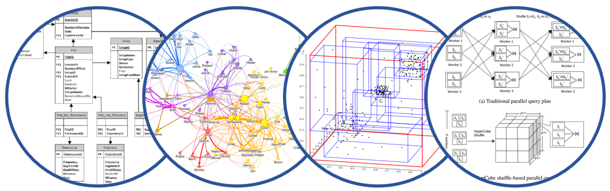

Database System Internals

Query Optimization (part 3)

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Selinger Optimizer History

- 1960's: first database systems
  - Use tree and graph data models
- 1970: Ted Codd proposes relational model
  - E.F. Codd. A relational model of data for large shared data banks. Communications of the ACM, 1970
- 1974: System R from IBM Research
  - One of first systems to implement relational model
- 1979: Seminal query optimizer paper by P. Selinger et. al.
  - Invented cost-based query optimization
  - Dynamic programming algorithm for join order computation

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References

- P. Selinger, M. Astrahan, D. Chamberlin, R. Lorie, and T. Price. Access Path Selection in a Relational Database Management System. Proceedings of ACM SIGMOD, **1979**. Pages 22-34.

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Selinger Algorithm

Selinger enumeration algorithm considers

- Different logical and physical plans *at the same time*
- Cost of a plan is IO + CPU
- Concept of *interesting order* during plan enumeration
  - A sorted order as that requested by ORDER BY or GROUP GY
  - Or order on attributes that appear in equi-join predicates
    - Because they may enable cheaper sort-merge joins later

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More about the Selinger Algorithm

- Step 1: Enumerate all access paths for a single relation
  - File scan or index scan
  - Keep the cheapest for each *interesting order*
- Step 2: Consider all ways to join two relations
  - Use result from step 1 as the outer relation
  - Consider every other possible relation as inner relation
  - Estimate cost when using sort-merge or nested-loop join
  - Keep the cheapest for each *interesting order*
- Steps 3 and later: Repeat for three relations, etc.

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Example From Selinger Paper

EMP

NAME	DNO	JOB	SAL
SMITH	50	12	8500
JONES	50	5	15000
DOE	51	5	9500

DEPT

DNO	DNAME	LOC
50	MFG	DENVER
51	BILLING	BOULDER
52	SHIPPING	DENVER

JOB

JOB	TITLE
5	CLERK
6	TYPIST
8	SALES
12	MECHANIC

```
SELECT   NAME,TITLE,SAL,DNAME
FROM     EMP,DEPT,JOB
WHERE    TITLE='CLERK'
AND      LOC='DENVER'
AND      EMP.DNO=DEPT.DNO
AND      EMP.JOB=JOB.JOB
```

"Retrieve the name, salary, job title, and department name of employees who are clerks and work for departments in Denver."

Figure 1. JOIN example

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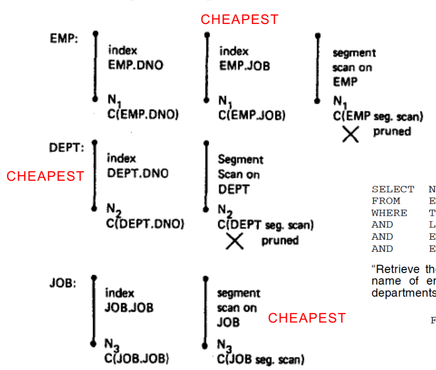
Step1: Access Path Selection for Single Relations

- Eligible Predicates: Local Predicates Only
- "Interesting" Orderings: DNO, JOB




```
SELECT   NAME,TITLE,SAL,DNAME
FROM     EMP,DEPT,JOB
WHERE    TITLE='CLERK'
AND      LOC='DENVER'
AND      EMP.DNO=DEPT.DNO
AND      EMP.JOB=JOB.JOB
```

"Retrieve the name, salary, job title, and department name of employees who are clerks and work for departments in Denver."

Figure 1. JOIN example

SELECT NAME, TITLE, SAL, DNAME
FROM EMP, DEPT, JOB
WHERE TITLE='CLERK' AND LOC='DENVER' AND EMP.DNO=DEPT.DNO AND EMP.JOB=JOB.JOB

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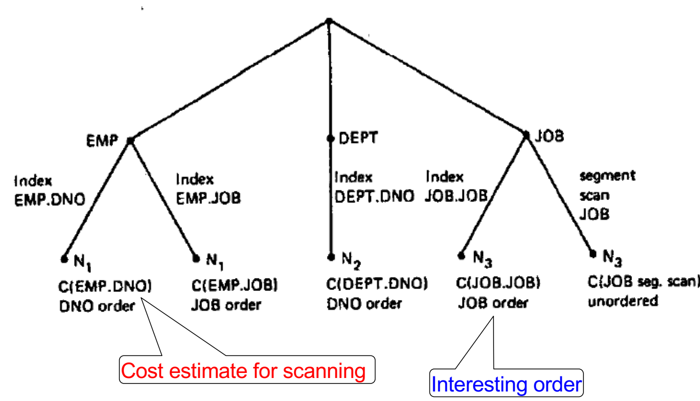
Step1: Resulting Plan Search Tree for Single Relations



SELECT NAME, TITLE, SAL, DNAME
FROM EMP, DEPT, JOB
WHERE TITLE='CLERK' AND LOC='DENVER' AND EMP.DNO=DEPT.DNO AND EMP.JOB=JOB.JOB

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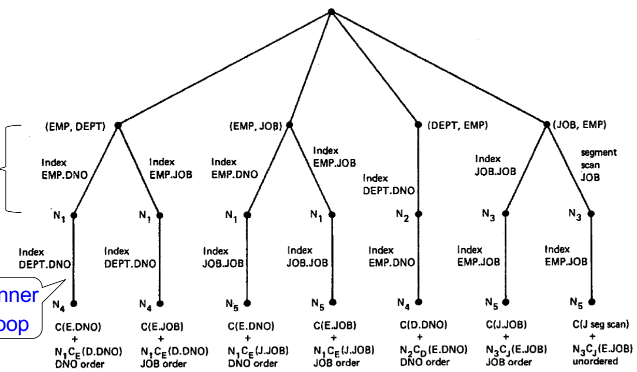
Step2: Pairs of Relations (nested loop joins)

From step 1

Add as inner nested loop



SELECT NAME, TITLE, SAL, DNAME
FROM EMP, DEPT, JOB
WHERE TITLE='CLERK' AND LOC='DENVER' AND EMP.DNO=DEPT.DNO AND EMP.JOB=JOB.JOB

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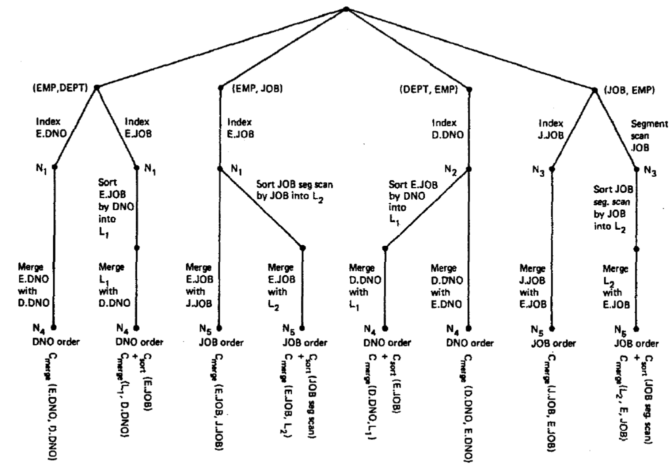
Step2: Pairs of Relations (sort-merge joins)



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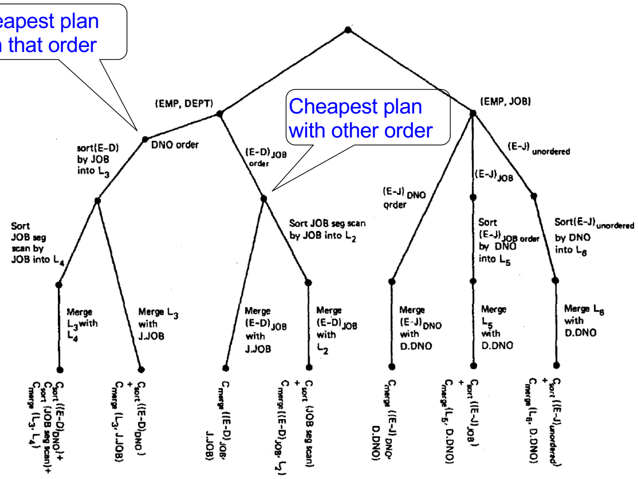
Step3:Add Third Relation (sort-merge join)

Cheapest plan with that order

Cheapest plan with other order



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Selinger Optimizer

Problem:

- How to order a series of joins over N tables A,B,C,…
  E.g. A.a = B.b AND A.c = D.d AND B.e = C.f
- N! ways to order joins; e.g. ABCD, ACBD, ….
- $C_{N-1} = \frac{1}{N}\binom{2(N-1)}{N-1}$ plans/ordering; e.g. (((AB)C)D),((AB)(CD)))
- Multiple implementations (hash, nested loops)
- Naïve approach does not scale
  - E.g. N = 20, #join orders 20! = 2.4 x 10^{18}; many more plans

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Selinger Optimizer

- Only left-deep plan: (((AB)C)D) – eliminate C_{N-1}.
  - In SimpleDB, we consider all linear plans, not only left-deep.
- Push down selections
- Don't consider cartesian products
- Dynamic programming algorithm

Next Example Acks

Implement variant of Selinger optimizer in SimpleDB

Designed to help you understand how this would work in SimpleDB

Many following slides from Sam Madden at MIT

SimpleDBs Optimizer

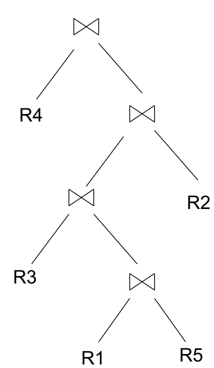
Exists within JoinOptimizer.java

In all the beginning labs, there is no optimization!

The relevant parts of JoinOptimizer are empty

One major difference in SimpleDB compared to Selinger optimizer:

We consider **linear trees**, not left-deep only



Dynamic Programming

OrderJoins(…):
R = set of relations to join
For d = 1 to N: /* where N = |R| */
For S in {all size-d subsets of R}:
optjoin(S) = (S – a) join a,
where a is the single relation that minimizes:
cost(optjoin(S – a)) +
min.cost to join (S – a) with a +
min.access cost for a

SimpleDB Lab5: you implement orderJoins

Use: enumerateSubsets

Use: computeCostAndCardOfSubplan

Note: optjoin(S-a) is cached from previous iterations

Example

- **orderJoins(A, B, C, D)**
- Assume all joins are Nested Loop

Subplan S	optJoin(S)	Cost(OptJoin(S))
A		

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Example

- **orderJoins(A, B, C, D)**
- Assume all joins are NL

- d = 1
  - A = best way to access A (sequential scan, predicate-pushdown on index, etc)
  - B = best way to access B
  - C = best way to access C
  - D = best way to access D

- Total number of steps: **choose(N, 1)**

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
C	Seq scan	120
D	B+tree scan	400

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Example

- **orderJoins(A, B, C, D)**

- d = 2
  - {A,B} = AB or BA use previously computed best way to access A and B

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
…		

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Example

- **orderJoins(A, B, C, D)**

- d = 2
  - {A,B} = AB or BA use previously computed best way to access A and B

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
…		
{A, B}	BA	156

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Example

- **orderJoins(A, B, C, D)**
- d = 2
  - {A,B} = AB or BA
    use previously computed
    best way to access A and B
  - {B,C} = BC or CB

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
…		
{A, B}	BA	156
{B, C}	BC	98

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Example

- **orderJoins(A, B, C, D)**
- d = 2
  - {A,B} = AB or BA
    use previously computed
    best way to access A and B
  - {B,C} = BC or CB

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
…		
{A, B}	BA	156
{B, C}	BC	98

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Example

- **orderJoins(A, B, C, D)**
- d = 2
  - {A,B} = AB or BA
    use previously computed
    best way to access A and B
  - {B,C} = BC or CB
  - {C,D} = CD or DC
  - {A,C} = AC or CA
  - {B,D} = BD or DB
  - {A,D} = AD or DA

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
…		
{A, B}	BA	156
{B, C}	BC	98
……..		

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Example

- **orderJoins(A, B, C, D)**
- d = 2
  - {A,B} = AB or BA
    use previously computed
    best way to access A and B
  - {B,C} = BC or CB
  - {C,D} = CD or DC
  - {A,C} = AC or CA
  - {B,D} = BD or DB
  - {A,D} = AD or DA
- Total number of steps: choose(N, 2) × 2

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
…		
{A, B}	BA	156
{B, C}	BC	98
……..		

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Example

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
….		
{A, B}	BA	156
{B, C}	BC	98
….		
{A, B, C}	BAC	500
……..		

- **orderJoins(A, B, C, D)**
- d = 3
  - {A,B,C} =
    Remove A: compare A({B,C}) to ({B,C})A

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Example

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
….		
{A, B}	BA	156
{B, C}	BC	98
….		
{A, B, C}	BAC	500
……..		

- **orderJoins(A, B, C, D)**
- d = 3
  - {A,B,C} =
    Remove A: compare A({B,C}) to ({B,C})A

optJoin(B,C) and its cost are already cached in table

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Example

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
….		
{A, B}	BA	156
{B, C}	BC	98
….		
{A, B, C}	BAC	500
……..		

- **orderJoins(A, B, C, D)**
- d = 3
  - {A,B,C} =
    Remove A: compare A({B,C}) to ({B,C})A
    Remove B: compare B({A,C}) to ({A,C})B
    Remove C: compare C({A,B}) to ({A,B})C

optJoin(B,C) and its cost are already cached in table

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Example

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
….		
{A, B}	BA	156
{B, C}	BC	98
….		
{A, B, C}	BAC	500
……..		

- **orderJoins(A, B, C, D)**
- d = 3
  - {A,B,C} =
    Remove A: compare A({B,C}) to ({B,C})A
    Remove B: compare B({A,C}) to ({A,C})B
    Remove C: compare C({A,B}) to ({A,B})C

optJoin(B,C) and its cost are already cached in table

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Example

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
….		
{A, B}	BA	156
{B, C}	BC	98
….		
{A, B, C}	BAC	500
……..		

- **orderJoins(A, B, C, D)**
- d = 3
  - {A,B,C} =
    Remove A: compare A({B,C}) to ({B,C})A
    Remove B: compare B({A,C}) to ({A,C})B
    Remove C: compare C({A,B}) to ({A,B})C
  - {A,B,D} =
    Remove A: compare A({B,D}) to ({B,D})A
    …
  - {A,C,D} =…
  - {B,C,D} =…
- Total number of steps: choose(N, 3) × 3 × 2

optJoin(B,C) and its cost are already cached in table

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Example

Subplan S	optJoin(S)	Cost(OptJoin(S))
A	Index scan	100
B	Seq. scan	50
{A, B}	BA	156
{B, C}	BC	98
{A, B, C}	BAC	500
{B, C, D}	DBC	150
……..		

- **orderJoins(A, B, C, D)**
- d = 4
  - {A,B,C,D} =

    Remove A: compare A({B,C,D}) to ({B,C,D})A
    Remove B: compare B({A,C,D}) to ({A,C,D})B
    Remove C: compare C({A,B,D}) to ({A,B,D})C
    Remove D: compare D({A,B,C}) to ({A,B,C})D
- Total number of steps: choose(N, 4) × 4 × 2

optJoin(B, C, D) and its cost are already cached in table

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Interesting Orders

- Some query plans produce data in sorted order
  - E.g scan over a primary index, merge-join
  - Called *interesting order*
- Next operator may use this order
  - E.g. can be another merge-join
- For each subset of relations, compute multiple optimal plans, one for each interesting order
- Increases complexity by factor k+1, where k=number of interesting orders

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Why Left-Deep

Asymmetric, cost depends on the order

- Left: Outer relation Right: Inner relation
- For nested-loop-join, we try to load the outer (typically smaller) relation in memory, then read the inner relation one page at a time
  B(R) + B(R)*B(S) or B(R) + B(R)/M * B(S)
- For index-join,
  we assume right (inner) relation has index

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Why Left-Deep

- Advantages of left-deep trees?
  1. Fits well with standard join algorithms (nested loop, one-pass), more efficient
  2. One pass join: Uses smaller memory
     1. ((R, S), T), can reuse the space for R while joining (R, S) with T
     2. (R, (S, T)): Need to hold R, compute (S, T), then join with R, worse if more relations
  3. Nested loop join, consider top-down iterator next()
     1. ((R, S), T), Reads the chunks of (R, S) once, reads stored base relation T multiple times
     2. (R, (S, T)): Reads the chunks of R once, reads computed relation (S, T) multiple times, either more time or more space

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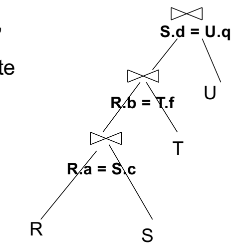
Implementation in SimpleDB (lab5)

1. JoinOptimizer.java (and the classes used there)
2. Returns vector of "LogicalJoinNode"
   Two base tables, two join attributes, predicate
   e.g. R(a, b), S(c, d), T(a, f), U(p, q)
   (R, S, R.a, S.c, =)
   Recall that SimpleDB keeps all attributes of R, S after their join R.a, R.b, S.c, S.d



3. Output vector looks like:
   <(R, S, R.a, S.c), (R, T, R.b, T.f), (S, U, S.d, U.q)>

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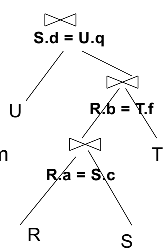
Implementation in SimpleDB (lab5)

Any advantage of returning pairs?

- Flexibility to consider all linear plans
  <(R, S, R.a,S.c), (R, T, R.b, T.f), (U, S, U.q, S.d)>



More Details:
1. You mainly need to implement "orderJoins(..)"
2. "CostCard" data structure stores a plan, its cost and cardinality: you would need to estimate them
3. "PlanCache" stores the table in dyn. Prog:
   Maps a set of LJN to
   a vector of LJN (best plan for the vector),
   its cost, and its cardinality
   LJN = LogicalJoinNode

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