CSE-4411

Database Management Systems

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CSE-3421 vs CSE-4411

CSE-4411 is a continuation of CSE-3421, right?
More of the same, eh?

Ha! *No way.*

In this class, we focus on how to *build* a database system.
In CSE-3421, we focused on what functionality a database
system provides, and how to *use* it.

Data Independence

Do not need to know how...

- a *compiler* works to write a program.

- an *operating system* is built to use one.

- a *car* works to drive one.

- a *database system* is built to use it.

- **physical data independence:** how the data is *logically* organized is independent of how it is *physically* organized. (There is also *logical data independence*...)

- **Codd's law**: Can only access and update the database via the "query language" (SQL).

- SQL is a *declarative* language.

How to build a Database System?

Okay, more specifically, a *relational* database *management* system (RDBMS).

E.g., Oracle, IBM DB2, Microsoft SQL Server, Informix, MySQL, & PostgreSQL.

In this class, we're going to build our own system!

How to build a Database System?
What is involved?

- What *functionality* do we need to support?

  - E.g., SQL

- What are our *design criteria*?

  - Should be fast. (At what?)

  - Must handle updates to the database and read-only queries efficiently.
    (Trade-offs involved!)

- What are our *design choices*? Our *design constraints*?

  - How will the available technology affect our design (*architecture*)?

    E.g., Main memory technologies (like CMOS) are volatile.

I. **The Physical Database**
Storage & Access

Ensure that data is *permanent* and *safe*.

Goals:

- permanence

- fast, random access

- fault tolerance (to support *crash recovery*)

Design questions:

- What devices / technology do we use?

- What data-structures do we use?
  How do we access given pieces of data quickly?

II. The Query Processor

How to evaluate (SQL) queries efficiently? Need a

- query parser

- plan generator / query optimizer
  Turns a valid SQL query into a "program" that answers the query.

- query plan evaluator

Problems:

- SQL is reasonably complex.

- Not all (equivalent) queries are equal.
  Some queries / query plans will evaluate inherently must faster.

Big issue:

- How to "pick", or design, a good query plan for a query?

A "Complex" Query

Supplier **S**: A (name), **C** (city)

Retailer **R**: B (name), **C** (city)

Query: *Which supplier has a location in every city of a retailer? Show such supplier (A) / retailer (B) pairs.*

$$\{\langle A, B \rangle \mid \forall \mathbf{C}(\langle B, C \rangle \in \mathbf{R} \rightarrow \langle A, C \rangle \in \mathbf{S})\}$$

$$\pi_{\mathsf{A,B}}(\mathbf{R} \times \mathbf{S}) - \pi_{\mathsf{A,B}}(\pi_{\mathsf{A,B,C}}(\pi_{\mathsf{A}}(\mathbf{S}) \times \mathbf{R}) - \mathbf{R} \bowtie \mathbf{S})$$

A "Complex" Query
in SQL

```
select A, B from R, S
except
select A, B from (
        select S.A, R.B, R.C from R, S
        except
        select S.A, R.B, R.C
                from R, S
                where R.C = S.C) as Z;
```

Any problems?

A "Complex" Query
Better?

```
select A, B
      from R, S
      where R.C = S.C
except
select A, B from (
      select S.A, R₁.B, R₂.C
            from R as R₁, R as R₂, S
            where R₁.C = S.C and R₁.B = R₂.B
      except
      select S.A, R.B, R.C from R, S
            where R.C = S.C
) as Z;
```

A "Complex" Query
cleaned up

```
with
      J (A, B, C) as (
              select S.A, R.B, R.C
                      from R, S
                      where R.C = S.C)
select distinct A, B from J
except
select J.A, J.B
      from J, R
      where J.B = R.B and
              (J.A, J.B, R.C) not in
                      (select A, B, C from J);
```

A "Complex" Query
via COUNT

```
select J.A, J.B
    from (select S.A, R.B, count(*) as Cs
            from R, S
            where R.C = S.C
            group by S.A, R.B) as J,
        (select B, count(*) as Cs
            from R
            group by B) as K
    where J.B = K.B and
        J.Cs = K.Cs;
```

The Query Optimizer

1. **Rewrite**

   – Rewrite the query into something "simpler", but that means the same thing.

2. **Cost-based**

   a. Determine a "best" over-all query tree.

   b. Pick the best method for each operator in the query tree.

      1) Pick the best *access path* for each table involved.

      2) Assign the "best" algorithm to each operator $(\bowtie, \pi, \sigma, \ldots)$.

   c. Do **a.** & **b.** simultaneously!

III. Database Management

- **transaction management**
  - *How do we ensure updates are made to the database correctly?*

- **concurrency control**
  - *How do we ensure that multiple X-act's occuring "simultaneously" are treated correctly?*

- **crash recovery**
  - *How do we recover from failures? (E.g., ARIES)*

Properties:

- **A**tomicity
- **C**onsistency
- **I**solation
- **D**urability

Building a Database System
Anything we miss?

- host language support
  e.g., JDBC

- data definition language
  (DDL)
  e.g., CREATE TABLE ...

- administrative functions
  (for DBA's) & security
  e.g., GRANT ...

- ...

What pieces / modules do we need to implement all this?
What's our architecture?
Need a

- query optimizer

- transaction manager
  - lock manager for concurrency control

- crash recovery mechanism

- ...

Building a Database System
Why study this?!

- It's fun!

- *Some* will get a job building RDBMSs.
  E.g., at IBM Toronto Laboratory (for DB2)

- Cannot be a *good* DB Administrator *without* understanding how the system works.

- Can be a better DB programmer when you understand how the system works.

- Lots of places are building database-like systems.
  Can reuse the techniques and technologies from RDBMSs.