Week 12

Query Processing

Query Processing

Q $\rightarrow$ Query Plan

Focus: Relational System

- Others?

Example

Select B,D

From R,S

Where R.A = “c” $\wedge$ S.E = 2 $\wedge$ R.C=S.C

R

A	B	C
a	1	10
b	1	20
c	2	10
d	2	35
e	3	45

S

C	D	E
10	x	2
20	y	2
30	z	2
40	x	1
50	y	3

Answer

B	D
2	x

- **How do we execute query?**

One idea

- Do Cartesian product
- Select tuples
- Do projection

R×S

R.A	R.B	R.C	S.C	S.D	S.E
a	1	10	10	x	2
a	1	10	20	y	2
.					
.					
C	2	10	10	x	2
.					
.					

Bingo!

Got one...

<u>Relational Algebra</u> - can be used to describe plans...

<u>Ex:</u> Plan I

$\Pi_{B,D}$

$\sigma_{R.A=\text{“c”} \wedge S.E=2 \wedge R.C=S.C}$

X

R S

<u>OR:</u> $\Pi_{B,D} [\, \sigma_{R.A=\text{“c”} \wedge S.E=2 \wedge R.C = S.C} (RXS)]$

Another idea:

Plan II

$\Pi_{B,D}$

$\bowtie$

$\sigma_{R.A = \text{“c”}}$ $\sigma_{S.E = 2}$

R S

$\bowtie$ natural join

R

A	B	C
a	1	10
b	1	20
c	2	10
d	2	35
e	3	45

σ (R)

A	B	C
c	2	10

σ(S)

C	D	E
10	x	2
20	y	2
30	z	2

S

C	D	E
10	x	2
20	y	2
30	z	2
40	x	1
50	y	3

$\bowtie$

Plan III

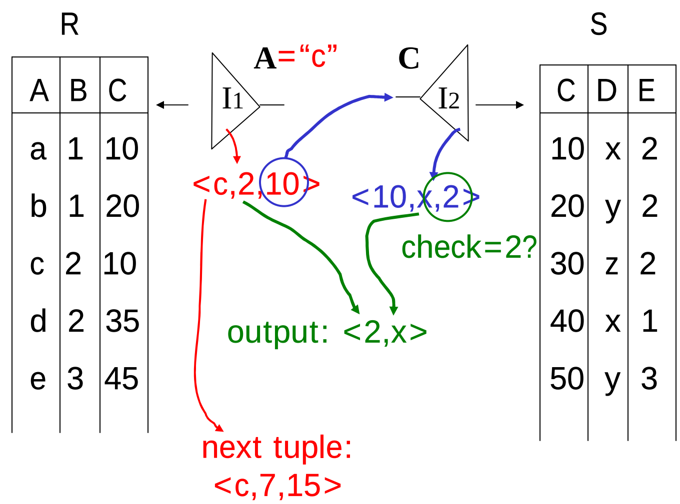
Use R.A and S.C Indexes

(1) Use R.A index to select R tuples with R.A = "c"

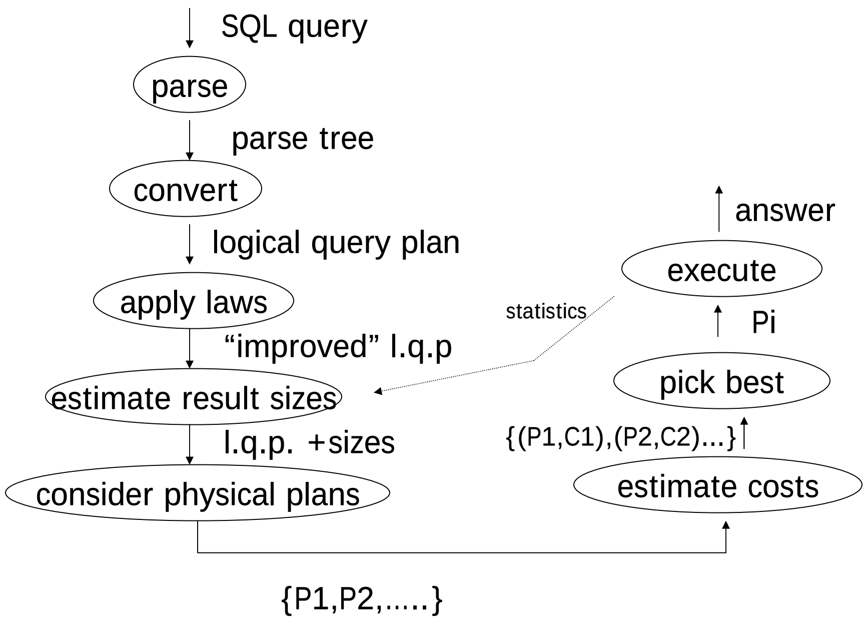
(2) For each R.C value found, use S.C index to find matching tuples

(3) Eliminate S tuples S.E ≠ 2

(4) Join matching R,S tuples, project B,D attributes and place in result



Overview of Query Optimization

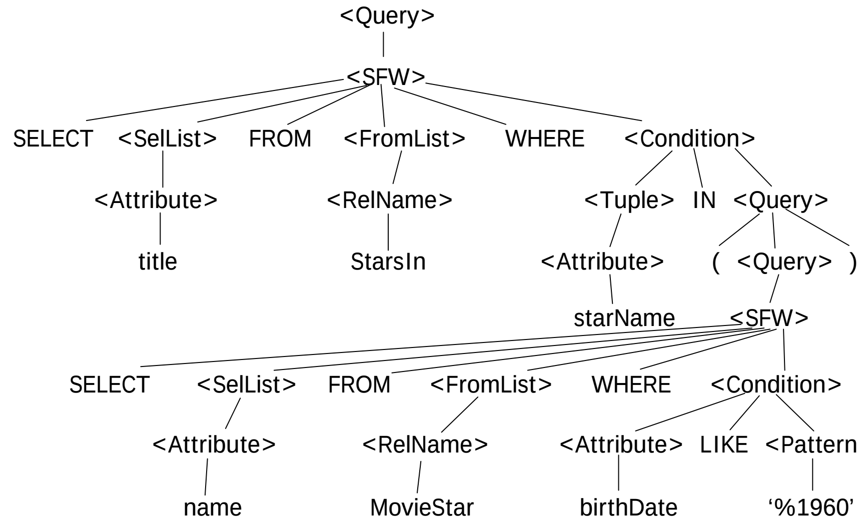


Example: SQL query

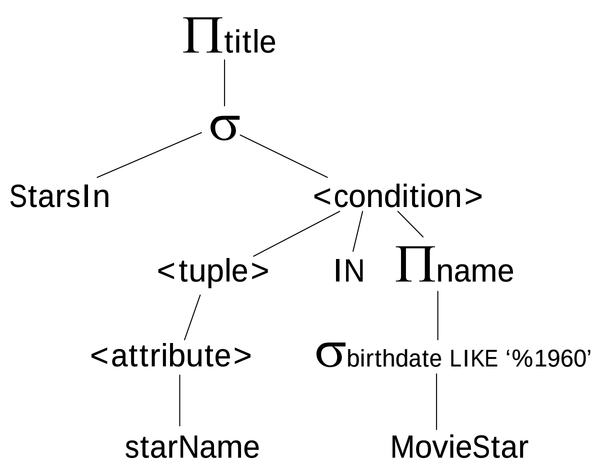
SELECT title
FROM StarsIn
WHERE starName IN (
    SELECT name
    FROM MovieStar
    WHERE birthdate LIKE '%1960'
);

(Find the movies with stars born in 1960)

Example: Parse Tree

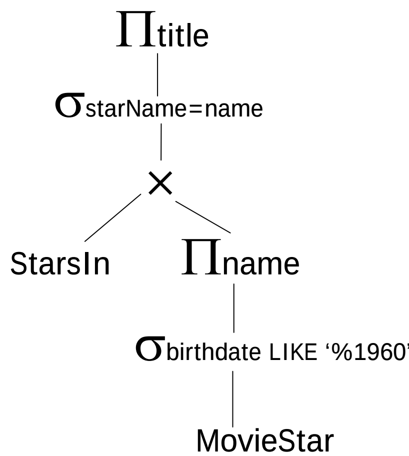


Example: Generating Relational Algebra



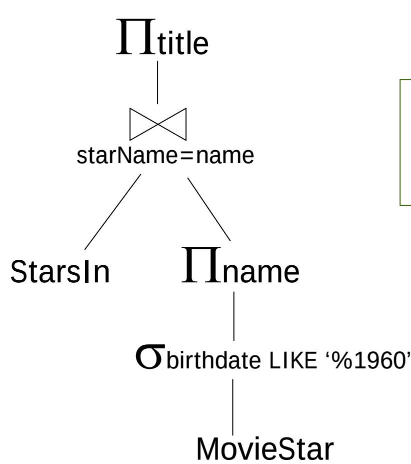
An expression using a two-argument σ, midway between a parse tree and relational algebra

Example: Logical Query Plan



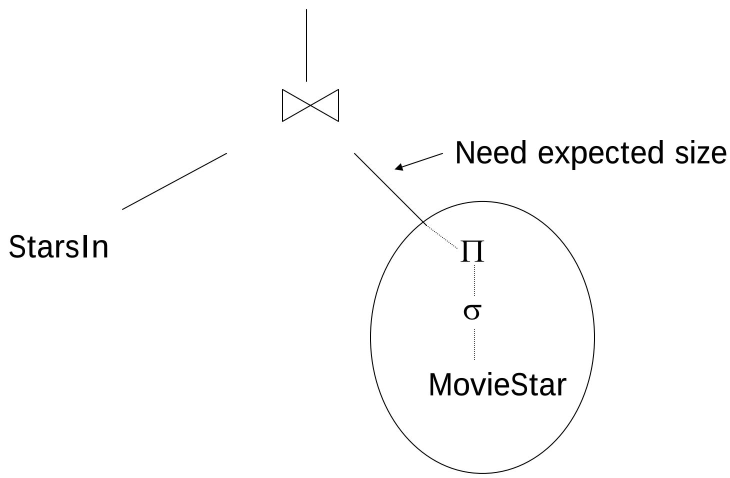
Applying the rule for IN conditions

Example: Improved Logical Query Plan

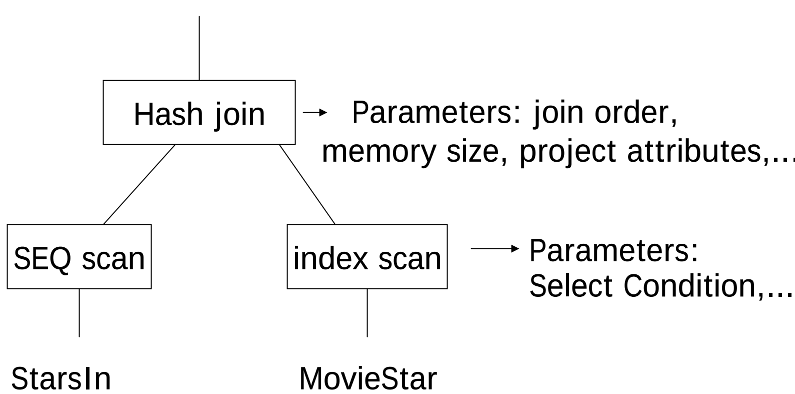


Question: Push projection to StarsIn?

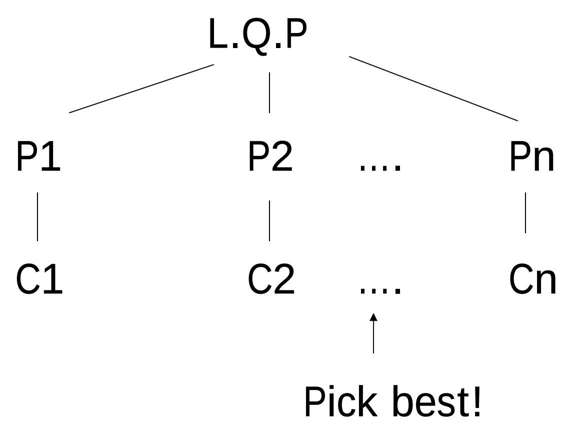
Example: Estimate Result Sizes



Example: One Physical Plan



Example: Estimate costs



Outline

Algebra for queries [bags vs sets]

- Select, project, join, ... [project list a,a+b->x,...]
- Duplicate elimination, grouping, sorting

Physical operators

- Scan,sort, ...

Implementing operators +
estimating their cost

Parsing

Algebraic laws

Parse tree -> logical query plan

Estimating result sizes

Cost based optimization

Query Optimization

- Relational algebra level
- Detailed query plan level
  - Estimate Costs
    - without indexes
    - with indexes
  - Generate and compare plans

Relational algebra optimization

- Transformation rules
  (preserve equivalence)
- What are good transformations?

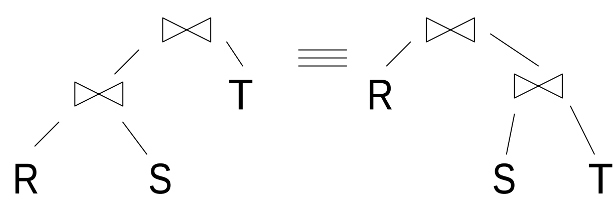
Rules: Natural joins & cross products & union

$R \bowtie S \quad = \quad S \bowtie R$

$(R \bowtie S) \bowtie T \quad = R \bowtie (S \bowtie T)$

Note:

- Carry attribute names in results, so order (of attributes!) is not important
- Can also write as trees, e.g.:



Rules: Natural joins & cross products & union

$R \bowtie S \quad = \quad S \bowtie R$

$(R \bowtie S) \bowtie T \quad = R \bowtie (S \bowtie T)$

R x S = S x R

(R x S) x T = R x (S x T)

R U S = S U R

R U (S U T) = (R U S) U T

Rules: Selects

$\sigma_{p1 \wedge p2}(R) = \quad \sigma_{p1} \; [\, \sigma_{p2} (R)]$

$\sigma_{p1 v p2}(R) = \quad [\, \sigma_{p1} (R)] \cup [\, \sigma_{p2} (R)]$

Bags vs. Sets

R = {a,a,b,b,b,c}

S = {b,b,c,c,d}

RUS = ?

- Option 1 SUM

  RUS = {a,a,b,b,b,b,b,c,c,c,d}
- Option 2 MAX

  RUS = {a,a,b,b,b,c,c,d}

Option 2 (MAX) makes this rule work:

$\sigma_{p1 \vee p2}(R) = \sigma_{p1}(R) \cup \sigma_{p2}(R)$

Example: R={a,a,b,b,b,c}

P1 satisfied by a,b; P2 satisfied by b,c

$\sigma_{p1 \vee p2}(R) = \{a,a,b,b,b,c\}$

$\sigma_{p1}(R) = \{a,a,b,b,b\}$

$\sigma_{p2}(R) = \{b,b,b,c\}$

$\sigma_{p1}(R) \cup \sigma_{p2}(R) = \{a,a,b,b,b,c\}$

"Sum" option makes more sense:

Senators (......) Rep (......)

T1 = $\pi_{yr,state}$ Senators; T2 = $\pi_{yr,state}$ Reps

T1

Yr	State
97	CA
99	CA
98	AZ

T2

Yr	State
99	CA
99	CA
98	CA

Union?

Executive Decision

→ Use “SUM” option for bag unions
→ Some rules cannot be used for bags

Rules: Project

Let: X = set of attributes
Y = set of attributes
XY = X U Y

$$\pi_{xy}(R) = \cancel{\pi_x[\pi_y(R)]}$$

Rules: $\sigma + \bowtie$ combined

Let p = predicate with only R attribs
q = predicate with only S attribs
m = predicate with only R,S attribs

$\sigma_p (R \bowtie S) = [\sigma_p (R)] \bowtie S$

$\sigma_q (R \bowtie S) = R \bowtie [\sigma_q (S)]$

Rules: $\sigma + \bowtie$ combined (continued)

Some Rules can be Derived:

$\sigma_{p \wedge q} (R \bowtie S) =$

$\sigma_{p \wedge q \wedge m} (R \bowtie S) =$

$\sigma_{p v q} (R \bowtie S) =$

Do one, others for homework:

$$\sigma_{p \wedge q} (R \bowtie S) = [\sigma_p (R)] \bowtie [\sigma_q (S)]$$

$$\sigma_{p \wedge q \wedge m} (R \bowtie S) =$$

$$\sigma_m \left[(\sigma_p R) \bowtie (\sigma_q S) \right]$$

$$\sigma_{p \vee q} (R \bowtie S) =$$

$$\left[(\sigma_p R) \bowtie S \right] \cup \left[R \bowtie (\sigma_q S) \right]$$

→ Derivation for first one:

$$\sigma_{p \wedge q} (R \bowtie S) =$$

$$\sigma_p \left[\sigma_q (R \bowtie S) \right] =$$

$$\sigma_p \left[R \bowtie \sigma_q (S) \right] =$$

$$[\sigma_p (R)] \bowtie [\sigma_q (S)]$$

Rules: π,σ combined

Let x = subset of R attributes

z = attributes in predicate P

(subset of R attributes)

$$\pi_x[\sigma_p(R)] = \pi_x\{\sigma_p[\overset{\pi_{xz}}{\cancel{\pi_x}}(R)]\}$$

Rules: π, $\bowtie$ combined

Let x = subset of R attributes

y = subset of S attributes

z = intersection of R,S attributes

$$\pi_{xy}(R \bowtie S) =$$

$$\pi_{xy}\{[\pi_{xz}(R)] \bowtie [\pi_{yz}(S)]\}$$

$$\pi_{xy} \{\sigma_p \ (R \bowtie S)\} \ =$$

$$\pi_{xy} \{\sigma_p \ [\pi_{xz'} (R) \bowtie \pi_{yz'} (S)]\}$$

$$z' = z \cup \{\text{attributes used in } P\}$$

Rules for σ, π combined with X

similar…

e.g., $\sigma_p (R \times S) = \ ?$

Rules σ, U combined:

$\sigma_p(R \cup S) = \sigma_p(R) \cup \sigma_p(S)$

$\sigma_p(R - S) = \sigma_p(R) - S = \sigma_p(R) - \sigma_p(S)$

Which are "good" transformations?

- $\sigma_{p1 \wedge p2}(R) \rightarrow \sigma_{p1}[\sigma_{p2}(R)]$
- $\sigma_p(R \bowtie S) \rightarrow [\sigma_p(R)] \bowtie S$
- $R \bowtie S \rightarrow S \bowtie R$
- $\pi_x[\sigma_p(R)] \rightarrow \pi_x\{\sigma_p[\pi_{xz}(R)]\}$

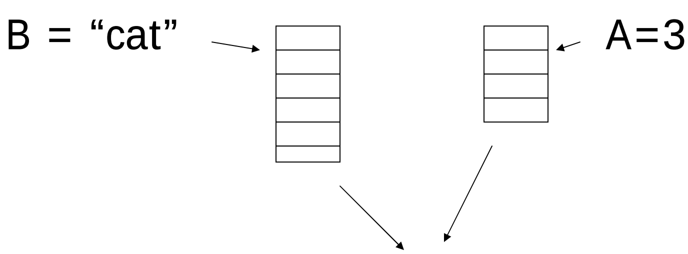
Conventional wisdom: do projects early (always?)

Example: R(A,B,C,D,E)   x={E}

P: (A=3) $\wedge$ (B="cat")

$$\pi_x \{\sigma_p\ (R)\} \quad \text{vs.} \quad \pi_E \left\{\sigma_p\{\pi_{ABE}(R)\}\right\}$$

$\boxed{\text{But}}$ What if we have A, B indexes?



Intersect pointers to get pointers to matching tuples

Bottom line:

- No transformation is always good
- Usually good: early selections

Outline - Query Processing

- Relational algebra level
  - transformations
  - good transformations
- Detailed query plan level
  - estimate costs
  - generate and compare plans

- **Estimating cost of query plan**

(1) Estimating <u>size</u> of results

(2) Estimating # of IOs

Estimating result size

- Keep statistics for relation R
  - T(R) : # tuples in R
  - S(R) : # of bytes in each R tuple
  - B(R): # of blocks to hold all R tuples
  - V(R, A) : # distinct values in R for attribute A

Example

R

A	B	C	D
cat	1	10	a
cat	1	20	b
dog	1	30	a
dog	1	40	c
bat	1	50	d

A: 20 byte string
B: 4 byte integer
C: 8 byte date
D: 5 byte string

$T(R) = 5$ $S(R) = 37$

$V(R,A) = 3$ $V(R,C) = 5$

$V(R,B) = 1$ $V(R,D) = 4$

Size estimates for W = R1 x R2

$T(W) = T(R1) \times T(R2)$

$S(W) = S(R1) + S(R2)$

<u>Size estimate</u> for $W = \sigma_{A=a}(R)$

$S(W) = S(R)$

$T(W) = ?$

<u>Example</u>

R

A	B	C	D
cat	1	10	a
cat	1	20	b
dog	1	30	a
dog	1	40	c
bat	1	50	d

$V(R,A)=3$
$V(R,B)=1$
$V(R,C)=5$
$V(R,D)=4$

$W = \sigma_{z=val}(R)$ $\quad T(W) = \dfrac{T(R)}{V(R,Z)}$

Assumption:

Values in select expression Z = val
are uniformly distributed
over possible V(R,Z) values.

Alternate Assumption:

Values in select expression Z = val
are uniformly distributed
over domain with DOM(R,Z) values.

<u>Example</u>

R

A	B	C	D
cat	1	10	a
cat	1	20	b
dog	1	30	a
dog	1	40	c
bat	1	50	d

Alternate assumption
V(R,A)=3 DOM(R,A)=10
V(R,B)=1 DOM(R,B)=10
V(R,C)=5 DOM(R,C)=10
V(R,D)=4 DOM(R,D)=10

$W = \sigma_{z=val}(R) \quad T(W) = ?$

$C{=}val \Rightarrow T(W) = (1/10)1 + (1/10)1 + \ldots$
$= (5/10) = 0.5$

$B{=}val \Rightarrow T(W) = (1/10)5 + 0 + 0 = 0.5$

$A{=}val \Rightarrow T(W) = (1/10)2 + (1/10)2 + (1/10)1$
$= 0.5$

Example

R

A	B	C	D
cat	1	10	a
cat	1	20	b
dog	1	30	a
dog	1	40	c
bat	1	50	d

Alternate assumption
V(R,A)=3 DOM(R,A)=10
V(R,B)=1 DOM(R,B)=10
V(R,C)=5 DOM(R,C)=10
V(R,D)=4 DOM(R,D)=10

$$W = \sigma_{z=val}(R) \qquad T(W) = \frac{T(R)}{DOM(R,Z)}$$

Selection cardinality

SC(R,A) = average # records that satisfy equality condition on R.A

$$SC(R,A) = \begin{cases} \dfrac{T(R)}{V(R,A)} \\ \\ \dfrac{T(R)}{DOM(R,A)} \end{cases}$$

What about W = $\sigma_{z \geq val}$ (R) ?

T(W) = ?

- Solution # 1:

  T(W) = T(R)/2

- Solution # 2:

  T(W) = T(R)/3

- Solution # 3: Estimate values in range

<u>Example</u> R

	Z

Min=1 ↕ Max=20

V(R,Z)=10

W= $\sigma_{z \geq 15}$ (R)

$$f = \frac{20-15+1}{20-1+1} = \frac{6}{20} \quad \text{(fraction of range)}$$

T(W) = f $\times$ T(R)

Equivalently:

$f \times V(R,Z)$ = fraction of distinct values

$$T(W) = [f \times V(Z,R)] \times \frac{T(R)}{V(Z,R)} = f \times T(R)$$

Size estimate for $W = R1 \bowtie R2$

Let x = attributes of R1

y = attributes of R2

$\boxed{\text{Case 1}}$ $X \cap Y = \varnothing$

Same as R1 x R2

$\boxed{\text{Case 2}}$ **W = R1 $\bowtie$ R2** **$X \cap Y = A$**

R1	A	B	C

R2	A	D

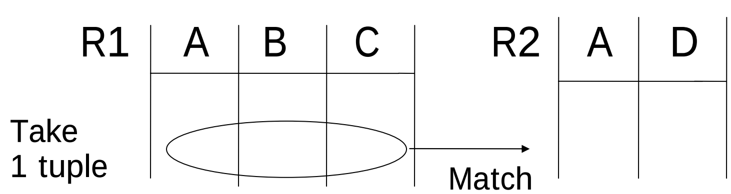
Assumption:

$V(R1,A) \leq V(R2,A) \Rightarrow$ Every A value in R1 is in R2

$V(R2,A) \leq V(R1,A) \Rightarrow$ Every A value in R2 is in R1

"containment of value sets"

Computing T(W) when $V(R1,A) \leq V(R2,A)$



1 tuple matches with $\frac{T(R2)}{V(R2,A)}$ tuples...

so $T(W) = \frac{T(R2)}{V(R2, A)} \times T(R1)$

- $V(R1,A) \leq V(R2,A) \quad T(W) = \dfrac{T(R2)\ T(R1)}{V(R2,A)}$

- $V(R2,A) \leq V(R1,A) \quad T(W) = \dfrac{T(R2)\ T(R1)}{V(R1,A)}$

[A is common attribute]

In general **W = R1 $\bowtie$ R2**

$$T(W) = \frac{T(R2)\ T(R1)}{\max\{ V(R1,A), V(R2,A) \}}$$

Case 2 with alternate assumption

Values uniformly distributed over domain

R1

A	B	C

R2

A	D

This tuple matches T(R2)/DOM(R2,A) so

$$T(W) = \frac{T(R2)\ T(R1)}{DOM(R2,\ A)} = \frac{T(R2)\ T(R1)}{DOM(R1,\ A)}$$

Assume the same

In all cases:

S(W) = S(R1) + S(R2) - S(A)

size of attribute A

Using similar ideas, we can estimate sizes of:

Π_{AB} (R) .....

$\sigma_{A=a \wedge B=b}$ (R) ....

R $\bowtie$ S with common attribs. A,B,C

Union, intersection, diff, ...

Note: for complex expressions, need intermediate T,S,V results.

E.g. $W = [\underbrace{\sigma_{A=a} (R1)}_{\text{Treat as relation U}}] \bowtie R2$

T(U) = T(R1)/V(R1,A) S(U) = S(R1)

Also need V (U, *) !!

To estimate Vs

E.g., $U = \sigma_{A=a}(R1)$

Say R1 has attribs A,B,C,D

V(U, A) =

V(U, B) =

V(U, C) =

V(U, D) =

Example

R1

A	B	C	D
cat	1	10	10
cat	1	20	20
dog	1	30	10
dog	1	40	30
bat	1	50	10

V(R1,A)=3

V(R1,B)=1

V(R1,C)=5

V(R1,D)=3

$U = \sigma_{A=a}(R1)$

V(U,A) =1 V(U,B) =1 V(U,C) = $\dfrac{T(R1)}{V(R1,A)}$

V(D,U) ... somewhere in between

Possible Guess $U = \sigma_{A=a}(R)$

V(U,A) = 1

V(U,B) = V(R,B)

For Joins $U = R1(A,B) \bowtie R2(A,C)$

V(U,A) = min { V(R1, A), V(R2, A) }

V(U,B) = V(R1, B)

V(U,C) = V(R2, C)

["preservation of value sets"]

Example:

$Z = R1(A,B) \bowtie R2(B,C) \bowtie R3(C,D)$

R1	$T(R1) = 1000$	$V(R1,A)=50$	$V(R1,B)=100$
R2	$T(R2) = 2000$	$V(R2,B)=200$	$V(R2,C)=300$
R3	$T(R3) = 3000$	$V(R3,C)=90$	$V(R3,D)=500$

Partial Result: $U = R \bowtie S$

$$T(U) = \frac{1000 \times 2000}{200}$$

$V(U,A) = 50$

$V(U,B) = 100$

$V(U,C) = 300$

$Z = U \bowtie R3$

$$T(Z) = \frac{1000 \times 2000 \times 3000}{200 \times 300}$$

$V(Z,A) = 50$
$V(Z,B) = 100$
$V(Z,C) = 90$
$V(Z,D) = 500$

Summary

- Estimating size of results is an "art"

- Don't forget:

  Statistics must be kept up to date...

  (cost?)

Outline

- Estimating cost of query plan
  - Estimating size of results ← done!
  - Estimating # of IOs ← occurs next...

- Generate and compare plans ...Final step