L22
Query Execution & Optimization
Continued

Indexed Nested Loops Join

```
for row in outer:
    for irow in index.get(row[0], []):
        yield (row, irow)
```

Slightly less flexible

- Only supports conditions that the index supports

Indexed Nested Loops Join

What this means in terms of disk IO

outer join inner on sid

M pages in outer, N pages in inner, T tuples/page

inner has primary key index on sid

Cost of looking up in index is C_I

predicate on outer has 5% selectivity

$M + T \times M \times 0.05 \times C_I$

for each tuple t in the outer: (M pages, TM tuples)

    if predicate(t): (5% of tuples satisfy pred)

        lookup_in_index(t.sid) (C_I disk IO)

Sort Merge Join

Sort outer and inner tables on join key

Cost: 2-3 scans of each table

Merge the tables and compute the join

Cost: 1 scan of each table

Overall Properties

cost: 3(M+N) to 4(M+N)

results are sorted

highly sequential access

(weapon of choice for very large datasets)

Sort Merge Join

What does this mean in terms of disk IO?

R join T on sid

R has M pages, T has N pages, 50 tuples/page

Assume sort takes 3 scans, merge takes 1 scan

$3 * M + 1 * M + 3 * N + 1 * N$

(note, tuples/page didn't matter)

Join Cost Summary

\# tuples (S) = N_s

\# tuples (T) = N_T

\# pages (S) = P_S

\# pages (T) = P_T

\# index values (S) = I_S

\# index values (T) = I_T

Secondary index on T.id

Height of index = H

S NLJ T

$P_S + N_S \times P_T$

T NLJ S

$P_T + N_T \times P_S$

S INLJ T

$P_S + N_S \times$ (index cost)

index cost:

H + # leaf pages + # tuples

S SM T

$3 \times (P_S + P_T)$

Quick Recap

Single relation operator optimizations

- Access paths
- Primary vs secondary index costs
- Projection/distinct
- Predicate/project push downs

2 relation operators aka Joins

- Nested loops, index nested loops, sort merge

Selectivity estimation

- Statistics and simple models

Where we are

We’ve discussed

- Optimizations for a single operator
- Different types of access paths, join operators
- Simple optimizations e.g., predicate push-down

What about for multiple operators?

- System R Optimizer

Selinger Optimizer

Granddaddy of all existing optimizers

- don't go for best plan, go for *least worst plan*

2 Big Ideas

1. Cost Estimator
   - "predict" cost of query from statistics
   - Includes CPU, disk, memory, etc (can get sophisticated!)
   - It's an art
2. Plan Space
   - avoid cross product
   - push selections & projections to leaves as much as possible
   - only join ordering remaining

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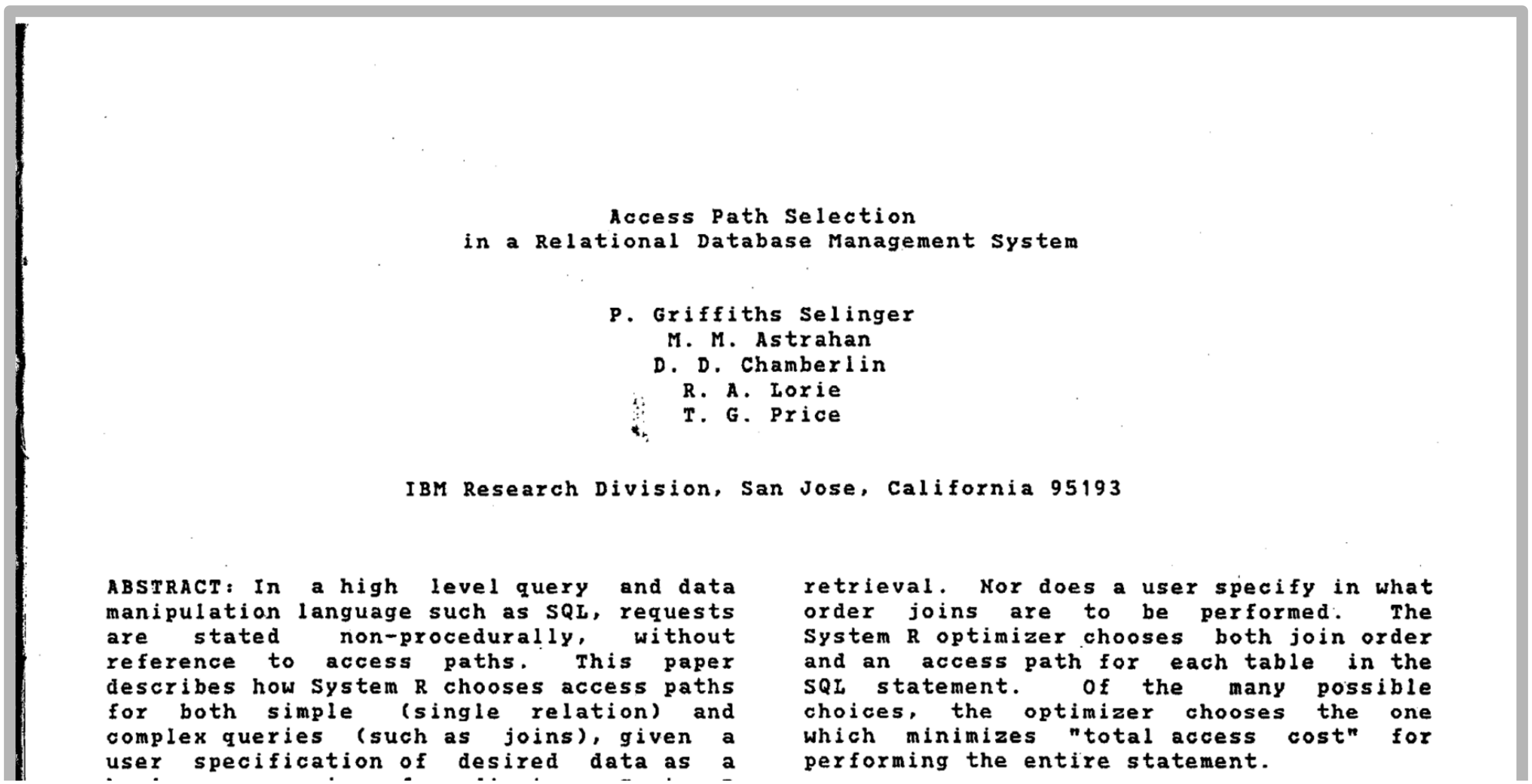
2 Big Ideas

1.

2.



Access Path Selection
in a Relational Database Management System

P. Griffiths Selinger
M. M. Astrahan
D. D. Chamberlin
R. A. Lorie
T. G. Price

IBM Research Division, San Jose, California 95193

ABSTRACT: In a high level query and data manipulation language such as SQL, requests are stated non-procedurally, without reference to access paths. This paper describes how System R chooses access paths for both simple (single relation) and complex queries (such as joins), given a user specification of desired data as a

retrieval. Nor does a user specify in what order joins are to be performed. The System R optimizer chooses both join order and an access path for each table in the SQL statement. Of the many possible choices, the optimizer chooses the one which minimizes "total access cost" for performing the entire statement.

Cost Estimation

estimate(operator, inputs, stats) → cost

estimate cost for each operator

- depends on input *cardinalities* (# tuples)
- discussed earlier in lecture

estimate output size for each operator

- need to call estimate() on inputs!
- use selectivity. assume attributes are independent

Try it in PostgreSQL: `EXPLAIN <query>;`

Estimate Size of Output

```
Emp:   1000 Cardinality
Dept:  10 Cardinality

Cost(Emp join Dept)
```

Naïve

# total records	1000 * 10	= 10,000
Selectivity of Emp	1 / 1000	= 0.001
Selectivity of Dept	1 / 10	= 0.1
Join Selectivity	1 / max(1k, 10)	= 0.001
Output Card:	10,000 * 0.001	= 10

note: selectivity defined wrt cross product size

Note: estimate wrong if this is a key/fk join on emp.did = dept.did: 1000 results

Selinger Optimizer

Granddaddy of all existing optimizers

- don't go for best plan, go for *least worst plan*

- Cost Estimator
  - "predict" cost of query from statistics
  - Includes CPU, disk, memory, etc (can get sophisticated!)
  - It's an art
- Plan Space
  - avoid cross product
  - push selections & projections to leaves as much as possible
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Join Plan Space

A⋈B⋈C

(AB)C A(BC)

How many plans?

(AB)C	(AC)B	(BC)A	(BA)C	(CA)B	(CB)A
A(BC)	A(CB)	B(CA)	B(AC)	C(AB)	C(BA)

$$\text{\# parenthetizations} * \underbrace{\text{\#strings}}_{N!}$$

Join Plan Space

parenthetizations * #strings

A:	(A)
AB:	(AB)
ABC:	((AB)C), (A(BC))
ABCD:	(((AB)C)D), ((A(BC))D), ((AB)(CD)), (A((BC)D)), (A(B(CD)))
paren(n)	choose(2(N-1), (N-1)) / N

(choose(2(N-1), (N-1)) / N) * N!

N=10 #plans = 17,643,225,600

The Art of Computer Programming, Volume 4A, page 440-450

Selinger Optimizer

Simplify the set of plans so it's tractable and ~ok

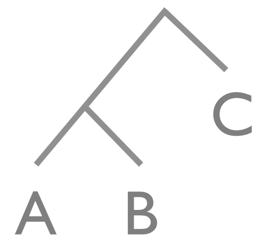
1. Push down selections and projections
2. Ignore cross products (S&T don't share attrs)
3. Left deep plans only
4. Dynamic programming optimization problem
5. Consider interesting sort orders

Selinger Optimizer

parens(N) = 1

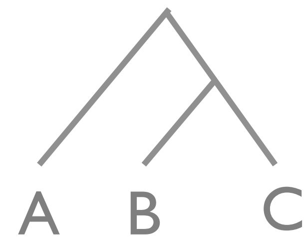
Only left-deep plans

ensures pipelining



(AB)C

✔



A(BC)

✗

Dynamic Programming

Idea: If considering ((ABC)DE)

compute best (ABC), cache, and reuse

figure out best way to combine with (DE)

```
Dynamic Programming Algorithm
    compute best join size 1, then size 2, …
```

~O(N*2^N)

Summary

Single operator optimizations

- Access paths
- Primary vs secondary index costs
- Projection/distinct
- Predicate/project push downs

2 operators aka Joins

- Nested loops, index nested loops, sort merge

Full plan optimizations

- Naïve vs Selinger join ordering

Selectivity estimation

- Statistics and simple models

Summary

Query optimization is a deep, complex topic

Pipelined plan execution

Different types of joins

Cost estimation of single and multiple operators

Join ordering is hard!

You should understand

Estimate query cardinality, selectivity

Apply predicate push down

Given primary/secondary indexes and statistics,

- pick best index for access method + est cost
- pick best index for join + est cost
- pick cheaper of two execution plans

Transactions, Concurrency, Recovery

Transfer $1000 from Evan to Neha

Check if Evan has $1000

Evan's Account -= $1000

Neha's Account += $1000

Transfer $1000 from Evan to Neha

Check if Evan has $1000

Evan's Account -= $1000

~~Neha's Account += $1000~~

Program crash or user presses cancel:

Money disappeared

Transfer $1000 from Evan to Neha

Check if Evan has $1000

~~Evan's Account -= $1000~~

~~Neha's Account += $1000~~

OOPS! Not enough money

Two transfers: Starting with $1500

Check if Evan has $1000

    Check if Evan has $1000

Evan's Account -= $1000

    Evan's Account -= $1000

Negative balance!

Neha's Account += $1000

    Eugene's Account += $1000

Transactions

Sequence of actions with additional guarantees

Atomicity: Apply all changes or none

("atomic" because it is indivisible)

Solves the crash problem

Isolation: Illusion that each transaction executes sequentially, without concurrency

Transaction Guarantees

Atomicity
- "all or nothing": All changes applied, or none are
- users never see in-between transaction state

Consistency
- database always satisfies Integrity Constraints
- Transactions move from valid database to valid database

Isolation:
- from transaction's point of view, it's the only one running

Durability:
- if transaction commits, its effects *must persist*

Transactions

Transaction: a sequence of actions

- action = read object, write object, commit, abort
- API between app semantics and DBMS's view

User's view

T1:	begin	A=A+100	B=B-100	END
T2:	begin	A=A-50	B=B+50	END

DBMS's logical view

T1:	begin	r(A) w(A)	r(B) w(B)	END
T2:	begin	r(A) w(A)	r(B) w(B)	END

Concepts

Concurrency Control

techniques to ensure correct results when running transactions concurrently

what does this mean?

Recovery

On crash or abort, how to get back to a consistent (correct) state?

The two are intertwined! The CC mechanism dictates the complexity of recovery!

What is Correct?

Serializability

Regardless of the interleaving of operations, result same as a serial ordering

Schedule

One specific interleaving of the operations

Serial Schedules

Logical xacts

T1: r(A) w(A)   r(B) w(B)   (e.g. A=A+100; B=B-100)

T2: r(A) w(A)   r(B) w(B)   (e.g. A=A*1.5;   B=B*1.5)

No concurrency (serial 1)

T1:	r(A) w(A) r(B) w(B)	
T2:		r(A) w(A) r(B) w(B)

No concurrency (serial 2)

T1:		r(A) w(A) r(B) w(B)
T2:	r(A) w(A) r(B) w(B)	

Are serial 1 and serial 2 equivalent?

More Example Schedules

Logical xacts e.g. A=0 B=0

T1:	r(A) w(A)	r(A) w(B)		e.g. A=A+1;	B=B+A
T2:	r(A) w(A)	r(B) w(B)		e.g. A=A+10;	B=B+1

Concurrency (bad)

T1:	r(A) w(A)		r(A) w(B)	
T2:		r(A) w(A)		r(B) w(B)

Concurrency (same as serial T1,T2!)

T1:	r(A) w(A)		r(A) w(B)	
T2:		r(A)		w(A) r(B) w(B)

Concepts

Serial schedule

One transaction at a time. no concurrency.

Equivalent schedule

the database state is the same at end of both schedules

Serializable schedule (gold standard)

equivalent to a serial schedule

SQL → R/W Operations

```
UPDATE  accounts
SET     bal = bal + 1000
WHERE   bal > 1M
```

Read all balances for every tuple

Update those with balances > 1000

Does the access method mater?

Why Serializable Schedule? Anomalies

Reading in-between (uncommitted) data

T1: R(A) W(A) R(B) W(B) abort

T2: R(A) W(A) commit

WR conflict or dirty reads

Reading same data gets different values

T1: R(A) R(A) W(A) commit

T2: R(A) W(A) commit

RW conflict or unrepeatable reads

Why Serializable Schedule? Anomalies

Stepping on someone else's writes

T1: W(A) W(B) commit

T2: W(A) W(B) commit

WW conflict or lost writes

Notice: all anomalies involve writing to data that is read/written to.

If we track our writes, maybe can prevent anomalies

Conflict Serializability

What is a conflict?

- For 2 operations, if run in different order, get different results

Conflict?	R	W
R	NO	YES
W	YES	YES