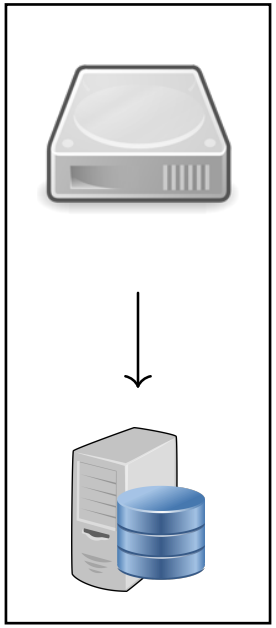
Parallelizing Queries

CSE 4/562: Database Systems | Lecture 14

DB. Sys.: T.C.B.: Ch. 20.1-20.4

Why Scale?

Scan 1 PB at 300MB/s (SATA r2)



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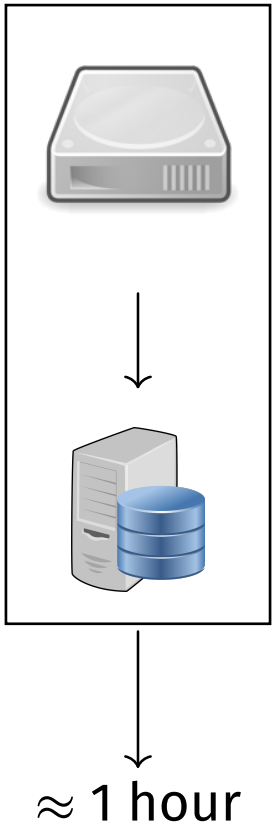
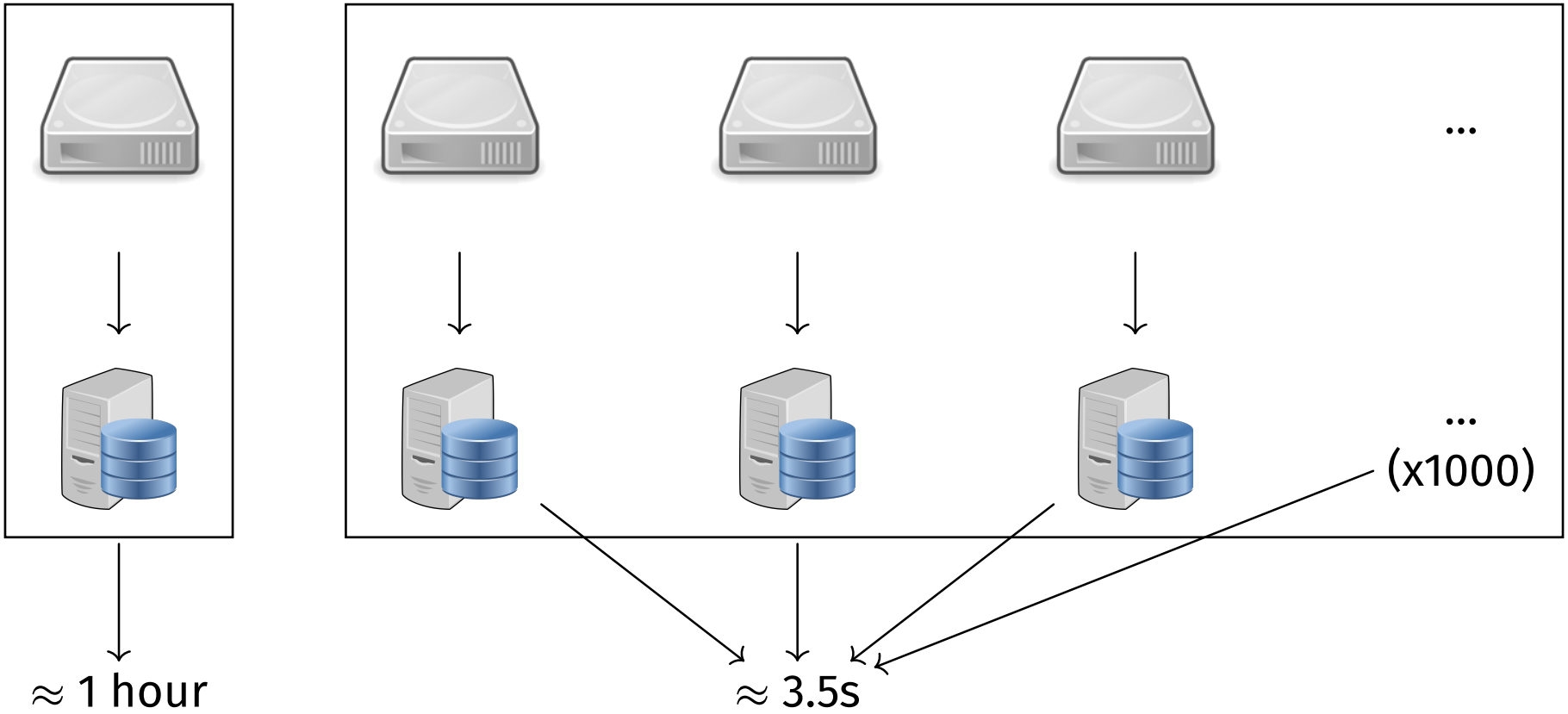


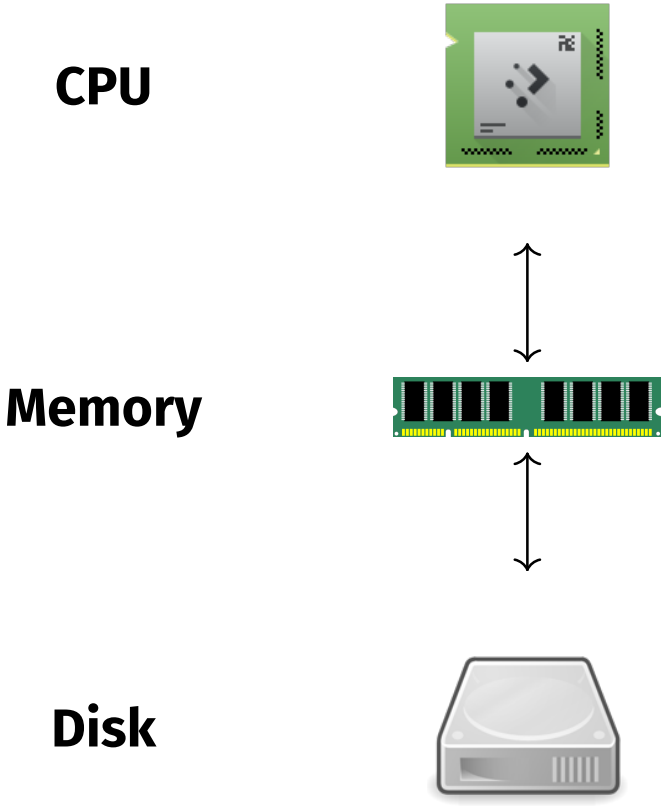
Advantages of Parallelization

Scan 1 PB at 300MB/s (SATA r2)

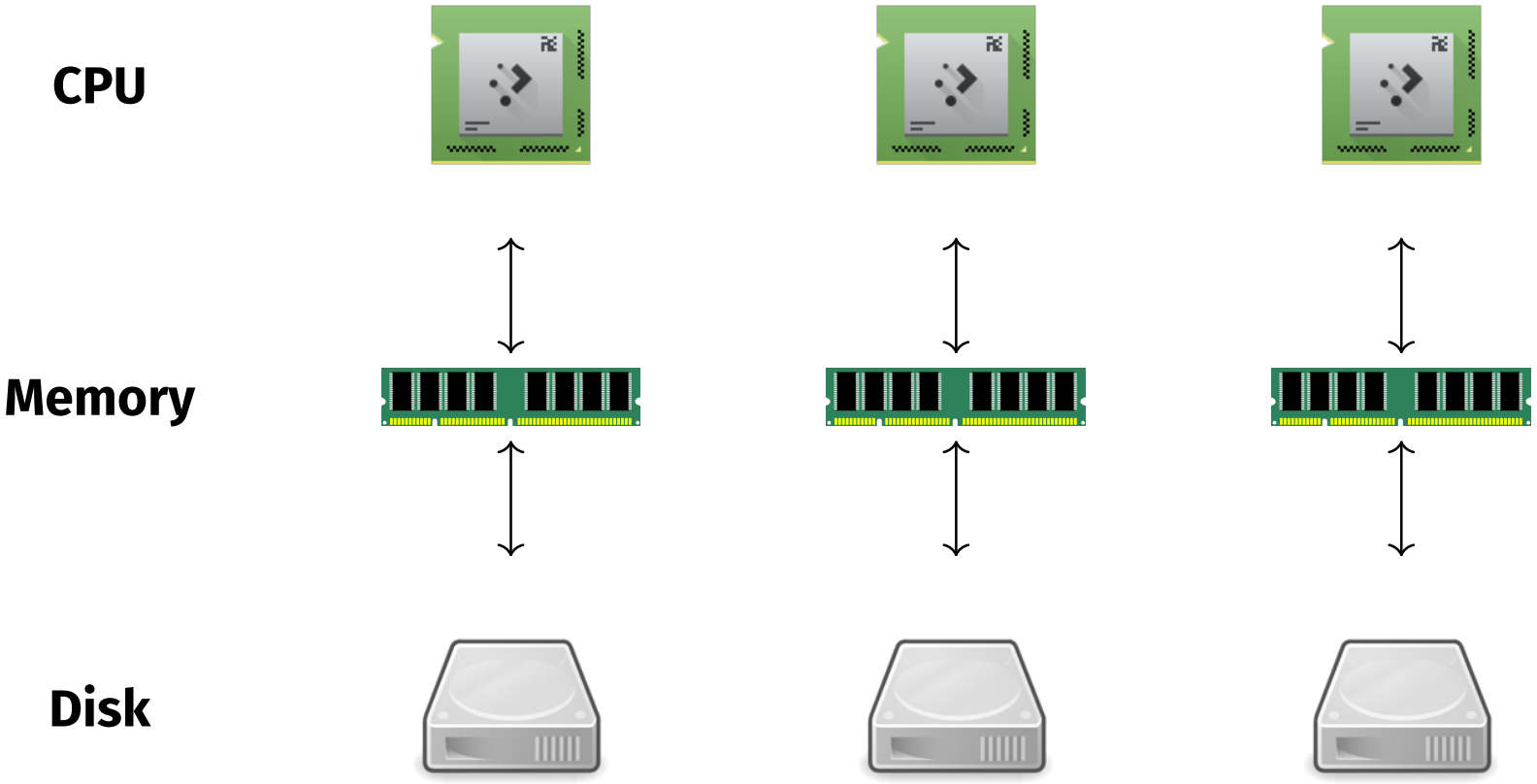


Communication Models

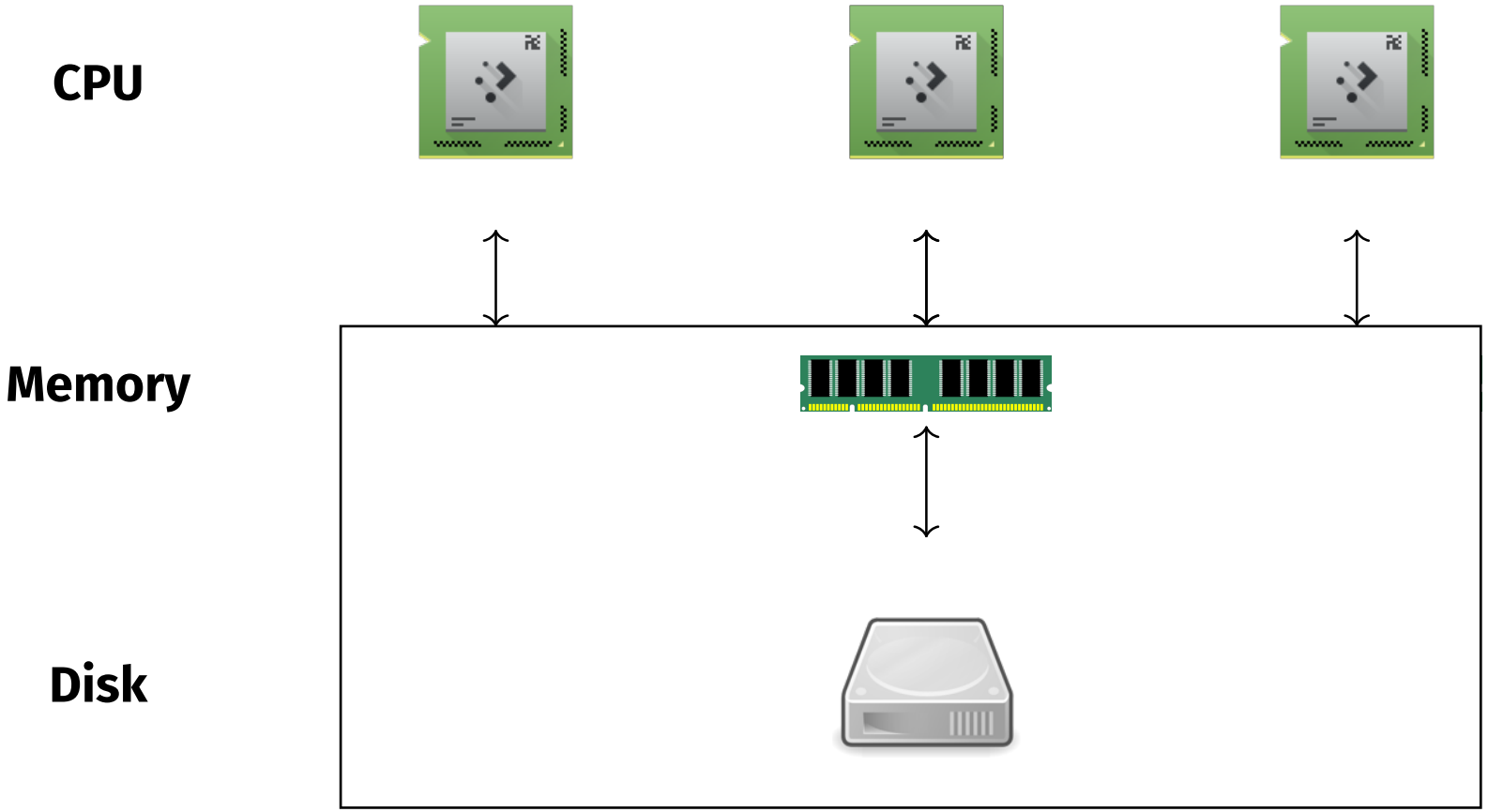
No Parallelism



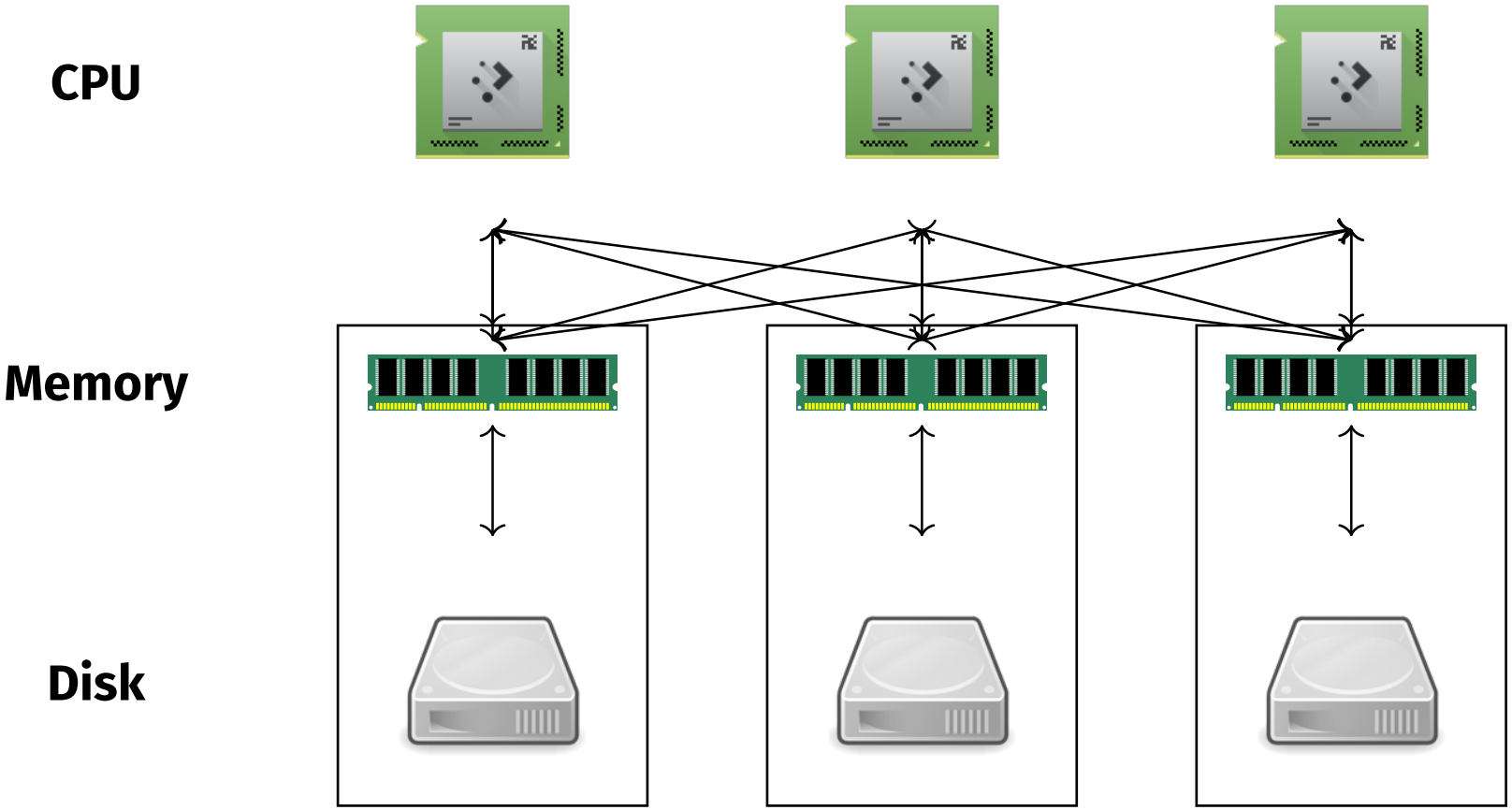
No Parallelism



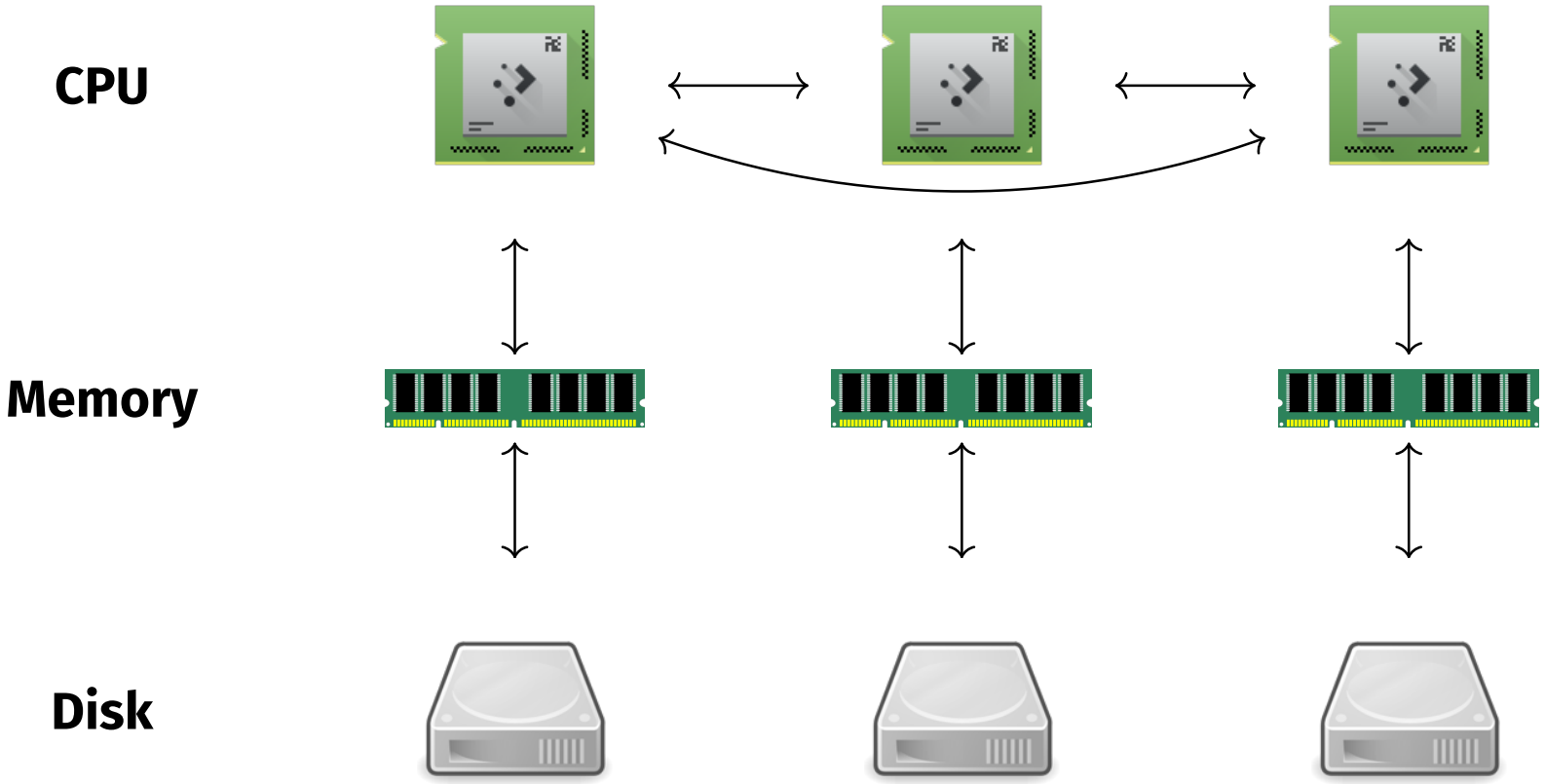
Shared Memory



Non-Uniform Memory Access



Shared Nothing / Message Passing



Shared Memory

- S3
- RAM/Modern OSes

NUMA

- AMD CPUs
- Hadoop

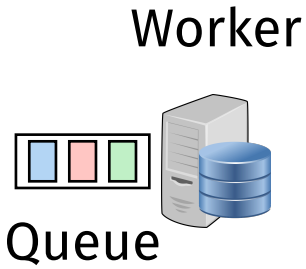
Shared Nothing

- MPP
- Apache Spark

Today: Shared Nothing

Worker

The Basic Model



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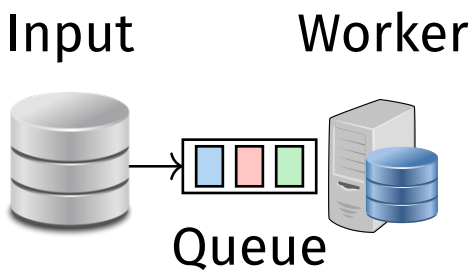
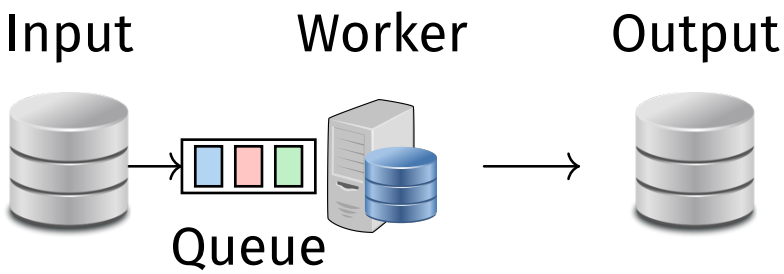


The Basic Model



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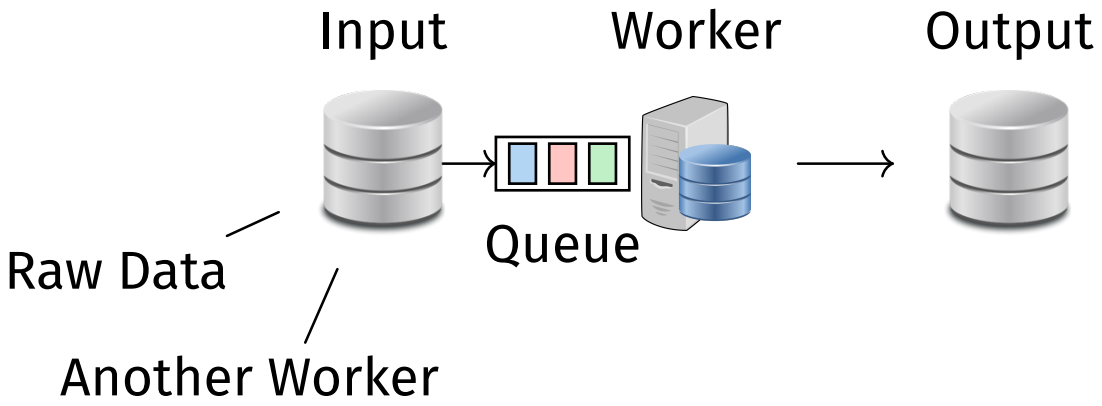
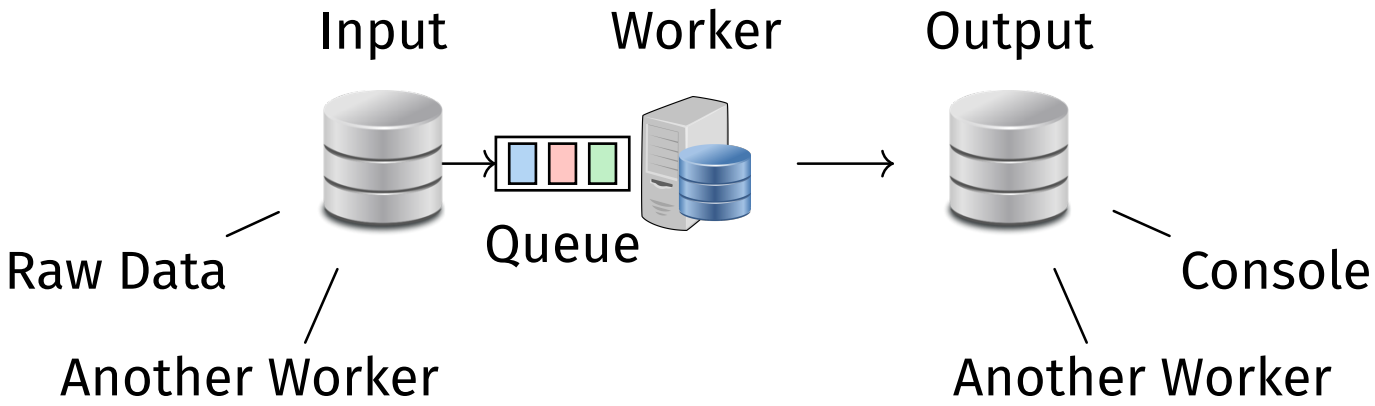
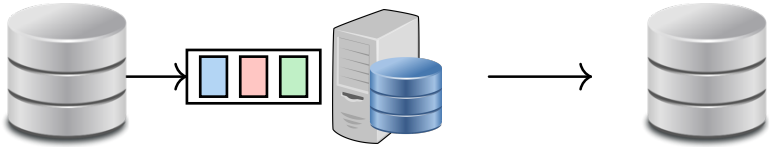


The Basic Model

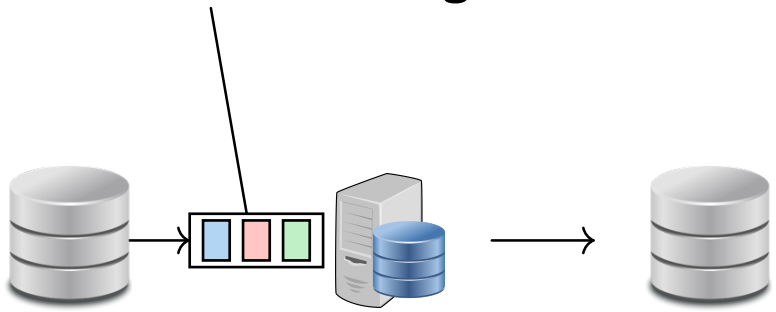


Potential Slowdowns



Potential Slowdowns

Data doesn’t arrive fast enough.



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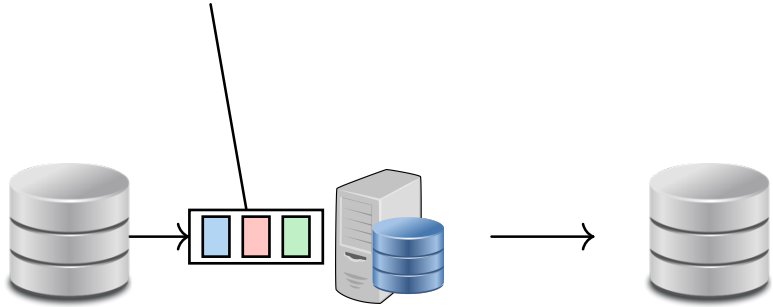
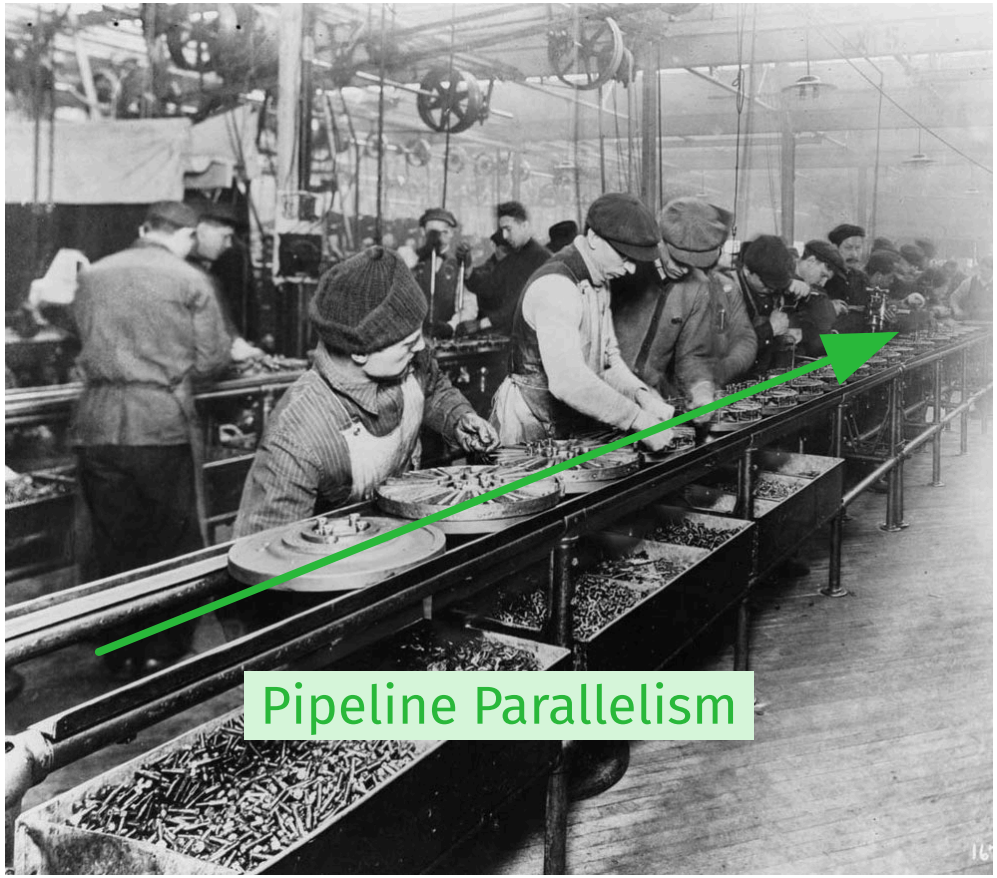


Worker processes data slower than it arrives.

Putting Workers Together

Image credit: Wikipedia - Public Domain Image - Photographer Unknown

Putting Workers Together



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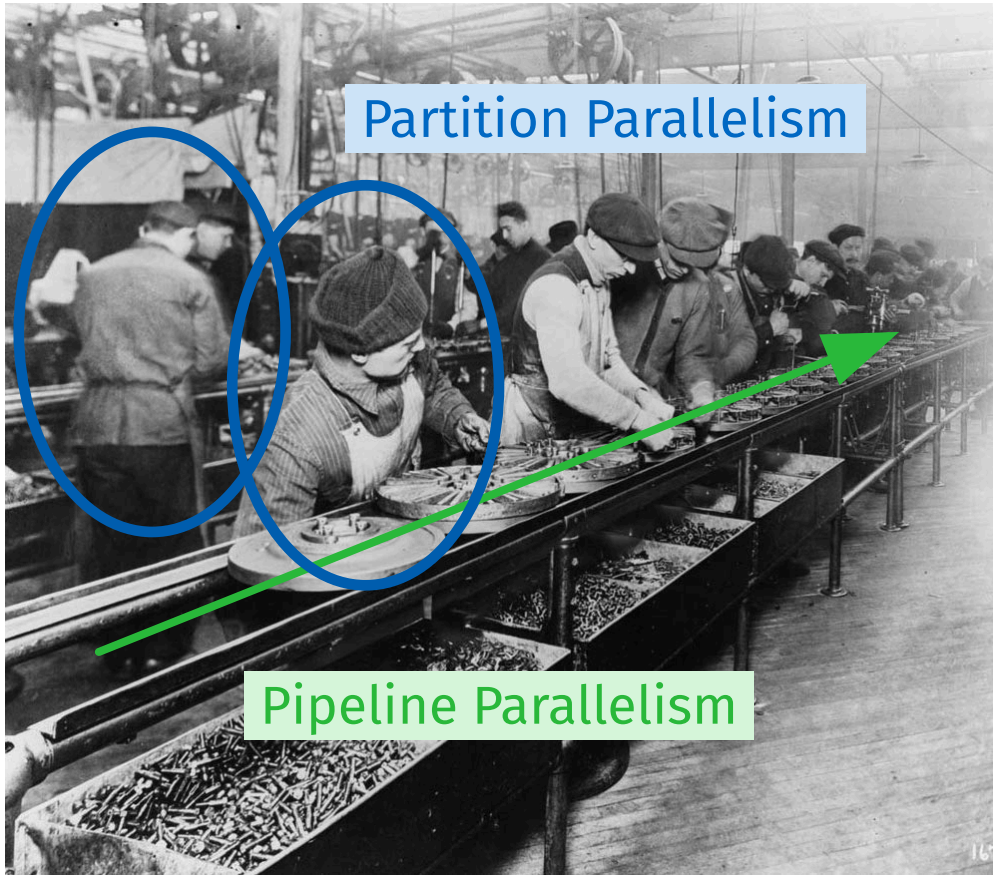
Putting Workers Together



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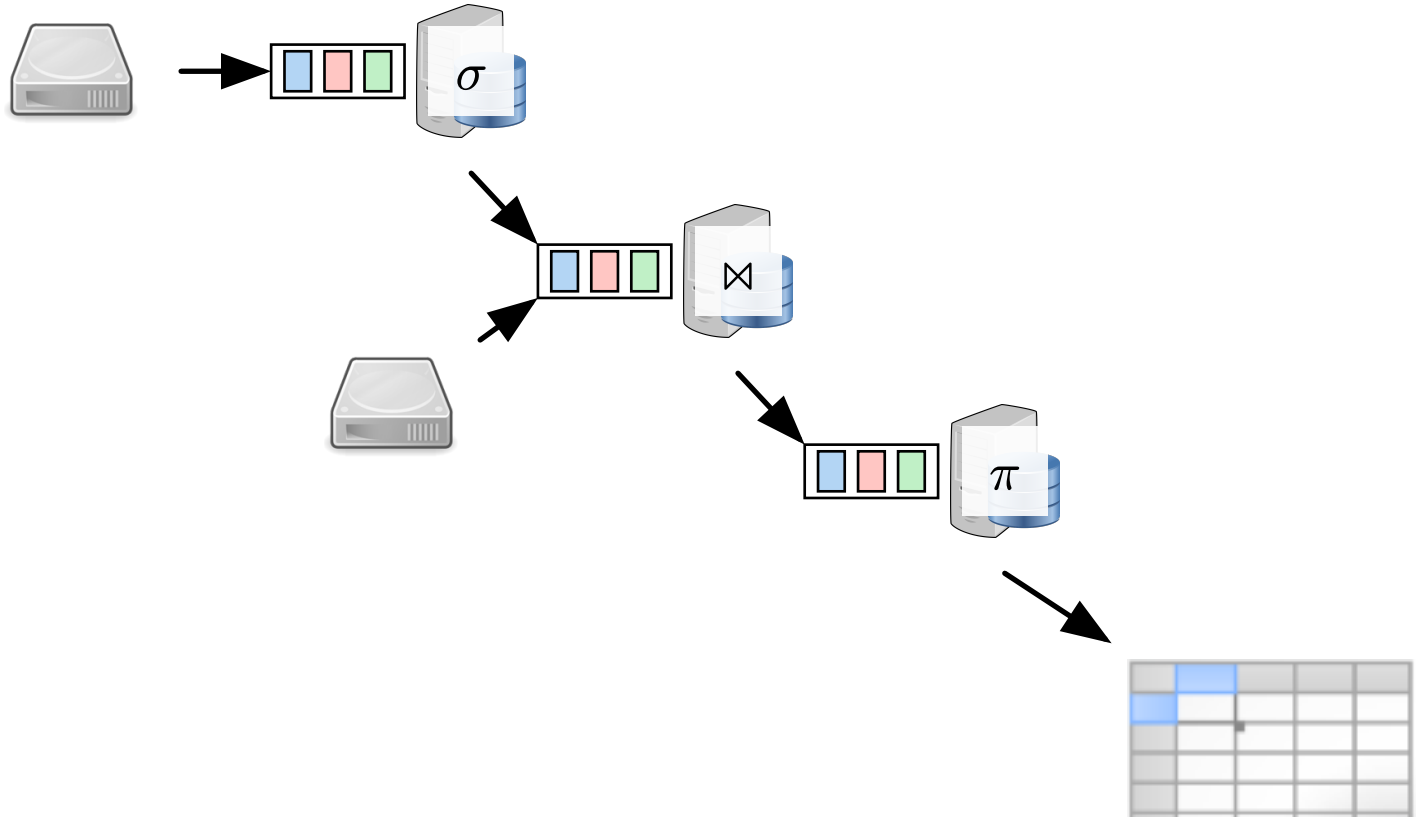
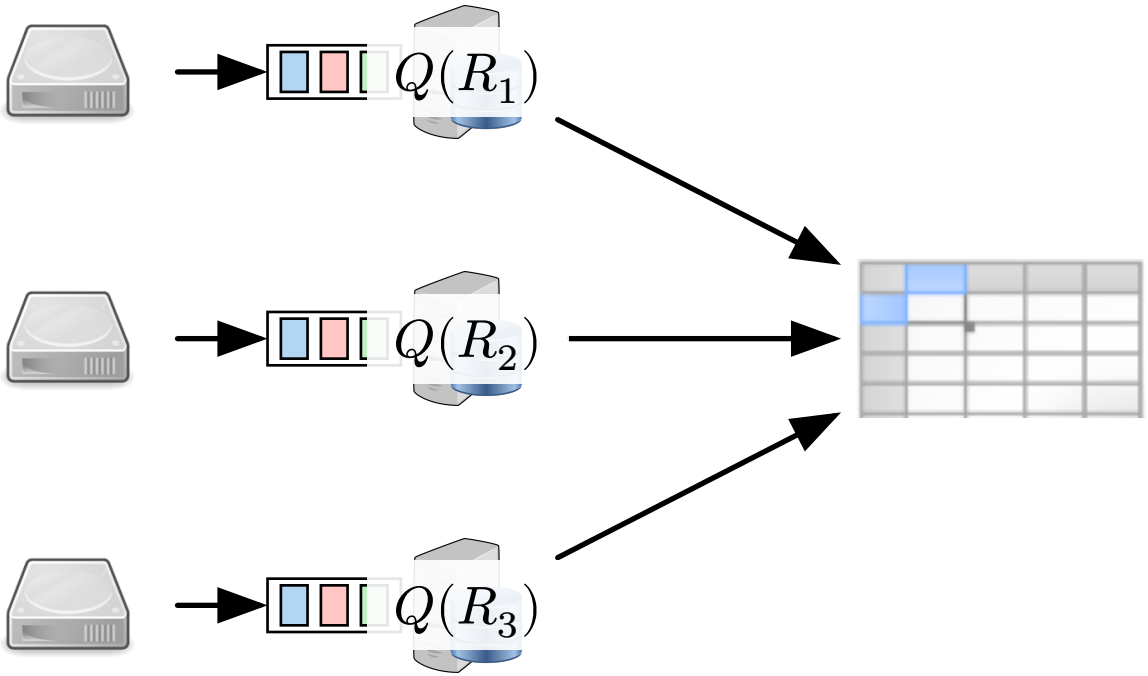
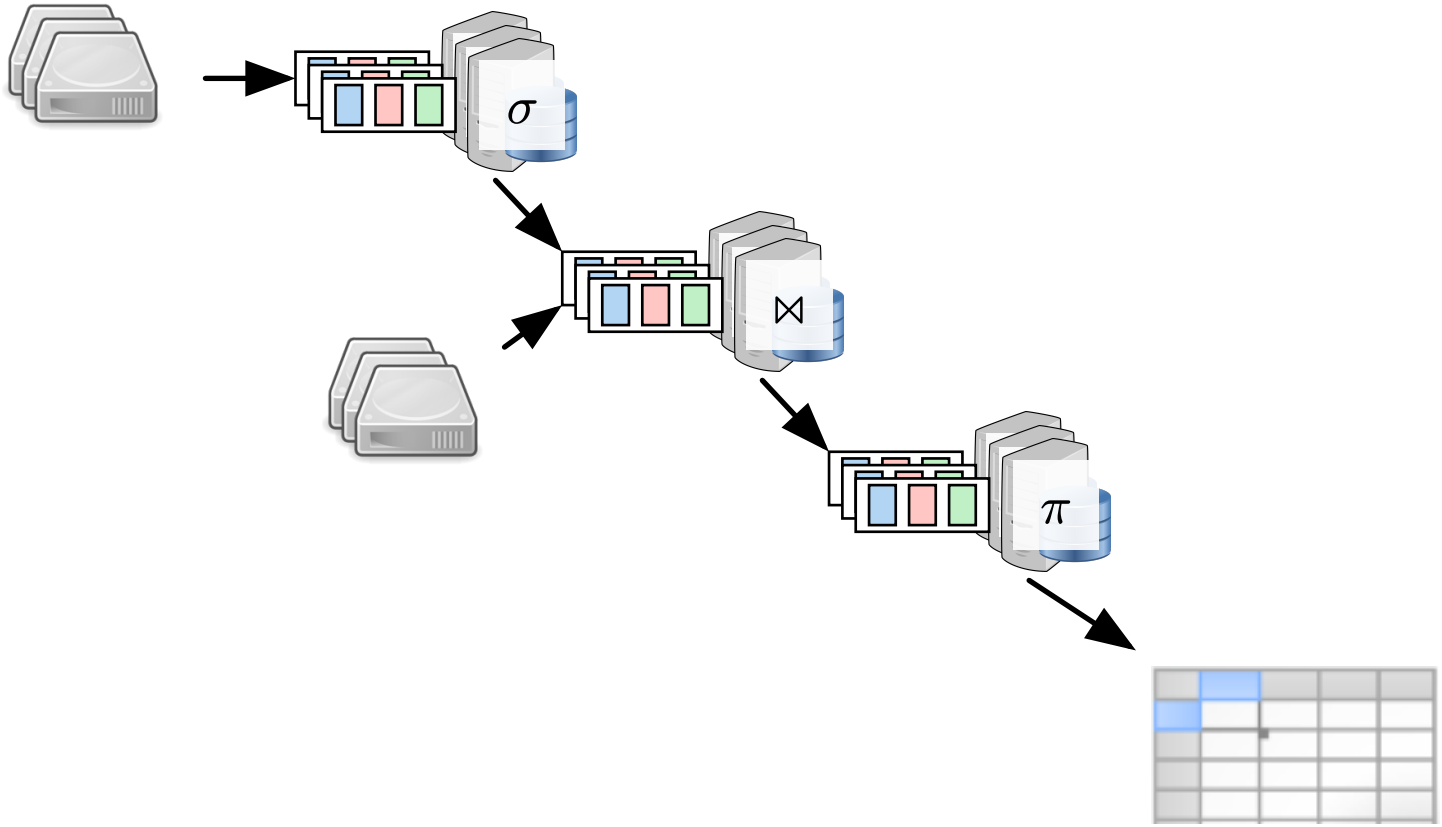
Pipeline Parallelism



Partition Parallelism



Together



Distributing Data

Replication

Partitioning (Sharding)

Partitioning Data

How do we pick what goes into each partition?

- Arbitrary
- Range
- Hash

Partitioning Data

How do we pick what goes into each partition?

- Arbitrary
- Range
- Hash

look familiar?

Partitioning Data

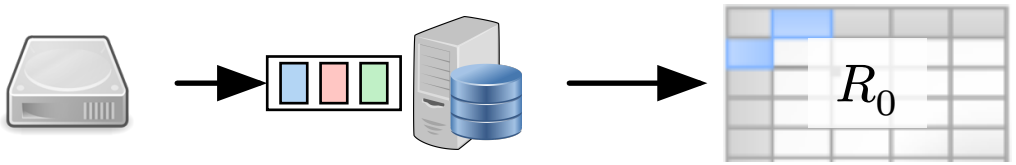
How do we pick what goes into each partition?

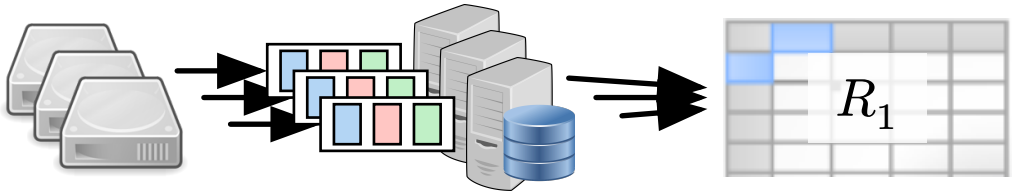
- Arbitrary
- Range
- Hash

look familiar?

How do we parallelize?

Equivalence





$$R_0 \stackrel{?}{=} R_1$$

Equivalence

Can we run each worker independently on one partition?

$$Q(R_0 \cup ... \cup R_N) \stackrel{?}{=} Q(R_0) \cup ... \cup Q(R_N)$$

Equivalence - The Easy Cases

Selection

- $\sigma(R_0 \cup ... \cup R_N) =$

Projection

- $\pi(R_0 \cup ... \cup R_N) =$

Union

- $(R_0 \cup ... \cup R_N) =$

Equivalence - The Easy Cases

Selection

- $\sigma(R_0 \cup ... \cup R_N) = \sigma(R_0) \cup ... \cup \sigma(R_N)$

Projection

- $\pi(R_0 \cup ... \cup R_N) =$

Union

- $(R_0 \cup ... \cup R_N) =$

Equivalence - The Easy Cases

Selection

- $\sigma(R_0 \cup ... \cup R_N) = \sigma(R_0) \cup ... \cup \sigma(R_N)$

Projection

- $\pi(R_0 \cup ... \cup R_N) = \pi(R_0) \cup ... \cup \pi(R_N)$

Union

- $(R_0 \cup ... \cup R_N) =$

Equivalence - The Easy Cases

Selection

- $\sigma(R_0 \cup ... \cup R_N) = \sigma(R_0) \cup ... \cup \sigma(R_N)$

Projection

- $\pi(R_0 \cup ... \cup R_N) = \pi(R_0) \cup ... \cup \pi(R_N)$

Union

- $(R_0 \cup ... \cup R_N) = (R_0) \cup ... \cup (R_N)$

Aggregation

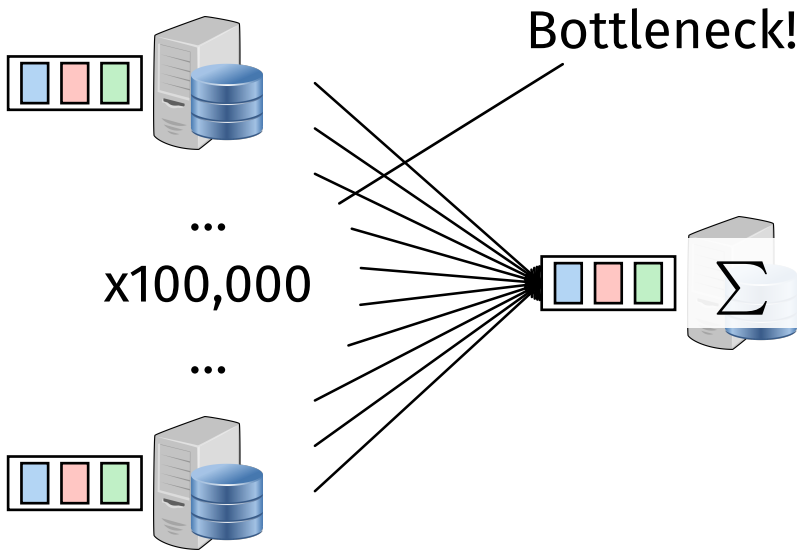
Single Row Aggregation

- $\sum(R_0 \cup ... \cup R_N) =$

Single Row Aggregation

- $\sum(R_0 \cup ... \cup R_N) =$???

Distributed Aggregation



Algebraic Aggregates

- `Init()`: The “default” value of the aggregate
- `Accumulate(agg, value)`: Incorporate a new value
- `Finalize(agg) -> value`: Post-process the aggregate

Algebraic Aggregates

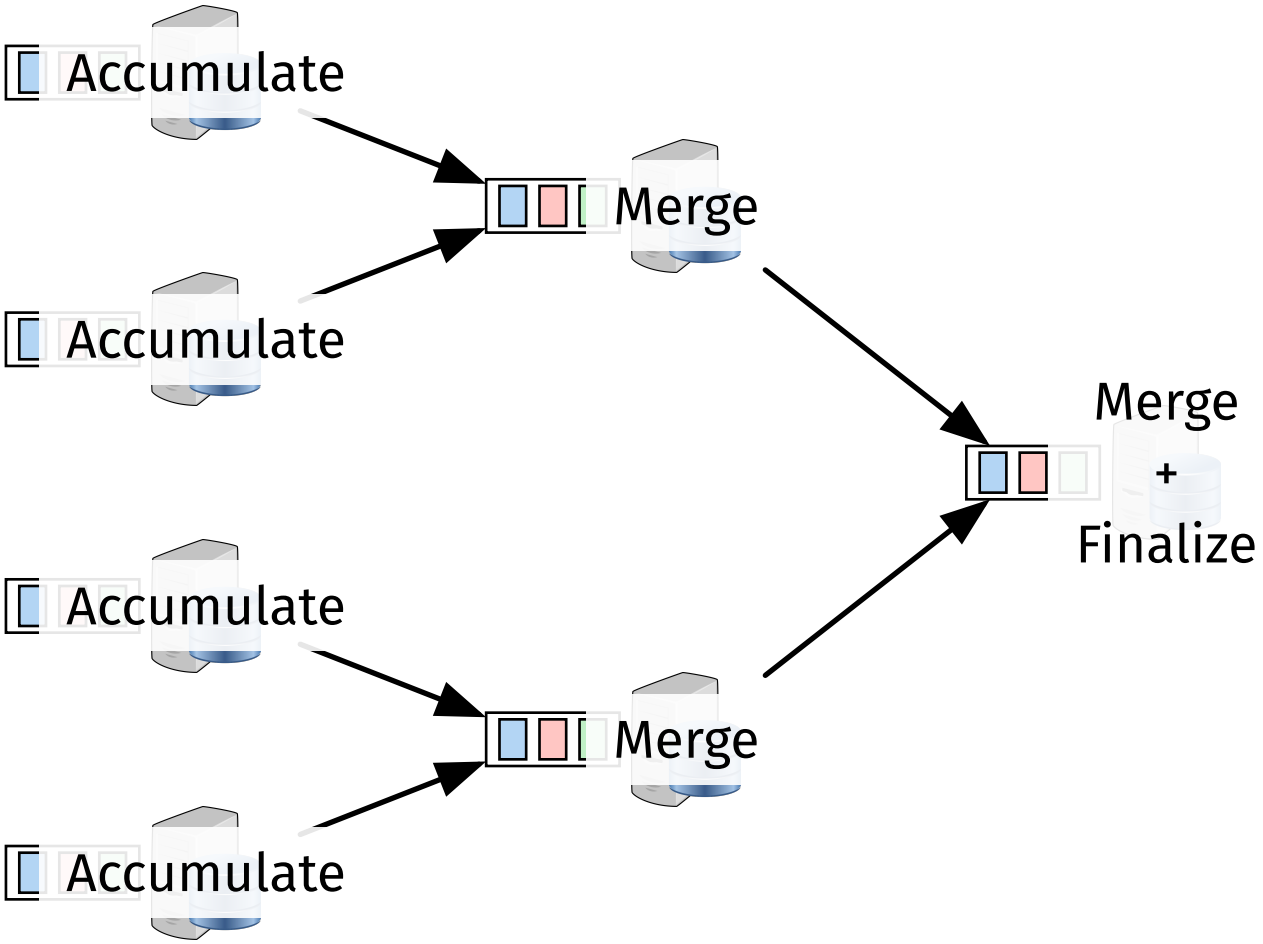
- `Init()`: The “default” value of the aggregate
- `Accumulate(agg, value)`: Incorporate a new value
- `Finalize(agg) -> value`: Post-process the aggregate
- `Merge(agg, agg)`: Combine independent intermediate aggregates

Single Row Aggregation

- $\sum(R_0 \cup ... \cup R_N) = \sum(R_0) + ... + \sum(R_N)$

Final “Merge” step only processes N tuples

Fold/Merge


Accumulate
Accumulate
Merge
Accumulate
Accumulate
Merge
Merge
+
Finalize

Multi-Row Aggregation

- **Arbitrary Partitioning**: As single-row
- **Hash/Range Partitioning**: Aggregate groups do not cross partitions

Joins

$$(R_1 \cup R_2) \bowtie (S_1 \cup S_2)$$

$$(R_1 \cup R_2) \bowtie (S_1 \cup S_2)$$

$$(R_1 \bowtie (S_1 \cup S_2)) \cup (R_2 \bowtie (S_1 \cup S_2))$$

$$(R_1 \cup R_2) \bowtie (S_1 \cup S_2)$$

$$(R_1 \bowtie (S_1 \cup S_2)) \cup (R_2 \bowtie (S_1 \cup S_2))$$

$$(R_1 \bowtie S_1) \cup (R_1 \bowtie S_2) \cup (R_2 \bowtie (S_1 \cup S_2))$$

$$(R_1 \bowtie S_1) \cup (R_1 \bowtie S_2) \cup (R_2 \bowtie S_1) \cup (R_2 \bowtie S_2)$$

$$(R_1 \cup ... \cup R_N) \bowtie (S_1 \cup ... \cup S_K)$$

$$=$$

$$(R_1 \bowtie S_1) \cup ... \cup (R_1 \bowtie S_K)$$

$$... \cup ... \cup ...$$

$$(R_N \bowtie S_1) \cup ... \cup (R_N \bowtie S_K)$$

	S_0	S_1	S_2	S_3	S_4
R_0	$R_0 \bowtie S_0$	$R_0 \bowtie S_1$	$R_0 \bowtie S_2$	$R_0 \bowtie S_3$	$R_0 \bowtie S_4$
R_1	$R_1 \bowtie S_0$	$R_1 \bowtie S_1$	$R_1 \bowtie S_2$	$R_1 \bowtie S_3$	$R_1 \bowtie S_4$
R_2	$R_2 \bowtie S_0$	$R_2 \bowtie S_1$	$R_2 \bowtie S_2$	$R_2 \bowtie S_3$	$R_2 \bowtie S_4$
R_3	$R_3 \bowtie S_0$	$R_3 \bowtie S_1$	$R_3 \bowtie S_2$	$R_3 \bowtie S_3$	$R_3 \bowtie S_4$
R_4	$R_4 \bowtie S_0$	$R_4 \bowtie S_1$	$R_4 \bowtie S_2$	$R_4 \bowtie S_3$	$R_4 \bowtie S_4$

	S_0	S_1	S_2	S_3	S_4
R_0	$R_0 \bowtie S_0$	$R_0 \bowtie S_1$	$R_0 \bowtie S_2$	$R_0 \bowtie S_3$	$R_0 \bowtie S_4$
R_1	$R_1 \bowtie S_0$	$R_1 \bowtie S_1$	$R_1 \bowtie S_2$	$R_1 \bowtie S_3$	$R_1 \bowtie S_4$
R_2	$R_2 \bowtie S_0$	$R_2 \bowtie S_1$	$R_2 \bowtie S_2$	$R_2 \bowtie S_3$	$R_2 \bowtie S_4$
R_3	$R_3 \bowtie S_0$	$R_3 \bowtie S_1$	$R_3 \bowtie S_2$	$R_3 \bowtie S_3$	$R_3 \bowtie S_4$
R_4	$R_4 \bowtie S_0$	$R_4 \bowtie S_1$	$R_4 \bowtie S_2$	$R_4 \bowtie S_3$	$R_4 \bowtie S_4$

N workers gets us $\sqrt{N}$ scaling

Partitioning Data

How do we pick what goes into each partition?

- Arbitrary
- Range
- Hash

Hash Partitioning

For $R \underset{A}{\bowtie} S$:

- $R_i \leftarrow \sigma_{\text{hash}(A)=i}(R)$
- $S_i \leftarrow \sigma_{\text{hash}(A)=i}(S)$

Distributed Joins

	S_0	S_1	S_2	S_3	S_4
R_0	$R_0 \bowtie S_0$	$R_0 \bowtie S_1$	$R_0 \bowtie S_2$	$R_0 \bowtie S_3$	$R_0 \bowtie S_4$
R_1	$R_1 \bowtie S_0$	$R_1 \bowtie S_1$	$R_1 \bowtie S_2$	$R_1 \bowtie S_3$	$R_1 \bowtie S_4$
R_2	$R_2 \bowtie S_0$	$R_2 \bowtie S_1$	$R_2 \bowtie S_2$	$R_2 \bowtie S_3$	$R_2 \bowtie S_4$
R_3	$R_3 \bowtie S_0$	$R_3 \bowtie S_1$	$R_3 \bowtie S_2$	$R_3 \bowtie S_3$	$R_3 \bowtie S_4$
R_4	$R_4 \bowtie S_0$	$R_4 \bowtie S_1$	$R_4 \bowtie S_2$	$R_4 \bowtie S_3$	$R_4 \bowtie S_4$

Distributed Joins

	S_0	S_1	S_2	S_3	S_4
R_0	$R_0 \bowtie S_0$	$R_0 \bowtie S_1$	$R_0 \bowtie S_2$	$R_0 \bowtie S_3$	$R_0 \bowtie S_4$
R_1	$R_1 \bowtie S_0$	$R_1 \bowtie S_1$	$R_1 \bowtie S_2$	$R_1 \bowtie S_3$	$R_1 \bowtie S_4$
R_2	$R_2 \bowtie S_0$	$R_2 \bowtie S_1$	$R_2 \bowtie S_2$	$R_2 \bowtie S_3$	$R_2 \bowtie S_4$
R_3	$R_3 \bowtie S_0$	$R_3 \bowtie S_1$	$R_3 \bowtie S_2$	$R_3 \bowtie S_3$	$R_3 \bowtie S_4$
R_4	$R_4 \bowtie S_0$	$R_4 \bowtie S_1$	$R_4 \bowtie S_2$	$R_4 \bowtie S_3$	$R_4 \bowtie S_4$

	S_0	S_1	S_2	S_3	S_4
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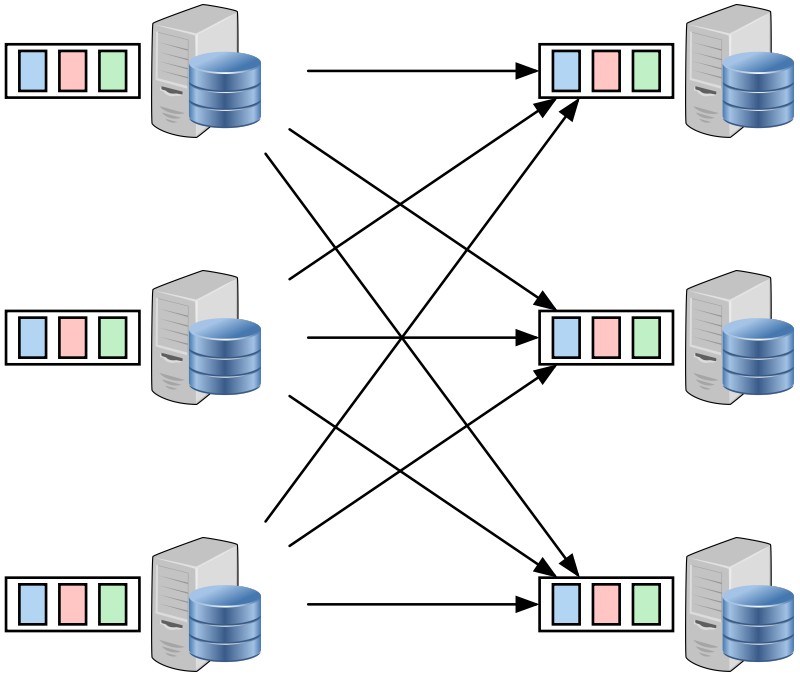
R_4	$R_4 \bowtie S_0$	$R_4 \bowtie S_1$	$R_4 \bowtie S_2$	$R_4 \bowtie S_3$	$R_4 \bowtie S_4$

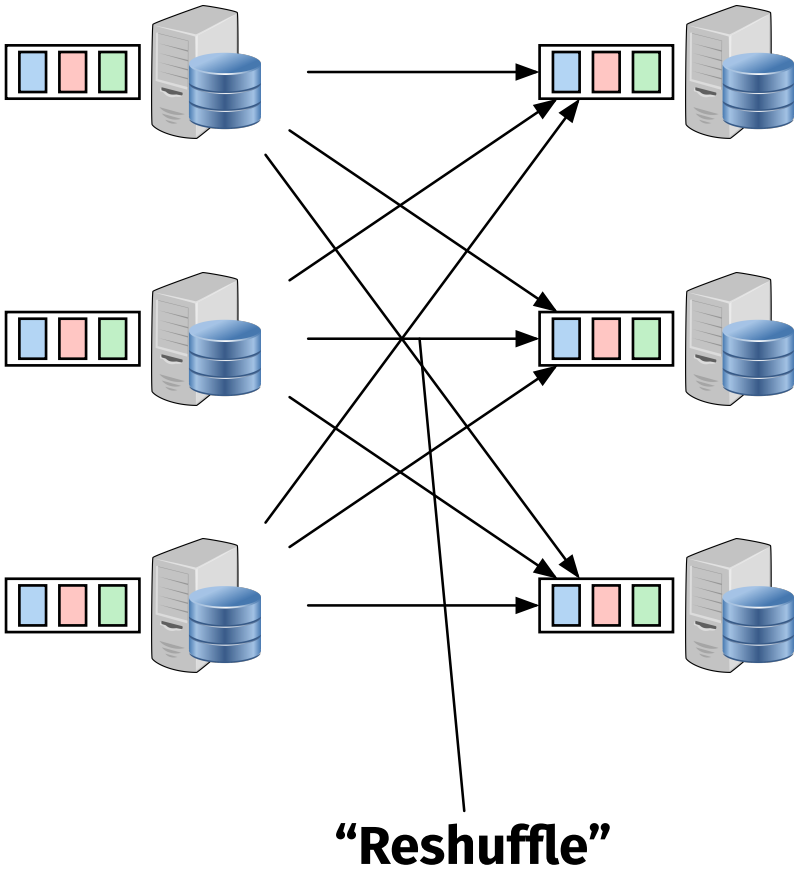
Hash gets us N scaling for N workers

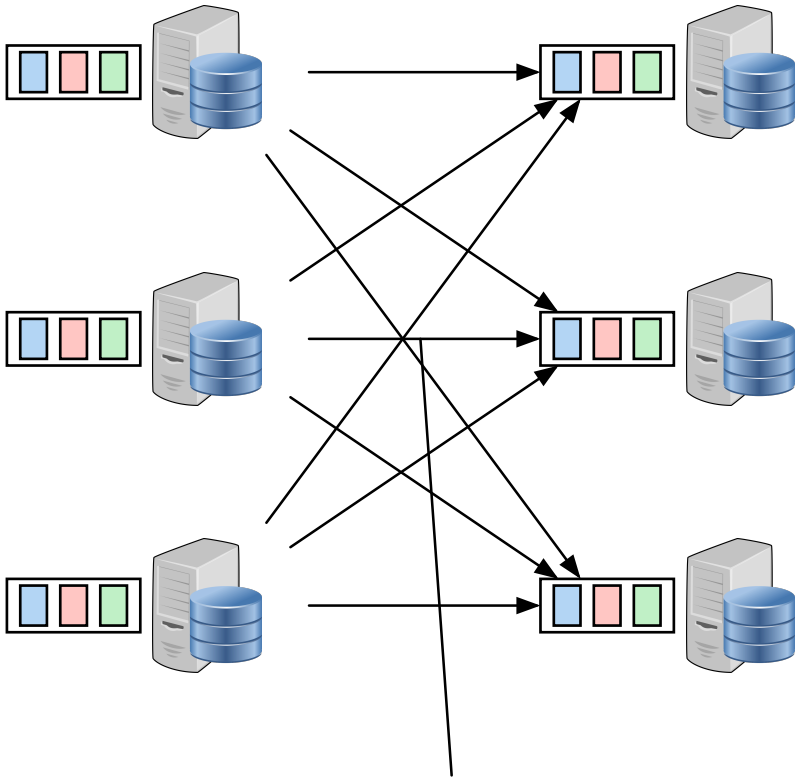
What if the partitions aren’t aligned so nicely?

Distributed Joins



Distributed Joins





“Reshuffle”

(Each tuple goes to exactly one place)

Reshuffling

- R_i is initially located at **X**
- S_i is initially located at **Y**

Then...

1. Copy S_i from **Y** to **X**
2. Compute $R_i \bowtie S_i$ at **X**

Can we reduce network use more?

Distributed Joins

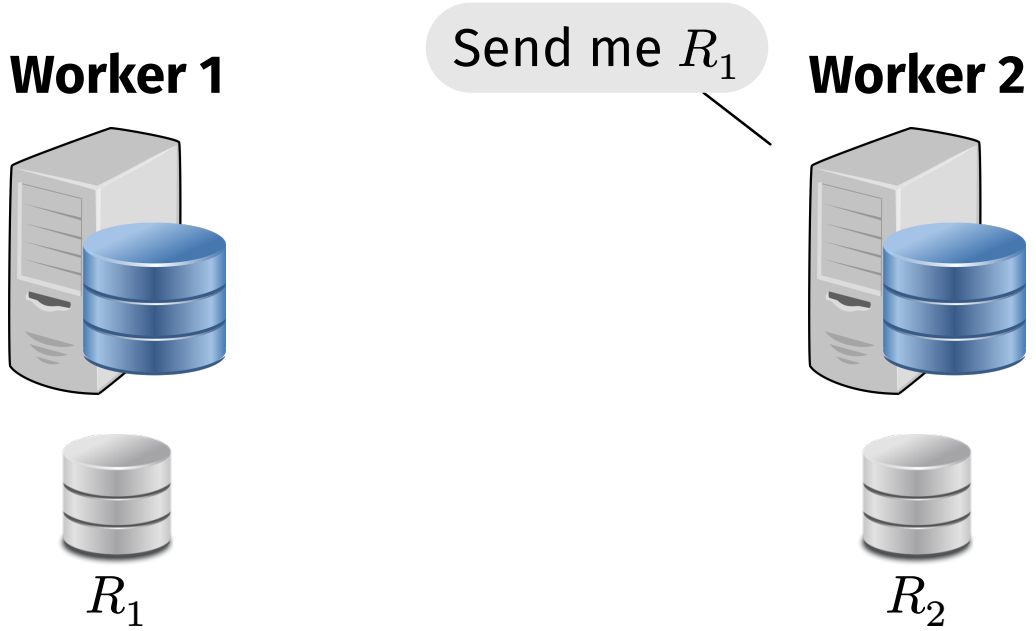
Worker 1

R_1

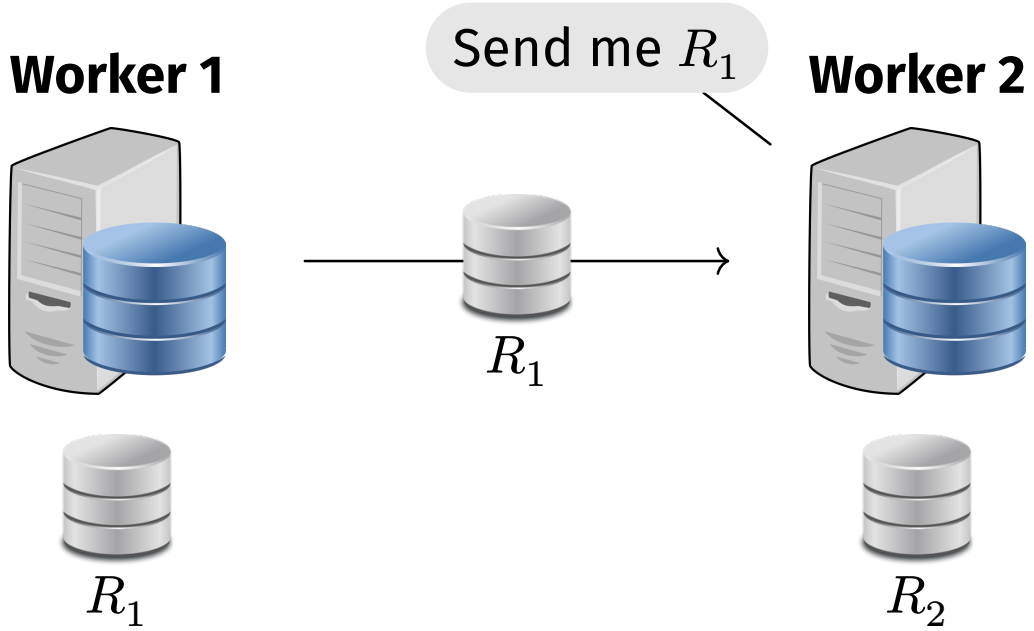
Worker 2

R_2

Distributed Joins



Distributed Joins



Distributed Joins

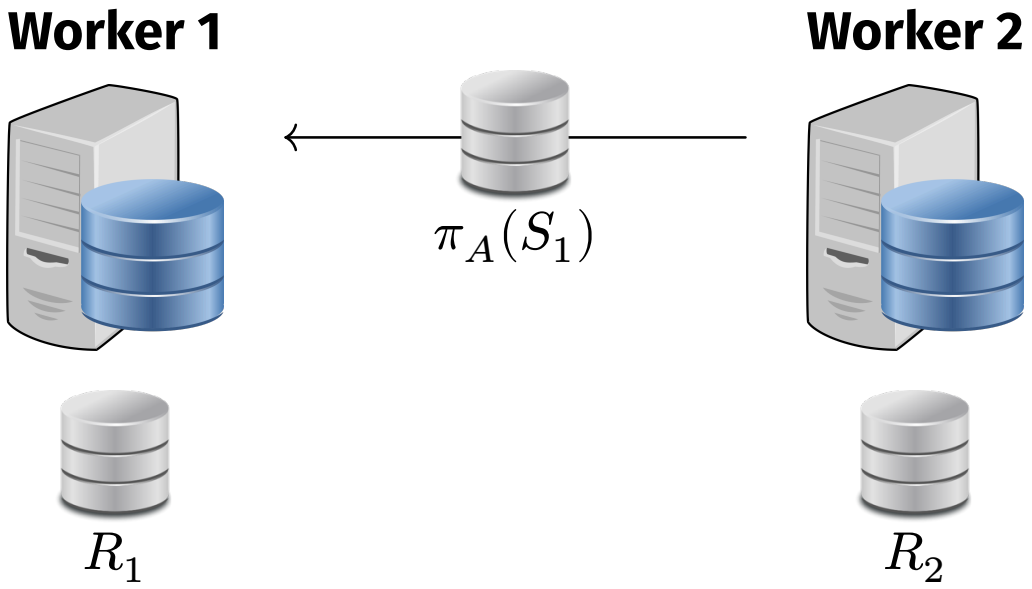
Worker 1

R_1

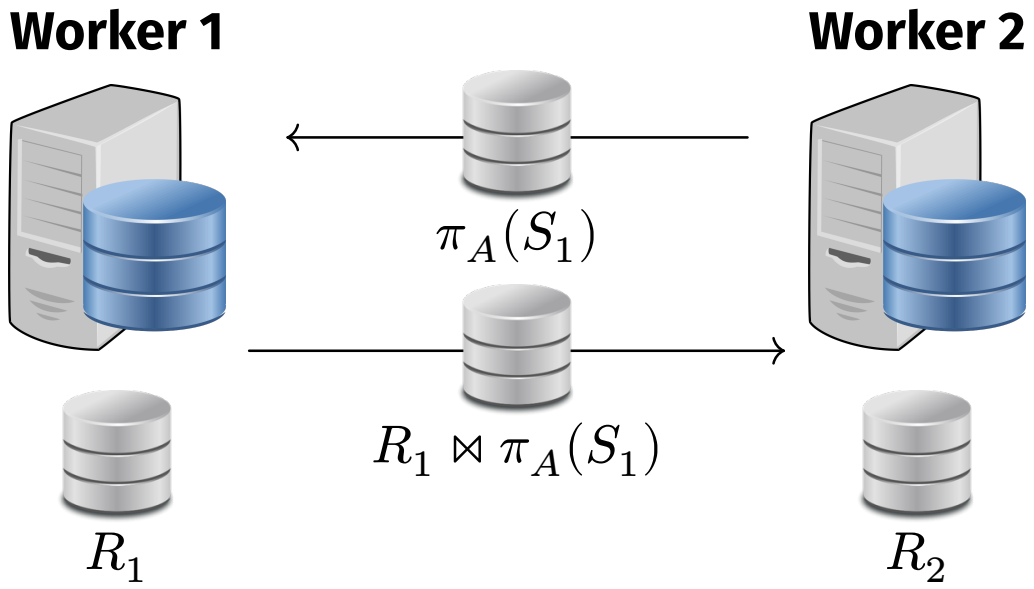
Worker 2

R_2

Distributed Joins



Distributed Joins



Semi-join

Worker 1

<M, 1>
<N, 2>
<O, 2>
<P, 3>
<Q, 4>

Worker 2

<2, X>
<3, Y>
<6, Y>

Semi-join

Worker 1

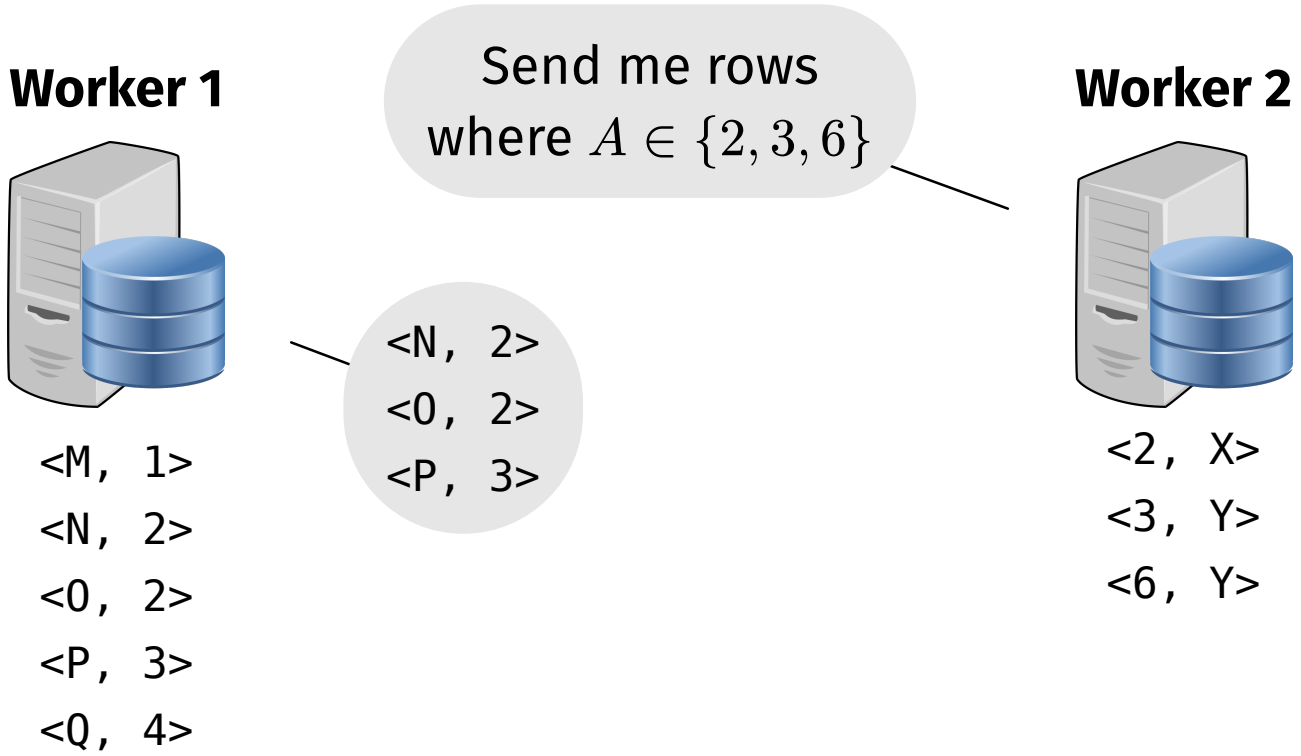
```
<M, 1>
<N, 2>
<O, 2>
<P, 3>
<Q, 4>
```

Send me rows where $A \in \{2, 3, 6\}$

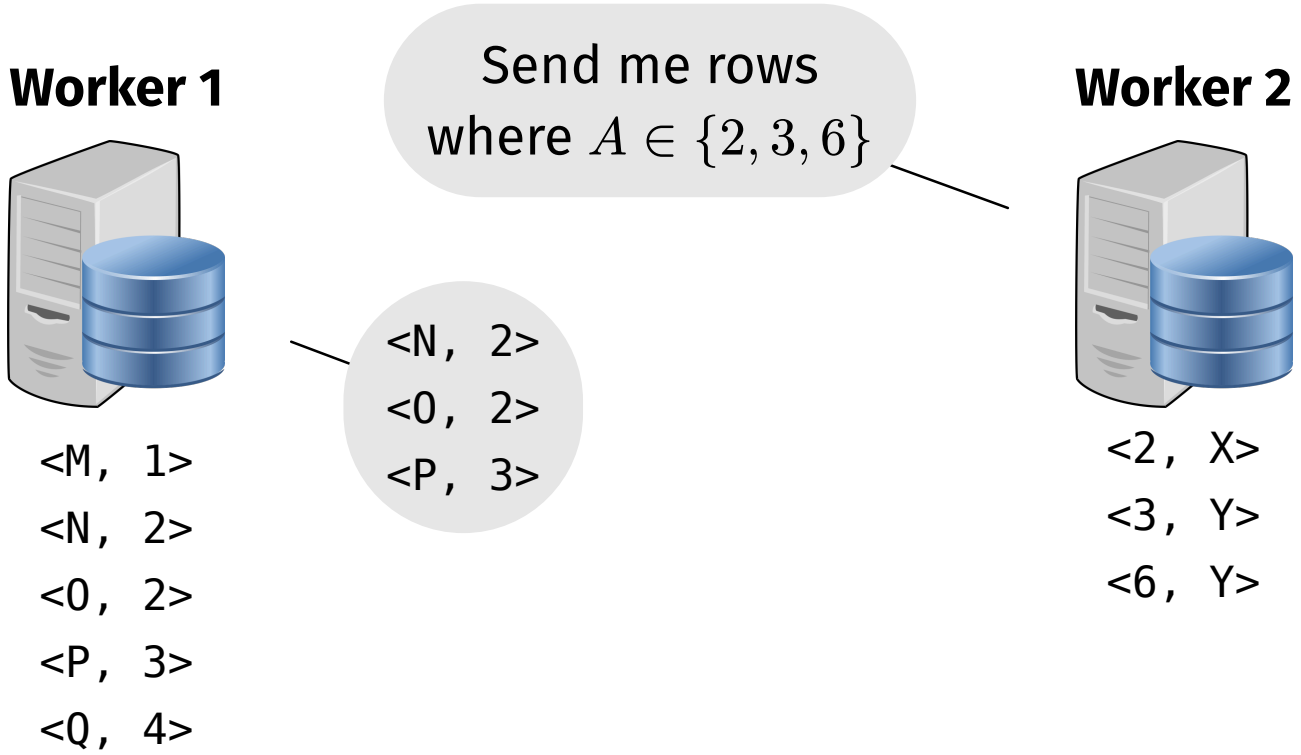
Worker 2

```
<2, X>
<3, Y>
<6, Y>
```

Semi-join


Worker 1
Send me rows where $A \in \{2, 3, 6\}$
Worker 2
<N, 2>
<O, 2>
<P, 3>
<M, 1>
<N, 2>
<O, 2>
<P, 3>
<Q, 4>
<2, X>
<3, Y>
<6, Y>

Semi-join



This is called a **semi-join**

Problem: Worker 2 is sending a lot of data

Problem: Worker 2 is sending a lot of data

Idea: Compress $\pi_A(S_1)$ using a bloom filter

Bloom Join

Worker 1

<M, 1>
<N, 2>
<O, 2>
<P, 3>
<Q, 4>

Worker 2

<2, X>
<3, Y>
<6, Y>

Bloom Join

Worker 1

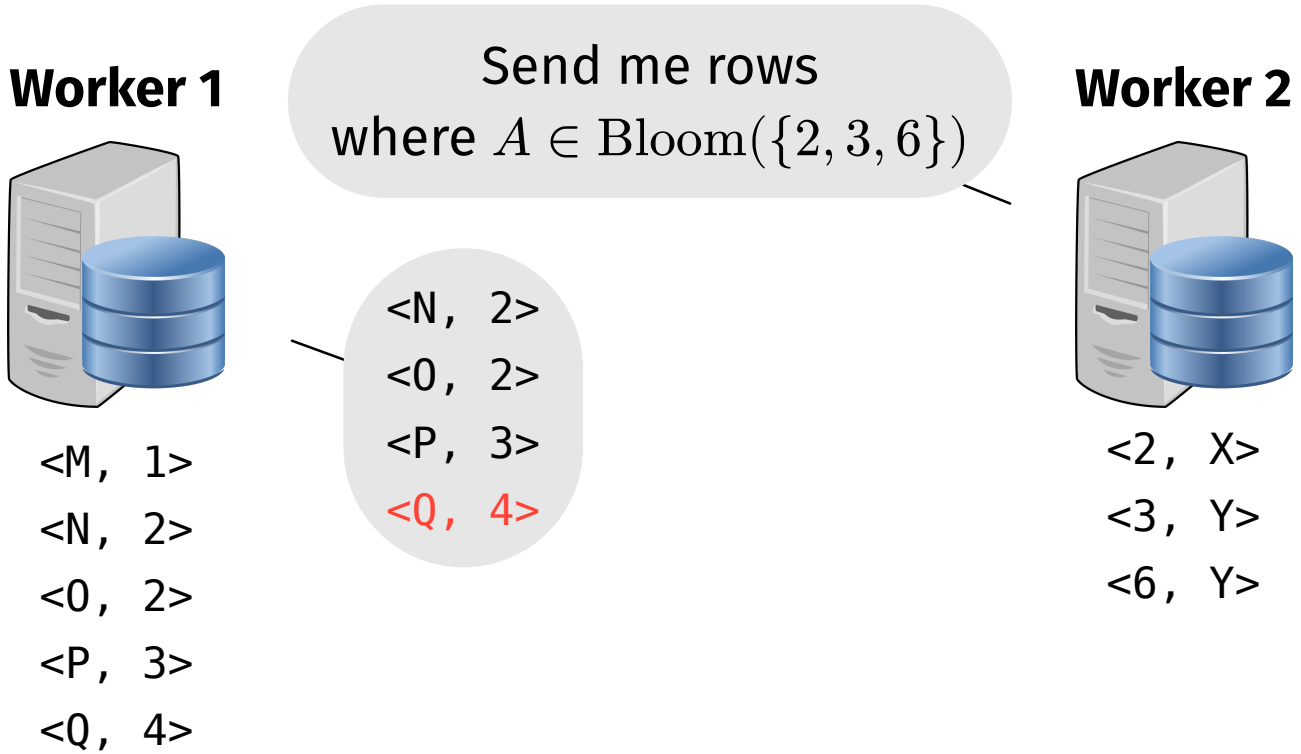
```
<M, 1>
<N, 2>
<O, 2>
<P, 3>
<Q, 4>
```

Send me rows
where $A \in \text{Bloom}(\{2, 3, 6\})$

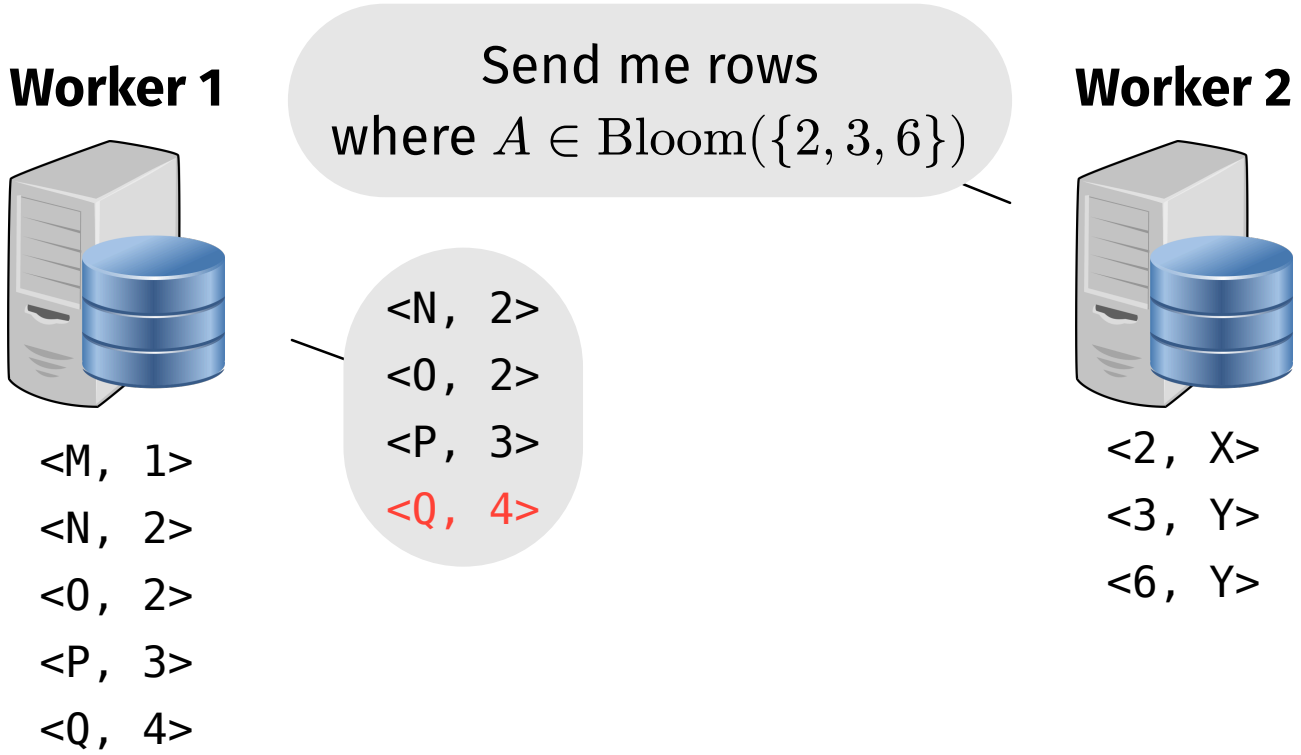
Worker 2

```
<2, X>
<3, Y>
<6, Y>
```

Bloom Join


Worker 1
Send me rows
where $A \in \text{Bloom}(\{2, 3, 6\})$
Worker 2
<N, 2>
<O, 2>
<P, 3>
<Q, 4>
<M, 1>
<N, 2>
<O, 2>
<P, 3>
<Q, 4>
<2, X>
<3, Y>
<6, Y>

Bloom Join



This is called a **Bloom Join**

Updates

- Deadline for checkpoint 3 extended by one week
- No class on Thursday (video lecture to be released soon)