Introduction to Data Management

Lecture #1
(Course “Trailer”)

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Today’s Topics

- Welcome to one of my biggest classes ever!
- Read (and live by) the course wiki page:
- Also follow (and live by) the Piazza page:
  - [https://piazza.com/uci/spring2016/cs122a/home](https://piazza.com/uci/spring2016/cs122a/home)
  - Let’s look at both of these, and then lets also look at a preview of what lies ahead.
- **Note:** There will be a quiz in this week’s discussions – and, you will need to prepare (by reading about Academic Honesty)…!
What is a Database System?

- What’s a database?
  - A very large, integrated collection of data

- Usually a model of a real-world enterprise
  - Entities (e.g., students, courses, Facebook users, …) with attributes (e.g., name, birthdate, GPA, …)
  - Relationships (e.g., Susan is taking CS 122A, Susan is a friend of Lynn, …)

- What’s a database management system (DBMS)?
  - A software system designed to store, manage, and provide access to one or more databases
File Systems vs. DBMS

- Application programs must sometimes stage large datasets between main memory and secondary storage (for buffering huge data sets, getting page-oriented access, etc.)
- Special code needed for different queries, and that code must be (stay) correct and efficient
- Must protect data from inconsistency due to multiple concurrent users
- Crash recovery is important since data is now the currency of the day (corporate jewels)
- Security and access control are also important(!)
Evolution of DBMS

Files

- Manual Coding
- Byte streams
- Majority of application development effort goes towards building and then maintaining data access logic

CODASYL/IMS

- Early DBMS Technologies
  - Records and pointers
  - Large, carefully tuned data access programs that have dependencies on physical access paths, indexes, etc.

Relational

- Relational DB Systems
  - Declarative approach
  - Tables and views bring “data independence”
  - Details left to system
  - Designed to simplify data-centric application development
Why Use a DBMS?

- Data independence.
- Efficient data access.
- Reduced application development time.
- Data integrity and security.
- Uniform data administration.
- Concurrent access, recovery from crashes.
Why Study Databases?

- Shift from *computation* to *information*
  - At the “low end”: explosion of the web (a mess!)
  - At the “high end”: scientific applications, social data analytics, …

- Datasets increasing in diversity and volume
  - Digital libraries, interactive video, Human Genome project, EOS project, the Web itself, …
  - Mobile devices, Internet of Things, …
  - … *need for DBMS exploding!*

- DBMS field encompasses most of CS!!
  - OS, languages, theory, AI, multimedia, logic, …
Data Models

- A **data model** is a collection of concepts for describing data
- A **schema** is a description of a particular collection of data, using a given data model
- The **relational model** is (still) the most widely used data model today
  - **Relation** – basically a table with rows and (named) columns
  - **Schema** – describes the tables and their columns
Levels of Abstraction

- Many *views* of one *conceptual (logical) schema* and an underlying *physical schema*
  - Views describe how different users see the data.
  - Conceptual schema defines the logical structure of the database
  - Physical schema describes the files and indexes used under the covers
Example: University DB

- Conceptual schema:
  - \textit{Students}(sid: string, name: string, login: string, age: integer, gpa: real)
  - \textit{Courses}(cid: string, cname: string, credits: integer)
  - \textit{Enrolled}(sid: string, cid: string, grade: string)

- Physical schema:
  - Relations stored as unordered files
  - Index on first and third columns of \textit{Students}

- External schema (\textit{a.k.a.} view):
  - \textit{CourseInfo}(cid: string, cname: string, enrollment: integer)
Data Independence

- Applications are *insulated* (at multiple levels) from how data is actually structured and stored
  - *Logical data independence*: Protection from changes in the *logical* structure of data
  - *Physical data independence*: Protection from changes in the *physical* structure of data

- *One of the most important benefits of DBMS use!*
  - Allows changes to occur – *w/o application rewrites!*
Example: University DB (cont.)

- User query (in SQL, against the external schema):
  - `SELECT c.cid, c.enrollment
    FROM CourseInfo c
    WHERE c.cname = 'Computer Game Design'

- Equivalent query (against the conceptual schema):
  - `SELECT e.cid, count(e.*)
    FROM Enrolled e, Courses c
    WHERE e.cid = c.cid  AND c.cname = 'Computer Game Design'
    GROUP BY c.cid`

- Under the hood (against the physical schema)
  - Access `Courses` – use index on `cname` to find associated `cid`
  - Access `Enrolled` – use index on `cid` to count the enrollments
Databases: The Cast

- End users and DBMS software vendors
- DB application programmers
  - *E.g.*, smart webmasters
- Database administrator (DBA)
  - Designs logical and physical schemas
  - Handles security and authorization
  - Ensures data availability, crash recovery
  - Tunes the database (physical schema) as needs evolve

⇒ *(DBA must understand how a DBMS works!)* ⇐
Concurrency Control

- **Concurrent execution** of user programs is essential for good DBMS performance.
  - Because disk accesses are frequent, and relatively slow, it is crucial to keep the CPUs (cores!) humming by working on multiple users’ programs concurrently.

- Interleaving actions of different user programs can lead to inconsistency: e.g., a bank transfer is run while a customer’s assets are being totalled.

- DBMS ensures that such problems don’t arise: users/programmers can pretend they’re using a single-user system.
Transaction: An Execution of a DB Program

- Key concept is **transaction**: An **atomic** sequence of database actions (e.g., reads/writes).

- Each transaction, when executed completely, must leave the DB in a **consistent state** if the DB is consistent before it was executed.
  - Users can specify simple **integrity constraints** on the data, and the DBMS will enforce these constraints.
  - Beyond this, the DBMS is happily clueless about the data semantics (e.g., how bank interest is computed).
  - Note: Ensuring that a given transaction (if run all by itself) preserves consistency is the user’s (app’s) job!
Concurrent DBMS Transactions

- DBMS ensures that execution of \{T_1, \ldots , T_n\} is equivalent to some (in fact, any!) **serial** execution.
  - Before reading/writing an object, a transaction requests a **lock** on the object and waits till the DBMS gives it the lock. (Locks are released together at end of transaction.)
  - **Key Idea:** If any action of Ti (e.g., writing X) impacts Tj (e.g., reading X), one will get a lock on X first and the other will wait until the first one is done; this orders the transactions!
Ensuring Atomicity

- DBMS ensures *atomicity* (all-or-nothing property) even if system crashes in the middle of a Xact.

- Idea: Keep a *log* (history) of all actions carried out by the DBMS while executing a set of Xacts:
  - Before a change is made to the database, a corresponding log entry is forced to a safe (different) location.
  - In the event of a crash, the effects of partially executed transactions can first be *undone* using the log.
v The following actions are recorded in the log:
  ▪ *Ti writes an object:* The old value and the new value.
    • Log record must go to disk **before** the changed DB page!
  ▪ *Ti commits/aborts:* A log record indicating the action.

v Log records are linked by Xact id, so it’s easy to undo a specific Xact (e.g., if it has to abort, or following a crash).

v Log is usually replicated on “stable” storage.

v All logging (and in fact, all the stuff we’re talking about) is handled transparently by the DBMS.
A typical DBMS has a layered architecture.

Note: This figure doesn’t show the locking and recovery components.

This is one of several possible architectures; each actual system has its own variations.
What’s **Exciting in DB Land Today?**

- The **Web** is full of database challenges
  - Click streams and social networks generate lots of data
    - How can I query and analyze all of that data?
  - A box for keywords only goes so far…
    - How can I query the web, e.g., “Find me 5-string Fender bass guitars for sale in the $1500-2000 price range”

- **Ubiquitous computing** is data-rich, too
  - Build, deploy, and use location-based data services
  - Query and aggregate streams of sensor or video data
  - “Internet of things”, SoLoMo (Social/Local/Mobile), …

- There’s **data everywhere**, and of all shapes and sizes
  - How do we integrate it, *e.g.*, for rapid crisis response?
  - And when we do, how do we ensure privacy/security?
Summary

- DBMS is used to maintain & query large datasets.
- Benefits include recovery from system crashes, concurrent access, quick application development, data integrity and security.
- Levels of abstraction give data independence.
- A DBMS typically has a layered architecture.
- DBAs (and friends) hold responsible jobs and they are also well-paid! (😊)
- Data-related R&D is one of the broadest, most exciting areas in CS.