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

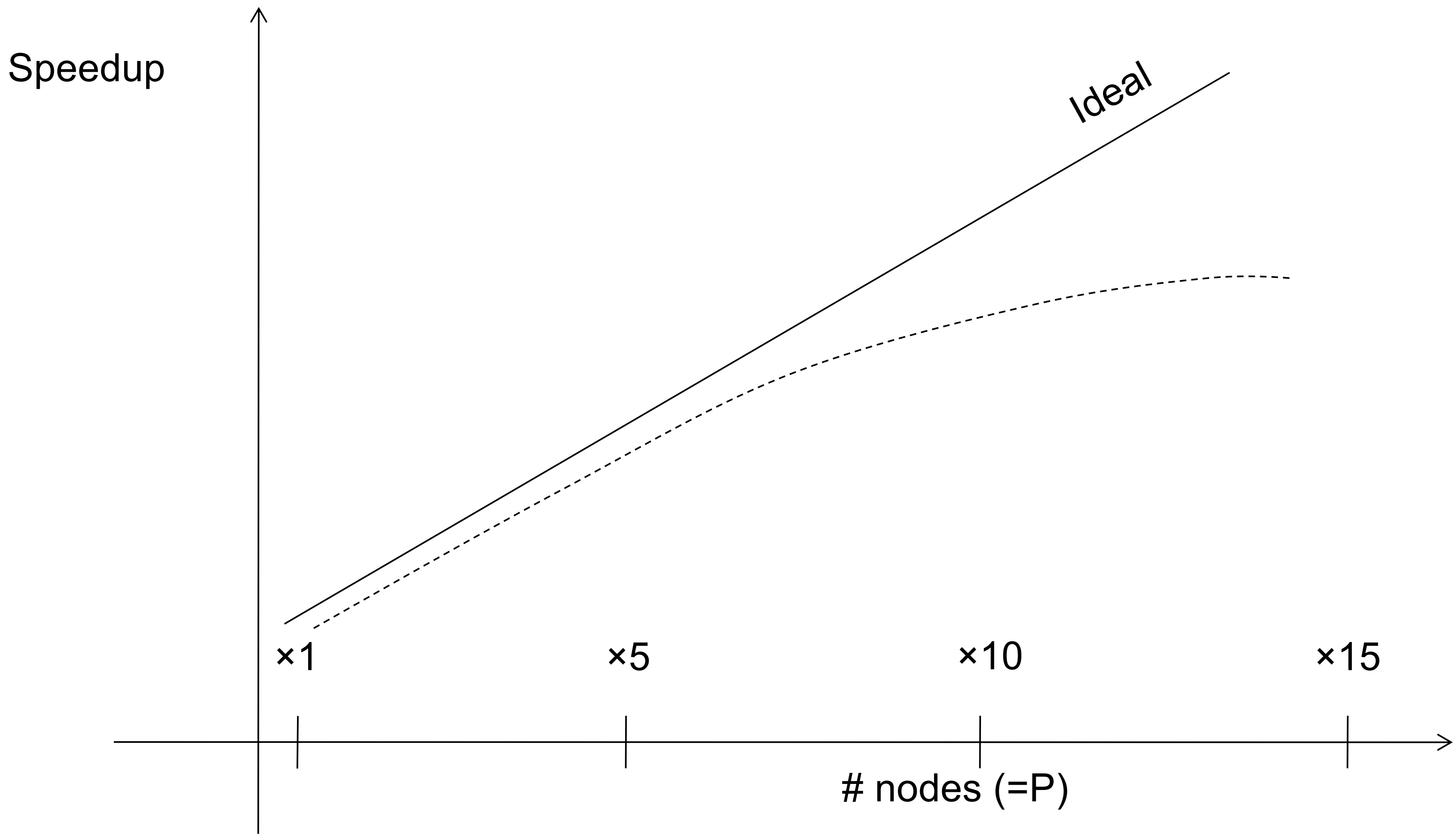
Performance Metrics for Parallel DBMSs

P = the number of nodes (processors, computers)

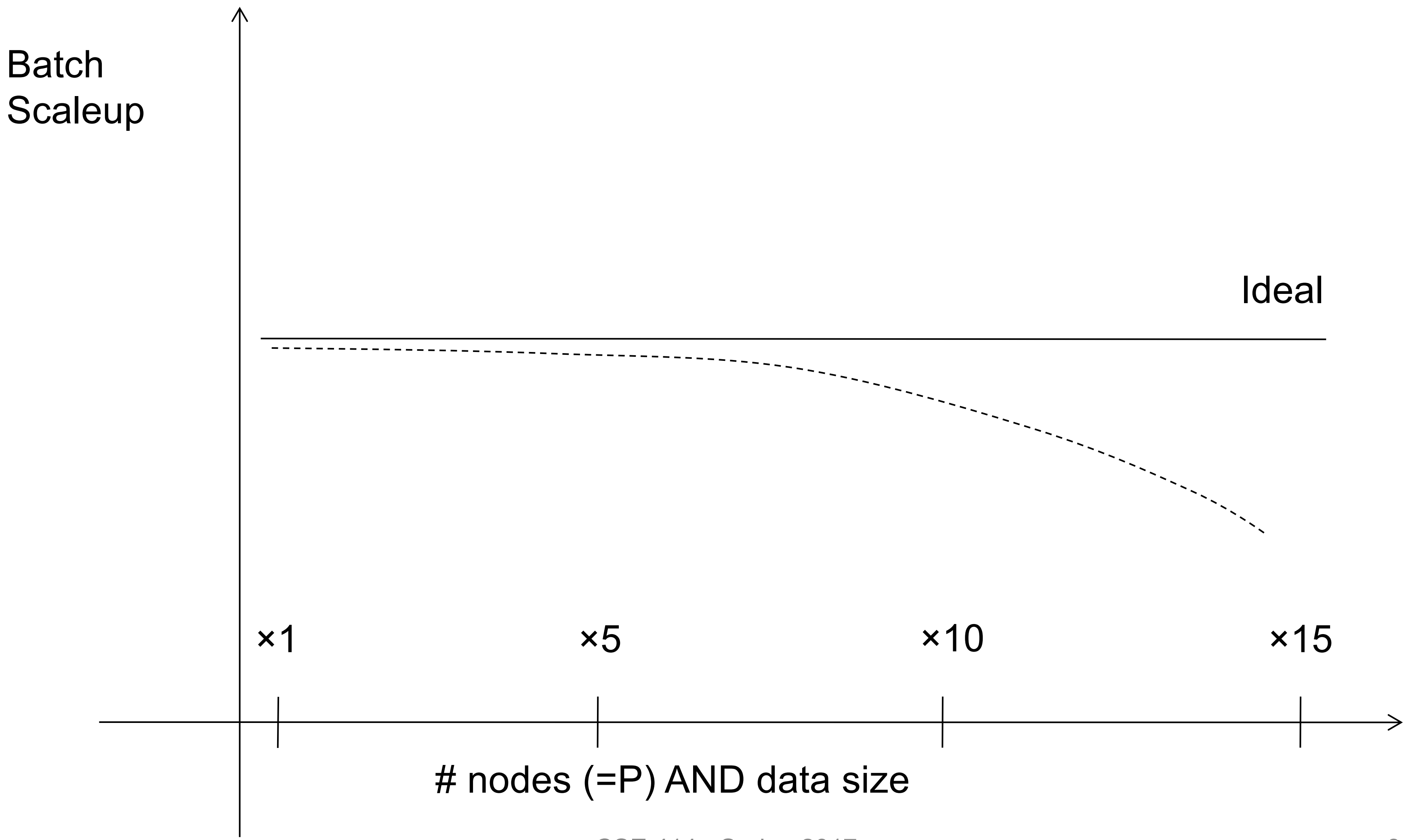
- Speedup:
  - More nodes, same data ➔ higher speed
- Scaleup:
  - More nodes, more data ➔ same speed

- OLTP: "Speed" = transactions per second (TPS)
- Decision Support: "Speed" = query time

Linear v.s. Non-linear Speedup



Linear v.s. Non-linear Scaleup



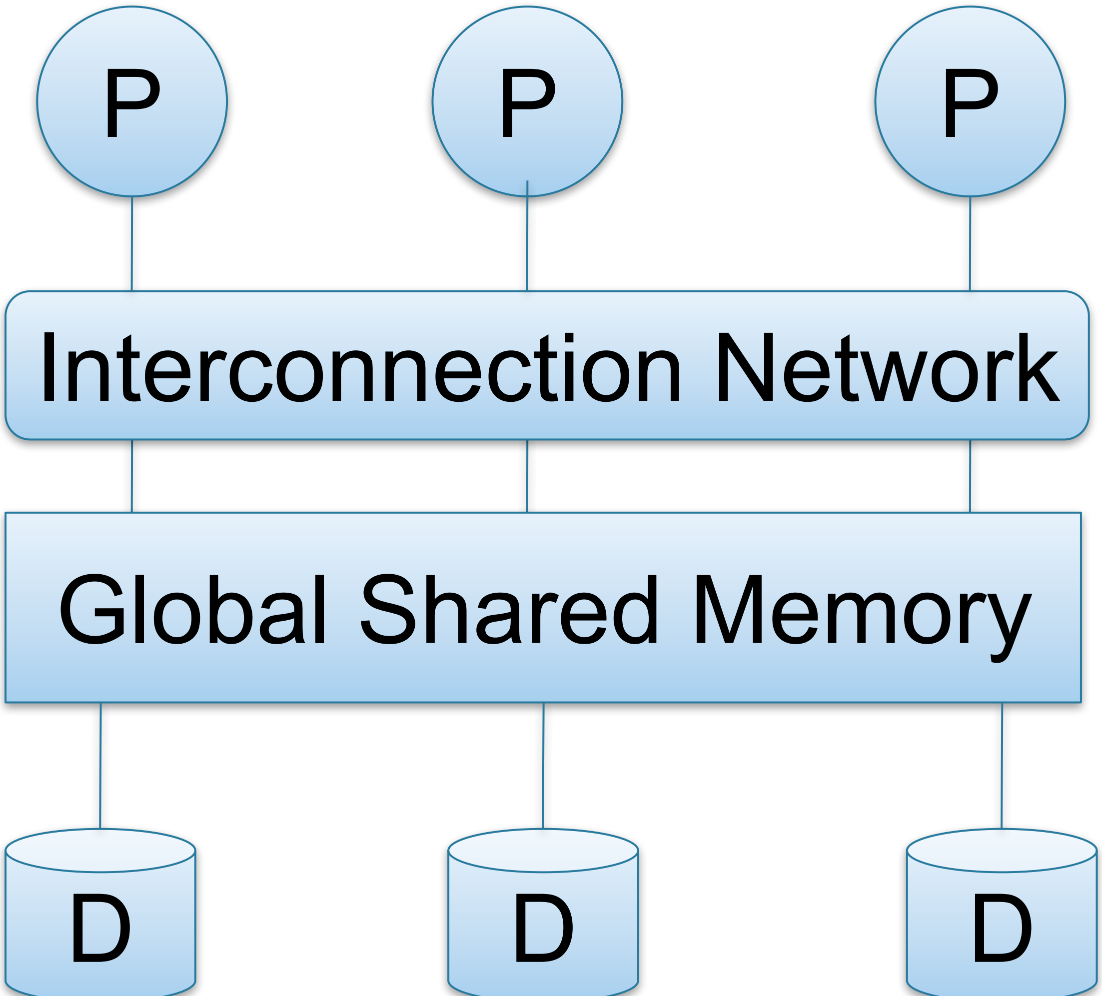
Challenges to Linear Speedup and Scaleup

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

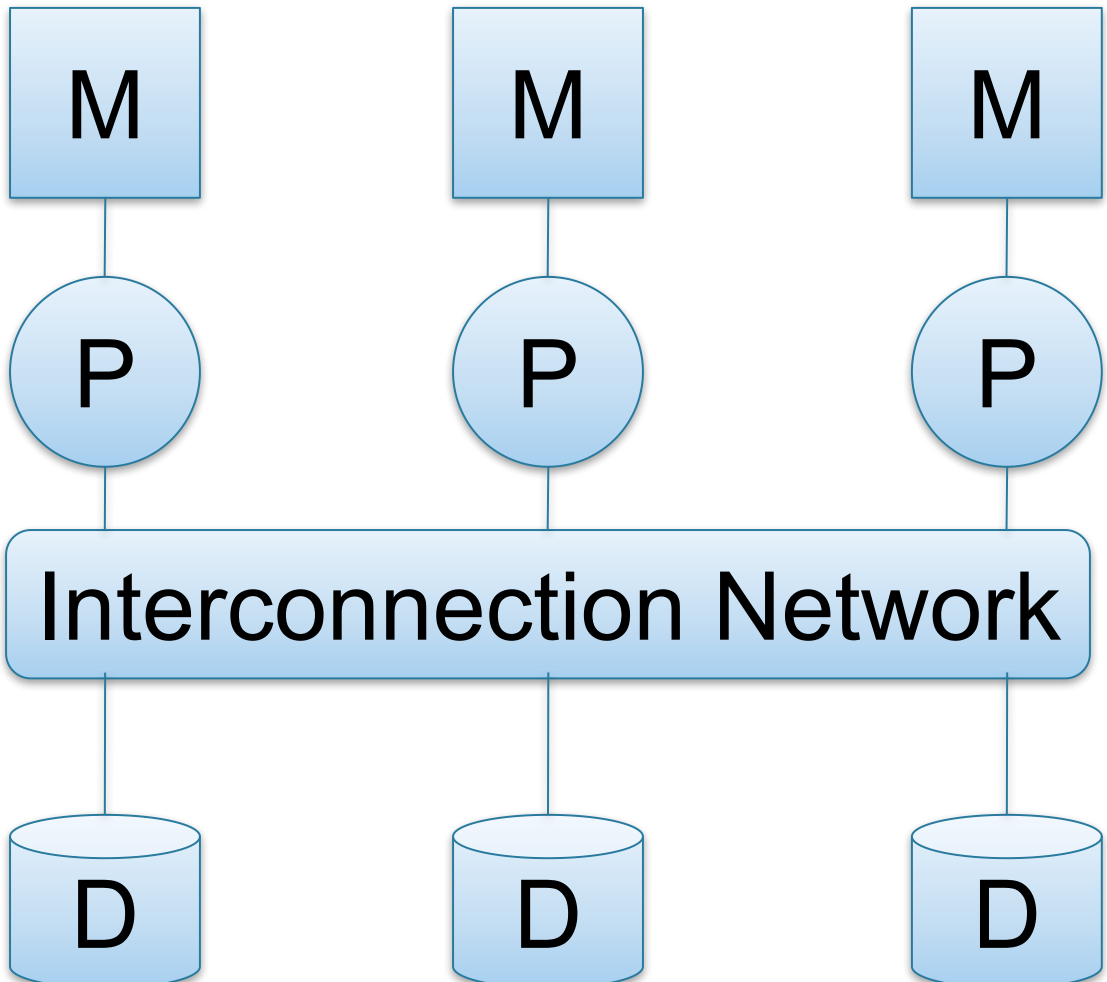
Architectures for Parallel Databases

- Shared memory
- Shared disk
- Shared nothing

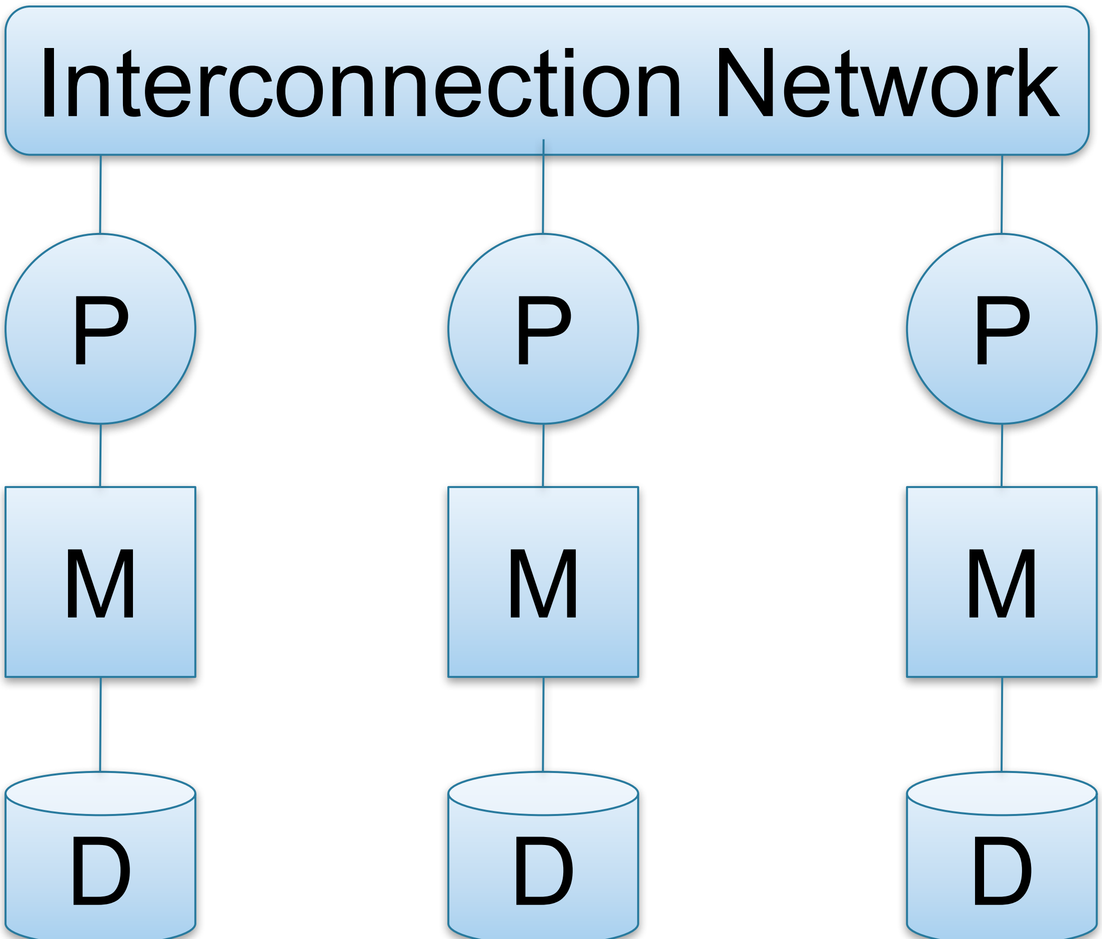
Shared Memory



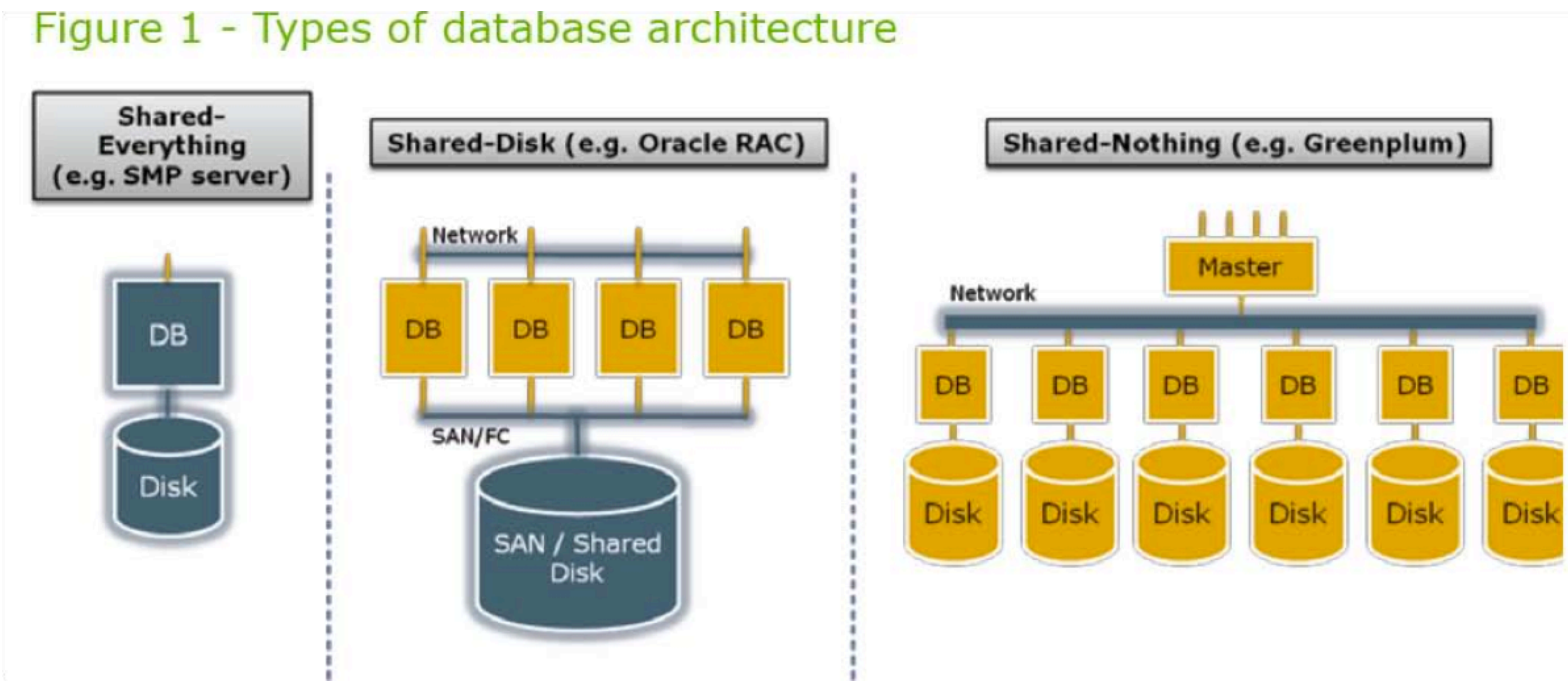
Shared Disk



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.

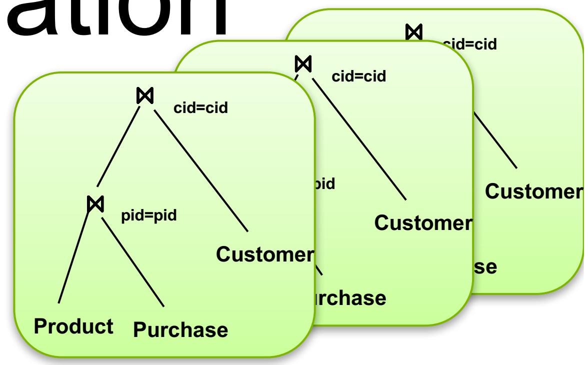
Characteristics:

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

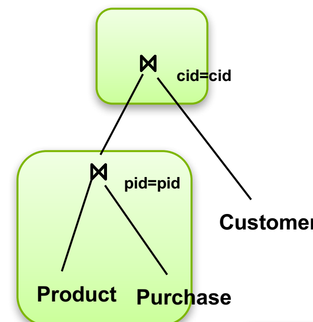
We discuss only Shared Nothing in class

Approaches to Parallel Query Evaluation

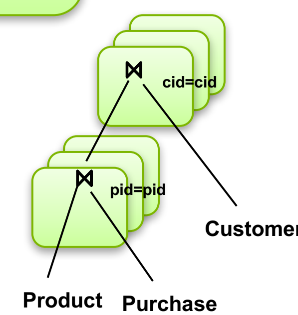
- Inter-query parallelism
  - Transaction per node
  - OLTP



- 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

Data:

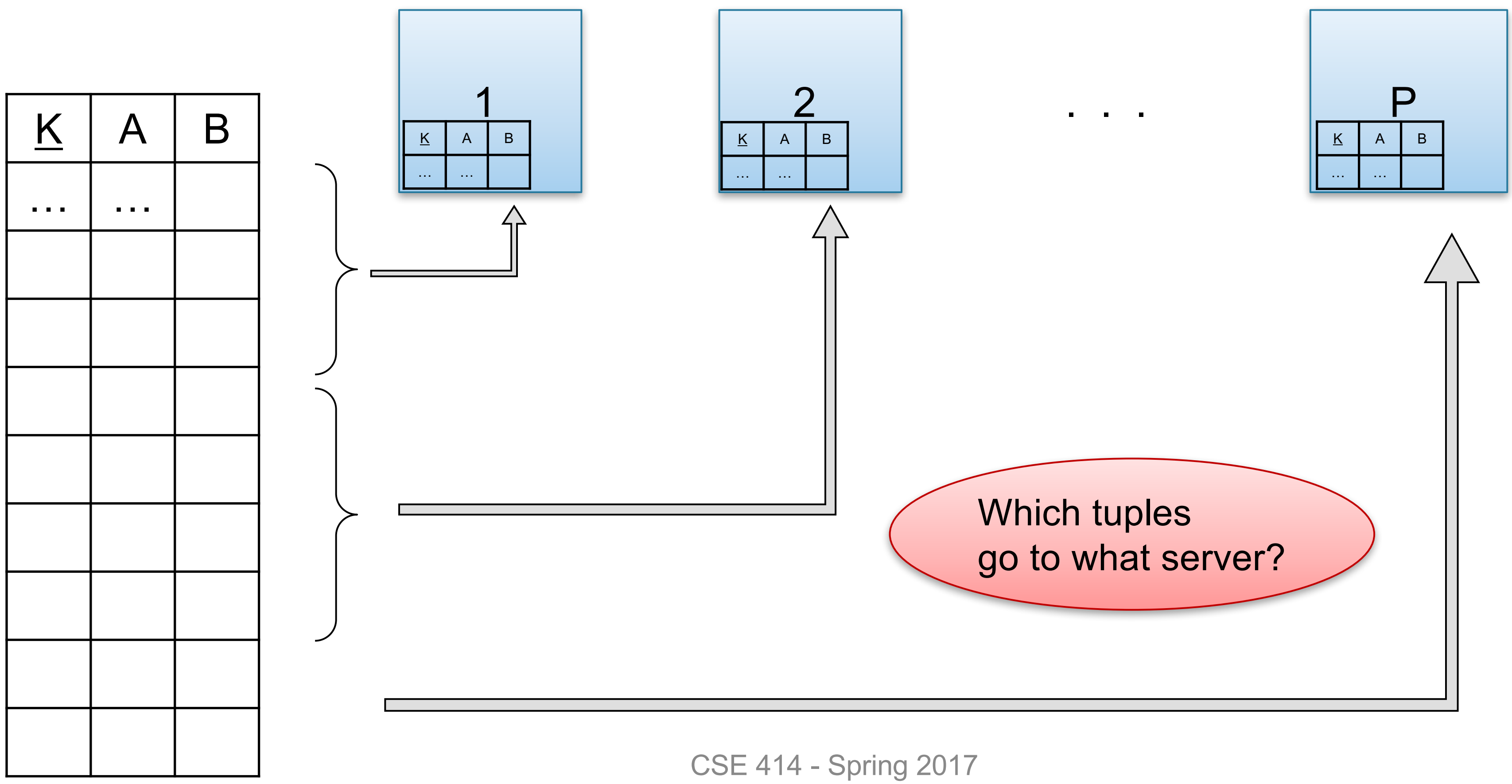
<u>K</u>	A	B
…	…	

Servers:

Horizontal Data Partitioning

Data:

Servers:



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(<u>K</u>,A,B,C)

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

How can we compute in each case?

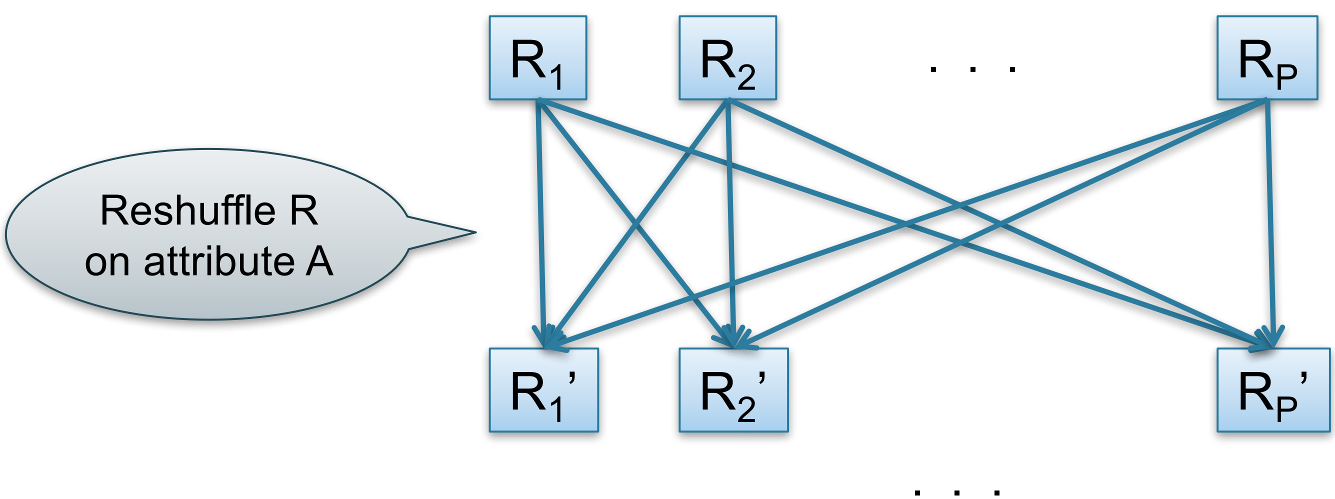
- R is hash-partitioned on A ← easy case!
- R is block-partitioned
- R is hash-partitioned on K

Parallel GroupBy

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

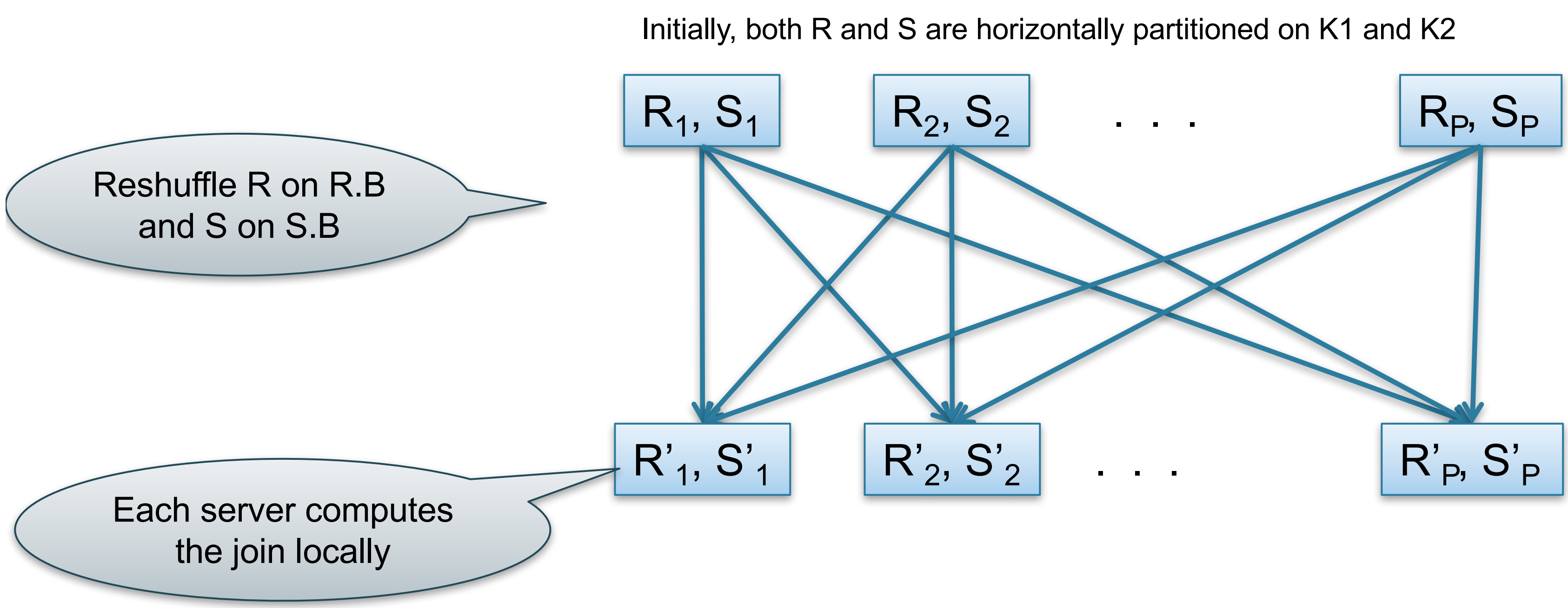
Query: $\gamma_{A,sum(C)}(R)$

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



Parallel Join

- Data: R(K1,A, B), S(K2, B, C)
- Query: R(K1,A,B) ⋈ S(K2,B,C)



Data: R(K1,A, B), S(K2, B, C)

Query: R(K1,A,B) $\bowtie$ S(K2,B,C)

Partition

M1

R1

K1	B
1	20
2	50

S1

K2	B
101	50
102	50

M2

R2

K1	B
3	20
4	20

S2

K2	B
201	20
202	50

Shuffle

Local Join

M1

R1'

K1	B
1	20
3	20
4	20

$\bowtie$

S1'

K2	B
201	20

M2

R2'

K1	B
2	50

$\bowtie$

S2'

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

- Block partition

  Uniform

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

  Uniform

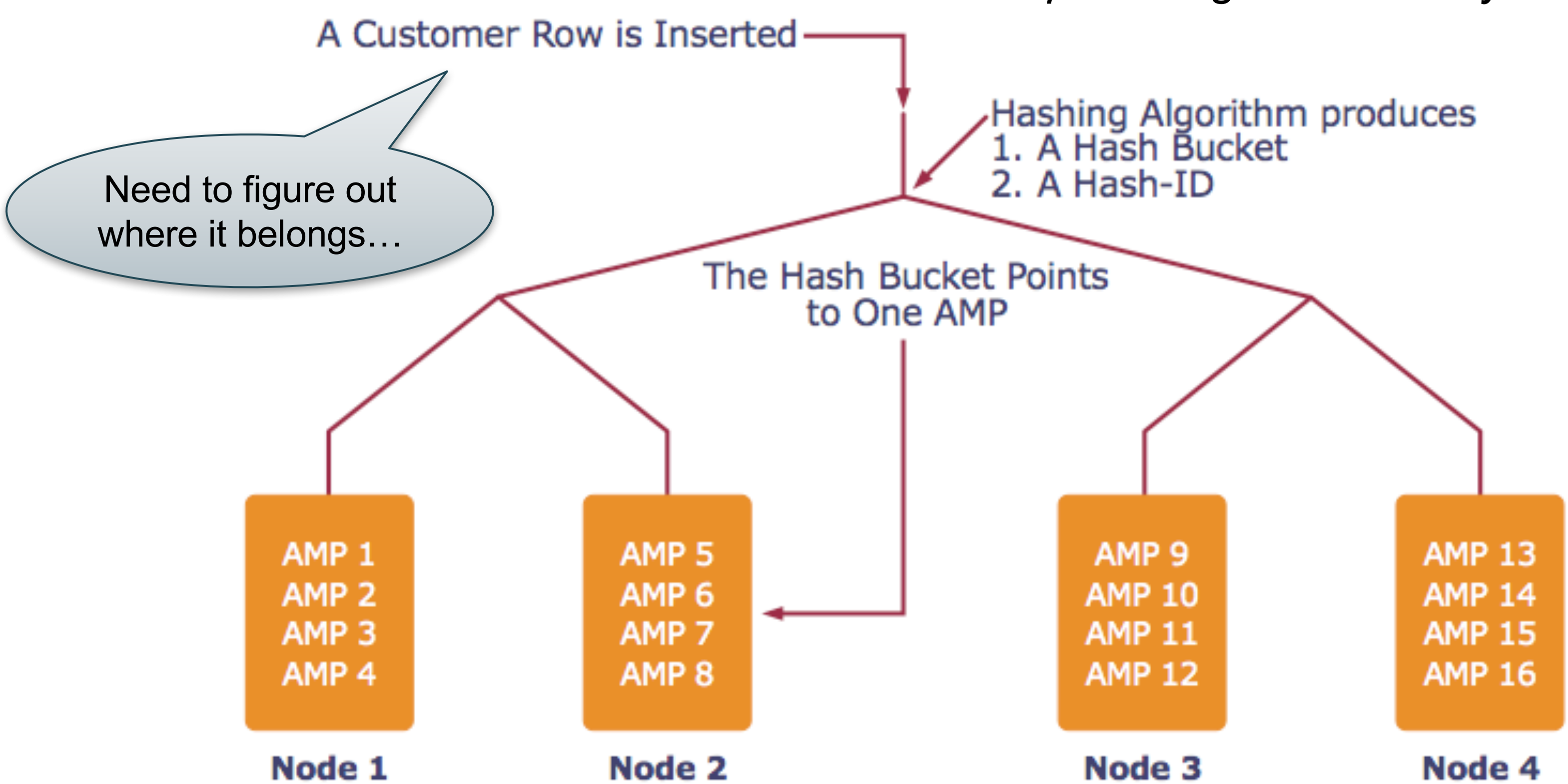
  May be skewed

Assuming good hash function

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

Example using Teradata System



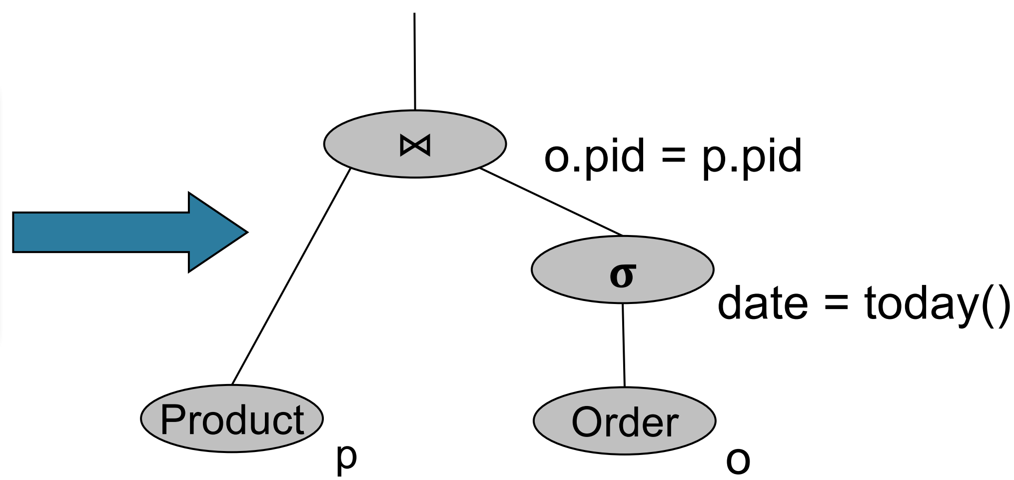
AMP = "Access Module Processor" = unit of parallelism

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()
```



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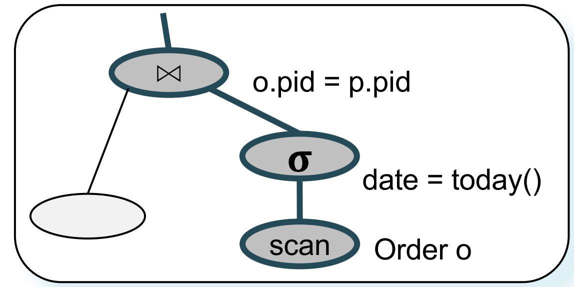

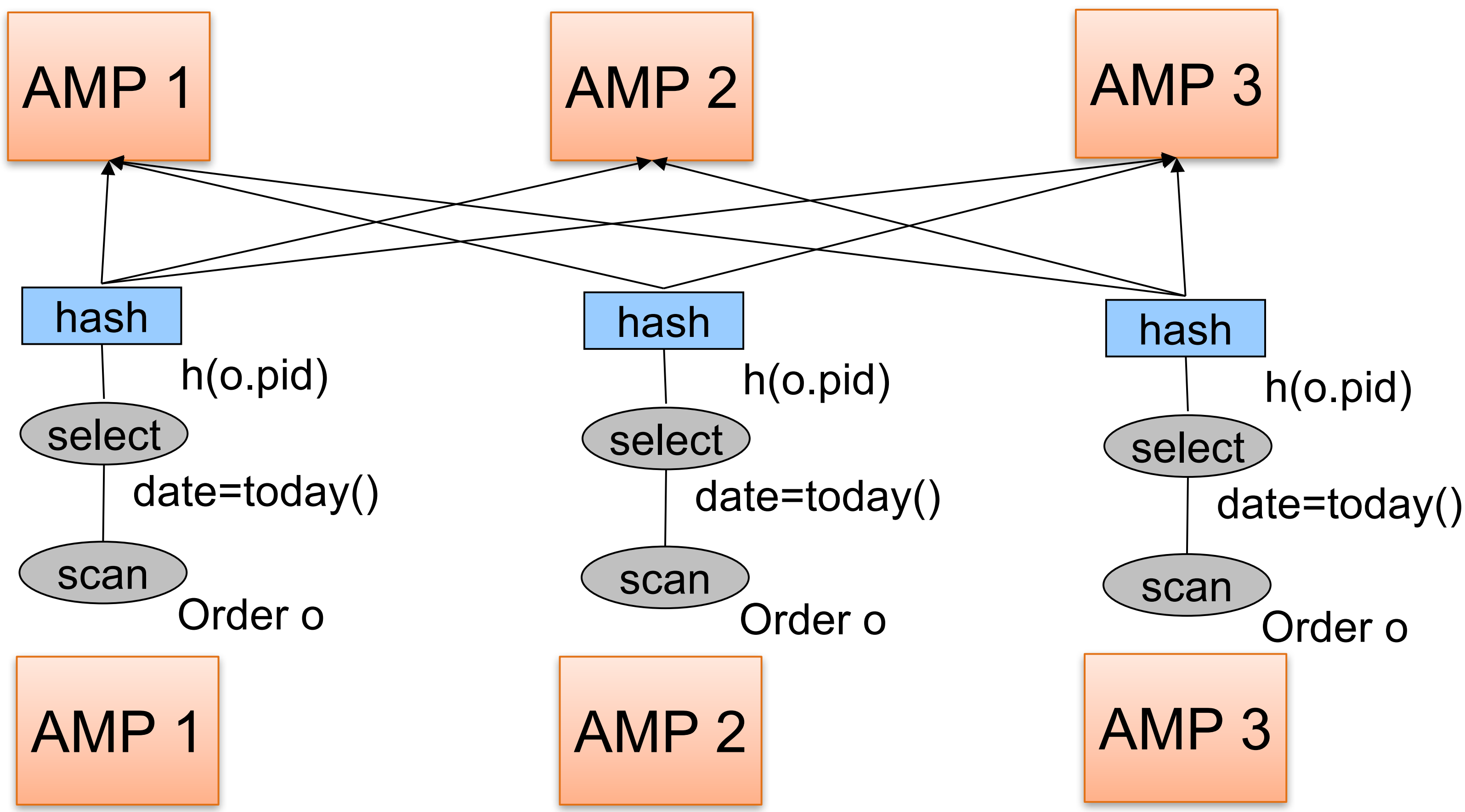

Order(oid, pid, date), Product(pid, …)

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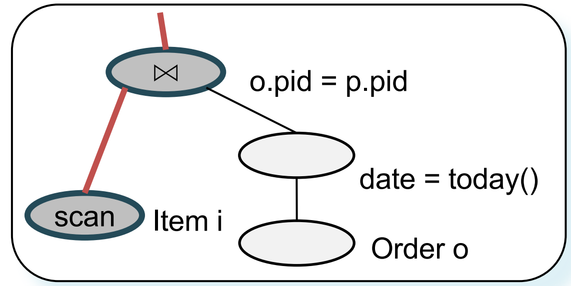

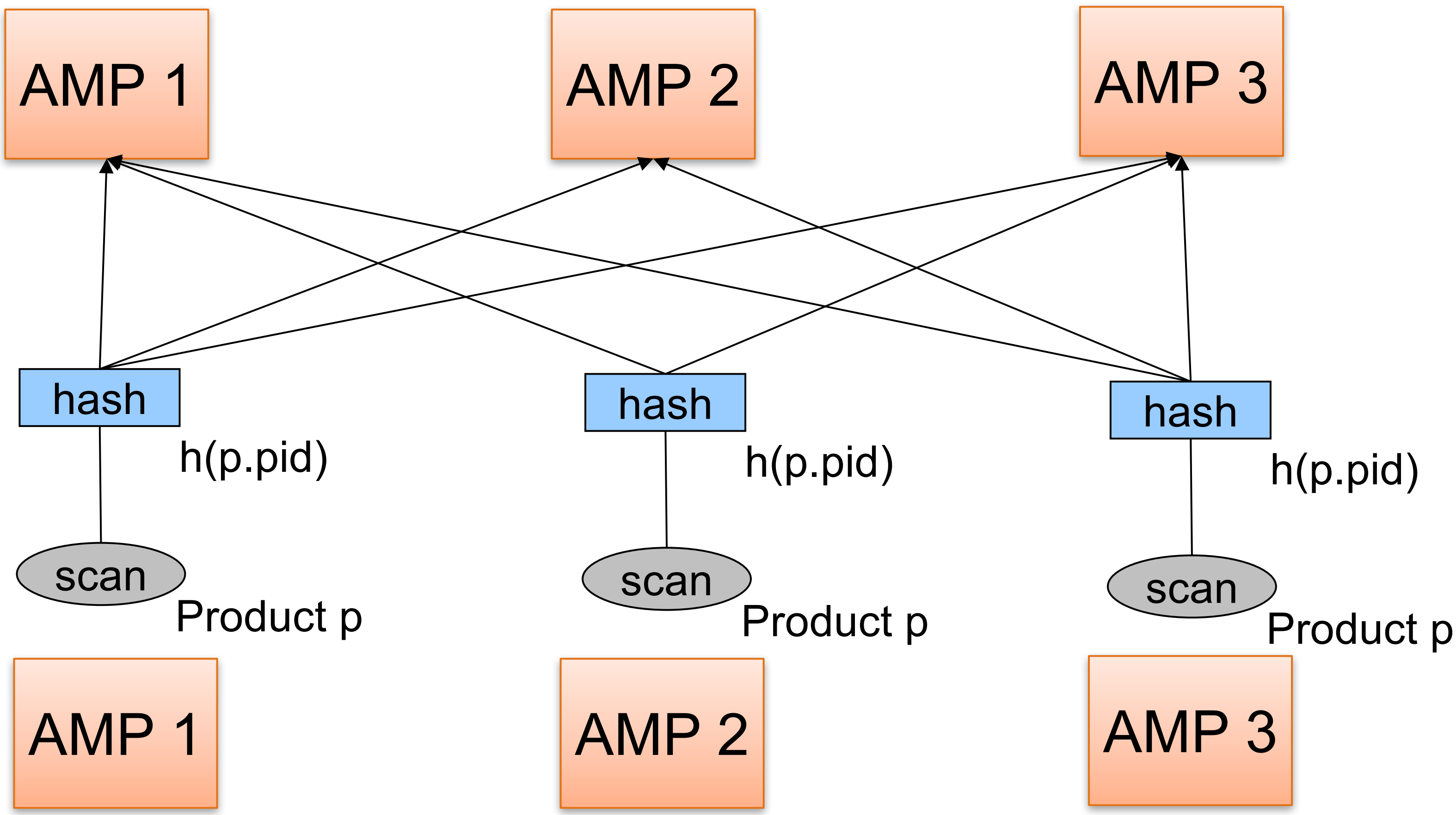

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Example Parallel Query Execution