Introduction to Database Systems CSE 444

Lecture 20: Overview of Query Optimization

Where We Are

- Back to how a DBMS executes a query
- What we learned so far
  - How data is stored and indexed (lectures 15 and 16)
  - Logical query plans: relational algebra (lecture 17)
  - Steps involved in processing a query (lecture 18)
  - Operator algorithms (lecture 19)
- Today
  - How to select logical & physical query plans
  - Chapter 16 in the book (recommended, not required)

Query Optimization Goal

- For a query
  - There exists many logical and physical query plans
  - Query optimizer needs to pick a good one

Query Optimization Algorithm

- Enumerate alternative plans
- Compute estimated cost of each plan
  - Compute number of I/Os
  - Compute CPU cost
- Choose plan with lowest cost
  - This is called cost-based optimization

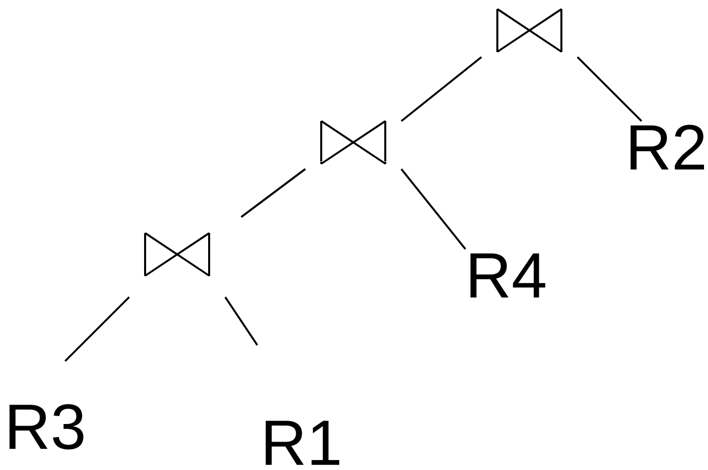
Outline

- Search space
- Algorithm for enumerating query plans
- Estimating the cost of a query plan

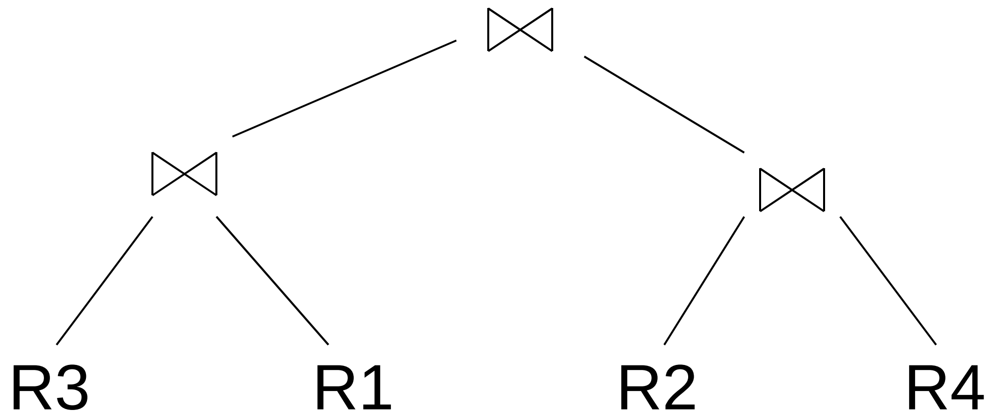
Relational Algebra Equivalences

- Selections
  - Commutative: $\sigma_{c1}(\sigma_{c2}(R))$ same as $\sigma_{c2}(\sigma_{c1}(R))$
  - Cascading: $\sigma_{c1 \wedge c2}(R)$ same as $\sigma_{c2}(\sigma_{c1}(R))$
- Projections
  - Cascading
- Joins
  - Commutative : $R \bowtie S$ same as $S \bowtie R$
  - Associative: $R \bowtie (S \bowtie T)$ same as $(R \bowtie S) \bowtie T$

Left-Deep Plans and Bushy Plans



Left-deep plan



Bushy plan

Relational Algebra Equivalences

- Selects, projects, and joins
  - We can commute and combine all three types of operators
  - We just have to be careful that the fields we need are available when we apply the operator
  - Relatively straightforward. See book 16.2

Search Space Challenges

- Search space is huge!
  - Many possible equivalent trees
  - Many implementations for each operator
  - Many access paths for each relation
    - File scan or index + matching selection condition

- Cannot consider ALL plans
- Want search space that includes low-cost plans

Outline

- Search space
- Algorithms for enumerating query plans
- Estimating the cost of a query plan

Key Decisions

- When selecting a plan, some of the most important decisions include:
  - Logical plan
    - Can we push selections down?
    - Can we push projections or aggregations down?
    - What order to use for joins?
  - Physical plan
    - What join algorithms to use?
    - What access paths to use (file scan or index)?

Plan Enumeration Algorithms

- Rule-based vs cost-based algorithms
- Logical plans
  - Heuristic-based algorithms
  - Use size of intermediate results as cost measure
- Physical plans
  - Top-down algorithms or
  - Bottom-up: dynamic programming approaches
    - Also called “Selinger-style” optimizers
  - Use heuristics to limit search space

Outline

- Search space
- Algorithms for enumerating query plans
- Estimating the cost of a query plan

Computing the Cost of a Plan

- Collect statistical summaries of stored data
- Compute cost in a bottom-up fashion
- For each operator compute
  - Estimate cost of executing the operation
  - Estimate statistical summary of the output data

Statistics on Base Data

- Collected information for each relation
  - Number of tuples (cardinality)
  - Indexes, number of keys in the index
  - Number of physical pages, clustering info
  - Statistical information on attributes
    - Min value, max value, number distinct values
    - Histograms
  - Correlations between columns (hard)
- Collection approach: periodic, using sampling

Retrieving data from Storage

- **Access path**: a way to retrieve tuples from a table
  - A file scan
  - An index *plus* a matching selection condition

- Index matches selection condition if it can be used to retrieve just tuples that satisfy the condition
  - Example: Supplier(sid,sname,scity,sstate)
  - B+-tree index on (scity,sstate)
    - matches scity='Seattle'
    - does not match sid=3, does not match sstate='WA'

Access Path Selection

- Supplier(sid,sname,scity,sstate)
- Selection condition: sid > 300 $\wedge$ scity='Seattle'
- Indexes: B+-tree on sid and B+-tree on scity
- Which access path should we use?
- We should pick the **most selective** access path

Access Path Selectivity

- **Access path selectivity is the number of pages retrieved if we use this access path**
  - Most selective retrieves fewest pages

- As we saw earlier, **for equality predicates**
  - Selection on equality: $\sigma_{a=v}(R)$
  - V(R, a) = # of distinct values of attribute a
  - 1/V(R,a) is thus the reduction factor
  - Clustered index on a: cost B(R)/V(R,a)
  - Unclustered index on a: cost T(R)/V(R,a)
  - (we are ignoring I/O cost of index pages for simplicity)

Selectivity for Range Predicates

- Selection on range: $\sigma_{a>v}(R)$

- How to compute the selectivity?
- Assume values are uniformly distributed
- Reduction factor X
- X = (Max(R,a) - v) / (Max(R,a) - Min(R,a))

- Clustered index on a, cost is B(R)*X
- Unclustered index on a, cost is T(R)*X

Back to Our Example

- Selection condition: **sid > 300 $\wedge$ scity='Seattle'**
  - Index I1: B+-tree on sid clustered
  - Index I2: B+-tree on scity unclustered

- Let's assume
  - V(Supplier,scity) = 20
  - Max(Supplier, sid) = 1000, Min(Supplier,sid)=1
  - B(Supplier) = 100, T(Supplier) = 1000

- **Cost I1: B(R) * (Max-v)/(Max-Min) = 100*700/999 $\approx$ 70**
- **Cost I2: T(R) * 1/V(Supplier,scity) = 1000/20 = 50**

Selectivity with Multiple Conditions

What if we have an index on multiple attributes?

- Example selection $\sigma_{a=v1 \wedge b=v2}(R)$ and index on <a,b>

How to compute the selectivity?

- Assume attributes are independent
- X = 1 / (V(R,a) * V(R,b))

- Clustered index on <a,b>: cost B(R)*X
- Unclustered index on <a,b>: cost T(R)*X

Computing Cost of an Operator

- The cost of executing an operator depends
  - On the operator implementation
  - On the input data

- We learned how to compute this in the previous lecture, so we do not repeat it here

Statistics on the Output Data

- Most important piece of information
  - **Size of operator result**
  - I.e., the number of output tuples
- Projection: output size same as input size
- Selection: multiply input size by reduction factor
  - Similar to what we did for estimating access path selectivity
  - Assume independence between conditions in the predicate
  - (use product of the reduction factors for the terms)

Estimating Result Sizes

- For joins R $\bowtie$ S
  - Take product of cardinalities of relations R and S
  - Apply reduction factors for each term in join condition
  - Terms are of the form: column1 = column2
  - Reduction: 1/ (MAX(V(R,column1), V(S,column2))
  - **Assumes each value in smaller set has a matching value in the larger set**

Our Example

- Suppliers(sid,sname,scity,sstate)
- Supplies(pno,sid,quantity)
- Some statistics
  - T(Supplier) = 1000 records
  - B(Supplier) = 100 pages
  - T(Supplies) = 10,000 records
  - B(Supplies) = 100 pages
  - V(Supplier,scity) = 20, V(Supplier,state) = 10
  - V(Supplies,pno) = 3,000
  - Both relations are clustered

Physical Query Plan 1

(On the fly) π_{sname}

(On the fly) $\sigma_{\text{scity='Seattle'} \wedge \text{sstate='WA'} \wedge \text{pno=2}}$

(Nested loop) $\bowtie_{\text{sno = sno}}$

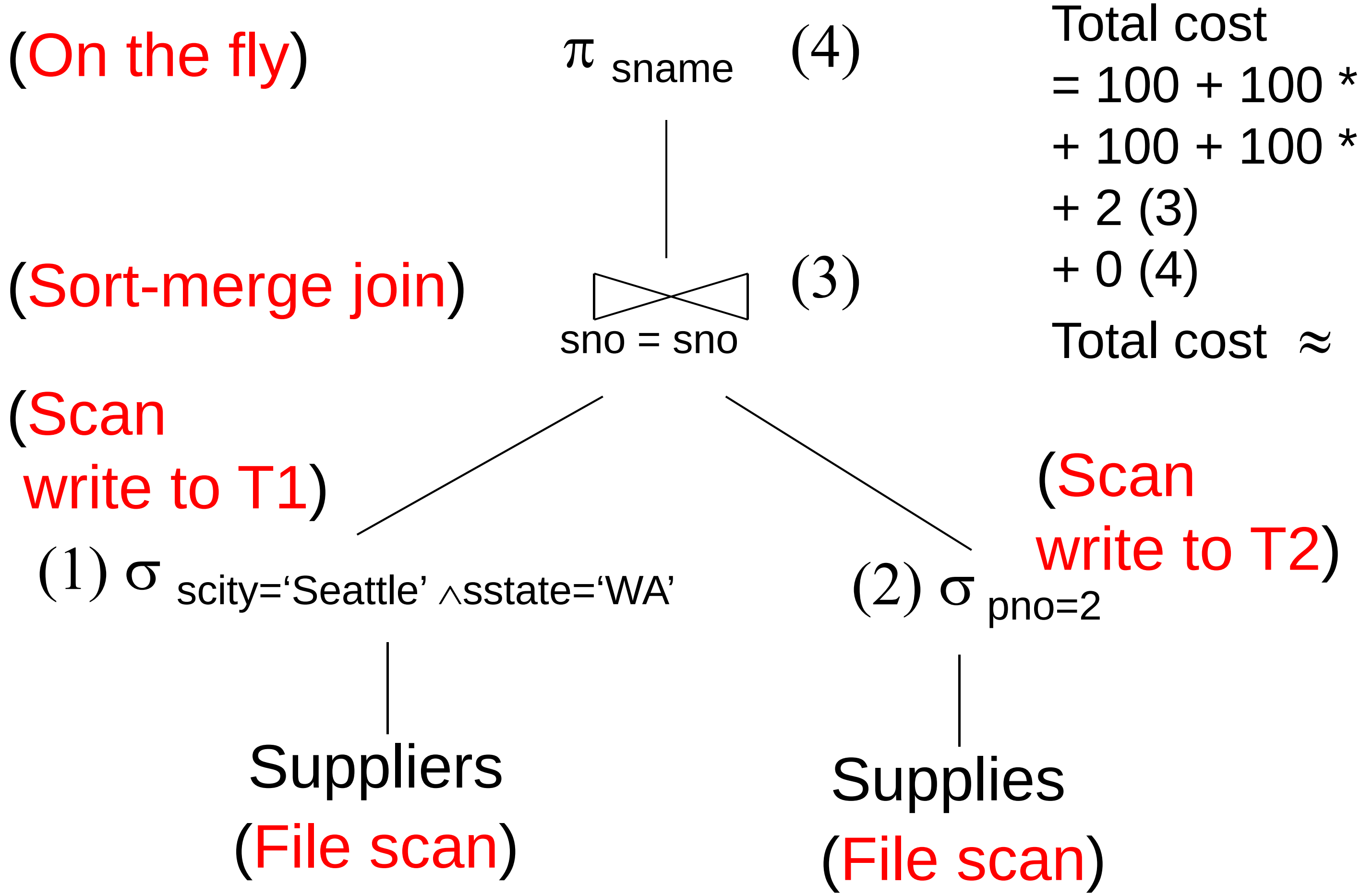
Suppliers (File scan)

Supplies (File scan)

Selection and project on-the-fly
-> No additional cost.

Total cost of plan is thus cost of join:
=
B(Supplier)+B(Supplier)*B(Supplies)
= 100 + 100 * 100
= 10,100 I/Os

Physical Query Plan 2



Total cost
= 100 + 100 * 1/20 * 1/10 (1)
+ 100 + 100 * 1/3000 (2)
+ 2 (3)
+ 0 (4)

Total cost ≈ **204 I/Os**

Physical Query Plan 3

(On the fly) (4) π_{sname}

(On the fly)

(3) $\sigma_{\text{scity='Seattle'} \wedge \text{sstate='WA'}}$

(2) $\bowtie_{\text{sno = sno}}$ (Index nested loop)

4 tuples

(Use hash index)

(1) $\sigma_{\text{pno=2}}$

Supplies

(Hash index on pno)

Assume: clustered

Suppliers

(Hash index on sno)

Clustering does not matter

Total cost

= 1 (1)

+ 4 (2)

+ 0 (3)

+ 0 (3)

Total cost $\approx$ **5 I/Os**

Simplifications

- In the previous examples, we assumed that all index pages were in memory
  - When this is not the case, we need to add the cost of fetching index pages from disk
- We also assumed that CPU time is irrelevant
  - Not the entire story in production systems