A Database Guy’s Journey Into RDMA Multicast

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   2. Which communication framework to choose?

2. Multicast and group communication operations in a distributed DBMS
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   3. What are open / unanswered questions?

3. RDMA multicast
   1. Benefits of hardware support for multicast
   2. Experimental setup
   3. Insights

4. Conclusions
Part 1) Project Hana Vora at SAP

- Vora is a distributed computing platform built on in-memory technology to scale to 1000s of nodes using commodity hardware both on-premise and in cloud deployments.
- Based on data-centric JIT compilation of SQL queries to byte / C / machine code with LLVM
- Uses NUMA-aware data structures and algorithms
- Extensibility: Provide easy to use APIs available for C, C++, go, Python, Java, Scala etc.
- Written from scratch but shares concepts from other in-memory projects
- Tight integration with Apache Hadoop ecosystem and Spark
Part 1) Communication framework requirements

- From an application developer’s perspective
  - Dead-simple interface
  - As few instructions as possible
  - One code line, best usage of available networking hardware
  - Additional language bindings (e.g. GO, python)
- Aware of NUMA regions, memory affinity for addressing and dispatching
- TCP stack that works anywhere (no matter which OS, hardware etc.)
- RDMA stack that supports
  - Rendezvous
  - Scatter/Gather for non-consecutive memory regions
  - Atomic operations
- (MPI-like) group communication operations
  - Basic one-to-all
  - Advanced all-to-all, barrier etc.
- Integration with external polling context
- Integration with custom memory allocators
Part 1) IB-verbs / Accelio / libfabric / MPI

• IB-verbs
  • Low-level and verbose
  • Take care of things you take for granted ( e.g. flow control )
  • Comparatively low developer productivity / easy to make mistakes

• Accelio / libfabric
  • No support of all popular operating systems
  • No support for any group communication operations ( broadcast, multicast )

• MPI
  • Mainly intended as tool for HPC community
  • Although there are ways to ensure fault-tolerance, dynamic scheduling rarely used in distributed data processing projects
Part 2) Which scenarios can benefit from group communication operations?

- **Transfer of data partitions**
  - Needed for load balancing, scale-out, recovery in failure cases
  - Requirements: High bandwidth, **basic one-to-many operations**, work on pinned memory, address memory on a per-NUMA level

- **Accessing (meta) data in the catalog**
  - Needed for storing table meta data, cluster information, possibly data dictionaries etc.
  - Requirements: Smart serialization needed, frequent operations on small data items, latency matters

- **Distribution of intermediate results during query execution**
  - Needed for supporting the exchange operator and execution of complex distributed operations
  - Requirements: High bandwidth, work on pinned memory, address memory on a per-NUMA level, extensive use of group communication operations (**one-to-many, many-to-one, all-to-all**)

- **Storing and accessing data in the distributed log**
  - Needed to provide persistent data storage
  - Requirements: similar as transfer of data slices plus RDMA atomic operations (e.g. increment operation for the sequencer)

- **Transaction processing**
  - Needed to provide some sort of isolation level, ACID properties
  - Requirements: Heavily exploit low latency, **basic one-to-many operations**, focus on RDMA-specific operations for acquiring/releasing locks etc.

- **Check pointing intermediate results**
  - Needed for storing intermediate results during query execution for failover cases
  - Requirements: High bandwidth, **basic one-to-many operations**, smart memory management (e.g. when are intermediate results no longer needed)

- **In general: deployment of Vora**
  - We want to be able to deploy Velocity anywhere
  - Requirements: Network stack must run on Windows, Linux, Mac, x86, ARM, high-end server etc.
Part 2) Joins + Multicast

- Back-of-the-envelope calculations how much data gets transferred with each group communication operator invocation. The goal is to get feedback from Intel what is feasible/what is not.
- We take join executions as example with a right semi join performed on relations (aka columns) $R$ and $S$ where the result includes the matching positions in $S$. We assume that one positional entry is of 8 bytes size
- We assume that $R$ holds 100.000.000 records per node and $S$ holds 10.000.000 records per node ($R = 10x S$). The record size is 4 bytes. We assume the selectivity of the join is 10%. The amount of records grows linearly with the number of nodes.
- The joins can be either executed via Grace Join or Distributed-Block-Nested-Loop Join (DBNL Join). The execution of the algorithms can benefit from the group communication operators in the following ways:
  - Grace Join:
    - initial redistribution of to be joined relations: multicast
    - consolidation of join result: gather
  - DBNL Join:
    - (non streaming) replication of relation $S$: multicast
    - (streaming of $S$, decentralized orchestration): redistribution of $S$: scatter
    - (streaming of $S$, centralized orchestration): redistribution of $S$: all-to-all
    - consolidation of join result: gather
## Part 2) Joins + Multicast

<table>
<thead>
<tr>
<th></th>
<th>10 nodes</th>
<th>100 nodes</th>
<th>1000 nodes</th>
<th>10000 nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grace Join</strong></td>
<td></td>
<td></td>
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<tr>
<td>redistribution of to be joined relations: <strong>scatter</strong> (one invocation per relation per node) Data transfer in GB</td>
<td>20 operator invocations total 4.4 GB total</td>
<td>200 operator invocations total 44 GB total</td>
<td>2000 operator invocations total 440 GB total</td>
<td>20000 operator invocations total 4400 GB total</td>
</tr>
<tr>
<td>consolidation of join result: <strong>gather</strong> Data transfer in GB per operator invocation</td>
<td>0.08 GB</td>
<td>0.8 GB</td>
<td>8 GB</td>
<td>80 GB</td>
</tr>
<tr>
<td><strong>DBNL Join</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(non streaming) replication of relation S: <strong>multicast</strong> Data transfer in GB</td>
<td>10 operator invocations total 0.4 GB total</td>
<td>100 operator invocations total 4 GB total</td>
<td>1000 operator invocations total 40 GB total</td>
<td>10000 operator invocations total 400 GB total</td>
</tr>
<tr>
<td>(streaming of S, decentralized orchestration): redistribution of S: <strong>scatter</strong> Data transfer in GB per operator invocation</td>
<td>10^2 operator invocations total 0.4 GB total</td>
<td>100^2 operator invocations total 4 GB total</td>
<td>1000^2 operator invocations total 40 GB total</td>
<td>10000^2 operator invocations total 400 GB total</td>
</tr>
<tr>
<td>(streaming of S, centralized orchestration): redistribution of S: <strong>alltoall</strong> Data transfer in GB per operator invocation</td>
<td>10 operator invocations total 0.4 GB total</td>
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**Note:** we ignore that in practice the overall data transfer amount and the number of operator invocations would be \(1/(\text{number of nodes})\) smaller.
Part 2) Open Questions

• How well do multicast operations scale...
  • ...with varying payload sizes?
  • ...with a varying number of participants?
  • ...with different levels of congestions?

• What are the costs for creating/modifying multicast groups?

• What are the performance benefits in comparison to unicasts?
Part 3) Hardware support for multicast

Traditional (Unicast) Messaging

- Data Flow
- “Control” Flow
Part 3) Hardware support for multicast

Unicast Low-Latency Messaging

- Data Flow
- “Control” Flow
Part 3) Hardware support for multicast

Multicast Low-Latency Messaging

Data Flow

“Control” Flow
Part 3) Hardware support for multicast

Complex Multicast Low-Latency Messaging

Node 0

RAM

CPU

HCA

Switch

Node 1

Switch

Node 2

Node 3

Node n

Data Flow

“Control” Flow
Part 3) How to make use of it?

- Nodes have to join multicast groups in order to receive messages
- Right now, only ibverbs (the lowest-level library) supports this out-of-the-box
- `rdma_join_multicast(id, addr, [context])`
- `id` is similar to a network socket, `addr` is the IB multicast address
Part 3) Management of multicast groups

• The join method asks the subnet manager to program the switches according to the multicast configuration
• From then on, everyone may send datagrams to the multicast group, even when they are not part of it
• One cycle of joining and leaving MC groups takes approx. 400 us
Part 3) Benchmarks

• Setup
  • 8 physical nodes equipped with Intel Xeon CPUs
  • Mellanox ConnectX-3 VPI adapter; single-port QSFP; QDR IB (40Gb/s) and 10GigE
  • Mellanox SwitchX®-2 InfiniBand Switch
  • Ibverbs + rdmacm, based on mckey

• Big thanks to Intel and Karthik Kumar for sponsoring the cluster and fruitful discussions
Part 3) Benchmarks

- RC = reliable connection, unicast (blue)
- UD = unreliable connection, unicast (green)
- MC = unreliable connection, multicast (red)
- Varying number of receivers
- Varying payload from 1 – 40 Megabytes
- Varying average execution time in milliseconds
Conclusions

• Communication framework
  • No one-size-fits-all framework available yet
  • Accelio / libfabric:
    • lack of supporting standard operating systems
    • no group communication support as of now

• Group communications
  • MPI is the top dog
  • Relevant for modern distributed data processing systems as they constantly grow in size
  • Currently, no/very little use of any group comm. patterns in modern data processing projects
  • Chicken / egg problem:
    • Network vendors make amazing hardware
    • Advanced features are hard to use (please use ibverbs if you want multicast)
    • No clear quantification of benefits of modern hardware
Thank you!

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