CS 4604: Introduction to Database Management Systems

B. Aditya Prakash

Lecture #1: Introduction

Based on material by Profs. T. M. Murali and Christos Faloutsos
Course Information

- **Instructor**
  B. Aditya Prakash, Torg 3160 F, [badityap@cs.vt.edu](mailto:badityap@cs.vt.edu)
  - Office Hours: 2-3:15pm Tuesdays and Thursdays
  - Include string **CS 4604** in subject

- **Teaching Assistant**
  Qianzhou Du, McBryde 106, [qiand12@vt.edu](mailto:qiand12@vt.edu)
  - Office Hours: 1:30-3:30pm Mondays and Wednesdays

- **Class Meeting Time**
  Tuesdays and Thursdays 3:30-4:45pm Randolph Hall 331

- **Keeping in Touch**
  Course web site [http://courses.cs.vt.edu/~cs4604](http://courses.cs.vt.edu/~cs4604)
  updated regularly through the semester
  - *Piazza link on the website*
Textbook

- **Required**
  Web page for the book (with errata)

- **Optional:**
  - Garcia-Molina, Ullman and Widom, 3rd Ed.
  - Silberschatz, Korth and Sudarshan, 6th Ed.
Pre-reqs and Force-adds

- Prerequisites: a grade of C or better in CS 3114, senior standing
  - every student must fill out a pre-requisite form, and must return it to me at the end of the class in order to remain enrolled

- Force-add requests:
  - Please fill out the add form as well, and return to me at the end of the class
  - We (=me or the dept) will let you know by this week
## Course Grading

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homework</td>
<td>30%</td>
<td>6-7</td>
</tr>
<tr>
<td>Midterm exam</td>
<td>20%</td>
<td>(Tentative) March 6, Thur., in class</td>
</tr>
<tr>
<td>Final exam</td>
<td>30%</td>
<td>May 10, Saturday, 7:45am-9:45am</td>
</tr>
<tr>
<td>Course project</td>
<td>20%</td>
<td>3 assignments</td>
</tr>
</tbody>
</table>

- Project is spread over 3 deliverables
- Submit hard copies of homeworks and project assignments at the start of class on the due date
- Each class has required reading (on course web page)
- No Pop-Quizzes 😊
Course Project

- Project overview
  
  http://courses.cs.vt.edu/~cs4604/Spring14/project/project.html

- 2, or 3 persons per project.

- Project runs the entire semester with regular assignments and a final implementation assignment.
Class Policies

- Make sure you go through the detailed policies on website:
  
  http://courses.cs.vt.edu/~cs4604/Spring14/policies.html

- Late policy: 4 ‘slip’ days

- Exams: no aids allowed, except:
  - 1 page with your notes (both sides), for the midterm
  - 2 such pages, for the final
Why Study Databases?

- **Academic**
  - Databases involve many aspects of computer science
  - Fertile area of research
  - Three Turing awards in databases

- **Programmer**
  - A plethora of applications involve using and accessing databases

- **Businessman**
  - Everybody needs databases => lots of money to be made

- **Student**
  - Get those last three credits and I don’t have to come back to Blacksburg ever again!
  - Google, Oracle, Microsoft, Facebook etc. will hire me!
  - Databases sound cool!
  - ???
What Will You Learn in CS 4604?

- Implementation
  - What is under-the-hood of a DB like Oracle/MySQL?

- Design
  - How do you model your data and structure your information in a database?

- Programming
  - How do you use the capabilities of a DBMS?

- CS 4604 achieves a balance between
  - a firm theoretical foundation to designing moderate-sized databases
  - creating, querying, and implementing realistic databases and connecting them to applications
Course Outline

- **Weeks 1–4: Query/Manipulation Languages and Data Modeling**
  - Relational Algebra
  - Data definition
  - Programming with SQL
  - Entity-Relationship (E/R) approach
  - Specifying Constraints
  - Good E/R design

- **Weeks 5–8: Indexes, Processing and Optimization**
  - Storing
  - Hashing/Sorting
  - Query Optimization
  - NoSQL and Hadoop

- **Week 9-10: Relational Design**
  - Functional Dependencies
  - Normalization to avoid redundancy

- **Week 11-12: Concurrency Control**
  - Transactions
  - Logging and Recovery

- **Week 13–14: Students’ choice**
  - Practice Problems
  - XML
  - Data mining and warehousing
What is the goal of a DBMS?

- Electronic record-keeping
  - Fast and convenient access to information

- DBMS == database management system
  - `Relational’ in this class
  - data + set of instructions to access/manipulate data

Prakash 2014
What is a DBMS?

- **Features of a DBMS**
  - Support massive amounts of data
  - Persistent storage
  - Efficient and convenient access
  - Secure, concurrent, and atomic access

- **Examples?**
  - Search engines, banking systems, airline reservations, corporate records, payrolls, sales inventories.
  - New applications: Wikis, social/biological/multimedia/scientific/geographic data, heterogeneous data.
Features of a DBMS

• Support **massive** amounts of data
  – Giga/tera/petabytes
  – Far too big for main memory

• **Persistent** storage
  – Programs update, query, manipulate data.
  – Data continues to live long after program finishes.

• **Efficient** and **convenient** access
  – Efficient: do not search entire database to answer a query.
  – Convenient: allow users to query the data as easily as possible.

• **Secure, concurrent, and atomic** access
  – Allow multiple users to access database simultaneously.
  – Allow a user access to only to authorized data.
  – Provide some guarantee of reliability against system failures.
Example Scenario

- Students, taking classes, obtaining grades
  - Find my GPA
  - <and other ad-hoc queries>
Obvious solution 1: Folders

- Advantages?
  - Cheap; Easy-to-use

- Disadvantages?
  - No ad-hoc queries
  - No sharing
  - Large Physical foot-print
Obvious Solution++

- Flat files and C (C++, Java...) programs
  - E.g. one (or more) UNIX/DOS files, with student records and their courses
Obvious Solution++

- Layout for student records?
  - CSV (‘comma-separated-values’)

  Hermione Grainger,123,Potions,A
  Draco Malfoy,111,Potions,B
  Harry Potter,234,Potions,A
  Ron Weasley,345,Potions,C
Obvious Solution++

- Layout for student records?
  - Other possibilities like
    - Hermione Grainger, 123
    - Draco Malfoy, 111
    - Harry Potter, 234
    - Ron Weasley, 345
    - 123, Potions, A
    - 111, Potions, B
    - 234, Potions, A
    - 345, Potions, C
Problems?

- inconvenient access to data (need ‘C++’ expertise, plus knowledge of file-layout)
  - data isolation
- data redundancy (and inconsistencies)
- integrity problems
- atomicity problems
- concurrent-access problems
- security problems
- ......
Problems-Why?

Two main reasons:

– file-layout description is buried within the C programs and

– there is no support for transactions (concurrency and recovery)

DBMSs handle exactly these two problems
Example Scenario

- RDBMS = “Relational” DBMS
- The relational model uses relations or tables to structure data
- ClassList relation:

<table>
<thead>
<tr>
<th>Student</th>
<th>Course</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hermione Grainger</td>
<td>Potions</td>
<td>A</td>
</tr>
<tr>
<td>Draco Malfoy</td>
<td>Potions</td>
<td>B</td>
</tr>
<tr>
<td>Harry Potter</td>
<td>Potions</td>
<td>A</td>
</tr>
<tr>
<td>Ron Weasley</td>
<td>Potions</td>
<td>C</td>
</tr>
</tbody>
</table>

- Relation separates the logical view (externals) from the physical view (internals)
- Simple query languages (SQL) for accessing/modifying data
  - Find all students whose grades are better than B.
  - SELECT Student FROM ClassList WHERE Grade >“B”
DBMS Architecture

Schema Modifications

Queries

Modifications

“Query” Processor

Transaction Manager

Storage Manager

Data

Metadata

Prakash 2014

VT CS 4604
Transaction Processing

- One or more database operations are grouped into a “transaction”
- Transactions should meet the “ACID test”
  - **Atomicity**: All-or-nothing execution of transactions.
  - **Consistency**: Databases have consistency rules (e.g. what data is valid). A transaction should NOT violate the database’s consistency. If it does, it needs to be *rolled back*.
  - **Isolation**: Each transaction must appear to be executed as if no other transaction is executing at the same time.
  - **Durability**: Any change a transaction makes to the database should persist and not be lost.
Disadvantages over (flat) files?
Disadvantages over (flat) files

- Price
- additional expertise (SQL/DBA)

(hence: over-kill for small, single-user data sets
But: mobile phones (eg., android) use sqlite)
A Brief History of DBMS

- The earliest databases (1960s) evolved from file systems
  - File systems
    - Allow storage of large amounts of data over a long period of time
    - File systems do not support:
      - Efficient access of data items whose location in a particular file is not known
      - Logical structure of data is limited to creation of directory structures
      - Concurrent access: Multiple users modifying a single file generate non-uniform results
    - Navigational and hierarchical
    - User programmed the queries by walking from node to node in the DBMS.

- Relational DBMS (1970s to now)
  - View database in terms of relations or tables
  - High-level query and definition languages such as SQL
  - Allow user to specify what (s)he wants, not how to get what (s)he wants

- Object-oriented DBMS (1980s)
  - Inspired by object-oriented languages
  - Object-relational DBMS
The DBMS Industry

- A DBMS is a software system.

- Major DBMS vendors: Oracle, Microsoft, IBM, Sybase

- Free/Open-source DBMS: MySQL, PostgreSQL, Firebird.
  - Used by companies such as Google, Yahoo, Lycos, BASF....

- All are “relational” (or “object-relational”) DBMS.

- A multi-billion dollar industry
Fundamental concepts

- 3-level architecture
- logical data independence
- physical data independence
3-level architecture

- view level
- logical level
- physical level
3-level architecture

- view level
- logical level: eg., tables
  - STUDENT(ssn, name)
  - TAKES (ssn, cid, grade)
- physical level:
  - how are these tables stored, how many bytes / attribute etc
3-level architecture

- view level, eg:
  - v1: select ssn from student
  - v2: select ssn, c-id from takes
- logical level
- physical level
3-level architecture

- hence, **physical** and **logical** data independence:
  - logical D.I.: ???
  - physical D.I.: ???
3-level architecture

- hence, **physical** and **logical** data independence:

  - logical D.I.:
    - can add (drop) column; add/drop table
  
  - physical D.I.:
    - can add index; change record order
Database users

- ‘naive’ users
- casual users
- application programmers
- [ DBA (Data base administrator)]
Casual users

```
select * from student
```

DBMS

data

and meta-data = catalog
“Naive” users

Pictorially:

- DBMS
- Data
- App. (e.g., report generator)

And meta-data = catalog
App. programmers

- those who write the applications (like the ‘report generator’ )
DB Administrator (DBA)

- Duties?
DB Administrator (DBA)

- schema definition ('logical' level)
- physical schema (storage structure, access methods)
- schemas modifications
- granting authorizations
- integrity constraint specification
Overall system architecture

- [Users]
- DBMS
  - query processor
  - storage manager
  - transaction manager
- [Files]
null
Overall system architecture

- query processor
  - DML compiler
  - embedded DML pre-compiler
  - DDL interpreter
  - Query evaluation engine
Overall system architecture (cont’d)

- storage manager
  - authorization and integrity manager
  - transaction manager
  - buffer manager
  - file manager
Overall system architecture (cont’d)

- Files
  - data files
  - data dictionary = catalog (= meta-data)
  - indices
  - statistical data
Some examples:

- DBA doing a DDL (data definition language) operation, eg.,
  create table student ...
Some examples:

- casual user, asking for an update, eg.:
  
  update student
  
  set name to ‘smith’
  
  where ssn = ‘345’
naive

app. pgmr

casual

DBA

users

data

meta-data

virginia tech

DDL int.

query proc.

app. pgm(o)

DML proc.

query eval.

emb. DML

trans. mgr

buff. mgr

file mgr

storage mgr.
DDL int.  
DML proc.  
query eval.  
app. pgm(o)  
emb. DML  
trans. mgr  
buff. mgr  
file mgr  
meta-data  
data  
storage mgr.  
query proc.  
DBA  
casual  
app. pgmr  
naive  
users
naive  app. pgmr  casual  DBA

DDL int.  DML proc.  query eval.

emb. DML  app. pgm(o)  query proc.

trans. mgr  buff. mgr  file mgr  storage mgr.

data  meta-data

users
Some examples:

- app. programmer, creating a report, eg
  main(){
    ....
    exec sql "select * from student"
    ...
  }
naive

app. pgmr

pgm (src)
casual

DBA

users

emb. DML

DML proc.

DDL int.

query eval.

query proc.

storage mgr.

trans. mgr

buff. mgr

file mgr

data

meta-data

app. pgm(o)

prakhs 2014

vt cs 4604
Some examples:

- ‘naive’ user, running the previous app.
Conclusions

- (relational) DBMSs: electronic record keepers
- customize them with **create table** commands
- ask SQL queries to retrieve info
Conclusions contd

main advantages over (flat) files & scripts:

- **logical + physical data independence** (i.e., flexibility of adding new attributes, new tables and indices)

- **concurrency control and recovery**