Scaling with PGAS Languages

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by

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MVAPICH2/MVAPICH2-X Software

- High Performance open-source MPI Library for InfiniBand, 10Gig/iWARP and RDMA over Converged Enhanced Ethernet (RoCE)
  - MVAPICH (MPI-1), MVAPICH2 (MPI-3.0), Available since 2002
  - MVAPICH2-X (MPI + PGAS), Available since 2012
  - Used by more than 2,000 organizations (HPC Centers, Industry and Universities) in 70 countries
  - More than 165,000 downloads from OSU site directly
  - Empowering many TOP500 clusters
    - 7th ranked 204,900-core cluster (Stampede) at TACC
    - 14th ranked 125,980-core cluster (Pleiades) at NASA
    - 17th ranked 73,278-core cluster (Tsubame 2.0) at Tokyo Institute of Technology
    - and many others
  - Available with software stacks of many IB, HSE and server vendors including Linux Distros (RedHat and SuSE)
  - http://mvapich.cse.ohio-state.edu
- Partner in the U.S. NSF-TACC Stampede (9 PFlop) System
Overview of MVAPICH2-X

- Can support the following programming models over OFA verbs
  - PGAS
    - UPC
    - OpenSHMEM
  - MPI (with OpenMP)
  - Hybrid (MPI and PGAS)
    - MPI (w/ OpenMP) + UPC
    - MPI (w/ OpenMP) + OpenSHMEM

- Unified communication runtime allows flexible support for all these programming models

- Can be downloaded from http://mvapich.cse.ohio-state.edu
Support for Flexible Hybrid (MPI+PGAS) Programming

• Application sub-kernels can be re-written in MPI/PGAS based on communication characteristics

• Benefits:
  – Best of Distributed Computing Model
  – Best of Shared Memory Computing Model

• Exascale Roadmap*:
  – “Hybrid Programming is a practical way to program exascale systems”

Q: Shared Memory Models: “Of the models for distributed computing, what in your view is the significance of the recent emergence of PGAS languages?”

- PGAS models improve programmability
- Can improve performance of irregular applications
- Hybrid Programming models allow incremental application development using MPI+PGAS models
PGAS Runtime Implementation

Q: Implementing PGAS: “Each of you has looked at various implementations of interfaces for PGAS languages. How have you implemented the interface, and what has your experience been with it to date?”

• Runtimes should provide flexibility to choose between PGAS and Message Passing semantics
• Runtimes for PGAS or Message Passing models have to address a core set of issues
• Critical to efficiently use network and memory resources
• MVAPICH2-X provides a unified runtime for hybrid MPI+PGAS models, offers deadlock-free communication progress across models, better performance and optimal network resource usage
• MVAPICH2-X UPC/OpenSHMEM bindings are implemented over active messages, one-sided operations, and atomic/synchronizations operations
Memory Consistency and Protection

**Q: memory consistency:** “UPC has a well defined memory consistency model governing the reading and writing characteristics of shared memory. What aspects of RDMA-capable networks have made conformity to this memory consistency model particularly challenging for UPC compilers?”

- UPC offers ‘strict’ and ‘relaxed’ modes
- Runtime can use RDMA completion events for implementing consistency modes

**Q: Memory Protection:** “Current IB architecture defines a system of memory keys which are exchanged between communicating partners. Is this an appropriate model to be used in PGAS implementations?”

- Registration cache in MVAPICH2-X alleviates registration costs
- Can register symmetric memory regions at initialization
Thread Safety in PGAS Runtime

**Q: thread safety:** “How important is it for a PGAS compiler that the API it uses for accessing the RDMA-capable network be thread safe?”

- Multi-end point design can enable thread-safety
- The multi-endpoint design offers more freedom to compiler
- Performance benefits with *Multi-threaded Multi-Network Endpoint Runtime for UPC*
  
Micro-Benchmark Performance (OpenSHMEM)

### Atomic Operations

- **fadd**, **finc**, **cswap**, **swap**, **add**, **inc**

![Bar Chart: Atomic Operations](image)

- **OpenSHMEM-GASNet**
- **OpenSHMEM-OSU**

**Results:**
- fadd: 41%
- inc: 16%

### Broadcast (256 bytes)

- **OpenSHMEM-GASNet**
- **OpenSHMEM-OSU**

![Bar Chart: Broadcast](image)

**Results:**
- 32: 41%
- 256: 35%

### Collect (256 bytes)

- **OpenSHMEM-GASNet**
- **OpenSHMEM-OSU**

![Bar Chart: Collect](image)

**Results:**
- 32: 36%

### Reduce (256 bytes)

- **OpenSHMEM-GASNet**
- **OpenSHMEM-OSU**

![Bar Chart: Reduce](image)

**Results:**
- 32: 35%
Hybrid MPI+OpenSHMEM Graph500 Design

- Performance of Hybrid (MPI+OpenSHMEM) Graph500 Design
  - 2,048 processes
    - 1.9X improvement over MPI-CSR (best performing MPI version)
    - 2.7X improvement over MPI-Simple (same communication characteristics)
  - 8,192 processes
    - 2.4X improvement over MPI-CSR
    - 7.6X improvement over MPI-Simple

J. Jose, S. Potluri, K. Tomko and D. K. Panda, Designing Scalable Graph500 Benchmark with Hybrid MPI+OpenSHMEM Programming Models, International Supercomputing Conference (ISC’13), June 2013

OFA Developer Workshop (April '13)