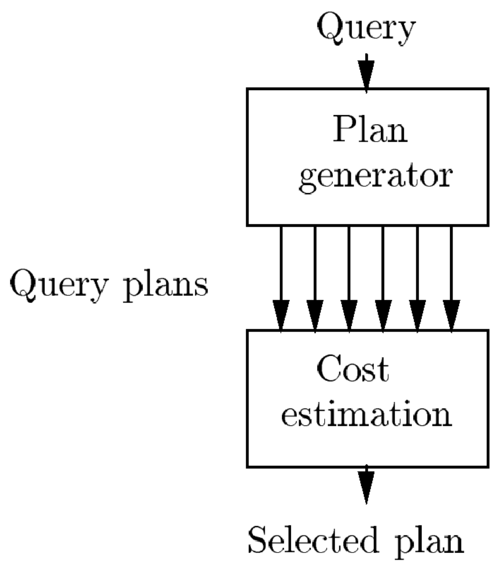
Query Processing

Overview Query Processing



Query Plans

Choose operations, e.g., σ, $\bowtie$

Order operations.

Detailed strategy of operations, e.g.:

- Join method.
- Pipelining: consume result of one operation by another, to avoid temporary storage on disk.
- Use of indexes?
- Sort intermediate results?

We focus on relational systems

Example

Select B,D

From R,S

Where R.A = “c” AND S.E = 2 AND 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 the Query?

One idea

- Do Cartesian product
- Select tuples
- Do projection

RXS

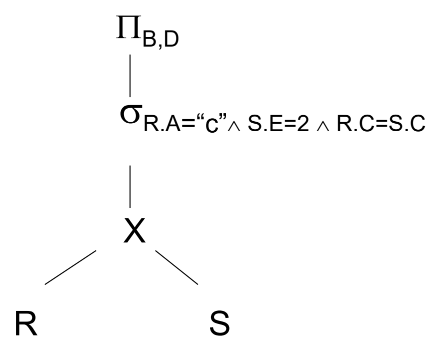
R.A	R.B	R.C	S.C	S.D	S.E
a	1	10	10	x	2
a	1	10	20	y	2
.					
.					
C	2	10	10	x	2
.					
.					

Bingo!

Got one...

Relational Algebra to Describe Plans

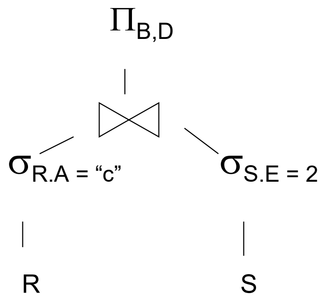
Ex: Plan I

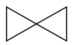


OR: $\Pi_{B,D} [\sigma_{R.A=\text{“c”} \wedge S.E=2 \wedge R.C = S.C} (RxS)]$

Another Plan

Plan II




natural join

Implementation of DBMS

R

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

σ (R)

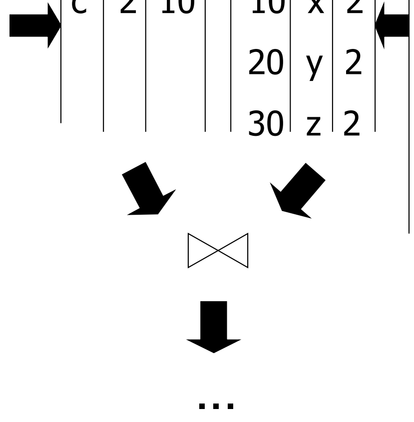
A	B	C
c	2	10

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



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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 with S.E ≠ 2
- (4) Join matching R,S tuples,
- (5) Project B,D attributes and place in result

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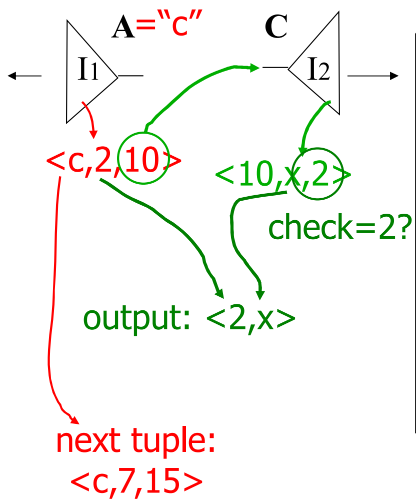
R

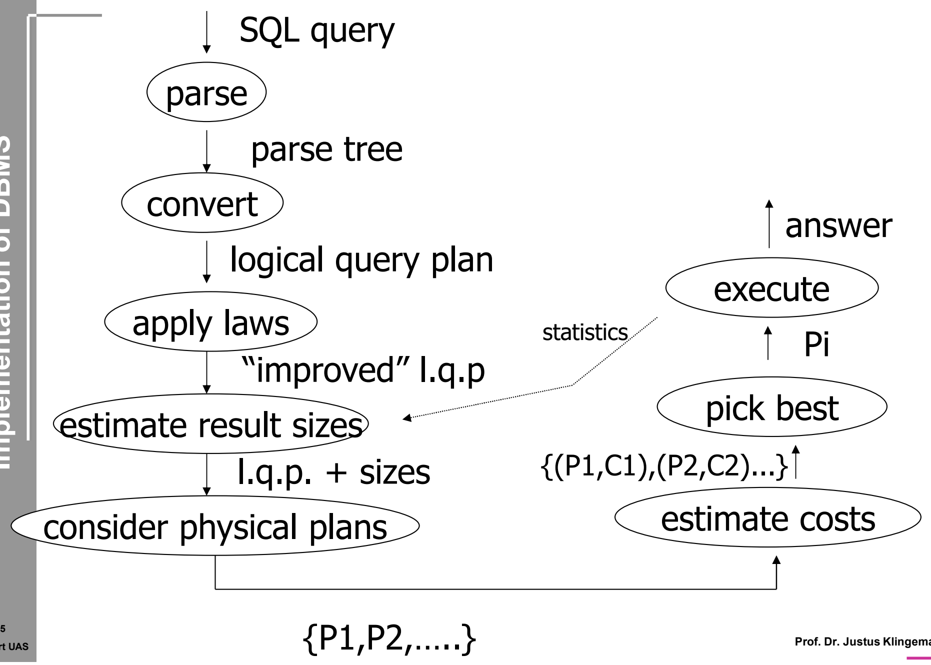
A	B	C
a	1	10
b	1	20
c	2	10
d	2	35
e	3	45



S

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

Overview of Query Optimization

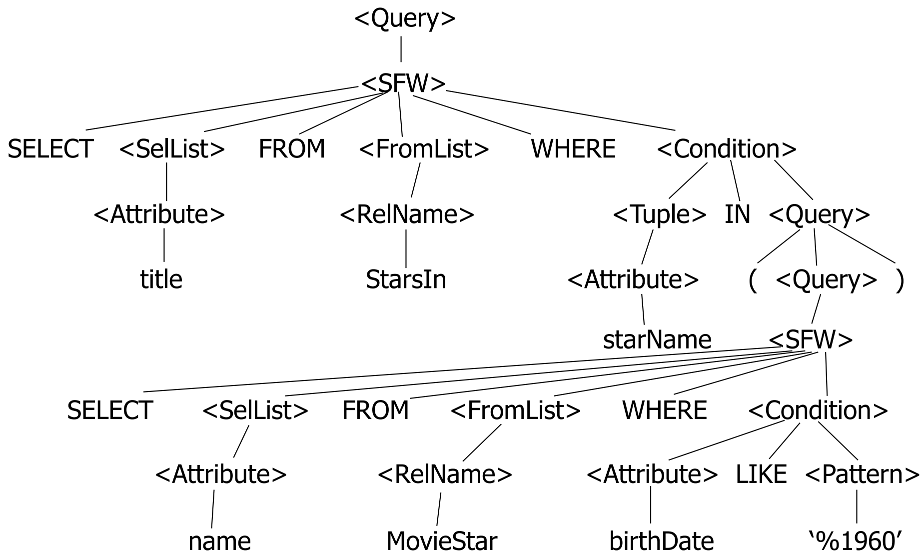


Example: SQL Query

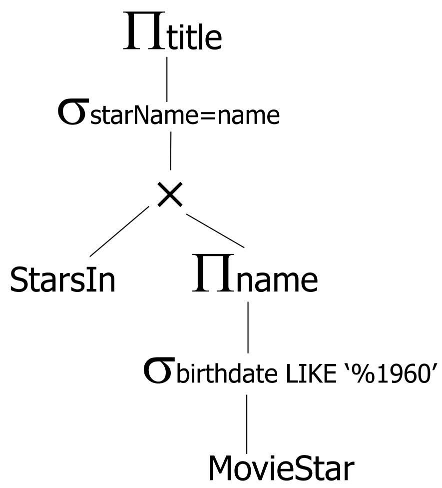
SELECT title
FROM StarsIn
WHERE starName IN (
    SELECT name
    FROM MovieStar
    WHERE birthdate LIKE '%1960'
);

(Find the movies with stars born in 1960)

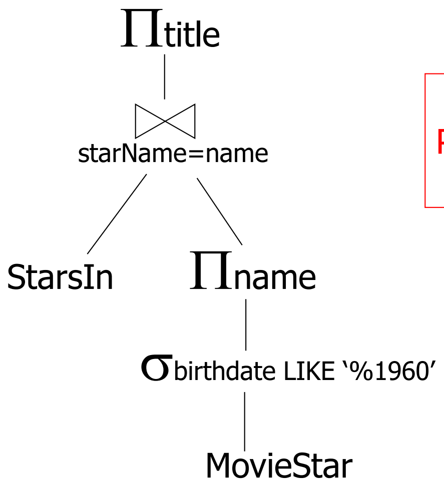
Example: Parse Tree



Example: Logical Query Plan



Example: Improved Locical Query Plan



Question:
Push project to
StarsIn?

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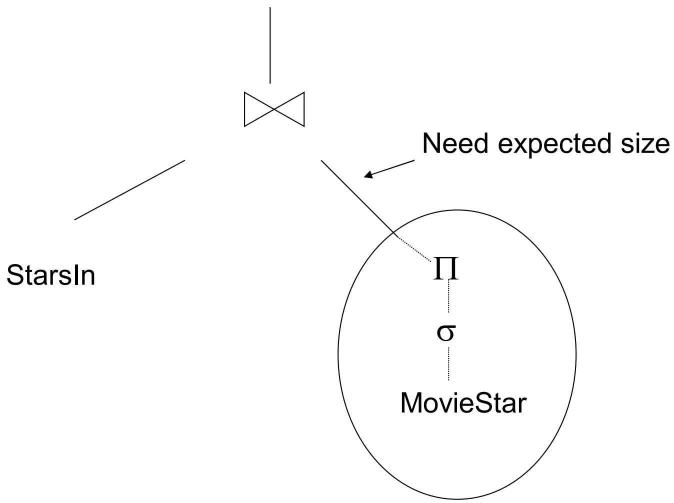
Example: Estimate Result Sizes



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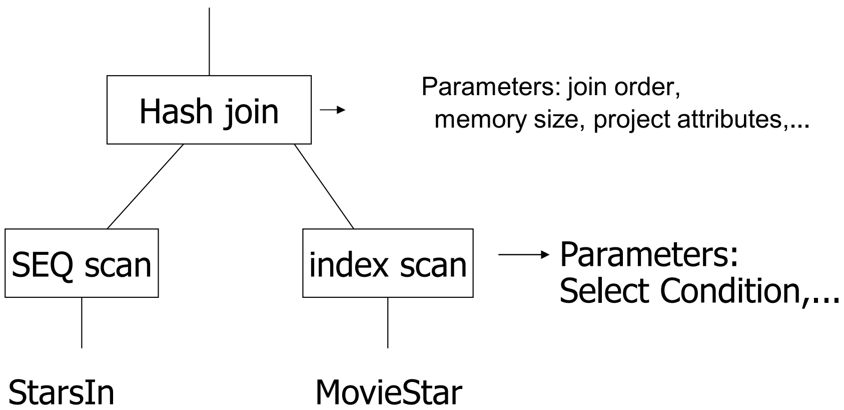
Example: One Physical Plan



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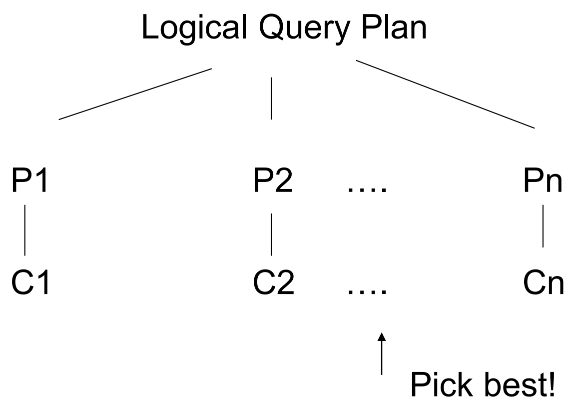
Example: Estimate Costs



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Algebraic Transformations

Generating Plans

- Start with query definition.
  - A plan, but usually a terrible one.
- Apply algebraic transformations to find other plans.
- Relational algebra is a good start, but we need also to consider: GROUP BY, duplicate elimination, HAVING, ORDER BY.

Algebraic Transformations

- Rules give equivalent expressions. meaning that whatever relations are substituted for variables, the results are the same.

Rules: Natural joins & cross products & union

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

$$R \times S = S \times R$$
$$(R \times S) \times T = R \times (S \times T)$$

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

But beware of thetajoin (join condition different from =)

- associative law does not hold.

Rules: Selects

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

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

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: σ + $\bowtie$ combined

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

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

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

Rules: σ + $\bowtie$ combined

Some rules can be derived:

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

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

$$\sigma_{p \vee q} (R \bowtie S) = \left[(\sigma_p R) \bowtie S\right] \cup \left[R \bowtie (\sigma_q S)\right]$$

Rules: π, σ combined

Let x = subset of R attributes
z = attributes in predicate P
(subset of R attributes)

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

Rules: π, $\bowtie$ combined

Let x = subset of R attributes
y = subset of S attributes
z = intersection of R, S attributes

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

Rules: π, $\bowtie$, and σ combined

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

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

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

Rules: 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?

$\sigma_{p1 \wedge p2}(R) \rightarrow \sigma_{p1}[\sigma_{p2}(R)]$

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

$R \bowtie S \rightarrow S \bowtie R$

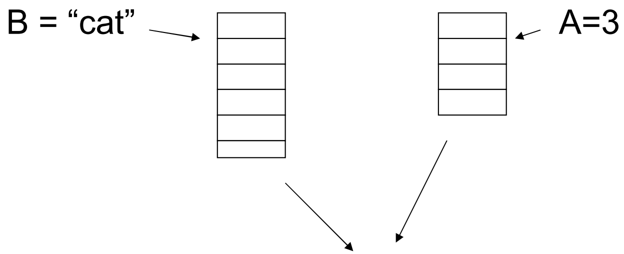
$\pi_x[\sigma_p(R)] \rightarrow \pi_x\{\sigma_p[\pi_{xz}(R)]\}$

Conventional wisdom: do projects early

<u>Example</u>: R(A,B,C,D,E) x={E}
P: (A=3) $\wedge$ (B="cat")

$\pi_x\{\sigma_p(R)\}$ vs. $\pi_E\{\sigma_p\{\pi_{ABE}(R)\}\}$

What if we have A, B indexes?



Intersect pointers to get pointers to matching tuples

Bottom line

There is no transformation that is good in any case

Usually good: early selections

- Variant: move selection up to the root and then down on multiple path

Estimating the Cost of a Query Plan

Goal is to count disk I/O's.

But we first have to estimate sizes of intermediate results.

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
- DOM (R, A): # possible distinct values for attribute A (size of domain for 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

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

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

Size estimate for $W = \sigma_{A=a}(R)$

$S(W) = S(R)$

$T(W) = ?$

Estimate Depends on Assumption

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

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

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

Alternate Assumption

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

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

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

Selections Involving Inequality

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

$T(W) = ?$

~~Solution # 1: T(W) = T(R)/2~~

- ~~Assumption: All split values are equally likely~~

Solution # 2: $T(W) = T(R)/3$

- Assumption: Queries involving inequality ask more likely for a small fraction of possible tuples
- This assumption is usually preferred

Implementation of DBMS

Selections Involving Inequality (cont.)

Solution # 3: Estimate values in range

Example R

	Z
	Min=1 ↕ Max=20

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

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

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

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Size estimate for $W = R1 \bowtie R2$

Let x = attributes of R1

y = attributes of R2

$\boxed{\text{Case 1}}$

$X \cap Y = \emptyset$

Same as R1 x R2

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Size estimate for $W = R1 \bowtie R2$

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

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

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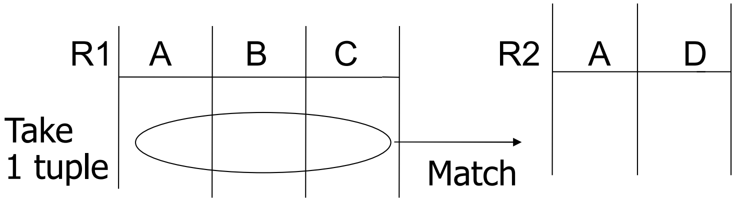
Size estimate for W = R1 ⋈ R2

Computing T(W) when V(R1,A) ≤ V(R2,A)



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

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

Size estimate for W = R1 ⋈ R2

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

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

In general:

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

In all cases:

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

Size estimate for W = R1 ⋈ R2

$\boxed{\text{Case 3}}$ W = R1 ⋈ R2 $|X \cap Y| > 1$

R1

A	B	C

R2

A	B	D

We can generalize the approach: The product of T(R1) and T(R2) is divided by the maximum of V(R1, K) and V(R2, K) for each attribute K that is common to R1 and R2

In the example above:

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

Size estimate for Equijoins

$$W = R1 \underset{A=D}{\bowtie} R2$$

R1

A	B	C

R2

D	E

The number of tuples can be calculated in a similar way as for a natural join.

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

Note, that the size of a tuple is different for an equijoin:

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

For Complex Expressions We Need Intermediate Values for T,S,V

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)

Problem: We also need V (U, *)

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 $V(U,C) = \frac{T(R1)}{V(R1,A)}$

V(U, D) somewhere in between

Estimates for Selections

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

V(U,A) = 1

V(U,X) = V(R,X) for $x \neq A$

“preservation of value sets”

Estimates 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)

also “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

Example

Partial Result: $U = R1 \bowtie R2$

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

$V(U,A) = 50$
$V(U,B) = 100$
$V(U,C) = 300$

$Z = U \bowtie R3$

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

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

Summary

Estimating size of results is an “art”

Prerequisite for estimates are statistics about the individual relations

- Statistics must be kept up to date