Outline

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- Distributed Database Design
- Semantic Data Control
- Distributed Query Processing
- Distributed Transaction Management
- Distributed Database Operating Systems
- Open Systems and Interoperability
- Parallel Database Systems
  - Parallel Architectures
  - Parallal Data Management Techniques
- Distributed Object Management
- Concluding Remarks

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The Information System Problem

- Enterprises depend on timely available, up-to-date information
  - information volume growth : 30 % per year
  - transaction rate growth : 10× over next five years
- Transaction load is changing
  - simple OLTP-like transactions
  - complex transactions (e.g., generated by decision-support systems)
  - very complex transactions (e.g., generated by expert systems)
- The need: database servers that provide high-throughput and good response times for mixed workloads on very large on-line databases

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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 will worsen

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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 ISP
- 1990's: same solution but using standard hardware components integrated in a multiprocessor
  - software-oriented
  - standard essential to exploit continuing technology improvements

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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

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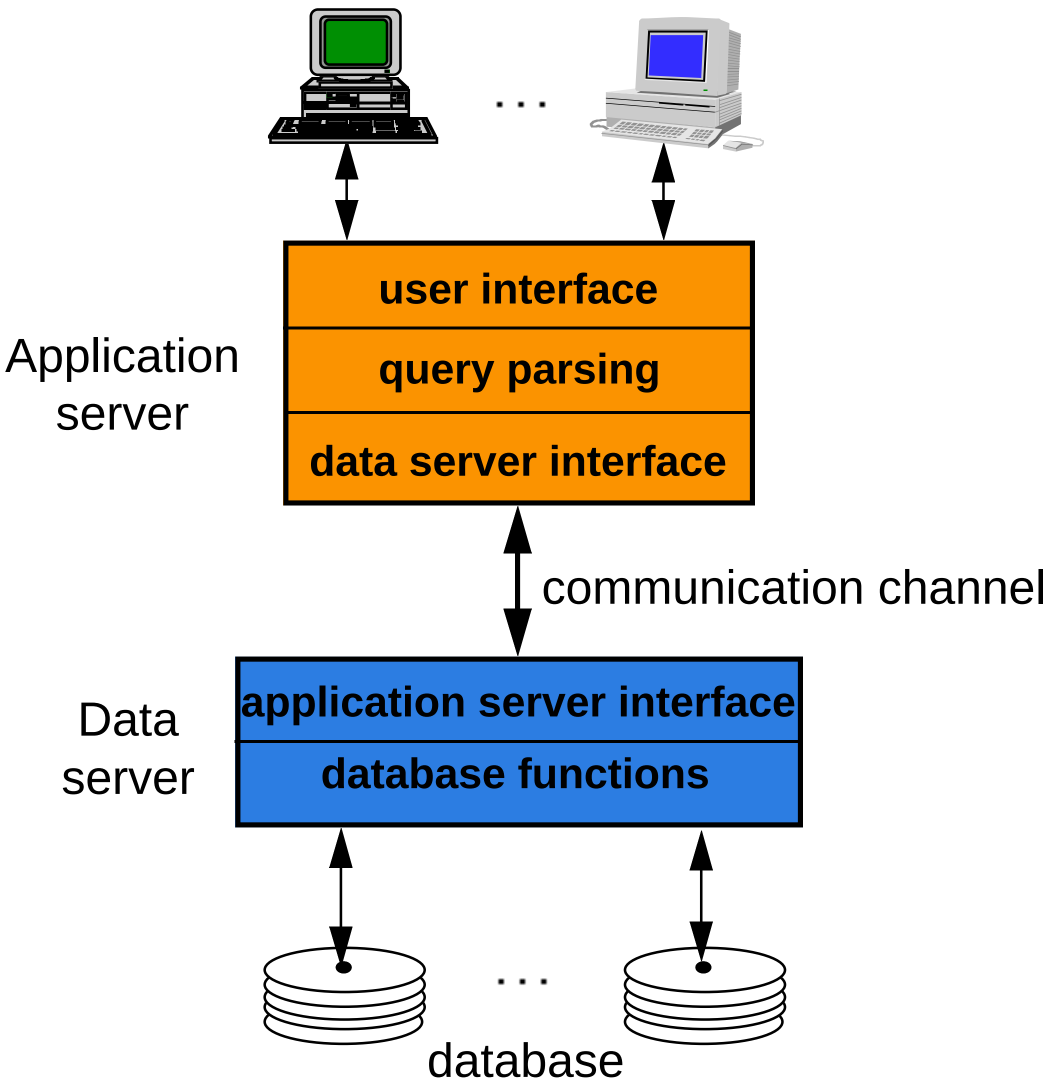
Data Server Architecture



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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 (host computer)
- data server (database computer, back-end computer)

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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

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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)

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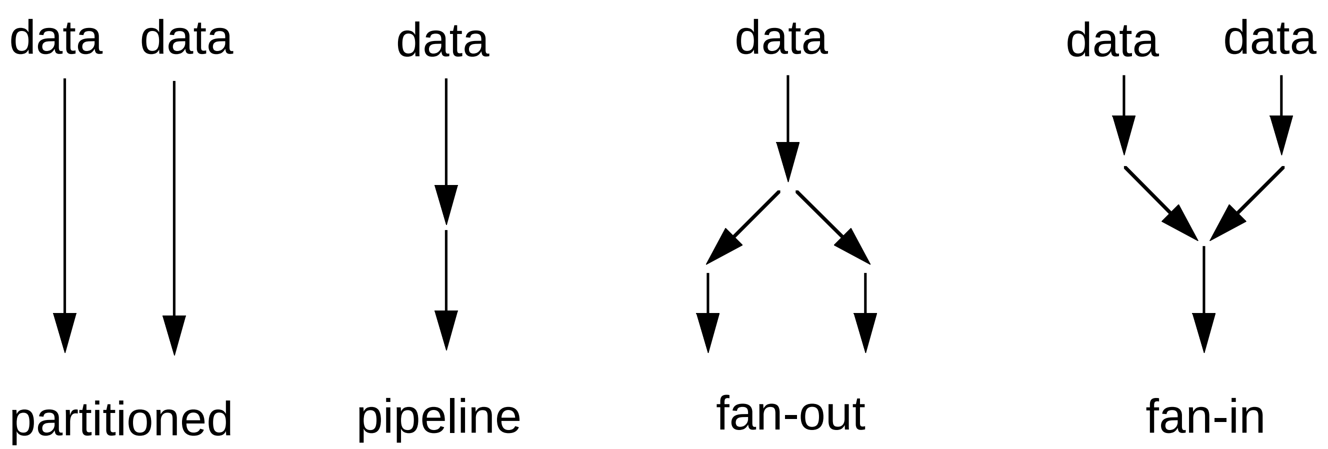
Data-based Parallelism

- Infer parallelism inherent in SQL queries
  - inter-query
  - intra-query
  - intra-operation



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Parallel Database Management System

- 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

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Parallel Database Systems - Objectives

- Much better cost / performance than mainframe solution
- High-performance through parallelism
  - high throuhput 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

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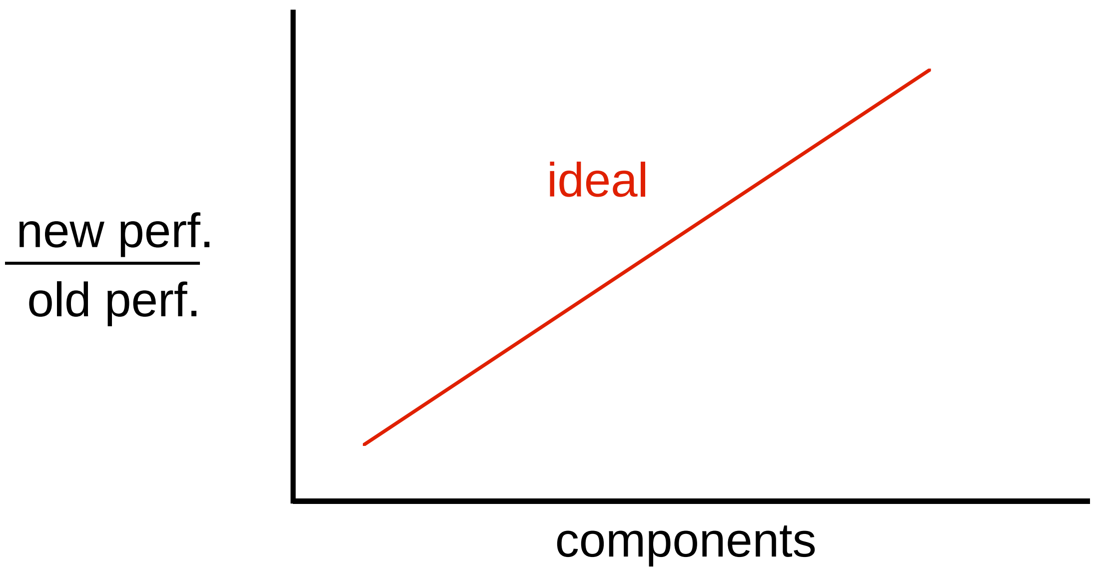
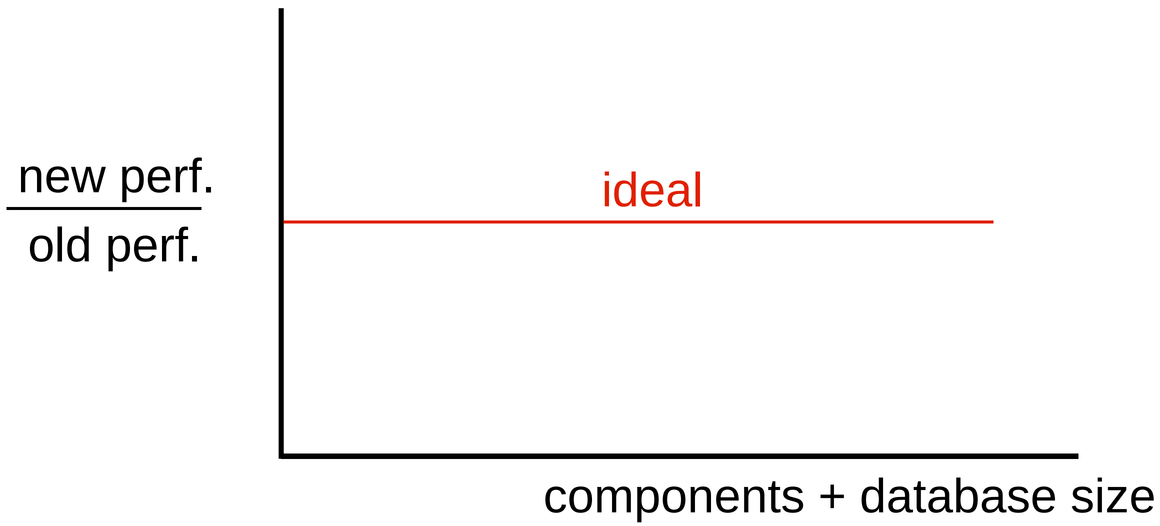
Linear Speed-up

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.



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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

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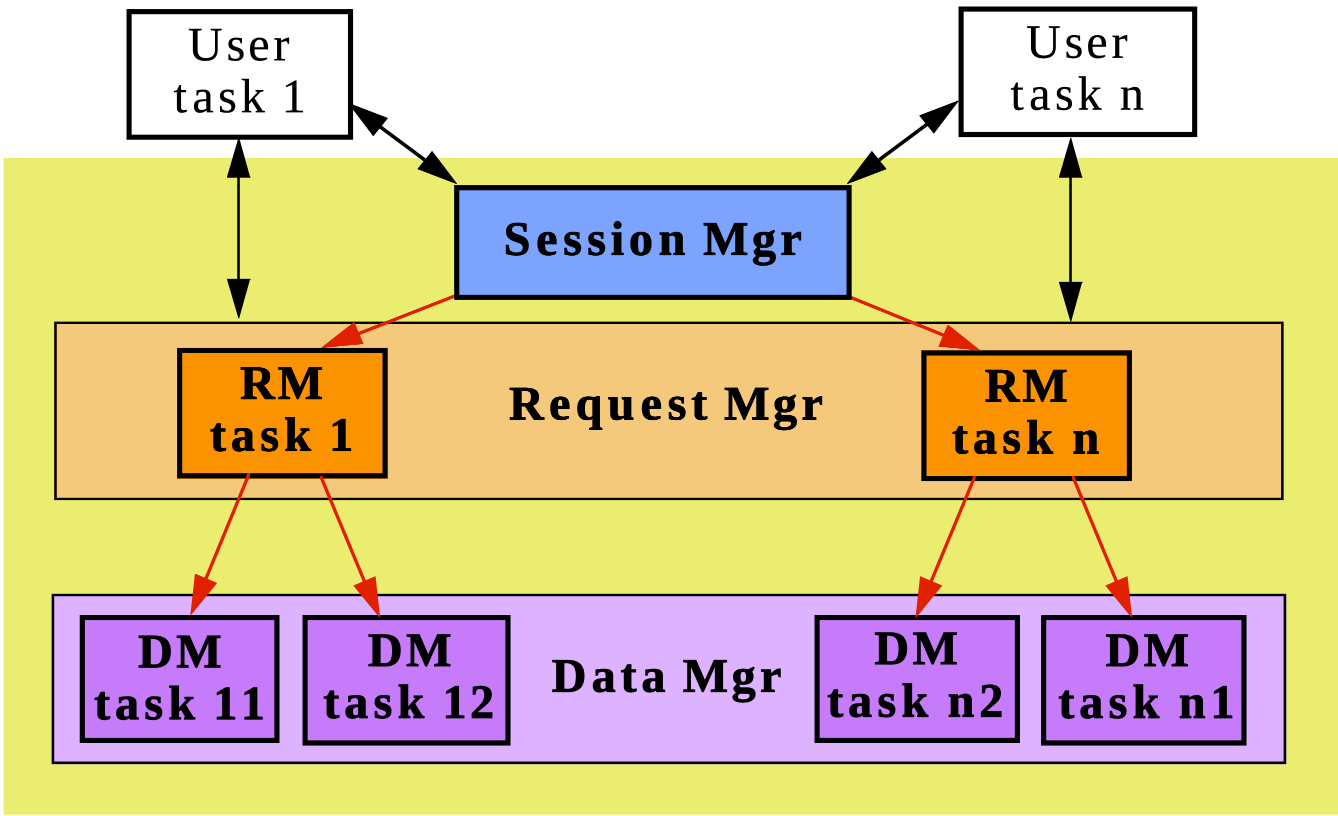
Functional Architecture of PDBS



Parallel DB 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

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Parallel System Architectures

- Multiprocessor architecture extremes
  - shared memory (shared everything)
  - shared nothing (message-passing)
- Intermediate architecture: shared-disk

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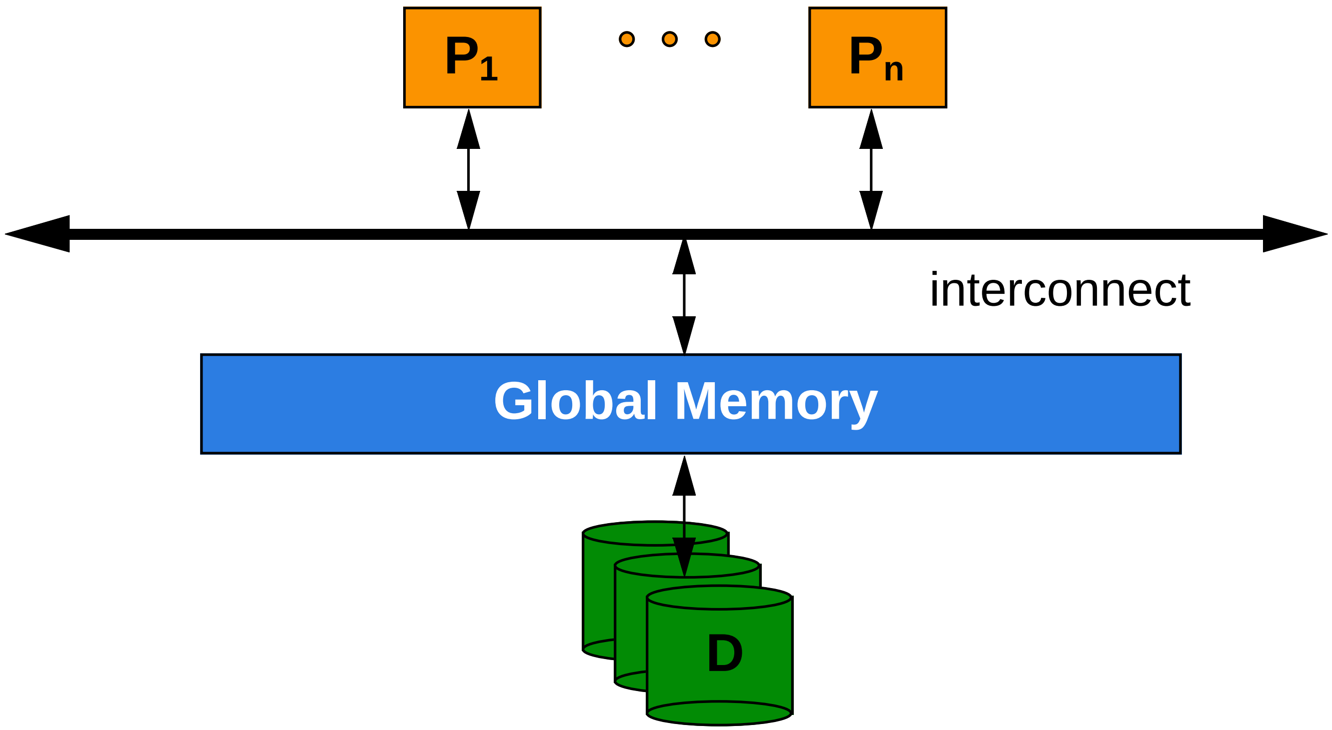
Shared-Memory Architecture



Examples: symmetric multiprocessors (Sequent, Encore, Bull's Escala), XPRS (U. of Berkeley), DBS3 (Bull)

- simplicity, load balancing, fast communication
- network cost, low extensibility, low availability

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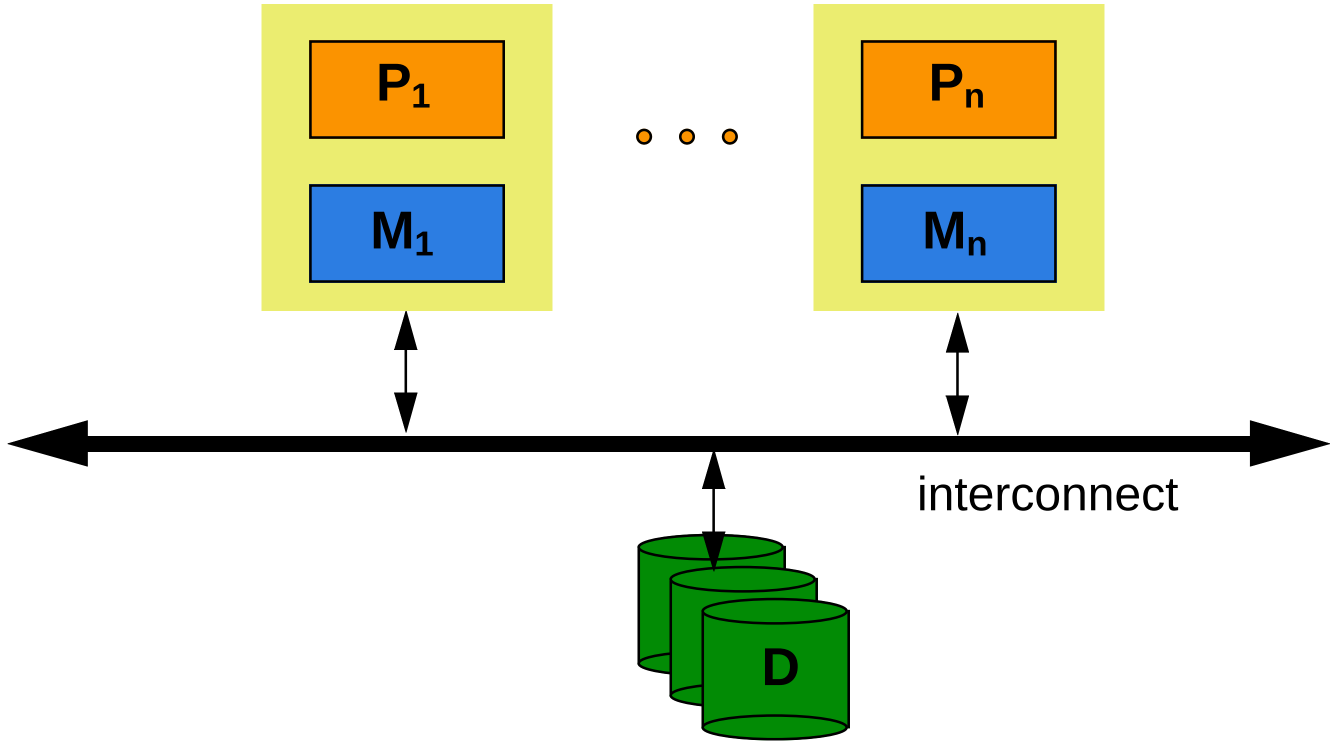
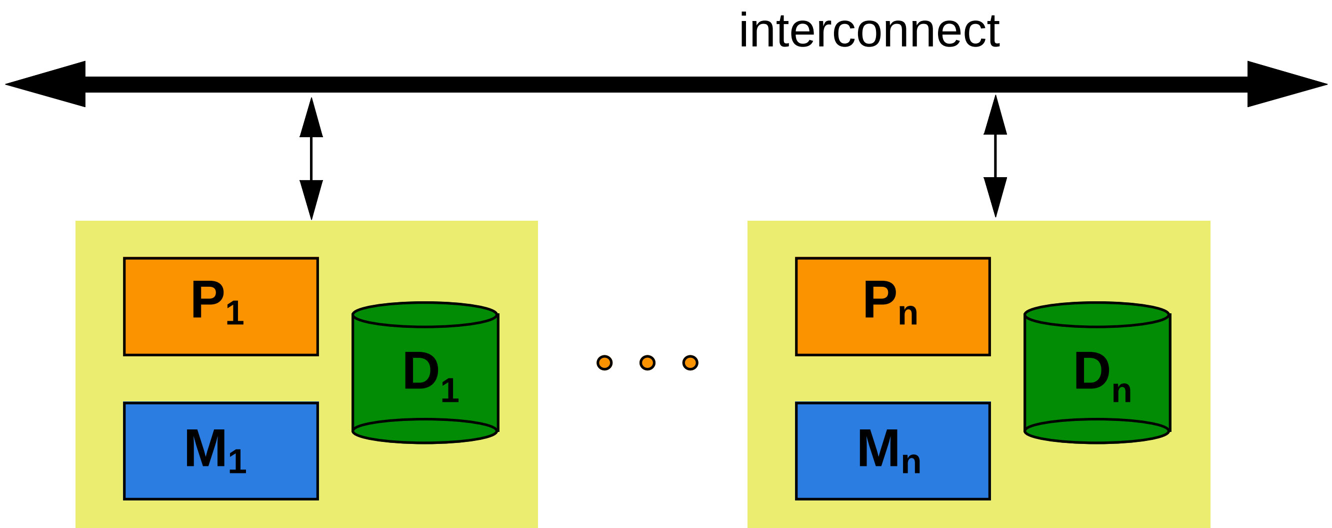
Shared-Disk Architecture



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 (ATT GIS), NonStopSQL (Tandem), Gamma (U. of Wisconsin), Bubba (MCC)

- cost, extensibility, availability
- complexity, difficult load balancing

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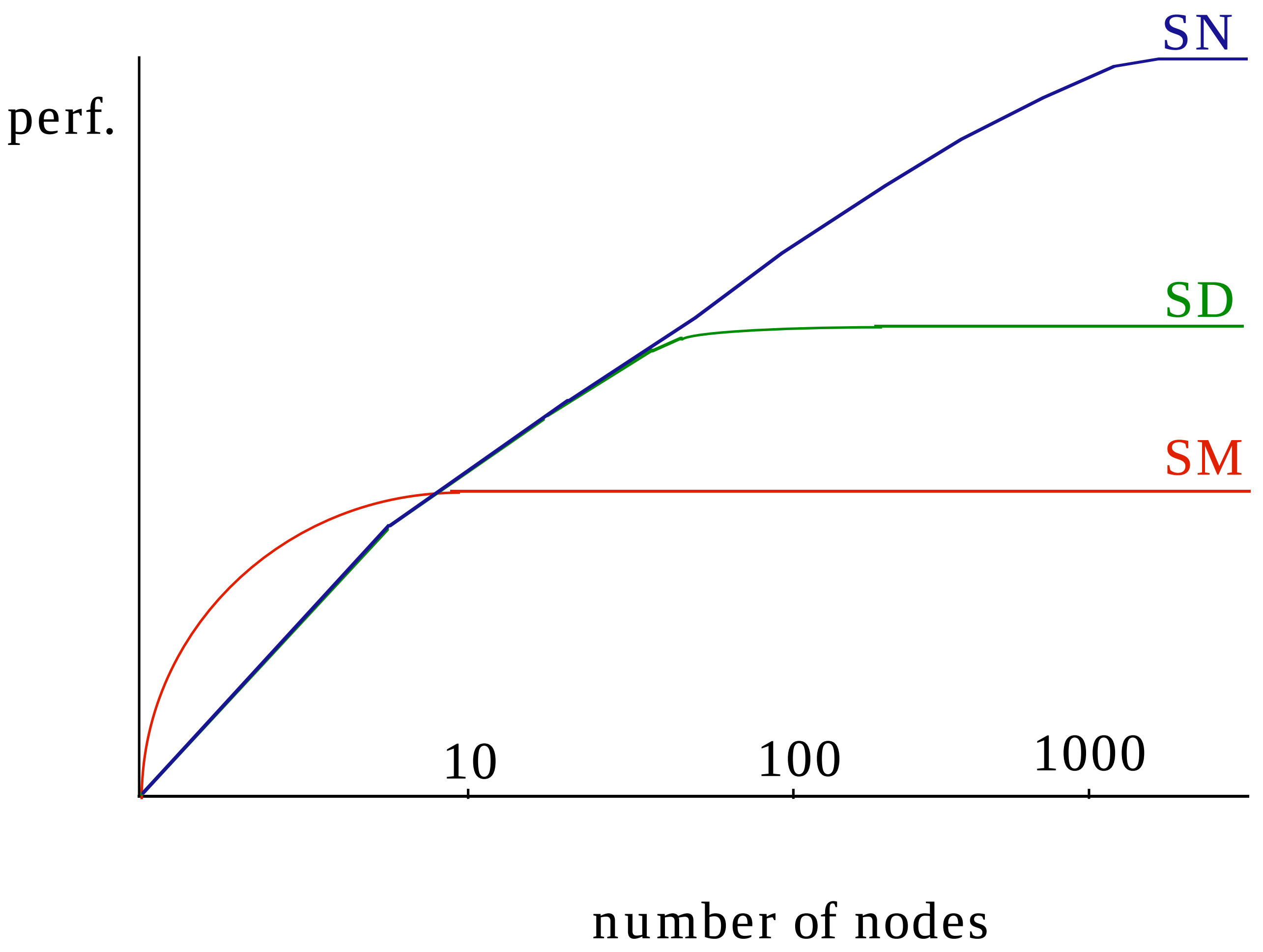
Performance Comparisons



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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
- Trend : single address space on distributed physical memory (KSR)
  - eases application portability
  - extensibility

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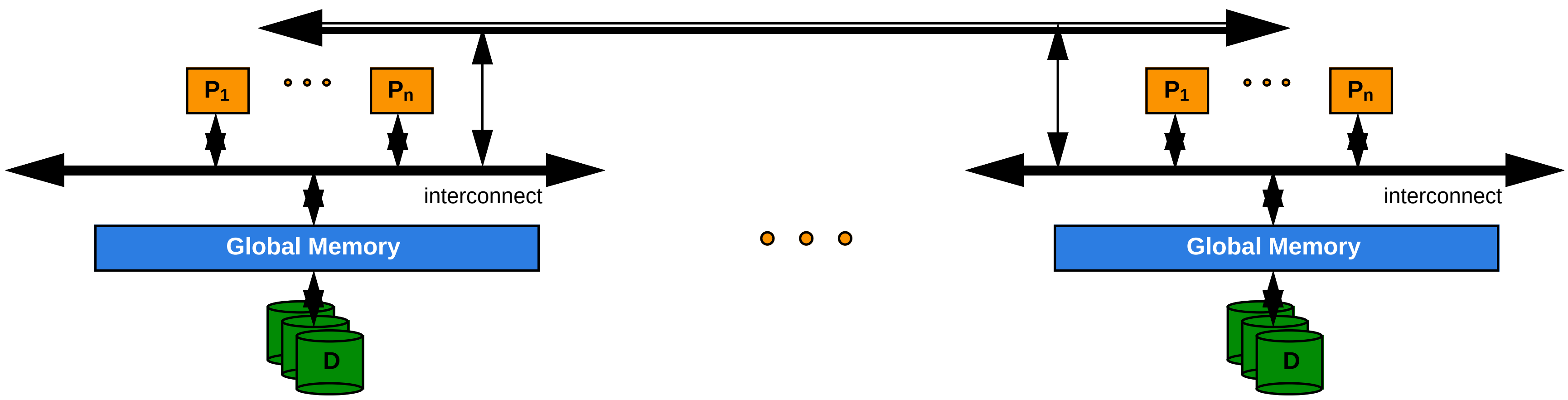
Cluster of SM Nodes



- 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)

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Basic 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 querie
- Transaction management
  - similar to distributed transaction management

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Parallel Data Placement

Parallel architecture
⇓
balance the load between all the nodes

Large volume of data
⇓
execute where the data is

⇓ ⇓

data placement determines performance

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Placement Alternatives

- Clustering
  - each relation entirely contained at one node
  - may minimize total amount of work (if all relevant relations at the same node)
- Declustering
  - each relation horizontally fragmented across all nodes by a hash function
  - may well minimize response time but increase total time

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Variable Declustering

- number of nodes of a relation (home) is a function of its size and access frequency
- varies dynamically for load balancing
- physical data placement known only at query run time ⇒ logical data placement needed at compile time

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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

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Placement Directory

- Performs two functions
  - f_1 (relname, placement attval) = lognode-id
  - f_2 (lognode-id) = phynode-id
- Implementation
  - round-robin (maps *i*-th elt 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
- In either case, the data structure for f_1 and f_2 should be available when needed at each node

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Join Processing

- Three basic join
  - 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

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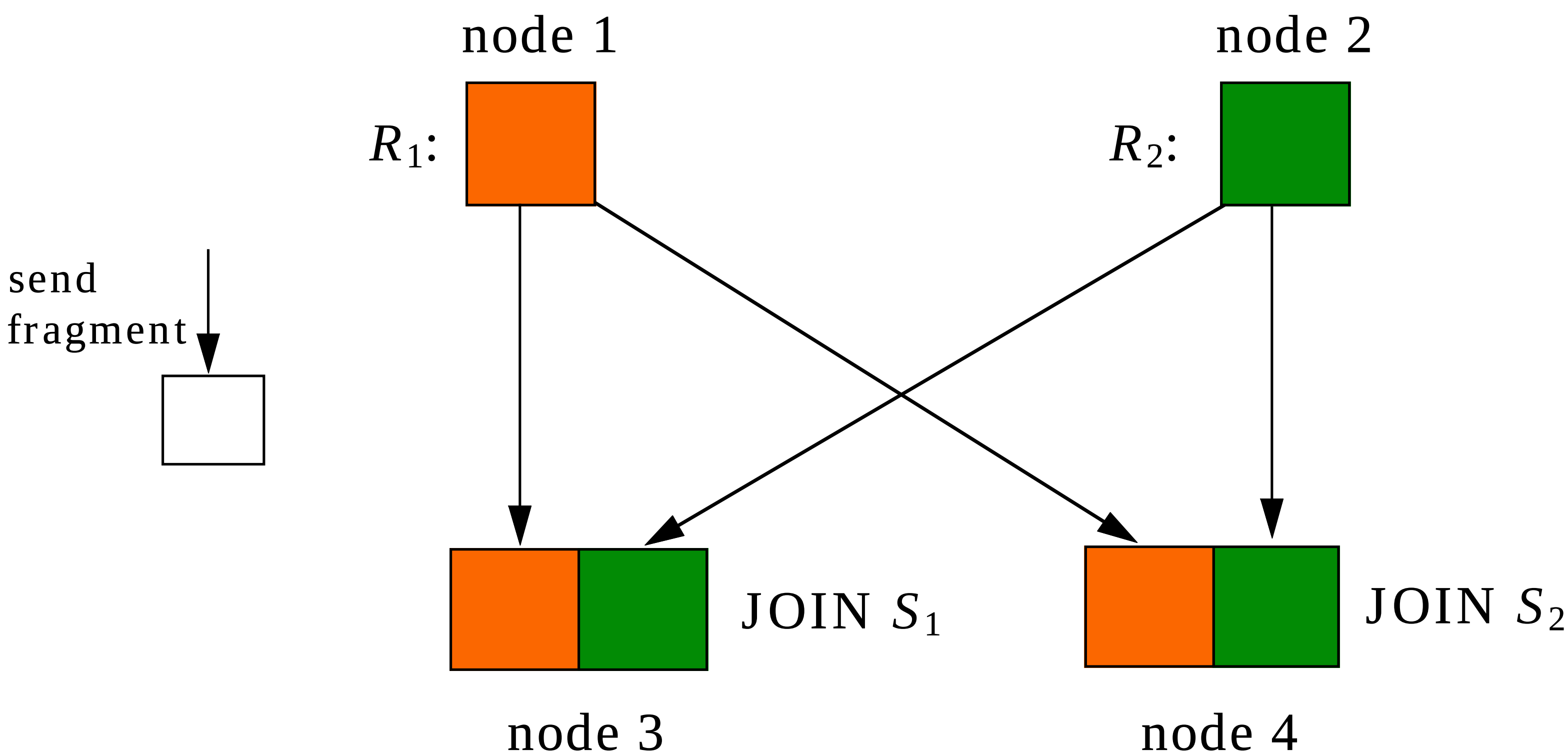
Parallel Nested Loop Join



$$R \text{ JOIN } S \rightarrow \text{UNION}_{i=1,n}(R \text{ JOIN } S_i)$$

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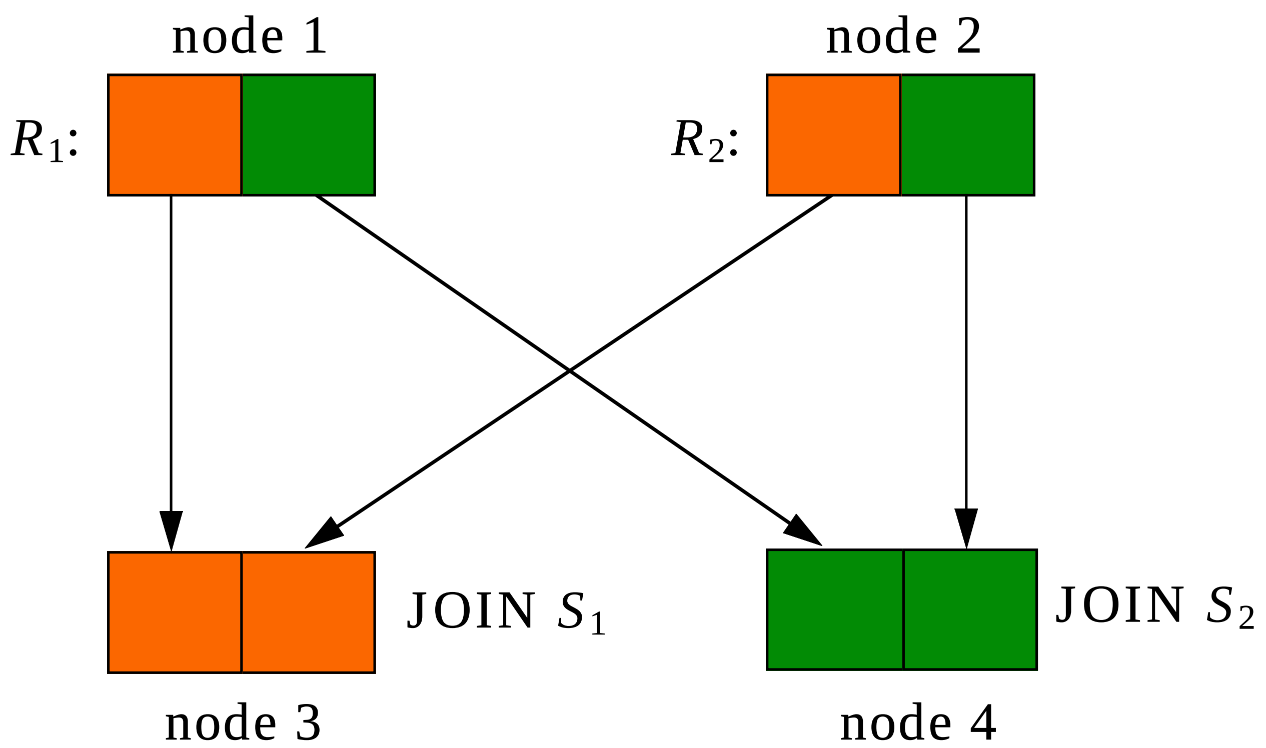
Parallel Associative Join



$$R \text{ JOIN } S \rightarrow \text{UNION}_{i=1,n}(R_i \text{ JOIN } S_i)$$

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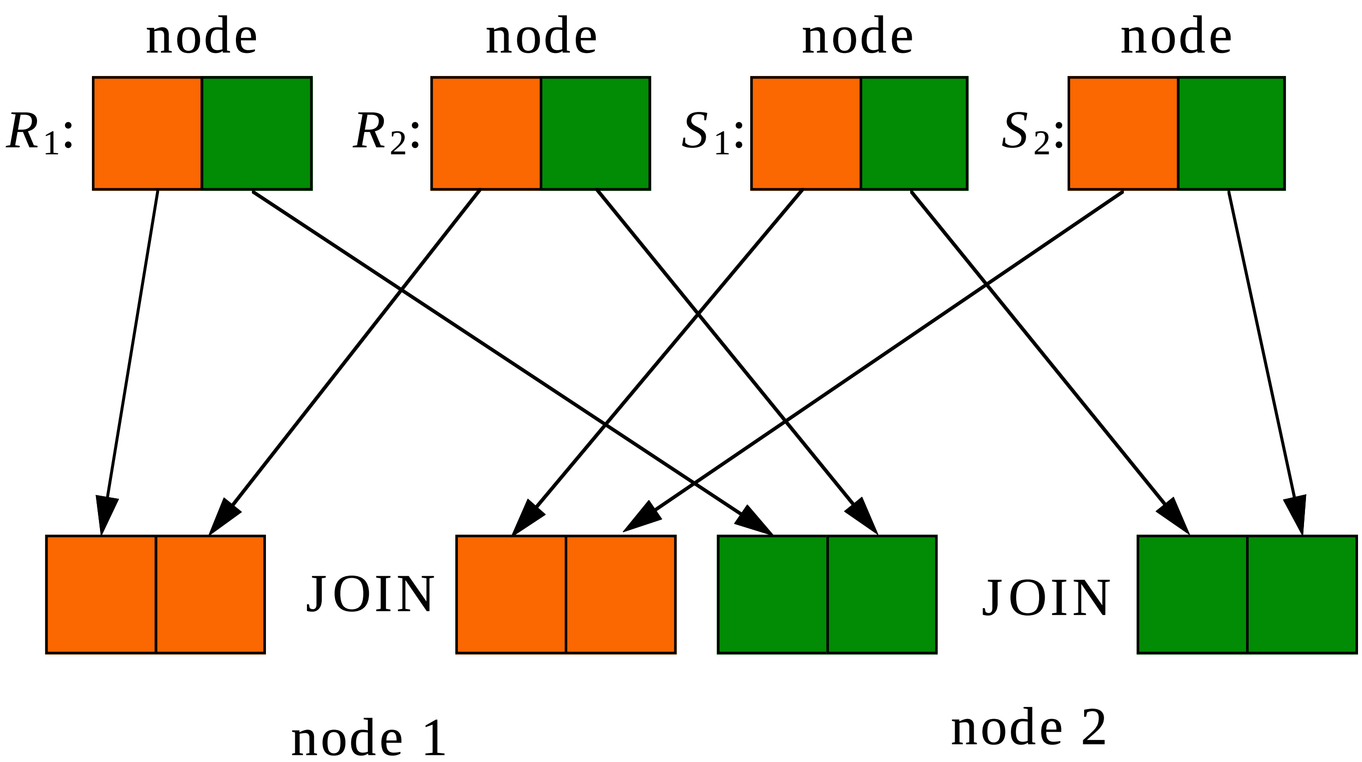
Parallel Hash Join



$$R \text{ JOIN } S \rightarrow \text{UNION}_{i=1,P}(R \text{ JOIN } S_i)$$

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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 processing 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. (declustering, indexes, etc.)
- statistics and cost functions

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Parallel Database Systems

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

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Open Research Problems

- Hybrid architectures,e.g.,SN composed of SM nodes
- OS support:using micro-kernels (Chorus, Mach)
- 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 decutive and object capabilities

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