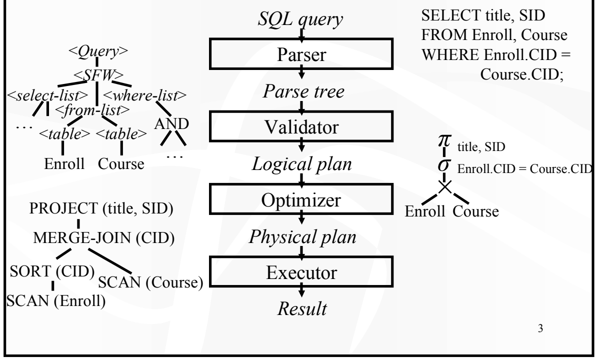
Query Processing/Optimization

CPS 216
Advanced Database Systems

Plan for today

- Overview of query processing
- Query execution
- Query plan enumeration
- Query rewrite heuristics
- Query rewrite in DB2

A query's trip through the DBMS



```
SELECT title, SID
FROM Enroll, Course
WHERE Enroll.CID =
        Course.CID;
```

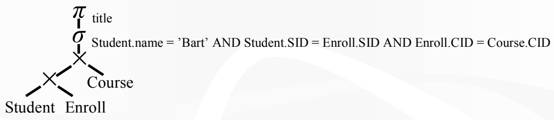
Parsing

- Parser: SQL → parse tree
  - Good old lex & yacc
  - Detect and reject syntax errors
- A short review of SQL
  - SELECT Course.title Step 3: π
    FROM Student, Enroll, Course Step 1: $\times$
    WHERE Student.name = 'Bart' Step 2: σ
    AND Student.SID = Enroll.SID
    AND Enroll.CID = Course.CID;
  - Subqueries, aggregates
  - Duplicates, NULLs

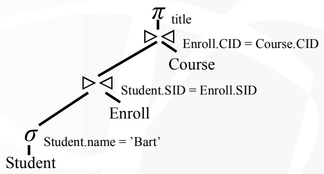
Validation

- Validator: parse tree → logical plan
- Detect and reject semantic errors
  - Nonexistent tables/views/columns?
  - Insufficient access privileges?
  - Type mismatches?
    - Examples: AVG(name), name + GPA, Student UNION Enroll
- Also
  - Expand *
  - Expand view definitions
- Where does the validator get the information required for semantic checking?
  - System catalog (contains all metadata/schema information)

Logical plan



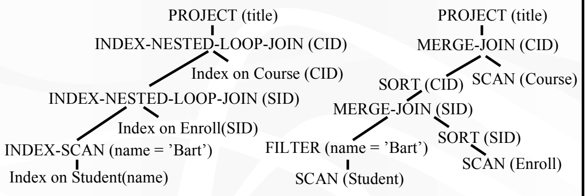
Another equivalent one:



Note: Not all systems use relational algebra to represent logical plans—DB2 uses QGM

Physical plan

Even more physical plans!



PROJECT (title)
INDEX-NESTED-LOOP-JOIN (CID)
Index on Course (CID)
INDEX-NESTED-LOOP-JOIN (SID)
Index on Enroll(SID)
INDEX-SCAN (name = ’Bart’)
Index on Student(name)

PROJECT (title)
MERGE-JOIN (CID)
SORT (CID)
SCAN (Course)
MERGE-JOIN (SID)
FILTER (name = ’Bart’)
SORT (SID)
SCAN (Enroll)
SCAN (Student)

- Equivalent semantics, but not costs or assumptions!
- Optimizer: one logical plan → “best” physical plan

Physical plan execution

- Executor: physical plan → result
  - Detect and report run-time errors
    - Example: scalar subquery returns multiple tuples
- Plan is a tree of operators
- How are intermediate results passed from children to parents?
  - Temporary files
    - Compute the tree bottom-up
    - Children write intermediate results to temporary files
    - Parents read temporary files
  - Iterator interface (next)

Iterator interface

- Every operator maintains its own execution state and implements the following methods:
  - open( ): Initialize state and get ready for processing
  - getNext( ): Return the next tuple in the result (or a null pointer if there are no more tuples); adjust state to allow subsequent tuples to be obtained
  - close( ): Clean up

An iterator for table scan

- open( )
  - Allocate buffer space
- getNext( )
  - If no block of *R* has been read yet, read the first block from the disk and return the first tuple in the block (or the null pointer if *R* is empty)
  - If there is no more tuple left in the current block, read the next block of *R* from the disk and return the first tuple in the block (or the null pointer if there are no more blocks in *R*)
  - Return the next tuple in the block
- close( )
  - Deallocate buffer space

An iterator for nested-loop join

- open( )
  - *R*.open( ); *S*.open( );
  - *r* = *R*.getNext( );
- getNext( )
  - Repeat until *r* and *s* join:

```
            s = S.getNext( );
            if (s = = null) {S.close( ); S.open( ); s = S.getNext( );
                              if (s = = null) return null;
                              r = R.getNext( );
                              if (r = = null) return null;}
    return rs;
```

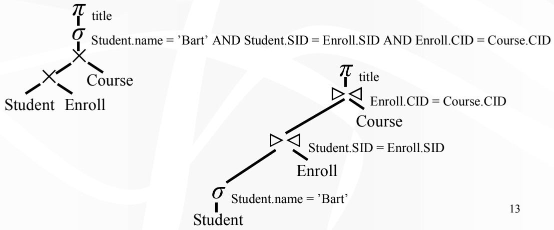
- close( )
  - *R*.close( ); *S*.close( );

Execution of an iterator tree

- Call root.open( ), root.getNext( ) (repeat until it returns a null pointer, and root.close( )
- Requests go down the tree
- Intermediate result tuples go up the tree
- No intermediate files are needed!
  - But still useful when an iterator is opened many times
    - Example:

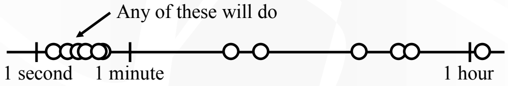
Back to query optimization

- One logical plan → "best" physical plan
- Why bother?
  - The difference in cost can be huge



Query optimization!

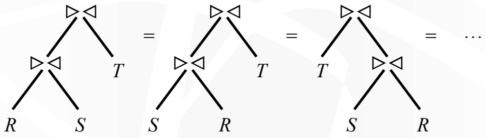
- Conceptually
  - Enumerate all possible plans (coming right up)
  - Estimate costs (next week)
  - Pick the "best" one (next week)
- Often the goal is not getting the optimum plan, but instead avoiding the horrible ones



Plan enumeration in relational algebra

Apply relation algebra equivalences

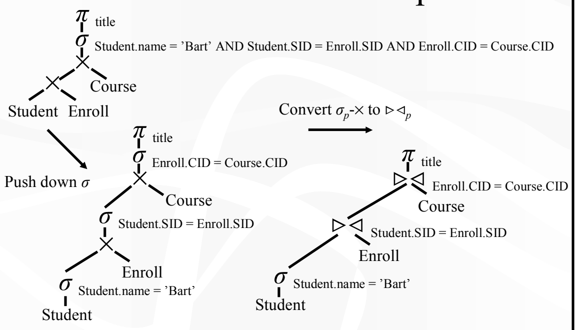
- × and ⋈ are associative and commutative
  - Except column ordering, but that is easy to fix
  - Join reordering



More relational algebra equivalences

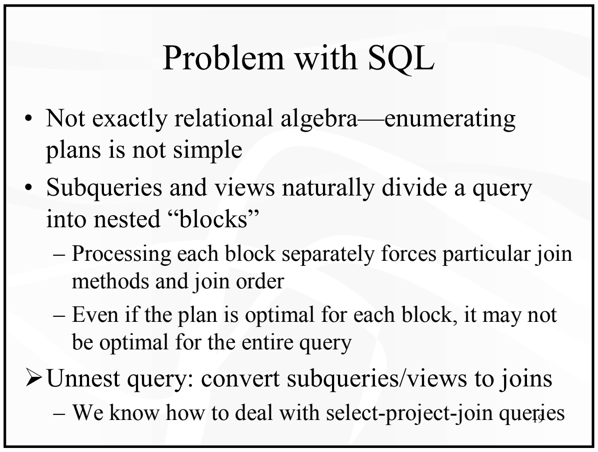
- Convert σ_p-× to/from $\rhd\lhd_p$: $\sigma_p(R \times S) = R \rhd\lhd_p S$
- Merge/split σ's: $\sigma_{p1}(\sigma_{p2}(R)) = \sigma_{p1 \text{ AND } p2}(R)$
- Merge/split π's: $\pi_{L1}(\pi_{L2}(R)) = \pi_{L1}(R)$, where $L1 \subseteq L2$
- Push down/pull up σ:
  $\sigma_{p \text{ AND } pr \text{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

Transformation Example



Too many plans!

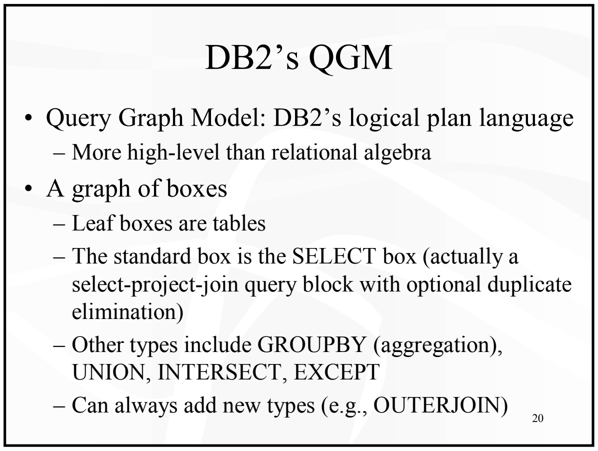
- Use heuristics
  - Push selections and projections down as much as possible
    - Why?
    - Why not?
  - Join smaller relations first, and avoid cross product
    - Why?
    - Why not?
- Rigorous cost-based approach (next week)



Problem with SQL

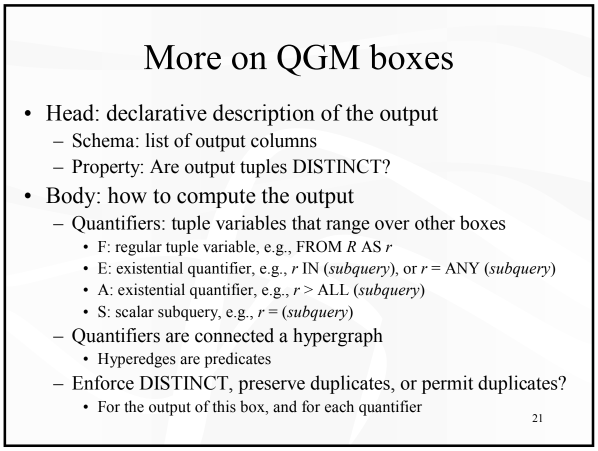
- Not exactly relational algebra—enumerating plans is not simple
- Subqueries and views naturally divide a query into nested “blocks”
  - Processing each block separately forces particular join methods and join order
  - Even if the plan is optimal for each block, it may not be optimal for the entire query

➢ Unnest query: convert subqueries/views to joins
  - We know how to deal with select-project-join queries



DB2’s QGM

- 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., *r* IN (*subquery*), or *r* = ANY (*subquery*)
    - A: existential quantifier, e.g., *r* > ALL (*subquery*)
    - S: scalar subquery, e.g., *r* = (*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

Query rewrite in DB2

- Goal: make the logical plan as general as possible, i.e., merge boxes
- Rule-based transformations on QGM (Leung et al., in red book)
  - Merge subqueries in FROM
  - Convert E to F (e.g., IN/ANY subqueries to joins)
  - Intersect 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

-
  ```
  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

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;
  ```
- Suppose…

A way of preserving duplicates

-
  ```
  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

- Sometimes an ANY subquery can be turned into an aggregate subquery without ANY

-
  ```
  SELECT * FROM Student s1
  WHERE GPA > ANY
  (SELECT GPA FROM Student s2
   WHERE s2.age > s1.age);
  ```

-
  ```
  SELECT * FROM Student s1
  WHERE GPA >
  (SELECT MIN(GPA) FROM Student s2
   WHERE s2.age > s1.age);
  ```

Does the same trick apply to ALL?

-
  ```
  SELECT * FROM Student s1
  WHERE GPA > ALL
  (SELECT GPA FROM Student s2
   WHERE s2.age < s1.age);
  ```

-
  ```
  SELECT * FROM Student s1
  WHERE GPA >
  (SELECT MAX(GPA) FROM Student s2
   WHERE s2.age < s1.age);
  ```
- Suppose…

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);
  ```

-
  ```
  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;
  ```
- Suppose…

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 example

- Original query

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

- Process the outer query without the subquery

```
– CREATE VIEW Supp_Course AS
  SELECT * FROM Course WHERE title LIKE ’CPS%’;
```

- Collect bindings

```
– CREATE VIEW Magic AS
  SELECT DISTINCT CID FROM Supp_Course;
```

Magic example

- Evaluate the subquery with 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 Enroll.CID, 0 AS cnt          (the COUNT patch)
  FROM Enroll
  WHERE Enroll.CID NOT IN (SELECT CID FROM Magic);
```

- Finally, refine the outer query

```
– SELECT Supp_Course.CID FROM Supp_Course, DS
  WHERE Supp_Course.CID = DS.CID
  AND min_enroll > DS.cnt;
```

Summary of query rewrite

- Break the artificial boundary between queries and subqueries
- Combine as many query blocks as possible in a select-project-join block, where clean rules of relational algebra apply
- Extremely tricky stuff with duplicates, NULLs, empty tables, and correlation
- Next step
  - Cost-based (Tuesday) optimization (Thursday) on each select-project-join block