

Introduction

CPS 216
Advanced Database Systems

Course goals

- ❖ Become a “power user” of commercial database systems
- ❖ Learn to apply database ideas/techniques to new applications and other areas of computer science
- ❖ Get a solid background for doing database research

CPS 216 vs. CPS 196.3

- ❖ Undergraduate database courses (e.g., CPS 196.3 last semester) tend to emphasize more on database design and application programming
- ❖ CPS 216 emphasizes more on the implementation techniques of database systems
 - More advanced indexing, query processing, and optimization techniques (e.g., R-trees, linear hashing, histograms, adaptive query processing, distributed databases, XML indexing, etc.)
- ☞ Those of you who took CPS 196.3 (or an equivalent undergrad database course) before may get different homework problems from the rest of the class

Course roadmap

- ❖ The basics
 - Relational algebra, database design, SQL, application programming
 - ☞ Materials overlap with CPS 196.3 and are covered at a faster pace
- ❖ The internals
 - Storage, indexing, query processing and optimization, concurrency control and recovery
 - ☞ Some fundamentals overlap with CPS 196.3, but the rest is new
- ❖ The extras
 - XML and XML indexing
 - ☞ Introduction overlaps with CPS 196.3, but indexing is new

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

What do you want from a DBMS?

- ❖ Answer queries (questions) about data
- ❖ Update data
- ❖ And keep data around (persistent)

- ❖ Example: a traditional banking application
 - Each account belongs to a branch, has a number, an owner, a balance, ...
 - Each branch has a location, a manager, ...
 - Query: What's the balance in Homer Simpson's account?
 - Modification: Homer withdraws \$100
 - Persistency: Homer will be pretty upset if his balance disappears after a power outage

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: Those owned by "A..." go into file A; those owned by "B..." go into file B; etc.
 - Change the script to decide which file to search
 - ☞ Keep the accounts sorted by owner name
 - Change the script to do binary search
 - ☞ Hash accounts according to owner name
 - Change the script to hash the name and get the file offset
 - ☞ Index accounts by owner name: Index entries have the form $\langle \text{owner_name}, \text{file_offset} \rangle$
 - Change the script to search the index for file offset
 - ☞ And the list goes on...
- ❖ What happens when the query changes to: What's the balance in accounts 00142-00857?

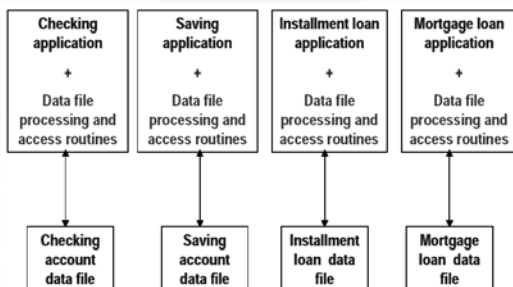
Observations

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- ❖ Tons of tricks (not only in query processing, but also in storage, concurrency control, recovery, etc.)
- ❖ Different tricks may work better in different usage scenarios
- ❖ Same tricks get used over and over again in different applications
 - ☞ We need a library, or better yet, a server (to support sharing, backup, etc.)

The birth of DBMS – 1

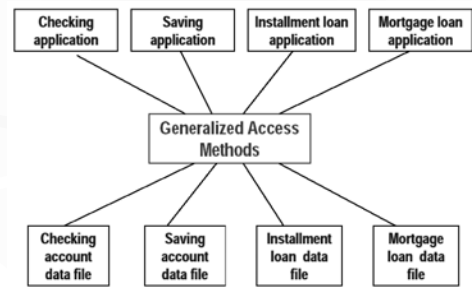
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(Pretty drawing stolen from Hans-J. Schek's VLDB 2000 slides)

The birth of DBMS – 2

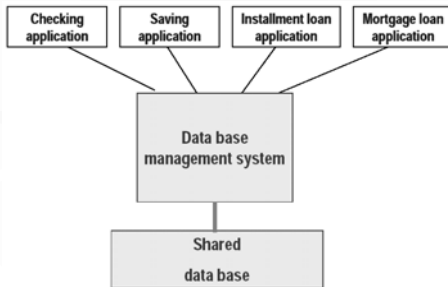
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(Pretty drawing stolen from Hans-J. Schek's VLDB 2000 slides)

The birth of DBMS – 3

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(Pretty drawing stolen from Hans-J. Schek's VLDB 2000 slides)

Early efforts

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- ❖ “Factoring out” data management functionalities and from applications 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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- ❖ When data/workload characteristics change
 - The best navigation strategy changes
 - The best way of organizing the data changes
- ❖ 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 change!

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

Major DBMS today

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- ❖ 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 and Microsoft Access?

*relational
inside*

Modern 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 is 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

Final balance = \$300

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```
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
```

Final balance = \$350

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```
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

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

Concurrency control in DBMS

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- ❖ Appears similar to concurrent programming problems?
 - But data not main-memory variables
- ❖ Appears similar to file system concurrent access?
 - Approach taken by MySQL initially
(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!

Recovery in DBMS

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- ❖ 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
- ❖ Log updates; undo/redo during recovery

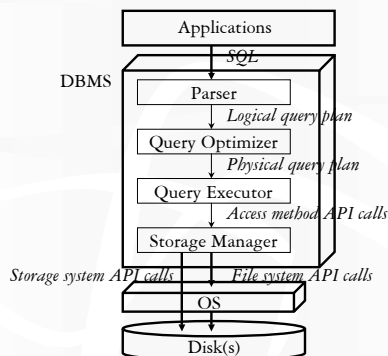
Summary of modern DBMS features

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- ❖ 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)

Modern DBMS architecture

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People working with databases

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- ❖ 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 inside DBMS

Course information

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- ❖ Books
 - Required: *Readings in Database Systems* (a.k.a. the red book), 3rd Ed., edited by M. Stonebraker and J. M. Hellerstein.
 - Recommended: *Database Systems: The Complete Book*, by H. Garcia-Molina, J. D. Ullman, and J. Widom.
- ❖ Web site: <http://www.cs.duke.edu/courses/spr02/cps216/>
 - Course info, office hours, syllabus, reference sections in GMUW
 - Lecture slides, assignments, programming notes
- ❖ Blackboard: for posting grades only
- ❖ Newsgroup: duke.cs.cps216

Course load

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- ❖ 4 homework assignments (30%)
 - Programming included
- ❖ Open-ended course project (30%)
 - Details to be given in the third week of class
- ❖ Midterm (20%)
- ❖ Final (20%)
 - Comprehensive, but with emphasis on the second half of the course

Reading assignment for next week

❖ In the red book:

*A Relational Model of Data for Large Shared Data
Banks*, by E. F. Codd

- Note: If you are new to relational model and algebra, do not read this paper until we cover these topics in lecture on Monday