CS 133: Databases

Fall 2019
Lec 12 – 10/15
Prof. Beth Trushkowsky

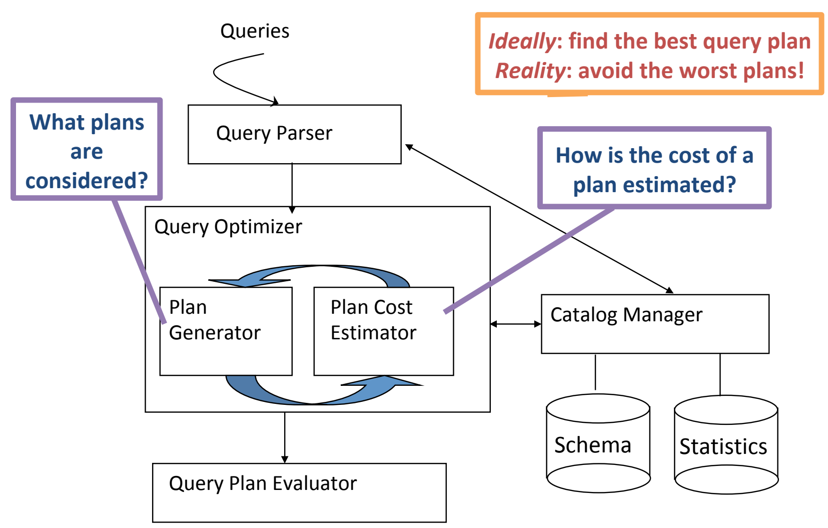
Administrivia

- Midterm this Thursday 10/17
- Assignments
  - Lab 2 ends tomorrow night, don't forget write up!
  - Lab 3 starts after fall break
  - No problem set out this week

Goals for Today

- Reason about the stages of query optimization
- Understand how to estimate the cost of a full query plan
  - Pipelining vs. materialization
  - Intermediate result sizes

Cost-based Query Sub-System



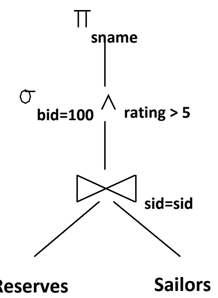
Query Optimization Overview

- Query converted to relational algebra expression
- Relational algebra converted to tree, joins as branches
- ***Operators can also be applied in different order!***

Each operator has implementation choices
→ Choosing forms physical plan

```
SELECT  S.sname
FROM  Reserves R, Sailors S
WHERE  R.sid=S.sid AND
   R.bid=100 AND S.rating>5
```

$\pi_{(sname)}\sigma_{(bid=100 \wedge rating > 5)}$ (Reserves $\bowtie_{sid=sid}$ Sailors)



Left branch is the "outer" relation

Query Optimizer algorithm

- *Goal*: **given a a query**, the optimizer wants to
  - Decide which query plans to consider
  - Compare plans and choose the "best" one (best = shortest time to run)
- How about this algorithm?
  - Step 1: **enumerate the space of all possible plans**
  - Step 2: **run each query plan, measure its runtime**
  - Step 3: **choose the plan that ran the fastest!**

Query Optimizer algorithm

- *Goal*: **given a a query**, the optimizer wants to
  - Decide which query plans to consider
  - Compare plans and choose the "best" one (best = shortest time to run)
- ***Actual*** algorithm
  - Step 1: **consider a set of possible plans**
  - Step 2: **estimate cost for each plan**
  - Step 3: **choose the plan with lowest cost**

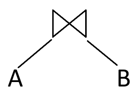
Estimating Cost

- Don't want to execute a plan to figure out its run-time!
  - Instead **estimate cost** of the plan
  - Use cost as a **proxy for run-time**
- Cost of a plan = **sum of costs for each operator in plan**

Exercise 2: Reasoning about cost

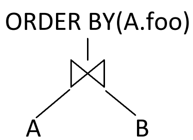
- Assume:
  - Each relation is 5 pages and stored as a heap file, no indexes
  - Buffer pool has 4 frames
  - Join algorithm is **page**-nested-loop-join (PNLJ)
  - *Order by* operator uses general external merge-sort

1. (Review) What is the cost in I/Os for this plan, ignoring cost of final output?



5 + 5*5

2. Now what about the cost of this plan? *What information are you missing?*



Need Input size to ORDER BY, determined by output size of JOIN

Pipelined vs. Materialized

- Each query plan operator's output could be generated in either ***materialized*** or ***pipelined*** fashion
- **Materialized**
  - Complete output of an operator saved (typically **written back to disk)** as a temporary relation before its parent reads it in
- **Pipelining** ("on-the-fly")
  - Parts of output of operator **immediately given to parent** as input

Pipelining

- Parent and child operators ***executing concurrently***
  - Iterator model
  - Parent calls next() on child/children
  - (As needed) child calls next() on *its* child/children
- Savings compared to materialization to disk
  - **No write I/O cost** for child's output
  - **No read I/O cost** for parent's input
- Operator algorithm(s) must support pipelining for this to work!

Exercise 3: Pipelining

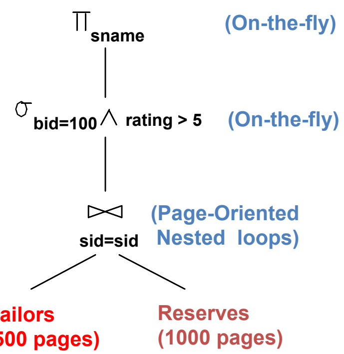
- Use Page-Nested-Loop joins for the join algorithm
- Some examples:
  - (A join B) join C
    - Pipelined
  - C join (A join B)
    - Since (A join B) is the inner relation for the second join, need to materialize it

Motivating Example

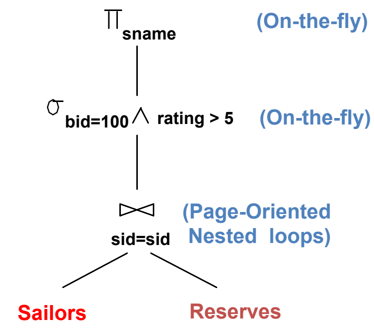
```
SELECT S.sname
FROM   Reserves R, Sailors S
WHERE  R.sid=S.sid
   AND R.bid=100 AND S.rating>5
```

- Suppose there are
  - **100 boats** (uniformly distributed)
  - **10 ratings** (uniformly distributed 1-10)
- Cost: 500 + 500*1000 I/Os
- *Misses several opportunities*:
  - Selections could have been “pushed” earlier
  - No use is made of any available indexes...
- ***Goal of optimization***: find more efficient plans that compute the same answer.

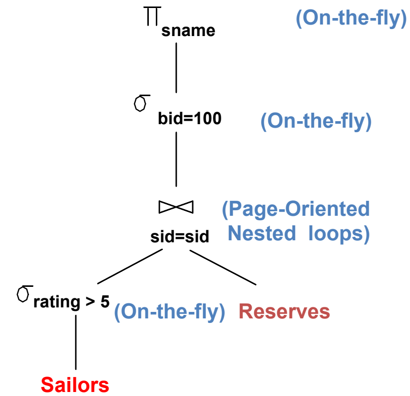
Query Plan:



Alternative Plans – Push SELECTs (No Indexes)

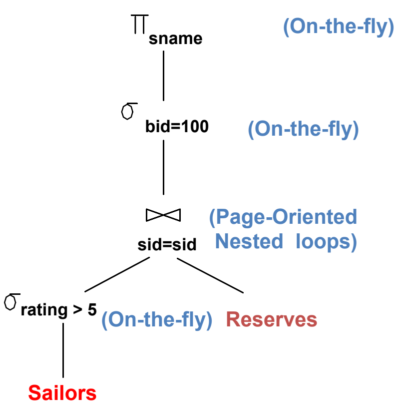


500,500 IOs
(previous slide)



250,500 IOs

Alternative Plans – Push SELECTs (No Indexes)



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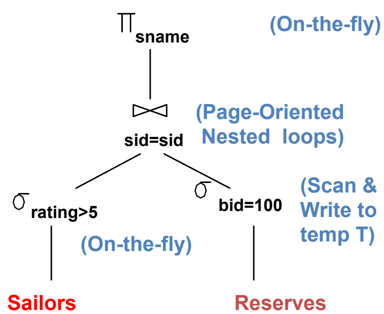
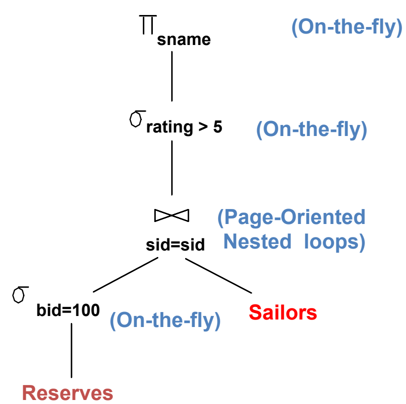
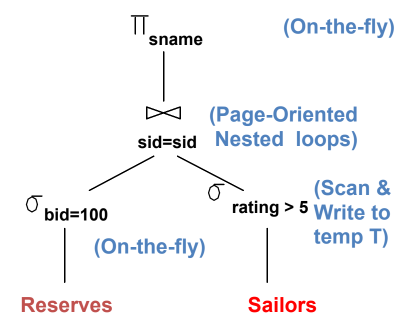


4010 IOs
500 + 1000 +10 +(250 *10)

Exercise 4-5: Estimate I/O cost

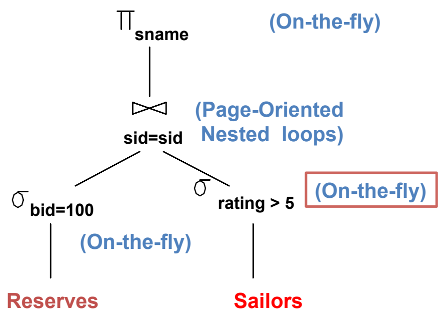


6000 IOs



4250 IOs
1000 + 500+ 250 + (10 * 250)

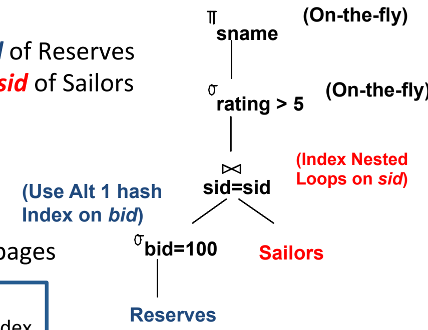
Exercise 5: Estimate I/O cost



6000 IOs
1000 + (10 * 500)

Alternative Plans: Indexes

- Suppose these indexes exist:
  - Clustered Alt 1 **hash index on *bid*** of Reserves
  - Unclustered Alt 2 **hash index on *sid*** of Sailors



- Accessing Reserves, *bid*=100:
  - Get 100,000/100 boats = 1000 records→ 1000/100=10 pages

Since using clustered index

- **Cost**: Selection on Reserves (10 I/Os); then, for each tuple, get **[one]** matching Sailors tuple: → 1000 tuples * (1.2+1)
  = **2210 I/Os**

Join column *sid* is a key for Sailors!

Query Blocks: Units of Optimization

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.age IN
   (SELECT  MAX (S2.age)
    FROM  Sailors S2
    GROUP BY  S2.rating)
```

Outer block

Nested block

- An SQL query is parsed into a set of *query blocks*, and these are optimized one block at a time
- Inner blocks are usually treated as *subroutines*
- Computed:
  - once per **query** (for uncorrelated sub-queries)
  - *or* once per **outer tuple** (for correlated sub-queries)

The System R aka "Selinger-style" Query Optimizer

- **Impact**:
  - Inspired most optimizers in use today
  - Works well for small-medium complexity queries (< 10 joins)
- **Cost estimation**:
  - Very inexact, but works ok in practice.
  - Statistics, maintained in system catalogs, used to estimate cost of operations and result sizes.
  - Considers a simple combination of CPU and I/O costs.
- **Plan Space**: Too large, must be pruned!

Pat Selinger: https://www-03.ibm.com/ibm/history/witexhibit/wit_fellows_selinger.html

Statistics and cardinality estimation

- ***Catalogs*** typically contain at least:
  - # tuples (NTuples) and # pages (NPages) per relation

  and for each index:

  - # distinct key values (Nkeys)
  - low/high key values (Low/High)
  - Index height (Height) for each tree index.
  - Index size (NPages) (e.g., # leaf pages for tree)
- Statistics in catalogs updated periodically.
  - Updating whenever data changes is too expensive; lots of approximation anyway, so slight inconsistency ok.

Size Estimation and Reduction Factors

- Consider a query block:

```
SELECT attribute list
FROM relation list
WHERE term1 AND ... AND termk
```

- ***Reduction factor (RF)*** associated with each ***term*** reflects the impact of the ***term*** in reducing result size
- *RF is also called "**selectivity**"*
- How to predict size of output?
  - Need to know/estimate input size
  - Need to know/estimate RFs
  - Need to know/assume how terms are related

Result Size Estimation for Selections

- Result cardinality (for conjunctive terms) =

  # input tuples * product of all RF's

Assumptions:

1. Values are uniformly distributed and *terms* are independent!
2. In System R, stats only tracked for **indexed** attributes (modern systems have removed this restriction)

Term	Reduction Factor
col = *value*	1 / Nkeys(I)
col > *value*	(High(I)-*value*) / (High(I)-Low(I))

Note: in System R, if missing indexes, assume RF = 1/10

Exercise 6

- RF = 16/40 * 1/10 = 1/25
  - Result size: 20 pages or 1600 tuples