# Parallel Query Processing

# Contents

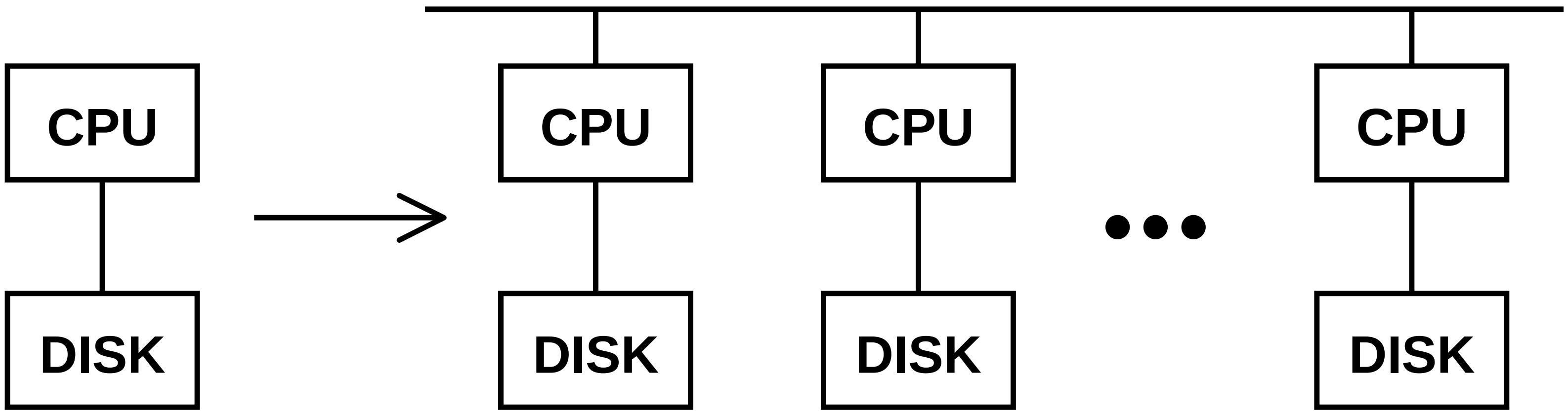
# Concepts and goals

**Main problem: I/O bottleneck**

***transferring the data from disk to main memory***

**Solution**

***increase the I/O bandwidth through parallelism***



# Ideal advantages of parallel systems

**High performance**

- ***short response time or total time***
- ***good load balancing among processors***

**High availability**

- ***handling failures of hardware elements***
- ***redundancy and consistency***

**Extensibility**

- ***more processing and storage power can be added***

# Speedup and scaleup

**Speedup**

***twice as much hardware results in half elapsed time***

**Scaleup**

***twice as much hardware can perform twice as large a task in the same elapsed time***

# Bottlenecks

**Start-up** many processors ⇒ long start-up time

**Interference** more processors ⇒ more communications

**Data skew** it makes data distribution difficult

# Multiprocessor architectures

**Shared-memory architectures**

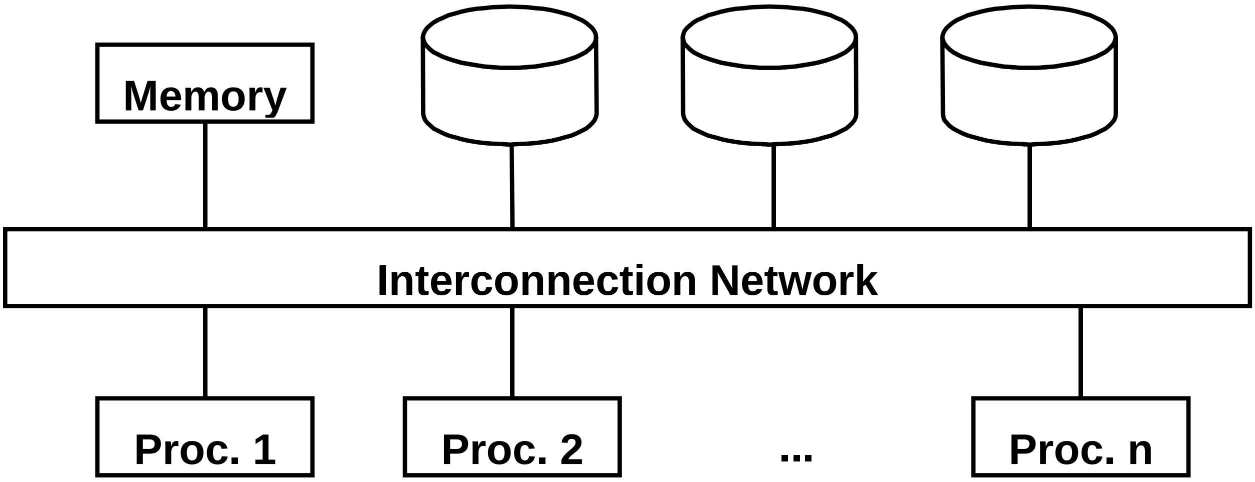
**Shared-disk architectures**

**Shared-nothing architectures**

**Hybrid architectures**

# Shared-memory architectures

More processors - one memory



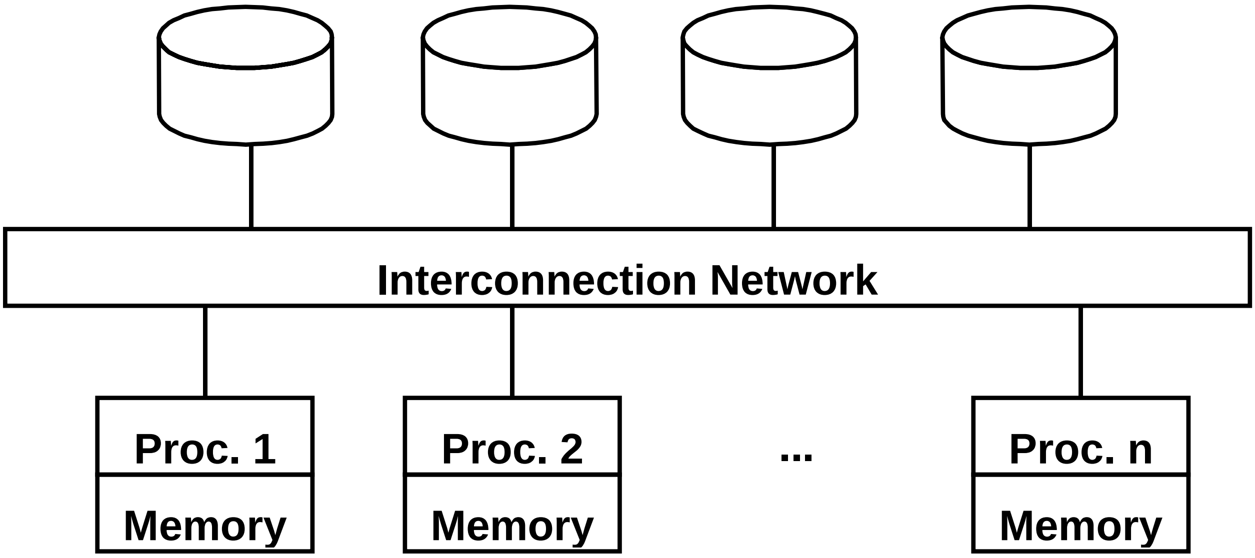

## Characteristics

**any *CPU has access to* any *memory module or disk unit***

| **Advantages** | **Disadvantages** |
| --- | --- |
| **simplicity** | **cost** |
| **load balancing** | **little extensibility** |
| | **low availability** |

# Shared-disk architectures

More processors and memory units




## Characteristics

***any CPU has access to any disk unit but exclusive access to its main memory***

**Advantages**

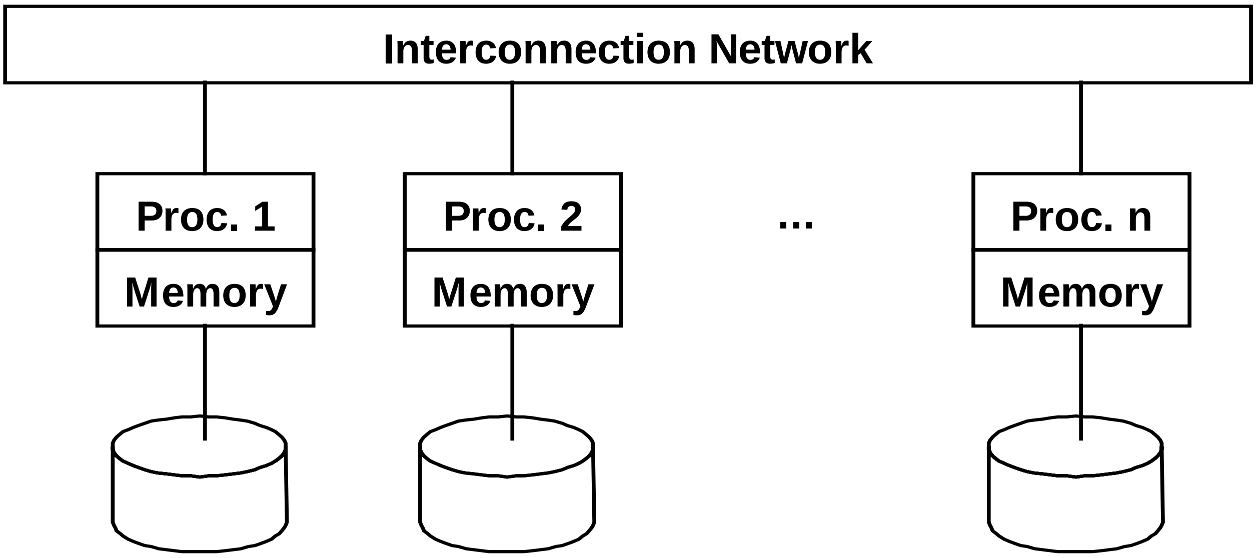
**cost**
**extensibility**
**load balancing**
**availability**
**easy migration**

**Disadvantages**

**higher complexity**
**potential performance problems**

# Shared-nothing architectures

## Exclusive access to memory and disk




## Characteristics

***any CPU has only exclusive access to its main memory and disk***

**Advantages**

**cost**
**extensibility**
**availability**

**Disadvantages**

**higher complexity**
**load balancing**

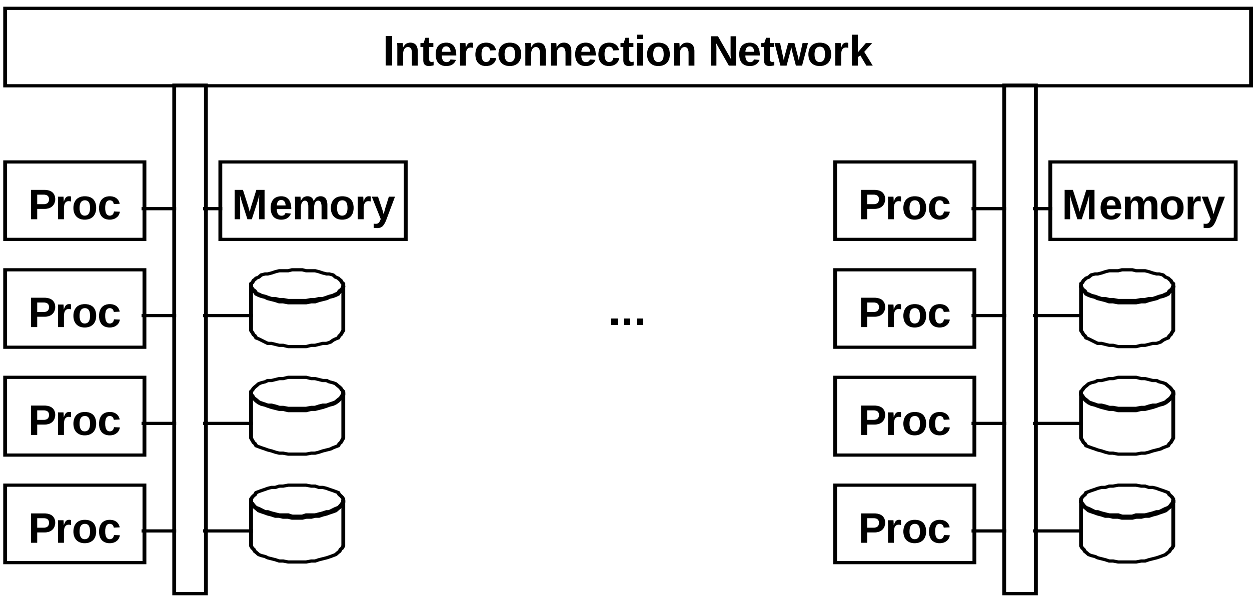
# Hybrid architectures

**Goals:**

**combine the advantages of different architectures**

**use different processing elements in the system**

**The system is basically a shared-nothing architecture where each node can be a multicomputer of any architecture.**



# Parallel relational operators

**Data partitioning**

**Parallelisation of relational operators**

**Join**

- **Parallelisation of join**
- **Pipelined hash-join**

# Data partitioning

**Partitioning = distributing the tuples of a relation over several disks**

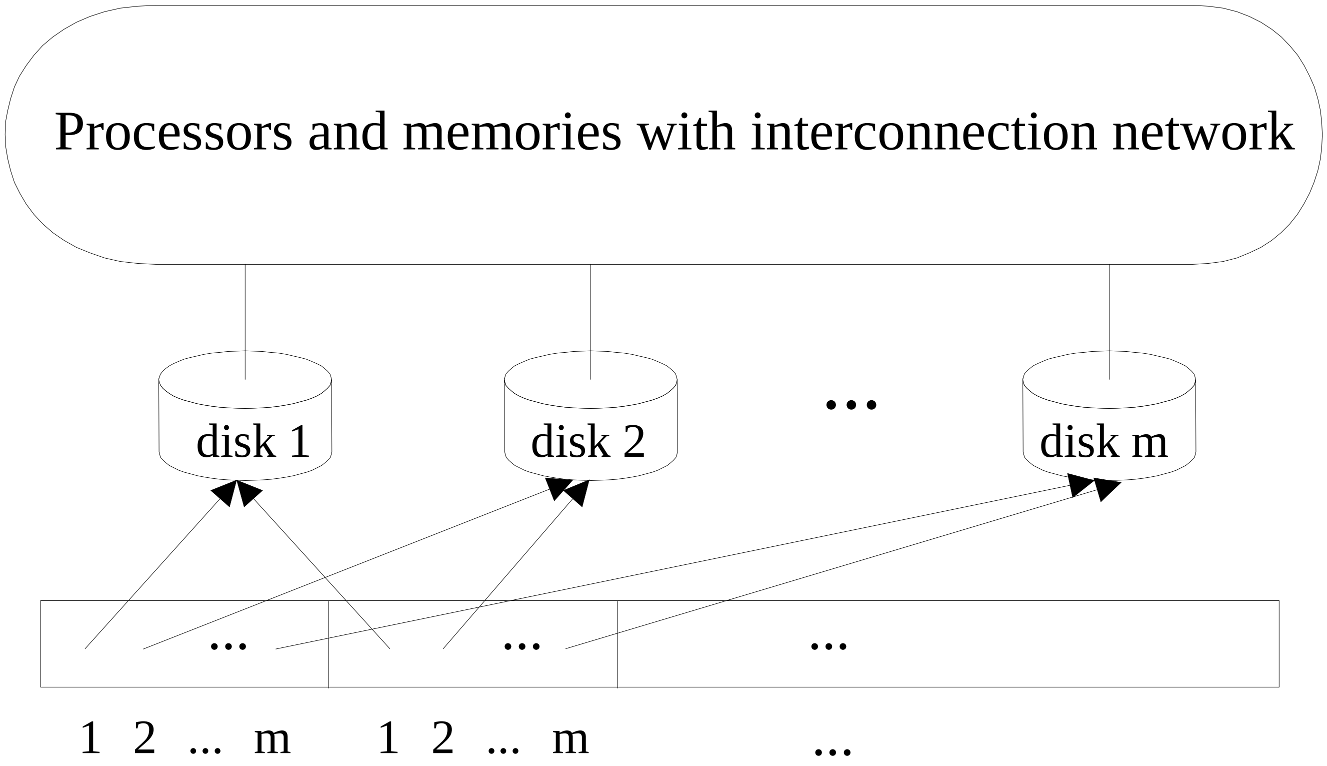
**Goal: allowing parallel databases to exploit the I/O bandwidth of multiple disks by reading and writing them in parallel**

**Relations are declustered (partitioned horizontally) based on a function:**

- **round-robin**
- **range index**
- **hash function**

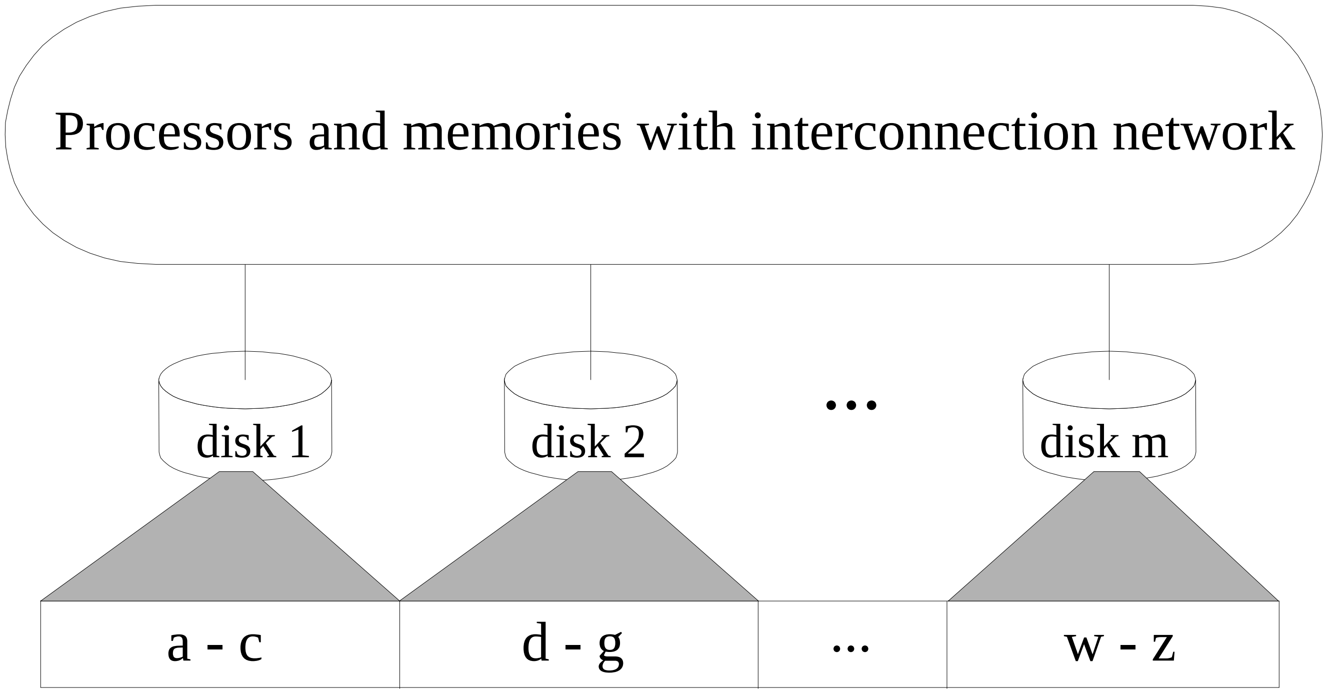
# Round-robin partitioning

***It maps the i'th tuple to disk i mod n***



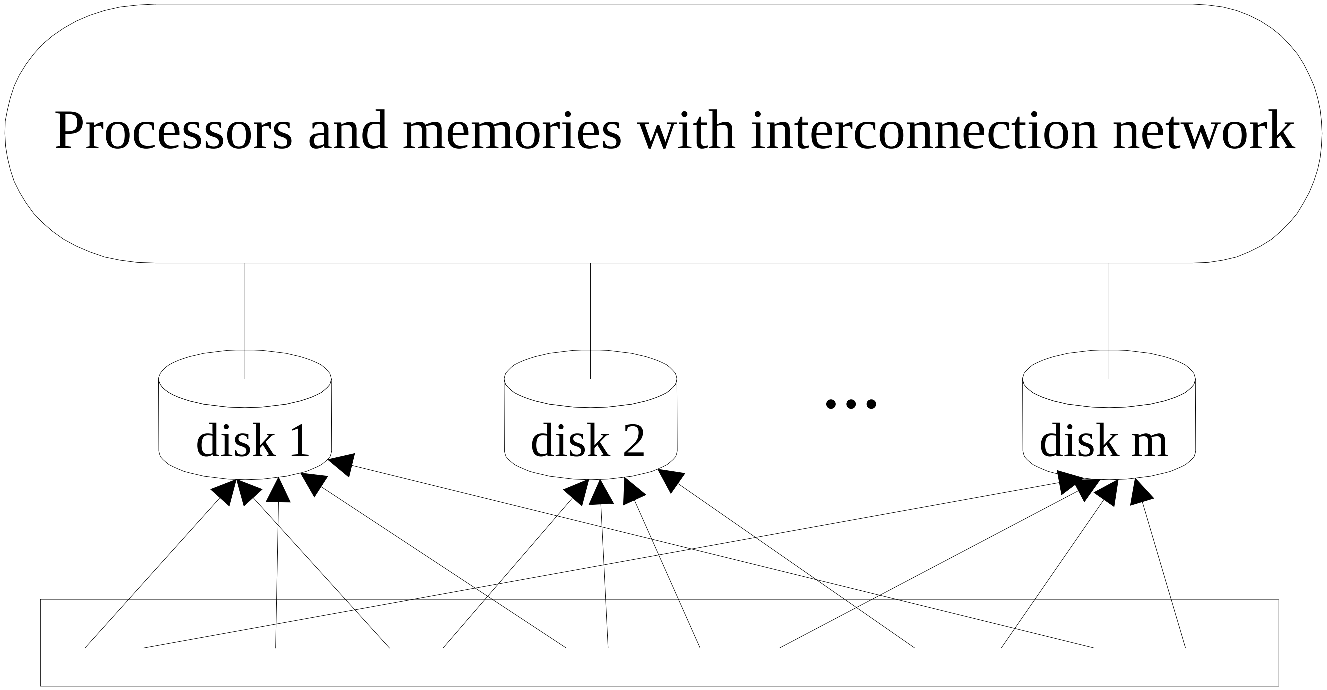
# Range index partitioning

***It clusters tuples with similar attributes together in the same partition***



# Hash partitioning

***It maps each tuple to a location based on a hash function. Hashing tends to randomise data rather than cluster it.***



# Advantages of the partitioning strategies

## Round-robin

- Sequential scan of all tuples in each query

## Range index

- Sequential scan of all tuples in each query
- Associative search for data
- Clustering data

## Hash

- Sequential scan of all tuples in each query
- Associative search for data

# Problems with data partitioning

**data skew** ***A query may work mainly on one partition because of the actual data placement ⇒ unbalanced load on the processors***

## Dynamic reorganisation of relations

***With a given partitioning the criteria used for data placement can change to the extent that load balancing degrades significantly ⇒ the relation should be reorganised. This should be done***

**on-line**

**efficiently**

**transparently to the users and compiled queries**

# Parallel relational operators

**Relational algebra allows parallel processing due to its properties**

**set-oriented processing**

**simple operations**

**limited number of operations**

**simple improvements have substantial effect (large volume of data)**

**relatively independent of hardware architecture**

# Parallel relational operators

## Basic idea

**use parallel data streams instead of writing new parallel operators ⇒ use existing sequential relational operators in parallel**

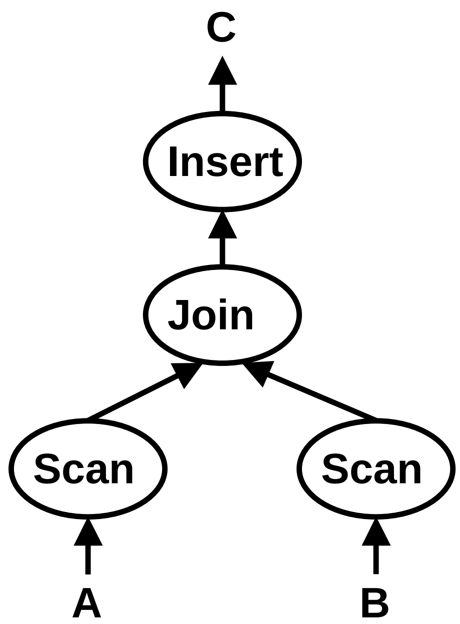
## Solution

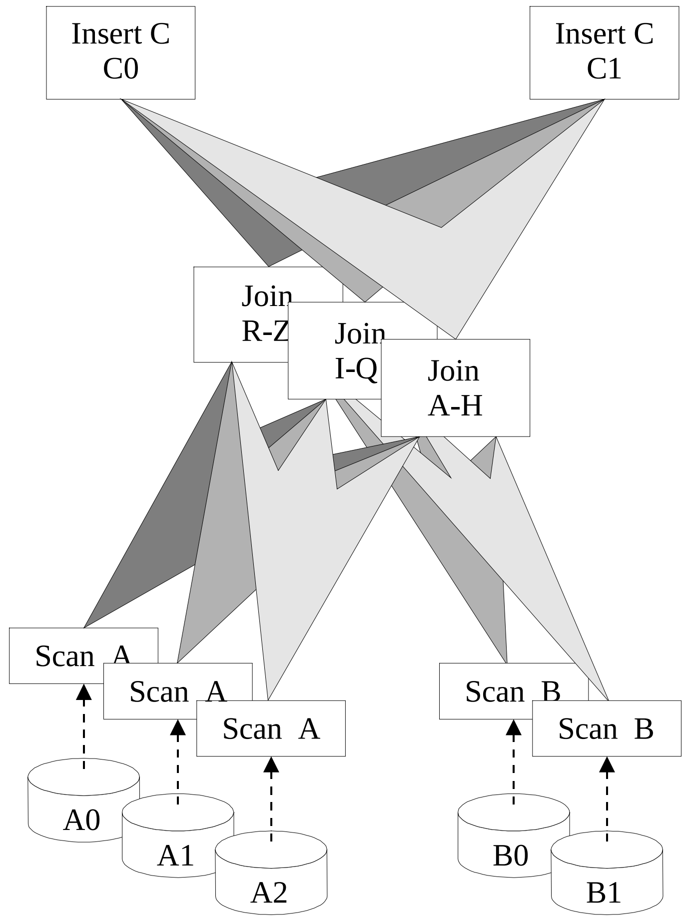
**each relational operator has a set of *input ports* on which input tuples arrive and an *output port* to which the operator's output stream is sent**

**The parallel dataflow works by partitioning and merging data streams into these sequential ports**

# From sequential to parallel execution

***insert into C***
***select ****
***from A, B***
***where A.x = B.y;***



# Extending relational algebra for parallel query processing

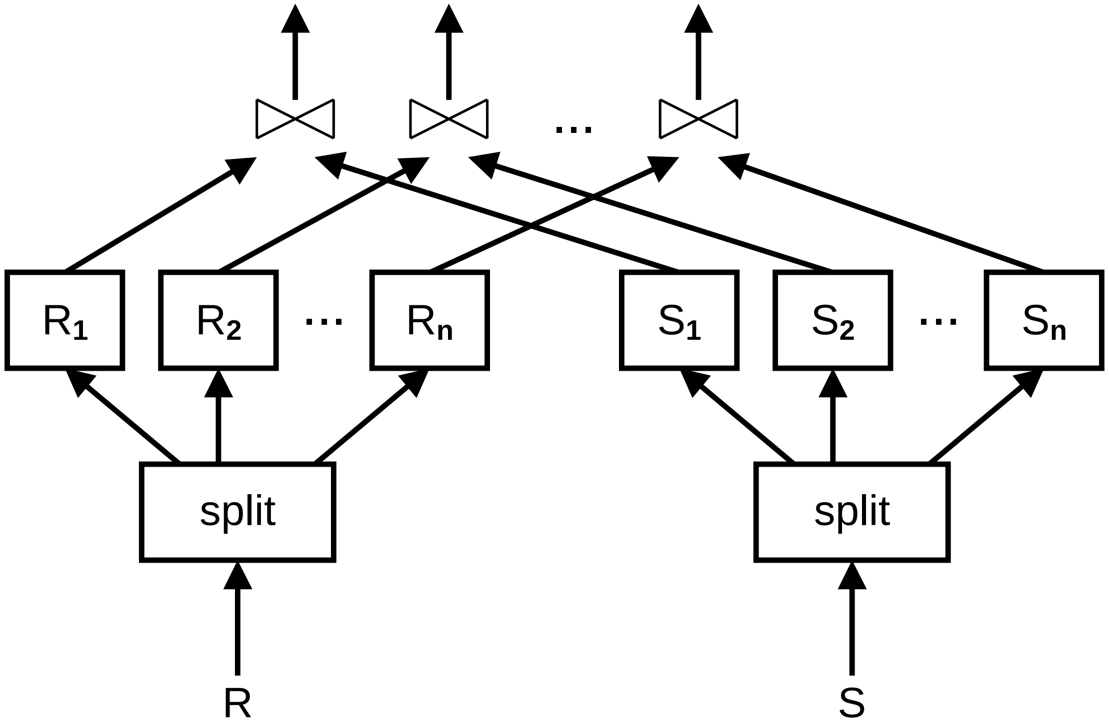
**Relational operations**
**(select, project, cp, join, union, diff, inters)**

**Splitting of results over multiple output streams**

**Operands consisting of multiple input streams**

**Explicit allocation of processes to processors**

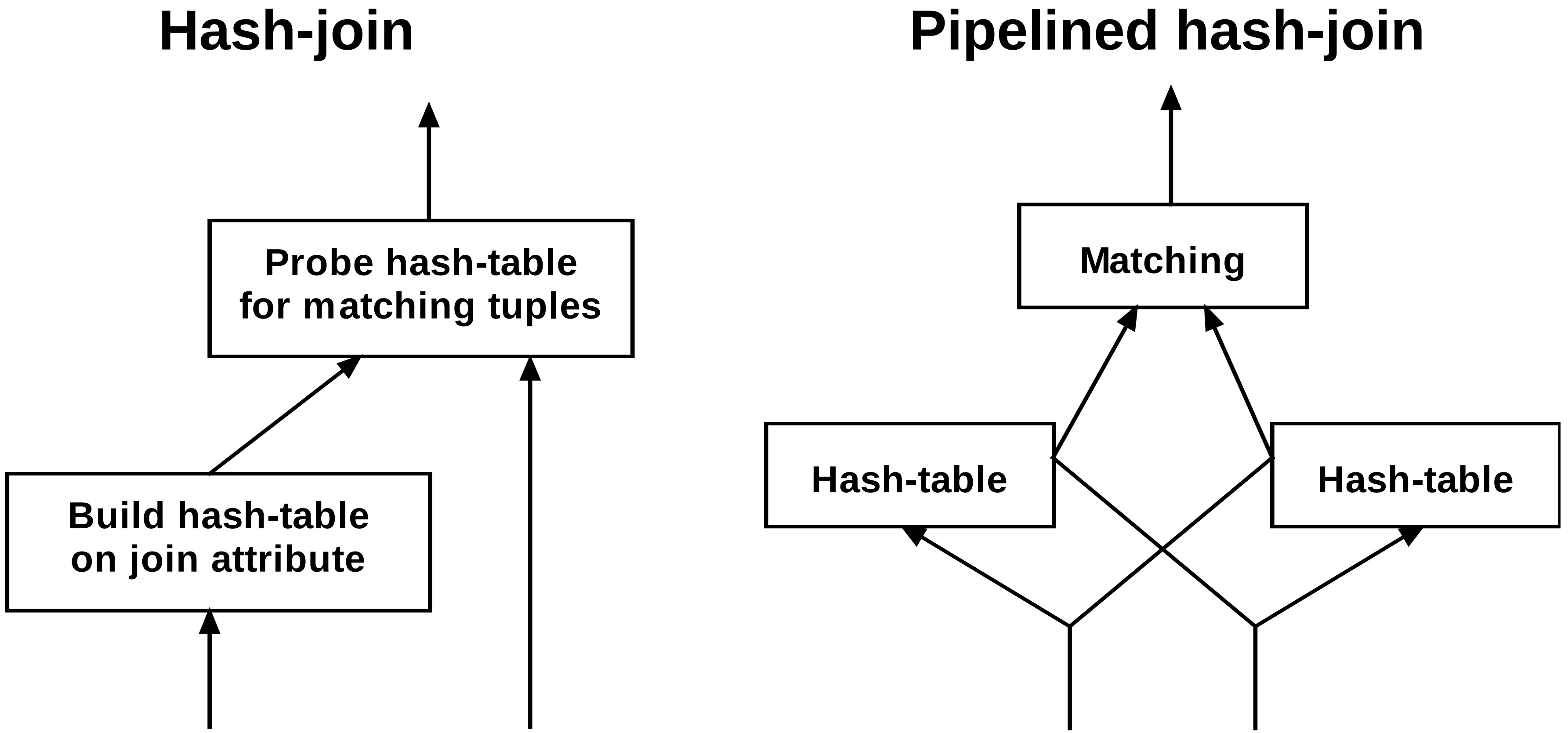
# Parallelisation of join




**Splitting is consistent if**

$$R_i \bowtie S_j = \emptyset \quad \text{if} \quad i \neq j$$

# Pipelined hash-join




**Goal: produce output tuples as early as possible**

# Parallel query processing

**=**

**automatic translation of a query into**
**an efficient execution plan**

**+**

**its parallel execution**

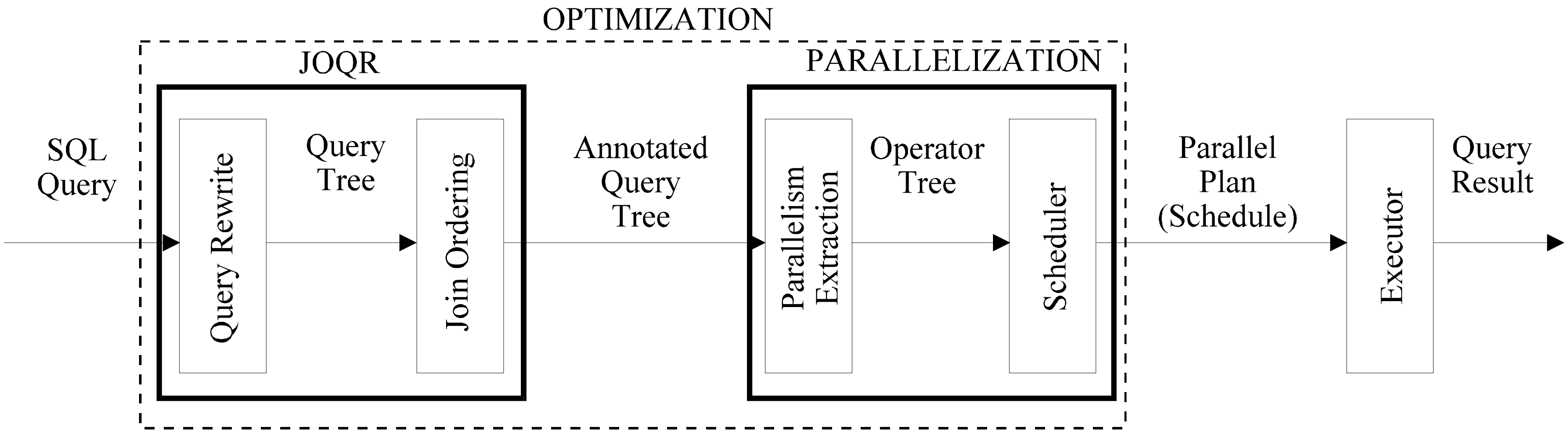
**The translation must be correct**

***the execution of the plan produces the expected result***

**The execution plan must be optimal**

***in that it minimises a cost function that captures resource consumption***

# Parallel query processing




***JOQR: Join Ordering and Query Rewrite***

# Parallel query processing

**1. translation**

***of the relational algebra expression to a query tree***

**2. optimisation**

***reordering of join operations in the query tree and choose among different join algorithms to minimise the cost of the execution***

**3. parallelisation**

***transforming the query tree to a physical operator tree and loading the plan to the processors***

**4. execution**

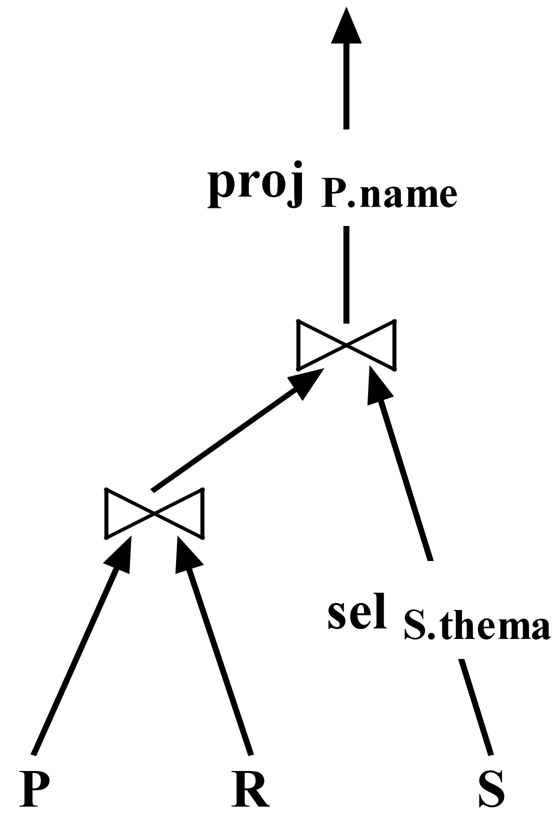
***running the concurrent transactions***

# Translation to query tree

**Relational query ⇒ (rewrite) ⇒ query tree**

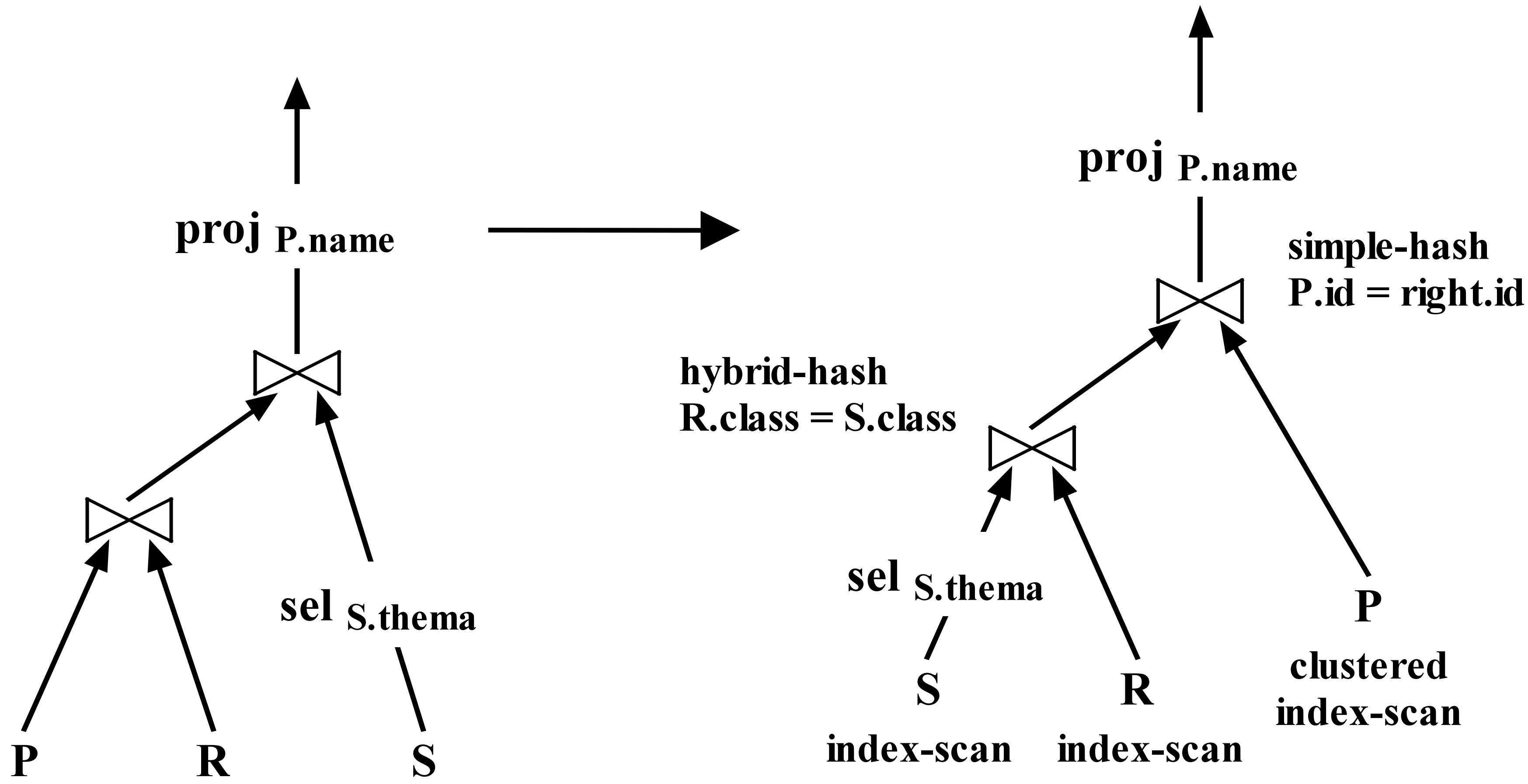
```
SELECT P.name
   FROM P, R, S
      WHERE    S.thema LIKE 'Computing'
        AND    S.class = R.class
        AND    R.id = P.id
```

*Query Tree*



# Optimisation

**Reordering of the join operations and choosing an evaluation algorithm for each join operation**



# Parallelisation of the query

1. **Extract parallelism by macro-expansion of the annotated query tree to an operator tree**

   **The operator tree identifies**

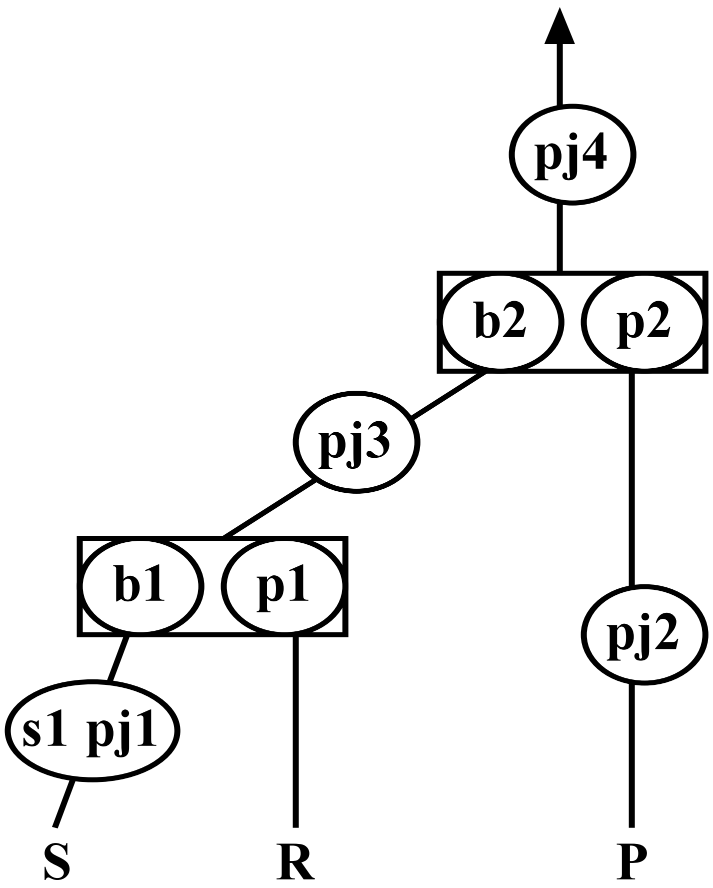
   **atomic code pieces (operators)**

   **timing constraints between the operators**

2. **Schedule the operator tree on the parallel machine**

   **Goal: allocate machine resources so as to exploit the available parallelism while respecting timing and data placement constraints.**

# Parallelisation of the query




*Physical operator tree*

s1=sel S.thema

pj1=proj S.class
pj2=proj P.id, P.name
pj3=proj R.id
pj4=proj P.name

b1, b2:
build hash-table

p1, p2:
probe hash-table

# Constraints on available parallelism

## Precedence constraint

***timing constraints between operators***
***e.g. hash table must be built completely before probing***

## Parallel constraint

***piping the output of an operator to the input of another one*** $\Rightarrow$
***eliminating the need of buffering intermediate results***

## Data placement constraint

***in shared-nothing systems the scan operations must be localised to specific processors that can access the relation***

# Parallel execution control strategies

## Control flow

- a single control node controls all processes related to a query
- it starts all processes and synchronise them
- scheduling is performed by the control node

## Data flow

- no centralised control
- processes on different nodes trigger each other with data messages
- data driven execution: if enough input is available the process starts automatically

# Parallel execution control strategies

**Control flow is the traditional approach**

**Advantages of data flow control**

- **reduces the control messages transferred trough the network**
- **reduces the workload of a particular node (the control node)**
- **provides pipelining naturally**

**Disadvantages of data flow control**

- **it means more asynchronous activity**
- **more competition for a processor**
- **higher protocol complexity**
- **providing data allocation information to all nodes is difficult**

# Parallel Database Systems

## Research systems and projects

Gamma | Bubba | Prisma/DB
HC16-186 | XPRS project | Volcano project

## Commercial systems

Oracle Parallel Server | Sybase MPP
Informix Online XPS | IBM DB2 Parallel Edition
NCR Teradata DBS | Tandem NonStop SQL

## Gamma

**University of Wisconsin (David DeWitt)**

**hypercube, 32 nodes**

**horizontal partition**

**hash-based parallel algorithms for operations**

**data flow query execution (no pipelining)**

**hybrid hash-join**

**ported to an Intel iPSC/2 hypercube with 32 nodes**

## Bubba

**MCC, Austin**

**never completely implemented**

**OLTP and DSS load**

**horizontal data partition over *all* disks**

**compiled PFAD, a parallel, set-oriented execution model**

**data flow query execution (no pipelining)**

**operations take place where data is**

# PRISMA/DB

**University of Twente**
**(Peter M.G. Apers)**

**main-memory parallel**
**database system**

**shared-nothing architecture**

**data flow query execution**
**(with pipelining)**

**simple, grace and hybrid**
**hash-join**

# HC16-186

**Trondheim, Norway**

**hypercube intrerconnect,**
**16 nodes**

**not a fullfledge DBMS**

**horizontal partition of the data**
**over *all* disks**

**redistribution of data**

## XPRS

**M. Stonebraker**

**Shared-memory system**

**Based on the Postgres next-generation DBMS**

**intra- and inter-operator parallelism**

**high performance and availability**

## Volcano project

**Götz Graefe**

**Extensible and parallel query evaluation system**

**supports shared-memory, shared-nothing and hybrid architectures**

**provides a rich environment for research and education**

**data flow query execution**

# Commercial parallel database systems (brief)

## Architecture

- SMP, Symmetric Multiprocessing (shared memory)
- Clustered SMP
- MPP, Massively Parallel Processors (shared nothing)

## Oracle Parallel Server

- shared-disk
- parallel cache management

## Sybase MPP

- shared-nothing (MPP)
- partitioned database

# Commercial parallel database systems (brief)

## Informix Online XPS

- combination of shared-memory and shared-nothing architecture
- partitioned database

## Tandem NonStop SQL

- primarily designed for OLTP transactions
- shared-nothing architecture

## NCR Teradata DBS

- first commercial system
- shared-nothing architecture
- installed on systems with more than 100 processors

## IBM DB2 Parallel Edition

- shared-nothing architecture