CSE 544: Principles of Database Systems

Anatomy of a DBMS, Parallel Databases

Announcements

- Lecture on Thursday, May 2nd:
  - Moved to 9am-10:30am, CSE 403
- Paper reviews:
  - Anatomy paper was due yesterday; will discuss today in class
  - Join processing paper due Wednesday
- HW2 is due on Monday, May 6th
  - Lots of work! You should have already started!

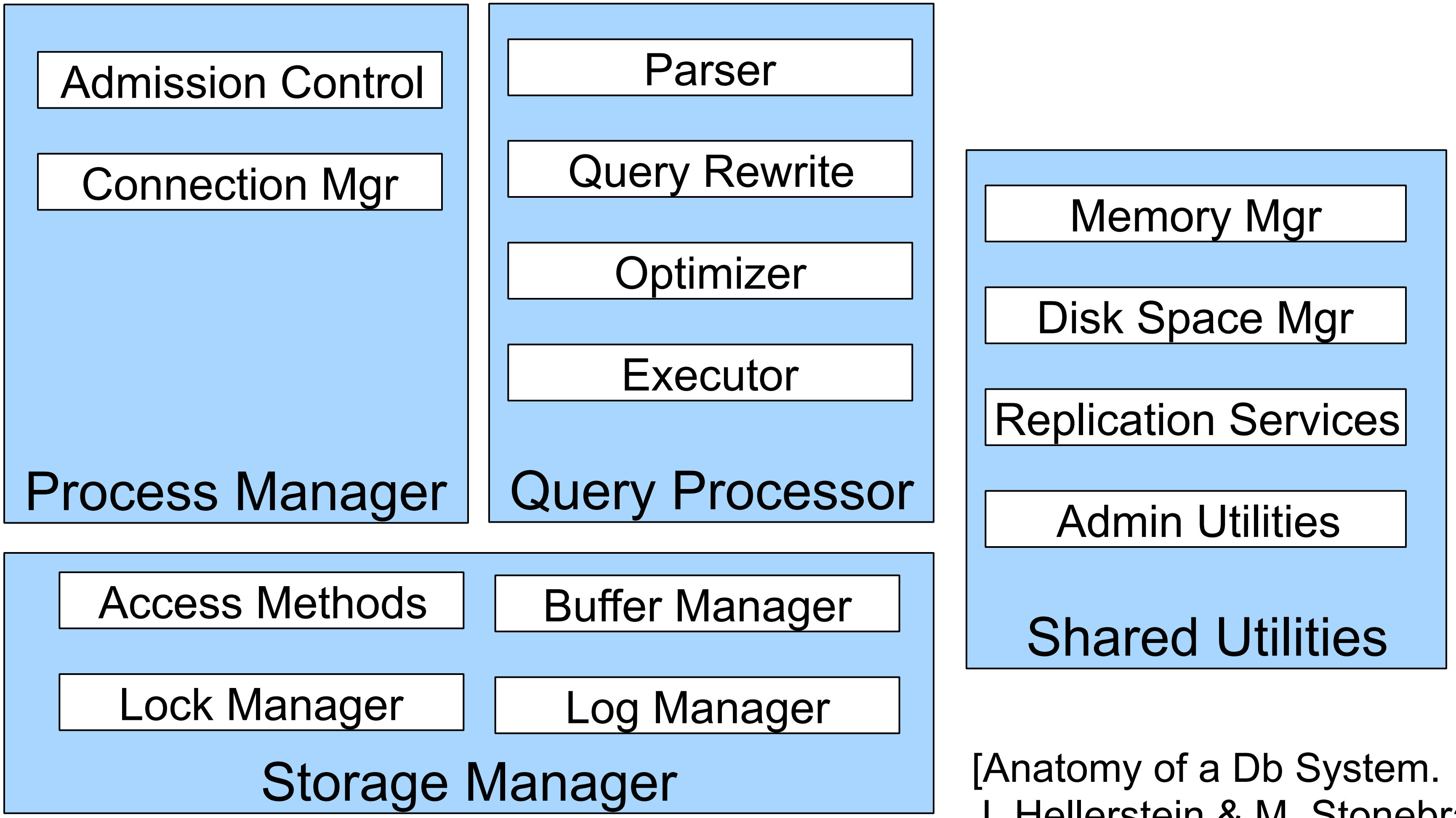
Overview of Today's Lecture

- Discuss in class the *Anatomy* paper
- Parallel databases (Chapter 22.1 – 22.5)

DMBS Architecture: Outline

- Main components of a modern DBMS
- Process models
- Storage models
- Query processor

DBMS Architecture



[Anatomy of a Db System.
J. Hellerstein & M. Stonebraker.
Red Book. 4ed.]

DMBS Architecture: Outline

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Process Model

Q: Why not simply queue all user requests, and serve them one at the time?

Process Model

Q: Why not simply queue all user requests, and serve them one at the time?

A: Because of the high disk I/O latency

Corollary: in a main memory db you can service transactions sequentially!

Alternatives

1. **Process per connection**
2. **Server process** (thread per connection)
   - OS threads or DBMS threads
3. **Server process with I/O process**

Process Per Connection

- **Overview**
  – DB server forks one process for each client connection

- **Advantages**
  – ?

- **Drawbacks**
  – ?

Process Per Connection

- **Overview**
  - DB server forks one process for each client connection
- **Advantages**
  - Easy to implement (OS time-sharing, OS isolation, debuggers, etc.)
- **Drawbacks**
  - Need OS-supported “shared memory” (for lock table, buffer pool)
  - Not scalable: memory overhead and expensive context switches

Server Process

- **Overview**
  - *Dispatcher* thread listens to requests, dispatches *worker* threads

- **Advantages**
  - ?
  - ?

- **Drawbacks**
  - ?

Server Process

- **Overview**
  - *Dispatcher* thread listens to requests, dispatches *worker* threads
- **Advantages**
  - Shared structures can simply reside on the heap
  - Threads are lighter weight than processes: memory, context switching
- **Drawbacks**
  - Concurrent programming is hard to get right (race conditions, deadlocks)
  - Subtle API thread differences across different operating systems make portability difficult

Sever Process with I/O Process

Problem: entire process blocks on synchronous I/O calls

- Solution 1: Use separate process(es) for I/O tasks
- Solution 2: Modern OS provide asynchronous I/O

DBMS Threads vs OS Threads

- **Why do DBMSs implement their own threads?**

DBMS Threads vs OS Threads

- **Why do DBMSs implement their own threads?**
  - Legacy: originally, there were no OS threads
  - Portability: OS thread packages are not completely portable
  - Performance: fast task switching
- **Drawbacks**
  - Replicating a good deal of OS logic
  - Need to manage thread state, scheduling, and task switching
- **How to map DBMS threads onto OS threads or processes?**
  - Rule of thumb: one OS-provided dispatchable unit per physical device
  - See page 9 and 10 of Hellerstein and Stonebraker's paper

Historical Perspective (1981)

In 1981:

- No OS threads
- No shared memory between processes
  - Makes one process per user hard to program
- Some OSs did not support many to one communication
  - Thus forcing the one process per user model
- No asynchronous I/O
  - But inter-process communication expensive
  - Makes the use of I/O processes expensive

- Common original design: DBMS threads, frequently yielding control to a scheduling routine

Commercial Systems

- Oracle
  - Unix default: process-per-user mode
  - Unix: DBMS threads multiplexed across OS processes
  - Windows: DBMS threads multiplexed across OS threads

- DB2
  - Unix: process-per-user mode
  - Windows: OS thread-per-user

- SQL Server
  - Windows default: OS thread-per-user
  - Windows: DBMS threads multiplexed across OS threads

DMBS Architecture: Outline

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- Storage models
- Query processor

Storage Model

- **Problem**: DBMS needs spatial and temporal control over storage
  - Spatial control for performance
  - Temporal control for correctness and performance

- **Alternatives**
  - Use “raw” disk device interface directly
  - Use OS files

Spatial Control
Using “Raw” Disk Device Interface

- **Overview**
  - DBMS issues low-level storage requests directly to disk device

- **Advantages**
  - ?
  - ?

- **Disadvantages**
  - ?

Spatial Control
Using "Raw" Disk Device Interface

- **Overview**
  - DBMS issues low-level storage requests directly to disk device
- **Advantages**
  - DBMS can ensure that important queries access data sequentially
  - Can provide highest performance
- **Disadvantages**
  - Requires devoting entire disks to the DBMS
  - Reduces portability as low-level disk interfaces are OS specific
  - Many devices are in fact "virtual disk devices"
    - SAN = storage area network; NAS = network attached device

Spatial Control Using OS Files

- **Overview**
  - DBMS creates one or more very large OS files
- **Advantages**
  - ?
- **Disadvantages**
  - ?

Spatial Control Using OS Files

- **Overview**
  - DBMS creates one or more very large OS files
- **Advantages**
  - Allocating large file on empty disk can yield good physical locality
- **Disadvantages**
  - Must control the timing of writes for *correctness* and *performance*
  - OS may further delay writes
  - OS may lead to double buffering, leading to unnecessary copying
  - DB must fine tune when the log tail is flushed to disk

Historical Perspective (1981)

- Recognizes mismatch problem between OS files and DBMS needs
  - If DBMS uses OS files and OS files grow with time, blocks get scattered
  - OS uses tree structure for files but DBMS needs its own tree structure

- Other proposals at the time
  - Extent-based file systems
  - Record management inside OS

Commercial Systems

- Most commercial systems offer both alternatives
  - Raw device interface for peak performance
  - OS files more commonly used

- In both cases, we end-up with a DBMS file abstraction implemented on top of OS files or raw device interface

Temporal Control
Buffer Manager

- Correctness problems
  - DBMS needs to control when data is written to disk in order to provide **transactional semantics** (we will study transactions later)
  - OS buffering can **delay writes**, causing problems when crashes occur

- Performance problems
  - OS optimizes buffer management for general workloads
  - DBMS understands its workload and can do better
  - Areas of possible optimizations
    - Page replacement policies
    - Read-ahead algorithms (physical vs logical)
    - Deciding when to flush tail of write-ahead log to disk

Historical Perspective (1981)

- Problems with OS buffer pool management long recognized
  - Accessing OS buffer pool involves an expensive system call
  - Faster to access a DBMS buffer pool in user space
  - LRU replacement does not match DBMS workload
  - DBMS can do better
  - OS can do only sequential prefetching, DBMS knows which page it needs next and that page may not be sequential
  - DBMS needs ability to control when data is written to disk

Commercial Systems

- DBMSs implement their own buffer pool managers
- Modern filesystems provide good support for DBMSs
  - Using large files provides good spatial control
  - Using interfaces like the mmap suite
    - Provides good temporal control
    - Helps avoid double-buffering at DBMS and OS levels

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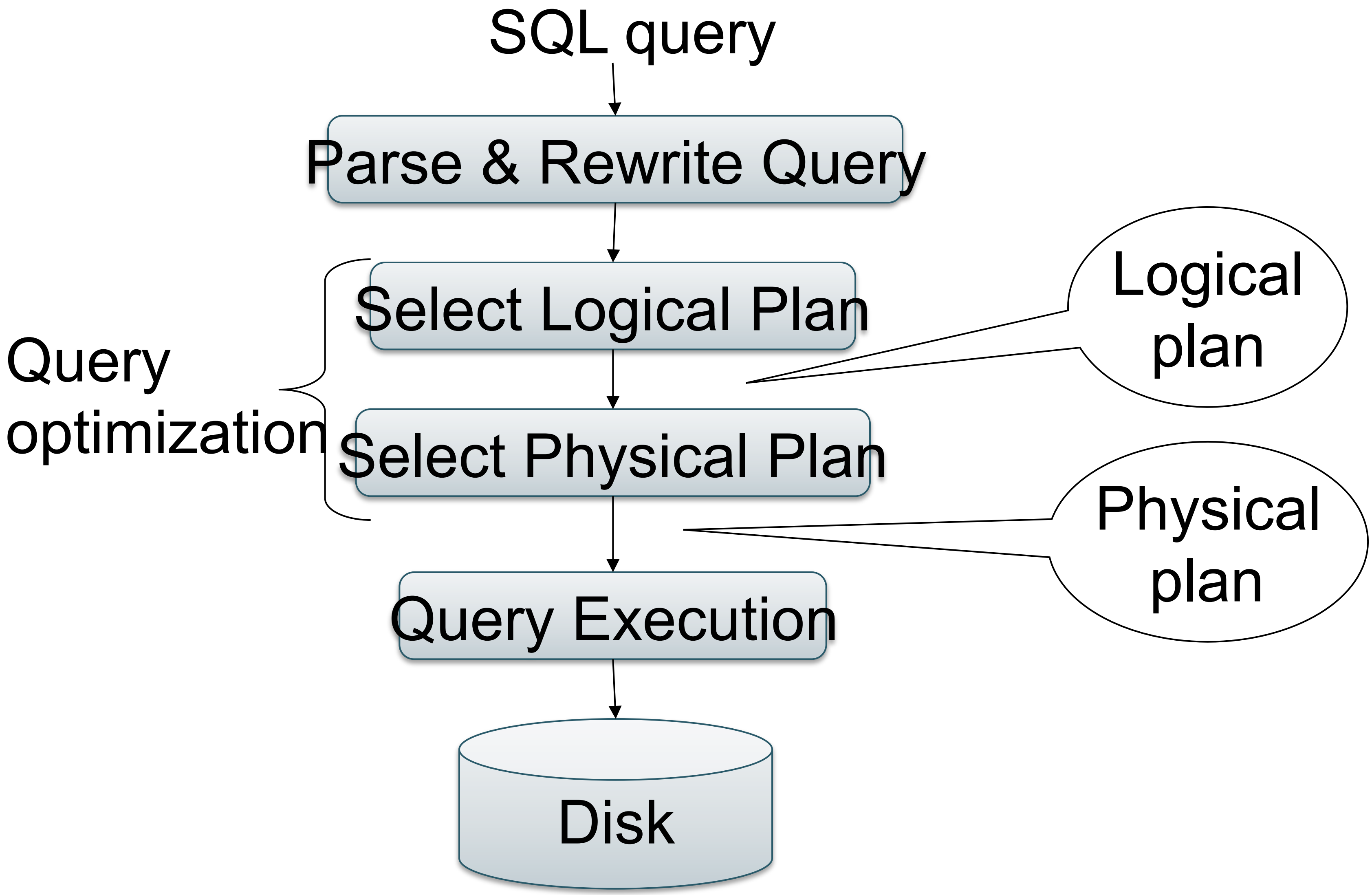
Query Processor



Query Processor

1. Parsing and Authorization
   – Catalog management
2. Query rewrite
   – View inlining, etc
3. Optimizer
   – System R v.s. Volcano/Cascades style
   – Selectivity estimation
4. Query execution
   – Iterator model: init(), get_next(), close()
   – What is the "Halloween problem"?
5. Access methods
   – Pass a *search predicate* (SARG) to init()

Query Compilation/Recompilation

[Chaudhuri]

The “prepare” statement must choose a plan without knowing the actual predicate values. Discuss the *Anatomy* paper

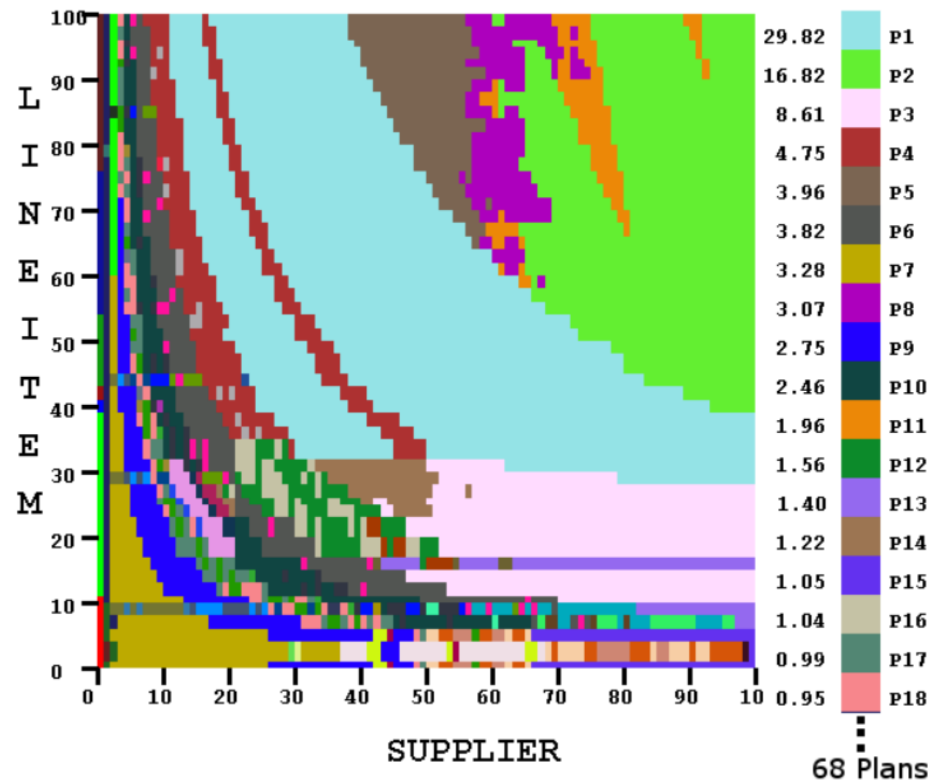


Figure 1: Plan diagram for TPC-H Query 8

Parallel Databases

Parallel v.s. Distributed Databases

- Parallel database system:
  - Improve performance through parallel implementation
  - Will discuss in class
- Distributed database system:
  - Data is stored across several sites, each site managed by a DBMS capable of running independently
  - Will not discuss in class

Parallel DBMSs

- Goal
  – Improve performance by executing multiple operations in parallel
- Key benefit
  – Cheaper to scale than relying on a single increasingly more powerful processor
- Key challenge
  – Ensure overhead and contention do not kill performance

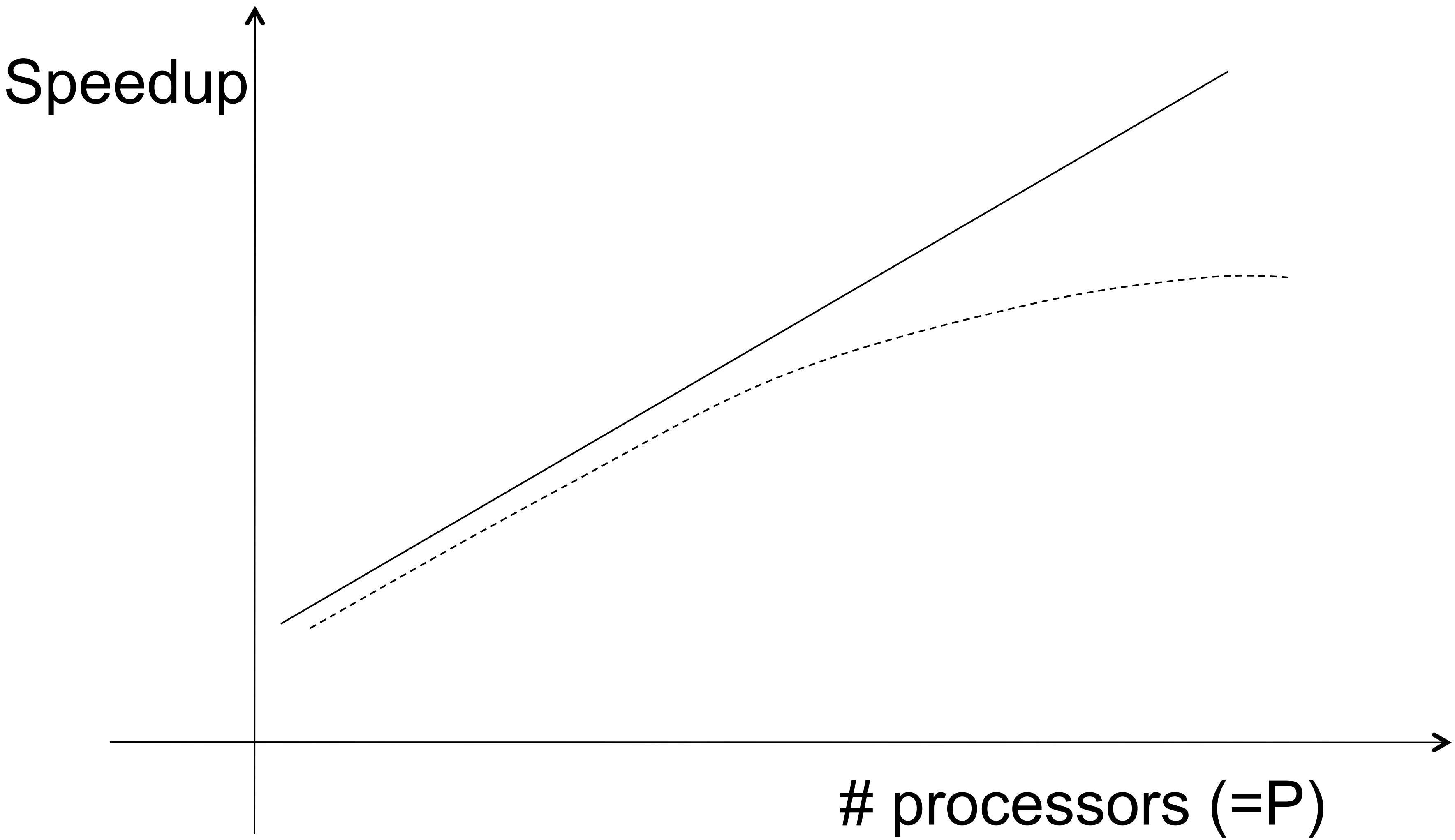
Performance Metrics for Parallel DBMSs

- Speedup
  - More processors ➔ higher speed

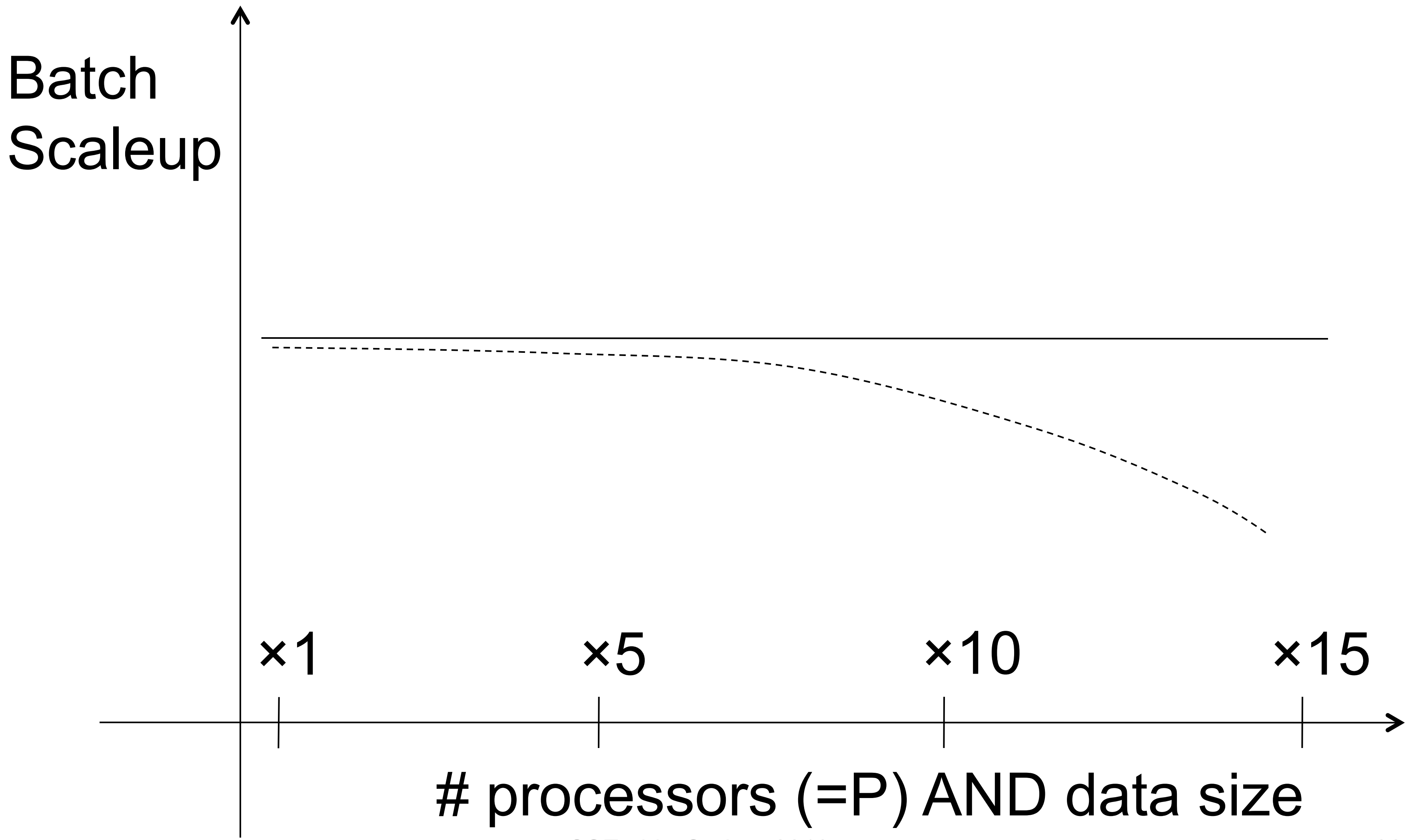
- Scaleup
  - More processors ➔ can process more data

- Batch scaleup/speedup
  - Decision Support: individual query should run faster (speedup) or same speed (scaleup)
- Transaction scaleup/speedup
  - OLTP: Transactions Per Second (TPS) should increase (speedup) or should stay constant (scaleup)

Linear v.s. Non-linear Speedup



Linear v.s. Non-linear Scaleup



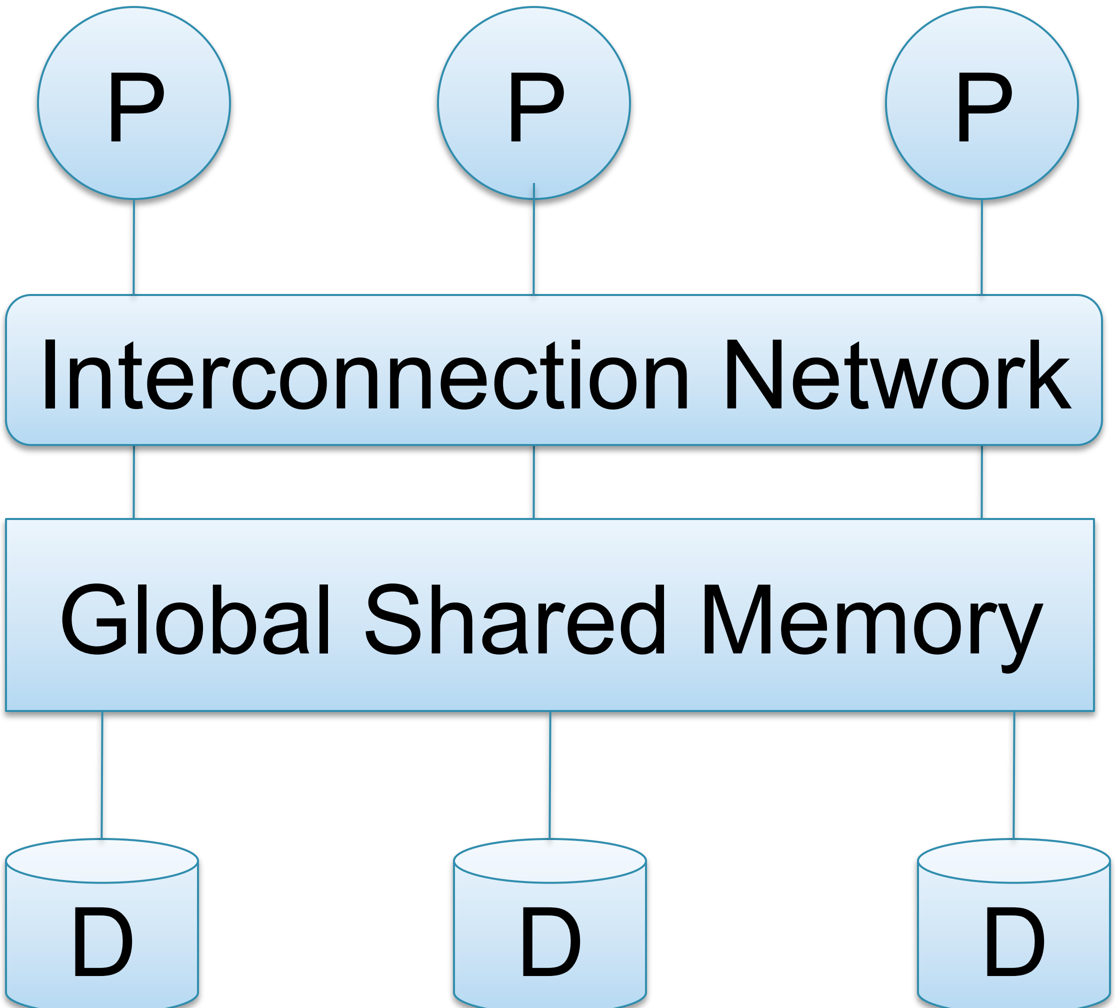
Challenges to Linear Speedup and Scaleup

- Startup cost
  - Cost of starting an operation on many processors
- Interference
  - Contention for resources between processors
- Skew
  - Slowest processor becomes the bottleneck

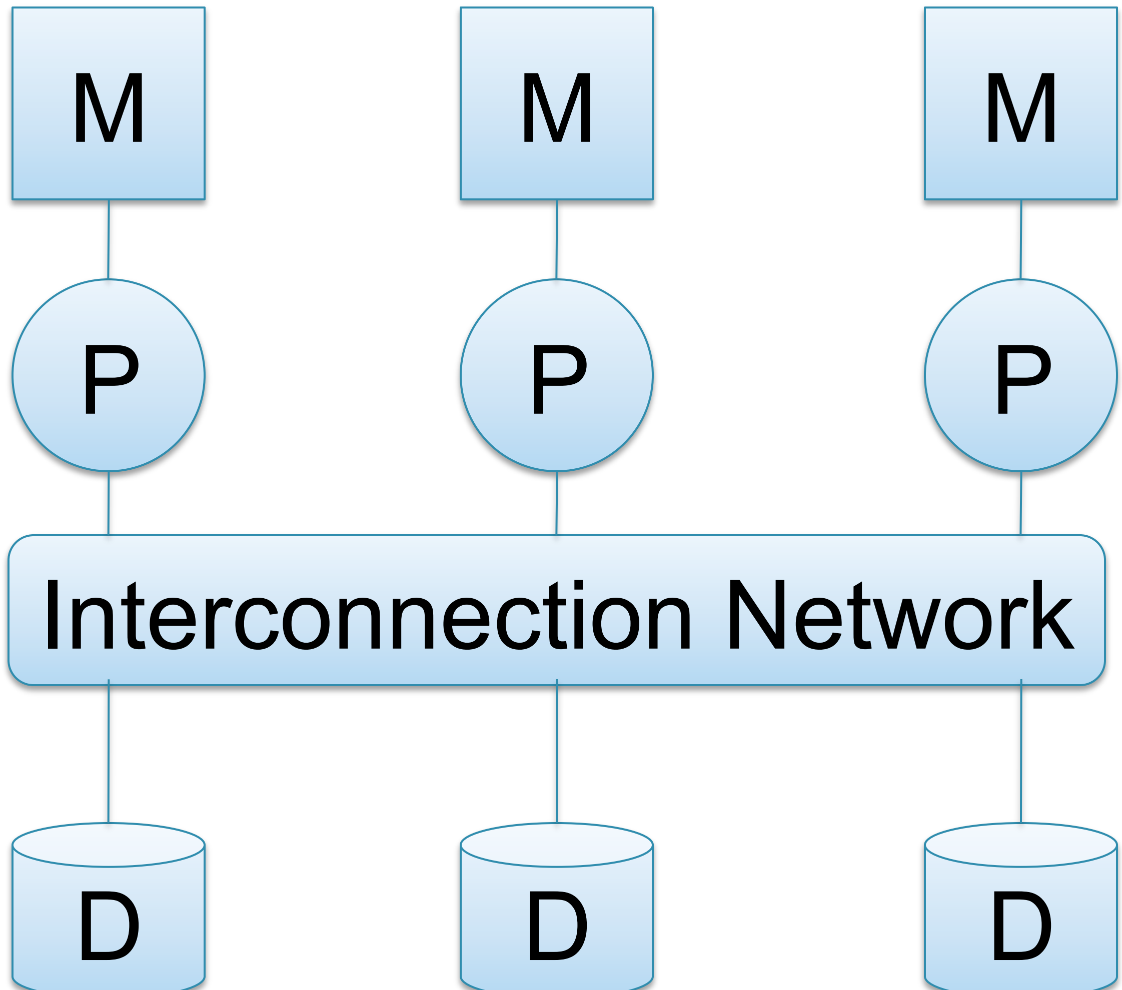
Architectures for Parallel Databases

- Shared memory
- Shared disk
- Shared nothing

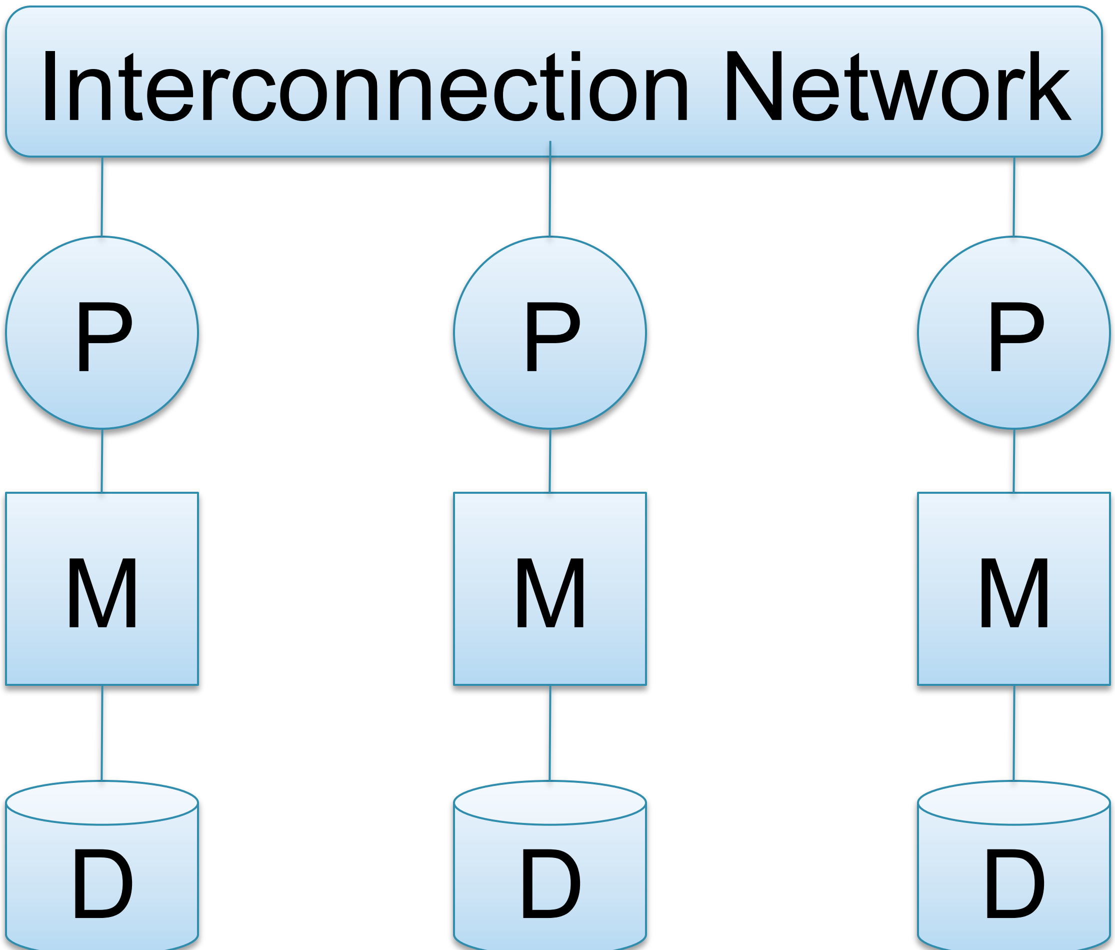
Shared Memory



Shared Disk



Shared Nothing



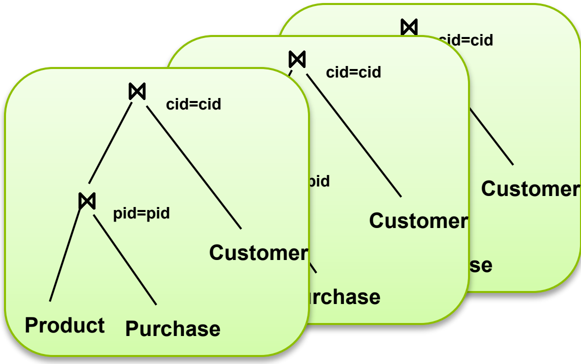
Shared Nothing

- Most scalable architecture
  - Minimizes interference by minimizing resource sharing
  - Can use commodity hardware
  - Terminology: processor = server = node
  - P = number of nodes

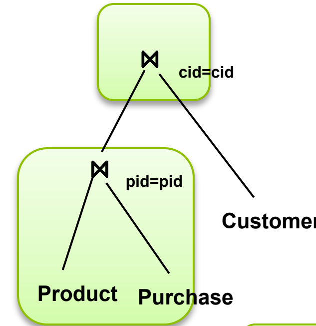
- Also most difficult to program and manage

Taxonomy

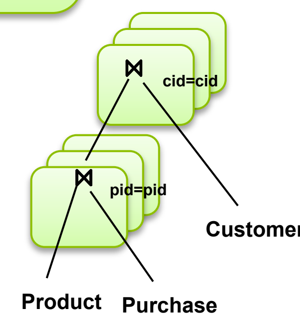
- Inter-query parallelism
  - Transaction per node
  - OLTP



- Inter-operator parallelism
  - Operator per node
  - Both OLTP and Decision Support



- Intra-operator parallelism
  - Operator on multiple nodes
  - Decision Support



We study only intra-operator parallelism: most scalable

Review in Class

Basic query processing on one node.

Given relations R(A,B) and S(B, C), compute:

- Selection: $\sigma_{A=123}(R)$
- Group-by: $\gamma_{A,sum(B)}(R)$
- Join: $R \bowtie S$

Horizontal Data Partitioning

- Partition a table $R(\underline{K}, A, B, C)$ into P chunks $R_1, \ldots, R_P$, stored at the P nodes
- Block Partition: $size(R_1) \approx \ldots \approx size(R_P)$
- Hash partitioned on attribute A:
  - Tuple t goes to chunk $i = (h(t.A) \bmod P) + 1$
- Range partitioned on attribute A:
  - Partition the range of A into $-\infty = v_0 < v_1 < \ldots < v_P = \infty$
  - Tuple t goes to chunk i, if $v_{i-1} \leq t.A < v_i$

Parallel GroupBy

R(<u>K</u>,A,B,C), discuss in class how to compute these GroupBy's, for each of the partitions

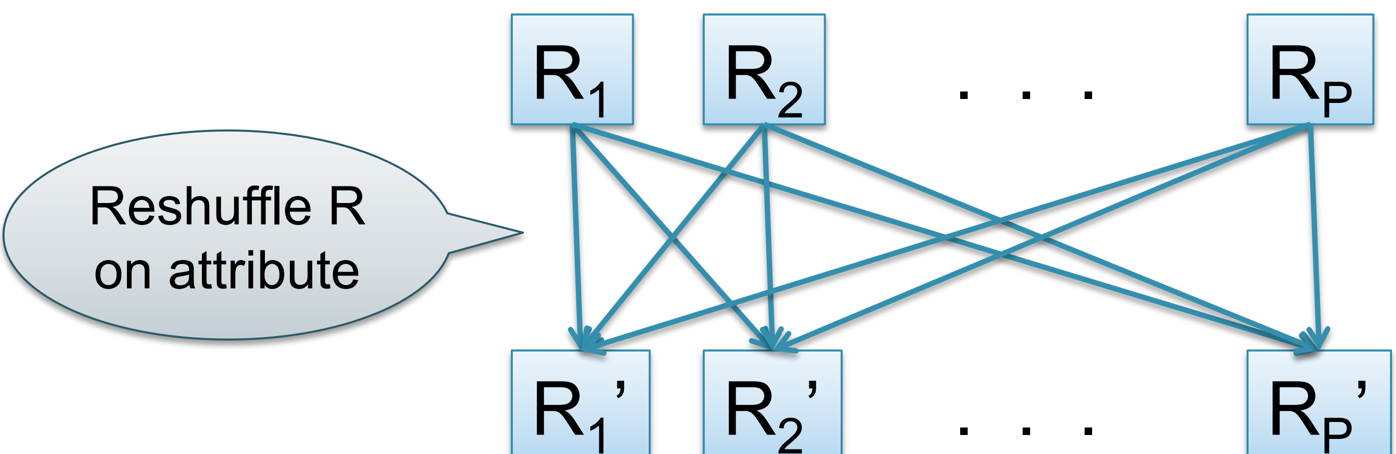
- $\gamma_{A,sum(C)}(R)$

- $\gamma_{B,sum(C)}(R)$

Parallel GroupBy

$\gamma_{A,sum(C)}(R)$

- If R is partitioned on A, then each node computes the group-by locally
- Otherwise, hash-partition $R(\underline{K},A,B,C)$ on A, then compute group-by locally:



Speedup and Scaleup

- The runtime is dominated by the time to read the chunks from disk, i.e. size(R_i)
- If we double the number of nodes P, what is the new running time of $\gamma_{A,sum(C)}(R)$?
- If we double both P and the size of the relation R, what is the new running time?

Uniform Data v.s. Skewed Data

- Uniform partition:
  - $size(R_1) \approx \ldots \approx size(R_P) \approx \quad size(R) / P$
  - Linear speedup, constant scaleup

- Skewed partition:
  - For some i, $size(R_i) \gg size(R) / P$
  - Speedup and scaleup will suffer

Uniform Data v.s. Skewed Data

- Let R(<u>K</u>,A,B,C); which of the following partition methods may result in skewed partitions?

- Block partition

- Hash-partition
  - On the key K
  - On the attribute A

- Range-partition
  - On the key K
  - On the attribute A

Uniform Data v.s. Skewed Data

- Let R(K,A,B,C); which of the following partition methods may result in skewed partitions?

- Block partition

  Uniform

- Hash-partition
  - On the key K

    Uniform

    Assuming uniform hash function
  - On the attribute A

    May be skewed

    E.g. when all records have the same value of the attribute A, then all records end up in the same partition

- Range-partition
  - On the key K
  - On the attribute A

    May be skewed

    Difficult to partition the range of A uniformly.

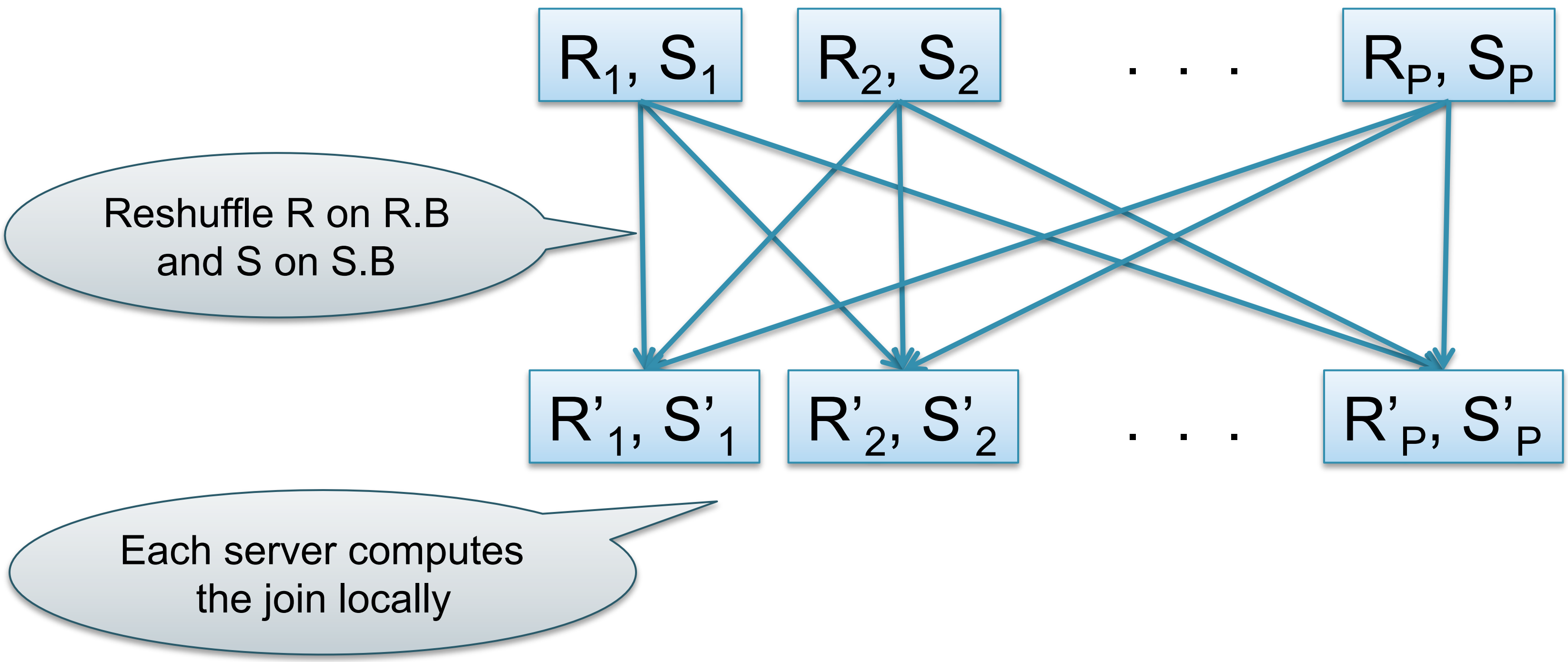
Parallel Join

- In class: compute $R(A,B) \bowtie S(B,C)$

R_1, S_1 | R_2, S_2 | . . . | R_P, S_P

Parallel Join

- In class: compute $R(A,B) \bowtie S(B,C)$



Parallel Query Plans

- Same relational operators
- Add special split and merge operators
  - Handle data routing, buffering, and flow control
- Example: exchange operator
  - Inserted between consecutive operators in the query plan