Introduction

CPS 116

Introduction to Database Systems

A few words about myself (and databases)

- Have been doing (and enjoying) research in databases ever since grad school (1995)
  - Didn't take any database course as an undergrad
- ☞ Now, why would you want to take 116?
- ☞ It's not really about databases per se—it's about principles of data management
- E.g., Google probably won't care if you know SQL, but…
  - They still ask you "big data" questions in interviews
  - Brin was a grad student in the Stanford Database Group

Trend: Moore's Law reversed

- Moore's Law: *Processing power doubles every 18 months*
- Amount of data doubles every 9 months
  - Disk sales (# of bits) doubles every 9 months
  - Parkinson's Law: *Data expands to fill the space available for storage*
  - As of 2009, Facebook ingests 15 terabytes of data per day and maintains a 2.5-petabyte data warehouse
  - CERN's Large Hadron Collider will produce 15 petabytes per year
- ☞ Moore's Law reversed:

  Time to process all data doubles every 18 months!
- Does your attention span double every 18 months?
  - No, so we need smarter data management techniques

Misc. course information

- Course website: `http://www.cs.duke.edu/courses/fall11/cps116/`
  - Course information; tentative syllabus and reference sections in the book; lecture slides, assignments, programming notes
- Book: *Database Systems: The Complete Book*, by H. Garcia-Molina, J. D. Ullman, and J. Widom. 2nd Ed.
- Gradiance: see course website for sign-up information
- Blackboard: for grades only
- Mailing list: `cps116@cs.duke.edu`
  - Messages of general interest only
- No "official" recitation sessions; help sessions for assignments, project, and exams to be scheduled
- TA: Rohit Paravastu

Grading

[90%, 100%]	A- / A / A+
[80%, 90%)	B- / B / B+
[70%, 80%)	C- / C / C+
[60%, 70%)	D
[0%, 60%)	F

- No curves
- Scale may be adjusted downwards (i.e., grades upwards) if, for example, an exam is too difficult
- Scale will not go upwards—mistake would be mine alone if I made an exam too easy

Course load

- Four homework assignments (35%)
  - Including Gradiance as well as additional written and programming problems
- Course project (25%)
  - Details to be given in the third week of class
- Midterm and final (20% each)
  - Open book, open notes
  - Final is comprehensive, but emphasizes the second half of the course

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Example past projects

- ePrint iPhone app
  - Ben Getson and Lucas Best, 2009
- Making iTunes social
  - Nick Patrick, 2006; Peter Williams and Nikhil Arun, 2009
- Duke Schedulator: ditch ACES—plan your schedule visually!
  - Alex Beutel, 2008
- SensorDB: managing, cleansing, and visualizing sensor data collected from the Duke Forest
  - Ashley DeMass, Jonathan Jou, Jonathan Odom, 2007
- SuperDatabase: GUI for creating schema with rich datatypes, as well as editing and querying such data
  - Andy Ewing, MacRae Linton, Congyi Wu, and David Zhang, 2007
- Facebook^{+}
  - Tyler Brock and Beth Trushkowsky, 2005
- Web-based K-ville tenting management
  - Zach Marshall, 2005

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A few projects ideas for this semester

- Computational journalism
  - Media's watchdog role is at risk because of traditional media's decline ⇒ leveraging computer science to help saving investigative and public-interest journalism
  - Checking validity and robustness of claims
  - Crowd-based/collaborative querying
  - Automatic lead-finding from data
  - … and more (see me during office hours)

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So, what is a database system?

From Oxford Dictionary:

- Database: an organized body of related information
- Database system, DataBase Management System (DBMS): a software system that facilitates the creation and maintenance and use of an electronic database

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What do you want from a DBMS?

- Keep data around (persistent)
- Answer questions (queries) about data
- Update data

- Example: a traditional banking application
  - Data: Each account belongs to a branch, has a number, an owner, a balance, …; each branch has a location, a manager, …
  - Persistency: Balance can't disappear after a power outage
  - Query: What's the balance in Homer Simpson's account? What's the difference in average balance between Springfield and Capitol City accounts?
  - Modification: Homer withdraws $100; charge account with lower than $500 balance with a $5 fee

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Sounds simple!

```
1001#Springfield#Mr. Morgan
```

```
… …
00987-00654#Ned Flanders#2500.00
00123-00456#Homer Simpson#400.00
00142-00857#Montgomery Burns#1000000000.00
… …
```

- ASCII file
- Accounts/branches separated by newlines
- Fields separated by #'s

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Query

```
1001#Springfield#Mr. Morgan
```

```
… …
00987-00654#Ned Flanders#2500.00
00123-00456#Homer Simpson#400.00
00142-00857#Montgomery Burns#1000000000.00
… …
```

- What's the balance in Homer Simpson's account?
- A simple script
  - Scan through the accounts file
  - Look for the line containing "Homer Simpson"
  - Print out the balance

Query processing tricks

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- Tens of thousands of accounts are not Homer's
  - ☞Cluster accounts by owner's initial: those owned by "A..." go into file A; those owned by "B..." go into file B; etc. → decide which file to search using the initial
  - ☞Keep accounts sorted by owner name → binary search?
  - ☞Hash accounts using owner name → compute file offset directly
  - ☞Index accounts by owner name: index entries have the form ⟨ *owner_name*, *file_offset* ⟩ → search index to get file offset
  - ☞And the list goes on…

- What happens when the query changes to: What's the balance in account 00142-00857?

Observations

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- Tons of tricks (not only in storage and query processing, but also in concurrency control, recovery, etc.)
- Different tricks may work better in different usage scenarios (example?)
- Same tricks get used over and over again in different applications

The birth of DBMS – 1

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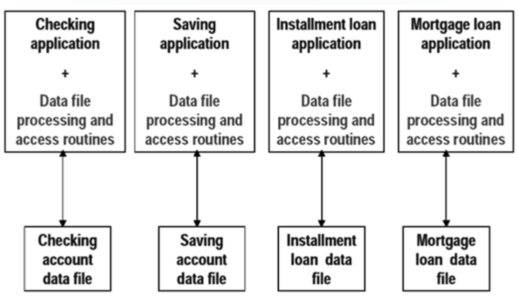

(Figure from Hans-J. Schek's *VLDB* 2000 slides)

The birth of DBMS – 2

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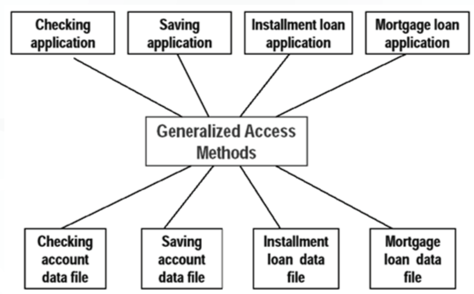

(Figure from Hans-J. Schek's *VLDB* 2000 slides)

The birth of DBMS – 3

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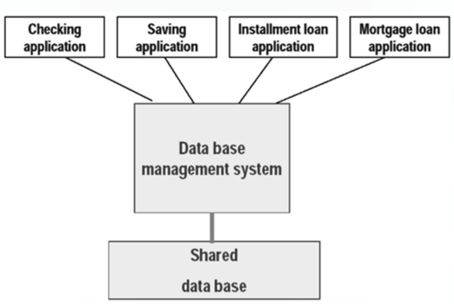

(Figure from Hans-J. Schek's *VLDB* 2000 slides)

Early efforts

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- "Factoring out" data management functionalities from applications and standardizing these functionalities is an important first step
  - CODASYL standard (circa 1960's)
    - ☞Bachman got a Turing award for this in 1973

- But getting the abstraction right (the API between applications and the DBMS) is still tricky

CODASYL

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- Query: Who have accounts with 0 balance managed by a branch in Springfield?
- Pseudo-code of a CODASYL application:

```
Use index on account(balance) to get accounts with 0 balance;
For each account record:
  Get the branch id of this account;
  Use index on branch(id) to get the branch record;
  If the branch record's location field reads "Springfield":
    Output the owner field of the account record.
```

- Programmer controls "navigation": accounts → branches
  - How about branches → accounts?

What's wrong?

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- The best navigation strategy & the best way of organizing the data depend on data/workload characteristics
- With the CODASYL approach
  - To write correct code, programmers need to know how data is organized physically (e.g., which indexes exist)
  - To write efficient code, programmers also need to worry about data/workload characteristics

  ☞Can't cope with changes in data/workload characteristics

The relational revolution (1970's)

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- A simple data model: data is stored in relations (tables)
- A declarative query language: SQL

```
SELECT Account.owner
FROM Account, Branch
WHERE Account.balance = 0
AND Branch.location = 'Springfield'
AND Account.branch_id = Branch.branch_id;
```

- Programmer specifies what answers a query should return, but not how the query is executed
- DBMS picks the best execution strategy based on availability of indexes, data/workload characteristics, etc.

☞ Provides physical data independence

Physical data independence

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- Applications should not need to worry about how data is physically structured and stored
- Applications should work with a logical data model and declarative query language
- Leave the implementation details and optimization to DBMS
- The single most important reason behind the success of DBMS today
  - And a Turing Award for E. F. Codd in 1981

Standard DBMS features

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- Persistent storage of data
- Logical data model; declarative queries and updates → physical data independence
  - Relational model is the dominating technology today
  - XML has been a hot wanna-be

☞ What else?

DBMS is multi-user

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- Example

```
get account balance from database;
if balance > amount of withdrawal then
    balance = balance - amount of withdrawal;
    dispense cash;
    store new balance into database;
```

- Homer at ATM1 withdraws $100
- Marge at ATM2 withdraws $50
- Initial balance = $400, final balance = ?
  - Should be $250 no matter who goes first

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Final balance = $300

Homer withdraws $100:

```
read balance; $400
```

Marge withdraws $50:

```
read balance; $400
if balance > amount then
    balance = balance - amount; $350
    write balance; $350
```

Homer:

```
if balance > amount then
    balance = balance - amount; $300
    write balance; $300
```

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Final balance = $350

Homer withdraws $100:

```
read balance; $400
```

Marge withdraws $50:

```
read balance; $400
```

Homer:

```
if balance > amount then
    balance = balance - amount; $300
    write balance; $300
```

Marge:

```
if balance > amount then
    balance = balance - amount; $350
    write balance; $350
```

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Concurrency control in DBMS

- Appears similar to concurrent programming problems?
  - But data not main-memory variables
- Appears similar to file system concurrent access?
  - Approach taken by MySQL in the old days (fun reading: `http://openacs.org/philosophy/why-not-mysql.html`)
  - Still used by SQLite (as of Version 3)
  - But want to control at much finer granularity
    - Or else one withdrawal would lock up all accounts!

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Recovery in DBMS

- Example: balance transfer
  ```
  decrement the balance of account X by $100;
  increment the balance of account Y by $100;
  ```
- Scenario 1: Power goes out after the first instruction
- Scenario 2: DBMS buffers and updates data in memory (for efficiency); before they are written back to disk, power goes out
- How can DBMS deal with these failures?

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Summary of standard DBMS features

- Persistent storage of data
- Logical data model; declarative queries and updates $\rightarrow$ physical data independence
- Multi-user concurrent access
- Safety from system failures
- Performance, performance, performance
  - Massive amounts of data (terabytes ~ petabytes)
  - High throughput (thousands ~ millions transactions per minute)
  - High availability ($\geq$ 99.999% uptime)

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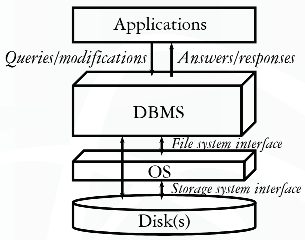
Major DBMS today

- Oracle
- IBM DB2 (from System R, System R*, Starburst)
- Microsoft SQL Server
- Teradata
- Sybase (acquired by SAP)
- Informix (acquired by IBM)
- PostgreSQL (from UC Berkeley's Ingres, Postgres)
- Tandem NonStop (acquired by Compaq, now HP)
- MySQL (acquired by Sun, then Oracle)
- ? SQLite
- ? Microsoft Access
- ? BerkeleyDB (acquired by Oracle)

Relational inside

DBMS architecture today



- ❖ Much of the OS is bypassed for performance and safety
- ❖ We will be filling in many details for the DBMS box

AYBABTU?

"Us" = relational databases

(Use of AYBABTU inspired by Garcia-Molina)

- ❖ Most data is not in them!
  - Personal data, web, scientific data, system data, …
- ❖ "NoSQL" movement
  - Less structure, less consistency
  - More flexibility, more availability, more scalability

- ❖ This course will look beyond relational databases

Course components

- ❖ Relational databases
  - Relational algebra, database design, SQL, app programming
- ❖ XML
  - Data model and query languages, app programming, interplay between XML and relational databases
- ❖ Database internals
  - Storage, indexing, query processing and optimization, concurrency control and recovery
- ❖ Topics beyond databases (TBD)
  - Privacy in data publishing, data warehousing and data mining, Web search, indexing, Map/Reduce, etc.