

Ullman et al. : Database System Principles

Notes 6: Query Processing

Query Processing

$Q \rightarrow \text{Query Plan}$

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	S	C	D	E
a	1	10	10	10	x	2	
b	1	20	20	20	y	2	
c	2	10	30	30	z	2	
d	2	35	40	40	x	1	
e	3	45	50	50	y	3	

Answer

B	D
2	x

- How do we execute query?



One idea

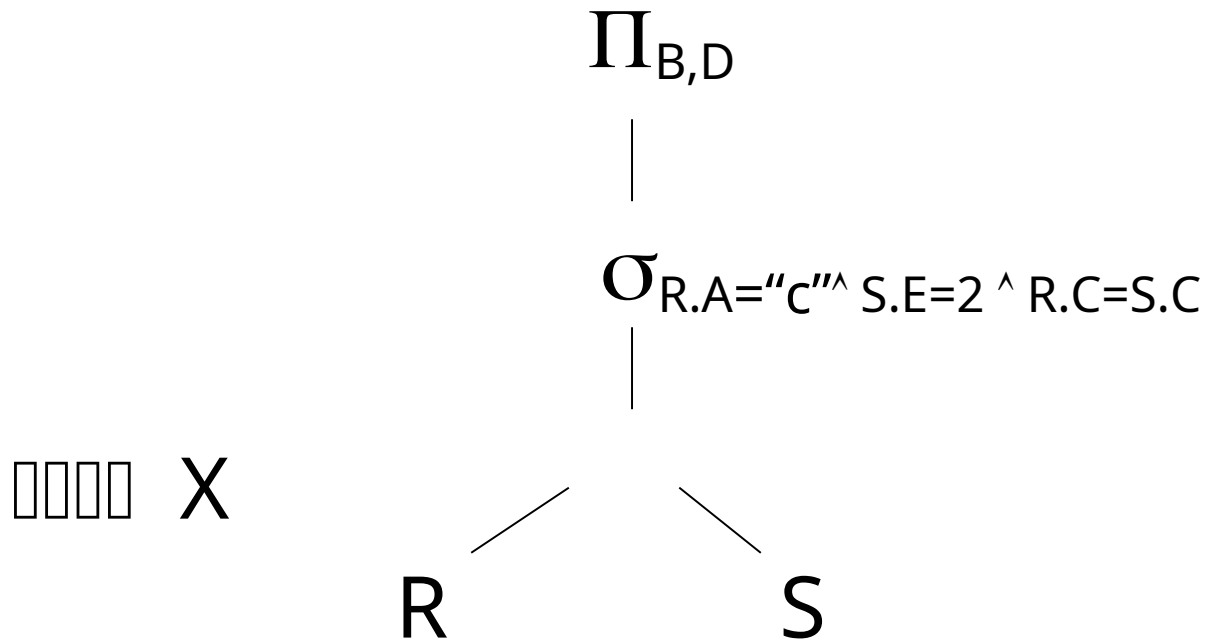
- Do Cartesian product
- Select tuples
- Do projection

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
	.					
	.					
Bingo! →	C	2	10	10	x	2
Got one...	.					
	.					

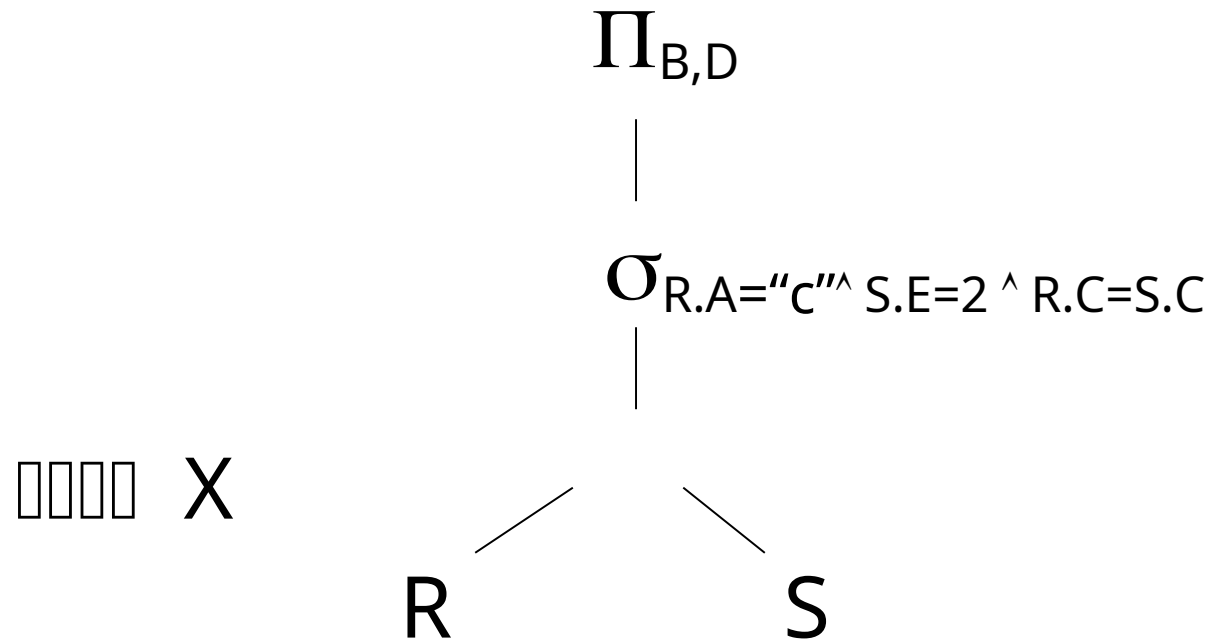
Relational Algebra - can be used to describe plans...

Ex: Plan I



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

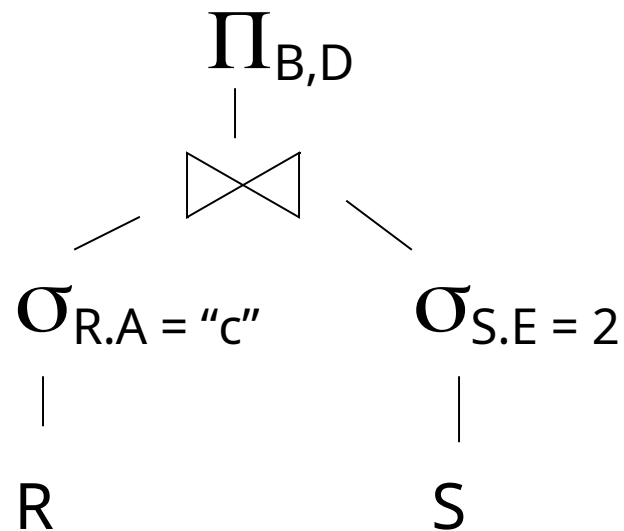
Ex: Plan I



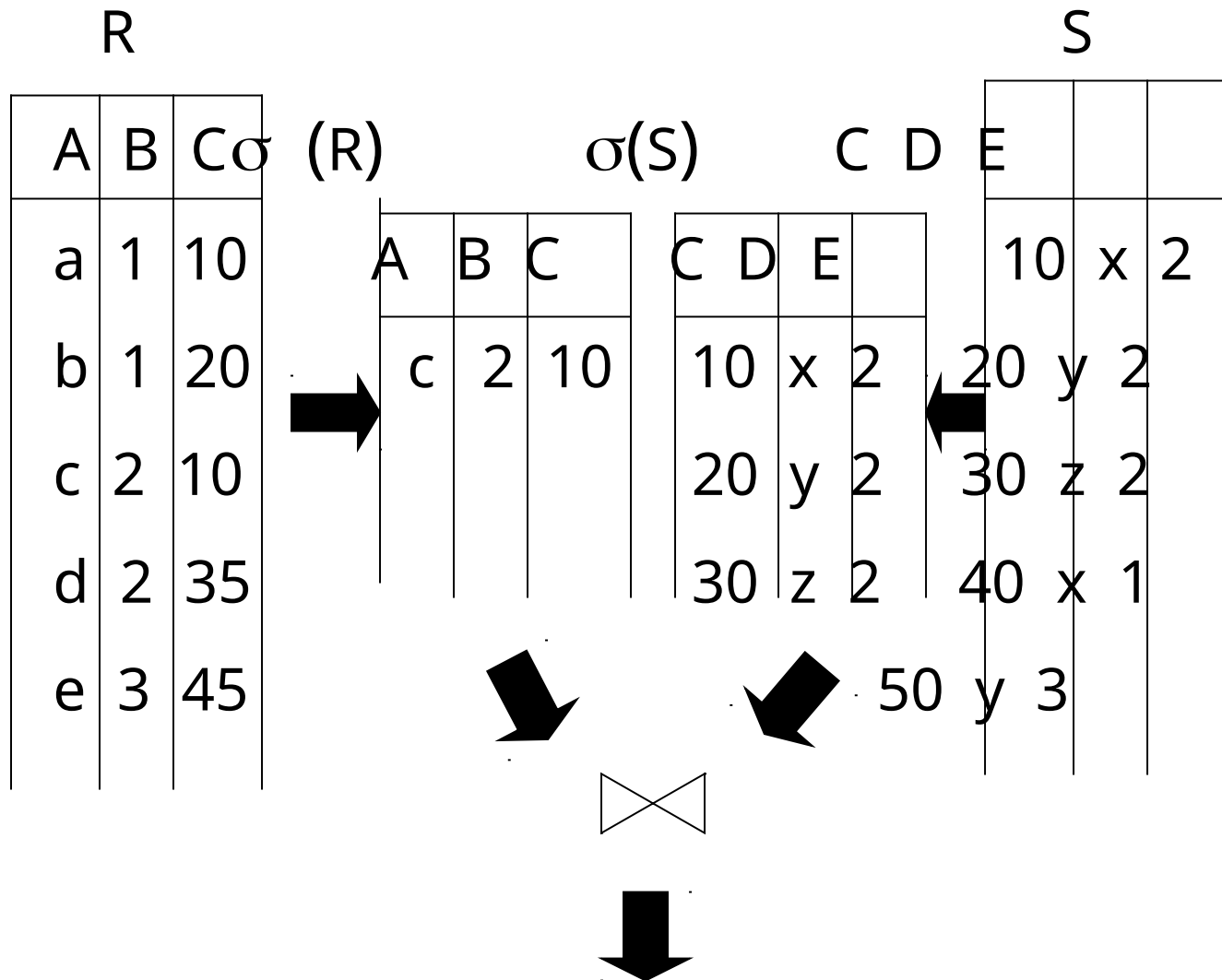
OR: $\Pi_{B,D} [\sigma_{R.A='c' \wedge S.E=2 \wedge R.C=S.C} (RXS)]$

Another idea:

Plan II



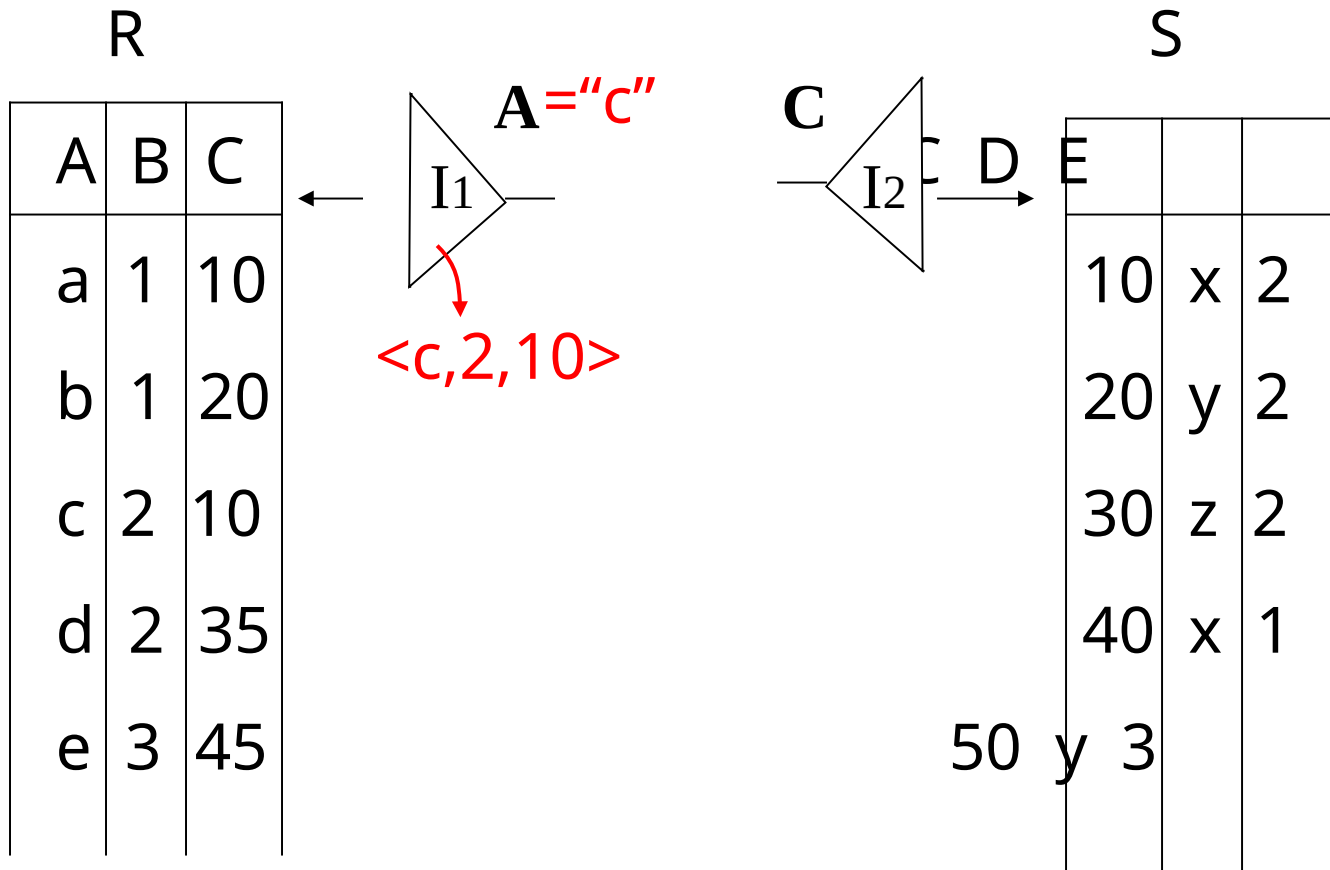

natural join

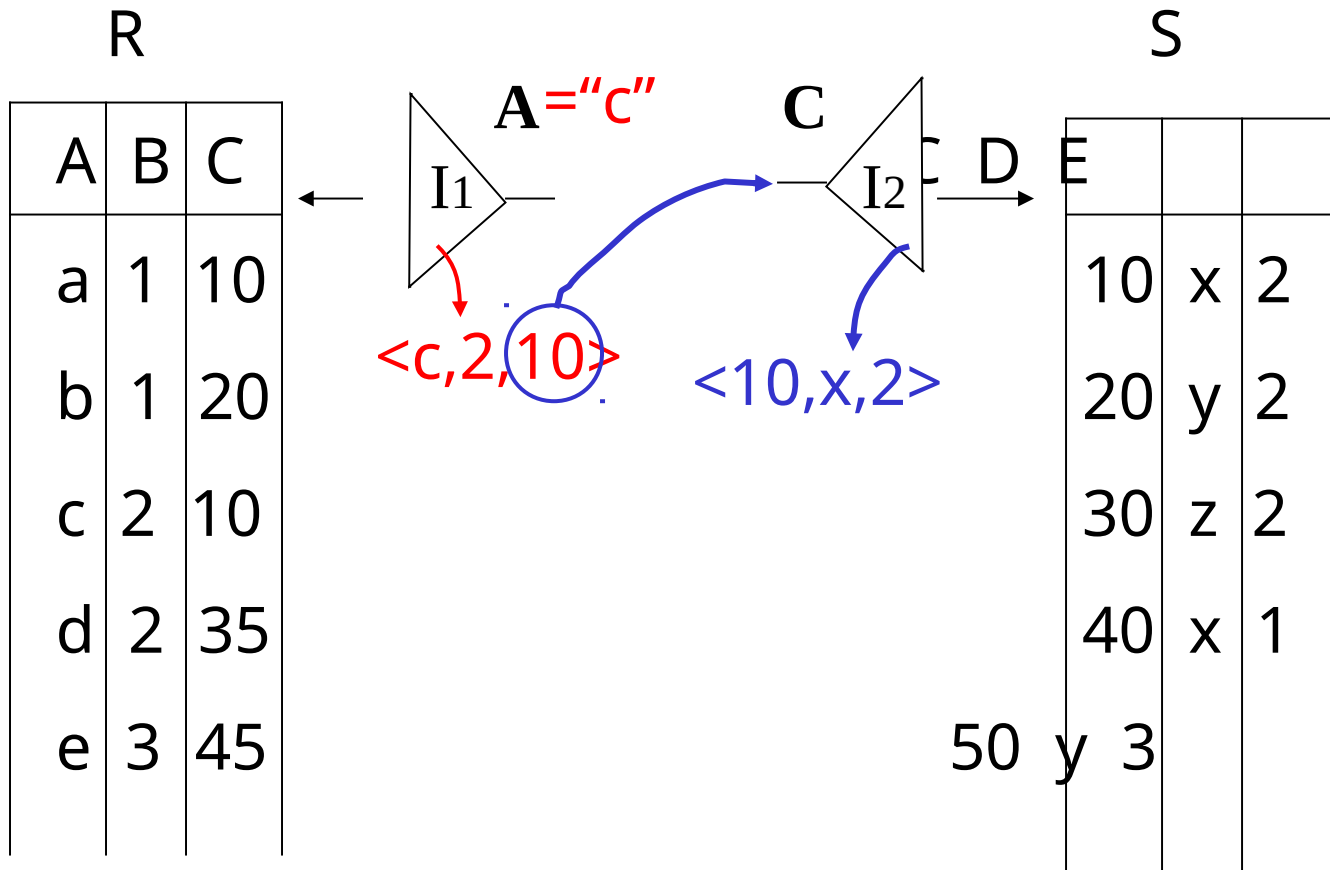


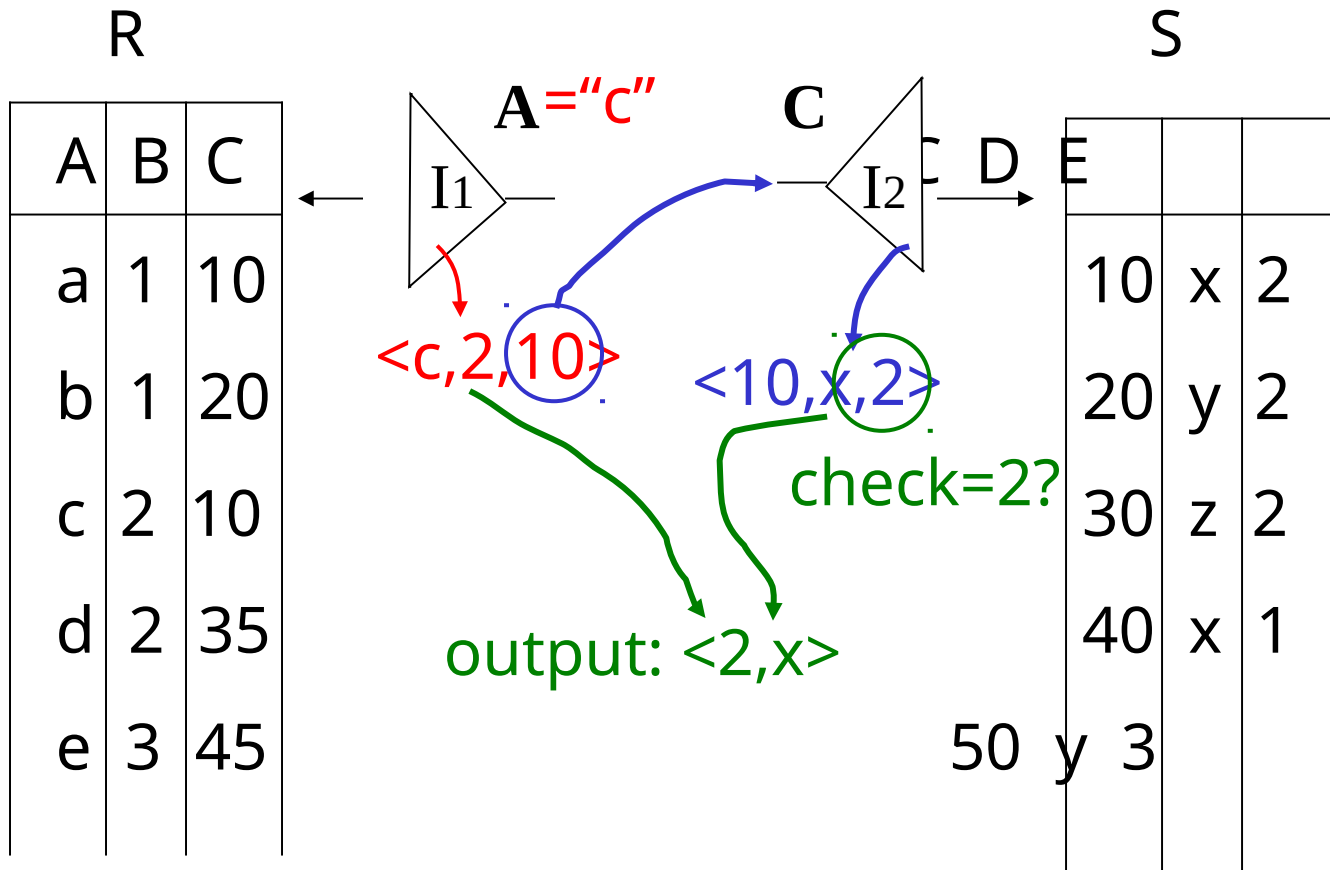
Plan III

Use R.A and S.C Indexes

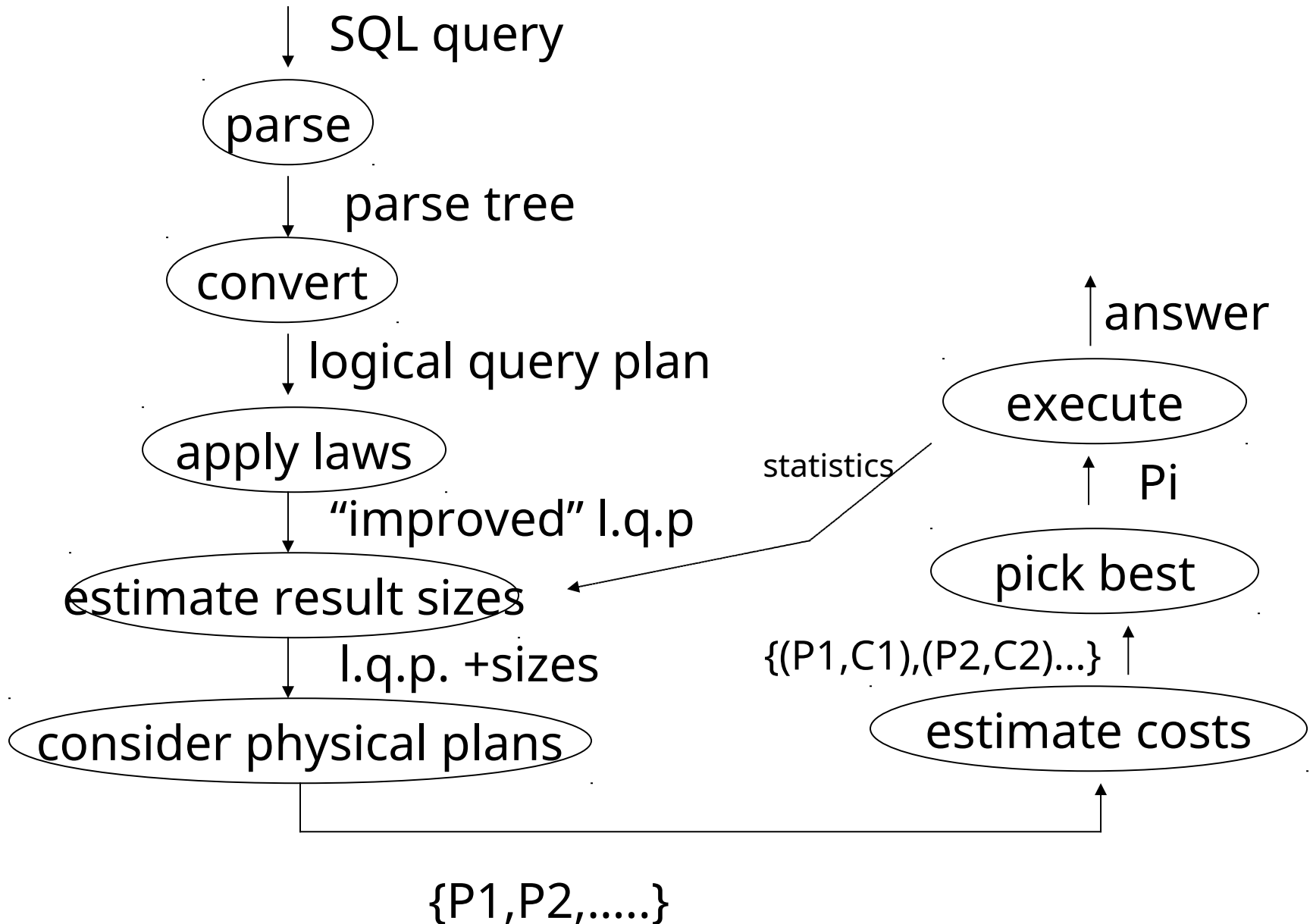
- (1) Use R.A index to select R tuples with $R.A = "c"$
- (2) For each R.C value found, use S.C index to find matching tuples
- (3) Eliminate S tuples $S.E \neq 2$
- (4) Join matching R,S tuples, project B,D attributes and place in result







Overview of Query Optimization

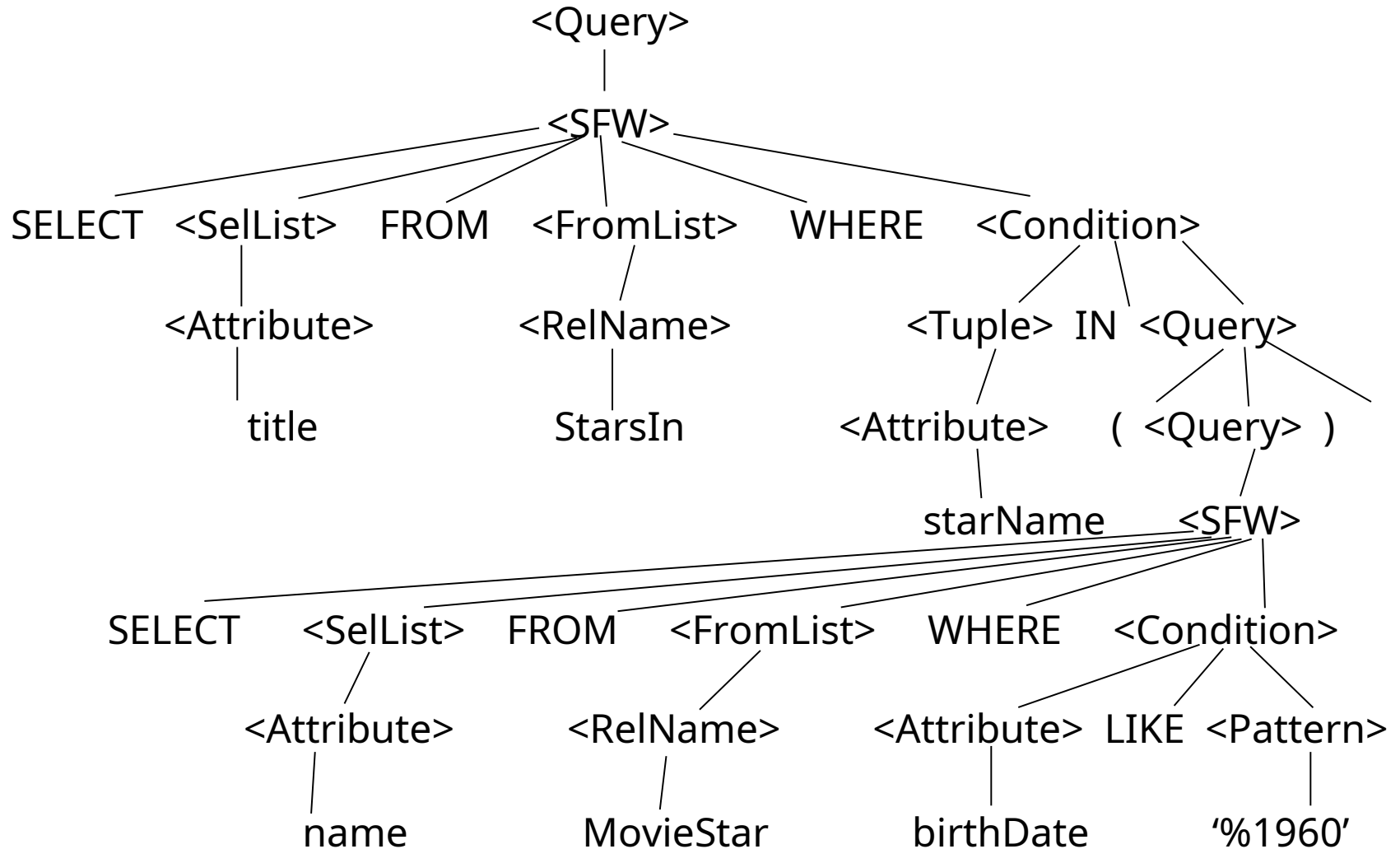


Example: SQL query

```
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

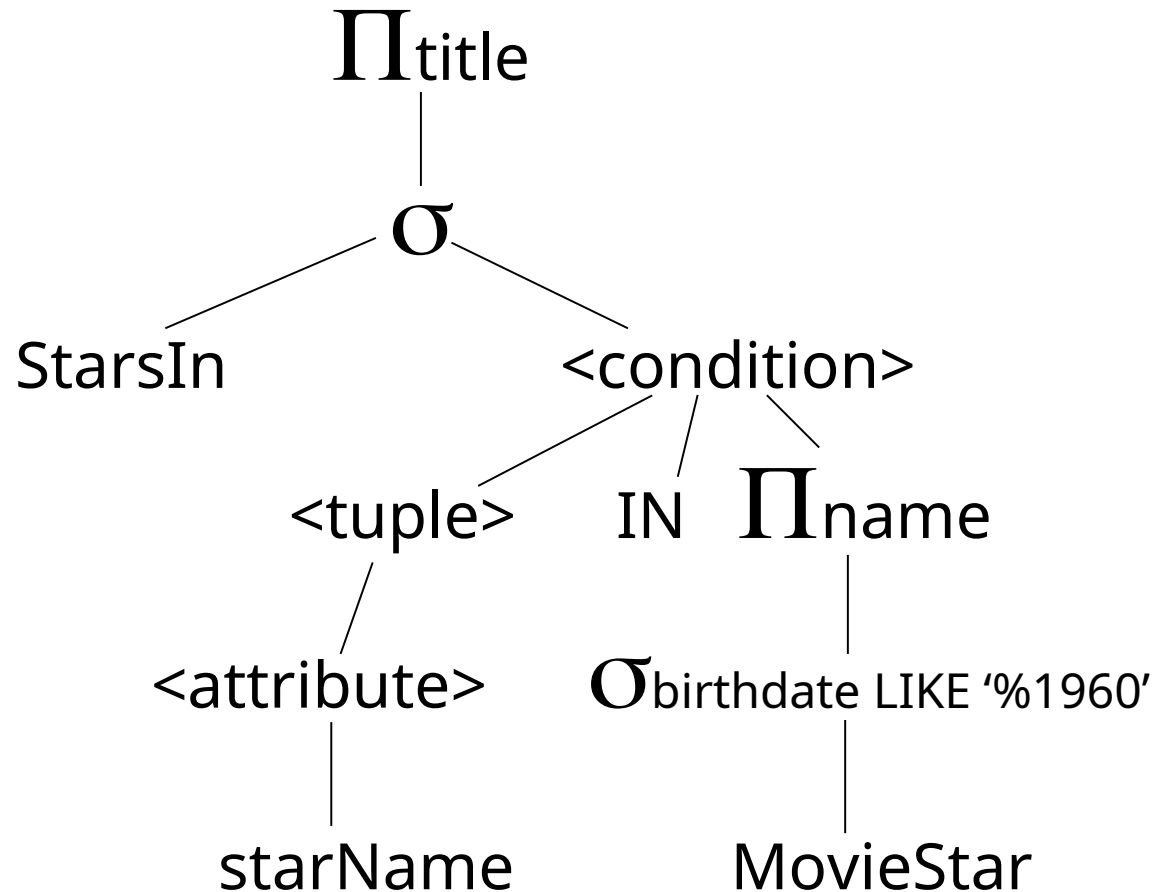


Fig. 7.15: An expression using a two-argument σ , midway between a parse tree and relational algebra

Example: Logical Query Plan

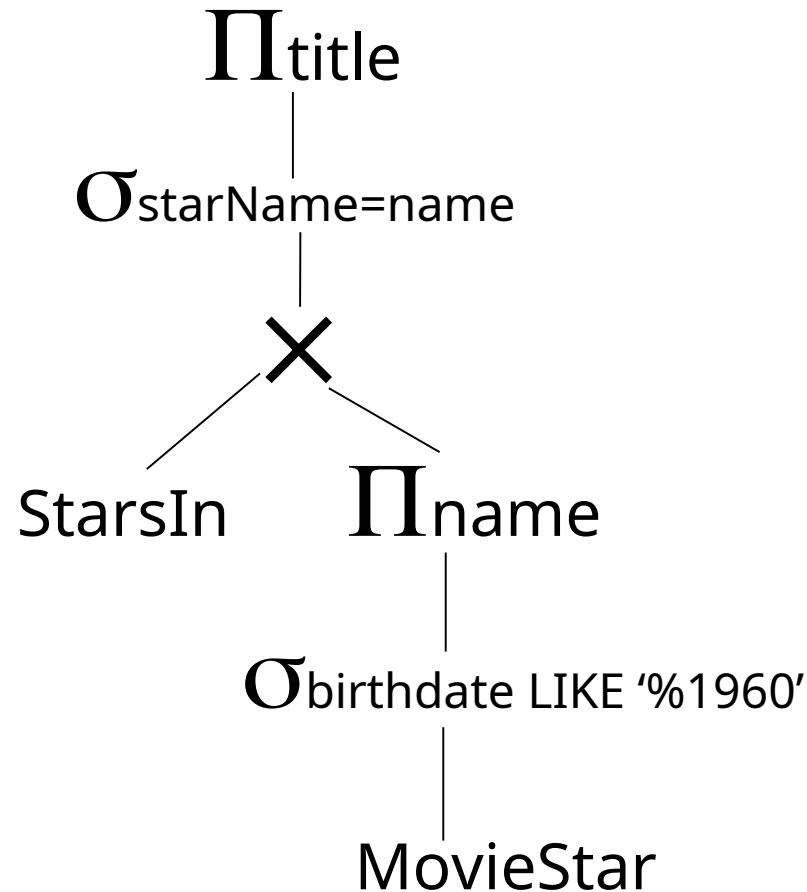
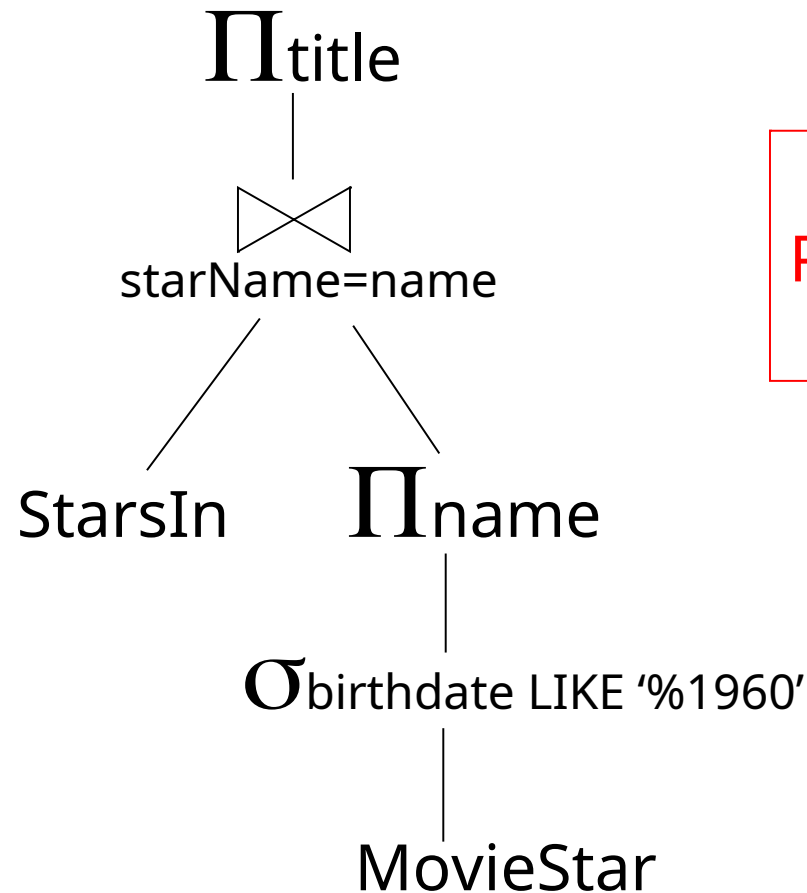


Fig. 7.18: Applying the rule for IN conditions

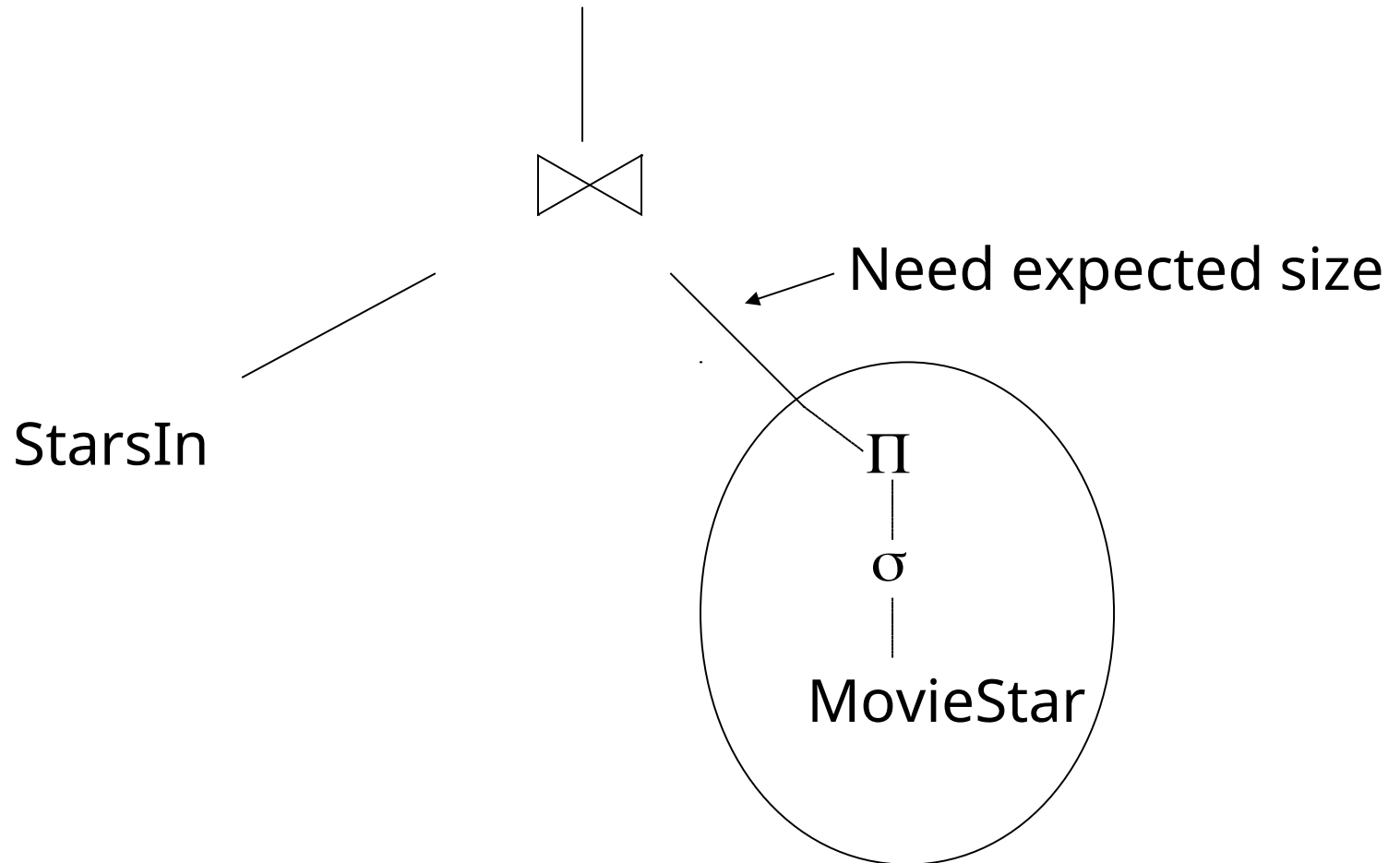
Example: Improved Logical Query Plan



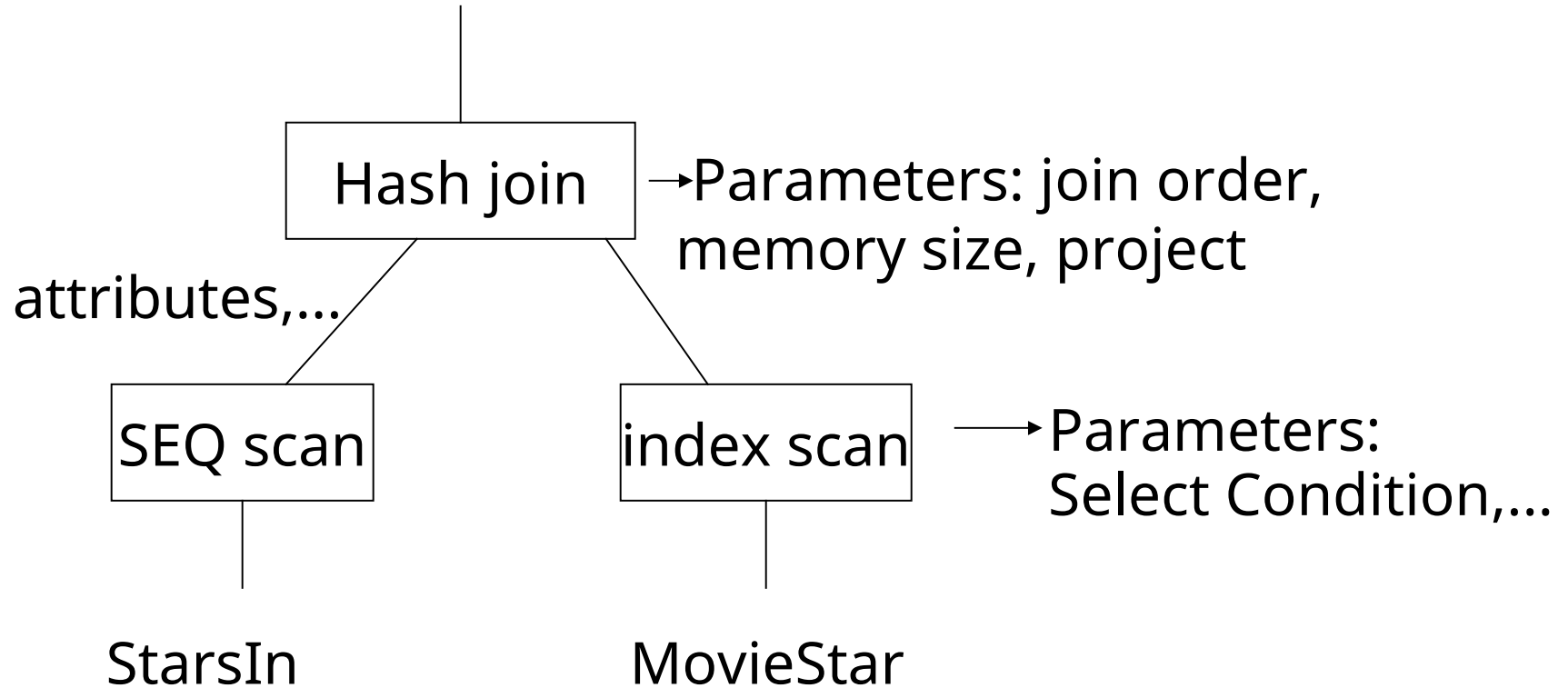
Question:
Push project to
StarsIn?

Fig. 7.20: An improvement on fig. 7.18.

Example: Estimate Result Sizes

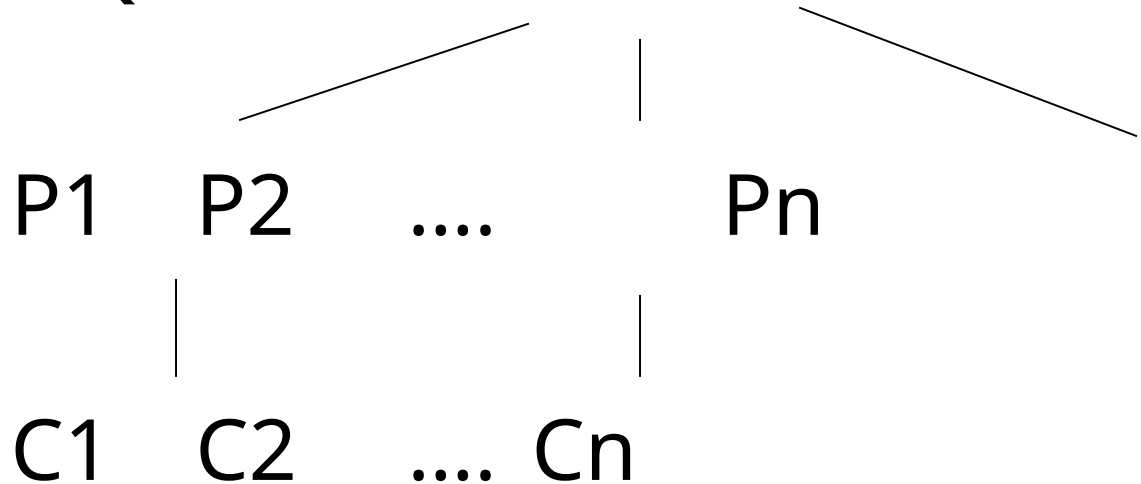


Example: One Physical Plan



Example: Estimate costs

L.Q.P



Pick best!

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?

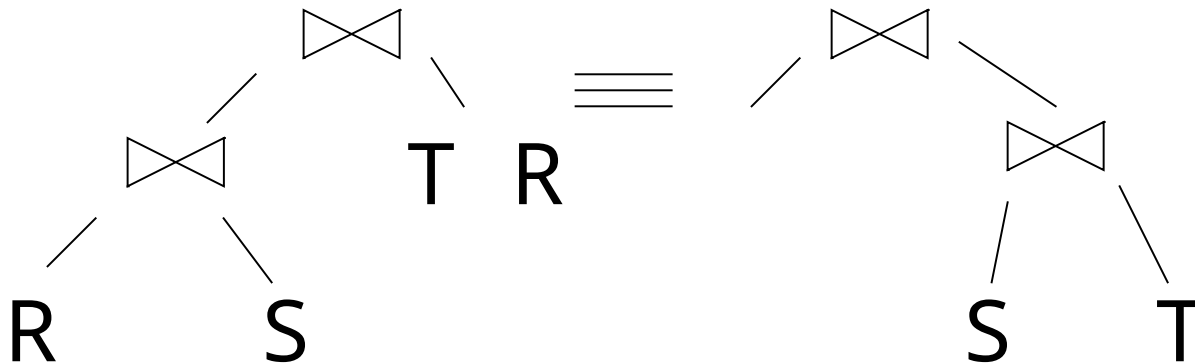
Rules: Natural joins & cross products & union

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

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

Note:

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



Rules: Natural joins & cross products & union

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

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

$$R \times S = S \times R$$

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

$$R \cup S = S \cup R$$

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

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

$$XY = X \cup Y$$

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

Rules: σ + \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 +  combined
(continued)

Some Rules can be Derived:

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

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

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

Rules: π, σ combined

Let x = subset of R attributes

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

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

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

Rules σ , \cup 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

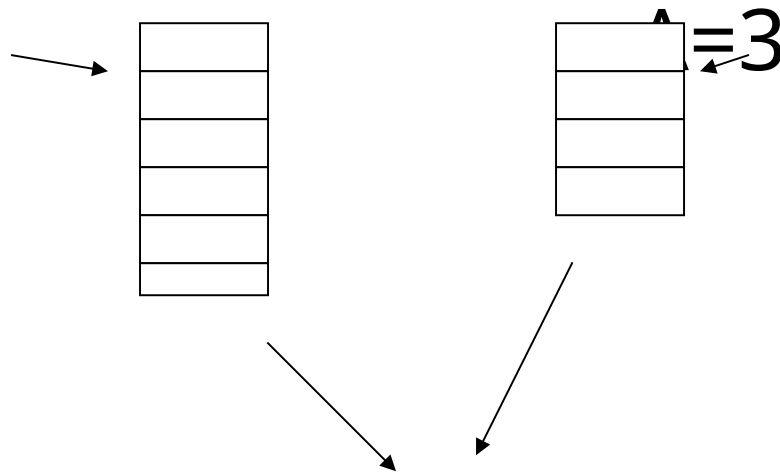
Example: $R(A,B,C,D,E)$ $x=\{E\}$
 $P: (A=3) \wedge (B=\text{"cat"})$

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

Usually good: early selections

But What if we have A, B indexes?

B = "cat"



Intersect pointers to get
pointers to matching tuples

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 size of results

(2) Estimating # of IOs

Estimating result size

Keep statistics for relation R

- $T(R)$: # tuples in R
- $L(R)$: # 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
- b : block size
- $bf(R)$ (blocking factor): # of tuples in a block
 $bf(R) = b/L(R)$

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

$$T(R) = 5 \quad L(R) = 37$$

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

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

Size estimates for $W = R \times S$

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

$$L(W) = L(R) + L(S)$$

$$bf(W) = b/(L(R)+L(S))$$

$$\begin{aligned} B(W) &= T(R)*T(S)/bf(W) = \\ &= T(R)*T(S)*L(S)/b + T(S)*T(R)*L(R)/b = \\ &= T(R)*T(S)/bf(S) + T(S)*T(R)/bf(R) = \\ &= T(R)*B(S) + T(S)*B(R) \end{aligned}$$

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

$$L(W) = L(R)$$

$$T(W) = ?$$

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

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

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

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

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

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

Selection cardinality

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

$$SC(R,A) = T(R) / V(R,A)$$

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

$$T(W) = ?$$

- Solution # 1:

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

- Solution # 2:

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

- Solution # 3: Estimate values in range

Example

R	Z

Min=1 $V(R,Z)=10$

↕

Max=20 $W = \sigma_{z \geq 15}(R)$

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

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

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 $R2$

Case 1

$$X \cap Y = \emptyset$$

Same as $R1 \times R2$

Case 2

$$W = R1 \bowtie R2 \quad X \cap Y = A$$

R1	A	B	C

R2	A	D

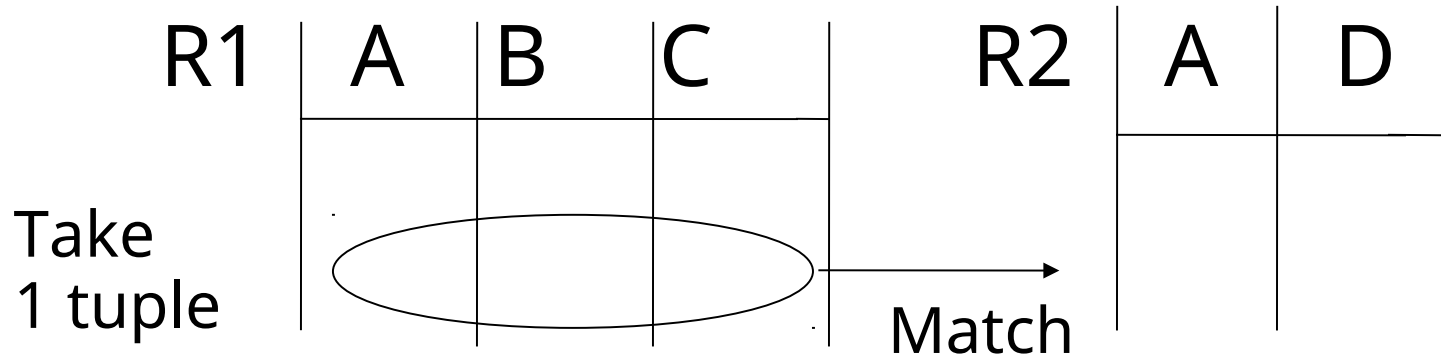
Assumption:

$V(R1,A) \leq V(R2,A) \Rightarrow$ 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...

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

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

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

[A is common attribute]

In general $W = R1 \bowtie R2$

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

Size Estimation Summary (1/2)

$$\sigma_{A=v}(R) \quad SC(R,A) \text{ (--> } SC(R,A) = T(R) / V(R,A))$$

$$\sigma_{A \leq v}(R) \quad T(R) * \frac{v - \min(A, R)}{\max(A, R) - \min(A, R)}$$

$$\sigma_{\theta_1 \wedge \theta_2 \wedge \dots \wedge \theta_n}(R) \text{ multiplying probabilities}$$

$$T(R) * [(sc_1/T(R)) * (sc_2/T(R)) * \dots * (sc_n/T(R))]$$

$$\sigma_{\theta_1 \vee \theta_2 \vee \dots \vee \theta_n}(R) \text{ probability that a record satisfy none of } \theta:$$

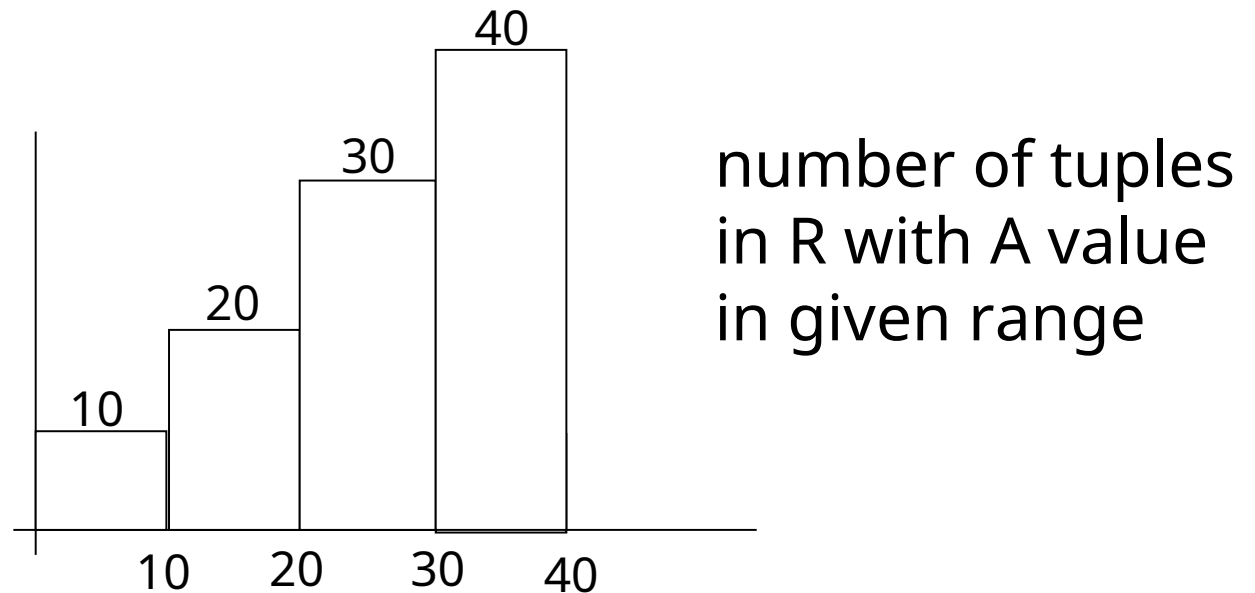
$$[(1 - sc_1/T(R)) * (1 - sc_2/T(R)) * \dots * (1 - sc_n/T(R))]$$

$$T(R) * (1 - [(1 - sc_1/T(R)) * (1 - sc_2/T(R)) * \dots * (1 - sc_n/T(R))])$$

Size Estimation Summary(2/2)

- $R \times S$
 $T(R \times S) = T(R) * T(S)$
- $R \bowtie S$
 - $R \cap S = \emptyset$: $T(R) * T(S)$
 - $R \cap S$ key for R : maximum output size is $T(S)$
 - $R \cap S$ foreign key for R : $T(S)$
 - $R \cap S = \{A\}$, neither key of R nor S
 - $T(R) * T(S) / V(S, A)$
 - $T(R) * T(S) / V(R, A)$

A Note on Histograms



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

Summary

- Estimating size of results is an “art”
- Don't forget:
Statistics must be kept up to date...
(cost?)