Fall 2013

# QUERY OPTIMIZATION
## [CH 15]

# Example

SELECT distinct ename FROM Emp E, Dept D
WHERE E.did = D.did and D.dname = 'Toy'

EMP (ssn, ename, addr, sal, did)

10, 000 employees
1,000 pages

DEPT (did, dname, floor, mgr)

500 departments
50 pages

Query: $\Pi_{ename}\ \sigma_{dname = \text{'Toy'}}$ (EMP $\bowtie$ DEPT)

$\rho$ ( R, $\Pi_{ename}$ T3)

$\rho$ ( T3, $\sigma_{dname=\text{'Toy'}}$ T2)

$\rho$ ( T2, $\sigma_{EMP.did=DEPT.did}$ T1)

$\rho$ ( T1, EMP X DEPT)

50 + 50,000 + 1,000, 000 writes
(5 tuples per page in T1)

# Example

EMP (ssn, ename, addr, sal, did)

10, 000 employees

1,000 pages

DEPT (did, dname, floor, mgr)

500 departments

50 pages

$\pi_{ename}$ $\rho\,(\,R,\ \Pi_{ename}\ T2)$

$\sigma_{dname=\text{'Toy'}}$ $\rho\,(\,T2,\ \sigma_{dname=\text{'Toy'}}\ T1)$

Page NL, write to T1

50 + 50,000 + 2000 writes

$\bowtie$ $\rho\,(\,T1,\ EMP \bowtie DEPT)$

**EMP** **DEPT**

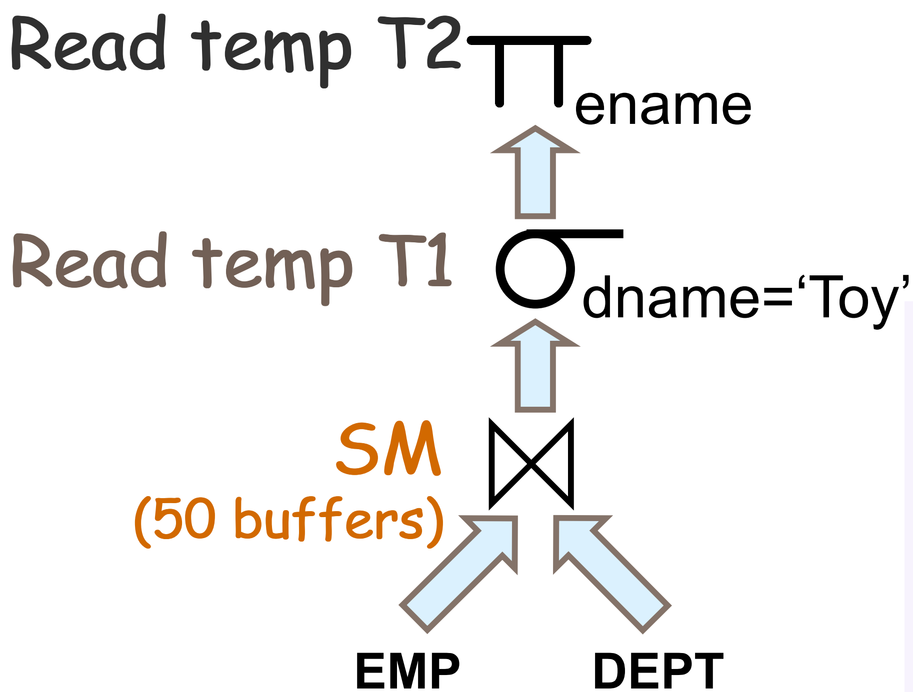
# Example

EMP (ssn, ename, addr, sal, did)

10, 000 employees
1,000 pages

DEPT (did, dname, floor, mgr)

500 departments
50 pages




Operator Interface:

- Open
- GetNext
- Close

Supports **both** paradigms

# Example

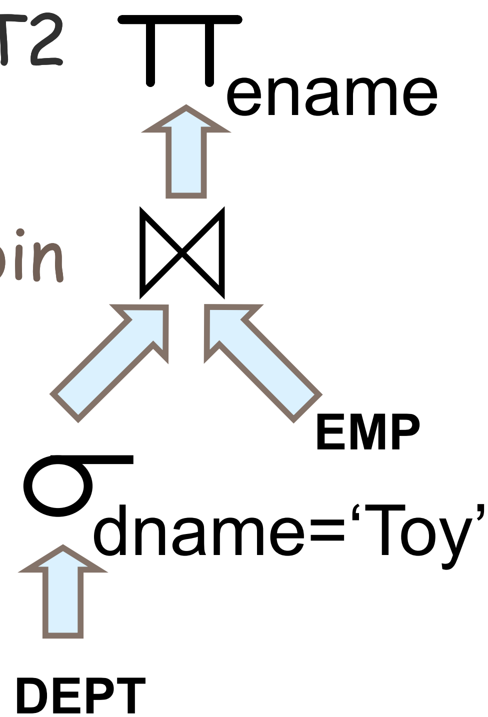
EMP (ssn, ename, addr, sal, did)
10, 000 employees
1,000 pages

DEPT (did, dname, floor, mgr)
500 departments
50 pages

Read temp T2

Read T1, NL-IDX Join

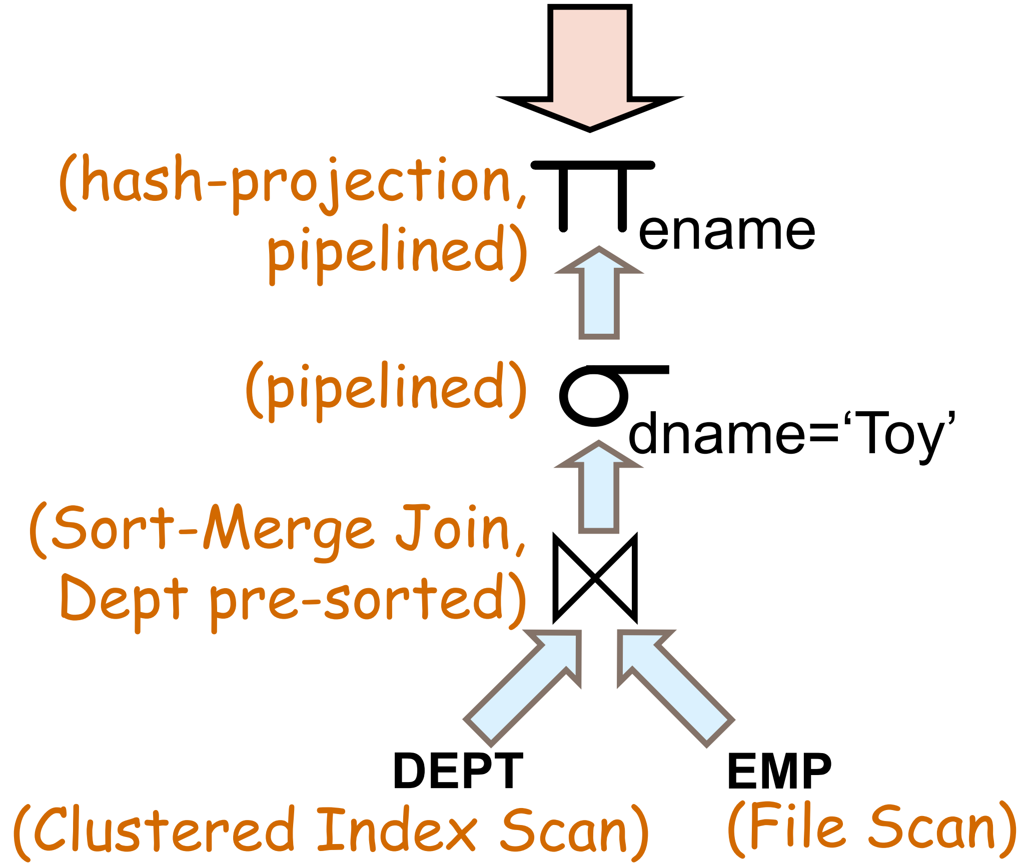
Index Select on name



# Query Optimization

Select distinct ename
from Emp E, Dept D
where E.did = D.did
and D.dname = 'Toy'

$$\Pi_{ename}\ \sigma_{dname = \text{'Toy'}}\ (EMP \bowtie DEPT)$$




***Annotated RA Tree***

1. Identify candidate equivalent trees
2. For each candidate find best annotated version
3. Choose the best overall

Practically: Choose from a **subset** of all possible plans

# Extended RA

$\text{HAVING}_{\text{MAX(SALARY)} > 2}( \ldots )$

$\text{GROUP BY}_{\text{D.did}} ( \ldots )$

SELECT E.did, Max (E.Salary)
FROM Emp E
WHERE addr LIKE '%Palo Alto%'
GROUP BY E.did
HAVING count(*) > 10

$\Pi_{\text{did, Max(salary)}}$
$\text{Having}_{\text{count(*)>10}}(\text{Group By}_{\text{did}} (\sigma_{\text{addr LIKE '...'}} \text{EMP}))$

Simplification: Only optimize the $\sigma$, $\Pi$, X

- Project Group By/Having attributes
- Choose from different aggregate algorithms

# Overview of Query Optimization

- *Plan*: *Annotated RA Tree*
  - Operator interface: Open/getNext/close
  - Pipelined or materialized
- Two main issues:
  - What plans are considered?
    - Algorithm to search plan space for cheapest (estimated) plan.
  - How is the cost of a plan estimated?
- Ideally: Want to find best plan.
- Practically: Avoid worst plans! Look at a subset of all plans

# Cost Estimation

- Estimate *cost* of each operation in plan tree.
  - Depends on input cardinalities.
  - Algorithm cost (see previous lectures)
- Estimate *size of result*
  - Use information about the input relations.
  - For selections and joins, assume independence of predicates.
- We'll discuss the System R cost estimation approach.
  - Very inexact, but works ok in practice.
  - More sophisticated techniques known now.

# Pricing Plans: Statistics

- Statistics stored in the catalogs
  - Relation
    - Cardinality
    - Size in pages
  - Index
    - Cardinality (# distinct keys)
    - Size in pages
    - Height
    - Range
- Catalogs update periodically
  - Can be slightly inconsistent
- Commercial systems use histograms
  - More accurate estimates

# Size Estimation and Reduction Factors

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

Question: What is the cardinality of the result set?

- Max # tuples: product of input relation cardinalities
- Each term “filters” out some tuples: *Reduction factor*
- *Result cardinality* = Max # tuples  *  product of all RF’s.
- **Assumption: *terms* are independent!**
- Term *col=value*  RF: 1/NKeys(I), given index I on col
- Term col1=col2  RF: 1/MAX(NKeys(I1), NKeys(I2))
- Term col>value  RF: (High(I)-value)/(High(I)-Low(I))

# Equivalence

- $\sigma_{P1}(\sigma_{P2}(R)) \equiv \sigma_{P2}(\sigma_{P1}(R))$ ($\sigma$ commutativity)
- $\sigma_{P1 \wedge P2 \ldots \wedge Pn}(R) \equiv \sigma_{P1}(\sigma_{P2}(\ldots \sigma_{Pn}(R)))$ (cascading $\sigma$)
- $\Pi_{a1}(R) \equiv \Pi_{a1}(\Pi_{a2}(\ldots\Pi_{ak}(R)\ldots))$, $a_i \subseteq a_{i+1}$ (cascading $\Pi$)
- $R \bowtie S \equiv S \bowtie R$ (commutativity)
- $R \bowtie (S \bowtie T) \equiv (R \bowtie S) \bowtie T$ (associativity)

- $\sigma_P(R \times S) \equiv (R \bowtie_P S)$ (if P is a join predicate)
- $\sigma_P(R \times S) \equiv \sigma_{P1}(\sigma_{P2}(R) \bowtie_{P4} \sigma_{P3}(S))$ $P=p1 \wedge p2 \wedge p3 \wedge p4$
- $\Pi_{A1,A2,\ldots An}(\sigma_P(R)) \equiv \Pi_{A1,A2,\ldots An}(\sigma_P(\Pi_{A1,\ldots An,\ B1,\ldots\ BM}R))$
  B1 … BM attributes in P

# System R Optimizer

- Most widely used currently; works well for < 10 joins
- Cost estimation: Approximate art at best.
  - Catalog statistics
    - cost of operation
    - result size
  - Combination of CPU and I/O costs.
- Plan Space:
  - Only *left-deep plans*
  - Avoid Cartesian products

# Query Blocks: Units of Optimization

- SQL query =>
  collection of *query blocks*
- Optimize one block at a time.
- Treat nested blocks as calls to a subroutine
  - Execute inner block once per outer tuple!
  - In reality more complex 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*

- For each block, consider the following plans:
  - All available access methods, for each relation in FROM clause.
  - All join permutations of left-deep join trees

# Plan Enumeration

- Two main cases:
  - Single-relation plans
  - Multiple-relation plans
- Single relation plan (no joins). Access Plans:
  - file scan
  - index scan(s): Clustered, Non-clustered
    - More than one index may "match" predicates
    - e.g. Clustered index I matching one or more selects:
      Cost: (NPages(I)+NPages(R)) * product of RF's of matching selects.
  - Choose the one with the least estimated cost.
  - Merge/pipeline selection and projection (and aggregate)
    - RID intersection techniques
    - Index aggregate evaluation

# Example

```
SELECT  E.ename
FROM    Emp E
WHERE   E.did=8
AND     E.sal > 40K
```

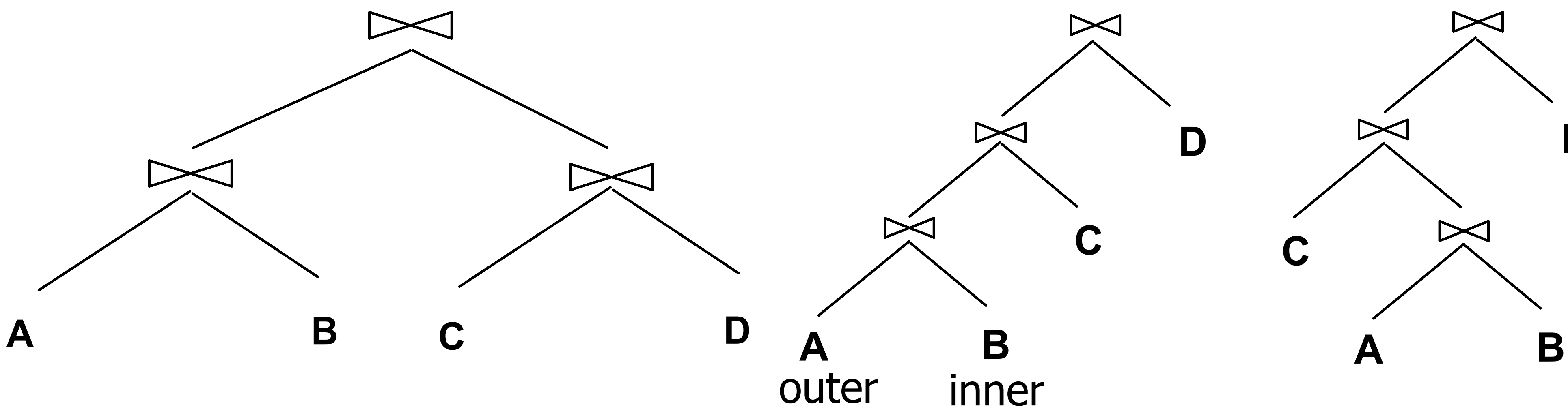
1,000 data pages, 10K tuples
100 pages in B+-tree
# depts: 10
Salary Range: 10K – 200K

EMP (ssn, ename, addr, sal, did)

- Index on did:
  - Tuples Retrieved: (1/10) * 10,000
  - Clustered index: (1/10) * (100+1,000) pages
  - Unclustered index: (1/10) * (100+10,000) pages
- Index on sal:
  - Clustered index: (200-40)/(200-10) * (100+1,000) pages
  - Unclustered index: …
- File scan: 1,000 pages

# Queries Over Multiple Relations

- System R: Only consider left-deep join trees
  - Used to restrict the search space
  - Left-deep plans can be *fully pipelined* plans.
    - Intermediate results not written to temporary files.
    - Not all left-deep trees are fully pipelined (e.g., SM join).




Linear Tree: at least 1 child in every join node is a base relation

# Enumeration of Left-Deep Plans

- Decide:
  - Join order
  - Join method for each join
- Enumerated using N passes (if N relations joined):
  - Pass 1: Find best 1-relation plan for each relation.
  - Pass 2: Find best way to join result of each 1-relation plan (as outer) to another relation. *(All 2-relation plans.)*
  - Pass N: Find best way to join result of a (N-1)-relation plan (as outer) to the N'th relation. *(All N-relation plans.)*
- For each subset of relations, retain only:
  - Cheapest plan overall, plus
  - Cheapest plan for each *interesting order* of the tuples.

$$\Pi_{ename}\ \sigma_{dname = \text{'Toy'}}\ (EMP \bowtie DEPT)$$

EMP (**ssn**, ename, addr, sal, did) DEPT (**did**, dname, floor, mgr)

Pass 1: EMP: E1: S(EMP), E2: I (EMP.did)

*Cost:*

DEPT: D1: S(DEPT), D2: I.(DEPT.did), D3: I(DEPT.dname)

*Cost:*

Pass 2: Consider EMP ⋈ DEPT and DEPT ⋈ EMP

EMP ⋈ DEPT, Alternatives:

1. E1 ⋈ D2: Algorithms …
2. E1 ⋈ D3: Algorithms …
3. E2 ⋈ D2: Algorithms SM, NL, BNL, NL-IDX, Hash
4. E2 ⋈ D3: Algorithms

Similarly consider DEPT ⋈ EMP

Pick cheapest 2-relation plan. Done (with join optimization)

**Next Consider GROUP BY (if present) …**

# Enumeration of Plans (Contd.)

- ORDER BY, GROUP BY handled as a final step,
- Only "join" relations if there is a connecting join condition i.e., avoid Cartesian products if possible.
- This approach is still exponential in the # of tables.

# Summary

- Query optimization critical to the DBMS performance
  - Helps understand performance impact of database design
- Two parts to optimizing a query:
  - Enumerate alternative plans. Typically, only consider left-deep plans
  - Estimate cost of each plan: size of result and cost of algorithm
    - *Key issues*: Statistics, indexes, operator implementations.
- Single-relation queries: Pick cheapest access plan + interesting order
- Multiple-relation queries:
  - All single-relation plans are first enumerated. Selections/projections considered as early as possible.
  - For each 1-relation plan, consider all ways of joining another relation (as inner)
  - Keep adding 1-relation plan until done
  - At each level, retain cheapest plan, and best plan for each interesting order