THE UNIVERSITY of EDINBURGH

Advanced Database Systems

Spring 2024

Lecture #23:

Query Optimisation: Searching

R&G: Chapter 15

1

Query Optimisation

Plan space

Cost estimation

Search algorithm

2

Finding the "Best" Query Plan

Holy grail of any DBMS implementation

Challenge: There may be more than one way to answer a given query

- Which one of the join operators should we pick?
- With which parameters (block size, buffer allocation, ...)?
- Which join ordering?

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Finding the "Best" Query Plan

The query optimiser

1. Enumerates all possible query execution plans
   If this yields too many plans, at least enumerate the "promising" plan candidates
2. Determines the cost (quality) of each plan
3. Chooses the best one as the final execution plan

Ideally: Want to find the best plan. Practically: Avoid worst plans!

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Enumeration of Alternative Plans

There are two main cases:

- Single-table plans (base case)
- Multiple-table plans (induction)

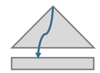
Single-table queries include selects, projects, and group-by / aggregate

- Consider each available access path (file scan vs. index)
- Choose the one with the least estimated cost

Single-Table Plans: Cost Estimates

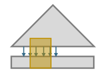
Index I on primary key matches selection:

- Cost is (Height(I) + 1) + 1 for a B+ tree *(variant B or C)*



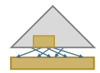
Clustered index I matching selection:

- (NPages(I) + NPages(R)) * selectivity *(approximately)*



Non-clustered index I matching selection:

- (NPages(I) + NTuples(R)) * selectivity *(approximately)*



Sequential scan of file

- NPages(R)

Recall: Must also charge for duplicate elimination if required

Single-Table Plan: Example

```
SELECT * FROM Sailors
 WHERE rating = 8
```

NTuples(Sailors) = 40,000
NPages(Sailors) = 500
NKeys(rating) = 10
NPages(I) = 50

If we have an index I on *rating*:

- Cardinality
  - = 1/ NKeys(rating) · NTuples(Sailors) = 1/10 · 40,000 = **4000 tuples**
- Clustered index
  - 1/ NKeys(rating) · (NPages(I) + NPages(Sailors)) = 1/10 · (50 + 500) = **55 pages** are retrieved
- Unclustered index
  - 1/ NKeys(rating) · (NPages(I) + NTuples(Sailors)) = 1/10 · (50 + 40,000) = **4005 pages** are retrieved
- Costs on indexes are approximate as we might not need to retrieve all index pages

If we have an index I on *sid:*

- Doing an index scan retrieves all pages & tuples
- Clustered index: ~ (50 + 500) pages retrieved. Unclustered index: ~ (50 + 40,000) pages retrieved

Doing a file scan retrieves all file pages: 500

Multiple-Table Plans

We have translated the query into a graph of query blocks

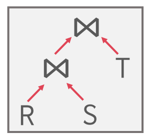
- Query blocks are essentially a multi-way product of relations with projections on top

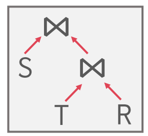
Task: enumerate all possible execution plans

- I.e., all possible 2-way join combinations for each query block

Example: three-way join

- 12 possible re-orderings
- 2 shown here





Enormous Search Space

# of relations n	# of different join trees
2	2
3	12
4	120
5	1,680
6	30,240
7	665,280
8	17,297,280
10	17,643,225,600

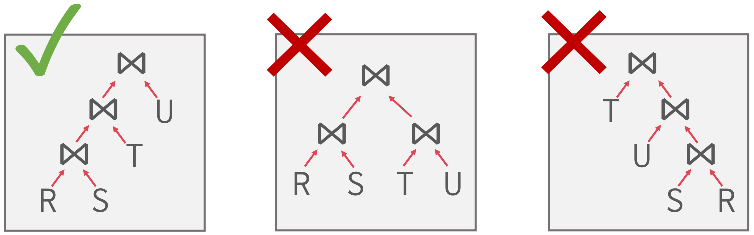
We have not even considered *different join algorithms*!

We need to restrict search space!

Multiple-Table Query Planning

Fundamental decision in IBM's **System R** (late 1970):

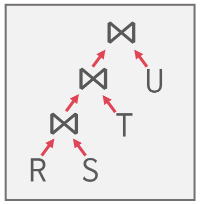
Only consider left-deep join trees



left-deep   bushy (everything else)   right-deep

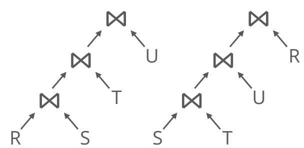
Left-Deep Join Trees

- DBMSs often prefer left-deep join trees
  - The inner (rhs) relation always is a base relation
  - Allows the use of index nested loops join
  - Allows for **fully pipelined plans** where intermediate results are not written to temporary files
    - Should be factored into global cost calculation
    - Not all left-deep trees are fully pipelined (e.g., sort-merge join)
    - Pipelining requires **non-blocking** operators
- Modern DBMSs may also consider non left-deep join trees



Multi-Table Query Planning

- **System R**-style join order enumeration
  - Left-deep tree #1, Left-deep tree #2…
  - Eliminate plans with cross products immediately
- Enumerate the plans for each operator
  - Hash, Sort-Merge, Nested Loop…
- Enumerate the access paths for each table
  - Index #1, Index #2, Sequential scan…
- Use **dynamic programming** to reduce the number of cost estimations



The Principle of Optimality

The best overall plan is composed of best decisions on the subplans

- Optimal result has optimal substructure

For example, the best left-deep plan to join tables R, S, T is either:

- (The best plan for joining R, S) ⋈ T
- (The best plan for joining R, T) ⋈ S
- (The best plan for joining S, T) ⋈ R

This is great!

- When optimising a subplan (e.g., R ⋈ S), don't worry how it will be used later (e.g., when joining with T)!
- When optimizing a higher-level plan (e.g., R ⋈ S ⋈ T), reuse the best results of subplans (e.g., R ⋈ S)!

Example: Dynamic Programming

Pass #1 (best 1-relation plans): Find best access path to each relation (index vs. full table scans)

```
SELECT * FROM R, S, T
 WHERE R.A = S.A
   AND S.B = T.B
```

Example: Dynamic Programming

Pass #2 (best 2-relation plans): determine best join order (R ⋈ S or S ⋈ R), choose best candidate

```
SELECT * FROM R, S, T
 WHERE R.A = S.A
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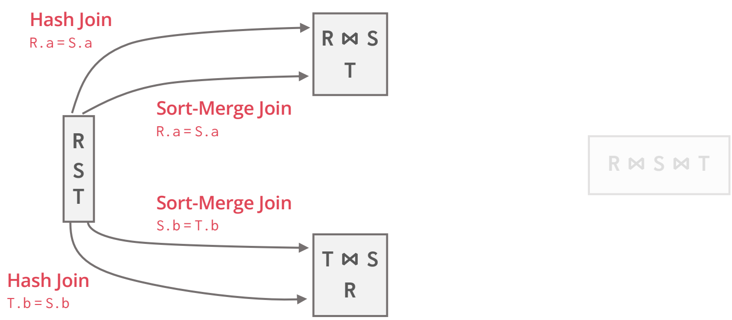

Example: Dynamic Programming

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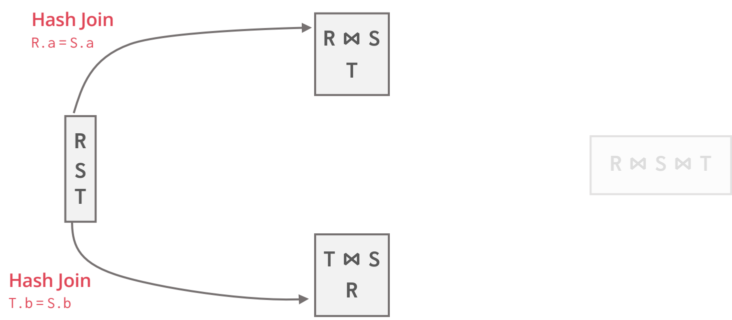
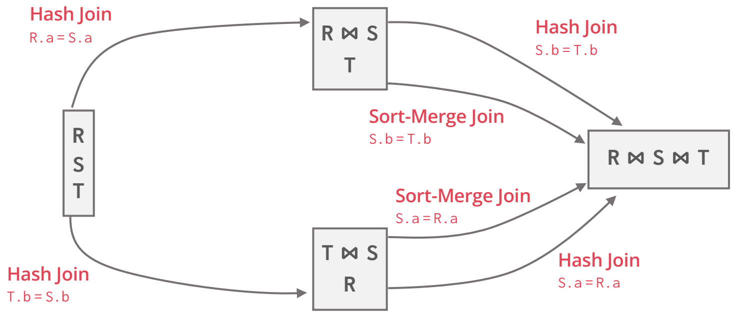


Example: Dynamic Programming

Pass #3 (best 3-relation plans):
best 2-relation plans + one other relation

```
SELECT * FROM R, S, T
 WHERE R.A = S.A
   AND S.B = T.B
```



Example: Dynamic Programming

Pass #3 (best 3-relation plans):
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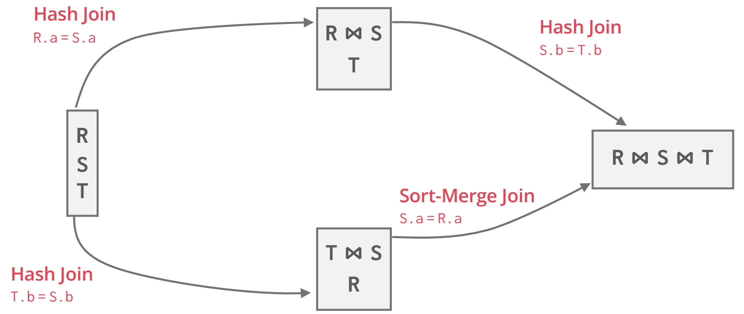

Example: Dynamic Programming

Pass #3 (best 3-relation plans):
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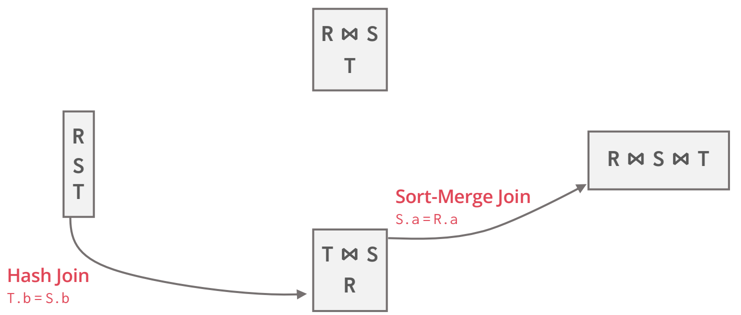


Interesting Orders

System R-style query optimisers also consider **interesting orders**

- Sorting orders of the input tables that may be beneficial later in the query plan
  - E.g., for a sort-merge join, projection with duplicate removal, order-by clause
- Determined by ORDER BY and GROUP BY clauses in the input query or join attributes of subsequent joins (to facilitate merging)

For each subset of relations, retain only:

- Cheapest plan overall, plus
- Cheapest plan for each **interesting order** of the tuples

EXAMPLE

```
SELECT S.sid, COUNT(*) AS number
  FROM Sailors S
  JOIN Reserves R ON S.sid = R.sid
  JOIN Boats B ON R.bid = B.bid
 WHERE B.color = 'red'
GROUP BY S.sid
```

Sailors:
- B+ tree on *sid*

Reserves:
- Clustered B+ tree on *bid*
- B+ tree on *sid*

Boats:
- B+ tree on *color*

Pass 1: Best plan for each relation

- **Sailors, Reserves:** File scan
- **Boats:** B+ tree on color
- Also B+ tree on Sailors.sid as interesting order (output sorted on *sid*)
- Also B+ tree on Reserves.bid as interesting order (output sorted on *bid*)
- Also B+ tree on Reserves.sid as interesting order (output sorted on *sid*)

EXAMPLE: PASS 2

Pass 2: Best 2-relation plans

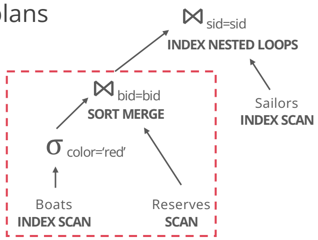
```
// for each left-deep logical plan
foreach plan P in Pass 1:
  foreach FROM table T not in P:
    // for each physical plan
    foreach access method M on T:
      foreach join method ⋈:
        generate P ⋈ M(T)
```

- Eliminate cross products
- Retain cheapest plan for each (pair of relations, order)

EXAMPLE: PASS 3

Using Pass 2 plans as outer relations, generate plans for the next join in the same way as Pass 2

- Example: the marked subplan is the best plan for { Reserves, Boats } and interesting order on Boats.bid and Reserves.bid



Then, add cost for group-by / aggregate:

- This is the cost to sort the result by *sid*
- *... unless it has already been sorted by a previous operator*

Finally, choose the cheapest plan

SUMMARY

Query optimisation is an important task in a relational DBMS

Explores a set of alternative plans

- Must prune search space; typically, left-deep plans only
- Uses dynamic programming for join orderings

Must estimate cost of each plan that is considered

- Must estimate the size of result and cost for each plan node

Query optimiser is the most complex part of database systems!