Open MPI
Join the Revolution
Supercomputing
November, 2005

http://www.open-mpi.org/

Open MPI Mini-Talks

- Introduction and Overview
  - Jeff Squyres, Indiana University
- Advanced Point-to-Point Architecture
  - Tim Woodall, Los Alamos National Lab
- Datatypes, Fault Tolerance and Other Cool Stuff
  - George Bosilca, University of Tennessee
- Tuning Collective Communications
  - Graham Fagg, University of Tennessee

Technical Contributors

- Indiana University
- The University of Tennessee
- Los Alamos National Laboratory
- High Performance Computing Center, Stuttgart
- Sandia National Laboratory - Livermore

Open MPI: Introduction and Overview

Jeff Squyres
Indiana University

http://www.open-mpi.org/

MPI From Scratch!

- Developers of FT-MPI, LA-MPI, LAM/MPI
  - Kept meeting at conferences in 2003
  - Culminated at SC 2003: Let’s start over
  - Open MPI was born

Jan 2004 SC 2004 Today Tomorrow
Started work Demonstrated Released v1.0 World peace

MPI From Scratch: Why?

- Each prior project had different strong points
  - Could not easily combine into one code base
- New concepts could not easily be accommodated in old code bases
- Easier to start over
  - Start with a blank sheet of paper
  - Decades of combined MPI implementation experience
MPI From Scratch: Why?
• Merger of ideas from
  ▪ FT-MPI (U. of Tennessee)
  ▪ LA-MPI (Los Alamos)
  ▪ LAM/MPI (Indiana U.)
  ▪ PACX-MPI (HLRS, U. Stuttgart)

Open MPI Project Goals
• All of MPI-2
• Open source
  ▪ Vendor-friendly license (modified BSD)
• Prevent “forking” problem
  ▪ Community / 3rd party involvement
  ▪ Production-quality research platform (targeted)
  ▪ Rapid deployment for new platforms
• Shared development effort

Open MPI Project Goals
• Actively engage the HPC community
  ▪ Users
  ▪ Researchers
  ▪ System administrators
  ▪ Vendors
• Solicit feedback and contributions
  ➔ True open source model

Design Goals
• Extend / enhance previous ideas
  ▪ Component architecture
  ▪ Message fragmentation / reassembly
  ▪ Design for heterogeneous environments
  ▪ Multiple networks (run-time selection and stripping)
  ▪ Node architecture (data type representation)
  ▪ Automatic error detection / retransmission
  ▪ Process fault tolerance
  ▪ Thread safety / concurrency

Design Goals
• Design for a changing environment
  ▪ Hardware failure
  ▪ Resource changes
  ▪ Application demand (dynamic processes)
• Portable efficiency on any parallel resource
  ▪ Small cluster
  ▪ “Big iron” hardware
  ▪ “Grid” (everyone a different definition)
  ▪ …

Plugins for HPC (!)
• Run-time plugins for combinatorial functionality
  ▪ Underlying point-to-point network support
  ▪ Different MPI collective algorithms
  ▪ Back-end run-time environment / scheduler support
• Extensive run-time tuning capabilities
  ▪ Allow power user or system administrator to tweak performance for a given platform
Plugins for HPC (!)

Networks
- Shmem
- TCP
- OpenIB
- mVAPI
- GM
- MX

Your MPI application

Run-time environments
- rsh/ssh
- SLURM
- PBS
- BProc
- Xgrid

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Current Status

- v1.0 released (see web site)
- Much work still to be done
  - More point-to-point optimizations
  - Data and process fault tolerance
  - New collective framework / algorithms
  - Support more run-time environments
  - New Fortran MPI bindings
  - ...
- Come join the revolution!

Advanced Point-to-Point Architecture

- Component-based
- High performance
- Scalable
- Multi-NIC capable
- Optional capabilities
  - Asynchronous progress
  - Data validation / reliability

Component Based Architecture

- Uses Modular Component Architecture (MCA)
  - Plugins for capabilities (e.g., different networks)
  - Tunable run-time parameters

Point-to-Point Component Frameworks

- Byte Transfer Layer (BTL)
  - Abstracts lowest native network interfaces
- Point-to-Point Messaging Layer (PML)
  - Implements MPI semantics, message fragmentation, and striping across BTLs
- BTL Management Layer (BML)
  - Multiplexes access to BTL's
- Memory Pool
  - Provides for memory management / registration
- Registration Cache
  - Maintains cache of most recently used memory registrations

Open MPI: Advanced Point-to-Point Architecture

Tim Woodall
Los Alamos National Laboratory

http://www.open-mpi.org/
Network Support
- Native support for:
  - Infiniband: Mellanox Verbs
  - Infiniband: OpenIB Gen2
  - Myrinet: GM
  - Myrinet: MX
  - Portals
  - Shared memory
  - TCP
- Planned support for:
  - IBM LAPI
  - DAPL
  - Quadrics Elan4

High Performance
- Component-based architecture does not impact performance
- Abstractions leverage network capabilities
  - RDMA read / write
  - Scatter / gather operations
  - Zero copy data transfers
- Performance on par with (and exceeding) vendor implementations

Third party contributions welcome!

Performance Results: Infiniband

Performance Results: Myrinet

Scalability
- On-demand connection establishment
  - TCP
  - Infiniband (RC based)
- Resource management
  - Infiniband Shared Receive Queue (SRQ) support
  - RDMA pipelined protocol (dynamic memory registration / deregistration)
  - Extensive run-time tuneable parameters:
    - Maximum fragment size
    - Number of pre-posted buffers

Memory Usage Scalability
Latency Scalability

Multi-NIC Support
- Low-latency interconnects used for short messages / rendezvous protocol
- Message stripping across high bandwidth interconnects
- Supports concurrent use of heterogeneous network architectures
- Fail-over to alternate NIC in the event of network failure (work in progress)

Multi-NIC Performance

Optional Capabilities (Work in Progress)
- Asynchronous Progress
  - Event based (non-polling)
  - Allows for overlap of computation with communication
  - Potentially decreases power consumption
  - Leverages thread safe implementation
- Data Reliability
  - Memory to memory validity check (CRC/checksum)
  - Lightweight ACK / retransmission protocol
  - Addresses noisy environments / transient faults
  - Supports running over connectionless services (Infiniband UD) to improve scalability

Open MPI: Datatypes, Fault Tolerance, and Other Cool Stuff

George Bosilca
University of Tennessee

http://www.open-mpi.org/
Problem With the Old Approach

- [Un]packing: intensive CPU operations.
  - No overlap between these operations and the network transfer
  - The requirement in memory is larger
- Both the sender and the receiver have to be involved in the operation
  - One to convert the data from its own memory representation to some standard one
  - The other to convert it from this standard representation in it's local representation.

How Can This Be Improved?

- No conversion to standard representation (XDR)
  - Let one process convert directly from the remote representation into its own
- Split the packing / unpacking into small parts
  - Allow overlapping between the network transfer and the packing
  - Exploit gather / scatter capabilities of some high performance networks

Open MPI Approach

- Reduce the memory pollution by overlapping the local operation with the network transfer

Improving Performance

- Others questions:
  - How to adapt to the network layer?
  - How to support RDMA operations?
  - How to handle heterogeneous communications?
  - How to split the data pack / unpack?
  - How to correctly convert between different data representations?
  - How to realize data type matching and transmission checksum?
- Who handles all this?
  - MPI library can solve these problems
  - User-level applications cannot

MPI 2 Dynamic Processes

- Increasing the number of processes in an MPI application:
  - MPI_COMM_SPAWN
  - MPI_COMM_CONNECT
  - MPI_COMM_ACCEPT
  - MPI_COMM_JOIN
- Resource discovery and diffusion
  - Allows the new universe to use the “best” available network(s)

MPI 2 Dynamic processes

- Discover the common interfaces
  - Ethernet and Myrinet switches
- Publish this information in the public registry
**MPI 2 Dynamic processes**

- Retrieve information about the remote universe
- Create the new universe

**Fault Tolerance Models Overview**

- Automatic (no application involvement)
  - Checkpoint / restart (coordinated)
  - Log Based (uncoordinated)
    - Optimistic, Pessimistic, Casual
- User-driven
  - Depends on application specifications, then the application recover the algorithmic requirements
  - Communication mode: rebuild, shrink, blank
  - Message mode: reset, continue

**Open Questions**

- Detection
  - How can we detect that a fault happens?
  - How can we globally decide the faulty processes?
- Fault management
  - How to propagate this information to everybody involved?
  - How to handle this information in a dynamic MPI-2 application?
- Recovery
  - Spawn new processes
  - Reconnect the new environment (scalability)
  - How can we handle the additional entities required by the FT models (memory channels, stable storages …)?

**Open MPI: Tuning Collective Communications; Managing the Choices**

Graham Fagg
Innovative Computing Laboratory
University of Tennessee
http://www.open-mpi.org/

**Overview**

- Why collectives are so important
- One size doesn’t fit all
- Tuned collectives component
  - Aims / goals
  - Design
  - Compile and run time flexibility
- Other tools
  - Custom tuning
  - The Future

**Why Are Collectives So Important?**

- Most applications use collective communication
  - Stuttgart HLRS profiled T3E/MPI applications
  - 95% used collectives extensively (i.e. more time spent in collectives than point to point)
- The wrong choice of a collective can increase runtime by orders of magnitude
- This becomes more critical as data and node sizes increase
One Size Does Not Fit All

- Many implementations perform a run-time decision based on either communicator size or data size (or layout, etc.)

The reduce shown for just a single small communicator size has multiple cross over points where one method performs better than the rest (note the LOG scales)

Tuned Collective Component: Aims and Goals

- Provide a number of methods for each of the MPI collectives
- Multiple algorithms/topologies/segmenting methods
- Low overhead efficient call stack
- Support for low level interconnects (i.e. RDMA)
- Allow the user to choose the best collective
- Both at compile time and at runtime
- Provide tools to help users understand which, why and how some collectives methods are chosen (including application specific configuration)

Four Part Design

- The MCA framework
  - The tuned collectives behaves as any other Open MPI component
- The collectives methods themselves
  - The MPI collectives backend
  - Topology and segmentation utilities
- The decision function
- Utilities to help users tune their system/application

Implementation

1. MCA framework
   - Has normal priority and verbose controls via MCA parameters
2. MPI collectives backend
   - Supports: Barrier, Bcast, Reduce, Allreduce, etc.
   - Topologies: Trees (binary, binomial, multi-fan in/out, k-chains, pipelines, N^d grids etc)

Implementation

3. Decision functions
   - Decided which algorithm to invoke based on:
     - Data previously provided by user (e.g., configuration)
     - Parameters of the MPI call (e.g., datatype, count)
     - Specific run-time knowledge (e.g., interconnects used)
   - Aims to choose the optimal (or best available) method

Method Invocation

- Open MPI communicators each have a function pointer to the backend collective implementation
Method Invocation

- The tuned collective component changes the method pointer to a decision pointer

User application
MPI API
Architecture services

Coll framework

Inside each communicators collects module

How to Tune?

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Inside each communicators collects module

Single decision function difficult to change once
Open MPI has loaded it

One decision function per Communicator per MPI call

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Fixed Decision Function

The fixed decision functions must decide a method for all possible [valid] input parameters (i.e., ALL communicator and message sizes)

Matlab

OCC tests

Dynamic Decision Function

- Dynamic means the decision functions are changeable as each communicator is created
- Controlled from a file or MCA parameters

Since this is a plugin, there is no need to recompile or re-link the application
Dynamic Decision Function

• Dynamic decision = run-time flexibility
• Allow the user to control each MPI collective individually via:
  * A fixed override (known as "forced")
  * A per-run configuration file
  * Or both
• Default to fixed decision rules if neither provided

MCA Parameters

• Everything is controlled via MCA parameters

<table>
<thead>
<tr>
<th>Collective</th>
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<th>Override 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alltoall</td>
<td>Fixed</td>
<td>Ngrid</td>
</tr>
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<td>Dynamic</td>
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```
mca_coll_tuned_use_dynamic_rules 0
```

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```
mca_coll_tuned_use_dynamic_rules 1
```

User-Forced Overrides

• For each collective:
  * Can choose a specific algorithm
  * Can tune the parameters of that algorithm
• Example: MPI_BARRIER
  * Algorithms
    * Linear, double ring, recursive doubling, Bruck, two process only, step-based bmree
  * Parameters
    * Tree degree, segment size

File-Based Overrides

• Configuration file holds detailed rule base
  * Specified for each collective
  * Only the overridden collectives need be specified
  * The rule base is only loaded once
  * Subsequent communicators share the information
  * Saves memory footprint

File-Based Overrides

• Pruned set of values
  * A complete set would have to map every possible comm size and data size/type to a method and its parameters (topology, segmentation etc)
  * Lots of data!
  * And lots of measuring to get that data
Pruning Values

- We know some things in advance
  - Communicator size
  - Can therefore prune
  - 2D grid of values
    - Communicator size vs. message size
    - Maps to algorithm and parameters

How to Prune

- Select communicator size, then search all elements
  - Linear: slow, but not too bad
  - Binary: faster, but more complex than linear

File-Based Overrides

- Separate fields for each MPI collective
- For each collective:
  - For each communicator size:
    - Message sizes in a run length compressed format
  - When a new communicator is created it only needs to know its communicator size rule

Automatic Rule Builder

- Replaces dedicated graduate students who love Matlab!
- Automatically determine which collective methods you should use
  - Performs a set of benchmarks
  - Uses intelligent ordering of tests to prune test set down to a manageable set
- Output is a set of file-based overrides
Example: Optimized MPI_SCATTER

- Search for:
  - Optimal algorithm
  - Optimal segment size
  - For 8 processes
  - For 4 algorithms
  - 1 message size (128k)
- Exhaustive search
  - 600 tests
  - Over 3 hours (!)

Example: Optimized MPI_SCATTER

- Search for:
  - Optimal algorithm
  - Optimal segment size
  - For 8 processes
  - For 4 algorithms
  - 1 message size (128k)
- Intelligent search
  - 90 tests
  - 40 seconds

Future Work

- Targeted Application tuning via Scalable Application Instrumentation System (SAIS)
- Used on DOE SuperNova TeraGrid application
  - Selectively profiles an application
  - Output compared to a mathematical model
  - Decide if current collectives are non-optimal
  - Non-optimal collective sizes can be retested
  - Results then produce a tuned configuration file for a particular application

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