Introduction

CPS 116

Introduction to Database Systems

Random things to do after this course

- Explain to friends
  - Since which version MySQL became a "real" database system
  - How to build a miniature Amazon or eBay in a week
  - Why Google doesn't use database systems for indexing
- Become a "power user" of database systems
- Develop database-driven applications and Web sites
- Upgrade your Web sites with XML
- Converse intelligently with buzzwords old and new like EII, datacube, streams, …
- Offer advice on your roommate's Web-based startup idea

Course roadmap

- 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 traditional databases
  - Data warehousing and data mining
  - Web and keyword searches
  - Streams and continuous queries

Misc. course information

- Book: *Database Systems: The Complete Book*, by H. Garcia-Molina, J. D. Ullman, and J. Widom
  - Either get the "value pack" bundled with Gradiance, or buy Gradiance separately
- Web site: `http://www.cs.duke.edu/courses/fall07/cps116/`
  - Course information; tentative syllabus and reference sections in GMUW; lecture slides, assignments, programming notes
- 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

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

Example projects

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- Facebook^{+}
  - Tyler Brock and Beth Trushkowsky, 2005
- Web-based K-ville tenting management
  - Zach Marshall, 2005
- yourTunes: social music networking
  - Nick Patrick, 2006
- ERS: a content management system for capturing experimental and computational workflows
  - Collaboration with Duke immunologists
- Babase tools: for a baboon life history database
  - Collaboration with Duke and Princeton biologists

So, what is a database system?

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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

What do you want from a DBMS?

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

Sounds simple!

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```
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

Query

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```
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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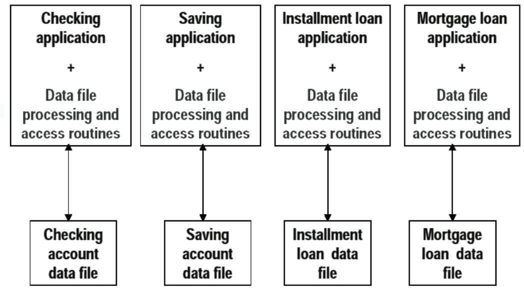
- Tens of thousands of accounts are not Homer's
  - ☞Cluster accounts by owner's initial: those owned by "A..." go into file A; those owned by "B..." go into file B; etc. → decide which file to search using the initial
  - ☞Keep accounts sorted by owner name → binary search?
  - ☞Hash accounts using 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

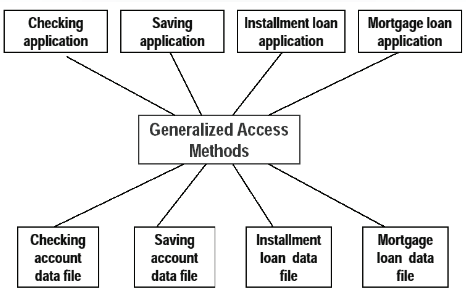
- Tons of tricks (not only in storage and query processing, but also in concurrency control, recovery, etc.)
- Different tricks may work better in different usage scenarios (example?)
- Same tricks get used over and over again in different applications

The birth of DBMS – 1



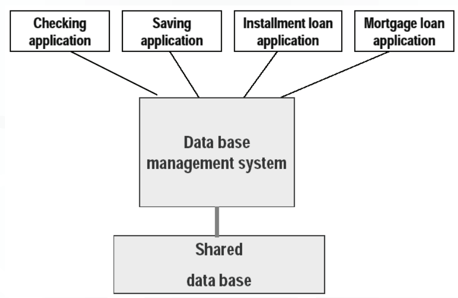
(Figure stolen from Hans-J. Schek's *VLDB* 2000 slides)

The birth of DBMS – 2



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

The birth of DBMS – 3



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

Early efforts

- "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

- 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?

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What's wrong?

- The best navigation strategy & the best way of organizing the data depend on data/workload characteristics
- With the CODASYL approach
  - To write correct code, application programmers need to know how data is organized physically (e.g., which indexes exist)
  - To write efficient code, application programmers also need to worry about data/workload characteristics
  - ☞Can't cope with changes in data/workload characteristics

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The relational revolution (1970's)

- 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

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Physical data independence

- 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

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Modern DBMS features

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

☞ What else?

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DBMS is multi-user

- 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:	Marge withdraws \$50:
`read balance; $400`	

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

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

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Final balance = $350

Homer withdraws $100:

```
read balance; $400

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

Marge withdraws $50:

```
read balance; $400

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`)
  - 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 modern DBMS features

- ❖ Persistent storage of data
- ❖ Logical data model; declarative queries and updates → 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
- ❖ NCR Teradata
- ❖ Sybase
- ❖ Informix (acquired by IBM)
- ❖ PostgreSQL (from UC Berkeley's Ingres, Postgres)
- ❖ Tandem NonStop (acquired by Compaq, now HP)
- ❖ MySQL
- ? Microsoft Access

Relational inside

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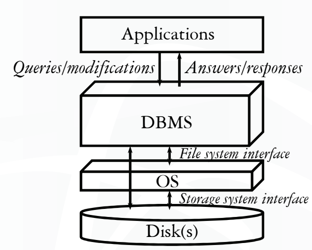
Modern DBMS architecture



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

People working with databases

- End users: query/update databases through application user interfaces (e.g., Amazon.com, 1-800-DISCOVER, etc.)
- Database designers: design database "schema" to model aspects of the real world
- Database application developers: build applications that interface with databases
- Database administrators (a.k.a. DBA's): load, back up, and restore data, fine-tune databases for performance
- DBMS implementors: develop the DBMS or specialized data management software, implement new techniques for query processing and optimization