ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

Συστήματα Διαχείρισης Βάσεων Δεδομένων

Φροντιστήριο 7: Tutorial on Query Optimization

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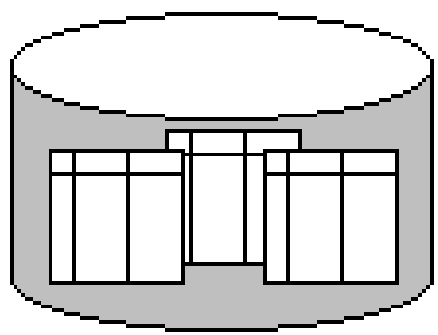
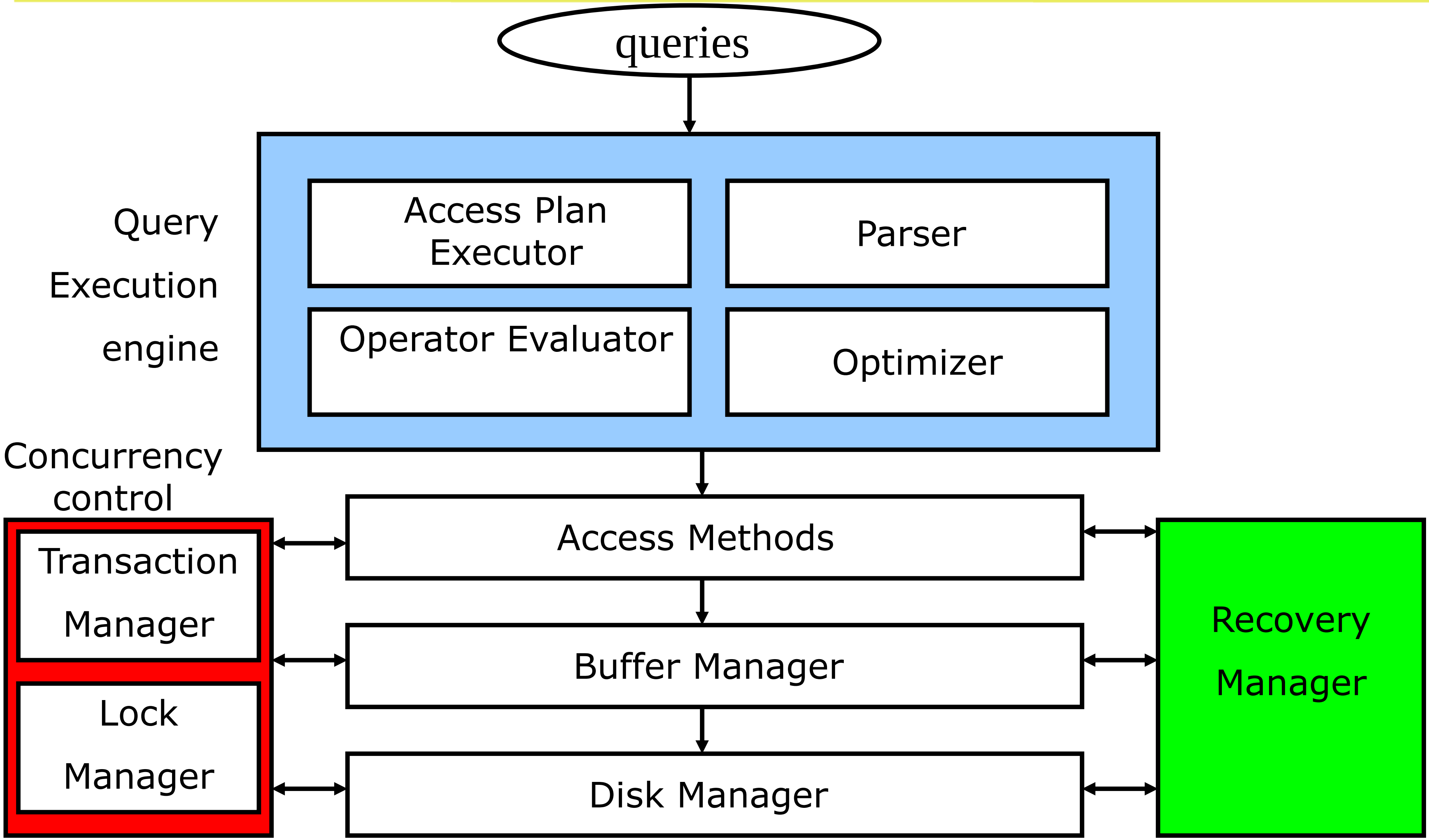
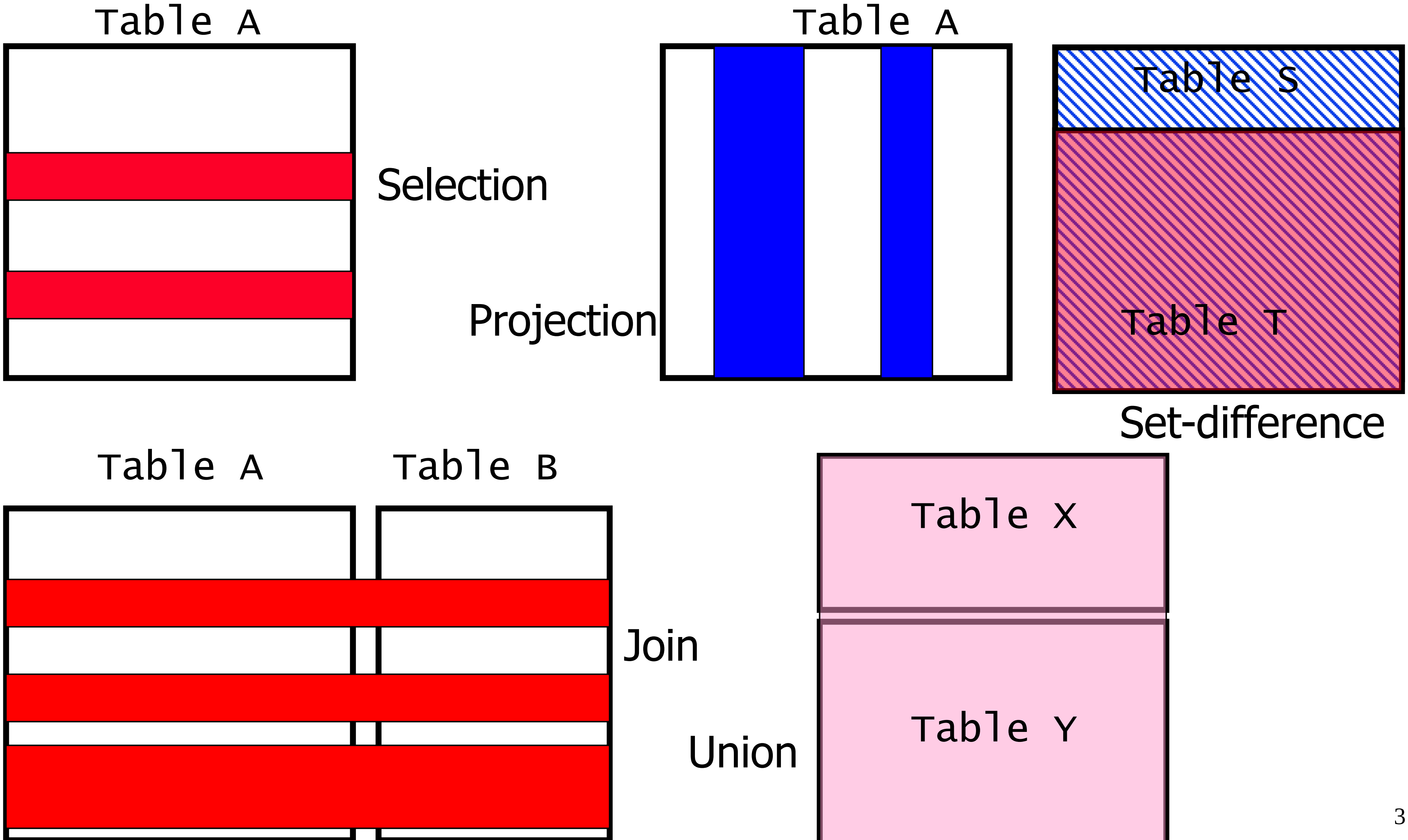
TUTORIAL ON QUERY OPTIMIZATION



DB Logical Architecture



Relational Operators



Measures of Query Cost

- Cost is generally measured as total elapsed time for answering query
  - Many factors contribute to time cost: disk accesses, CPU, or even network communication
- Typically disk access is the predominant cost, and is also relatively easy to estimate
  - Measured by taking into account
    - Number of blocks read * average-block-read-cost
    - Number of blocks written * average-block-write-cost
  - Cost to write a block is greater than cost to read a block
    - data is read back after being written to ensure that the write was successful

Measures of Query Cost

- For simplicity we just use number of block transfers from disk as the cost measure
  - We ignore the difference in cost between sequential and random I/O for simplicity
  - We also ignore CPU costs for simplicity
  - We do not include cost to writing output to disk in our cost formula
- Costs depends on the size of the buffer in main memory
  - Having more memory reduces need for disk access
  - Amount of real memory available to buffer depends on other concurrent OS processes, and hard to determine ahead of actual execution
  - We often use worst case estimates, assuming only the minimum amount of memory needed for the operation is available
- Real systems take CPU cost into account, differentiate between sequential and random I/O, and take buffer size into account

Nested-Loop Join

- Read in outer relation R block by block
  - ♦Then, for each tuples in R, we scan the entire inner relation S (read in S block by block)

- n_R : no. of record for R
- b_R : no. of block for R
- b_S : no. of block for S

```
foreach tuple r in R do
        foreach tuple in S do
                if ri == sj then add <r,s> to result
```

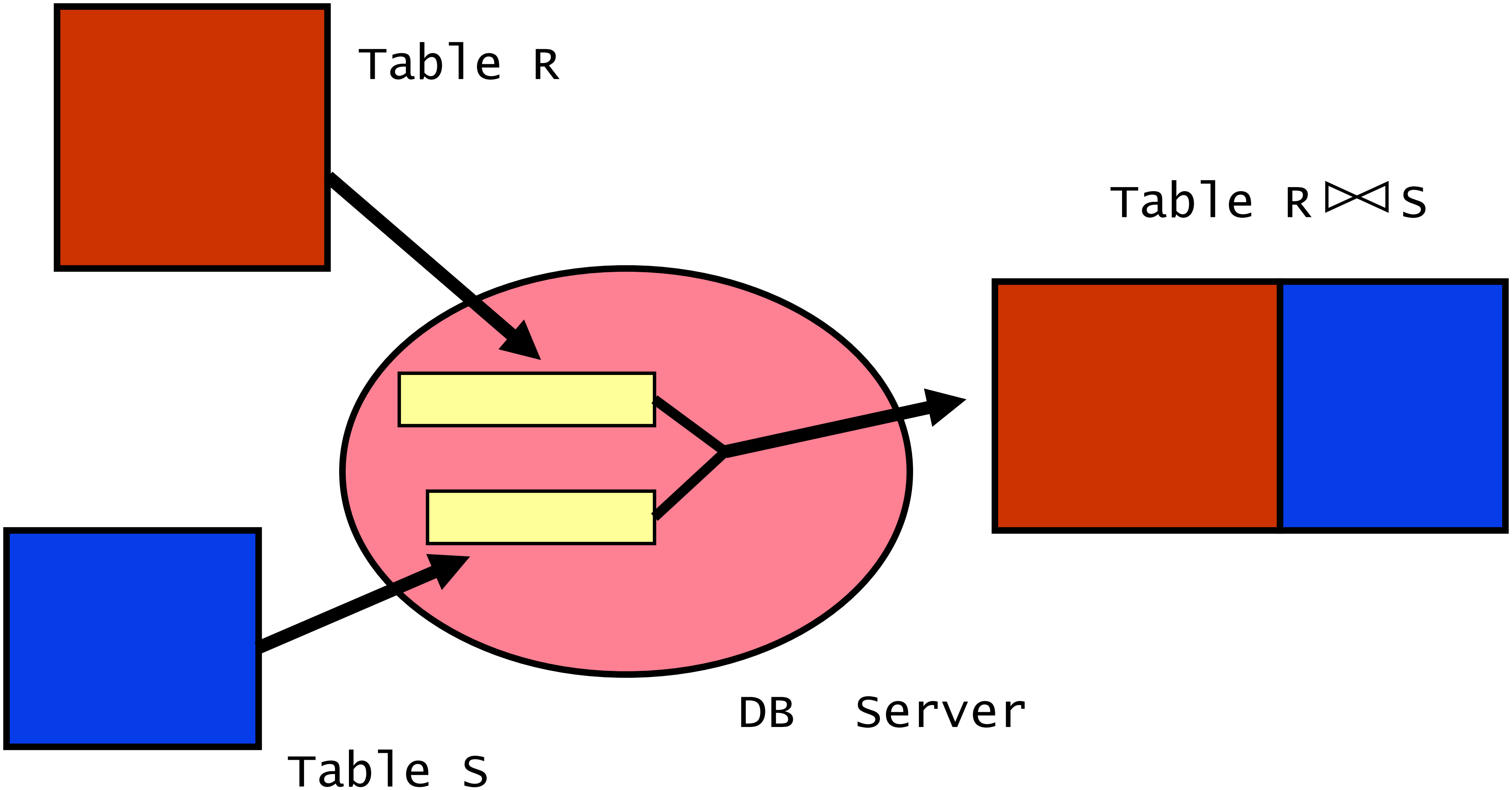
- Worst Cost: $b_R + n_R * b_S$

- Best Cost: $b_R + b_S$ (if smaller relation can fit in memory)

- Use small relation as outer relation

- Buffer: 3 pages (1 for R, 1 for S, 1 for output)

Nested Loops Join



Exercise

- Relations: `S(A,B,C)` and `R(C,D,E)`
- `S` has 20,000 tuples
- `R` has 45,000 tuples
- 25 tuples of `S` fit on one block (blocking factor)
- 30 tuples of `R` fit on one block
- `S JOIN R`
- `S` need 800 blocks (20000/25)
- `R` need 1500 blocks (45000/30)
- Assume M pages in memory
- If `M > 800`, cost = $b_R + b_S$ = 1500 + 800 = 2300 I/Os

- Consider only `M <=800,`

cost = $b_S + n_S * b_R$

- Using S as outer relation
  - ♦Cost: 800 +20000*1500 = 30000800 I/Os

cost = $b_R + n_R * b_S$

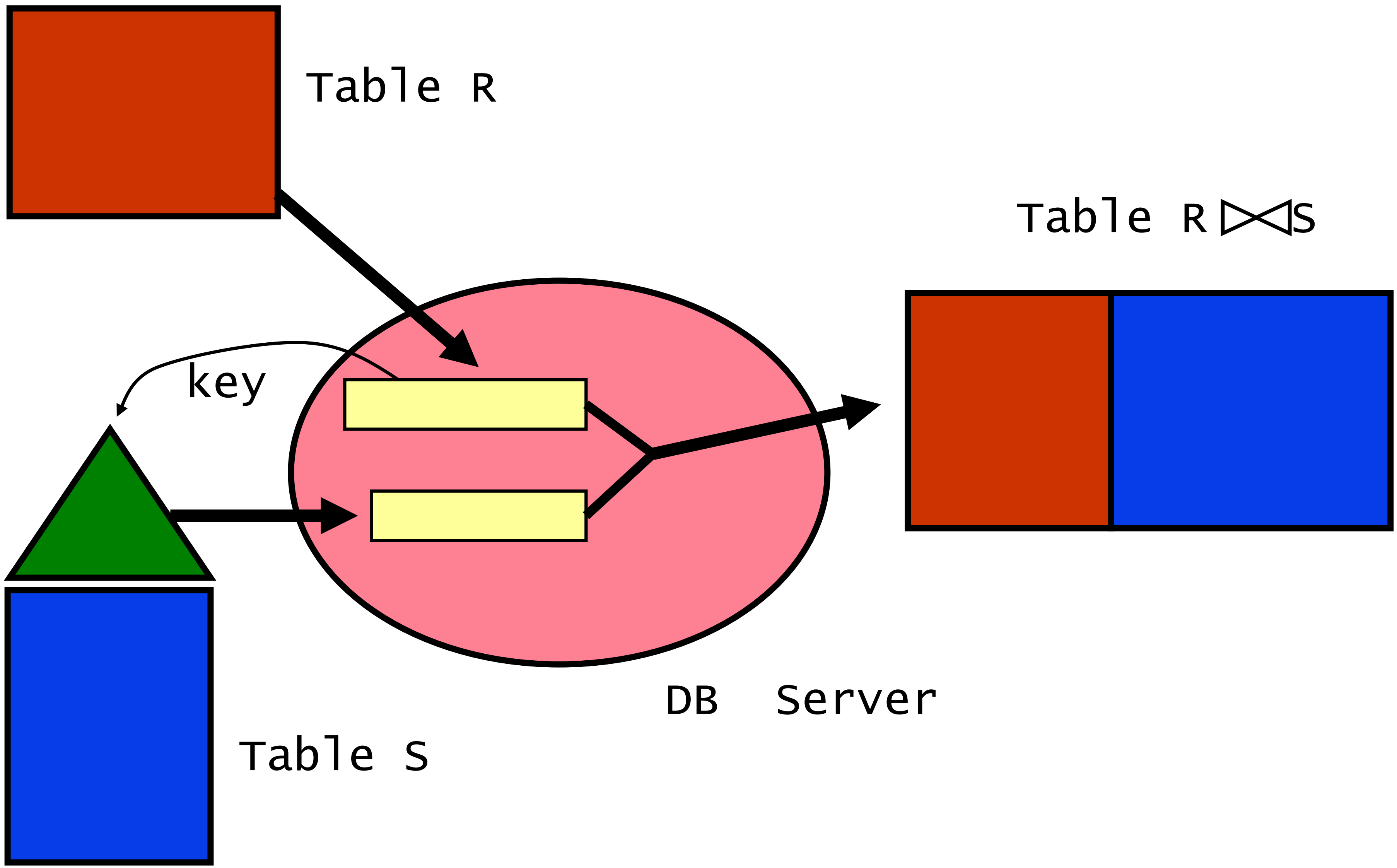
- If R as outer relation
  - ♦Cost: 1500 + 45000*800 = 36001500 I/Os

Block Nested Loop Join

```
foreach block of M – 2 pages of R do
    foreach page of S do
        for all matching in-memory tuples r in R-block and s in S-page
            add <r,s> to result
```

- If M buffer pages available
  - Cost: $b_R + \lceil b_R /(M-2) \rceil * b_S$
  - M buffer pages (1 for inner S, 1 for output and all remaining M-2 pages to hold “block” of outer R
- If S is outer
  - Cost = $\lceil 800 /(M-2) \rceil * 1500 + 800$ I/Os
- If R is outer
  - Cost = $\lceil 1500 /(M-2) \rceil * 800 + 1500$ I/Os

Index Nested-Loop Join



Index Nested-Loop Join

- Primary B+tree index on the join attribute of R:
  - $b_S + n_S * (x_R + 1)$

  where:
    - n_S (n_R) is the number of S (R) tuples
    - x_R is the height of the B+-tree index on the join attribute
    - $n_S * (x_R + 1)$ is the cost of using B+-tree index to find matching tuple in R

- Secondary B+tree index on the join attribute of R:
  - $b_S + n_R * (x_R + 1)$
  - where $n_R * (x_R + 1)$ is the cost of using B+-tree index to find matching tuple in R

Index Nested loop join

- Hash index on the join attribute of R:
  - $b_S + n_S * H$
  - Where H is the average number of page accesses necessary to retrieve a tuple from R with a given key

- We use:
  - H = 1.2 for a primary hash index and
  - H = 2.2 for a secondary hash index

External Sorting

- File has b_R pages
- M : number of main memory page buffers
- No. of runs in the first pass $R = b_R / M$
- No. of passes to sort file completely

  $$P = \lceil \log_{M-1} (b_R / M) \rceil + 1$$
  $$= \lceil \log_{M-1} R \rceil + 1$$

- Total cost for sorting

  $$= b_R * (2 * \lceil \log_{M-1} R \rceil + 1)$$
  $$= b_R * 2 * \lceil \log_{M-1} R \rceil + b_R$$

Merge Join

- Assuming S and R are not initially sorted on the join key
- Cost = Sorting + b_R + b_s
- Sorting = $1500 * (2 * \lceil \log_{M-1} (1500/M) \rceil + 1) + 800 * (2 * \lceil \log_{M-1} (800/M) \rceil + 1)$

Merge Join

- Assuming that there is a secondary B+tree on Rx
- Cost = $C_{R1} + C_{R2}$
- where $C_{Rx} = (n_{Rx} * ps)/(0.69 * bs) + b_{Rx}$ for the R which has the index on the join attribute
  - *ps* : the size of the tuple reference (tuple identifier, `rid`)
  - *bs* : the size of the block
- i.e.: the leaf nodes of the index tree (assumed to be 69% full) have to be scanned for pointers to the tuples of the relation and the blocks containing the tuples itself must be read at least once

Hash join

- Hash both relations on the join attribute using the same hash function
- Since S is smaller, we use it as the build relation and R as probe relation
- Assume no overflow occurs
- If M >= 800, no need for recursive partitioning, cost = 3(1500 + 800) = 6900 disk access = $3(b_R + b_s)$
- Else, cost = $2(1500 + 800)\lceil \log_{M-1}(800) - 1 \rceil + 1500 + 800$ disk access $= 2(b_R + b_s)\lceil \log_{M-1}(b_s) - 1 \rceil + b_R + b_s$

Why Optimize?

- Given a query and a database of size *m*, how big can the output of applying the query to the database be?

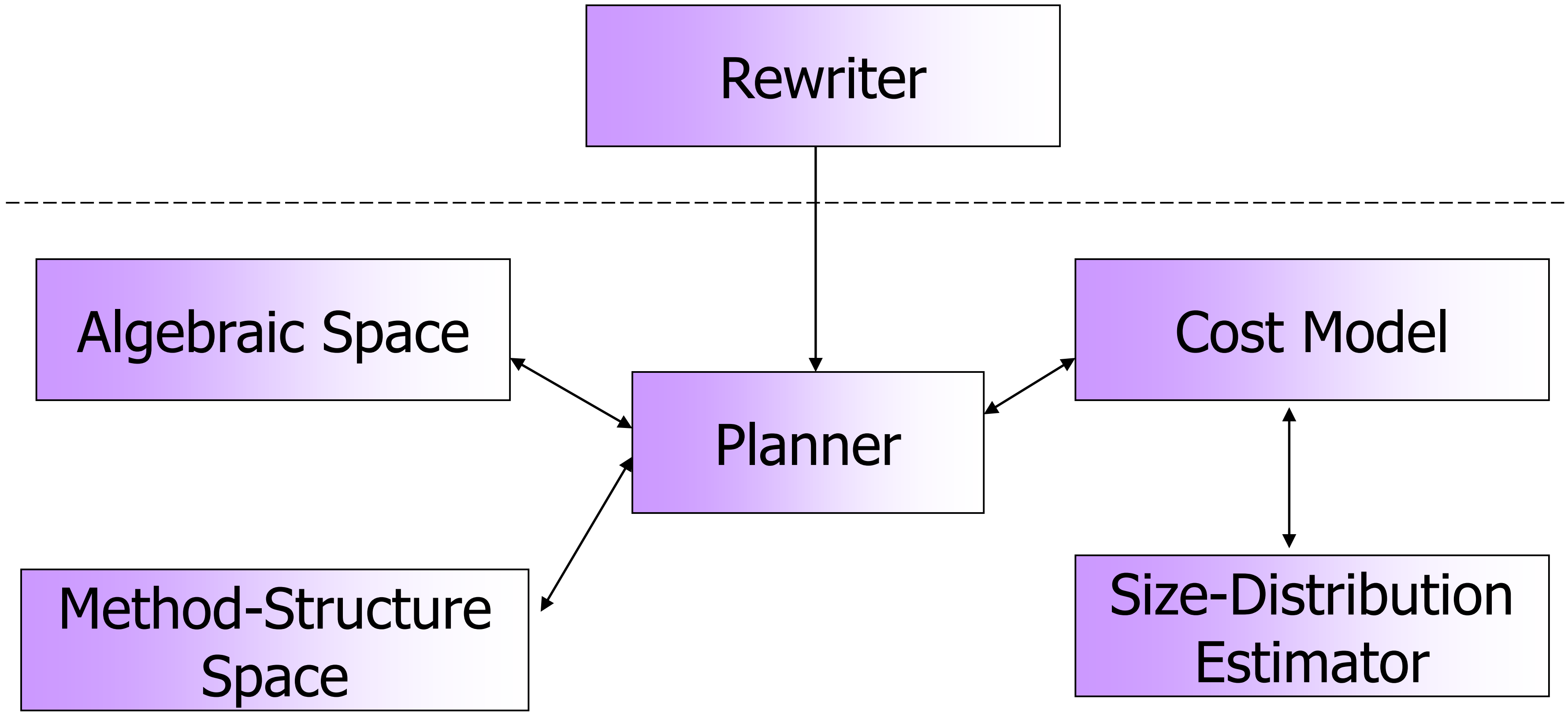
- Example: R(A) with 2 rows. One row has value 0. One row has value 1.
  - How many rows are in R x R?
  - How many in R x R x R?

→ Size of output as a function of input: O(?)

- Usually, queries are small
  - Therefore, it is usually assumed that queries are of a fixed size
  - Use term data complexity when we analyze time, assuming that query is constant

- What is the size of the output in this case?

Optimizer Architecture



Optimizer Architecture

- Rewriter: Finds equivalent queries that, perhaps can be computed more efficiently; all such queries are passed on to the Planner
  - Examples of Equivalent queries: Join orderings
- Planner: Examines all possible execution plans and chooses the cheapest one, i.e., fastest one
  - Uses other modules to find best plan
- Algebraic Space: Determines which types of queries will be examined
  - Example: Try to avoid Cartesian Products
- Method-Structure Space: Determines what types of indexes are available and what types of algorithms for algebraic operations can be used
  - Example: Which types of join algorithms can be used
- Cost Model: Estimates the cost of execution plans
  - Uses Size-Distribution Estimator for this
- Size-Distribution Estimator: Estimates size of tables, intermediate results, frequency distribution of attributes and size of indexes

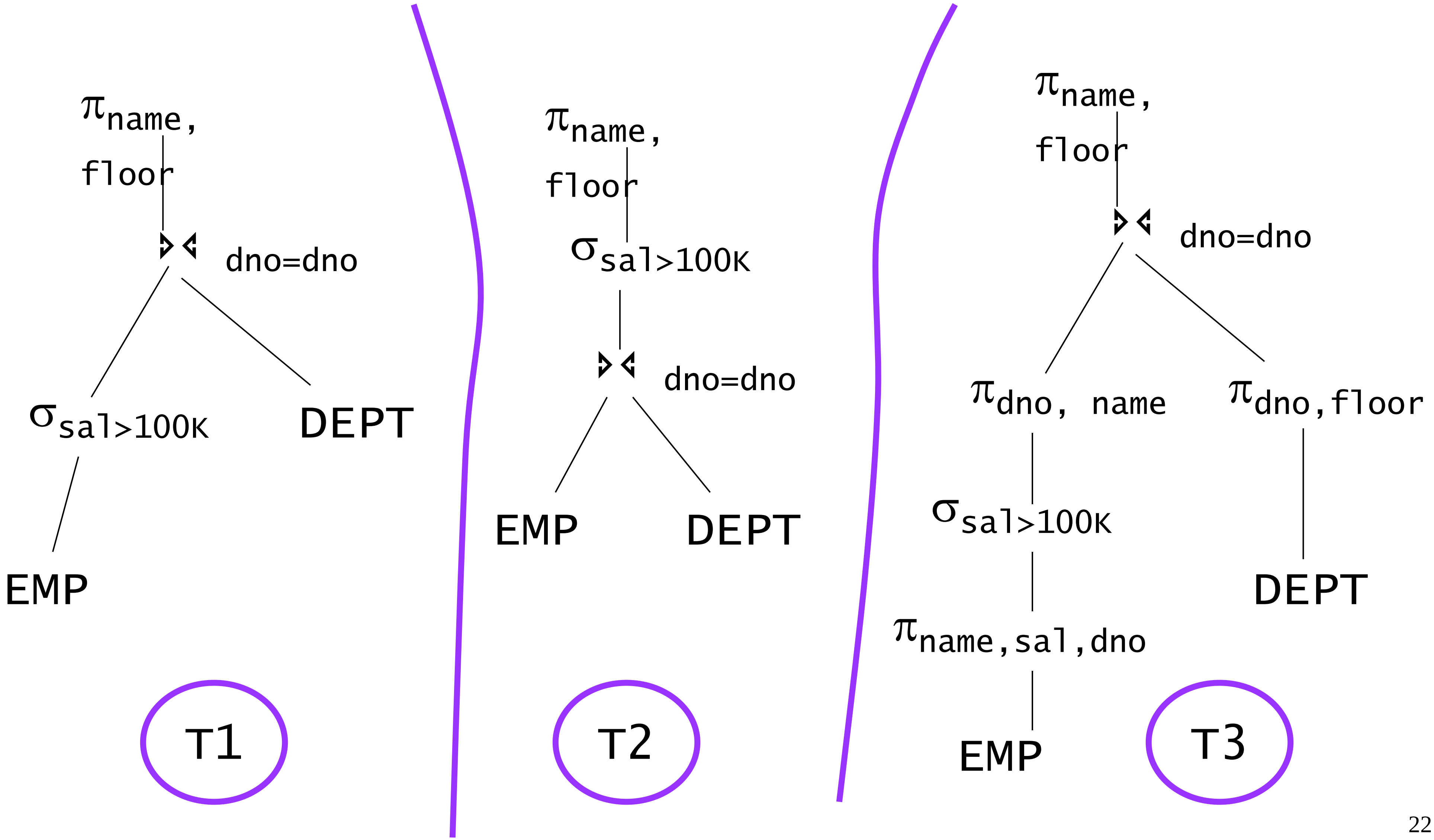
Algebraic Space

- We consider queries that consist of select, project and join (Cartesian product is a special case of join)
- Such queries can be represented by a tree.
- Example:

```
emp(name, age, sal, dno)
dept(dno, dname, floor, mgr, ano)
act(ano, type, balance, bno)
bank(bno, bname, address)
```

```
select name, floor
from emp, dept
where emp.dno=dept.dno and sal > 100K
```

3 Trees


πname, floor
⋈ dno=dno
σsal>100K
DEPT
EMP
T1
πname, floor
σsal>100K
⋈ dno=dno
EMP
DEPT
T2
πname, floor
⋈ dno=dno
πdno, name
πdno,floor
σsal>100K
DEPT
πname,sal,dno
EMP
T3

Restriction 1 of Algebraic Space

- Algebraic space may contain many equivalent queries
- Important to restrict space
- Restriction (heuristic) 1: Only allow queries for which selection and projection:
  - are processed as early as possible
  - are processed on the fly
- Which trees in our example conform to Restriction 1?

Performing Selection and Projection "On the Fly"

- Selection and projection are performed as part of other actions
- Projection and selection that appear one after another are performed one immediately after another
  - Projection and Selection do not require writing to the disk
- Selection is performed while reading relations for the first time
- Projection is performed while computing answers from previous action

Processing Selection/Projection as Early as Possible

- The three trees differ in the way that selection and projection are performed

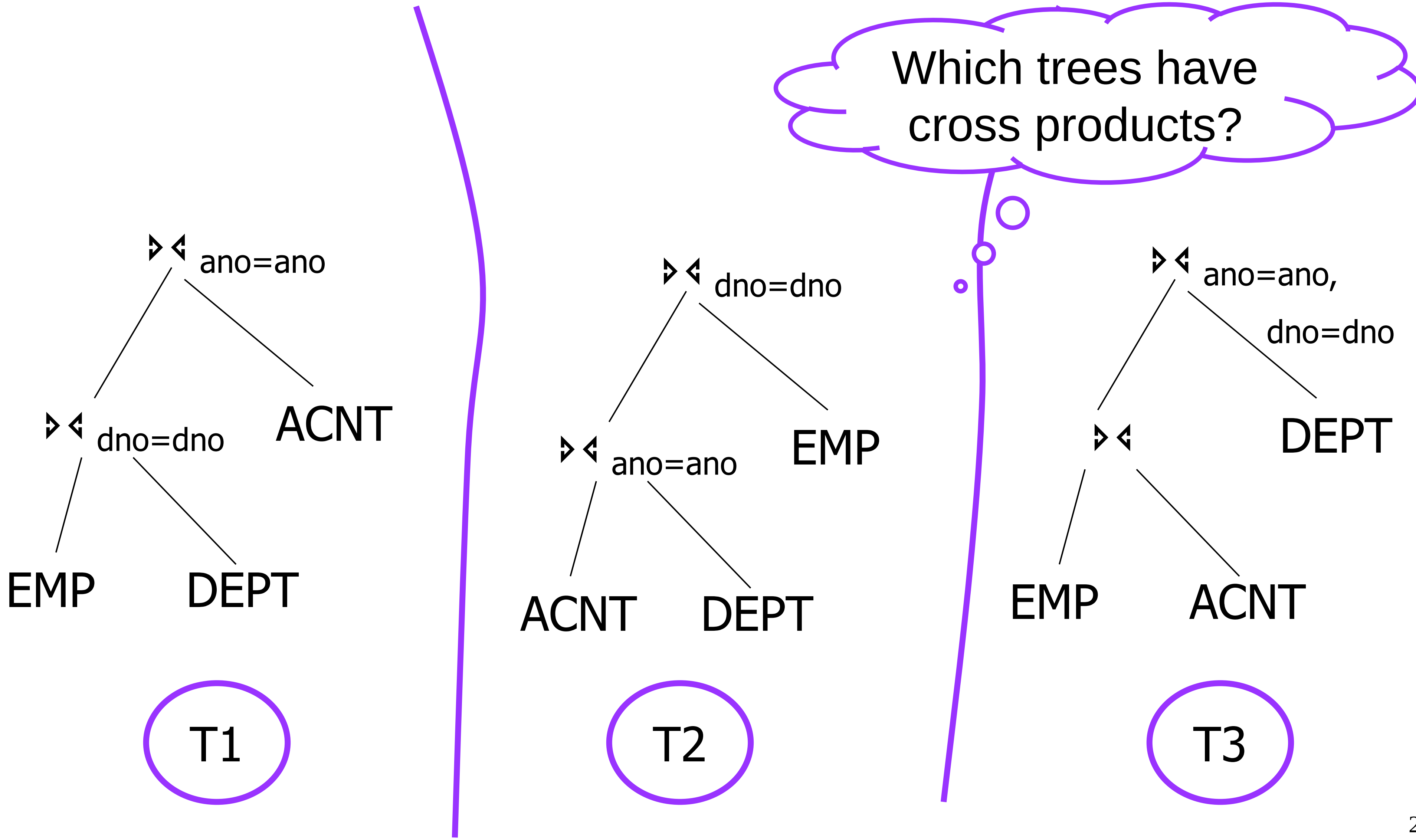
- In T3, there is "maximal pushing of selection and projection"
  - Rewriter finds such expressions

Restriction 2 of Algebraic Space

- Since the order of selection and projection is determined, we can write trees only with joins
- Restriction (heuristic) 2: Cross/Cartesian products are never formed, unless the query asks for them
- Why this restriction?
- Example:

```
select name, floor, balance
from emp, dept, acnt
where emp.dno=dept.dno and
      dept.ano = acnt.ano
```

3 Trees

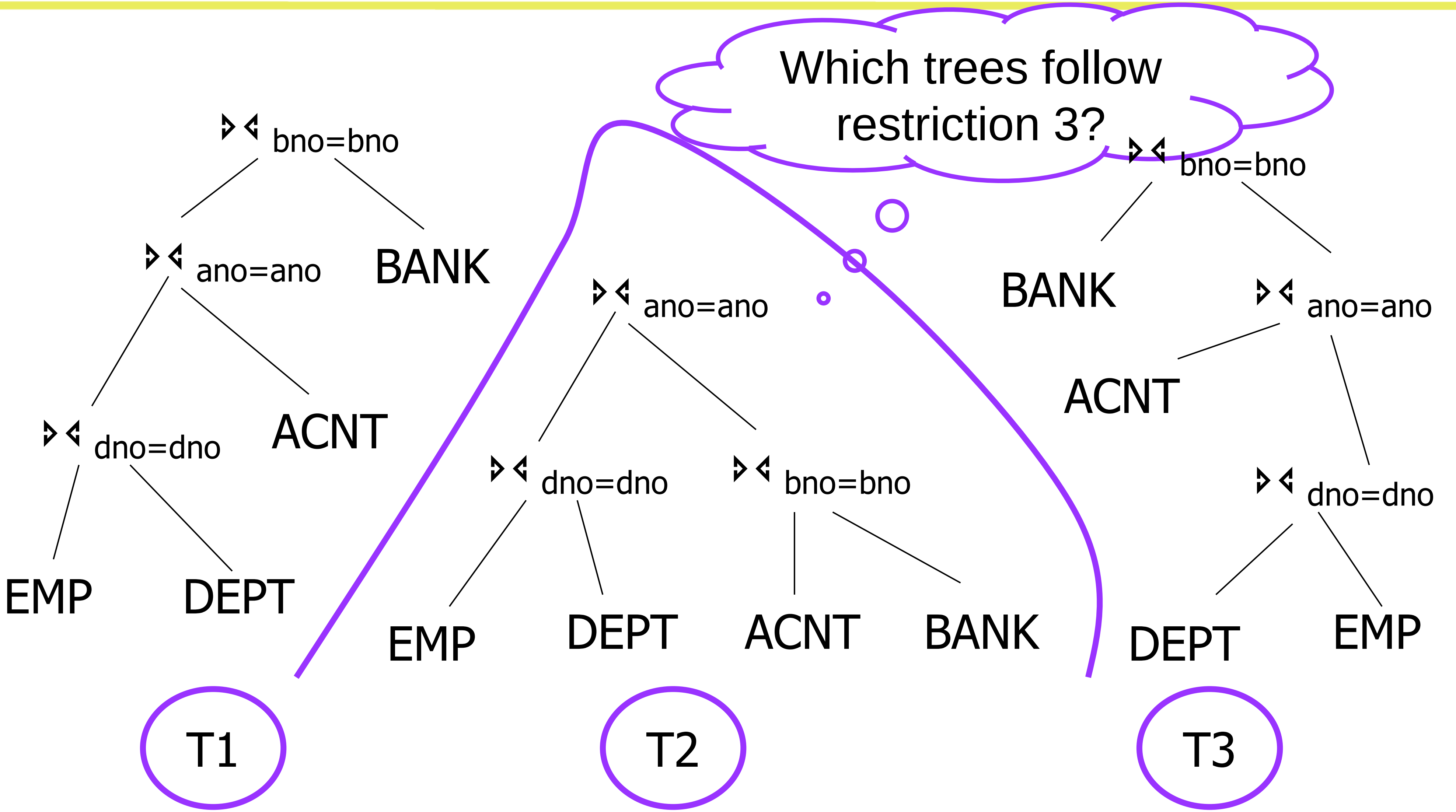

Which trees have cross products?
ano=ano
dno=dno
ACNT
EMP
DEPT
T1
dno=dno
ano=ano
EMP
ACNT
DEPT
T2
ano=ano,
dno=dno
DEPT
EMP
ACNT
T3

Restriction 3 of Algebraic Space

- The left relation is called the outer relation in a join and the right relation is the inner relation (as in terminology of nested loops algorithms)
- Restriction (heuristic) 3: The inner operand of each join is a database relation, not an intermediate result (left-deep plans)
- Example:

```
select name, floor, balance
from emp, dept, acnt, bank
where emp.dno=dept.dno and dept.ano=acnt.ano
     and acnt.bno = bank.bno
```

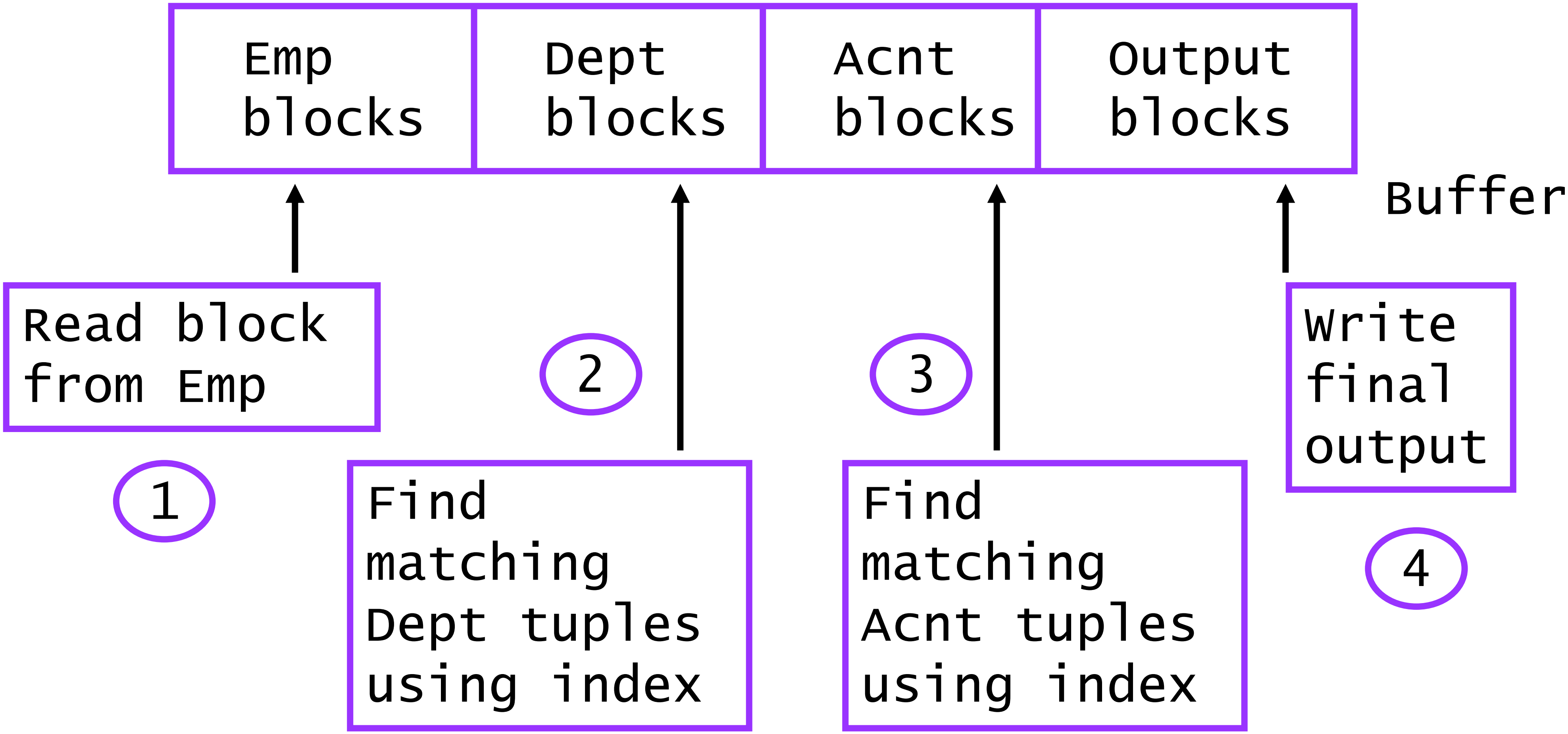
3 Trees


Which trees follow restriction 3?
⋈ bno=bno
⋈ ano=ano
BANK
⋈ dno=dno
ACNT
EMP
DEPT
⋈ ano=ano
⋈ dno=dno
⋈ bno=bno
EMP
DEPT
ACNT
BANK
⋈ bno=bno
BANK
⋈ ano=ano
ACNT
⋈ dno=dno
DEPT
EMP
T1
T2
T3

Pipelining Joins

- Consider computing: (Emp $\bowtie$ Dept) $\bowtie$ Acnt. In principle, we should
  - compute Emp $\bowtie$ Dept, write the result to the disk
  - then read it from the disk to join it with Acnt
- When using block and index nested loops join, we can avoid the step of writing to the disk
- We allow plans that
  - Perform selection and projection early and on the fly
  - Do not create cross products
  - Use database relations as inner relations (also called left – deep trees)

Pipelining Joins - Example



Planner

- Dynamic programming algorithm to find best plan for performing join of *N* relations
- Intuition:
  - Find all ways to access a single relation
    - Estimate costs and choose best access plan(s)
  - For each pair of relations, consider all ways to compute joins using all access plans from previous step
    - Choose best plan(s)...
  - For each i-1 relations joined, find best option to extend to i relations being joined...
  - Given all plans to compute join of n relations, output the best

Reminder: Dynamic Programming

- To find an optimal plan for joining S, R, R_3, R_4, choose the best among:
  - Optimal plan for joining R, R_3, R_4 + for reading S + optimal join of S with result of previous joins
  - Optimal plan for joining S, R_3, R_4 + for reading R + optimal join of R with result of previous joins
  - Optimal plan for joining S, R, R_4 + for reading R_3 + optimal join of R_3 with result of previous joins
  - Optimal plan for joining S, R, R_3 + for reading R_4 + optimal join of R_4 with result of previous joins

Not Good Enough: Interesting Orders

- Example, suppose we are computing (R(A,B) ⋈ S(B,C)) ⋈ T(B,D)
  - Maybe merge-sort join of R and S is not the most efficient, but the result is sorted on B
  - If T is sorted on B, the performing a sort-merge join of R and S, and then of the result with T, maybe the cheapest total plan
- For some joins, such as sort-merge join, the cost is cheaper if relations are ordered
  - Therefore, it is of interest to create plans where attributes that participate in a join are ordered on attributes in joins later on
- For each interesting order, save the best plan
  - We save plans for non interesting order if it better than all interesting order costs

Example

- We want to compute the query:

```
select name, mgr
from emp, dept
where emp.dno=dept.dno and sal>30K and floor = 2
```

- Available Indexes: B+tree index on `emp.sal`, B+tree index on `emp.dno`, hashing index on `dept.floor`
- Join Methods: nested loops and sort-merge
- In the example, all cost estimations are fictional

Step 1 – Accessing Single Relations

Relation	Interesting Order	Plan	Cost
emp	`emp.dno`	Access through B+tree on `emp.dno`	700
		Access through B+tree on `emp.sal` Sequential scan	200 600
dept		Access through hashing on `dept.floor` Sequential scan	50 200

- Which do we save for the next step?

Step 2 – Joining 2 Relations

Join Method	Outer/Inner	Plan	Cost
nested loops	`emp/dept`	● For each `emp` tuple obtained through B+Tree on `emp.sal`, scan `dept` through hashing index on `dept.floor` to find tuples matching on `dno`	1800
		● For each `emp` tuple obtained through B+Tree on `emp.dno` and satisfying selection, scan `dept` through hashing index on `dept.floor` to find tuples matching on `dno`	3000

Step 2 – Joining 2 Relations

Join Method	Outer/Inner	Plan	Cost
nested loops	`dept/emp`	●For each `dept` tuple obtained through hashing index on `dept.floor`, scan emp through B+Tree on `emp.sal` to find tuples matching on dno	2500
		●For each dept tuple obtained through hashing index on dept.floor, scan emp through B+Tree on `emp.dno` to find tuples satisfying the selection on `emp.sal`	1500

Step 2 – Joining 2 Relations

Join Method	Outer/ Inner	Plan	Cost
sort merge		• Sort the `emp` tuples resulting from accessing the B+Tree on `emp.sal` into L1 • Sort the `dept` tuples resulting from accessing the hashing index on `dept.floor` into L2 • Merge L1 and L2	2300
		• Sort the `dept` tuples resulting from accessing the hashing index on `dept.floor` into L2 • Merge L2 and the `emp` tuples resulting from accessing the B+Tree on `emp.dno` and satisfying the selection on `emp.sal`	2000

- Which plan will be chosen?

Picking a Query Plan

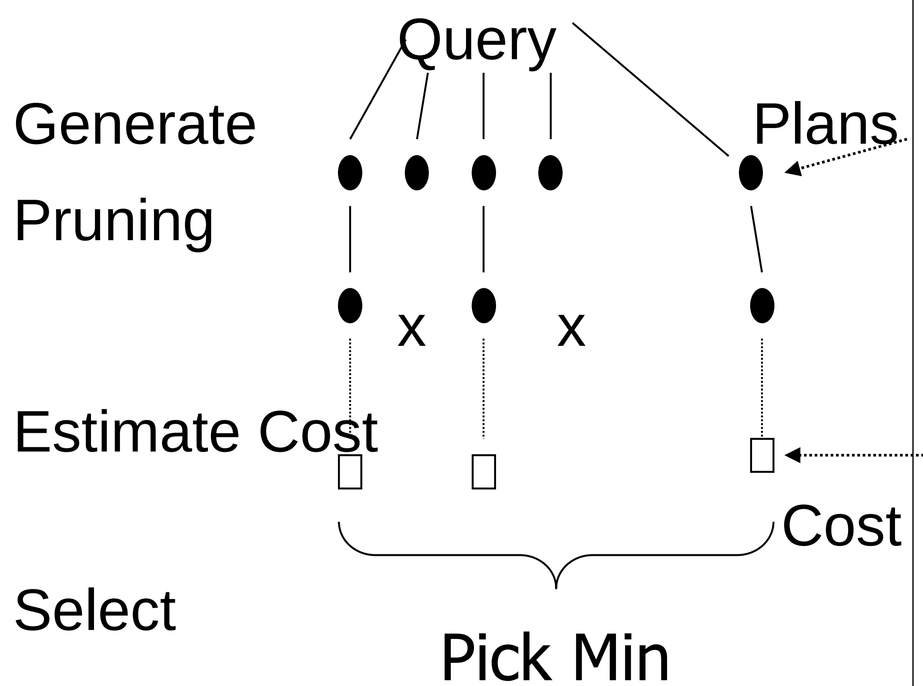
- Suppose we want to find the natural join of: `Reserves`, `Sailors`, `Boats`
- The 2 options that appear the best are (ignoring the order within a single join):

(Sailors $\bowtie$ Reserves) $\bowtie$ Boats

Sailors $\bowtie$ (Reserves $\bowtie$ Boats)

- We would like intermediate results to be as small as possible
  - Which is better?

--> Generating and comparing plans



Analyzing Result Sizes

- In order to answer the question in the previous slide, we must be able to estimate the size of (`Sailors`▷◁`Reserves`) and (`Reserves`▷◁`Boats`)
- The DBMS stores statistics about the relations and indexes
  - ♦Cardinality: Num of tuples *NTuples(R)* in each relation *R*
  - ♦Size: Num of pages *NPages(R)* in each relation *R*
  - ♦Index Cardinality: Num of distinct key values *NKeys(I)* for each index *I*
  - ♦Index Size: Num of pages *INPages(I)* in each index *I*
  - ♦Index Height: Num of non-leaf levels *IHeight(I)* in each B+ Tree index *I*
  - ♦Index Range: The minimum *ILow(I)* and maximum value *IHigh(I)* for each index *I*
- They are updated periodically (*not* every time the underlying relations are modified)

Estimating Result Sizes

- Consider

```
SELECT attribute-list
FROM relation-list
WHERE term1 and ... and termn
```

- The maximum number of tuples is the product of the cardinalities of the relations in the FROM clause
- The WHERE clause is associating a reduction factor with each term
  - ***column = value:*** 1/NKeys(I) if there is an index I on *column*. This assumes a uniform distribution; otherwise, System R assumes 1/10
  - ***column1 = column2:*** 1/Max(NKeys(I1),NKeys(I2)) if there is an index I1 on *column1* and I2 on *column2.* If only one column has an index, we use it to estimate the value; otherwise, use 1/10
  - ***column > value:*** (High(I)-value)/(High(I)-Low(I)) if there is an index I on *column*
- Estimated result size is: maximum size times product of reduction factors

Example

```
SELECT *
FROM Reserves R, Sailors S
WHERE R.sid = S.sid and S.rating > 3
      and R.agent = 'Joe'
```

- Cardinality(R) = 100,000
- Cardinality(S) = 40,000
- NKeys(Index on S.sid) = 40,000
- NKeys(Index on R.agent) = 100
- High(Index on Rating) = 10, Low = 0
- Maximum cardinality: 100,000 * 40,000
- Reduction factor of R.sid = S.sid: 1/40,000
- Reduction factor of S.rating > 3: (10–3)/(10-0) = 7/10
- Reduction factor of R.agent = 'Joe': 1/100
- Total Estimated size: (Maximum cardinality) * (Reduction factor of R.sid) * (Reduction factor of S.rating) * (Reduction factor of R.agent = S.sid) = 100,000 * 40,000 * (1/40,000) * (7/10) * (1/100) = 700

Second Example of Join Order Selection

- Consider the join of the four relations named R, S, T, U:

R(a,b), 1.000 total tuples	S(b,c), 1.000 total tuples	T(c,d), 1.000 total tuples	U(a,d), 1.000 total tuples
V(R,a) = 100			V(U,a) = 50
V(R,b) = 200	V(S,b) = 100		
	V(S,c) = 500	V(T,c) = 20	
		V(T,d) = 50	V(U,d) = 1000

Notes

- V(R,a) : # of **distinct** values for attribute
- Cost {R,S} = (size of R x size of S) / max (V(R,_), V(S,_)) , where _ is the join attribute
- Cost {R,S,U} = (size of R x size of S x size of U) / (2 greater nums from (V(R,_), V(S,_), V(U,_)) , where _ is the join attribute

Second Example of Join Order Selection

- For the singleton sets, the costs and best plans are given in the table below

	{R}	{S}	{T}	{U}
Size	1.000	1.000	1.000	1.000
Cost	0	0	0	0
Best plan	R	S	T	U

- As the costs for all relations are the same, the dynamic programming algorithm will consider them all.

Second Example of Join Order Selection

- Now, we consider the pairs of relations
  - Again, the cost is 0 for each, as we do not have intermediate results

	{R,S}	{R,T}	{R,U}	{S,T}	{S,U}	{T,U}
Size	5.000	1.000.000	10.000	2.000	1.000.000	1.000
Cost	0	0	0	0	0	0
Best plan	RxS	RxT	RxU	SxT	SxU	TxU

- The dynamic programming algorithm again keeps them all for the next run, as the costs are 0.

Second Example of Join Order Selection

- Now, we consider the join of three out of these four relations:

	{R,S,T}	{R,S,U}	{R,T,U}	{S,T,U}
Size	10.000	50.000	10.000	2.000
Cost	2.000	5.000	1.000	1.000
Best plan	(SxT)xR	(RxS)xU	(TxU)xR	(TxU)xS

- As you can see, the best plan is clearly “(TxU)xS”, with the least cost and size.

Second Example of Join Order Selection

- Finally, we consider the join of all relations. We come to these four final results (for dynamic programming):

((SxT)xR)xU	12.000
((RxS)xU)xT	55.000
((TxU)xR)xS	11.000
((TxU)xS)xR	**3.000**
((TxU)x(RxS)	6.000
((RxT)x(SxU)	2.000.000
((SxT)x(RxU)	12.000

Selecting Algorithms for Plan Operators

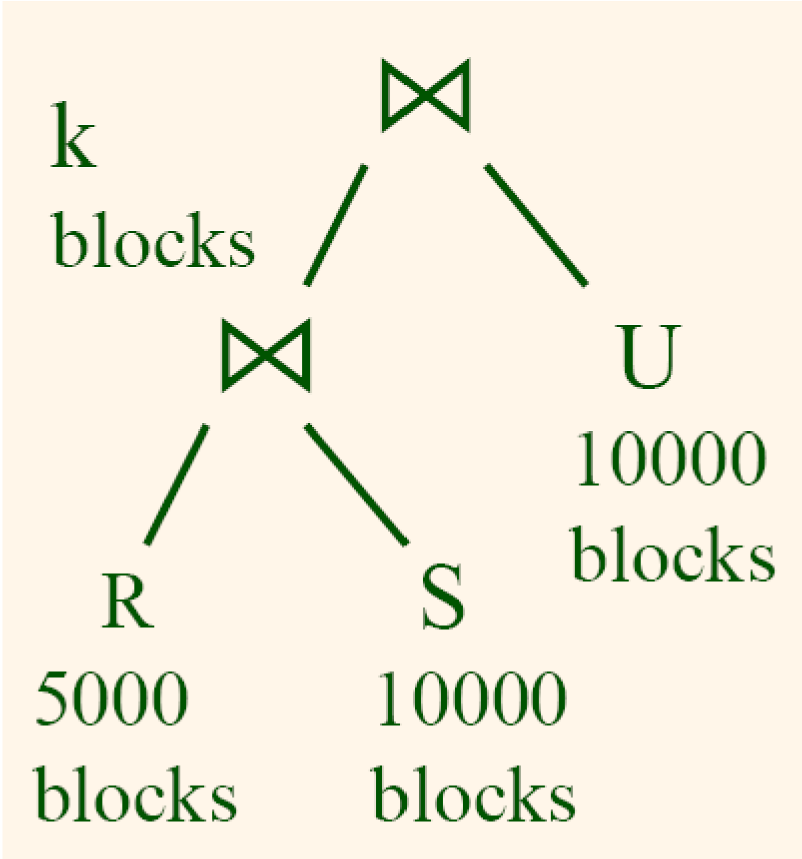
- For each operator, select algorithms based on I/O cost estimation
- For selection operator, consider
  - ♦Index-scan algorithms that use single attribute indexes, multiple indexes, or multidimensional indexes
  - ♦Table-scan algorithm using no index
- For join operator, consider
  - ♦All types of join algorithms if enough statistics is available
  - ♦If statistics is in sufficient, follow some simple ideas
    - Try one-pass algorithm or nested-loops
    - Use sort-join if one or both arguments are already sorted
    - If index is available, use index-join
    - If sort and index are not available and multi-pass join is necessary, use a hash join

Pipelining Example

- Relations:

  R(W,X), b_R = 5000
  S(X,Y), b_S = 10000
  U(Y,Z), b_U = 10000

- Buffer: M = 101 blocks
- Both joins are hash join
- Size k is estimated, and used to choose join algorithms



Case 1: $k \leq 49$

- Can pipeline result of 1st join into 2nd join
- Two-pass hash join for $R \bowtie S$:
  - Both R and S are hashed into 100 partitions, where each R partition has 50 blocks
  - Join corresponding R & S partitions using 50 buffer blocks for R partition, 1 block for S partition, and store the result in 49 blocks as a hash table
- One-pass hash join for the 2nd join:
  - Use 1 buffer block for U (no need to partition U), join with the intermediate result that is already in buffer
- Cost = 3(5000+10000) + 10000 = 55000

Case 2: 49 < k ≤5000

- Overlap the 1st join with the hash partitioning of the 2nd join
- Two-pass hash join for the 1st join:
  - Partition R & S into 100 partitions, so that each R partition contains 50 blocks
  - Join corresponding R & S partitions (using 51 buffer blocks)
  - During the join, hash the result into 50 partitions (using the remaining 50 buffer blocks) & write the partitions to disk
- Two-pass hash join for the 2nd join:
  - Partition U into 50 partitions
  - Join corresponding partitions of intermediate result & U, using intermediate result partition as build relation (use 1 to 100 buffer blocks)
- Cost = 3(10000+5000) + k + 2(10000) + (k+10000) = 75000 + 2k

Case 3: k > 5000

- Cannot use pipelining

- Two-pass hash join for the 1st join:
  - Partition R & S into 51 partitions, so that each R partition has <100 blocks
  - Join corresponding R & S partitions, write results to disk

- Two-pass hash join for the 2nd join:
  - Partition intermediate result & U into more than 50 partitions
  - Join corresponding partitions of U & intermediate result, using the smaller partition as the build relation

- Cost = 3(5000+10000) + k + 3(10000+k) = 75000 + 4k

Pipelining vs. Materialization

- Pipelining: Apply next operator to the output of one stage, as the output is generated.
- Materialization: Create a temporary relation as the output of a stage, pass to next stage

Pipelining vs. Materialization

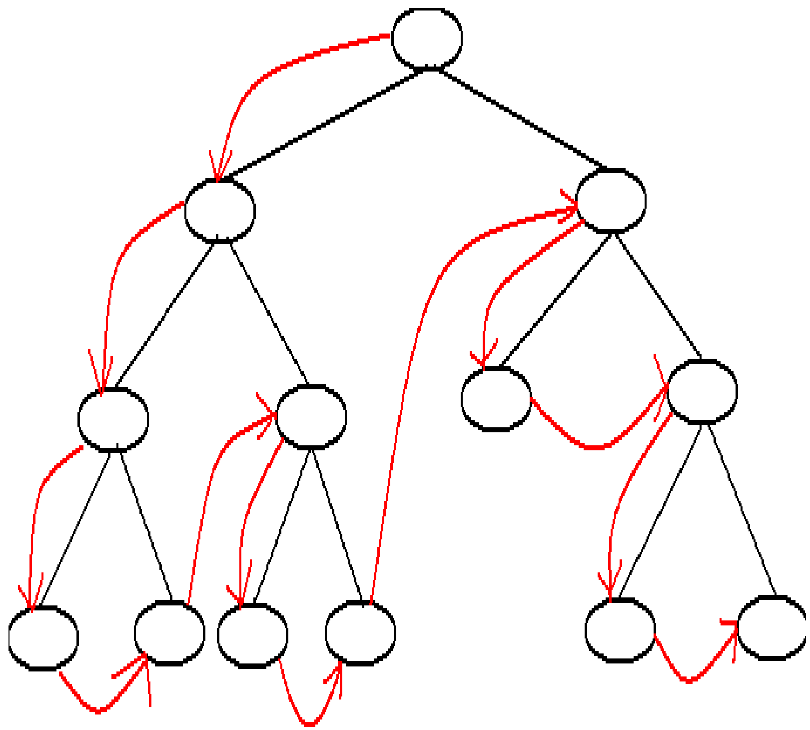
- Advantages of 64 bit processors
  - More main memory possible
    - And so, more pipelining operations possible without having to write intermediate results to disk
  - Complex in-memory processing does not require intermediate results being temporarily written to disk
    - Saves costly disk I/O's and increases scalability

- Disadvantages of 64 bit processors
  - Application must be fully supporting 64 bit to make full use of the speed advantages
  - Upgrading to a 32 bit system with (more) parallel processors (using shared memory perhaps) might be cheaper to implement

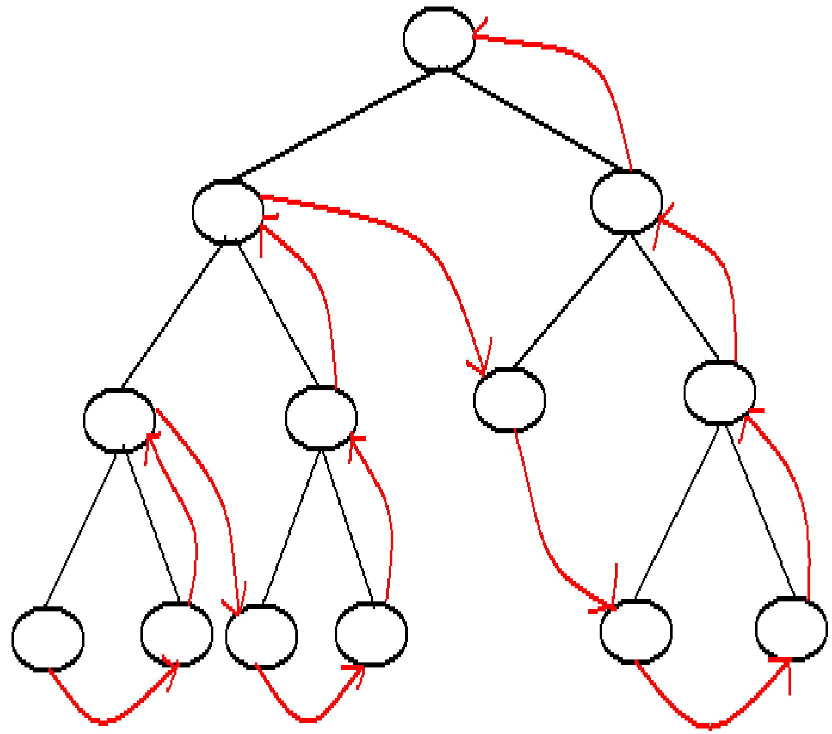
- DBMS's implementing 64 bit are e.g. Oracle 10g

Ordering of Physical Operations

- Pre-order traversal

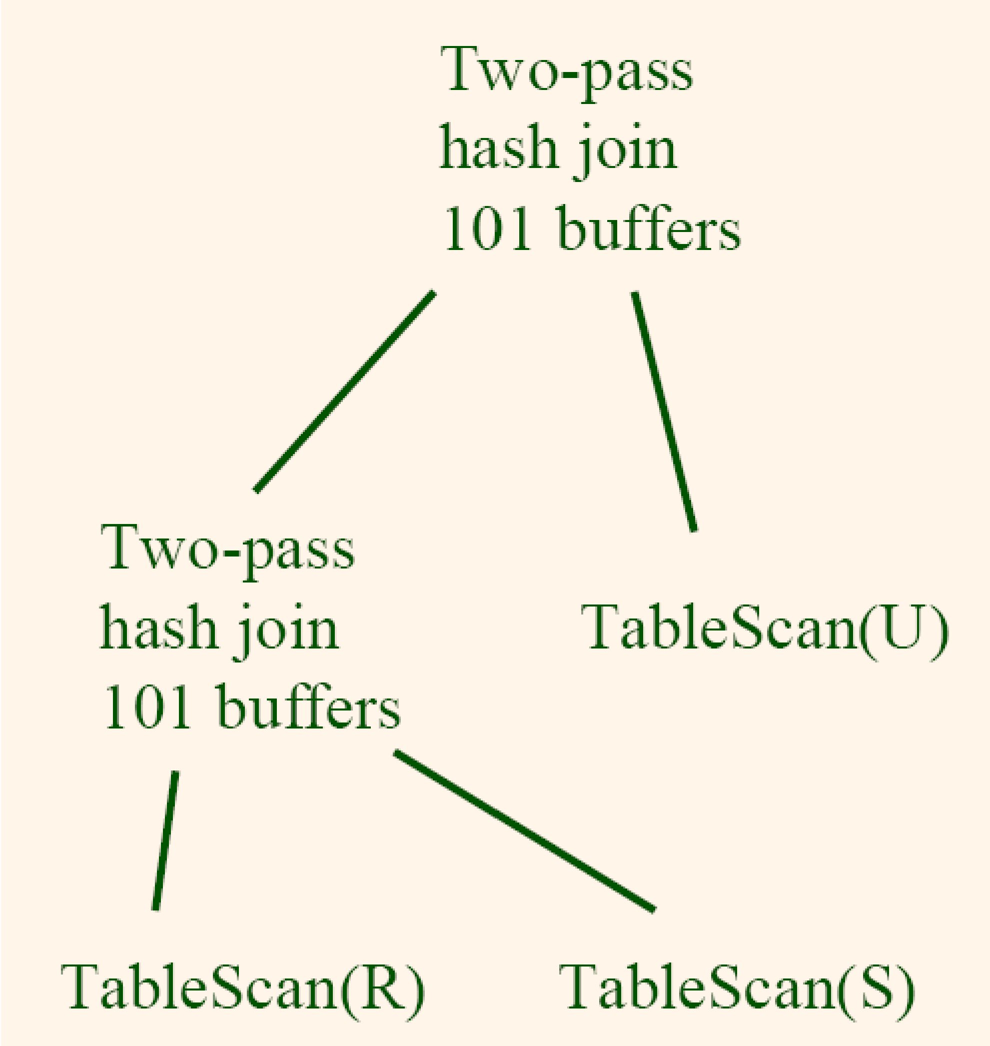


- Post-order traversal



Notation for Physical Query Plans

- Non-standard among DBMSs
- Typical physical plan operators include
  - For leave nodes: `TableScan(R)`, `SortScan(R,AttrList)`, `IndexScan(R,A)`, `IndexScan(R, AθC)`
  - For selection nodes: combination of `TableScan(R)`, `Filter(Cond)`, `SortScan(R, AttrList)`



Points to Remember

- Step 1: Choose a *logical* plan
  - Involves choosing a query tree, which indicates the order in which algebraic operations are applied
  - *Heuristic*: Pushed trees are good, but sometimes “nearly fully pushed” trees are better due to indexing
  - **So**: Take the initial “master plan” tree and produce a *fully pushed* tree plus several *nearly fully pushed* trees
- Step 2: Reduce *search space*
  - Deal with *associativity* of binary operators (join, union, …)
  - Choose a particular *shape* of a tree (left-deep trees)
    - Equals the number of ways to parenthesize N-way join – grows very rapidly
  - Choose a particular permutation of the leaves
    - E.g., 4! permutations of the leaves A, B, C, D
- Step 3: Use a *heuristic search* to further reduce complexity
  - The choice of left-deep trees still leaves open too many options
  - A heuristic algorithm is used to get a ‘good’ plan

Τέλος Ενότητας

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Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

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Σημειώματα

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Σημείωμα αδειοδότησης

Σημείωμα Αναφοράς

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