Outline

- Introduction
- Background
- Distributed DBMS Architecture
- Distributed Database Design
- Semantic Data Control
- Distributed Query Processing
- Distributed Transaction Management
  - Data server approach
  - Parallel architectures
  - Parallel DBMS techniques
  - Parallel execution models
- Parallel Database Systems
- Distributed Object DBMS
- Database Interoperability
- Concluding Remarks

The Database Problem

- Large volume of data ⇨ use disk and large main memory
- I/O bottleneck (or memory access bottleneck)
  - Speed(disk) << speed(RAM) << speed(microprocessor)
- Predictions
  - (Micro-) processor speed growth : 50 % per year
  - DRAM capacity growth : 4× every three years
  - Disk throughput : 2× in the last ten years
- Conclusion : the I/O bottleneck worsens

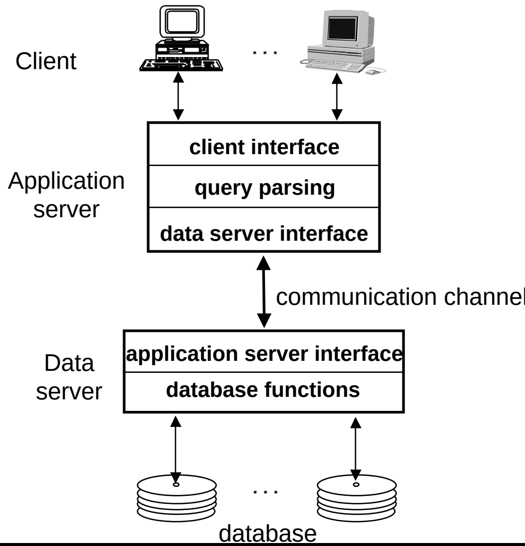
The Solution

- Increase the I/O bandwidth
  - ➠ Data partitioning
  - ➠ Parallel data access
- Origins (1980's): database machines
  - ➠ Hardware-oriented ⇨ bad cost-performance ⇨ failure
  - ➠ Notable exception : ICL's CAFS Intelligent Search Processor
- 1990's: same solution but using standard hardware components integrated in a multiprocessor
  - ➠ Software-oriented
  - ➠ Standard essential to exploit continuing technology improvements

Multiprocessor Objectives

- High-performance with better cost-performance than mainframe or vector supercomputer
- Use many nodes, each with good cost-performance, communicating through network
  - ➠ Good cost via high-volume components
  - ➠ Good performance via bandwidth
- Trends
  - ➠ Microprocessor and memory (DRAM): off-the-shelf
  - ➠ Network (multiprocessor edge): custom
- The real chalenge is to parallelize applications to run with good load balancing

Data Server Architecture



Objectives of Data Servers

Avoid the shortcomings of the traditional DBMS approach

- Centralization of data and application management
- General-purpose OS (not DB-oriented)

By separating the functions between

- Application server (or host computer)
- Data server (or database computer or back-end computer)

Data Server Approach: Assessment

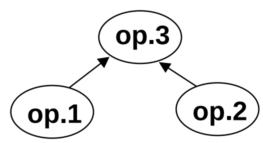
- Advantages
  - ➠ Integrated data control by the server (black box)
  - ➠ Increased performance by dedicated system
  - ➠ Can better exploit parallelism
  - ➠ Fits well in distributed environments
- Potential problems
  - ➠ Communication overhead between application and data server
    - ◆ High-level interface
  - ➠ High cost with mainframe servers

Parallel Data Processing

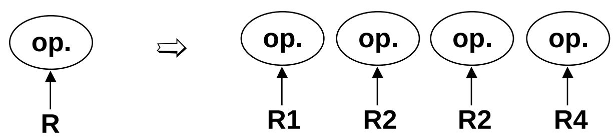
- Three ways of exploiting high-performance multiprocessor systems:
  - ❶ Automatically detect parallelism in sequential programs (e.g., Fortran, OPS5)
  - ❷ Augment an existing language with parallel constructs (e.g., C*, Fortran90)
  - ❸ Offer a new language in which parallelism can be expressed or automatically inferred
- Critique
  - ❶ Hard to develop parallelizing compilers, limited resulting speed-up
  - ❷ Enables the programmer to express parallel computations but too low-level
  - ❸ Can combine the advantages of both (1) and (2)

Data-based Parallelism

- Inter-operation
  - p operations of the same query in parallel



- Intra-operation
  - the same operation in parallel on different data partitions



Parallel DBMS

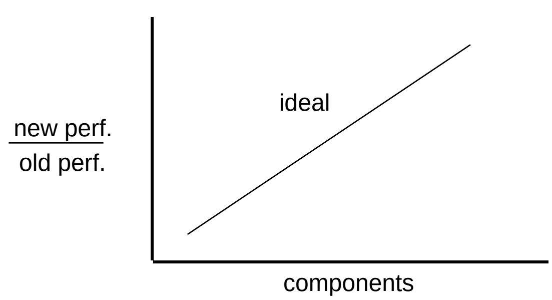
- Loose definition: a DBMS implemented on a tighly coupled multiprocessor
- Alternative extremes
  - Straighforward porting of relational DBMS (the software vendor edge)
  - New hardware/software combination (the computer manufacturer edge)
- Naturally extends to distributed databases with one server per site

Parallel DBMS - Objectives

- Much better cost / performance than mainframe solution
- High-performance through parallelism
  - High throughput with inter-query parallelism
  - Low response time with intra-operation parallelism
- High availability and reliability by exploiting data replication
- Extensibility with the ideal goals
  - Linear speed-up
  - Linear scale-up

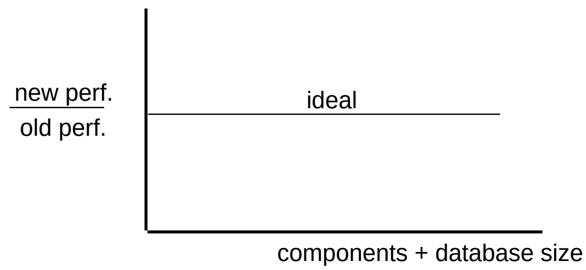
Linear Speed-up

Linear increase in performance for a constant DB size and proportional increase of the system components (processor, memory, disk)



Linear Scale-up

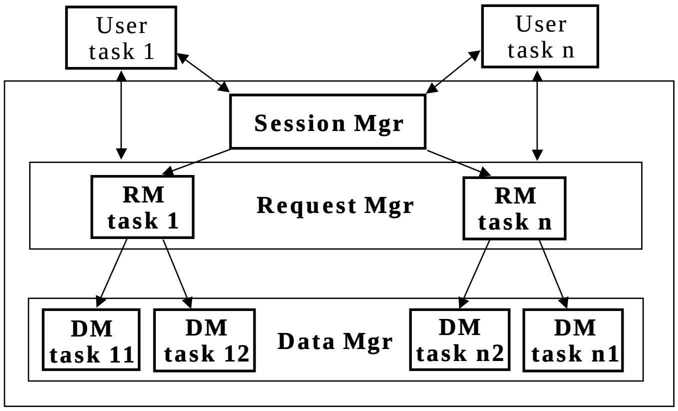
Sustained performance for a linear increase of database size and proportional increase of the system components.



Barriers to Parallelism

- Startup
  - ➠ The time needed to start a parallel operation 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
- Parallel data management techniques intend to overcome these barriers

Parallel DBMS – Functional Architecture



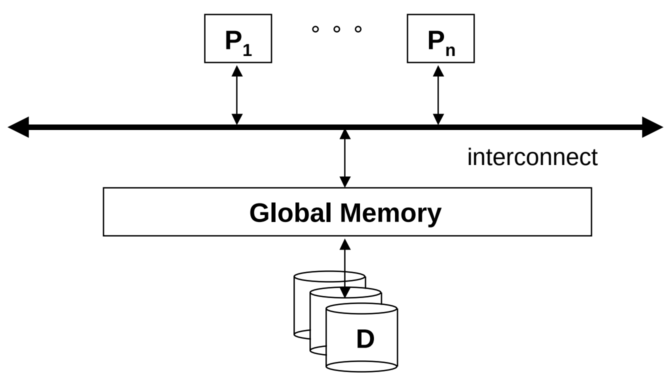
Parallel DBMS Functions

- Session manager
  - Host interface
  - Transaction monitoring for OLTP
- Request manager
  - Compilation and optimization
  - Data directory management
  - Semantic data control
  - Execution control
- Data manager
  - Execution of DB operations
  - Transaction management support
  - Data management

Parallel System Architectures

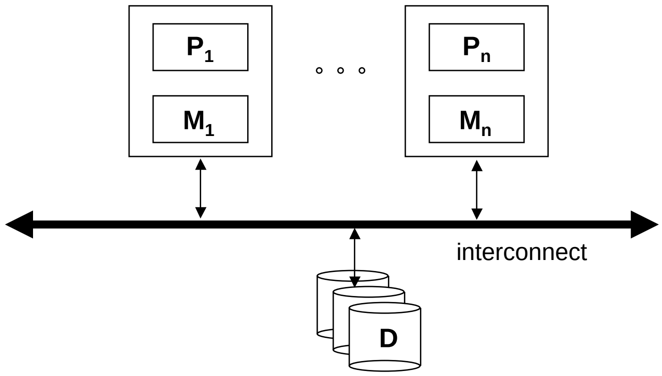
- Multiprocessor architecture alternatives
  - Shared memory (shared everything)
  - Shared disk
  - Shared nothing (message-passing)
- Hybrid architectures
  - Hierarchical (cluster)
  - Non-Uniform Memory Architecture (NUMA)

Shared-Memory Architecture



Examples: DBMS on symmetric multiprocessors (Sequent, Encore, Sun, etc.)
- Simplicity, load balancing, fast communication
- Network cost, low extensibility

Shared-Disk Architecture

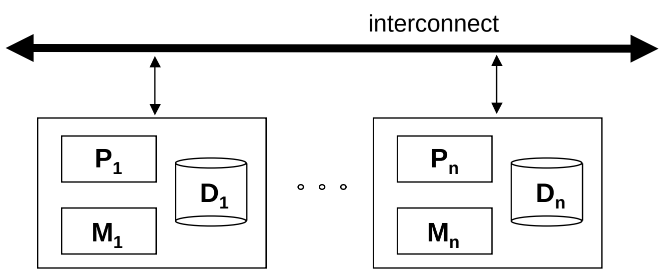


Examples : DEC's VAXcluster, IBM's IMS/VS Data Sharing

➠ network cost, extensibility, migration from uniprocessor

➠ complexity, potential performance problem for copy coherency

Shared-Nothing Architecture

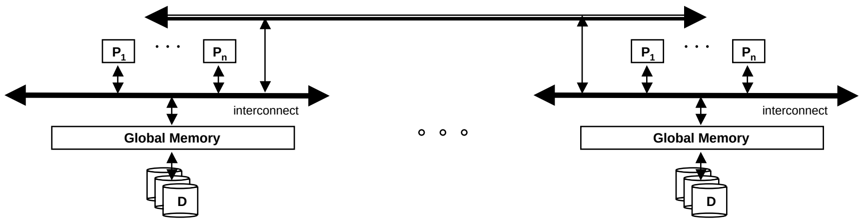


Examples : Teradata (NCR), NonStopSQL (Tandem-Compaq), Gamma (U. of Wisconsin), Bubba (MCC)

➠ Extensibility, availability

➠ Complexity, difficult load balancing

Hierarchical Architecture



- Combines good load balancing of SM with extensibility of SN
- Alternatives
  - Limited number of large nodes, e.g., 4 x 16 processor nodes
  - High number of small nodes, e.g., 16 x 4 processor nodes, has much better cost-performance (can be a cluster of workstations)

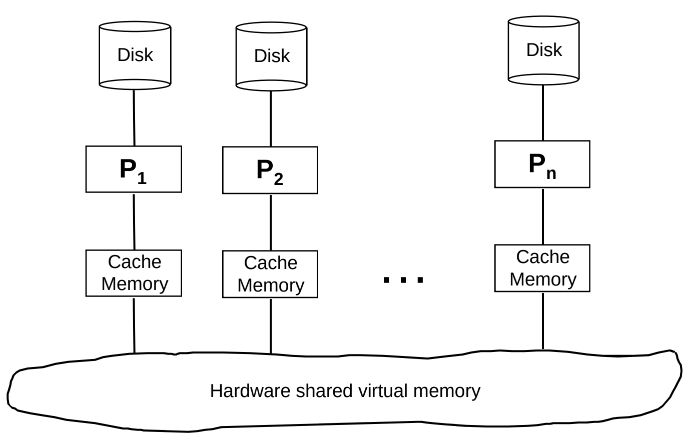
Shared-Memory vs. Distributed Memory

- Mixes two different aspects : addressing and memory
  - Addressing
    - Single address space : Sequent, Encore, KSR
    - Multiple address spaces : Intel, Ncube
  - Physical memory
    - Central : Sequent, Encore
    - Distributed : Intel, Ncube, KSR
- NUMA : single address space on distributed physical memory
  - Eases application portability
  - Extensibility

NUMA Architectures

- Cache Coherent NUMA (CC-NUMA)
  - ➠ statically divide the main memory among the nodes
- Cache Only Memory Architecture (COMA)
  - ➠ convert the per-node memory into a large cache of the shared address space

COMA Architecture



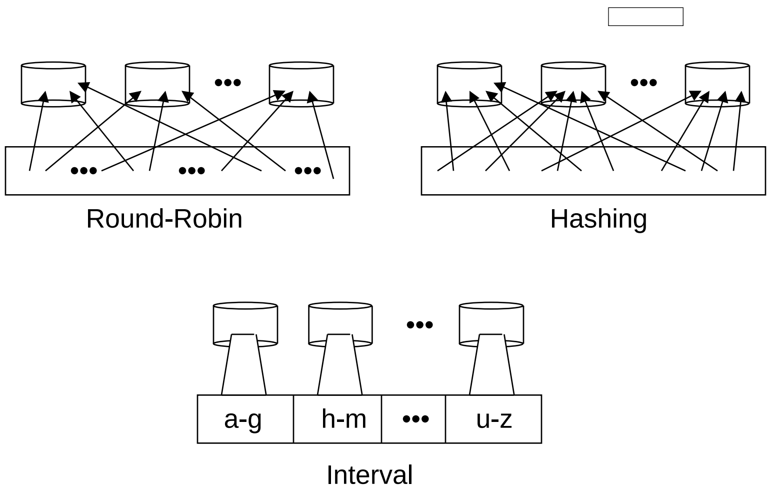
Parallel DBMS Techniques

- Data placement
  - Physical placement of the DB onto multiple nodes
  - Static vs. Dynamic
- Parallel data processing
  - Select is easy
  - Join (and all other non-select operations) is more difficult
- Parallel query optimization
  - Choice of the best parallel execution plans
  - Automatic parallelization of the queries and load balancing
- Transaction management
  - Similar to distributed transaction management

Data Partitioning

- Each relation is divided in *n* partitions (subrelations), where *n* is a function of relation size and access frequency
- Implementation
  - Round-robin
    - Maps *i*-th element to node *i* mod *n*
    - Simple but only exact-match queries
  - B-tree index
    - Supports range queries but large index
  - Hash function
    - Only exact-match queries but small index

Partitioning Schemes



Replicated Data Partitioning

- High-availability requires data replication
  - ➠ simple solution is mirrored disks
    - ◆ hurts load balancing when one node fails
  - ➠ more elaborate solutions achieve load balancing
    - ◆ interleaved partitioning (Teradata)
    - ◆ chained partitioning (Gamma)

Interleaved Partitioning

Node	1	2	3	4
Primary copy	R1	R2	R3	R4
Backup copy		r 1.1	r 1.2	r 1.3
	r 2.3		r 2.1	r 2.2
	r 3.2	r 3.2		r 3.1

Chained Partitioning

Node	1	2	3	4
Primary copy	R1	R2	R3	R4
Backup copy	r4	r1	r2	r3

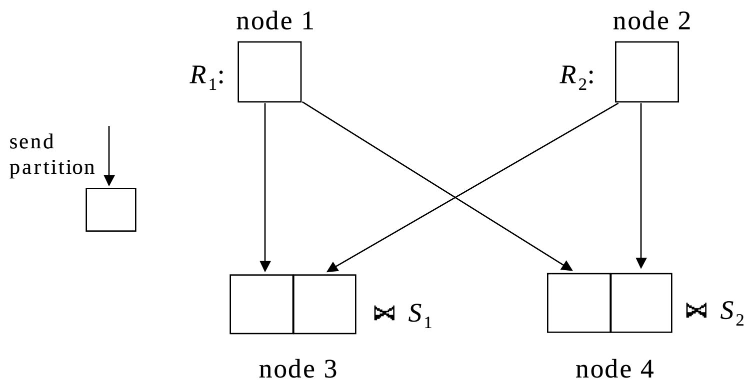
Placement Directory

- Performs two functions
  - ➠ F_1 (relname, placement attval) = lognode-id
  - ➠ F_2 (lognode-id) = phynode-id
- In either case, the data structure for f_1 and f_2 should be available when needed at each node

Join Processing

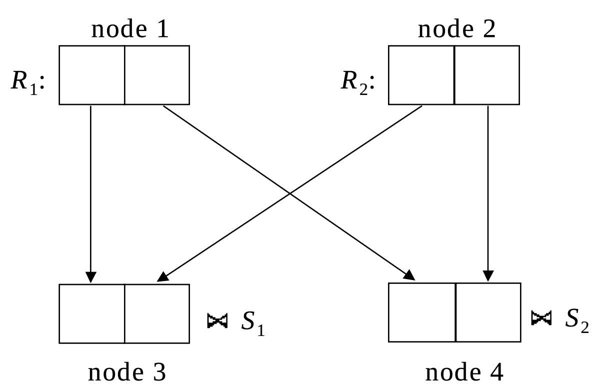
- Three basic algorithms for intra-operator parallelism
  - ➠ Parallel nested loop join: no special assumption
  - ➠ Parallel associative join: one relation is declustered on join attribute and equi-join
  - ➠ Parallel hash join: equi-join
- They also apply to other complex operators such as duplicate elimination, union, intersection, etc. with minor adaptation

Parallel Nested Loop Join



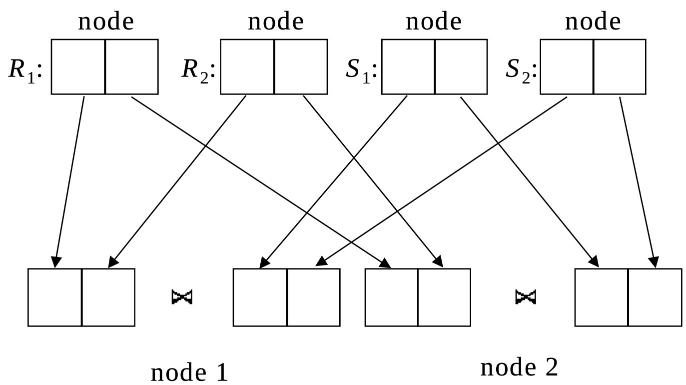
$$R \bowtie S \rightarrow \quad {}_{i=1,n}(R \bowtie S_i)$$

Parallel Associative Join



$$R \bowtie S \rightarrow \quad {}_{i=1,n}(R_i \bowtie S_i)$$

Parallel Hash Join



$$R \bowtie S \rightarrow {}_{i=1,P}(R_i \bowtie S_i)$$

Parallel Query Optimization

The objective is to select the "best" parallel execution plan for a query using the following components

Search space

- ➠ Models alternative execution plans as operator trees
- ➠ Left-deep vs. Right-deep vs. Bushy trees

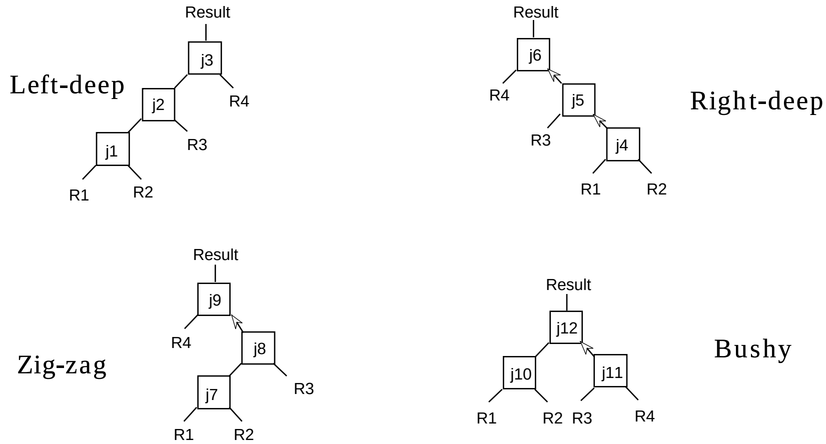
Search strategy

- ➠ Dynamic programming for small search space
- ➠ Randomized for large search space

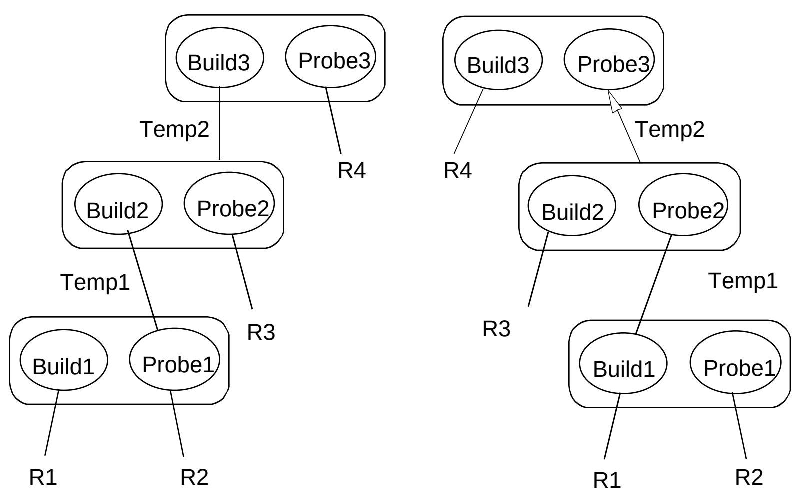
Cost model (abstraction of execution system)

- ➠ Physical schema info. (partitioning, indexes, etc.)
- ➠ Statistics and cost functions

Execution Plans as Operators Trees



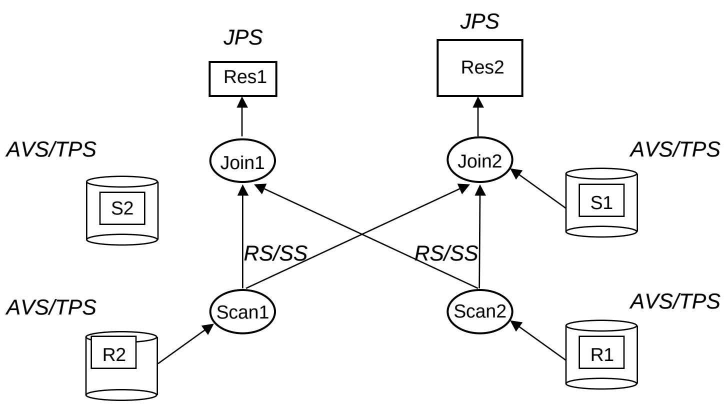
Equivalent Hash-Join Trees with Different Scheduling



Load Balancing

- Problems arise for intra-operator parallelism with *skewed* data distributions
  - ➠ attribute data skew (AVS)
  - ➠ tuple placement skew (TPS)
  - ➠ selectivity skew (SS)
  - ➠ redistribution skew (RS)
  - ➠ join product skew (JPS)
- Solutions
  - ➠ sophisticated parallel algorithms that deal with skew
  - ➠ dynamic processor allocation (at execution time)

Data Skew Example



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Some Parallel DBMSs

- Prototypes
  - EDS and DBS3 (ESPRIT)
  - Gamma (U. of Wisconsin)
  - Bubba (MCC, Austin, Texas)
  - XPRS (U. of Berkeley)
  - GRACE (U. of Tokyo)
- Products
  - Teradata (NCR)
  - NonStopSQL (Tandem-Compac)
  - DB2 (IBM), Oracle, Informix, Ingres, Navigator (Sybase) ...

Open Research Problems

- Hybrid architectures
- OS support:using micro-kernels
- Benchmarks to stress speedup and scaleup under mixed workloads
- Data placement to deal with skewed data distributions and data replication
- Parallel data languages to specify independent and pipelined parallelism
- Parallel query optimization to deal with mix of precompiled queries and complex ad-hoc queries
- Support of higher functionality such as rules and objects

