CSCI 4707: Practice of Database Systems

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Instructor:

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What we will study in the Course

- **PART 1: Outside the Database Engine as a User**
  - How to do conceptual database design (Chapter 2)
  - How to do a logical database design (Chapter 3)
  - How to query the database (Chapters 4, 5)
  - How to enhance the logical design (Chapter 19)

- **PART 2: Inside the Database Engine**
  - Storage and indexing modules (Chapters 8-10)
  - Query processing & optimization (Chapters 12-15)
  - Transaction Processing (Chapters 16-18)
What Is a DBMS?

- How do you store your phone contacts:

<table>
<thead>
<tr>
<th>Name</th>
<th>Home</th>
<th>Cell</th>
<th>Address</th>
<th>Email</th>
</tr>
</thead>
</table>

- Designing, storing, and managing such “simple” tables is the core of DBMS
What Is a DBMS?

- A very large, integrated collection of data.
- Models real-world enterprise.
  - Entities (e.g., students, courses)
  - Relationships (e.g., Madonna is taking CSCI 1234)
- A Database Management System (DBMS) is a software package designed to store and manage databases.
History of DBMS

- Early 60’s
  - First general-purpose DBMS by Charles Bachman at General Electric (First recipient of ACM Turing Award in databases in 1973)

- Late 60’s
  - Hierarchical data model developed at IBM
  - The SABRE system for airline reservation is jointly developed by American Airlines and IBM where several people can access the same data through a network
History of DBMS

- **70’s**
  - The relational data model is proposed by Edgar Codd at IBM (*ACM Turing Award* at 1981)
  - Two main prototypes for relational database management systems are developed. Ingres at UCB and System R at IBM (*Mike Stonebraker received the ACM Turing Award* at 2014)
  - Peter Chen (MIT) proposed the entity-relationship model

- **80’s**
  - SQL query language is developed (part of System R)
  - The concept of read/write transactions is developed to allow concurrent execution of database operations (*Jim Gray received the ACM Turing Award* at 1998)
  - Commercial databases are in the market (DB2, Oracle, Informix)
History of DBMS

- 90’s – 10’s
  - DBMSs are well-established in industry and academia
  - More applications
  - Big data: volume, velocity, and variety

- 10’s – present
  - New DBMS architectures
  - Cloud native
  - DBMS as a service
Files vs. DBMS

- Special code for different queries

- Must protect data from inconsistency due to multiple concurrent users

- Crash recovery

- Security and access control
Why Use a DBMS?

- **Data independence**
  - Applications are independent from data representation
- **Efficient data access**
  - Through indexing and query optimization techniques
- **Data integrity and security**
  - DBMS enforce integrity constraints and access control
- **Concurrent access**
  - Multiple users are allowed to use the same tables
- **Crash recovery**
  - DBMS protects the user from the system failure
- **Reduced application development time**
  - DBMS supports functions that are common to many applications
Why Study Databases??

- Shift from \textit{computation} to \textit{information}
  - at the “low end”: scramble to webspace (a mess!)
  - at the “high end”: scientific applications
- Datasets increasing in diversity and volume.
  - Digital libraries, interactive video, Human Genome project, EOS project
  - ... need for DBMS exploding
- DBMS encompasses most of CS
  - OS, languages, theory, AI, networking, systems
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 the given data model.
- The **relational model of data** is the most widely used model today.
  - Main concept: *relation*, basically a table with rows and columns.
  - Every relation has a **schema**, which describes the columns, or fields.
Levels of Abstraction

- Many *views*, single *conceptual (logical) schema* and *physical schema*.
  - Views describe how users see the data.
  - Conceptual schema defines logical structure
  - Physical schema describes the files and indexes used.

- Schemas are defined using DDL; data is modified/queried using DML.
Example: University Database

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

- Physical schema:
  - Relations stored as unordered files.
  - Index on first column of Students.

- External Schema (View):
  - Course_info(cid: string, enrollment: integer)
Data Independence *

- Applications insulated from how data is structured and stored.
- **Logical data independence**: Protection from changes in *logical* structure of data.
- **Physical data independence**: Protection from changes in *physical* structure of data.

👉 One of the most important benefits of using a DBMS!
Concurrency Control

- Concurrent execution of user programs is essential for good DBMS performance.
  - Because disk accesses are frequent, and relatively slow, it is important to keep the cpu humming by working on several user programs concurrently.

- Interleaving actions of different user programs can lead to inconsistency: e.g., check is cleared while account balance is being computed.

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

- Key concept is **transaction**, which is an **atomic** sequence of database actions (reads/writes).
- Each transaction, executed completely, must leave the DB in a **consistent state** if DB is consistent when the transaction begins.
  - Users can specify some simple **integrity constraints** on the data, and the DBMS will enforce these constraints.
  - Beyond this, the DBMS does not really understand the semantics of the data. (e.g., it does not understand how the interest on a bank account is computed).
  - Thus, ensuring that a transaction (run alone) preserves consistency is ultimately the **user’s responsibility**!
Example

- Consider two transactions (Xacts):

  | T1: BEGIN A=A+100, B=B-100 END |
  | T2: BEGIN A=1.06*A, B=1.06*B END |

- Intuitively, the first transaction is transferring $100 from B’s account to A’s account. The second is crediting both accounts with a 6% interest payment.

- There is no guarantee that T1 will execute before T2 or vice-versa, if both are submitted together. However, the net effect **must** be equivalent to these two transactions running serially in some order.
Example (Contd.)

- Consider a possible interleaving (schedule):

  T1: \( A = A + 100, \quad B = B - 100 \)
  T2: \( A = 1.06 * A, \quad B = 1.06 * B \)

- This is OK. But what about:

  T1: \( A = A + 100, \quad B = B - 100 \)
  T2: \( A = 1.06 * A, \quad B = 1.06 * B \)

- The DBMS’s view of the second schedule:

  T1: \( R(A), W(A), \quad R(B), W(B) \)
  T2: \( R(A), W(A), R(B), W(B) \)
Scheduling Concurrent Transactions

- DBMS ensures that execution of \{T_1, \ldots, T_n\} is equivalent to some serial execution T_{1'} \ldots T_{n'}.
  - Before reading/writing an object, a transaction requests a lock on the object, and waits till the DBMS gives it the lock. All locks are released at the end of the transaction. (Strict 2PL locking protocol.)
  - Idea: If an action of Ti (say, writing X) affects Tj (which perhaps reads X), one of them, say Ti, will obtain the lock on X first and Tj is forced to wait until Ti completes; this effectively orders the transactions.
  - What if Tj already has a lock on Y and Ti later requests a lock on Y? (Deadlock!) Ti or Tj is aborted and restarted!
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, the corresponding log entry is forced to a safe location. *(WAL protocol; OS support for this is often inadequate.)*
  - After a crash, the effects of partially executed transactions are *undone* using the log. (Thanks to WAL, if log entry wasn’t saved before the crash, corresponding change was not applied to database!)

Database Management Systems 3ed, R. Ramakrishnan and J. Gehrke
The Log

- 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 page!
  - *Ti commits/aborts*: A log record indicating this action.

- Log records chained together by Xact id, so it’s easy to undo a specific Xact (e.g., to resolve a deadlock).

- Log is often *duplexed* and *archived* on “stable” storage.

- All log related activities (and in fact, all CC related activities such as lock/unlock, dealing with deadlocks etc.) are handled transparently by the DBMS.
Databases make these folks happy ...

- End users and DBMS vendors
- DB application programmers
  - E.g., smart webmasters
- **Database administrator (DBA)**
  - Designs logical / physical schemas
  - Handles security and authorization
  - Data availability, crash recovery
  - Database tuning as needs evolve

Must understand how a DBMS works!
Structure of a DBMS

- A typical DBMS has a layered architecture.
- The figure does not show the concurrency control and recovery components.
- This is one of several possible architectures; each system has its own variations.
Summary

- DBMS 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 data scientists jobs are well-paid! 😊
- DBMS R&D is one of the broadest, most exciting areas in CS.
Acknowledgement

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