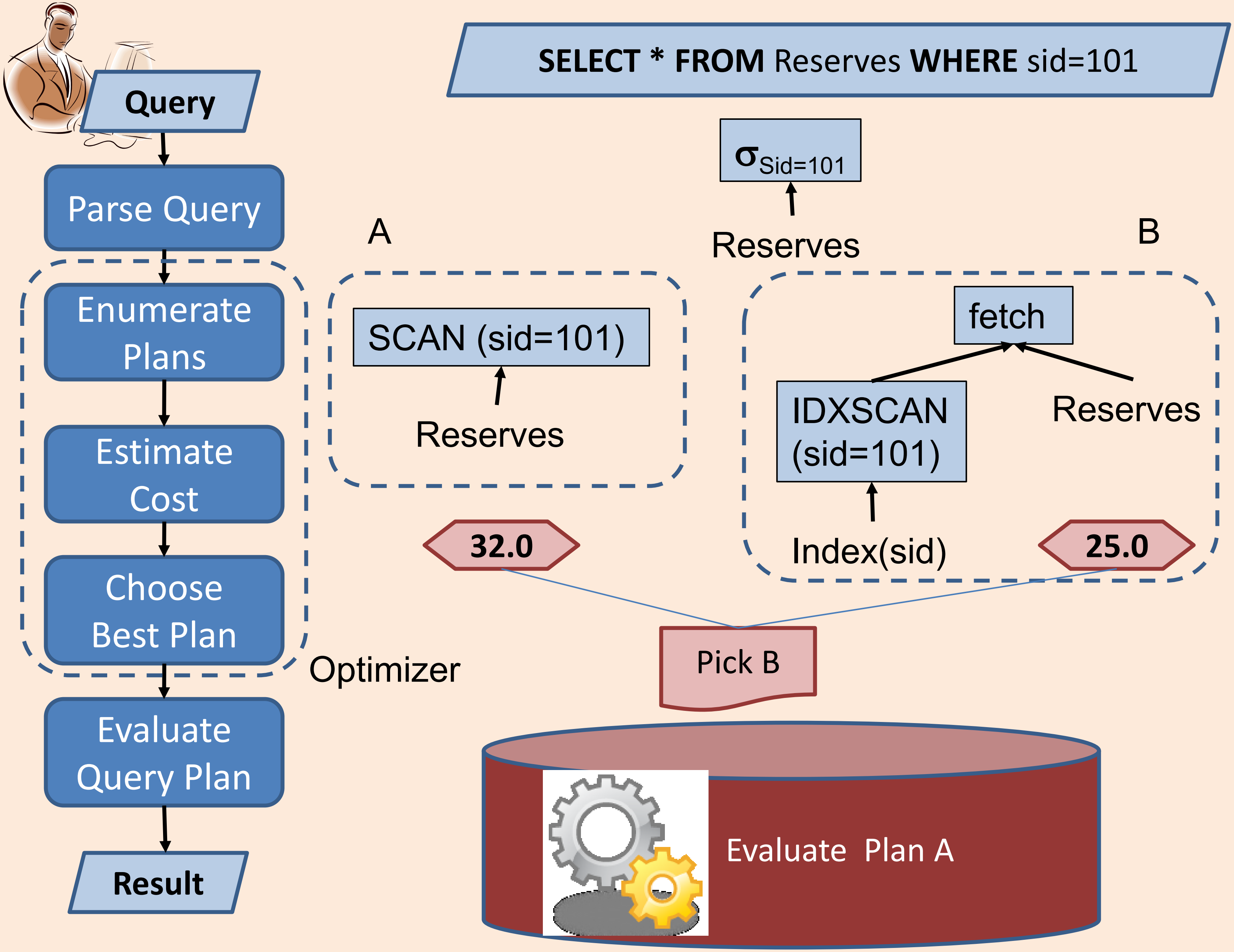
# ICS 321 Fall 2010

# Overview of Query Processing

Asst. Prof.  Lipyeow Lim
Information & Computer Science Department
University of Hawaii at Manoa



**Query**

Parse Query

Enumerate Plans

Estimate Cost

Choose Best Plan

Optimizer

Evaluate Query Plan

**Result**

**SELECT * FROM** Reserves **WHERE** sid=101

$\sigma_{Sid=101}$

Reserves

A

SCAN (sid=101)

Reserves

**32.0**

B

fetch

IDXSCAN (sid=101)

Reserves

Index(sid)

**25.0**

Pick B

Evaluate Plan A

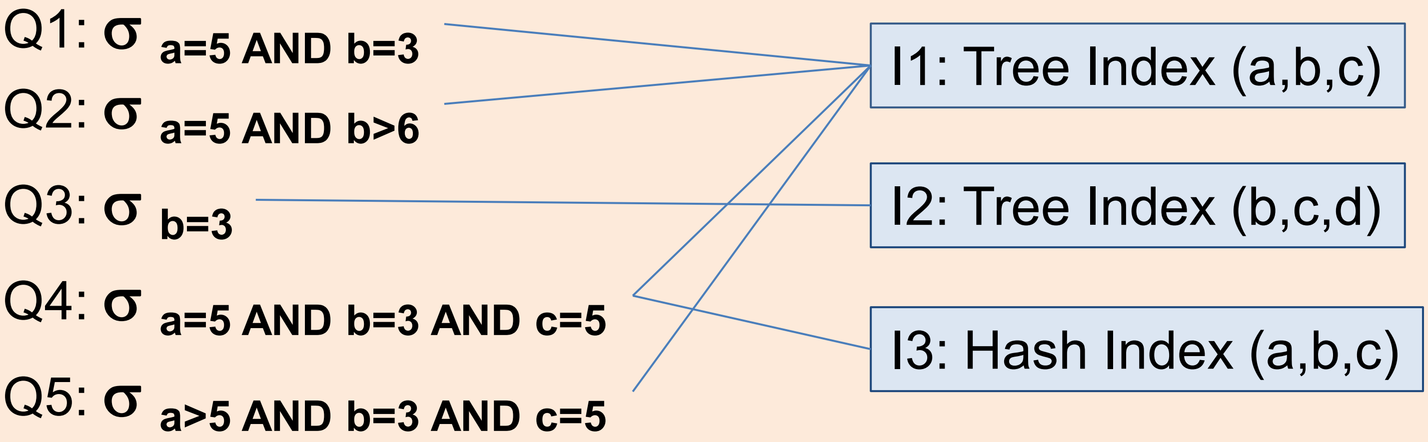
# Query Processing

- **Query Execution Plan** (QEP): tree of database operators.
  - At high-level, relational algebra operators are used
  - At low-level, RA operators with particular implementation algorithm.
- **Plan enumeration**: find equivalent plans
  - Different QEPs that return the same results
  - Query rewriting : transformation of one QEP to another equivalent QEP.
- **Cost estimation:** a mapping of a QEP to a cost
  - **Cost Model:** a model of what counts in the cost estimate. Eg. Disk accesses, CPU cost …
- **Query Optimizer:**
  - Explores the space of equivalent plan for a query
  - Chooses the best plan according to a cost model

# Access Paths

- An **access path** is a method of retrieving tuples. Eg. Given a query with a selection condition:
  - File or table scan
  - Index scan
- **Index matching problem:** given a selection condition, which indexes can be used for the selection, i.e., matches the selection ?
  - Selection condition normalized to conjunctive normal form (CNF), where each term is a *conjunct*
  - Eg. (day<8/9/94 **AND** rname='Paul') **OR** bid=5 **OR** sid=3
  - **CNF**: (day<8/9/94 **OR** bid=5 **OR** sid=3 ) AND (rname='Paul' **OR** bid=5 **OR** sid=3)

# Index Matching



Q1: $\sigma_{a=5 \text{ AND } b=3}$

Q2: $\sigma_{a=5 \text{ AND } b>6}$

Q3: $\sigma_{b=3}$

Q4: $\sigma_{a=5 \text{ AND } b=3 \text{ AND } c=5}$

Q5: $\sigma_{a>5 \text{ AND } b=3 \text{ AND } c=5}$

I1: Tree Index (a,b,c)

I2: Tree Index (b,c,d)

I3: Hash Index (a,b,c)

- A tree index matches a selection condition if the selection condition is a prefix of the index search key.
- A hash index matches a selection condition if the selection condition has a term *attribute=value* for every attribute in the index search key

# One Approach to Selections

1. Find the *most selective access path,* retrieve tuples using it
2. Apply remaining terms in selection not matched by the chosen access path

- The **selectivity** of an access path is the size of the result set (in terms of tuples or pages).
  - Sometimes selectivity is also used to mean **reduction factor:** fraction of tuples in a table retrieved by the access path or selection condition.
- Eg. Consider the selection:

  day<8/9/94 **AND** bid=5 **AND** sid=3
  - Tree Index(day)
  - Hash index (bid,sid)

# Query Execution Plans

- A tree of database operators: each operator is a RA operator with specific implementation
- Selection $\sigma$: Index Scan or Table Scan
- Projection $\pi$:
  - Without DISTINCT : Table Scan
  - With DISTINCT : requires sorting or index scan
- Join $\bowtie$ :
  - Nested loop joins (naïve)
  - Index nested loop joins
  - Sort merge joins

# Nested Loop Join

**S1**

| sid | sname | rating | age |
|---|---|---|---|
| 22 | Dustin | 7 | 45.0 |
| 31 | Lubber | 8 | 55.5 |
| 58 | Rusty | 10 | 35.0 |

$\bowtie$

**R1**

| sid | bid | day |
|---|---|---|
| 22 | 101 | 10/10/96 |
| 58 | 103 | 11/12/96 |

```
For each data page $P_{S1}$ of S1
  For each tuple s in $P_{S1}$
    For each data page $P_{R1}$ of R1
      For each tuple r in $P_{R1}$
        if (s.sid==r.sid)
        then output s,r
```

- Worst case number of disk reads

  = Npages(S1) + |S1|*Npages(R1)

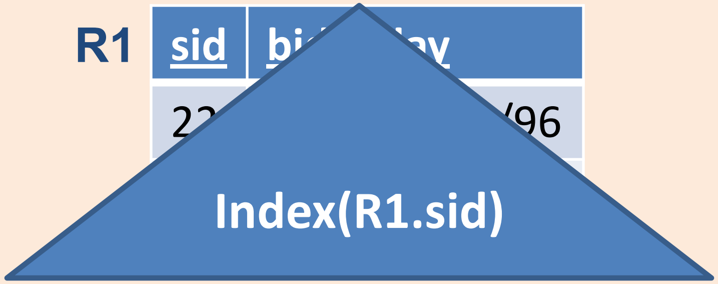
# Index Nested Loop Join

**S1**

| sid | sname | rating | age |
|---|---|---|---|
| 22 | Dustin | 7 | 45.0 |
| 31 | Lubber | 8 | 55.5 |
| 58 | Rusty | 10 | 35.0 |

$\bowtie$

**R1**



```
For each data page $P_{S1}$ of S1
    For each tuple s in $P_{S1}$
        if (s.sid ∈ Index(R1.sid))
        then fetch r & output <s,r>
```

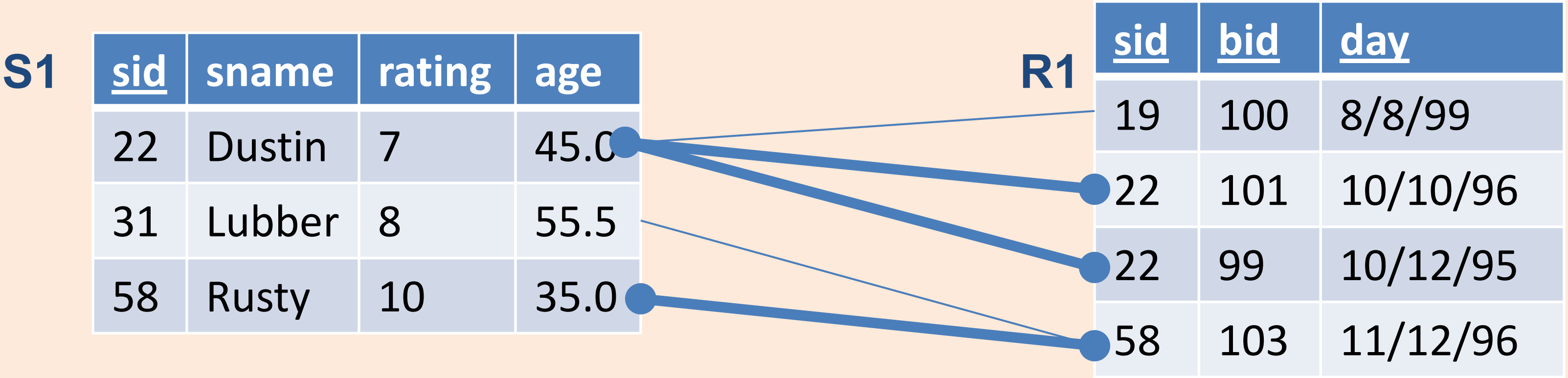
- Worst case number of disk reads with tree index

  $= \text{Npages}(S1) + |S1|*( 1 + \log_F \text{Npages}(R1))$

- Worst case number of disk reads with hash index

  $= \text{Npages}(S1) + |S1|*2$

# Sort Merge Join



**S1**

| sid | sname | rating | age |
|---|---|---|---|
| 22 | Dustin | 7 | 45.0 |
| 31 | Lubber | 8 | 55.5 |
| 58 | Rusty | 10 | 35.0 |

**R1**

| sid | bid | day |
|---|---|---|
| 19 | 100 | 8/8/99 |
| 22 | 101 | 10/10/96 |
| 22 | 99 | 10/12/95 |
| 58 | 103 | 11/12/96 |

1. `Sort S1 on SID`
2. `Sort R1 on SID`
3. `Compute join on SID using Merging algorithm`

- If join attributes are relatively unique, the number of disk pages

  = Npages(S1) log Npages(S1)

  + Npages(R1) log Npages(R1)

  + Npages(S1) + Npages(R1)

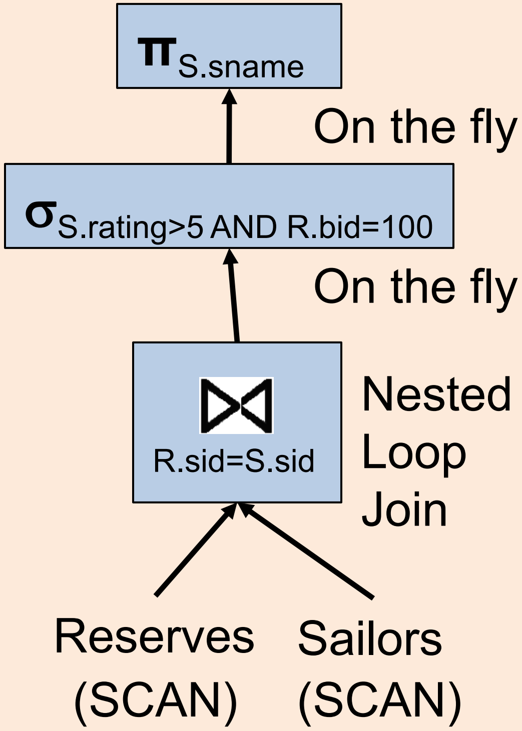
- What if the number of duplicates is large?
  - the number of disk pages approaches that of nested loop join.

# Example

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

| | | | |
|---|---|---|---|
| Reserves | 40 bytes/tuple | 100 tuples/page | 1000 pages |
| Sailors | 50 bytes/tuple | 80 tuples/page | 500 pages |

- Nested Loop Join cost 1K+ 100K*500
- On the fly selection and project does not incur any disk access.
- Total disk access = 500001K (worst case)



$\pi_{S.sname}$

On the fly

$\sigma_{S.rating>5 \text{ AND } R.bid=100}$

On the fly

$\bowtie_{R.sid=S.sid}$

Nested Loop Join

Reserves (SCAN)

Sailors (SCAN)

# Example: Predicate Pushdown

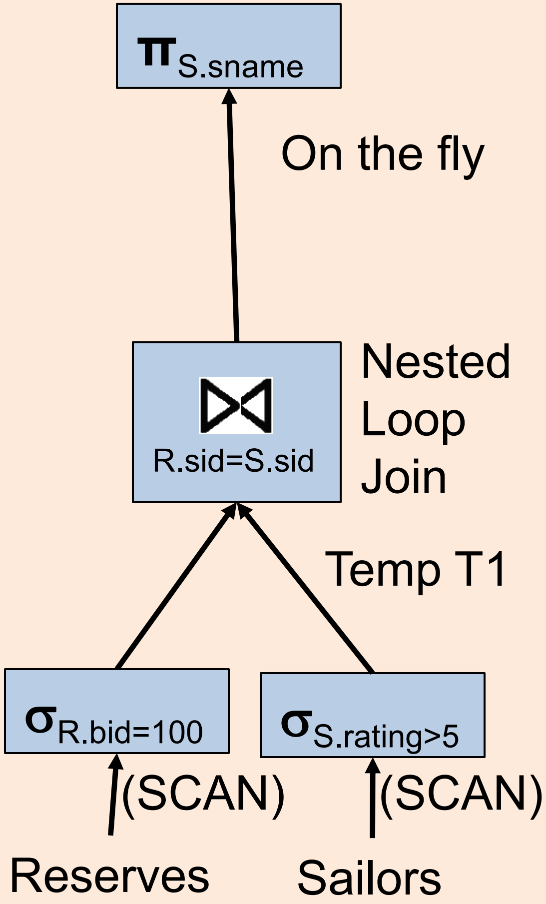
**SELECT** S.sname
**FROM** Reserves R, Sailors S
**WHERE** R.sid=S.sid **AND** R.bid=100 **AND** S.rating>5

**10%**

**50%**

| | | | |
|---|---|---|---|
| Reserves | 40 bytes/tuple | 100 tuples/page | 1000 pages |
| Sailors | 50 bytes/tuple | 80 tuples/page | 500 pages |

- Nested Loop Join requires materializing the inner table as T1.
- With 50% selectivity, T1 has 250 pages
- With 10% selectivity, outer “table” in join has 10K tuples
- Disk accesses for scans = 1000 + 500
- Writing T1 = 250
- NLJoin = 10K * 250
- Total disk access = 2500.175 K (worst case)



What happens if we make the left leg the inner table of the join ?

# Example: Sort Merge Join

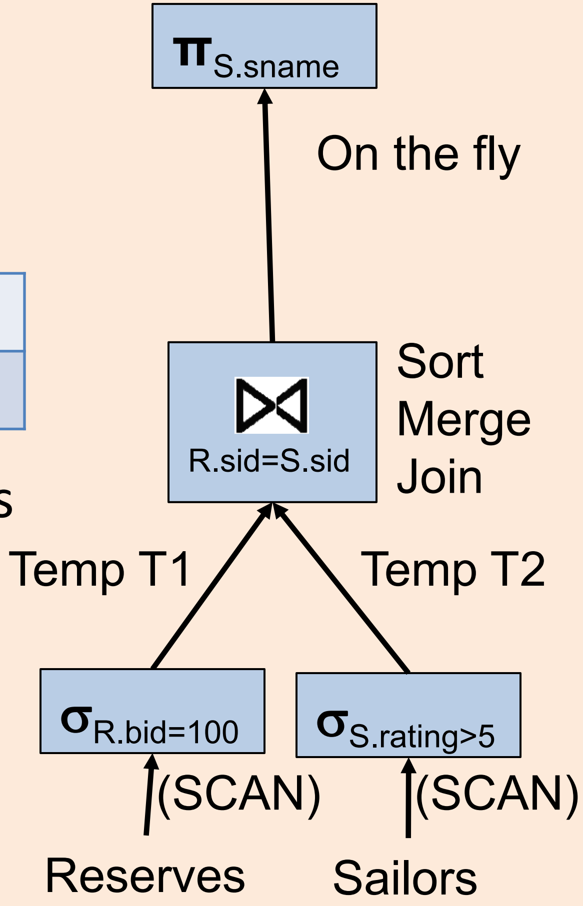
**SELECT** S.sname
**FROM** Reserves R, Sailors S
**WHERE** R.sid=S.sid **AND** R.bid=100 **AND** S.rating>5

**10%**

**50%**

| | | | |
|---|---|---|---|
| Reserves | 40 bytes/tuple | 100 tuples/page | 1000 pages |
| Sailors | 50 bytes/tuple | 80 tuples/page | 500 pages |

- Sort Merge Join requires materializing both legs for sorting.
- With 10% selectivity, T1 has 100 pages
- With 50% selectivity, T2 has 250 pages
- Disk accesses for scans = 1000 + 500
- Writing T1 & T2 = 100 + 250
- Sort Merge Join = 100 log 100 + 250 log 250 + 100+250 (assume 10 way merge sort)
- Total disk access = 52.8 K



$\pi_{S.sname}$

On the fly

$\bowtie$ R.sid=S.sid

Sort Merge Join

Temp T1

Temp T2

$\sigma_{R.bid=100}$

$\sigma_{S.rating>5}$

(SCAN)

(SCAN)

Reserves

Sailors

What happens if we make the left leg the inner table of the join ?

# Example: Index Nested Loop Join

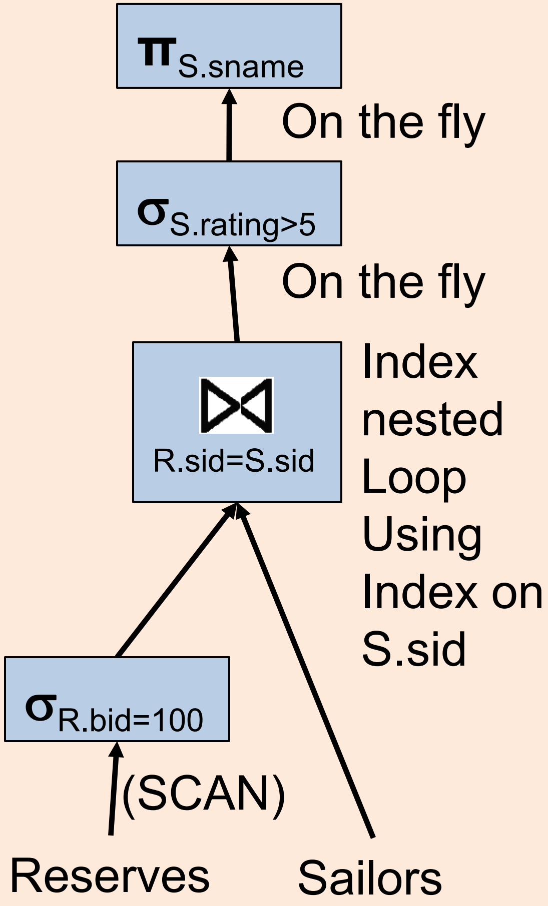
**SELECT** S.sname
**FROM** Reserves R, Sailors S
**WHERE** R.sid=S.sid **AND** R.bid=100 **AND** S.rating>5

**10%**

**50%**

| | | | |
|---|---|---|---|
| Reserves | 40 bytes/tuple | 100 tuples/page | 1000 pages |
| Sailors | 50 bytes/tuple | 80 tuples/page | 500 pages |

- With 10% selectivity, selection on R has 10K tuples
- Disk accesses for scan = 1000
- Index Nested Loop Join = 10K*( 1 + $\log_{10}$ 500) = 37K
- Total disk access = 38 K



$\pi_{S.sname}$

On the fly

$\sigma_{S.rating>5}$

On the fly

$\bowtie$ R.sid=S.sid

Index nested Loop Using Index on S.sid

$\sigma_{R.bid=100}$

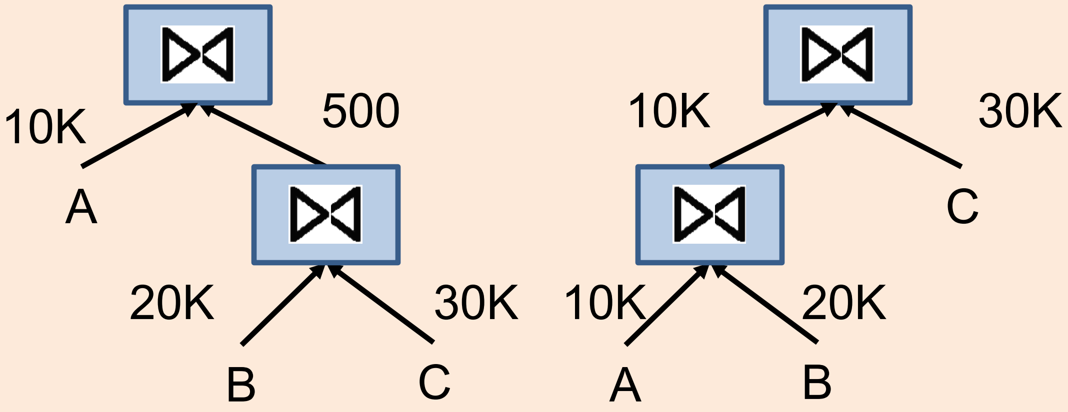
(SCAN)

Reserves

Sailors

What happens if we make the left leg the inner table of the join ?

# Join Ordering



| Relations | Tuples | Pages |
|---|---|---|
| A | 10K | 1000 |
| B | 20K | 2000 |
| C | 30K | 3000 |
| A join B | 10K | 1000 |
| B join C | 1K | 100 |

- Independent of what join algorithm is chosen, the order in which joins are perform affects the performance.
- Rule of thumb: do the most "selective" join first
- In practice, left deep trees (eg. the right one above) are preferred --- why ?

# Statistics & Cost Estimation

- Page size
- Data Statistics:
  - Record size -> number of records per data page
  - Cardinality of relations (including temporary tables)
  - Selectivity of selection operator on different columns of a relation
- (Tree) Index Statistics
  - number of leaf pages, index entries
  - Height
- Statistics collection is user triggered
  - DB2: RUNSTATS ON TABLE mytable AND INDEXES ALL