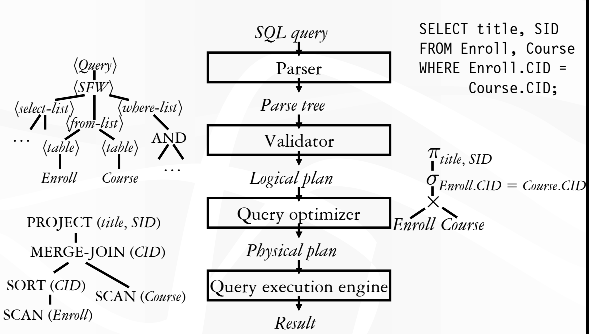
Query Optimization
Part I

CPS 216
Advanced Database Systems

Announcements (April 8)

- Reading assignments for next week
  - Selinger et al. "Access Path Selection in a Relational Database Management System." *SIGMOD* 1979
  - Ioannidis and Kang. "Randomized Algorithms for Optimizing Large Join Queries." *SIGMOD* 1990
- Homework #4 (short) will be assigned next Tuesday and due the following Tuesday
- Final exam in 18 days (Monday, April 26)

A query's trip through the DBMS

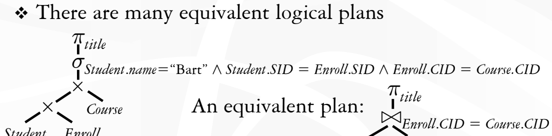


Parsing & validation

- Parser: SQL → parse tree
  - Good old lex & yacc
  - Detect and reject syntax errors
- Validator: parse tree → logical plan
  - Detect and reject semantic errors
    - Nonexistent tables/views/columns
    - Type mismatches (e.g., `AVG(name)`, `name + GPA`, `Student UNION Enroll`)
  - Wildcard (`SELECT *`) and view expansion
  - Use information stored in system catalog tables (contains all metadata/schema information)

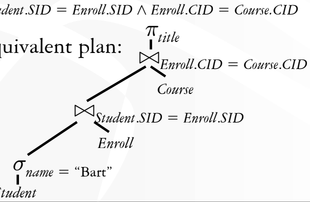
Logical plan

- A tree whose nodes are logical operators
  - Often a tree of relational algebra operators
  - DB2 uses QGM (Query Graph Model)
- There are many equivalent logical plans



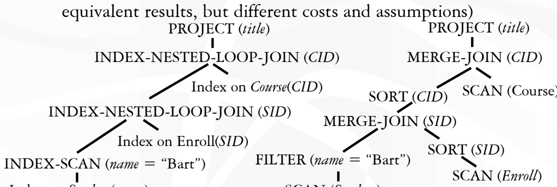

```
SELECT Course.title
FROM Student, Enroll, Course
WHERE Student.name = 'Bart'
AND Student.SID = Enroll.SID
AND Enroll.CID = Course.CID;
```

An equivalent plan:



Query optimization and execution

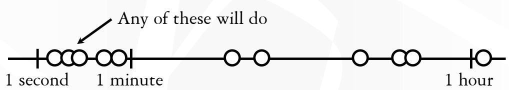
- Recall that a physical plan tells the DBMS query execution engine how to execute the query
  - One logical plan can have many possible physical plans (with equivalent results, but different costs and assumptions)



- Query optimizer: one logical plan → “best” physical plan
- Query execution engine: physical plan → results

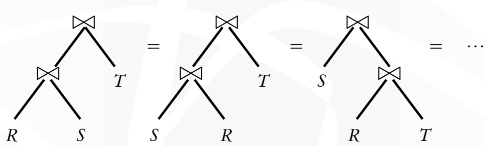
Query optimization

- Conceptually
  - Consider a space of possible plans (next)
  - Estimate costs of plans in the search space (next Tuesday)
  - Search through the space for the "best" plan (next Thursday)
- Often the goal is not picking the absolute optimum, but instead avoiding the horrible ones



Plan enumeration in relational algebra

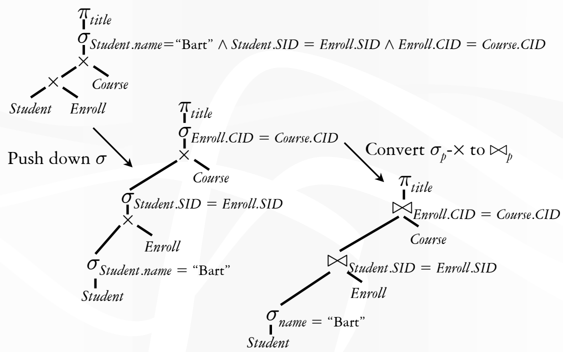
- Apply relational algebra equivalences
- ☞ Join reordering: $\times$ and $\bowtie$ are associative and commutative (except when column ordering is considered, but that is unimportant)



More relational algebra equivalences

- Convert σ_p-$\times$ to/from $\bowtie_p$: $\sigma_p(R \times S) = R \bowtie_p S$
- Merge/split σ's: $\sigma_{p1}(\sigma_{p2}\, R) = \sigma_{p1 \wedge p2}\, R$
- Merge/split π's: $\pi_{L1}(\pi_{L2}\, R) = \pi_{L1}\, R$, where $L1 \subseteq L2$
- Push down/pull up σ:
  $\sigma_{p \wedge pr \wedge ps}\,(R \times S) = (\sigma_{pr}\, R) \bowtie_p (\sigma_{ps}\, S)$, where
  - pr is a predicate involving only R columns
  - ps is a predicate involving only S columns
  - p is a predicate involving both R and S columns
- Push down π: $\pi_L\,(\sigma_p\, R) = \pi_L\,(\sigma_p\,(\pi_{L\,L'}\, R))$, where
  - L' is the set of columns referenced by p that are not in L
- Many more (seemingly trivial) equivalences…
  - Can be systematically used to transform a plan to new ones

Relational query rewrite example



Heuristics-based query optimization

- Start with a logical plan
- Push selections/projections down as much as possible
  - Why?
  - Why not?
- Join smaller relations first, and avoid cross product
  - Why?
  - Why not?
- Convert the transformed logical plan to a physical plan (by choosing appropriate physical operators)

SQL query rewrite

- More complicated—subqueries and views divide a query into nested "blocks"
  - Processing each block separately forces particular join methods and join order
  - Even if the plan is optimal for each block, it may not be optimal for the entire query
- Unnest query: convert subqueries/views to joins
- ☞ Then we just deal with select-project-join queries
  - Where the clean rules of relational algebra apply

DB2's QGM

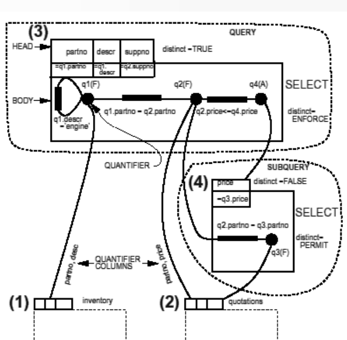
Leung et al. "Query Rewrite Optimization Rules in IBM DB2 Universal Database."

- Query Graph Model: DB2's logical plan language
  - More high-level than relational algebra
- A graph of boxes
  - Leaf boxes are tables
  - The standard box is the `SELECT` box (actually a select-project-join query block with optional duplicate elimination)
  - Other types include `GROUPBY` (aggregation), `UNION`, `INTERSECT`, `EXCEPT`
  - Can always add new types (e.g., `OUTERJOIN`)

More on QGM boxes

- Head: declarative description of the output
  - Schema: list of output columns
  - Property: Are output tuples `DISTINCT`?
- Body: how to compute the output
  - Quantifiers: tuple variables that range over other boxes
    - F: regular tuple variable, e.g., `FROM` *R* `AS` *r*
    - E: existential quantifier, e.g., `IN (`*subquery*`)`, or `= ANY(`*subquery*`)`
    - A: universal quantifier, e.g., `> ALL(`*subquery*`)`
    - S: scalar subquery, e.g., `= (`*subquery*`)`
  - Quantifiers are connected a hypergraph
    - Hyperedges are predicates
  - Enforce `DISTINCT`, preserve duplicates, or permit duplicates?
    - For the output of this box, and for each quantifier

QGM example




```
SELECT DISTINCT
  q1.partno, q1.descr, q2.suppno
FROM inventory q1, quotations q2
WHERE q1.partno = q2.partno
AND q1.descr = 'engine'
AND q2.price <= ALL
    (SELECT q3.price
     FROM quotations q3
     WHERE q2.partno = q3.partno);
```

Query rewrite in DB2

16

- Goal: make the logical plan as general as possible, i.e., merge boxes
- Rule-based transformations on QGM
  - Merge subqueries in `FROM`
  - Convert E to F (e.g., `IN`/`ANY` subqueries to joins)
  - Convert intersection to join
  - Convert S to F (i.e., scalar subqueries to joins)
  - Convert outerjoin to join
  - Magic (i.e., correlated subqueries to joins)

E to F conversion

17

- ```
  SELECT DISTINCT name
  FROM Student
  WHERE SID = ANY (SELECT SID FROM Enroll);
  ```
- ```
  SELECT DISTINCT name
  FROM Student, (SELECT SID FROM Enroll) t
  WHERE Student.SID = t.SID;
  ```
  (EtoF rule)
- ```
  SELECT DISTINCT name
  FROM Student, Enroll
  WHERE Student.SID = Enroll.SID;
  ```
  (SELMERGE rule)

Problem with duplicates

18

Same query, without `DISTINCT`

- ```
  SELECT name
  FROM Student
  WHERE SID = ANY (SELECT SID FROM Enroll);
  ```
- ```
  SELECT name
  FROM Student, Enroll
  WHERE Student.SID = Enroll.SID;
  ```
  ```

A way of preserving duplicates

19

- ```
  SELECT name
  FROM Student
  WHERE SID = ANY (SELECT SID FROM Enroll);
  ```

Suppose that `SID` is a key of `Student`

- ```
  SELECT DISTINCT Student.SID, name
  FROM Student, Enroll
  WHERE Student.SID = Enroll.SID;
  ```
  (ADDKEYS rule)
- Then simply project out `Student.SID`

Another E to F trick

20

- Sometimes an `ANY` subquery can be turned into an aggregate subquery without `ANY`, to improve performance further
- ```
  SELECT * FROM Student s1
  WHERE GPA > ANY
  (SELECT GPA FROM Student s2
   WHERE s2.name = 'Bart');
  ```
- ```
  SELECT * FROM Student s1
  WHERE GPA >
  (SELECT MIN(GPA) FROM Student s2
   WHERE s2.name = 'Bart');
  ```

Does the same trick apply to `ALL`?

21

- ```
  SELECT * FROM Student s1
  WHERE GPA > ALL
  (SELECT GPA FROM Student s2
   WHERE s2.name = 'Bart');
  ```
- ```
  SELECT * FROM Student s1
  WHERE GPA >
  (SELECT MAX(GPA) FROM Student s2
   WHERE s2.name = 'Bart');
  ```

Correlated subqueries

❖
```
SELECT CID FROM Course
WHERE title LIKE 'CPS%'
AND min_enroll >
    (SELECT COUNT(*) FROM Enroll
     WHERE Enroll.CID = Course.CID);
```

- ❖ Executing correlated subquery is expensive
  - The subquery is evaluated once for every CPS course
- ☞ Decorrelate!

COUNT bug

❖
```
SELECT CID FROM Course
WHERE title LIKE 'CPS%'
AND min_enroll > (SELECT COUNT(*) FROM Enroll
                  WHERE Enroll.CID = Course.CID);
```

❖ First compute the enrollment for all(?) courses

```
SELECT CID
FROM Course, (SELECT CID, COUNT(*) AS cnt
              FROM Enroll GROUP BY CID) t
WHERE t.CID = Course.CID AND min_enroll > t.cnt
AND title LIKE 'CPS%';
```

Magic decorrelation

- ❖ Simple idea
  - Process the outer query using other predicates
    - To collect bindings for correlated variables in the subquery
  - Evaluate the subquery using the bindings collected
    - It is a join
    - Once for the entire set of bindings
      - Compared to once per binding in the naïve approach
  - Use the result of the subquery to refine the outer query
    - Another join
- ❖ Name “magic” comes from a technique in recursive processing of Datalog queries

Magic decorrelation example

25

- ```
  SELECT CID FROM Course
  WHERE title LIKE 'CPS%'
  AND min_enroll > (SELECT COUNT(*) FROM Enroll
                    WHERE Enroll.CID = Course.CID);
  ```
- ```
  CREATE VIEW Supp_Course AS
  SELECT * FROM Course WHERE title LIKE 'CPS%';
  ```
  Process the outer query without the subquery

  ```
  CREATE VIEW Magic AS
  SELECT DISTINCT CID FROM Supp_Course;
  ```
  Collect bindings

  ```
  CREATE VIEW DS AS
  (SELECT Enroll.CID, COUNT(*) AS cnt
   FROM Magic, Enroll WHERE Magic.CID = Enroll.CID
   GROUP BY Enroll.CID) UNION
  (SELECT Magic.CID, 0 AS cnt FROM Magic
   WHERE Magic.CID NOT IN (SELECT CID FROM Enroll);
  ```
  Evaluate the subquery with bindings

  ```
  SELECT Supp_Course.CID FROM Supp_Course, DS
  WHERE Supp_Course.CID = DS.CID
  AND min_enroll > DS.cnt;
  ```
  Finally, refine the outer query

Summary of query rewrite

26

- Break the artificial boundary between queries and subqueries
- Combine as many query blocks as possible in a select-project-join block, where the clean rules of relational algebra apply
- Handle with care—extremely tricky with duplicates, `NULL`'s, empty tables, and correlation