Introduction

CPS 216
Advanced Database Systems

Why are you here?

- Aren't databases just
  - Trivial exercises in first-order logic (says AI)?
  - Bunch of out-of-fashion I/O-efficient indexes and algorithms (says Algorithms)?
  - A fancy file system with a narrow application (says OS)?
- False—but they do show databases cut across many different areas of computer science research
  - Chances are you will find something interesting even if you primary interest is elsewhere

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

Course roadmap

- The basics
  - Relational algebra, database design, SQL
  - ☞Covered at a fast pace in the first few weeks
- The internals
  - Storage, indexing, query processing and optimization, transaction processing
- The extras
  - XML: basics, storage, indexing, query processing
  - Selected topics: TBD

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!

```
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

```
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

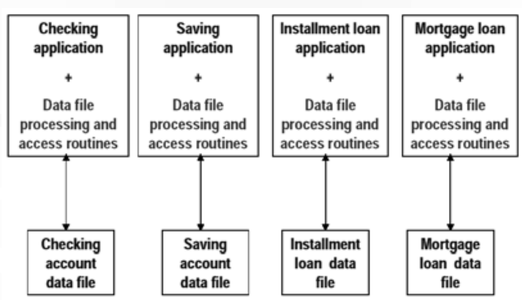
Query processing tricks

- 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.
  - ☞Keep the accounts sorted by owner name
  - ☞Hash accounts according to owner name
  - ☞Index accounts by owner name: Index entries have the form ⟨ *owner_name*, *file_offset* ⟩
  - ☞And the list goes on…
- What happens when the query changes to: What's the balance in accounts 00142-00857?

Observations

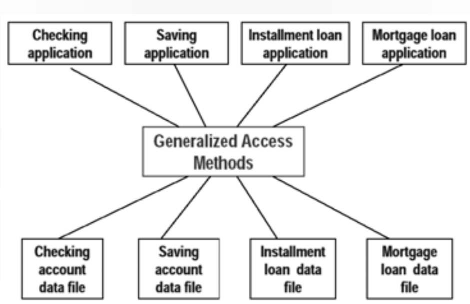
- Tons of tricks (not only in storage and query processing, but also in concurrency control, recovery, etc.)
- Different tricks may work better in different usage scenarios
- Same tricks get used over and over again in different applications

The birth of DBMS – 1



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

The birth of DBMS – 2



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The birth of DBMS – 3

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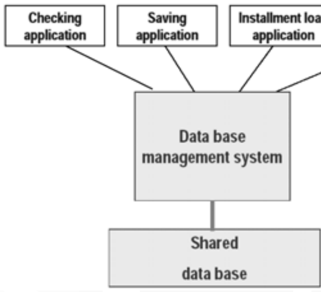

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Early efforts

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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?

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What's wrong?

- When data/workload characteristics change
  - The best navigation strategy changes
  - The best way of organizing the data changes
- With the CODASYL approach
  - ☞Can't cope with change!
  - 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

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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

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 and Microsoft Access?

Modern DBMS features

- ❖ Persistent storage of data
- ❖ Logical data model; declarative queries and updates → physical data independence
  - Relational model is the dominating technology today
  - Object-oriented model works in some niche markets
  - XML is a wanna-be
  - ☞In practice, many vendors extend relational model with object-oriented and XML features
- ☞ What else?

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:

```
read balance; $400
```

Marge withdraws $50:

```
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

- Similar to concurrent programming problems
  - But data not main-memory variables
- Appears similar to file system concurrent access?
  - Approach taken by MySQL initially; now MySQL offers better alternatives (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

- Example: balance transfer

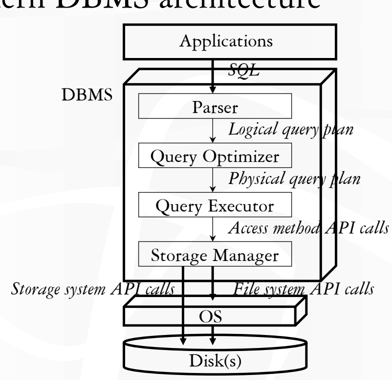
```
decrement the balance of account X by $100;
increment the balance of account Y by $100;
```

- 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

- 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



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 inside DBMS

Course information

- Book
  - Recommended reference: *Database Systems: The Complete Book*, by H. Garcia-Molina, J. D. Ullman, and J. Widom
- Web site (`http://www.cs.duke.edu/courses/fall05/cps216/`)
  - Course info, office hours, syllabus, reference sections in GMUW
  - Lecture slides, assignments, programming notes
- Blackboard: for posting grades only
- Newsgroup (`duke.cs.cps216`): for questions and answers

Course load

- Reading assignments (11%)
- 4 homework assignments (24%)
  - Programming included
- Course project (35%)
  - Details to be given in the third week of class
- Open-book, open-notes midterm (15%)
- Open-book, open-notes final (15%)
  - Comprehensive, but with emphasis on the second half of the course

Reading assignment for next week

- Codd. "A Relational Model of Data for Large Shared Data Banks." *Comm. of ACM*, 13(6), 1970
  - Note: If you are new to relational model and algebra, do *NOT* read this paper until we cover these topics in lecture next Tuesday