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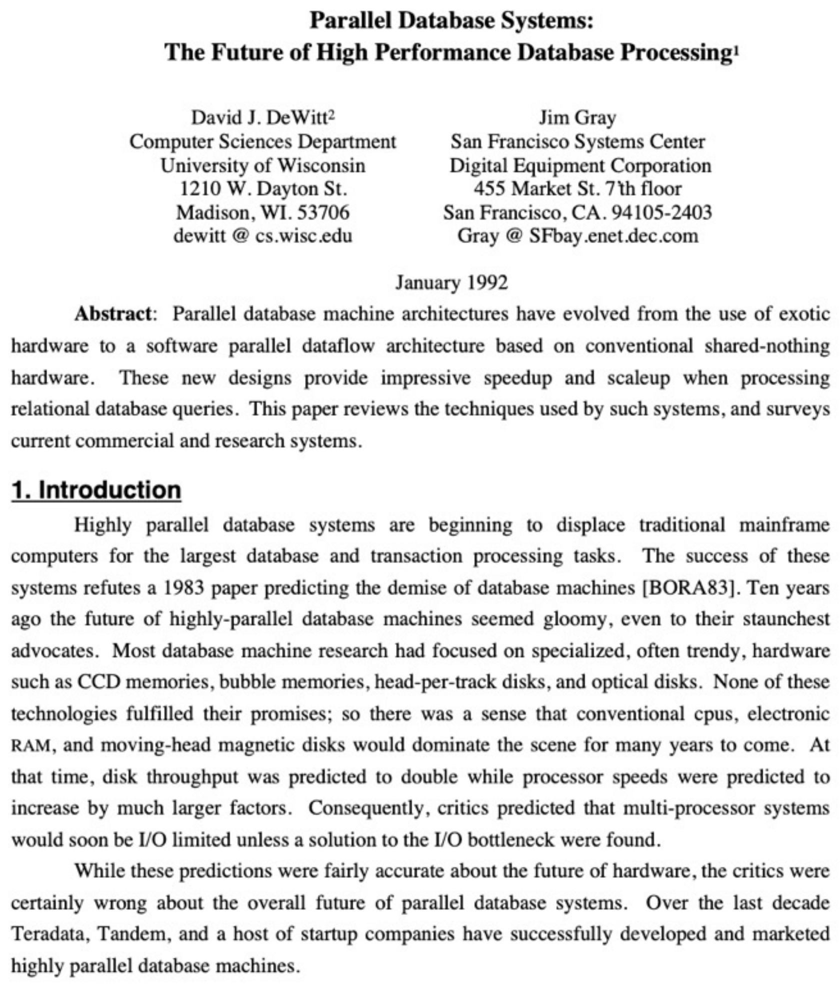
UNIVERSITY OF WISCONSIN–MADISON

CS 764: Topics in Database Management Systems
Lecture 8: Parallel Database

Xiangyao Yu
10/3/2022

Today’s Paper: Parallel DBMSs



Parallel Database Systems:
The Future of High Performance Database Processing[1]

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January 1992

Abstract: Parallel database machine architectures have evolved from the use of exotic hardware to a software parallel dataflow architecture based on conventional shared-nothing hardware. These new designs provide impressive speedup and scaleup when processing relational database queries. This paper reviews the techniques used by such systems, and surveys current commercial and research systems.

1. Introduction

Highly parallel database systems are beginning to displace traditional mainframe computers for the largest database and transaction processing tasks. The success of these systems refutes a 1983 paper predicting the demise of database machines [BORA83]. Ten years ago the future of highly-parallel database machines seemed gloomy, even to their staunchest advocates. Most database machine research had focused on specialized, often trendy, hardware such as CCD memories, bubble memories, head-per-track disks, and optical disks. None of these technologies fulfilled their promises; so there was a sense that conventional cpus, electronic RAM, and moving-head magnetic disks would dominate the scene for many years to come. At that time, disk throughput was predicted to double while processor speeds were predicted to increase by much larger factors. Consequently, critics predicted that multi-processor systems would soon be I/O limited unless a solution to the I/O bottleneck were found.

While these predictions were fairly accurate about the future of hardware, the critics were certainly wrong about the overall future of parallel database systems. Over the last decade Teradata, Tandem, and a host of startup companies have successfully developed and marketed highly parallel database machines.

Communications of the ACM, 1992

Agenda

Parallelism metrics

Parallel architecture

Parallel OLAP operators

Cloud parallel database

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Parallel Database History

1980’s: database machines

- Specialized hardware to make databases run fast
- Special hardware cannot catch up with Moore’s Law

1980’s – 2010’s: shared-nothing architecture

- Connecting machines using a network

2010’s – future?

Scaling in Parallel Systems

Linear speedup

- Twice as much hardware can perform the task in half the elapsed time
- $\text{Speedup} = \dfrac{small\ system\ elapsed\ time}{big\ system\ elapsed\ time}$
- Linear speedup = N, where the big system is N times larger than the small system

Scaling in Parallel Systems

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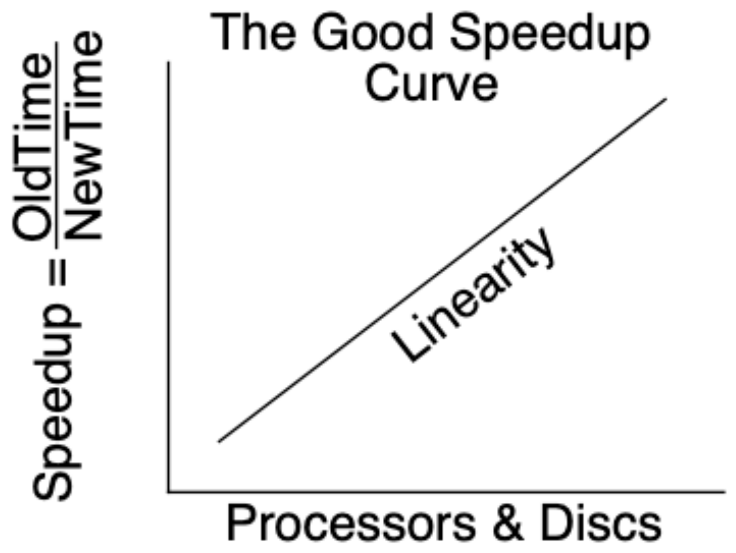
Linear scaleup

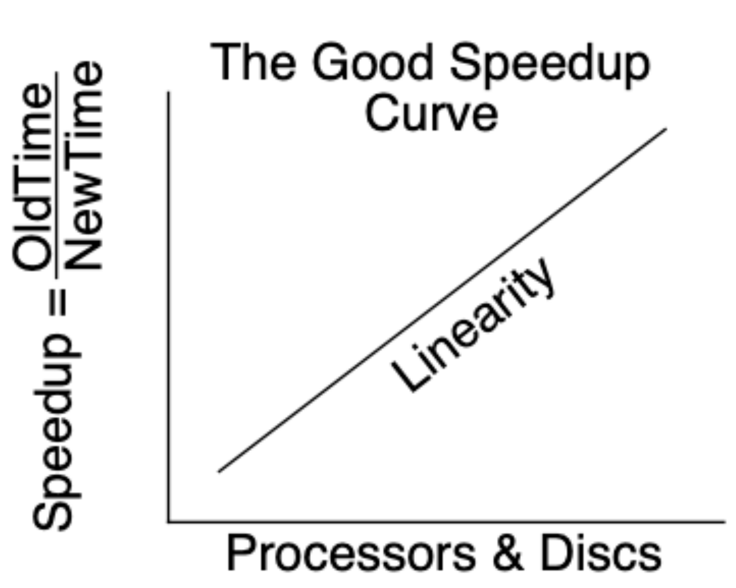
- Twice as much hardware can perform twice as large a task in the same elapsed time
- $\text{Scaleup} = \frac{small\ system\ elapsed\ time\ on\ small\ problem}{big\ system\ elapsed\ time\ on\ big\ problem}$
- Linear scaleup = 1

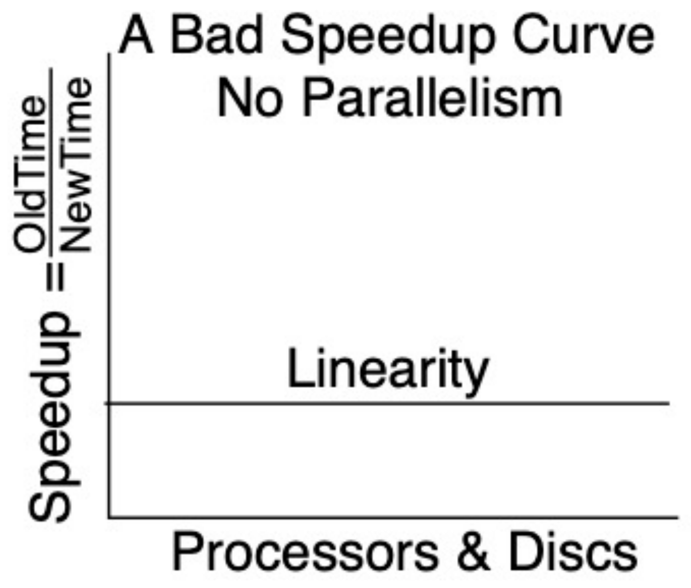
Scaling in Parallel Systems



Ideal speedup

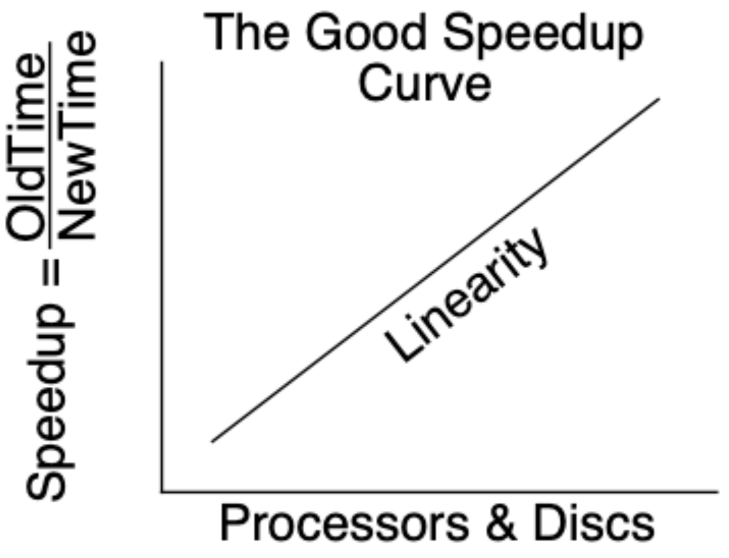
Scaling in Parallel Systems



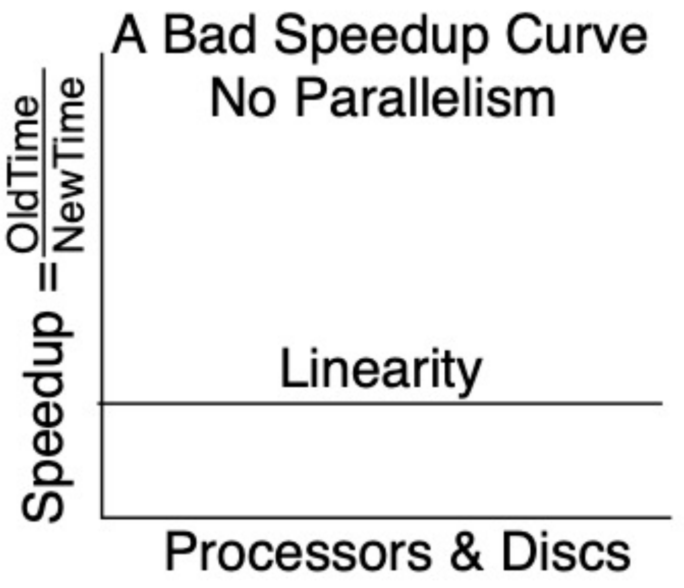


Ideal speedup **No speedup**

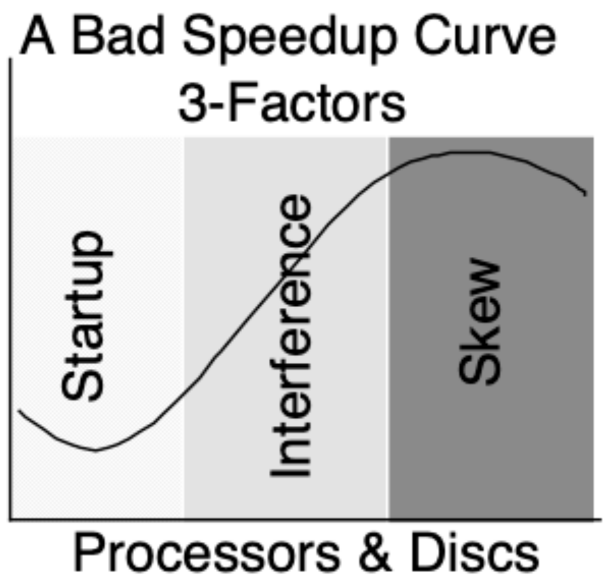
Scaling in Parallel Systems



Ideal speedup

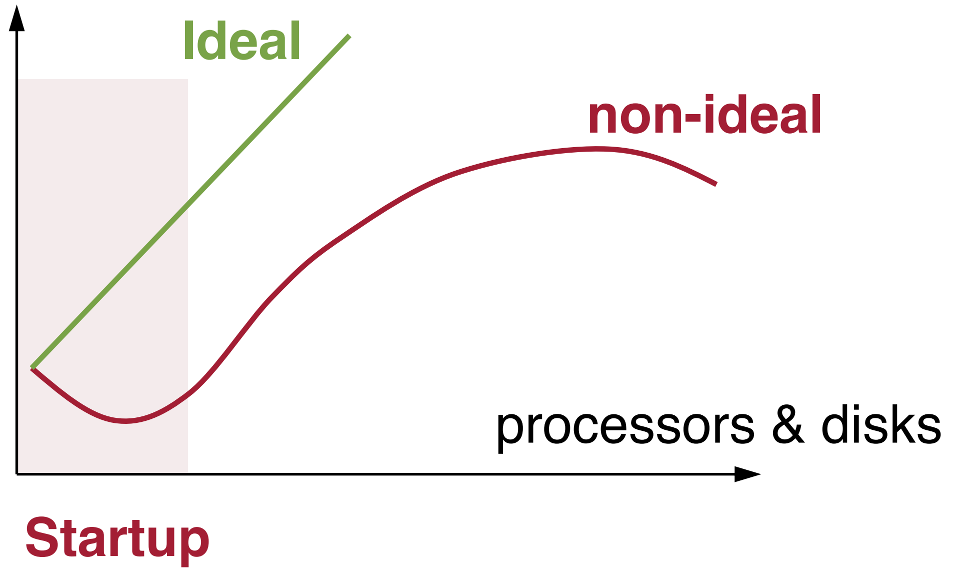


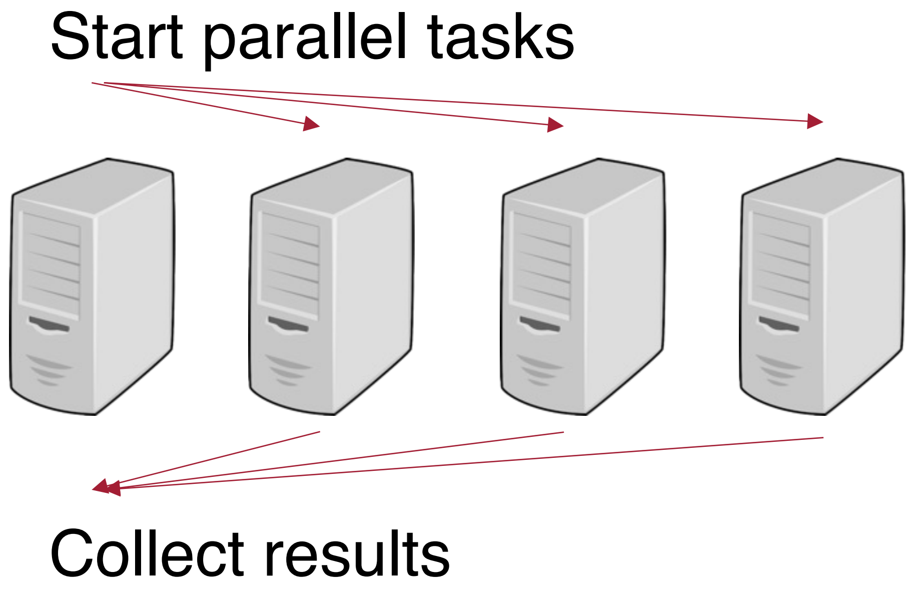
No speedup



In practice

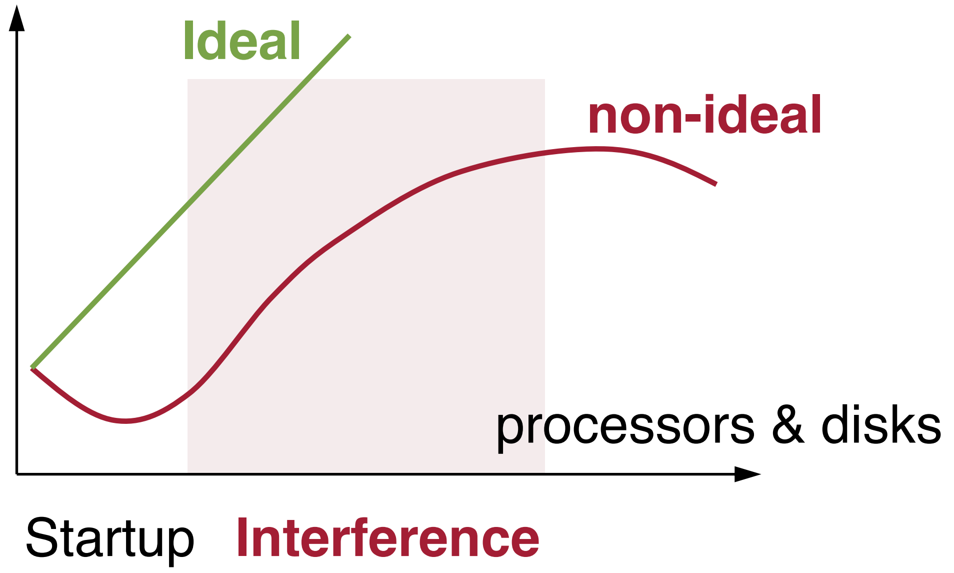
Threats to Parallelism

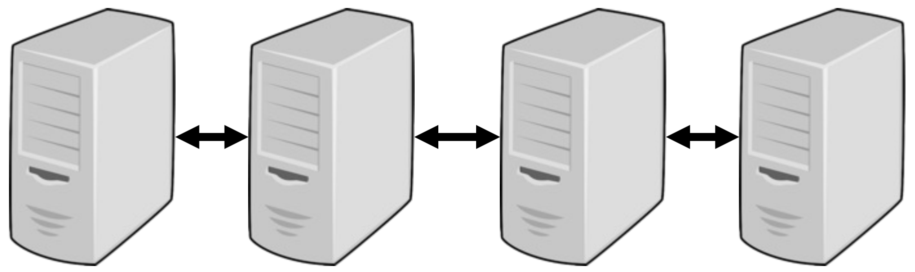




Starting remote tasks incurs performance overhead

Threats to Parallelism

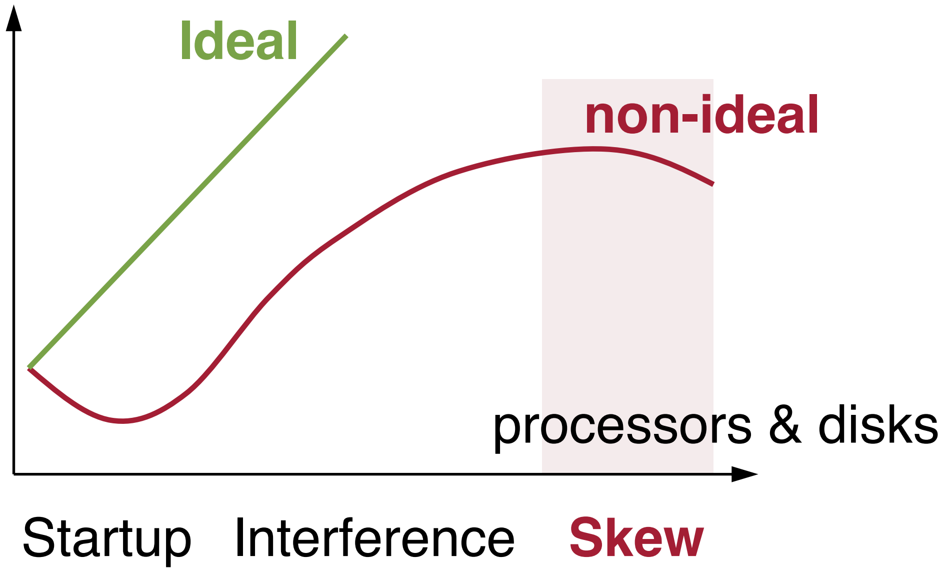


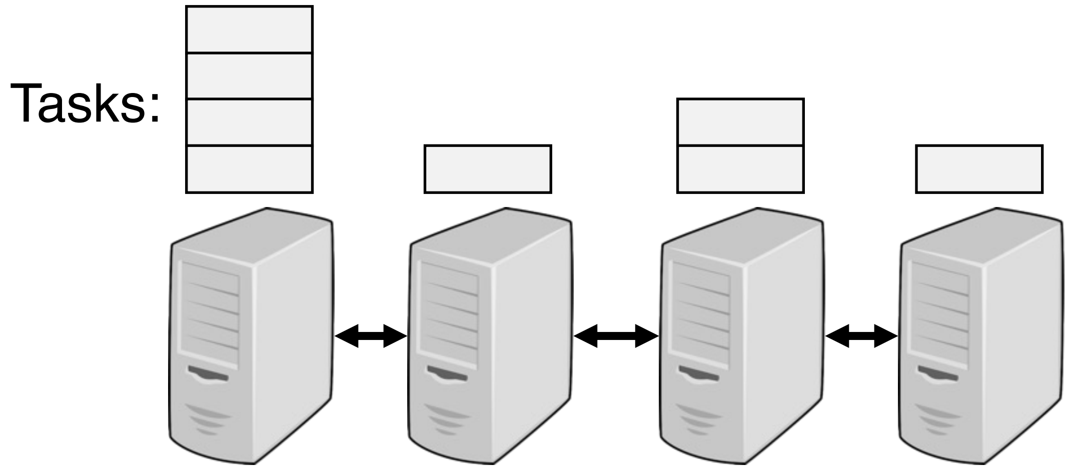


Examples of interference

- Shared hardware resources (e.g., memory, disk, network)
- Synchronization (e.g., locking)

Threats to Parallelism





Some nodes take more time to execute the assigned tasks, e.g.,

- More tasks assigned
- More computational intensive tasks assigned
- Node has slower hardware

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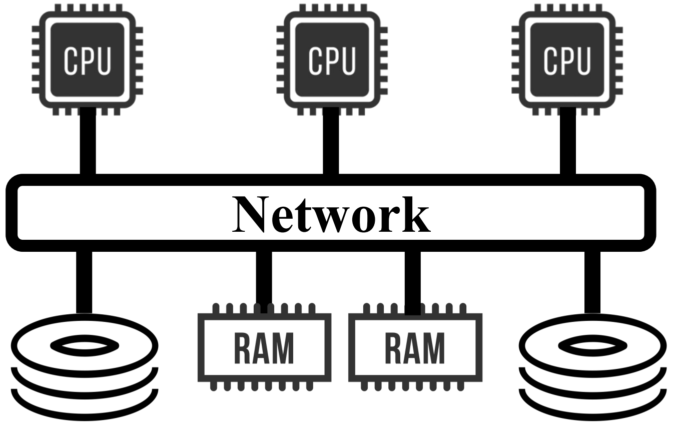
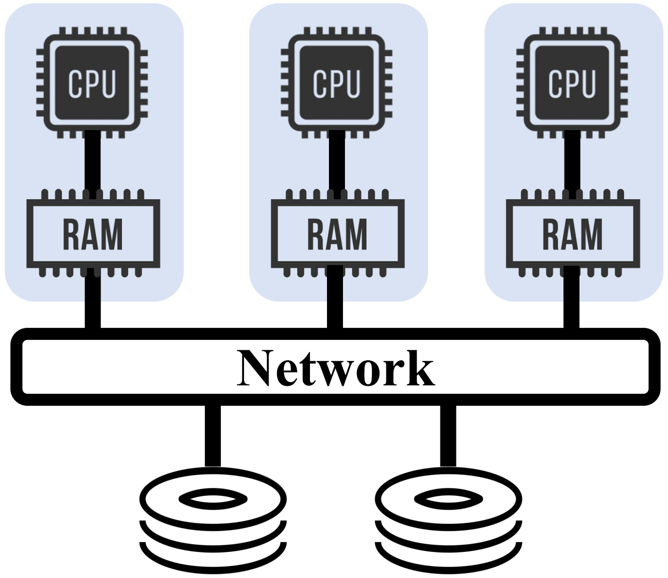
Parallel architecture

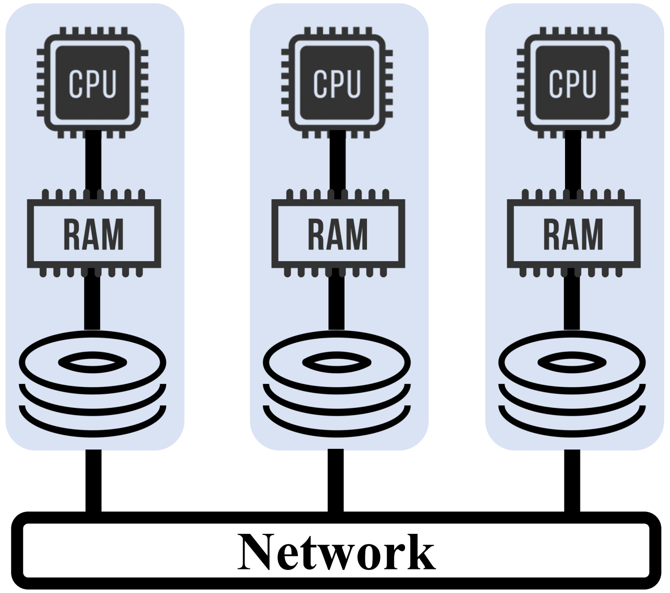
Parallel OLAP operators

Cloud parallel database

Design Spectrum







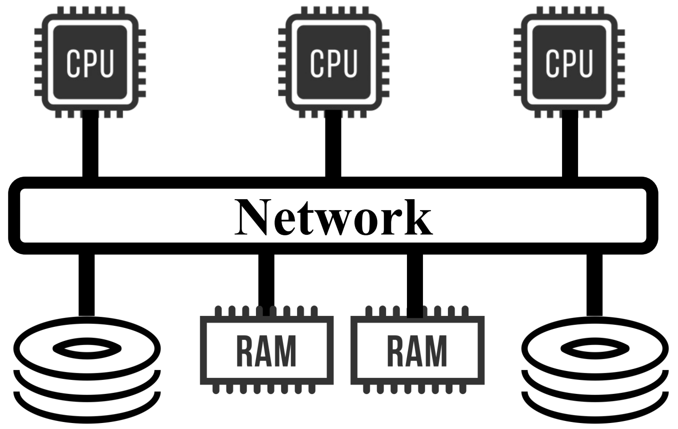
Shared Memory **Shared Disk** **Shared Nothing**

Design Spectrum – Shared Memory (SM)

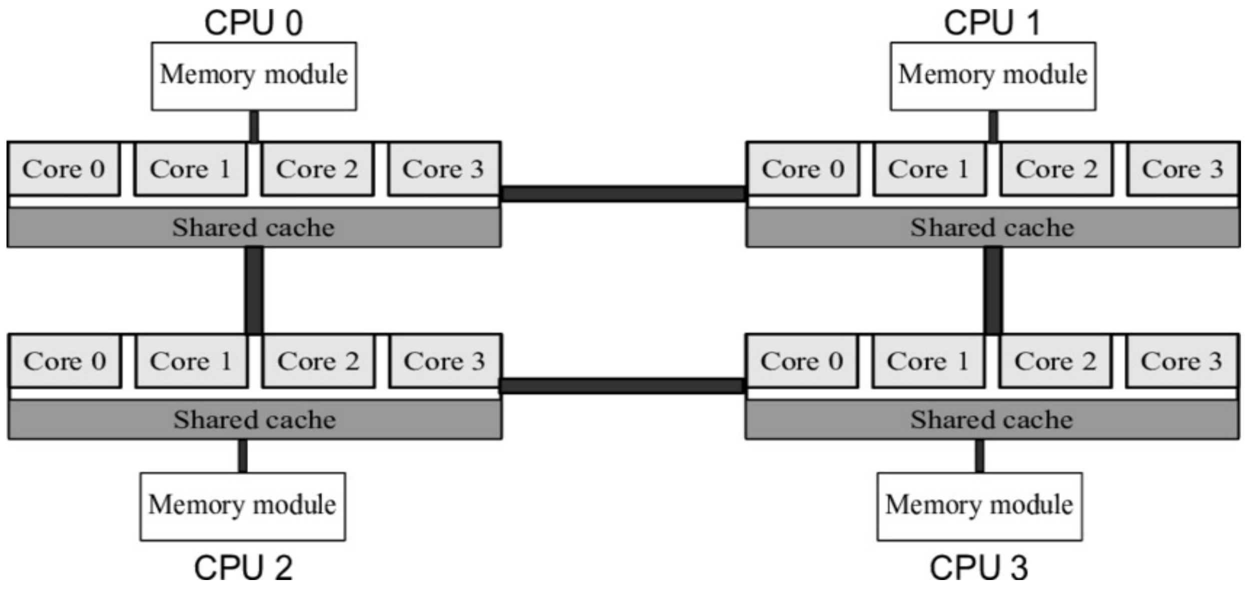
All processors share direct access to a common global memory and to all disks

- Does not scale beyond **a single server**

Example: multicore processors



Shared Memory

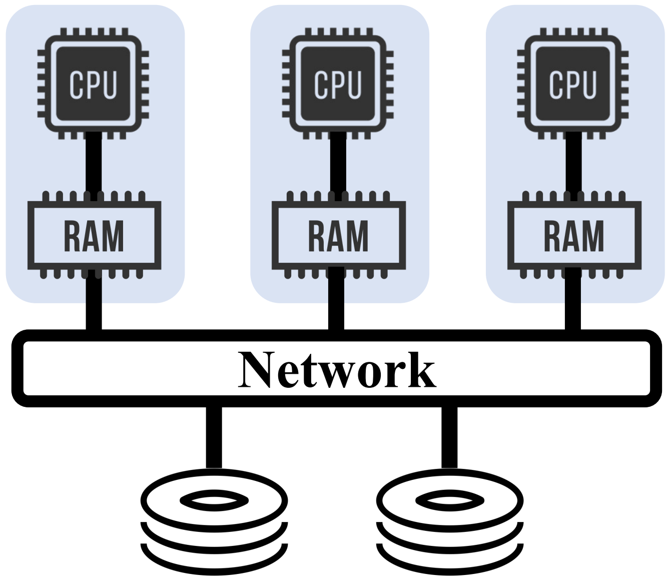


Design Spectrum – Shared Disk (SD)

Each processor has a private memory but has direct access to all disks

- Does not scale beyond **tens of servers**

Example: Network attached storage (NAS) and storage area network (SAN)



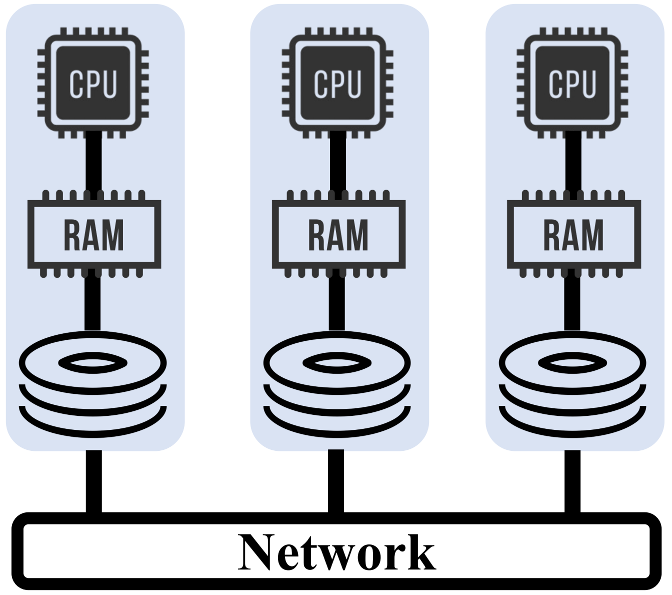
Shared Disk

Design Spectrum – Shared Nothing (SN)

Each memory and disk is owned by some processor that acts as a server for that data

- Scales to **thousands of servers and beyond**

Important optimization goal: minimize network data transfer



Shared Nothing

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How to Build Parallel Database?

Old uni-processor software must be rewritten to benefit from parallelism

Most database programs are written in relational language SQL

- **Can make SQL work on parallel hardware without rewriting**
- Benefits of a high-level programming interface

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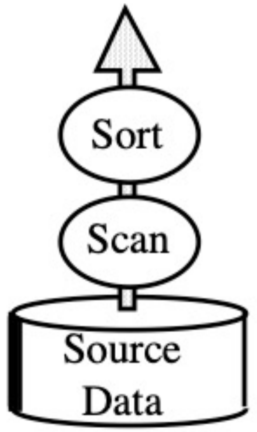
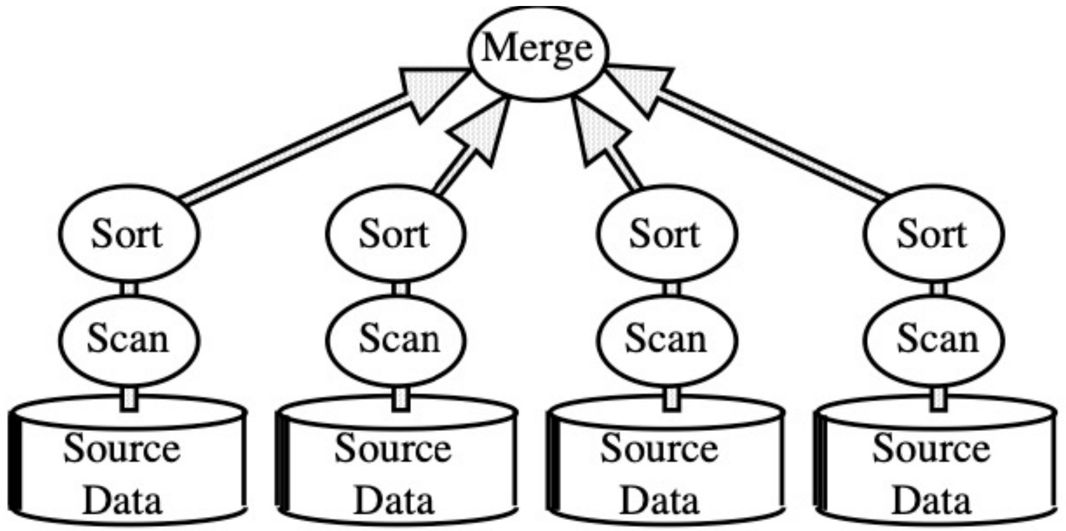


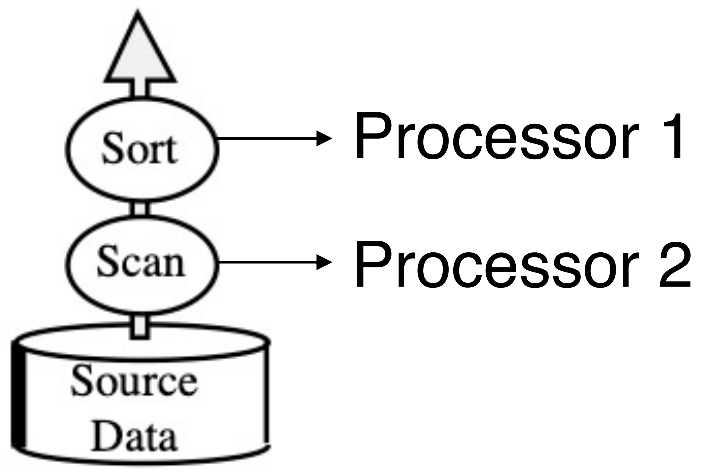
Pipelined Parallelism



Partitioned Parallelism

Pipelined Parallelism

Pipelined parallelism: pipeline of operators

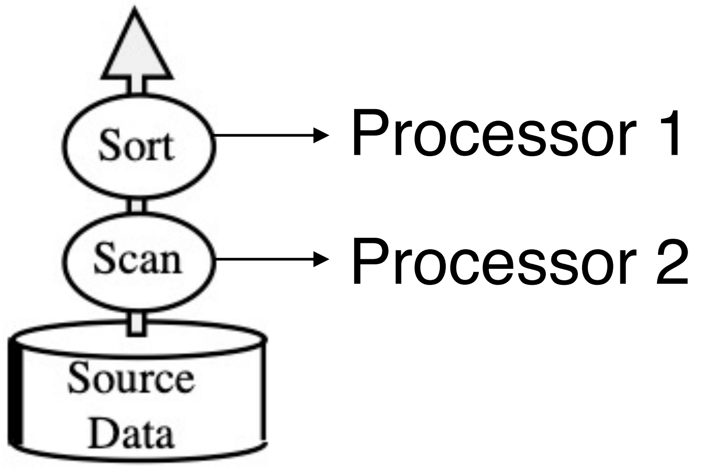


Pipelined Parallelism

Pipelined parallelism: pipeline of operators

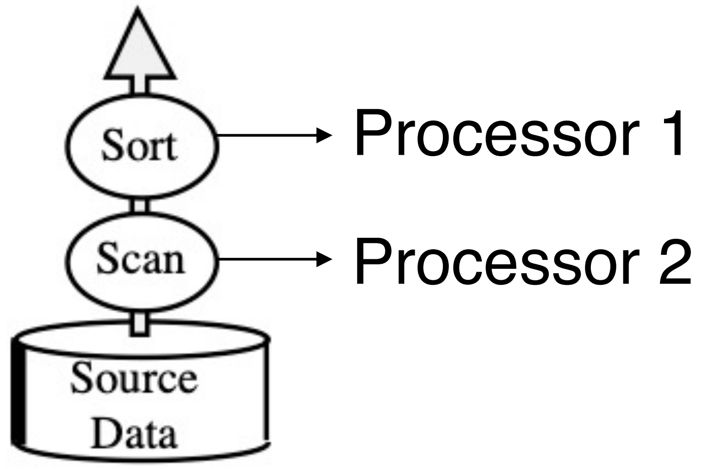
Advantages

- Avoid writing intermediate results back to disk



Pipelined Parallelism

Pipelined parallelism: pipeline of operators



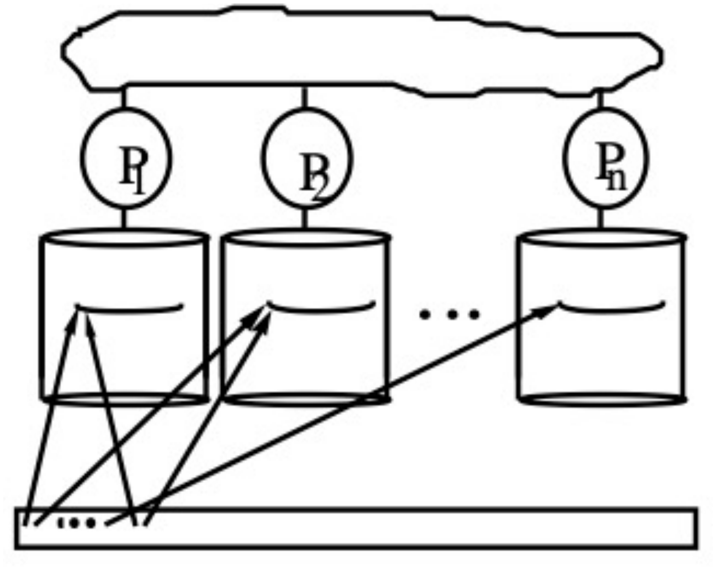
Advantages

- Avoid writing intermediate results back to disk

Disadvantages

- Small number of stages in a query
- Blocking operators: e.g., sort and aggregation
- Different speed: scan faster than join. Slowest operator becomes the bottleneck

Partitioned Parallelism

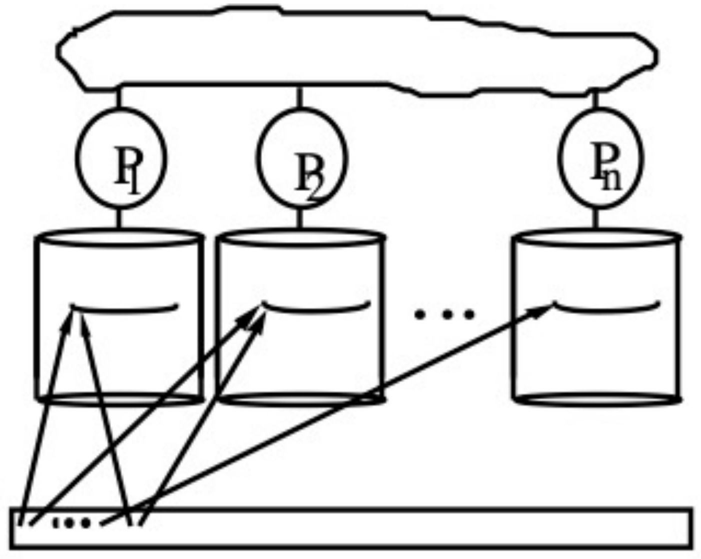


Round robin

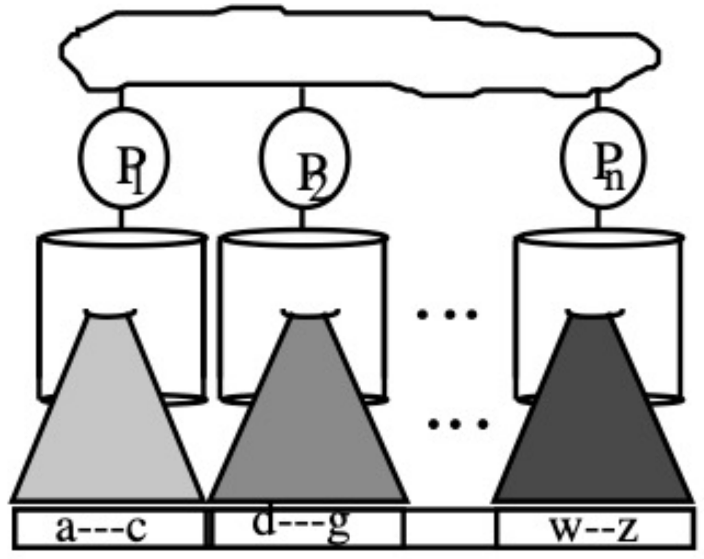
Map tuple *i* to disk (*i mode n*)

- **Advantage**: Simplicity, good load balancing
- **Disadvantage**: Hard to identify the partition of a particular record

Partitioned Parallelism



Round robin

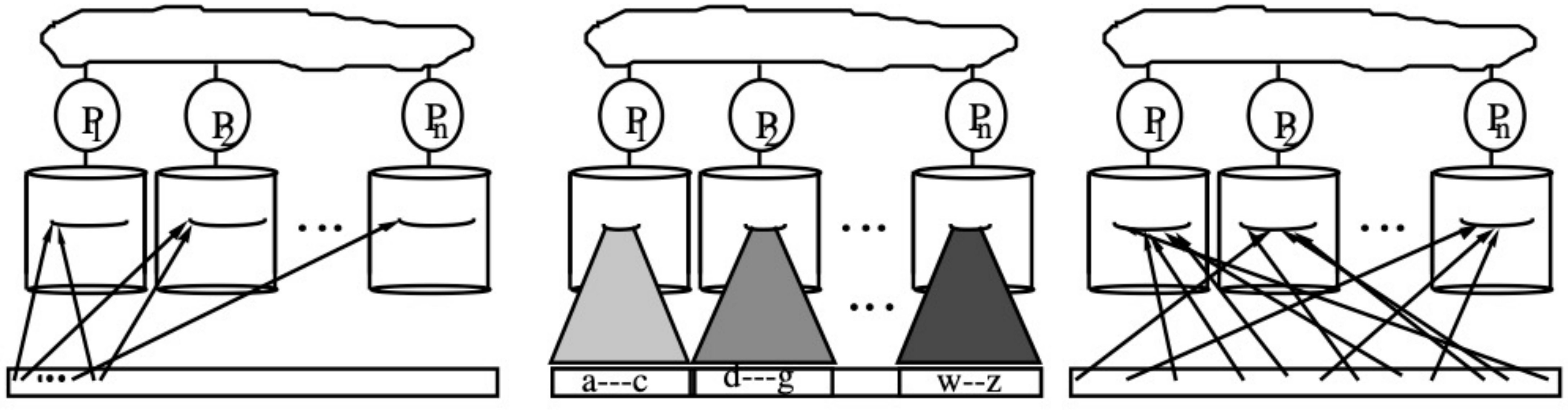


Range Partitioning

Map contiguous attribute ranges to partitions

- **Advantage**: Good locality due to clustering
- **Disadvantage**: May suffer from skewness

Partitioned Parallelism



Round robin Range Partitioning Hash Partitioning

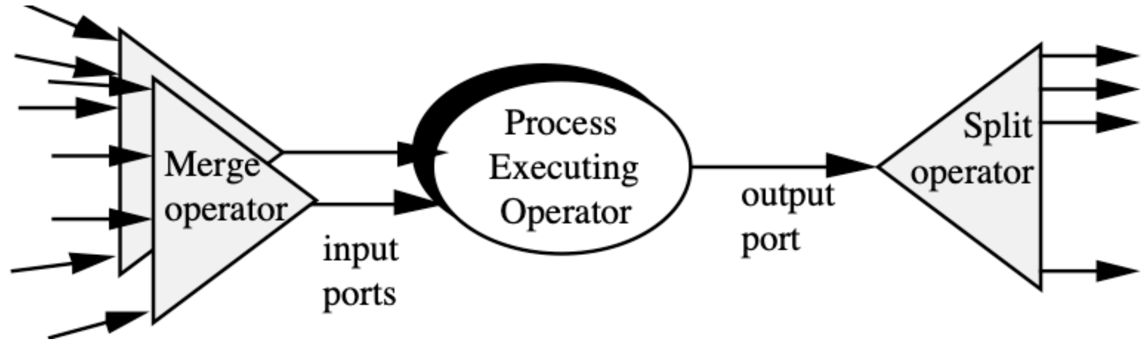
Map based on the hash value of tuple attributes

- **Advantage**: Good load balance, low skewness
- **Disadvantage**: Bad locality

Parallelism within Relational Operators

Parallel data streams so that sequential operator code is not modified

- Each operator has a set of input and output ports
- Partition and merge these ports to sequential ports so that **an operator is not aware of parallelism**



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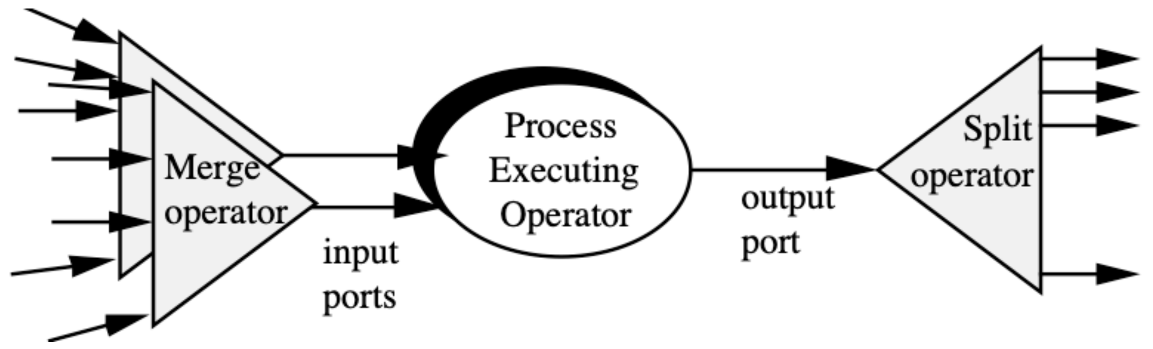

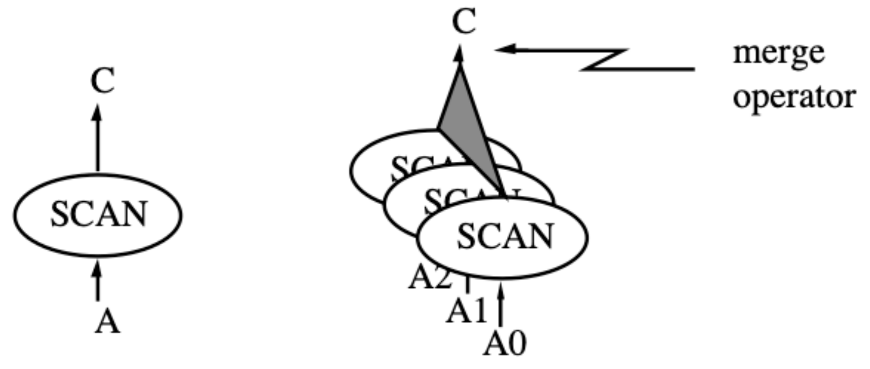

Parallelism within Relational Operators

Parallel data streams so that sequential operator code is not modified

- Each operator has a set of input and output ports
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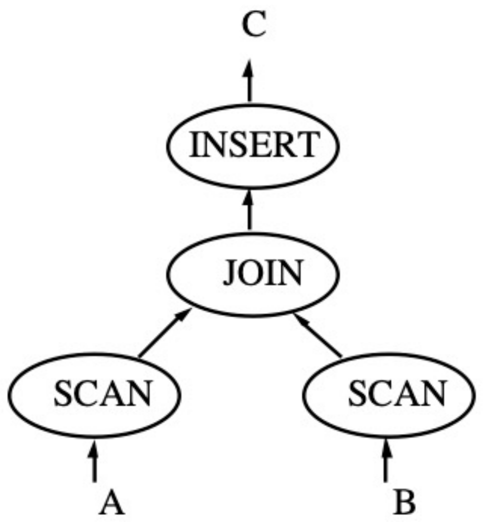
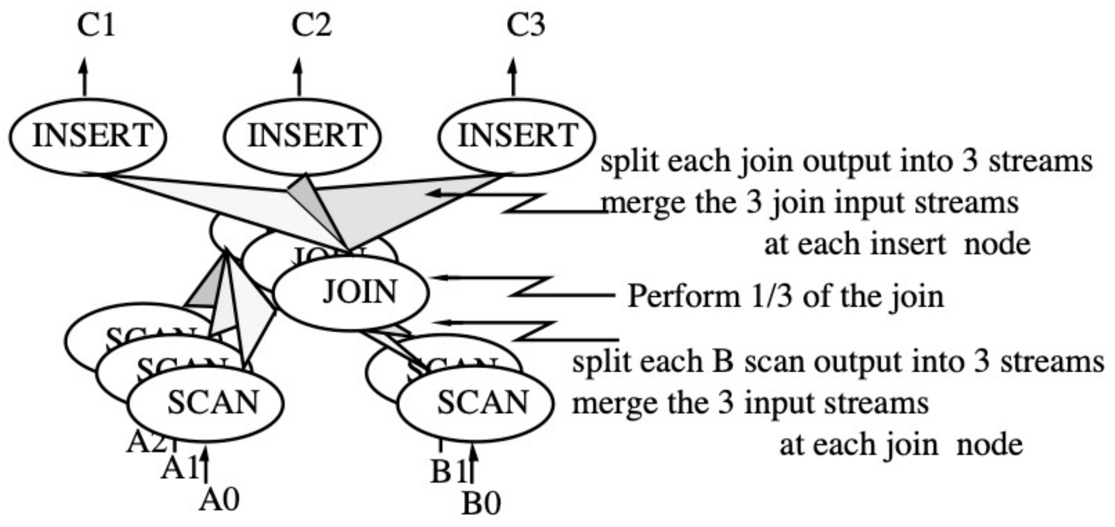
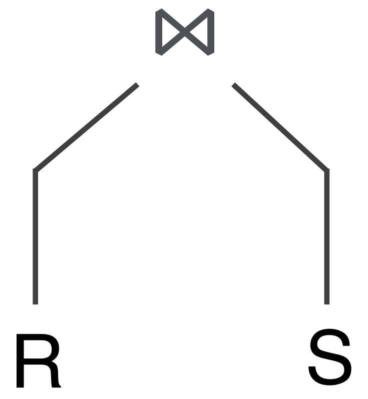
```
insert into C
  select    *
  from      A, B
  where     A.x = B.y;
```



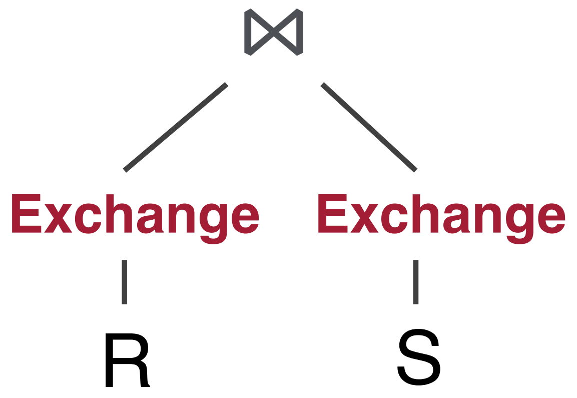

C1
C2
C3
INSERT
INSERT
INSERT
split each join output into 3 streams
merge the 3 join input streams
at each insert node
JOIN
Perform 1/3 of the join
SCAN
SCAN
split each B scan output into 3 streams
merge the 3 input streams
at each join node
A2
A1
A0
B1
B0

Data Shuffle

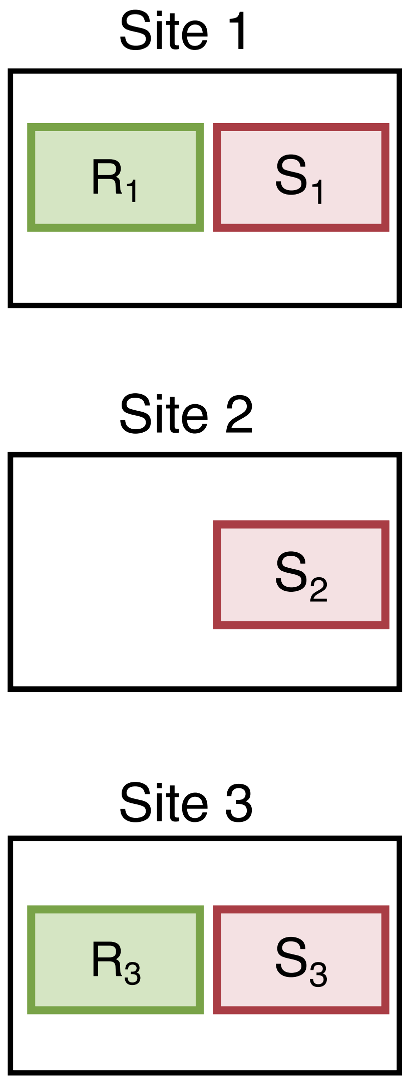
Single-node query plan



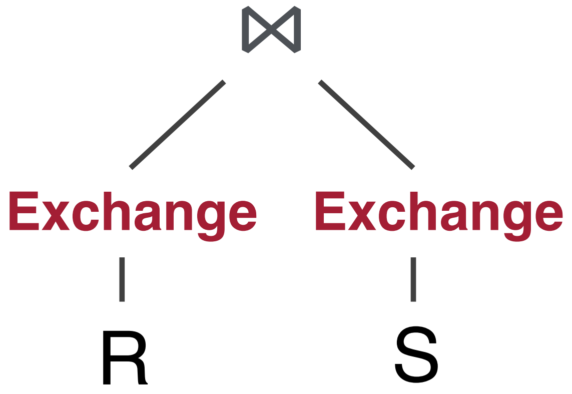
Distributed query plan



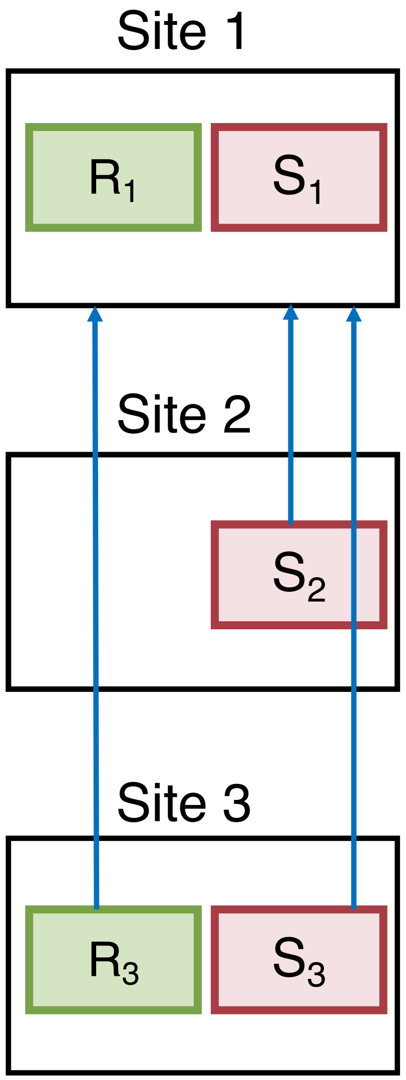
Data Shuffle – Example



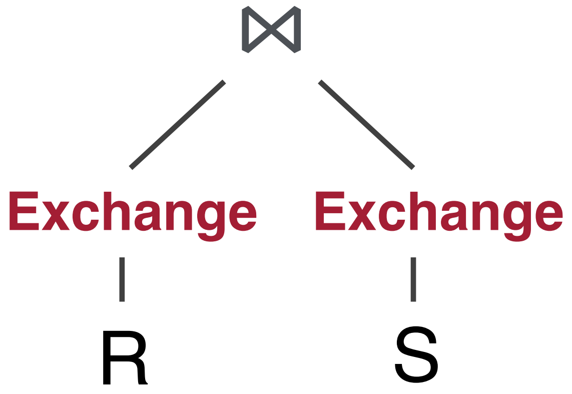
Query plan



Data Shuffle – Single-Site



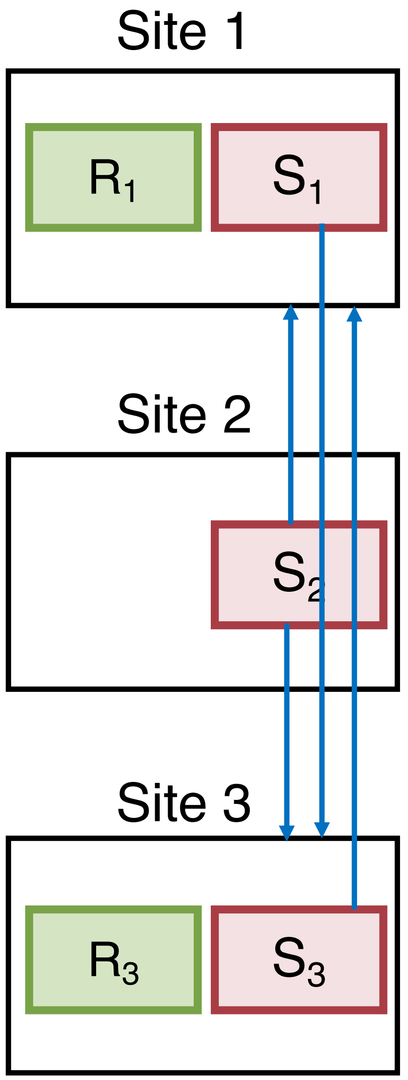
Query plan



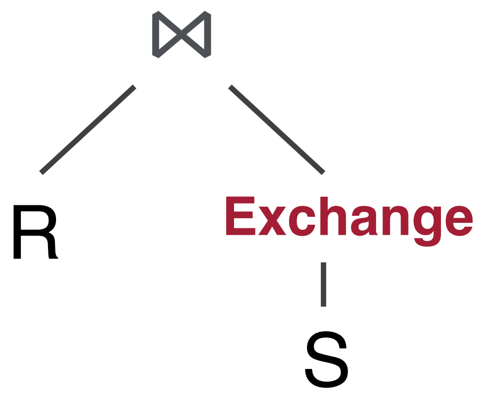
Solution 1: send all the involved tables to a single site

- **Advantage**: Single-site query execution is a solved problem
- **Disadvantage**: (1) Single site execution can be slow (2) Data may not fit in single site's memory or disk

Data Shuffle – Broadcast



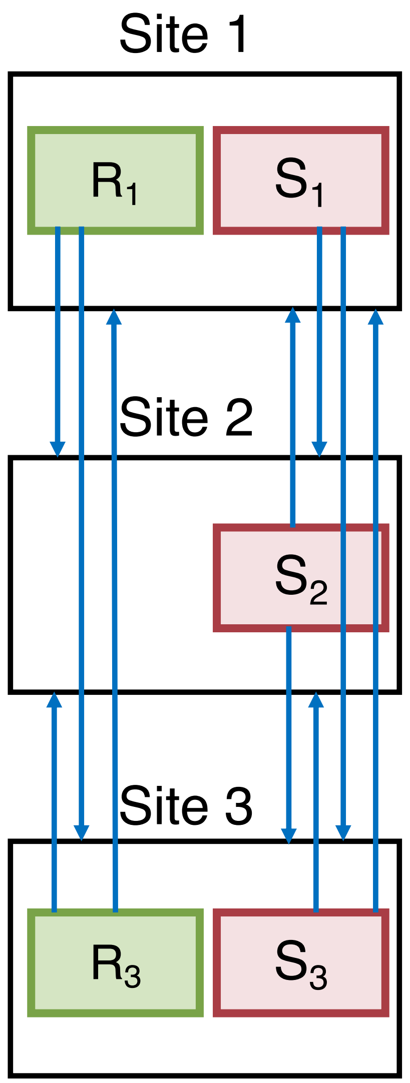
Query plan



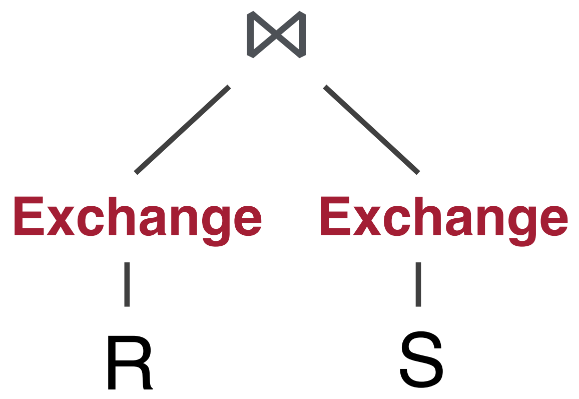
Solution 2: Keep one relation partitioned and broadcast the other relation to all sites

- **Advantage**: One relation does not need to move
- **Disadvantage**: Still need to broadcast the other relation to all sites

Data Shuffle – Co-partition



Query plan



Solution 3: Partition both relations using the join key

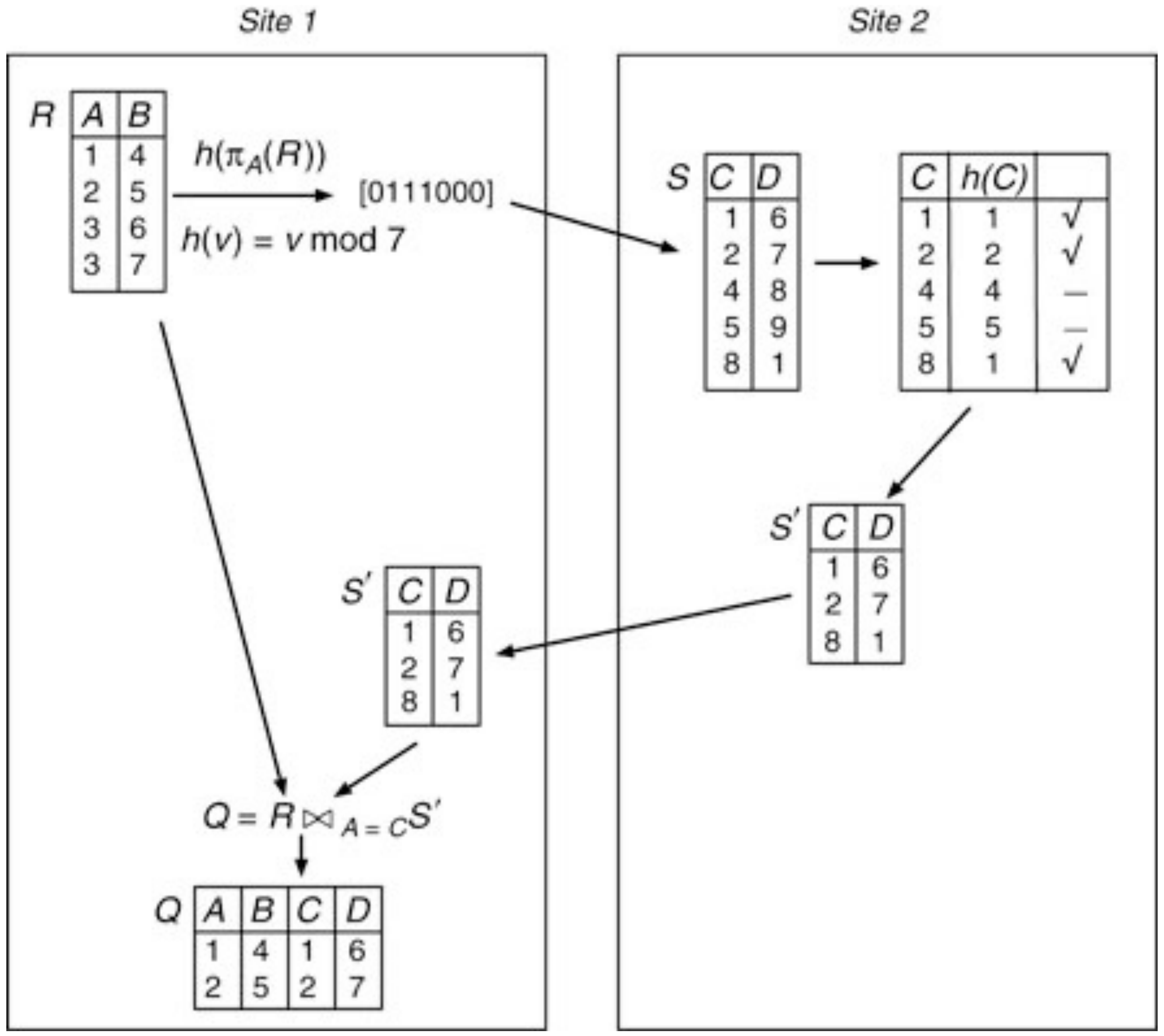
- **Advantage**: Each site has less data to process
- **Disadvantage**: Both relations are shuffled (if not already partitioned based on join key)

Specialized Parallel Operators

Semi-join

- Example:

```
SELECT *
 FROM T1, T2
 WHERE T1.A = T2.C
```



A	B
1	4
2	5
3	6
3	7

C	D
1	6
2	7
4	8
5	9
8	1

C	h(C)	
1	1	√
2	2	√
4	4	—
5	5	—
8	1	√

C	D
1	6
2	7
8	1

A	B	C	D
1	4	1	6
2	5	2	7

* Source: Sattler KU. (2009) Semijoin. Encyclopedia of Database Systems.

Agenda

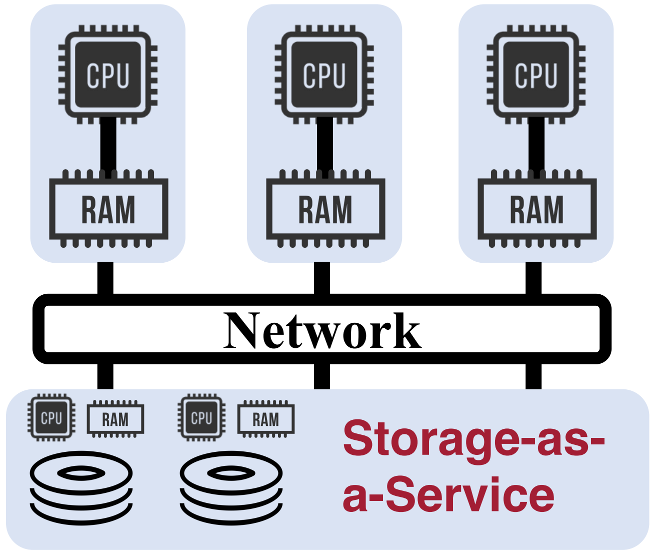
Parallelism metrics

Parallel architecture

Parallel OLAP operators

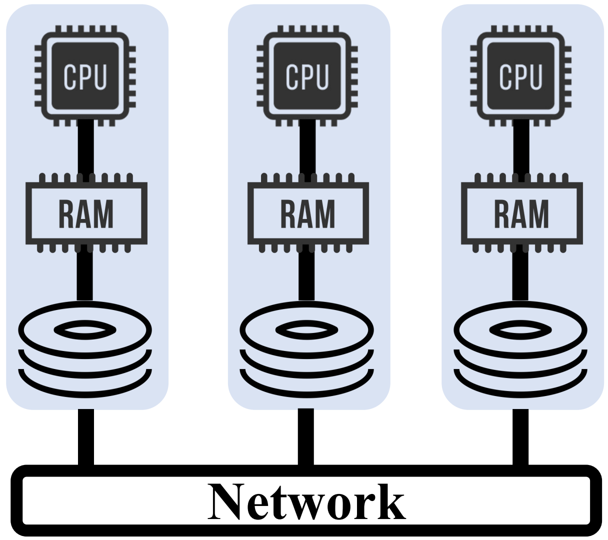
Cloud parallel database

Paradigm Shift in Architecture — Disaggregation

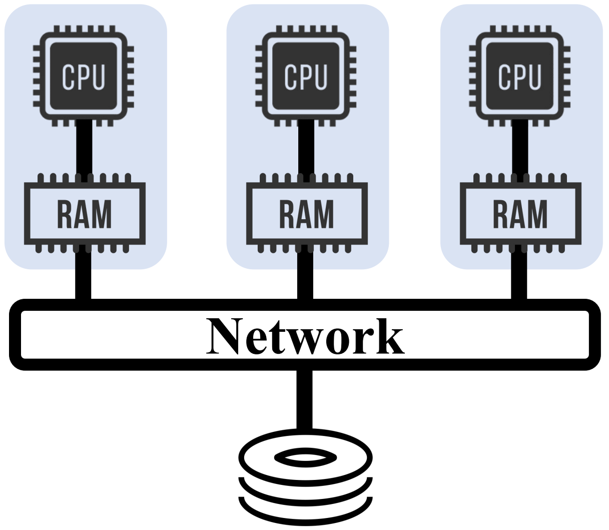


Storage Disaggregation

vs.

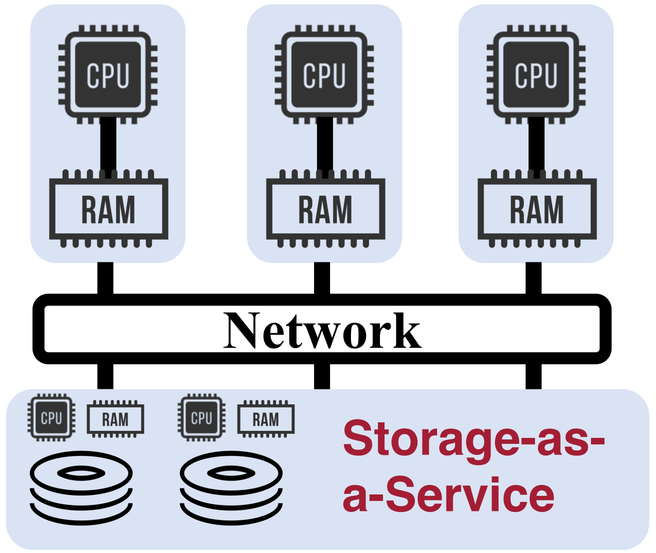


Shared Nothing



Shared Disk

Paradigm Shift in Architecture — Disaggregation



Storage Disaggregation

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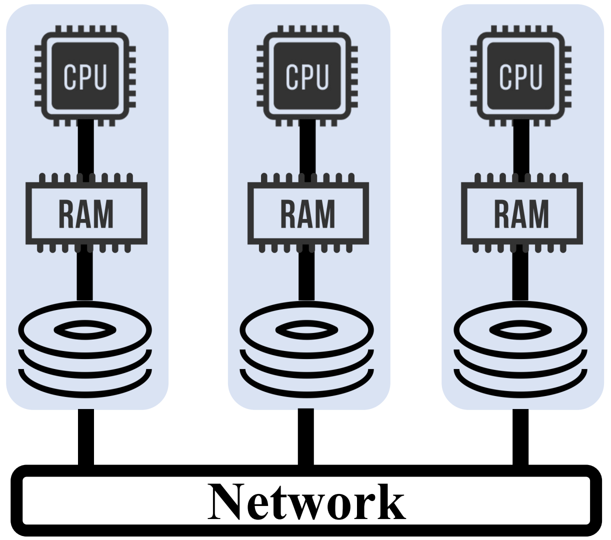
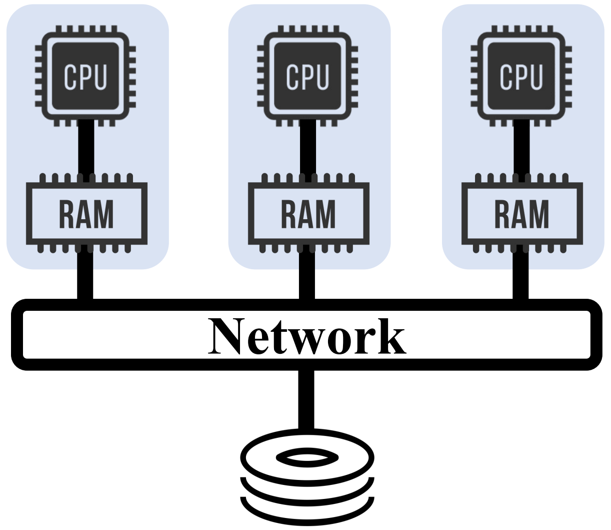


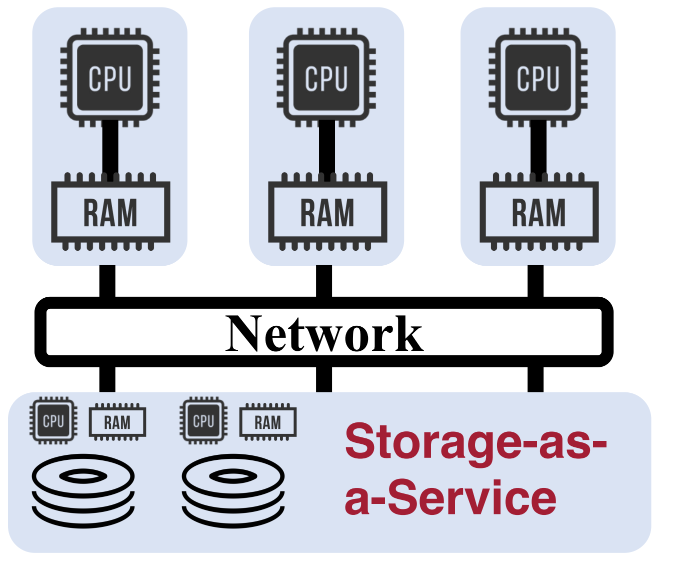
Shared Nothing



Shared Disk

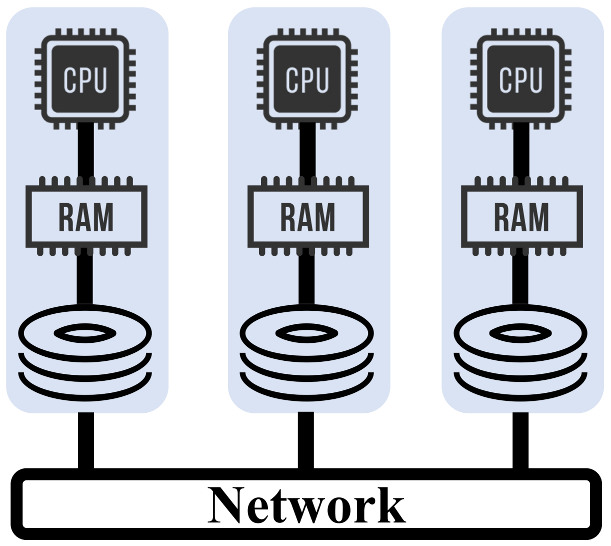
Feature 1: All compute nodes can access the entire storage service
Feature 2: Can perform limited computation in the storage service
Feature 3: The storage service is highly available

Paradigm Shift in Architecture — Disaggregation

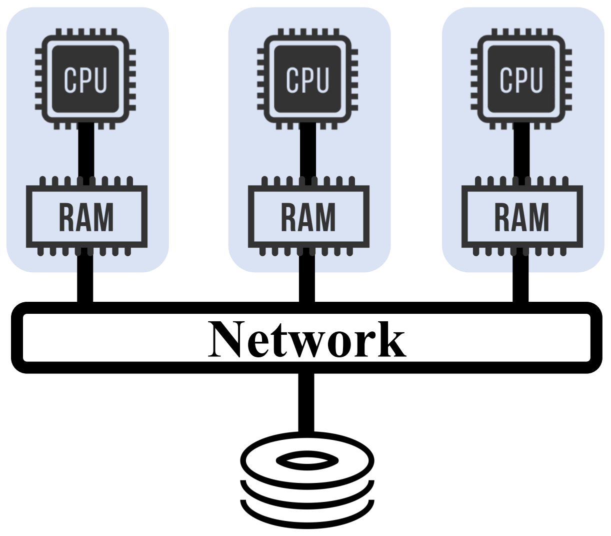


Storage Disaggregation

vs.



Shared Nothing



Shared Disk

Key challenge: **Network becomes a bottleneck**

- Performance of disaggregation can be 10x lower than shared-nothing [1]

More on this topic in a few lectures

[1] Junjay Tan, et al. *Choosing A Cloud DBMS: Architectures and Tradeoffs,* VLDB'19

Q/A – Parallel Database

How is data skew handled by hash partitioning?

Is partitioning part of the SQL interface or is it hidden from users?

The paper mentioned that SM and SD systems failed to scale well because of limited network bandwidth; Is this still true today?

No quantitative comparison of scalability

How to cope with locking in a shared-nothing database?

Before Next Lecture

Submit review for

Jim Gray, et al., Granularity of Locks and Degrees of Consistency in a Shared Data Base. Modelling in Data Base Management Systems, 1976