

Query Optimization

CPS 116
Introduction to Database Systems

Announcements (November 20)

- ❖ Homework #4 (last one and short) assigned today
 - Due next Thursday

Query optimization

- ❖ One logical plan → “best” physical plan
- ❖ Questions
 - How to enumerate possible plans
 - How to estimate costs
 - How to pick the “best” one
- ❖ Often the goal is not getting the optimum plan, but instead avoiding the horrible ones

Plan enumeration in relational algebra

- ❖ Apply relational algebra equivalences
- ⊕ Join reordering: \bowtie and \ltimes are associative and commutative (except column ordering, but that is unimportant)

More relational algebra equivalences

- ❖ Convert $\sigma_p \ltimes$ to/from \bowtie_p : $\sigma_p(R \times S) = R \bowtie_p S$
- ❖ Merge/split σ 's: $\sigma_{p_1}(\sigma_{p_2} R) = \sigma_{p_1 \wedge p_2} R$
- ❖ Merge/split π 's: $\pi_{L_1}(\pi_{L_2} R) = \pi_{L_1} R$, where $L_1 \subseteq L_2$
- ❖ Push down/pull up σ :
 - $\sigma_{p \wedge p_r \wedge p_s}(R \bowtie_p S) = (\sigma_{p_r} R) \bowtie_p (\sigma_{p_s} S)$, where
 - p_r is a predicate involving only R columns
 - p_s is a predicate involving only S columns
 - p and p' are predicates involving both R and S columns
- ❖ Push down π : $\pi_L(\sigma_p R) = \pi_L(\sigma_p(\pi_{L'} R))$, 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 ⁷

- ❖ Start with a logical plan
- ❖ Push selections/projections down as much as possible
 - Why? Reduce the size of intermediate results
 - Why not? May be expensive; maybe joins filter better
- ❖ Join smaller relations first, and avoid cross product
 - Why? Reduce the size of intermediate results
 - Why not? Size depends on join selectivity too
- ❖ Convert the transformed logical plan to a physical plan (by choosing appropriate physical operators)

SQL query rewrite ⁸

- ❖ 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
- ☞ We can just deal with select-project-join queries
 - Where the clean rules of relational algebra apply

SQL query rewrite example ⁹

- ❖ `SELECT name`
`FROM Student`
`WHERE SID = ANY (SELECT SID FROM Enroll);`
- ❖ `SELECT name`
`FROM Student, Enroll`
`WHERE Student.SID = Enroll.SID;`
 - Wrong—consider two Bart’s, each taking two classes
- ❖ `SELECT name`
`FROM (SELECT DISTINCT Student.SID, name`
`FROM Student, Enroll`
`WHERE Student.SID = Enroll.SID);`
 - Right—assuming Student.SID is a key

Dealing with correlated subqueries ¹⁰

- ❖ `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`
`AND title LIKE 'CPS%';`
 - New subquery is inefficient (computes enrollment for *all* courses)
 - Suppose a CPS class is empty?

“Magic” decorrelation ¹¹

- ❖ `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

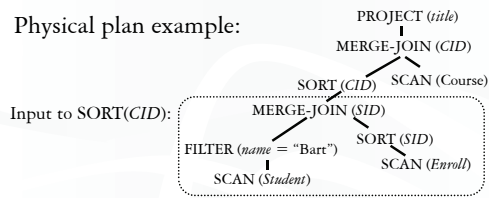
Heuristics- vs. cost-based optimization ¹²

- ❖ Heuristics-based optimization
 - Apply heuristics to rewrite plans into cheaper ones
- ❖ Cost-based optimization
 - Rewrite logical plan to combine “blocks” as much as possible
 - Optimize query block by block
 - Enumerate logical plans (already covered)
 - Estimate the cost of plans
 - Pick a plan with acceptable cost
 - Focus: select-project-join blocks

Cost estimation

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Physical plan example:



- ❖ We have: cost estimation for each operator
 - Example: SORT(CID) takes $2 \times B(\text{input})$
 - But what is $B(\text{input})$?
- ❖ We need: size of intermediate results

Selections with equality predicates

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- ❖ $Q: \sigma_{A=v} R$
- ❖ Suppose the following information is available
 - Size of R : $|R|$
 - Number of distinct A values in R : $|\pi_A R|$
- ❖ Assumptions
 - Values of A are uniformly distributed in R
 - Values of v in Q are uniformly distributed over all $R.A$ values
- ❖ $|Q| \approx |R| / |\pi_A R|$
 - Selectivity factor of $(A = v)$ is $1 / |\pi_A R|$

Conjunctive predicates

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- ❖ $Q: \sigma_{A=u \text{ and } B=v} R$
- ❖ Additional assumptions
 - $(A = u)$ and $(B = v)$ are independent
 - Counterexample: major and advisor
 - No “over”-selection
 - Counterexample: A is the key
- ❖ $|Q| \approx |R| / (|\pi_A R| \cdot |\pi_B R|)$
 - Reduce total size by all selectivity factors

Negated and disjunctive predicates

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- ❖ $Q: \sigma_{A \neq v} R$
 - $|Q| \approx |R| \cdot (1 - 1 / |\pi_A R|)$
 - Selectivity factor of $\neg p$ is $(1 - \text{selectivity factor of } p)$
- ❖ $Q: \sigma_{A=u \text{ or } B=v} R$
 - $|Q| \approx |R| \cdot (1 / |\pi_A R| + 1 / |\pi_B R|)$
 - No! Tuples satisfying $(A = u)$ and $(B = v)$ are counted twice
 - $|Q| \approx |R| \cdot (1 - (1 - 1 / |\pi_A R|) \cdot (1 - 1 / |\pi_B R|))$
 - Intuition: $(A = u) \text{ or } (B = v)$ is equivalent to $\neg(\neg(A = u) \text{ AND } \neg(B = v))$

Range predicates

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- ❖ $Q: \sigma_{A > v} R$
- ❖ Not enough information!
 - Just pick, say, $|Q| \approx |R| \cdot 1/3$
- ❖ With more information
 - Largest $R.A$ value: $\text{high}(R.A)$
 - Smallest $R.A$ value: $\text{low}(R.A)$
 - $|Q| \approx |R| \cdot (\text{high}(R.A) - v) / (\text{high}(R.A) - \text{low}(R.A))$
 - In practice: sometimes the second highest and lowest are used instead
 - The highest and the lowest are often used by inexperienced database designer to represent invalid values!

Two-way equi-join

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- ❖ $Q: R(A, B) \bowtie S(A, C)$
- ❖ Assumption: containment of value sets
 - Every tuple in the “smaller” relation (one with fewer distinct values for the join attribute) joins with some tuple in the other relation
 - That is, if $|\pi_A R| \leq |\pi_A S|$ then $\pi_A R \subseteq \pi_A S$
 - Certainly not true in general
 - But holds in the common case of foreign key joins
- ❖ $|Q| \approx |R| \cdot |S| / \max(|\pi_A R|, |\pi_A S|)$
 - Selectivity factor of $R.A = S.A$ is $1 / \max(|\pi_A R|, |\pi_A S|)$

Multiway equi-join

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- ❖ $Q: R(A, B) \bowtie S(B, C) \bowtie T(C, D)$
- ❖ What is the number of distinct C values in the join of R and S ?
- ❖ Assumption: preservation of value sets
 - A non-join attribute does not lose values from its set of possible values
 - That is, if A is in R but not S , then $\pi_A(R \bowtie S) = \pi_A R$
 - Certainly not true in general
 - But holds in the common case of foreign key joins (for value sets from the referencing table)

Multiway equi-join (cont'd)

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- ❖ $Q: R(A, B) \bowtie S(B, C) \bowtie T(C, D)$
- ❖ Start with the product of relation sizes
 - $|R| \cdot |S| \cdot |T|$
- ❖ Reduce the total size by the selectivity factor of each join predicate
 - $R.B = S.B: 1/\max(|\pi_B R|, |\pi_B S|)$
 - $S.C = T.C: 1/\max(|\pi_C S|, |\pi_C T|)$
 - $|Q| \approx (|R| \cdot |S| \cdot |T|) / (\max(|\pi_B R|, |\pi_B S|) \cdot \max(|\pi_C S|, |\pi_C T|))$

Cost estimation: summary

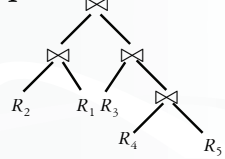
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- ❖ Using similar ideas, we can estimate the size of projection, duplicate elimination, union, difference, aggregation (with grouping)
- ❖ Lots of assumptions and very rough estimation
 - Accurate estimate is not needed
 - Maybe okay if we overestimate or underestimate consistently
 - May lead to very nasty optimizer "hints"


```
SELECT * FROM Student WHERE GPA > 3.9;
SELECT * FROM Student WHERE GPA > 3.9 AND GPA > 3.9;
```
- ❖ Not covered: better estimation using histograms

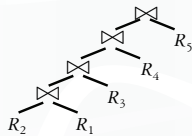
Search for the best plan

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- ❖ Huge search space
- ❖ "Bushy" plan example:
 
- ❖ Just considering different join orders, there are $(2n - 2)! / (n - 1)$ bushy plans for $R_1 \bowtie \dots \bowtie R_n$
 - 30240 for $n = 6$
- ❖ And there are more if we consider:
 - Multiway joins
 - Different join methods
 - Placement of selection and projection operators

Left-deep plans

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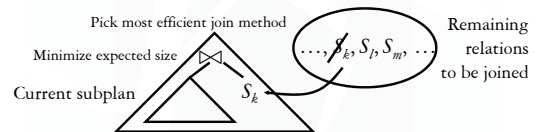


- ❖ Heuristic: consider only "left-deep" plans, in which only the left child can be a join
 - Tend to be better than plans of other shapes, because many join algorithms scan inner (right) relation multiple times—you will not want it to be a complex subtree
- ❖ How many left-deep plans are there for $R_1 \bowtie \dots \bowtie R_n$?
 - Significantly fewer, but still lots— $n!$ (720 for $n = 6$)

A greedy algorithm

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- ❖ S_1, \dots, S_n
 - Say selections have been pushed down; i.e., $S_i = \sigma_p R_i$
- ❖ Start with the pair S_i, S_j with the smallest estimated size for $S_i \bowtie S_j$
- ❖ Repeat until no relation is left:
 - Pick S_k from the remaining relations such that the join of S_k and the current result yields an intermediate result of the smallest size



A dynamic programming approach 25

- ❖ Generate optimal plans bottom-up
 - Pass 1: Find the best single-table plans (for each table)
 - Pass 2: Find the best two-table plans (for each pair of tables) by combining best single-table plans
 - ...
 - Pass k : Find the best k -table plans (for each combination of k tables) by combining two smaller best plans found in previous passes
 - ...
- ❖ Rationale: Any subplan of an optimal plan must also be optimal (otherwise, just replace the subplan to get a better overall plan)
- ☞ Well, not quite...

The need for “interesting order” 26

- ❖ Example: $R(A, B) \bowtie S(A, C) \bowtie T(A, D)$
- ❖ Best plan for $R \bowtie S$: hash join (beats sort-merge join)
- ❖ Best overall plan: sort-merge join R and S , and then sort-merge join with T
 - Subplan of the optimal plan is not optimal!
- ❖ Why?
 - The result of the sort-merge join of R and S is sorted on A
 - This is an interesting order that can be exploited by later processing (e.g., join, duplicate elimination, GROUP BY, ORDER BY, etc.)!

Dealing with interesting orders 27

- ❖ When picking the best plan
 - Comparing their costs is not enough
 - Plans are not totally ordered by cost anymore
 - Comparing interesting orders is also needed
 - Plans are now partially ordered
 - Plan X is better than plan Y if
 - Cost of X is lower than Y
 - Interesting orders produced by X subsume those produced by Y
- ❖ Need to keep a set of optimal plans for joining every combination of k tables
 - At most one for each interesting order

Summary 28

- ❖ Relational algebra equivalence
- ❖ SQL rewrite tricks
- ❖ Heuristics-based optimization
- ❖ Cost-based optimization
 - Need statistics to estimate sizes of intermediate results
 - Greedy approach
 - Dynamic programming approach