Locality-Sensitive Operators for Parallel Main-Memory Database Clusters

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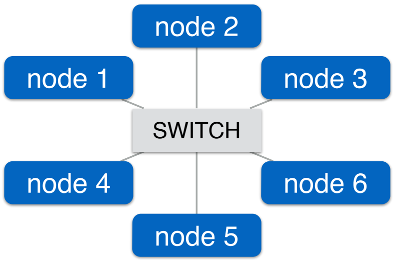
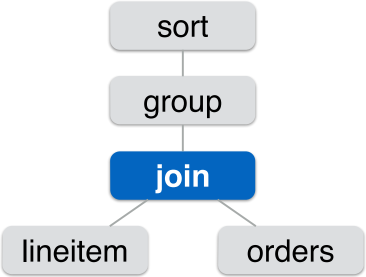
Scale Out

- **HyPer:** High-performance in-memory transaction and query processing system
- **Scale out** to process extremely large inputs
- Aiming at **clusters** with large main memory capacity



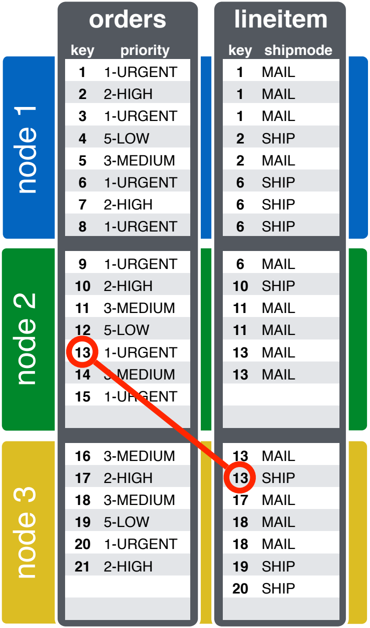
Running Example (1)

- Focus on **analytical** query processing in this talk
- TPC-H query 12 used as **running example**
- Runtime dominated by **join** orders ⋈ lineitem



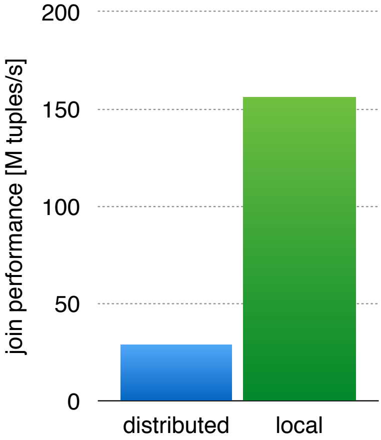
Running Example (2)

- Relations are **equally** distributed across nodes
- We make **no** other assumptions on data distribution
- **Network communication** required as tuples join with tuples on remote nodes



Scale Out: Network is the Bottleneck

- **Single node:** Performance is bound algorithmically
- **Cluster:** Network is bottleneck for query processing
- We propose a novel join algorithm called **Neo-Join**
- **Goal:**
  Increase local processing to close the performance gap



Neo-Join: Network-optimized Join

1. **Open Shop Scheduling**
   Efficient network communication

2. **Optimal Partition Assignment**
   Increase local processing

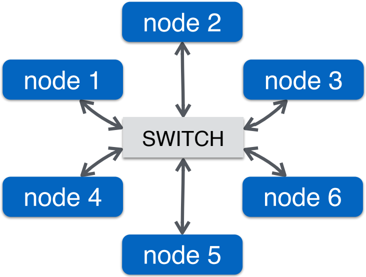
3. **Selective Broadcast**
   Handle value skew

Open Shop Scheduling

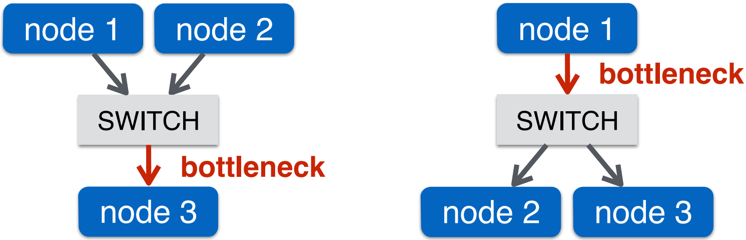
Efficient network communication

Standard Network Model

- **Star topology**
  Nodes are connected to a central switch
- **Fully switched**
  All links can be used simultaneously
- **Fully duplex**
  Nodes can both send and receive at full speed

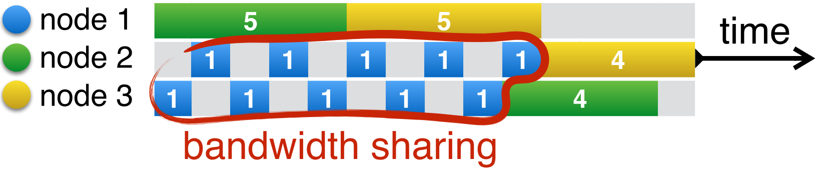


Bandwidth Sharing



- Simultaneous use of a single link creates a **bottleneck**
- **Reduces bandwidth** by at least a factor of **2**

Naïve Schedule



- Node 2 and 3 send to node 1 **at the same time**
- Bandwidth sharing increases **network duration** significantly

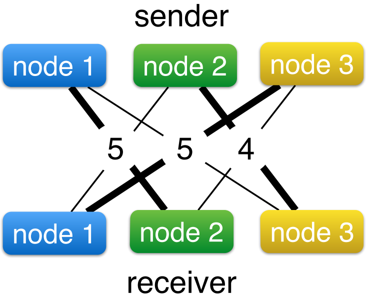
Open Shop Scheduling (1)

- Avoiding bandwidth sharing **translates directly** to open shop scheduling
- **Network Transfer:** Receivers receive from at most **one** sender, senders send to at most **one** receiver
- **Open Shop:** Processors perform **one** task at a time, only **one** task of a job is processed at a time

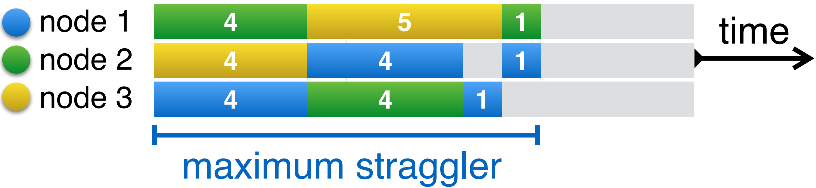
Open Shop	**Network Transfer**
task	data transfer
processor	receiver
job	sender
execution time	message size

Open Shop Scheduling (2)

- **Bipartite graph** of senders and receivers
- **Edge weights** represent transfer size
- Scheduler repeatedly finds **perfect matchings**
- Each matching specifies one **communication phase**
- Transfers in a phase will **never** share bandwidth



Optimal Schedule



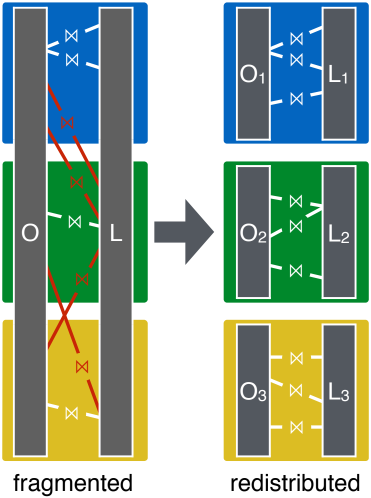
- Open shop schedule achieves minimal **network duration**
- Schedule duration determined by **maximum straggler**

Optimal Partition Assignment

Minimize network duration for distributed joins

Distributed Join

- Tuples may join with tuples on **remote nodes**
- Repartition and redistribute **both relations** for local join
- Tuples will join only with the **corresponding partition**
- Using hash, range, radix, or other **partitioning** scheme
- **In any case:** Decide how to **assign** partitions to nodes



Running Example: Hash Partitioning

orders

node	key	priority
node 1	1	1-URGENT
node 1	2	2-HIGH
node 1	3	1-URGENT
node 1	4	5-LOW
node 1	5	3-MEDIUM
node 1	6	1-URGENT
node 1	7	2-HIGH
node 1	8	1-URGENT
node 2	9	1-URGENT
node 2	10	2-HIGH
node 2	11	3-MEDIUM
node 2	12	5-LOW
node 2	13	1-URGENT
node 2	14	3-MEDIUM
node 2	15	1-URGENT
node 3	16	3-MEDIUM
node 3	17	2-HIGH
node 3	18	3-MEDIUM
node 3	19	5-LOW
node 3	20	1-URGENT
node 3	21	2-HIGH

lineitem

node	key	shipmode
node 1	1	MAIL
node 1	1	MAIL
node 1	1	MAIL
node 1	2	SHIP
node 1	2	MAIL
node 1	6	SHIP
node 1	6	SHIP
node 1	6	SHIP
node 2	6	MAIL
node 2	10	SHIP
node 2	11	MAIL
node 2	11	MAIL
node 2	13	MAIL
node 2	13	MAIL
node 3	13	MAIL
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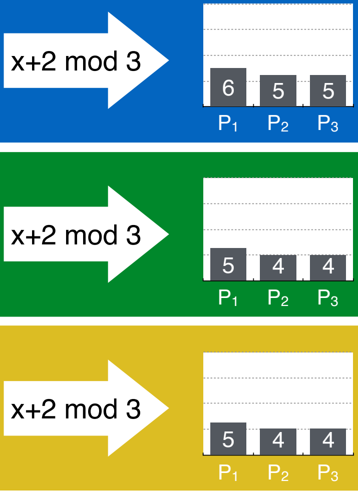
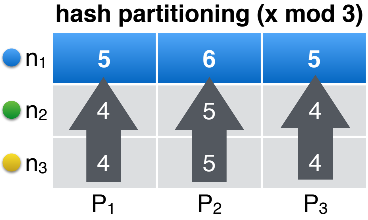
node 3	17	MAIL
node 3	18	MAIL
node 3	18	MAIL
node 3	19	SHIP
node 3	20	SHIP

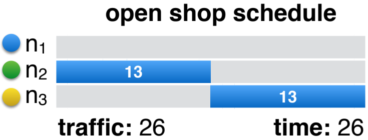


Assign Partitions to Nodes (1)

Option 1: Minimize network traffic

- Assign partition to node that owns its **largest part**
- Only the **small fragments** of a partition sent over the network
- Schedule with minimal network traffic may have **high duration**

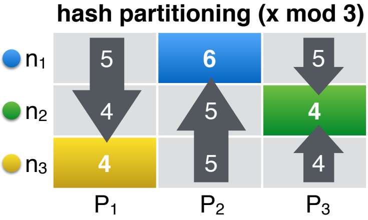


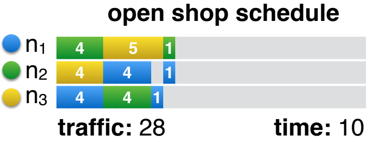


Assign Partitions to Nodes (2)

Option 2: Minimize response time:

- **Query response time** is time from request to result
- Query response time dominated by **network duration**
- To minimize network duration, minimize **maximum straggler**





Minimize Maximum Straggler

- Formalized as mixed-integer **linear program**
- Objective function minimizes **maximum straggler**
- Shown to be **NP-hard** (see paper for proof sketch)
- In practice **fast enough** using CPLEX or Gurobi (< 0.5 % overhead for 32 nodes, 200 M tuples each)
- Partition assignment can optimize **any partitioning**

minimize w**, subject to**

$$w \geq \sum_{j=0}^{p-1} h_{ij}(1 - x_{ij}) \qquad 0 \leq i < n$$

$$w \geq \sum_{j=0}^{p-1} \left(x_{ij} \sum_{k=0, i \neq k}^{n-1} h_{kj} \right) \qquad 0 \leq i < n$$

$$1 = \sum_{i=0}^{n-1} x_{ij} \qquad 0 \leq j < p$$

Running Example: Locality

orders

node	key	priority
node 1	1	1-URGENT
node 1	2	2-HIGH
node 1	3	1-URGENT
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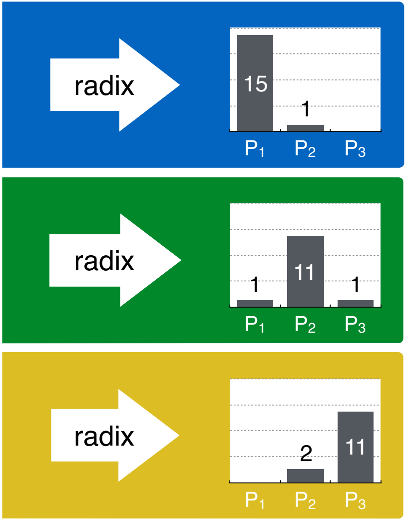
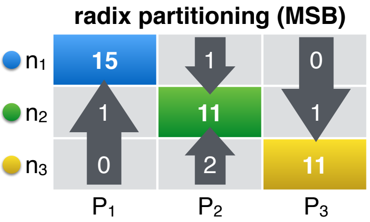


Locality

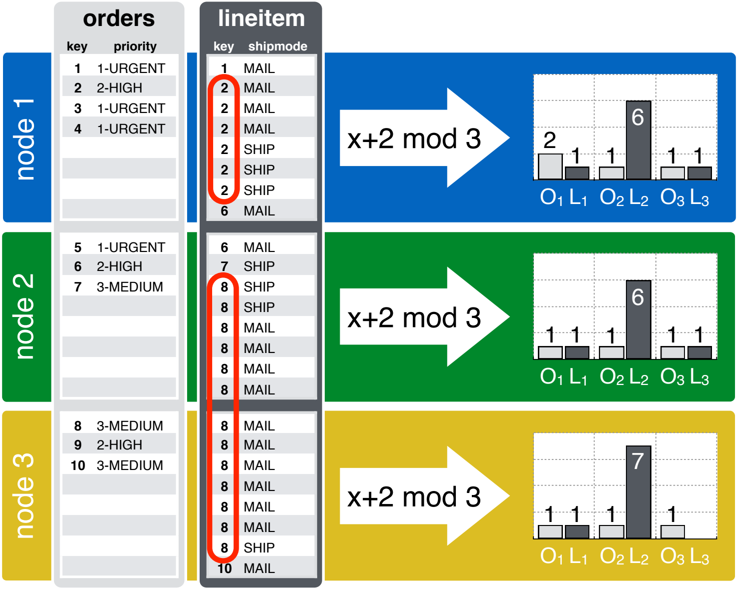
- Running example exhibits **time-of-creation** clustering
- **Radix repartitioning** on most significant bits retains locality
- Partition assignment can **exploit locality**
- Significantly reduces **query response time**



Selective Broadcast

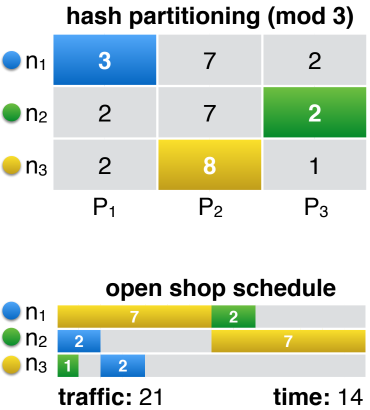
Handle value skew

Running Example: Skew



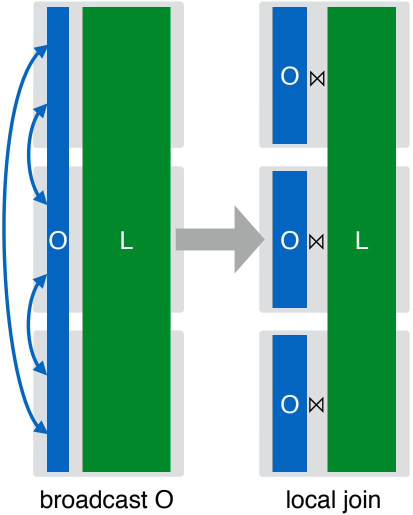
Skew

- **Value skew** can lead to some very large partitions
- Assignment of these partitions increases **network duration**
- One may try to balance skewed partitions by partitioning the input into **more partitions**
- **High skew** is still a problem



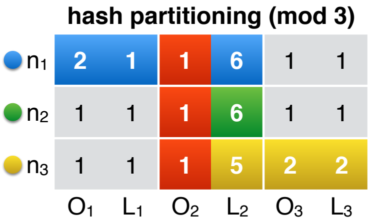
Broadcast

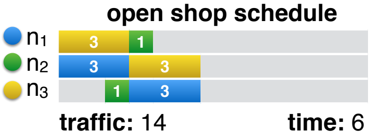
- **Alternative** data redistribution scheme
- **Replicate** the smaller relation between all nodes
- Larger relation **remains fragmented** across nodes



Selective Broadcast

- Decide **per partition** whether to assign or broadcast
- **Broadcast** partitions with large relation size difference
- **Assign** the other partitions taking locality into account
- **Role reversal possible:** Broadcast different partitions by different relations

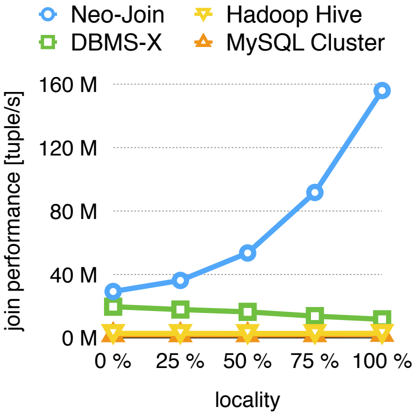




Evaluation

Locality

- Vary **locality** from **0 %** (uniform distribution) to **100 %** (range partitioning)
- Neo-Join improves **join performance** from 29 M to 156 M tuples/s (> 500 %)
- 3 nodes (Core i7, 4 cores, 3.4 GHz, 32 GB RAM), 600 M tuples (64 bit key, 64 bit payload)



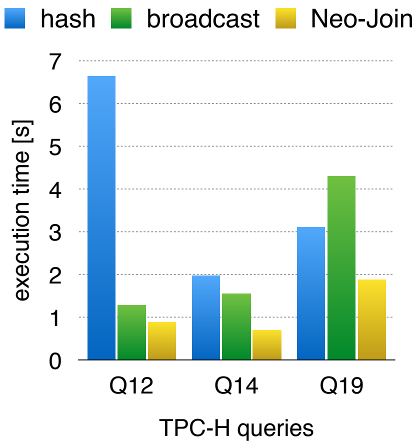
Skew

- **Zipfian distribution** models realistic data skew
- Using **more partitions** alleviates the problem
- Selective broadcast actually **improves** performance for skewed inputs
- 4 nodes, 400 M tuples

	Zipf factor s				
partitions	0.00	0.25	0.50	0.75	1.00
16	27 s	24 s	23 s	**29s**	**44s**
512	23 s	23 s	23 s	23 s	**33s**
16 (SB)	24 s	24 s	23 s	**20s**	**10s**

TPC-H Results (scale factor 100)

- Results for three selected **TPC-H** queries
- **Broadcast** outperforms **hash** for large relation size differences
- Neo-Join always performs better due to **selective broadcast** and **locality**
- 4 nodes, scale factor 100



Summary

Motivation:

- Network is the **bottleneck** for distributed query processing
- Increase **local processing** to close the performance gap

Contributions:

- **Open Shop Scheduling** avoids bandwidth sharing
- **Optimal Partition Assignment** minimizes query response time and can exploit locality in the data distribution
- **Selective Broadcast** combines repartitioning and broadcast to improve the performance for skewed inputs