CS 5614: (Big) Data Management Systems

B. Aditya Prakash

Lecture #1: Introduction
$600 to buy a disk drive that can store all of the world’s music

5 billion mobile phones in use in 2010

30 billion pieces of content shared on Facebook every month

40% projected growth in global data generated per year vs.

$5 million vs. $400 Price of the fastest supercomputer in 1975¹ and an iPhone 4 with equal performance

235 terabytes data collected by the US Library of Congress by April 2011

15 out of 17 sectors in the United States have more data stored per company than the US Library of Congress

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Data contains value and knowledge

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Data and Business

Recommended links
+79% clicks
vs. randomly selected

Personalized News Interests
+250% clicks
vs. editorial one-size-fits-all

Top Searches
+43% clicks
vs. editor selected

Source: A. Machhanavajjhala
Detecting influenza epidemics using search engine query data

http://www.nature.com/nature/journal/v457/n7232/full/nature07634.html

Red: official numbers from Center for Disease Control and Prevention; weekly
Black: based on Google search logs; daily (potentially instantaneously)
Data and Government

http://www.washingtonpost.com/opinions/obama-the-big-data-president/2013/06/14/1d71fe2e-d391-11e2-b05f-3ea3f0e7bb5a_story.html


http://www.whitehouse.gov/blog/Democratizing-Data


Source: A. Machhanavajjhala
Data and Culture

- Word frequencies in English-language books in Google’s database


Source: A. Machhanavajjhala
Data and _______ your favorite subject

Sports

Journalism

Every year in America, 6,000 killers get away with murder. Why do police fail to solve so many homicides, even with more advanced investigative techniques? Can we stop these murderers from killing again and bring justice to their victims?
Good news: Demand for Data Mining

Demand for deep analytical talent in the United States could be 50 to 60 percent greater than its projected supply by 2018

Supply and demand of deep analytical talent by 2018

<table>
<thead>
<tr>
<th>Year</th>
<th>Employment</th>
<th>Graduates with deep analytical talent</th>
<th>Others</th>
<th>2018 Supply</th>
<th>Talent Gap</th>
<th>2018 Projected Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>150</td>
<td>180</td>
<td>30</td>
<td>300</td>
<td>140-190</td>
<td>440-490</td>
</tr>
</tbody>
</table>

50-60% gap relative to 2018 supply

1 Other supply drivers include attrition (-), immigration (+), and reemploying previously unemployed deep analytical talent (+).

Source: US Bureau of Labor Statistics; US Census, Dun & Bradstreet; company interviews; McKinsey Global Institute analysis

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How to extract value from data?

- Manipulate Data
  - CS, Domain expertise

- Analyze Data
  - Math, CS, Stat...

- Communicate your results
  - CS, Domain Expertise
Communication is important!

“The British government spends £13 billion a year on universities.”

– So?

– Try instead

http://wheredoesmymoneygo.org/bubbletree-map.html#/~/total/education/university
What is Data Mining?

- **Given lots of data**
- **Discover patterns and models that are:**
  - **Valid:** hold on new data with some certainty
  - **Useful:** should be possible to act on the item
  - **Unexpected:** non-obvious to the system
  - **Understandable:** humans should be able to interpret the pattern
Data Mining Tasks

- **Descriptive methods**
  - Find human-interpretable patterns that describe the data
    - **Example:** Clustering

- **Predictive methods**
  - Use some variables to predict unknown or future values of other variables
    - **Example:** Recommender systems
Big data

Theory & Algo.

Physics

Social Science

Econ.

ML & Stats.

Comp. Systems

Biology

Social Science

Econ.

ML & Stats.

Comp. Systems

Biology

Physics

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Econ.

ML & Stats.

Comp. Systems

Biology

Physics

Social Science

Econ.
COURSE LOGISTICS
Course Information

- **Instructor**
  B. Aditya Prakash, Torgersen Hall 3160 F, badityap@cs.vt.edu
  - Office Hours: TBD
  - Include string **CS 5614** in subject

- **Teaching Assistant**
  TBD
  - Office Hours: TBD

- **Class Meeting Time**
  Tuesdays, Thursdays, 9:30-10:45am, McBryde Hall 226

- **Syllabus:** Relational Database Systems, Big data Technologies (MR and new software stack), Streams, Recommendation Systems, Large Scale Machine Learning, and Graph Mining
Course Information

- Keeping in Touch

  Course web site

  http://www.cs.vt.edu/~badityap/classes/cs5614-Spr17/

  updated regularly through the semester

  – Piazza link on the website
Textbook

- Required

Web page for the book (with FREE PDF!)
www.mmds.org
Textbook

- Recommended (for database internals)

Raghu Ramakrishnan and Johannes Gehrke
Pre-reqs

(A) Should enjoy the course 😊

(B) Background in

1. Algorithms
2. Probability and Stats
3. Undergraduate level Databases
4. Linear Algebra (helps)
5. Graph theory (helps)

(C) Graduate-level Programming Skills (i.e. ability to use unfamiliar software, picking up new languages, comfortable with at least one of Python/C/C++/Ruby/Java etc. (Matlab/R a plus))
Force-add

- Talk to me once after class

AND

- Fill-in this survey by 6pm EST today
  https://goo.gl/forms/APfoI5CymKqKg0Pk1
Course Grading

- Details coming soon (next lecture)

- Broadly
  - Some hws
  - No midterm
  - Take-home Final
  - Project
  - Class participation
Course Project

- 2, or 3 (max) persons per project.
- Major work for this class.
- Pick your own topic
  - You have to justify why the topic is interesting, and relevant to the course, and of suitable difficulty
- Harder way:
  - Joint projects with other courses are also negotiable. In that case, you will need the approval of the instructor, and you also need to clarify exactly what steps will be done for this course, as well as for the other course.
  - Projects related to your dissertation/master-project are also possible, as long as there is no 'double-dipping', i.e., you clearly specify what the project will do, in addition to what you were planning to do for your thesis anyway.
- Ask me if you need help and ideas (I may release a list of suitable topics later)
Course Project

- Proposal
- Milestone
- Final Report
- Poster Presentation (or in-class presentation TBD)
WARM-UP AND BASICS
Relational Databases: What we will cover (next 1 month)

- 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?

- Achieves a balance between
  - a firm theoretical foundation to designing moderate-sized databases
  - creating, querying, and implementing realistic databases and connecting them to applications
CS4604: 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

*We will go over all of this quickly!* 😊
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
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
- ......

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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

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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

and meta-data = catalog
``Naive’’ users

Pictorially:

DBMS

app. (eg., report generator)

and meta-data = catalog

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

app. pgmr
casual

DBA

users

trans. mgr
buff. mgr
file mgr

naive
app. pgmr
casual

DBA

users
Some examples:

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

Data

meta-data

DDL int.

DDC

DML proc.

DML

proc.

app. pgm(o)

trans. mgr

buff. mgr

file mgr

query eval.

query proc.

storage mgr.

users
Some examples:

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

Some examples:

- ‘naive’ user, running the previous app.
The diagram illustrates the components and processes involved in managing data in a database system. It includes:

- **Data**: The primary source of information.
- **Meta-data**: Information about the data and its management.

The processes and components are as follows:

- **DDL int.** (DDL Integration): Handles the definition and manipulation of database schemas.
- **DML proc.** (DML Processing): Processes Data Manipulation Language (DML) commands.
- **query eval.** (Query Evaluation): Evaluates queries to retrieve or manipulate data.
- **app. pgm(o)** (Application Program): Performs specific tasks based on user requests.
- **app. pgmr** (Application Programmer): Develops applications to interact with the database.
- **casual** (Casual User): Performs basic data manipulation.
- **DBA** (Database Administrator): Manages the database system and its resources.
- **trans. mgr** (Transaction Manager): Handles transactions to ensure data integrity.
- **buff. mgr** (Buffer Manager): Manages the buffer pool for efficient data access.
- **file mgr** (File Manager): Manages file systems or storage devices.
- **emb. DML** (Embedded DML): Integrates DML directly into application programs.

The diagram also highlights the organization of users and different roles within the database management system.
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** (ie., flexibility of adding new attributes, new tables and indices)

- **concurrency control and recovery**