Database Systems CSE 414

Lectures 23: Parallel Databases

Announcement

- WQ7 due tonight
  - (was due yesterday)
- HW7 due on Wednesday
- HW8 (last!) on Spark
  - will be posted later this week

Why compute in parallel?

- Multi-cores:
  - Most processors have multiple cores
  - This trend will increase in the future
- Big data: too large to fit in main memory
  - Distributed query processing on 100-1000 servers
  - Widely available now using cloud services

Big Data

- Companies, organizations, scientists have data that is **too big (**and sometimes too complex) to be managed without changing tools and processes
- Complex data processing:
  - Decision support queries (SQL w/ aggregates)
  - Machine learning (adds linear algebra and iteration)

Two Kinds to Parallel Data Processing

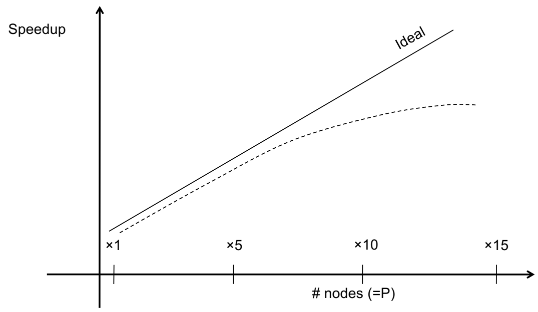
- Parallel databases, developed starting with the 80s (this lecture)
  - OLTP (Online Transaction Processing)
  - OLAP (Online Analytic Processing, or Decision Support)
- General purpose distributed processing: MapReduce, Spark
  - Mostly for Decision Support Queries

Performance Metrics for Parallel DBMSs

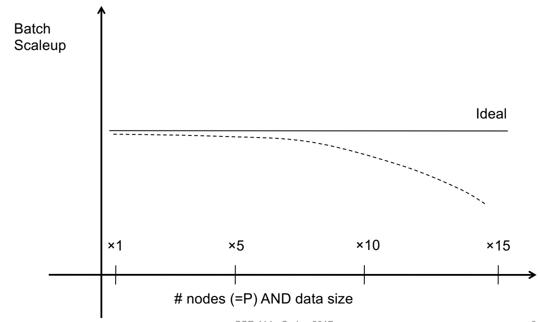
P = the number of nodes (processors, computers)

- Speedup:
  - More nodes, same data ➔ higher speed
- Scaleup:
  - More nodes, more data ➔ same speed
- OLTP: “Speed” = transactions per second (TPS)
- Decision Support: “Speed” = query time

Linear v.s. Non-linear Speedup



Linear v.s. Non-linear Scaleup



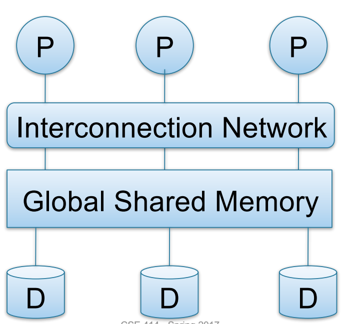
Challenges to Linear Speedup and Scaleup

- Startup cost
  – Cost of starting an operation on many nodes
- Interference
  – Contention for resources between nodes
- Stragglers
  – Slowest node becomes the bottleneck

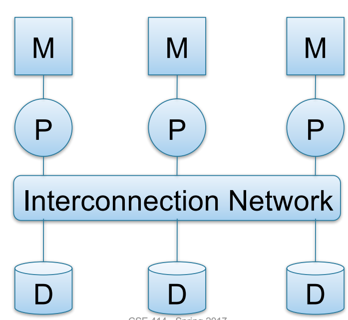
Architectures for Parallel Databases

- Shared memory
- Shared disk
- Shared nothing

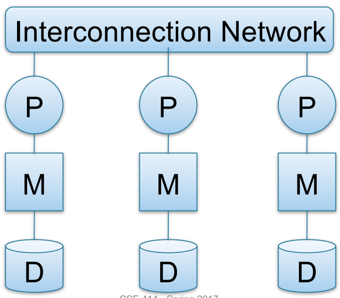
Shared Memory



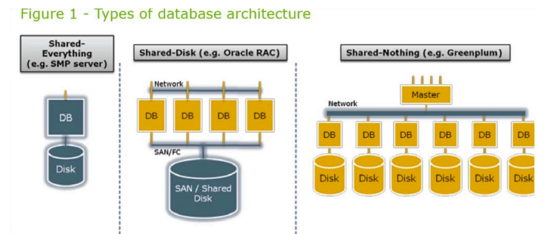
Shared Disk



Shared Nothing



A Professional Picture…



From: Greenplum (now EMC) Database Whitepaper

SAN = "Storage Area Network"

Shared Memory

- Nodes share both RAM and disk
- Dozens to hundreds of processors

Example: SQL Server runs on a single machine and can leverage many threads to get a query to run faster (see query plans)

- *Easier* to program and easy to use
- But very expensive to scale: last remaining cash cows in the hardware industry

Shared Disk

- All nodes access the same disks
- Found in the largest "single-box" (non-cluster) multiprocessors

Oracle dominates this class of systems.

Characteristics:
- Also hard to scale past a certain point: existing deployments typically have fewer than 10 machines

Shared Nothing

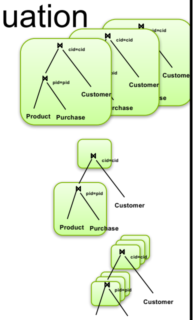
- Cluster of machines on high-speed network
- Each machine has its own memory and disk:
  - lowest contention

NOTE: Because all machines today have many cores and many disks, then shared-nothing systems typically run many "nodes" on a single physical machine.

Characteristics:
- Today, this is the most scalable architecture.
- Most difficult to administer and tune.

We discuss only Shared Nothing in class

Approaches to Parallel Query Evaluation



- 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

Single Node Query Processing (Review)

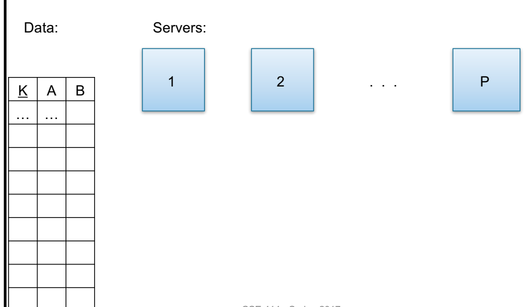
Given relations R(A,B) and S(B, C), no indexes:

- Selection: $\sigma_{A=123}(R)$
  - Scan file R, select records with A=123
- Group-by: $\gamma_{A,sum(B)}(R)$
  - Scan file R, insert into a hash table using attr. A as key
  - When a new key is equal to an existing one, add B to the value
- Join: $R \bowtie S$
  - Scan file S, insert into a hash table using attr. B as key
  - Scan file R, probe the hash table using attr. B

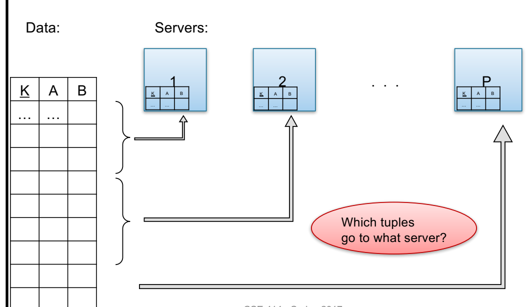
Distributed Query Processing

- Data is horizontally **partitioned** across many servers
- Operators may require data reshuffling
  - not all the needed data is in one place

Horizontal Data Partitioning



Horizontal Data Partitioning



Horizontal Data Partitioning

- Block Partition:
  - Partition tuples arbitrarily s.t. $size(R_1) \approx \ldots \approx size(R_P)$
- Hash partitioned on attribute A:
  - Tuple t goes to chunk i, where i = h(t.A) mod 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 $v_{i-1} < t.A < v_i$

Parallel GroupBy

Data: R(K,A,B,C)

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

How can we compute in each case?

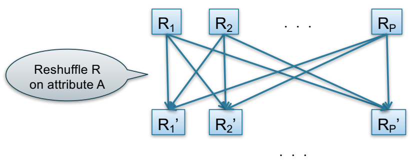
- R is hash-partitioned on A — easy case!
- R is block-partitioned
- R is hash-partitioned on K

Parallel GroupBy

Data: R(<u>K</u>,A,B,C)

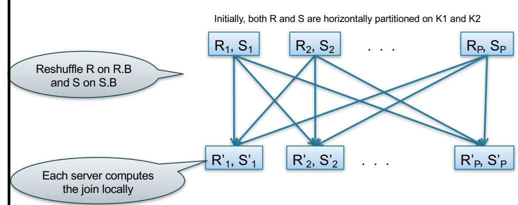
Query: $\gamma_{A,sum(C)}(R)$

- R is block-partitioned or hash-partitioned on K



Parallel Join

- Data: R(<u>K1</u>,A, B), S(<u>K2</u>, B, C)
- Query: R(<u>K1</u>,A,B) ⋈ S(<u>K2</u>,B,C)



Data: R(<u>K1</u>,A, B), S(<u>K2</u>, B, C)

Query: R(<u>K1</u>,A,B) ⋈ S(<u>K2</u>,B,C)

Partition

M1: R1

K1	B
1	20
2	50

M1: S1

K2	B
101	50
102	50

M2: R2

K1	B
3	20
4	20

M2: S2

K2	B
201	20
202	50

Shuffle

Local Join

M1: R1' ⋈ S1'

K1	B
1	20
3	20
4	20

K2	B
201	20

M2: R2' ⋈ S2'

K1	B
2	50

K2	B
101	50
102	50
202	50

Speedup and Scaleup

- Consider:
  - Query: $\gamma_{A,sum(C)}(R)$
  - Runtime: dominated by reading chunks from disk
- If we double the number of nodes P, what is the new running time?
  - Half (each server holds ½ as many chunks)
- If we double both P and the size of R, what is the new running time?
  - Same (each server holds the same # of chunks)

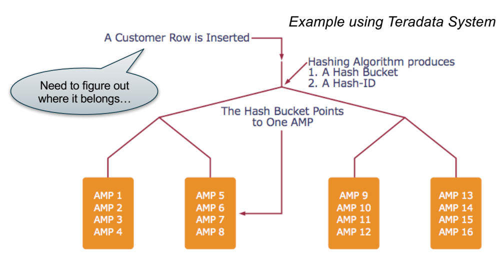
Uniform Data v.s. Skewed Data

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

- Block partition — Uniform

- Hash-partition
  - On the key K — Uniform (Assuming good 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)

Loading Data into a Parallel DBMS



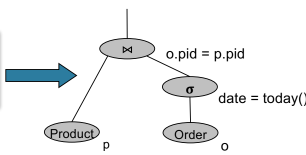
AMP = "Access Module Processor" = unit of parallelism

Order(oid, pid, date), Product(pid, ...)

Example Parallel Query Execution

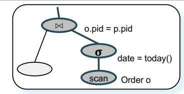
Find all orders from today, along with the items ordered

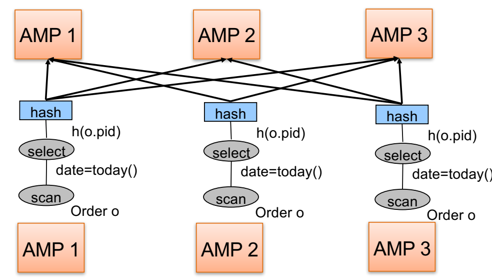
```
SELECT *
  FROM Order o, Product p
 WHERE o.pid = p.pid
   AND o.date = today()
```



Order(oid, pid, date), Product(pid, ...)

Example Parallel Query Execution





Order(oid, pid, date), Product(pid, ...)

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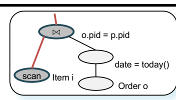

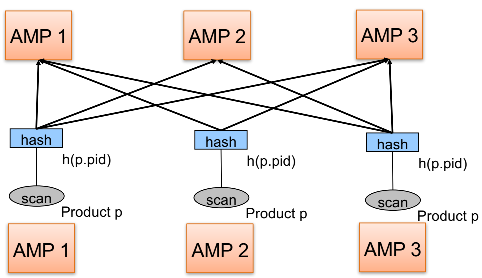

Order(oid, pid, date), Product(pid, ...)

Example Parallel Query Execution