CS 245: Database System Principles

Notes 6: Query Processing

Hector Garcia-Molina

Query Processing

Q $\rightarrow$ Query Plan

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

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

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
.					
.					

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...

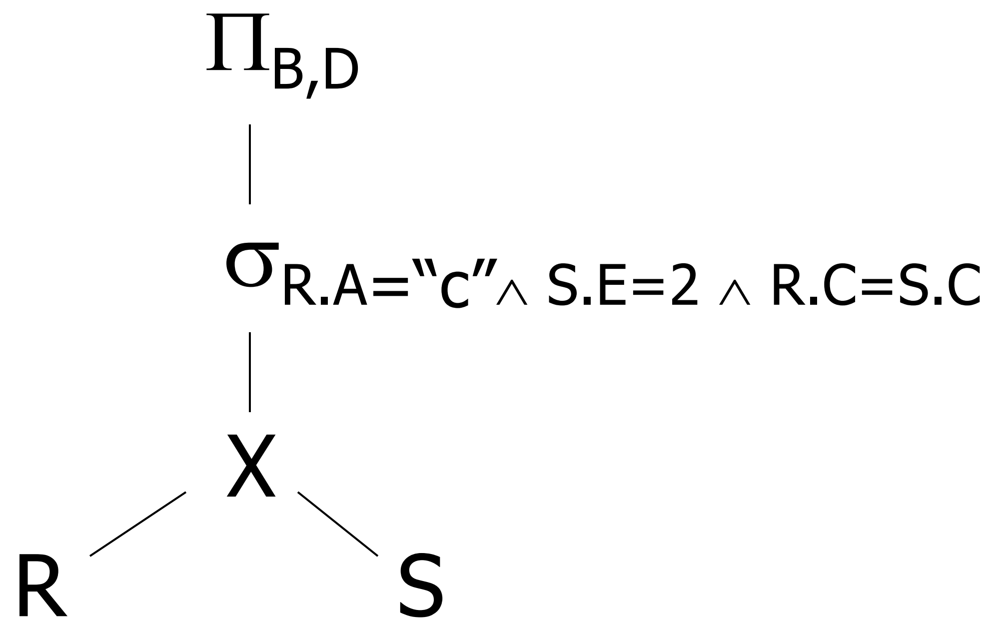
Relational Algebra - can be used to describe plans...

Ex: Plan I

$$
\begin{tikzcd}
 & \Pi_{B,D} \arrow[d, dash] & \\
 & \sigma_{R.A=\text{“c”} \wedge S.E=2 \wedge R.C=S.C} \arrow[d, dash] & \\
 & \times \arrow[dl, dash] \arrow[dr, dash] & \\
R & & S
\end{tikzcd}
$$

Relational Algebra - can be used to describe plans...

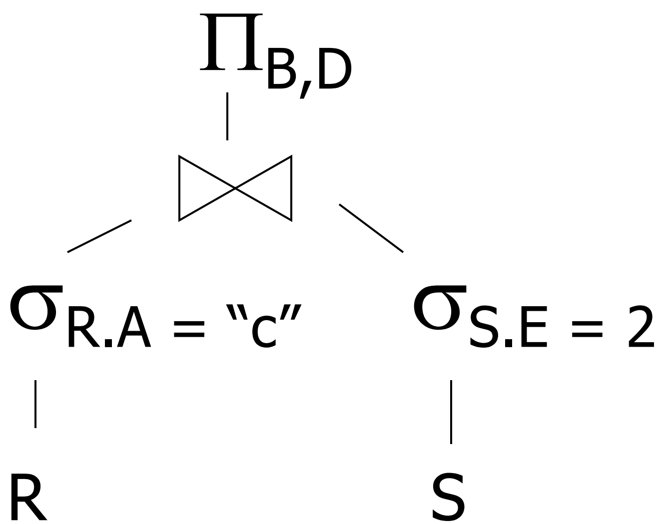
Ex: Plan I



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

Another idea:

Plan II



$\bowtie$ 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

Plan III

Use R.A and S.C Indexes

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

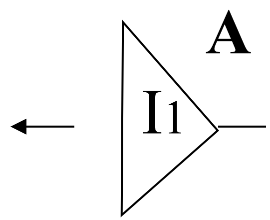
(2) For each R.C value found, use S.C index to find matching tuples

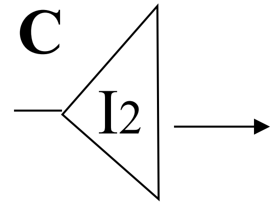
(3) Eliminate S tuples S.E $\neq$ 2

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

R

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



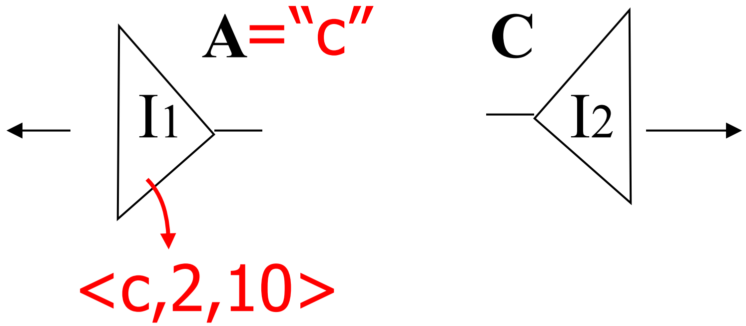


S

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

R

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

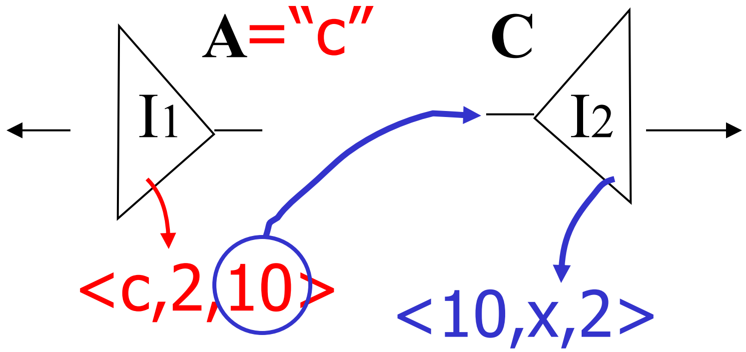


S

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

R

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

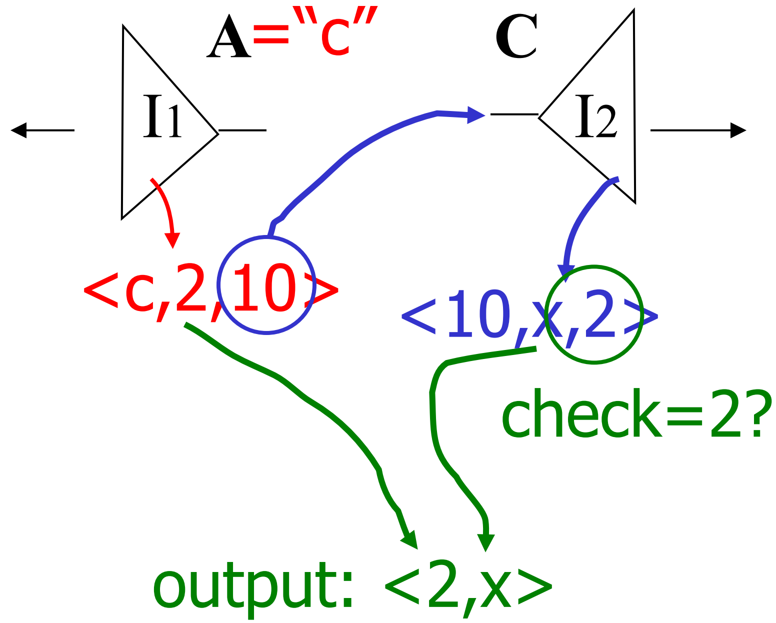


S

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

R

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

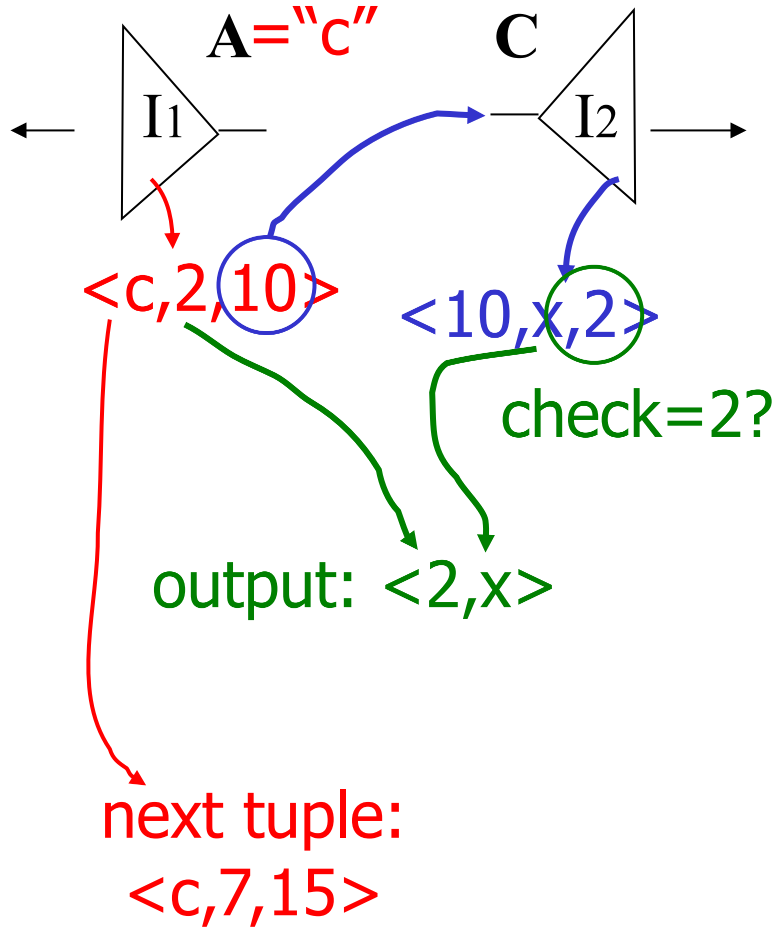


S

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

R

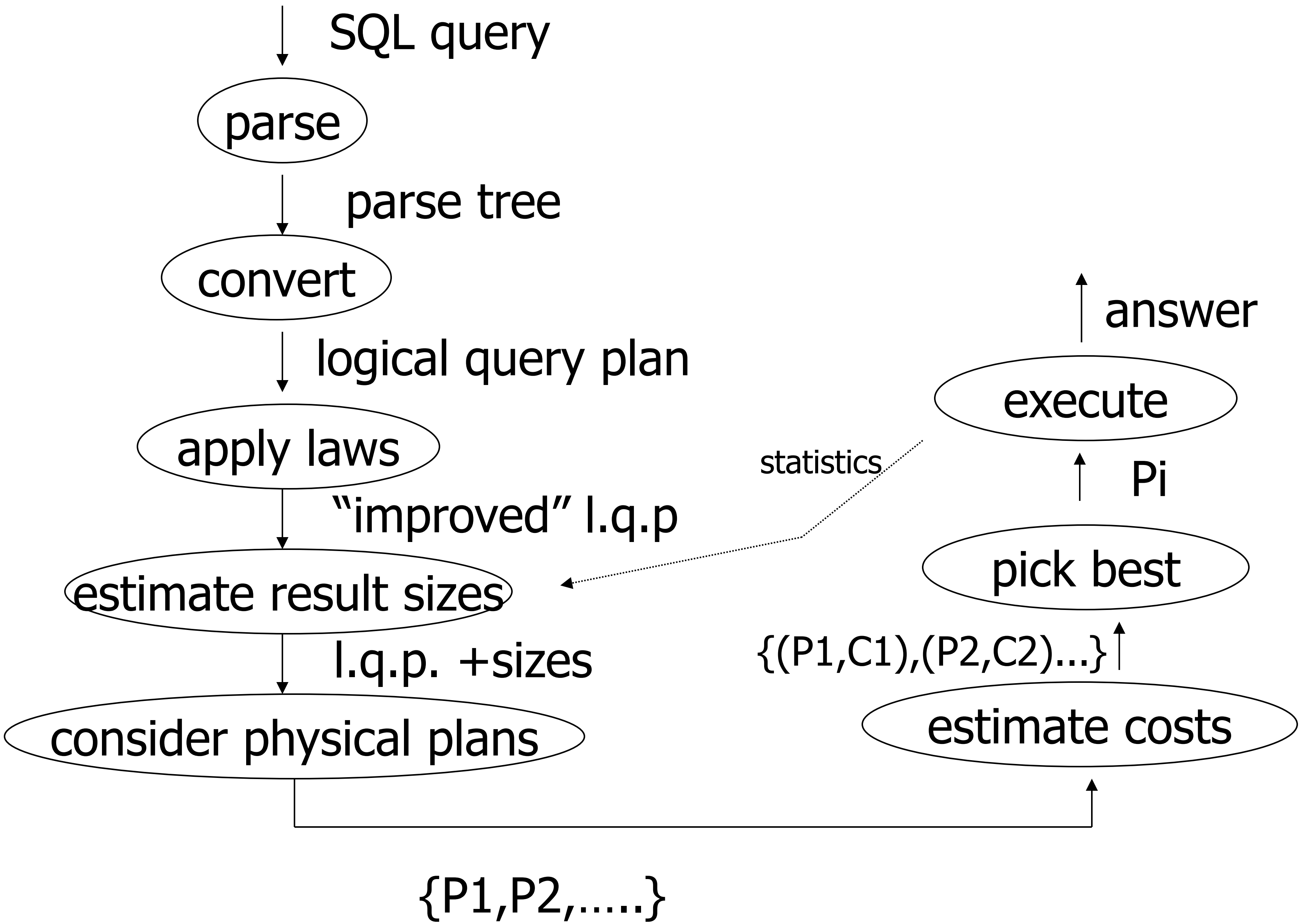
A	B	C
a	1	10
b	1	20
c	2	10
d	2	35
e	3	45



S

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

Overview of Query Optimization

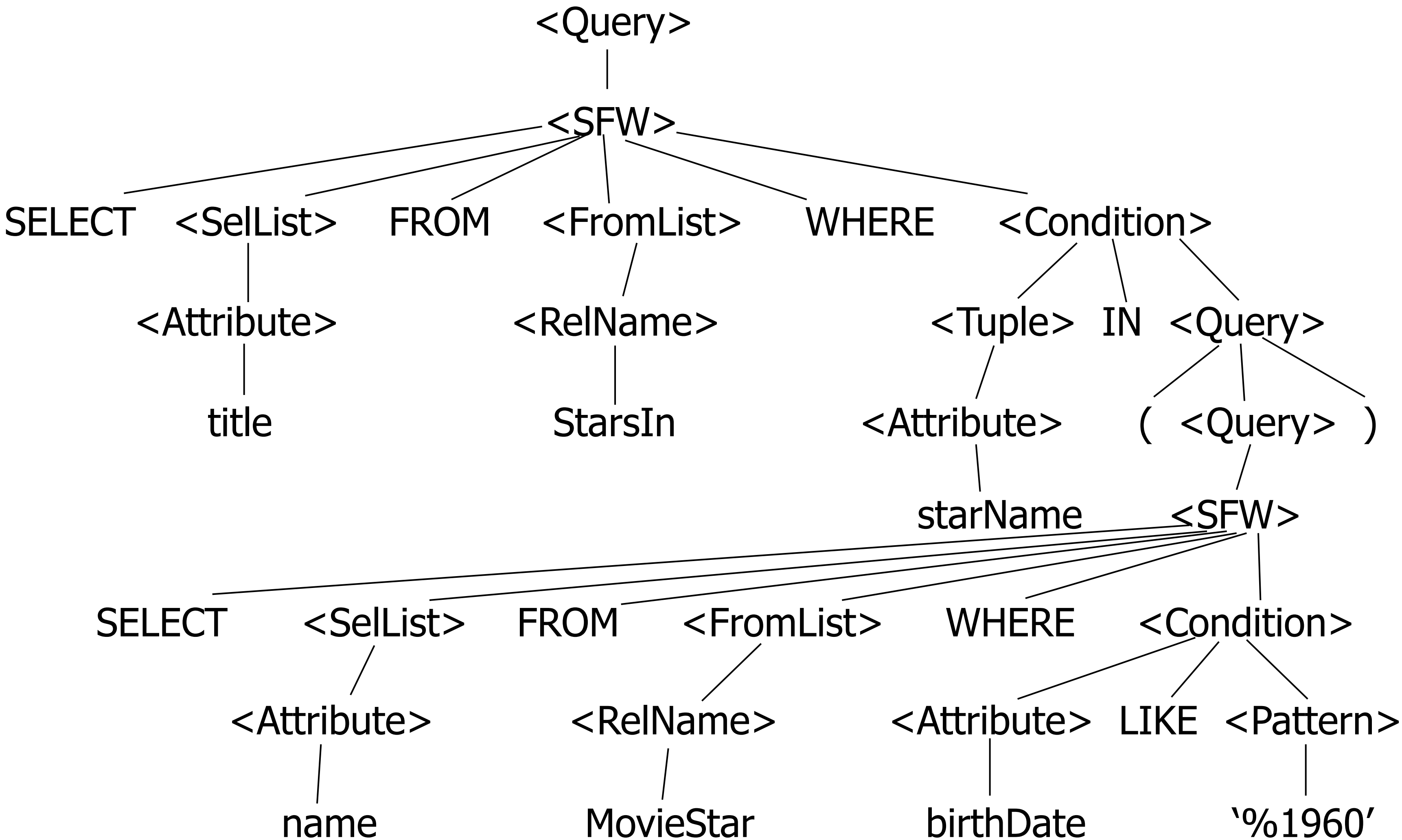

SQL query
parse
parse tree
convert
logical query plan
apply laws
"improved" l.q.p
estimate result sizes
l.q.p. +sizes
consider physical plans
{P1,P2,…..}
estimate costs
{(P1,C1),(P2,C2)...}
pick best
Pi
execute
answer
statistics

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

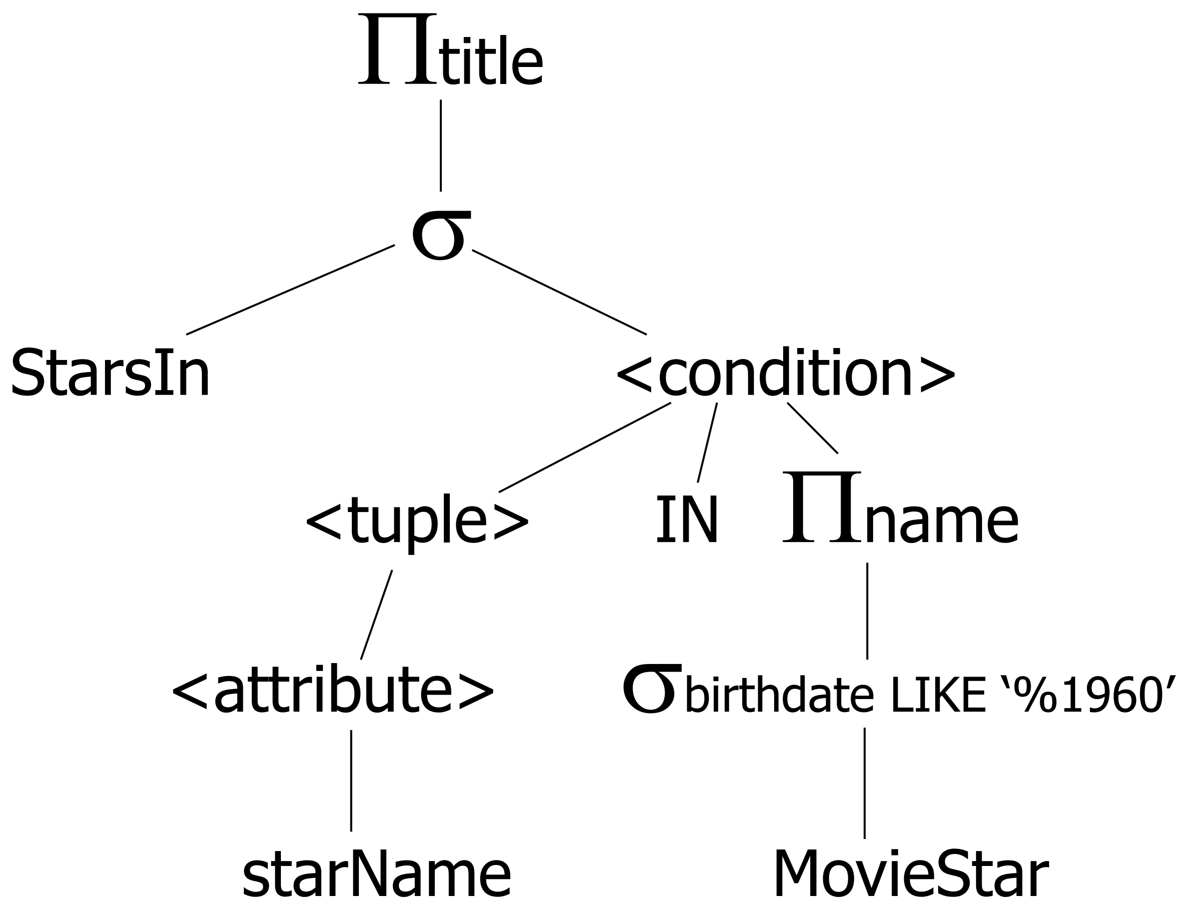


Fig. 7.15: An expression using a two-argument σ, midway between a parse tree and relational algebra

Example: Logical Query Plan

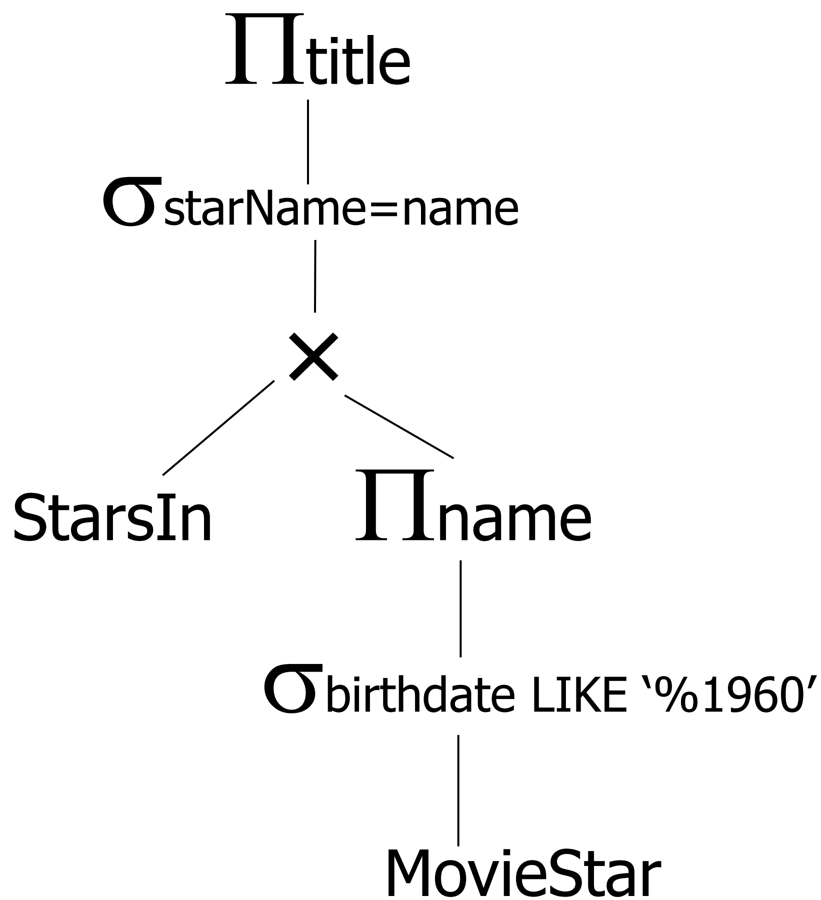
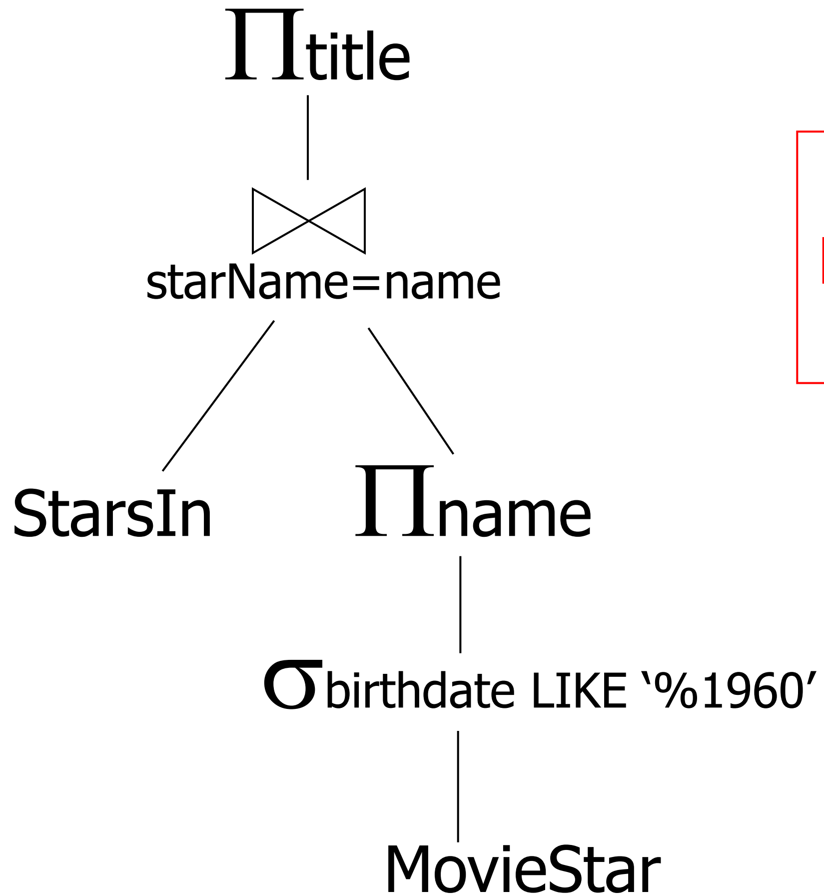


Fig. 7.18: Applying the rule for IN conditions

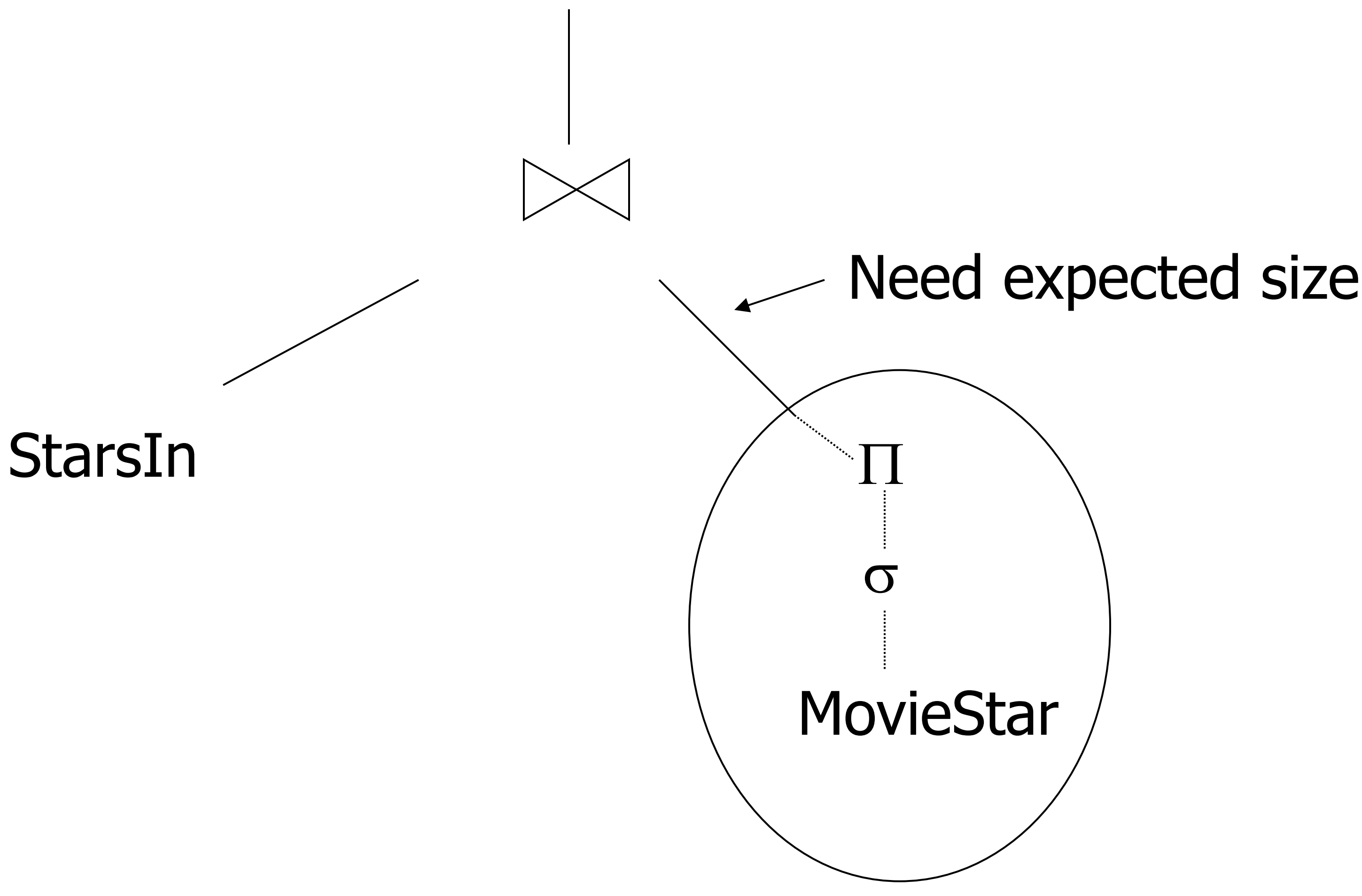
Example: Improved Logical Query Plan



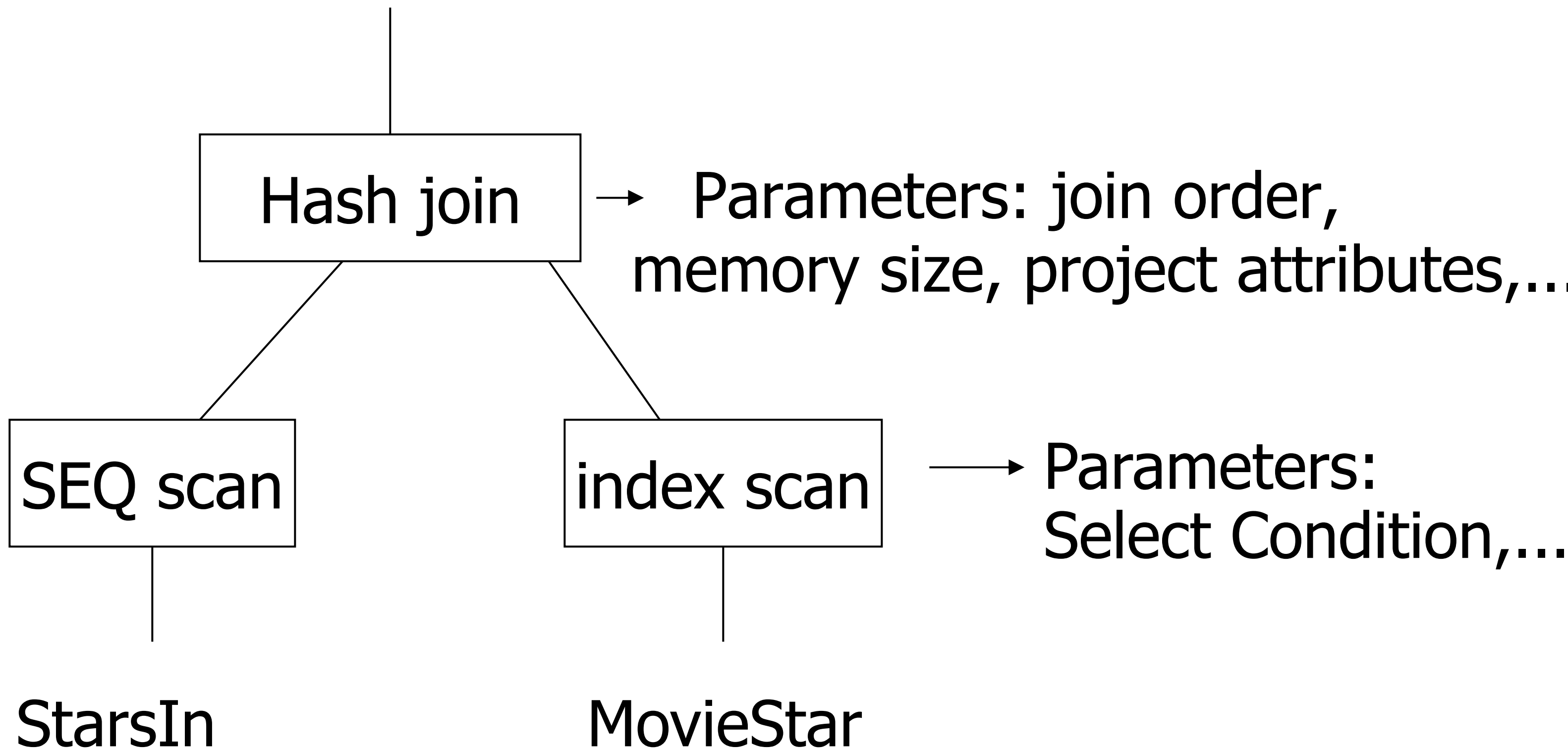
Question:
Push project to
StarsIn?

Fig. 7.20: An improvement on fig. 7.18.

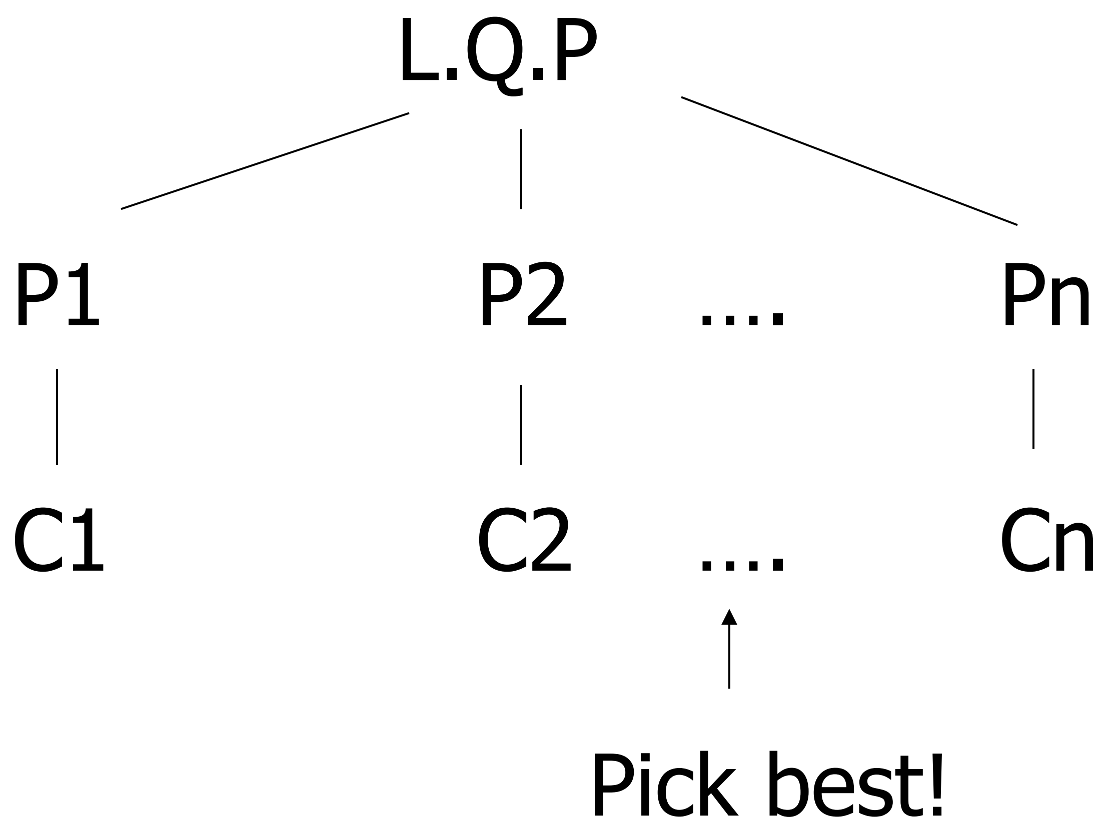
Example: Estimate Result Sizes



Example: One Physical Plan



Example: Estimate costs



Textbook outline

Chapter 15

5 Algebra for queries [bags vs sets]

[Ch 5]

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

15.1 Physical operators

[15.1]

- Scan,sort, …

15.2 - 15.6 Implementing operators + estimating their cost

[15.2-15.6]

Chapter 16

16.1[16.1]	Parsing
16.2[16.2]	Algebraic laws
16.3[16.3]	Parse tree -> logical query plan
16.4[16.4]	Estimating result sizes
16.5-7[16.5-7]	Cost based optimization

Reading textbook - Chapters 15, 16

Optional:

- Sections 15.7, 15.8, 15.9 [15.7, 15.8]
- Sections 16.6, 16.7 [16.6, 16.7]

Optional: Duplicate elimination operator
grouping, aggregation operators

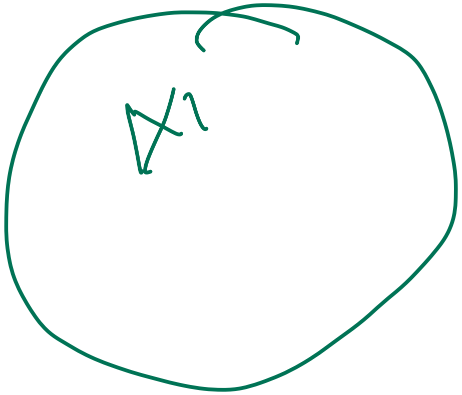
Query Optimization - In class order

- Relational algebra level
- Detailed query plan level

Heuristic QO

$\bowtie \quad \sigma \quad \pi$

Naive



Query Optimization - In class order

- 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?

$\alpha \text{ (op) } \beta = \text{op}(\alpha)\ \beta$

Same result

Rules: Natural joins & cross products & union

$R \bowtie S = S \bowtie R$

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

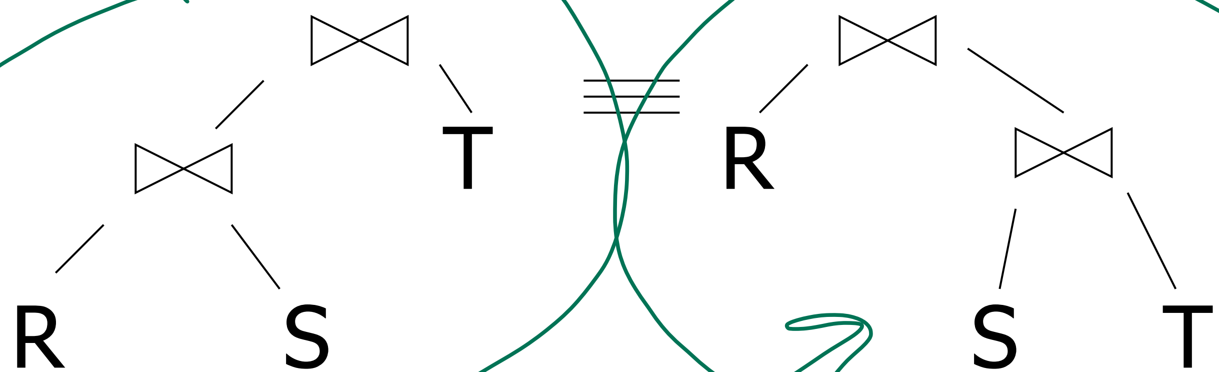
Commutative

$R \bowtie S = S \bowtie R$

Note:

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

$R \bowtie S \bowtie T$



Rules: Natural joins & cross products & union

$R \bowtie S = S \bowtie R$

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

$R \times S = S \times R$

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

$R \cup S = S \cup R$

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

$\cup$
$\cap$
$\bowtie$
$\times$

Commutative
Associative
work

Rules: Selects

$\sigma_{p1 \wedge p2}(R) =$? $\sigma_{p_1}(\sigma_{p_2}(R))$ Cascade $\sigma_{p_1 \wedge p_2}(R \bowtie S)$

$\sigma_{p1 \vee p2}(R) =$ $\Rightarrow$ $\sigma_{p_1}(R) \cup \sigma_{p_2}(R)$

Union

Rules: Selects

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

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

Bags vs. Sets

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

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

RUS = ?

SUM Union

aa bbbbb ccc d

MAX Union

aa bbb cc d

SQL DISTINCT

bag set

Select SSN

Union

Select SSN

(bag)

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

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:

LS

Senators (……)

RS

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?

Q

Sum / MAX ?

Same Senators are diff'nt

Executive Decision

Explicit

SUM

MAX

-> 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

$\pi_{xy}(R) = \pi_x \, \pi_y (R)$

Rules: Project

Let: X = set of attributes

Y = set of attributes

XY = X U Y

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

In general No

$X \subseteq Y$

Rules: Project

Let: X = set of attributes

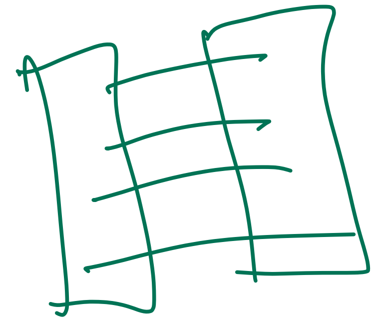
Y = set of attributes

XY = X U Y

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

$X \subseteq Y(R)$

Concatenate



Rules: $\sigma + \bowtie$ combined

Let p = predicate with only R attribs

q = predicate with only S attribs

m = predicate with only R,S attribs

$\sigma_p \, (R \bowtie S) =$ $\quad \sigma_p(R) \bowtie S.$

$\sigma_q \, (R \bowtie S) =$ $\quad R \bowtie \sigma_q(S).$

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: σ + $\bowtie$ combined (continued)

Some Rules can be Derived:

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

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

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

Do one, others for homework:

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

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

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

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

$$\sigma_p(R \bowtie S) \cup \sigma_q(R \bowtie S)$$

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

--> 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)

$\pi_x[\sigma_p(R)] =$

$\sigma_p(\pi_x(R))$

$= \sigma_p(\pi_{xz}(R))$

$R(a_1 \ldots a_n)$

$x \subset (a_1 \ldots a_n)$

$z \subset (a_1 \ldots$

$z \subseteq x$

True

in general false

$x \cap z = \emptyset$

Rules: π, σ combined

Let x = subset of R attributes

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

$$\pi_x[\sigma_p(R)] = \qquad \{\sigma_p[\cancel{\pi_x}(R)]\}$$

Rules: π,σ combined

Let x = subset of R attributes

z = attributes in predicate P

(subset of R attributes)

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

1 2

Rules: π, $\bowtie$ combined

Let x = subset of R attributes

y = subset of S attributes

z = intersection of R,S attributes

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

$\pi_{Lname,\,Pname}(E \bowtie_{SSN=ESSN} P) = \pi_{Lname}\left[\pi_{Lname,\,SSN}(E) \bowtie_{SSN=ESSN} \pi_{ESSN,\,Pname}(P)\right]$

Rules: π, $\bowtie$ combined

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

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

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

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

$$\pi_{xz}(\sigma_p(R)) \bowtie (\pi_{yz}(S))$$

$$\pi_{xy}\left\{\sigma_{p}\left(R \bowtie S\right)\right\} =$$

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

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

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

Rules for σ, π combined with X

similar...

e.g., σ_p (R X S) = ?

$\sigma \quad \pi$

$\times$

X, σ, π, $\cup$, $-$

<u>Rules</u> 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?

- $\sigma_{p1 \wedge p2}(R) \rightarrow \sigma_{p1}[\sigma_{p2}(R)]$ ✓
- $\sigma_{p}(R \bowtie S) \rightarrow [\sigma_{p}(R)] \bowtie S$ ✓
- $R \bowtie S \rightarrow S \bowtie R$?
- $\pi_{x}[\sigma_{p}(R)] \rightarrow \pi_{x}\{\sigma_{p}[\pi_{xz}(R)]\}$ ✓

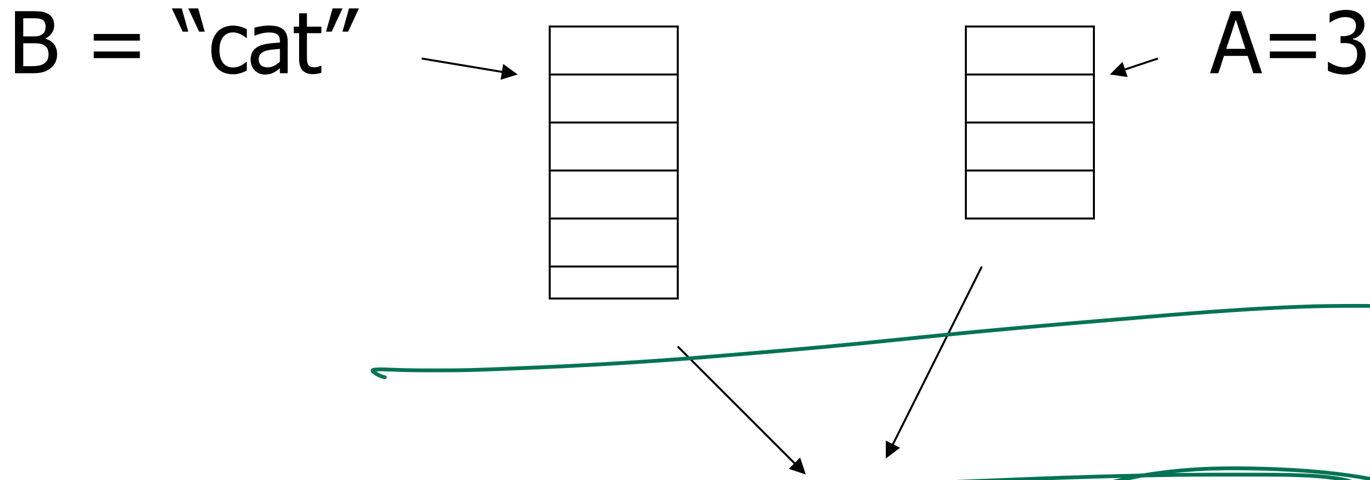
Conventional wisdom:
do projects early

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

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

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

$\boxed{\text{But}}$ 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

In textbook: more transformations

- Eliminate common sub-expressions
- Other operations: duplicate elimination

Outline - Query Processing

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

12

R

K1	A	B	FK
1	a1	b1	a
2	a1	b2	a
3	a2	b3	b
4	a3	b4	c

S

K2	C	D	E
a	b5	a1	e1
b	b1	a1	e2
c	b6	a1	e3.

R 4 row

S 3 row

$\pi_{K_1, K_2}(R \bowtie S)$

R.FK = S.K

1	a
2	a
3	b
4	c

4 row

R.B = S.C

1 row

12

1	b

R.A = S.D

6 Rows

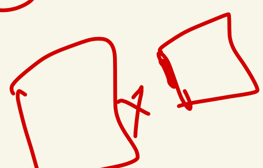
1, 4, 6,

R ⋈ S

$(R \bowtie S)$ → No. of rows in results is not empty

$|R|$, $|S|$, $(R \times S)$

Mini Cartesian product



m a

A

n a

B

= $m \times n$

$R \bowtie S$ unless I result Cardinality

Card$(R \bowtie S)$

Many

Multi

A.value R

Estimate of relational op result size

$T(R)$ # of tuples in a Relation

$T(\Pi_{X}(R)) = T(R)$ $\quad T(R).$

$\leq T(R)$

$T(\sigma_{C}(R)) = ?\; T(R)$

$\ll T(R)$

Estimate the number of rows

$$T\left(\Pi_A\left(\sigma_{c_1}(R) \bowtie \sigma_{c_2}(S)\right) \bowtie \sigma_{c_3}(T)\right)$$

?

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

Π What is the useful entity

← useful

Accurate

- Estimating cost of query plan

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

(2) Estimating # of IOs

rows in rel

$\left\lceil \frac{n}{bfr} \right\rceil$

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

$\sqrt{(R, A)} \rightarrow$

$T(R)$ $\quad V(R, A)$ $\quad B_R$ 300 $\quad$ 60,000

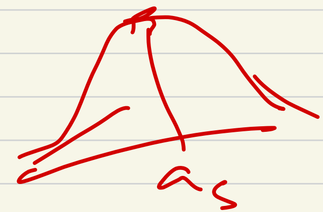
$\overline{1000}$

$V(R, A) = 10$

$a_1 \quad a_2 \ \ldots \ a_n$

$$1000 = \sum_{i=1}^{10} T(\sigma_{A=a_i}(R)) \quad T(\sigma_{A=a_i}(R)) \quad a_2 \quad 200$$

$T(\sigma_{A=a_2}(R))$



a_5

100

990

$\sigma_{A=a_{20}}$

$A=a_5$

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

A: 20 byte string

B: 4 byte integer

C: 8 byte date

D: 5 byte string

$T(R) = 5$

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

A: 20 byte string

B: 4 byte integer

C: 8 byte date

D: 5 byte string

Stats of R

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

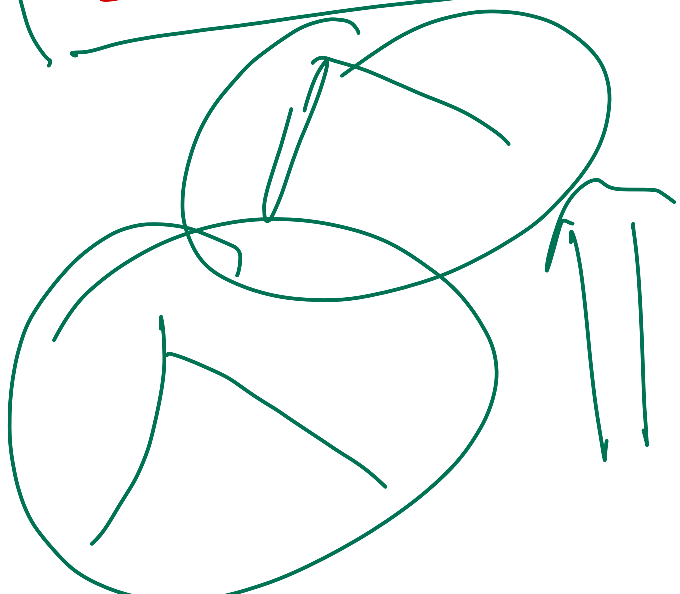
R1 X R2

T(W) = T(R1) x T(R2)

S(W) = $\boxed{S(R1) + S(R2)}$

$\sigma_{A=a}$

$\sigma_{(A=a \wedge B=5 \wedge C=c)}$



|||r

Size estimates for W = R1 x R2

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

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

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

$S(W) = S(R)$

$T(W) = ?$

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

$$\boxed{T(W) = \frac{T(R)}{\mathrm{Dom}(R, A)}}$$

$V(R, A) \lesssim \mathrm{Dom}(R, A)$

Conservative estimate

$\exists\, v \in \mathrm{Dom}(R, A)$

$v \notin V(R, A)$

will ommit at least one row with $\underline{A = v}$

DOM(R,A)

$a \in \mathrm{Dom}(A)$ Maximum number of values A can take.

$a \in V(R, A)$

$V(R, A)$

in R A has $V(R, A)$ default value

$$\frac{T(R)}{Dom(R,A)}$$

Each value of domain occurs uniformly in R

$$Dom(R,A) = 20$$

$$T(R) = 1000,$$

$$\frac{T(R)}{Dom(R,A)} = \frac{1000}{20} = 50$$

$$T(W) = 50$$

$$W = \sigma_{A=a}(R),$$

one value $A = 125$ w/ max

$$\frac{T(R)}{V(R,A)} = \frac{1000}{8} = 125$$

$$V(R,A) = 8$$

we may get realistic estimate

$$T(W) = 125 = 2.5 \times 50$$

How wrong?

$\Downarrow$

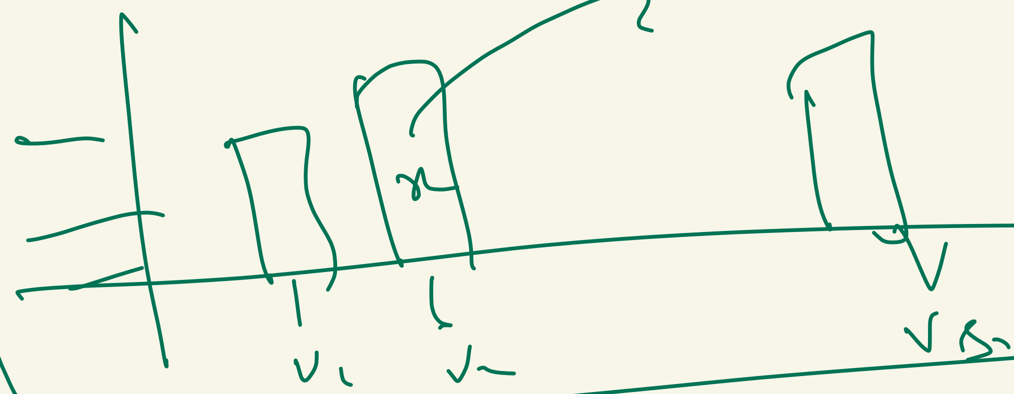
$V(R, A)$ stronger

$DOM(R, A)$ is weaker estm

$$W = \sigma_{A=val}(R)$$

$$T(W) = \frac{T(R)}{V(R, A)} \quad (i)$$

accurate estimate (R)



$\frac{x}{\text{Not ~~there~~}}$

In many scenarios (A)

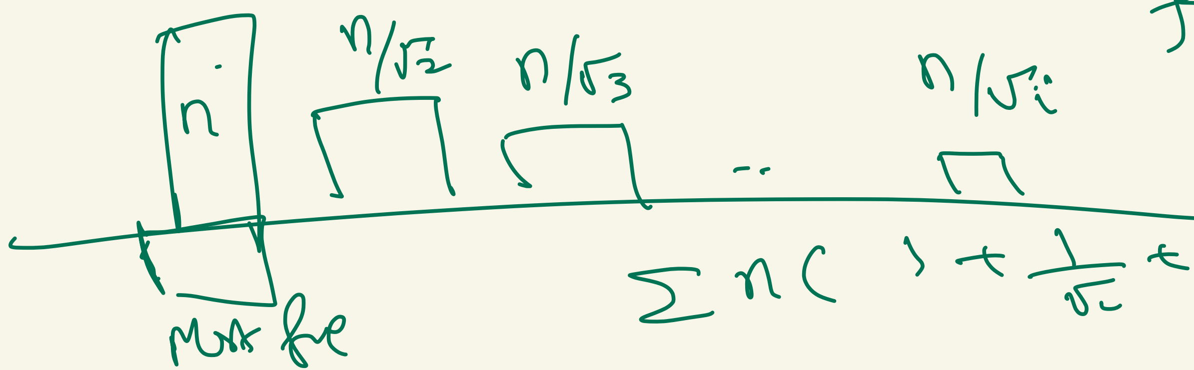
one value large

tail

Zipfian distribution

i^{th} most common value $\frac{1}{\sqrt{i}}$ times.

for the first value n

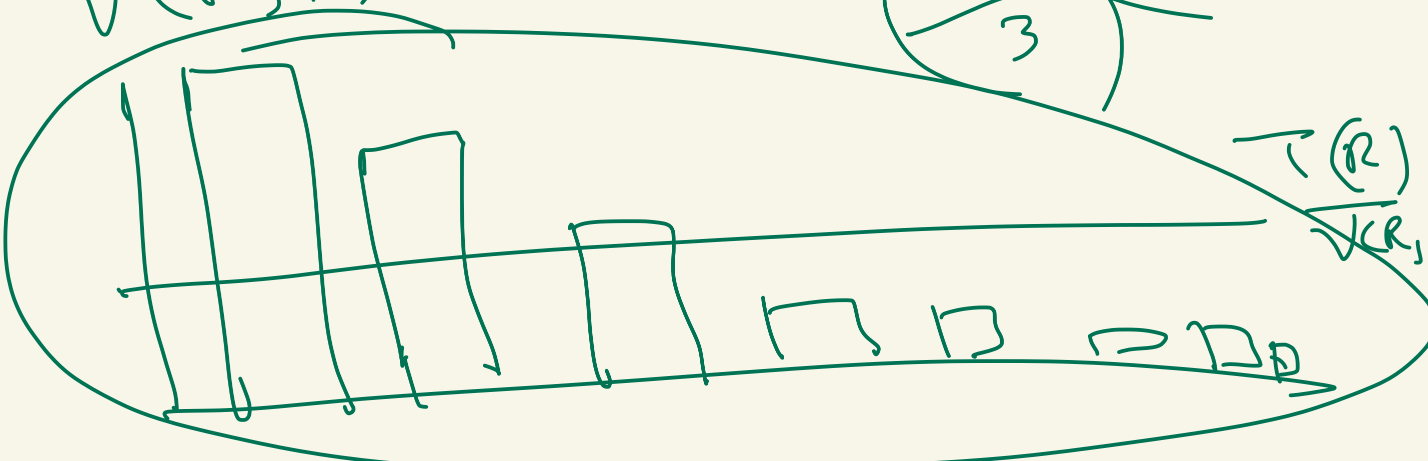


$$\sum n \left(1 + \frac{1}{\sqrt{2}} + \frac{1}{\sqrt{3}} + \dots \right)$$

$$\frac{1000}{} \qquad \frac{1000}{\sqrt{2}} = 707 \qquad \frac{1000}{\sqrt{3}} = 577$$

$$\frac{T(R)}{V(R,A)}$$

estimate $\left(\frac{T(R)}{2}\right)$ $\frac{T(R)}{3}$



$$W = \sigma_{A \geq val}(R) \qquad T(W) = \frac{T(R)}{2}$$

Inclined in humans to not get more rows

$$T(W) = \frac{T(R)}{3}$$

$T(R) = 1000$

$V(R, A) = 10$

$V(R, B) = 5$

$$W = \sigma_{A \geq val \text{ AND } B = x}(R)$$

$$= \frac{T(R)}{(A \geq val)} \times \frac{1}{(B = x)} = \frac{1000}{3 \times 5} = \frac{\cancel{1000}\ 200}{\cancel{15}\ 3}$$

$= 66$

$P(A \wedge B)$

AWP 7

$W = \neg\left((A = val) \text{ or } (B = val)\right)(R)$

$1 - (A = val)$

$A \neq val$

$\left(1 - \left(1 - (A \neq val)\right)\left(1 - (B \neq val)\right)\right)$

$$T(W) = \left(1 - \left(1 - \frac{m_1}{n}\right)\left(1 - \frac{m_2}{n}\right)\right) T(R)$$

$T(R)$

m_1 $A = val$

m_2 $B = val$

See later slide

$$= \left(1 - \left(1 - \frac{900}{1000}\right)\left(1 - \frac{800}{1000}\right)\right) 1000$$

$$= \left(1 - \left(\frac{100}{1000} \times \frac{200}{1000}\right)\right) 1000$$

$$= 1000 - 20 = 980$$

$A = val$

$$1 - \left(\frac{A \neq val}{n}\right)$$

σ_c

$\sigma_{c_1 \text{ AND } c_2}$

$\sigma_{c_1 \text{ OR } c_2}$

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

V(R,A)=3

V(R,B)=1

V(R,C)=5

V(R,D)=4

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

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

$V(R,A)=3$

$V(R,B)=1$

$V(R,C)=5$

$V(R,D)=4$

what is probability this tuple will be in answer?

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

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

$V(R,A)=3$

$V(R,B)=1$

$V(R,C)=5$

$V(R,D)=4$

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

$$\boxed{T(W) = \frac{T(R)}{V(R,Z)}}$$

Assumption:

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

Alternate Assumption:

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

Car Make

Color

weather

Dom(Color)

~1,000

~2,000

$V(R,A) \leq DOM(R,A)$

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

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

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

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

what is probability this tuple will be in answer?

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

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

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

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

Selection cardinality

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

$$SC(R,A) = \begin{cases} \dfrac{T(R)}{V(R,A)} & \checkmark \\[2ex] \dfrac{T(R)}{DOM(R,A)} & \times \end{cases}$$

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

$T(W) = ?$

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

$T(W) = ?$

- Solution # 1:

  $T(W) = T(R)/2$

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

$T(W) = ?$

- Solution # 1:

  $T(W) = T(R)/2$

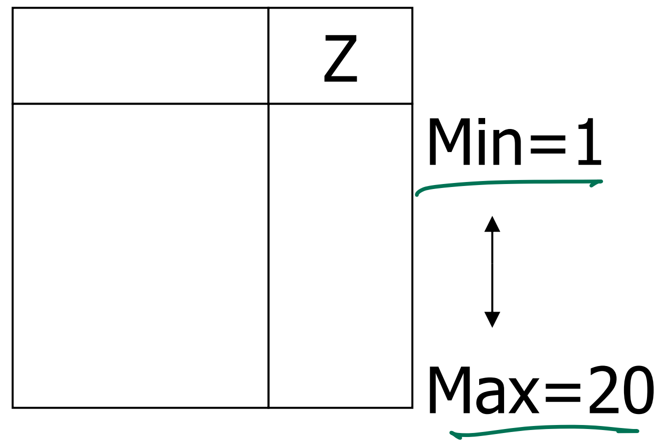
- Solution # 2:

  $T(W) = T(R)/3$

Humm includes to reduce query cost

- Solution # 3: Estimate values in range

Example R



$V(R,Z)=10$

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

- Solution # 3: Estimate values in range

<u>Example</u> R

	Z

Min=1

Max=20

$V(R,Z)=10$

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

15

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

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

15

20

A ≥ Val

Val ... max

how many vals in V(R,A)

V(R,A)

A > 2, And A in (- - -)

Equivalently:

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

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

✓ $R \bowtie S \bowtie T \bowtie U$ ~ $4!$ =

✓ $R \bowtie T \bowtie S \bowtie U$ — Join order

$((R \bowtie_1 U) \bowtie_2 T) \bowtie_3 S$ — left deep

I_1

I_2

R,

I_1 is very small

I_2, R

$R \bowtie T \quad T \bowtie S \quad S \bowtie U \quad U \bowtie R \; - \; - \; \cdot$

relation t_2

$\Downarrow$

$\boxed{}$ smallest

Estimate $W = R \bowtie S \quad T(W)$?

$R \bowtie_A S$

$V(R,A)$ R

$V(S,A)$

(A) is

Two Assumptions

Containment of Value set:

Y occurs in $R_1, R_2, \ldots, R_k$

$R_i \quad y_1 \; y_2 \; \cdots \; y_j$

dom(Y)

$V(R_i, Y)$

$R_i \quad R_j$

$x \in Y$ in R_i

$x \in Y$ in R_j

$V(R_i, Y) \leq V(R_j, Y)$

fewer values

Dom(R_j, Y)

Dom(R_j, Y)

$R_1 \qquad R_2 \qquad\qquad R_K$

$V(R_1, Y) \leq V(R_2, Y) \leq \qquad \leq V(R_K, Y)$

$S_1 \subseteq S_2 \qquad \subseteq S_K$

$PK = FK$

$S_{FK} \subseteq (S_{PK})$

A is join attribute

R B is an attribute of R.

$$V(R, B)$$

\# of distinct values of tuples in R.

$$V(R, A)$$

$$W = R \bowtie_A S$$

$$V(W, A) = V(R, A)$$

R does not loose any value of JA ~~after~~ the join.

$$W = R \bowtie_A S$$

$$\left(S\left(\pi\left(R, A\right)\right)\right) \wedge \left(S\left(\pi\left(S, A\right)\right)\right) = \phi$$

$R \bowtie S$

Color Cars — Color Cars — Toyota

Honda = =

$$T(W) = \phi.$$

$$\left(R \bowtie (S)\right) = T(S)$$

PK. $\underline{PK = FK}$ FK.

deleted with FK

$$\text{Set of } (S) \subseteq \text{Set of } (R)$$

S.FK is one value ϕ.

$$S = \sigma_{C_1 \text{ or } C_2}(R)$$

$$\neg\left(\neg(C_1) \text{ AND } \neg(C_2)\right)$$

$$1 - (\;\;)$$

Independent

$A = C_1 \qquad B = C_2$

$$T(R) = 1000\left(1 - \left(1 - \frac{\text{Value}}{T(R)}\right)\left(1 - \frac{\text{Value}}{T(R)}\right)\right)$$

$$1000\left(1 - \left(1 - \frac{100}{1000}\right)\left(1 - \frac{200}{1000}\right)\right)$$

$$1000\left(1 - \left(\frac{900}{1000}\right)\frac{800}{1000}\right)$$

$$1000 - 720 = \boxed{280}$$

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

if each row of R joins with each row of S & vice-versa

R, $T(R)$

$V(R,A)$.

S, $T(S)$

$V(S,A)$

$$\boxed{\frac{T(R)}{V(R,A)}}$$

$$\frac{T(S)}{V(S,A)}$$

$V(R,A) \leq V(S,A)$

$\in$

$$\frac{T(R)}{V(R,A)}$$

$$\frac{T(S)}{V(S,A)}$$

one which has more values dominates

R

S

$\frac{T(S)}{V(S,A)}$

$V(S,A) - V(R,A)$

$\boxed{\equiv}$

$V(S,A) > V(R,A)$

$\frac{T(R)}{T(R,A)}$

$$\frac{T(R) \cdot T(S)}{V(R,A)} > \frac{T(R) \cdot T(S)}{V(S,A)}$$

$V(S,A) > V(R,A)$

$$T(R \bowtie S) = \frac{T(R) \cdot T(S)}{\max(V(R,A), V(S,A))}$$

$$R \bowtie_A S$$

$$T(R \bowtie_A S) = \frac{T(R) \cdot T(S)}{\max(V(R,A),\, V(S,A))}$$

$$R \bowtie_{A,B} S$$

R.A = S.A AND
R.B = S.B.

$$= \frac{T(R) \cdot T(S)}{\max(V(R,A),\, V(S,A)) \cdot \max(V(R,B),\, V(S,B))}$$

$R(a,b)$ $\quad S(b,c)$ $\quad U(c,d)$

$T(R) = 1000$ $\quad T(S) = 2000$ $\quad T(U) = 5000$

$V(R,b) = 20$ $\quad V(S,b) = 50$ $\quad \cancel{V}(U,b) = 100$

$V(S,c) = 100$ $\quad V(U,c) = 500$

$V(R \bowtie S, c) = 100$

$T(R \bowtie_b S \bowtie_c U)$

$$T(R \bowtie_b S) = \frac{T(R) \cdot T(S)}{\max(20, 50)} = \frac{1000 \times \cancel{2000}^{40}}{\cancel{50}} = 40{,}000$$

$$T((R \bowtie_b S) \bowtie_c U) = \frac{40{,}000 \times 5000}{\max(100, 500)}$$

$$= 40{,}0000$$

$(S \bowtie_c U) \bowtie_b R)$

$$\frac{200 \times 50\cancel{0}\cancel{0}}{5\cancel{0}\cancel{0}} = 20,000$$

$$\frac{1000 \times \overset{400}{\cancel{2000}}}{\cancel{5}\cancel{0}} = 600,000$$

Size estimate for $W = R1 \bowtie R2$

Let x = attributes of R1

y = attributes of R2

$R(a, b), \quad S(b, c), \quad U(b, d)$

$$(R \bowtie_b S)$$

$$V(R \bowtie_b S, b) = \min \left(V(R, b), V(S, b) \right)$$

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

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

R1

A	B	C

R2

A	D

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

R1

A	B	C

R2

A	D

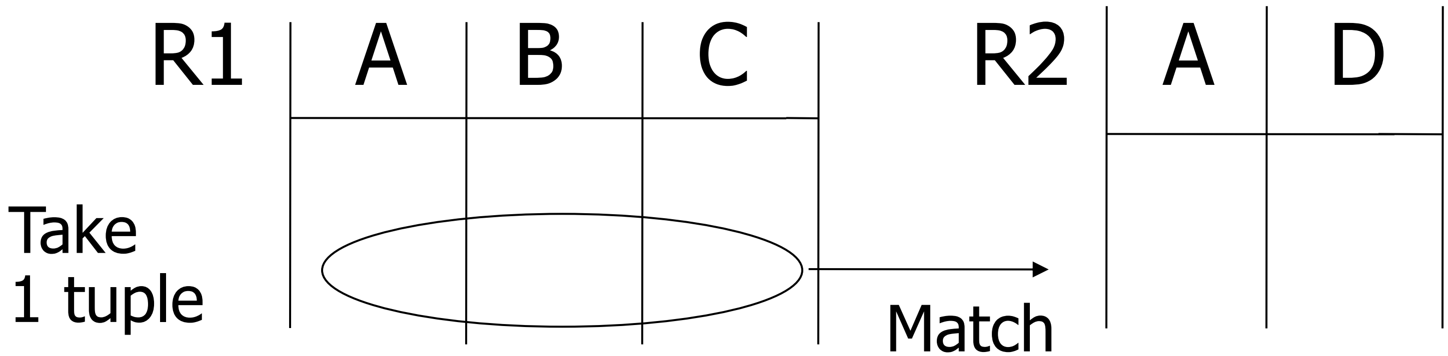
<u>Assumption:</u>

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

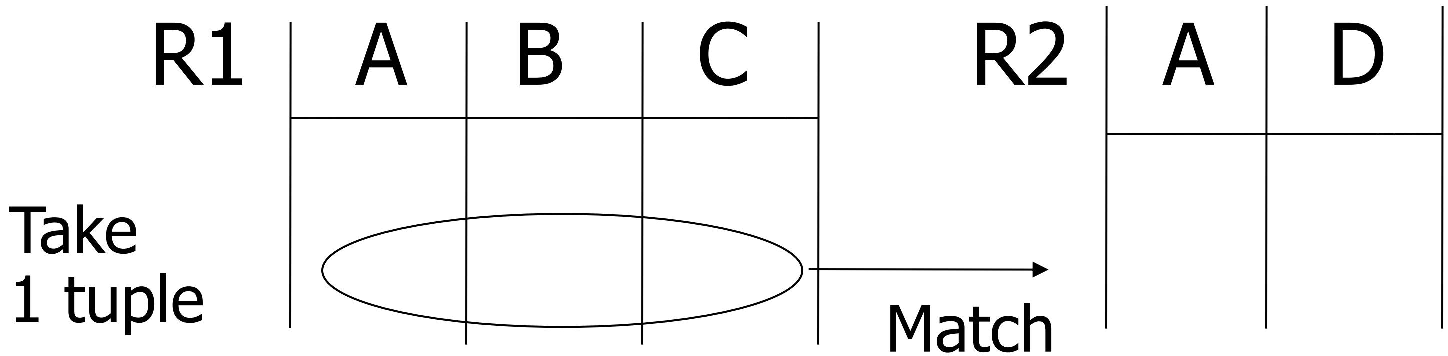
$V(R2,A) \leq V(R1,A) \Rightarrow$ Every A value in R2 is in R1

"containment of value sets" Sec. 7.4.4

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



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



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

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

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

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

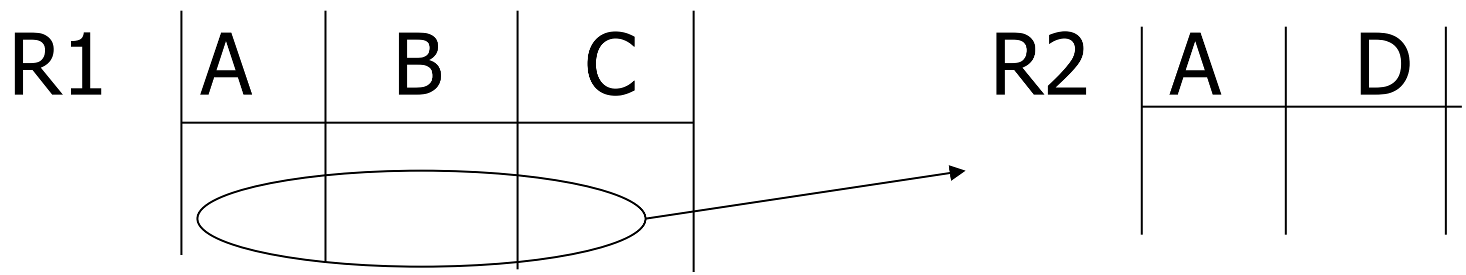
[A is common attribute]

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

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

$\boxed{\text{Case 2}}$ with alternate assumption

Values uniformly distributed over domain



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) ..... Sec. 16.4.2 (same for either edition)

$\sigma_{A=a \wedge B=b}$ (R) .... Sec. 16.4.3

R $\bowtie$ S with common attribs. A,B,C
Sec. 16.4.5

Union, intersection, diff, ...
Sec. 16.4.7

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)

Treat as relation U

$T(U) = T(R1)/V(R1,A)$ $\quad$ $S(U) = S(R1)$

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

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

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(D,U) ... somewhere in between

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

$V(U,A) = 1$

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

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

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

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

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

[called “preservation of value sets” in section 7.4.4]

Example:

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

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

Partial Result: $U = R1 \bowtie R2$

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

$V(U,A) = 50$

$V(U,B) = 100$

$V(U,C) = 300$

$$Z = U \bowtie R3$$

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

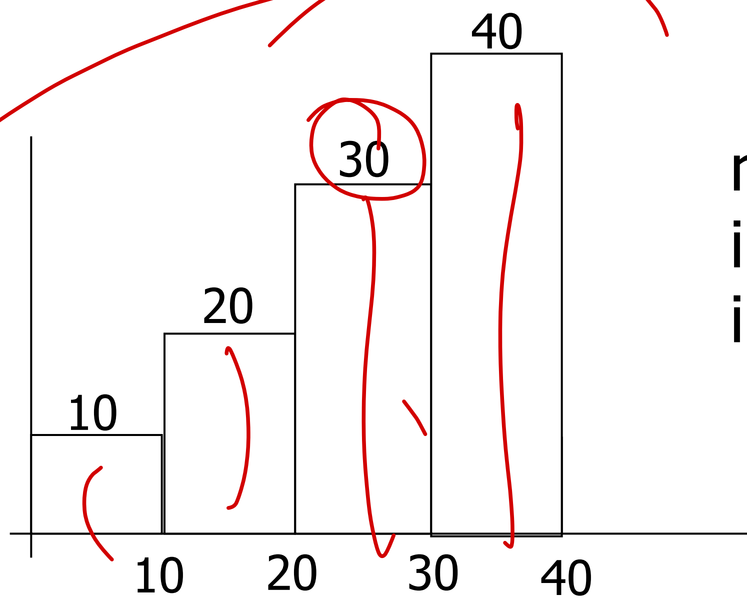
$V(Z,A) = 50$

$V(Z,B) = 100$

$V(Z,C) = 90$

$V(Z,D) = 500$

A Note on Histograms



number of tuples in R with A value in given range

$\sigma_{A=val}(R) = ?$

A = 30 — 30

A = 60 = 10

Summary

$U(R, A)$

$A \leftarrow R$

- 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 ← next…
- Generate and compare plans

$\sigma_{(A=val)} R \bowtie_{K_1} \sigma_{(B=val)} S \bowtie_{K_2} \sigma_{(C=val)} T \bowtie_{K_3} \sigma_{(d=val)} U$

$V(R, K_1) = V(R_1, K_1)$

$R_1 \bowtie_{K_1} S_1 \bowtie_{K_2} T_1 \bowtie_{K_3} U_1$

Index: A, B, C, D

R	S	T	U
Index	Ind	Ind	Ind
R_1	S_1	T_1	U_1

R_1


R1
Indn
σ A=val
R
S1
Indn
σ B=val
S
T1
Indn
σ C=val
T
U1
Indn
σ D=val
U

1	R	S	T	U
Q2	between nodes	linear		
	R_1	S_1	T_1	U_1

R_1 $\quad S_1$ $\quad T_1$ $\quad U_1$

$R_1 \bowtie S_1$ $\quad R_1 \bowtie T_1$ $\quad \cancel{R_1 \bowtie U_1}$ Cartesian product

lhs outer $\quad$ rhs inner

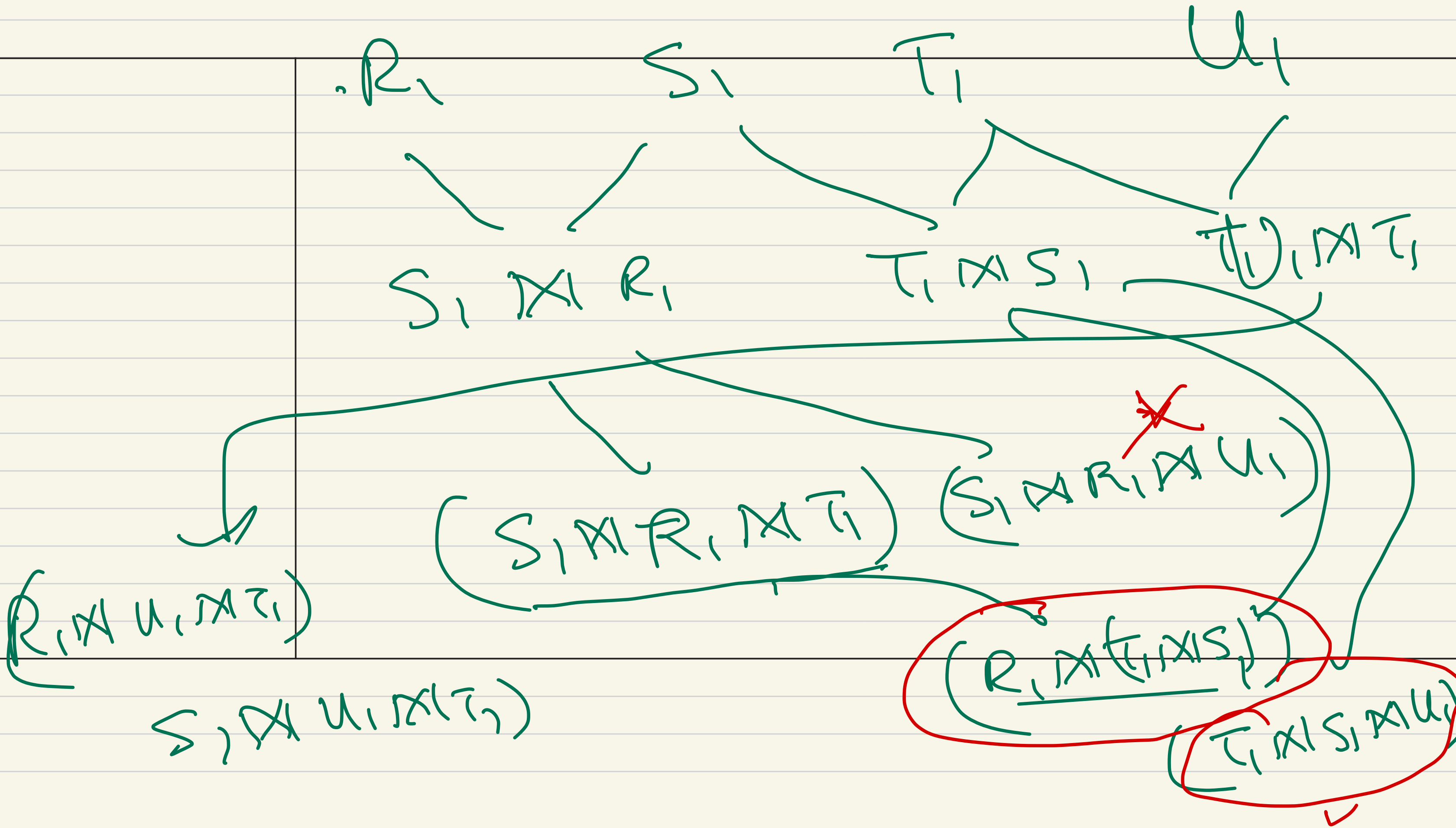
$S_1 \bowtie R_1$ $\quad S_1 \bowtie T_1$ $\quad S_1 \bowtie U_1$

$T_1 \bowtie R_1$ $\quad T_1 \bowtie S_1$ $\quad T_1 \bowtie U_1$

$U_1 \bowtie T_1$ $\quad U_1 \bowtie S_1$ $\quad U_1 \bowtie R_1$

All ways to Join.

$R_1 \bowtie S_1 \equiv S_1 \bowtie R_1$



R1
S1
T1
U1
S1 ⋈ R1
T1 ⋈ S1
U1 ⋈ T1
(S1 ⋈ R1 ⋈ T1)
(S1 ⋈ R1 ⋈ U1)
(R1 ⋈ U1 ⋈ T1)
S1 ⋈ U1 ⋈ (T1)
(R1 ⋈ (T1 ⋈ S1))
(T1 ⋈ S1 ⋈ U1)

$R_1 \quad S_1 \quad T_1 \quad U_1$

$S_1 \bowtie R_1 \quad T_1 \bowtie S_1 \quad T_1 \bowtie U_1$

$R_1 \bowtie (T_1 \bowtie S_1) \quad (T_1 \bowtie S_1) \bowtie U_1$

$R_1 \bowtie (T_1 \bowtie S_1) \bowtie U_1 \neq R_1 \bowtie ((T_1 \bowtie S_1) \bowtie U_1)$

1

2

3

R_1 $\quad$ T_1 $\quad$ S_1 $\quad$ U_1

$T_1 \bowtie S_1$

$R_1 \bowtie (T_1 \bowtie S_1)$

$R_1 \bowtie (T_1 \bowtie S_1) \bowtie U_1$

$R_1 \bowtie R_2 \bowtie \cdots \bowtie R_n$

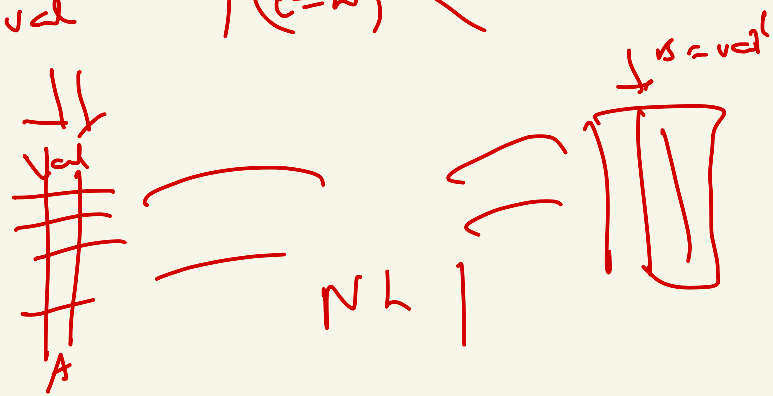
index on R | R is ordered on A

$\sigma_{A=val}(R)$

$\left(\sigma_{A=val}(R)\right) \bowtie_{C=D} \left(\sigma_{B=val}(R)\right)$

σ_B

O [I



Select Avg(Sal) from E.

$$\left(\sigma_{A=val_1}(R) \bowtie_{C=D} \sigma_{B=val_2}(S)\right) \bowtie_{E=F} \sigma_{C=val_3}(T)$$

Salary

✓ $(R' \bowtie S') \bowtie T'$

$R \bowtie (S \bowtie T)$ ✓

✓ Cost $((R' \bowtie S') \bowtie T')$ ① ②

Cost $(R' \bowtie (S' \bowtie T'))$ ② ①

Same

Equivalent Relational Algebra expression.

$R_1 \bowtie R_2 \bowtie \dots \bowtie R_k$.

how do you systematically get better solutions

Query Optimization Algorithm

ϕ.

$R_1, \quad R_2, \quad R_k \quad R,$

$(R_i \bowtie R_j) \quad {}^nC_2$

$R_i \bowtie R_j \bowtie R_k \quad {}^nC_3$

R_2

$\vdots$

$R_n.$

Centre

Join tree

k relations.

φ

Index(R_1) Scan(R_1) R_2 (Index A) R_k (Index C)   select the best access method cost

$R_1 \bowtie R_2$ logical expression

NLJ((A scan A R_1) $\bowtie$ Scan(R_2))

$R_i \bowtie R_j$ nC_2

Cost

cost($R_1 \bowtie R_2$)   Cost($R_2 \bowtie R_3$).

[Cost($R_1 \bowtie R_2$)] $\bowtie$ R_3 — A

($R_1 \bowtie$ Cost($R_2 \bowtie R_3$)) — B cost

R_3 | R_1 3

$R_1 \bowtie R_2 \bowtie R_3$.

cost

Equivalent expression

($R_1 \bowtie R_2 \bowtie R_3$) ✓

$T(R_1 \bowtie R_2 \bowtie R_3)$ $(R_1 \bowtie R_2 \bowtie R_3)$ A | B which is relevant

$V(R_{es}, A)$

$((R_1 \bowtie R_2 \bowtie R_3) \bowtie R_4$ $T(R$ $T(C$ $V(C,A)$

R_4

$(R_1 \bowtie R_2) \bowtie (R_3 \bowtie R_4)$

$(R_1 \bowtie R_3) \bowtie (R_2 \bowtie R_4)$

Cost $(R_1 \bowtie (R_2 \bowtie R_3 \bowtie R_4)$

$R_2 \bowtie (R_1 \bowtie R_3 \bowtie R_4)$

$R_3 \bowtie (R_2 \bowtie R_1 \bowtie R_4)$

best execution plan for $(R_1 \bowtie R_2 \bowtie R_3 \bowtie' R_4)$

$(T(R_1) \times T(C R)$ / $\max(V(R_1, A), V(C R_4 A))$

& relation

best plan for $(R_4 \bowtie R_5 \bowtie R_6 \bowtie R_7)$

join of them to relation

$$\underbrace{R_1 \times R_2 \times \cdots \times R_n}$$

K^{k}

$\ell.$

for $i = 1, \ldots, K$.

(if $i=1$

take R_i

get its best plan.

TempResult(R_i) $\in S$

if $i > 1$

(a) Take each TempResult $\in S$

add a relation $R_i \notin$ TempResult

determine cost (R_i + TempRes relation) $\in S$

(b) If there are equivalent results keep the smallest

cost one in S.

$((R \bowtie S) \bowtie T) \bowtie U$.