Welcome to CS 186, Section 7!

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OH: Mondays 11-12pm and Thursdays 2:30-3:30pm (651 Soda)
DISC: Tuesdays 11-12am (136 Barrows) and Wednesdays 10-11am (130 Wheeler)

Announcements and Such

- **Mid-semester survey! Please fill it out!! (plz plz plz)**

- **Homework 4 out soon! (or it’s already out LOL)**

- **Midterm 2 on November 9th**

Discussion 6: Query Optimization

Overview:

1. Query Optimization
2. Worksheet walkthrough

(A majority of the slides are from Michelle and lecture!)

Query Optimization

Context and Problem

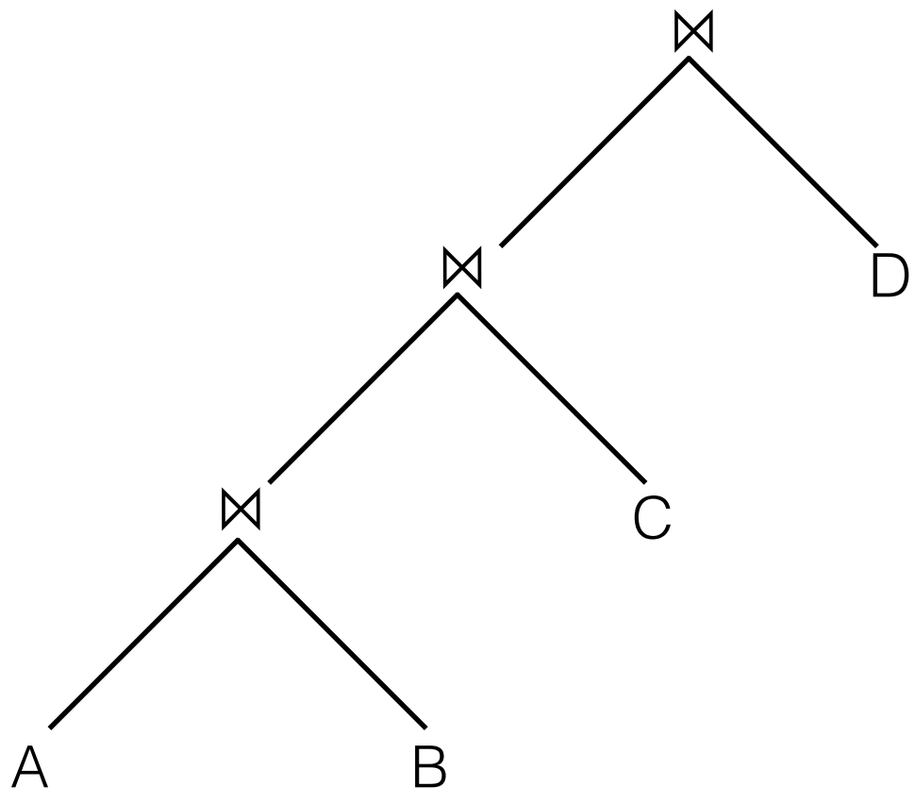
- We’re given a SQL query where we have to do more than 2 or 3 table joins (e.g. multiple equijoins)
- But in the end we really only want a small subset of that result, like A.name = “Bryan”
- This is a specific case, but I’m sure there are more types of queries out there that can be really optimized
- Is there anyway we can optimize this?

Solution: Query Optimization

- What is the best way to run a query?
- Change order and methods of operators for:
  - Faster queries, better resource utilization
  - Smaller # of total I/Os

Plan Space

- Based on relational equivalences
- Only consider left-deep join trees
  - Includes all join orders and join methods



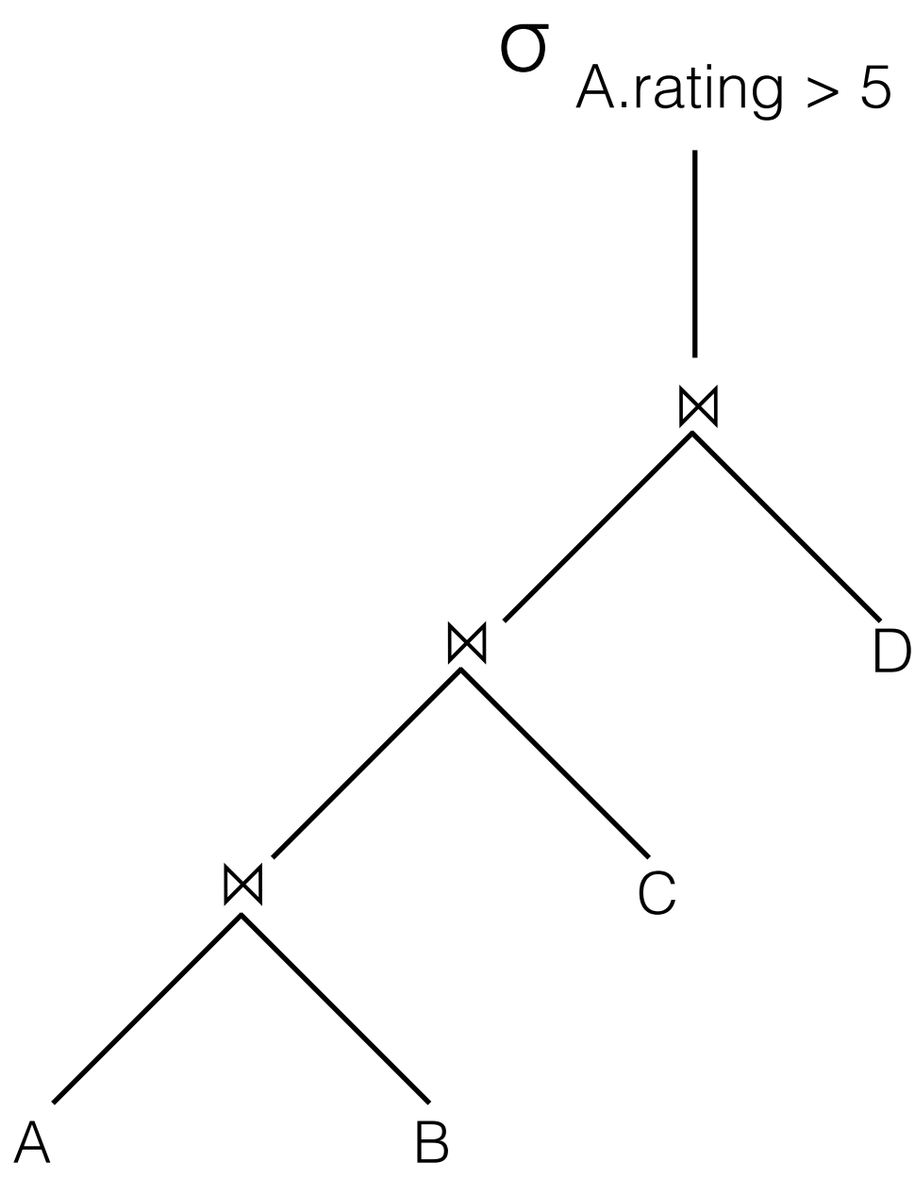
Determinants of Plan Cost

- Access method of base tables
  - Scan, index, range vs. lookup, clustered vs. unclustered
- Join ordering
  - Do we want to keep rereading a big table over and over again?
- Join method
  - Sort-merge? Hash? BNL?

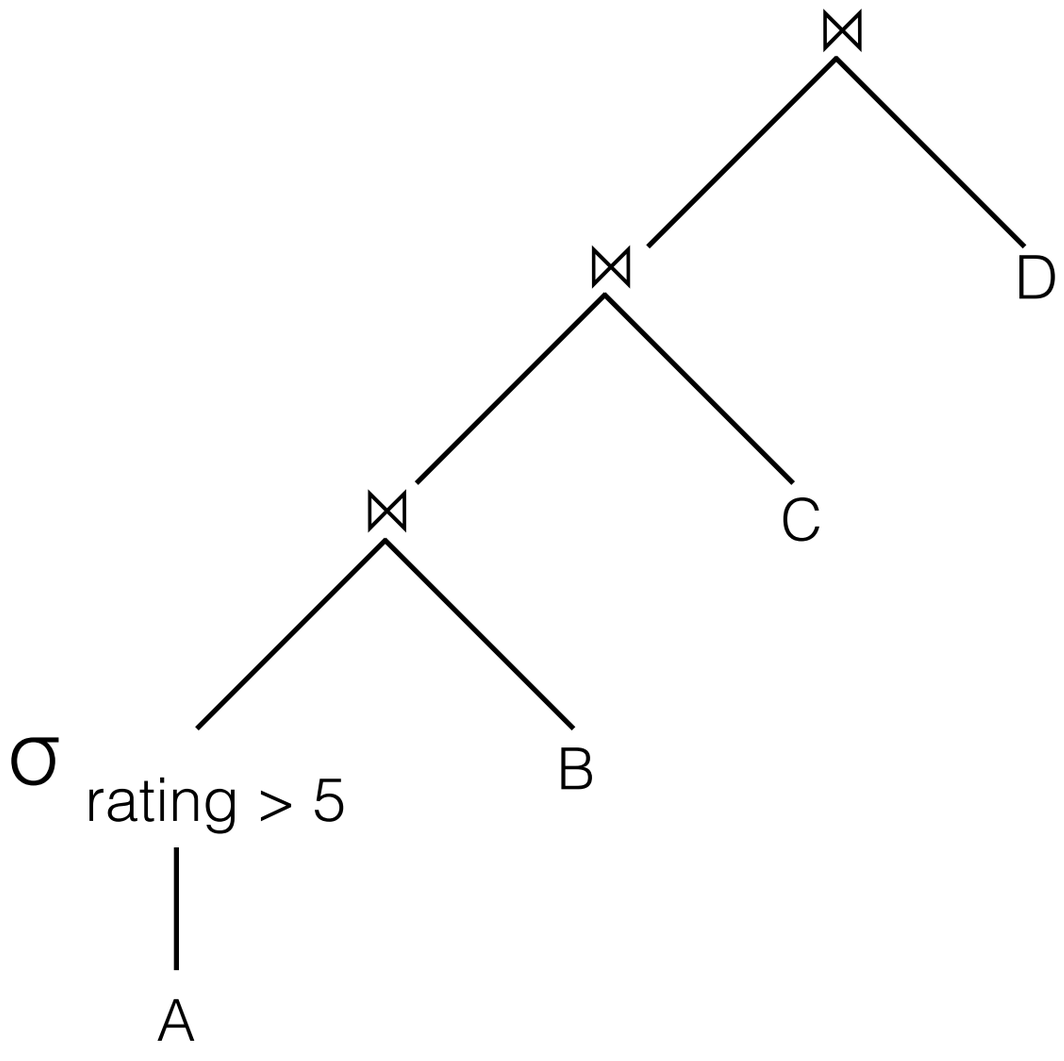
Cost Estimation

- Estimate cost of each operation in plan tree
- Must estimate size of result for each operation using info from system catalog
- For System R, cost: #I/Os + CPU-factor * #tuples
- **On-the-fly**: The result of one operator is pipelined to another operator without creating a temporary table to hold intermediate result (e.g. push select on the fly)

Push Select



Push Select



Selectivity

- Selectivity represents a predicate's impact on reducing result size
  - |output| / |input|
  - Tuples that contain rating 0 to 100:
    - $\sigma_{\text{rating} > 0}$ has large selectivity
    - $\sigma_{\text{rating} > 99}$ has smaller selectivity
- If missing info to estimate selectivity, assume 1/10!
- Selectivity also known as reduction factor (RF)

Selectivity

- Predicate col=value
  - Selectivity = 1/NKeys(col)
- Predicate col1=col2
  - Selectivity = 1/MAX(NKeys(col1), NKeys(col2))
- Predicate col>value
  - Selectivity= (High(col)-value)/(High(col)-Low(col) + 1)
- Assumes that values and uniformly distributed and independent!
- Result Cardinality: Max # tuples * product of all selectivities

```
Car(license, owner_ssn, year, company, model)
Accident(license, accident_date, damage_amount,
                        zipcode)
Owner(ssn, license, name, gender, street, city,
                        zipcode)
```

- For the query: “SELECT * FROM Accident A, Car C WHERE A.license = C.license AND A.damage_amount > X;” For what types of values of X would selection push-down significantly improve the cost of the query (Car is the inner table of the join)?”

```
Car(license, owner_ssn, year, company, model)
Accident(license, accident_date, damage_amount,
                        zipcode)
Owner(ssn, license, name, gender, street, city,
                        zipcode)
```

- For the query: “SELECT * FROM Accident A, Car C WHERE A.license = C.license AND A.damage_amount > X;” For what types of values of X would selection push-down significantly improve the cost of the query (Car is the inner table of the join)?”

- Selection push-down will help with very large values of X, since that would be more selective, and thus result in fewer resulting tuples for the rest of the plan.

```
Car(license, owner_ssn, year, company, model)
Accident(license, accident_date, damage_amount,
                        zipcode)
Owner(ssn, license, name, gender, street, city,
                        zipcode)
```

- For the query: "SELECT O.name FROM Car C, Owner O WHERE C.license = O.license AND C.company = 'Volvo';" What is the expected cardinality of the Car relation after the initial selections are applied (before the join)?

NTuples(Car) = 1000 ; NPages(Car) = 100
NTuples(Accident) = 500 ; NPages(Accident) = 20
NTuples(Owner) = 800 ; NPages(Owner) = 50
NDistinct(Car.company) = 50;

```
Car(license, owner_ssn, year, company, model)
Accident(license, accident_date, damage_amount,
                        zipcode)
Owner(ssn, license, name, gender, street, city,
                        zipcode)
```

- For the query: "SELECT O.name FROM Car C, Owner O WHERE C.license = O.license AND C.company = 'Volvo';" What is the expected cardinality of the Car relation after the initial selections are applied (before the join)?

- You can only push down the Car.company = 'Volvo' selection predicate. NDistinct(Car.company) = 50, so we can estimate Selectivity(Car.company) = 1/50. Cardinality(Car.company = 'Volvo') = Selectivity(Car.company) * NTuples(Car) = 1000 / 50 = 20

Another Example

Schema for Examples

Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: dates, *rname*: string)

As seen in previous lectures…

- **Reserves:**
  - Each tuple is 40 bytes long, 100 tuples per page, 1000 pages.
  - Assume there are 100 boats
- **Sailors:**
  - Each tuple is 50 bytes long, 80 tuples per page, 500 pages.
  - Assume there are 10 different ratings

- Assume we have 5 pages in our buffer pool!

Another Example

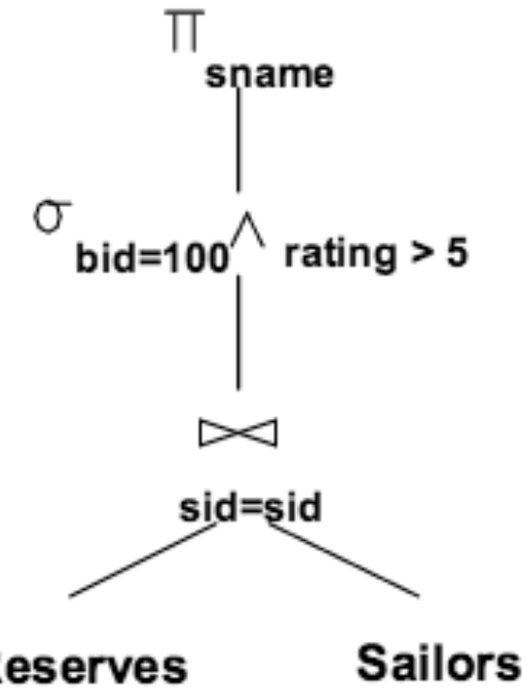
Query Optimization Overview

- Query can be converted to relational algebra
  - Relational algebra converts to a tree
- Each operator has implementation choices
- Operators can also be applied in different orders!

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

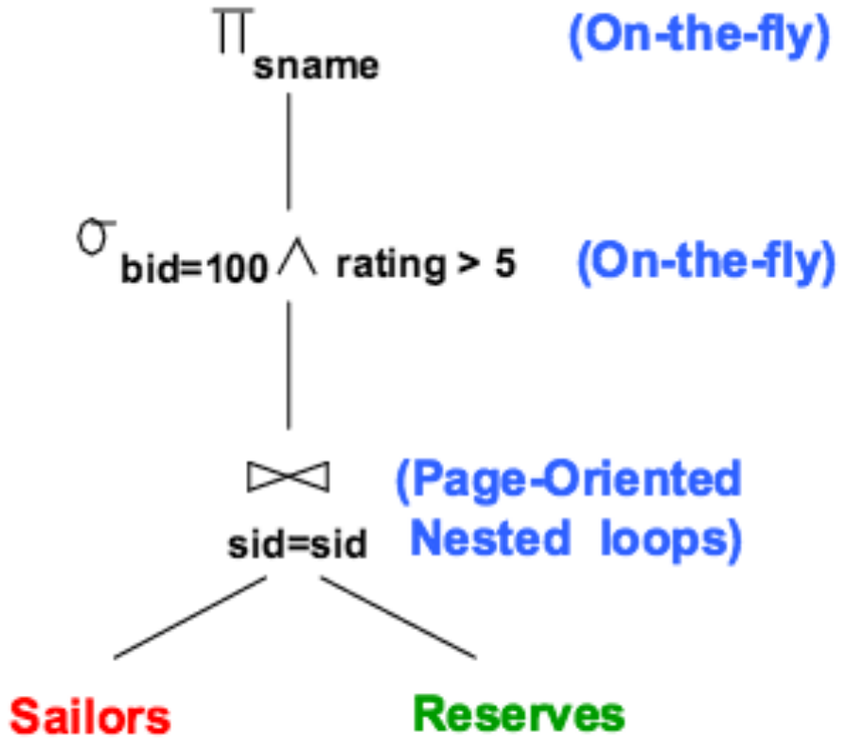
$\pi_{(sname)}\sigma_{(bid=100 \wedge rating > 5)}$

(Reserves ⋈ Sailors)

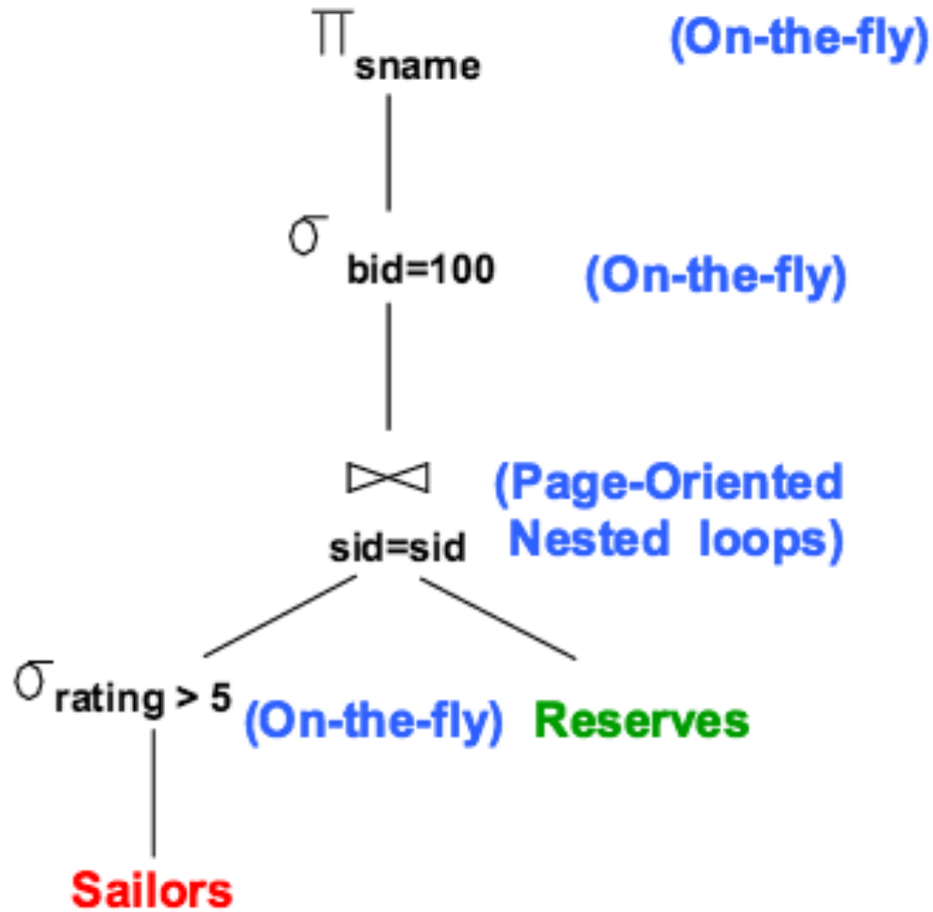


Another Example

Alternative Plans – Push Selects (No Indexes)



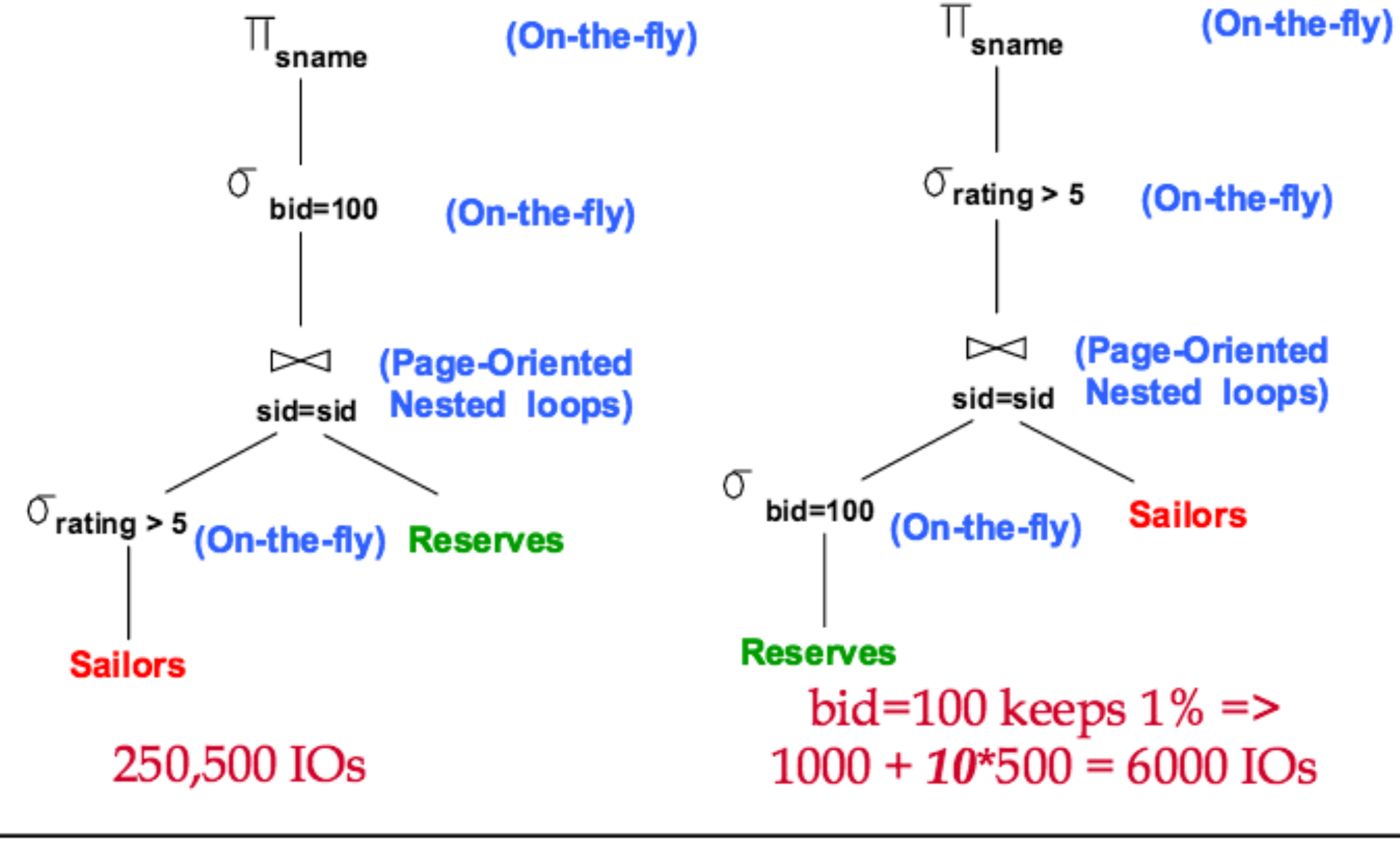
500,500 IOs



rating > 5 throws out half =>
250,500 IOs

Another Example

Alternative Plans – Push Selects (No Indexes)



Aside: Histograms

- Represent distribution of one or more attributes
- Better estimate of selectivity than assuming uniformity
  - Can be Gaussian (Normal), exponential, etc.
- Think of as lossy compression, more buckets, more accurate

System R (Selinger) Optimizer

1. Plan Space
    - only consider left-deep join trees
    - avoid cartesian products
    - push selects and joins
    - consider interesting orders
2. Cost estimation
    - use cost formulas and size estimations
    - Selectivity (reduction factor) estimation = |output| / |input|
3. Search Algorithm
    - dynamic programming, consider using AI

Interesting Orders

- Operator returns an “interesting order” if its result is in order of:
  - some *ORDER BY* attribute
    - means we don’t have to sort later!
  - some *GROUP BY* attribute
    - means we can use a nice scan method for our group-by later!
  - some Join attribute of other joins
    - Means we can use sort-merge far cheaper!

Search Algorithm

- Find the best 1-table access method.
- Given the best 1-table method as the outer, find the best 2-table.
- …
- Given the best (N-1)-table method as the outer, find the best N-table.
- ** Instead of “strictly the best” we return the best for each interesting order of the tuples.
- ** Do cross products last!

Example

```
Select S.sid, COUNT(*) AS number
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid
      AND B.color = “red”
GROUP BY S.sid
```

Sailors:

- Hash, B+ on sid

Reserves:

- Clustered B+ tree on bid
- B+ on sid

Boats

- B+ on color

Example

Find the best 1-table access method for each relation (only consider the predicates dealing with one table).

```
Select S.sid, COUNT(*) AS number
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid
      AND B.color = “red”
GROUP BY S.sid
```

Sailors:

- Hash, B+ on sid

Reserves:

- Clustered B+ tree on bid
- B+ on sid

Boats

- B+ on color

Example

Find the best 1-table access method for each relation.

- Sailors, Reserves: File Scan
  - (B+ tree on Reserves.bid as interesting order)
  - (B+ tree on Sailors.sid as interesting order)
- Boats: B+ tree on color

```
Select S.sid, COUNT(*) AS number
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid
      AND B.color = “red”
GROUP BY S.sid
```

Sailors:

Hash, B+ on sid

Reserves:

Clustered B+ tree on bid

B+ on sid

Boats

B+ on color

Example

Given the best 1-table method as the outer, find the best 2-table.

- Sailors, Reserves: File Scan
  - B+ tree on Reserves.bid as interesting order
  - B+ tree on Sailors.sid as interesting order
- Boats: B+ tree on color

Example

Given the best 1-table method as the outer, find the best 2-table.

- Sailors, Reserves: File Scan
  - B+ tree on Reserves.bid as interesting order
  - B+ tree on Sailors.sid as interesting order
- Boats: B+ tree on color

- File Scan Reserves (outer) with Boats (inner)
- File Scan Reserves (outer) with Sailors (inner)

Example

Given the best 1-table method as the outer, find the best 2-table.

- Sailors, Reserves: File Scan
  - B+ tree on Reserves.bid as interesting order
  - B+ tree on Sailors.sid as interesting order
- Boats: B+ tree on color

- Reserves Btree on bid (outer) with Boats (inner)
- Reserves Btree on bid (outer) with Sailors (inner)

Example

Given the best 1-table method as the outer, find the best 2-table.

- Sailors, Reserves: File Scan
  - B+ tree on Reserves.bid as interesting order
  - B+ tree on Sailors.sid as interesting order
- Boats: B+ tree on color

- File Scan Sailors (outer) with Boats (inner)
- File Scan Sailors (outer) with Reserves (inner)

Example

Given the best 1-table method as the outer, find the best 2-table.

- Sailors, Reserves: File Scan
  - B+ tree on Reserves.bid as interesting order
  - B+ tree on Sailors.sid as interesting order
- Boats: B+ tree on color

- B+ tree Sailors (outer) with Boats (inner)
- B+ tree Sailors (outer) with Reserves (inner)

Example

Given the best 1-table method as the outer, find the best 2-table.

- Sailors, Reserves: File Scan
  - B+ tree on Reserves.bid as interesting order
  - B+ tree on Sailors.sid as interesting order
- Boats: B+ tree on color
  - Boats Btree on color with Sailors (inner)
  - Boats Btree on color with Reserves (inner)

Example

Given the best 1-table method as the outer, find the best 2-table.

- File Scan Reserves (outer) with Boats (inner)
- File Scan Reserves (outer) with Sailors (inner)
- Reserves Btree on bid (outer) with Boats (inner)
- Reserves Btree on bid (outer) with Sailors (inner)
- File Scan Sailors (outer) with Boats (inner)
- File Scan Sailors (outer) with Reserves (inner)
- B+ tree Sailors (outer) with Boats (inner)
- B+ tree Sailors (outer) with Reserves (inner)
- Boats Btree on color with Sailors (inner)
- Boats Btree on color with Reserves (inner)

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

Remember that we're **estimating** the optimality our proposed optimization! This doesn't mean that the values we compute are exact!

Worksheet

What are the best single-table plans?

You should be calculating the number of I/Os it takes per access method you're given, corresponding to single table predicates in the query (like we did in the previous slides)

What are the best single-table plans?

- Kitties: B+ tree on cuteness
  - **File scan = 100**
    - **see note in discussion answers for food4thought!**
- Puppies: B+ tree on yappiness
  - File scan = 50
  - **B+ tree = (5+200)*1/10 = about 20**

- Humans: File Scan
  - **File scan = 1000**
  - B+ tree = (20 + 50,000)*1,200/50,000)

List the pairs of tables the optimizer will consider for 2-way joins

List the pairs of tables the optimizer will consider for 2-way joins

- Kitties[file scan] ⋈ Puppies
- Kitties[file scan] ⋈ Humans
- Puppies[unclustered B+] ⋈ Kitties
- Puppies[unclustered B+] ⋈ Humans
- Humans[file scan] ⋈ Kitties
- Humans[file scan] ⋈ Puppies

Which plans will be avoided?

- Kitties[file scan] ⋈ Puppies
- Kitties[file scan] ⋈ Humans
- Puppies[unclustered B+] ⋈ Kitties
- Puppies[unclustered B+] ⋈ Humans
- Humans[file scan] ⋈ Kitties
- Humans[file scan] ⋈ Puppies

Which plans will be avoided?

- Kitties[file scan] ⋈ Puppies
- ~~Kitties[file scan] x Humans~~

Humans and kitties don’t have a join predicate!

- Puppies[unclustered B+] ⋈ Kitties
- Puppies[unclustered B+] ⋈ Humans
- ~~Humans[file scan] x Kitties~~
- Humans[file scan] ⋈ Puppies

What would be the IO cost of doing index nested loops join using Puppies as the outer, with the optimal single table selection methods?

What would be the IO cost of doing index nested loops join using Puppies as the outer, with the optimal single table selection methods?

- Index scan: (5+200)*1/10 = ~21 I/Os to select puppies
- # selected puppies = 200 * 1/10 = 20
- 20*(5+400)*1/10 = 810 I/Os
- 21 + 810 = 831 I/Os

#tuples in puppies * index lookup on K.cuteness = P.yappiness

What would be the IO cost of doing index nested loops join using Kitties as the outer, with the optimal single table selection methods?

What would be the IO cost of doing index nested loops join using Kitties as the outer, with the optimal single table selection methods?

- (5+400)*1/10 = 41 I/Os to select kitties
- Clustered lookup for (owner = val and yappiness = 7)
  - (15+50)*(1/10)*(1/10) = 1 I/O — just an estimate!
- 41 + 40*1 = 81 I/Os