# CS186: Introduction to Database Systems

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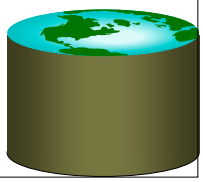
and Joe Hellerstein

Fall 2005

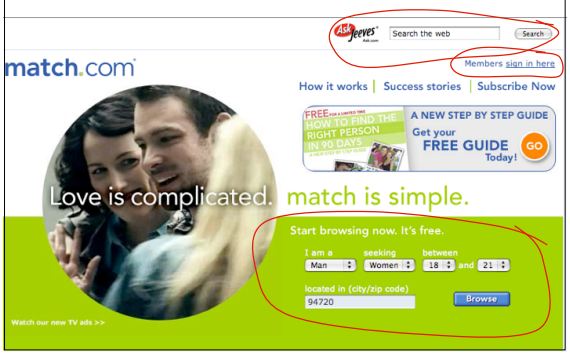


## Queries for Today

- What?
- Why?
- Who?
- How?
- For instance?

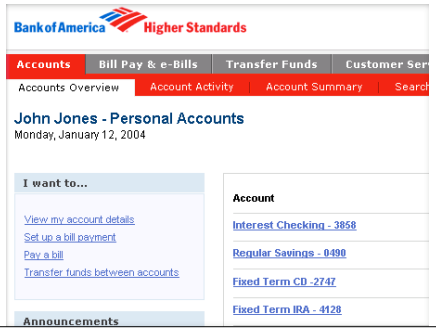
## What: Database Systems Then

## What: Database Systems Today

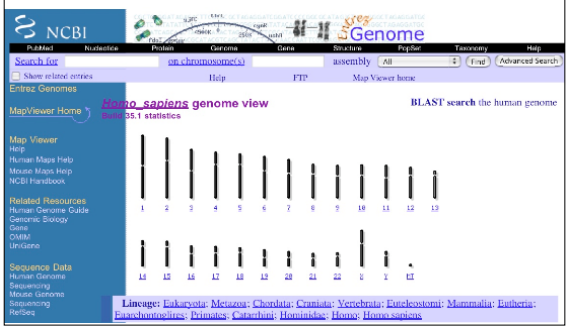



## What: Database Systems Today


## What: Database Systems Today



## What: Database Systems Today




## So… What is a Database?

- We will be broad in our interpretation
- A Database:
  - A very large, integrated collection of data.
- Typically models a real-world "enterprise"
  - Entities (e.g., teams, games)
  - Relationships (e.g. The A's are playing in the World Series)
- Might surprise you how flexible this is
  - Web search:
    - Entities: words, documents
    - Relationships: word in document, document links to document.
  - P2P filesharing:
    - Entities: words, filenames, hosts
    - Relationships: word in filename, file available at host

## What is a Database Management System?

- A Database Management System (DBMS) is:
  - A software system designed to store, manage, and facilitate access to databases.
- Typically this term used narrowly
  - Relational databases with transactions
    - E.g. Oracle, DB2, SQL Server
  - Mostly because they predate other large repositories
    - Also because of technical richness
  - When we say DBMS in this class we will usually follow this convention
    - But keep an open mind about applying the ideas!

## What: Is the WWW a DBMS?

- Fairly sophisticated search available
  - Crawler indexes pages on the web
  - Keyword-based search for pages
- But, currently
  - data is mostly unstructured and untyped
  - search only:
    - can't modify the data
    - can't get summaries, complex combinations of data
  - few guarantees provided for freshness of data, consistency across data items, fault tolerance, …
  - Web sites typically have a (relational) DBMS in the background to provide these functions.
- The picture is changing
  - New standards e.g., XML, Semantic Web can help data modeling
  - Research on combining/summarizing data across documents

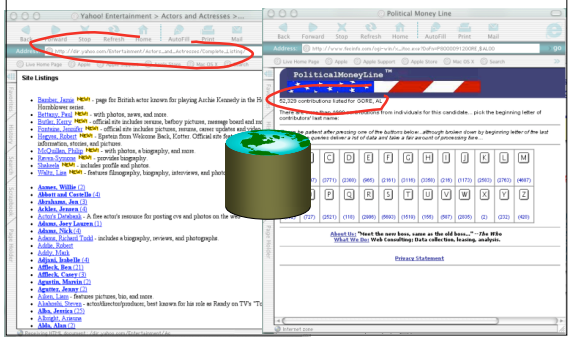
## What: "Search" vs. Query

- What if you wanted to find out which actors donated to John Kerry's presidential campaign?
- Try "actors donated to john kerry" in your favorite search engine.


## What: "Search" vs. Query II

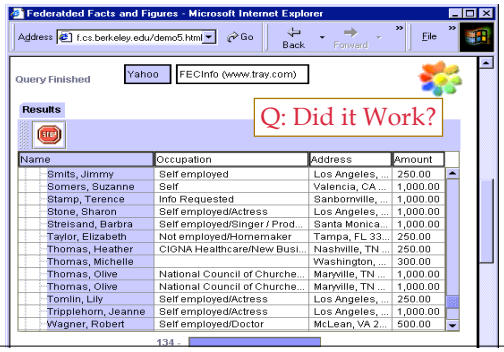
- What if you wanted to find out which musicians donated to John Kerry's presidential campaign?
- Try "musicians donated to john kerry" in your favorite search engine.
- If it isn't "published", it can't be searched ??

## What: A "Database Query" Approach



## "Yahoo Actors" JOIN "FECInfo"

(Courtesy of the Telegraph research group @Berkeley)




## What: Is a File System a DBMS?

- Thought Experiment 1:
  - You and your project partner are editing the same file.
  - You both save it at the same time.
  - Whose changes survive?

**A) Yours B) Partner's C) Both D) Neither E) ???**

- Thought Experiment 2:
  - –You're updating a file.
  - –The power goes out.
  - –Which changes survive?

**A) All B) None C) All Since Last Save D) ???**

Q: How do you write programs over a subsystem when it promises you only "???" ?
A: Very, very carefully!!

## OS Support for Data Management

- Data can be stored in RAM
  - this is what every programming language offers!
  - RAM is fast, and random access
  - Isn't this heaven?
- Every OS includes a File System
  - manages *files* on a magnetic disk
  - allows *open, read, seek, close* on a file
  - allows protections to be set on a file
  - drawbacks relative to RAM?

## Database Management Systems

- What more could we want than a file system?
  - Simple, efficient *ad hoc*[1] queries
  - concurrency control
  - recovery
  - benefits of good data modeling
- S.M.O.P.[2]? Not really…
  - as we'll see this semester
  - in fact, the OS often gets in the way!

[1] ad hoc: formed or used for specific or immediate problems or needs
[2] SMOP: Small Matter Of Programming

## Current Commercial Outlook

- A major part of the software industry:
  - Oracle, IBM, Microsoft
  - also Sybase, Informix (now IBM), Teradata
  - smaller players: java-based dbms, devices, OO, …
- Well-known benchmarks (esp. TPC)
- Lots of related industries
  - data warehouse, document management, storage, backup, reporting, business intelligence, ERP, CRM, app integration
- Traditional Relational DBMS products dominant and evolving
  - adapting for extensibility (user-defined types), native XML support.
  - Microsoft merging file system/DB for next OS release (??)
- Open Source coming on strong
  - MySQL, PostgreSQL, BerkeleyDB
- And of course, the other "database" technologies
  - Search engines, P2P, etc.

## What database systems will we cover?

- We will be try to be broad and touch upon
  - Relational DBMS (e.g. Oracle, SQL Server, DB2, Postgres)
  - Document search engines (e.g. Google, Verity, Spotlight)
  - "Semi-structured" DB systems (e.g. XML repositories like Xindice)
- Starting point
  - We assume you have used web search engines
  - We assume you don't know relational databases
    - Yet they pioneered many of the key ideas
  - So focus will be on relational DBMSs
    - With frequent side-notes on search engines, XML issues

## Why take this class?

A. Database systems are at the core of CS
B. They are incredibly important to society
C. The topic is intellectually rich
D. A capstone course for undergrad
~~E. It isn't that much work~~
F. Looks good on your resume

Let's spend a little time on each of these

## Why take this class?

**A. Database systems are the core of CS**

- Shift from computation to information
  - True in corporate computing for years
  - Web, p2p made this clear for personal computing
  - Increasingly true of scientific computing
- Need for DB technology has exploded in the last years
  - Corporate: retail swipe/clickstreams, "customer relationship mgmt", "supply chain mgmt", "data warehouses", etc.
  - Web:not just "documents". Search engines, e-commerce, blogs, wikis, other "web services".
  - Scientific: digital libraries, genomics, satellite imagery, physical sensors, simulation data
  - Personal: Music, photo, & video libraries. Email archives. File contents ("desktop search").

## Why take this class?

**B. DBs are incredibly important to society**

- "Knowledge is power." -- Sir Francis Bacon
- "With great power comes great responsibility." -- SpiderMan's Uncle Ben


Policy-makers should understand technological possibilities.
Informed Technologists needed in public discourse on usage.

## Why take this class?

**C. The topic is intellectually rich.**

- representing information
  - data modeling
- languages and systems for querying data
  - complex queries & query semantics*
  - over massive data sets
- concurrency control for data manipulation
  - controlling concurrent access
  - ensuring transactional semantics
- reliable data storage
  - maintain data semantics even if you pull the plug

* semantics: the meaning or relationship of meanings of a sign or set of signs

## Why take this class?

**D. The course is a capstone.**

- We will see
  - Algorithms and cost analyses
  - System architecture and implementation
  - Resource management and scheduling
  - Computer language design, semantics and optimization
  - Applications of AI topics including logic and planning
  - Statistical modeling of data

## Why take this class?

~~E. It isn't that much work.~~

- Bad news: It is a lot of work.
- Good news: the course is front loaded
  - Most of the hard work is in the first half of the semester
  - Load balanced with most other classes

## Why take this class?

**F. Looks good on my resume.**

- Yes, but why? This is not a course for:
  - Oracle administrators
  - IBM DB2 engine developers
    - Though it's useful for both!
- It is a course for well-educated computer scientists
  - Database system concepts and techniques increasingly used "outside the box"
    - Ask your friends at Microsoft, Google, Apple, etc.
    - Actually, they may or may not realize it!
  - A rich understanding of these issues is a basic and (un?)fortunately unusual skill.

## Who?

- Instructors
  - Prof. Joe Hellerstein, UC Berkeley
  - Dr. Minos Garofalakis, Intel Research
  - cs186profs@db.cs.berkeley.edu
- TAs
  - Tyson Condie
  - Varun Kacholia
  - Benjamin Mellblom

## How? Workload

- Projects with a "real world" focus:
  - Modify the internals of a "real" open-source database system: PostgreSQL
    - Serious C system hacking
    - Measure the benefits of our changes
  - Build a web-based application w/PostgreSQL, Apache & PHP): SQL + PHP
- Other homework assignments and/or quizzes
- Exams – 1 Midterm & 1 Final
- Projects to be done in groups of 2
  - Pick your partner ASAP
- The course is "front-loaded"
  - most of the hard work is in the first half

## How? Administrivia

- http://inst.eecs.berkeley.edu/~cs186
- Prof. Office Hours:
  - Hellerstein: 685 Soda Hall, Tu/Th 2:30-3:30
  - Garofalakis: TBA (check web page)
- TAs
  - Office Hours: TBA (check web page)
- Discussion Sections WILL meet this week

## How? Administrivia, cont.

- Textbook
  - Ramakrishnan and Gehrke, 3rd Edition
- Grading, hand-in policies, etc. will be on Web Page
- Cheating policy: zero tolerance
  - We have the technology…
- Team Projects
  - Teams of 2
  - Peer evaluations.
    - Be honest! Feedback is important. Trend is more important than individual project.
- Class bulletin board - ucb.class.cs186
  - read it regularly and post questions/comments.
  - mail broadcast to all TAs will not be answered
  - mail to the cs186 course account will not be answered
- Class Blog for announcements

## For Instance?

- Rest of today: "free tasting" of things to come in this class:
  - data modeling & query languages
  - file systems & DBMSs
  - concurrent, fault-tolerant data management
  - DBMS architecture
- We may not get through all of it
  - That's OK, we'll see it in more detail later.
- Next Time
  - The Relational Model
- The following mostly from Chapter 1 in R&G

## Describing Data: Data Models

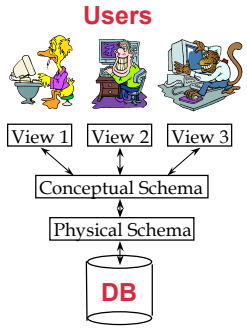
- A data model is a collection of concepts for describing data.
- A schema is a description of a particular collection of data, using a given data model.

## Some common data models

- The relational model of data is the most widely used for record keeping.
  - Main concept: relation, basically a table with rows and columns.
  - Every relation has a schema, which describes the columns
- Free text (and hypertext) widely used as well
  - Data represented for human consumption
    - Visual aspects and linguistic subtlety more important than clearly structured data
- Semi-structured models in increasing use (e.g. XML)
  - Main concept: self-describing (tagged) document, basically a textual hierarchy (tree) of labeled values
  - Document Type Definition (DTD) or Schema possible, but not required

## Levels of Abstraction

- Views describe how users see the data.
- Conceptual schema defines logical structure
- Physical schema describes the files and indexes used.
- (sometimes called the ANSI/SPARC architecture)

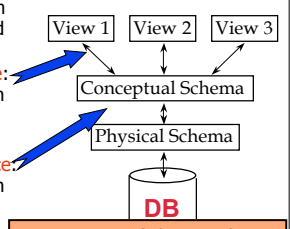



## Example: University Database

- Data Model: Relations
- 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

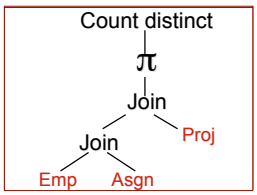
- Applications insulated from how data is structured and stored.
- Logical data independence: Protection from changes in logical structure of data.
- Physical data independence: Protection from changes in physical structure of data.
- Q: Why are these particularly important for DBMS?




Because rate of change of DB applications is incredibly slow.
More generally:
dapp/dt << dplatform/dt

## Queries, Query Plans, and Operators

```
SELECT
    COUNT DISTINCT (E.eid)
FROM Emp E, Proj P, Asgn A
WHERE E.eid = A.eid
        AND P.pid = A.pid
        AND E.loc <> P.loc
```




- System handles query plan generation & optimization; ensures correct execution.


Issues: view reconciliation, operator ordering, physical operator choice, memory management, access path (index) use, …

## Concurrency Control

- Concurrent execution of user programs: key to good DBMS performance.
  - Disk accesses frequent, pretty slow
  - Keep the CPU working on several programs concurrently.
- Interleaving actions of different programs: trouble!
  - e.g., account-transfer & print statement at same time
- DBMS ensures such problems don't arise.
  - Users/programmers can pretend they are using a single-user system. (called "Isolation")
  - Thank goodness! Don't have to program "very, very carefully".

## Transactions: ACID Properties

- Key concept is a transaction: a sequence of database actions (reads/writes).
- DBMS ensures *atomicity* (all-or-nothing property) even if system crashes in the middle of a Xact.
- Each transaction, executed completely, must take the DB between *consistent* states or must not run at all.
- DBMS ensures that concurrent transactions appear to run in *isolation*.
- DBMS ensures *durability* of *committed* Xacts even if system crashes.
- Note: can specify simple integrity constraints on the data. The DBMS enforces these.
  - Beyond this, the DBMS does not understand the semantics of the data.
  - Ensuring that a single transaction (run alone) preserves consistency is largely the user's responsibility!

## Scheduling Concurrent Transactions

- DBMS ensures that execution of {T1, ... , Tn} is equivalent to some serial execution T1' ... Tn'.
  - 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 held until the end of the transaction. (Strict 2PL locking protocol.)
  - Idea: If an action of Ti (say, writing X) affects Tj (which perhaps reads X),
    … say Ti obtains the lock on X first
    … so 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 Transaction Properites

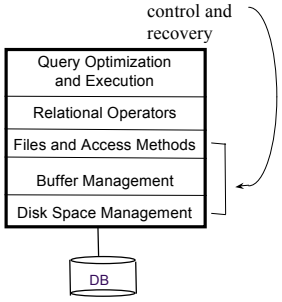
- DBMS ensures atomicity (all-or-nothing property) even if system crashes in the middle of a Xact.
- DBMS ensures durability of committed Xacts even if system crashes.
- Idea: Keep a log (history) of all actions carried out by the DBMS while executing a set of Xacts:
  - Before a change is made to the 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. Effects of committed transactions are redone using the log.
  - trickier than it sounds!

## 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.

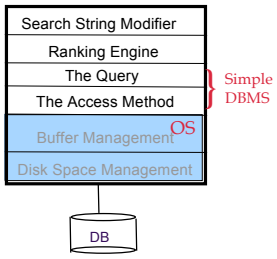
## Structure of a DBMS

- A typical RDBMS has a layered architecture.
- The figure does not show the concurrency control and recovery components.
- Each system has its own variations.
- The book shows a somewhat more detailed version.
- You will see the "real deal" in PostgreSQL.
  - It's a pretty full-featured example




## FYI: A text search engine

- Less "system" than DBMS
  - Uses OS files for storage
  - Just one access method
  - One hardwired query
    - regardless of search string
- Typically no concurrency or recovery management
  - Read-mostly
  - Batch-loaded, periodically
  - No updates to recover
  - OS a reasonable choice
- Smarts: text tricks
  - Search string modifier (e.g. "stemming" and synonyms)
  - Ranking Engine (sorting the output, e.g. by word or document popularity)
  - no semantics: WYGIWIGY




## Advantages of a Full-Service DBMS

- Data independence
- Efficient data access
- Data integrity & security
- Data administration
- Concurrent access, crash recovery
- Reduced application development time
- So why not use them always?
  - Expensive/complicated to set up & maintain
  - This cost & complexity must be offset by need
  - General-purpose, not suited for special-purpose tasks (e.g. text search!)

## DBMSs make these folks happy ...

- DBMS vendors, programmers
  - Oracle, IBM, MS, Sybase, NCR, …
- End users in many fields
  - Business, education, science, …
- DB application programmers
  - Build enterprise applications on top of DBMSs
  - Build web services that run off DBMSs
- Database administrators (DBAs)
  - Design logical/physical schemas
  - Handle security and authorization
  - Data availability, crash recovery
  - Database tuning as needs evolve

…must understand how a DBMS works

## Summary (part 1)

- DBMS used to maintain, query large datasets.
  - can manipulate data and exploit *semantics*
- Most systems over "databases" use related technologies
- Other benefits of DBMSs include:
  - recovery from system crashes,
  - concurrent access,
  - quick application development,
  - data integrity and security.
- Levels of abstraction provide data independence
  - Key when *dapp/dt << dplatform/dt*
- In this course we will explore:
  1) How to be a sophisticated user of database technologies
     - Relational, (hyper)text, XML
  2) What goes on inside a DBMS
     - And related systems

## Summary, cont.

- DBAs, DB developers the bedrock of the information economy

- DBMS R&D represents a broad, fundamental branch of the science of computation