improvement rather than waterfall model
- Tuning is best done by
  1) identifying bottlenecks, and
  2) eliminating them
- Three levels of tuning
  - Hardware, e.g., add disks, memory, use faster processor
  - Database system parameters, e.g., buffer size, checkpointing intervals
  - Higher level database design, e.g., schema, indices, and transactions

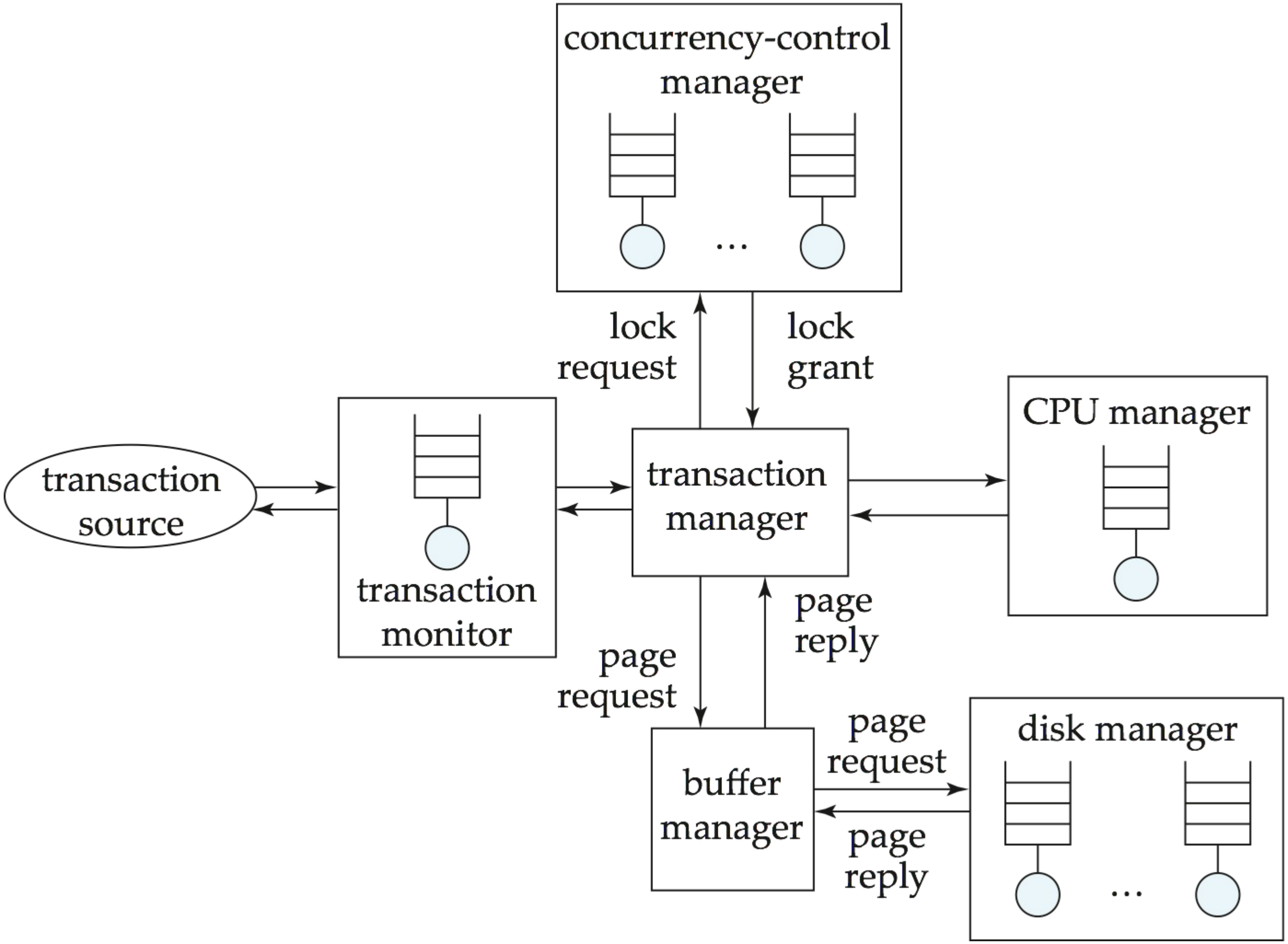
Bottlenecks

- Performance of most systems (at least before they are tuned) usually limited by performance of one or a few components
  - these are called **bottlenecks**
  - 80/20 rule: 20% of code consume 80% of execution time
    - spend more time on those 20%
- Bottlenecks may be in hardware (e.g., disks are very busy, CPU is idle), or in software
- Removing one bottleneck often exposes another
- De-bottlenecking consists of repeatedly finding bottlenecks, and removing them

Identifying Bottlenecks

- Transactions request a sequence of services
  - E.g., CPU, Disk I/O, locks
- Concurrent transactions wait for a requested service while others are being served
- Notion: database as a **queueing system** with a queue for each service
  - Transactions repeatedly do the following
    - request a service, wait in queue for the service, and get serviced
- Bottlenecks in a database system typically show up as very high utilizations (very long queues) of a particular service
  - e.g., disk vs. CPU utilization
  - 100% utilization leads to very long waiting time:
    - Rule of thumb: design system for about 70% utilization at peak load
    - utilization over 90% should be avoided

Queues in a Database System



Tuning of Hardware

- Even well-tuned transactions typically require a few I/O operations
  - Typical disk supports about 100 random I/O operations per second
  - Suppose each transaction requires just 2 random I/O operations
    - to support *n* transactions per second,
      we need to distribute data across *n*/50 disks (ignoring skew)
- Number of I/O operations per transaction can be reduced by keeping more data in memory
  - If all data is in memory, I/O needed only for writes
  - Keeping frequently used data in memory reduces disk accesses, reducing number of disks required, but has a memory cost
- Five minute rule:
  - if a page that is randomly accessed is used **more frequently than once in five minutes**, it should be kept in memory

Tuning the Database Design

- **Schema tuning**
  - Vertically partition relations to isolate the data that is accessed most often
    - e.g., split *account* into two, (*account-number*, *branch-name*) and (*account-number*, *balance*).
      - branch name need not be fetched unless required
      - More rows per block → less block transfers
  - Improve performance by storing a **denormalized relation**
    - E.g., store join of *account* and *depositor*; branch-name and balance information is repeated for each holder of an account
      - join need not be computed repeatedly
      - trade-off: more space and more work for programmer to keep relation consistent on updates
      - Better to use materialized views (see later)

Tuning the Database Design (Cont.)

- Incidental violations of normal forms
  - e.g., storing join tables that would be split by normalization
- Incidental violations of domain model
  - Example: each person can have many phone numbers (1:n)
  - Theoretically sound solution: two tables (person, phone)
  - Practical observation: not more than four in 1M persons
    - rather introduce attributes phone1, phone2, phone3, phone4
    - avoids joins with long tables

Tuning the Database Design (Cont.)

Materialized Views

- Materialized views can help speed up certain queries
  - Particularly aggregate queries
- Overheads
  - Space
  - Time for view maintenance
    - Immediate view maintenance: done as part of update transaction
      - time overhead paid by update transaction
    - Deferred view maintenance: done only when required
      - update transaction is not affected, but system time is spent on view maintenance
      - until updated, the view may be out-of-date
- Preferable to denormalized schema since view maintenance is systems responsibility, not programmers
  - Avoids inconsistencies caused by errors in update programs

Tuning the Database Design (Cont.)

- How to choose set of materialized views
  - Helping one transaction type by introducing a materialized view may hurt others
    - selections including aggregates will be speed up
    - updates are slowed down
  - Choice of materialized views depends on costs
    - Users often have no idea of actual cost of operations
  - Overall, manual selection of materialized views is tedious
- Some database systems provide tools to help DBA choose views to materialize
  - "Materialized view selection wizards"

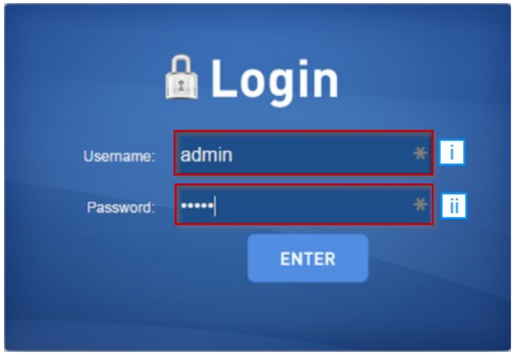
Tuning the Database Design (Cont.)

- **Index tuning**
  - Create appropriate indices to speed up slow queries/updates
  - Speed up slow updates by removing excess indices (tradeoff between queries and updates)
  - Choose type of index (B-tree/hash) appropriate for most frequent types of queries
  - Choose which index to make clustered
- Index tuning wizards look at past history of queries and updates (the **workload**) and recommend which indices would be best for the workload

Application Security

SQL Injection

- In an application,users enter data
  - this is a possible entry point for hackers!

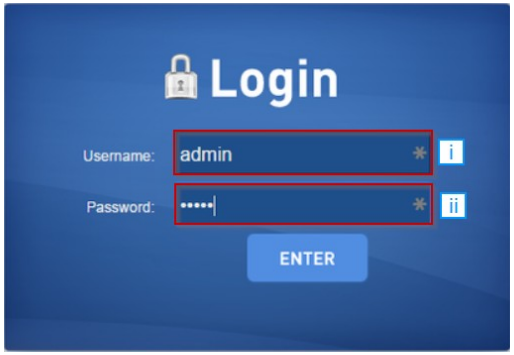


- Consider the following code:

```
String user = request.getParameter(“username”);
String password = request.getParameter(“password”);
String query = “SELECT * FROM users
                 WHERE username = ‘“ + user + ”’
                 AND password = ‘“ + password ”’”;
// execute query
// if there is a result, the login attempt was successful
```

SQL Injection

- Good user:
  - username “John”, password “test123”
- Bad user:
  - username “Jack”, password “test123’ OR 1=1”



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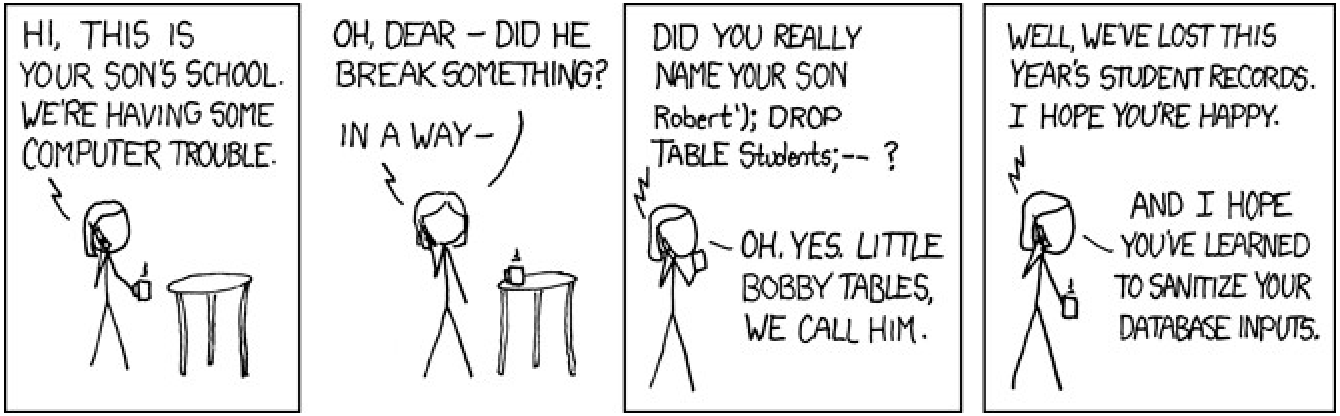
                AND password = ‘“ + password ”’;
// execute query
// if there is a result, the login attempt was successful
```

SQL Injection

- Variant 1: Manual
  - Check input for and mask/replace/remove special characters
- Variant 2: Using prepared statements in Java

```
PreparedStatement stmt = connection.prepareStatement
  ("SELECT * FROM users WHERE username=? AND password=?");
stmt.setString(1, user);
stmt.setString(2, password);
ResultSet rs = stmt.executeQuery();
```



https://xkcd.com/327

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

Password Leakage

- **Never** store user passwords as plain text in a database!
- Hackers may get access to the database and read them
  - e.g., username “Jack”, password “test123; SELECT * FROM users”
- Typical best practice: store password hashes, e.g., md5
  - hashing is fast in one direction, hard in the other
  - Query:
    - SELECT * FROM users WHERE user=? and password=md5(?)
  - Changing passwords
    - UPDATE users SET password=md5(?) WHERE user=?
  - This way, passwords are never stored in plain text anywhere

Password Leakage

- Attacks for hashed passwords: dictionary and brute force attacks

Dictionary Attack

Trying apple	: failed
Trying blueberry	: failed
Trying justinbieber	: failed
...	
Trying letmein	: failed
Trying s3cr3t	: success!

Brute Force Attack

Trying aaaa	: failed
Trying aaab	: failed
Trying aaac	: failed
...	
Trying acdb	: failed
Trying acdc	: success!

- Lookup Tables

  2cf24dba5fb0a30e26e8043362938b9824 = hash(“hello”)
  232bc6bd9ec38f616560b120fda8e90f383 = hash(“hbllo”)

- Adding Salt to the password (appending a random string)
  - Lookup tables won’t work
- Do not implement your own crypto algorithm (use e.g. phpass)

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 = USER()*

  no SQL standard; varies from implementation to implementation

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

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

Summary

- Databases do not run by themselves, but in context
  - applications work on top
- A good database design is essential, but there's also
  - security
  - performance,
  - …
- There's quite a few trade offs
  - storage vs. velocity
  - update vs. read time
  - …

→ there's no once size fits all solution!

What's Next?

- Database Systems II (FSS, Moerkotte)
  - e.g., distributed DBMS, object-relational DBs, deductive DBs
- Query Optimization (HWS, Moerkotte)
  - more sophisticated query optimization
- Transaction Systems (FSS, Moerkotte)
  - more on multi-user synchronization protocols and methods
- Large-Scale Data Management (HWS, Gemulla)
  - e.g., parallel & distributed databases, MapReduce, SPARQL, NoSQL

What’s Next?

- Data Security (FSS, Armknecht)
  - also covers encryption, privacy, etc.
- Web Data Integration (HWS, Bizer)
  - dealing with multiple databases
  - automatically integrating them into a single one
- Data Mining (FSS/HWS, Bizer/Paulheim)
  - finding patterns in data
  - entry point to more specific lectures in the data analytics field

Questions?