Distributed Databases

CS347

Lecture 14

May 30, 2001

Topics for the Day

- Query processing in distributed databases
  - Localization
  - Distributed query operators
  - Cost-based optimization

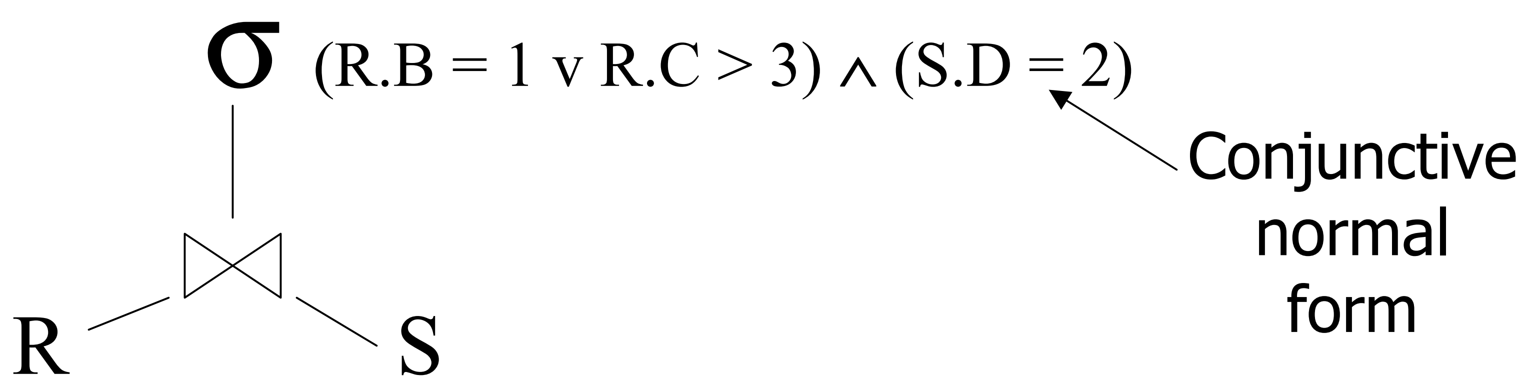
Query Processing Steps

- Decomposition
  - Given SQL query, generate one or more algebraic query trees
- Localization
  - Rewrite query trees, replacing relations by fragments
- Optimization
  - Given cost model + one or more localized query trees
  - Produce minimum cost query execution plan

Decomposition

- Same as in a centralized DBMS
- Normalization (usually into relational algebra)

Select A,C
From R Natural Join S
Where (R.B = 1 and S.D = 2) or (R.C > 3 and S.D = 2)



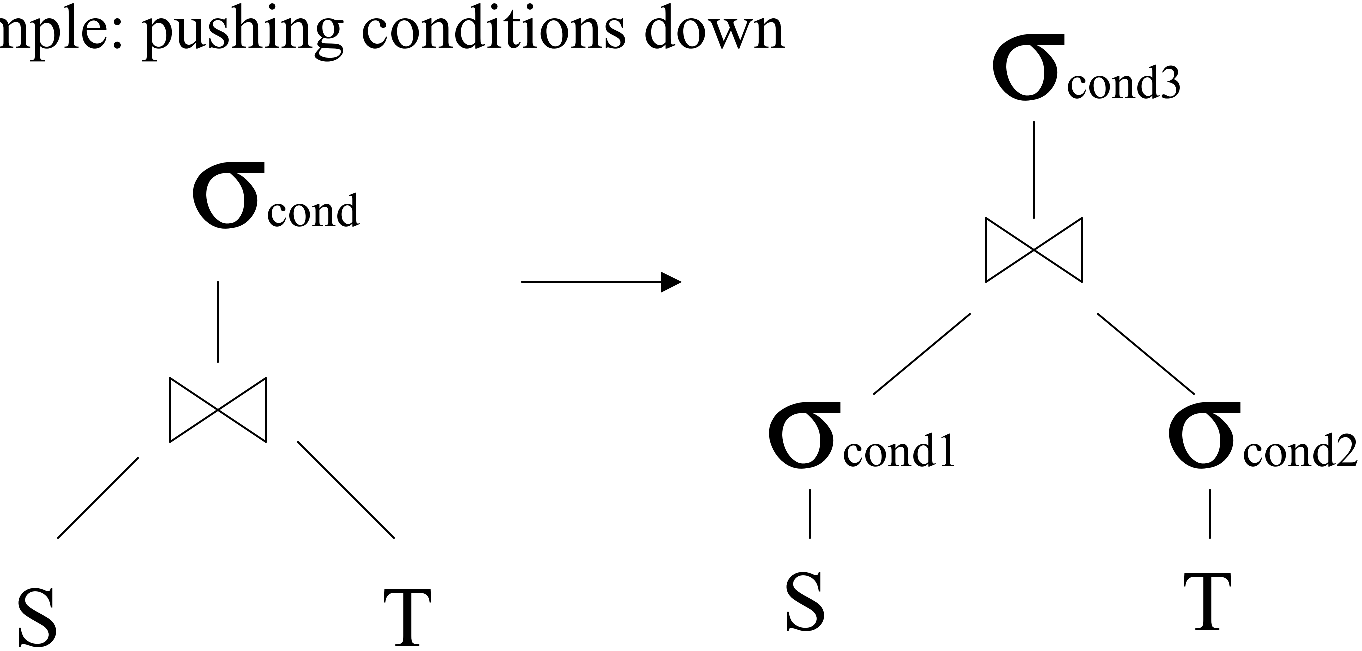
Decomposition

- Redundancy elimination

  $(S.A = 1) \wedge (S.A > 5) \Rightarrow \text{False}$

  $(S.A < 10) \wedge (S.A < 5) \Rightarrow S.A < 5$

- Algebraic Rewriting
  - Example: pushing conditions down



Localization Steps

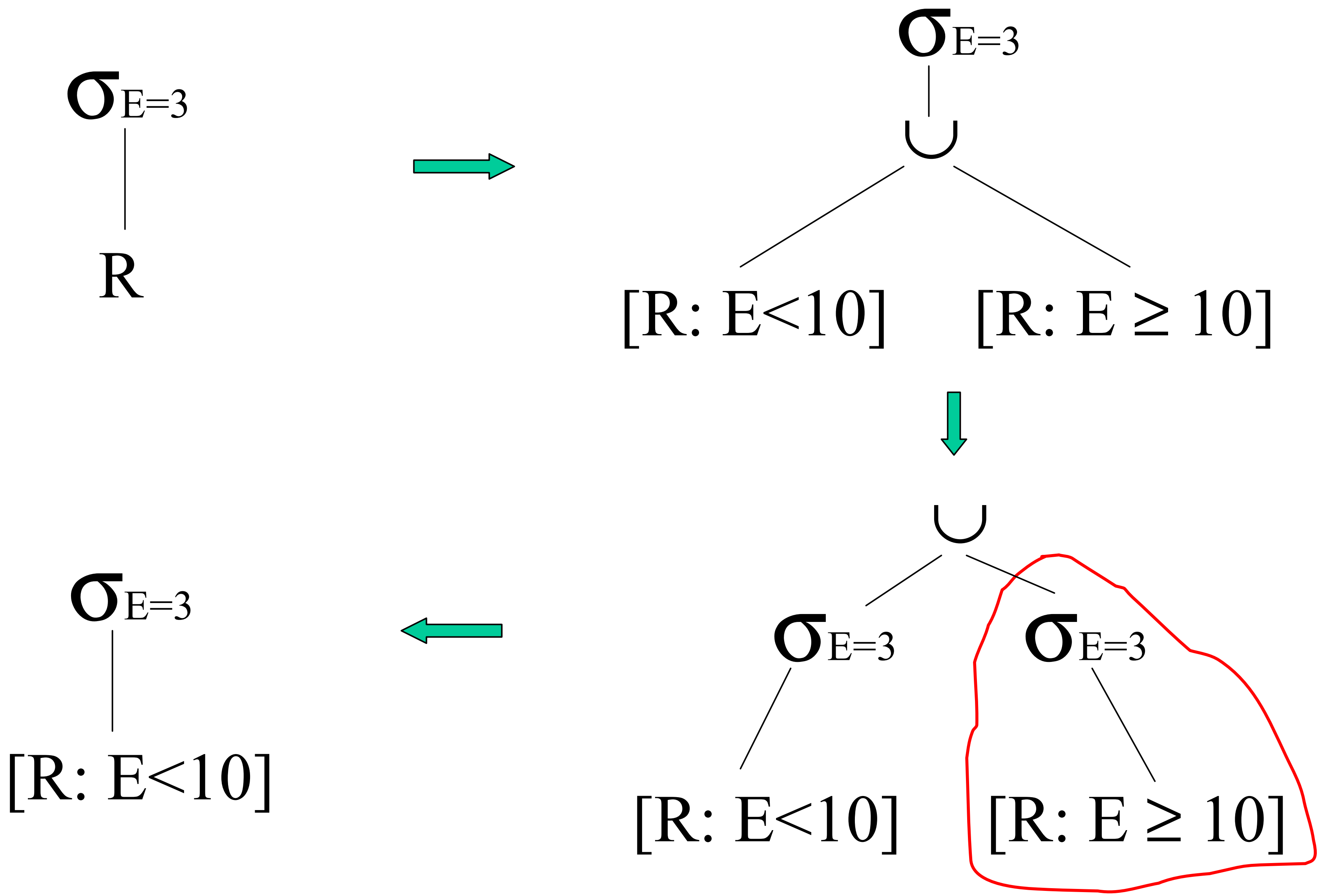
1. Start with query tree
2. Replace relations by fragments
3. Push $\cup$ up & π, σ down (CS245 rules)
4. Simplify – eliminating unnecessary operations

Note: To denote fragments in query trees

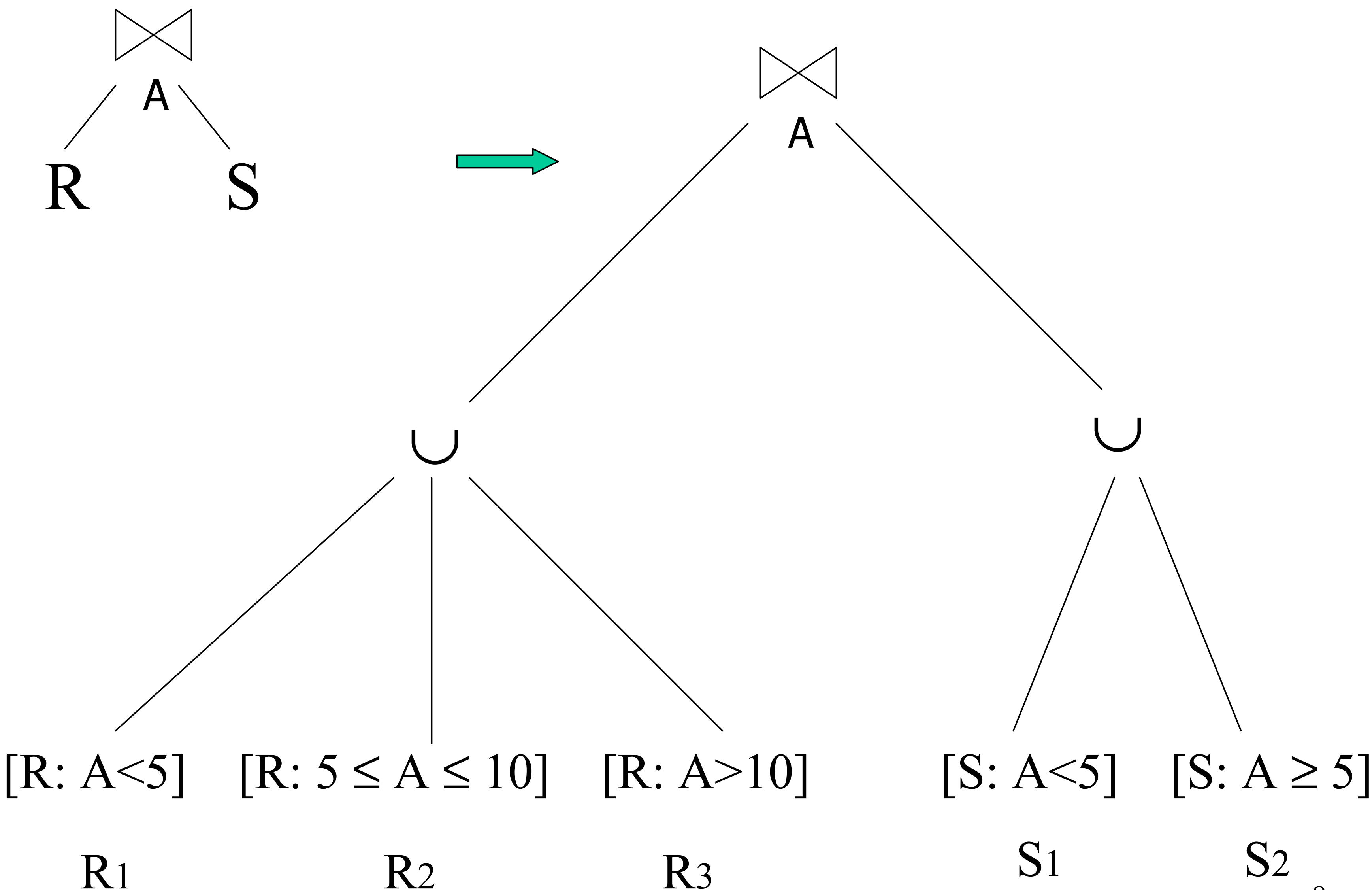
[R: cond]

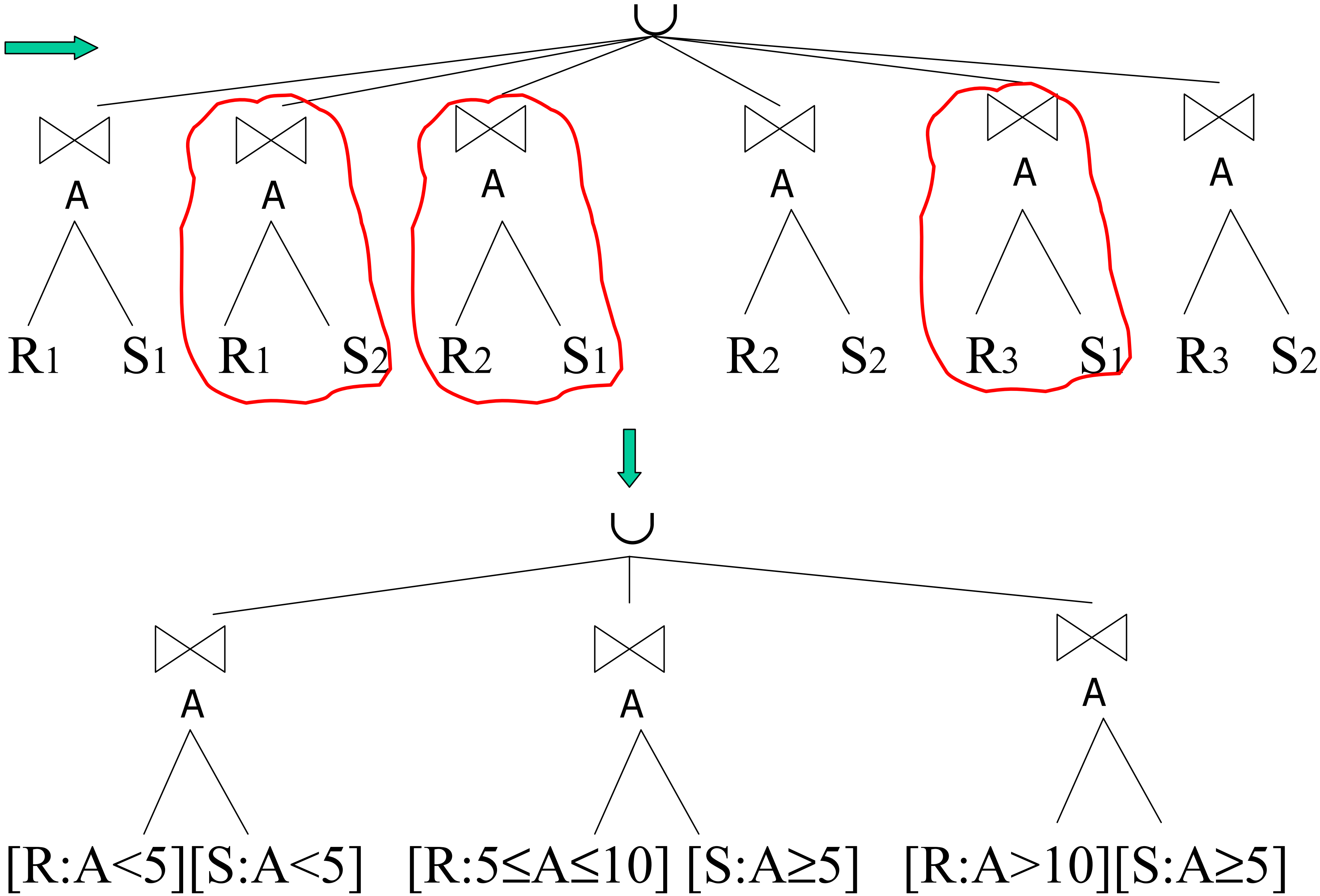
Relation that fragment belongs to   Condition its tuples satisfy

Example 1



Example 2




A
A
A
A
A
A
R1
S1
R1
S2
R2
S1
R2
S2
R3
S1
R3
S2
A
A
A
[R:A<5][S:A<5]
[R:5≤A≤10] [S:A≥5]
[R:A>10][S:A≥5]

Rules for Horiz. Fragmentation

- $\sigma_{C1}[R: C_2] \Rightarrow [R: C_1 \wedge C_2]$
- $[R: \text{False}] \Rightarrow \emptyset$
- $[R: C_1] \underset{A}{\bowtie} [S: C_2] \Rightarrow [R \underset{A}{\bowtie} S: C_1 \wedge C_2 \wedge R.A = S.A]$

- In Example 1:

  $\sigma_{E=3}[R_2: E \geq 10] \Rightarrow [R_2: E=3 \wedge E \geq 10]$

  $\Rightarrow [R_2: \text{False}] \Rightarrow \emptyset$
- In Example 2:

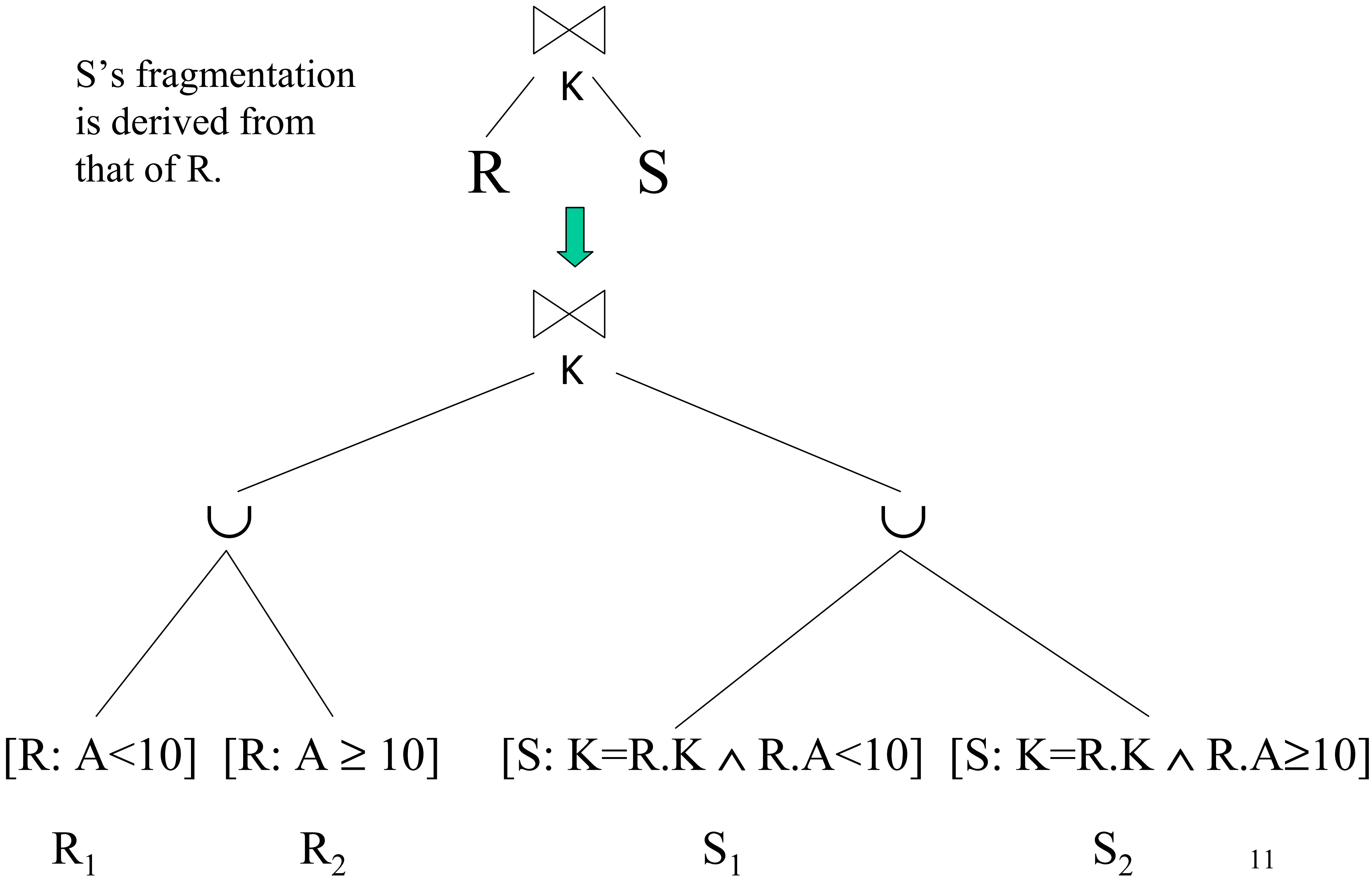
  $[R: A<5] \underset{A}{\bowtie} [S: A \geq 5]$

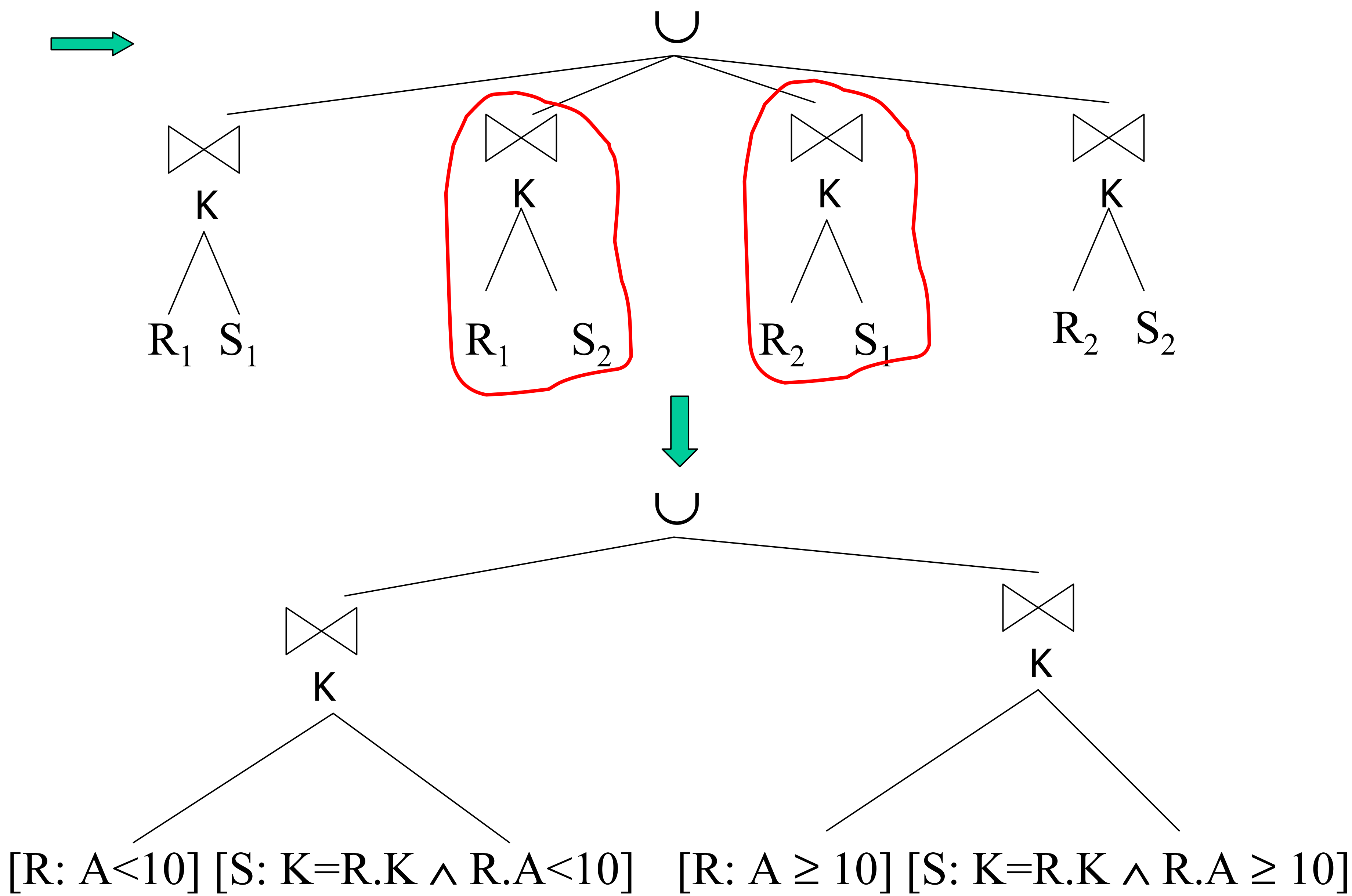
  $\Rightarrow [R \underset{A}{\bowtie} S: R.A < 5 \wedge S.A \geq 5 \wedge R.A = S.A]$

  $\Rightarrow [R \underset{A}{\bowtie} S: \text{False}] \Rightarrow \emptyset$

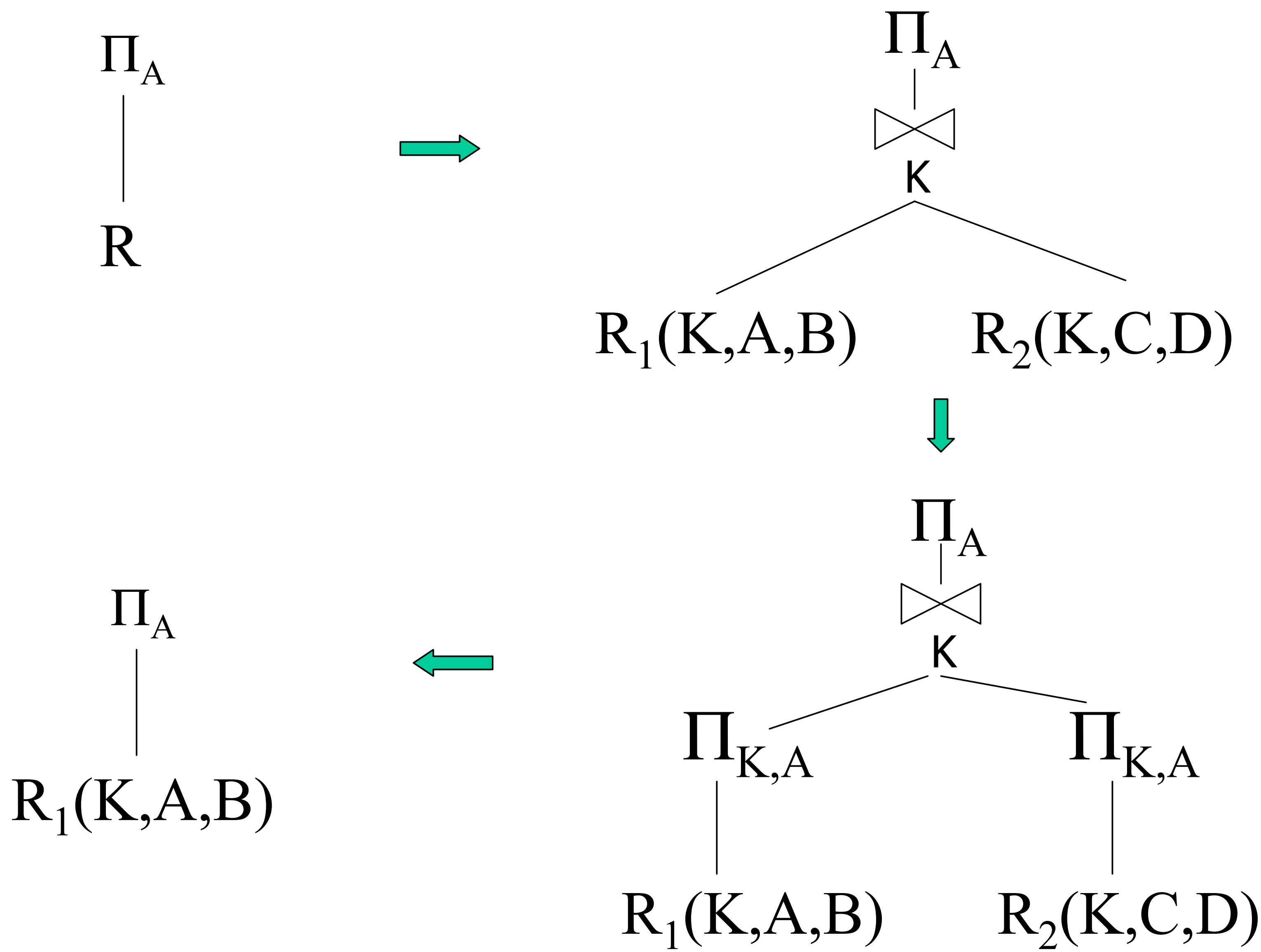
Example 3 – Derived Fragmentation

S's fragmentation is derived from that of R.




∪
K
K
K
K
R1 S1
R1 S2
R2 S1
R2 S2
∪
K
K
[R: A<10] [S: K=R.K ∧ R.A<10]
[R: A ≥ 10] [S: K=R.K ∧ R.A ≥ 10]

Example 4 – Vertical Fragmentation



Rule for Vertical Fragmentation

- Given vertical fragmentation of R(A):

$$R_i = \Pi_{Ai}(R), \;\; A_i \subseteq A$$

- For any $B \subseteq A$:

$$\Pi_B\,(R) = \Pi_B\,[\,\bowtie_i R_i \mid B \cap A_i \neq \emptyset]$$

Parallel/Distributed Query Operations

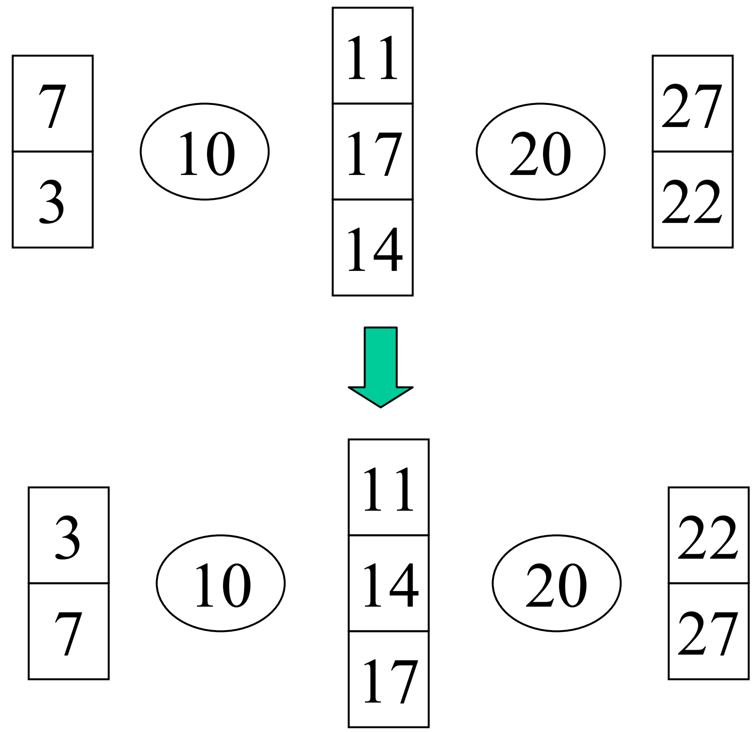
- Sort
  - Basic sort
  - Range-partitioning sort
  - Parallel external sort-merge
- Join
  - Partitioned join
  - Asymmetric fragment and replicate join
  - General fragment and replicate join
  - Semi-join programs
- Aggregation and duplicate removal

Parallel/distributed sort

- Input: relation R on
  - single site/disk
  - fragmented/partitioned by sort attribute
  - fragmented/partitioned by some other attribute
- Output: sorted relation R
  - single site/disk
  - individual sorted fragments/partitions

Basic sort

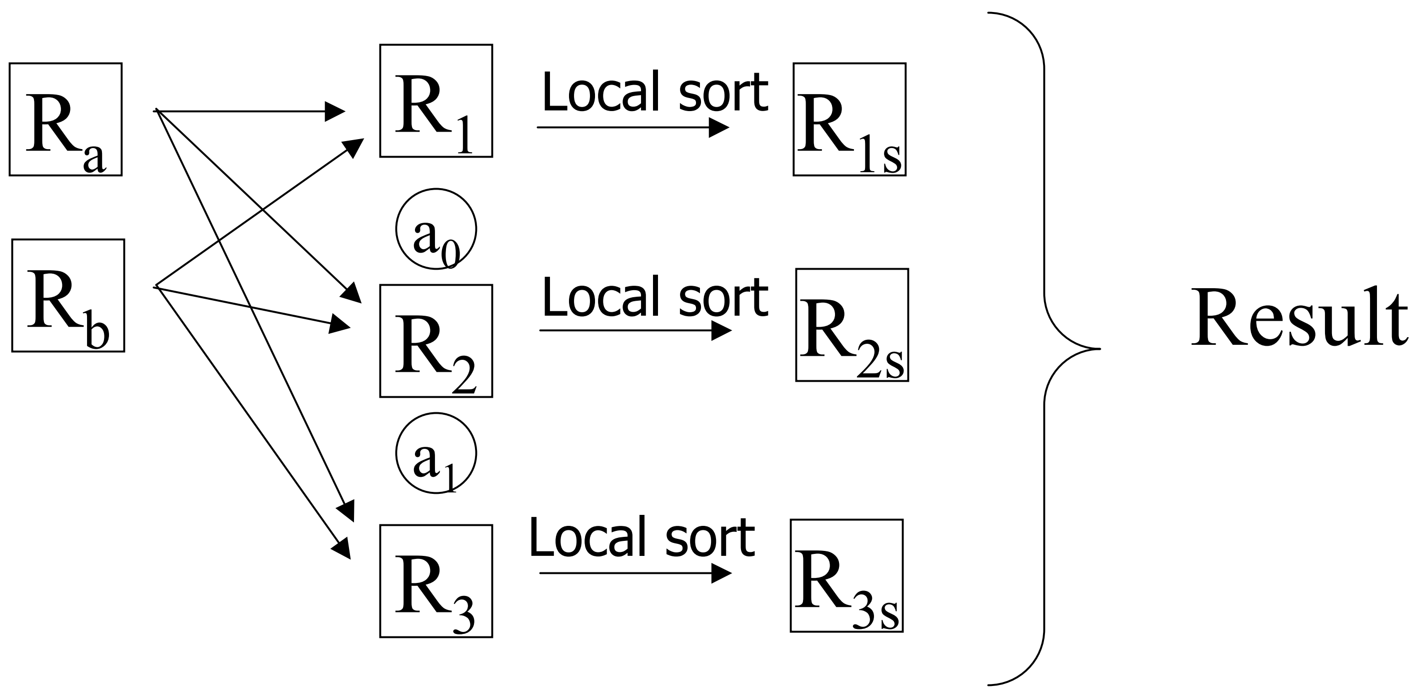
- Given R(A,…) range partitioned on attribute A, sort R on A



- Each fragment is sorted independently
- Results shipped elsewhere if necessary

Range partitioning sort

- Given R(A,….) located at one or more sites, not fragmented on A, sort R on A
- Algorithm: range partition on A and then do basic sort

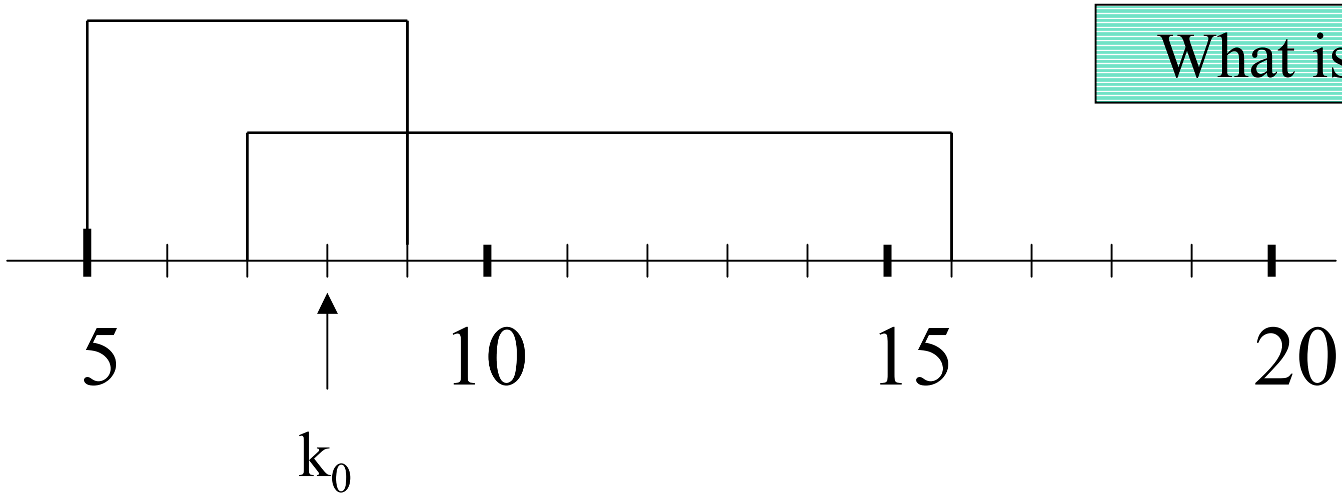


Selecting a partitioning vector

- Possible centralized approach using a "coordinator"
  - Each site sends *statistics* about its fragment to coordinator
  - Coordinator decides # of sites to use for local sort
  - Coordinator computes and distributes partitioning vector
- For example,
  - Statistics could be (min sort key, max sort key, # of tuples)
  - Coordinator tries to choose vector that equally partitions relation

Example

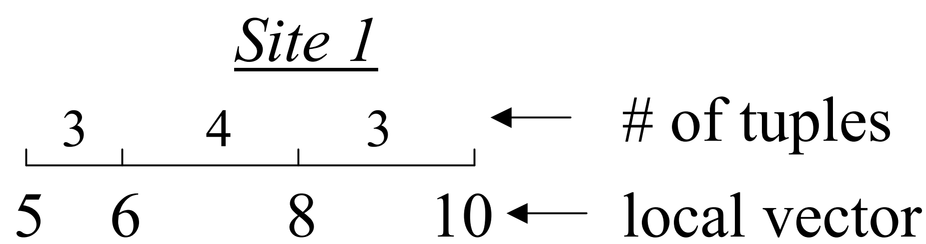
- Coordinator receives:
  - From site 1: Min 5, Max 9, 10 tuples
  - From site 2: Min 7, Max 16, 10 tuples
- Assume sort keys distributed uniformly within [min,max] in each fragment
- Partition R into two fragments



What is k_0?

Variations

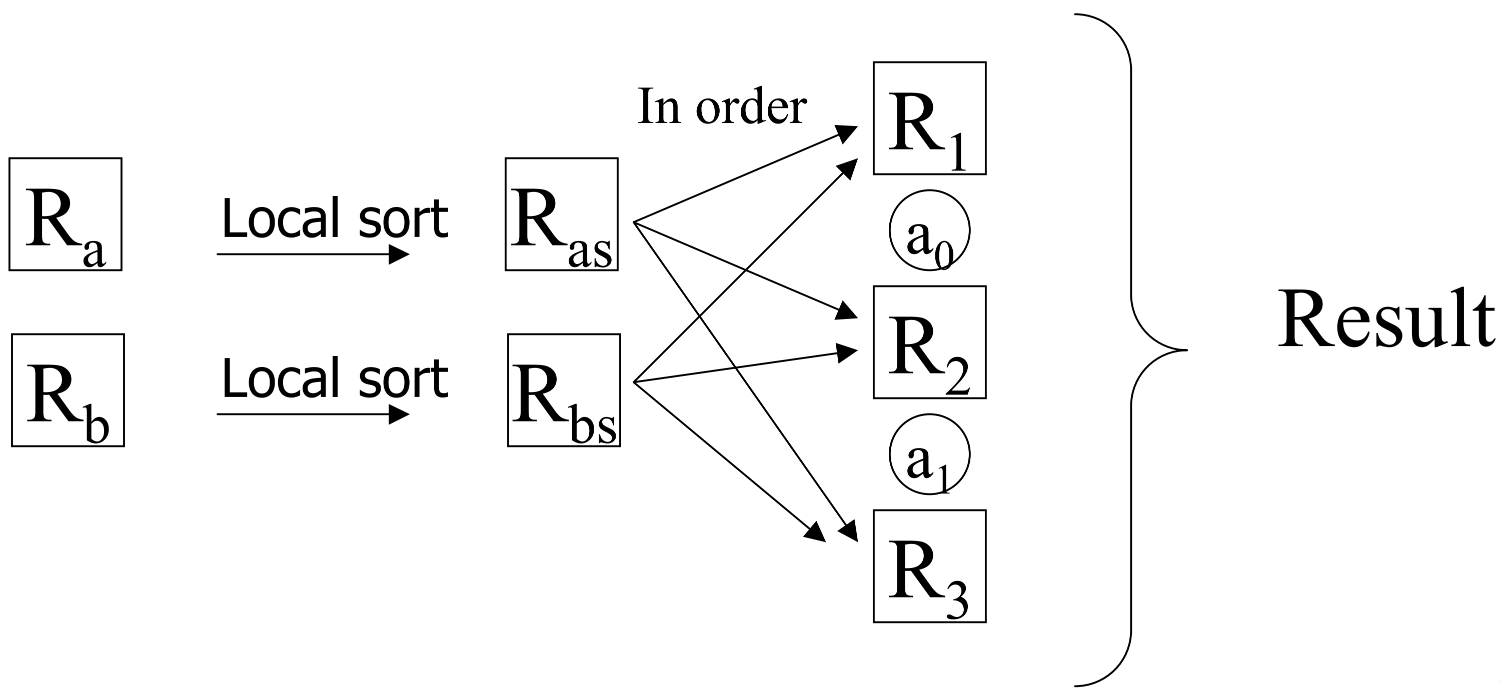
- Different kinds of statistics
  - Local partitioning vector
  - Histogram



- Multiple rounds between coordinator and sites
  - Sites send statistics
  - Coordinator computes and distributes initial vector V
  - Sites tell coordinator the number of tuples that fall in each range of V
  - Coordinator computes final partitioning vector V_f

Parallel external sort-merge

- Local sort
- Compute partition vector
- Merge sorted streams at final sites



Parallel/distributed join

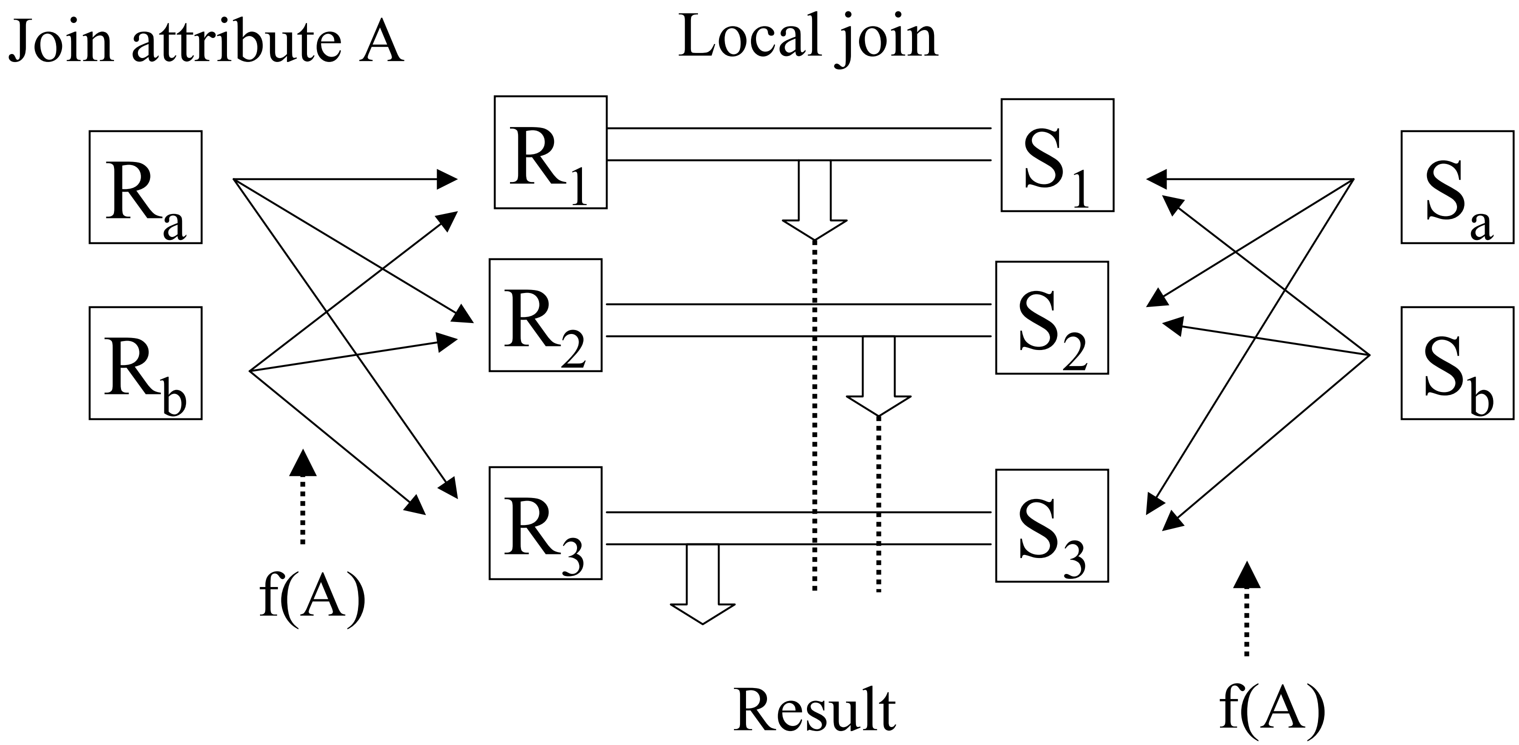
Input: Relations R, S

May or may not be partitioned

Output: $R \bowtie S$

Result at one or more sites

Partitioned Join

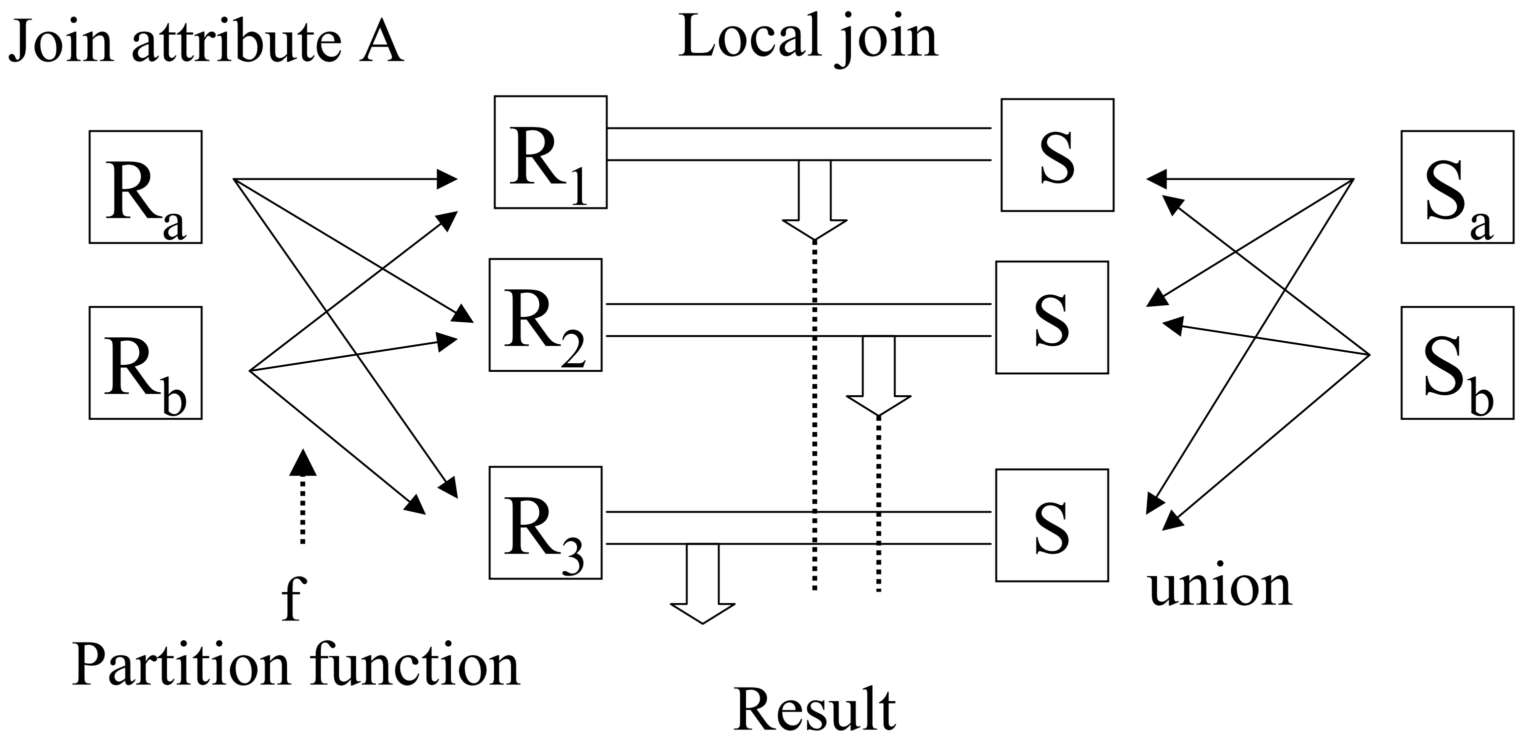


Note: Works only for equi-joins

Partitioned Join

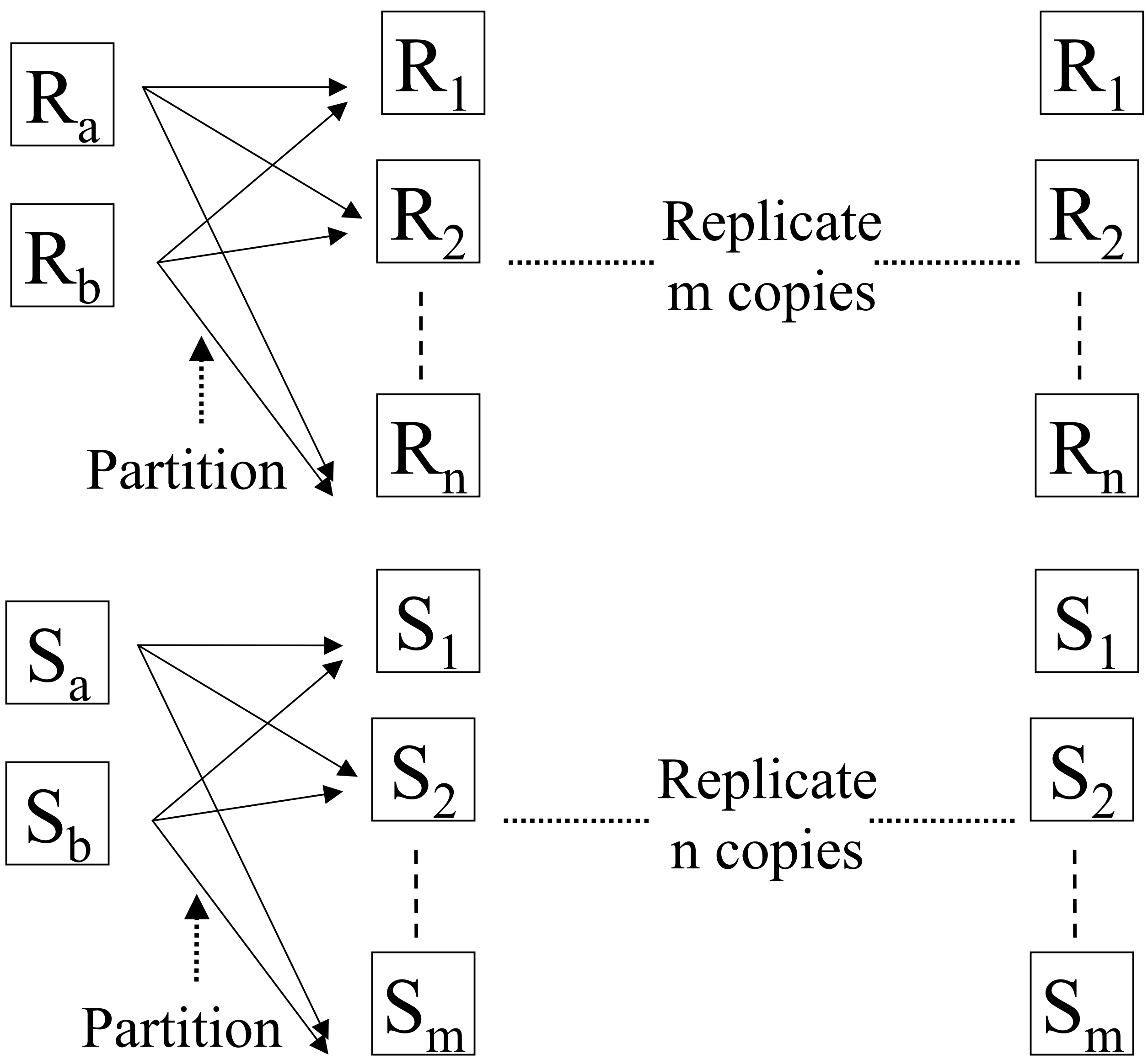
- Same partition function (f) for both relations
- f can be range or hash partitioning
- Any type of local join (nested-loop, hash, merge, etc.) can be used
- Several possible scheduling options. Example:
  - partition R; partition S; join
  - partition R; build local hash table for R; partition S and join
- Good partition function important
  - Distribute join load evenly among sites

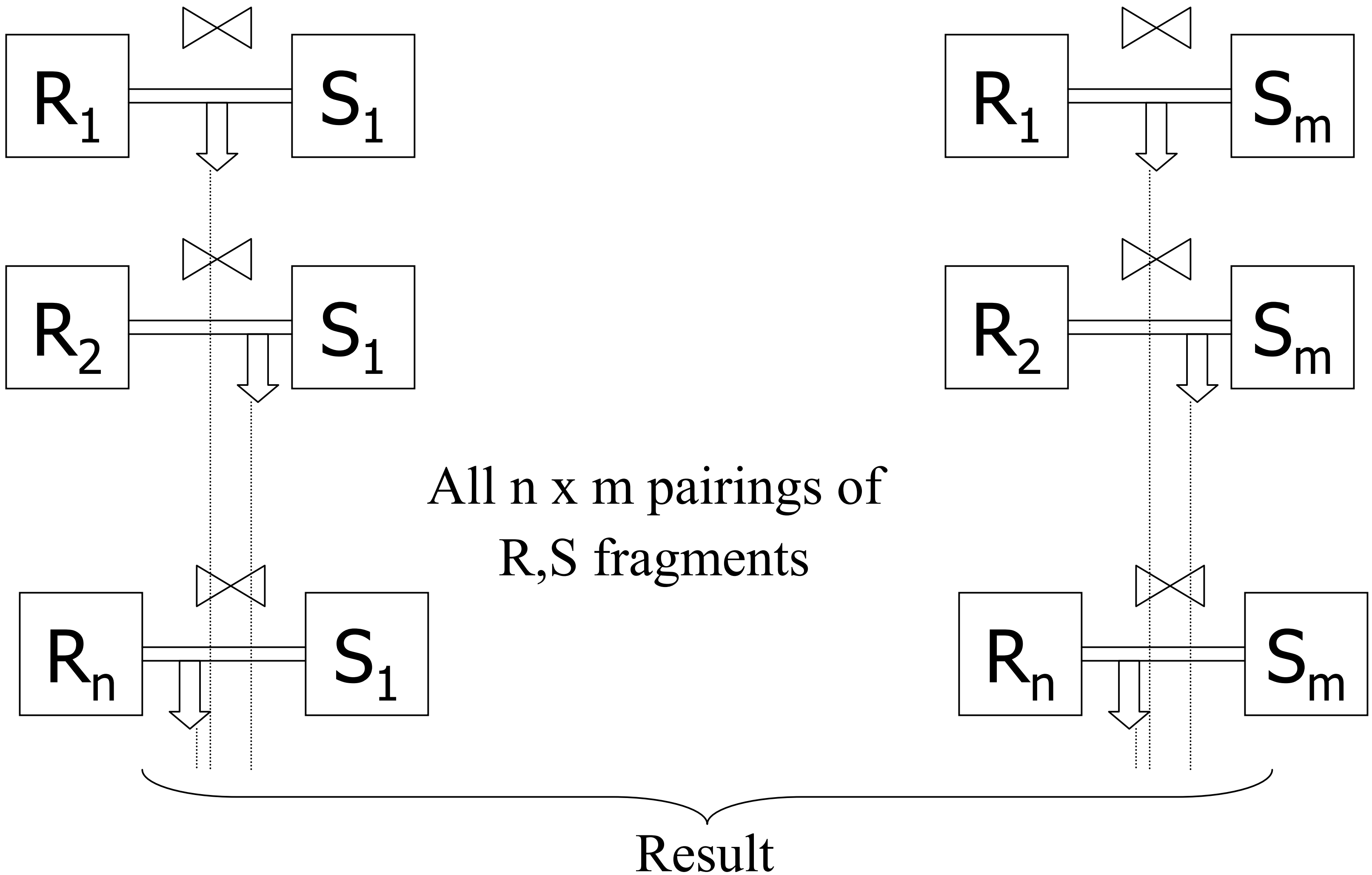
Asymmetric fragment + replicate join



- Any partition function f can be used (even round-robin)
- Can be used for any kind of join, not just equi-joins

General fragment + replicate join





- Asymmetric F+R join is a special case of general F+R.
- Asymmetric F+R is useful when S is small.

Semi-join programs

- Used to reduce communication traffic during join processing
- $R \bowtie S = (R \ltimes S) \bowtie S$

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

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

Example

S

A	B
2	a
10	b
25	c
30	d

R

A	C
3	x
10	y
15	z
25	w
32	x

$\Pi_A(S) = [2,10,25,30]$

$R \ltimes S =$

10	y
25	w

Compute

$S \bowtie (R \ltimes S)$

- Using semi-join, communication cost = 4 A + 2 (A + C) + result
- Directly joining R and S, communication cost = 4 (A + B) + result

Comparing communication costs

- Say R is the smaller of the two relations R and S
- $(R \ltimes S) \bowtie S$ is cheaper than $R \bowtie S$ if

  size $(\Pi_A S)$ + size $(R \ltimes S)$ < size (R)
- Similar comparisons for other types of semi-joins
- Common implementation trick:
  - Encode $\Pi_A S$ (or $\Pi_A R$) as a bit vector
  - 1 bit per domain of attribute A

0 0 1 1 0 1 0 0 0 1 0 1 0 0

n-way joins

- To compute $R \bowtie S \bowtie T$
  - Semi-join program 1: $R' \bowtie S' \bowtie T$

    where $R' = R \ltimes S$ & $S' = S \ltimes T$
  - Semi-join program 2: $R'' \bowtie S' \bowtie T$

    where $R'' = R \ltimes S'$ & $S' = S \ltimes T$
  - Several other options

- In general, number of options is exponential in the number of relations

Other operations

- Duplicate elimination
  - Sort first (in parallel), then eliminate duplicates in the result
  - Partition tuples (range or hash) and eliminate duplicates locally
- Aggregates
  - Partition by grouping attributes; compute aggregates locally at each site

Example

R_a

#	dept	sal
1	toy	10
2	toy	20
3	sales	15

R_b

#	dept	sal
4	sales	5
5	toy	20
6	mgmt	15
7	sales	10
8	mgmt	30

#	dept	sal
1	toy	10
2	toy	20
5	toy	20
6	mgmt	15
8	mgmt	30

sum

dept	sum
toy	50
mgmt	45

#	dept	sal
3	sales	15
4	sales	5
7	sales	10

sum

dept	sum
sales	30

sum(sal) group by dept

Example

R_a

#	dept	sal
1	toy	10
2	toy	20
3	sales	15

R_b

#	dept	sal
4	sales	5
5	toy	20
6	mgmt	15
7	sales	10
8	mgmt	30

sum

dept	sum
toy	30
toy	20
mgmt	45

sum

dept	sum
sales	15
sales	15

sum

dept	sum
toy	50
mgmt	45

sum

dept	sum
sales	30

Does this work for all kinds of aggregates?

Aggregate during partitioning to reduce communication cost

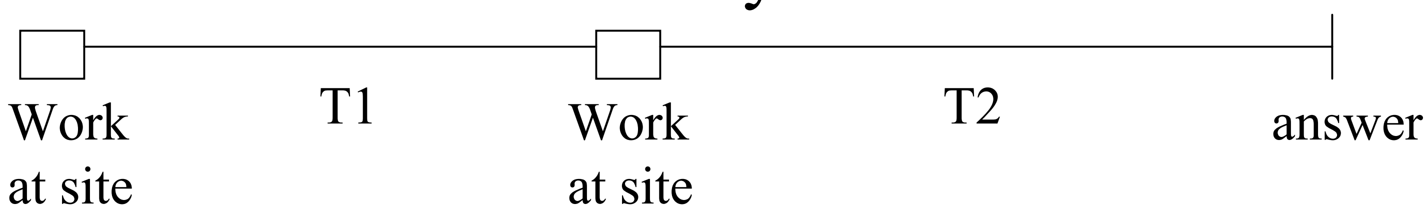
Query Optimization

- Generate query execution plans (QEPs)
- Estimate cost of each QEP ($,time,…)
- Choose minimum cost QEP

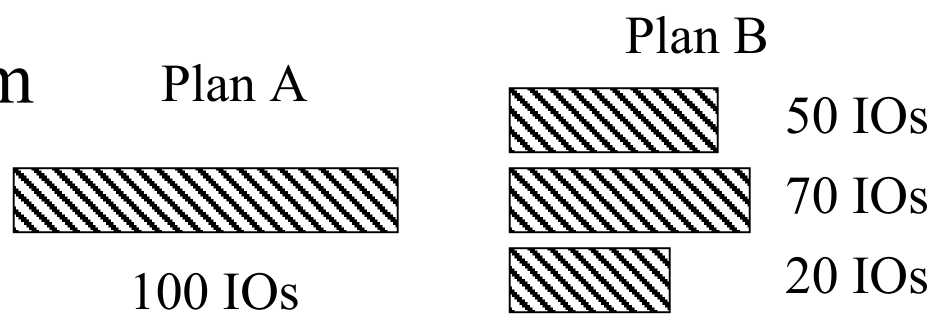
- What's different for distributed DB?
  - New strategies for some operations (semi-join, range-partitioning sort,…)
  - Many ways to assign and schedule processors
  - Some factors besides number of IO's in the cost model

Cost estimation

- In centralized systems - estimate sizes of intermediate relations
- For distributed systems
  - Transmission cost/time may dominate



  - Account for parallelism



  - Data distribution and result re-assembly cost/time

Optimization in distributed DBs

- Two levels of optimization
- Global optimization
  - Given localized query and cost function
  - Output optimized (min. cost) QEP that includes relational and communication operations on fragments
- Local optimization
  - At each site involved in query execution
  - Portion of the QEP at a given site optimized using techniques from centralized DB systems

Search strategies

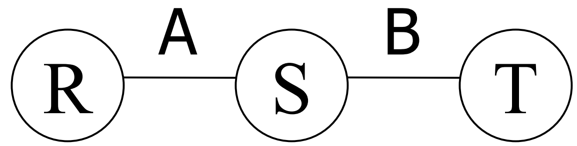
1. Exhaustive (with pruning)
2. Hill climbing (greedy)
3. Query separation

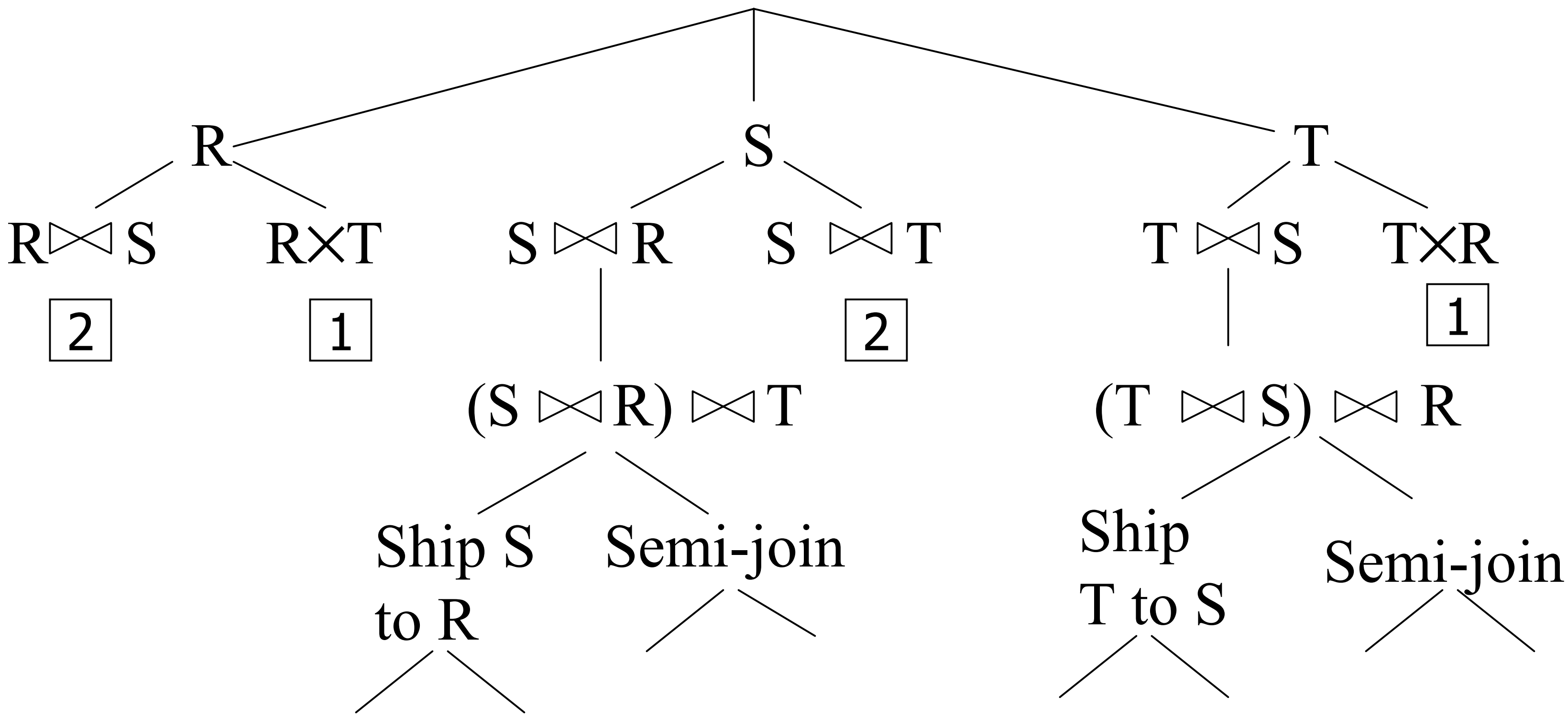
Exhaustive with Pruning

- A fixed set of techniques for each relational operator
- Search space = “all” possible QEPs with this set of techniques
- Prune search space using heuristics
- Choose minimum cost QEP from rest of search space

Example

|R|>|S|>|T|

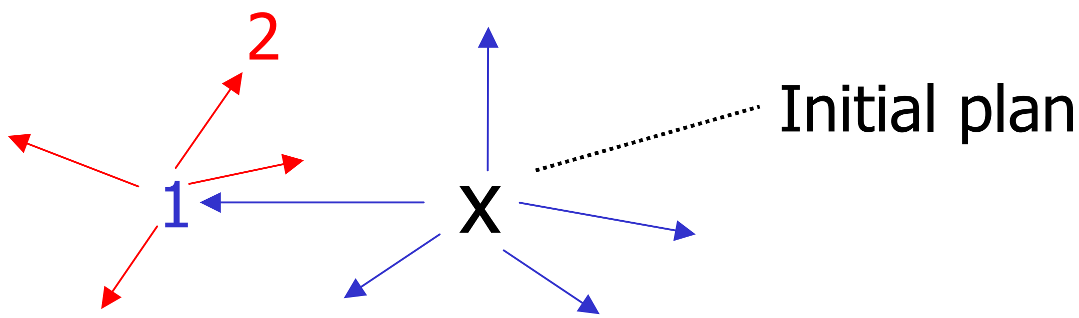




1 Prune because cross-product not necessary

2 Prune because larger relation first

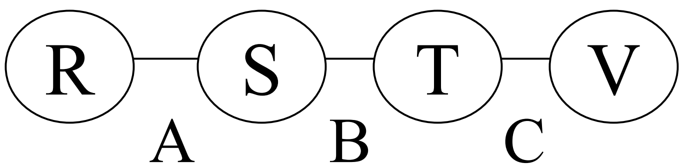
Hill Climbing



- Begin with initial feasible QEP
- At each step, generate a set S of new QEPs by applying 'transformations' to current QEP
- Evaluate cost of each QEP in S
- Stop if no improvement is possible
- Otherwise, replace current QEP by the minimum cost QEP from S and iterate

Example

$R \bowtie S \bowtie T \bowtie V$



Rel.	Site	# of tuples
R	1	10
S	2	20
T	3	30
V	4	40

- Goal: minimize communication cost
- Initial plan: send all relations to one site

  To site 1: cost=20+30+40= 90

  To site 2: cost=10+30+40= 80

  To site 3: cost=10+20+40= 70

  To site 4: cost=10+20+30= 60
- Transformation: send a relation to its neighbor

Local search

- Initial feasible plan

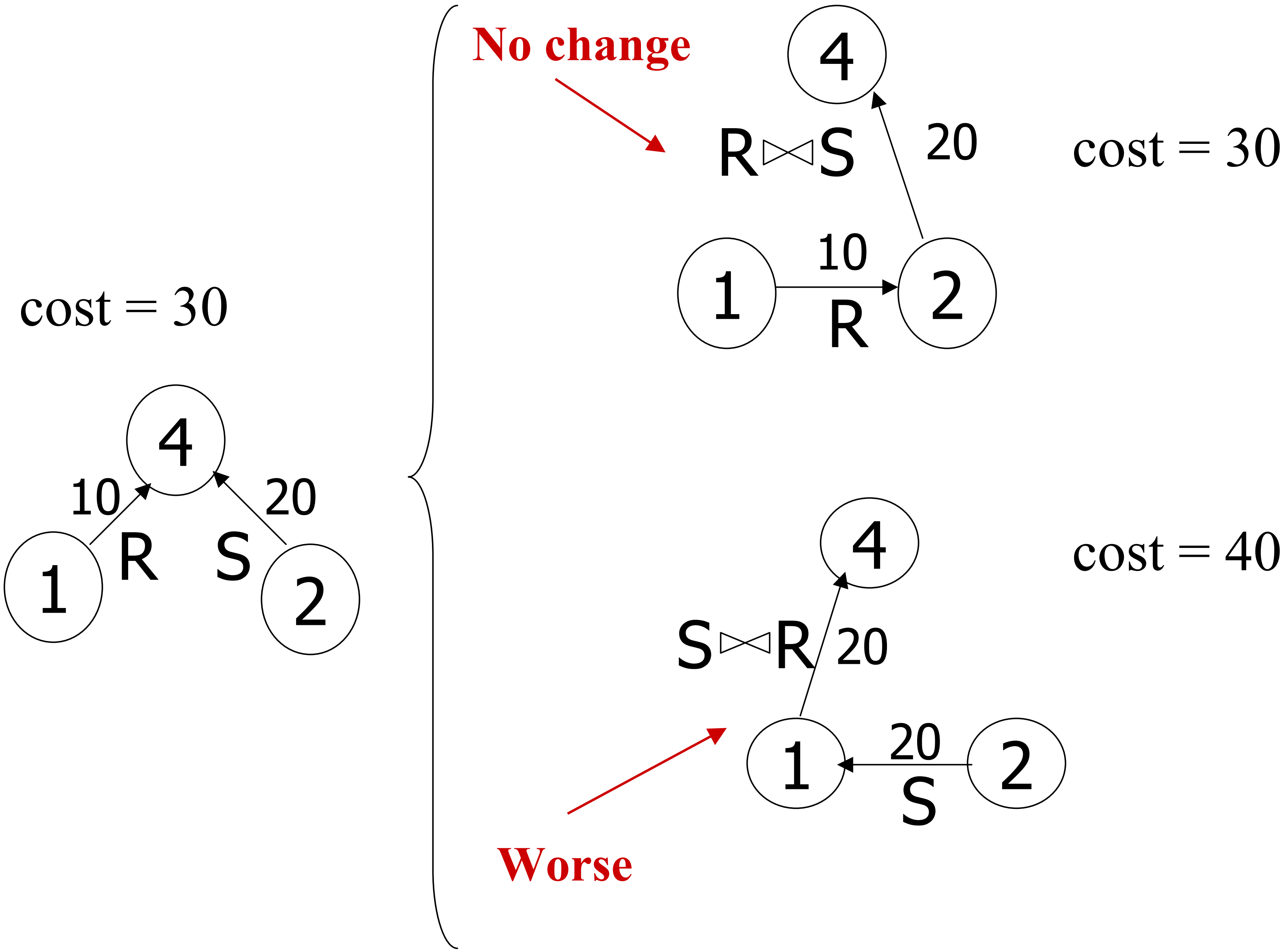
  P0: R $(1 \rightarrow 4)$; S $(2 \rightarrow 4)$; T $(3 \rightarrow 4)$

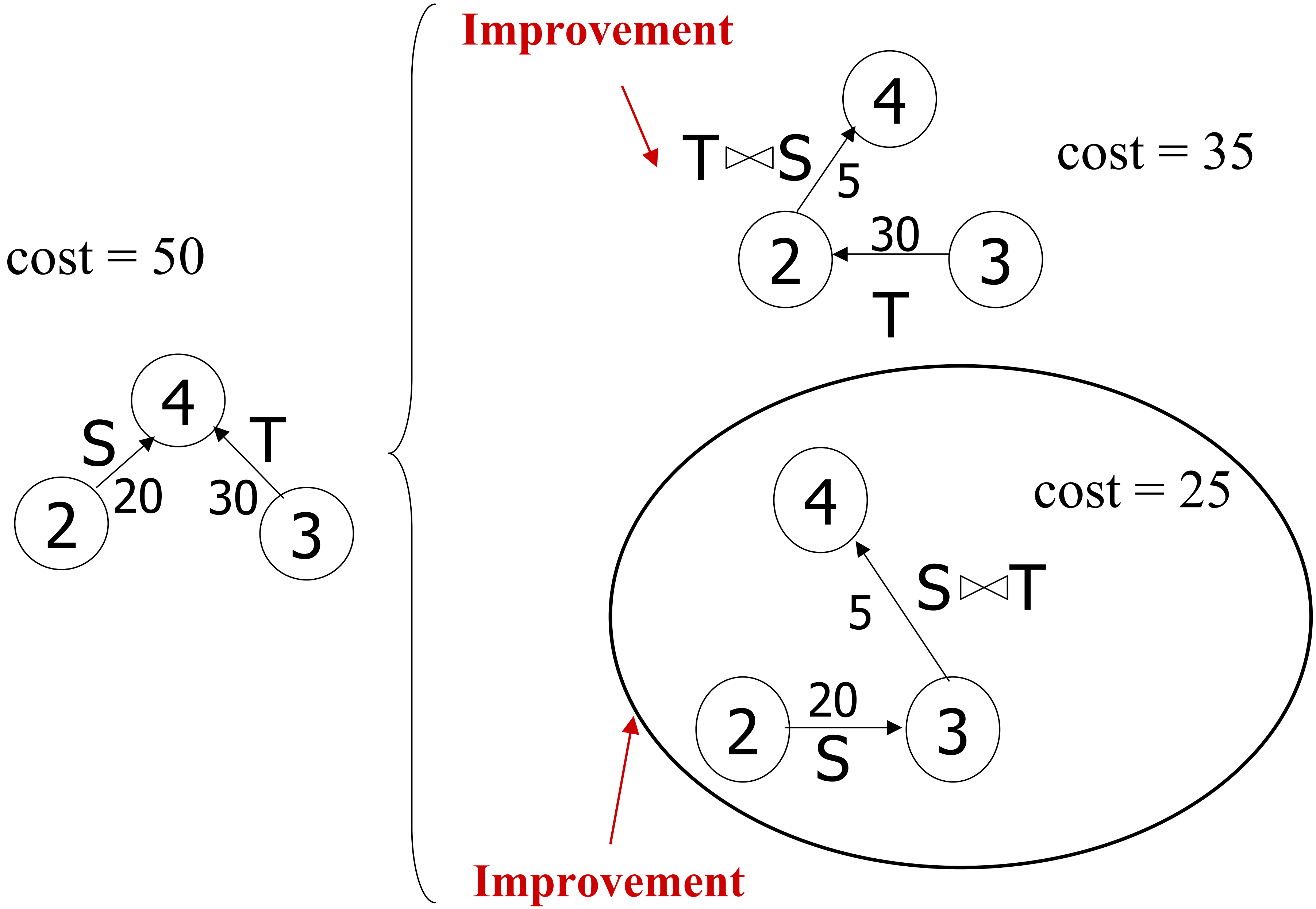
  Compute join at site 4

- Assume following sizes: $R \bowtie S \Rightarrow 20$

  $S \bowtie T \Rightarrow 5$

  $T \bowtie V \Rightarrow 1$


cost = 30
4
10
20
1
R
S
2
No change
4
R⋈S
20
cost = 30
10
1
R
2
4
cost = 40
S⋈R
20
20
1
S
2
Worse

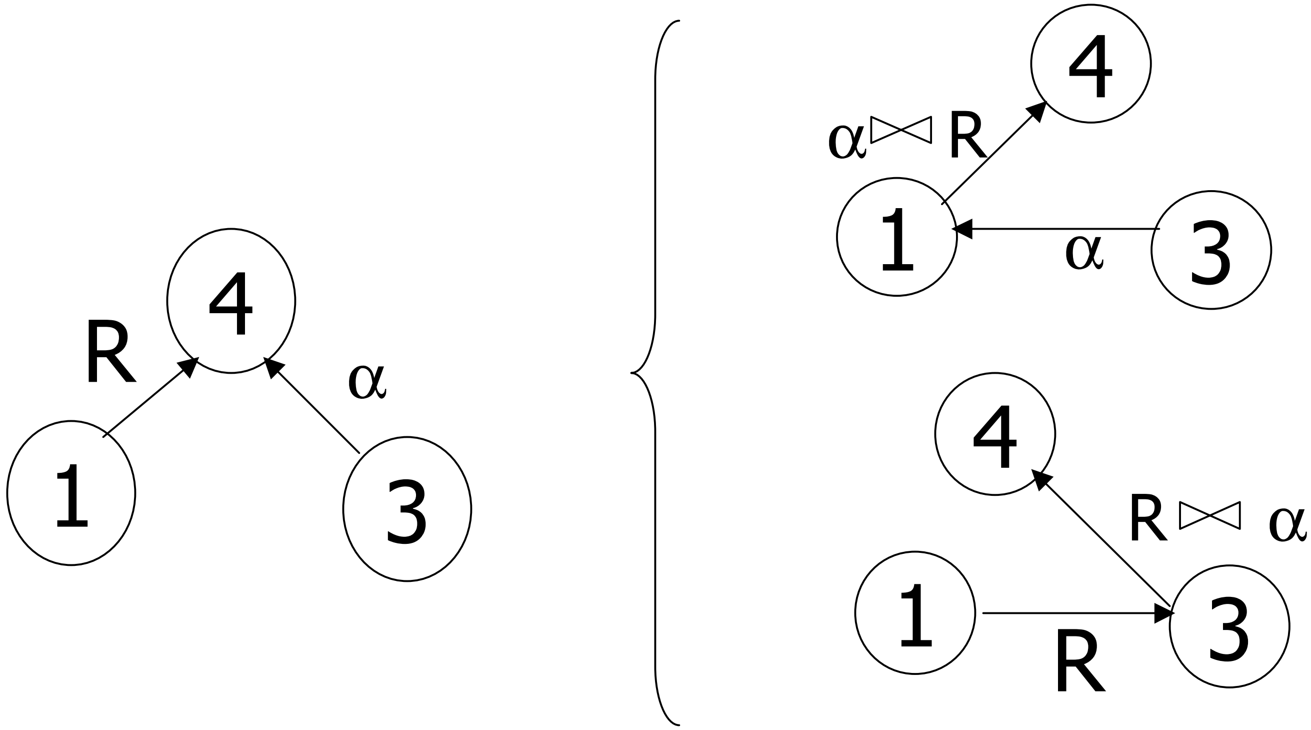

cost = 50
Improvement
T⋈S
cost = 35
Improvement
S⋈T
cost = 25
S
T
20
30
5
4
2
3

Next iteration

- P1: S (2 $\rightarrow$ 3); R (1 $\rightarrow$ 4); α (3 $\rightarrow$ 4)

  where $\alpha = S \bowtie T$

  Compute answer at site 4
- Now apply same transformation to R and α



Resources

- Ozsu and Valduriez. “Principles of Distributed Database Systems” – Chapters 7, 8, and 9.