CS186: Introduction to Database Systems

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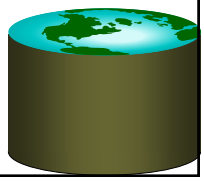
Fall 2007

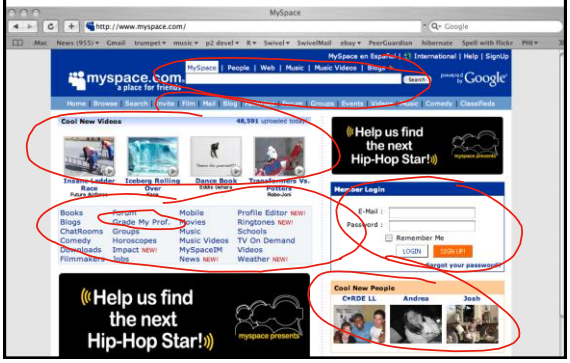


Queries for Today

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

What: Database Systems Then

What: Database Systems Today



What: Database Systems Today

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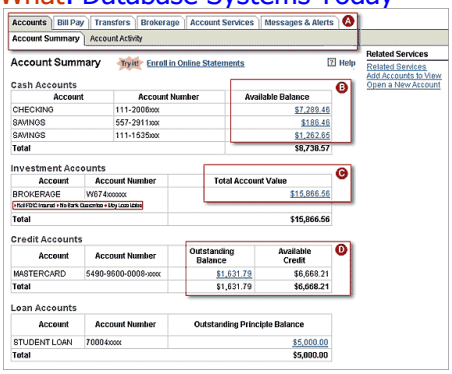

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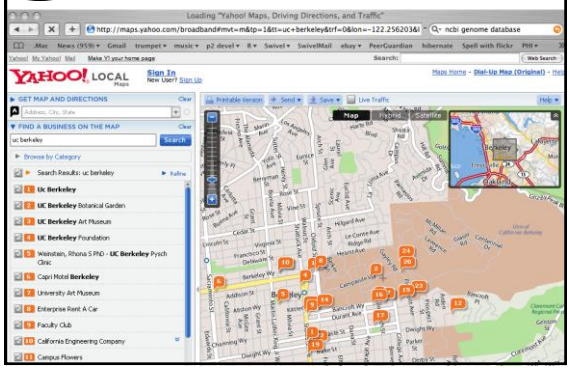
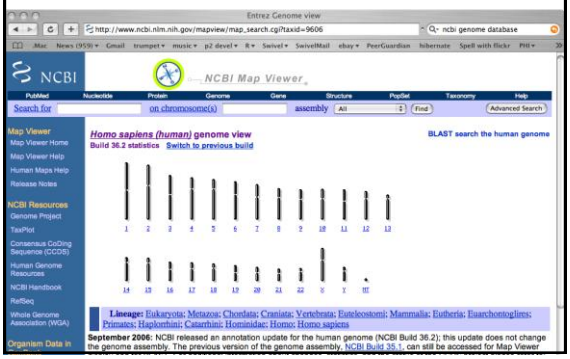


What: Database Systems Today



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?

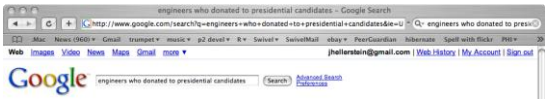
- A Database Management System (DBMS) is:
  - A software system designed to store, manage, and facilitate access to databases.
- Typically this term used narrowly
  - Relational databases with transactions
    - E.g. Oracle, DB2, SQL Server
  - Mostly because they predate other large repositories
    - 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?

- That's a complicated question!
- The "surface web": docs and search
  - Crawler indexes pages on the web
  - Keyword-based search for pages
- Web-cache SW at Google/Yahoo is a kind of DBMS
- Notes
  - source data is mostly "prose": unstructured and untyped
  - public interface is 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, …

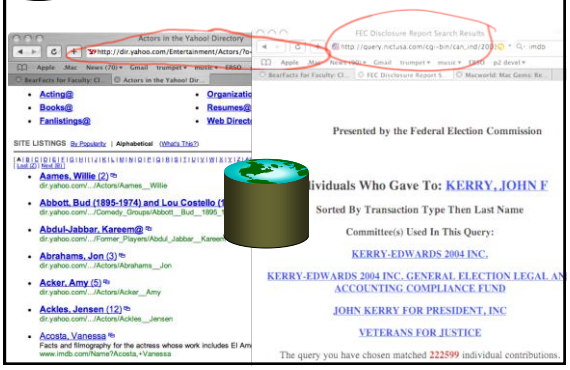
What: "Search" vs. Query

- Try actors who donated to presidential candidates in your favorite search engine.
- Now try engineers who donated to presidential candidates



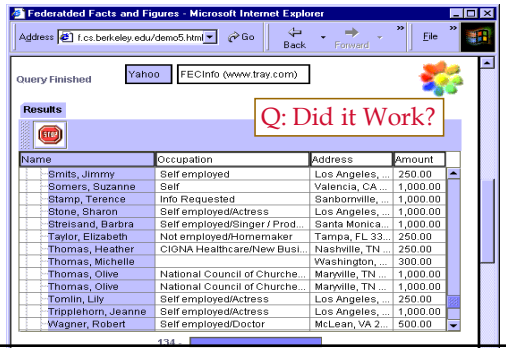
- If it isn't "published", it can't be searched!

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) ???

What: Is a File System a DBMS?

- Thought Experiment 1:

Q: How do you write programs over a subsystem when it promises you only "???" ?

A: Very, very carefully!!

–Which changes survive?

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

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

- Relational DBs a major part of the software industry
  - Oracle, IBM, Microsoft, HP, Teradata, Sybase, …
- Open Source coming on strong
  - Relational: MySQL, PostgreSQL, Apache Derby, SQLite, Ingres, …
  - text-Search: Lucene, Ferret, …
- Well-known benchmarks (TPC, TREC)
- Tons of applications, related industries
  - Alphabet soup!
- Related database technologies have niches
  - P2P, XML repositories, etc.

What 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, Yahoo! Search, Lucene, Ferret)
- Ground things in relevant applications

Quiz Question

- Name some widely-used applications

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 made this clear for "the rest of us" by the end of 90's
  - 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, maps, e-commerce, blogs, wikis, social networks. Web 2.0.
  - 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
  - Language design, semantics and optimization
  - 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 fair bit of work.
  - varies from year to year
- 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, Yahoo!, 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?

- Instructor
  - Prof. Joe Hellerstein
  - cs186profs@db.cs.berkeley.edu
- TAs
  - David Chu
  - Eirinaios Michelakis

How? Workload

- Projects with a "real world" focus:
  - Modify the internals of a "real" open-source database system: PostgreSQL
    - Serious C system hacking in a ~500KLoc codebase
    - Measure the benefits of our changes
  - Build web-based applications
    - Using Ruby on Rails, PostgreSQL, Ferret text search
- 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
- Office Hours:
  - JMH:
    - Tues 12:30-1:30
    - Thurs 11:00-12:00 (in 685 Soda)
  - DC: Mon 1-2
  - EM: Fri 11-12 (locations TBA)
- Discussion Sections WILL meet this week

How? Administrivia, cont.

- textbook
  - *Database Management Systems, 3rd Edition*
    - Ramakrishnan and Gehrke
  - *Agile Web Development with Rails, 2nd edition*
    - e-book is fine (better?)
  - *Programming Ruby, 2nd edition*
    - *Free online*
- Grading, hand-in policies, etc. will be on Web Page
- Cheating policy: zero tolerance
  - We have the technology…

How? Administrivia, cont.

- Team Projects
  - Teams of 2
  - Think about this now!
- 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

Agenda for the rest of today

- A "free tasting" of central concepts in DB field:
  - queries and search
  - data independence
  - transactions
- Next Time
  - the Relational data model
  - object-relational mapping using Ruby on Rails
- Today's lecture is from Chapter 1 in R&G
- Read Chapter 2 for next class.

Describing Data: Data Models

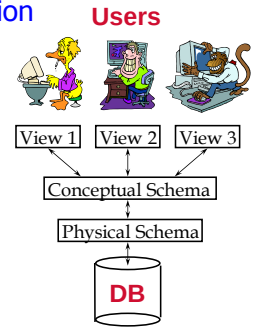
- A *data model* is a collection of concepts for describing data.
- A *schema* is a description of a particular collection of data, using a given data model.
- The *relational model of data* is the most widely used model today.
  - Main concept: *relation*, basically a table with rows and columns.
  - Every relation has a *schema*, which describes the columns, or fields.

Example: University Database

- Schema:
  - `Students(sid text, name text, login text, age integer, gpa float)`
  - `Courses(cid text, cname text, credits integer)`
  - `Enrolled(sid text, cid text, grade text)`

Levels of Abstraction

- Views describe how users see the data.
- Conceptual schema defines logical structure
- Physical schema describes the files and indexes used.



Example: University Database

- Conceptual schema:
  - `Students(sid text, name text, login text, age integer, gpa float)`
  - `Courses(cid text, cname text, credits integer)`
  - `Enrolled(sid text, cid text, grade text)`
- Physical schema:
  - Relations stored as unordered files.
  - Index on first column of Students.
- External Schema (View):
  - `Course_info(cid text, 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 is this particularly important for DBMS?

Because databases and their associated applications persist.

Hellerstein's Inequality

$$\frac{dapp}{dt} << \frac{denv}{dt}$$

Agenda …

- A "free tasting" of central concepts in DB field:
  - queries (vs. search)
  - data independence
  - transactions

Concurrent execution of user programs

- Why?
  - Utilize CPU while waiting for disk I/O
    - (database programs make heavy use of disk)
  - Avoid short programs waiting behind long ones
    - e.g. ATM withdrawal while bank manager sums balance across all accounts

Concurrent execution

- Interleaving actions of different programs: trouble!

  Example:
  - Bill transfers $100 from savings to checking
    Savings –= 100; Checking += 100
  - Meanwhile, Bill's wife requests account info.

  Bad interleaving:
  - Savings –= 100
  - Print balances
  - Checking += 100

  – Printout is missing $100 !

Concurrency Control

- DBMS ensures such problems don't arise
- Users can pretend they are using a single-user system. (called "Isolation")
  – Thank goodness!

Key concept: **Transaction**

- an atomic sequence of database actions (reads/writes)
- takes DB from one consistent state to another

Example

- Here, *consistency* is based on our knowledge of banking "semantics"
- In general, up to writer of transaction to ensure transaction preserves consistency
- DBMS provides (limited) automatic enforcement, via integrity constraints
  – e.g., balances must be >= 0

Concurrent transactions

- Goal: **execute xacts {T1, T2, … Tn}, and ensure a consistent outcome**
- *One option:* **"serial" schedule (one after another)**
- *Better:* **allow interleaving of xact actions, as long as outcome is equivalent to some serial schedule**

Possible Enforcement Methods

- Optimistic: **permit arbitrary interleaving, then check equivalence to serial sched.**
- Pessimistic: **xacts set *locks* on data objects, such that illegal interleaving is impossible**

Locking example

- T1 (Bill): *Savings –= 100; Checking += 100*
- T2 (Bill's wife): *Print(Checking); Print(Savings)*

– T1 and T2 both lock Savings and Checking objects
– If T1 locks Savings & Checking first, T2 must wait

A wrinkle …

- T1 (Bill): *Savings –= 100; Checking += 100*
- T2 (Bill's wife): *Print(Checking); Print(Savings)*

Suppose:
1. T1 locks Savings
2. T2 locks Checking
- Now neither transaction can proceed!

– called "deadlock"
– DBMS will abort and restart one of T1 and T2
– Need "undo" mechanism that preserves consistency

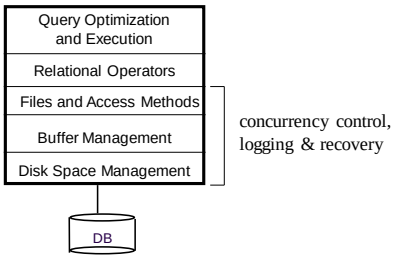
– Undo mechanism also necessary if system crashes between "Savings –= 100" and "Checking += 100" …

Ensuring Transaction Properties

- DBMS ensures:
  - ***atomicity*** **even if xact aborted (due to deadlock, system crash, …)**
  - ***durability*** **of committed xacts, even if system crashes.**
- Idea: Keep a *log* of all actions carried out by the DBMS:
  - Record all DB modifications in log, *before* they are executed
  - To abort a xact, undo logged actions in reverse order
  - If system crashes, must:
    1) **undo** partially executed xacts (ensures **atomicity**)
    2) **redo** committed xacts (ensures **durability**)
  - *trickier than it sounds!*

Architecture of a DBMS …

Typical DBMS architecture



Advantages of a Traditional 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!)

Databases make these folks happy …

- Web & enterprise app developers
- Computing infrastructure providers
- DBMS vendors, programmers
  - Oracle, IBM, MS …
- End users in *many* fields
  - Business, education, science, …
- Database administrators (DBAs)

…must understand how a DBMS works

Summary

- Relational DBMS: maintain/query structured data
  - broadly applicable
  - can manipulate data and exploit *semantics*
  - recovery from system crashes
  - concurrent access
  - robust application development and *evolution*
  - data integrity and security
- Text search engine
  - similar to relations underneath
  - many "application-specific" smarts

Summary, cont

- Levels of abstraction & data independence.
  - Hellerstein's inequality
  - classic idea, resonates in the most modern SW
- Goals of the course
  1) How to be a sophisticated user of database technology
  2) What goes on inside a DBMS and search engine
  3) How to architect data-intensive systems