

# Architecture and Implementation of Database Systems (Winter 2016/17)

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# Part IX

## Parallel Databases

It is increasingly attractive to leverage **parallelism** available in hardware.

## Reduced Cost:

- Large monolithic systems are extremely complex to build.
- Smaller systems sell at much higher volumes, with much better price/performance ratio.

## Reduced Energy Consumption:

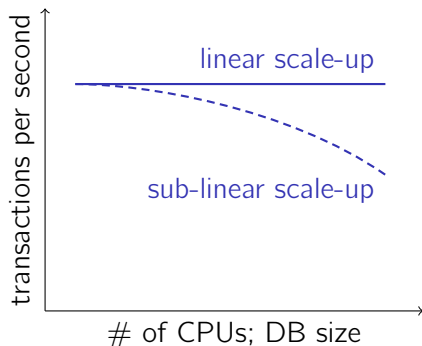
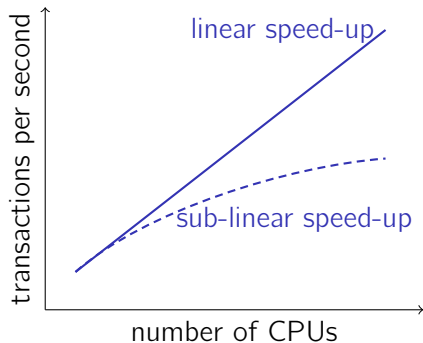
- Performance scales linearly with clock frequency; energy consumption scales quadratically.
- Additional **cooling cost** makes this even worse.
- Modern chip designs are **power-limited** ( $\rightsquigarrow$  multi-core)

## Prepare for Hardware Failures?

- A spare COTS system is cheaper than a spare mainframe.

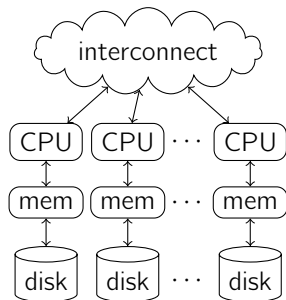
# Scaling with Parallelism

Desirable: **speed-up** and **scale-up**

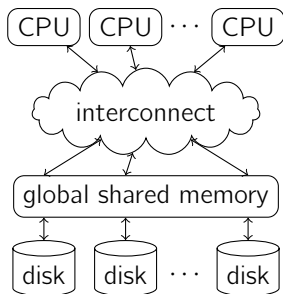


# Parallel Database Architectures

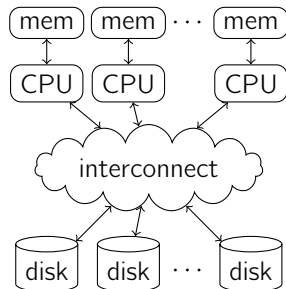
Different architectures have been proposed for **parallel databases**.



shared nothing



shared memory



shared disk

**Advantages** of shared memory architectures:

- Porting to shared memory architecture (relatively) easy.

**Problems** of shared memory architectures:

- **Contention** in interconnect

→ Here: **memory contention**

→ Hard to build scalable and fast interconnect.

- **Interference:**

→ Addl. CPUs **slow down** existing ones (e.g., due to contention).

→ Suitable for **low degrees of parallelism** (up to few tens).

Shared disk architectures have similar problems.

→ **contention** and **interference** problems

Further:

■ For **read/write** access, **coherence** tricky to get right.

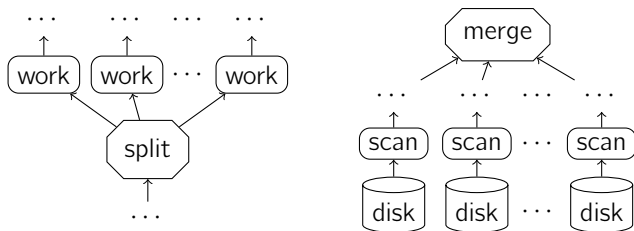
→ **Shared nothing** seems to be the method of choice.

## Intra-query parallelism:

### ■ Pipeline parallelism:

- Assign plan operators to CPUs; send tuples from CPU to CPU.
- Only works for **non-blocking operators**.
- **Limited scalability**: few operators per plan; load balancing?

### ■ Data parallelism:





Data parallelism goes particularly well with **data partitioning**.

→ **Distribute** tuples over nodes (→ **horizontal partitioning**)

↪ **Parallel scan**; high I/O bandwidth

## Round-Robin Partitioning:

- Easy, trivial **load balancing**

## Range Partitioning:

- Need to access only those nodes that hold relevant data.
- **Data skew** may lead to trouble.
- May be beneficial for **sorting**, **joining**, etc.
- Range boundaries?

## Hash Partitioning:

- **Data skew** less of a problem
- May also help certain operations (e.g., **joins**)
- **No knowledge** about data or types required

## Scan: Easy

→ Scan-heavy queries benefit easily from data parallelism.

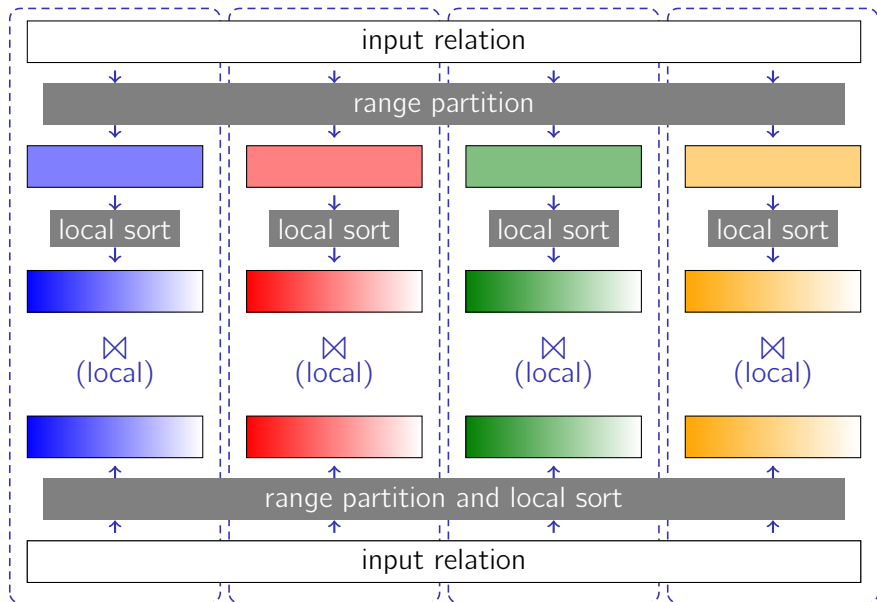
## Sort:

- Merge sort/external sort: run early stages in parallel, then merge
- With **range partitioning**, merging becomes trivial.
  - Thus, first range-partition (re-distribute) data, then sort.
  - Determine range boundaries with help of **sampling**.

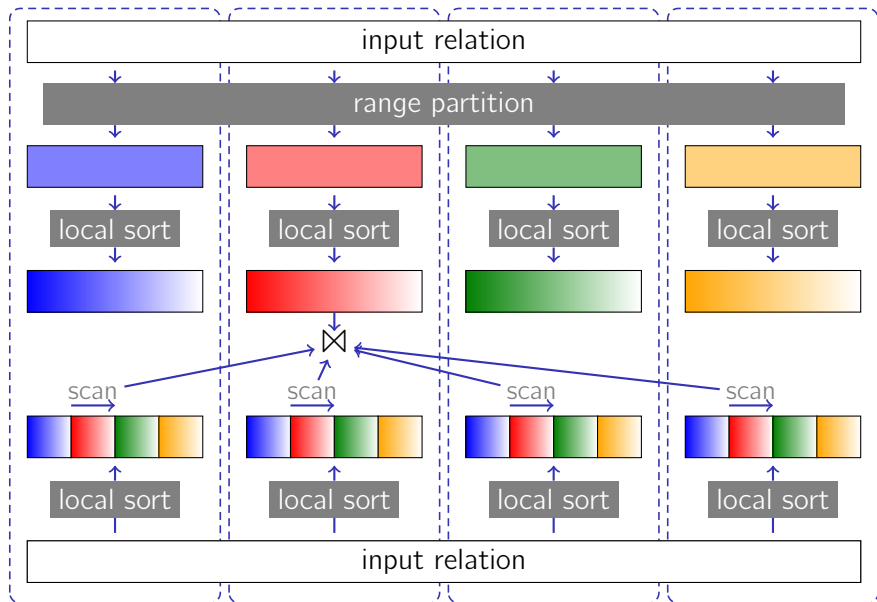
## Join:

- **Partition** (re-distribute) tuples (hash or range partitioning)
- $R_i \bowtie S_j$  joins can now be computed locally.

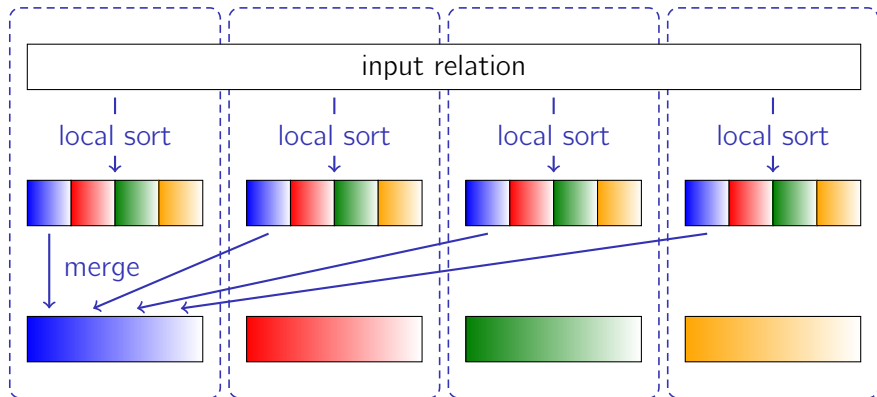
# Parallel Joins (Using Merge Sort Locally)



# Parallel Joins (here: MPSM)



# Instead: Sort, then Merge/Partition



- Re-distributes ("shuffles") likely limited by interconnect bandwidth.
- Perform merge/join during shuffle
  - Leverage available CPU capacity while I/O-limited.

**Bloom filters**<sup>23</sup> can help reduce communication cost.

- 1 Partition and distribute outer join relation  $R$ .
- 2 On each node  $H_i$ , compute Bloom filter vector for  $R_i$ .
- 3 Broadcast all Bloom filters to all nodes.
- 4 Partition and distribute  $S$ , but filter tuples before sending.
- 5 Compute  $R_i \bowtie S_i$  locally on all  $H_i$ .

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<sup>23</sup>A Bloom filter is a compact data structure that can be used to filter data according to a set of valid key values. We'll discuss Bloom filters later in this course.