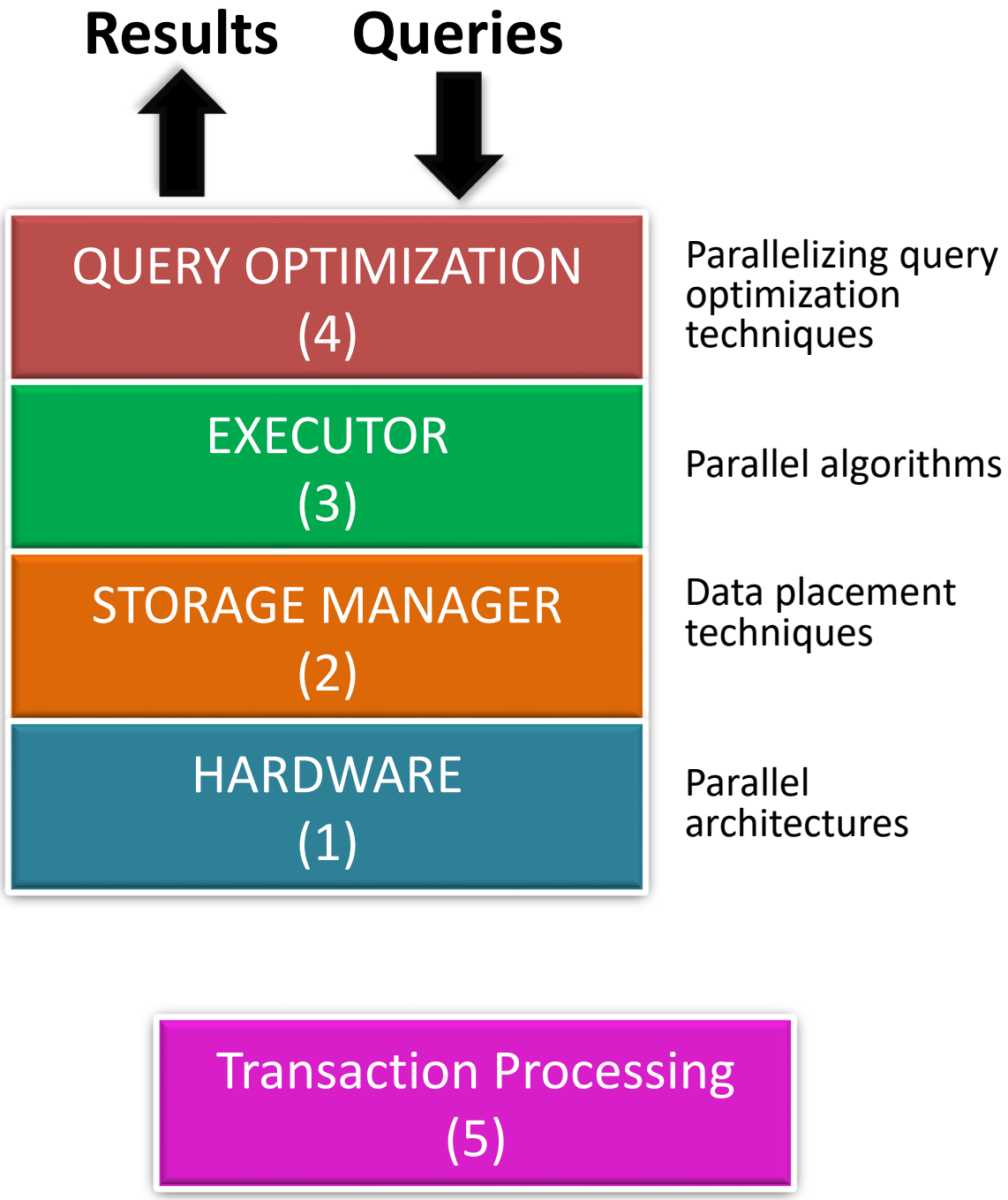
PARALLEL DATABASE TECHNOLOGY

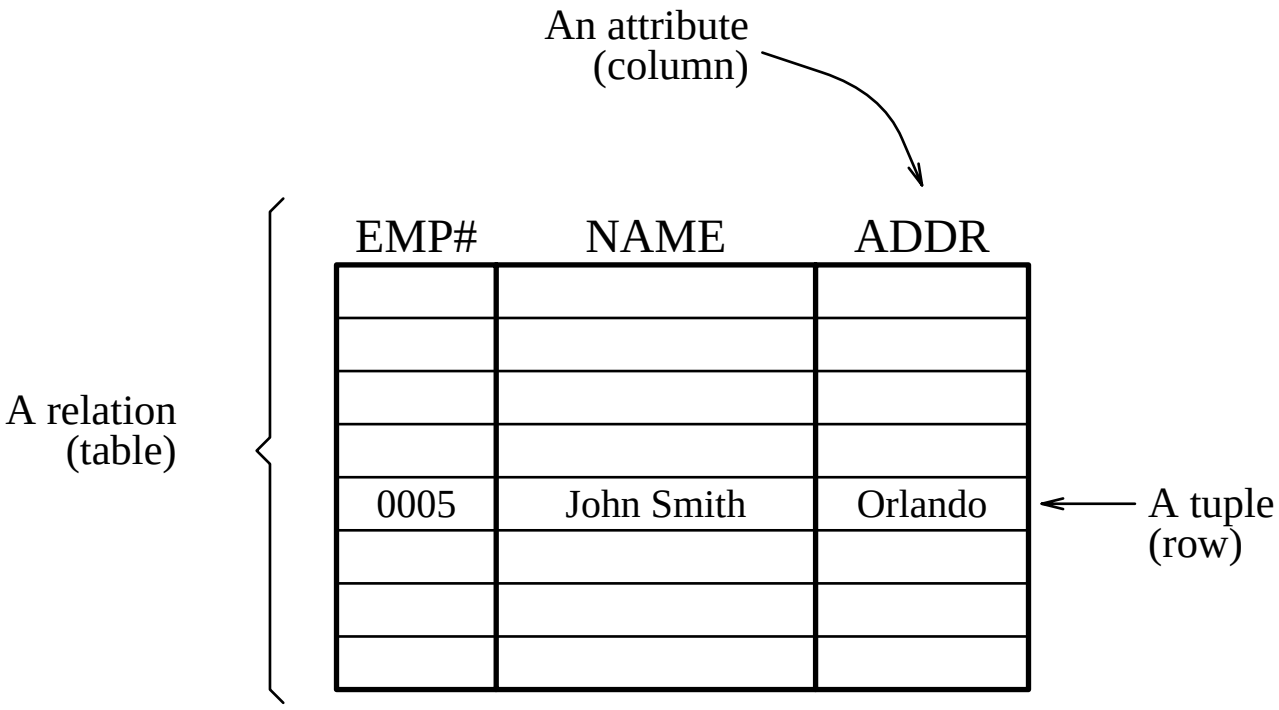
Kien A. Hua

School of Computer Science
University of Central Florida
Orlando, FL 32816-2362

Topics


Results
Queries
QUERY OPTIMIZATION
(4)
EXECUTOR
(3)
STORAGE MANAGER
(2)
HARDWARE
(1)
Parallelizing query optimization techniques
Parallel algorithms
Data placement techniques
Parallel architectures
Transaction Processing
(5)

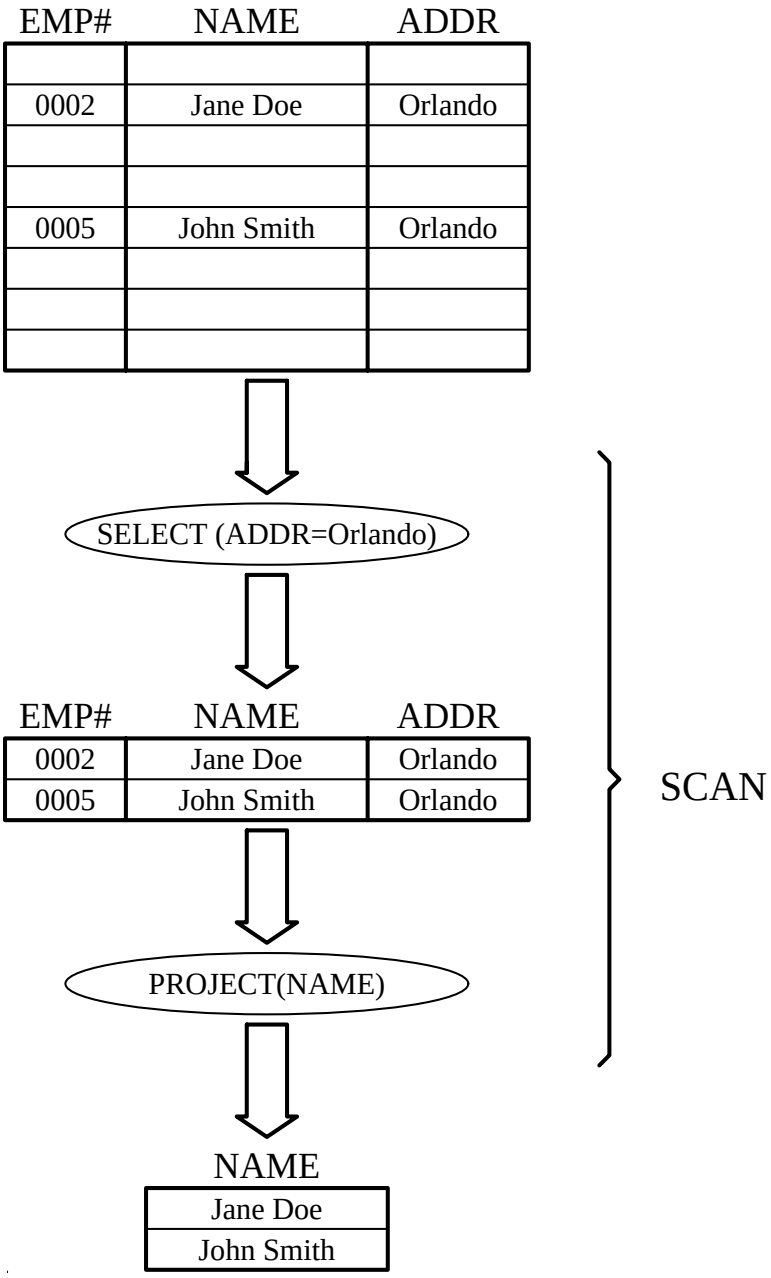
Relational Data Model



- A database structure is a collection of *tables*.
- Each table is organized into rows and columns.
- The persistent objects of an application are captured in these tables.

Relational Operator: **SCAN**

SELECT NAME
FROM EMPLOYEE
WHERE ADDR = "Orlando";



Relational Operator: **JOIN**

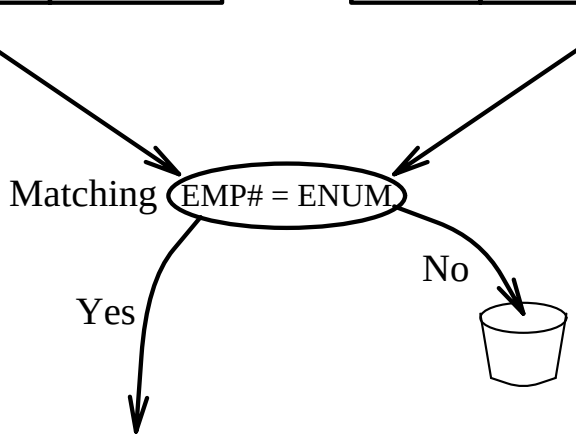
SELECT *
FROM EMPLOYEE, PROJECT
WHERE EMP# = ENUM

EMPLOYEE:

EMP#	NAME	ADDR
0002	Jane Doe	Orlando

PROJECT:

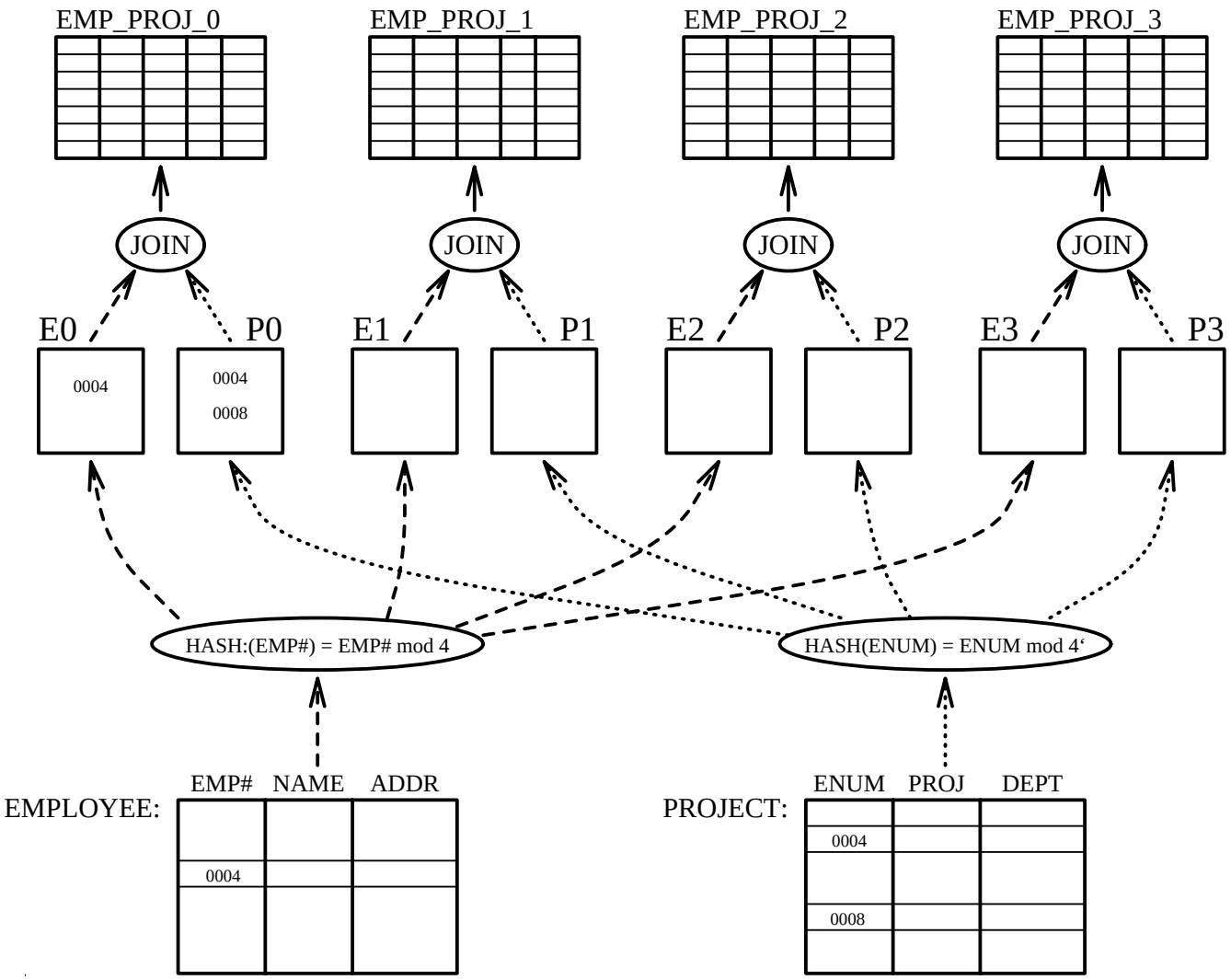
ENUM	PROJECT	DEPT
0002	Database	Research
0002	GUI	Research



EMP_PROJ:

EMP#	NAME	ADDR	PROJECT	DEPT
0002	Jane Doe	Orlando	Database	Research
0002	Jane Doe	Orlando	GUI	Research

Hash-Based Join



Examples:

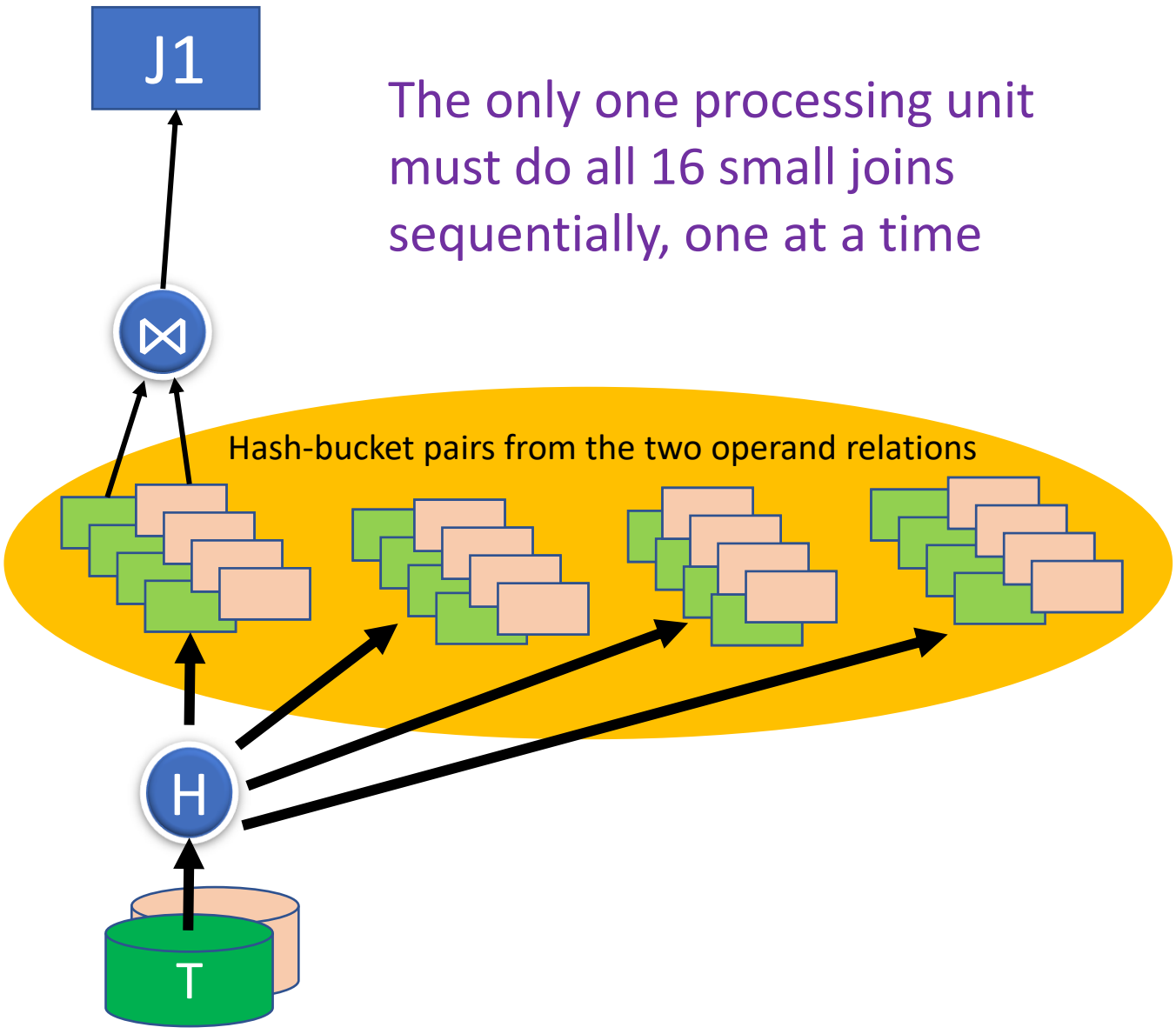
$0 \bmod 4 = 0 \qquad 4 \bmod 4 = 0$

$1 \bmod 4 = 1 \qquad 5 \bmod 4 = 1$

$2 \bmod 4 = 2 \qquad 6 \bmod 4 = 2$

$3 \bmod 4 = 3 \qquad 7 \bmod 4 = 3$

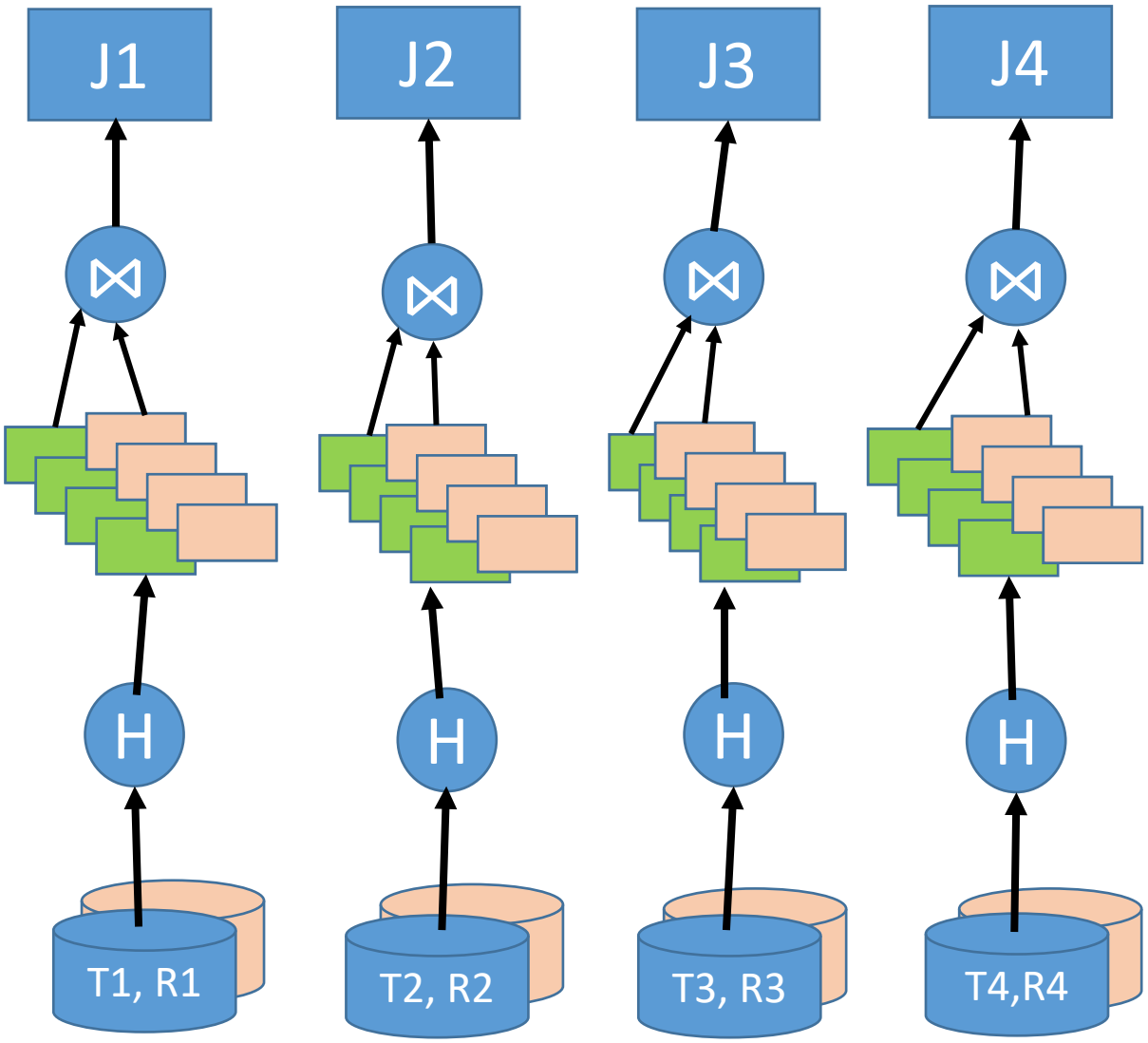
“Divide and Concur” done sequentially



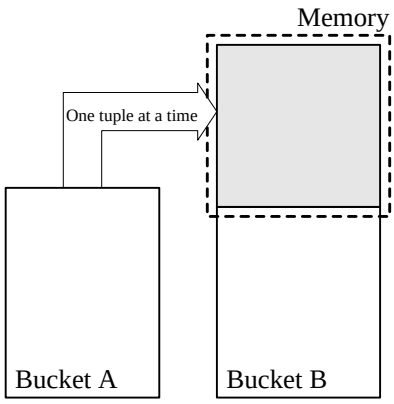
“Divide and Concur” Done on Four Processing Nodes

The same divide and concur can be done on four processing nodes in parallel.

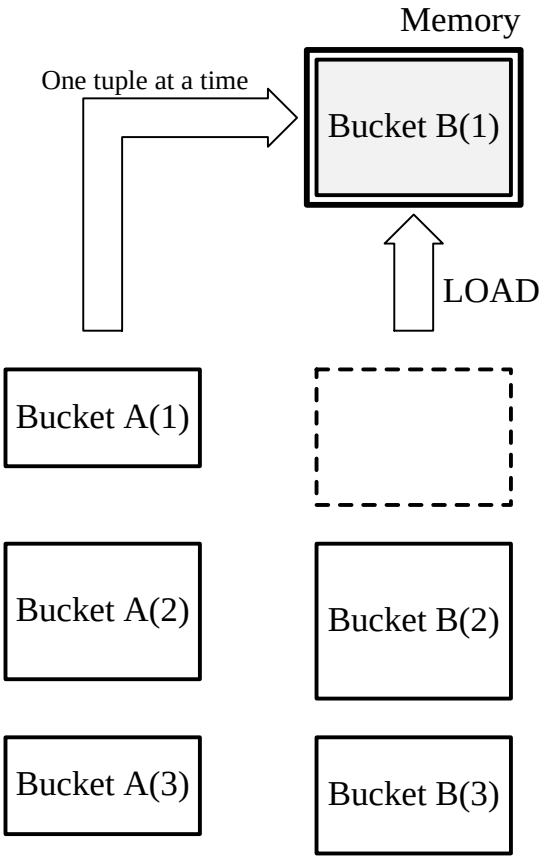
Each PN must finish its read and write for the current phase before the next phase can start



Bucket Sizes and I/O Costs



Bucket B does not fit in the memory in its entirety. Bucket A must be loaded several times.



Bucket B(1) fits in the memory.
A(1) needs to be loaded only once.

Speedup and Scaleup

The ideal parallel systems demonstrates two key properties:

1. Linear Speedup:

$$Speedup = \frac{small\_system\_elapsed\_time}{big\_system\_elapsed\_time}$$

Linear Speedup : Twice as much hardware can perform the task in half the elapse time (i.e., speedup = number of processors.)

2. Linear Scaleup:

$$Scaleup = \frac{small\_system\_elapsed\_time\_on\_small\_problem}{big\_system\_elapsed\_time\_on\_big\_problem}$$

Linear Scaleup : Twice as much hardware can perform twice as large a task in the same elapsed time (i.e., scaleup = 1.)

Barriers to Parallelism

- **Startup**:

  The time needed to start a parallel operation (thread creation/connection overhead) may dominate the actual computation time.

- **Interference**:

  When accessing shared resources, each new process slows down the others (hot spot problem).

- **Skew**:

  The response time of a set of parallel processes is the time of the slowest one.

The Challenge

- The ideal database machine has:

  1. a single infinitely fast processor,
  2. an infinitely large memory with infinite bandwidth

  $\longrightarrow$ *Unfortunately, technology is not delivering such machines !*

- The challenge is:

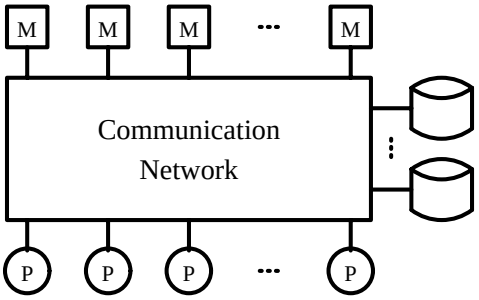
  1. to build an infinitely fast processor out of infinitely many processors of finite speed, and
  2. to build an infinitely large memory with infinitely many storage units of finite speed.

Performance of Hardware Components

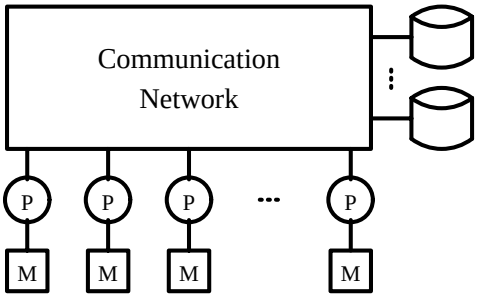
- **Processor**:
  - Density increases by 25% per year.
  - Speed doubles in three years.
- **Memory**:
  - Density increases by 60% per year.
  - Cycle time decreases by $\frac{1}{3}$ in ten years.
- **Disk**:
  - Density increases by 25% per year.
  - Cycle time decreases by $\frac{1}{3}$ in ten years.

The Database Problem: The I/O bottleneck will worsen.

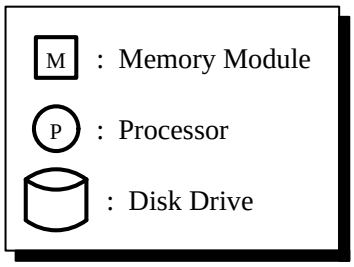
Hardware Architectures

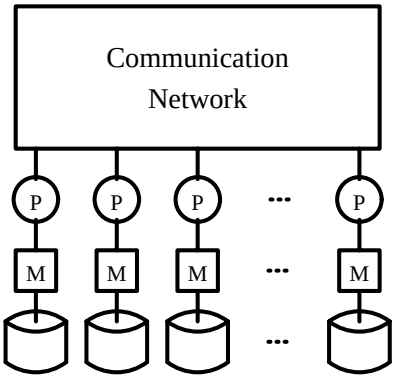


(c) Shared Everything (SE)



(b) Shared Disk (SD)

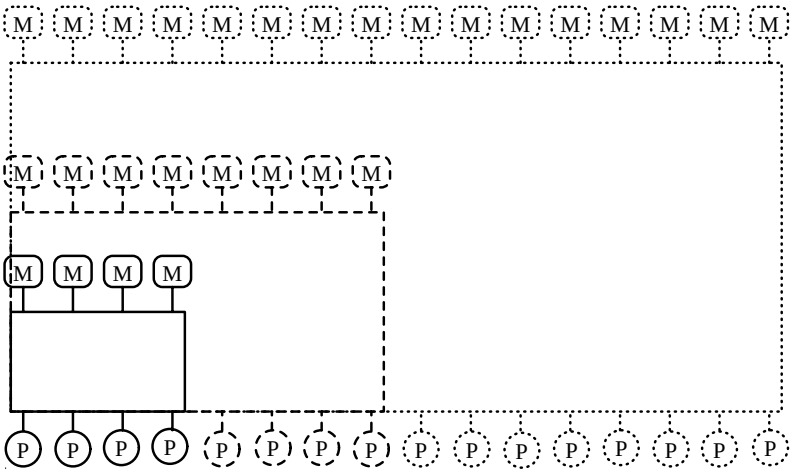


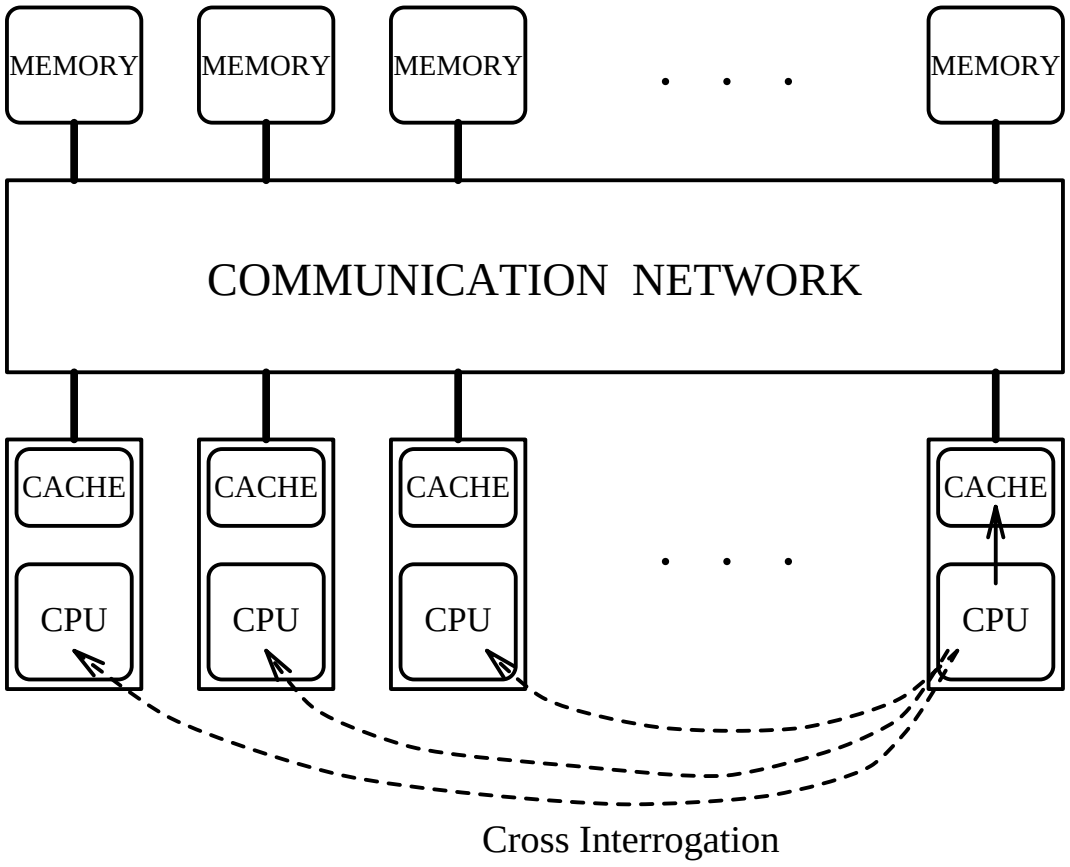


(a) Shared Nothing (SN)

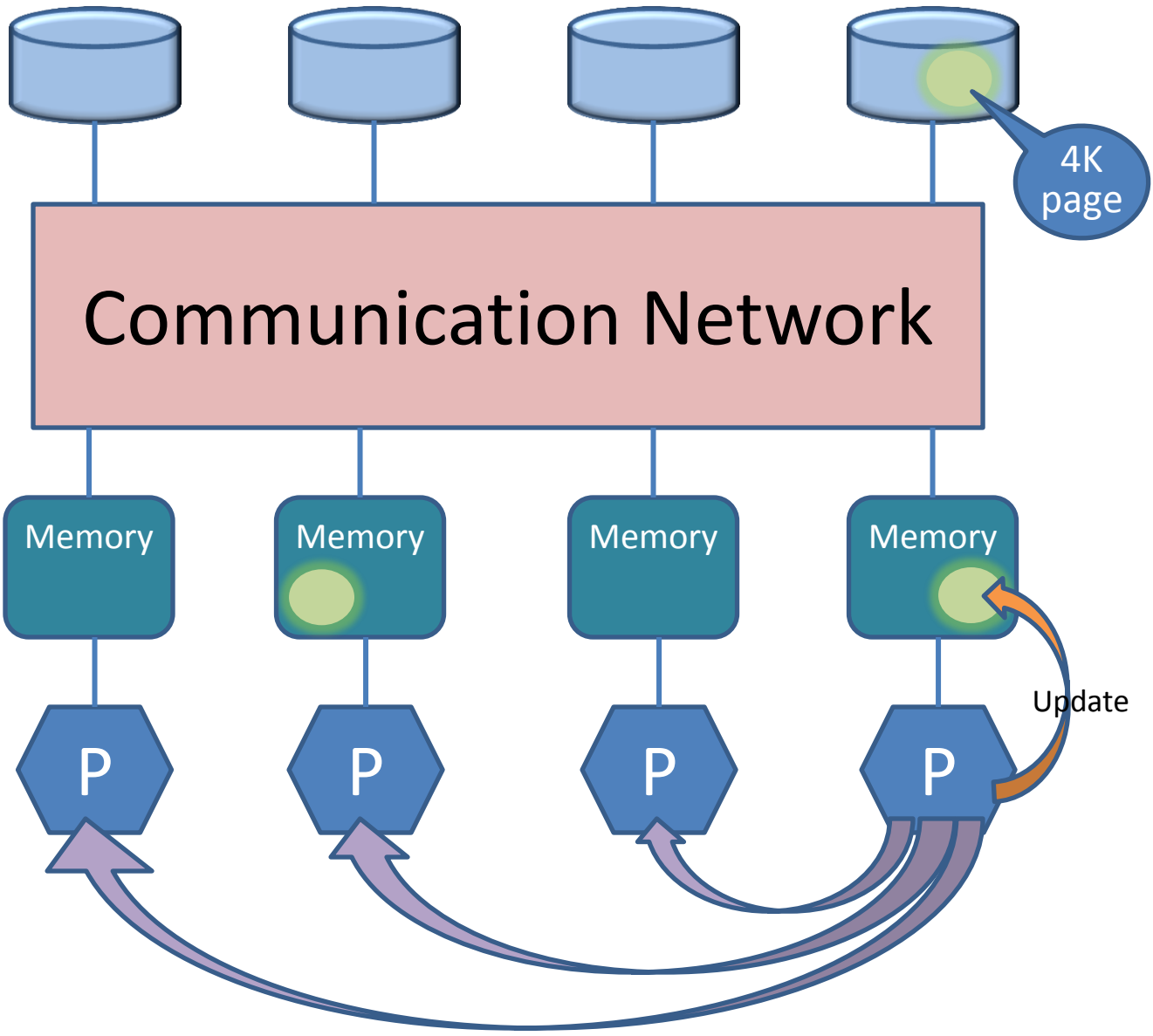
Shared Nothing is more scalable for very large database systems

Shared-Everything Systems



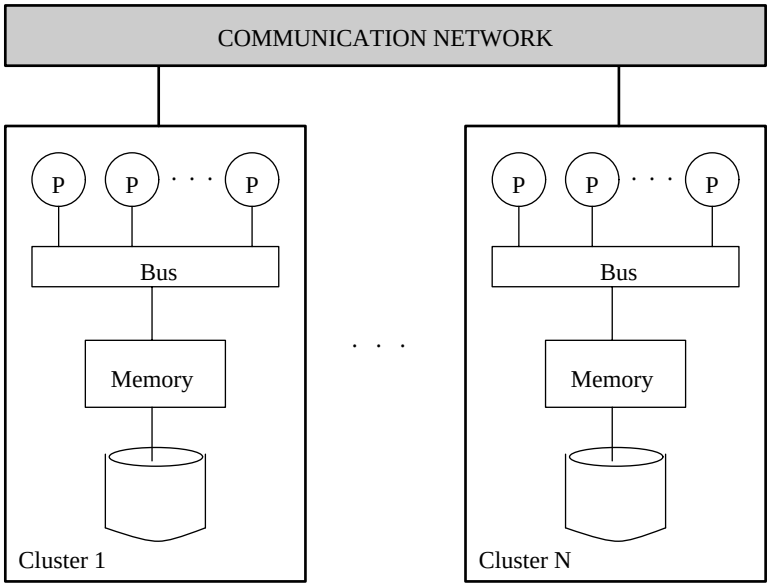


Shared Disk Architecture



Cross Interrogation for a small change to a page. Processing units interfere each other even they work on different records of the same page.

Hybrid Architecture



- SE clusters are interconnected through a communication network to form an SN structure at the inter-cluster level.

- This approach minimizes the communication overhead associated with the SN structure, and yet each cluster size is kept small within the limitation of the local memory and I/O bandwidth.

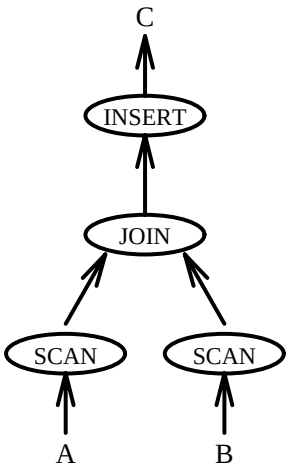
- Examples of this architecture include Sequent computers, NCR 5100M and Bull PowerCluster.

- Some of the DBMSs designed for this structure are the Teradata Database System for the NCR WorldMark 5100 computer, Sybase MPP, Informix Online Extended Parallel Server.

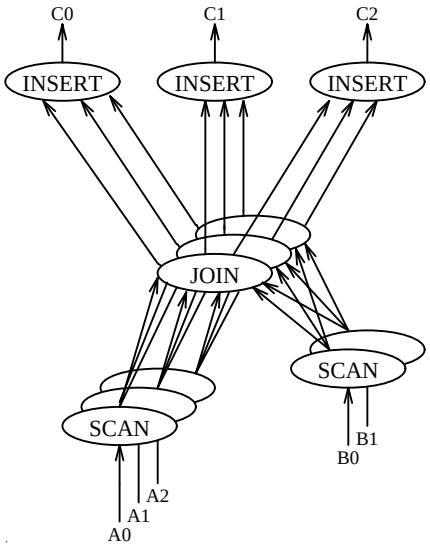
Parallelism in Relational Data Model

- **Pipeline Parallelism**: If one operator sends its output to another, the two operators can execute in parallel.

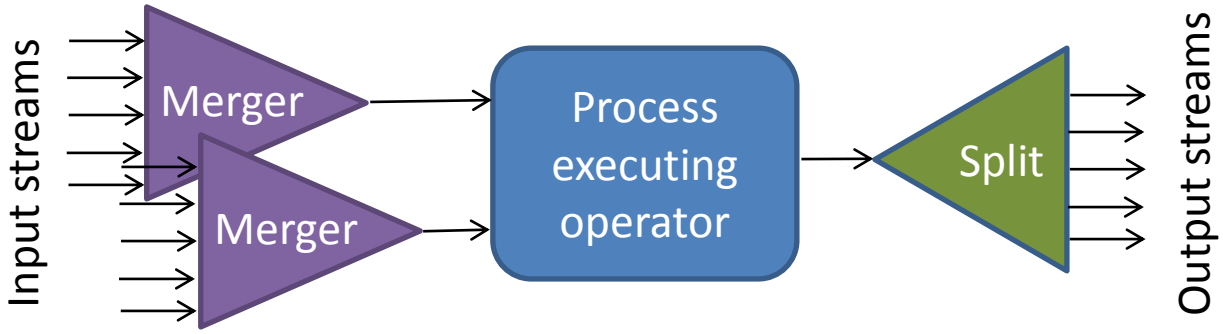
```
INSERT INTO C
    SELECT    *
    FROM      A, B
    WHERE     A.x = B.y;
```

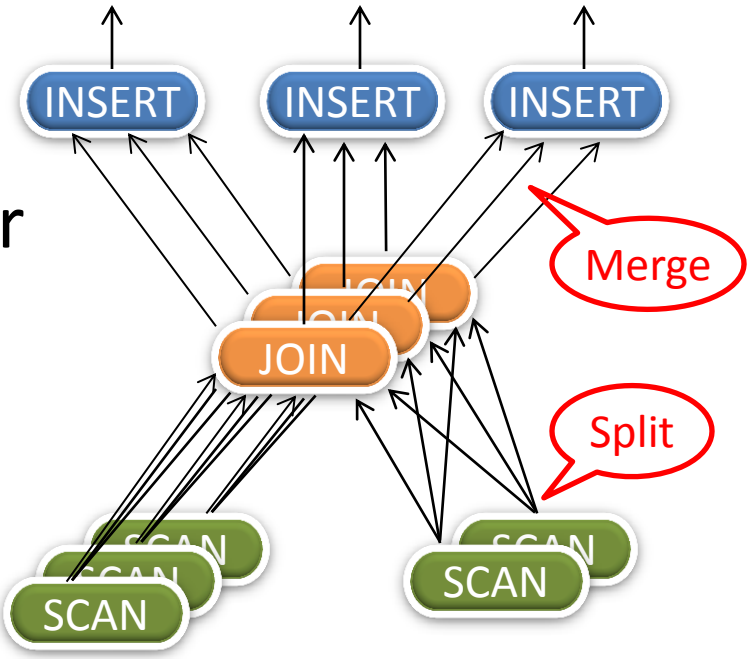


- **Partitioned Parallelism**: By taking the large relational operators and partitioning their inputs and outputs, it is possible to turn one big job into many concurrent independent little ones.



Merge & Split Operators



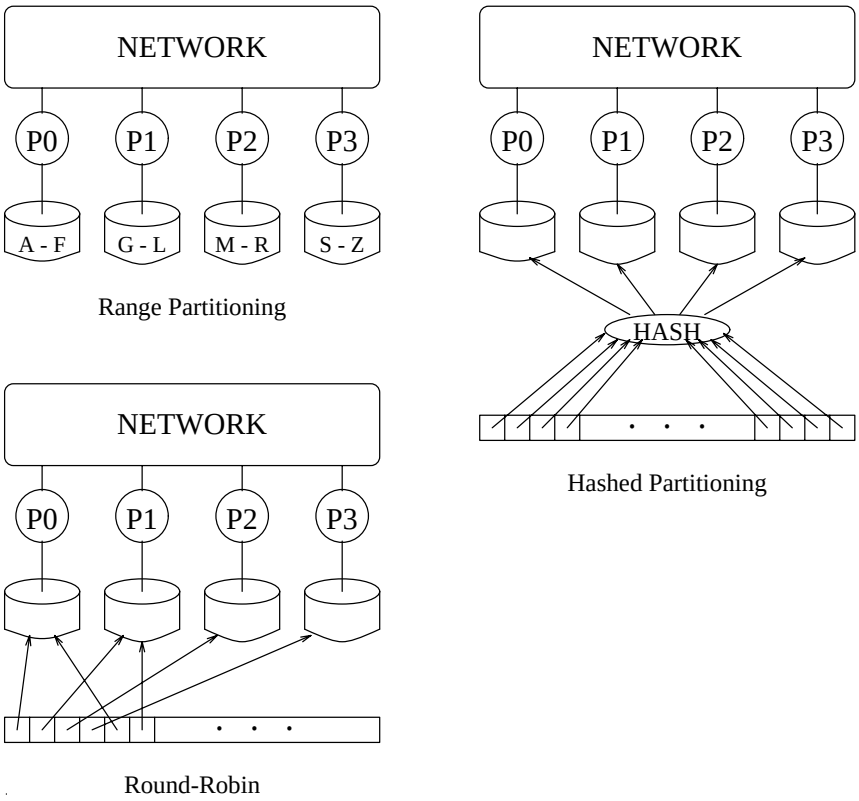


- Merge operator combines several parallel data streams into a simple sequential stream
- Split operator is used to partition or replicate the stream of tuples
- With split and merge operators, a web of simple sequential dataflow nodes can be connected to form a parallel execution plan

Data Partitioning Strategies

Data partitioning is the key to partitioned execution:

- **Round-Robin**: maps the ith tuple to disk i mod n.
- **Hash Partitioning**: maps each tuple to a disk location based on a hash function.
- **Range Partitioning**: maps contiguous attribute ranges of a relation to various disks.



Comparing Data Partitioning Strategies

- **Round Robin Partitioning**:

  Advantage: *simple*

  Disadvantage: *It does not support associative search.*

- **Hash Partitioning**:

  Advantage: *Associative access to the tuples with a specific attribute value can be directed to a single disk.*

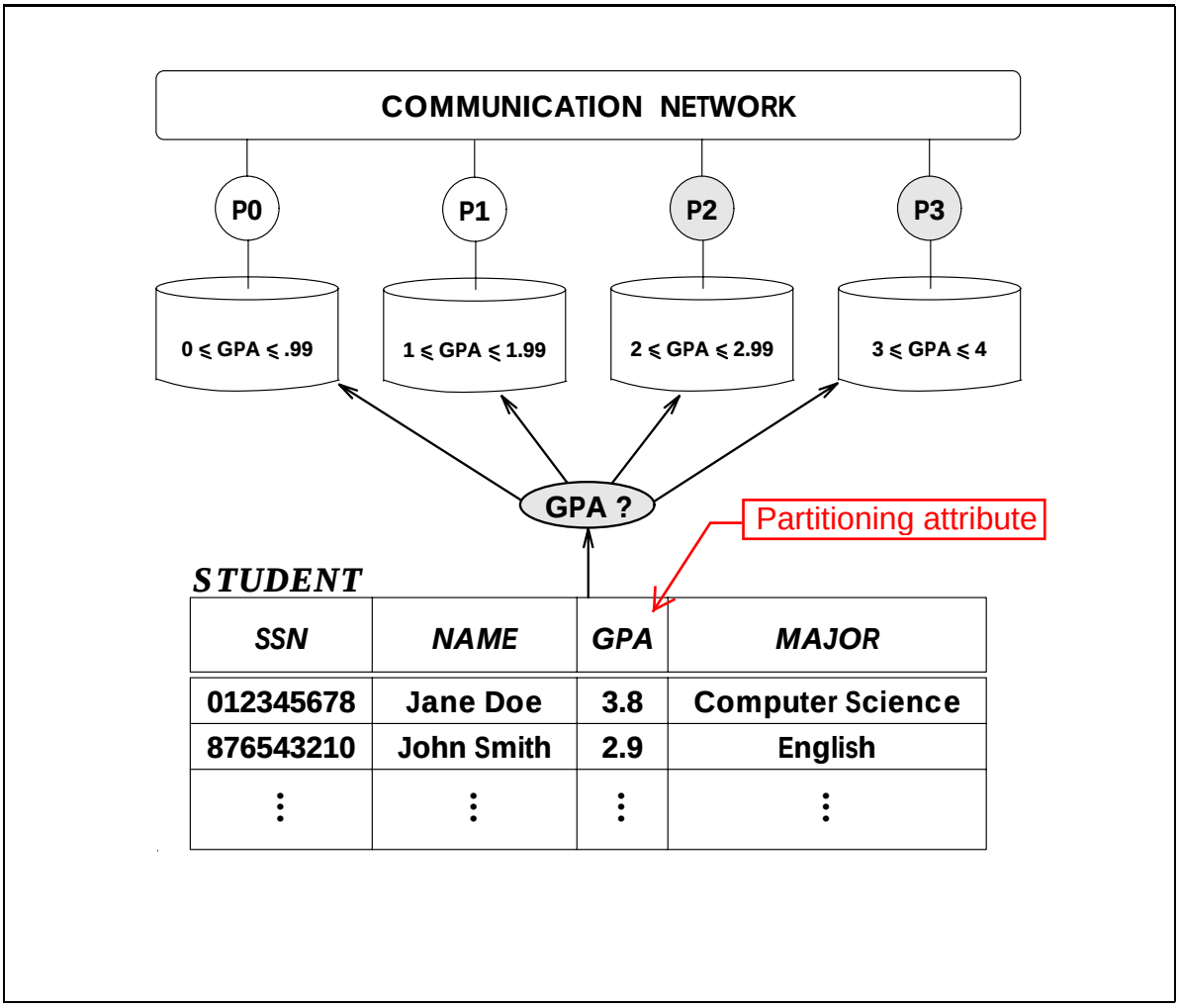
  Disadvantage: *It tends to randomize data rather than cluster it.*

- **Range Partitioning**:

  Advantage: *It is good for associative search and clustering data.*

  Disadvantage: *It risks execution skew in which all the execution occurs in one partition.*

Horizontal Data Partitioning



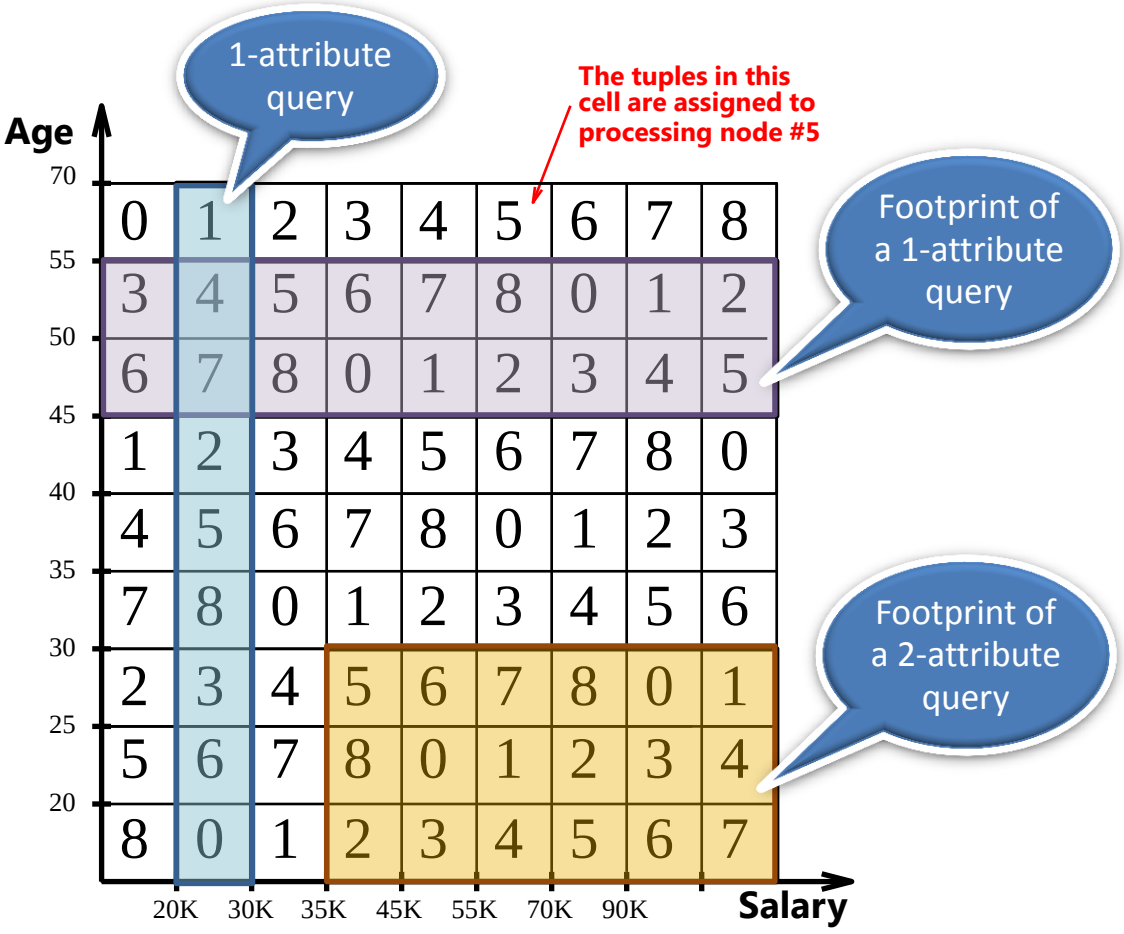
Query 1: Retrieve the names of students who have a **GPA** better than 2.0.

$\Longrightarrow$ Only P2 and P3 can participate.

Query 2: Retrieve the names of students who **major** in Anthropology.

$\Longrightarrow$ The whole file must be searched.

Multidimensional Data Partitioning



Advantages:

- Degree of parallelism is maximized (i.e., using as many processing nodes as possible)
- Search space is minimized (i.e., searching only relevant data blocks)

Query Types

Query Shape: *The shape of the data subspace accessed by a range query.*

Square Query: *The query shape is a square.*

Row Query: *The query shape is a rectangle containing a number of rows.*

Column Query: *The query shape is a rectangle containing a number of columns.*

Optimality

- A data allocation strategy is **usage optimal** with respect to a query type if the execution of these queries can always use all the PNs available in the system.

- A data allocation strategy is **balance optimal** with respect to a query type if the execution of these queries always results in a balance workload for all the PNs involved.

- A data allocation strategy is **optimal** with respect to a query type if it is usage optimal and balance optimal with respect to this query type.

Coordinate Modulo Declustering (CMD)

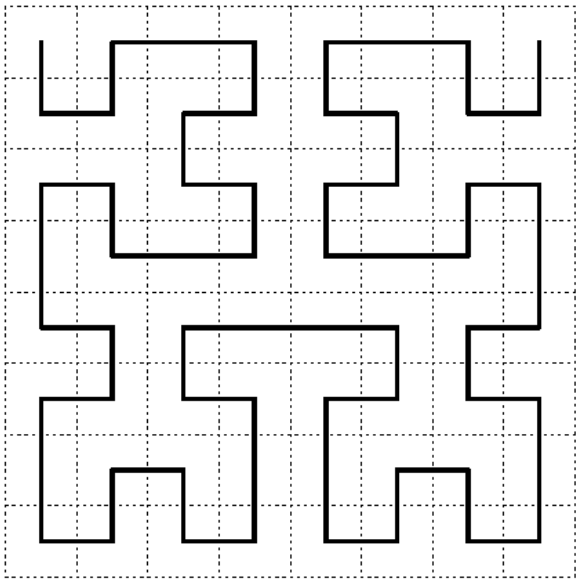
0	1	2	3	4	5	6	7
1	2	3	4	5	6	7	0
2	3	4	5	6	7	0	1
3	4	5	6	7	0	1	2
4	5	6	7	0	1	2	3
5	6	7	0	1	2	3	4
6	7	0	1	2	3	4	5
7	0	1	2	3	4	5	6

Advantages: *Optimal for row and column queries.*

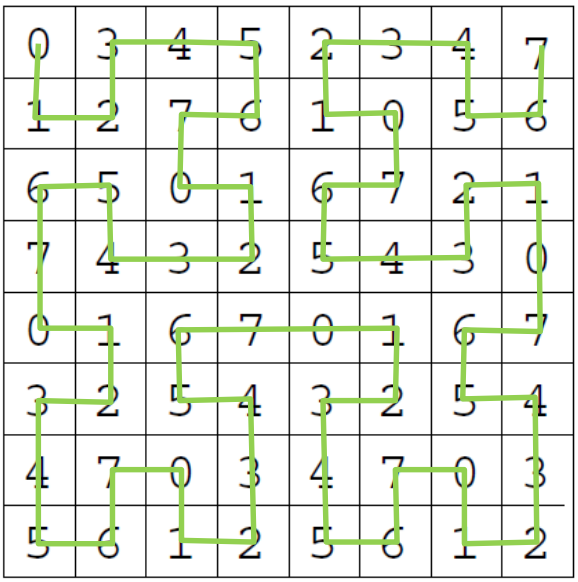
Disadvantages: *Poor for square queries.*

Hilbert Curve Allocation (HCA) Method

Hilbert curve in the 2D space



Navigate the Hilbert curve to label the data cells



There are 8 processing nodes

- Property: A space-filling curve that preserves locality fairly well

  $\Longrightarrow$ Two data points which are close to each other in 1D space are also close to each other in the high-dimensional space

- Advantage: Good for square range queries

- Disadvantage: Poor for row and column queries

General Multidimensional Data Allocation (GMDA)

Row 0	0	1	2	3	4	5	6	7	8	← *Check row*
Row 1	3	4	5	6	7	8	0	1	2	
Row 2	6	7	8	0	1	2	3	4	5	
Row 3	1	2	3	4	5	6	7	8	0	← *Check row*
Row 4	4	5	6	7	8	0	1	2	3	
Row 5	7	8	0	1	2	3	4	5	6	
Row 6	2	3	4	5	6	7	8	0	1	← *Check row*
Row 7	5	6	7	8	0	1	2	3	4	
Row 8	8	0	1	2	3	4	5	6	7	

N is the number of processing nodes

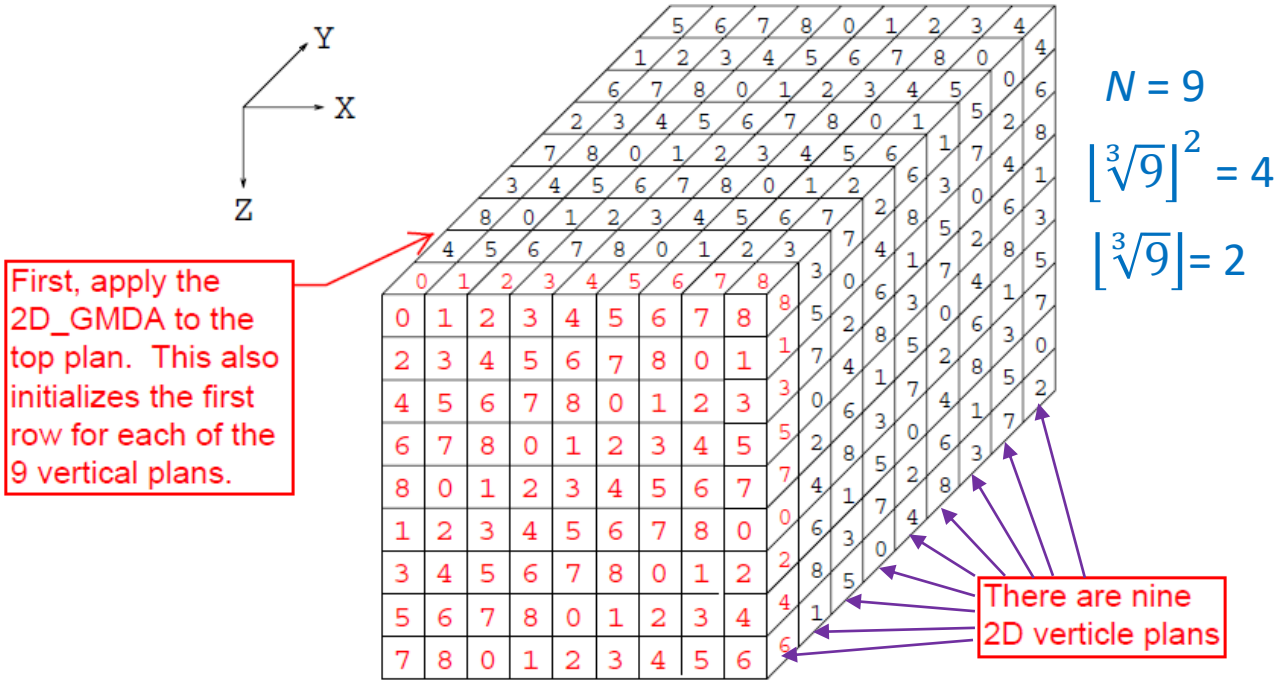
Regular Rows: Circular left shift $\lfloor\sqrt{N}\rfloor$ positions.

Check Rows: Circular left shift $\lfloor\sqrt{N}\rfloor + 1$ positions.

Advantages: optimal for row, column, and small square range queries ($|Q| < \lfloor\sqrt{N}\rfloor^2$).

Handling 3D

A cube with N^3 grid blocks can be seen as N 2D planes stacked up in the third dimension



Algorithm 3D_GMDA:

1. We compute the mapping for the first rows of all the 2-dimensional planes

   by considering these rows collectively as forming a plane along the third dimension. We apply the 2D_GMDA algorithm to this plane, except that the shifting distance is set to $\lfloor \sqrt[3]{N} \rfloor^2$.

2. We apply the 2D_GMDA algorithm to each of the 2-dimensional planes using the shifting distance $\lfloor \sqrt[3]{N} \rfloor$ and the first row already computed in Step 1.

Handling Higher Dimensions: Mapping Function

A grid block $(X_1, X_2, ..., X_d)$ is assigned to PN $GeMDA(X_1, X_2, ..., X_d)$, where

$$GeMDA(X_1, ..., X_d) = \left[\sum_{i=2}^{d} \left\lfloor \frac{X_i \cdot GCD_i}{N} \right\rfloor + \sum_{i=1}^{d} (X_i \cdot Shf\_dist_i)\right] \bmod N,$$

$$N = \text{ number of PNs,}$$

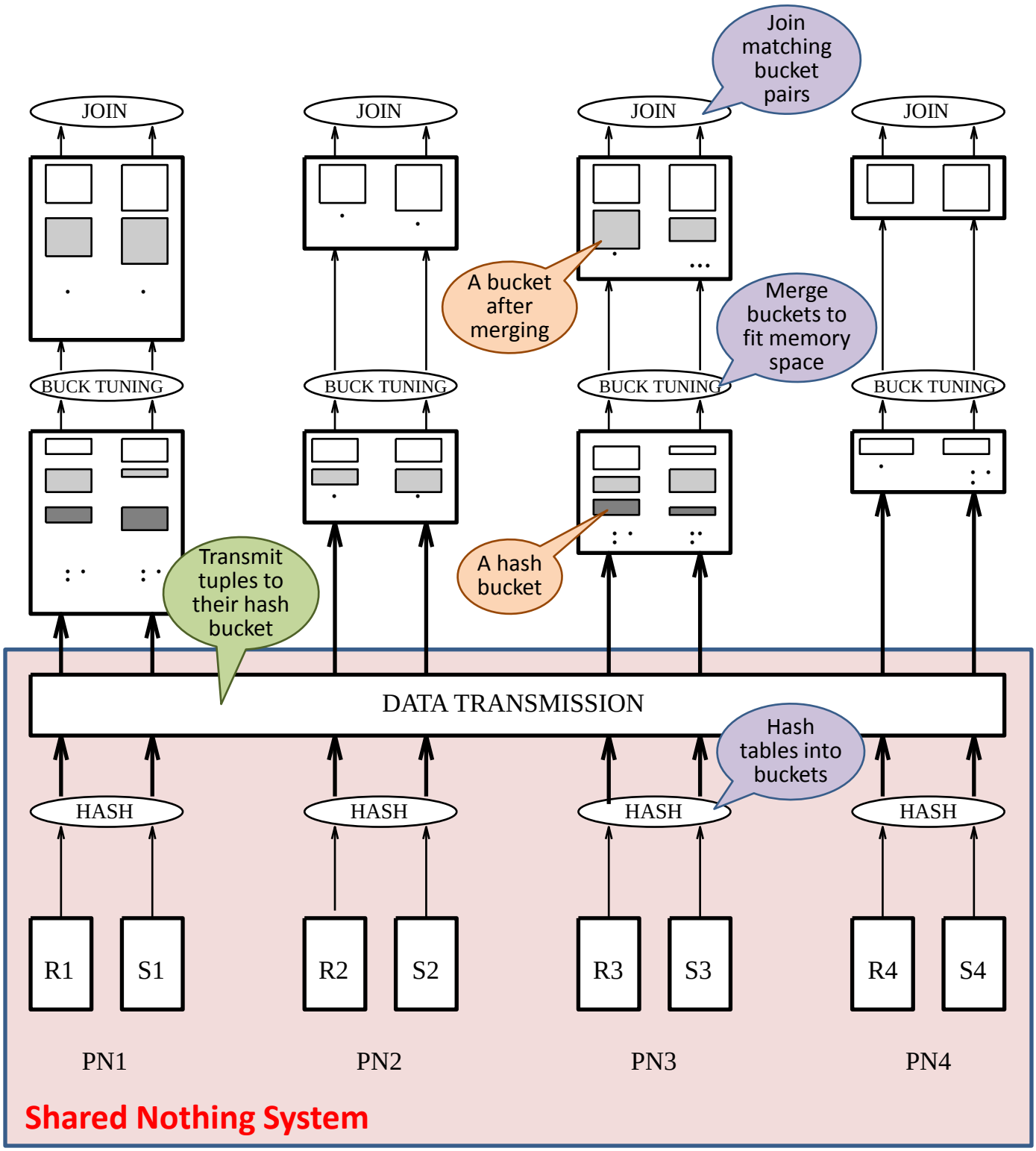
$$Shf\_dist_i = \lfloor \sqrt[d]{N} \rfloor^{i\text{-}1}, \text{ and}$$

$$GCD_i = gcd(Shf\_dist_i, N).$$

Optimality Comparison

Allocation scheme	**Optimal with respect to**		
	row queries	**column queries**	**small square queries**
HCAM	*No*	*No*	*No*
CMD	*Yes*	*Yes*	*No*
GeMDA	*Yes*	*Yes*	*Yes*

Conventional Parallel Hash-based Join: Grace Algorithm

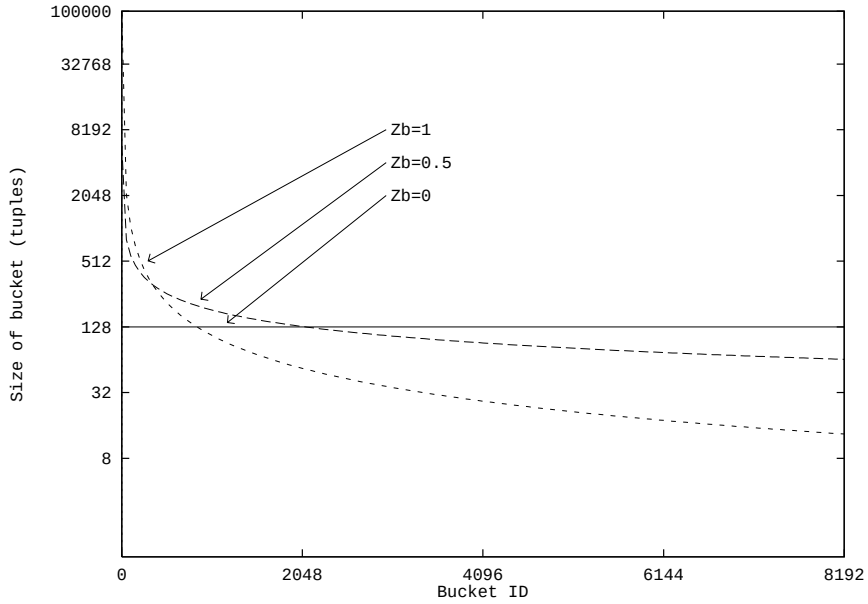


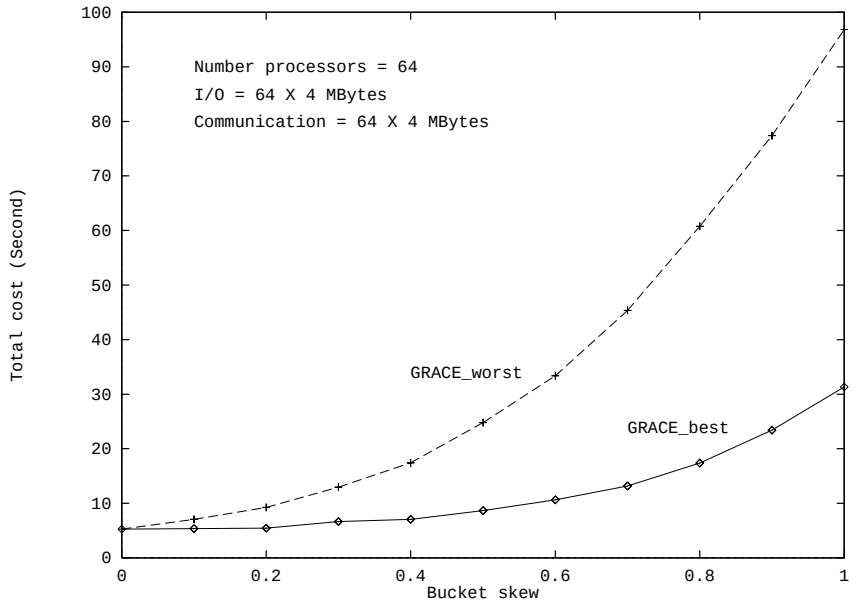
Grace Algorithm

- Hash Phase: The hash buckets are evenly assigned among the PNs. Each PN hashes its local partition of each relation and sends each tuple to the target hash bucket according to the hash result (i.e., the remainder)
- Bucket Tuning Phase: The small buckets are logically combined (disk access not required) to form a larger bucket to better fit the local memory[+]. The buckets of the two relations must be combined in the same way according to the same hash codes (i.e., same remainders).
- Join Phase: The PNs perform in parallel their local joins.

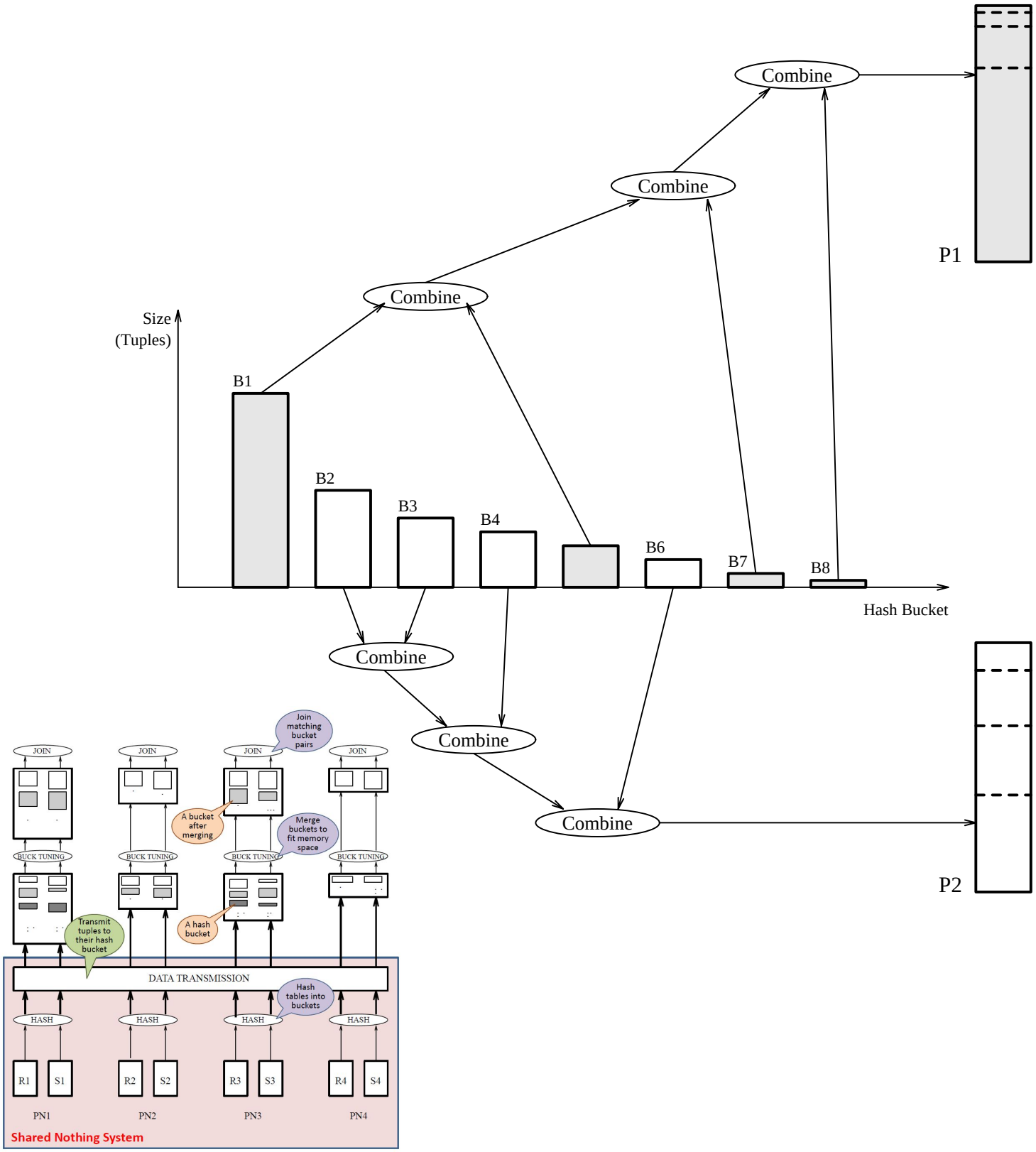
[+]Only one bucket of each bucket pair needs to fit in the memory in its entirety so that the other bucket needs to be scanned only once.

The Effect of Imbalanced Workloads

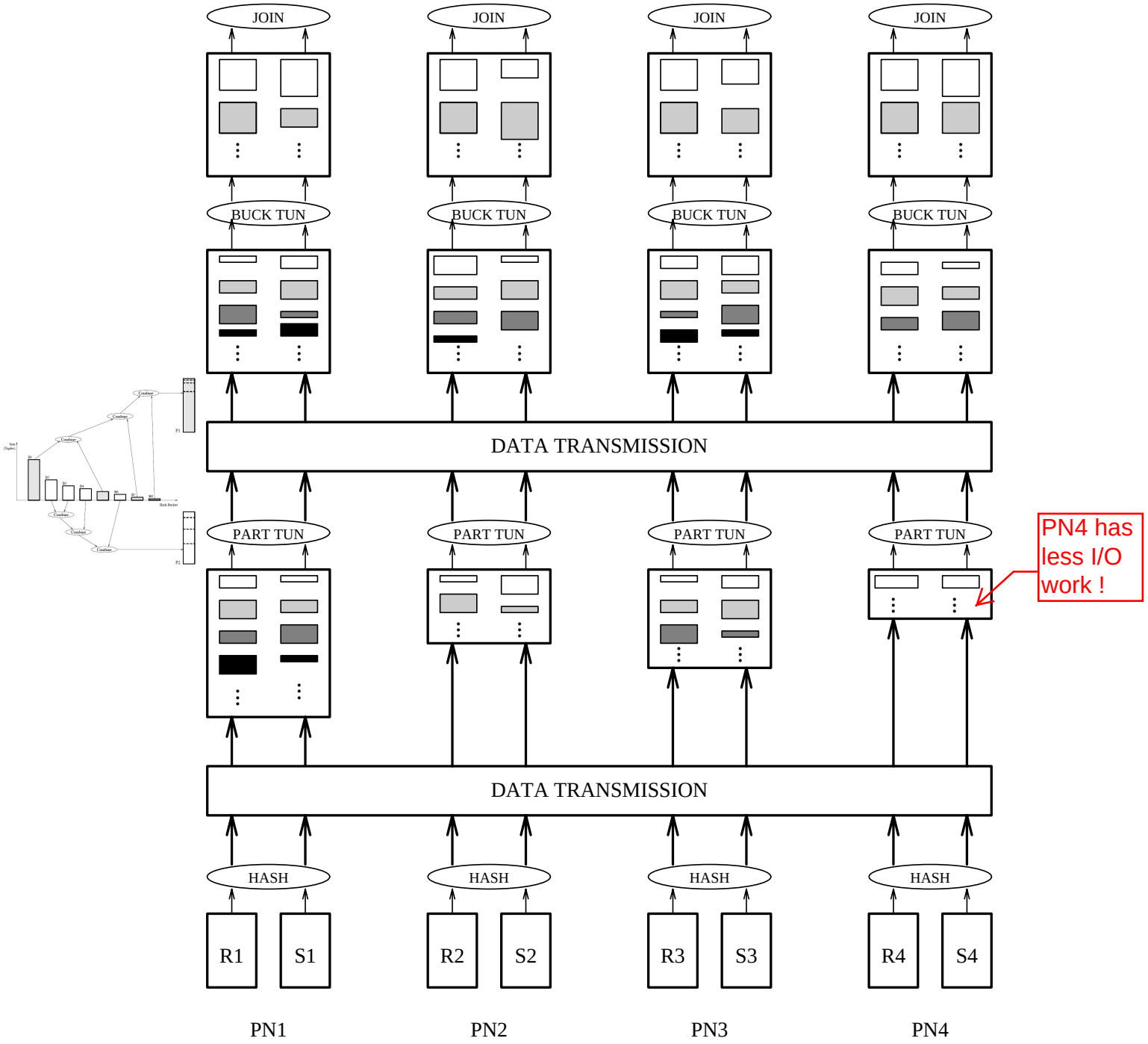




Partition Tuning: *Largest Processing Time (LPT) First Strategy* - Bin Packing



Naive Load Balancing Parallel Hash Join (NBJ)



Partition Tuning: Re-distribute the hash bucket among the PNs using Bin Packing to balance their workload

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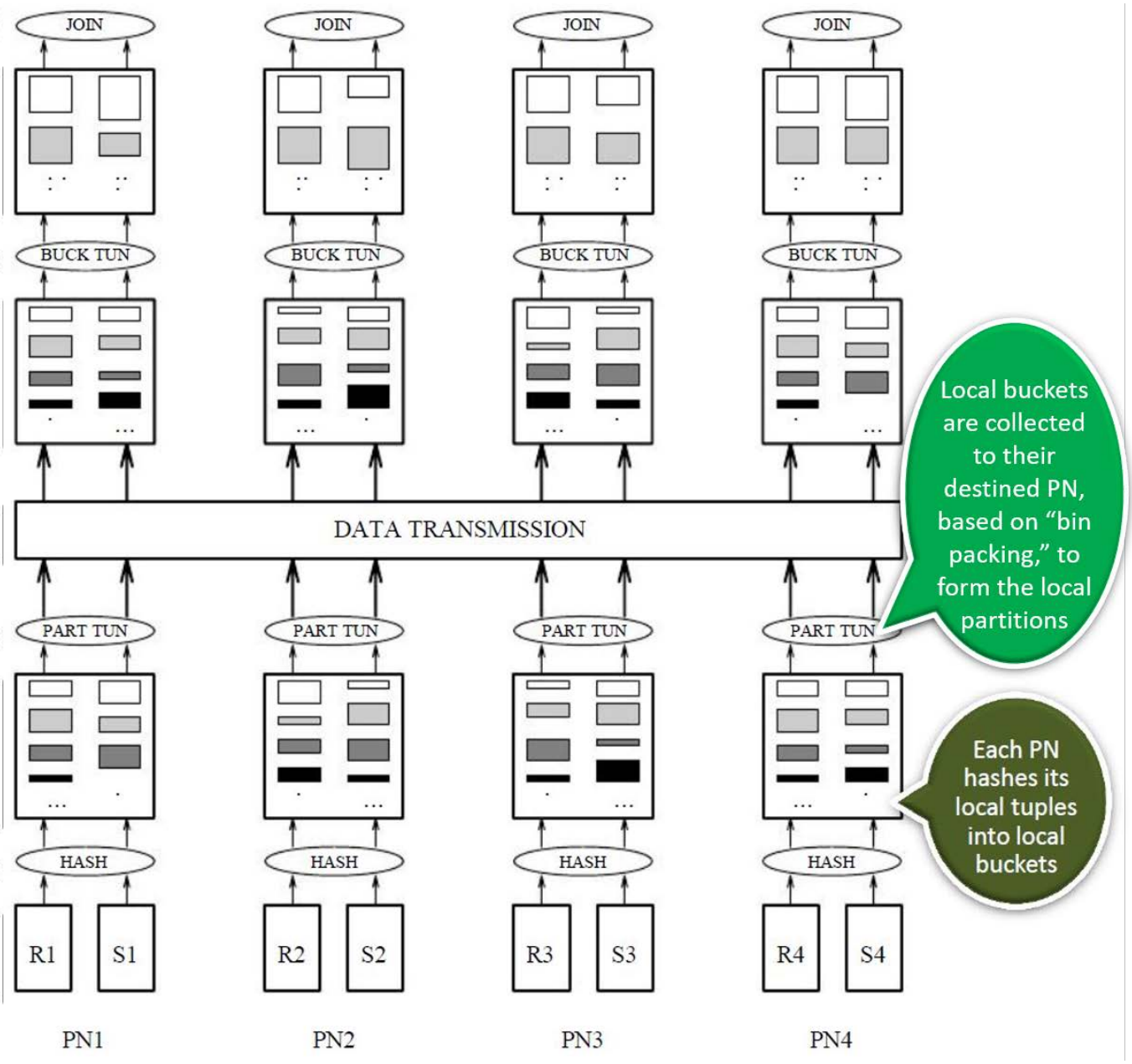
Adaptive Load Balancing Parallel Hash Join (ABJ)



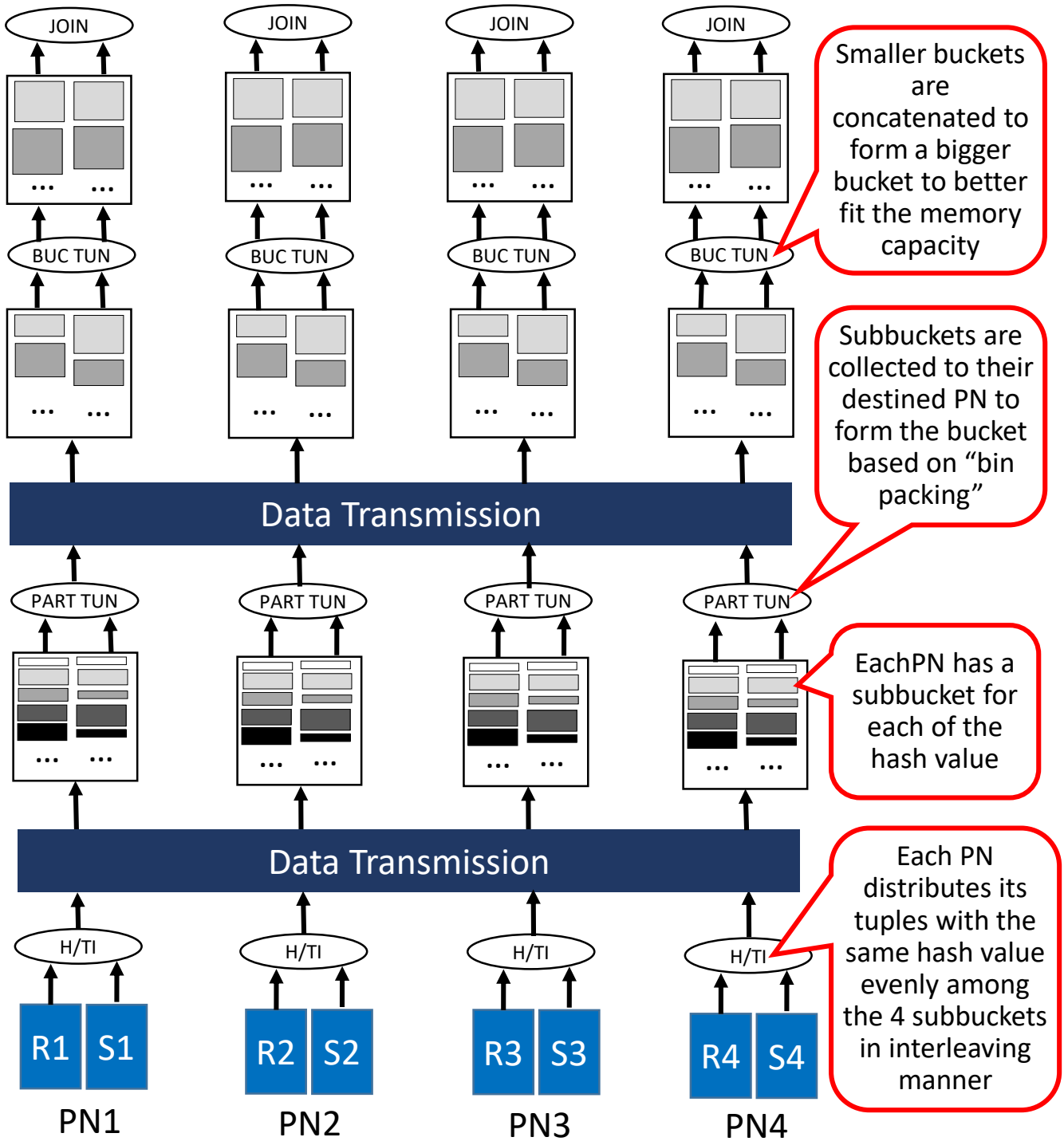
Workload is balanced among the PN's throughout the computation

What if the partitioning is skew initially ?

ABJ Algorithm

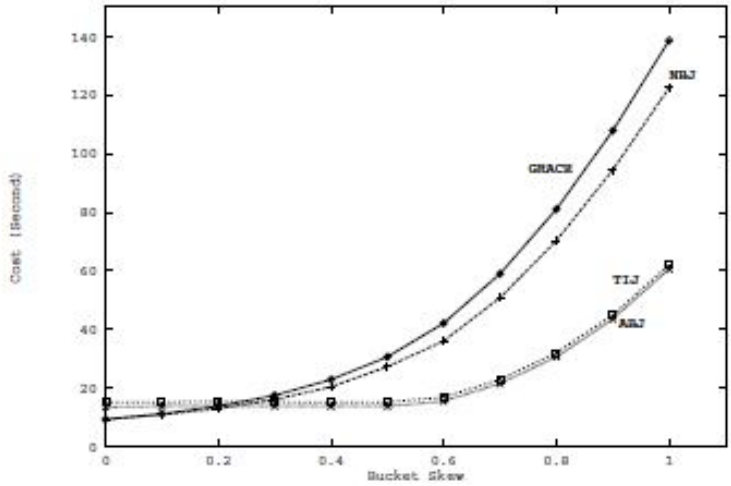
- Hash: Each PN maintains a subbucket for each of the hash buckets. Each PN hashes its local partition of each relation and stores each tuple to the appropriate subbucket according to the hash result (i.e., no data transmission)
- Partition Tuning: The coordinating PN computes the total size of each bucket by summing up the sizes of its subbuckets. This size information is used to run the bin packing algorithm to assign the bucket pairs among the PNs to achieve load balancing.
- Bucket Tuning: The small buckets are logically combined (disk access not required) to form a larger bucket to better fit the local memory[+]. The buckets of the two relations must be combined in the same way according to the same hash codes (i.e., same remainders).
- Join: The PNs perform in parallel their local joins.

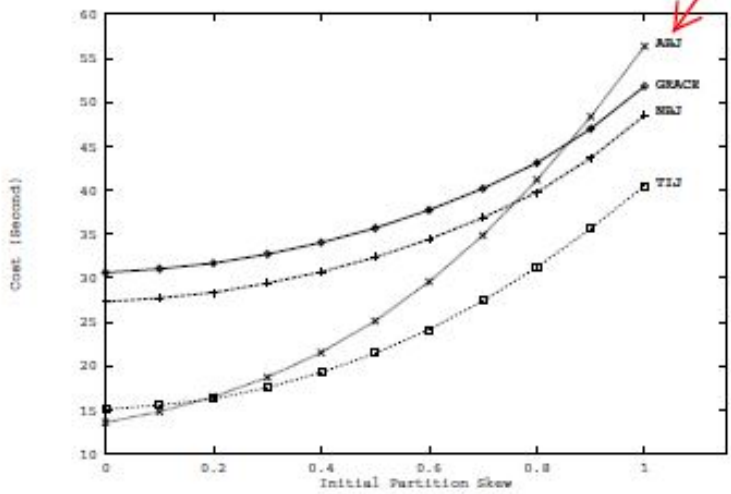
Tuple Interleaving Parallel Hash Join (TIJ)



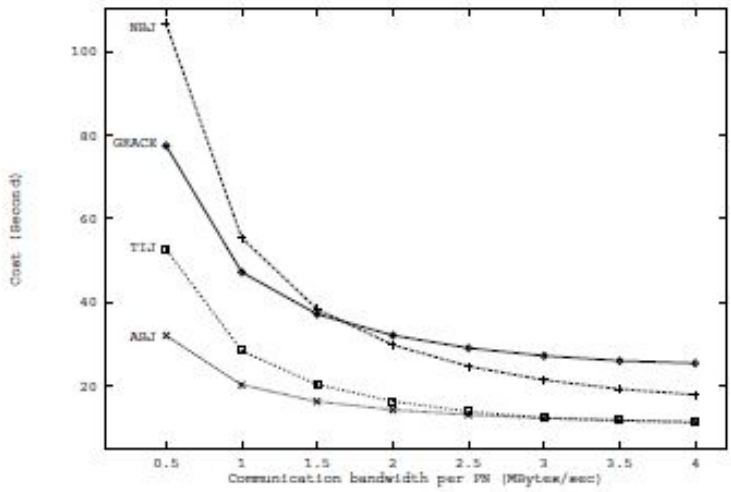
Workload is balanced among the PN's throughout the computation

Simulation Results



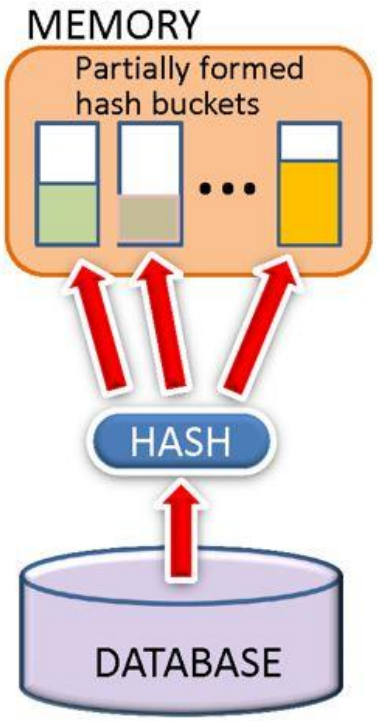


ABJ continues to suffer the initial skew after the hash phase resulting in a performance worse than even that of GRACE under a severe initial skew condition



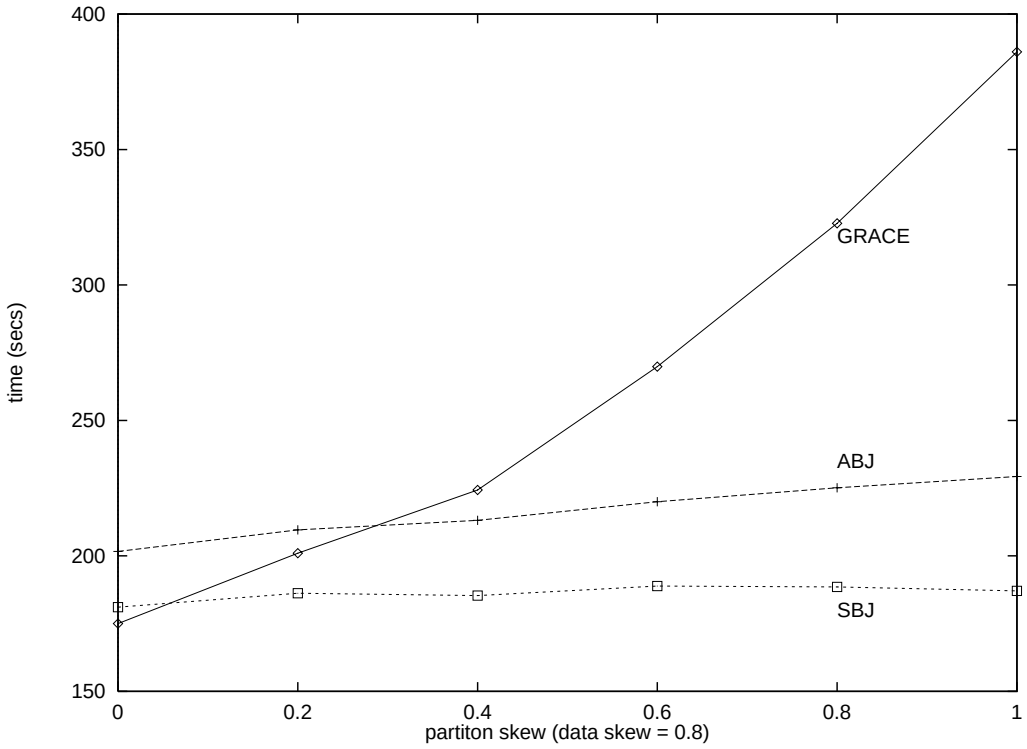
Sampling-based Load Balancing (SLB) Join Algorithm

- Sampling Phase: Each PN loads a small percentage of its tuples into memory, and hash them into a large number of in-memory hash buckets (hash on the join attribute)
- Partition Tuning: The coordinating PN applies "bin packing" to the in-memory buckets to determine the optimal *bucket allocation scheme* (BAS)
- Split Phase:
  - The in-memory buckets are collected to their destined PN in accordance with the BAS to form the initial partial buckets
  - Each PN loads the remaining tuples and forwards them to their destined hash buckets ("bin packing" not needed)



- Join Phase: Each PN performs the local joins of respectively matching buckets

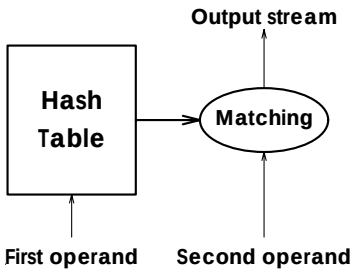
nCUBE/2 Results: SLB vs. ABJ vs. GRACE



- The performance of SLB approaches that of GRACE on very mild skew conditions, and
- it can avoid the disastrous performance that GRACE suffers on severe skew conditions.

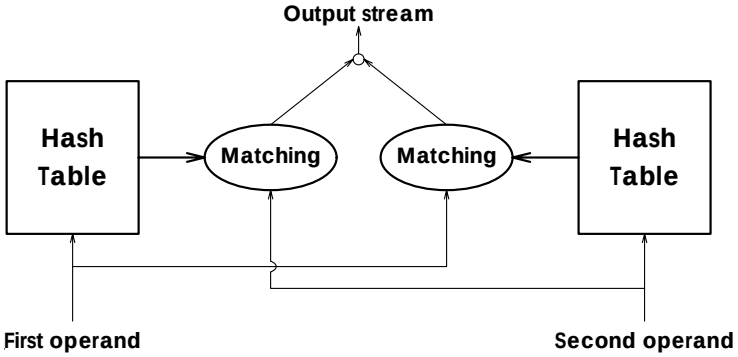
Pipelining Hash-Join Algorithms

- Two-Phase Approach:



  - Advantage: requires only one hash table.
  - Disadvantage: pipelining along the outer relation must be suspended during the build phase (i.e., building the hash table).

- One-Phase Approach: As a tuple comes in, it is first inserted into its hash table, and then used to probe that part of the hash table of the other operand that has already been constructed.



  - Advantage: pipelining along both operands is possible.
  - Disadvantage: requires larger memery space.

Aggregate Functions

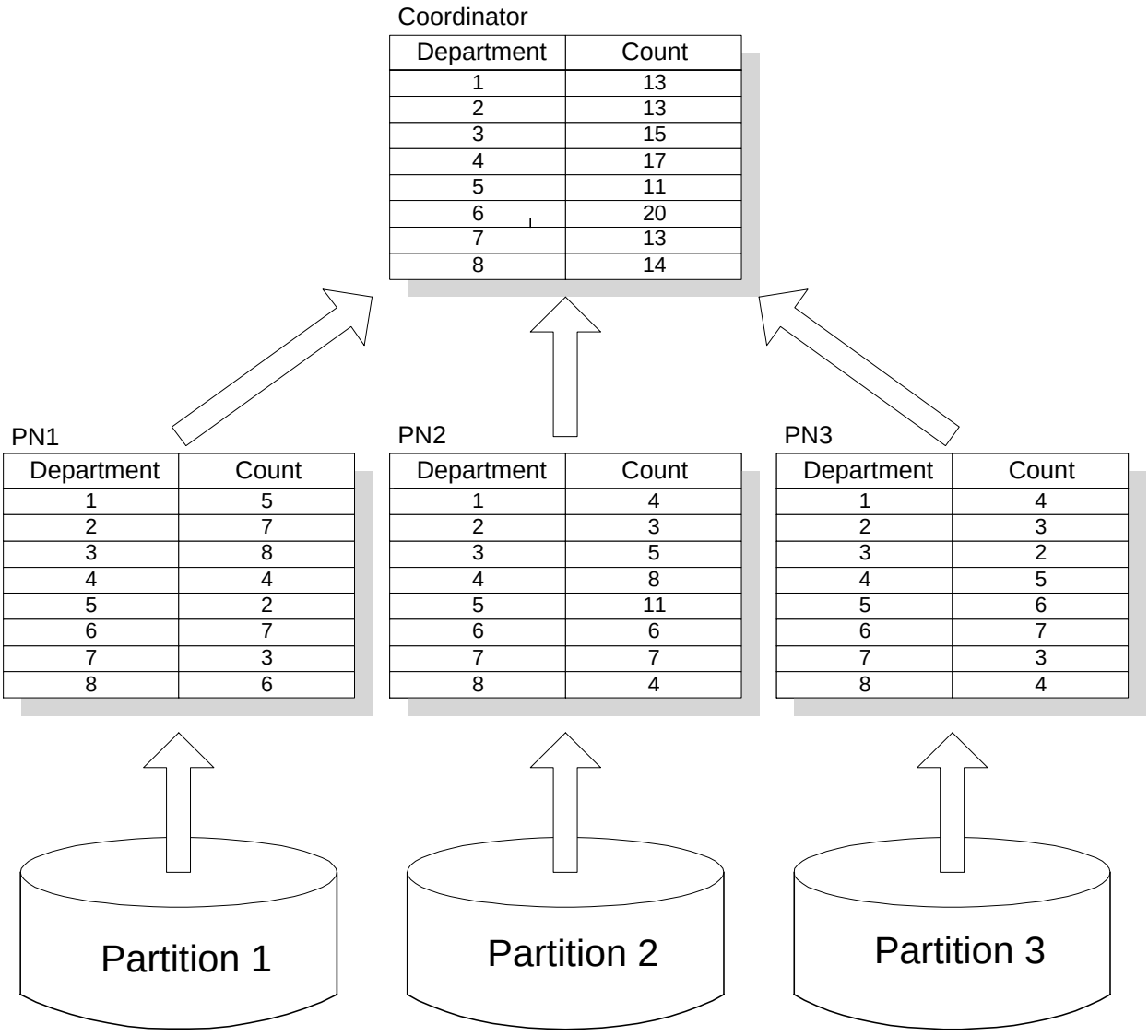
- An SQL aggregate function is a function that operates on groups of tuples.

Example:

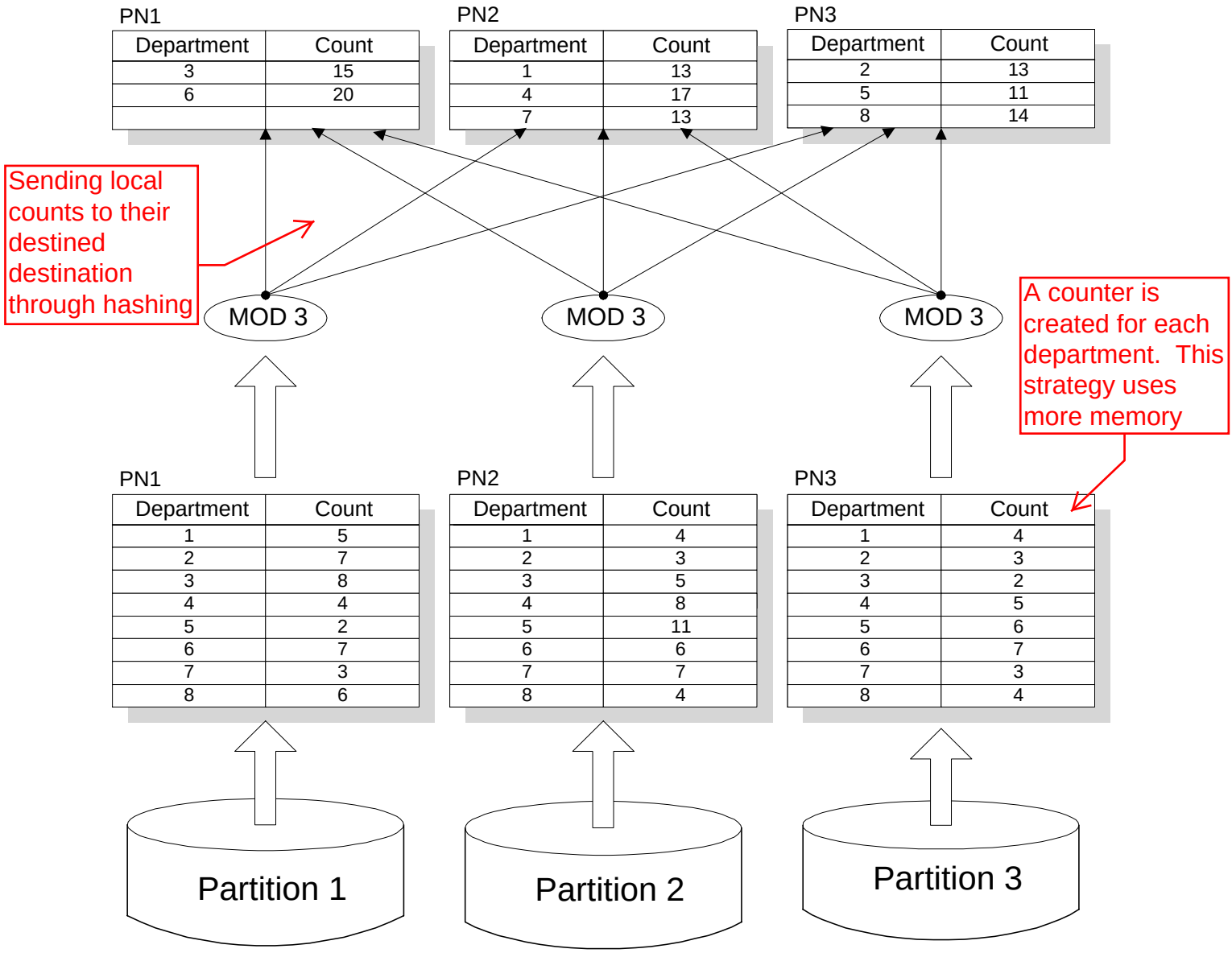
```
SELECT    department, COUNT(*)
FROM      Employee
WHERE     age > 50
GROUP BY  department
```

- The number of result tuples depends on the selectivity of the GROUP BY attributes (i.e., *department*).

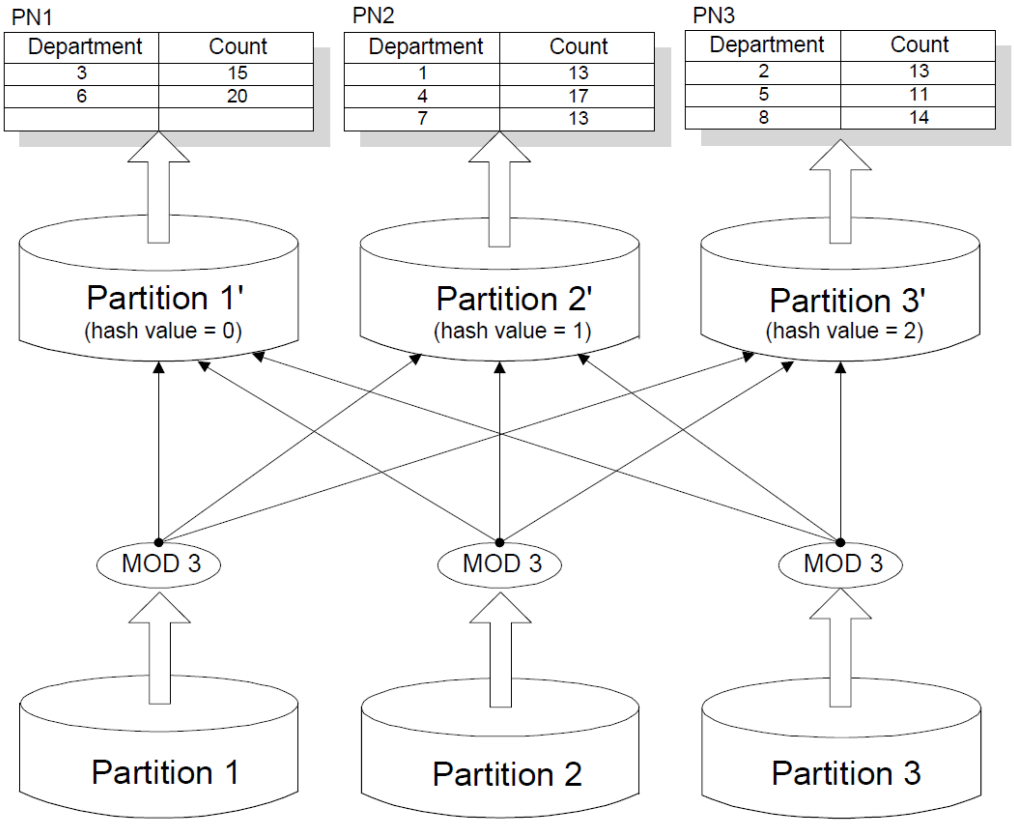
Centralized Merging



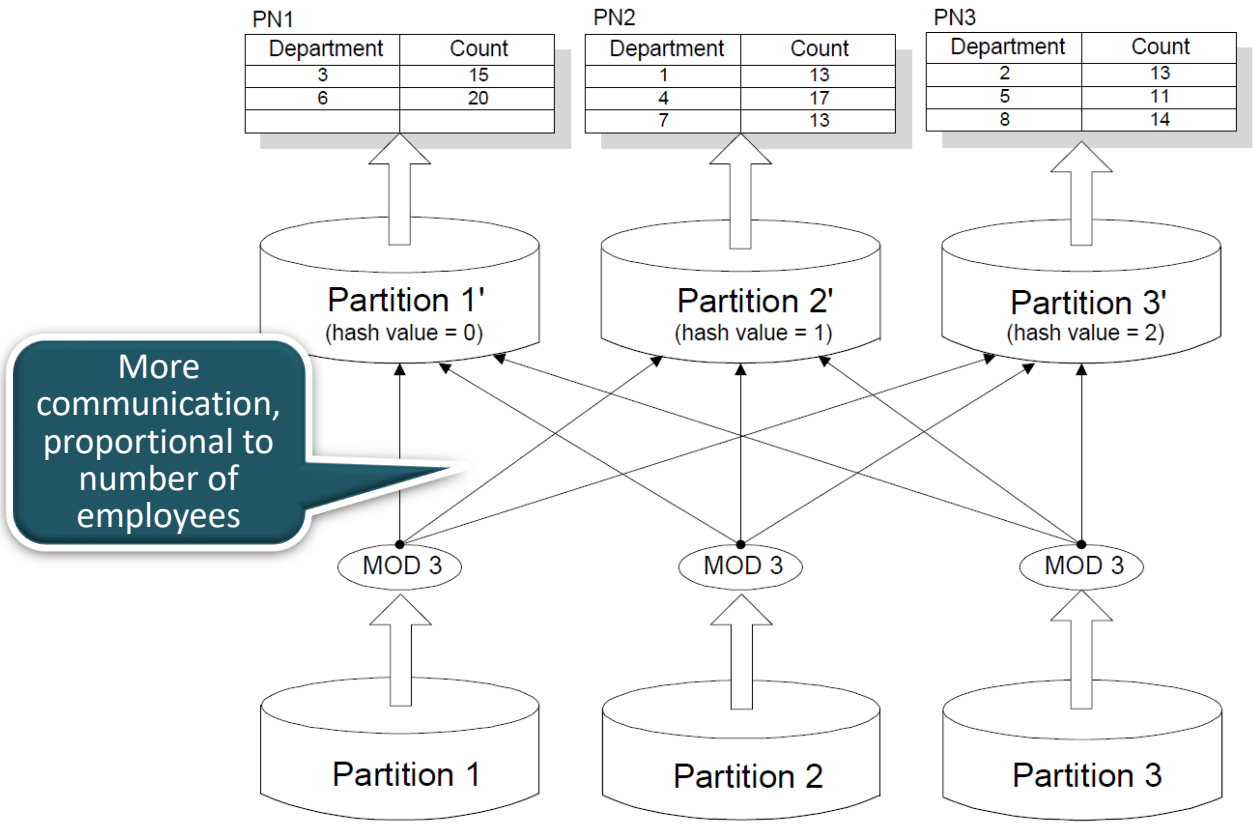
Distributed Merging

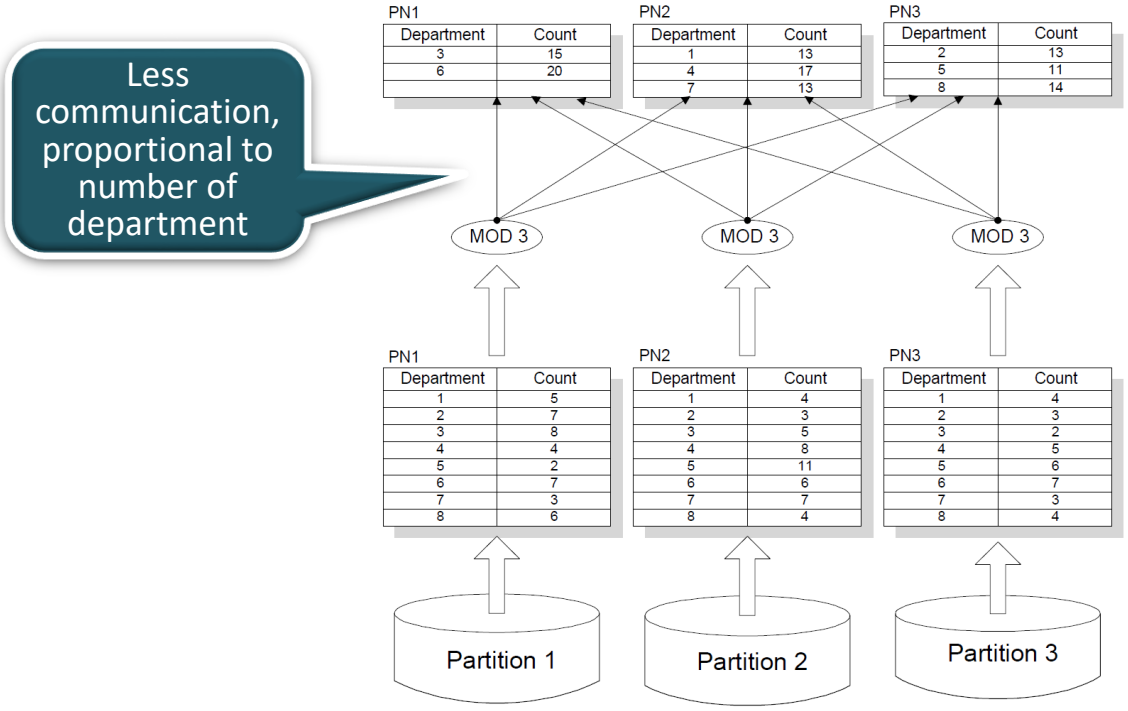


Repartitioning



Repartitioning





Performance Characteristics

- Centralized Merging Algorithm:

  Advantage: It works well when the number of tuples is small.

  Disadvantage: The merging phase is sequential.

- Distributed Merging Algorithm:

  Advantage: The merging step is not a bottleneck.

  Disadvantage: Since a group value is being accumulted on potentially all the PNs the overall memory requirement can be large.

- Repartitioning Algorithm:

  Advantage: It reduces the memory requrement as each group value is stored in one place only.

  Disadvantage: It incurs more network traffic.

Coventional Aggregation Algorithms

- Centralized Merging (CM) Algorithm:

  Phase 1: Each PN does aggregation on its local tuples.

  Phase 2: The local aggregate values are merged at a predetermined central coordinator.

- Distributed Merging (DM) Algorithm:

  Phase 1: Each PN does aggregation on its local tuples.

  Phase 2: The local aggregate values are then hash-partitioned (based on the GROUP BY attribute) and the PNs merge these local aggregate values in parallel.

- Repartitioning (Rep) Algorithm:

  Phase 1: The relation is repartitioned using the GROUP BY attributes.

  Phase 2: The PNs do aggreation on their local partitions in parallel.

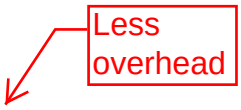
Performance Comparison:

- CM and DM work well when the number of result tuples is small.
- Rep works better when the number of groups is large.

Adaptive Aggregation Algorithms

- Sampling Based (Samp) Approach:
  - CM algorithm is first applied to a small Page-oriented random sample of the relation.
  - If the number of groups obtained from the sample is small then DM strategy is used; Rep algorithm is used otherwise.

- Adaptive DM (A-DM) Algorithm:
  - This algorithm starts with the DM strategy under the common case assumption that the number of group is small.
  - However, if the algorithm detects that the number of groups is large (i.e., memory full is detected) it switches to the Rep strategy.



- The Adaptive Repartitioning (A-Rep) Algorithm:
  - This algorithm starts with the Rep strategy.
  - It switches to DM if the number of groups is not large enough (i.e., number of groups is too few given the number of seen tuples).

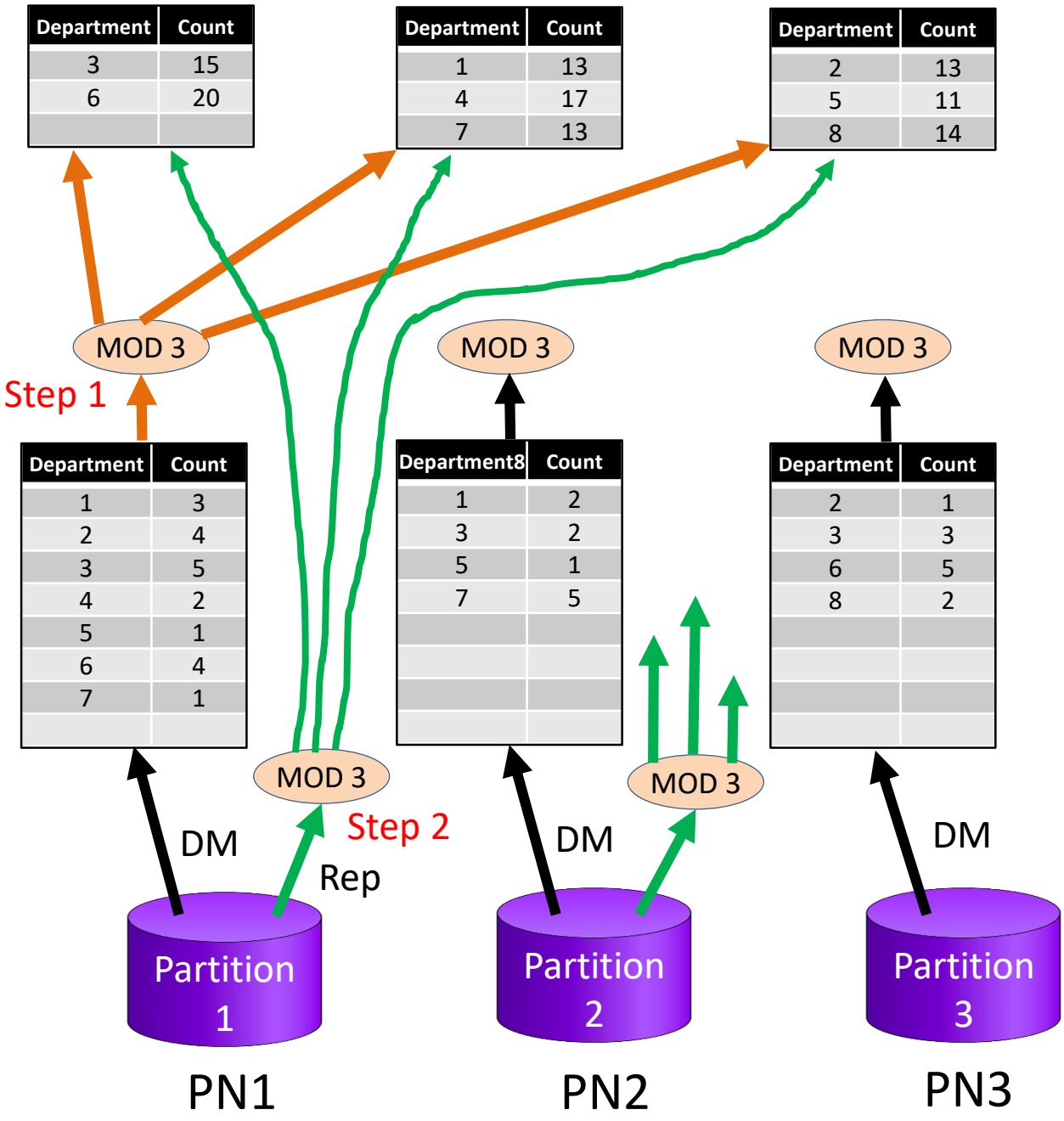
Performance Comparison:

- In general, A-DM performs the best.
- However, A-Rep should be used if the number of groups is suspected to be very large.

Implementation Techniques for A-DM

- Global Switch:
  - When the first PN detects a memory full condition, it informs all the PNs to switch to the Rep strategy.
  - Each PN first partitions and sends the so far accumulated local results to PNs they hash to. Then, it proceeds to read and repartition the remaining tuples.
  - Once the repartitioning phase is complete, the PNs do aggregate on the local partitions in parallel (as in the Rep algorithm).
- Local Switch:
  - A PN upon detecting memory full stops processing its local tuples. It first partitions and sends the so far accumulated local results to the PNs they hash to. Then it proceeds to read and repartition the remaining tuples.
  - During Phase one, one set of PNs may be executing the DM algorithm while other are executing the Rep algorithm. When the latter receives an aggregate value from another PN, it accumulates it to the corresponding local aggregate value.
  - Once all PNs have completed their Phase 1, The local aggregate values are merged as in the DM algorithm.

A-DM: Global Switch

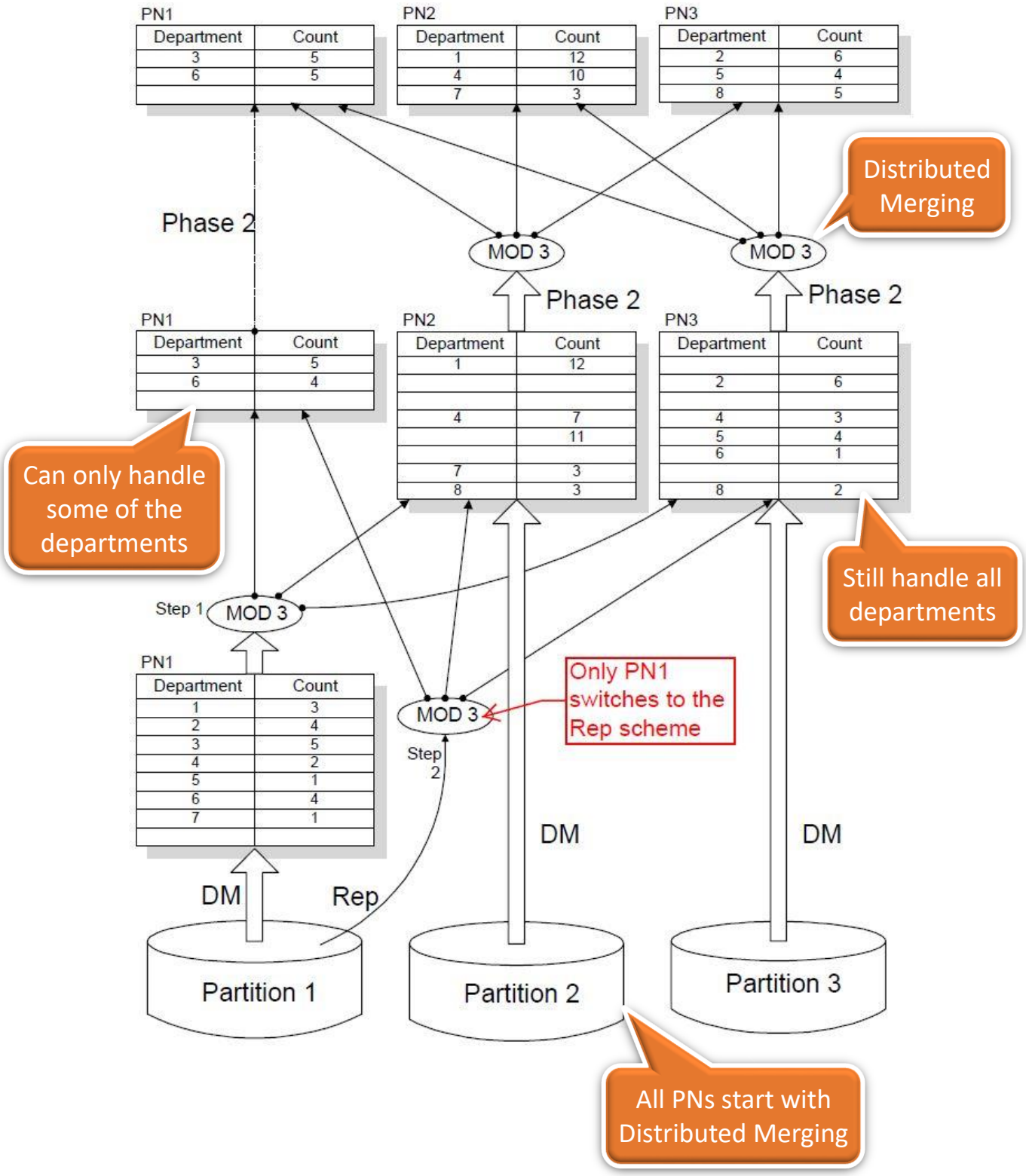


PN2 and PN3 must also switch with PN1 (i.e., global switch)

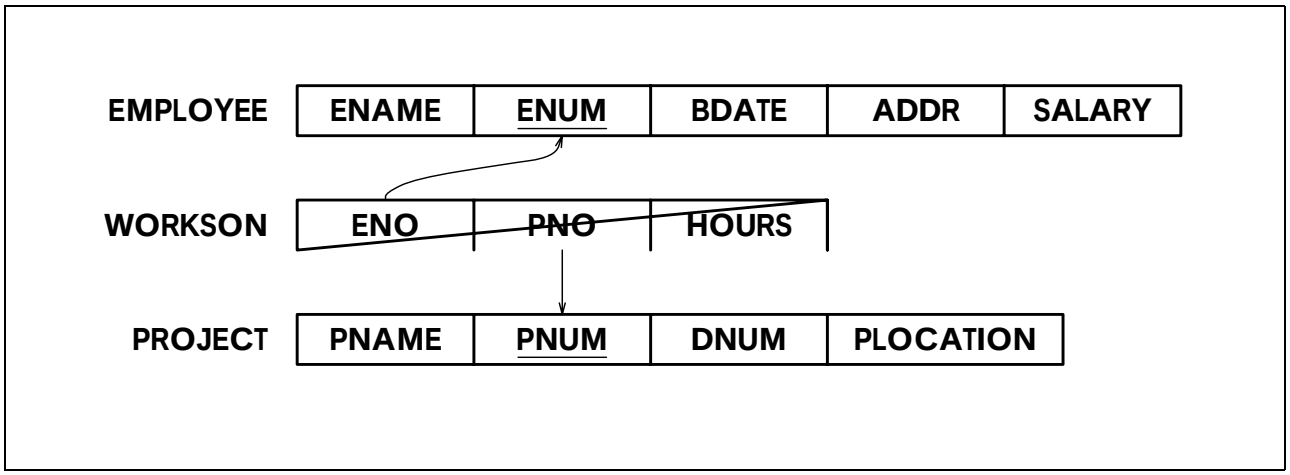
Switching to Rep

- Step 1: Prepare for Repartitioning
- Step 2: Apply Repartitioning to the remaining tuples

A-DM: Local Switch



SQL (*S*tructured *Q*uery *L*anguage)



An SQL query:

```
SELECT  ENAME
FROM    EMPLOYEE, WORKSON, PROJECT
WHERE   PNAME= 'database' AND
        PNUM = PNO AND
        ENO = ENUM AND
        BDATE > '1965'
```

- SQL is *nonprocedural*.
- The Compiler must generate the *execution plan*.
  1. Transforms the query from SQL into *relational algebra*.
  2. Restructures (optimizes) the algebra to improve performance.

Relational Algebra

Relation T1

ENAME	SALARY	ENUM
Andrew	*$98,000*	*005*
Casey	*$150,000*	*003*
James	*$120,000*	*007*
Kathleen	*$115,00*	*001*

Relation T2

ENUM	ADDRESS	BDATE
001	*Orlando*	*1964*
003	*New York*	*1966*
005	*Los Angeles*	*1968*
007	*London*	*1958*

- **Select**: Selects rows.

$$\sigma_{SALARY \geq 120{,}000}(T1) = \left\{ \begin{array}{l} (Casey, 150000, 003) \\ (James, 120000, 007) \end{array} \right\}$$

- **Project**: Selects columns.

$$\pi_{ENAME,SALARY}(T1) = \left\{ \begin{array}{l} (Andrew, 98000), \\ (Casey, 150000), \\ (James, 120000), \\ (Kathleen, 115000) \end{array} \right\}$$

- **Cartesian Product**: Selects all possible combinations.

$$T1 \times T2 = \left\{ \begin{array}{l} (Andrew, 98000, 005, 001, Orlando, 1964), \\ (Andrew, 98000, 005, 003, New\ York, 1966), \\ \vdots \\ (Kathleen, 150000, 001, 005, Los\ Angeles, 1968) \\ (Kathleen, 115000, 001, 007, London, 1958) \end{array} \right\}$$

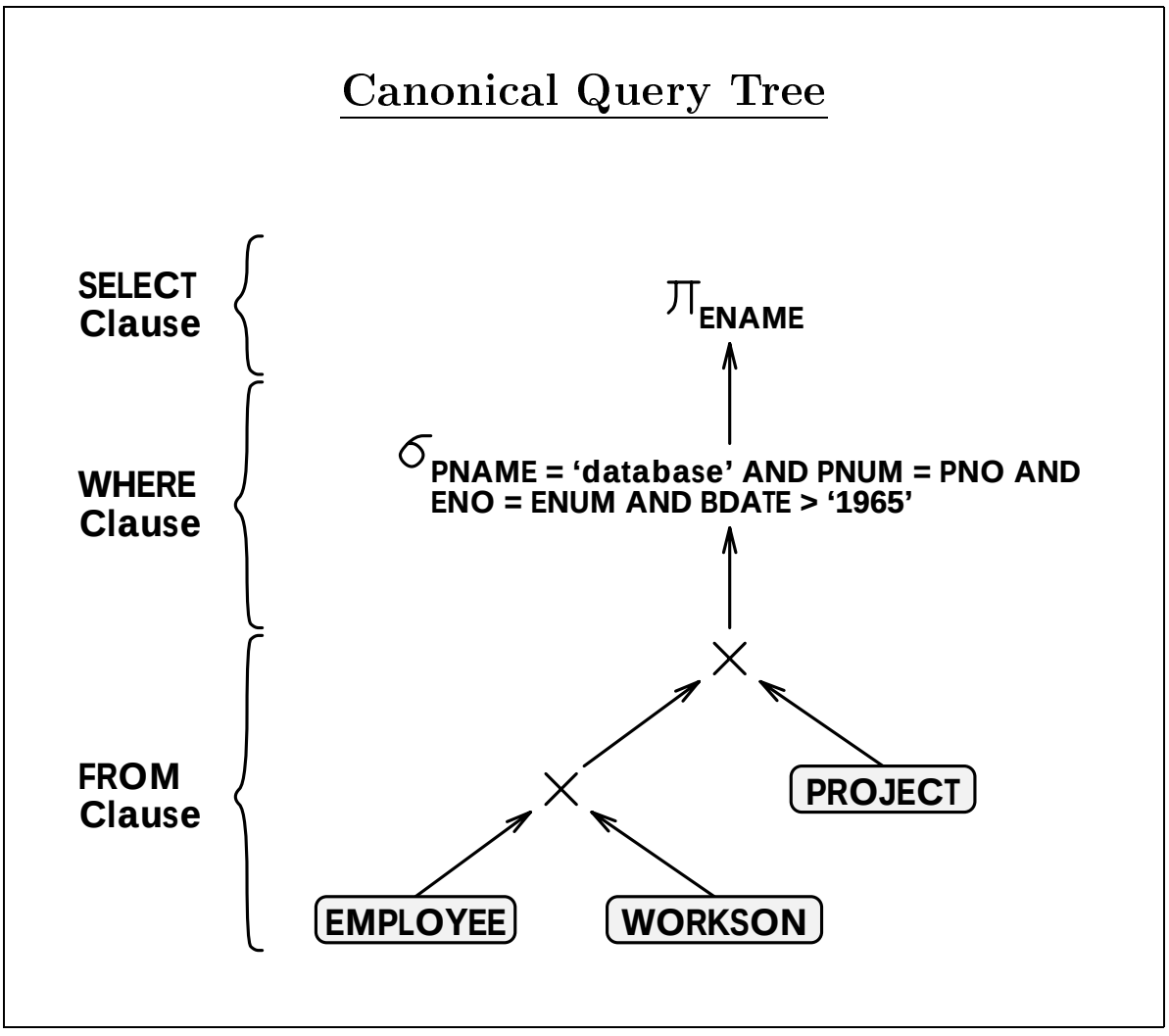
- **Join**: Selects some combinations.

$$T1 \bowtie T2 = \left\{ \begin{array}{l} (Andrew, 98000, 005, Los\ Angeles, 1968), \\ (Casey, 150000, 003, New\ York, 1966), \\ (James, 120000, 007, London, 1958), \\ (Kathleen, 115000, 001, Orlando, 1964) \end{array} \right\}$$

Transforming SQL into Algebra

An SQL query:

```
SELECT  ENAME
FROM    EMPLOYEE, WORKSON, PROJECT
WHERE   PNAME = 'database' AND
        PNUM = PNO AND
        ENO = ENUM AND
        BDATE > '1965'
```



This query tree (procedure) will compute the correct result. However, the performance will be very poor. $\Longrightarrow$ *needs optimization !*

Optimization Strategies

GOAL: Reducing the sizes of the intermediate results as quickly as possible.

STRATEGY:

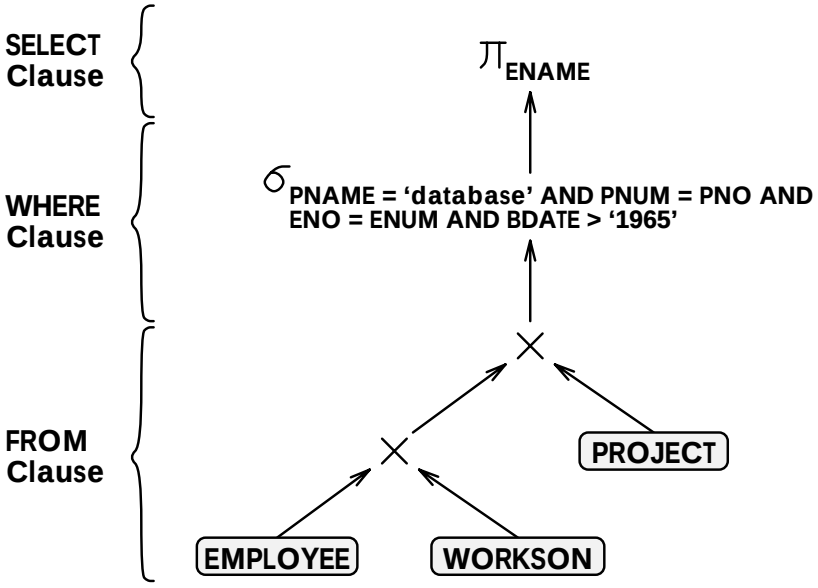
1. Move SELECTs and PROJECTs as far down the query tree as possible.

2. Among SELECTs, reordering the tree to perform the one with lowest selectivity factor first.

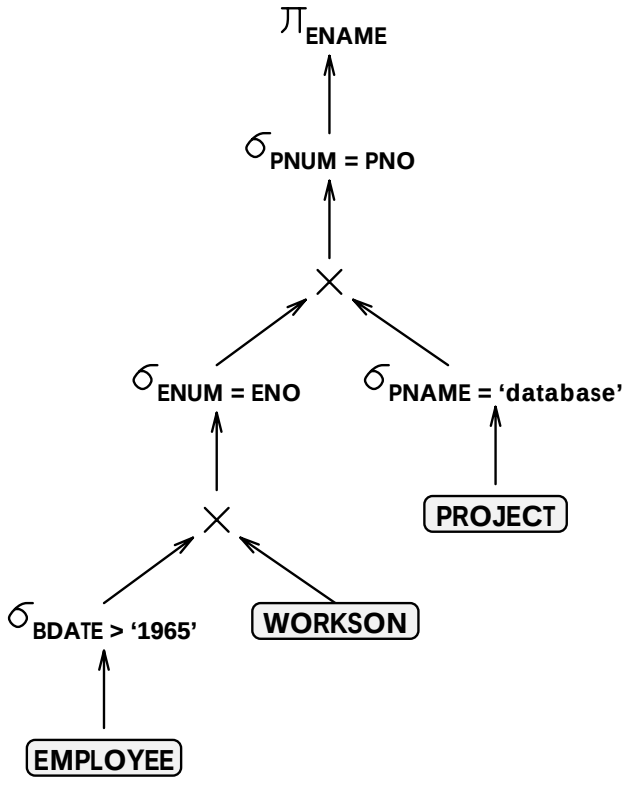
3. Among JOINs, reordering the tree to perform the one with lowest join selectivity first.

Example: Apply SELECTs First

Canonical Query Tree

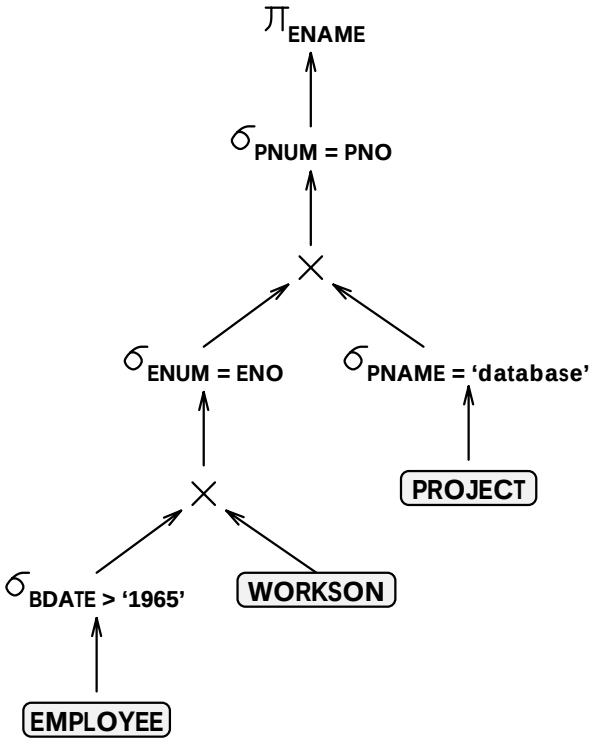


After Optimization

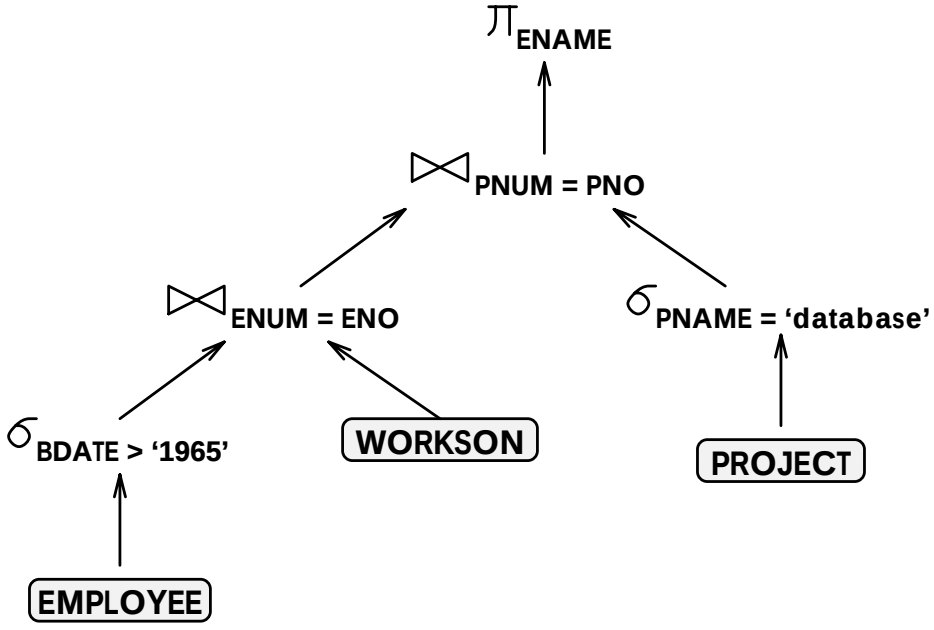


Example: Replace "$\sigma - \times$" by "$\bowtie$"

Before Optimization

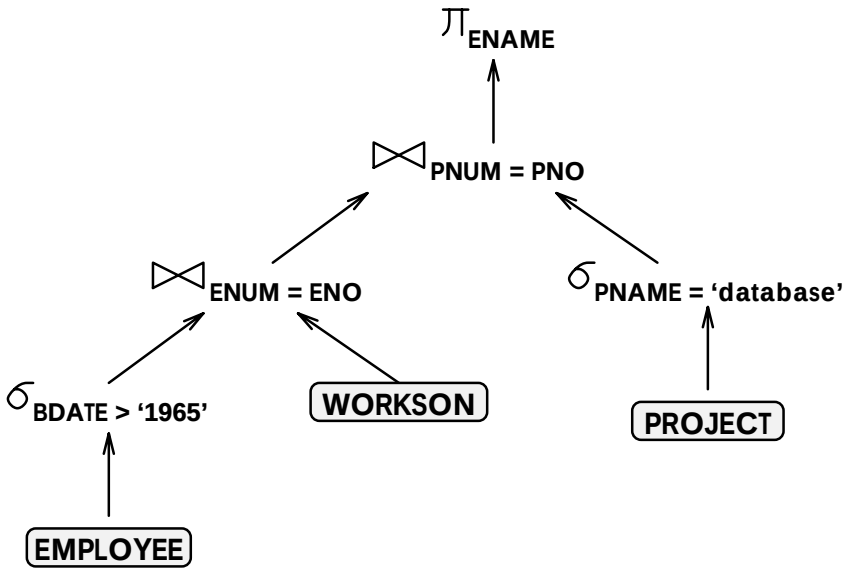


After Optimization

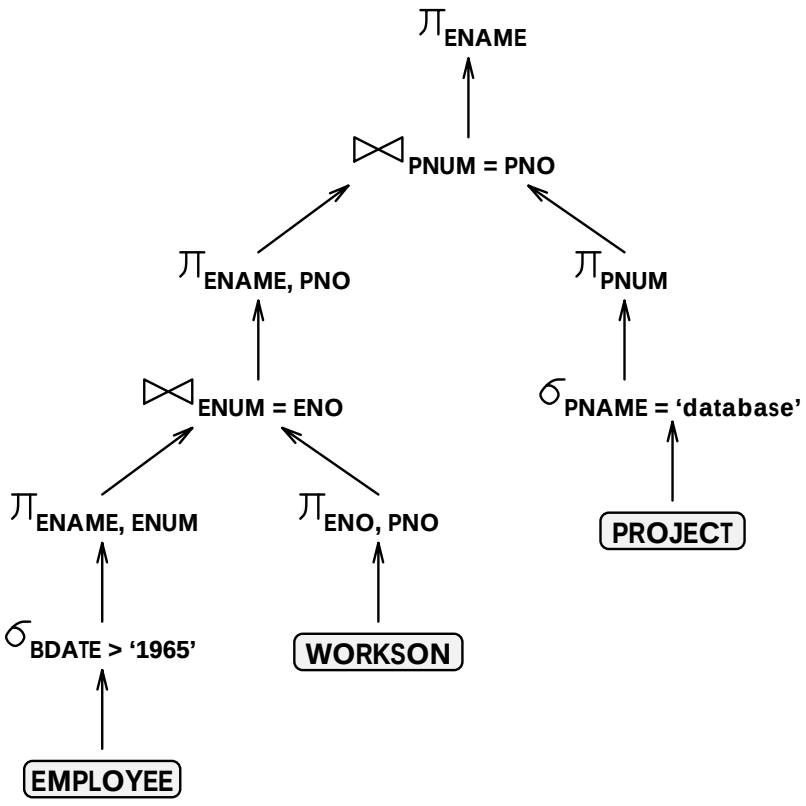


Example: Move PROJECTs Down

Before Optimization



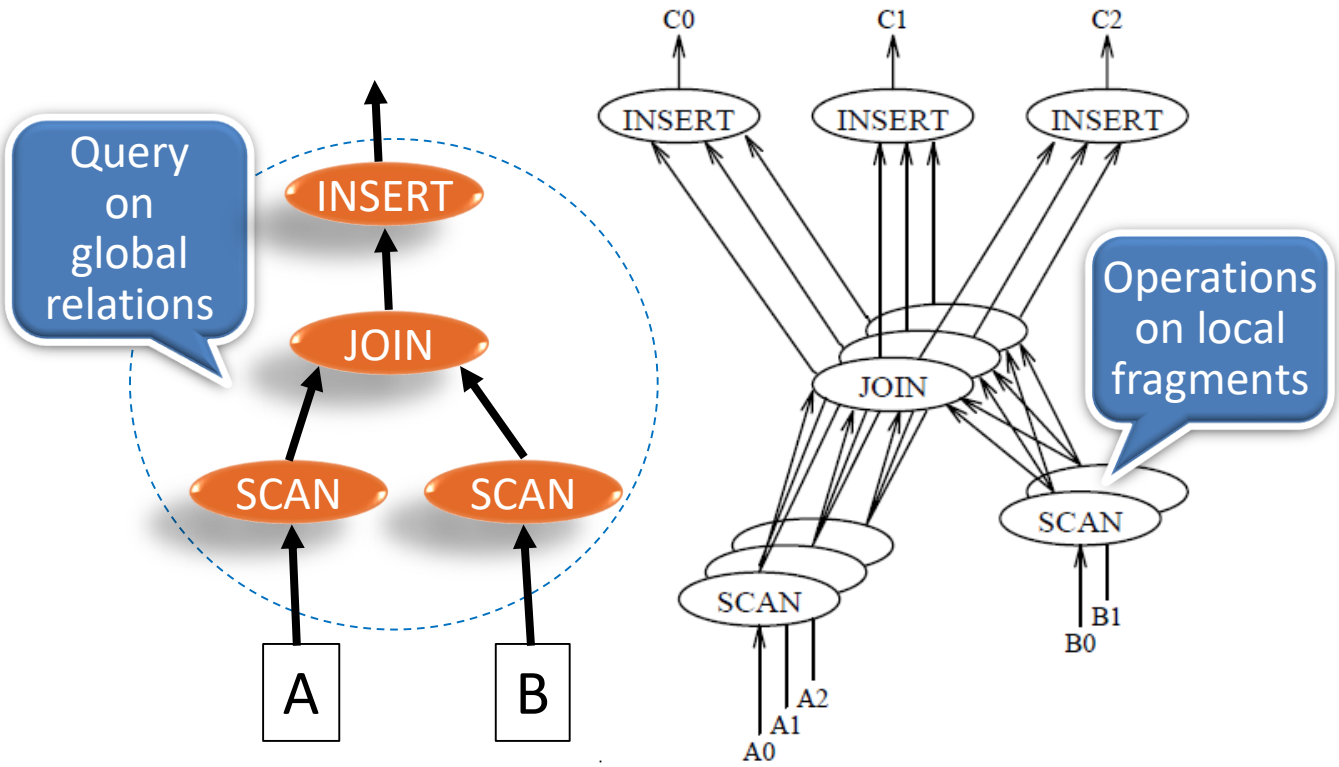
After Optimization



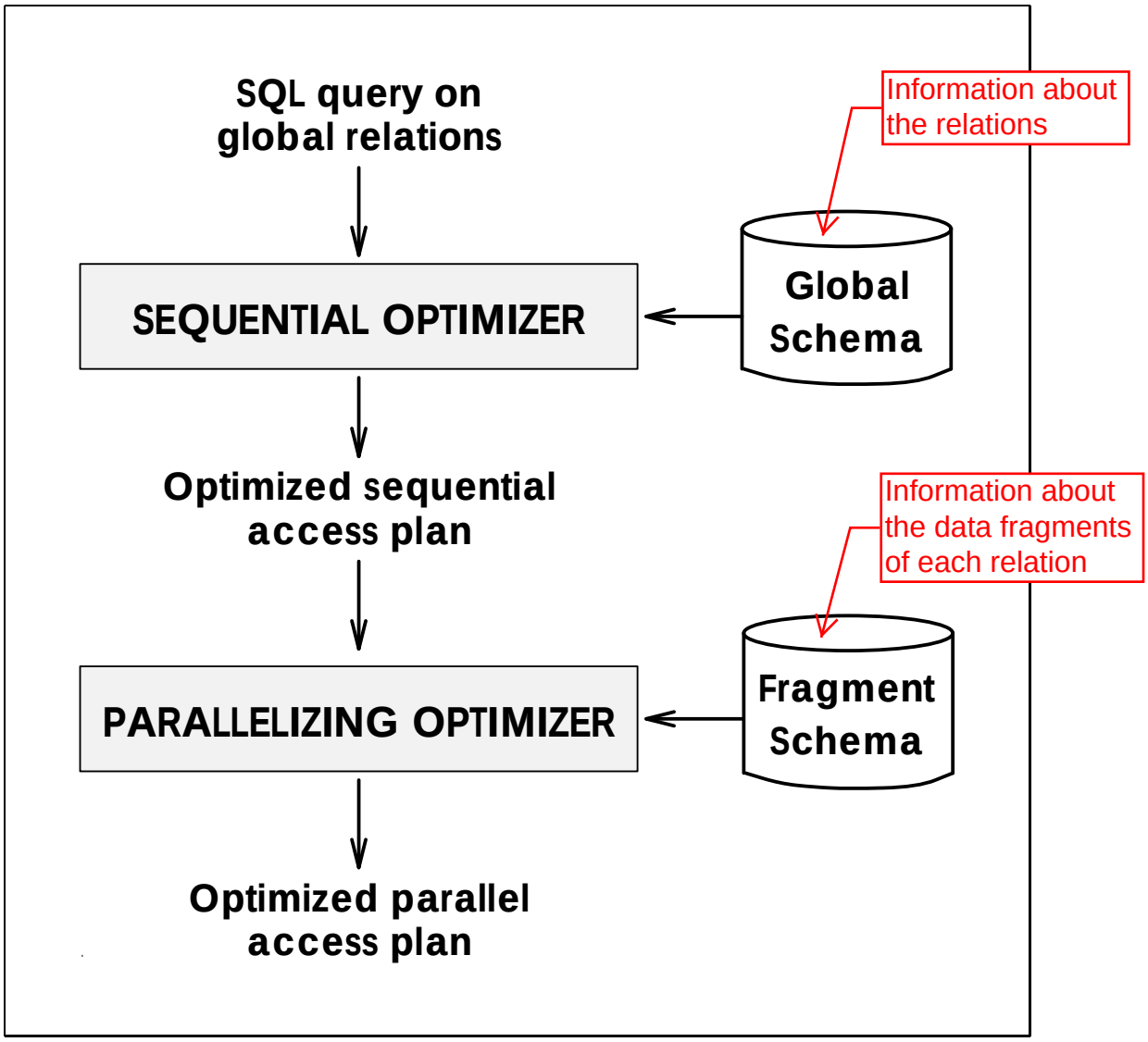
Parallelizing Query Optimizer

Relations are fragmented and allocated to multiple processing nodes:

- The role of a parallelizing optimizer is to map a query on a global relations into a sequence of local operations acting on local relation fragments
- Besides the choice of ordering relational operations, the parallelizing optimizer must select the best PNs to process data



Parallelizing Query Optimization



Parallelizing Optimizer:

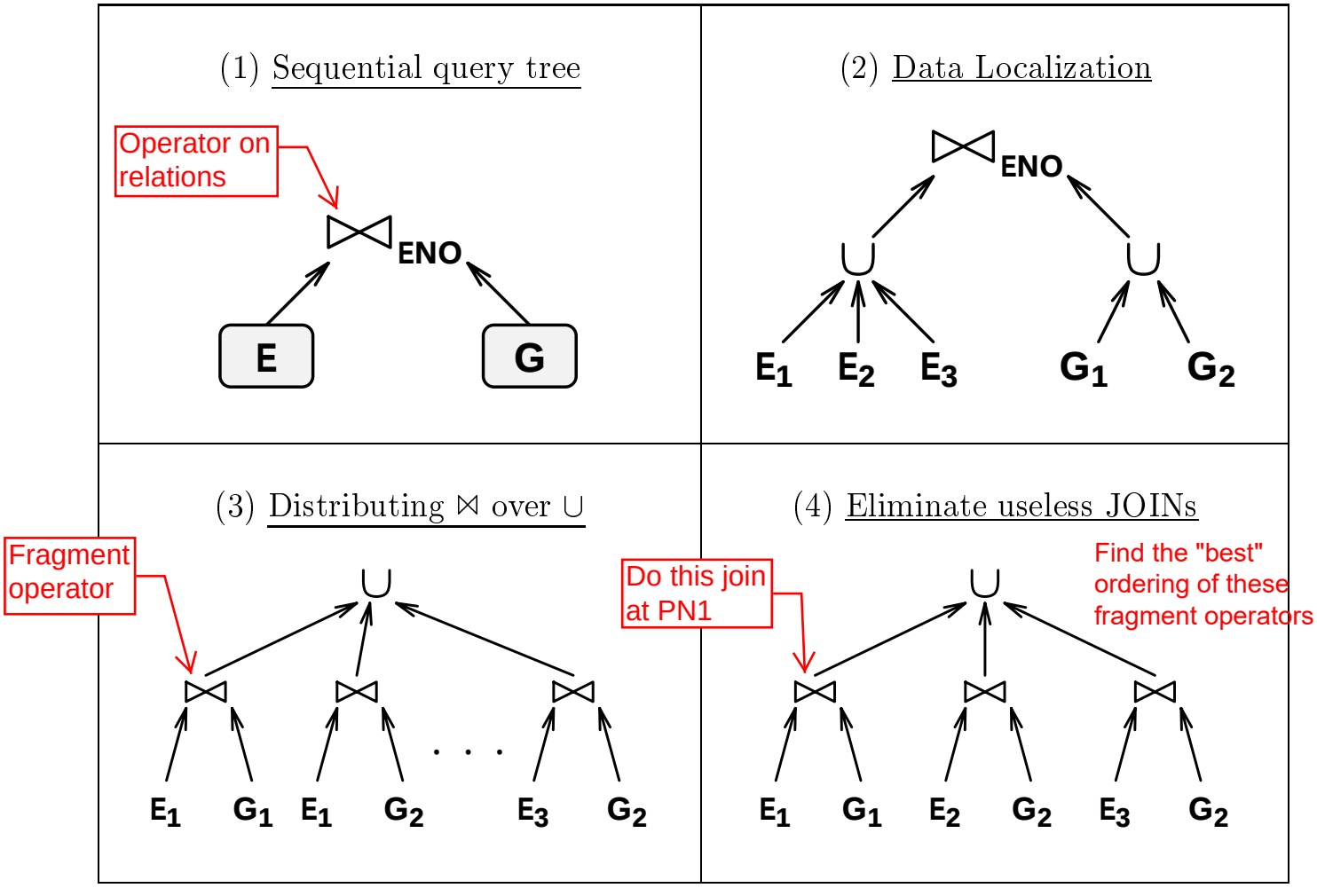
- Parallelizes the relational operators.
- Selects the best processing nodes for each parallelized relational operator.

Parallelizing Example

Fragments: (Range Partitioning)

$$E_1 = \sigma_{ENO \leq E3}(E) \qquad G_1 = \sigma_{ENO \leq E3}(G)$$
$$E_2 = \sigma_{E3 < ENO \leq E6}(E) \qquad G_2 = \sigma_{ENO > E3}(G)$$
$$E_3 = \sigma_{ENO > E6}(E)$$

Query : **SELECT** *
FROM E, G
WHERE E.ENO = G.ENO



(5) Select the best processing node for each fragment operator

Parallelizing Query Optimization

1. Determines which fragments are involved and transforms the global operators into fragment operators.

2. Eliminates useless fragment operators.

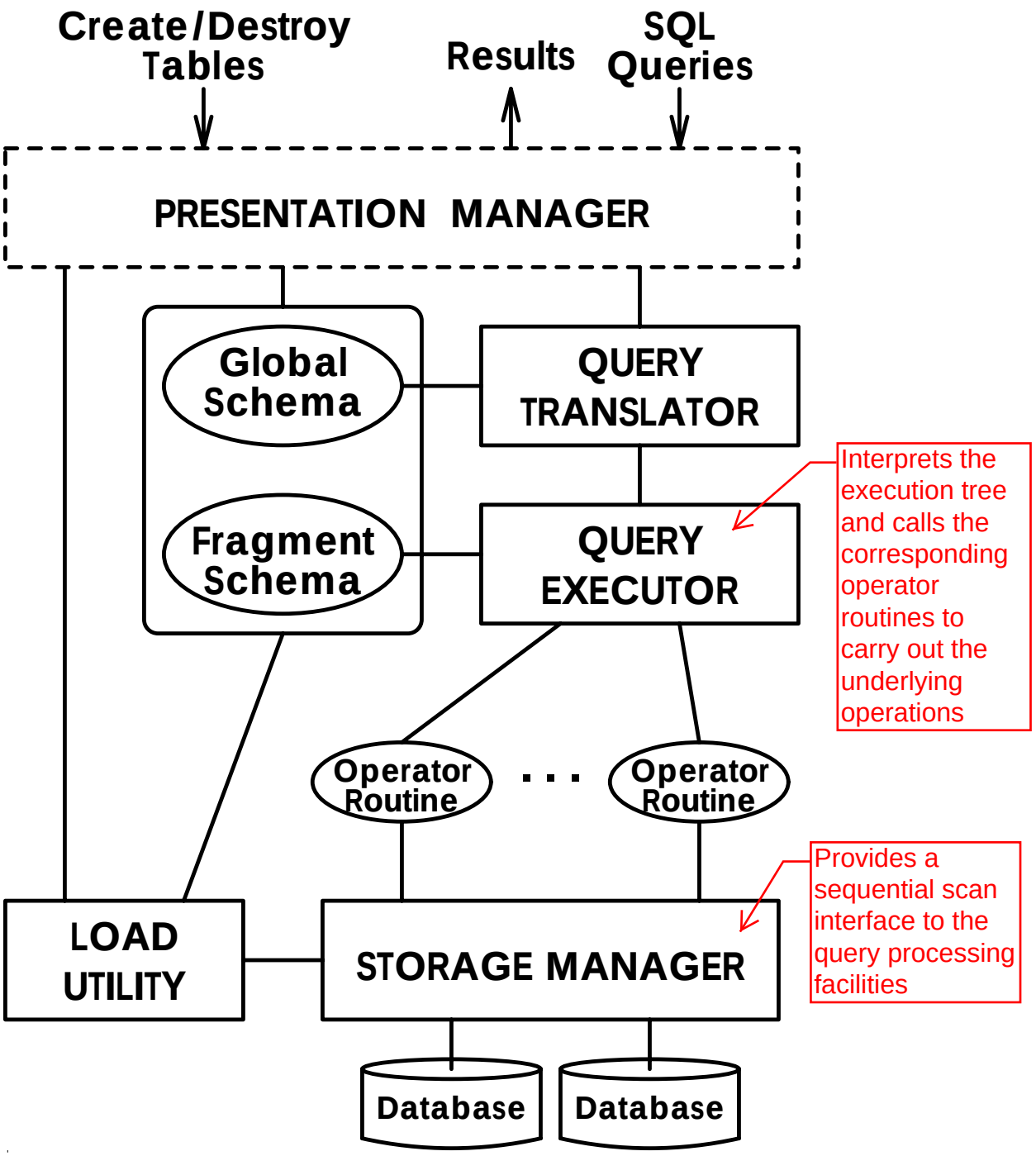
3. Finds the "best" ordering of the fragment operators.

4. Selects the best processing node for each fragment operator and specifies the communication operations.

Prototype at UCF

- A prototype of a shared-nothing system is implanted on a 64-processor nCUBE/2 computer
- Our system was implemented to demonstrate:
  - GeMDA multidimensional data partitioning technique,
  - Dynamic optimization scheme with load balancing capability, and
  - Competition-based scheduling policy

System Architecture

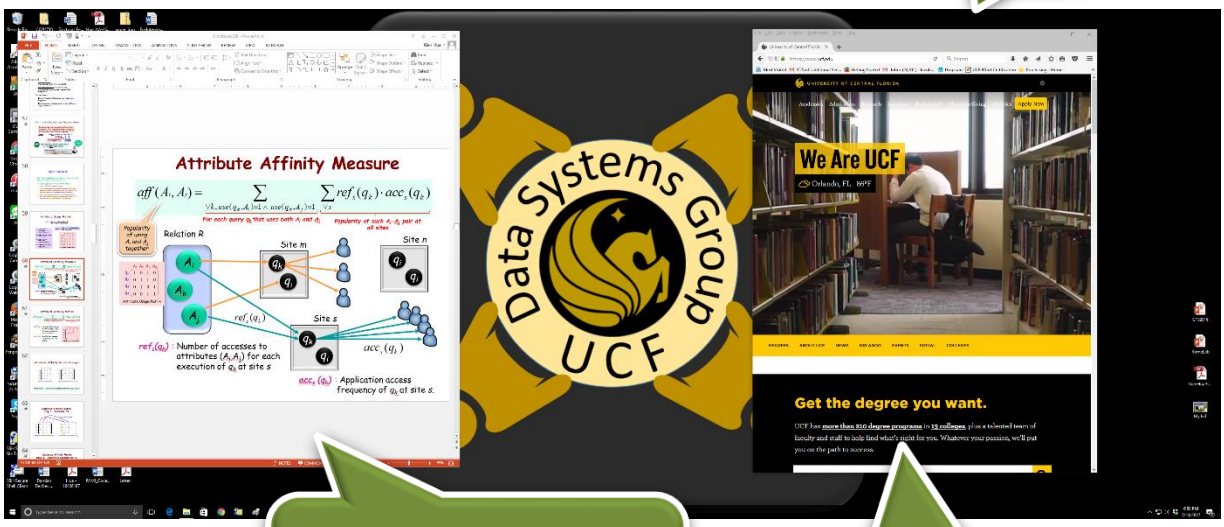


Software Componets

- **Storage Manager**: This component manages physical disk devices and schedules all I/O activities. It provides a sequential scan interface to the query processing facilities.
- **Catalog Manager**: It acts as a central repository of all global and fragment schemas.
- **Load Utility**: This program allows the users to populate a relation using an external file. It distributes the fragments of a relation across the processing nodes using GeMDA.
- **Query Translator**: This component provides an interface for queries. It translates an SQL query into a query graph. It also caches the global schema information locally.
- **Query Executor**: This component performs dynamic query optimization. It schedules the execution of the operators in the query graph.
- **Operator Routines**: Each routine implements a primitive database operator. To execute an operator in a query graph, the Query Executor calls the appropriate operator routine to carry out the underlying operation.
- **Presentation Manager**: This module provides an interactive interface for the user to create/destroy tables, and query the database. The user can also use this interface to browse query results.

Processes

Windows

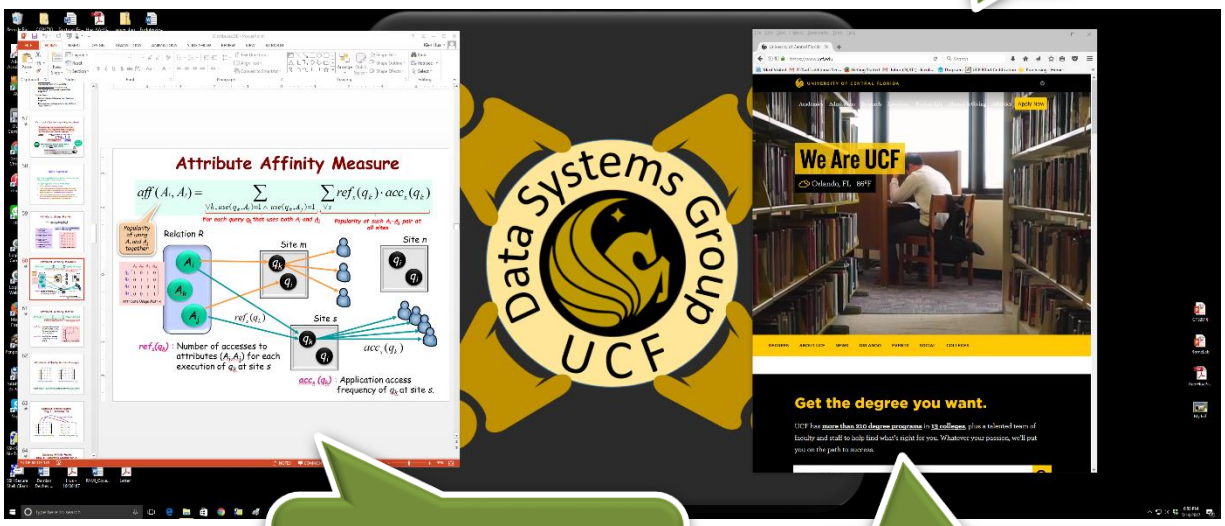


Process 1 runs “PowerPoint”

Process 2 runs a browser

Server Class

Windows



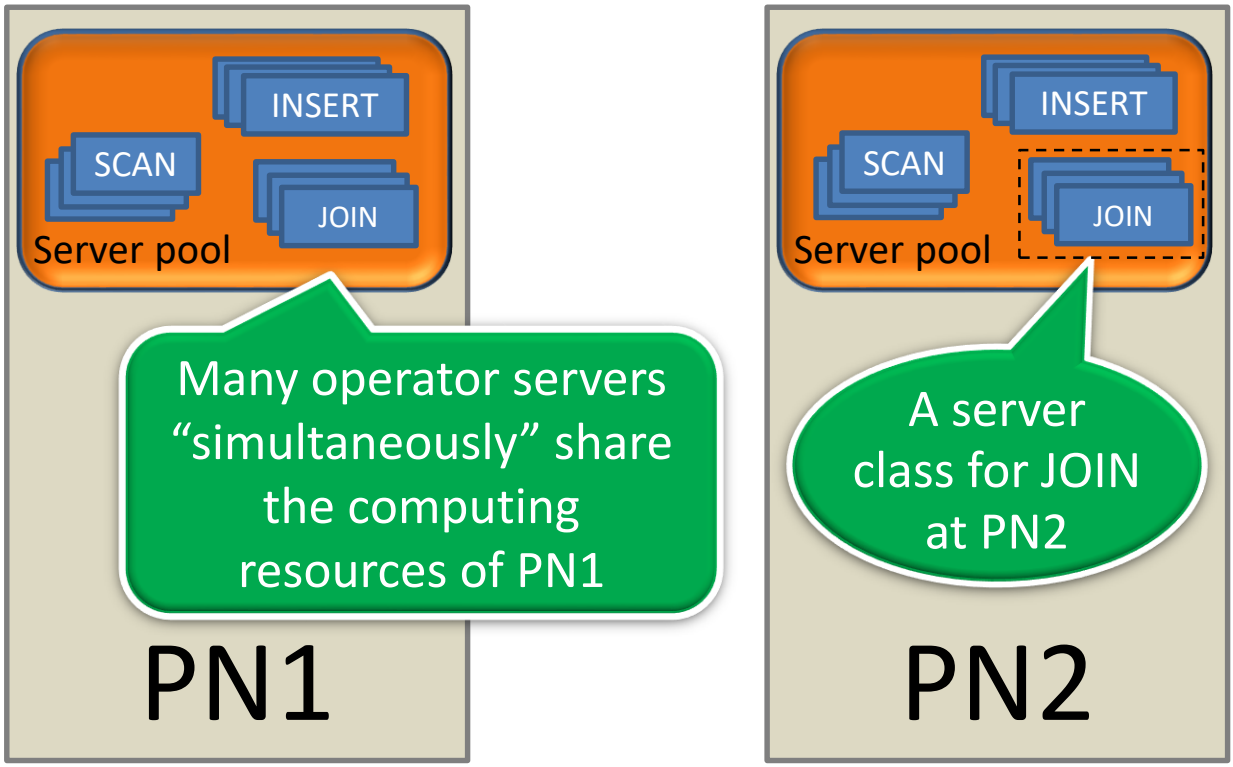
Process 1 runs "PowerPoint"

Process 2 runs a browser

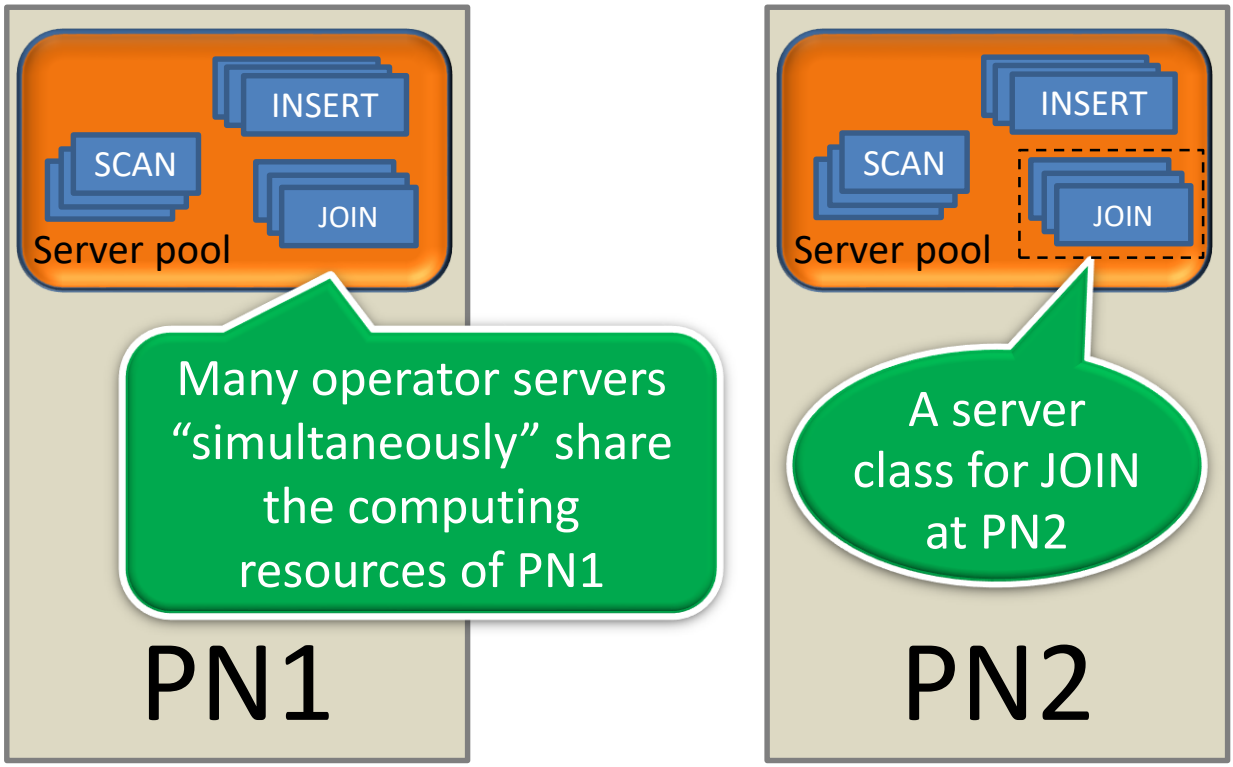
Server Class: A group of processes, each providing the same service (e.g., JOIN).

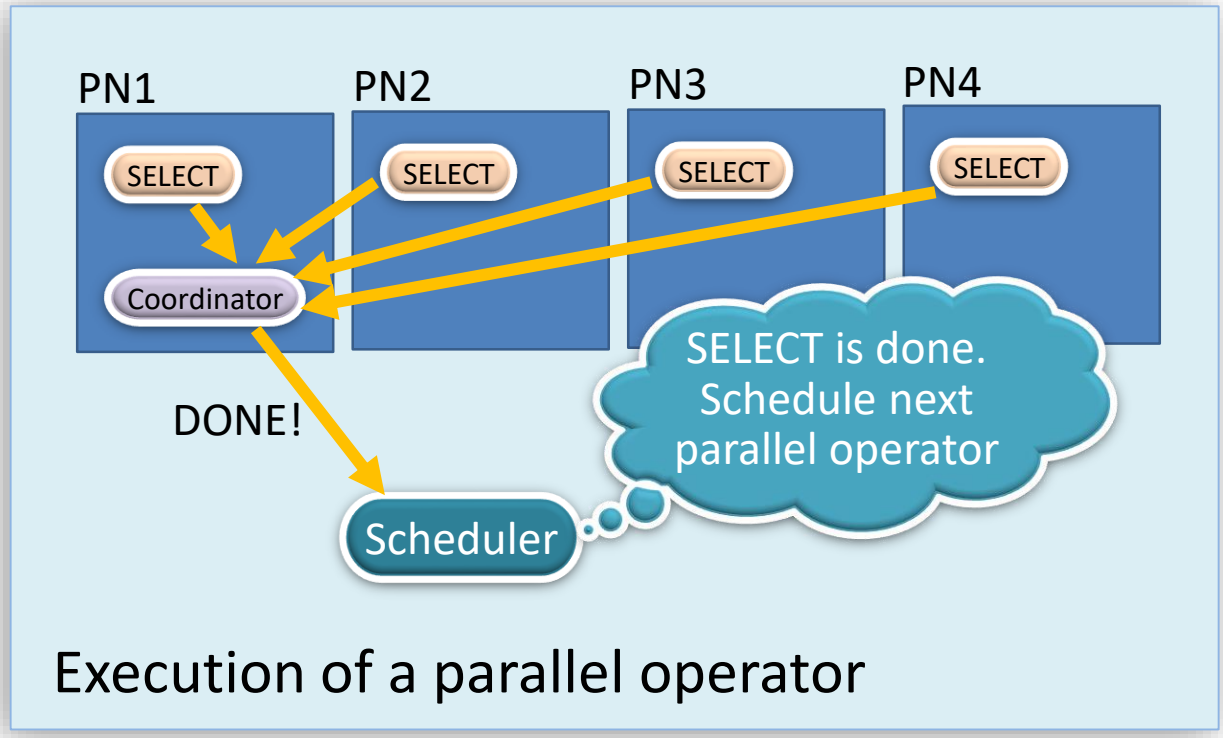
An operator server

Many Server Classes per PN

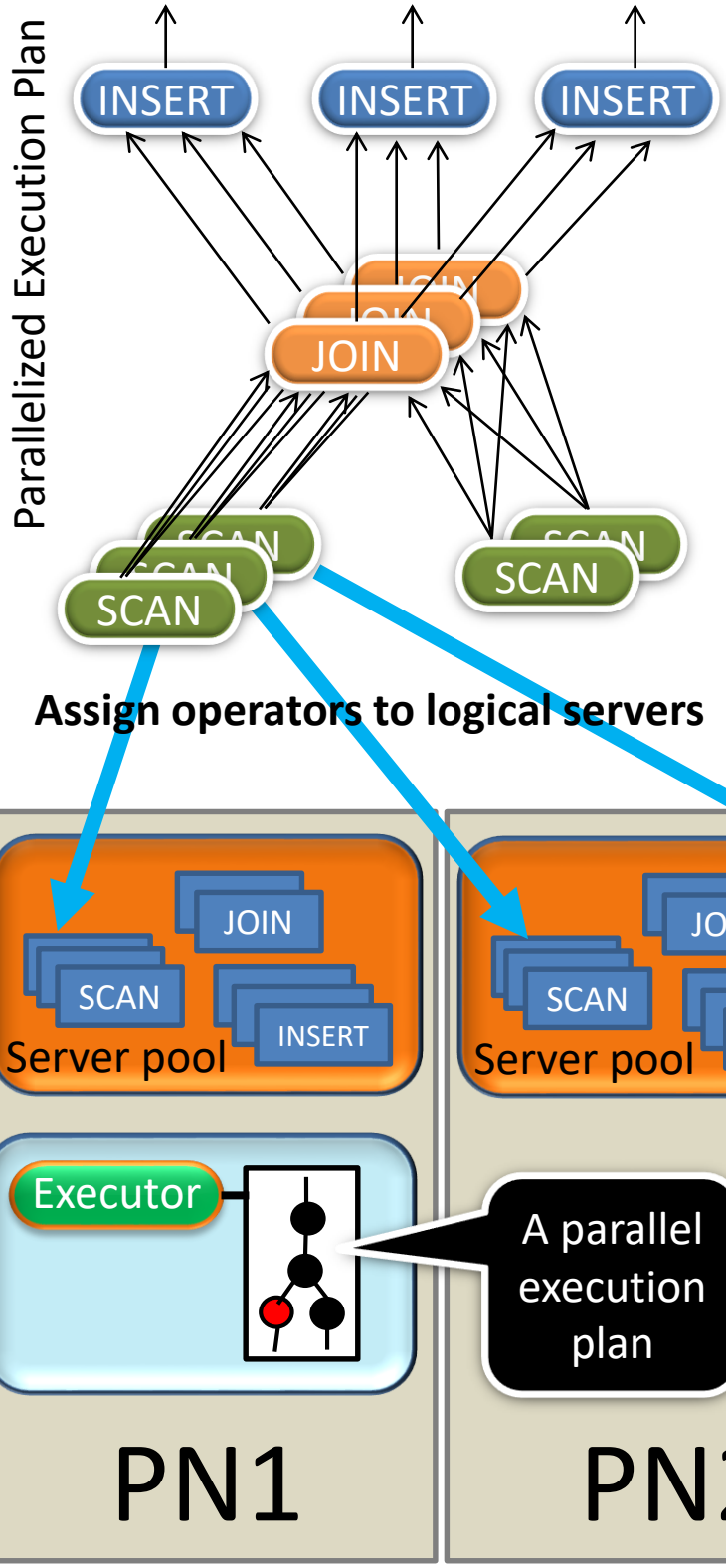


Parallel Processing





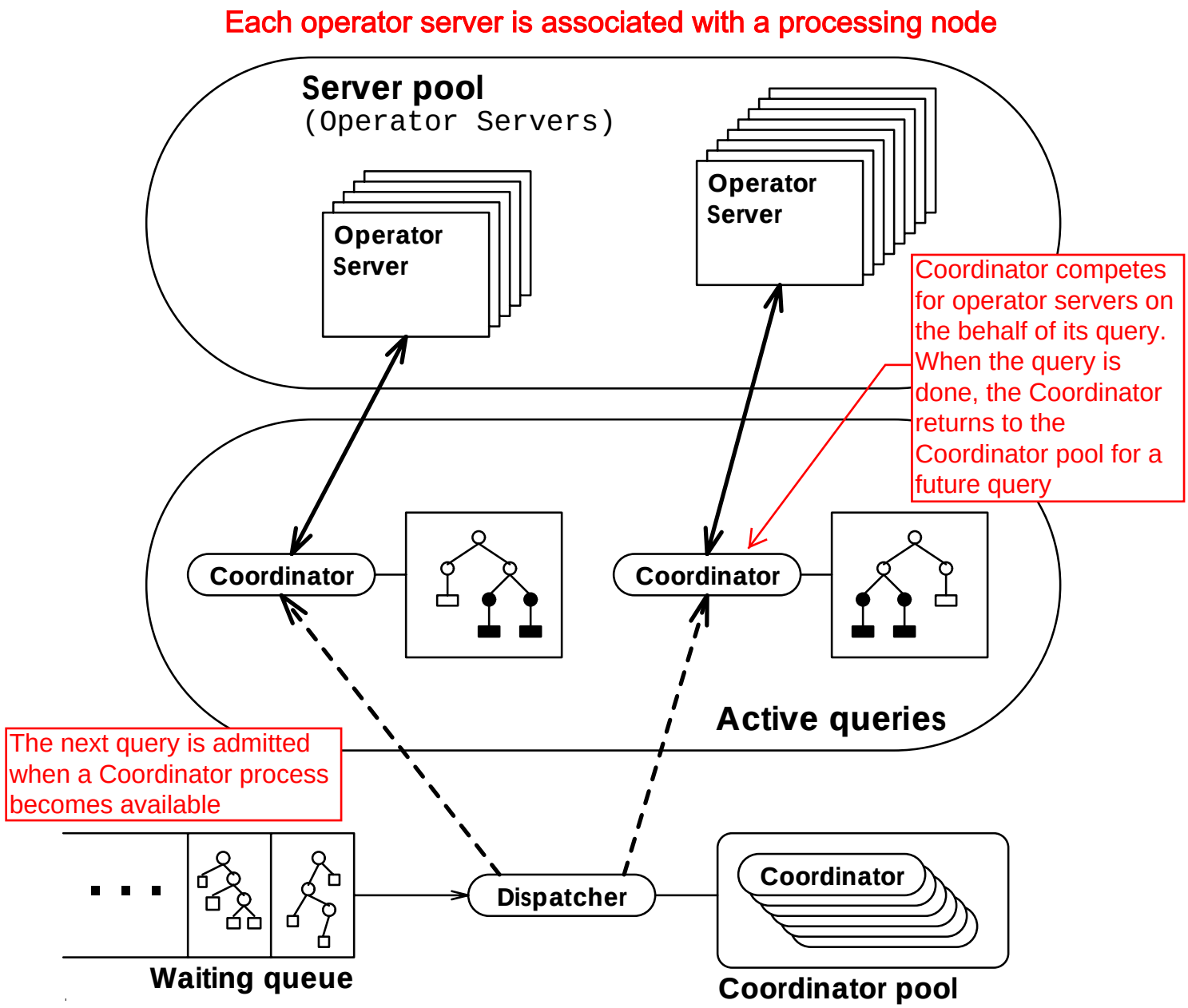
Execution of a parallel operator



Query Executor assigns operators in the *parallelized execution plan* to logical servers in the different server pools of the different PNs for parallel execution

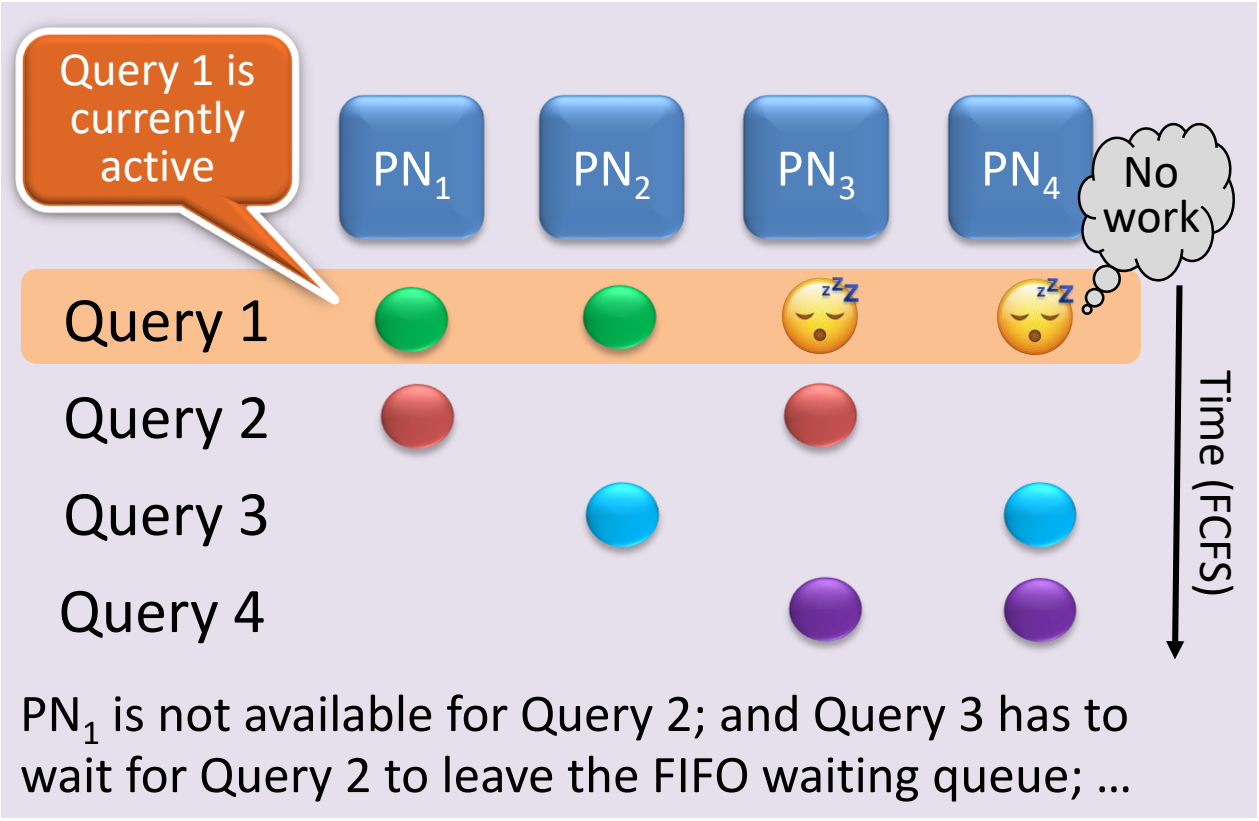
A logical server is software running in a process, capable of performing a certain basic database operation (e.g., INSERT)

Competition-Based Scheduling



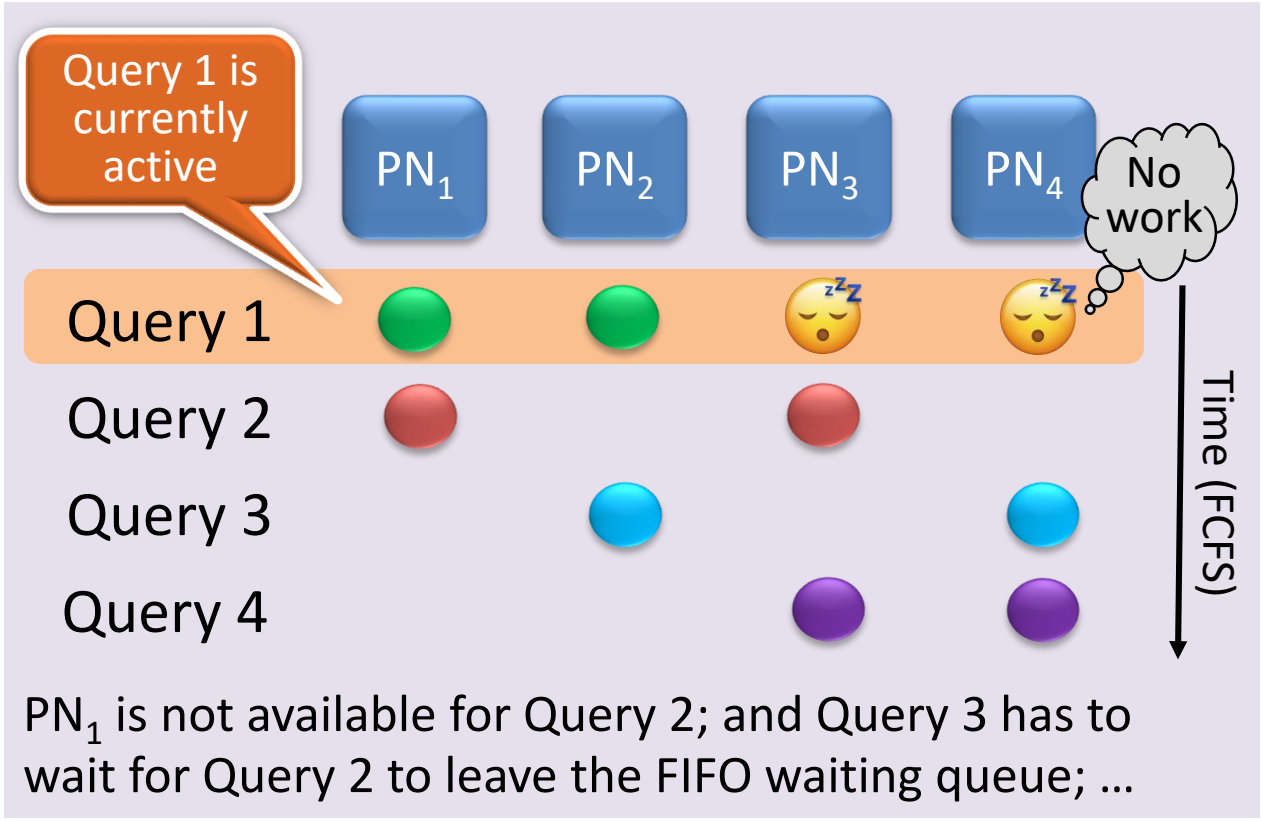
Advantage: Fair.
Disadvantage: System utilization is not maximized.

Competition-based: Potential drawbacks



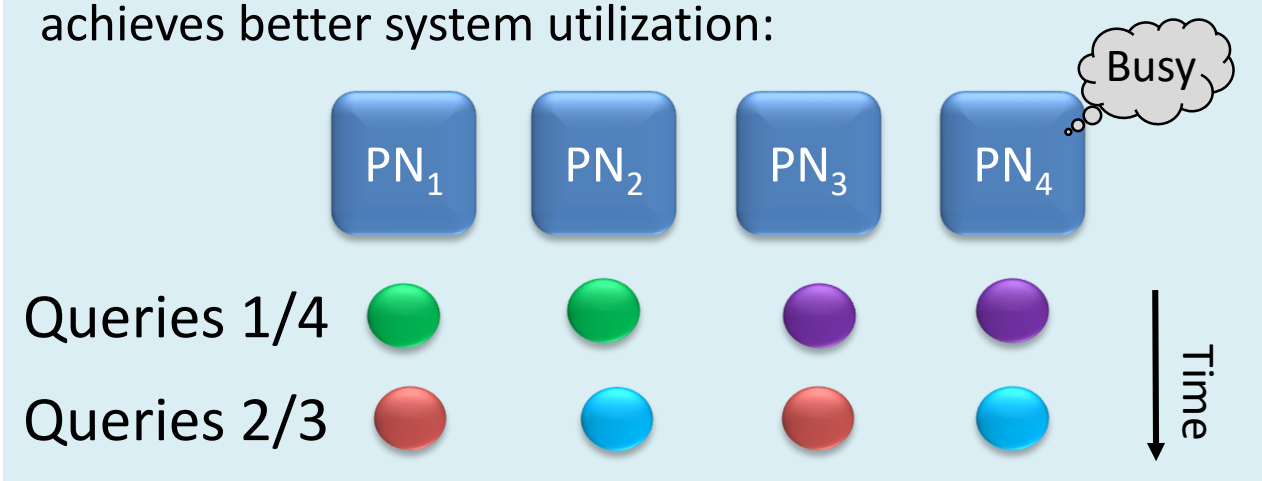
PN_1 is not available for Query 2; and Query 3 has to wait for Query 2 to leave the FIFO waiting queue; …

Competition-based: Potential drawbacks

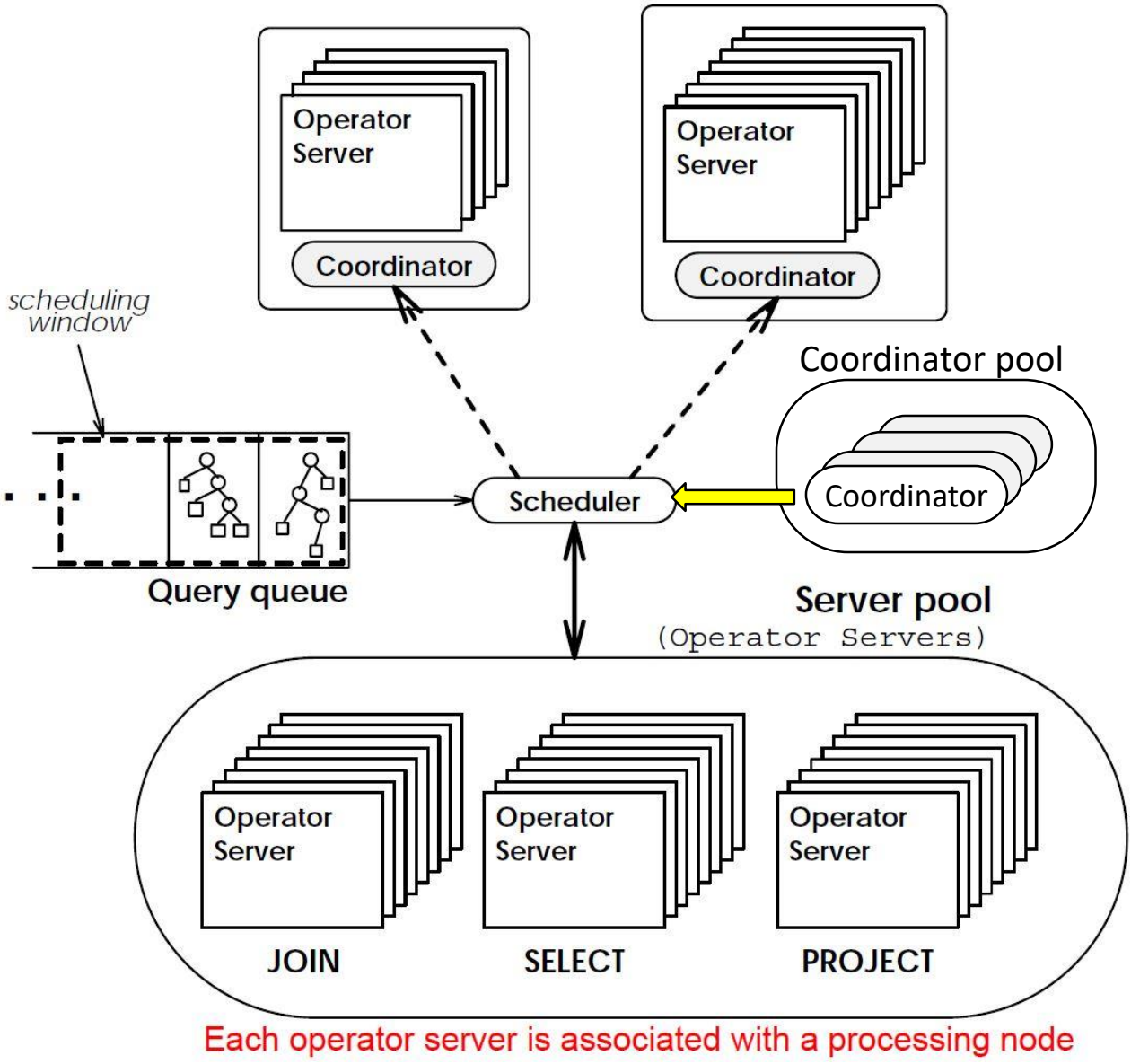


PN_1 is not available for Query 2; and Query 3 has to wait for Query 2 to leave the FIFO waiting queue; …

With some planning (vs. FCFS), the following schedule achieves better system utilization:

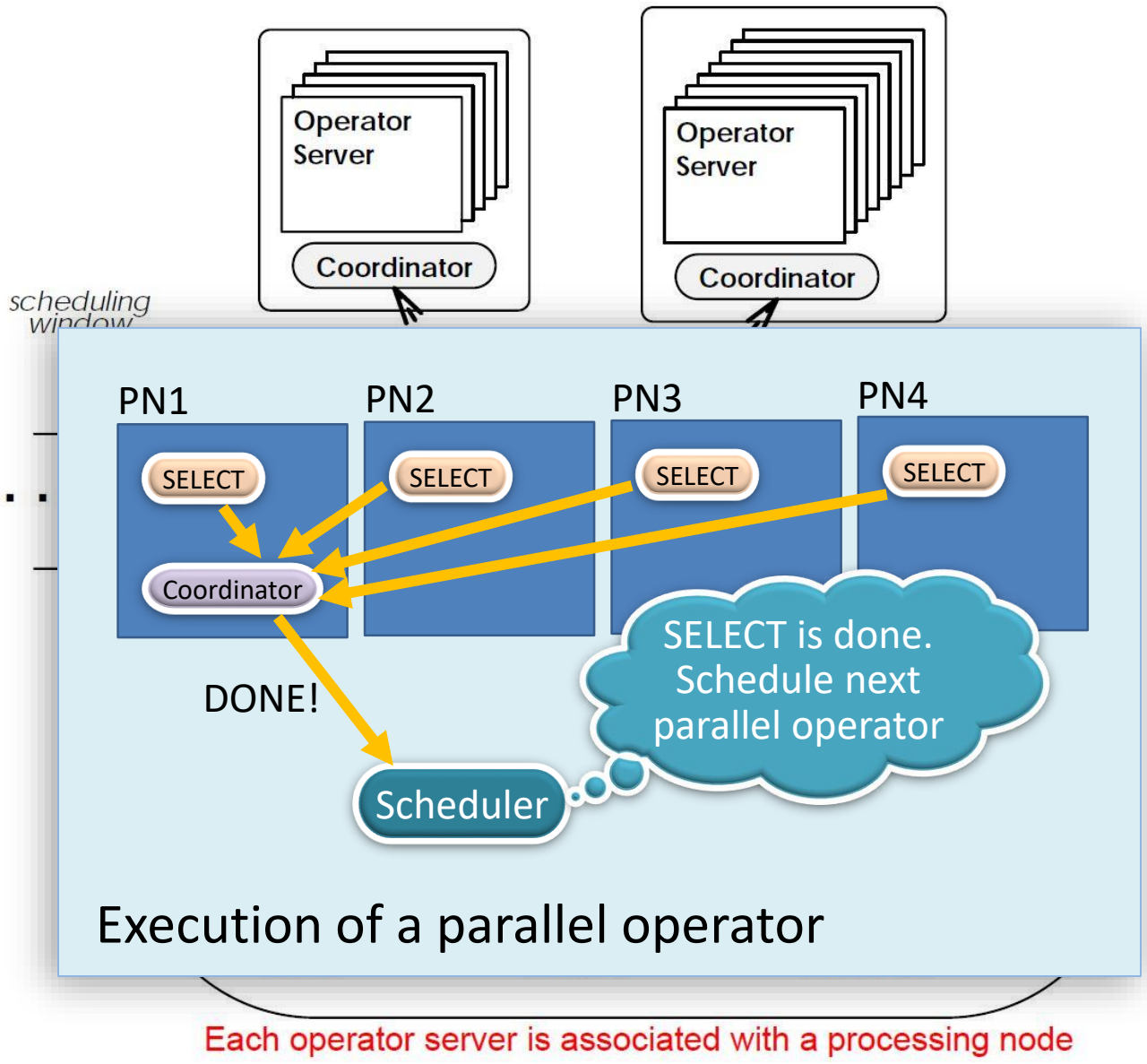


Planning-based Scheduling



- **Scheduler**: It plans and schedules the execution of operators from multiple queries currently within the scheduling window
- **Coordinator**: It coordinates the parallel execution of each query operator scheduled by the Scheduler

Planning-based Scheduling



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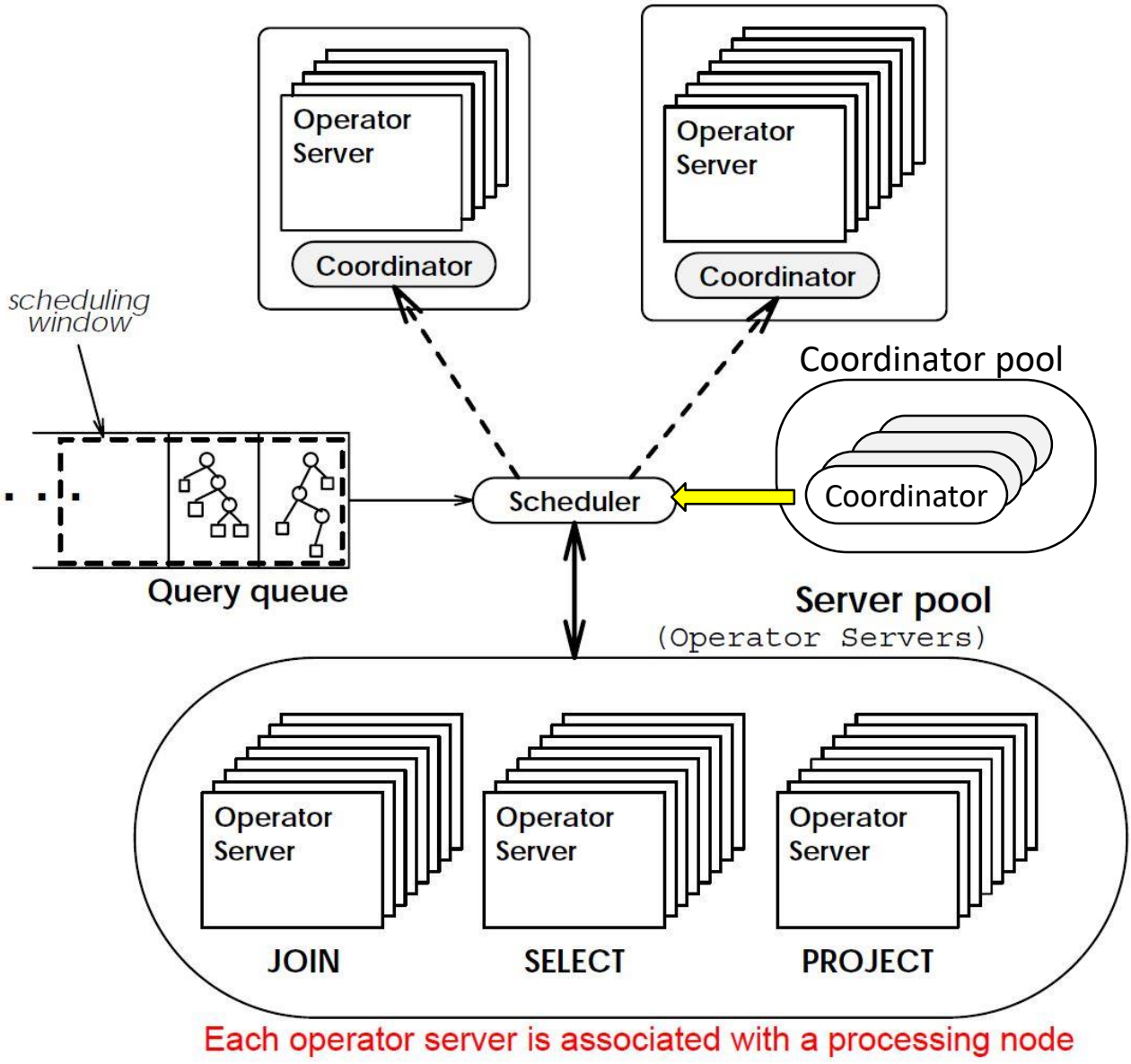
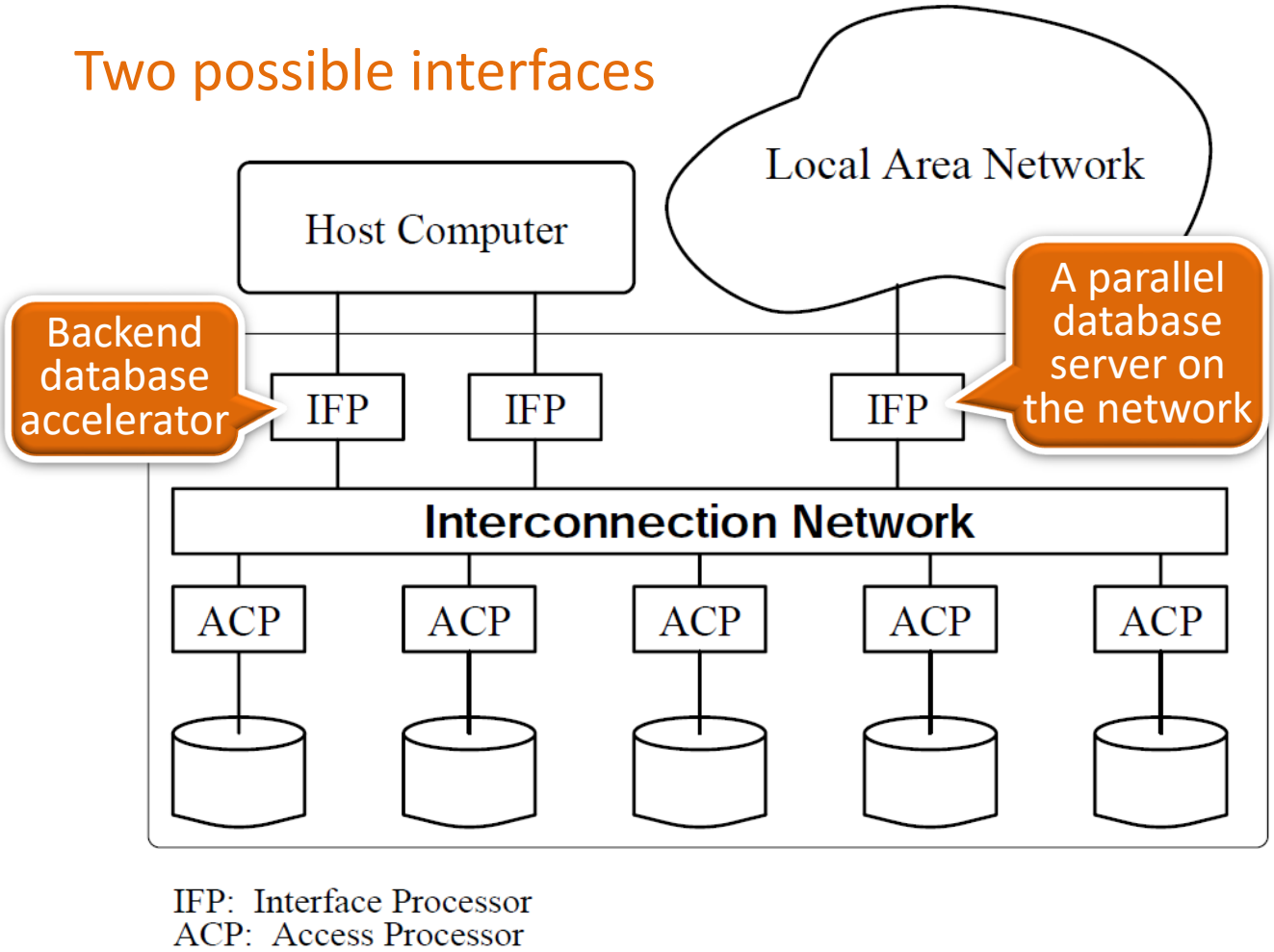


- Advantage: Better system utilization
- Disadvantage: Less fair

Hardware Organization

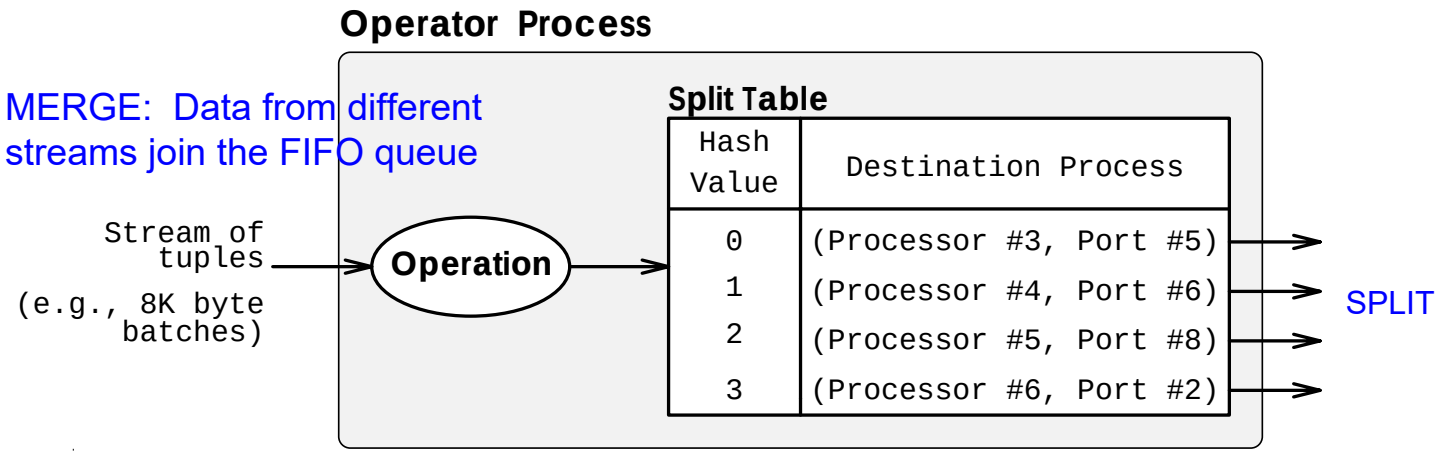
Two possible interfaces



IFP: Interface Processor
ACP: Access Processor

- Catalog Manager, Query Manager, and Scheduler processes run on IFP's
- Operator processes run on ACP's for parallel query computation

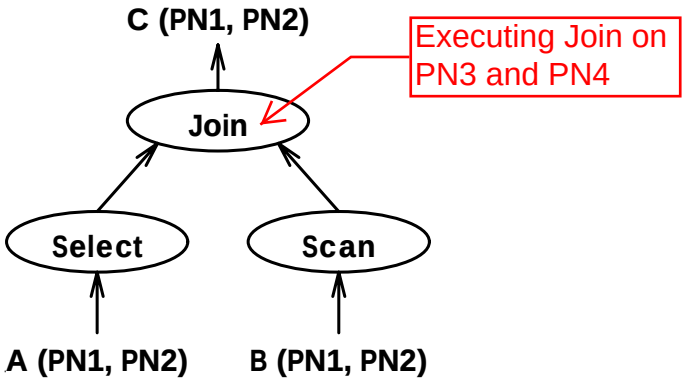
Structure of Operator Processes



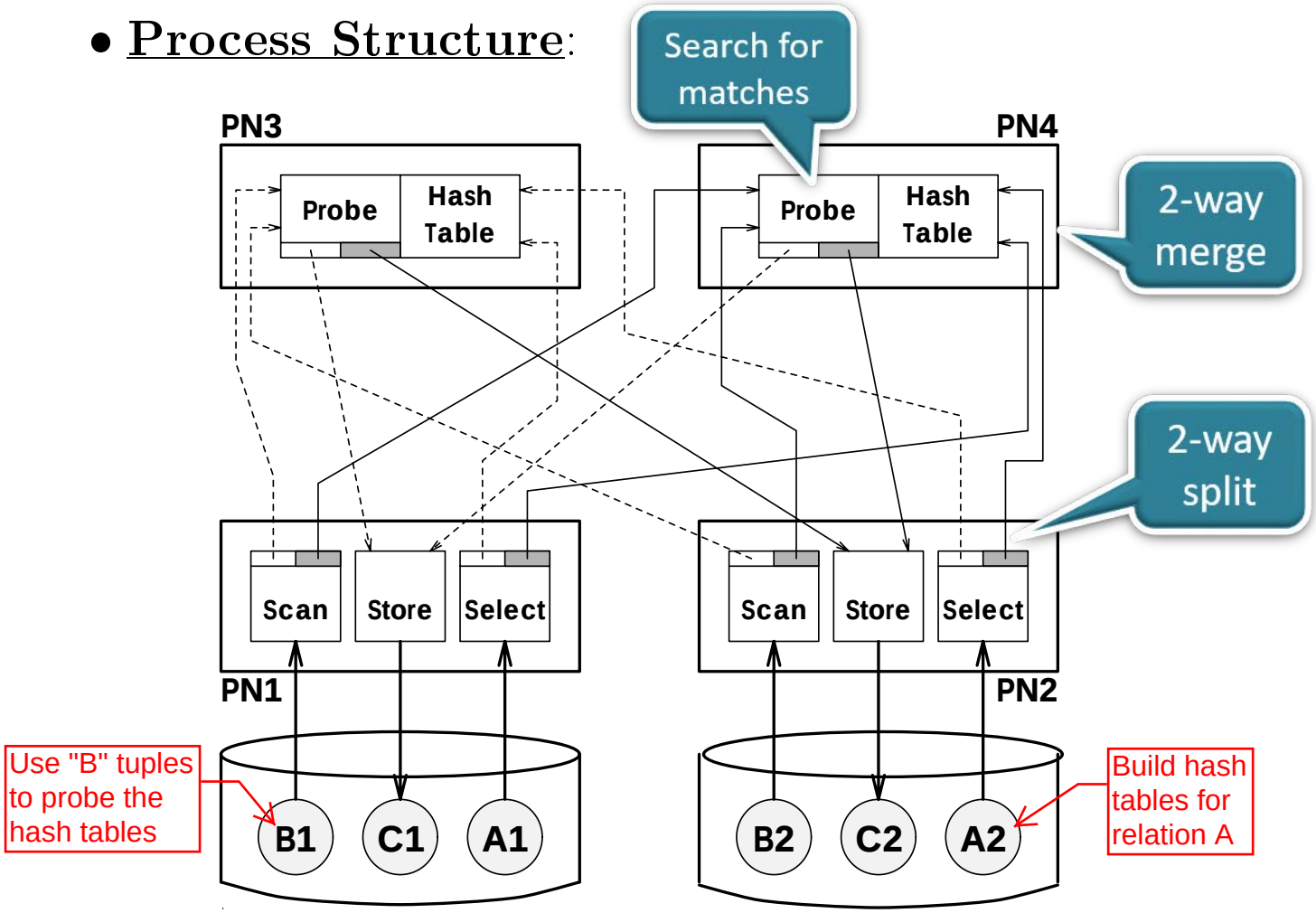
- The output is demultiplexed through a split table.
- When the process detects the end of its input stream,
  - it first closes the output streams and
  - then sends a control message to its coordinator process indicating that it has completed execution.

Example: Operator and Process Structure

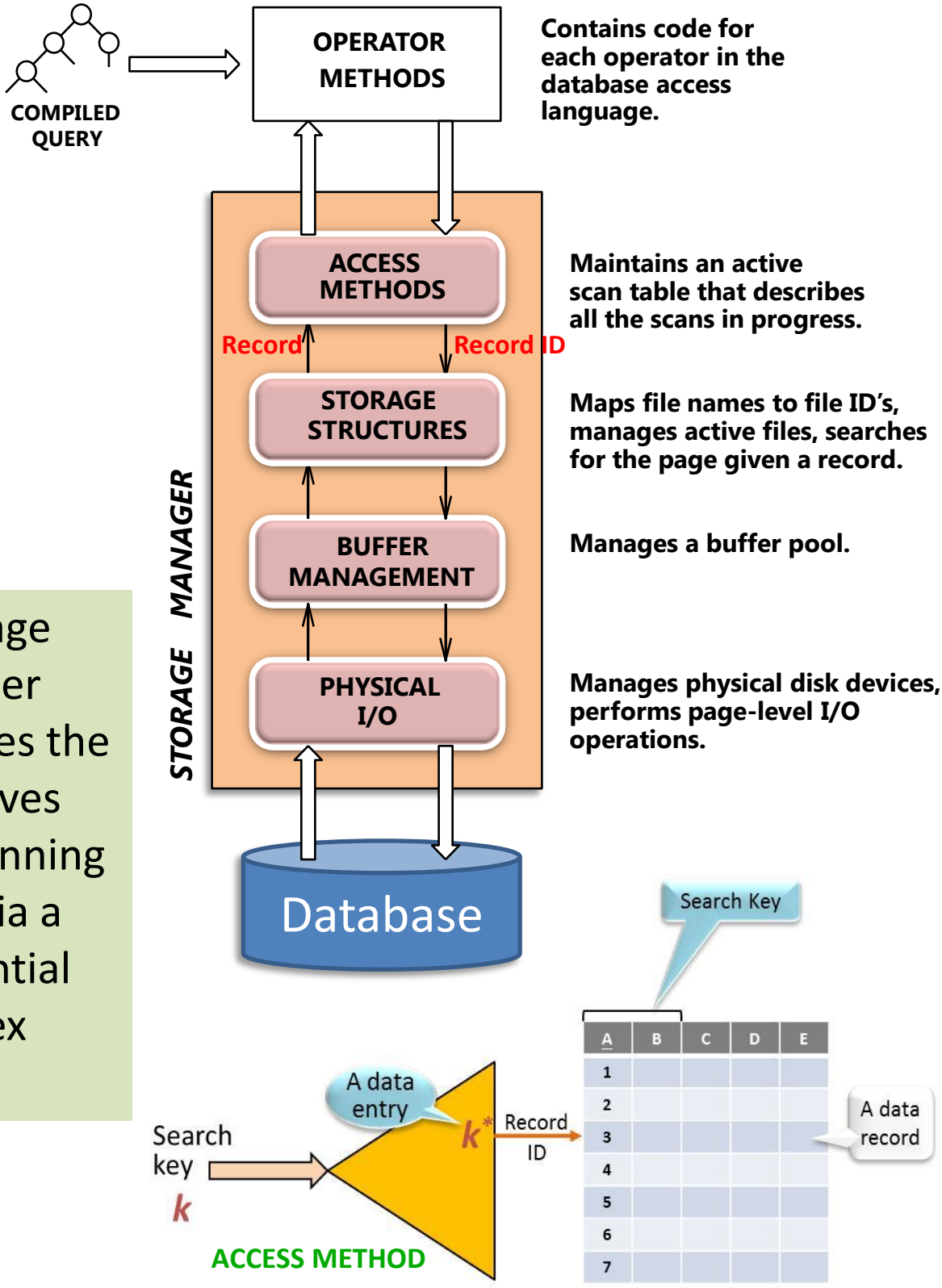
- **Query Tree**:



- **Process Structure**:



Storage Manager

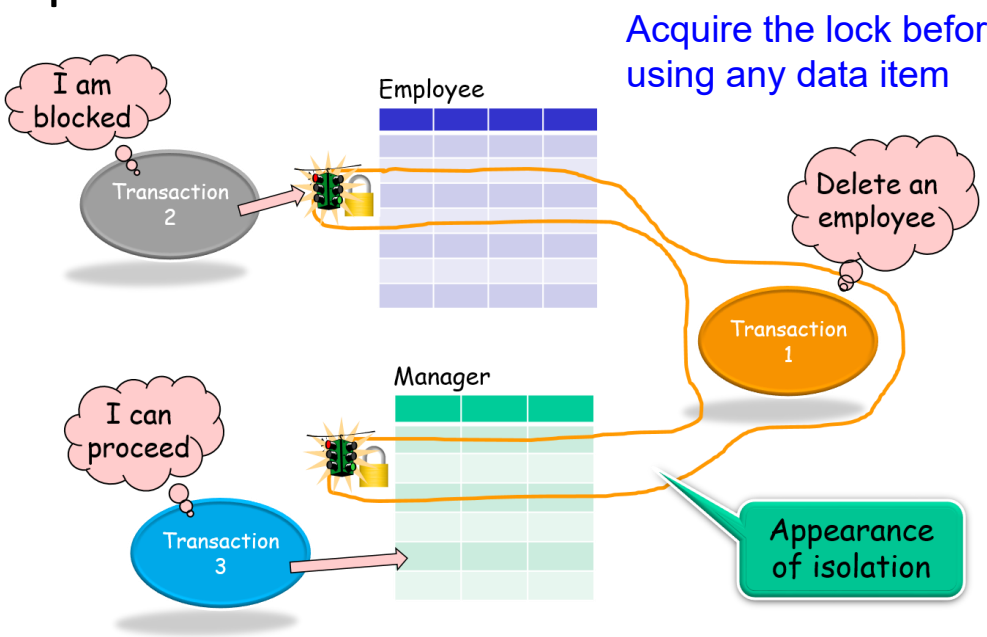


A storage manager provides the primitives for scanning a file via a sequential or index scan

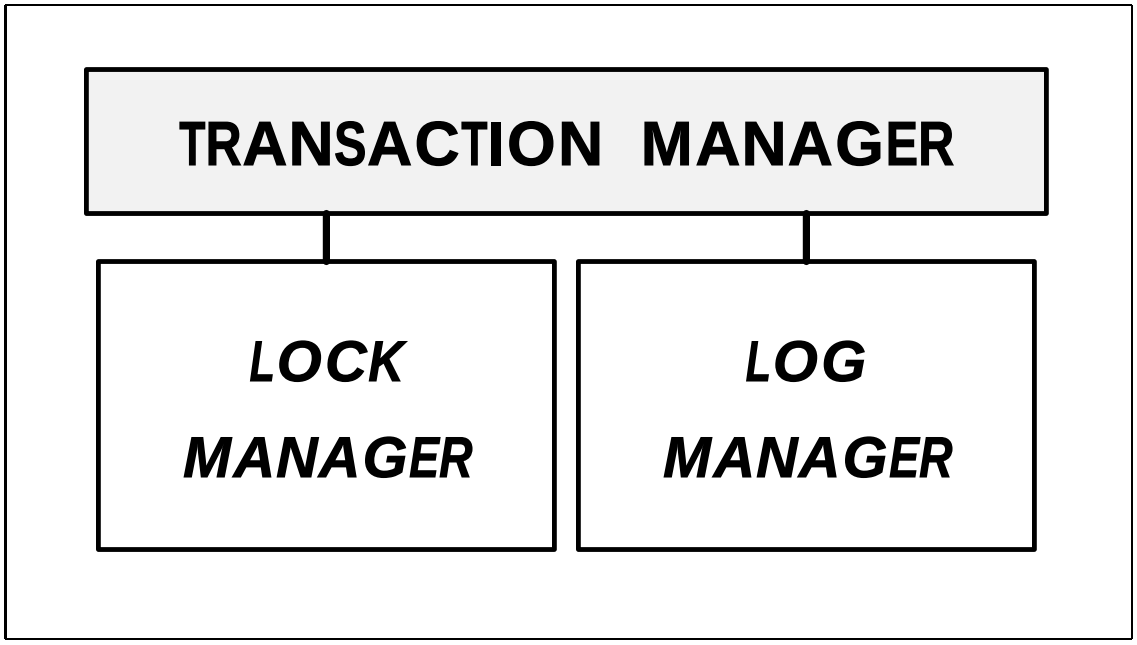
Transaction Processing

The consistency and reliability aspects of transactions are due to four properties

- **Atomicity**: A transaction is either performed in its entirety or not performed at all
- **Consistency**: A correct execution of the transaction must take the database from one consistent state to another
- **Isolation**: A transaction should not make its updates visible to other transaction until it is committed
- **Durability**: Once a transaction changes the database and changes are committed, these changes must never be lost because of subsequent failure



Transaction Manager

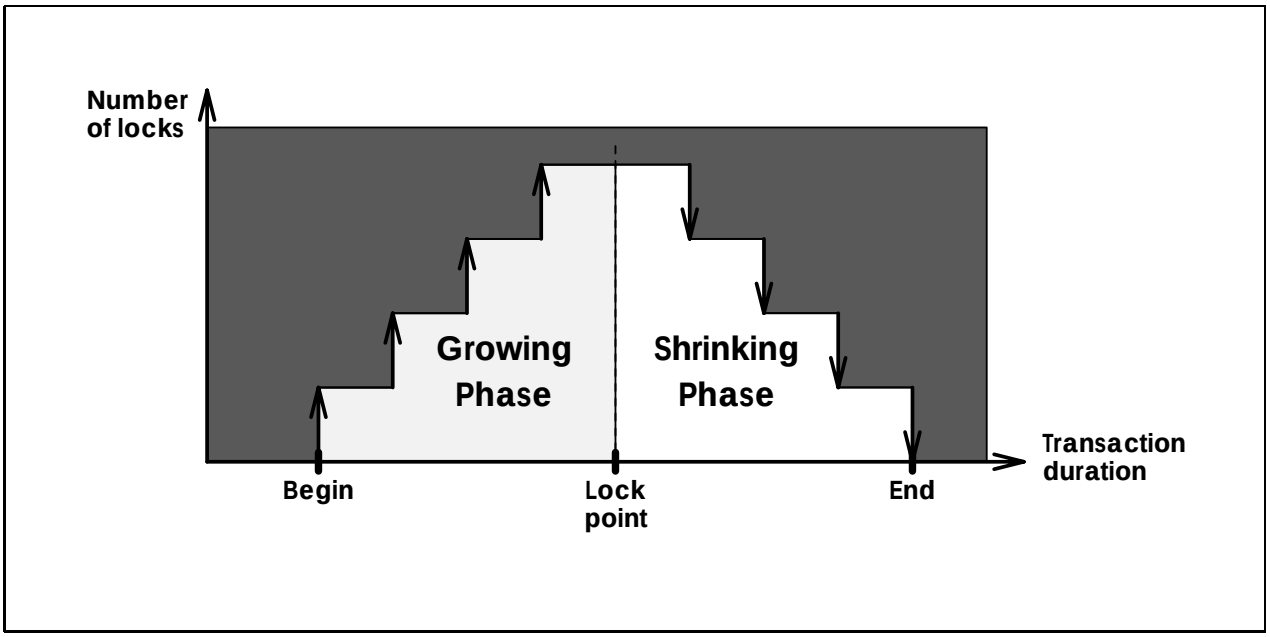


- **Lock Manager**:
  - Each local lock manager is responsible for the lock units local to that processing node.
  - They provide *concurrency control*.

Isolation property

- **Log Manager**:
  - Each local log manager logs the local database operations.
  - They provide *recovery services*.

Two-Phase Locking Protocol



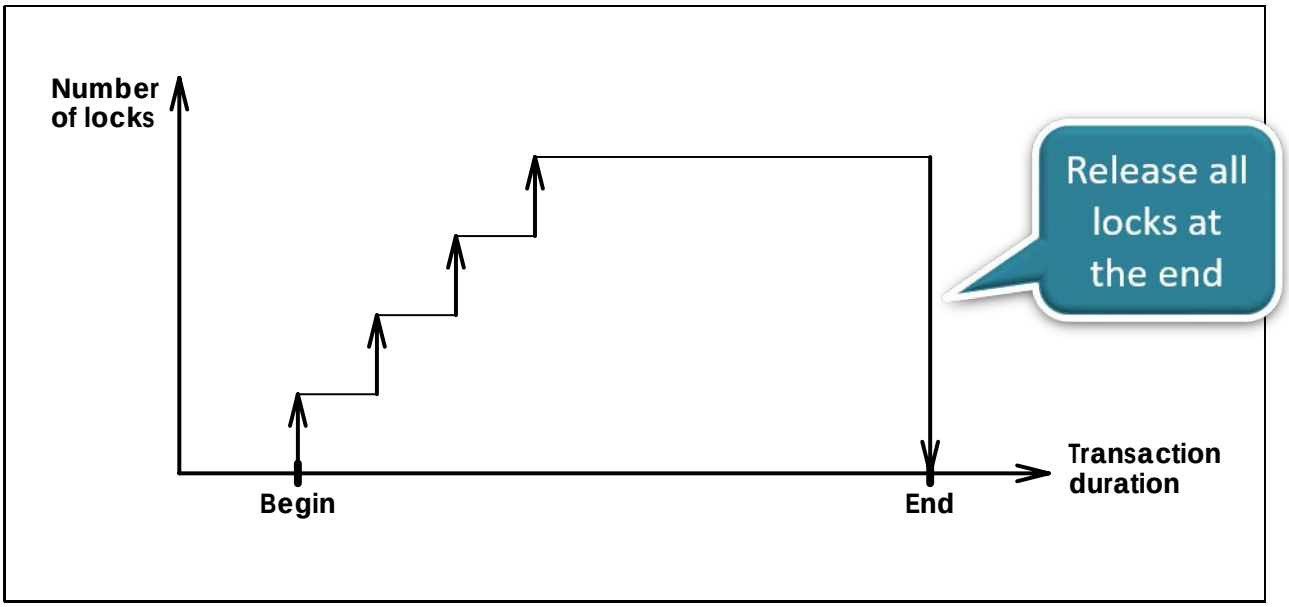
- Any *schedule* generated by a concurrency control algorithm that obeys the 2PL protocol is serializable (i.e., the isolation property is guaranteed).

- 2PL is difficult to implement. The lock manager has to know:

  1. the transaction has obtained all its locks, and
  2. the transaction no longer needs to access the data item in question. (so that the lock can be released).

- Cascading aborts can occur.
  (because transactions reveal updates before they commit)

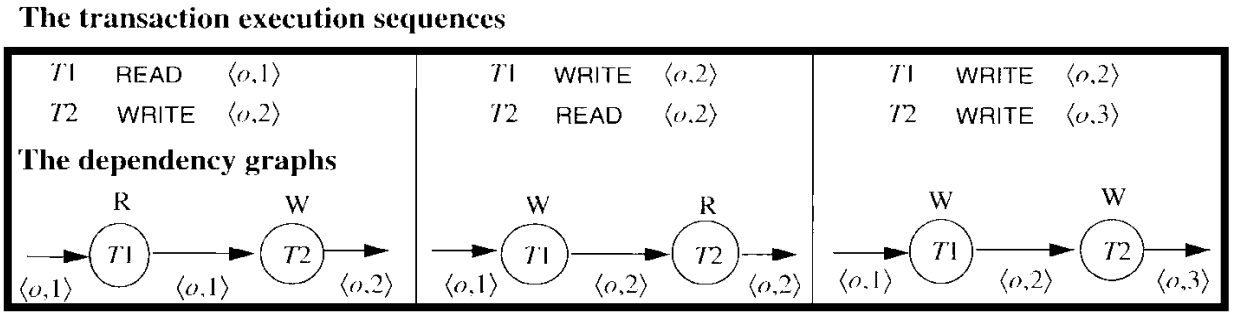
Strict Two-Phase Locking Protocol



The lock manager releases all the locks together when the transaction terminates (commits or aborts).

Wait-for Graph

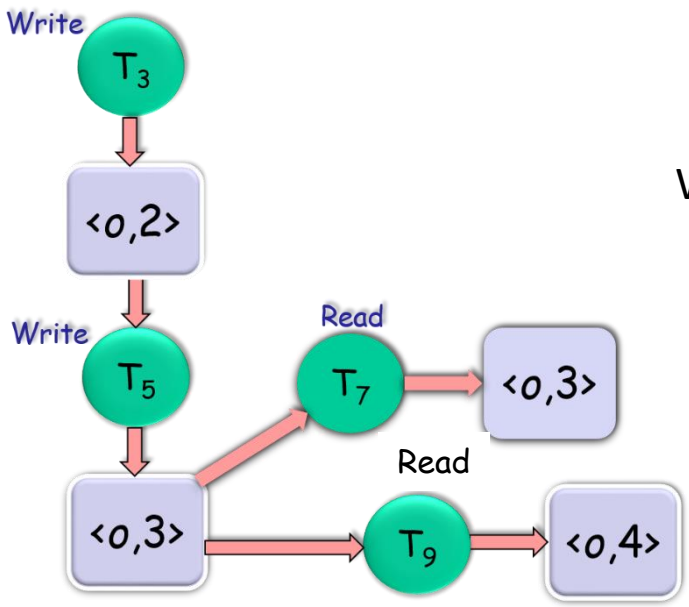
- If a transaction reads an object, the transaction depends on that object version
- If the transaction writes an object, the resulting object version depends on the writing transaction.

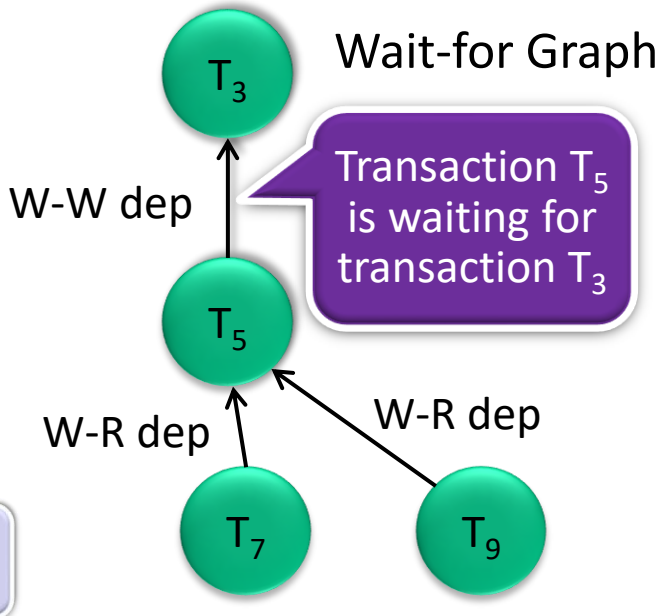


READ → WRITE dependency

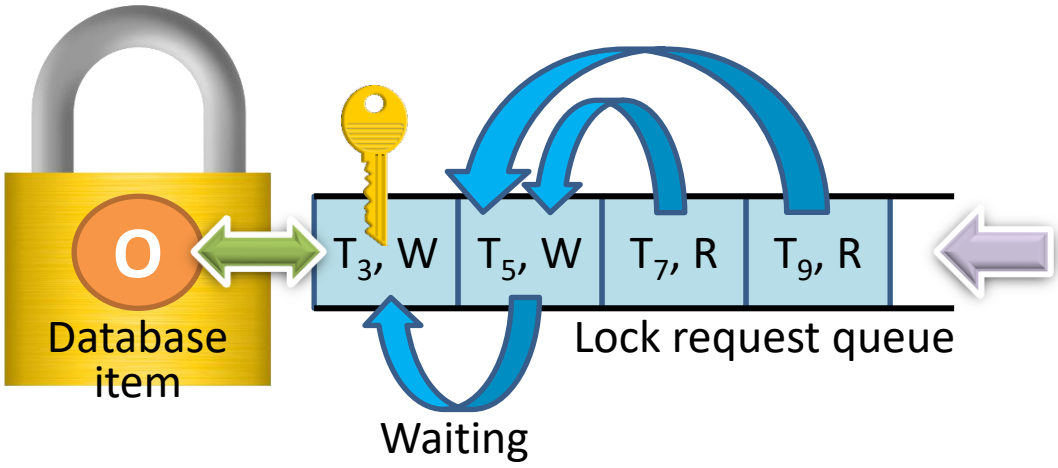
WRITE → READ dependency

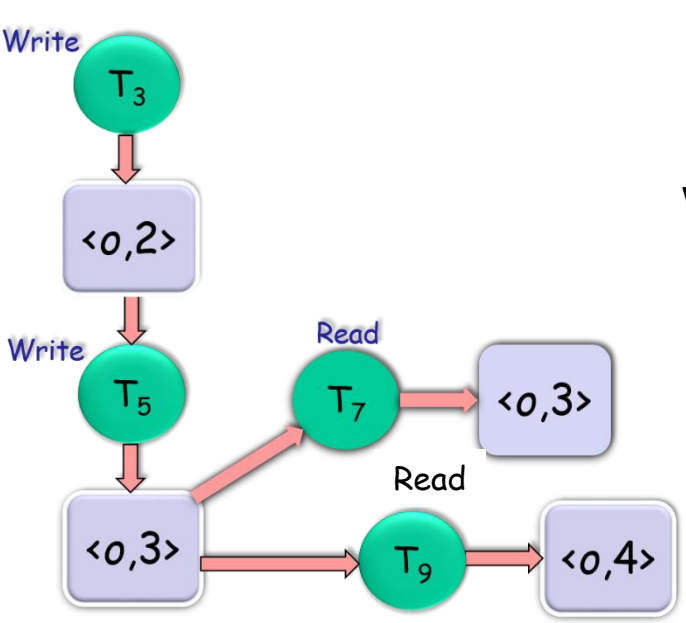
WRITE → WRITE dependency

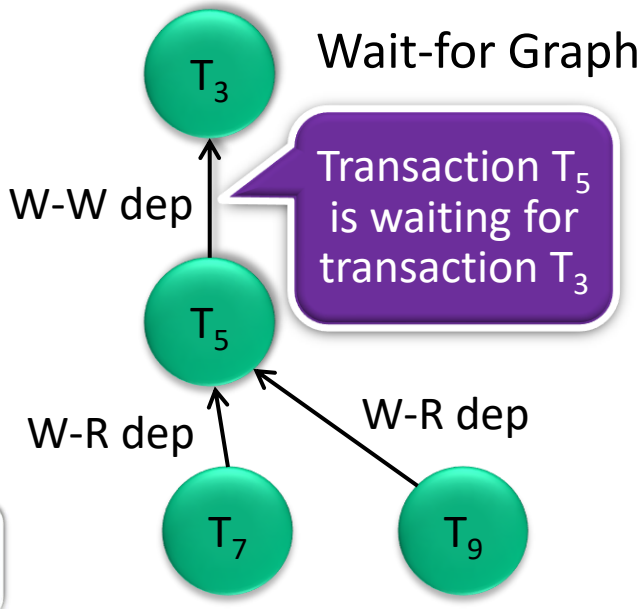




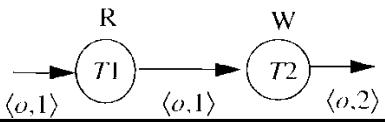
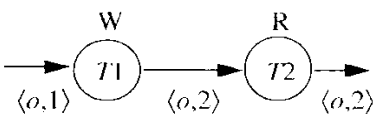
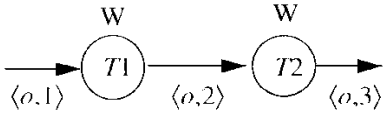
Implementation







The transaction execution sequences

T1 READ ⟨o,1⟩ T2 WRITE ⟨o,2⟩	T1 WRITE ⟨o,2⟩ T2 READ ⟨o,2⟩	T1 WRITE ⟨o,2⟩ T2 WRITE ⟨o,3⟩
The dependency graphs		
		
READ → WRITE dependency	WRITE → READ dependency	WRITE → WRITE dependency

Handling Deadlocks

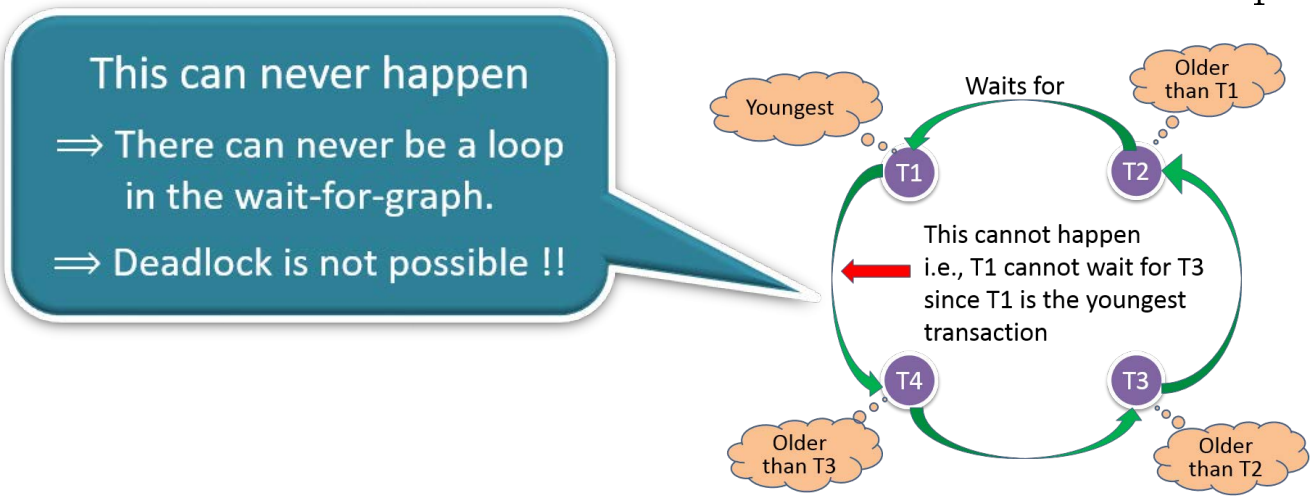
- **Detection and Resolution**:
  - Abort and restart a transaction if it has waited for a lock for a long time.
  - Detect cycles in the wait-for graph and select a transaction (involved in a cycle) to abort.

- **Prevention**:

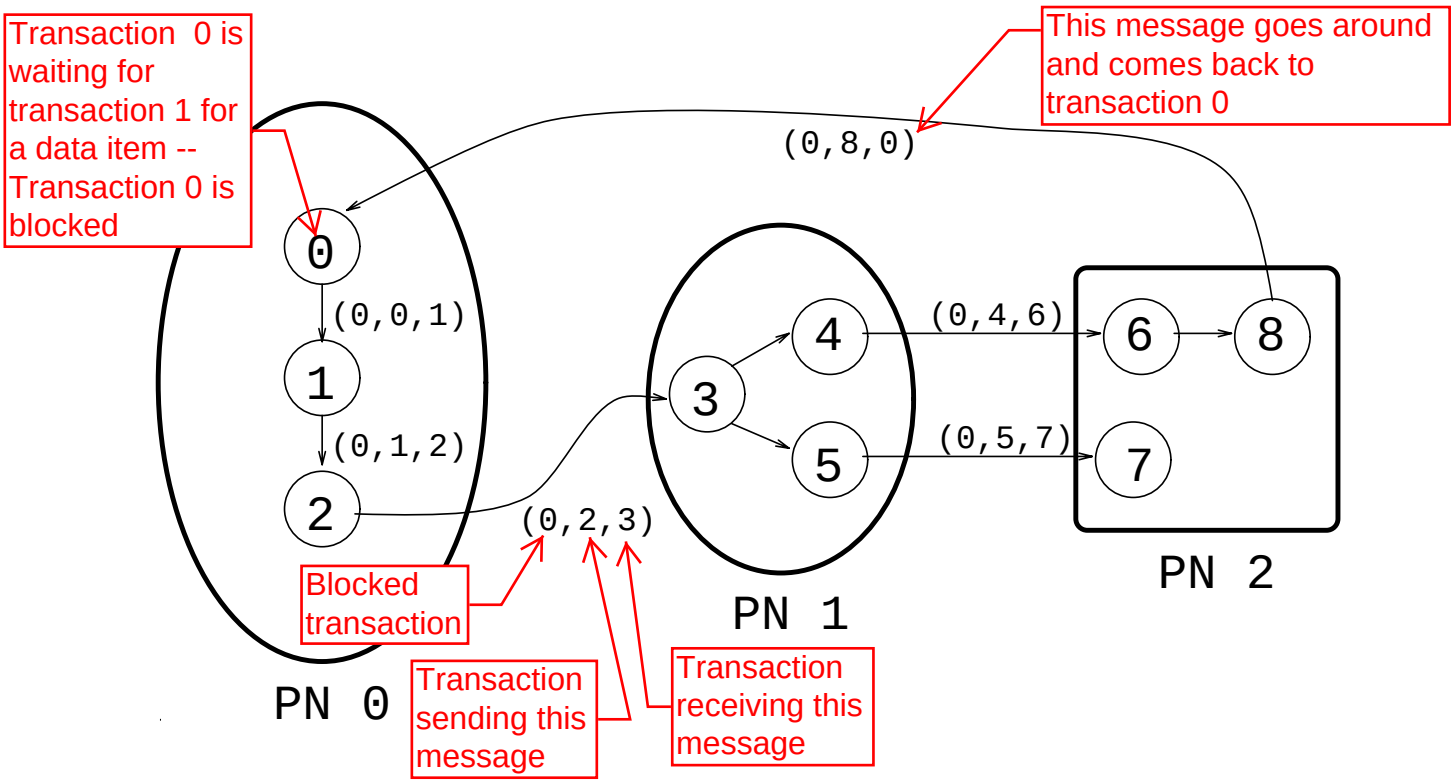
  If T_i requires a lock held by T_j,

  $\star$ If T_i is older $\Longrightarrow$ T_i can wait.

  $\star$ If T_i is younger $\Longrightarrow$ T_i is aborted and restarted with the same timestamp.



Distributed Deadlock Detection



- When a transaction is blocked, it sends a special probe message to the blocking transaction.

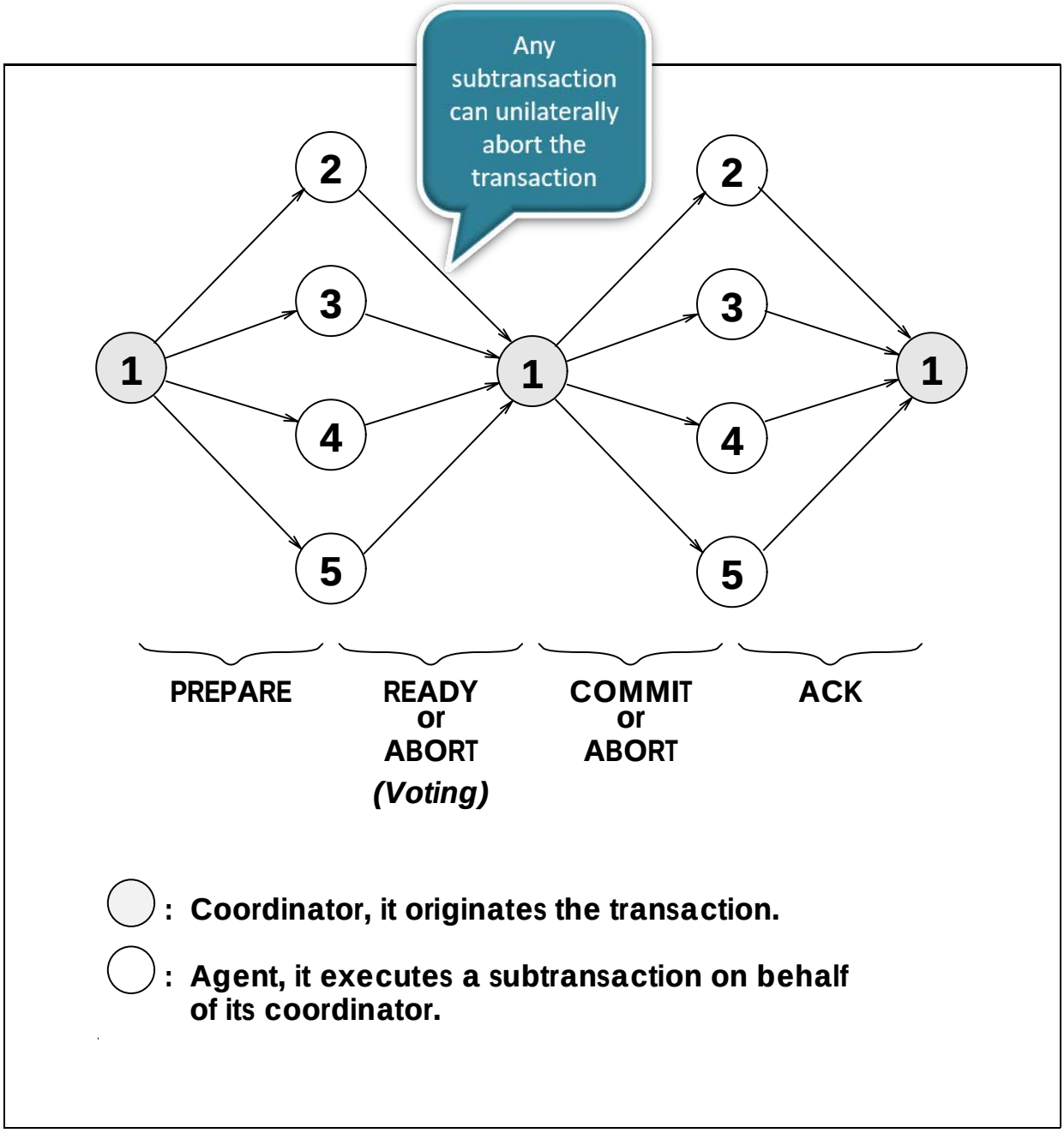
  The message consists of three numbers: the transaction that just blocked, the transaction sending the message, and the transaction to whom it is being sent.

- When the message arrives, the recipient checks to see if it itself is waiting for any transaction. If so, the message is updated, replacing the second field by its own TID and the third one by the TID of the transaction it is waiting for. The message is then sent to the blocking transaction.

- If a message goes all the way around and come back to the original sender, a deadlock is detected.

Two-Phase Commit Protocol

To ensure the atomicity property, a 2P commit protocol can be used to coordinate the commit process among subtransactions.



Recovery

- An entry is made in the local log file at a processing node each time one of the following commands is issued by a transaction:
  - begin transaction
  - write (insert, delete, update)
  - commit transaction
  - abort transaction

Record the current and the new values of the data record being updated

- Write-ahead log protocol:
  - It is essential that log records be written before the corresponding write to the database.

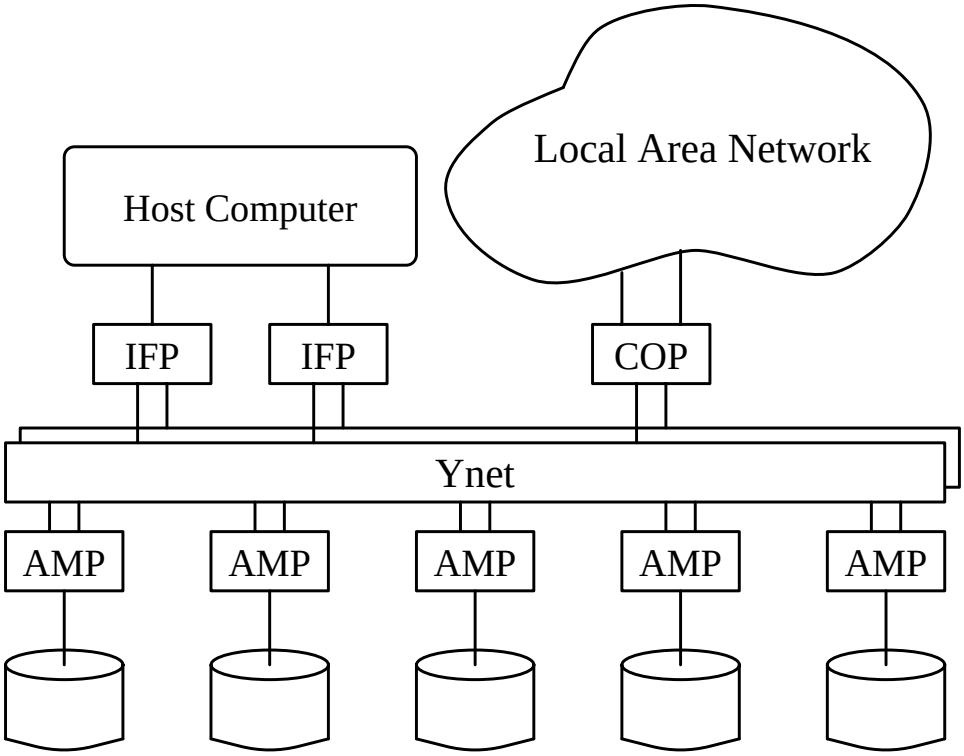
An entry in the log file

If log entry wasn't saved before the crash, corresponding change was not applied to database!

  - If there is no commit transaction entry in the log for a particular transaction, then that transaction was still active at the time of failure and must therefore be undone.

This is to ensure the atomicity property

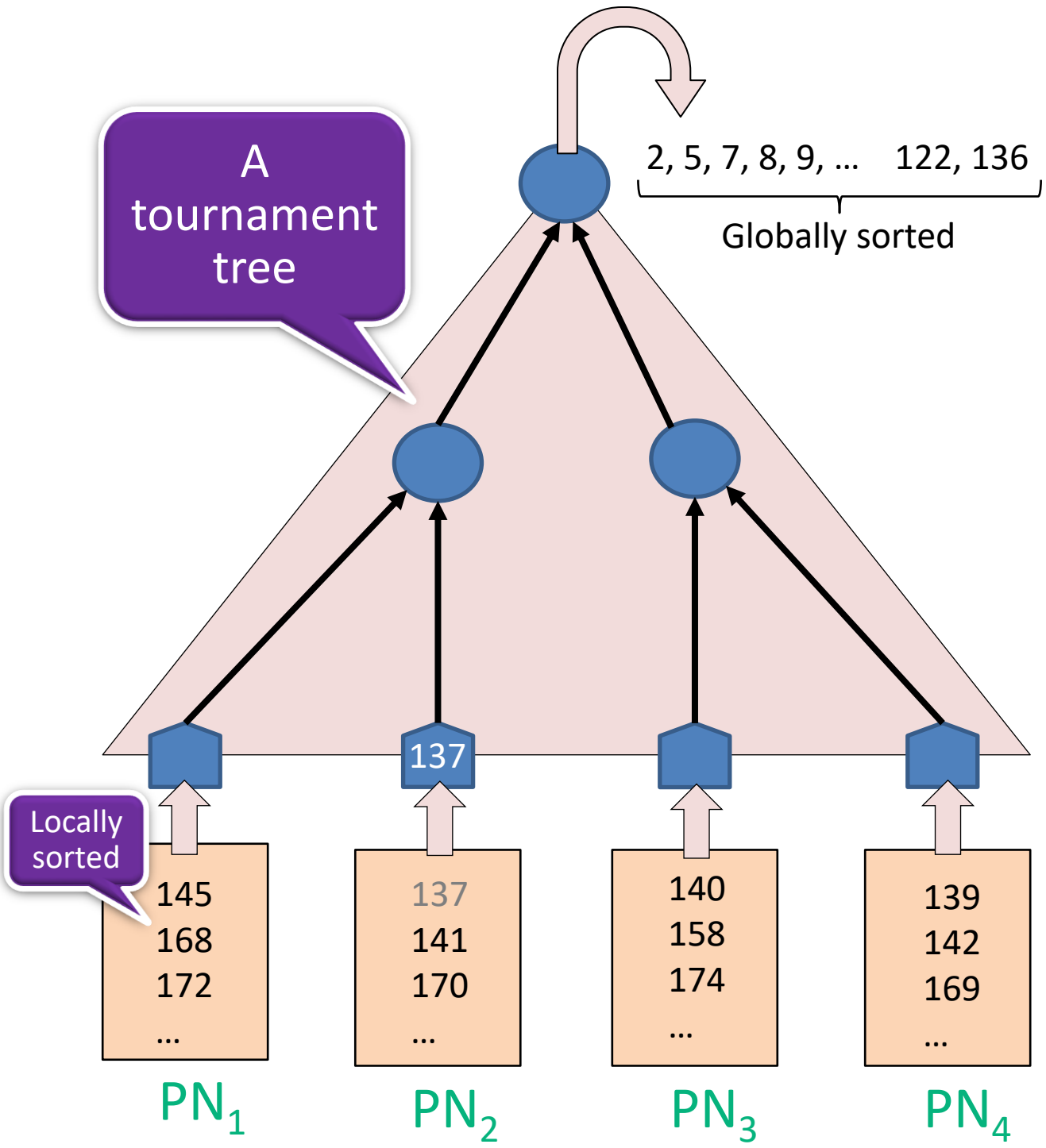
Commercial Product: Teradata DBC/1012



IFP: Interface Processor
AMP: Access Module Processor
COP: Communication Processor

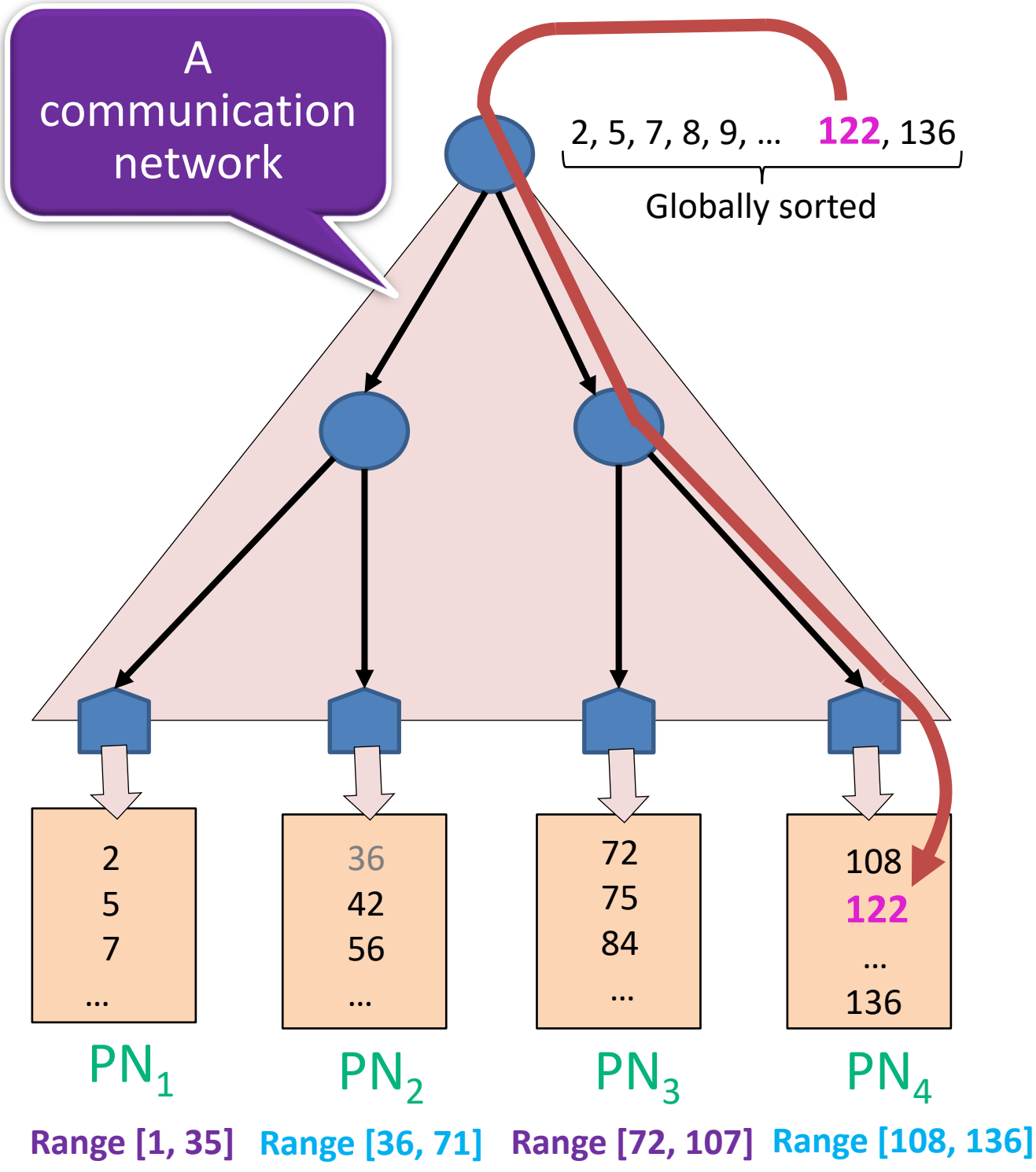
- It may have over 1,000 processors and many thousands of disks.
- Each relation is hash partitioned over a subset of the AMPs.
- Near-linear speedup and scaleup on queries have been demonstrated for systems containing over 100 processors.

Ynet (1)


A tournament tree
2, 5, 7, 8, 9, … 122, 136
Globally sorted
Locally sorted
137
145
168
172
…
137
141
170
…
140
158
174
…
139
142
169
…
PN1
PN2
PN3
PN4

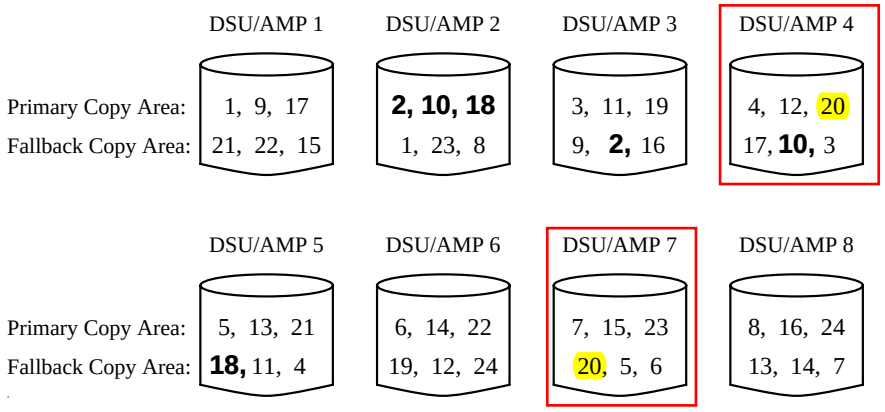
Ynet (2)

As each globally sorted tuple emerges from the root , it is transmitted to a PN in accordance with the data range.

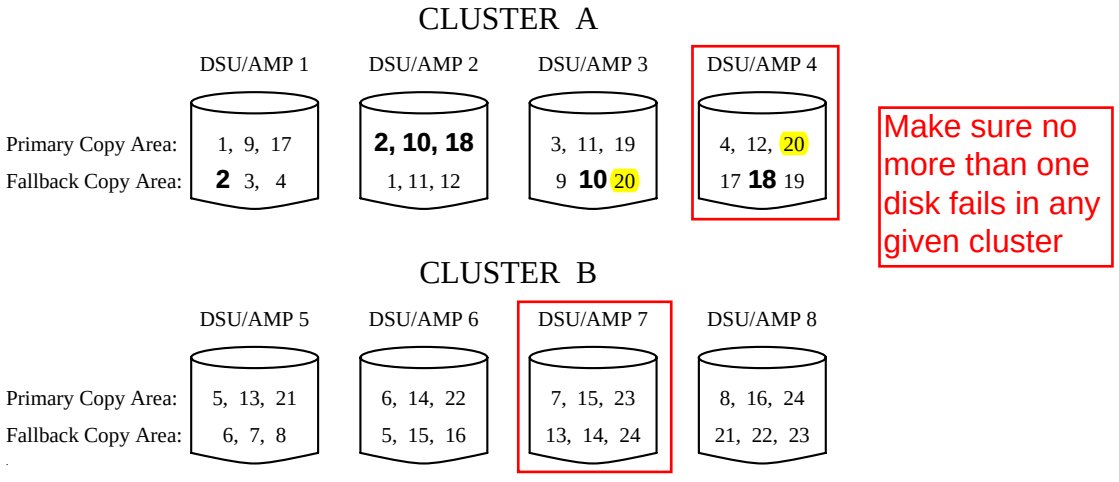


Teradata DBC/1012: Distribution of Data

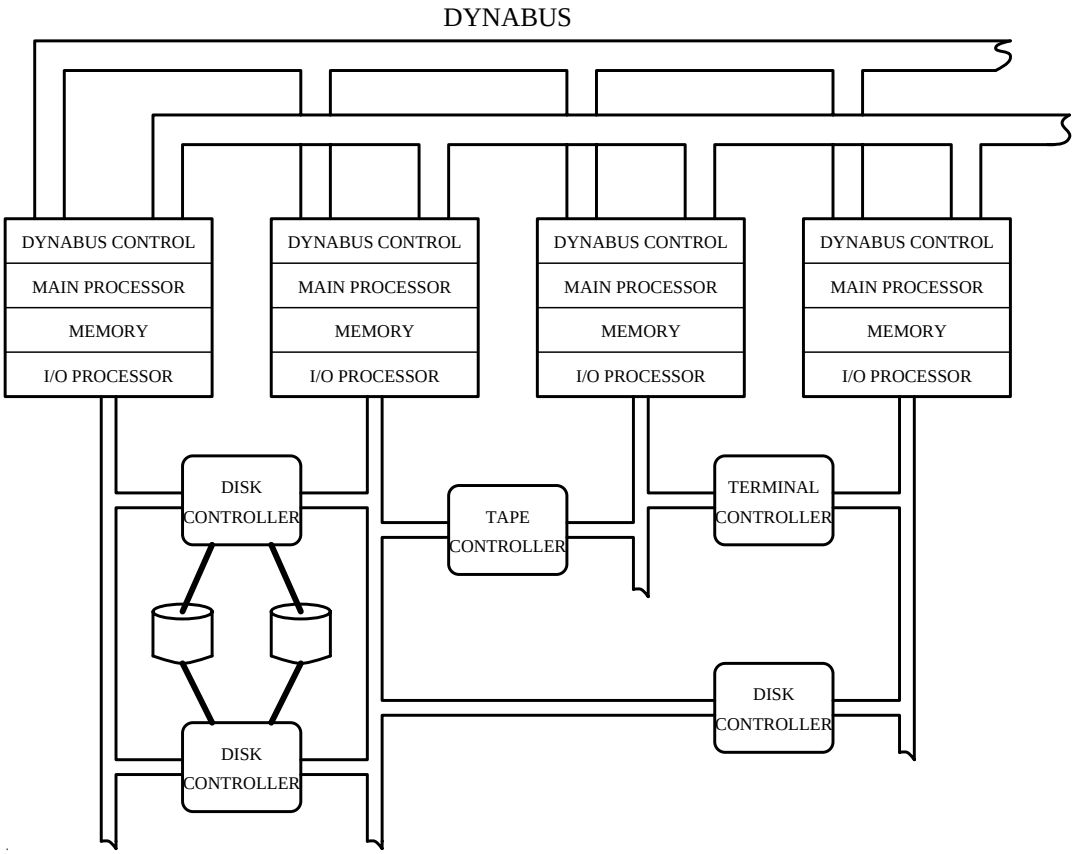
- The fallback copy ensures that the data remains available on other AMPs if an AMP should fail.
- In the following example, if AMPs 4 and 7 were to fail simultaneously, however, there would be a loss of data availability.



- Additional data protection can be achieved by "clustering" the AMPs in groups.
- In the following example, If both AMPs 4 and 7 were to fail, all data would still be available.



Commercial Product: Tandem NonStop SQL



- Tandem systems run the applications on the same processors as the database servers.
- Relations may be range partitioned across multiple disks.
- It is primarily designed for OLTP. It scales linearly well beyond the largest reported mainframes on the TPC-A benchmarks.
- It is three times cheaper than a comparable mainframe system.