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.
- Do not need to know how an *operating system* is built to use one.
- Don't need to know how a *car* works to drive one.
- Don't need to know how 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, & Postgres.

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? We need a

- query parser
- plan generator (and 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.*

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

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

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

- **Rewrite**
  - Rewrites the query into something "simpler", but means the same thing.
- **Cost-based**
  - Determine a "best" over-all query tree.
  - Pick the best *access path* for each table involved.
  - Assign the "best" algorithm to each operator ($\bowtie$, π, σ, $\ldots$).

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

Buliding 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

- need a query optimizer
- a transaction manager
  - a lock manager for concurrency control
- a crash recovery mechanism
- . . .

Buliding 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.