HP-MPI User's Guide

10th Edition

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Table 1 Revision history

Edition	MPN	Description
Tenth	B6060-96022	Released with HP-MPI V2.2.5 June, 2007.
Ninth	B6060-96018	Released with HP-MPI V2.1 April, 2005.
Eighth	B6060-96013	Released with HP MPI V2.0 September, 2003.
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First	B6011-90001	Released with HP MPI V1.1 January, 1997.

Notice

Contents

Figures

Figures

Tables

Tables

Preface

This guide describes the HP-MPI (version 2.2.5) implementation of the Message Passing Interface (MPI) standard. The guide helps you use HP-MPI to develop and run parallel applications.

You should already have experience developing UNIX applications. You should also understand the basic concepts behind parallel processing, be familiar with MPI, and with the MPI 1.2 and MPI-2 standards (*MPI: A Message-Passing Interface Standard* and *MPI-2: Extensions to the Message-Passing Interface*, respectively).

You can access HTML versions of the MPI 1.2 and 2 standards at http://www.mpi-forum.org. *This guide supplements the material in the MPI standards and MPI: The Complete Reference.*

Some sections in this book contain command line examples used to demonstrate HP-MPI concepts. These examples use the /bin/csh syntax for illustration purposes.

Platforms supported

Table 2 Supported platforms, interconnects, and operating systems

Platform	Interconnect	Operating System
Intel IA 32	TCP/IP	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	Myrinet™ GM-2 and MX	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	InfiniBand™	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	RDMA Ethernet	Red Hat 3 WS/ES, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10

Table 2 **Supported platforms, interconnects, and operating systems**

Platform	Interconnect	Operating System
Intel Itanium™-based	TCP/IP	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10 Windows CCS, HP-UX 11i, HP-UX 11i V2
	QsNet Elan4	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	InfiniBand™	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10 Windows CCS, HP-UX 11i V2[1]
	Myrinet™ GM-2 and MX	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10

Table 2 Supported platforms, interconnects, and operating systems

Platform	Interconnect	Operating System
AMD Opteron™-based	TCP/IP	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	Myrinet™ GM-2 and MX	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	InfiniBand™	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	QsNet Elan4	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
Intel®64	Myrinet™ GM-2 and MX	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	TCP/IP	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
	InfiniBand™	Red Hat Enterprise Linux AS 3.0 and 4.0, SuSE Linux Enterprise Server 9, 9.1, 9.2, 9.3, 10
HP XC3000 Clusters	Myrinet™ GM-2 and MX	HP XC Linux
	TCP/IP	
	InfiniBand™	

Table 2 **Supported platforms, interconnects, and operating systems**

Platform	Interconnect	Operating System
HP XC4000 Clusters	QsNet Elan4	HP XC Linux
	Myrinet™ GM-2 and MX	
	TCP/IP	
	InfiniBand™	
HP XC6000 Clusters	TCP/IP	HP XC Linux
	QsNet Elan4	
	InfiniBand™	
HP Cluster Platforms	TCP/IP InfiniBand™	Microsoft™ Windows™ Compute Cluster Pack (CCP)
PA-RISC	TCP/IP	HP-UX
[1]Supported on HP InfiniBand™ solutions for HP-UX.		

Notational conventions

This section describes notational conventions used in this book.

Table 3 **Typographic conventions**

`bold monospace`	In command examples, **`bold monospace`** identifies input that must be typed exactly as shown.
`monospace`	In paragraph text, `monospace` identifies command names, system calls, and data structures and types. In command examples, `monospace` identifies command output, including error messages.
`italic`	In paragraph text, *`italic`* identifies titles of documents. In command syntax diagrams, *`italic`* identifies variables that you must provide. The following command example uses brackets to indicate that the variable *`output_file`* is optional: `command` *`input_file`* [*`output_file`*]
Brackets ([ ])	In command examples, square brackets designate optional entries.
KeyCap	In paragraph text, **KeyCap** indicates the keyboard keys or the user-selectable buttons on the Graphical User Interface (GUI) that you must press to execute a command.

NOTE A note highlights important supplemental information.

CAUTION A caution highlights procedures or information necessary to avoid damage to equipment, damage to software, loss of data, or invalid test results.

Documentation resources

Documentation resources include:

- HP-MPI product information available at http://www.hp.com/go/hpmpi
- *MPI: The Complete Reference* (2 volume set), MIT Press
- MPI 1.2 and 2.0 standards available at http://www.mpi-forum.org:
  - — *MPI: A Message-Passing Interface Standard*
  - — *MPI-2: Extensions to the Message-Passing Interface*
- TotalView documents available at http://www.totalviewtech.com:
  - — *TotalView Command Line Interface Guide*
  - — *TotalView User's Guide*
  - — *TotalView Installation Guide*
- *Parallel Programming Guide for HP-UX Systems*
- HP-MPI release notes available at http://www.hp.com/go/hpmpi and http://docs.hp.com
- Argonne National Laboratory's MPICH implementation of MPI at http://www-unix.mcs.anl.gov//mpi
- Argonne National Laboratory's implementation of MPI I/O at http://www-unix.mcs.anl.gov/romio
- University of Notre Dame's LAM implementation of MPI at http://www.lam-mpi.org/
- Intel Trace Collector/Analyzer product information (formally known as Vampir) at http://www.intel.com/software/products/cluster/tcollector/index.htm and http://www.intel.com/software/products/cluster/tanalyzer/index.htm
- LSF product information at http://www.platform.com
- HP XC product information at http://docs.hp.com
- HP Windows CCS product information at http://docs.hp.com

Credits

HP-MPI is based on MPICH from Argonne National Laboratory and LAM from the University of Notre Dame and Ohio Supercomputer Center.

HP-MPI includes ROMIO, a portable implementation of MPI I/O developed at the Argonne National Laboratory.

1 Introduction

This chapter provides a brief introduction about basic Message Passing Interface (MPI) concepts and the HP implementation of MPI.

This chapter contains the syntax for some MPI functions. Refer to *MPI: A Message-Passing Interface Standard* for syntax and usage details for all MPI standard functions. Also refer to *MPI: A Message-Passing Interface Standard* and to *MPI: The Complete Reference* for in-depth discussions of MPI concepts. The introductory topics covered in this chapter include:

- The message passing model
- MPI concepts
  - Point-to-point communication
  - Collective operations
  - MPI datatypes and packing
  - Multilevel parallelism
  - Advanced topics

The message passing model

Programming models are generally categorized by how memory is used. In the shared memory model each process accesses a shared address space, while in the message passing model an application runs as a collection of autonomous processes, each with its own local memory. In the message passing model processes communicate with other processes by sending and receiving messages. When data is passed in a message, the sending and receiving processes must work to transfer the data from the local memory of one to the local memory of the other.

Message passing is used widely on parallel computers with distributed memory, and on clusters of servers. The advantages of using message passing include:

- Portability—Message passing is implemented on most parallel platforms.
- Universality—Model makes minimal assumptions about underlying parallel hardware. Message-passing libraries exist on computers linked by networks and on shared and distributed memory multiprocessors.
- Simplicity—Model supports explicit control of memory references for easier debugging.

However, creating message-passing applications may require more effort than letting a parallelizing compiler produce parallel applications.

In 1994, representatives from the computer industry, government labs, and academe developed a standard specification for interfaces to a library of message-passing routines. This standard is known as MPI 1.0 (*MPI: A Message-Passing Interface Standard*). Since this initial standard, versions 1.1 (June 1995), 1.2 (July 1997), and 2.0 (July 1997) have been produced. Versions 1.1 and 1.2 correct errors and minor omissions of MPI 1.0. MPI-2 (*MPI-2: Extensions to the Message-Passing Interface*) adds new functionality to MPI 1.2. You can find both standards in HTML format at http://www.mpi-forum.org.

MPI-1 compliance means compliance with MPI 1.2. MPI-2 compliance means compliance with MPI 2.0. Forward compatibility is preserved in the standard. That is, a valid MPI 1.0 program is a valid MPI 1.2 program and a valid MPI-2 program.

MPI concepts

The primary goals of MPI are efficient communication and portability.

Although several message-passing libraries exist on different systems, MPI is popular for the following reasons:

- Support for full asynchronous communication—Process communication can overlap process computation.
- Group membership—Processes may be grouped based on context.
- Synchronization variables that protect process messaging—When sending and receiving messages, synchronization is enforced by source and destination information, message labeling, and context information.
- Portability—All implementations are based on a published standard that specifies the semantics for usage.

An MPI program consists of a set of processes and a logical communication medium connecting those processes. An MPI process cannot directly access memory in another MPI process. Inter-process communication requires calling MPI routines in both processes. MPI defines a library of routines through which MPI processes communicate.

The MPI library routines provide a set of functions that support

- Point-to-point communications
- Collective operations
- Process groups
- Communication contexts
- Process topologies
- Datatype manipulation.

Although the MPI library contains a large number of routines, you can design a large number of applications by using the six routines listed in Table 1-1.

Table 1-1 Six commonly used MPI routines

MPI routine	Description
`MPI_Init`	Initializes the MPI environment
`MPI_Finalize`	Terminates the MPI environment
`MPI_Comm_rank`	Determines the rank of the calling process within a group
`MPI_Comm_size`	Determines the size of the group
`MPI_Send`	Sends messages
`MPI_Recv`	Receives messages

You must call `MPI_Finalize` in your application to conform to the MPI Standard. HP-MPI issues a warning when a process exits without calling `MPI_Finalize`.

CAUTION There should be no code before `MPI_Init` and after `MPI_Finalize`. Applications that violate this rule are non-portable and may give incorrect results.

As your application grows in complexity, you can introduce other routines from the library. For example, `MPI_Bcast` is an often-used routine for sending or broadcasting data from one process to other processes in a single operation. Use broadcast transfers to get better performance than with point-to-point transfers. The latter use `MPI_Send` to send data from each sending process and `MPI_Recv` to receive it at each receiving process.

The following sections briefly introduce the concepts underlying MPI library routines. For more detailed information refer to *MPI: A Message-Passing Interface Standard*.

Point-to-point communication

Point-to-point communication involves sending and receiving messages between two processes. This is the simplest form of data transfer in a message-passing model and is described in Chapter 3, “Point-to-Point Communication” in the MPI 1.0 standard.

The performance of point-to-point communication is measured in terms of total transfer time. The total transfer time is defined as

total_transfer_time = *latency* + (*message_size*/*bandwidth*)

where

latency	Specifies the time between the initiation of the data transfer in the sending process and the arrival of the first byte in the receiving process.
message_size	Specifies the size of the message in Mbytes.
bandwidth	Denotes the reciprocal of the time needed to transfer a byte. Bandwidth is normally expressed in Mbytes per second.

Low latencies and high bandwidths lead to better performance.

Communicators

A communicator is an object that represents a group of processes and their communication medium or context. These processes exchange messages to transfer data. Communicators encapsulate a group of processes such that communication is restricted to processes within that group.

The default communicators provided by MPI are `MPI_COMM_WORLD` and `MPI_COMM_SELF`. `MPI_COMM_WORLD` contains all processes that are running when an application begins execution. Each process is the single member of its own `MPI_COMM_SELF` communicator.

Communicators that allow processes within a group to exchange data are termed intracommunicators. Communicators that allow processes in two different groups to exchange data are called intercommunicators.

Many MPI applications depend upon knowing the number of processes and the process rank within a given communicator. There are several communication management functions; two of the more widely used are `MPI_Comm_size` and `MPI_Comm_rank`. The process rank is a unique number assigned to each member process from the sequence 0 through (*size*-1), where *size* is the total number of processes in the communicator.

To determine the number of processes in a communicator, use the following syntax:

```
MPI_Comm_size (MPI_Comm comm, int *size);
```

where

comm	Represents the communicator handle
size	Represents the number of processes in the group of *comm*

To determine the rank of each process in comm, use

```
MPI_Comm_rank(MPI_Comm comm, int *rank);
```

where

comm	Represents the communicator handle
rank	Represents an integer between zero and (*size* - 1)

A communicator is an argument to all communication routines. The C code example, "communicator.c" on page 231 displays the use `MPI_Comm_dup`, one of the communicator constructor functions, and `MPI_Comm_free`, the function that marks a communication object for deallocation.

Sending and receiving messages

There are two methods for sending and receiving data: blocking and nonblocking.

In blocking communications, the sending process does not return until the send buffer is available for reuse.

In nonblocking communications, the sending process returns immediately, and may only have started the message transfer operation, not necessarily completed it. The application may not safely reuse the message buffer after a nonblocking routine returns until `MPI_Wait` indicates that the message transfer has completed.

In nonblocking communications, the following sequence of events occurs:

1. The sending routine begins the message transfer and returns immediately.

2. The application does some computation.
3. The application calls a completion routine (for example, `MPI_Test` or `MPI_Wait`) to test or wait for completion of the send operation.

Blocking communication Blocking communication consists of four send modes and one receive mode.

The four send modes are:

Standard (`MPI_Send`) The sending process returns when the system can buffer the message or when the message is received and the buffer is ready for reuse.

Buffered (`MPI_Bsend`) The sending process returns when the message is buffered in an application-supplied buffer.

Avoid using the `MPI_Bsend` mode because it forces an additional copy operation.

Synchronous (`MPI_Ssend`) The sending process returns only if a matching receive is posted and the receiving process has started to receive the message.

Ready (`MPI_Rsend`) The message is sent as soon as possible.

You can invoke any mode by using the appropriate routine name and passing the argument list. Arguments are the same for all modes.

For example, to code a standard blocking send, use

```
MPI_Send (void *buf, int count, MPI_Datatype dtype, int
dest, int tag, MPI_Comm comm);
```

where

buf	Specifies the starting address of the buffer.
count	Indicates the number of buffer elements.
dtype	Denotes the datatype of the buffer elements.
dest	Specifies the rank of the destination process in the group associated with the communicator *comm*.
tag	Denotes the message label.
comm	Designates the communication context that identifies a group of processes.

To code a blocking receive, use

`MPI_Recv (void *`*`buf`*`, int `*`count`*`, MPI_datatype `*`dtype`*`, int `*`source`*`, int `*`tag`*`, MPI_Comm `*`comm`*`, MPI_Status *`*`status`*`);`

where

buf	Specifies the starting address of the buffer.
count	Indicates the number of buffer elements.
dtype	Denotes the datatype of the buffer elements.
source	Specifies the rank of the source process in the group associated with the communicator *comm*.
tag	Denotes the message label.
comm	Designates the communication context that identifies a group of processes.
status	Returns information about the received message. Status information is useful when wildcards are used or the received message is smaller than expected. Status may also contain error codes.

Examples “send_receive.f” on page 205, “ping_pong.c” on page 207, and “master_worker.f90” on page 225 all illustrate the use of standard blocking sends and receives.

NOTE You should not assume message buffering between processes because the MPI standard does not mandate a buffering strategy. HP-MPI does sometimes use buffering for `MPI_Send` and `MPI_Rsend`, but it is dependent on message size. Deadlock situations can occur when your code uses standard send operations and assumes buffering behavior for standard communication mode.

Nonblocking communication MPI provides nonblocking counterparts for each of the four blocking send routines and for the receive routine. Table 1-2 lists blocking and nonblocking routine calls.

Table 1-2 MPI blocking and nonblocking calls

Blocking mode	Nonblocking mode
`MPI_Send`	`MPI_Isend`

Table 1-2 MPI blocking and nonblocking calls

Blocking mode	Nonblocking mode
`MPI_Bsend`	`MPI_Ibsend`
`MPI_Ssend`	`MPI_Issend`
`MPI_Rsend`	`MPI_Irsend`
`MPI_Recv`	`MPI_Irecv`

Nonblocking calls have the same arguments, with the same meaning as their blocking counterparts, plus an additional argument for a request.

To code a standard nonblocking send, use

```
MPI_Isend(void *buf, int count, MPI_datatype dtype, int
dest, int tag, MPI_Comm comm, MPI_Request *req);
```

where

req	Specifies the request used by a completion routine when called by the application to complete the send operation.

To complete nonblocking sends and receives, you can use `MPI_Wait` or `MPI_Test`. The completion of a send indicates that the sending process is free to access the send buffer. The completion of a receive indicates that the receive buffer contains the message, the receiving process is free to access it, and the status object, that returns information about the received message, is set.

Collective operations

Applications may require coordinated operations among multiple processes. For example, all processes need to cooperate to sum sets of numbers distributed among them.

MPI provides a set of collective operations to coordinate operations among processes. These operations are implemented such that all processes call the same operation with the same arguments. Thus, when sending and receiving messages, one collective operation can replace multiple sends and receives, resulting in lower overhead and higher performance.

Collective operations consist of routines for communication, computation, and synchronization. These routines all specify a communicator argument that defines the group of participating processes and the context of the operation.

Collective operations are valid only for intracommunicators. Intercommunicators are not allowed as arguments.

Communication

Collective communication involves the exchange of data among all processes in a group. The communication can be one-to-many, many-to-one, or many-to-many.

The single originating process in the one-to-many routines or the single receiving process in the many-to-one routines is called the root.

Collective communications have three basic patterns:

Broadcast and Scatter	Root sends data to all processes, including itself.
Gather	Root receives data from all processes, including itself.
Allgather and Alltoall	Each process communicates with each process, including itself.

The syntax of the MPI collective functions is designed to be consistent with point-to-point communications, but collective functions are more restrictive than point-to-point functions. Some of the important restrictions to keep in mind are:

- The amount of data sent must exactly match the amount of data specified by the receiver.
- Collective functions come in blocking versions only.
- Collective functions do not use a tag argument meaning that collective calls are matched strictly according to the order of execution.
- Collective functions come in standard mode only.

For detailed discussions of collective communications refer to Chapter 4, “Collective Communication” in the MPI 1.0 standard. The following examples demonstrate the syntax to code two collective operations; a broadcast and a scatter:

To code a broadcast, use

`MPI_Bcast(void *`*`buf`*`, int `*`count`*`, MPI_Datatype `*`dtype`*`, int `*`root`*`, MPI_Comm `*`comm`*`);`

where

buf	Specifies the starting address of the buffer.
count	Indicates the number of buffer entries.
dtype	Denotes the datatype of the buffer entries.
root	Specifies the rank of the root.
comm	Designates the communication context that identifies a group of processes.

For example “compute_pi.f” on page 223 uses `MPI_BCAST` to broadcast one integer from process 0 to every process in `MPI_COMM_WORLD`.

To code a scatter, use

`MPI_Scatter (void* `*`sendbuf`*`, int `*`sendcount`*`, MPI_Datatype `*`sendtype`*`, void* `*`recvbuf`*`, int `*`recvcount`*`, MPI_Datatype `*`recvtype`*`, int `*`root`*`, MPI_Comm `*`comm`*`);`

where

sendbuf	Specifies the starting address of the send buffer.
sendcount	Specifies the number of elements sent to each process.
sendtype	Denotes the datatype of the send buffer.
recvbuf	Specifies the address of the receive buffer.
recvcount	Indicates the number of elements in the receive buffer.
recvtype	Indicates the datatype of the receive buffer elements.
root	Denotes the rank of the sending process.
comm	Designates the communication context that identifies a group of processes.

Computation

Computational operations do global reduction operations, such as sum, max, min, product, or user-defined functions across all members of a group. There are a number of global reduction functions:

Reduce	Returns the result of a reduction at one node.

All–reduce	Returns the result of a reduction at all nodes.
Reduce-Scatter	Combines the functionality of reduce and scatter operations.
Scan	Performs a prefix reduction on data distributed across a group.

Section 4.9, “Global Reduction Operations” in the MPI 1.0 standard describes each of these functions in detail.

Reduction operations are binary and are only valid on numeric data. Reductions are always associative but may or may not be commutative.

You can select a reduction operation from a predefined list (refer to section 4.9.2 in the MPI 1.0 standard) or define your own operation. The operations are invoked by placing the operation name, for example `MPI_SUM` or `MPI_PROD`, in *op* as described in the `MPI_Reduce` syntax below.

To implement a reduction, use

```
MPI_Reduce(void *sendbuf, void *recvbuf, int count,
MPI_Datatype dtype, MPI_Op op, int root, MPI_Comm comm);
```

where

sendbuf	Specifies the address of the send buffer.
recvbuf	Denotes the address of the receive buffer.
count	Indicates the number of elements in the send buffer.
dtype	Specifies the datatype of the send and receive buffers.
op	Specifies the reduction operation.
root	Indicates the rank of the root process.
comm	Designates the communication context that identifies a group of processes.

For example “compute_pi.f” on page 223 uses `MPI_REDUCE` to sum the elements provided in the input buffer of each process in `MPI_COMM_WORLD`, using `MPI_SUM`, and returns the summed value in the output buffer of the root process (in this case, process 0).

Synchronization

Collective routines return as soon as their participation in a communication is complete. However, the return of the calling process does not guarantee that the receiving processes have completed or even started the operation.

To synchronize the execution of processes, call `MPI_Barrier`. `MPI_Barrier` blocks the calling process until all processes in the communicator have called it. This is a useful approach for separating two stages of a computation so messages from each stage do not overlap.

To implement a barrier, use

`MPI_Barrier(MPI_Comm` *comm*);

where

comm	Identifies a group of processes and a communication context.

For example, "cart.C" on page 227 uses `MPI_Barrier` to synchronize data before printing.

MPI datatypes and packing

You can use predefined datatypes (for example, `MPI_INT` in C) to transfer data between two processes using point-to-point communication. This transfer is based on the assumption that the data transferred is stored in contiguous memory (for example, sending an array in a C or Fortran application).

When you want to transfer data that is not homogeneous, such as a structure, or that is not contiguous in memory, such as an array section, you can use derived datatypes or packing and unpacking functions:

Derived datatypes

Specifies a sequence of basic datatypes and integer displacements describing the data layout in memory. You can use user-defined datatypes or predefined datatypes in MPI communication functions.

Packing and Unpacking functions

Provide `MPI_Pack` and `MPI_Unpack` functions so that a sending process can pack noncontiguous data into a contiguous buffer and a receiving process can unpack data received in a contiguous buffer and store it in noncontiguous locations.

Using derived datatypes is more efficient than using `MPI_Pack` and `MPI_Unpack`. However, derived datatypes cannot handle the case where the data layout varies and is unknown by the receiver, for example, messages that embed their own layout description.

Section 3.12, “Derived Datatypes” in the MPI 1.0 standard describes the construction and use of derived datatypes. The following is a summary of the types of constructor functions available in MPI:

- Contiguous (`MPI_Type_contiguous`)—Allows replication of a datatype into contiguous locations.
- Vector (`MPI_Type_vector`)—Allows replication of a datatype into locations that consist of equally spaced blocks.
- Indexed (`MPI_Type_indexed`)—Allows replication of a datatype into a sequence of blocks where each block can contain a different number of copies and have a different displacement.
- Structure (`MPI_Type_struct`)—Allows replication of a datatype into a sequence of blocks such that each block consists of replications of different datatypes, copies, and displacements.

After you create a derived datatype, you must commit it by calling `MPI_Type_commit`.

HP-MPI optimizes collection and communication of derived datatypes.

Section 3.13, “Pack and unpack” in the MPI 1.0 standard describes the details of the pack and unpack functions for MPI. Used together, these routines allow you to transfer heterogeneous data in a single message, thus amortizing the fixed overhead of sending and receiving a message over the transmittal of many elements.

Refer to Chapter 3, “User-Defined Datatypes and Packing” in *MPI: The Complete Reference* for a discussion of this topic and examples of construction of derived datatypes from the basic datatypes using the MPI constructor functions.

Multilevel parallelism

By default, processes in an MPI application can only do one task at a time. Such processes are single-threaded processes. This means that each process has an address space together with a single program counter, a set of registers, and a stack.

A process with multiple threads has one address space, but each process thread has its own counter, registers, and stack.

Multilevel parallelism refers to MPI processes that have multiple threads. Processes become multi threaded through calls to multi threaded libraries, parallel directives and pragmas, or auto-compiler parallelism. Refer to “Thread-compliant library” on page 54 for more information on linking with the thread-compliant library.

Multilevel parallelism is beneficial for problems you can decompose into logical parts for parallel execution; for example, a looping construct that spawns multiple threads to do a computation and joins after the computation is complete.

The example program, “multi_par.f” on page 233 is an example of multilevel parallelism.

Advanced topics

This chapter only provides a brief introduction to basic MPI concepts. Advanced MPI topics include:

- Error handling
- Process topologies
- User-defined datatypes
- Process grouping
- Communicator attribute caching
- The MPI profiling interface

To learn more about the basic concepts discussed in this chapter and advanced MPI topics refer to *MPI: The Complete Reference* and *MPI: A Message-Passing Interface Standard*.

2 Getting started

This chapter describes how to get started quickly using HP-MPI. The semantics of building and running a simple MPI program are described, for single- and multiple-hosts. You learn how to configure your environment before running your program. You become familiar with the file structure in your HP-MPI directory. The HP-MPI licensing policy is explained.

The goal of this chapter is to demonstrate the basics to getting started using HP-MPI. It is separated into two major sections: Getting started using HP-UX or Linux, and Getting started using Windows.

For complete details about running HP-MPI and analyzing and interpreting profiling data, refer to "Understanding HP-MPI" on page 39 and "Profiling" on page 157. The topics covered in this chapter are:

- Getting started using HP-UX or Linux
  - Configuring your environment
    - Setting PATH
    - Setting shell
  - Compiling and running your first application
    - Building and running on a single host
    - Building and running on a Linux cluster using appfiles
    - Building and running on an XC cluster using srun
  - Directory structure for HP-UX and Linux
  - HP-UX and Linux man pages
  - Licensing Policy for Linux
  - Version identification
- Getting started using Windows
  - Configuring your environment
  - Compiling and running your first application
    - Building and running on a single host
    - Building and running multihost on Windows CCS clusters
    - Building an MPI application on Windows with Visual Studio and using the property pages
  - Directory structure for Windows
  - Windows man pages

— Licensing Policy for Windows

Getting started using HP-UX or Linux

Configuring your environment

Setting PATH

If you move the HP-MPI installation directory from its default location in /opt/mpi for HP-UX, and /opt/hpmpi for Linux:

- Set the `MPI_ROOT` environment variable to point to the location where MPI is installed.
- Add `$MPI_ROOT/bin` to `PATH`.
- Add `$MPI_ROOT/share/man` to `MANPATH`.

MPI must be installed in the same directory on every execution host.

Setting shell

By default, HP-MPI attempts to use `ssh` on Linux and `remsh` on HP-UX. On Linux, we recommend that `ssh` users set `StrictHostKeyChecking=no` in their `~/.ssh/config`.

To use `rsh` on Linux instead, the following script needs to be run as root on each node in the cluster:

```
% /opt/hpmpi/etc/mpi.remsh.default
```

Or, to use `rsh` on Linux, use the alternative method of manually populating the files `/etc/profile.d/hpmpi.csh` and `/etc/profile.d/hpmpi.sh` with the following settings respectively:

```
% setenv MPI_REMSH rsh
```

```
% export MPI_REMSH=rsh
```

On HP-UX, `MPI_REMSH` specifies a command other than the default `remsh` to start remote processes. The `mpirun`, `mpijob`, and `mpiclean` utilities support `MPI_REMSH`. For example, you can set the environment variable to use a secure shell:

```
% setenv MPI_REMSH /bin/ssh
```

HP-MPI allows users to specify the remote execution tool to use when HP-MPI needs to start processes on remote hosts. The tool specified must have a call interface similar to that of the standard utilities: `rsh`, `remsh` and `ssh`.

An alternate remote execution tool, such as `ssh`, can be used on HP-UX by setting the environment variable `MPI_REMSH` to the name or full path of the tool to use:

```
% export MPI_REMSH=ssh
```

```
% $MPI_ROOT/bin/mpirun <options> -f <appfile>
```

HP-MPI supports setting `MPI_REMSH` using the `-e` option to `mpirun`:

```
% $MPI_ROOT/bin/mpirun -e MPI_REMSH=ssh <options> -f \
<appfile>
```

HP-MPI also supports setting `MPI_REMSH` to a command which includes additional arguments:

```
% $MPI_ROOT/bin/mpirun -e MPI_REMSH="ssh -x" <options> \
-f <appfile>
```

When using `ssh` on HP-UX, first ensure that it is possible to use `ssh` from the host where `mpirun` is executed to the other nodes without `ssh` requiring any interaction from the user.

Compiling and running your first application

To quickly become familiar with compiling and running HP-MPI programs, start with the C version of a familiar hello_world program. This program is called `hello_world.c` and prints out the text string "Hello world! I'm *r* of *s* on *host*" where *r* is a process's rank, *s* is the size of the communicator, and *host* is the host on which the program is run. The processor name is the host name for this implementation.

The source code for `hello_world.c` is stored in $MPI_ROOT/help and is shown below.

```
#include <stdio.h>
#include "mpi.h"

void main(argc, argv)

int                      argc;
char                     *argv[];

{

        int              rank, size, len;

        char             name[MPI_MAX_PROCESSOR_NAME];

        MPI_Init(&argc, &argv);

        MPI_Comm_rank(MPI_COMM_WORLD, &rank);

        MPI_Comm_size(MPI_COMM_WORLD, &size);

        MPI_Get_processor_name(name, &len);

        printf("Hello world!I'm %d of %d on %s\n", rank, size,
                                         name);

        MPI_Finalize();

        exit(0);

}
```

Building and running on a single host

This example teaches you the basic compilation and run steps to execute `hello_world.c` on your local host with four-way parallelism. To build and run `hello_world.c` on a local host named jawbone:

Step 1. Change to a writable directory.

Step 2. Compile the hello_world executable file:

```
% $MPI_ROOT/bin/mpicc -o hello_world \
$MPI_ROOT/help/hello_world.c
```

Step 3. Run the hello_world executable file:

```
% $MPI_ROOT/bin/mpirun -np 4 hello_world
```

where `-np 4` specifies 4 as the number of processes to run.

Step 4. Analyze hello_world output.

HP-MPI prints the output from running the hello_world executable in non-deterministic order. The following is an example of the output:

```
Hello world! I'm 1 of 4 on jawbone
Hello world! I'm 3 of 4 on jawbone
Hello world! I'm 0 of 4 on jawbone
Hello world! I'm 2 of 4 on jawbone
```

For information on running more complex applications, refer to “Running applications on HP-UX and Linux” on page 62.

Building and running on a Linux cluster using appfiles

The following is an example of basic compilation and run steps to execute `hello_world.c` on a cluster with 4-way parallelism. To build and run `hello_world.c` on a cluster using an appfile:

Step 1. Change to a writable directory.

Step 2. Compile the hello_world executable file:

```
% $MPI_ROOT/bin/mpicc -o hello_world \
$MPI_ROOT/help/hello_world.c
```

Step 3. Create a file "appfile" for running on nodes n01 and n02 as:

```
-h n01 -np 2 /path/to/hello_world
-h n02 -np 2 /path/to/hello_world
```

Step 4. Run the hello_world executable file:

```
% $MPI_ROOT/bin/mpirun -f appfile
```

By default, `mpirun` will rsh/remsh to the remote machines n01 and n02. If desired, the environment variable `MPI_REMSH` can be used to specify a different command, such as `/usr/bin/ssh` or `"ssh -x"`.

Step 5. Analyze hello_world output.

HP-MPI prints the output from running the hello_world executable in non-deterministic order. The following is an example of the output:

```
Hello world! I'm 1 of 4 n01
Hello world! I'm 3 of 4 n02
Hello world! I'm 0 of 4 n01
Hello world! I'm 2 of 4 n02
```

Refer to "LSF on non-XC systems" on page 74 for examples using LSF.

Building and running on an XC cluster using srun

The following is an example of basic compilation and run steps to execute `hello_world.c` on a XC cluster with 4-way parallelism. To build and run `hello_world.c` on a XC cluster (assuming LSF is not installed):

Step 1. Change to a writable directory.

Step 2. Compile the hello_world executable file:

```
% $MPI_ROOT/bin/mpicc -o hello_world \
$MPI_ROOT/help/hello_world.c
```

Step 3. Run the hello_world executable file:

```
% $MPI_ROOT/bin/mpirun -srun -n4 hello_world
```

where `-n4` specifies 4 as the number of processes to run from SLURM.

Step 4. Analyze hello_world output.

HP-MPI prints the output from running the hello_world executable in non-deterministic order. The following is an example of the output:

```
I'm 1 of 4 n01 Hello world!
I'm 3 of 4 n02 Hello world!
I'm 0 of 4 n01 Hello world!
I'm 2 of 4 n02 Hello world!
```

Refer to "LSF on XC systems" on page 74 for examples using LSF.

Directory structure for HP-UX and Linux

All HP-MPI files are stored in the /opt/mpi directory for HP-UX and the /opt/hpmpi directory for Linux. The directory structure is organized as described in Table 2-1.

If you move the HP-MPI installation directory from its default location in /opt/mpi, set the `MPI_ROOT` environment variable to point to the new location. Refer to “Configuring your environment” on page 20.

Table 2-1 **Directory Structure for HP-UX and Linux**

Subdirectory	Contents
bin	Command files for the HP-MPI utilities gather_info script
help	Source files for the example programs
include	Header files
lib/pa2.0	HP-MPI PA-RISC 32-bit libraries
lib/pa20_64	HP-MPI PA-RISC 64-bit libraries
lib/hpux32	HP-MPI HP-UX Itanium 32-bit libraries
lib/hpux64	HP-MPI HP-UX Itanium 64-bit libraries
lib/linux_ia32	HP-MPI Linux 32-bit libraries
lib/linux_ia64	HP-MPI Linux 64-bit libraries for Itanium
lib/linux_amd64	HP-MPI Linux 64-bit libraries for Opteron and Intel®64
MPICH1.2/	MPICH compatibility wrapper libraries
newconfig/	Configuration files and release notes
share/man/man1*	man pages for the HP-MPI utilities
share/man/man3*	man pages for HP-MPI library
doc	Release notes

HP-UX and Linux man pages

The man pages are located in the $MPI_ROOT/share/man/man1* subdirectory for HP-UX and Linux. They can be grouped into three categories: general, compilation, and run time. There is one general man page, MPI.1, that is an overview describing general features of HP-MPI. The compilation and run-time man pages are those that describe HP-MPI utilities.

Table 2-2 describes the three categories of man pages in the man1 subdirectory that comprise man pages for HP-MPI utilities.

Table 2-2 HP-UX and Linux man page categories

Category	man pages	Description
General	MPI.1	Describes the general features of HP-MPI
Compilation	mpicc.1 mpiCC.1 mpif77.1 mpif90.1	Describes the available compilation utilities. Refer to “Compiling applications” on page 42 for more information
Runtime	mpiclean.1 mpidebug.1 mpienv.1 mpiexec.1 mpijob.1 mpimtsafe.1 mpirun.1 mpirun.all.1 mpistdio.1 autodbl.1	Describes runtime utilities, environment variables, debugging, thread-safe and diagnostic libraries

Licensing Policy for Linux

HP-MPI for Linux uses FLEXlm licensing technology. A license is required to use HP-MPI for Linux. Licenses can be purchased from HP’s software depot at http://www.software.hp.com, or contact your HP representative.

Demo licenses for HP-MPI are also available from HP’s software depot.

If you’re running on an HP XC system, no license is required at runtime.

HP-MPI has an Independent Software Vendor (ISV) program that allows participating ISVs to freely distribute HP-MPI with their applications. When the application is part of the HP-MPI ISV program, there is no licensing requirement for the end user. The ISV provides a licensed copy of HP-MPI. Contact your application vendor to find out if they participate in the HP-MPI ISV program. The copy of HP-MPI distributed with a participating ISV will only work with that application. An HP-MPI license is required for all other applications.

Licensing for Linux

HP-MPI for Linux uses FLEXlm licensing technology. A license file can be named either as `license.dat` or any file name with an extension of `.lic`. The default location to place MPI license files is in the default installation directory `/opt/hpmpi/licenses`.

You will need to provide the hostname and hostid number of the system where the FLEXlm daemon for HP-MPI for Linux will run. The hostid, which is the MAC address of eth0, can be obtained by typing the following command if HP-MPI is already installed on the system:

```
% /opt/hpmpi/bin/licensing/<arch>/lmutil lmhostid
```

Or:

```
% /sbin/ifconfig | egrep "^eth0" | awk'{print $5}' | \
sed s/://g
```

The hostname can be obtained by entering the command **hostname**.

The default search path used to find an MPI license file is:

```
% $MPI_ROOT/licenses:/opt/hpmpi/licenses:.
```

For example, if `MPI_ROOT=/home/hpmpi`, license files will be searched in the following order:

```
/home/hpmpi/licenses/license.dat

/home/hpmpi/licenses/*.lic

/opt/hpmpi/licenses/license.dat

/opt/hpmpi/licenses/*.lic

./license.dat

./*.lic
```

If the license needs to be placed in another location which would not be found by the above search, the user may set the environment variable `LM_LICENSE_FILE` to explicitly specify the location of the license file.

For more information, see http://licensing.hp.com.

Installing License Files A valid license file contains the system hostid and the associated license key. License files can be named either as `license.dat` or any name with extension of `*.lic` (like `mpi.lic`, for example). Copy the license file under the directory `/opt/hpmpi/licenses`.

The command to run the license server is:

```
% $MPI_ROOT/bin/licensing/<arch>/lmgrd -c mpi.lic
```

License Testing Build and run the hello_world program in `$MPI_ROOT/help/hello_world.c` to check for a license. If your system is not properly licensed, you will receive the following error message:

```
("MPI BUG: Valid MPI license not found in search path")
```

Merging Licenses Newer HP-MPI licenses use the INCREMENT feature which allows separate HP-MPI licenses to be used in combination by concatenating files. For example:

License 1:

```
    SERVER myserver 0014c2c1f34a
    DAEMON HPQ
    INCREMENT HP-MPI HPQ 1.0 permanent 8 9A40ECDE2A38 \
            NOTICE="License Number = AAAABBBB1111"
SIGN=E5CEDE3E5626
```

License 2:

```
    SERVER myserver 0014c2c1f34a
    DAEMON HPQ
    INCREMENT HP-MPI HPQ 1.0 permanent 16 BE468B74B592 \
            NOTICE="License Number = AAAABBBB2222"
SIGN=9AB4034C6CB2
```

Here, License 1 is for 8 ranks, and License 2 is for 16 ranks. The two licenses can be combined into a single file:

```
SERVER myserver 0014c2c1f34a
DAEMON HPQ
INCREMENT HP-MPI HPQ 1.0 permanent 8 9A40ECDE2A38 \
        NOTICE="License Number = AAAABBBB1111"
SIGN=E5CEDE3E5626
```

```
SERVER myserver 0014c2c1f34a
DAEMON HPQ
INCREMENT HP-MPI HPQ 1.0 permanent 16 BE468B74B592 \
        NOTICE="License Number = AAAABBBB2222"
SIGN=9AB4034C6CB2
```

The result is a valid license for 24 ranks.

Version identification

To determine the version of an HP-MPI installation, use the `what` command on HP-UX. Use the `ident` or `rpm` command on Linux.

For example:

```
% what $MPI_ROOT/bin/mpirun
```

or

```
% ident $MPI_ROOT/bin/mpirun
```

or

```
% rpm -qa | grep hpmpi
```

Getting started using Windows

Configuring your environment

The default install directory location for HP-MPI for Windows is one of the following directories:

On 64-bit Windows:

C:\Program Files (x86)\Hewlett-Packard\HP-MPI

On 32-bit Windows:

C:\Program Files \Hewlett-Packard\HP-MPI

The default install will define the system environment variable `MPI_ROOT`, but will not put "%MPI_ROOT%\bin" in the system path or your user path.

If you choose to move the HP-MPI installation directory from its default location:

- Change the system environment variable `MPI_ROOT` to reflect the new location.
- You may need to add "%MPI_ROOT%\bin\mpirun.exe" and "%MPI_ROOT%\bin\mpid.exe" to the firewall exceptions depending on how your system is configured.

HP-MPI must be installed in the same directory on every execution host.

To determine the version of an HP-MPI installation, use the `-version` flag on the **`mpirun`** command:

```
C:\> "%MPI_ROOT%\bin\mpirun" -version
```

Compiling and running your first application

To quickly become familiar with compiling and running HP-MPI programs, start with the C version of the familiar hello_world program. This program is called `hello_world.c` and prints out the text string "Hello world! I'm *`r`* of *`s`* on *`host`*" where *`r`* is a process's rank, *`s`* is the size of the communicator, and *`host`* is the host on which the program is run.

The source code for **hello_world.c** is stored in %MPI_ROOT%\help and can be seen in “Compiling and running your first application” on page 22.

Building and running on a single host

The example teaches you the basic compilation and run steps to execute **hello_world.c** on your local host with four-way parallelism. To build and run **hello_world.c** on a local host named mpiccp1:

Step 1. Change to a writable directory.

Step 2. Open a Visual Studio command window. (This example uses a 64-bit version, so a Visual Studio x64 command window is opened.)

Step 3. Compile the hello_world executable file:

```
C:\demo> "%MPI_ROOT%\bin\mpicc" -mpi64 ^
"%MPI_ROOT%\help\hello_world.c"
```

```
Microsoft® C/C++ Optimizing Compiler Version 14.00.50727.42 for
x64
Copyright© Microsoft Corporation. All rights reserved.

hello_world.c
Microsoft® Incremental Linker Version 8.00.50727.42
Copyright© Microsoft Corporation. All rights reserved.

/out:hello_world.exe
"/libpath:C:\Program Files (x86)\Hewlett-Packard\HP-MPI\lib"
/subsystem:console
libhpmpi64.lib
libmpio64.lib
hello_world.obj
```

Step 4. Run the hello_world executable file:

```
C:\demo> "%MPI_ROOT%\bin\mpirun" -np 4 hello_world.exe
```

where `-np 4` specifies 4 as the number of processors to run.

Step 5. Analyze hello_world output.

HP-MPI prints the output from running the hello_world executable in non-deterministic order. The following is an example of the output:

```
Hello world! I'm 0 of 4 on mpiccp1
Hello world! I'm 3 of 4 on mpiccp1
Hello world! I'm 1 of 4 on mpiccp1
Hello world! I'm 2 of 4 on mpiccp1
```

Building and running multihost on Windows CCS clusters

The following is an example of basic compilation and run steps to execute **hello_world.c** on a cluster with 16-way parallelism. To build and run **hello_world.c** on a CCS cluster:

Step 1. Change to a writable directory.

Step 2. Open a Visual Studio command window. (This example uses a 64-bit version, so a Visual Studio x64 command window is opened.)

Step 3. Compile the hello_world executable file:

```
C:\demo> "%MPI_ROOT%\bin\mpicc" -mpi64 ^
"%MPI_ROOT%\help\hello_world.c"

Microsoft® C/C++ Optimizing Compiler Version 14.00.50727.42 for
x64
Copyright© Microsoft Corporation. All rights reserved.

hello_world.c
Microsoft® Incremental Linker Version 8.00.50727.42
Copyright© Microsoft Corporation. All rights reserved.

/out:hello_world.exe
"/libpath:C:\Program Files (x86)\Hewlett-Packard\HP-MPI\lib"
/subsystem:console
libhpmpi64.lib
libmpio64.lib
hello_world.obj
```

Step 4. Create a new job requesting the number of CPUs to use. Resources are not yet allocated, but the job is given a JOBID number which is printed to stdout:

```
> job new /numprocessors:16
```

Step 5. Add a single-CPU **mpirun** task to the newly created job. Note that **mpirun** will create more tasks filling the rest of the resources with the compute ranks, resulting in a total of 16 compute ranks for this example:

```
> job add JOBID /numprocessors:1
    /stdout:\\node\path\to\a\shared\file.out
    /stderr:\\node\path\to\a\shared\file.err
    "%MPI_ROOT%\bin\mpirun" -ccp \\node\path ^
     \to\hello_world.exe
```

Step 6. Submit the job. The machine resources are allocated and the job is run.

```
> job submit /id:JOBID
```

To run Multiple-Program Multiple-Data (MPMD) applications or other more complex configurations that require further control over the application layout or environment, dynamically create an appfile within the job using the utility **`"%MPI_ROOT%\bin\mpi_nodes.exe"`** as in the following example. Note that the environment variable `%CCP_NODES%` cannot be used for this purpose because it only contains the single CPU resource used for the task that executes the **`mpirun`** command. See “Running HP-MPI from CCP” on page 91. To create the executable, perform Steps 1 through 3 from the previous section. Then continue with:

Step 1. Create a new job.

```
> job new /numprocessors:16
```

Step 2. Submit a script. Verify `MPI_ROOT` is set in the environment (See the mpirun man page for more information):

```
> job add JOBID /numprocessors:1
   /env:MPI_ROOT="%MPI_ROOT%"
   /stdout:\\node\path\to\a\shared\file.out
   /stderr:\\node\path\to\a\shared\file.err
   path\submission_script.vbs
```

Where **`submission_script.vbs`** contains code such as:

```
Option Explicit
Dim sh, oJob, JobNewOut, appfile, Rsrc, I, fs
Set sh = WScript.CreateObject("WScript.Shell")
Set fs = CreateObject("Scripting.FileSystemObject")
Set oJob = sh.exec("%MPI_ROOT%\bin\mpi_nodes.exe")
JobNewOut = oJob.StdOut.Readall

Set appfile = fs.CreateTextFile("<path>\appfile", True)

Rsrc = Split(JobNewOut, " ")

For I = LBound(Rsrc) + 1 to UBound(Rsrc) Step 2
    appfile.WriteLine("-h" + Rsrc(I) + "-np" + Rsrc(I+1) + _
         " ""<path>\foo.exe"" ")
Next

appfile.Close
```

```
Set oJob = sh.exec("%MPI_ROOT%\bin\mpirun.exe -TCP -f _
    ""<path>\appfile"" ")

wscript.Echo oJob.StdOut.Readall
```

Step 3. Submit the job as in the previous example:

```
> job submit /id:JOBID
```

The above example using **submission_script.vbs** is only an example. Other scripting languages can be used to convert the output of **mpi_nodes.exe** into an appropriate appfile.

Building an MPI application on Windows with Visual Studio and using the property pages

To build an MPI application on Windows in C or C++ with VS2005, use the property pages provided by HP-MPI to help link applications.

Two pages are included with HP-MPI, and are located at the installation location (`MPI_ROOT`) in `help\HPMPI.vsprops` and `HPMPI64.vsprops`.

Go to **VS Project**, select **View**, select **Property Manager** and expand the project. This will display the different configurations and platforms set up for builds. Include the appropriate property page (`HPMPI.vsprops` for 32-bit apps, `HPMPI64.vsprops` for 64-bit apps) in the **Configuration/Platform** section.

Select this page by either double-clicking the page or by right-clicking on the page and selecting **Properties**. Go to the **User Macros** section. Set `MPI_ROOT` to the desired location (i.e. the installation location of HP-MPI). This should be set to the default installation location:

```
%ProgramFiles(x86)%\Hewlett-Packard\HP-MPI
```

NOTE This is the default location on 64-bit machines. The location for 32-bit machines is **%ProgramFiles%\Hewlett-Packard\HP-MPI**

The MPI application can now be built with HP-MPI.

The property page sets the following fields automatically, but can also be set manually if the property page provided is not used:

- C/C++ — Additional Include Directories

  Set to "`%MPI_ROOT%\include\[32|64]`"
- Linker — Additional Dependencies

  Set to `libhpmpi32.lib` or `libhpmpi64.lib` depending on the application.
- Additional Library Directories

  Set to "`%MPI_ROOT%\lib`"

Directory structure for Windows

All HP-MPI for Windows files are stored in the directory specified at install time. The default directory is C:\Program Files (x86)\Hewlett-Packard\HP-MPI. The directory structure is organized as described in Table 2-3. If you move the HP-MPI installation directory from its default location, set the `MPI_ROOT` environment variable to point to the new location.

Table 2-3 Directory Structure for Windows

Subdirectory	Contents
bin	Command files for the HP-MPI utilities
help	Source files for the example programs, Visual Studio Property pages
include\32	32-bit header files
include\64	64-bit header files
lib	HP-MPI libraries
man	HP-MPI man pages in HTML format
devtools	Windows HP-MPI services
licenses	Repository for HP-MPI license file
doc	Release notes, Debugging with HP-MPI Tutorial

Windows man pages

The man pages are located in the "%MPI_ROOT%\man\" subdirectory for Windows. They can be grouped into three categories: general, compilation, and run time. There is one general man page, MPI.1, that is an overview describing general features of HP-MPI. The compilation and run-time man pages are those that describe HP-MPI utilities.

Table 2-4 describes the three categories of man pages in the man1 subdirectory that comprise man pages for HP-MPI utilities.

Table 2-4 Windows man page categories

Category	**man pages**	**Description**
General	MPI.1	Describes the general features of HP-MPI
Compilation	mpicc.1 mpif90.1	Describes the available compilation utilities. Refer to “Compiling applications” on page 42 for more information
Runtime	mpidebug.1 mpienv.1 mpimtsafe.1 mpirun.1 mpistdio.1 autodbl.1	Describes runtime utilities, environment variables, debugging, thread-safe and diagnostic libraries

Licensing Policy for Windows

HP-MPI 1.0 for Windows uses FLEXlm licensing technology. A license is required to use HP-MPI for Windows. Licenses can be purchased from HP’s software depot at http://www.hp.com/go/softwaredepot, or contact your HP representative.

Demo licenses for HP-MPI are also available from HP’s software depot.

HP-MPI has an Independent Software Vendor (ISV) program that allows participating ISVs to freely distribute HP-MPI with their applications. When the application is part of the HP-MPI ISV program, there is no licensing requirement for the end user. The ISV provides a licensed copy of HP-MPI. Contact your application vendor to find out if they participate in the HP-MPI ISV program. The copy of HP-MPI distributed with a participating ISV will only work with that application. An HP-MPI license is required for all other applications.

Licensing for Windows

HP-MPI 1.0 for Windows uses FLEXlm licensing technology. A license file can be named either as `license.dat` or any file name with an extension of `.lic`. The license file must be placed in the installation directory (default `C:\Program Files (x86)\Hewlett-Packard\HP-MPI\licenses`) on all the runtime systems, and on the license server.

You will need to provide the hostname and hostid number of the system where the FLEXlm daemon for HP-MPI for Windows will run. The hostid can be obtained by typing the following command if HP-MPI is already installed on the system:

`%MPI_ROOT%\bin\licensing\<arch>\lmutil lmhostid`

The hostname can be obtained using the control panel by following **`Control Panel`** -> **`System`** -> **`Computer Name`** tab.

The default search path used to find an MPI license file is:

`"%MPI_ROOT%\licenses:."`.

If the license needs to be placed in another location which would not be found by the above search, the user may set the environment variable `LM_LICENSE_FILE` to explicitly specify the location of the license file.

For more information, see http://licensing.hp.com.

Installing License Files A valid license file contains the system hostid and the associated license key. License files can be named either as `license.dat` or any name with extension of `*.lic` (like `mpi.lic`, for example). The license file must be copied to the installation directory (default `C:\Program Files (x86)\Hewlett-Packard\HP-MPI\licenses`) on all runtime systems, and to the license server.

The command to run the license server is:

`"%MPI_ROOT%\bin\licensing\<arch>\lmgrd" -c mpi.lic`

License Testing Build and run the hello_world program in **`%MPI_ROOT%\help\hello_world.c`** to check for a license. If your system is not properly licensed, you will receive the following error message:

```
(“MPI BUG: Valid MPI license not found in search path”)
```

3 Understanding HP-MPI

This chapter provides information about the HP-MPI implementation of MPI. The topics covered include details about compiling and running your HP-MPI applications:

- Compilation wrapper script utilities
  - Compiling applications
    - Fortran 90
    - C command line basics for Windows systems
    - Fortran command line basics for Windows systems
- C++ bindings (for HP-UX and Linux)
  - Non-g++ ABI compatible C++ compilers
- Autodouble functionality
- MPI functions
- 64-bit support
  - HP-UX
  - Linux
  - Windows
- Thread-compliant library
- CPU binding
- MPICH object compatibility for HP-UX and Linux
- Examples of building on HP-UX and Linux
- Running applications on HP-UX and Linux
  - More information about appfile runs
  - Running MPMD applications
    - MPMD with appfiles
    - MPMD with prun
    - MPMD with srun
  - Modules on Linux
  - Runtime utility commands
    - mpirun
    - mpirun.all
    - mpiexec

- mpijob
- mpiclean

- Interconnect support
  - Protocol-specific options and information
  - Interconnect selection examples
- Running applications on Windows
  - Running HP-MPI from CCP
  - Submitting jobs
  - Submitting jobs from the CCS GUI
  - Running HP-MPI from command line on CCP systems
  - Automatic job submittal
  - Running on CCP with an appfile
- MPI options
  - mpirun options
  - Runtime environment variables
  - List of runtime environment variables
- Scalability
- Improved deregistration via ptmalloc (Linux only)
- Signal Propagation (HP-UX and Linux only)
- Dynamic Processes
- MPI-2 name publishing support
- Native language support

Compilation wrapper script utilities

HP-MPI provides compilation utilities for the languages shown in Table 3-1. In general, if a particular compiler is desired, it is best to set the appropriate environment variable such as `MPI_CC`. Without such a setting, the utility script will search the PATH and a few default locations for a variety of possible compilers. Although in many environments this search produces the desired results, explicitly setting the environment variable is safer. Command line options take precedence over environment variables.

Table 3-1 **Compiler selection**

Language	Wrapper Script	Environment Variable	Command Line
C	`mpicc`	`MPI_CC`	-mpicc <*compiler*>
C++	`mpiCC`	`MPI_CXX`	-mpicxx <*compiler*>
Fortran 77	`mpif77`	`MPI_F77`	-mpif77 <*compiler*>
Fortran 90	`mpif90`	`MPI_F90`	-mpif90 <*compiler*>
	`mpisyntax`	`MPI_WRAPPER_ SYNTAX`	-mpisyntax \ <*windows/unix*>

Compiling applications

The compiler you use to build HP-MPI applications depends upon which programming language you use. The HP-MPI compiler utilities are shell scripts that invoke the appropriate native compiler. You can pass the pathname of the MPI header files using the `-I` option and link an MPI library (for example, the diagnostic or thread-compliant library) using the `-Wl`, `-L` or `-l` option.

By default, HP-MPI compiler utilities include a small amount of debug information in order to allow the TotalView debugger to function. However, certain compiler options are incompatible with this debug information. Use the `-notv` option to exclude debug information. The `-notv` option will also disable TotalView usage on the resulting executable. The `-notv` option applies to archive libraries only.

HP-MPI offers a `-show` option to compiler wrappers. When compiling by hand, run as `mpicc -show` and a line will print displaying exactly what the job was going to do (and skips the actual build).

Fortran 90

In order to use the 'mpi' Fortran 90 module, the user must create the module file by compiling the `module.F` file in `/opt/hpmpi/include/64/module.F` for 64-bit compilers. For 32-bit compilers, compile the `module.F` file in `/opt/hpmpi/include/32/module.F`.

NOTE Each vendor (e.g. PGI, Qlogic/Pathscale, Intel, Gfortran, etc.) has a different module file format. Since compiler implementations vary in their representation of a module file, a PGI module file is not usable with Intel and so on. Additionally, we cannot guarantee forward compatibility from older to newer versions of a specific vendor's compiler. Because of compiler version compatibility and format issues, we do not build the module files.

In each case, you will need to build (just once) the module that corresponds to 'mpi' with the compiler you intend to use.

For example, with `hpmpi/bin` and `pgi/bin` in `path`:

```
pgf90 -c  /opt/hpmpi/include/64/module.F
cat >hello_f90.f90 program main

    use mpi
    implicit none
    integer :: ierr, rank, size


    call MPI_INIT(ierr)
    call MPI_COMM_RANK(MPI_COMM_WORLD, rank, ierr)
    call MPI_COMM_SIZE(MPI_COMM_WORLD, size, ierr)
    print *, "Hello, world, I am ", rank, " of ", size
    call MPI_FINALIZE(ierr)

End

mpif90 -mpif90 pgf90 hello_f90.f90
hello_f90.f90:

mpirun ./a.out
Hello, world, I am             0  of             1
```

C command line basics for Windows systems

The utility `"%MPI_ROOT%\bin\mpicc"` is included to aid in command line compilation. To compile with this utility, set `MPI_CC` to the path of the command line compiler you want to use. Specify `-mpi32` or `-mpi64` to indicate if you are compiling a 32- or 64-bit application. Specify the command line options that you would normally pass to the compiler on the `mpicc` command line. The `mpicc` utility will add additional command line options for HP-MPI include directories and libraries. The `-show` option can be specified to indicate that `mpicc` should display the command generated without actually executing the compilation command. See the mpicc man page for more information.

To compile C code and link against HP-MPI without utilizing the **mpicc** tool, start a command prompt that has the appropriate environment settings loaded for your compiler, and use it with the compiler option:

```
/I"%MPI_ROOT%\include\[32|64]"
```

and the linker options:

```
/libpath:"%MPI_ROOT%\lib" /subsystem:console ^
[libhpmpi64.lib|libhpmpi32.lib]
```

The above assumes the environment variable `MPI_ROOT` is set.

For example, to compile **hello_world.c** from the Help directory using Visual Studio (from a Visual Studio 2005 command prompt window):

```
cl hello_world.c /I"%MPI_ROOT%\include\64"
     /link /out:hello_world.exe
     /libpath:"%MPI_ROOT%\lib"
     /subsystem:console libhpmpi64.lib
```

The PGI compiler uses a more UNIX-like syntax. From a PGI command prompt:

```
pgcc hello_world.c -I"%MPI_ROOT%\include\64"
     -o hello_world.exe -L"%MPI_ROOT%\lib" -lhpmpi64
```

Fortran command line basics for Windows systems

The utility `"%MPI_ROOT%\bin\mpif90"` is included to aid in command line compilation. To compile with this utility, set `MPI_F90` to the path of the command line compiler you want to use. Specify `-mpi32` or `-mpi64` to indicate if you are compiling a 32- or 64-bit application. Specify the command line options that you would normally pass to the compiler on the `mpif90` command line. The `mpif90` utility will add additional command line options for HP-MPI include directories and libraries. The `-show` option can be specified to indicate that `mpif90` should display the command generated without actually executing the compilation command. See the mpif90 man page for more information.

To compile **`compute_pi.f`** using Intel Fortran without utilizing the **`mpif90`** tool (from a command prompt that has the appropriate environment settings loaded for your Fortran compiler):

```
ifort compute_pi.f /I"%MPI_ROOT%\include\64"
     /link /out:compute_pi.exe
     /libpath:"%MPI_ROOT%\lib"
     /subsystem:console libhpmpi64.lib
```

C++ bindings (for HP-UX and Linux)

HP-MPI supports C++ bindings as described in the MPI-2 Standard. (See "Documentation resources" on page xxii.) If compiling and linking with the `mpiCC` command, no additional work is needed to include and use the bindings. You can include either `mpi.h` or `mpiCC.h` in your C++ source files.

The bindings provided by HP-MPI are an interface class, calling the equivalent C bindings. To profile your application, users should profile the equivalent C bindings.

If the user builds without the `mpiCC` command, they will need to include `-lmpiCC` to resolve C++ references.

If you want to use an alternate `libmpiCC.a` with `mpiCC`, use the `-mpiCClib` <*LIBRARY*> option. A 'default' g++ ABI compatible library is provided for each architecture except Alpha.

Non-g++ ABI compatible C++ compilers

The C++ library provided by HP-MPI, `libmpiCC.a`, was built with g++.

If you are using a C++ compiler which is not g++ ABI compatible (e.g. Portland Group Compiler), you must build your own `libmpiCC.a` and include this in your build command. The sources and Makefiles to build an appropriate library are located in `/opt/hpmpi/lib/ARCH/mpiCCsrc`.

To build your private version of `libmpiCC.a` and include it in the builds using `mpiCC`, do the following:

NOTE This example assumes your HP-MPI install directory is `/opt/hpmpi`. It also assumes that the pgCC compiler is in your path and working properly.

1. Copy the file needed to build `libmpiCC.a` into a working location.

```
% setenv MPI_ROOT /opt/hpmpi

% cp -r $MPI_ROOT/lib/linux_amd64/mpiCCsrc ~

% cd ~/mpiCCsrc
```

2. Compile and create the `libmpiCC.a` library.

```
% make CXX=pgCC MPI_ROOT=$MPI_ROOT
```

```
pgCC -c intercepts.cc -I/opt/hpmpi/include
-DHPMP_BUILD_CXXBINDING PGCC-W-0155-Nova_start()
seen (intercepts.cc:33)
PGCC/x86 Linux/x86-64 6.2-3: compilation completed with
warnings pgCC -c mpicxx.cc - I/opt/hpmpi/include
-DHPMP_BUILD_CXXBINDING ar rcs libmpiCC.a intercepts.o
mpicxx.o
```

3. Using a testcase, test that the library works as expected.

```
% mkdir test ; cd test

% cp $MPI_ROOT/help/sort.C .

% $MPI_ROOT/bin/mpiCC HPMPI_CC=pgCC sortC -mpiCClib \
../libmpiCC.a
```

```
sort.C:
```

```
% $MPI_ROOT/bin/mpirun -np 2 ./a.out
```

```
Rank 0
-980
-980
     .
     .
     .
965
965
```

Autodouble functionality

HP-MPI supports Fortran programs compiled 64-bit with any of the following options (some of which are not supported on all Fortran compilers):

For HP-UX:

- `+i8`

  Set default KIND of integer variables is 8.
- `+r8`

  Set default size of REAL to 8 bytes.
- `+autodbl4`

  Same as `+i8` and `+r8`.
- `+autodbl`

  Same as `+i8`, `+r8`, and set default size of REAL to 16 bytes.

For Linux:

- `-i8`

  Set default KIND of integer variables is 8.
- `-r8`

  Set default size of REAL to 8 bytes.
- `-r16`

  Set default size of REAL to 16 bytes.
- `-autodouble`

  Same as `-r8`.

The decision of how the Fortran arguments will be interpreted by the MPI library is made at link time.

If the `mpif90` compiler wrapper is supplied with one of the above options at link time, the necessary object files will automatically link, informing MPI how to interpret the Fortran arguments.

NOTE This autodouble feature is supported in the regular and multithreaded MPI libraries, but not in the diagnostic library.

For Windows CCP:

```
/integer_size:64
/4I8
-i8
/real_size:64
/4R8
/Qautodouble
-r8
```

If these flags are given to the **`mpif90.bat`** script at link time, then the application will be linked enabling HP-MPI to interpret the datatype `MPI_REAL` as 8 bytes (etc. as appropriate) at runtime.

However, if your application is written to explicitly handle the autodoubled datatypes (e.g. if a variable is declared real and the code is compiled `-r8` and corresponding MPI calls are given `MPI_DOUBLE` for the datatype), then the autodouble related command line arguments should not be passed to **`mpif90.bat`** at link time (because that would cause the datatypes to be automatically changed).

MPI functions

The following MPI functions accept user-defined functions and require special treatment when autodouble is used:

- `MPI_Op_create()`
- `MPI_Errhandler_create()`
- `MPI_Keyval_create()`
- `MPI_Comm_create_errhandler()`
- `MPI_Comm_create_keyval()`
- `MPI_Win_create_errhandler()`
- `MPI_Win_create_keyval()`

The user-defined callback passed to these functions should accept normal-sized arguments. These functions are called internally by the library where normally-sized data types will be passed to them.

64-bit support

HP-MPI provides support for 64-bit libraries as shown in Table 3-2. More detailed information about HP-UX, Linux, and Windows systems is provided in the following sections.

Table 3-2 **32- and 64-bit support**

OS/ Architecture	Supported Libraries	Default	Notes
HP-UX 11i and higher	32- and 64-bit	32-bit	Compile with `+DD64` to build/link with 64-bit libraries
Linux IA-32	32-bit	32-bit	
Linux Itanium2	64-bit	64-bit	
Linux Opteron & Intel®64	32- and 64-bit (InfiniBand only supports 64-bit)	64-bit	Use `-mpi32` and appropriate compiler flag. See compiler man page for 32-bit flag
Windows	32- and 64-bit	N/A	

HP-UX

HP-MPI supports a 64-bit version on platforms running HP-UX 11.i and higher. Both 32- and 64-bit versions of the library are shipped with this platform, however you cannot mix 32-bit and 64-bit executables in the same application.

The `mpicc` and `mpiCC` compilation commands link the 64-bit version of the library if you compile with the `+DD64` option on HP-UX. Use the following syntax:

```
[mpicc|mpiCC] +DD64 -o filename filename.c
```

When you use `mpif90`, compile with the `+DD64` option to link the 64-bit version of the library. Otherwise, `mpif90` links the 32-bit version. For example, to compile the program myprog.f90 and link the 64-bit library enter:

```
% mpif90 +DD64 -o myprog myprog.f90
```

If you're using a third party compiler on HP-UX, you must implicitly pass `-mpi32` and `-mpi64` options to the compiler wrapper.

Linux

HP-MPI supports both 32- and 64-bit versions running Linux on AMD Opteron or Intel®64 systems. Both 32- and 64-bit versions of the library are shipped with these systems, however, you cannot mix 32-bit and 64-bit executables in the same application.

HP-MPI includes `-mpi32` and `-mpi64` options for the compiler wrapper script on Opteron and Intel®64 systems. These options should be used to indicate the bitness of the application to be invoked so that the availability of interconnect libraries can be properly determined by the HP-MPI utilities `mpirun` and `mpid`. The default is `-mpi64`.

Mellanox only provides a 64-bit InfiniBand driver. Therefore, 32-bit apps are not supported on InfiniBand when running on Opteron or Intel®64 machines.

The following table summarizes 32- and 64-bit libraries supported by HP-MPI. Refer to the appropriate compiler man page for compiler options.

Windows

HP-MPI supports both 32- and 64-bit versions running Windows on AMD Opteron or Intel®64. Both 32- and 64-bit versions of the library are shipped with these systems, however you cannot mix 32-bit and 64-bit executables in the same application.

HP-MPI includes `-mpi32` and `-mpi64` options for the compiler wrapper script on Opteron and Intel®64 systems. These options are only necessary for the wrapper scripts so the correct libhpmpi32.dll or libhpmpi64.dll is linked with the application. It is not necessary when invoking the application.

HP-MPI uses Windows CCS to launch applications on remote nodes. Even though HP-MPI supports 32-bit applications, Windows CCS will only run on Windows x64 operating systems. Also, HP-MPI currently only supports the 64-bit IBAL drivers, so only 64-bit applications can be run using the -IBAL interconnect. Both 32-bit and 64-bit applications can use WSD.

Thread-compliant library

HP-MPI provides a thread-compliant library. By default, the non thread-compliant library (libmpi) is used when running HP-MPI jobs. Linking to the thread-compliant library is now required only for applications that have multiple threads making MPI calls simultaneously. In previous releases, linking to the thread-compliant library was required for multithreaded applications even if only one thread was making a MPI call at a time. See Table B-1 on page 262.

To link with the thread-compliant library on HP-UX and Linux systems, specify the `-libmtmpi` option to the build scripts when compiling the application.

To link with the thread-compliant library on Windows systems, specify the `-lmtmpi` option to the build scripts when compiling the application.

Application types that no longer require linking to the thread-compliant library include:

- Implicit compiler-generated parallelism (e.g. +O3 +Oparallel in HP-UX)
- Thread parallel applications utilizing the HP MLIB math libraries
- OpenMP applications
- pthreads (Only if no two threads call MPI at the same time. Otherwise, use the thread-compliant library for pthreads.)

CPU binding

The `mpirun` option `-cpu_bind` binds a rank to an ldom to prevent a process from moving to a different ldom after startup. The binding occurs before the MPI application is executed.

To accomplish this, a shared library is loaded at startup which does the following for each rank:

- Spins for a short time in a tight loop to let the operating system distribute processes to CPUs evenly. This duration can be changed by setting the `MPI_CPU_SPIN` environment variable which controls the number of spins in the initial loop. Default is 3 seconds.
- Determines the current CPU and ldom
- Checks with other ranks in the MPI job on the host for oversubscription by using a "shm" segment created by `mpirun` and a lock to communicate with other ranks. If no oversubscription occurs on the current CPU, then lock the process to the ldom of that CPU. If there is already a rank reserved on the current CPU, then find a new CPU based on least loaded free CPUs and lock the process to the ldom of that CPU.

Similar results can be accomplished using "mpsched" but the procedure outlined above has the advantage of being a more load-based distribution, and works well in psets and across multiple machines.

HP-MPI supports CPU binding with a variety of binding strategies (see below). The option `-cpu_bind` is supported in appfile, command line, and `srun` modes.

```
% mpirun -cpu_bind[_mt]=[v,][option][,v] -np \ 4 a.out
```

Where `_mt` implies thread aware CPU binding; `v,` and `,v` request verbose information on threads binding to CPUs; and [*option*] is one of:

`rank` — Schedule ranks on CPUs according to packed rank id.

`map_cpu` — Schedule ranks on CPUs in cyclic distribution through `MAP` variable.

`mask_cpu` — Schedule ranks on CPU masks in cyclic distribution through `MAP` variable.

`ll` — least loaded (ll) Bind each rank to the CPU it is currently running on.

For NUMA-based systems, the following options are also available:

`ldom` — Schedule ranks on ldoms according to packed rank id.

`cyclic` — Cyclic dist on each ldom according to packed rank id.

`block` — Block dist on each ldom according to packed rank id.

`rr` — round robin (rr) Same as cyclic, but consider ldom load average.

`fill` — Same as block, but consider ldom load average.

`packed` — Bind all ranks to same ldom as lowest rank.

`slurm` — slurm binding.

`ll` — least loaded (ll) Bind each rank to ldoms it is currently running on.

`map_ldom` — Schedule ranks on ldoms in cyclic distribution through MAP variable.

To generate the current supported options:

```
% mpirun -cpu_bind=help ./a.out
```

Environment variables for CPU binding:

- `MPI_BIND_MAP` allows specification of the integer CPU numbers, ldom numbers, or CPU masks. These are a list of integers separated by commas (,).
- `MPI_CPU_AFFINITY` is an alternative method to using `-cpu_bind` on the command line for specifying binding strategy. The possible settings are LL, RANK, MAP_CPU, MASK_CPU, LDOM, CYCLIC, BLOCK, RR, FILL, PACKED, SLURM, AND MAP_LDOM.
- `MPI_CPU_SPIN` allows selection of spin value. The default is 2 seconds. This value is used to let processes busy spin such that the operating system schedules processes to processors. The the processes bind themselves to the appropriate processor, or core, or ldom as appropriate.

  For example, the following selects a 4 second spin period to allow 32 MPI ranks (processes) to settle into place and then bind to the appropriate processor/core/ldom.

  ```
  % mpirun -e MPI_CPU_SPIN=4 -cpu_bind -np\ 32 ./linpack
  ```

- `MPI_FLUSH_FCACHE` Can be set to a threshold percent of memory (0-100) which, if the file cache currently in use meets or exceeds, initiates a flush attempt after binding and essentially before the user's MPI program starts. Refer to See "MPI_FLUSH_FCACHE" on page 127 for more information.
- `MPI_THREAD_AFFINITY` controls thread affinity. Possible values are:

  `none` — Schedule threads to run on all cores/ldoms. This is the default.

  `cyclic` — Schedule threads on ldoms in cyclic manner starting after parent.

  `cyclic_cpu` — Schedule threads on cores in cyclic manner starting after parent.

  `block` — Schedule threads on ldoms in block manner starting after parent.

  `packed` — Schedule threads on same ldom as parent.

  `empty` — No changes to thread affinity are made.
- `MPI_THREAD_IGNSELF` When set to 'yes', parent is not included in scheduling consideration of threads across remaining cores/ldoms. This method of thread control can be used for explicit pthreads or OpenMP threads.

Three `-cpu_bind` options require the specification of a map/mask description. This allows for very explicit binding of ranks to processors. The three options are `map_ldom`, `map_cpu`, and `mask_cpu`.

Syntax:
`-cpu_bind=[map_ldom,map_cpu,mask_cpu] [:<`*`settings`*`>, =<`*`settings`*`>, -e MPI_BIND_MAP=<`*`settings`*`>]`

Examples:

`-cpu_bind=MAP_LDOM -e MPI_BIND_MAP=0,2,1,3`
# map rank 0 to ldom 0, rank 1 to ldom 2, rank 2 to ldom1 and rank 3 to ldom 3.

`-cpu_bind=MAP_LDOM=0,2,3,1`
# map rank 0 to ldom 0, rank 1 to ldom 2, rank 2 to ldom 3 and rank 3 to ldom 1.

`-cpu_bind=MAP_CPU:0,6,5`
# map rank 0 to cpu 0, rank 1 to cpu 6, rank 2 to cpu 5.

`-cpu_bind=MASK_CPU:1,4,6`
# map rank 0 to cpu 0 (0001), rank 1 to cpu 2 (0100), rank 2 to cpu 1 or 2 (0110).

A rank binding on a clustered system uses the number of ranks and the number of nodes combined with the rank count to determine the CPU binding. Cyclic or blocked launch is taken into account.

On a cell-based system with multiple users, the LL strategy is recommended rather than RANK. LL allows the operating system to schedule the computational ranks. Then the `-cpu_bind` capability locks the ranks to the CPU as selected by the operating system scheduler.

MPICH object compatibility for HP-UX and Linux

The MPI standard specifies the function prototypes for the MPI functions, but does not specify the types of the MPI opaque objects like communicators or the values of the MPI constants. Hence an object file compiled using one vendor's MPI will generally not function correctly if linked against another vendor's MPI library.

There are some cases where such compatibility would be desirable. For instance a third party tool such as Intel trace/collector might only be available using the MPICH interface.

To allow such compatibility, HP-MPI includes a layer of MPICH wrappers which provides an interface identical to MPICH 1.2.5, and translates these calls into the corresponding HP-MPI interface. This MPICH compatibility interface is only provided for functions defined in MPICH 1.2.5 and cannot be used by an application which calls functions outside the scope of MPICH 1.2.5.

HP-MPI can be used in MPICH mode by compiling using "`mpicc.mpich`" and running using "`mpirun.mpich`". The compiler script `mpicc.mpich` uses an include file which defines the interfaces the same as MPICH 1.2.5, and at link time it links against `libmpich.so` which is the set of wrappers defining MPICH 1.2.5 compatible entrypoints for the MPI functions. The `mpirun.mpich` takes the same arguments as the traditional HP-MPI `mpirun`, but sets `LD_LIBRARY_PATH` so that `libmpich.so` is found.

An example of using a program with Intel Trace Collector:

```
% export MPI_ROOT=/opt/hpmpi

% $MPI_ROOT/bin/mpicc.mpich -o prog.x \
  $MPI_ROOT/help/communicator.c -L/path/to/itc/lib \
  -lVT -lvtunwind -ldwarf -lnsl -lm -lelf -lpthread

% $MPI_ROOT/bin/mpirun.mpich -np 2 ./prog.x
```

Here, the program `communicator.c` is being compiled with MPICH compatible interfaces and is being linked against Intel's Trace Collector `libVT.a` first from the command line option, followed by HP-MPI's `libmpich.so` then `libmpi.so` which are added by the `mpicc.mpich` compiler wrapper script. Thus `libVT.a` sees only the MPICH compatible interface to HP-MPI.

In general, object files built with HP-MPI's MPICH mode can be used in an MPICH application, and conversely object files built under MPICH can be linked into an HP-MPI app using MPICH mode. However using MPICH compatibility mode to produce a single executable to run under both MPICH and HP-MPI will be problematic and is not advised.

`communicator.c` could be compiled under HP-MPI MPICH compatibility mode as:

```
% export MPI_ROOT=/opt/hpmpi

% $MPI_ROOT/bin/mpicc.mpich -o prog.x \
$MPI_ROOT/help/communicator.c
```

and run the resulting prog.x under MPICH. However, various problems will be encountered. First, the MPICH installation will need to be built to include shared libraries and a soft link would need to be created for `libmpich.so`, since their libraries might be named differently.

Next an appropriate `LD_LIBRARY_PATH` setting must be added manually since MPICH expects the library path to be hard coded into the executable at link time via `-rpath`.

Finally, while the resulting executable would run over any supported interconnect under HP-MPI, it would not under MPICH due to not being linked against libgm/libelan etc.

Similar problems would be encountered if linking under MPICH and running under HP-MPI's MPICH compatibility. MPICH's use of `-rpath` to hard code the library path at link time would keep the executable from being able to find the HP-MPI MPICH compatibility library via HP-MPI's `LD_LIBRARY_PATH` setting.

C++ bindings are not supported with MPICH compatibility mode.

MPICH compatibility mode is not supported on HP-MPI V1.0 for Windows.

Examples of building on HP-UX and Linux

This example shows how to build `hello_world.c` prior to running.

Step 1. Change to a writable directory that is visible from all hosts on which the job will run.

Step 2. Compile the hello_world executable file.

```
% $MPI_ROOT/bin/mpicc -o hello_world \
$MPI_ROOT/help/hello_world.c
```

This example uses shared libraries, which is recommended.

HP-MPI also includes archive libraries which can be used by specifying the appropriate compiler option.

NOTE HP-MPI uses the dynamic loader to interface with various interconnect libraries. Therefore, dynamic linking is required when building applications that will use HP-MPI.

Running applications on HP-UX and Linux

This section introduces the methods to run your HP-MPI application on HP-UX and Linux. Using one of the `mpirun` methods is required. The examples below demonstrate six basic methods. Refer to "mpirun" on page 71 for all the `mpirun` command line options.

HP-MPI includes `-mpi32` and `-mpi64` options for the launch utility `mpirun` on Opteron and Intel®64. These options should be used to indicate the bitness of the application to be invoked so that the availability of interconnect libraries can be properly determined by the HP-MPI utilities `mpirun` and `mpid`. The default is `-mpi64`.

There are six methods you can use to start your application, depending on what kind of system you are using:

- Use `mpirun` with the `-np #` option and the name of your program. For example,

  ```
  % $MPI_ROOT/bin/mpirun -np 4 hello_world
  ```

  starts an executable file named `hello_world` with four processes. This is the recommended method to run applications on a single host with a single executable file.

- Use `mpirun` with an appfile. For example,

  ```
  % $MPI_ROOT/bin/mpirun -f appfile
  ```

  where `-f appfile` specifies a text file (appfile) that is parsed by `mpirun` and contains process counts and a list of programs.

  Although you can use an appfile when you run a single executable file on a single host, it is best used when a job is to be run across a cluster of machines which does not have its own dedicated launching method such as `srun` or `prun` (which are described below), or when using multiple executables. For details about building your appfile, refer to "Creating an appfile" on page 75.

- Use `mpirun` with `-prun` using the Quadrics Elan communication processor on Linux. For example,

  ```
  % $MPI_ROOT/bin/mpirun [mpirun options] -prun \
  <prun options> <program> <args>
  ```

  This method is only supported when linking with shared libraries.

Some features like `mpirun -stdio` processing are unavailable.

Rank assignments within HP-MPI are determined by the way `prun` chooses mapping at runtime.

The `-np` option is not allowed with `-prun`. The following `mpirun` options are allowed with `-prun`:

```
% $MPI_ROOT/bin/mpirun [-help] [-version] [-jv] [-i
<spec>] [-universe_size=#] [-sp <paths>] [-T] [-prot]
[-spawn] [-1sided] [-tv] [-e var[=val]] -prun <prun
options> <program> [<args>]
```

For more information on `prun` usage:

```
% man prun
```

The following examples assume the system has the Quadrics Elan interconnect and is a collection of 2-CPU nodes.

```
% $MPI_ROOT/bin/mpirun -prun -N4 ./a.out
```

will run `a.out` with 4 ranks, one per node, ranks are cyclically allocated.

```
n00 rank1
n01 rank2
n02 rank3
n03 rank4
```

```
% $MPI_ROOT/bin/mpirun -prun -n4 ./a.out
```

(assuming nodes have 2 processors/cores each) will run `a.out` with 4 ranks, 2 ranks per node, ranks are block allocated. Two nodes used.

```
n00 rank1
n00 rank2
n01 rank3
n01 rank4
```

Other forms of usage include allocating the nodes you wish to use, which creates a subshell. Then jobsteps can be launched within that subshell until the subshell is exited.

```
% $MPI_ROOT/bin/mpirun -prun -A -N6
```

This allocates 6 nodes and creates a subshell.

```
% $MPI_ROOT/bin/mpirun -prun -n4 -m block ./a.out
```

This uses 4 ranks on 4 nodes from the existing allocation. Note that we asked for block.

n00 rank1
n00 rank2
n02 rank3
n03 rank4

- Use `mpirun` with `-srun` on HP XC clusters. For example,

  ```
  % $MPI_ROOT/bin/mpirun <mpirun options> -srun \
  <srun options> <program> <args>
  ```

  Some features like `mpirun -stdio` processing are unavailable.

  The `-np` option is not allowed with `-srun`. The following options are allowed with `-srun`:

  ```
  % $MPI_ROOT/bin/mpirun [-help] [-version] [-jv] [-i
  <spec>] [-universe_size=#] [-sp <paths>] [-T] [-prot]
  [-spawn] [-tv] [-1sided] [-e var[=val]] -srun <srun
  options> <program> [<args>]
  ```

  For more information on `srun` usage:

  ```
  % man srun
  ```

  The following examples assume the system has the Quadrics Elan interconnect, SLURM is configured to use Elan, and the system is a collection of 2-CPU nodes.

  ```
  % $MPI_ROOT/bin/mpirun -srun -N4 ./a.out
  ```

  will run `a.out` with 4 ranks, one per node, ranks are cyclically allocated.

  n00 rank1
  n01 rank2
  n02 rank3
  n03 rank4

  ```
  % $MPI_ROOT/bin/mpirun -srun -n4 ./a.out
  ```

  will run `a.out` with 4 ranks, 2 ranks per node, ranks are block allocated. Two nodes used.

  Other forms of usage include allocating the nodes you wish to use, which creates a subshell. Then jobsteps can be launched within that subshell until the subshell is exited.

```
% srun -A -n4
```

This allocates 2 nodes with 2 ranks each and creates a subshell.

```
% $MPI_ROOT/bin/mpirun -srun ./a.out
```

This runs on the previously allocated 2 nodes cyclically.

```
n00 rank1
n00 rank2
n01 rank3
n01 rank4
```

- Use XC LSF and HP-MPI

  HP-MPI jobs can be submitted using LSF. LSF uses the SLURM `srun` launching mechanism. Because of this, HP-MPI jobs need to specify the `-srun` option whether LSF is used or `srun` is used.

  ```
  % bsub -I -n2 $MPI_ROOT/bin/mpirun -srun ./a.out
  ```

  LSF creates an allocation of 2 processors and `srun` attaches to it.

  ```
  % bsub -I -n12 $MPI_ROOT/bin/mpirun -srun -n6 \
  -N6 ./a.out
  ```

  LSF creates an allocation of 12 processors and srun uses 1 CPU per node (6 nodes). Here, we assume 2 CPUs per node.

  LSF jobs can be submitted without the `-I` (interactive) option.

  An alternative mechanism for achieving the one rank per node which uses the `-ext` option to LSF:

  ```
  % bsub -I -n3 -ext "SLURM[nodes=3]" \
  $MPI_ROOT/bin/mpirun -srun ./a.out
  ```

  The `-ext` option can also be used to specifically request a node. The command line would look something like the following:

  ```
  % bsub -I -n2 -ext "SLURM[nodelist=n10]" mpirun -srun \
  ./hello_world
  ```

  ```
  Job <1883> is submitted to default queue <interactive>.
  <<Waiting for dispatch ...>>
  <<Starting on lsfhost.localdomain>>
  Hello world! I'm 0 of 2 on n10
  Hello world! I'm 1 of 2 on n10
  ```

Including and excluding specific nodes can be accomplished by passing arguments to SLURM as well. For example, to make sure a job includes a specific node and excludes others, use something like the following. In this case, n9 is a required node and n10 is specifically excluded:

```
% bsub -I -n8 -ext "SLURM[nodelist=n9;exclude=n10]" \
mpirun -srun ./hello_world
```

```
Job <1892> is submitted to default queue <interactive>.
<<Waiting for dispatch ...>>
<<Starting on lsfhost.localdomain>>
Hello world! I'm 0 of 8 on n8
Hello world! I'm 1 of 8 on n8
Hello world! I’m 6 of 8 on n12
Hello world! I’m 2 of 8 on n9
Hello world! I’m 4 of 8 on n11
Hello world! I’m 7 of 8 on n12
Hello world! I’m 3 of 8 on n9
Hello world! I’m 5 of 8 on n11
```

In addition to displaying interconnect selection information, the mpirun -prot option can be used to verify that application ranks have been allocated in the desired manner:

```
% bsub -I -n12 $MPI_ROOT/bin/mpirun -prot -srun \
-n6 -N6 ./a.out
```

```
Job <1472> is submitted to default queue <interactive>.
<<Waiting for dispatch ...>>
<<Starting on lsfhost.localdomain>>
Host 0 -- ip 172.20.0.8 -- ranks 0
Host 1 -- ip 172.20.0.9 -- ranks 1
Host 2 -- ip 172.20.0.10 -- ranks 2
Host 3 -- ip 172.20.0.11 -- ranks 3
Host 4 -- ip 172.20.0.12 -- ranks 4
Host 5 -- ip 172.20.0.13 -- ranks 5

host | 0    1    2    3    4    5
======|================================
0 : SHM  VAPI VAPI VAPI VAPI VAPI
1 : VAPI SHM  VAPI VAPI VAPI VAPI
2 : VAPI VAPI SHM  VAPI VAPI VAPI
```

```
3 : VAPI VAPI VAPI SHM  VAPI VAPI
4 : VAPI VAPI VAPI VAPI SHM  VAPI
5 : VAPI VAPI VAPI VAPI VAPI SHM

Hello world! I'm 0 of 6 on n8
Hello world! I'm 3of 6 on n11
Hello world! I’m 5 of 6 on n13
Hello world! I’m 4 of 6 on n12
Hello world! I’m 2 of 6 on n10
Hello world! I’m 1 of 6 on n9
```

- Use LSF on non-XC systems

  On non-XC systems, to invoke the Parallel Application Manager (PAM) feature of LSF for applications where all processes execute the same program on the same host:

  ```
  % bsub <lsf_options> pam -mpi mpirun \
  <mpirun_options> program <args>
  ```

  In this case, LSF assigns a host to the MPI job.

  For example:

  ```
  % bsub pam -mpi $MPI_ROOT/bin/mpirun -np 4 compute_pi
  ```

  requests a host assignment from LSF and runs the `compute_pi` application with four processes.

  The load-sharing facility (LSF) allocates one or more hosts to run an MPI job. In general, LSF improves resource utilization for MPI jobs that run in multihost environments. LSF handles the job scheduling and the allocation of the necessary hosts and HP-MPI handles the task of starting up the application's processes on the hosts selected by LSF.

  By default `mpirun` starts the MPI processes on the hosts specified by the user, in effect handling the direct mapping of host names to IP addresses. When you use LSF to start MPI applications, the host names, specified to `mpirun` or implicit when the -h option is not used, are treated as symbolic variables that refer to the IP addresses that LSF assigns. Use LSF to do this mapping by specifying a variant of `mpirun` to execute your job.

  To invoke LSF for applications that run on multiple hosts:

  ```
  % bsub [lsf_options] pam -mpi mpirun [mpirun_options] -f
  appfile [-- extra_args_for_appfile]
  ```

In this case, each host specified in the appfile is treated as a symbolic name, referring to the host that LSF assigns to the MPI job.

For example:

```
% bsub pam -mpi $MPI_ROOT/bin/mpirun -f my_appfile
```

runs an appfile named my_appfile and requests host assignments for all remote and local hosts specified in my_appfile. If my_appfile contains the following items:

```
-h voyager -np 10 send_receive
-h enterprise -np 8 compute_pi
```

Host assignments are returned for the two symbolic links voyager and enterprise.

When requesting a host from LSF, you must ensure that the path to your executable file is accessible by all machines in the resource pool.

More information about appfile runs

This example teaches you to run the `hello_world.c` application that you built in Examples of building on HP-UX and Linux (above) using two hosts to achieve four-way parallelism. For this example, the local host is named jawbone and a remote host is named wizard. To run `hello_world.c` on two hosts, use the following procedure, replacing jawbone and wizard with the names of your machines:

Step 1. Edit the .rhosts file on jawbone and wizard.

Add an entry for wizard in the .rhosts file on jawbone and an entry for jawbone in the .rhosts file on wizard. In addition to the entries in the .rhosts file, ensure that the correct commands and permissions are set up on all hosts so that you can start your remote processes. Refer to “Setting shell” on page 20 for details.

Step 2. Ensure that the executable is accessible from each host either by placing it in a shared directory or by copying it to a local directory on each host.

Step 3. Create an appfile.

An appfile is a text file that contains process counts and a list of programs. In this example, create an appfile named my_appfile containing the following two lines:

```
-h jawbone -np 2 /path/to/hello_world
-h wizard -np 2 /path/to/hello_world
```

The appfile file should contain a separate line for each host. Each line specifies the name of the executable file and the number of processes to run on the host. The `-h` option is followed by the name of the host where the specified processes must be run. Instead of using the host name, you may use its IP address.

Step 4. Run the hello_world executable file:

```
% $MPI_ROOT/bin/mpirun -f my_appfile
```

The `-f` option specifies the filename that follows it is an appfile. `mpirun` parses the appfile, line by line, for the information to run the program. In this example, `mpirun` runs the hello_world program with two processes on the local machine, jawbone, and two processes on the remote machine, wizard, as dictated by the `-np 2` option on each line of the appfile.

Step 5. Analyze hello_world output.

HP-MPI prints the output from running the hello_world executable in non-deterministic order. The following is an example of the output:

```
Hello world! I'm 2 of 4 on wizard
Hello world! I'm 0 of 4 on jawbone
Hello world! I'm 3 of 4 on wizard
Hello world! I'm 1 of 4 on jawbone
```

Notice that processes 0 and 1 run on jawbone, the local host, while processes 2 and 3 run on wizard. HP-MPI guarantees that the ranks of the processes in `MPI_COMM_WORLD` are assigned and sequentially ordered according to the order the programs appear in the appfile. The appfile in this example, my_appfile, describes the local host on the first line and the remote host on the second line.

Running MPMD applications

A multiple program multiple data (MPMD) application uses two or more separate programs to functionally decompose a problem. This style can be used to simplify the application source and reduce the size of spawned processes. Each process can execute a different program.

MPMD with appfiles

To run an MPMD application, the `mpirun` command must reference an appfile that contains the list of programs to be run and the number of processes to be created for each program.

A simple invocation of an MPMD application looks like this:

```
% $MPI_ROOT/bin/mpirun -f appfile
```

where *`appfile`* is the text file parsed by `mpirun` and contains a list of programs and process counts.

Suppose you decompose the poisson application into two source files: poisson_master (uses a single master process) and poisson_child (uses four child processes).

The appfile for the example application contains the two lines shown below (refer to “Creating an appfile” on page 75 for details).

```
-np 1 poisson_master
-np 4 poisson_child
```

To build and run the example application, use the following command sequence:

```
% $MPI_ROOT/bin/mpicc -o poisson_master poisson_master.c
% $MPI_ROOT/bin/mpicc -o poisson_child poisson_child.c
% $MPI_ROOT/bin/mpirun -f appfile
```

See “Creating an appfile” on page 75 for more information about using appfiles.

MPMD with prun

`prun` also supports running applications with MPMD using procfiles. Please refer to the `prun` documentation at http://www.quadrics.com.

MPMD with srun

MPMD is not directly supported with `srun`. However, users can write custom wrapper scripts to their application to emulate this functionality. This can be accomplished by using the environment variables `SLURM_PROCID` and `SLURM_NPROCS` as keys to selecting the appropriate executable.

Modules on Linux

Modules are a convenient tool for managing environment settings for various packages. HP-MPI for Linux provides an `hp-mpi` module at /opt/hpmpi/modulefiles/hp-mpi which sets `MPI_ROOT` and adds to PATH and MANPATH. To use it, either copy this file to a system-wide module directory, or append /opt/hpmpi/modulefiles to the `MODULEPATH` environment variable.

Some useful module-related commands are:

`%` **`module avail`**	what modules can be loaded
`%` **`module load hp-mpi`**	load the hp-mpi module
`%` **`module list`**	list currently loaded modules
`%` **`module unload hp-mpi`**	unload the hp-mpi module

Modules are only supported on Linux.

NOTE On XC Linux, the HP-MPI module is named `mpi/hp/default` and can be abbreviated '`mpi`'.

Runtime utility commands

HP-MPI provides a set of utility commands to supplement the MPI library routines. These commands are listed below and described in the following sections:

- `mpirun`
- `mpirun.all` (see restrictions under “mpirun.all” on page 79)
- `mpiexec`
- `mpijob`
- `mpiclean`

mpirun

This section includes a discussion of `mpirun` syntax formats, `mpirun` options, appfiles, the multipurpose daemon process, and generating multihost instrumentation profiles.

The HP-MPI start-up `mpirun` requires that MPI be installed in the same directory on every execution host. The default is the location from which `mpirun` is executed. This can be overridden with the `MPI_ROOT` environment variable. Set the `MPI_ROOT` environment variable prior to starting `mpirun`. See “Configuring your environment” on page 20.

`mpirun` syntax has six formats:

- Single host execution
- Appfile execution
- prun execution
- srun execution
- LSF on XC systems
- LSF on non-XC systems

Single host execution

- To run on a single host, the `-np` option to `mpirun` can be used.

  For example:

  ```
  % $MPI_ROOT/bin/mpirun -np 4 ./a.out
  ```

  will run 4 ranks on the local host.

Appfile execution

- For applications that consist of multiple programs or that run on multiple hosts, here is a list of the most common options. For a complete list, see the `mpirun` man page:

  `mpirun [-help] [-version] [-djpv] [-ck] [-t` *`spec`*`] [-i` *`spec`*`] [-commd] [-tv] -f` *`appfile`* `[--` *`extra_args_for_ appfile`*`]`

  Where `--` *`extra_args_for_appfile`* specifies extra arguments to be applied to the programs listed in the appfile—A space separated list of arguments. Use this option at the end of your command line to append extra arguments to each line of your appfile. Refer to the example in “Adding program arguments to your appfile” on page 75 for details. These extra args also apply to spawned ne applications if specified on the `mpirun` command line.

  In this case, each program in the application is listed in a file called an appfile. Refer to “Appfiles” on page 75 for more information.

For example:

```
% $MPI_ROOT/bin/mpirun -f my_appfile
```

runs using an appfile named my_appfile, which might have contents such as:

-h hostA -np 2 /path/to/a.out

-h hostB -np 2 /path/to/a.out

which specify that two ranks are to run on hostA and two on hostB.

prun execution

- Use the `-prun` option for applications that run on the Quadrics Elan interconnect. When using the `-prun` option, `mpirun` sets environment variables and invokes `prun` utilities. Refer to “Runtime environment variables” on page 115 for more information about `prun` environment variables.

  The `-prun` argument to `mpirun` specifies that the `prun` command is to be used for launching. All arguments following `-prun` are passed unmodified to the `prun` command.

  ```
  % $MPI_ROOT/bin/mpirun <mpirun options> -prun \
  <prun options>
  ```

  The `-np` option is not allowed with `prun`. Some features like `mpirun -stdio` processing are unavailable.

  ```
  % $MPI_ROOT/bin/mpirun -prun -n 2 ./a.out
  ```

  launches a.out on two processors.

  ```
  % $MPI_ROOT/bin/mpirun -prot -prun -n 6 -N 6 ./a.out
  ```

  turns on the print protocol option (`-prot` is an `mpirun` option, and therefore is listed before `-prun`) and runs on 6 machines, one CPU per node.

  For more details about using `prun`, refer to “Running applications on HP-UX and Linux” on page 62.

  HP-MPI also provides implied `prun` mode. The implied `prun` mode allows the user to omit the `-prun` argument from the `mpirun` command line with the use of the environment variable `MPI_USEPRUN`. For more information about the implied `prun` mode see Appendix C, on page 267.

srun execution

- Applications that run on XC clusters require the -srun option. Startup directly from srun is not supported. When using this option, mpirun sets environment variables and invokes srun utilities. Refer to “Runtime environment variables” on page 115 for more information about srun environment variables.

  The -srun argument to mpirun specifies that the srun command is to be used for launching. All arguments following -srun are passed unmodified to the srun command.

  ```
  % $MPI_ROOT/bin/mpirun <mpirun options> -srun \
  <srun options>
  ```

  The -np option is not allowed with srun. Some features like mpirun -stdio processing are unavailable.

  ```
  % $MPI_ROOT/bin/mpirun -srun -n 2 ./a.out
  ```

  launches a.out on two processors.

  ```
  % $MPI_ROOT/bin/mpirun -prot -srun -n 6 -N 6 ./a.out
  ```

  turns on the print protocol option (-prot is an mpirun option, and therefore is listed before -srun) and runs on 6 machines, one CPU per node.

  For more details about using srun, refer to “Running applications on HP-UX and Linux” on page 62.

  HP-MPI also provides implied srun mode. The implied srun mode allows the user to omit the -srun argument from the mpirun command line with the use of the environment variable MPI_USESRUN. For more information about the implied srun mode see Appendix C, on page 267.

LSF on XC systems HP-MPI jobs can be submitted using LSF. LSF uses the SLURM srun launching mechanism. Because of this, HP-MPI jobs need to specify the -srun option whether LSF is used or srun is used.

```
% bsub -I -n2 $MPI_ROOT/bin/mpirun -srun ./a.out
```

For more details on using LSF on XC systems, refer to “Running applications on HP-UX and Linux” on page 62.

LSF on non-XC systems On non-XC systems, to invoke the Parallel Application Manager (PAM) feature of LSF for applications where all processes execute the same program on the same host:

```
% bsub <lsf_options> pam -mpi mpirun \
<mpirun_options> program <args>
```

For more details on using LSF on non-XC systems, refer to "Running applications on HP-UX and Linux" on page 62.

Appfiles An appfile is a text file that contains process counts and a list of programs. When you invoke `mpirun` with the name of the appfile, `mpirun` parses the appfile to get information for the run.

Creating an appfile The format of entries in an appfile is line oriented. Lines that end with the backslash (\) character are continued on the next line, forming a single logical line. A logical line starting with the pound (#) character is treated as a comment. Each program, along with its arguments, is listed on a separate logical line.

The general form of an appfile entry is:

```
[-h remote_host] [-e var[=val] [...]] [-l user] [-sp paths]
[-np #] program [args]
```

where

`-h` *remote_host*	Specifies the remote host where a remote executable file is stored. The default is to search the local host. *remote_host* is either a host name or an IP address.
`-e` *var=val*	Sets the environment variable *var* for the program and gives it the value *val*. The default is not to set environment variables. When you use `-e` with the `-h` option, the environment variable is set to *val* on the remote host.
`-l` *user*	Specifies the user name on the target host. The default is the current user name.
`-sp` *paths*	Sets the target shell PATH environment variable to *paths*. Search paths are separated by a colon. Both -sp path and -e PATH=path do the same thing. If both are specified, the -e PATH=path setting is used.
`-np #`	Specifies the number of processes to run. The default value for # is 1.
program	Specifies the name of the executable to run. `mpirun` searches for the executable in the paths defined in the PATH environment variable.

args	Specifies command line arguments to the program. Options following a program name in your appfile are treated as program arguments and are not processed by `mpirun`.

Adding program arguments to your appfile When you invoke `mpirun` using an appfile, arguments for your program are supplied on each line of your appfile—Refer to “Creating an appfile” on page 75. HP-MPI also provides an option on your `mpirun` command line to provide additional program arguments to those in your appfile. This is useful if you wish to specify extra arguments for each program listed in your appfile, but do not wish to edit your appfile.

To use an appfile when you invoke `mpirun`, use one of the following as described in “mpirun” on page 71:

- `mpirun [mpirun_options] -f` *`appfile`* `\`
  `[--` *`extra_args_for_appfile`*`]`
- `bsub [`*`lsf_options`*`] pam -mpi mpirun [`*`mpirun_options`*`] -f` *`appfile`* `\`
  `[--` *`extra_args_for_appfile`*`]`

The `--` *`extra_args_for_appfile`* option is placed at the end of your command line, after *`appfile`*, to add options to each line of your appfile.

CAUTION Arguments placed after - - are treated as program arguments, and are not processed by `mpirun`. Use this option when you want to specify program arguments for each line of the appfile, but want to avoid editing the appfile.

For example, suppose your appfile contains

```
-h voyager -np 10 send_receive arg1 arg2
-h enterprise -np 8 compute_pi
```

If you invoke `mpirun` using the following command line:

`mpirun -f` *`appfile`* `--` *`arg3 -arg4 arg5`*

- The `send_receive` command line for machine `voyager` becomes:

  ```
  send_receive arg1 arg2 arg3 -arg4 arg5
  ```

- The `compute_pi` command line for machine `enterprise` becomes:

  ```
  compute_pi arg3 -arg4 arg5
  ```

When you use the `--` *`extra_args_for_appfile`* option, it must be specified at the end of the `mpirun` command line.

Setting remote environment variables To set environment variables on remote hosts use the `-e` option in the appfile. For example, to set the variable MPI_FLAGS:

```
-h remote_host -e MPI_FLAGS=val [-np #] program [args]
```

For instructions on how to set environment variables on HP-UX and Linux, refer to “Setting environment variables on the command line for HP-UX and Linux” on page 115.

For instructions on how to set environment variables on Windows CCP, refer to “Runtime environment variables for Windows CCP” on page 93.

Assigning ranks and improving communication The ranks of the processes in `MPI_COMM_WORLD` are assigned and sequentially ordered according to the order the programs appear in the appfile.

For example, if your appfile contains

```
-h voyager -np 10 send_receive
-h enterprise -np 8 compute_pi
```

HP-MPI assigns ranks 0 through 9 to the 10 processes running send_receive and ranks 10 through 17 to the 8 processes running compute_pi.

You can use this sequential ordering of process ranks to your advantage when you optimize for performance on multihost systems. You can split process groups according to communication patterns to reduce or remove interhost communication hot spots.

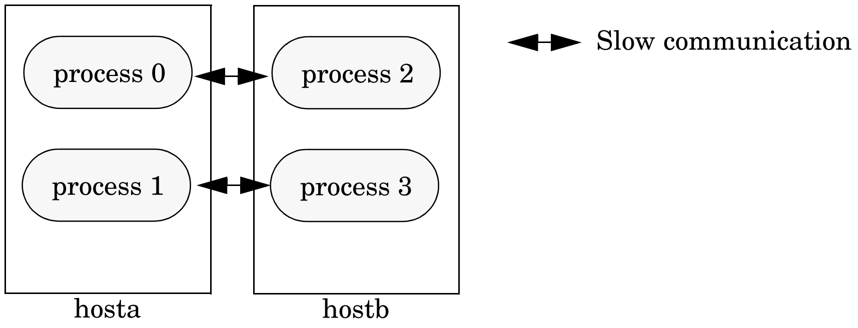
For example, if you have the following:

- A multi-host run of four processes
- Two processes per host on two hosts
- There is higher communication traffic between ranks 0—2 and 1—3.

You could use an appfile that contains the following:

```
-h hosta -np 2 program1
-h hostb -np 2 program2
```

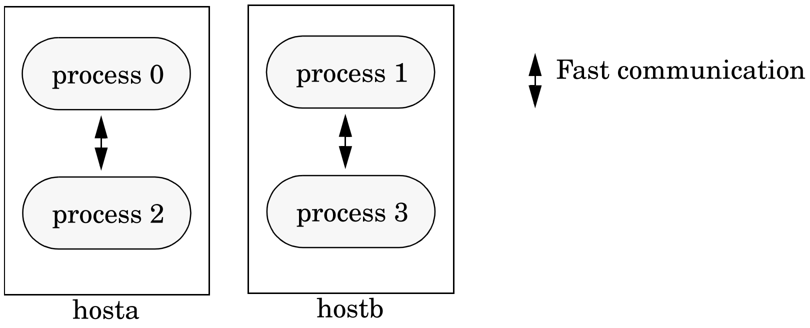
However, this places processes 0 and 1 on hosta and processes 2 and 3 on hostb, resulting in interhost communication between the ranks identified as having slow communication:



A more optimal appfile for this example would be

```
-h hosta -np 1 program1
-h hostb -np 1 program2
-h hosta -np 1 program1
-h hostb -np 1 program2
```

This places ranks 0 and 2 on hosta and ranks 1 and 3 on hostb. This placement allows intrahost communication between ranks that are identified as communication hot spots. Intrahost communication yields better performance than interhost communication.



Multipurpose daemon process HP-MPI incorporates a multipurpose daemon process that provides start–up, communication, and termination services. The daemon operation is transparent. HP-MPI sets up one daemon per host (or appfile entry) for communication.

NOTE Because HP-MPI sets up one daemon per host (or appfile entry) for communication, when you invoke your application with `-np x`, HP-MPI generates x+1 processes.

Generating multihost instrumentation profiles When you enable instrumentation for multihost runs, and invoke `mpirun` either on a host where at least one MPI process is running, or on a host remote from all your MPI processes, HP-MPI writes the instrumentation output file (*prefix*.instr) to the working directory on the host that is running rank 0.

mpirun.all

We recommend using the `mpirun` launch utility. However, for HP-UX and PA-RISC systems, HP-MPI provides a self-contained launch utility, `mpirun.all` that allows HP-MPI to be used without installing it on all hosts.

The restrictions for `mpirun.all` include

- Applications must be linked statically
- Start-up may be slower
- TotalView® is unavailable to executables launched with `mpirun.all`
- Files will be copied to a temporary directory on target hosts
- The remote shell must accept stdin

`mpirun.all` is not available on HP-MPI for Linux or Windows.

mpiexec

The MPI-2 standard defines `mpiexec` as a simple method to start MPI applications. It supports fewer features than `mpirun`, but it is portable. `mpiexec` syntax has three formats:

- `mpiexec` offers arguments similar to a `MPI_Comm_spawn` call, with arguments as shown in the following form:

```
mpiexec [-n maxprocs][-soft ranges][-host host][-arch
arch][-wdir dir][-path dirs][-file file]command-args
```

For example:

```
% $MPI_ROOT/bin/mpiexec -n 8 ./myprog.x 1 2 3
```

creates an 8 rank MPI job on the local host consisting of 8 copies of the program myprog.x, each with the command line arguments 1, 2, and 3.

- It also allows arguments like a `MPI_Comm_spawn_multiple` call, with a colon separated list of arguments, where each component is like the form above.

  For example:

  ```
  % $MPI_ROOT/bin/mpiexec -n 4 ./myprog.x : -host host2 -n \
  4 /path/to/myprog.x
  ```

  creates a MPI job with 4 ranks on the local host and 4 on host2.

- Finally, the third form allows the user to specify a file containing lines of data like the arguments in the first form.

`mpiexec [-configfile` *`file`*`]`

For example:

```
% $MPI_ROOT/bin/mpiexec -configfile cfile
```

gives the same results as in the second example, but using the -configfile option (assuming the file cfile contains -n 4 ./myprog.x -host host2 -n 4 -wdir /some/path ./myprog.x)

where `mpiexec` options are:

`-n` *`maxprocs`*	Create *maxprocs* MPI ranks on the specified host.
`-soft` *`range-list`*	Ignored in HP-MPI.
`-host` *`host`*	Specifies the host on which to start the ranks.
`-arch` *`arch`*	Ignored in HP-MPI.
`-wdir` *`dir`*	Working directory for the created ranks.
`-path` *`dirs`*	PATH environment variable for the created ranks.
`-file` *`file`*	Ignored in HP-MPI.

This last option is used separately from the options above.

`-configfile` *`file`*	Specify a file of lines containing the above options.

`mpiexec` does not support `prun` or `srun` startup.

`mpiexec` is not available on HP-MPI V1.0 for Windows.

mpijob

`mpijob` lists the HP-MPI jobs running on the system. `mpijob` can only be used for jobs started in appfile mode. Invoke `mpijob` on the same host as you initiated `mpirun`. `mpijob` syntax is shown below:

`mpijob [-help] [-a] [-u] [-j` *`id`*`] [`*`id id`*` ...]]`

where

`-help`	Prints usage information for the utility.
`-a`	Lists jobs for all users.
`-u`	Sorts jobs by user name.
`-j` *`id`*	Provides process status for job *`id`*. You can list a number of job IDs in a space-separated list.

When you invoke `mpijob`, it reports the following information for each job:

JOB	HP-MPI job identifier.
USER	User name of the owner.
NPROCS	Number of processes.
PROGNAME	Program names used in the HP-MPI application.

By default, your jobs are listed by job ID in increasing order. However, you can specify the `-a` and `-u` options to change the default behavior.

An `mpijob` output using the `-a` and `-u` options is shown below listing jobs for all users and sorting them by user name.

```
JOB      USER      NPROCS   PROGNAME
22623    charlie   12       /home/watts
22573    keith     14       /home/richards
22617    mick      100      /home/jagger
22677    ron        4        /home/wood
```

When you specify the `-j` option, `mpijob` reports the following for each job:

RANK	Rank for each process in the job.
HOST	Host where the job is running.
PID	Process identifier for each process in the job.

LIVE	Indicates whether the process is running (an x is used) or has been terminated.
PROGNAME	Program names used in the HP-MPI application.

`mpijob` does not support `prun` or `srun` startup.

`mpijob` is not available on HP-MPI V1.0 for Windows.

mpiclean

`mpiclean` kills processes in HP-MPI applications started in appfile mode. Invoke `mpiclean` on the host on which you initiated `mpirun`.

The MPI library checks for abnormal termination of processes while your application is running. In some cases, application bugs can cause processes to deadlock and linger in the system. When this occurs, you can use `mpijob` to identify hung jobs and `mpiclean` to kill all processes in the hung application.

`mpiclean` syntax has two forms:

1. `mpiclean [-help] [-v] -j` *`id`* `[`*`id id`* `....]`
2. `mpiclean [-help] [-v] -m`

where

`-help`	Prints usage information for the utility.
`-v`	Turns on verbose mode.
`-m`	Cleans up your shared-memory segments.
`-j` *`id`*	Kills the processes of job number *`id`*. You can specify multiple job IDs in a space-separated list. Obtain the job ID using the `-j` option when you invoke `mpirun`.

You can only kill jobs that are your own.

The second syntax is used when an application aborts during `MPI_Init`, and the termination of processes does not destroy the allocated shared-memory segments.

`mpiclean` does not support `prun` or `srun` startup.

`mpiclean` is not available on HP-MPI V1.0 for Windows.

Interconnect support

HP-MPI supports a variety of high-speed interconnects. On HP-UX and Linux, HP-MPI will attempt to identify and use the fastest available high-speed interconnect by default. On Windows, the selection must be made explicitly by the user.

On HP-UX and Linux, the search order for the interconnect is determined by the environment variable `MPI_IC_ORDER` (which is a colon separated list of interconnect names), and by command line options which take higher precedence.

Table 3-3 Interconnect command line options

command line option	protocol specified	applies to OS
`-ibv` / `-IBV`	IBV— OpenFabrics InfiniBand	Linux
`-vapi` / `-VAPI`	VAPI— Mellanox Verbs API	Linux
`-udapl` / `-UDAPL`	uDAPL—InfiniBand and some others	Linux
`-psm` / `-PSM`	PSM—QLogic InfiniBand	Linux
`-mx` / `-MX`	MX—Myrinet	Linux
`-gm` / `-GM`	GM—Myrinet	Linux
`-elan` / `-ELAN`	Quadrics Elan3 or Elan4	Linux
`-itapi` / `-ITAPI`	ITAPI—InfiniBand	HP-UX
`-ibal` / `-IBAL`	IBAL—Windows IB Access Layer	Windows
`-TCP`	TCP/IP	All

The interconnect names used in `MPI_IC_ORDER` are like the command line options above, but without the dash. On Linux, the default value of `MPI_IC_ORDER` is

ibv:vapi:udapl:psm:mx:gm:elan:tcp

If command line options from the above table are used, the effect is that the specified setting is implicitly prepended to the `MPI_IC_ORDER` list, thus taking higher precedence in the search.

Interconnects specified in the command line or in the `MPI_IC_ORDER` variable can be lower or upper case. Lower case means the interconnect will be used if available. Upper case instructs HP-MPI to abort if the specified interconnect is unavailable.

The availability of an interconnect is determined based on whether the relevant libraries can be `dlopened` / `shl_loaded`, and on whether a recognized module is loaded in Linux. If either condition is not met, the interconnect is determined to be unavailable.

On Linux, the names and locations of the libraries to be opened, and the names of the recognized interconnect module names are specified by a collection of environment variables which are contained in `$MPI_ROOT/etc/hpmpi.conf`.

The `hpmpi.conf` file can be used for any environment variables, but arguably its most important use is to consolidate the environment variables related to interconnect selection.

The default value of `MPI_IC_ORDER` is specified there, along with a collection of variables of the form

```
MPI_ICLIB_XXX__YYY
MPI_ICMOD_XXX__YYY
```

where `XXX` is one of the interconnects (IBV, VAPI, etc.) and `YYY` is an arbitrary suffix. The `MPI_ICLIB_*` variables specify names of libraries to be `dlopened`. The `MPI_ICMOD_*` variables specify regular expressions for names of modules to search for.

An example is the following two pairs of variables for PSM:

```
MPI_ICLIB_PSM__PSM_MAIN = libpsm_infinipath.so.1
MPI_ICMOD_PSM__PSM_MAIN = "^ib_ipath "
```

and

```
MPI_ICLIB_PSM__PSM_PATH = /usr/lib64/libpsm_infinipath.so.1
MPI_ICMOD_PSM__PSM_PATH = "^ib_ipath "
```

The suffixes `PSM_MAIN` and `PSM_PATH` are arbitrary, and represent two different attempts that will be made when determining if the PSM interconnect is available.

The list of suffixes is contained in the variable `MPI_IC_SUFFIXES` which is also set in the `hpmpi.conf` file.

So, when HP-MPI is determining the availability of the PSM interconnect, it will first look at

```
MPI_ICLIB_PSM__PSM_MAIN
MPI_ICMOD_PSM__PSM_MAIN
```

for the library to `dlopen` and module name to look for. Then, if that fails, it will continue on to the next pair

```
MPI_ICLIB_PSM__PSM_PATH
MPI_ICMOD_PSM__PSM_PATH
```

which in this case specifies a full path to the PSM library.

The `MPI_ICMOD_*` variables allow relatively complex values to specify what module names will be considered as evidence that the specified interconnect is available. Consider the example

```
MPI_ICMOD_VAPI__VAPI_MAIN = \
    "^mod_vapi " || "^mod_vip " || "^ib_core "
```

This means any of those three names will be accepted as evidence that VAPI is available. Each of the three strings individually is a regular expression that will be grepped for in the output from `/sbin/lsmod`.

In many cases, if a system has a high-speed interconnect that is not found by HP-MPI due to changes in library names and locations or module names, the problem can be fixed by simple edits to the `hpmpi.conf` file. Contacting HP-MPI support for assistance is encouraged.

Protocol-specific options and information

This section briefly describes the available interconnects and illustrates some of the more frequently used interconnects options.

The environment variables and command line options mentioned below are described in more detail in “mpirun options” on page 105, and “List of runtime environment variables” on page 117.

TCP/IP TCP/IP is supported on many types of cards.

Machines often have more than one IP address, and a user may wish to specify which interface is to be used to get the best performance.

HP-MPI does not inherently know which IP address corresponds to the fastest available interconnect card.

By default IP addresses are selected based on the list returned by `gethostbyname()`. The `mpirun` option `-netaddr` can be used to gain more explicit control over which interface is used.

IBAL IBAL is only supported on Windows. Lazy deregistration is not supported with IBAL.

IBV HP-MPI claims support for OpenFabrics V1.0 and V1.1. OpenFabrics is not supported on Itanium2 platforms.

In order to use OpenFabrics on Linux, the memory size for locking must be specified. It is controlled by the `/etc/security/limits.conf` file for Red Hat and the `/etc/syscntl.conf` file for SuSE.

```
*  soft  memlock 524288
*  hard  memlock 524288
```

The example above uses the max locked-in-memory address space in KB units. The recommendation is to set the value to half of the physical memory.

Machines can have multiple InfiniBand cards. By default each HP-MPI rank selects one card for its communication, and the ranks cycle through the available cards on the system, so the first rank uses the first card, the second rank uses the second card, etc.

The environment variable `MPI_IB_CARD_ORDER` can be used to control which card the different ranks select. Or, for increased potential bandwidth and greater traffic balance between cards, each rank can be instructed to use multiple cards by using the variable `MPI_IB_MULTIRAIL`.

Lazy deregistration is a performance enhancement used by HP-MPI on several of the high speed interconnects on Linux. This option is turned on by default, and requires the application to be linked in such a way that HP-MPI is able to intercept calls to `malloc`, `munmap`, etc. Most applications are linked that way, but if one is not then HP-MPI's lazy deregistration can be turned off with the command line `-ndd`.

Some applications decline to directly link against `libmpi` and instead link against a wrapper library which is in turn linked against `libmpi`. In this case it is still possible for HP-MPI's `malloc` etc. interception to be used by supplying the `--auxiliary` option to the linker when creating the wrapper library, by using a compiler flag such as `-Wl, --auxiliary, libmpi.so`.

Note that dynamic linking is required with all InfiniBand use on Linux.

HP-MPI does not use the Connection Manager (CM) library with OpenFabrics.

VAPI The `MPI_IB_CARD_ORDER` card selection option and the `-ndd` option described above for IBV applies to VAPI.

uDAPL The `-ndd` option described above for IBV applies to uDAPL.

GM The `-ndd` option described above for IBV applies to GM.

Elan HP-MPI supports the Elan3 and Elan4 protocols for Quadrics.

By default HP-MPI uses Elan collectives for broadcast and barrier.

If messages are outstanding at the time the Elan collective is entered and the other side of the message enters a completion routine on the outstanding message before entering the collective call, it is possible for the application to hang due to lack of message progression while inside the Elan collective. This is actually a rather uncommon situation in real applications. But if such hangs are observed, then the use of Elan collectives can be disabled by using the environment variable `MPI_USE_LIBELAN=0`.

ITAPI On HP-UX InfiniBand is available by using the ITAPI protocol, which requires MLOCK privileges. When setting up InfiniBand on an HP-UX system, all users (other than root) who wish to use InfiniBand need to have their group id in the /etc/privgroup file and the permissions for access must be enabled via:

```
% setprivgrp -f /etc/privgroup
```

The above may be done automatically at boot time, but should also be performed once manually after setup of the InfiniBand drivers to ensure access. For example:

```
% grep user /etc/passwd

user:UJqaKNCCsESLo,O.fQ:836:1007:User Name:/home/user:/bin/tcsh

% grep 1007 /etc/group

ibusers::1007:
```

```
% cat /etc/privgroup

ibusers MLOCK

#add entries to /etc/privgroup

% setprivgrp -f /etc/privgroup
```

A one-time setting can also be done using:

```
/usr/sbin/setprivgrp <group> MLOCK
```

The above setting will not survive a reboot.

Interconnect selection examples

The default `MPI_IC_ORDER` will generally result in the fastest available protocol being used. The following example uses the default ordering and also supplies a `-netaddr` setting, in case TCP/IP is the only interconnect available.

```
% echo MPI_IC_ORDER
ibv:vapi:udapl:psm:mx:gm:elan:tcp

% export MPIRUN_SYSTEM_OPTIONS="-netaddr 192.168.1.0/24"

% export MPIRUN_OPTIONS="-prot"

% $MPI_ROOT/bin/mpirun -srun -n4 ./a.out
```

The command line for the above will appear to `mpirun` as `$MPI_ROOT/bin/mpirun -netaddr 192.168.1.0/24 -prot -srun -n4 ./a.out` and the interconnect decision will look for IBV, then VAPI, etc. down to TCP/IP. If TCP/IP is chosen, it will use the 192.168.1.* subnet.

If TCP/IP is desired on a machine where other protocols are available, the `-TCP` option can be used.

This example is like the previous, except TCP is searched for and found first. (TCP should always be available.) So TCP/IP would be used instead of IBV or Elan, etc.

```
% $MPI_ROOT/bin/mpirun -TCP -srun -n4 ./a.out
```

The following example output shows three runs on an Elan system; first using Elan as the protocol, then using TCP/IP over GigE, then using TCP/IP over the Quadrics card.

- This runs on Elan

```
[user@opte10 user]$ bsub -I -n3 -ext "SLURM[nodes=3]"
$MPI_ROOT/bin/mpirun -prot -srun ./a.out
Job <59304> is submitted to default queue <normal>.

<<Waiting for dispatch ...>>
<<Starting on lsfhost.localdomain>>
Host 0 -- ELAN node 0 -- ranks 0
Host 1 -- ELAN node 1 -- ranks 1
Host 2 -- ELAN node 2 -- ranks 2

 host | 0    1    2
======|================
     0 : SHM  ELAN ELAN
     1 : ELAN SHM  ELAN
     2 : ELAN ELAN SHM

Hello world! I'm 0 of 3 on opte6
Hello world! I'm 1 of 3 on opte7
Hello world! I'm 2 of 3 on opte8
```

- This runs on TCP/IP over the GigE network configured as 172.20.x.x on eth0

```
[user@opte10 user]$ bsub -I -n3 -ext "SLURM[nodes=3]"
$MPI_ROOT/bin/mpirun -prot -TCP -srun ./a.out
Job <59305> is submitted to default queue <normal>.
<<Waiting for dispatch ...>>
<<Starting on lsfhost.localdomain>>
Host 0 -- ip 172.20.0.6 -- ranks 0
Host 1 -- ip 172.20.0.7 -- ranks 1
Host 2 -- ip 172.20.0.8 -- ranks 2

 host | 0    1    2
======|================
    0 : SHM  TCP  TCP
    1 : TCP  SHM  TCP
    2 : TCP  TCP  SHM

Hello world! I'm 0 of 3 on opte6
Hello world! I'm 1 of 3 on opte7
Hello world! I'm 2 of 3 on opte8
```

- This uses TCP/IP over the Elan subnet using the `-TCP` option in combination with the `-netaddr` option for the Elan interface 172.22.x.x

```
[user@opte10 user]$ bsub -I -n3 -ext "SLURM[nodes=3]"
$MPI_ROOT/bin/mpirun -prot -TCP -netaddr 172.22.0.10 -srun
./a.out
Job <59307> is submitted to default queue <normal>.
<<Waiting for dispatch ...>>
<<Starting on lsfhost.localdomain>>
Host 0 -- ip 172.22.0.2 -- ranks 0
Host 1 -- ip 172.22.0.3 -- ranks 1
Host 2 -- ip 172.22.0.4 -- ranks 2

 host | 0    1    2
```

```
======|================
    0 : SHM  TCP  TCP
    1 : TCP  SHM  TCP
    2 : TCP  TCP  SHM

Hello world! I'm 0 of 3 on opte2
Hello world! I'm 1 of 3 on opte3
Hello world! I'm 2 of 3 on opte4
```

- Elan interface

```
[user@opte10 user]$ /sbin/ifconfig eip0
eip0      Link encap:Ethernet  HWaddr 00:00:00:00:00:0F
          inet addr:172.22.0.10  Bcast:172.22.255.255
          Mask:255.255.0.0
          UP BROADCAST RUNNING MULTICAST  MTU:65264  Metric:1
          RX packets:38 errors:0 dropped:0 overruns:0 frame:0
          TX packets:6 errors:0 dropped:3 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:1596 (1.5 Kb)  TX bytes:252 (252.0 b)
```

- GigE interface

```
[user@opte10 user]$ /sbin/ifconfig eth0
eth0      Link encap:Ethernet  HWaddr 00:00:1A:19:30:80
          inet addr:172.20.0.10  Bcast:172.20.255.255
          Mask:255.0.0.0
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:133469120 errors:0 dropped:0 overruns:0
          frame:0
          TX packets:135950325 errors:0 dropped:0 overruns:0
          carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:24498382931 (23363.4 Mb)  TX bytes:29823673137
          (28442.0Mb)
          Interrupt:31
```

Running applications on Windows

Running HP-MPI from CCP

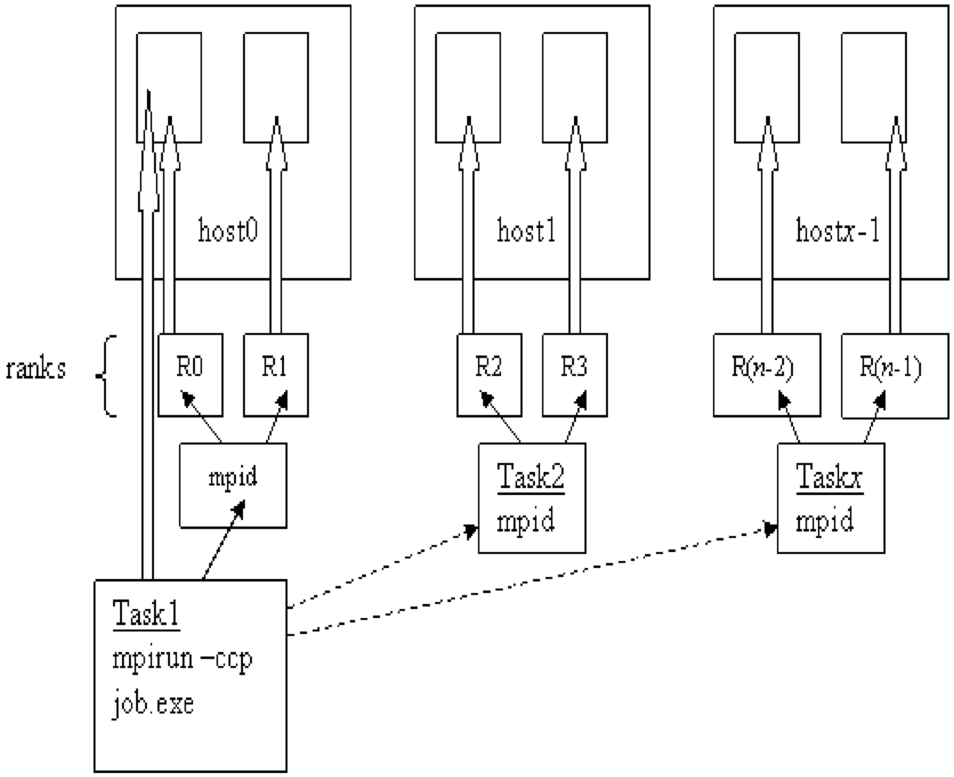
There are two ways to run HP-MPI: command line and scheduler GUI. Both approaches can be used to access the functionality of the scheduler. The command line scheduler options are similar to the GUI options.

The following instructions are in the context of the GUI, but equivalent command line options are also listed.

Microsoft Compute Cluster Pack job scheduler uses the term 'job' to refer to an allocation of resources, while a 'task' is command that is scheduled to run using a portion of a job allocation. It is important that HP-MPI's **`mpirun`** be submitted as a task that uses only a single processor. This allows the remaining resources within the job to be used for the creation of the remaining application ranks (and daemons). This is different from MSMPI, which requires that all of the processors in the job be allocated to the MSMPI **`mpiexec`** task.

Figure 3-1 shows the relationship between HP-MPI processes and the job allocation. A single task, "Task 1" is submitted and assigned a single CPU resource inside a larger job allocation. This task contains the **`mpirun`** command. Solid lines show the creation of local daemons and ranks using standard process creation calls. The creation of remote ranks are handled by **`mpirun`** by creating additional tasks within the job allocation. Only the task which starts **`mpirun`** is submitted by the user.

Figure 3-1 Job Allocation



To run an MPI application, submit the **mpirun** command to the scheduler. HP-MPI uses the environment of the task and job where **mpirun** is executing to launch the required mpids that start the ranks.

It is important that **mpirun** uses only a single processor for its task within the job so the resources can be used by the other processes within the MPI application. (This is the opposite of MSMPI, which requires all of the processor to be allocated to the **mpiexec** task by the MPI application.)

Submitting jobs

The section includes general information for submitting jobs either from the GUI or the command line.

As part of the **mpirun** task submitted, the following flags are commonly used with **mpirun**:

-ccp	Automatically creates an appfile which matches the CCP job allocation. The number of ranks run will equal the number of processors requested.
-nodex	When used in conjunction with the `-ccp` flag, will run one rank per node in the CCP job allocation. (i.e. number of ranks equals number of nodes, one rank per node.)
-netaddr XX.XX.XX.XX	Specifies the TCP network to use.
-TCP or -IBAL	Specifies the network protocol to use.

Verify that **rank.exe** is on a shared directory.

Included in the help directory is an example template (.xml file). To use this template, change the processor count on the **Submit Jobs** window, **Processors** tab, and edit the **Tasks** command to include flags and the rank executable. The job will run with ranks being equal to the number of processors, or the number of nodes if the `-nodex` flag is used.

Runtime environment variables for Windows CCP

Below are some useful CCP environment variables for naming the job name or stdout/err fileshare:

- `CCP_CLUSTER_NAME` - Cluster name
- `CCP_JOBID` - Job ID
- `CCP_JOBNAME` - Job name
- `CCP_TASKCONTEXT` - Task ‘content’ (jobid.taskid)
- `CCP_TASKID` - Task ID

The method for setting environment variables for a Windows HP-MPI job depends on how you submit the job.

From the GUI, use the **Task Properties** window, **Environment** tab to set the desired environment variable. Environment variables should be set on the **mpirun** task.

Environment variables can also be set using the flag `/env`. For example:

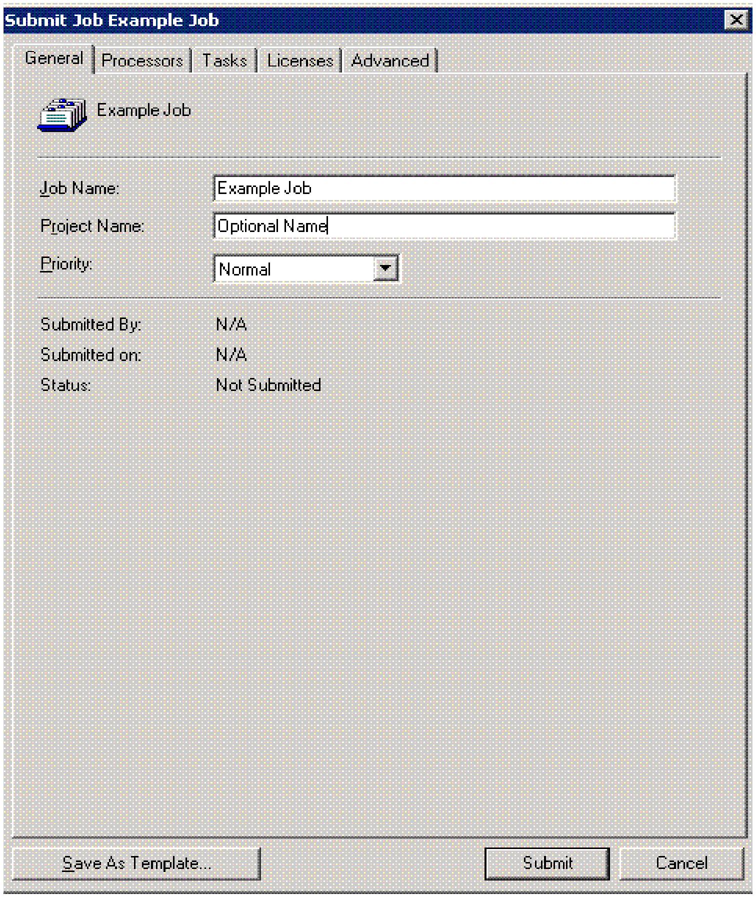
```
> job add JOBID /numprocessors:1/env: ^
"MPI_ROOT=\\shared\alternate\location" ...
```

Submitting jobs from the CCS GUI

To execute an HP-MPI job from the CCS GUI:

1. Bring up the **`Compute Cluster Job Manager`**. If a cluster name is requested, use the name of the head node. If running on the **`Compute Cluster Job Manager`** from the head node, select **`localhost`**.
2. Select **`File`**->**`Submit Job`**. This will bring up the **`Submit Job`** window.
3. On the **`General`** tab, enter the job name (and project name if desired).

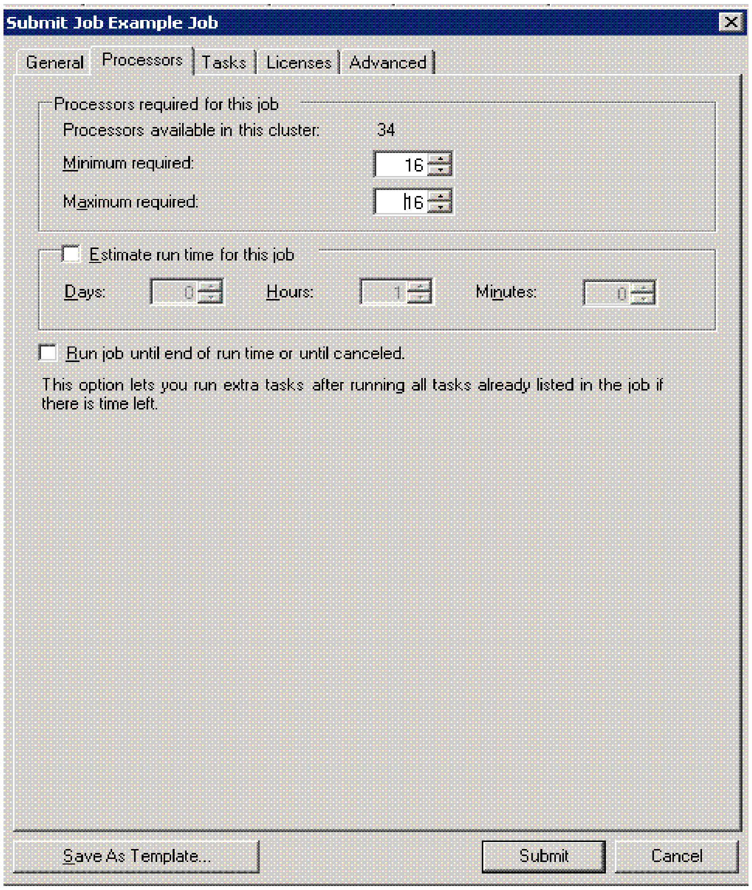
NOTE Examples were generated using CCP V1.0.



Job Name: Example Job
Project Name: Optional Name
Priority: Normal

Submitted By: N/A
Submitted on: N/A
Status: Not Submitted

4. On the **`Processors`** tab, select the total number of processors to allocate to the job (usually the number of ranks).


Submit Job Example Job

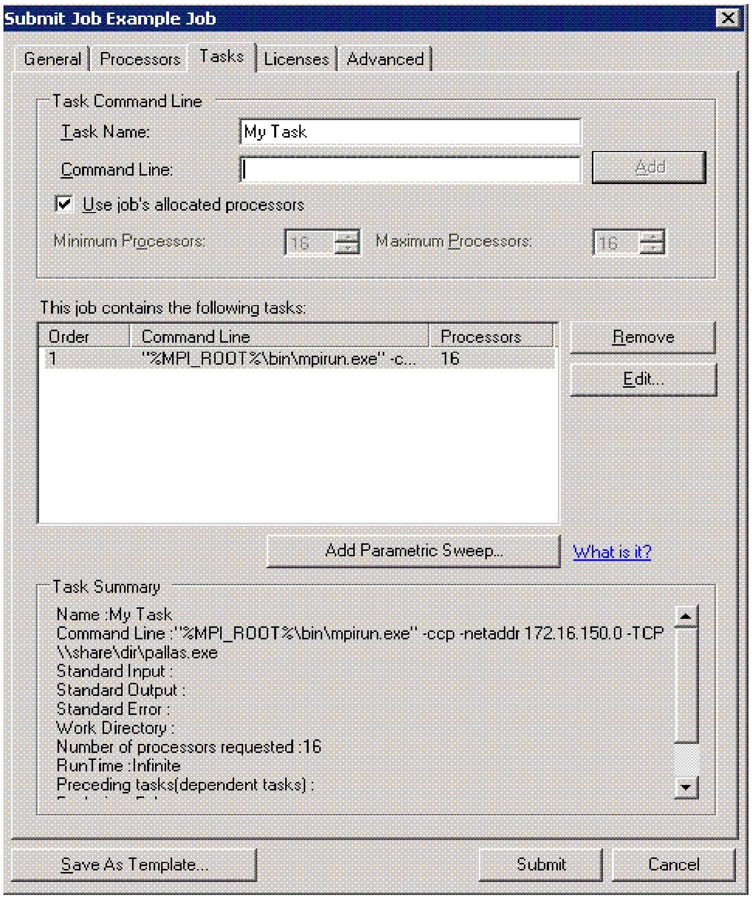
Processors required for this job
Processors available in this cluster: 34
Minimum required: 16
Maximum required: 16

☐ Estimate run time for this job
Days: 0 Hours: 1 Minutes: 0

☐ Run job until end of run time or until canceled.

This option lets you run extra tasks after running all tasks already listed in the job if there is time left.

5. Select the **Tasks** tab and enter the '**mpirun**' command as the task. Then highlight the task and select edit.



Submit Job Example Job

General | Processors | Tasks | Licenses | Advanced

Task Command Line

Task Name: My Task

Command Line:

Add

☑ Use job's allocated processors

Minimum Processors: 16 Maximum Processors: 16

This job contains the following tasks:

Order	Command Line	Processors
1	"%MPI_ROOT%\bin\mpirun.exe" -c...	16

Remove

Edit...

Add Parametric Sweep... What is it?

Task Summary

```
Name :My Task
Command Line :"%MPI_ROOT%\bin\mpirun.exe" -ccp -netaddr 172.16.150.0 -TCP
\\share\dir\pallas.exe
Standard Input :
Standard Output :
Standard Error :
Work Directory :
Number of processors requested :16
RunTime :Infinite
Preceding tasks(dependent tasks) :
```

Save As Template... Submit Cancel

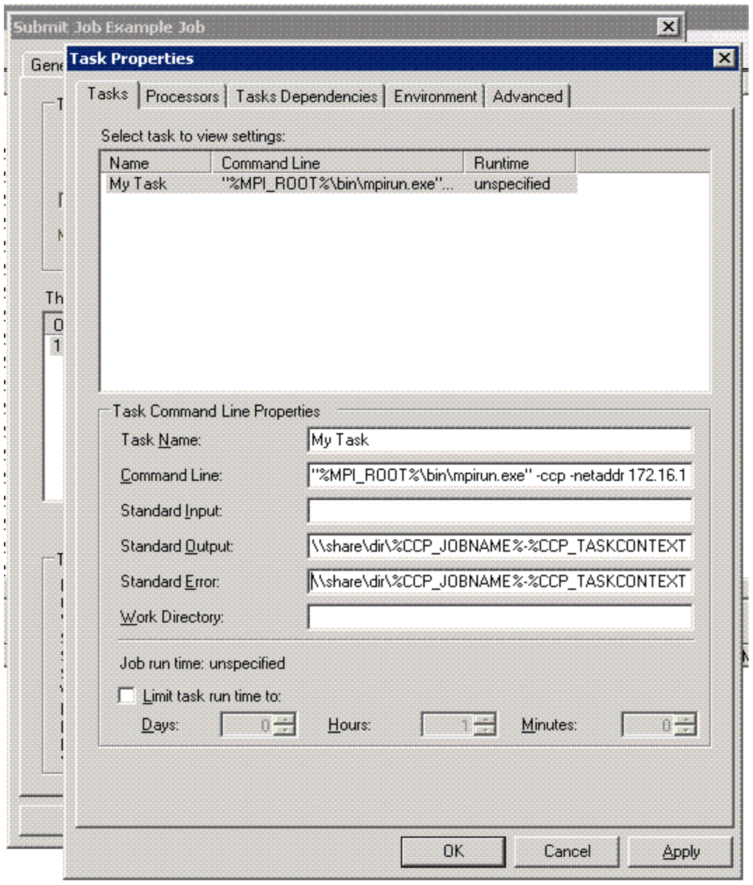
In the above example, the following line has been added into the "Command Line:" by selecting the text box and clicking **Add**.

```
"%MPI_ROOT%\bin\mpirun.exe" -ccp -netaddr 172.16.150.0 ^
-TCP \\share\dir\pallas.exe
```

NOTE

Unselecting "Use job’s allocated processors" and setting the processors count to 1 now will eliminate Step 7.

6. Specify stdout, stderr, and stdin (if necessary) on the **`Tasks`** tab.



Select task to view settings:

Name	Command Line	Runtime
My Task	"%MPI_ROOT%\bin\mpirun.exe"...	unspecified

Task Command Line Properties

Task Name:	My Task
Command Line:	"%MPI_ROOT%\bin\mpirun.exe" -ccp -netaddr 172.16.1
Standard Input:	
Standard Output:	\\share\dir\%CCP_JOBNAME%-%CCP_TASKCONTEXT
Standard Error:	\\share\dir\%CCP_JOBNAME%-%CCP_TASKCONTEXT
Work Directory:	

Job run time: unspecified

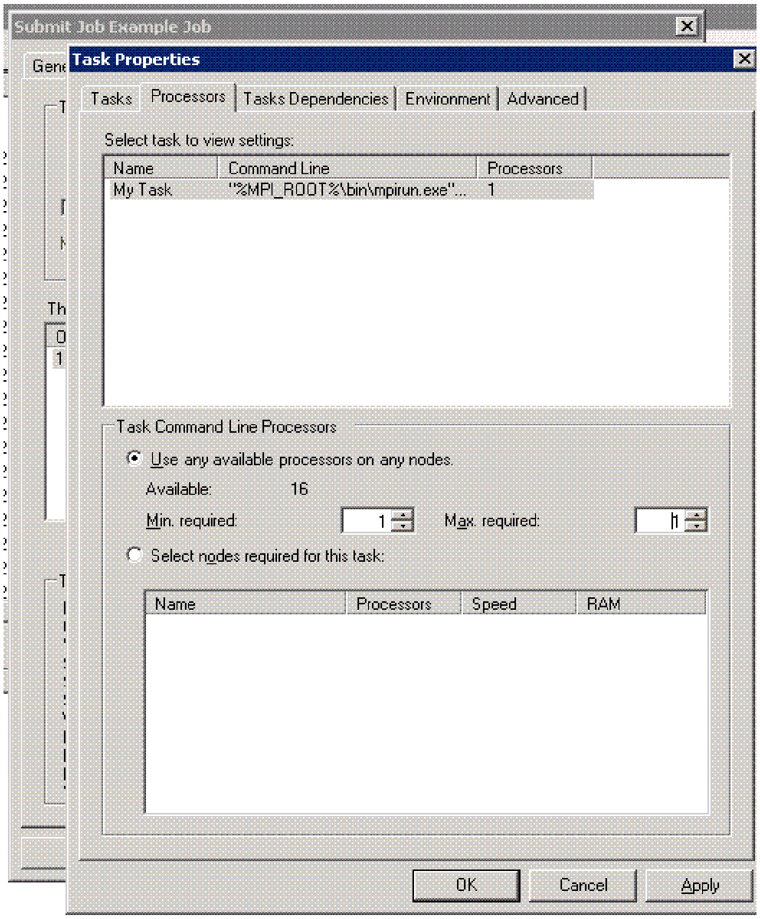
☐ Limit task run time to:

Days: 0 Hours: 1 Minutes: 0

In the above example, the stderr and stdout files are specified using CCP environment variables defined by the job. This is an easy way to create output files unique for each task.

`\\share\dir\%CCP_JOBNAME%-%CCP_TASKCONTEXT%.out`

7. On the **`Task Properties`** window, select the **`Processors`** tab and set to one processor for the **`mpirun`** task.



Select task to view settings:

Name	Command Line	Processors
My Task	"%MPI_ROOT%\bin\mpirun.exe"...	1

Task Command Line Processors

(●) Use any available processors on any nodes.

Available: 16

Min. required: 1 Max. required: 1

( ) Select nodes required for this task:

Name	Processors	Speed	RAM

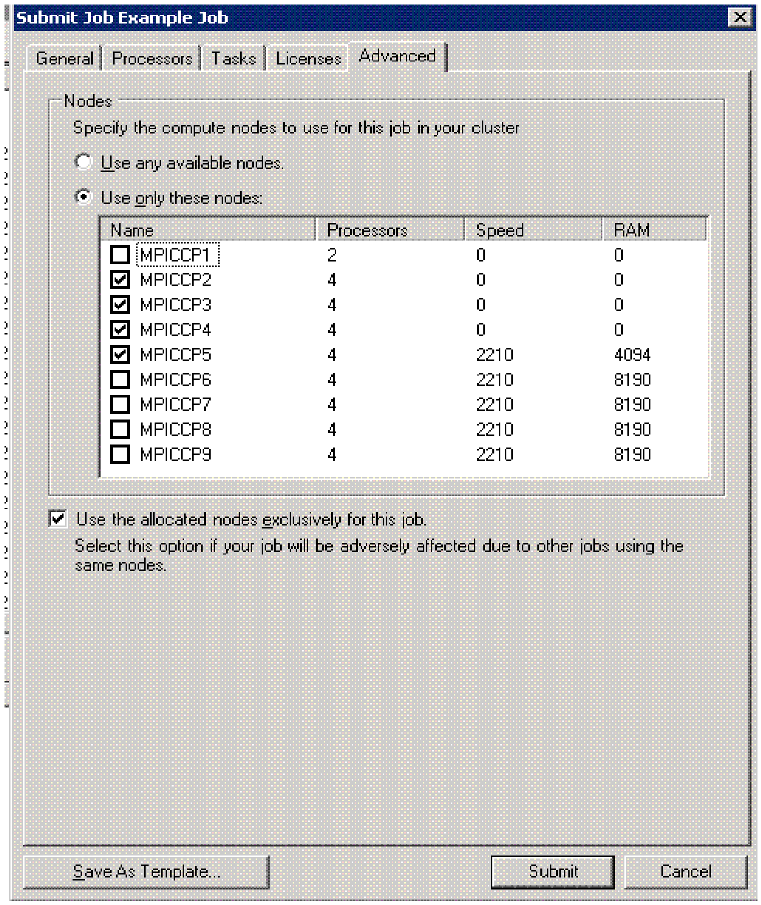
NOTE

In Step 5, you can unselect the "Use job’s allocated processors" box and set the processors count to 1. This eliminates setting the processor count in the task window as shown here in Step 7.

8. To set environment variables for the MPI job, use the **`Environment`** tab in the **`Task Properties`** window.

9. Select **`OK`** on the **`Task Properties`** window.

10. If you want to restrict the run to a set of machines, on the **Submit Job** window select the **Advanced** tab and set the desired machines.



Nodes

Specify the compute nodes to use for this job in your cluster

Use any available nodes. [✓ Use only these nodes:]

Name	Processors	Speed	RAM
☐ MPICCP1	2	0	0
✓ MPICCP2	4	0	0
✓ MPICCP3	4	0	0
✓ MPICCP4	4	0	0
✓ MPICCP5	4	2210	4094
☐ MPICCP6	4	2210	8190
☐ MPICCP7	4	2210	8190
☐ MPICCP8	4	2210	8190
☐ MPICCP9	4	2210	8190

✓ Use the allocated nodes exclusively for this job.

Select this option if your job will be adversely affected due to other jobs using the same nodes.

NOTE This step is not necessary. The job will select from any available processors if this step is not done.

11. To run the job, select the **Submit** on the **Submit Job** window.

For convenience, generic templates can be created and saved using **Save As Template** in the **Submit Job** window.

Running HP-MPI from command line on CCP systems

To perform the same steps via command line, execute 3 commands:

1. **job new [*options*]**
2. **job add *JOBID* mpirun [*mpirun options*]**
3. **job submit /id:*JOBID***

For example:

```
> job new /jobname:[example job]/numprocessors:12 ^
/projectname:HPMPI
Job Queued, ID: 242
```

This will create a job resource and return a jobid, but not submit it.

```
> job add 242 /stdout:"\\shared\dir\%CCP_JOBNAME%-^
%CCPTASKCONTEXT%.out"/stderr:"\\shared\dir\%CCP_JOBNAME%-^
%CCPTASKCONTEXT%.err""%MPI_ROOT%\bin\mpirun" -ccp -prot ^
-netaddr 172.16.150.20/24 -TCP \\shared\dir\rank.exe -arg1 ^
-arg2
```

```
> job submit /id:242
```

Automatic job submittal

HP-MPI has added functionality which will automatically create, schedule, and submit an **mpirun** command to the scheduler from the command line. Although this functionality is limited, it is the easiest way to quickly start **mpirun**.

To have HP-MPI submit the **mpirun** to the CCP scheduler, type your **mpirun** command from the command prompt, and include the `-ccp` flag. **mpirun** will detect it is not running in a CCP job and will automatically submit the **mpirun** command to the scheduler. `-np` is required to indicate the size of the job to schedule.

Flags that have special meaning when doing so are as follows:

`-np N`

Indicates the number of ranks to execute. This is a required flag for automatic job submittal.

`-hostlist <`*`quoted-host-list`*`>`

Indicates what nodes to use for the job.

`-e MPI_WORKDIR=<directory>`

Used to indicate the working directory. Default is the current directory.

When submitting a job, **mpirun** will set the job's 'working directory' to the current directory, or `MPI_WORKDIR` if provided, with the assumption the resulting directory name will be valid across the entire cluster. It will construct the stdout and stderr filenames from the root name of the rank, and append the jobid and taskid to the filenames, with the extensions .out and .err respectively.

The following is an example of submitting a job via the automatic submittal:

```
C:\> Documents and Settings\smith> ^
"%MPI_ROOT%\bin\mpirun.exe" -ccp -np 6 ^
\\share\directory\smith\HelloWorld.exe
mpirun: Submitting job to scheduler and exiting
Submitting job to ccp scheduler on this node
mpirun: Drive is not a network mapped - using local drive.
mpirun: HPMPI Job 1116 submitted to cluster mpiccp1
```

This will schedule and run 6 ranks of **HelloWorld.exe**. Standard output and standard error are placed in the current directory, 'HelloWorld-1116.1.out' and 'HelloWorld-1116.1.err' respectively.

The following example changes the directory to a share drive, and uses the current directory as the work directory for the submitted job:

```
C:\> Documents and Settings\smith>s:
S:\> cd smith
S:\smith> "%MPI_ROOT%\bin\mpirun.exe" -ccp -np 6 ^
-hostlist mpiccp1,mpiccp2 HelloWorld.exe
mpirun: Submitting job to scheduler and exiting
Submitting job to ccp scheduler on this node
mpirun: HPMPI Job 1117 submitted to cluster mpiccp1
```

Here the 'S:' drive is interpreted as the mapped network drive. The rank **HelloWorld.exe** is located in the current directory, and the stdout and stderr files are placed in the current working directory.

Running on CCP with an appfile

mpirun jobs submitted to CCP can run using appfile mode. The resources in the appfile must match the allocated job resources for this to run correctly.

The `-ccp` flag will generate an appfile that uses the allocated CCP job resources as the machines and rank counts in the appfile, then launches the **mpirun** job using this appfile.

If the user wishes to provide their own appfile, the tools described below have been provided.

The executable **mpi_nodes.exe** (located in `"%MPI_ROOT%\bin"`) has been provided which will return the job resources, in the same format as the `CCP_NODES` environment variable. Alternately, the user could write an appfile, then select the exact resources needed from the Submit jobs window, then the Advanced tab as needed. But this defeats the purpose of the job scheduler because the `CCP_NODES` environment variable only lists the resources allocated to the task, not the job.

```
<Node-Count> [<Node> <Processors-on-node>] ...
```

The script **submission_script.vbs** (found in `"%MPI_ROOT%\help"`) is an example of using **mpi_nodes.exe** to generate an appfile, and submit the **mpirun** command.

There are many other ways to accomplish the same thing. Other scripting languages can be used to convert the output of **mpi_nodes.exe** into the appropriate appfile.

Or a script using all the job resources and the `CCP_NODES` environment variable can construct the appropriate appfile, then submit a single processor **mpirun** task to `CCP_JOBID` and exit. Here the **mpirun** task will be queued up with no available processors until the script (using all job processors) finishes, then start executing.

NOTE If using this method, don't forget to include `/stdout` and `/stderr` options to the CCP **job add** command when adding the **mpirun** task.

Again, there are many different ways to generate your own appfile for use by **mpirun**. In all cases, the **mpirun** command that is launched will look like a 'normal' HP-MPI appfile launch:

```
mpirun -f generated-appfile [other HP-MPI options]
```

Refer to “More information about appfile runs” on page 68.

MPI options

The following sections provide definitions of `mpirun` options and runtime environment variables.

mpirun options

This section describes the specific options included in <*`mpirun_options`*> for all of the preceding examples. They are listed by the categories:

- Interconnect selection
- Launching specifications
- Debugging and informational
- RDMA control
- MPI-2 functionality
- Environment control
- Special HP-MPI mode
- Windows CCP

Interconnect selection options

Network selection

`-elan/-ELAN`	Explicit command line interconnect selection to use Quadrics Elan (available on Linux only). The lower case option is taken as advisory and indicates that the interconnect should be used if it is available. The upper case option is taken as mandatory and instructs MPI to abort if the interconnect is unavailable. The interaction between these options and the related `MPI_IC_ORDER` variable is that any command line interconnect selection here is implicitly prepended to `MPI_IC_ORDER`.

`-gm/-GM`	Explicit command line interconnect selection to use Myrinet GM (available on Linux only). The lower and upper case options are analogous to the Elan options (explained above).
`-ibal/-IBAL`	Explicit command line interconnect selection to use the Windows IB Access Layer (available on Windows only). The lower and upper case options are analogous to the Elan options (explained above).
`-ibv/-IBV`	Explicit command line interconnect selection to use OpenFabrics InfiniBand (available on Linux only). The lower and upper case options are analogous to the Elan options (explained above).
`-itapi/-ITAPI`	Explicit command line interconnect selection to use ITAPI (available on HP-UX only). The lower and upper case options are analogous to the Elan options (explained above).
`-mx/-MX`	Explicit command line interconnect selection to use Myrinet MX (available on Linux only). The lower and upper case options are analogous to the Elan options (explained above).
`-psm/-PSM`	Explicit command line interconnect selection to use QLogic InfiniBand (available on Linux only). The lower and upper case options are analogous to the Elan options (explained above).
`-TCP`	Specifies that TCP/IP should be used instead of another high-speed interconnect. If you have multiple TCP/IP interconnects, use `-netaddr` to specify which one to use. Use `-prot` to see which one was selected. Example: `% $MPI_ROOT/bin/mpirun -TCP -srun -N8 ./a.out`
`-udapl/-UDAPL`	Explicit command line interconnect selection to use uDAPL (available on Linux only). The lower and upper case options are analogous to the Elan options (explained above). Dynamic linking is required with uDAPL. Do not link `-static`.

`-vapi/-VAPI`	Explicit command line interconnect selection to use Mellanox Verbs API (available on Linux only). The lower and upper case options are analogous to the Elan options (explained above). Dynamic linking is required with VAPI. Do not link `-static`.
`-commd`	Routes all off-host communication through daemons rather than between processes.

Local host communication method

`-intra=mix`	This same functionality is available through the environment variable `MPI_INTRA` which can be set to `shm`, `nic`, or `mix`. Use shared memory for small messages. The default is 256k bytes, or what is set by `MPI_RDMA_INTRALEN`. For larger messages, the interconnect is used for better bandwidth. This option does not work with TCP, Elan, MX, or PSM.
`-intra=nic`	Use the interconnect for all intra-host data transfers. (Not recommended for high performance solutions.)
`-intra=shm`	Use shared memory for all intra-host data transfers. This is the default.

TCP interface selection

`-netaddr`	This option is similar to `-subnet`, but allows finer control of the selection process for TCP/IP connections. MPI has two main sets of connections: those between ranks and/or daemons where all the real message traffic occurs, and connections between `mpirun` and the daemons where little traffic occurs (but are still necessary). The `-netaddr` option can be used to specify a single IP/mask to use for both of these purposes, or specify them individually. The latter might be needed if `mpirun` happens to be run on a remote machine that doesn't have access to the same ethernet network as the rest of the cluster. To specify both, the syntax would be **`-netaddr`** ***`IP-specification`*****`[`*****`/mask`*****`]`**. To specify

them individually it would be **-netaddr mpirun:*spec*,*rank*:*spec***. The string launch: can be used in place of mpirun:.

The IP-specification can be a numeric IP address like 172.20.0.1 or it can be a hostname. If a hostname is used, the value will be the first IP address returned by **gethostbyname()**. The optional mask can be specified as a dotted quad, or can be given as a number representing how many bits are to be matched. So, for example, a mask of "11" would be equivalent to a mask of "255.224.0.0".

If an IP and mask are given, then it is expected that one and only one IP will match at each lookup. An error or warning is printed as appropriate if there are no matches, or too many. If no mask is specified, then the IP matching will simply be done by the longest matching prefix.

This functionality can also be accessed using the environment variable MPI_NETADDR.

-subnet
: Allows the user to select which default interconnect should be used for communication for TCP/IP. The interconnect is chosen by using the subnet associated with the hostname or IP address specified with -subnet.

```
% $MPI_ROOT/bin/mpirun -subnet \
<hostname-or-IP-address>
```

This option will be deprecated in favor of -netaddr in a future release.

Launching specifications options

Job launcher/scheduler

Options for LSF users

These options launch ranks as they are in appfile mode on the hosts specified in the environment variable.

`-lsb_hosts` Launches the same executable across multiple hosts. Uses the list of hosts in the environment variable `$LSB_HOSTS`. Can be used with `-np` option.

`-lsb_mcpu_hosts` Launches the same executable across multiple hosts. Uses the list of hosts in the environment variable `$LSB_MCPU_HOSTS`. Can be used with `-np` option.

Options for `prun` users

`-prun` Enables start-up with Elan usage. Only supported when linking with shared libraries. Some features like `mpirun -stdio` processing are unavailable. The `-np` option is not allowed with `-prun`. Any arguments on the `mpirun` command line that follow `-prun` are passed down to the `prun` command.

Options for SLURM users

`-srun` Enables start-up on XC clusters. Some features like `mpirun -stdio` processing are unavailable. The `-np` option is not allowed with `-srun`. Any arguments on the `mpirun` command line that follow `-srun` are passed to the `srun` command. Start-up directly from the `srun` command is not supported.

Remote shell launching

`-f` *`appfile`* Specifies the *`appfile`* that `mpirun` parses to get program and process count information for the run. Refer to “Creating an appfile” on page 75 for details about setting up your appfile.

`-hostfile <`*`filename`*`>`

Launches the same executable across multiple hosts. Filename is a text file with hostnames separated by spaces or new lines. Can be used with the `-np` option.

`-hostlist <`*`list`*`>`

Launches the same executable across multiple hosts. Can be used with the `-np` option. This hostlist may be delimited with spaces or commas. Hosts can be followed with an optional rank count, which is delimited from the hostname with either a space or colon. If spaces are used as delimiters anywhere in the hostlist, it may be necessary to place the entire hostlist inside quotes to prevent the command shell from interpreting it as multiple options.

`-h` *`host`* Specifies a host on which to start the processes (default is *`local_host`*). Only applicable when running in single host mode (`mpirun -np ...`). Refer to the `-hostlist` option which provides more flexibility.

`-l` *`user`* Specifies the username on the target host (default is local username).

`-l` is not available on HP-MPI for Windows.

`-np #` Specifies the number of processes to run. Generally used in single host mode, but also valid with `-hostfile`, `-hostlist`, `-lsb_hosts`, and `-lsb_mcpu_hosts`.

`-stdio=[`*`options`*`]` Specifies standard IO options. Refer to “External input and output” on page 193 for more information on standard IO, as well as a complete list of stdio options. This applies to appfiles only.

Process placement

`-cpu_bind` Binds a rank to an ldom to prevent a process from moving to a different ldom after startup. Refer to “CPU binding” on page 55 for details on how to use this option.

Application bitness specification

`-mpi32` Option for running on Opteron and Intel®64. Should be used to indicate the bitness of the application to be invoked so that the availability of interconnect libraries can be properly determined by the HP-MPI utilities `mpirun` and `mpid`. The default is `-mpi64`.

`-mpi64` Option for running on Opteron and Intel®64. Should be used to indicate the bitness of the application to be invoked so that the availability of interconnect libraries can be properly determined by the HP-MPI utilities `mpirun` and `mpid`. The default is `-mpi64`.

Debugging and informational options

`-help`	Prints usage information for `mpirun`.
`-version`	Prints the major and minor version numbers.
`-prot`	Prints the communication protocol between each host (e.g. TCP/IP or shared memory). The exact format and content presented by this option is subject to change as new interconnects and communication protocols are added to HP-MPI.
`-ck`	Behaves like the `-p` option, but supports two additional checks of your MPI application; it checks if the specified host machines and programs are available, and also checks for access or permission problems. This option is only supported when using appfile mode.
`-d`	Debug mode. Prints additional information about application launch.
`-j`	Prints the HP-MPI job ID.
`-p`	Turns on pretend mode. That is, the system goes through the motions of starting an HP-MPI application but does not create processes. This is useful for debugging and checking whether the appfile is set up correctly. This option is for appfiles only.
`-v`	Turns on verbose mode.
`-i` *spec*	Enables runtime instrumentation profiling for all processes. *spec* specifies options used when profiling. The options are the same as those for the environment variable `MPI_INSTR`. For example, the following is a valid command line: `% $MPI_ROOT/bin/mpirun -i mytrace:l:nc \ -f appfile` Refer to “MPI_INSTR” on page 131 for an explanation of `-i` options.
`-T`	Prints user and system times for each MPI rank.

`-tv`	Specifies that the application runs with the TotalView® debugger for LSF launched applications. TV is only supported on XC systems.

RDMA control options

`-dd`	Use deferred deregistration when registering and deregistering memory for RDMA message transfers. The default is to use deferred deregistration. Note that using this option also produces a statistical summary of the deferred deregistration activity when `MPI_Finalize` is called. The option is ignored if the underlying interconnect does not use an RDMA transfer mechanism, or if the deferred deregistration is managed directly by the interconnect library. Occasionally deferred deregistration is incompatible with a particular application or negatively impacts performance. Use `-ndd` to disable this feature if necessary. Deferred deregistration of memory on RDMA networks is not supported on HP-MPI for Windows.
`-ndd`	Disable the use of deferred deregistration. Refer to the `-dd` option for more information.
`-rdma`	Specifies the use of envelope pairs for short message transfer. The pre-pinned memory will increase continuously with the job size.
`-srq`	Specifies use of the shared receiving queue protocol when OpenFabrics, Myrinet GM, ITAPI, Mellanox VAPI or uDAPL V1.2 interfaces are used. This protocol uses less pre-pinned memory for short message transfers. For more information, refer to “Scalability” on page 146.

MPI-2 functionality options

`-1sided`	Enables one-sided communication. Extends the communication mechanism of HP-MPI by allowing one process to specify all communication parameters, both for the sending side and for the receiving side. The best performance is achieved if an RDMA enabled interconnect, like InfiniBand, is used. With this interconnect, the memory for the one-sided windows can come from `MPI_Alloc_mem` or from malloc. If TCP/IP is used, the performance will be lower, and in that case the memory for the one-sided windows must come from `MPI_Alloc_mem`.
`-spawn`	Enables dynamic processes. See “Dynamic Processes” on page 152 for more information.

Environment control options

`-e` *`var`*`[=`*`val`*`]`	Sets the environment variable *`var`* for the program and gives it the value *`val`* if provided. Environment variable substitutions (for example, $FOO) are supported in the *`val`* argument. In order to append additional settings to an existing variable, %VAR can be used as in the example in “Setting remote environment variables” on page 76.
`-sp` *`paths`*	Sets the target shell PATH environment variable to *`paths`*. Search paths are separated by a colon.

Special HP-MPI mode option

`-ha`	Eliminates a teardown when ranks exit abnormally. Further communications involved with ranks that are unreachable return error class `MPI_ERR_EXITED`, but do not force the application to teardown, as long as the `MPI_Errhandler` is set to `MPI_ERRORS_RETURN`. Some restrictions apply: • Communication is done via TCP/IP (Does not use shared memory for intranode communication.) • Cannot be used with the diagnostic library. • Cannot be used with `-i` option

Windows CCP

The following are specific **mpirun** command line options for Windows CCP users.

`-ccp` Indicates that the job is being submitted through the Windows CCP job scheduler/launcher. This is the recommended method for launching jobs. Required when the user doesn't provide an appfile.

`-ccperr` <*filename*>

Assigns the job's standard error file to the given filename when starting a job through the Windows CCP automatic job scheduler/launcher feature of HP-MPI. This flag has no effect if used for an existing CCP job.

`-ccpin` <*filename*>

Assigns the job's standard input file to the given filename when starting a job through the Windows CCP automatic job scheduler/launcher feature of HP-MPI. This flag has no effect if used for an existing CCP job.

`-ccpout` <*filename*>

Assigns the job's standard output file to the given filename when starting a job through the Windows CCP automatic job scheduler/launcher feature of HP-MPI. This flag has no effect if used for an existing CCP job.

`-ccpwait` Causes the **mpirun** command to wait for the CCP job to finish before returning to the command prompt when starting a job through automatic job submittal feature of HP-MPI. By default, **mpirun** automatic jobs will not wait. This flag has no effect if used for an existing CCP job.

`-headnode` <*headnode*>

This option is used on Windows CCP to indicate the headnode to submit the **mpirun** job. If omitted, localhost is used. This option can only be used as a command line option when using the **mpirun** automatic submittal functionality.

`-hosts` This option used on Windows CCP allows you to specify a node list to HP-MPI. Ranks are scheduled according to the host list. The nodes in the list must be in the job allocation or a scheduler error will occur. The HP-MPI program **`%MPI_ROOT%\bin\mpi_nodes.exe`** returns a string in the proper -hosts format with scheduled job resources.

`-jobid <`*`job-id`*`>`

This flag used on Windows CCP will schedule an HP-MPI job as a task to an existing job. It will submit the command as a single CPU **`mpirun`** task to the existing job indicated by the parameter job-id. This option can only be used as a command line option when using the **`mpirun`** automatic submittal functionality.

`-nodex` Used on Windows CCP in addition to `-ccp` to indicate that only one rank is to be used per node, regardless of the number of CPU's allocated with each host.

Runtime environment variables

Environment variables are used to alter the way HP-MPI executes an application. The variable settings determine how an application behaves and how an application allocates internal resources at runtime.

Many applications run without setting any environment variables. However, applications that use a large number of nonblocking messaging requests, require debugging support, or need to control process placement may need a more customized configuration.

Launching methods influence how environment variables are propagated. To ensure propagating environment variables to remote hosts, specify each variable in an appfile using the `-e` option. See "Creating an appfile" on page 75 for more information.

Setting environment variables on the command line for HP-UX and Linux

Environment variables can be set globally on the `mpirun` command line. Command line options take precedence over environment variables. For example, on HP-UX and Linux:

```
% $MPI_ROOT/bin/mpirun -e MPI_FLAGS=y -f appfile
```

In the above example, if some MPI_FLAGS setting was specified in the appfile, then the global setting on the command line would override the setting in the appfile. To add to an environment variable rather than replacing it, use *%VAR* as in the following command:

```
% $MPI_ROOT/bin/mpirun -e MPI_FLAGS=%MPI_FLAGS,y -f appfile
```

In the above example, if the appfile specified MPI_FLAGS=z, then the resulting MPI_FLAGS seen by the application would be z, y.

```
% $MPI_ROOT/bin/mpirun -e \
LD_LIBRARY_PATH=%LD_LIBRARY_PATH:/path/to/third/party/lib \
-f appfile
```

In the above example, the user is appending to LD_LIBRARY_PATH.

Setting environment variables in an hpmpi.conf file

HP-MPI supports setting environment variables in an hpmpi.conf file. These variables are read by mpirun and exported globally, as if they had been included on the mpirun command line as "-e VAR=VAL" settings. The hpmpi.conf file search is performed in three places and each one is parsed, which allows the last one parsed to overwrite values set by the previous files. The three locations are:

- $MPI_ROOT/etc/hpmpi.conf
- /etc/hpmpi.conf
- $HOME/.hpmpi.conf

This feature can be used for any environment variable, and is most useful for interconnect specifications. A collection of variables is available which tells HP-MPI which interconnects to search for and which libraries and modules to look for with each interconnect. These environment variables are the primary use of hpmpi.conf.

Syntactically, single and double quotes in hpmpi.conf can be used to create values containing spaces.

If a value containing a quote is desired, two adjacent quotes are interpreted as a quote to be included in the value. When not contained within quotes, spaces are interpreted as element separators in a list, and are stored as tabs.

NOTE This explanation of the `hpmpi.conf` file is provided only for awareness that this functionality is available. Making changes to the `hpmpi.conf` file without contacting HP-MPI support is strongly discouraged.

List of runtime environment variables

The environment variables that affect the behavior of HP-MPI at runtime are described in the following sections categorized by the following functions:

- General
- CPU bind
- Miscellaneous
- Interconnect
- InfiniBand
- Memory usage
- Connection related
- RDMA
- prun/srun
- TCP
- Elan
- Rank ID

All environment variables are listed below in alphabetical order.

- `MPI_2BCOPY`
- `MPI_BIND_MAP`
- `MPI_COMMD`
- `MPI_CPU_AFFINITY`
- `MPI_CPU_SPIN`
- `MPI_DLIB_FLAGS`
- `MPI_ELANLOCK`

- `MPI_FLAGS`
- `MPI_FLUSH_FCACHE`
- `MP_GANG`
- `MPI_GLOBMEMSIZE`
- `MPI_IB_CARD_ORDER`
- `MPI_IB_PKEY`
- `MPI_IBV_QPPARAMS`
- `MPI_IC_ORDER`
- `MPI_IC_SUFFIXES`
- `MPI_INSTR`
- `MPI_LOCALIP`
- `MPI_MAX_REMSH`
- `MPI_MAX_WINDOW`
- `MPI_MT_FLAGS`
- `MPI_NETADDR`
- `MPI_NO_MALLOCLIB`
- `MPI_NOBACKTRACE`
- `MPI_PAGE_ALIGN_MEM`
- `MPI_PHYSICAL_MEMORY`
- `MPI_PIN_PERCENTAGE`
- `MPI_PRUNOPTIONS`
- `MPI_RANKMEMSIZE`
- `MPI_RDMA_INTRALEN`
- `MPI_RDMA_MSGSIZE`
- `MPI_RDMA_NENVELOPE`
- `MPI_RDMA_NFRAGMENT`
- `MPI_RDMA_NONESIDED`
- `MPI_RDMA_NSRQRECV`

- MPI_REMSH
- MPI_ROOT
- MPI_SHMEMCNTL
- MPI_SOCKBUFSIZE
- MPI_SPAWN_PRUNOPTIONS
- MPI_SPAWN_SRUNOPTIONS
- MPI_SRUNOPTIONS
- MPI_TCP_CORECVLIMIT
- MPI_USE_LIBELAN
- MPI_USE_LIBELAN_SUB
- MPI_USE_MALLOPT_AVOID_MMAP
- MPI_USEPRUN
- MPI_USEPRUN_IGNORE_ARGS
- MPI_USESRUN
- MPI_USESRUN_IGNORE_ARGS
- MPI_VAPI_QPPARAMS
- MPI_WORKDIR
- MPIRUN_OPTIONS
- TOTALVIEW

General environment variables

MPIRUN_OPTIONS MPIRUN_OPTIONS is a mechanism for specifying additional command line arguments to mpirun. If this environment variable is set, then any mpirun command will behave as if the arguments in MPIRUN_OPTIONS had been specified on the mpirun command line. For example:

```
% export MPIRUN_OPTIONS="-v -prot"
```

```
% $MPI_ROOT/bin/mpirun -np 2 /path/to/program.x
```

would be equivalent to running

```
% $MPI_ROOT/bin/mpirun -v -prot -np 2 /path/to/program.x
```

When settings are supplied on the command line, in the MPIRUN_OPTIONS variable, and in an hpmpi.conf file, the resulting command line is as if the hpmpi.conf settings had appeared first, followed by the MPIRUN_OPTIONS, followed by the actual command line. And since the settings are parsed left to right, this means the later settings have higher precedence than the earlier ones.

MPI_FLAGS MPI_FLAGS modifies the general behavior of HP-MPI. The MPI_FLAGS syntax is a comma separated list as follows:

```
[edde,][exdb,][egdb,][eadb,][ewdb,][l,][f,][i,]
[s[a|p][#],][y[#],][o,][+E2,][C,][D,][E,][T,][z]
```

where

edde	Starts the application under the dde debugger. The debugger must be in the command search path. See “Debugging HP-MPI applications” on page 181 for more information.
exdb	Starts the application under the xdb debugger. The debugger must be in the command search path. See “Debugging HP-MPI applications” on page 181 for more information.
egdb	Starts the application under the gdb debugger. The debugger must be in the command search path. See “Debugging HP-MPI applications” on page 181 for more information.
eadb	Starts the application under adb—the absolute debugger. The debugger must be in the command search path. See “Debugging HP-MPI applications” on page 181 for more information.
ewdb	Starts the application under the wdb debugger. The debugger must be in the command search path. See “Debugging HP-MPI applications” on page 181 for more information.
epathdb	Starts the application under the path debugger. The debugger must be in the command search path. See “Debugging HP-MPI applications” on page 181 for more information.

`l`	Reports memory leaks caused by not freeing memory allocated when an HP-MPI job is run. For example, when you create a new communicator or user-defined datatype after you call `MPI_Init`, you must free the memory allocated to these objects before you call `MPI_Finalize`. In C, this is analogous to making calls to malloc() and free() for each object created during program execution. Setting the `l` option may decrease application performance.
f	Forces MPI errors to be fatal. Using the f option sets the `MPI_ERRORS_ARE_FATAL` error handler, ignoring the programmer's choice of error handlers. This option can help you detect nondeterministic error problems in your code. If your code has a customized error handler that does not report that an MPI call failed, you will not know that a failure occurred. Thus your application could be catching an error with a user-written error handler (or with `MPI_ERRORS_RETURN`) which masks a problem.
i	Turns on language interoperability concerning the `MPI_BOTTOM` constant. `MPI_BOTTOM` Language Interoperability—Previous versions of HP-MPI were not compliant with Section 4.12.6.1 of the MPI-2 Standard which requires that sends/receives based at `MPI_BOTTOM` on a data type created with absolute addresses must access the same data regardless of the language in which the data type was created. If compliance with the standard is desired, set `MPI_FLAGS`=i to turn on language interoperability concerning the `MPI_BOTTOM` constant. Compliance with the standard can break source compatibility with some MPICH code.
`s[a|p][#]`	Selects signal and maximum time delay for guaranteed message progression. The `sa` option selects `SIGALRM`. The `sp` option selects `SIGPROF`. The # option is the number of seconds to wait before issuing a signal to trigger message progression. The default value for the MPI library is `sp0`, which never issues a progression

related signal. If the application uses both signals for its own purposes, you cannot enable the heart-beat signals.

This mechanism may be used to guarantee message progression in applications that use nonblocking messaging requests followed by prolonged periods of time in which HP-MPI routines are not called.

Generating a UNIX signal introduces a performance penalty every time the application processes are interrupted. As a result, while some applications will benefit from it, others may experience a decrease in performance. As part of tuning the performance of an application, you can control the behavior of the heart-beat signals by changing their time period or by turning them off. This is accomplished by setting the time period of the `s` option in the `MPI_FLAGS` environment variable (for example: s600). Time is in seconds.

You can use the `s[a][p]#` option with the thread-compliant library as well as the standard non thread-compliant library. Setting s[a][p]# for the thread-compliant library has the same effect as setting `MPI_MT_FLAGS=ct` when you use a value greater than 0 for #. The default value for the thread-compliant library is `sp0`. `MPI_MT_FLAGS=ct` takes priority over the default `MPI_FLAGS=sp0`.

Refer to “MPI_MT_FLAGS” on page 126 and “Thread-compliant library” on page 54 for additional information.

Set `MPI_FLAGS=sa1` to guarantee that `MPI_Cancel` works for canceling sends.

To use gprof on XC systems, set to environment variables:

`MPI_FLAGS=s0`

`GMON_OUT_PREFIX=/tmp/app/name`

These options are ignored on HP-MPI for Windows.

`y[#]` Enables spin-yield logic. # is the spin value and is an integer between zero and 10,000. The spin value specifies the number of milliseconds a process should block waiting for a message before yielding the CPU to another process.

How you apply spin-yield logic depends on how well synchronized your processes are. For example, if you have a process that wastes CPU time blocked, waiting for messages, you can use spin-yield to ensure that the process relinquishes the CPU to other processes. Do this in your appfile, by setting `y[#]` to `y0` for the process in question. This specifies zero milliseconds of spin (that is, immediate yield).

If you are running an application stand-alone on a dedicated system, the default setting which is `MPI_FLAGS`=y allows MPI to busy spin, thereby improving latency. To avoid unnecessary CPU consumption when using more ranks than cores, consider using a setting such as `MPI_FLAGS`=y40.

Specifying y without a spin value is equivalent to `MPI_FLAGS=y10000`, which is the default.

NOTE Except when using `srun` or `prun` to launch, if the ranks under a single mpid exceed the number of CPUs on the node and a value of `MPI_FLAGS=y` is not specified, the default is changed to `MPI_FLAGS=y0`.

If the time a process is blocked waiting for messages is short, you can possibly improve performance by setting a spin value (between 0 and 10,000) that ensures the process does not relinquish the CPU until after the message is received, thereby reducing latency.

The system treats a nonzero spin value as a recommendation only. It does not guarantee that the value you specify is used.

o The option writes an optimization report to stdout. `MPI_Cart_create` and `MPI_Graph_create` optimize the mapping of processes onto the virtual topology only if rank reordering is enabled (set reorder=1).

In the declaration statement below, see reorder=1

```
int numtasks, rank, source, dest, outbuf, i,
tag=1,
inbuf[4]={MPI_PROC_NULL,MPI_PROC_NULL,MPI_PROC_
NULL,MPI_PROC_NULL,}, nbrs[4], dims[2]={4,4},
periods[2]={0,0}, reorder=1, coords[2];
```

For example:

```
/opt/mpi/bin/mpirun -np 16  -e MPI_FLAGS=o
./a.out
Reordering ranks for the call
MPI_Cart_create(comm(size=16), ndims=2,
                 dims=[4 4], periods=[false
false], reorder=true)
Default mapping of processes would result
communication paths
         between hosts                    :
0
         between subcomplexes             :
0
         between hypernodes               :
0
         between CPUs within a hypernode/SMP:
24
Reordered mapping results communication paths
         between hosts                    :
0
         between subcomplexes             :
0
         between hypernodes               :
0
         between CPUs within a hypernode/SMP:
24
Reordering will not reduce overall
communication cost.
Void the optimization and adopted unreordered
mapping.
rank= 2 coords= 0 2  neighbors(u,d,l,r)= -1 6 1
3
rank= 0 coords= 0 0  neighbors(u,d,l,r)= -1 4 -1
```

```
1
rank= 1 coords= 0 1  neighbors(u,d,l,r)= -1 5 0
2
rank= 10 coords= 2 2  neighbors(u,d,l,r)= 6 14 9
11
rank= 2                  inbuf(u,d,l,r)= -1 6 1 3
rank= 6 coords= 1 2  neighbors(u,d,l,r)= 2 10 5
7
rank= 7 coords= 1 3  neighbors(u,d,l,r)= 3 11 6
-1
rank= 4 coords= 1 0  neighbors(u,d,l,r)= 0 8 -1
5
rank= 0                 inbuf(u,d,l,r)= -1 4 -1 1
rank= 5 coords= 1 1  neighbors(u,d,l,r)= 1 9 4 6
rank= 11 coords= 2 3  neighbors(u,d,l,r)= 7 15
10 -1
rank= 1                  inbuf(u,d,l,r)= -1 5 0 2
rank= 14 coords= 3 2  neighbors(u,d,l,r)= 10 -1
13 15
rank= 9 coords= 2 1  neighbors(u,d,l,r)= 5 13 8
10
rank= 13 coords= 3 1  neighbors(u,d,l,r)= 9 -1
12 14
rank= 15 coords= 3 3  neighbors(u,d,l,r)= 11 -1
14 -1
rank= 10                  inbuf(u,d,l,r)= 6 14 9
11
rank= 12 coords= 3 0  neighbors(u,d,l,r)= 8 -1
-1 13
rank= 8 coords= 2 0  neighbors(u,d,l,r)= 4 12 -1
9
rank= 3 coords= 0 3  neighbors(u,d,l,r)= -1 7 2
-1
rank= 6                  inbuf(u,d,l,r)= 2 10 5 7
rank= 7                 inbuf(u,d,l,r)= 3 11 6 -1
rank= 4                  inbuf(u,d,l,r)= 0 8 -1 5
rank= 5                   inbuf(u,d,l,r)= 1 9 4 6
rank= 11                  inbuf(u,d,l,r)= 7 15 10
-1
rank= 14                   inbuf(u,d,l,r)= 10 -1
13 15
rank= 9                 inbuf(u,d,l,r)= 5 13 8 10
rank= 13                  inbuf(u,d,l,r)= 9 -1 12
14
rank= 15                   inbuf(u,d,l,r)= 11 -1
14 -1
```

```
rank= 8                inbuf(u,d,l,r)= 4 12 -1 9
rank= 12                inbuf(u,d,l,r)= 8 -1 -1
13
rank= 3                 inbuf(u,d,l,r)= -1 7 2 -
```

`+E2`	Sets -1 as the value of .TRUE. and 0 as the value for .FALSE. when returning logical values from HP-MPI routines called within Fortran 77 applications.
`C`	Disables ccNUMA support. Allows you to treat the system as a symmetric multiprocessor. (SMP)
`D`	Dumps shared memory configuration information. Use this option to get shared memory values that are useful when you want to set the `MPI_SHMEMCNTL` flag.
`E[on|off]`	Function parameter error checking is turned off by default. It can be turned on by setting `MPI_FLAGS=Eon`.
`T`	Prints the user and system times for each MPI rank.
`z`	Enables zero-buffering mode. Set this flag to convert `MPI_Send` and `MPI_Rsend` calls in your code to `MPI_Ssend`, without rewriting your code.

MPI_MT_FLAGS `MPI_MT_FLAGS` controls runtime options when you use the thread-compliant version of HP-MPI. The `MPI_MT_FLAGS` syntax is a comma separated list as follows:

`[ct,][single,][fun,][serial,][mult]`

where

`ct`	Creates a hidden communication thread for each rank in the job. When you enable this option, be careful not to oversubscribe your system. For example, if you enable `ct` for a 16-process application running on a 16-way machine, the result will be a 32-way job.
`single`	Asserts that only one thread executes.
`fun`	Asserts that a process can be multithreaded, but only the main thread makes MPI calls (that is, all calls are funneled to the main thread).
`serial`	Asserts that a process can be multithreaded, and multiple threads can make MPI calls, but calls are serialized (that is, only one call is made at a time).

`mult`	Asserts that multiple threads can call MPI at any time with no restrictions.

Setting `MPI_MT_FLAGS=ct` has the same effect as setting `MPI_FLAGS=s[a][p]#`, when the value of # that is greater than 0. `MPI_MT_FLAGS=ct` takes priority over the default `MPI_FLAGS=sp0` setting. Refer to “MPI_FLAGS” on page 120.

The `single`, `fun`, `serial`, and `mult` options are mutually exclusive. For example, if you specify the `serial` and `mult` options in MPI_MT_FLAGS, only the last option specified is processed (in this case, the `mult` option). If no runtime option is specified, the default is `mult`.

For more information about using `MPI_MT_FLAGS` with the thread-compliant library, refer to “Thread-compliant library” on page 54.

`MPI_ROOT` `MPI_ROOT` indicates the location of the HP-MPI tree. If you move the HP-MPI installation directory from its default location in /opt/mpi for HP-UX and /opt/hpmpi for Linux, set the `MPI_ROOT` environment variable to point to the new location. See “Directory structure for HP-UX and Linux” on page 24 for more information.

`MPI_WORKDIR` `MPI_WORKDIR` changes the execution directory. This variable is ignored when `srun` or `prun` is used.

CPU Bind environment variables

`MPI_BIND_MAP` `MPI_BIND_MAP` allows specification of the integer CPU numbers, ldom numbers, or CPU masks. These are a list of integers separated by commas (,).

`MPI_CPU_AFFINITY` `MPI_CPU_AFFINITY` is an alternative method to using -cpu_bind on the command line for specifying binding strategy. The possible settings are LL, RANK, MAP_CPU, MASK_CPU, LDOM, CYCLIC, BLOCK, RR, FILL, PACKED, SLURM, and MAP_LDOM.

`MPI_CPU_SPIN` `MPI_CPU_SPIN` allows selection of spin value. The default is 2 seconds.

`MPI_FLUSH_FCACHE` `MPI_FLUSH_FCACHE` clears the file-cache (buffer-cache). Add "**`-e MPI_FLUSH_FCACHE[=x]`**" to the `mpirun` command line and the file-cache will be flushed before the code starts; where `=x` is an optional percent of memory at which to flush. If the memory in the file-cache is greater than x, the memory is flushed. The default value is 0 (in which case a flush is always performed). Only the lowest rank# on each host flushes the file-cache; limited to one flush per host/job.

Setting this environment variable saves time if, for example, the file-cache is currently using 8% of the memory and `=x` is set to 10. In this case, no flush is performed.

Example output:

```
MPI_FLUSH_FCACHE set to 0, fcache pct = 22, attempting to flush
fcache on host opteron2
```

```
MPI_FLUSH_FCACHE set to 10, fcache pct = 3, no fcache flush
required on host opteron2
```

Memory is allocated with `mmap`, then `munmap`'d afterwards.

MP_GANG `MP_GANG` enables gang scheduling on HP-UX systems only. Gang scheduling improves the latency for synchronization by ensuring that all runable processes in a gang are scheduled simultaneously. Processes waiting at a barrier, for example, do not have to wait for processes that are not currently scheduled. This proves most beneficial for applications with frequent synchronization operations. Applications with infrequent synchronization, however, may perform better if gang scheduling is disabled.

Process priorities for gangs are managed identically to timeshare policies. The timeshare priority scheduler determines when to schedule a gang for execution. While it is likely that scheduling a gang will preempt one or more higher priority timeshare processes, the gang-schedule policy is fair overall. In addition, gangs are scheduled for a single time slice, which is the same for all processes in the system.

MPI processes are allocated statically at the beginning of execution. As an MPI process creates new threads, they are all added to the same gang if `MP_GANG` is enabled.

The `MP_GANG` syntax is as follows:

```
[ON|OFF]
```

where

`ON`	Enables gang scheduling.
`OFF`	Disables gang scheduling.

For multihost configurations, you need to set `MP_GANG` for each appfile entry. Refer to the `-e` option in “Creating an appfile” on page 75.

You can also use the HP-UX utility mpsched to enable gang scheduling. Refer to the HP-UX gang_sched and mpsched man pages for more information.

NOTE The `MP_GANG` feature will be deprecated in a future release.

Miscellaneous environment variables

`MPI_2BCOPY` Point-to-point bcopy() is disabled by setting MPI_2BCOPY to 1. Valid on PA-RISC only.

`MPI_MAX_WINDOW` `MPI_MAX_WINDOW` is used for one-sided applications. It specifies the maximum number of windows a rank can have at the same time. It tells HP-MPI to allocate enough table entries. The default is 5.

```
% export MPI_MAX_WINDOW=10
```

The above example allows 10 windows to be established for one-sided communication.

Diagnostic/debug environment variables

`MPI_DLIB_FLAGS` `MPI_DLIB_FLAGS` controls runtime options when you use the diagnostics library. The `MPI_DLIB_FLAGS` syntax is a comma separated list as follows:

```
[ns,][h,][strict,][nmsg,][nwarn,][dump:prefix,]
[dumpf:prefix][xNUM]
```

where

ns	Disables message signature analysis.
h	Disables default behavior in the diagnostic library that ignores user specified error handlers. The default considers all errors to be fatal.

`strict`	Enables MPI object-space corruption detection. Setting this option for applications that make calls to routines in the MPI-2 standard may produce false error messages.
`nmsg`	Disables detection of multiple buffer writes during receive operations and detection of send buffer corruptions.
`nwarn`	Disables the warning messages that the diagnostic library generates by default when it identifies a receive that expected more bytes than were sent.
dump:*prefix*	Dumps (unformatted) all sent and received messages to *prefix*.msgs.*rank* where rank is the rank of a specific process.
dumpf:*prefix*	Dumps (formatted) all sent and received messages to *prefix*.msgs.*rank* where rank is the rank of a specific process.
x*NUM*	Defines a type-signature packing size. *NUM* is an unsigned integer that specifies the number of signature leaf elements. For programs with diverse derived datatypes the default value may be too small. If *NUM* is too small, the diagnostic library issues a warning during the MPI_Finalize operation.

Refer to “Using the diagnostics library” on page 185 for more information.

MPI_NOBACKTRACE On PA-RISC systems, a stack trace is printed when the following signals occur within an application:

- SIGILL
- SIGBUS
- SIGSEGV
- SIGSYS

In the event one of these signals is not caught by a user signal handler, HP-MPI will display a brief stack trace that can be used to locate the signal in the code.

```
Signal 10: bus error
PROCEDURE TRACEBACK:
```

```
(0)    0x0000489c    bar + 0xc    [././a.out]
(1)    0x000048c4    foo + 0x1c    [,/,/a.out]
(2)    0x000049d4    main + 0xa4    [././a.out]
(3)    0xc013750c    _start + 0xa8    [/usr/lib/libc.2]
(4)   0x0003b50    $START$ + 0x1a0  [././a.out]
```

This feature can be disabled for an individual signal handler by declaring a user-level signal handler for the signal. To disable for all signals, set the environment variable `MPI_NOBACKTRACE`:

```
% setenv MPI_NOBACKTRACE
```

See “Backtrace functionality” on page 187 for more information.

`MPI_INSTR` `MPI_INSTR` enables counter instrumentation for profiling HP-MPI applications. The `MPI_INSTR` syntax is a colon-separated list (no spaces between options) as follows:

`prefix``[:l][:nc][:off]`

where

`prefix`	Specifies the instrumentation output file prefix. The rank zero process writes the application’s measurement data to *`prefix`*.instr in ASCII. If the prefix does not represent an absolute pathname, the instrumentation output file is opened in the working directory of the rank zero process when `MPI_Init` is called.
`l`	Locks ranks to CPUs and uses the CPU’s cycle counter for less invasive timing. If used with gang scheduling, the :l is ignored.
`nc`	Specifies no clobber. If the instrumentation output file exists, `MPI_Init` aborts.
`off`	Specifies counter instrumentation is initially turned off and only begins after all processes collectively call `MPIHP_Trace_on`.

Refer to “Using counter instrumentation” on page 159 for more information.

Even though you can specify profiling options through the `MPI_INSTR` environment variable, the recommended approach is to use the `mpirun` command with the `-i` option instead. Using `mpirun` to specify profiling options guarantees that multihost applications do profiling in a consistent manner. Refer to "mpirun" on page 71 for more information.

Counter instrumentation and trace-file generation are mutually exclusive profiling techniques.

NOTE When you enable instrumentation for multihost runs, and invoke `mpirun` either on a host where at least one MPI process is running, or on a host remote from all your MPI processes, HP-MPI writes the instrumentation output file (*prefix*.instr) to the working directory on the host that is running rank 0.

TOTALVIEW When you use the TotalView debugger, HP-MPI uses your PATH variable to find TotalView. You can also set the absolute path and TotalView specific options in the TOTALVIEW environment variable. This environment variable is used by `mpirun`.

```
% setenv TOTALVIEW /opt/totalview/bin/totalview
```

Interconnect selection environment variables

MPI_IC_ORDER `MPI_IC_ORDER` is an environment variable whose default contents are "ibv:vapi:udapl:psm:mx:gm:elan:itapi:TCP" and instructs HP-MPI to search in a specific order for the presence of an interconnect. Lowercase selections imply use if detected, otherwise keep searching. An uppercase option demands that the interconnect option be used, and if it cannot be selected the application will terminate with an error. For example:

```
% export MPI_IC_ORDER="ibv:vapi:udapl:psm:mx:gm:elan: \
itapi:TCP"

% export MPIRUN_OPTIONS="-prot"

% $MPI_ROOT/bin/mpirun -srun -n4 ./a.out
```

The command line for the above will appear to `mpirun` as `$MPI_ROOT/bin/mpirun -prot -srun -n4 ./a.out` and the interconnect decision will look for the presence of Elan and use it if found. Otherwise, interconnects will be tried in the order specified by `MPI_IC_ORDER`.

The following is an example of using TCP over GigE, assuming GigE is installed and 192.168.1.1 corresponds to the ethernet interface with GigE. Note the implicit use of `-netaddr` 192.168.1.1 is required to effectively get TCP over the proper subnet.

```
% export MPI_IC_ORDER="ibv:vapi:udapl:psm:mx:gm:elan: \
itapi:TCP"
```

```
% export MPIRUN_SYSTEM_OPTIONS="-netaddr 192.168.1.1"
```

```
% $MPI_ROOT/bin/mpirun -prot -TCP -srun -n4 ./a.out
```

On an XC system, the cluster installation will define the MPI interconnect search order based on what is present on the system.

`MPI_IC_SUFFIXES` When HP-MPI is determining the availability of a given interconnect on Linux, it tries to open libraries and find loaded modules based on a collection of variables of the form

This is described in more detail in “Interconnect support” on page 82.

The use of interconnect environment variables `MPI_ICLIB_ELAN`, `MPI_ICLIB_GM`, `MPI_ICLIB_ITAPI`, `MPI_ICLIB_MX`, `MPI_ICLIB_UDAPL`, `MPI_ICLIB_VAPI`, and `MPI_ICLIB_VAPIDIR` has been deprecated. Refer to “Interconnect support” on page 82 for more information on interconnect environment variables.

`MPI_COMMD` `MPI_COMMD` routes all off-host communication through daemons rather than between processes. The `MPI_COMMD` syntax is as follows:

```
out_frags,in_frags
```

where

`out_frags`	Specifies the number of 16Kbyte fragments available in shared memory for outbound messages. Outbound messages are sent from processes on a given host to processes on other hosts using the communication daemon.

	The default value for *`out_frags`* is 64. Increasing the number of fragments for applications with a large number of processes improves system throughput.
`in_frags`	Specifies the number of 16Kbyte fragments available in shared memory for inbound messages. Inbound messages are sent from processes on one or more hosts to processes on a given host using the communication daemon.
	The default value for *`in_frags`* is 64. Increasing the number of fragments for applications with a large number of processes improves system throughput.

Only works with the `-commd` option. When `-commd` is used, `MPI_COMMD` specifies daemon communication fragments.

InfiniBand environment variables

`MPI_IB_CARD_ORDER` Defines mapping of ranks to IB cards.

`%` **`setenv MPI_IB_CARD_ORDER`** ***`<card#>`*** **`[:`*****`port#`*****`]`**

Where:

card#	ranges from 0 to N-1
port#	ranges from 0 to 1

Card:port can be a comma separated list which drives the assignment of ranks to cards and ports within the cards.

Note that HP-MPI numbers the ports on a card from 0 to N-1, whereas utilities such as `vstat` display ports numbered 1 to N.

Examples:

To use the 2nd IB card:

```
% mpirun -e MPI_IB_CARD_ORDER=1 ...
```

To use the 2nd port of the 2nd card:

```
% mpirun -e MPI_IB_CARD_ORDER=1:1 ...
```

To use the 1st IB card:

```
% mpirun -e MPI_IB_CARD_ORDER=0 ...
```

To assign ranks to multiple cards:

% **mpirun -e MPI_IB_CARD_ORDER=0,1,2**
will assign the local ranks per node in order to each card.

% **mpirun -hostlist "host0 4 host1 4"**
creates ranks 0-3 on host0 and ranks 4-7 on host1. Will assign rank 0 to card 0, rank 1 to card 1, rank 2 to card 2, rank 3 to card 0 all on host0. And will assign rank 4 to card 0, rank 5 to card 1, rank 6 to card 2, rank 7 to card 0 all on host1.

% **mpirun -hostlist -np 8 "host0 host1"**
creates ranks 0 through 7 alternatingly on host0, host1, host0, host1, etc. Will assign rank 0 to card 0, rank 2 to card 1, rank 4 to card 2, rank 6 to card 0 all on host0. And will assign rank 1 to card 0, rank 3 to card 1, rank 5 to card 2, rank 7 to card 0 all on host1.

MPI_IB_PKEY HP-MPI supports IB partitioning via Mellanox VAPI and OpenFabrics Verbs API.

By default, HP-MPI will search the unique full membership partition key from the port partition key table used. If no such pkey is found, an error is issued. If multiple pkeys are found, all such pkeys are printed and an error message is issued.

If the environment variable `MPI_IB_PKEY` has been set to a value, either in hex or decimal, the value is treated as the pkey, and the pkey table is searched for the same pkey. If the pkey is not found, an error message is issued.

When a rank selects a pkey to use, a check is made to make sure all ranks are using the same pkey. If ranks are not using the same pkey, and error message is issued.

MPI_IBV_QPPARAMS `MPI_IBV_QPPARAMS=a,b,c,d,e` Specifies QP settings for IBV where:

a	Time-out value for IBV retry if no response from target. Minimum is 1. Maximum is 31. Default is 18.
b	The retry count after time-out before error is issued. Minimum is 0. Maximum is 7. Default is 7.
c	The minimum Receiver Not Ready (RNR) NAK timer. After this time, an RNR NAK is sent back to the sender. Values: 1(0.01ms) - 31(491.52ms); 0(655.36ms). The default is 24(40.96ms).

`d`	RNR retry count before error is issued. Minimum is 0. Maximum is 7. Default is 7 (infinite).
`e`	The max inline data size. Default is 128 bytes.

`MPI_VAPI_QPPARAMS` `MPI_VAPI_QPPARAMS=a,b,c,d` specifies time-out setting for VAPI where:

`a`	Time out value for VAPI retry if no response from target. Minimum is 1. Maximum is 31. Default is 18.
`b`	The retry count after time-out before error is issued. Minimum is 0. Maximum is 7. Default is 7.
`c`	The minimum Receiver Not Ready (RNR) NAK timer. After this time, an RNR NAK is set back to the sender. Values: 1(0.01ms) - 31(491.52ms); 0(655.36ms). The default is 24(40.96ms).
`d`	RNR retry count before error is issued. Minimum is 0. Maximum is 7. Default is 7 (infinite).

Memory usage environment variables

`MPI_GLOBMEMSIZE` `MPI_GLOBMEMSIZE=e` Where e is the total bytes of shared memory of the job. If the job size is N, then each rank has e/N bytes of shared memory. 12.5% is used as generic. 87.5% is used as fragments. The only way to change this ratio is to use `MPI_SHMEMCNTL`.

`MPI_NO_MALLOCLIB` Set `MPI_NO_MALLOCLIB` to avoid using HP-MPI's ptmalloc implementation and instead use the standard libc implementation (or perhaps a malloc implementation contained in the application).

See "Improved deregistration via ptmalloc (Linux only)" on page 149 for more information.

`MPI_PAGE_ALIGN_MEM` `MPI_PAGE_ALIGN_MEM` causes the HP-MPI library to page align and page pad memory. This is for multi-threaded InfiniBand support.

```
% export MPI_PAGE_ALIGN_MEM=1
```

`MPI_PHYSICAL_MEMORY` `MPI_PHYSICAL_MEMORY` allows the user to specify the amount of physical memory in kilobytes available on the system. MPI normally attempts to determine the amount of physical memory for the purpose of determining how much memory to pin for RDMA message transfers on InfiniBand and Myrinet GM. The value determined by HP-MPI can be displayed using the `-dd` option. If HP-MPI specifies an incorrect value for physical memory, this environment variable can be used to specify the value explicitly:

```
% export MPI_PHYSICAL_MEMORY=1048576
```

The above example specifies that the system has 1GB of physical memory.

`MPI_PIN_PERCENTAGE` and `MPI_PHYSICAL_MEMORY` are ignored unless InfiniBand or Myrinet GM is in use.

MPI_RANKMEMSIZE `MPI_RANKMEMSIZE=d` Where d is the total bytes of shared memory of the rank. Specifies the shared memory for each rank. 12.5% is used as generic. 87.5% is used as fragments. The only way to change this ratio is to use `MPI_SHMEMCNTL`. `MPI_RANKMEMSIZE` differs from `MPI_GLOBMEMSIZE`, which is the total shared memory across all the ranks on the host. `MPI_RANKMEMSIZE` takes precedence over `MPI_GLOBMEMSIZE` if both are set. Both `MPI_RANKMEMSIZE` and `MPI_GLOBMEMSIZE` are mutually exclusive to `MPI_SMEMCNTL`. If `MPI_SHMEMCNTL` is set, then the user cannot set the other two, and vice versa.

MPI_PIN_PERCENTAGE `MPI_PIN_PERCENTAGE` communicates the maximum percentage of physical memory (see `MPI_PHYSICAL_MEMORY`) that can be pinned at any time. The default is 20%.

```
% export MPI_PIN_PERCENTAGE=30
```

The above example permits the HP-MPI library to pin (lock in memory) up to 30% of physical memory. The pinned memory is shared between ranks of the host that were started as part of the same `mpirun` invocation. Running multiple MPI applications on the same host can cumulatively cause more than one application's `MPI_PIN_PERCENTAGE` to be pinned. Increasing `MPI_PIN_PERCENTAGE` can improve communication performance for communication intensive applications in which nodes send and receive multiple large messages at a time, such as is common with collective operations. Increasing `MPI_PIN_PERCENTAGE` allows more large messages to be progressed in parallel using RDMA transfers, however pinning too much of physical memory may negatively impact computation performance. `MPI_PIN_PERCENTAGE` and `MPI_PHYSICAL_MEMORY` are ignored unless InfiniBand or Myrinet GM is in use.

`MPI_SHMEMCNTL` `MPI_SHMEMCNTL` controls the subdivision of each process's shared memory for the purposes of point-to-point and collective communications. It cannot be used in conjunction with `MPI_GLOBMEMSIZE`. The `MPI_SHMEMCNTL` syntax is a comma separated list as follows:

`nenv, frag, generic`

where

`nenv`	Specifies the number of envelopes per process pair. The default is 8.
`frag`	Denotes the size in bytes of the message-passing fragments region. The default is 87.5 percent of shared memory after mailbox and envelope allocation.
`generic`	Specifies the size in bytes of the generic-shared memory region. The default is 12.5 percent of shared memory after mailbox and envelope allocation. The generic region is typically used for collective communication.

`MPI_SHMEMCNTL=a,b,c` where:

`a`	The number of envelopes for shared memory communication. The default is 8.
`b`	The bytes of shared memory to be used as fragments for messages.
`c`	The bytes of shared memory for other generic use, such as `MPI_Alloc_mem()` call.

`MPI_USE_MALLOPT_AVOID_MMAP` Instructs the underlying malloc implementation to avoid mmaps and instead use sbrk() to get all the memory used. The default is `MPI_USE_MALLOPT_AVOID_MMAP`=0.

Connection related environment variables

`MPI_LOCALIP` `MPI_LOCALIP` specifies the host IP address that is assigned throughout a session. Ordinarily, `mpirun` determines the IP address of the host it is running on by calling `gethostbyaddr`. However, when a host uses a SLIP or PPP protocol, the host's IP address is dynamically assigned only when the network connection is established. In this case, `gethostbyaddr` may not return the correct IP address.

The MPI_LOCALIP syntax is as follows:

xxx.xxx.xxx.xxx

where *xxx.xxx.xxx.xxx* specifies the host IP address.

MPI_MAX_REMSH MPI_MAX_REMSH=N HP-MPI includes a startup scalability enhancement when using the -f option to mpirun. This enhancement allows a large number of HP-MPI daemons (mpid) to be created without requiring mpirun to maintain a large number of remote shell connections.

When running with a very large number of nodes, the number of remote shells normally required to start all of the daemons can exhaust the available file descriptors. To create the necessary daemons, mpirun uses the remote shell specified with MPI_REMSH to create up to 20 daemons only, by default. This number can be changed using the environment variable MPI_MAX_REMSH. When the number of daemons required is greater than MPI_MAX_REMSH, mpirun will create only MPI_MAX_REMSH number of remote daemons directly. The directly created daemons will then create the remaining daemons using an n-ary tree, where n is the value of MPI_MAX_REMSH. Although this process is generally transparent to the user, the new startup requires that each node in the cluster is able to use the specified MPI_REMSH command (e.g. rsh, ssh) to each node in the cluster without a password. The value of MPI_MAX_REMSH is used on a per-world basis. Therefore, applications which spawn a large number of worlds may need to use a small value for MPI_MAX_REMSH. MPI_MAX_REMSH is only relevant when using the -f option to mpirun. The default value is 20.

MPI_NETADDR Allows control of the selection process for TCP/IP connections. The same functionality can be accessed by using the -netaddr option to mpirun. See “mpirun options” on page 105 for more information.

MPI_REMSH By default, HP-MPI attempts to use ssh on Linux and remsh on HP-UX. On Linux, we recommend that ssh users set StrictHostKeyChecking=no in their ~/.ssh/config.

To use rsh on Linux instead, the following script needs to be run as root on each node in the cluster:

```
% /opt/hpmpi/etc/mpi.remsh.default
```

Or, to use `rsh` on Linux, use the alternative method of manually populating the files `/etc/profile.d/hpmpi.csh` and `/etc/profile.d/hpmpi.sh` with the following settings respectively:

```
setenv MPI_REMSH rsh
```

```
export MPI_REMSH=rsh
```

On HP-UX, `MPI_REMSH` specifies a command other than the default `remsh` to start remote processes. The `mpirun`, `mpijob`, and `mpiclean` utilities support `MPI_REMSH`. For example, you can set the environment variable to use a secure shell:

```
% setenv MPI_REMSH /bin/ssh
```

HP-MPI allows users to specify the remote execution tool to use when HP-MPI needs to start processes on remote hosts. The tool specified must have a call interface similar to that of the standard utilities: `rsh`, `remsh` and `ssh`.

An alternate remote execution tool, such as `ssh`, can be used on HP-UX by setting the environment variable `MPI_REMSH` to the name or full path of the tool to use:

```
% export MPI_REMSH=ssh
```

```
% $MPI_ROOT/bin/mpirun <options> -f <appfile>
```

HP-MPI also supports setting `MPI_REMSH` using the `-e` option to `mpirun`:

```
% $MPI_ROOT/bin/mpirun -e MPI_REMSH=ssh <options> -f \
<appfile>
```

This release also supports setting `MPI_REMSH` to a command which includes additional arguments:

```
% $MPI_ROOT/bin/mpirun -e MPI_REMSH="ssh -x" <options> \
-f <appfile>
```

When using `ssh`, first ensure that it is possible to use `ssh` from the host where `mpirun` is executed to the other nodes without `ssh` requiring any interaction from the user.

RDMA tunable environment variables

MPI_RDMA_INTRALEN `-e MPI_RDMA_INTRALEN=262144` Specifies the size (in bytes) of the transition from shared memory to interconnect when `-intra=mix` is used. For messages less than or equal to the specified size, shared memory will be used. For messages greater than that size, the interconnect will be used. TCP/IP, Elan, MX, and PSM do not have mixed mode.

MPI_RDMA_MSGSIZE `MPI_RDMA_MSGSIZE=a,b,c` Specifies message protocol length where:

a	Short message protocol threshold. If the message length is bigger than this value, middle or long message protocol is used. The default is 16384 bytes, but on HP-UX 32768 bytes is used.
b	Middle message protocol. If the message length is less than or equal to b, consecutive short messages are used to send the whole message. By default, b is set to 16384 bytes, the same as a, to effectively turn off middle message protocol. On IBAL, the default is 131072 bytes.
c	Long message fragment size. If the message is greater than b, the message is fragmented into pieces up to c in length (or actual length if less than c) and the corresponding piece of the user's buffer is pinned directly. The default is 4194304 bytes, but on Myrinet GM and IBAL the default is 1048576 bytes.

MPI_RDMA_NENVELOPE `MPI_RDMA_NENVELOPE=N` Specifies the number of short message envelope pairs for each connection if RDMA protocol is used, where N is the number of envelope pairs. The default is between 8 and 128 depending on the number of ranks.

MPI_RDMA_NFRAGMENT `MPI_RDMA_NFRAGMENT=N` Specifies the number of long message fragments that can be concurrently pinned down for each process, either sending or receiving. The max number of fragments that can be pinned down for a process is 2*N. The default value of N is 128.

MPI_RDMA_NONESIDED `MPI_RDMA_NONESIDED=N` Specifies the number of one-sided operations that can be posted concurrently for each rank, no matter the destination. The default is 8.

MPI_RDMA_NSRQRECV `MPI_RDMA_NSRQRECV=K` Specifies the number of receiving buffers used when the shared receiving queue is used, where K is the number of receiving buffers. If N is the number of offhost connection from a rank, then the default value can be calculated as:

The smaller of the values Nx8 and 2048.

In the above example, the number of receiving buffers are calculated as 8 times the number of offhost connections. If this number is greater than 2048, then 2048 is used as the maximum number.

prun/srun environment variables

`MPI_SPAWN_PRUNOPTIONS` Allows `prun` options to be implicitly added to the launch command when SPAWN functionality is used to create new ranks with `prun`.

`MPI_SPAWN_SRUNOPTIONS` Allows `srun` options to be implicitly added to the launch command when SPAWN functionality is used to create new ranks with `srun`.

`MPI_SRUNOPTIONS` Allows additional `srun` options to be specified such as `--label`.

```
% setenv MPI_SRUNOPTIONS <option>
```

`MPI_USEPRUN` HP-MPI provides the capability to automatically assume that `prun` is the default launching mechanism. This mode of operation automatically classifies arguments into '`prun`' and '`mpirun`' arguments and correctly places them on the command line.

The assumed `prun` mode also allows appfiles to be interpreted for command line arguments and translated into `prun` mode. The implied `prun` method of launching is useful for applications which embed or generate their `mpirun` invocations deeply within the application.

See Appendix C for more information.

`MPI_USEPRUN_IGNORE_ARGS` Provides an easy way to modify the arguments contained in an appfile by supplying a list of space-separated arguments that `mpirun` should ignore.

```
% setenv MPI_USEPRUN_IGNORE_ARGS <option>
```

`MPI_USESRUN` HP-MPI provides the capability to automatically assume that `srun` is the default launching mechanism. This mode of operation automatically classifies arguments into '`srun`' and '`mpirun`' arguments and correctly places them on the command line.

The assumed `srun` mode also allows appfiles to be interpreted for command line arguments and translated into `srun` mode. The implied `srun` method of launching is useful for applications which embed or generate their `mpirun` invocations deeply within the application. This allows existing ports of an application from an HP-MPI supported platform to XC.

See Appendix C for more information.

`MPI_USESRUN_IGNORE_ARGS` Provides an easy way to modify the arguments contained in an appfile by supplying a list of space-separated arguments that `mpirun` should ignore.

```
% setenv MPI_USESRUN_IGNORE_ARGS <option>
```

In the example below, the command line contains a reference to `-stdio=bnone` which is filtered out because it is set in the ignore list.

```
% setenv MPI_USESRUN_VERBOSE 1

% setenv MPI_USESRUN_IGNORE_ARGS -stdio=bnone

% setenv MPI_USESRUN 1

% setenv MPI_SRUNOPTION --label

% bsub -I -n4 -ext "SLURM[nodes=4]" \
$MPI_ROOT/bin/mpirun -stdio=bnone -f appfile -- pingpong
```

```
Job <369848> is submitted to default queue <normal>.
<<Waiting for dispatch ...>>
<<Starting on lsfhost.localdomain>>
/opt/hpmpi/bin/mpirun
unset
MPI_USESRUN;/opt/hpmpi/bin/mpirun
-srun  ./pallas.x -npmin 4 pingpong
```

`MPI_PRUNOPTIONS` Allows `prun` specific options to be added automatically to the `mpirun` command line. For example:

```
% export MPI_PRUNOPTIONS="-m cyclic -x host0"

% mpirun -prot -prun -n2 ./a.out
```

is equivalent to:

```
% mpirun -prot -prun -m cyclic -x host0 -n2 ./a.out
```

TCP environment variables

MPI_TCP_CORECVLIMIT The integer value indicates the number of simultaneous messages larger than 16KB that may be transmitted to a single rank at once via TCP/IP. Setting this variable to a larger value can allow HP-MPI to utilize more parallelism during its low-level message transfers, but can greatly reduce performance by causing switch congestion. Setting `MPI_TCP_CORECVLIMIT` to zero will not limit the number of simultaneous messages a rank may receive at once. The default value is 0.

MPI_SOCKBUFSIZE Specifies, in bytes, the amount of system buffer space to allocate for sockets when using the TCP/IP protocol for communication. Setting `MPI_SOCKBUFSIZE` results in calls to `setsockopt` (..., `SOL_SOCKET`, `SO_SNDBUF`, ...) and `setsockopt` (..., `SOL_SOCKET`, `SO_RCVBUF`, ...). If unspecified, the system default (which on many systems is 87380 bytes) is used.

Elan environment variables

MPI_USE_LIBELAN By default when Elan is in use, the HP-MPI library uses Elan's native collective operations for performing `MPI_Bcast` and `MPI_ Barrier` operations on `MPI_COMM_WORLD` sized communicators. This behavior can be changed by setting `MPI_USE_LIBELAN` to "false" or "0", in which case these operations will be implemented using point-to-point Elan messages.

To turn off:

```
% export MPI_USE_LIBELAN=0
```

MPI_USE_LIBELAN_SUB The use of Elan's native collective operations may be extended to include communicators which are smaller than `MPI_COMM_WORLD` by setting the `MPI_USE_LIBELAN_SUB` environment variable to a positive integer. By default, this functionality is disabled due to the fact that libelan memory resources are consumed and may eventually cause runtime failures when too many sub-communicators are created.

```
% export MPI_USE_LIBELAN_SUB=10
```

MPI_ELANLOCK By default, HP-MPI only provides exclusive window locks via Elan lock when using the Elan interconnect. In order to use HP-MPI shared window locks, the user must turn off Elan lock and use window locks via shared memory. In this way, both exclusive and shared locks are from shared memory. To turn off Elan locks, set `MPI_ELANLOCK` to zero.

```
% export MPI_ELANLOCK=0
```

Rank Identification Environment Variables

HP-MPI sets several environment variables to let the user access information about the MPI rank layout prior to calling `MPI_Init`. These variables differ from the others in this section in that the user doesn't set these to provide instructions to HP-MPI; HP-MPI sets them to give information to the user's application.

`HPMPI=1`	This variable is set so that an application can conveniently tell if it is running under HP-MPI.
`MPI_NRANKS`	This is set to the number of ranks in the MPI job.
`MPI_RANKID`	This is set to the rank number of the current process.
`MPI_LOCALNRANKS`	This is set to the number of ranks on the local host.
`MPI_LOCALRANKID`	This is set to the rank number of the current process relative to the local host (0.. `MPI_LOCALNRANKS`-1).

Note that these settings are not available when running under `srun` or `prun`. However, similar information can be gathered from the variables set by those systems; such as `SLURM_NPROCS` and `SLURM_PROCID`.

Scalability

Interconnect support of MPI-2 functionality

HP-MPI has been tested on InfiniBand clusters with as many as 2048 ranks using the VAPI protocol. Most HP-MPI features function in a scalable manner. However, a few are still subject to significant resource growth as the job size grows.

Table 3-4 Scalability

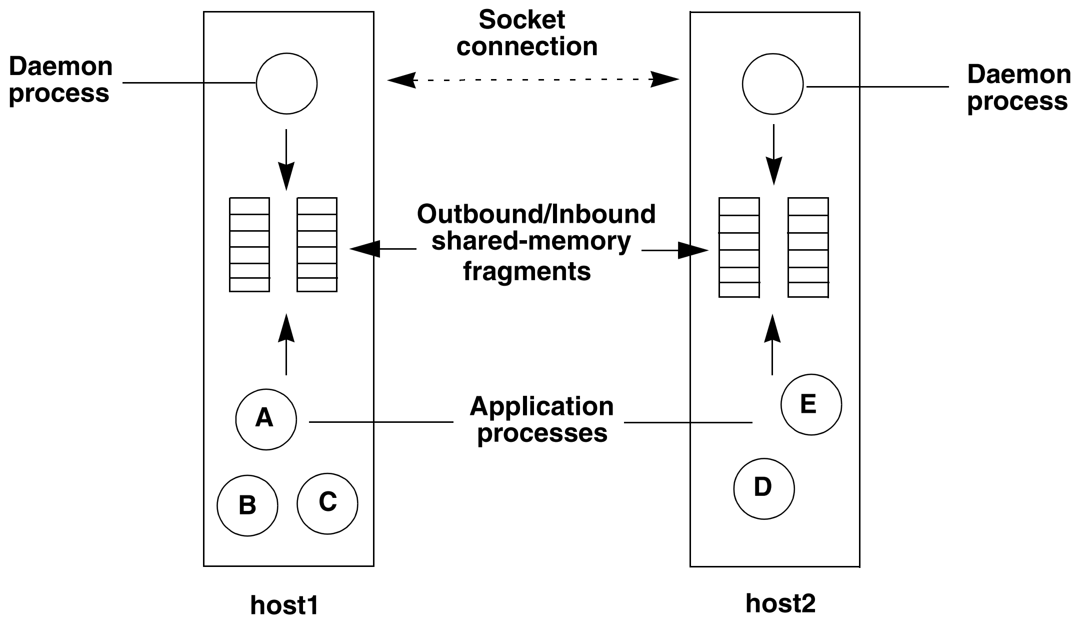
Feature	Affected Interconnect/ Protocol	Scalability Impact
spawn	All	Forces use of pairwise socket connections between all mpid's (typically one mpid per machine)
one-sided shared lock/unlock	All except VAPI and IBV	Only VAPI and IBV provide low-level calls to efficiently implement shared lock/unlock. All other interconnects require mpid's to satisfy this feature.
one-sided exclusive lock/unlock	All except VAPI, IBV, and Elan	VAPI, IBV, and Elan provide low-level calls which allow HP-MPI to efficiently implement exclusive lock/unlock. All other interconnects require mpid's to satisfy this feature.
one-sided other	TCP/IP	All interconnects other than TCP/IP allow HP-MPI to efficiently implement the remainder of the one-sided functionality. Only when using TCP/IP are mpid's required to satisfy this feature.

Resource usage of TCP/IP communication

HP-MPI has also been tested on large Linux TCP/IP clusters with as many as 2048 ranks. Because each HP-MPI rank creates a socket connection to each other remote rank, the number of socket descriptors required increases with the number of ranks. On many Linux systems, this requires increasing the operating system limit on per-process and system-wide file descriptors.

The number of sockets used by HP-MPI can be reduced on some systems at the cost of performance by using daemon communication. In this case, the processes on a host use shared memory to send messages to and receive messages from the daemon. The daemon, in turn, uses a socket connection to communicate with daemons on other hosts. Using this option, the maximum number of sockets opened by any HP-MPI process grows with the number of hosts used by the MPI job rather than the number of total ranks.

Figure 3-2 Daemon communication



To use daemon communication, specify the `-commd` option in the `mpirun` command. Once you have set the `-commd` option, you can use the `MPI_COMMD` environment variable to specify the number of shared-memory fragments used for inbound and outbound messages.

Refer to "mpirun" on page 71 and "MPI_COMMD" on page 133 for more information. Daemon communication can result in lower application performance. Therefore, it should only be used to scale an application to a large number of ranks when it is not possible to increase the operating system file descriptor limits to the required values.

Resource usage of RDMA communication modes

When using InfiniBand or GM, a certain amount of memory is pinned, which means it is locked to physical memory and cannot be paged out. The amount of pre-pinned memory HP-MPI uses can be adjusted using several tunables, such as `MPI_RDMA_MSGSIZE`, `MPI_RDMA_NENVELOPE`, `MPI_RDMA_NSRQRECV`, and `MPI_RDMA_NFRAGMENT`.

By default when the number of ranks is less than or equal to 512, each rank will pre-pin 256k per remote rank; thus making each rank pin up to 128Mb. If the number of ranks is above

512 but less than or equal to 1024, then each rank will only pre-pin 96k per remote rank; thus making each rank pin up to 96Mb. If the number of ranks is over 1024, then the 'shared receiving queue' option is used which reduces the amount of pre-pinned memory used for each rank to a fixed 64Mb regardless of how many ranks are used.

HP-MPI also has a safeguard variables `MPI_PHYSICAL_MEMORY` and `MPI_PIN_PERCENTAGE` which set an upper bound on the total amount of memory an HP-MPI job will pin. An error will be reported during startup if this total is not large enough to accommodate the pre-pinned memory.

Improved deregistration via ptmalloc (Linux only)

To achieve the best performance on RDMA enabled interconnects like InfiniBand and Myrinet, the MPI library must be aware when memory is returned to the system in malloc() and free() calls. To enable more robust handling of that information, HP-MPI contains a copy of the ptmalloc implementation and uses it by default.

For applications with particular needs, there are a number of available modifications to this default configuration. To avoid using HP-MPI's ptmalloc implementation and instead use the standard libc implementation (or perhaps a malloc implementation contained in the application), set the environment variable `MPI_NO_MALLOCLIB` at runtime.

If the above option is applied so that the ptmalloc contained in HP-MPI is not used, then there is a risk of MPI not being informed of when memory is returned to the system. This can be alleviated with the settings `MPI_USE_MALLOPT_SBRK_PROTECTION` and `MPI_USE_MALLOPT_AVOID_MMAP` at runtime, which essentially results in the libc malloc implementation not returning memory to the system.

There are cases where these two settings cannot keep libc from returning memory to the system, in particular when multiple threads call malloc/free at the same time. In these cases, the only remaining option is to disable HP-MPI's lazy deregistration by giving the `-ndd` flag to `mpirun`.

Note that in the default case where the ptmalloc contained within HP-MPI is used, the above cases are all avoided and lazy deregistration works correctly as is. So the above tunables are only recommended for applications with special requirements concerning their malloc/free usage.

Signal Propagation (HP-UX and Linux only)

HP-MPI supports the propagation of signals from `mpirun` to application ranks. The `mpirun` executable traps the following signals and propagates them to the ranks:

SIGINT
SIGTERM
SIGABRT
SIGALRM
SIGFPE
SIGHUP
SIGILL
SIGPIPE
SIGQUIT
SIGSEGV
SIGUSR1
SIGUSR2
SIGBUS
SIGPROF
SIGSYS
SIGTRAP
SIGURG
SIGVTALRM
SIGPOLL
SIGCONT
SIGTSTP

If `prun`/`srun` is used for launching the application, then `mpirun` sends the signal to the responsible launcher and relies on the signal propagation capabilities of the launcher to ensure that the signal is propagated to the ranks. When using `prun`, SIGTTIN is also intercepted by `mpirun`, but is not propagated.

When using an appfile, HP-MPI propagates these signals to remote HP-MPI daemons (mpid) and local ranks. Each daemon propagates the signal to the ranks it created. An exception is the treatment of SIGTSTP. When a daemon receives a SIGTSTP signal, it propagates SIGSTOP to the ranks it created and then raises SIGSTOP on itself. This allows all processes related to an HP-MPI execution to be suspended and resumed using SIGTSTP and SIGCONT.

The HP-MPI library also changes the default signal handling properties of the application in a few specific cases. When using the `-ha` option to `mpirun`, SIGPIPE is ignored. When using `MPI_FLAGS=U`, an MPI signal handler for printing outstanding message status is established for SIGUSR1. When using `MPI_FLAGS=sa`, an MPI signal handler used for message propagation is established for SIGALRM. When using `MPI_FLAGS=sp`, an MPI signal handler used for message propagation is established for SIGPROF.

In general, HP-MPI relies on applications terminating when they are sent SIGTERM. Applications which intercept SIGTERM may not terminate properly.

Dynamic Processes

HP-MPI provides support for dynamic process management, specifically the spawn, join, and connecting of new processes. `MPI_Comm_spawn()` starts MPI processes and establishes communication with them, returning an intercommunicator.

`MPI_Comm_spawn_multiple()` starts several different binaries (or the same binary with different arguments), placing them in the same comm_world and returning an intercommunicator. The `MPI_Comm_spawn()` and `MPI_Comm_spawn_multiple()` routines provide an interface between MPI and the runtime environment of an MPI application.

`MPI_Comm_accept()` and `MPI_Comm_connect()` along with `MPI_Open_port()` and `MPI_Close_port()` allow two independently run MPI applications to connect to each other and combine their ranks into a single communicator.

`MPI_Comm_join()` allows two ranks in independently run MPI applications to connect to each other and form an intercommunicator given a socket connection between them.

Each collection of spawned ranks only talks to the others through the comm daemons via sockets. Even if two `comm_worlds` are on the same host, the ranks within one `comm_world` will talk among themselves through shared memory, but ranks between the two `comm_worlds` will not talk to each other through shared memory.

Spawn functions supported in HP MPI:

- `MPI_Comm_get_parent()`
- `MPI_Comm_spawn()`
- `MPI_Comm_spawn_multiple()`
- `MPI_Comm_accept()`
- `MPI_Comm_connect()`
- `MPI_Open_port()`
- `MPI_Close_port()`
- `MPI_Comm_join()`

Keys interpreted in the `info` argument to the spawn calls:

- host -- We accept standard host.domain strings and start the ranks on the specified host. Without this key, the default is to start on the same host as the root of the spawn call.
- wdir -- We accept /some/directory strings.
- path -- We accept /some/directory:/some/other/directory:..

A mechanism for setting arbitrary environment variables for the spawned ranks is not provided.

Dynamic processes are not supported in HP-MPI V1.0 for Windows.

MPI-2 name publishing support

HP-MPI supports the MPI-2 dynamic process functionality MPI_Publish_name, MPI_Unpublish_name, MPI_Lookup_name, with the restriction that a separate nameserver must be started up on a server.

The service can be started as:

```
% $MPI_ROOT/bin/nameserver
```

and it will print out an IP and port. Then when running mpirun, the extra option -nameserver with an IP address and port must be provided:

```
% $MPI_ROOT/bin/mpirun -spawn -nameserver <IP:port> ...
```

The scope over which names are published and retrieved consists of all mpiruns which are started using the same IP:port for the nameserver.

Native language support

By default, diagnostic messages and other feedback from HP-MPI are provided in English. Support for other languages is available through the use of the Native Language Support (NLS) catalog and the internationalization environment variable NLSPATH.

The default NLS search path for HP-MPI is $NLSPATH. Refer to the environ(5) man page for NLSPATH usage.

When an MPI language catalog is available, it represents HP-MPI messages in two languages. The messages are paired so that the first in the pair is always the English version of a message and the second in the pair is the corresponding translation to the language of choice.

Refer to the hpnls (5), environ (5), and lang (5) man pages for more information about Native Language Support.

4 Profiling

This chapter provides information about utilities you can use to analyze HP-MPI applications. The topics covered are:

- Using counter instrumentation

  - Creating an instrumentation profile
  - Viewing ASCII instrumentation data
- Using the profiling interface
  - Fortran profiling interface
  - C++ profiling interface

Using counter instrumentation

Counter instrumentation is a lightweight method for generating cumulative runtime statistics for your MPI applications. When you create an instrumentation profile, HP-MPI creates an output file in ASCII format.

You can create instrumentation profiles for applications linked with the standard HP-MPI library. For applications linked with HP-MPI version 2.1 or later, you can also create profiles for applications linked with the thread-compliant library (`-lmtmpi`). Instrumentation is not supported for applications linked with the diagnostic library (`-ldmpi`).

Creating an instrumentation profile

Counter instrumentation is a lightweight method for generating cumulative runtime statistics for MPI applications. When you create an instrumentation profile, HP-MPI creates an ASCII format file containing statistics about the execution.

Instrumentation is not supported for applications linked with the diagnostic library (`-ldmpi`).

The syntax for creating an instrumentation profile is:

```
mpirun -i prefix[:l][:nc][:off]
```

where

`prefix`	Specifies the instrumentation output file prefix. The rank zero process writes the application's measurement data to *`prefix`*.instr in ASCII. If the prefix does not represent an absolute pathname, the instrumentation output file is opened in the working directory of the rank zero process when `MPI_Init` is called.
`l`	Locks ranks to CPUs and uses the CPU's cycle counter for less invasive timing. If used with gang scheduling, the :l is ignored.
`nc`	Specifies no clobber. If the instrumentation output file exists, `MPI_Init` aborts.

`off`	Specifies counter instrumentation is initially turned off and only begins after all processes collectively call `MPIHP_Trace_on`.

For example, to create an instrumentation profile for an executable called `compute_pi`:

```
% $MPI_ROOT/bin/mpirun -i compute_pi -np 2 compute_pi
```

This invocation creates an ASCII file named `compute_pi.instr` containing instrumentation profiling.

Although `-i` is the preferred method of controlling instrumentation, the same functionality is also accessible by setting the `MPI_INSTR` environment variable. Refer to “MPI_INSTR” on page 131 for syntax information.

Specifications you make using `mpirun -i` override any specifications you make using the `MPI_INSTR` environment variable.

MPIHP_Trace_on and MPIHP_Trace_off

By default, the entire application is profiled from `MPI_Init` to `MPI_Finalize`. However, HP-MPI provides the nonstandard `MPIHP_Trace_on` and `MPIHP_Trace_off` routines to collect profile information for selected code sections only.

To use this functionality:

1. Insert the `MPIHP_Trace_on` and `MPIHP_Trace_off` pair around code that you want to profile.
2. Build the application and invoke `mpirun` with the `-i <prefix> off;` option. `-i <index> off;` specifies that counter instrumentation is enabled but initially turned off (refer to “mpirun” on page 71 and “MPI_INSTR” on page 131). Data collection begins after all processes collectively call `MPIHP_Trace_on`. HP-MPI collects profiling information only for code between `MPIHP_Trace_on` and `MPIHP_Trace_off`

Viewing ASCII instrumentation data

The ASCII instrumentation profile is a text file with the .instr extension. For example, to view the instrumentation file for the compute_pi.f application, you can print the *`prefix`*.instr file. If you defined *`prefix`* for the file as compute_pi, as you did when you created the instrumentation file in “Creating an instrumentation profile” on page 159, you would print compute_pi.instr.

The ASCII instrumentation profile provides the version, the date your application ran, and summarizes information according to application, rank, and routines. Figure 4-1 on page 161 is an example of an ASCII instrumentation profile.

The information available in the *prefix*.instr file includes:

- Overhead time—The time a process or routine spends inside MPI. For example, the time a process spends doing message packing or spinning waiting for message arrival.
- Blocking time—The time a process or routine is blocked waiting for a message to arrive before resuming execution.

NOTE Overhead and blocking times are most useful when using `-e MPI_FLAGS=y0`.

- Communication hot spots—The processes in your application between which the largest amount of time is spent in communication.
- Message bin—The range of message sizes in bytes. The instrumentation profile reports the number of messages according to message length.

Figure 4-1 displays the contents of the example report compute_pi.instr.

Figure 4-1 ASCII instrumentation profile

```
Version: HP MPI 01.08.00.00 B6060BA - HP-UX 11.0
Date:    Mon Apr 01 15:59:10 2002
Processes: 2
User time:   6.57%
MPI time :  93.43% [Overhead:93.43% Blocking:0.00%]
-----------------------------------------------------------------
--------------------   Instrumentation Data --------------------
-----------------------------------------------------------------
Application Summary by Rank (second):
Rank        Proc CPU Time     User Portion       System Portion
-----------------------------------------------------------------
0      0.040000        0.010000( 25.00%)     0.030000( 75.00%)
1      0.030000        0.010000( 33.33%)     0.020000( 66.67%)
```

```
-----------------------------------------------------------------
Rank       Proc Wall Time      User                     MPI
-----------------------------------------------------------------
0        0.126335     0.008332(  6.60%)       0.118003( 93.40%)
1        0.126355     0.008260(  6.54%)       0.118095( 93.46%)
-----------------------------------------------------------------
Rank       Proc MPI Time      Overhead                Blocking
-----------------------------------------------------------------
0         0.118003       0.118003(100.00%)    0.000000(  0.00%)
1         0.118095       0.118095(100.00%)    0.000000(  0.00%)
-----------------------------------------------------------------
Routine Summary by Rank:
Rank Routine   Statistic   Calls   Overhead(ms)   Blocking(ms)
-----------------------------------------------------------------
0
MPI_Bcast                    1         5.397081        0.000000
MPI_Finalize                 1         1.238942        0.000000
MPI_Init                     1       107.195973        0.000000
MPI_Reduce                   1         4.171014        0.000000
-----------------------------------------------------------------
1
MPI_Bcast                    1         5.388021        0.000000
MPI_Finalize                 1         1.325965        0.000000
MPI_Init                     1       107.228994        0.000000
MPI_Reduce                   1         4.152060        0.000000
-----------------------------------------------------------------
Message Summary by Rank Pair:
SRank    DRank  Messages (minsize,maxsize)/[bin]    Totalbytes
-----------------------------------------------------------------
0
             1       1          (4, 4)                   4
                     1          [0..64]                  4
-----------------------------------------------------------------
1
             0       1          (8, 8)                   8
                     1         [0..64]                   8
-----------------------------------------------------------------
```

Using the profiling interface

The MPI profiling interface provides a mechanism by which implementors of profiling tools can collect performance information without access to the underlying MPI implementation source code.

Because HP-MPI provides several options for profiling your applications, you may not need the profiling interface to write your own routines. HP-MPI makes use of MPI profiling interface mechanisms to provide the diagnostic library for debugging. In addition, HP-MPI provides tracing and lightweight counter instrumentation. For details, refer to

- "Using counter instrumentation" on page 159
- "Using the diagnostics library" on page 185

The profiling interface allows you to intercept calls made by the user program to the MPI library. For example, you may want to measure the time spent in each call to a certain library routine or create a log file. You can collect your information of interest and then call the underlying MPI implementation through an alternate entry point as described below.

All routines in the HP-MPI library begin with the `MPI_` prefix. Consistent with the "Profiling Interface" section of the MPI 1.2 standard, routines are also accessible using the `PMPI_` prefix (for example, `MPI_Send` and `PMPI_Send` access the same routine).

To use the profiling interface, write wrapper versions of the MPI library routines you want the linker to intercept. These wrapper routines collect data for some statistic or perform some other action. The wrapper then calls the MPI library routine using its `PMPI_` prefix.

Fortran profiling interface

When writing profiling routines, do not call Fortran entry points from C profiling routines, and visa versa. In order to profile Fortran routines, separate wrappers need to be written for the Fortran calls.

For example:

```
#include <stdio.h>
#include <mpi.h>

int MPI_Send(void *buf, int count, MPI_Datatype type,
              int to, int tag, MPI_Comm comm)
{
     printf("Calling C MPI_Send to %d\n", to);
     return PMPI_Send(buf, count, type, to, tag, comm);
}
#pragma weak (mpi_send mpi_send)
void mpi_send(void *buf, int *count, int *type, int *to,
               int *tag, int *comm, int *ierr)
{
     printf("Calling Fortran MPI_Send to %d\n", *to);
     pmpi_send(buf, count, type, to, tag, comm, ierr);
}
```

C++ profiling interface

The HP-MPI C++ bindings are wrappers to the C calls. No profiling library exists for the C++ bindings. To profile the C++ interface, write the equivalent C wrapper version of the MPI library routines you want to profile. See the section above for details on profiling the C MPI libraries.

5 Tuning

This chapter provides information about tuning HP-MPI applications to improve performance. The topics covered are:

- Tunable parameters

- Message latency and bandwidth
- Multiple network interfaces
- Processor subscription
- Processor locality
- MPI routine selection
- Multilevel parallelism
- Coding considerations
- Using HP Caliper

The tuning information in this chapter improves application performance in most but not all cases. Use this information together with the output from counter instrumentation to determine which tuning changes are appropriate to improve your application's performance.

When you develop HP-MPI applications, several factors can affect performance. These factors are outlined in this chapter.

Tunable parameters

HP-MPI provides a mix of command line options and environment variables that can be used to influence the behavior, and thus the performance of the library. The full list of command line options and environment variables are presented in the sections “mpirun options” and “Runtime environment variables” of Chapter 3. The options and variables of interest to performance tuning include the following:

MPI_FLAGS=y

This option can be used to control the behavior of the HP-MPI library when waiting for an event to occur, such as the arrival of a message. See “MPI_FLAGS” on page 120 for more information.

MPI_TCP_CORECVLIMIT

Setting this variable to a larger value can allow HP-MPI to utilize more parallelism during its low-level message transfers, but can greatly reduce performance by causing switch congestion. See “MPI_TCP_CORECVLIMIT” on page 144 for more information.

MPI_SOCKBUFSIZE

Increasing this value has shown performance gains for some applications running on TCP networks. See “MPI_SOCKBUFSIZE” on page 144 for more information.

-cpu_bind, MPI_BIND_MAP, MPI_CPU_AFFINITY, MPI_CPU_SPIN

The `-cpu_bind` command line option and associated environment variables can improve the performance of many applications by binding a process to a particular CPU. See “mpirun options” on page 105, “CPU Bind environment variables” on page 127, and “Binding ranks to ldoms (-cpu_bind)” on page 174 for more information.

-intra

The `-intra` command line option controls how messages are transferred to local processes and can impact performance when multiple ranks execute on a host. See “Local host communication method” on page 107 for more information.

MPI_RDMA_INTRALEN, MPI_RDMA_MSGSIZE, MPI_RDMA_NENVELOPE

These environment variables control various aspects of the way message traffic is handled on RDMA networks. The default settings have been carefully selected to be appropriate for the majority of applications. However, some applications may benefit from adjusting these values depending on their communication patterns. See the corresponding man pages for more information.

MPI_USE_LIBELAN_SUB

Setting this environment variable may provide some performance benefits on the ELAN interconnect. However, some applications may experience resource problems. See “MPI_USE_LIBELAN_SUB” on page 144 for more information.

Message latency and bandwidth

Latency is the time between the initiation of the data transfer in the sending process and the arrival of the first byte in the receiving process.

Latency is often dependent upon the length of messages being sent. An application's messaging behavior can vary greatly based upon whether a large number of small messages or a few large messages are sent.

Message bandwidth is the reciprocal of the time needed to transfer a byte. Bandwidth is normally expressed in megabytes per second. Bandwidth becomes important when message sizes are large.

To improve latency or bandwidth or both:

- Reduce the number of process communications by designing applications that have coarse-grained parallelism.
- Use derived, contiguous data types for dense data structures to eliminate unnecessary byte-copy operations in certain cases. Use derived data types instead of `MPI_Pack` and `MPI_Unpack` if possible. HP-MPI optimizes noncontiguous transfers of derived data types.
- Use collective operations whenever possible. This eliminates the overhead of using `MPI_Send` and `MPI_Recv` each time when one process communicates with others. Also, use the HP-MPI collectives rather than customizing your own.
- Specify the source process rank whenever possible when calling MPI routines. Using `MPI_ANY_SOURCE` may increase latency.
- Double-word align data buffers if possible. This improves byte-copy performance between sending and receiving processes because of double-word loads and stores.
- Use `MPI_Recv_init and MPI_Startall` instead of a loop of `MPI_Irecv` calls in cases where requests may not complete immediately.

  For example, suppose you write an application with the following code section:

```
j = 0
for (i=0; i<size; i++) {
   if (i==rank) continue;
   MPI_Irecv(buf[i], count, dtype, i, 0, comm, &requests[j++]);
}
MPI_Waitall(size-1, requests, statuses);
```

Suppose that one of the iterations through `MPI_Irecv` does not complete before the next iteration of the loop. In this case, HP-MPI tries to progress both requests. This progression effort could continue to grow if succeeding iterations also do not complete immediately, resulting in a higher latency.

However, you could rewrite the code section as follows:

```
j = 0
for (i=0; i<size; i++) {
   if (i==rank) continue;
   MPI_Recv_init(buf[i], count, dtype, i, 0, comm,
                                    &requests[j++]);
}
MPI_Startall(size-1, requests);
MPI_Waitall(size-1, requests, statuses);
```

In this case, all iterations through `MPI_Recv_init` are progressed just once when `MPI_Startall` is called. This approach avoids the additional progression overhead when using `MPI_Irecv` and can reduce application latency.

Multiple network interfaces

You can use multiple network interfaces for interhost communication while still having intrahost exchanges. In this case, the intrahost exchanges use shared memory between processes mapped to different same-host IP addresses.

To use multiple network interfaces, you must specify which MPI processes are associated with each IP address in your appfile.

For example, when you have two hosts, host0 and host1, each communicating using two ethernet cards, ethernet0 and ethernet1, you have four host names as follows:

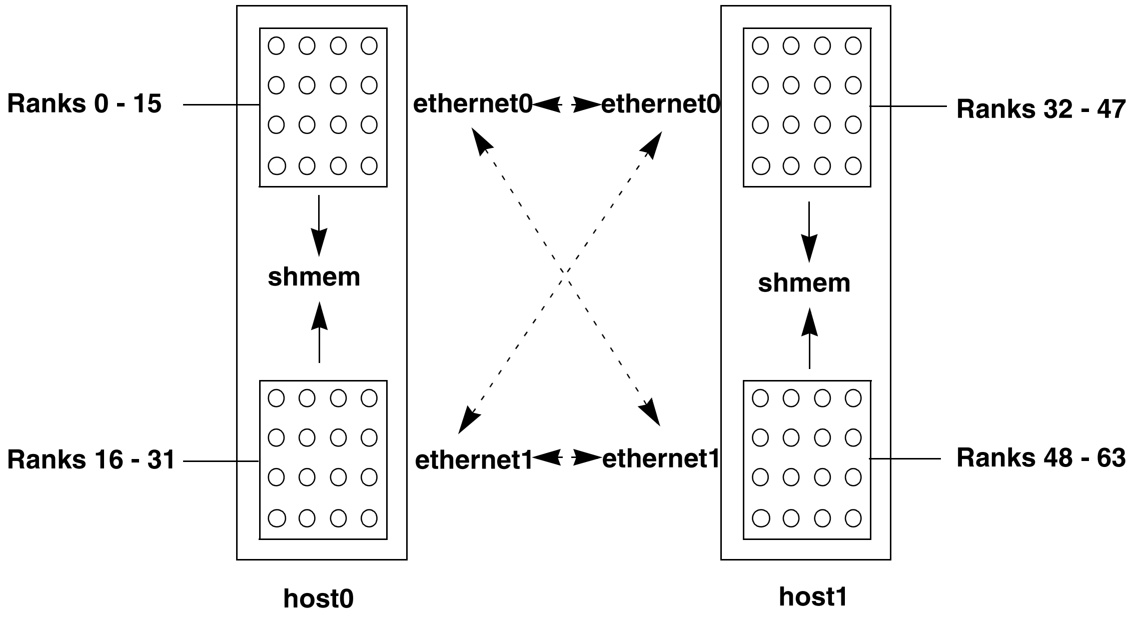
- host0-ethernet0
- host0-ethernet1
- host1-ethernet0
- host1-ethernet1

If your executable is called work.exe and uses 64 processes, your appfile should contain the following entries:

```
-h host0-ethernet0 -np 16 work.exe
-h host0-ethernet1 -np 16 work.exe
-h host1-ethernet0 -np 16 work.exe
-h host1-ethernet1 -np 16 work.exe
```

Now, when the appfile is run, 32 processes run on host0 and 32 processes run on host1 as shown in Figure 5-1.

Figure 5-1 Multiple network interfaces



Host0 processes with rank 0 - 15 communicate with processes with rank 16 - 31 through shared memory (shmem). Host0 processes also communicate through the host0-ethernet0 and the host0-ethernet1 network interfaces with host1 processes.

Processor subscription

Subscription refers to the match of processors and active processes on a host. Table 5-1 lists possible subscription types.

Table 5-1 Subscription types

Subscription type	Description
Under subscribed	More processors than active processes
Fully subscribed	Equal number of processors and active processes
Over subscribed	More active processes than processors

When a host is over subscribed, application performance decreases because of increased context switching.

Context switching can degrade application performance by slowing the computation phase, increasing message latency, and lowering message bandwidth. Simulations that use timing–sensitive algorithms can produce unexpected or erroneous results when run on an over-subscribed system.

In a situation where your system is oversubscribed but your MPI application is not, you can use gang scheduling to improve performance. Refer to "MP_GANG" on page 128 for details. This is only available on HP-UX systems.

Processor locality

The `mpirun` option `-cpu_bind` binds a rank to a locality domain (ldom) to prevent a process from moving to a different ldom after startup. The binding occurs before the MPI application is executed.

Similar results can be accomplished using "mpsched" but this has the advantage of being more load-based distribution, and works well in psets and across multiple machines.

Binding ranks to ldoms (-cpu_bind)

On SMP systems, processes sometimes move to a different ldom shortly after startup or during execution. This increases memory latency and can cause slower performance as the application is now accessing memory across cells.

Applications which are very memory latency sensitive can show large performance degradation when memory access is mostly off-cell.

To solve this problem, ranks need to reside in the same ldom which they were originally created. To accomplish this, HP-MPI provides the `-cpu_bind` flag, which locks down a rank to a specific ldom and prevents it from moving during execution. To accomplish this, the -cpu_bind flag will preload a shared library at startup for each process, which does the following:

1. Spins for a short time in a tight loop to let the operating system distribute processes to CPUs evenly.
2. Determines the current CPU and ldom of the process and if no oversubscription occurs on the current CPU, it will lock the process to the ldom of that CPU.

This will evenly distribute the ranks to CPUs, and prevents the ranks from moving to a different ldom after the MPI application starts, preventing cross-memory access.

See `-cpu_bind` under “mpirun options” on page 105 for more information.

MPI routine selection

To achieve the lowest message latencies and highest message bandwidths for point-to-point synchronous communications, use the MPI blocking routines `MPI_Send` and `MPI_Recv`. For asynchronous communications, use the MPI nonblocking routines `MPI_Isend` and `MPI_Irecv`.

When using blocking routines, try to avoid pending requests. MPI must advance nonblocking messages, so calls to blocking receives must advance pending requests, occasionally resulting in lower application performance.

For tasks that require collective operations, use the appropriate MPI collective routine. HP-MPI takes advantage of shared memory to perform efficient data movement and maximize your application's communication performance.

Multilevel parallelism

There are several ways to improve the performance of applications that use multilevel parallelism:

- Use the MPI library to provide coarse-grained parallelism and a parallelizing compiler to provide fine-grained (that is, thread-based) parallelism. An appropriate mix of coarse- and fine-grained parallelism provides better overall performance.
- Assign only one multithreaded process per host when placing application processes. This ensures that enough processors are available as different process threads become active.

Coding considerations

The following are suggestions and items to consider when coding your MPI applications to improve performance:

- Use HP-MPI collective routines instead of coding your own with point-to-point routines because HP-MPI's collective routines are optimized to use shared memory where possible for performance.

  Use commutative MPI reduction operations.

  - Use the MPI predefined reduction operations whenever possible because they are optimized.
  - When defining your own reduction operations, make them commutative. Commutative operations give MPI more options when ordering operations allowing it to select an order that leads to best performance.

- Use MPI derived datatypes when you exchange several small size messages that have no dependencies.

- Minimize your use of MPI_Test() polling schemes to reduce polling overhead.

- Code your applications to avoid unnecessary synchronization. In particular, strive to avoid MPI_Barrier calls. Typically an application can be modified to achieve the same end result using targeted synchronization instead of collective calls. For example, in many cases a token-passing ring may be used to achieve the same coordination as a loop of barrier calls.

Using HP Caliper

HP Caliper is a general-purpose performance analysis tool for applications, processes, and systems.

HP Caliper allows you to understand the performance and execution of an application, and identify ways to improve runtime performance.

NOTE When running HP-MPI applications under HP Caliper on Linux hosts, it may be necessary to set the `HPMPI_NOPROPAGATE_SUSP` environment variable to prevent application aborts.

```
% setenv HPMPI_NOPROPAGATE_SUSP 1
```

```
% export HPMPI_NOPROPAGATE_SUSP=1
```

For more information, refer to the HP Caliper User Guide available at http://docs.hp.com.

6 Debugging and troubleshooting

This chapter describes debugging and troubleshooting HP-MPI applications. The topics covered are:

- Debugging HP-MPI applications

  - Using a single-process debugger
  - Using a multi-process debugger
  - Using the diagnostics library
  - Enhanced debugging output
  - Backtrace functionality
- Troubleshooting HP-MPI applications
  - Building on HP-UX and Linux
  - Building on Windows
  - Starting on HP-UX and Linux
  - Starting on Windows
  - Running on HP-UX, Linux, and Windows
  - Completing
  - Testing the network on HP-UX and Linux
  - Testing the network on Windows

Debugging HP-MPI applications

HP-MPI allows you to use single-process debuggers to debug applications. The available debuggers are ADB, DDE, XDB, WDB, GDB, and PATHDB. You access these debuggers by setting options in the `MPI_FLAGS` environment variable. HP-MPI also supports the multithread, multiprocess debugger, TotalView on Linux and HP-UX for Itanium-based systems.

In addition to the use of debuggers, HP-MPI provides a diagnostic library (DLIB) for advanced error checking and debugging. HP-MPI also provides options to the environment variable `MPI_FLAGS` that report memory leaks (`l`), force MPI errors to be fatal (`f`), print the MPI job ID (`j`), and other functionality.

This section discusses single- and multi-process debuggers and the diagnostic library; refer to “MPI_FLAGS” on page 120 for information about using the MPI_FLAGS option.

Using a single-process debugger

Because HP-MPI creates multiple processes and ADB, DDE, XDB, WDB, GDB, and PATHDB only handle single processes, HP-MPI starts one debugger session per process. HP-MPI creates processes in `MPI_Init`, and each process instantiates a debugger session. Each debugger session in turn attaches to the process that created it. HP-MPI provides `MPI_DEBUG_CONT` to control the point at which debugger attachment occurs. `MPI_DEBUG_CONT` is a variable that HP-MPI uses to temporarily halt debugger progress beyond MPI_Init. By default, `MPI_DEBUG_CONT` is set to 0 and you must reset it to 1 to allow the debug session to continue past `MPI_Init`.

The following procedure outlines the steps to follow when you use a single-process debugger:

Step 1. Set the `eadb`, `exdb`, `edde`, `ewdb`, `egdb`, or `epathdb` option in the `MPI_FLAGS` environment variable to use the ADB, XDB, DDE, WDB, GDB, or PATHDB debugger respectively. Refer to “MPI_FLAGS” on page 120 for information about `MPI_FLAGS` options.

Step 2. On remote hosts, set DISPLAY to point to your console. In addition, use `xhost` to allow remote hosts to redirect their windows to your console.

Step 3. Run your application.

When your application enters `MPI_Init`, HP-MPI starts one debugger session per process and each debugger session attaches to its process.

Step 4. (Optional) Set a breakpoint anywhere following `MPI_Init` in each session.

Step 5. Set the global variable `MPI_DEBUG_CONT` to 1 using each session's command line interface or graphical user interface. The syntax for setting the global variable depends upon which debugger you use:

```
(adb) mpi_debug_cont/w 1
```

```
(dde) set mpi_debug_cont = 1
```

```
(xdb) print *MPI_DEBUG_CONT = 1
```

```
(wdb) set MPI_DEBUG_CONT = 1
```

```
(gdb) set MPI_DEBUG_CONT = 1
```

Step 6. Issue the appropriate debugger command in each session to continue program execution.

Each process runs and stops at the breakpoint you set after `MPI_Init`.

Step 7. Continue to debug each process using the appropriate commands for your debugger.

CAUTION To improve performance on HP-UX systems, HP-MPI supports a process-to-process, one-copy messaging approach. This means that one process can directly copy a message into the address space of another process. Because of this process-to-process bcopy (p2p_bcopy) implementation, a kernel thread is created for each process that has p2p_bcopy enabled. This thread deals with page and protection faults associated with the one-copy operation.

This extra kernel thread can cause anomalous behavior when you use DDE on HP-UX 11i and higher. If you experience such difficulty, you can disable p2p_bcopy by setting the `MPI_2BCOPY` environment variable to 1.

Using a multi-process debugger

HP-MPI supports the TotalView debugger on Linux and HP-UX for Itanium-based systems. The preferred method when you run TotalView with HP-MPI applications is to use the `mpirun` runtime utility command.

For example,

```
% $MPI_ROOT/bin/mpicc myprogram.c -g
% $MPI_ROOT/bin/mpirun -tv -np 2 a.out
```

In this example, myprogram.c is compiled using the HP-MPI compiler utility for C programs (refer to "Compiling and running your first application" on page 22). The executable file is compiled with source line information and then `mpirun` runs the a.out MPI program:

`-g`	Specifies that the compiler generate the additional information needed by the symbolic debugger.
`-np` *2*	Specifies the number of processes to run (2, in this case).
`-tv`	Specifies that the MPI ranks are run under TotalView.

Alternatively, use `mpirun` to invoke an appfile:

```
% $MPI_ROOT/bin/mpirun -tv -f my_appfile
```

`-tv`	Specifies that the MPI ranks are run under TotalView.
`-f` *`appfile`*	Specifies that `mpirun` parses *`my_appfile`* to get program and process count information for the run. Refer to "Creating an appfile" on page 75 for details about setting up your appfile.

Refer to "mpirun" on page 71 for details about `mpirun`.

Refer to the "MPI_FLAGS" on page 120 and the TotalView documentation for details about `MPI_FLAGS` and TotalView command line options, respectively.

By default, `mpirun` searches for TotalView in your `PATH`.You can also define the absolute path to TotalView using the `TOTALVIEW` environment variable:

```
% setenv TOTALVIEW /opt/totalview/bin/totalview \
[totalview-options]
```

The `TOTALVIEW` environment variable is used by `mpirun`.

NOTE When attaching to a running MPI application that was started using appfiles, you should attach to the MPI daemon process to enable debugging of all the MPI ranks in the application. You can identify the daemon process as the one at the top of a hierarchy of MPI jobs (the daemon also usually has the lowest PID among the MPI jobs).

Limitations

The following limitations apply to using TotalView with HP-MPI applications:

1. All the executable files in your multihost MPI application must reside on your local machine, that is, the machine on which you start TotalView. Refer to “TotalView multihost example” on page 184 for details about requirements for directory structure and file locations.
2. TotalView sometimes displays extra HP-UX threads that have no useful debugging information. These are kernel threads that are created to deal with page and protection faults associated with one-copy operations that HP-MPI uses to improve performance. You can ignore these kernel threads during your debugging session.

   To improve performance, HP-MPI supports a process-to-process, one-copy messaging approach. This means that one process can directly copy a message into the address space of another process. Because of this process-to-process bcopy (p2p_bcopy) implementation, a kernel thread is created for each process that has p2p_bcopy enabled. This thread deals with page and protection faults associated with the one-copy operation.

TotalView multihost example

The following example demonstrates how to debug a typical HP-MPI multihost application using TotalView, including requirements for directory structure and file locations.

The MPI application is represented by an appfile, named my_appfile, which contains the following two lines:

```
-h local_host -np 2 /path/to/program1
-h remote_host -np 2 /path/to/program2
```

my_appfile resides on the local machine (local_host) in the /work/mpiapps/total directory.

To debug this application using TotalView (in this example, TotalView is invoked from the local machine):

1. Place your binary files in accessible locations.
   - /path/to/program1 exists on local_host
   - /path/to/program2 exists on remote_host

     To run the application under TotalView, the directory layout on your local machine, with regard to the MPI executable files, must mirror the directory layout on each remote machine. Therefore, in this case, your setup must meet the following additional requirement:
   - /path/to/program2 exists on local_host
2. In the /work/mpiapps/total directory on local_host, invoke TotalView by passing the `-tv` option to `mpirun`:

   ```
   % $MPI_ROOT/bin/mpirun -tv -f my_appfile
   ```

Using the diagnostics library

HP-MPI provides a diagnostics library (DLIB) for advanced run time error checking and analysis. DLIB provides the following checks:

- Message signature analysis—Detects type mismatches in MPI calls. For example, in the two calls below, the send operation sends an integer, but the matching receive operation receives a floating-point number.

  ```
  if (rank == 1) then
    MPI_Send(&buf1, 1, MPI_INT, 2, 17, MPI_COMM_WORLD);
  else if (rank == 2)
    MPI_Recv(&buf2, 1, MPI_FLOAT, 1, 17, MPI_COMM_WORLD,
                                                  &status);
  ```
- MPI object-space corruption—Detects attempts to write into objects such as MPI_Comm, MPI_Datatype, MPI_Request, MPI_Group, and MPI_Errhandler.
- Multiple buffer writes—Detects whether the data type specified in a receive or gather operation causes MPI to write to a user buffer more than once.

To disable these checks or enable formatted or unformatted printing of message data to a file, set the `MPI_DLIB_FLAGS` environment variable options appropriately. See "MPI_DLIB_FLAGS" on page 129 for more information.

To use the diagnostics library, specify the `-ldmpi` option to the build scripts when you compile your application. This option is supported on HP-UX, Linux, and Windows.

NOTE Using DLIB reduces application performance. Also, you cannot use DLIB with instrumentation.

Enhanced debugging output

HP-MPI provides the stdio option to allow improved readability and usefulness of MPI processes stdout and stderr. Options have been added for handling standard input:

- `Directed`: Input is directed to a specific MPI process.
- `Broadcast`: Input is copied to the stdin of all processes.
- `Ignore`: Input is ignored.

The default behavior when using stdio is to ignore standard input.

Additional options are available to avoid confusing interleaving of output:

- Line buffering, block buffering, or no buffering
- Prepending of processes ranks to their stdout and stderr
- Simplification of redundant output

For more information on stdio, refer to "External input and output" on page 193.

This functionality is not provided when using `-srun` or `-prun`. See `--label` option of `srun` in Appendix C for similar functionality.

Backtrace functionality

HP-MPI handles several common termination signals on PA-RISC differently than earlier versions of HP-MPI. If any of the following signals are generated by an MPI application, a stack trace is printed prior to termination:

- `SIGBUS` - bus error
- `SIGSEGV` - segmentation violation
- `SIGILL` - illegal instruction
- `SIGSYS` - illegal argument to system call

The backtrace is helpful in determining where the signal was generated and the call stack at the time of the error. If a signal handler is established by the user code before calling `MPI_Init`, no backtrace will be printed for that signal type and the user's handler will be solely responsible for handling the signal. Any signal handler installed after `MPI_Init` will also override the backtrace functionality for that signal after the point it is established. If multiple processes cause a signal, each of them will print a backtrace.

In some cases, the prepending and buffering options available in HP-MPI standard IO processing are useful in providing more readable output of the backtrace information.

The default behavior is to print a stack trace.

Backtracing can be turned off entirely by setting the environment variable `MPI_NOBACKTRACE`. See"MPI_NOBACKTRACE" on page 130.

Troubleshooting HP-MPI applications

This section describes limitations in HP-MPI, some common difficulties you may face, and hints to help you overcome those difficulties and get the best performance from your HP-MPI applications. Check this information first when you troubleshoot problems. The topics covered are organized by development task and also include answers to frequently asked questions:

- Building on HP-UX and Linux
- Starting on HP-UX and Linux
- Running on HP-UX, Linux, and Windows
- Completing
- Testing the network on HP-UX and Linux

To get information about the version of HP-MPI installed on your HP-UX system, use the `what` command. The following is an example of the command and its output:

```
% what $MPI_ROOT/bin/mpicc
```

```
$MPI_ROOT/bin/mpicc:
```

```
HP MPI 02.01.01.00 (dd/mm/yyyy) B6060BA - HP-UX 11.i
```

This command returns the HP-MPI version number, the release date, HP-MPI product numbers, and the operating system version.

For Linux systems, use

```
% ident $MPI_ROOT/bin/mpirun
```

or

```
% rpm -qa | grep hpmpi
```

For Windows systems, use

```
> "%MPI_ROOT%\bin\mprun" -version
```

```
mpirun: HP MPI 01.00.00.00 Windows 32
major version 100 minor version 0
```

Building on HP-UX and Linux

You can solve most build-time problems by referring to the documentation for the compiler you are using.

If you use your own build script, specify all necessary input libraries. To determine what libraries are needed, check the contents of the compilation utilities stored in the HP-MPI $MPI_ROOT/bin subdirectory.

HP-MPI supports a 64-bit version of the MPI library on 64-bit platforms. Both 32- and 64-bit versions of the library are shipped on 64-bit platforms. You cannot mix 32-bit and 64-bit executables in the same application.

HP-MPI does not support Fortran applications that are compiled with the following option:

- `+autodblpad`— Fortran 77 programs

Building on Windows

Make sure you are running the build wrappers (i.e. **`mpicc`**, **`mpif90`**) in a compiler command window. This window is usually an option on the **`Start`**->**`All Programs`** menu. Each compiler vendor provides their own command window option which includes all the necessary paths for compiler and libraries.

On Windows, the HP-MPI libraries include the 'bitness' in the library name. HP-MPI provides support for both 32- and 64-bit libraries. The .lib files are located in "%MPI_ROOT%\lib".

Starting on HP-UX and Linux

When starting multihost applications using an appfile, make sure that:

- All remote hosts are listed in your .rhosts file on each machine and you can `remsh` to the remote machines. The `mpirun` command has the `-ck` option you can use to determine whether the hosts and programs specified in your MPI application are available, and whether there are access or permission problems. Refer to “mpirun” on page 71. MPI `remsh` can be used to specify other commands to be used, such as `ssh`, instead of `remsh`.

- Application binaries are available on the necessary remote hosts and are executable on those machines
- The `-sp` option is passed to `mpirun` to set the target shell PATH environment variable. You can set this option in your appfile
- The .cshrc file does not contain `tty` commands such as `stty` if you are using a /bin/csh-based shell

Starting on Windows

When starting multihost applications using Windows CCS:

- Don't forget the `-ccp` flag.
- Use UNC paths for your file names. Drives are usually not mapped on remote nodes.
- If using the AutoSubmit feature, make sure you are running from a mapped network drive and don't specify file paths for binaries. HP-MPI will convert the mapped drive to a UNC path and set `MPI_WORKDIR` to your current directory. If you are running on a local drive, HP-MPI cannot map this to a UNC path.
- Don't submit any scripts or commands which require a command window. These commands usually fail when trying to 'change directory' to a UNC path.
- Don't forget to quote any filenames or commands with paths that have spaces. The default HP-MPI install location includes spaces:

  "C:\Program Files (x86)\Hewlett-Packard\HP-MPI\bin\mpirun"

  OR

  "%MPI_ROOT%\bin\mpirun"

Running on HP-UX, Linux, and Windows

Run time problems originate from many sources and may include:

- Shared memory
- Message buffering
- Propagation of environment variables
- Fortran 90 programming features

- UNIX open file descriptors
- External input and output

Shared memory

When an MPI application starts, each MPI daemon attempts to allocate a section of shared memory. This allocation can fail if the system-imposed limit on the maximum number of allowed shared-memory identifiers is exceeded or if the amount of available physical memory is not sufficient to fill the request.

After shared-memory allocation is done, every MPI process attempts to attach to the shared-memory region of every other process residing on the same host. This shared memory allocation can fail if the system is not configured with enough available shared memory. Consult with your system administrator to change system settings. Also, `MPI_GLOBMEMSIZE` is available to control how much shared memory HP-MPI tries to allocate. See “MPI_GLOBMEMSIZE” on page 136 for more information.

Message buffering

According to the MPI standard, message buffering may or may not occur when processes communicate with each other using `MPI_Send`. `MPI_Send` buffering is at the discretion of the MPI implementation. Therefore, you should take care when coding communications that depend upon buffering to work correctly.

For example, when two processes use `MPI_Send` to simultaneously send a message to each other and use `MPI_Recv` to receive the messages, the results are unpredictable. If the messages are buffered, communication works correctly. If the messages are not buffered, however, each process hangs in `MPI_Send` waiting for `MPI_Recv` to take the message. For example, a sequence of operations (labeled "Deadlock") as illustrated in Table 6-1 would result in such a deadlock. Table 6-1 also illustrates the sequence of operations that would avoid code deadlock.

Table 6-1 Non-buffered messages and deadlock

Deadlock		No Deadlock	
Process 1	**Process 2**	**Process 1**	**Process 2**
MPI_Send(,...2 ,....)	MPI_Send(,...1 ,....)	MPI_Send(,...2 ,....)	MPI_Recv(,...1 ,....)

Table 6-1 Non-buffered messages and deadlock (Continued)

Deadlock		No Deadlock	
Process 1	**Process 2**	**Process 1**	**Process 2**
MPI_Recv(,...2, ...)	MPI_Recv(,...1, ...)	MPI_Recv(,...2 ,....)	MPI_Send(,...1 ,....)

Propagation of environment variables

When working with applications that run on multiple hosts using an appfile, if you want an environment variable to be visible by all application ranks you must use the -e option with an appfile or as an argument to mpirun.

One way to accomplish this is to set the `-e` option in the appfile:

```
-h remote_host -e var=val [-np #] program [args]
```

Refer to “Creating an appfile” on page 75 for details.

On XC, systems the environment variables are automatically propagated by `srun`. Environment variables can be established by the user with either `setenv` or `export` and are passed along to the MPI processes by the SLURM `srun` utility. Thus, on XC systems, it is not necessary to use the "-e name=value" approach to passing environment variables. Although the "-e name=value" will also work on XC systems using SLURM’s `srun`.

Fortran 90 programming features

The MPI 1.1 standard defines bindings for Fortran 77 but not Fortran 90.

Although most Fortran 90 MPI applications work using the Fortran 77 MPI bindings, some Fortran 90 features can cause unexpected behavior when used with HP-MPI.

In Fortran 90, an array is not always stored in contiguous memory. When noncontiguous array data are passed to an HP-MPI subroutine, Fortran 90 copies the data into temporary storage, passes it to the HP-MPI subroutine, and copies it back when the subroutine returns. As a result, HP-MPI is given the address of the copy but not of the original data.

In some cases, this copy-in and copy-out operation can cause a problem. For a nonblocking HP-MPI call, the subroutine returns immediately and the temporary storage is deallocated. When HP-MPI tries to access the already invalid memory, the behavior is unknown. Moreover, HP-MPI operates close to the system level and needs to know the address of the original data. However, even if the address is known, HP-MPI does not know if the data are contiguous or not.

UNIX open file descriptors

UNIX imposes a limit to the number of file descriptors that application processes can have open at one time. When running a multihost application, each local process opens a socket to each remote process. An HP-MPI application with a large amount of off-host processes can quickly reach the file descriptor limit. Ask your system administrator to increase the limit if your applications frequently exceed the maximum.

External input and output

You can use stdin, stdout, and stderr in your applications to read and write data. By default, HP-MPI does not perform any processing on either stdin or stdout. The controlling tty determines stdio behavior in this case.

This functionality is not provided when using `-srun` or `-prun`.

If your application depends on `mpirun`'s "-stdio=i" to broadcast input to all ranks, and you are using SLURM's `srun` on an XC system, then a reasonable substitute is "--stdin=all". For example:

```
% mpirun -srun --stdin-all ...
```

See `--label` option of `srun` in Appendix C for similar functionality.

HP-MPI does provide optional stdio processing features. stdin can be targeted to a particular process, or can be broadcast to every process. stdout processing includes buffer control, prepending MPI rank numbers, and combining repeated output.

HP-MPI standard IO options can be set by using the following options to `mpirun`:

```
mpirun -stdio=[bline[#] | bnone[#] | b[#], [p], [r[#]], [i[#]]
```

where

`i`	Broadcasts standard input to all MPI processes.

`i` *`[#]`*	Directs standard input to the process with global rank #.

The following modes are available for buffering:

`b` *`[#>0]`*	Specifies that the output of a single MPI process is placed to the standard out of `mpirun` after # bytes of output have been accumulated.
`bnone` *`[#>0]`*	The same as b[#] except that the buffer is flushed both when it is full and when it is found to contain any data. Essentially provides no buffering from the user's perspective.
`bline` *`[#>0]`*	Displays the output of a process after a line feed is encountered, or the # byte buffer is full.

The default value of *#* in all cases is 10k bytes

The following option is available for prepending:

`p`	Enables prepending. The global rank of the originating process is prepended to stdout and stderr output. Although this mode can be combined with any buffering mode, prepending makes the most sense with the modes `b` and `bline`.

The following option is available for combining repeated output:

`r` *`[#>1]`*	Combines repeated identical output from the same process by prepending a multiplier to the beginning of the output. At most, # maximum repeated outputs are accumulated without display. This option is used only with `bline`. The default value of # is infinity.

Completing

In HP-MPI, `MPI_Finalize` is a barrier-like collective routine that waits until all application processes have called it before returning. If your application exits without calling `MPI_Finalize`, pending requests may not complete.

When running an application, `mpirun` waits until all processes have exited. If an application detects an MPI error that leads to program termination, it calls `MPI_Abort` instead.

You may want to code your error conditions using `MPI_Abort`, which cleans up the application.

Each HP-MPI application is identified by a job ID, unique on the server where `mpirun` is invoked. If you use the `-j` option, `mpirun` prints the job ID of the application that it runs. Then, you can invoke `mpijob` with the job ID to display the status of your application.

If your application hangs or terminates abnormally, you can use `mpiclean` to kill any lingering processes and shared-memory segments. `mpiclean` uses the job ID from `mpirun -j` to specify the application to terminate.

Testing the network on HP-UX and Linux

Often, clusters might have both ethernet and some form of higher speed interconnect such as InfiniBand. This section describes how to use the ping_pong_ring.c example program to confirm that you are able to run using the desired interconnect.

Running a test like this, especially on a new cluster, is useful to ensure that the appropriate network drivers are installed and that the network hardware is functioning properly. If any machine has defective network cards or cables, this test can also be useful at identifying which machine has the problem.

To compile the program, set the `MPI_ROOT` environment variable (not required, but recommended) to a value such as `/opt/hpmpi` (for Linux) or `/opt/mpi` (for HP-UX), then run

```
% export MPI_CC=gcc (whatever compiler you want)
```

```
% $MPI_ROOT/bin/mpicc -o pp.x \
$MPI_ROOT/help/ping_pong_ring.c
```

Although `mpicc` will perform a search for what compiler to use if you don't specify `MPI_CC`, it is preferable to be explicit.

If you have a shared filesystem, it is easiest to put the resulting `pp.x` executable there, otherwise you will have to explicitly copy it to each machine in your cluster.

Use the startup that is appropriate for your cluster. Your situation should resemble one of the following:

- If there is no job scheduler (such as srun, prun, or LSF) available, run a command like:

  ```
  $MPI_ROOT/bin/mpirun -prot -hostlist \
  hostA,hostB,...hostZ pp.x
  ```

You may need to specify what remote shell command to use (the default is ssh) by setting the `MPI_REMSH` environment variable. For example:

% **`export MPI_REMSH="rsh -x"`** (optional)

- If LSF is being used, create an appfile such as:

```
-h hostA -np 1 /path/to/pp.x
-h hostB -np 1 /path/to/pp.x
-h hostC -np 1 /path/to/pp.x
...
-h hostZ -np 1 /path/to/pp.x
```

  Then run one of the following commands:

```
% bsub pam -mpi $MPI_ROOT/bin/mpirun -prot -f appfile
```

```
% bsub pam -mpi $MPI_ROOT/bin/mpirun -prot -f appfile \
-- 1000000
```

  Note that when using LSF, the actual hostnames in the appfile are ignored.

- If the `srun` command is available, run a command like:

```
% $MPI_ROOT/bin/mpirun -prot -srun -N 8 -n 8 \
/path/to/pp.x
```

```
% $MPI_ROOT/bin/mpirun -prot -srun -N 8 -n 8 \
/path/to/pp.x 1000000
```

  replacing "8" with the number of hosts.

  Or if LSF is being used, then the command to run might be:

```
% bsub -I -n 16 $MPI_ROOT/bin/mpirun -prot -srun \
/path/to/pp.x
```

```
% bsub -I -n 16 $MPI_ROOT/bin/mpirun -prot -srun \
/path/to/pp.x 1000000
```

- If the `prun` command is available, use the same commands as above for `srun` replacing srun with `prun`.

In each case above, the first `mpirun` uses 0 bytes per message and is checking latency. The second `mpirun` uses 1000000 bytes per message and is checking bandwidth.

Example output might look like:

```
Host 0 -- ip 192.168.9.10 -- ranks 0
Host 1 -- ip 192.168.9.11 -- ranks 1
Host 2 -- ip 192.168.9.12 -- ranks 2
Host 3 -- ip 192.168.9.13 -- ranks 3

host  | 0    1    2    3
======|=====================
    0 : SHM  VAPI VAPI VAPI
    1 : VAPI SHM  VAPI VAPI
    2 : VAPI VAPI SHM  VAPI
    3 : VAPI VAPI VAPI SHM

[0:hostA] ping-pong 0 bytes ...
0 bytes: 4.24 usec/msg
[1:hostB] ping-pong 0 bytes ...
0 bytes: 4.26 usec/msg
[2:hostC] ping-pong 0 bytes ...
0 bytes: 4.26 usec/msg
[3:hostD] ping-pong 0 bytes ...
0 bytes: 4.24 usec/msg
```

The table showing SHM/VAPI is printed because of the `-prot` option (print protocol) specified in the `mpirun` command.

It could show any of the following settings:

- VAPI: VAPI on InfiniBand
- UDAPL: uDAPL on InfiniBand
- IBV: IBV on InfiniBand
- PSM: PSM on InfiniBand
- MX: Myrinet MX
- IBAL: on InfiniBand (for Windows only)
- IT: IT-API on InfiniBand
- GM: Myrinet GM2
- ELAN: Quadrics Elan4
- TCP: TCP/IP
- MPID: daemon communication mode
- SHM: shared memory (intra host only)

If the table shows TCP for one or more hosts, it is possible that the host doesn't have appropriate network drivers installed.

If one or more hosts show considerably worse performance than another, it can often indicate a bad card or cable.

Other possible reasons for failure could be:

- A connection on the switch is running in 1X mode instead of 4X mode.
- A switch has degraded a port to SDR (assumes DDR switch, cards).
- A degraded SDR port could be due to using a non-DDR cable.

If the run aborts with some kind of error message, it's possible that HP-MPI incorrectly determined what interconnect was available. One common way to encounter this problem is to run a 32-bit application on a 64-bit machine like an Opteron or Intel®64. It's not uncommon for some network vendors to provide only 64-bit libraries.

HP-MPI determines which interconnect to use before it even knows the application's bitness. So in order to have proper network selection in that case, one must specify if the app is 32-bit when running on Opteron/Intel®64 machines.

```
% $MPI_ROOT/bin/mpirun -mpi32 ...
```

Testing the network on Windows

Often, clusters might have both ethernet and some form of higher-speed interconnect such as InfiniBand. This section describes how to use the ping_pong_ring.c example program to confirm that you are able to run using the desired interconnect.

Running a test like this, especially on a new cluster, is useful to ensure that the appropriate network drivers are installed and that the network hardware is functioning properly. If any machine has defective network cards or cables, this test can also be useful for identifying which machine has the problem.

To compile the program, set the `MPI_ROOT` environment variable to the location of HP-MPI. The default is "C:\Program Files (x86)\Hewlett-Packard\HP-MPI" for 6-bit systems, and "C:\Program Files \Hewlett-Packard\HP-MPI" for 32-bit systems. This may already be set by the HP-MPI install.

Open a command window for the compiler you plan on using. This will include all libraries and compilers in path, and compile the program using the **mpicc** wrappers:

```
 > "%MPI_ROOT%\bin\mpicc" -mpi64 /out:pp.exe ^
"%MPI_ROOT%\help\ping_ping_ring.c"
```

Use the startup that is appropriate for your cluster. Your situation should resemble one of the following:

If running on Windows CCS using automatic scheduling:

Submit the command to the scheduler, but include the total number of processes needed on the nodes as the `-np` command. This is **NOT** the rank count when used in this fashion. Also include the `-nodex` flag to indicate only one rank/node.

Assume we have 4 CPUs/nodes in this cluster. The command would be:

```
> "%MPI_ROOT%\bin\mpirun" -ccp -np 12 -IBAL -nodex -prot ^
ping_ping_ring.exe
```

```
> "%MPI_ROOT%\bin\mpirun" -ccp -np 12 -IBAL -nodex -prot ^
ping_ping_ring.exe 10000
```

In each case above, the first **mpirun** uses 0 bytes per message and is checking latency. The second **mpirun** uses 1000000 bytes per message and is checking bandwidth.

Example output might look like:

```
Host 0 -- ip 172.16.159.3 -- ranks 0
Host 1 -- ip 172.16.150.23 -- ranks 1
Host 2 -- ip 172.16.150.24 -- ranks 2

host | 0    1    2
=====|================
   0 : SHM  IBAL IBAL
   1 : IBAL SHM  IBAL
   2 : IBAL IBAL SHM

[0:mpiccp3] ping-pong 1000000 bytes ...
1000000 bytes: 1089.29 usec/msg
1000000 bytes: 918.03 MB/sec
[1:mpiccp4] ping-pong 1000000 bytes ...
1000000 bytes: 1091.99 usec/msg
1000000 bytes: 915.76 MB/sec
[2:mpiccp5] ping-pong 1000000 bytes ...
1000000 bytes: 1084.63 usec/msg
1000000 bytes: 921.97 MB/sec
```

The table showing SHM/IBAL is printed because of the `-prot` option (print protocol) specified in the **mpirun** command.

It could show any of the following settings:
IBAL: IBAL on InfiniBand
TCP: TCP/IP
MPID: daemon communication mode
SHM: shared memory (intra host only)

If one or more hosts show considerably worse performance than another, it can often indicate a bad card or cable.

If the run aborts with some kind of error message, it is possible that HP-MPI incorrectly determined which interconnect was available.

A Example applications

This appendix provides example applications that supplement the conceptual information throughout the rest of this book about MPI in general and HP-MPI in particular. Table A-1 summarizes the examples in this appendix. The example codes are also included in the

`$MPI_ROOT/help` subdirectory in your HP-MPI product.

Table A-1 Example applications shipped with HP-MPI

Name	Language	Description	-np argument
send_receive.f	Fortran 77	Illustrates a simple send and receive operation.	-np >= 2
ping_pong.c	C	Measures the time it takes to send and receive data between two processes.	-np = 2
ping_pong_ring.c	C	Confirms that an app can run using the desired interconnect	-np >= 2
compute_pi.f	Fortran 77	Computes pi by integrating $f(x)=4/(1+x^2)$.	-np >= 1
master_worker.f90	Fortran 90	Distributes sections of an array and does computation on all sections in parallel.	-np >= 2
cart.C	C++	Generates a virtual topology.	-np = 4
communicator.c	C	Copies the default communicator `MPI_COMM_WORLD`.	-np = 2
multi_par.f	Fortran 77	Uses the alternating direction iterative (ADI) method on a 2-dimensional compute region.	-np >= 1

Table A-1 Example applications shipped with HP-MPI **(Continued)**

Name	Language	Description	-np argument
io.c	C	Writes data for each process to a separate file called iodata*x*, where *x represents each process rank in turn*. Then, the data in iodata*x* is read back.	-np >= 1
thread_safe.c	C	Tracks the number of client requests handled and prints a log of the requests to stdout.	-np >= 2
sort.C	C++	Generates an array of random integers and sorts it.	-np >= 1
compute_pi_spawn.f	Fortran 77	A single initial rank spawns 3 new ranks that all perform the same computation as in compute_pi.f	-np >= 1
ping_pong_clustertest.c	C	Identifies slower than average links in your high-speed interconnect	-np >2
hello_world.c	C	Prints host name and rank	-np >=1

These examples and the Makefile are located in the $MPI_ROOT/help subdirectory. The examples are presented for illustration purposes only. They may not necessarily represent the most efficient way to solve a given problem.

To build and run the examples follow the following procedure:

Step 1. Change to a writable directory.

Step 2. Copy all files from the help directory to the current writable directory:

```
% cp $MPI_ROOT/help/* .
```

Step 3. Compile all the examples or a single example.

To compile and run all the examples in the /help directory, at your prompt enter:

```
% make
```

To compile and run the thread_safe.c program only, at your prompt enter:

```
% make thread_safe
```

send_receive.f

In this Fortran 77 example, process 0 sends an array to other processes in the default communicator MPI_COMM_WORLD.

```
program main

include 'mpif.h'

integer rank, size, to, from, tag, count, i, ierr
integer src, dest
integer st_source, st_tag, st_count
integer status(MPI_STATUS_SIZE)
double precision data(100)

call MPI_Init(ierr)
call MPI_Comm_rank(MPI_COMM_WORLD, rank, ierr)
call MPI_Comm_size(MPI_COMM_WORLD, size, ierr)

if (size .eq. 1) then
        print *, 'must have at least 2 processes'
        call MPI_Finalize(ierr)
        stop
endif

print *, 'Process ', rank, ' of ', size, ' is alive'
dest = size - 1
src = 0

if (rank .eq. src) then
        to = dest
        count = 10
        tag = 2001

        do i=1, 10
                 data(i) = 1
        enddo

        call MPI_Send(data, count, MPI_DOUBLE_PRECISION,
+                      to, tag, MPI_COMM_WORLD, ierr)
endif

if (rank .eq. dest) then
         tag = MPI_ANY_TAG
         count = 10
         from = MPI_ANY_SOURCE
         call MPI_Recv(data, count, MPI_DOUBLE_PRECISION,
+                      from, tag, MPI_COMM_WORLD, status, ierr)


call MPI_Get_Count(status, MPI_DOUBLE_PRECISION,
+                           st_count, ierr)
```

```
st_source = status(MPI_SOURCE)
st_tag = status(MPI_TAG)

print *, 'Status info: source = ', st_source,
+                  ' tag = ', st_tag, ' count = ', st_count
print *, rank, ' received', (data(i),i=1,10)

endif

call MPI_Finalize(ierr)
stop
end
```

send_receive output

The output from running the send_receive executable is shown below. The application was run with `-np` = 10.

```
Process  0 of  10 is alive
Process  1 of  10 is alive
Process  2 of  10 is alive
Process  3 of  10 is alive
Process  4 of  10 is alive
Process  5 of  10 is alive
Process  6 of  10 is alive
Process  7 of  10 is alive
Process  8 of  10 is alive
Process  9 of  10 is alive
Status info: source =  0 tag =  2001 count =  10
9 received 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.
```

ping_pong.c

This C example is used as a performance benchmark to measure the amount of time it takes to send and receive data between two processes. The buffers are aligned and offset from each other to avoid cache conflicts caused by direct process-to-process byte-copy operations

To run this example:

- Define the CHECK macro to check data integrity.
- Increase the number of bytes to at least twice the cache size to obtain representative bandwidth measurements.

```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <mpi.h>


#define NLOOPS          1000
#define ALIGN           4096

main(argc, argv)
int                     argc;
char                    *argv[];

{
int             i, j;
        double          start, stop;
        int             nbytes = 0;
        int             rank, size;
        MPI_Status      status;
        char            *buf;

        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &size);

        if (size != 2) {

                   if ( ! rank) printf("ping_pong: must have two
processes\n");
                   MPI_Finalize();
                   exit(0);
        }

        nbytes = (argc > 1) ? atoi(argv[1]) : 0;
        if (nbytes < 0) nbytes = 0;


/*
```

```
* Page-align buffers and displace them in the cache to avoid
collisions.
*/

        buf = (char *) malloc(nbytes + 524288 + (ALIGN - 1));
        if (buf == 0) {
                   MPI_Abort(MPI_COMM_WORLD, MPI_ERR_BUFFER);
                   exit(1);
        }

        buf = (char *) (((unsigned long) buf) + (ALIGN - 1)) &
~(ALIGN - 1));
        if (rank == 1) buf += 524288;
        memset(buf, 0, nbytes);

/*
* Ping-pong.
*/

        if (rank == 0) {
                   printf("ping-pong %d bytes ...\n", nbytes);
/*
* warm-up loop
*/

                   for (i = 0; i < 5; i++) {
                        MPI_Send(buf, nbytes, MPI_CHAR, 1, 1,
MPI_COMM_WORLD);
                        MPI_Recv(buf, nbytes, MPI_CHAR,1, 1,
                                               MPI_COMM_WORLD,
&status);
                   }
/*
* timing loop
*/

        start = MPI_Wtime();
        for (i = 0; i < NLOOPS; i++) {
#ifdef CHECK
                   for (j = 0; j < nbytes; j++) buf[j] = (char)
(j + i);
#endif
                   MPI_Send(buf, nbytes, MPI_CHAR,1, 1000 + i,
MPI_COMM_WORLD);
#ifdef CHECK
                   memset(buf, 0, nbytes);
#endif
                   MPI_Recv(buf, nbytes, MPI_CHAR,1, 2000 + i,

MPI_COMM_WORLD,&status);
#ifdef CHECK
                  for (j = 0; j < nbytes; j++) {
                       if (buf[j] != (char) (j + i)) {
                              printf("error: buf[%d] = %d, not
%d\n",j,
                                    buf[j], j + i);
                              break;
                       }
                   }
#endif
        }
         stop = MPI_Wtime();

          printf("%d bytes: %.2f usec/msg\n",
                      nbytes, (stop - start) / NLOOPS / 2 *
1000000);

           if (nbytes > 0) {
                   printf("%d bytes: %.2f MB/sec\n",
nbytes,nbytes / 1000000./
                                       ((stop - start) / NLOOPS /
2));
           }
         }
         else {
/*
* warm-up loop
*/
         for (i = 0; i < 5; i++) {
                   MPI_Recv(buf, nbytes, MPI_CHAR,0, 1,
MPI_COMM_WORLD, &status);
                   MPI_Send(buf, nbytes, MPI_CHAR, 0, 1,
MPI_COMM_WORLD);
          }

          for (i = 0; i < NLOOPS; i++) {
                   MPI_Recv(buf, nbytes, MPI_CHAR,0, 1000 + i,

MPI_COMM_WORLD,&status);
                   MPI_Send(buf, nbytes, MPI_CHAR,0, 2000 + i,
MPI_COMM_WORLD);
           }
       }
       MPI_Finalize();
       exit(0);
}
```

ping_pong output

The output from running the ping_pong executable is shown below. The application was run with `-np2`.

```
ping-pong 0 bytes ...
0 bytes: 1.03 usec/msg
```

ping_pong_ring.c (HP-UX and Linux)

Often a cluster might have both regular ethernet and some form of higher speed interconnect such as InfiniBand. This section describes how to use the ping_pong_ring.c example program to confirm that you are able to run using the desired interconnect.

Running a test like this, especially on a new cluster, is useful to ensure that the appropriate network drivers are installed and that the network hardware is functioning properly. If any machine has defective network cards or cables, this test can also be useful at identifying which machine has the problem.

To compile the program, set the `MPI_ROOT` environment variable (not required, but recommended) to a value such as `/opt/hpmpi` (Linux) or `/opt/mpi` (HP-UX), then run

`%` **`export MPI_CC=gcc`** (whatever compiler you want)

```
% $MPI_ROOT/bin/mpicc -o pp.x \
$MPI_ROOT/help/ping_pong_ring.c
```

Although `mpicc` will perform a search for what compiler to use if you don't specify `MPI_CC`, it is preferable to be explicit.

If you have a shared filesystem, it is easiest to put the resulting `pp.x` executable there, otherwise you will have to explicitly copy it to each machine in your cluster.

As discussed elsewhere, there are a variety of supported startup methods, and you need to know which is appropriate for your cluster. Your situation should resemble one of the following:

- No `srun`, `prun`, or CCS job scheduler command is available

  For this case you can create an appfile such as the following:

```
-h hostA -np 1 /path/to/pp.x
-h hostB -np 1 /path/to/pp.x
-h hostC -np 1 /path/to/pp.x
...
-h hostZ -np 1 /path/to/pp.x
```

  And you can specify what remote shell command to use (Linux default is ssh) in the `MPI_REMSH` environment variable.

  For example you might want

% **export MPI_REMSH="rsh -x"** (optional)

Then run

% **$MPI_ROOT/bin/mpirun -prot -f appfile**

% **$MPI_ROOT/bin/mpirun -prot -f appfile -- 1000000**

Or if LSF is being used, then the hostnames in the appfile wouldn't matter, and the command to run would be

% **bsub pam -mpi $MPI_ROOT/bin/mpirun -prot -f appfile**

% **bsub pam -mpi $MPI_ROOT/bin/mpirun -prot -f appfile \
-- 1000000**

- The `srun` command is available

  For this case then you would run a command like

  % **$MPI_ROOT/bin/mpirun -prot -srun -N 8 -n 8 /path/to/pp.x**

  % **$MPI_ROOT/bin/mpirun -prot -srun -N 8 -n 8 /path/to/ \
pp.x 1000000**

  replacing "8" with the number of hosts.

  Or if LSF is being used, then the command to run might be

  % **bsub -I -n 16 $MPI_ROOT/bin/mpirun -prot -srun \
/path/to/pp.x**

  % **bsub -I -n 16 $MPI_ROOT/bin/mpirun -prot -srun \
/path/to/pp.x 1000000**

- The `prun` command is available

  This case is basically identical to the `srun` case with the obvious change of using `prun` in place of `srun`.

In each case above, the first `mpirun` uses 0-bytes of data per message and is for checking latency. The second `mpirun` uses 1000000 bytes per message and is for checking bandwidth.

```
#include <stdio.h>
#include <stdlib.h>
#ifndef _WIN32
#include <unistd.h>
#endif
#include <string.h>
#include <math.h>
#include <mpi.h>
```

```
#define NLOOPS      1000
#define ALIGN       4096

#define SEND(t)    MPI_Send(buf, nbytes, MPI_CHAR, partner, (t), \
                  MPI_COMM_WORLD)
#define RECV(t)   MPI_Recv(buf, nbytes, MPI_CHAR, partner, (t), \
                  MPI_COMM_WORLD, &status)
#ifdef CHECK
#   define SETBUF()for (j=0; j<nbytes; j++) { \
                   buf[j] = (char) (j + i); \
             }

#   define CLRBUF()memset(buf, 0, nbytes)
#   define CHKBUF()for (j = 0; j < nbytes; j++) { \
                   if (buf[j] != (char) (j + i)) { \
                        printf("error: buf[%d] = %d, " \
                             "not %d\n", \
                             j, buf[j], j + i); \
                       break; \

                   } \

             }

#else
#   define SETBUF()
#   define CLRBUF()
#   define CHKBUF()
#endif

int
main(argc, argv)

int              argc;
char            *argv[];

{
     int          i;
#ifdef CHECK
     int          j;

#endif
     double            start, stop;
     intn         bytes = 0;
     int          rank, size;
     int          root;
     int          partner;
     MPI_Status   status;
     char         *buf, *obuf;
     char         myhost[MPI_MAX_PROCESSOR_NAME];
     int          len;
     char         str[1024];

     MPI_Init(&argc, &argv);
     MPI_Comm_rank(MPI_COMM_WORLD, &rank);
     MPI_Comm_size(MPI_COMM_WORLD, &size);
     MPI_Get_processor_name(myhost, &len);
```

```
        if (size < 2) {
           if ( ! rank) printf("rping: must have two+ processes\n");
           MPI_Finalize();
           exit(0);
        }

        nbytes = (argc > 1) ? atoi(argv[1]) : 0;
        if (nbytes < 0) nbytes = 0;

   /*
    * Page-align buffers and displace them in the cache to avoid
        collisions.
    */
        buf = (char *) malloc(nbytes + 524288 + (ALIGN - 1));
        obuf = buf;
        if (buf == 0) {
              MPI_Abort(MPI_COMM_WORLD, MPI_ERR_BUFFER);
              exit(1);
        }

        buf = (char *) ((((unsigned long) buf) + (ALIGN - 1)) &
           ~(ALIGN - 1));
        if (rank > 0) buf += 524288;
        memset(buf, 0, nbytes);
   /*
    * Ping-pong.
    */
         for (root=0; root<size; root++) {
               if (rank == root) {
                   partner = (root + 1) % size;
                   sprintf(str, "[%d:%s] ping-pong %d bytes ...\n",
                        root, myhost, nbytes);
   /*
    * warm-up loop
    */

                    for (i = 0; i < 5; i++) {
                          SEND(1);
                          RECV(1);
                 }

   /*
    * timing loop
    */
                start = MPI_Wtime();
               for (i = 0; i < NLOOPS; i++) {
                    SETBUF();
                    SEND(1000 + i);
                    CLRBUF();
                    RECV(2000 + i);
                   CHKBUF();
               }
               stop = MPI_Wtime();

               sprintf(&str[strlen(str)],
                    "%d bytes: %.2f usec/msg\n", nbytes,
                    (stop - start) / NLOOPS / 2 * 1024 * 1024);
```

```
            if (nbytes > 0) {
                 sprintf(&str[strlen(str)],
                     "%d bytes: %.2f MB/sec\n", nbytes,
                     nbytes / (1024. * 1024.) /
                    ((stop - start) / NLOOPS / 2));
            }
            fflush(stdout);
      } else if (rank == (root+1)%size) {
/*
 * warm-up loop
 */
            partner = root;
            for (i = 0; i < 5; i++) {
                 RECV(1);
                 SEND(1);
            }
           for (i = 0; i < NLOOPS; i++) {
                CLRBUF();
                RECV(1000 + i);
                CHKBUF();
                SETBUF();
                SEND(2000 + i);
            }
       }

       MPI_Bcast(str, 1024, MPI_CHAR, root, MPI_COMM_WORLD);
       if (rank == 0) {
              printf("%s", str);
       }
    }

    free(obuf);
    MPI_Finalize();
    exit(0);

}
```

ping_pong_ring.c output

Example output might look like:

```
> Host 0 -- ip 192.168.9.10 -- ranks 0
> Host 1 -- ip 192.168.9.11 -- ranks 1
> Host 2 -- ip 192.168.9.12 -- ranks 2
> Host 3 -- ip 192.168.9.13 -- ranks 3
>
>  host | 0    1    2    3
> ======|=====================
>     0 : SHM  VAPI VAPI VAPI
>     1 : VAPI SHM  VAPI VAPI
>     2 : VAPI VAPI SHM  VAPI
>     3 : VAPI VAPI VAPI SHM
>
> [0:hostA] ping-pong 0 bytes ...
> 0 bytes: 4.57 usec/msg
> [1:hostB] ping-pong 0 bytes ...
> 0 bytes: 4.38 usec/msg
> [2:hostC] ping-pong 0 bytes ...
> 0 bytes: 4.42 usec/msg
> [3:hostD] ping-pong 0 bytes ...
> 0 bytes: 4.42 usec/msg
```

The table showing SHM/VAPI is printed because of the "`-prot`" option (print protocol) specified in the `mpirun` command. In general, it could show any of the following settings:

VAPI: InfiniBand

UDAPL: InfiniBand

IBV: InfiniBand

PSM: InfiniBand

MX: Myrinet MX

IBAL: InfiniBand (on Windows only)

IT: IT-API on InfiniBand

GM: Myrinet GM2

ELAN: Quadrics Elan4

TCP: TCP/IP

MPID: commd

SHM: Shared Memory (intra host only)

If the table shows TCP/IP for one or more hosts, it is possible that the host doesn't have the appropriate network drivers installed.

If one or more hosts show considerably worse performance than another, it can often indicate a bad card or cable.

If the run aborts with some kind of error message, it is possible that HP-MPI determined incorrectly what interconnect was available. One common way to encounter this problem is to run a 32-bit application on a 64-bit machine like an Opteron or Intel®64. It is not uncommon for the network vendors for InfiniBand and others to only provide 64-bit libraries for their network.

HP-MPI makes its decision about what interconnect to use before it even knows the application's bitness. In order to have proper network selection in that case, one must specify if the app is 32-bit when running on Opteron and Intel®64 machines:

```
% $MPI_ROOT/bin/mpirun -mpi32 ...
```

ping_pong_ring.c (Windows)

Often, clusters might have both ethernet and some form of higher-speed interconnect such as InfiniBand. This section describes how to use the ping_pong_ring.c example program to confirm that you are able to run using the desired interconnect.

Running a test like this, especially on a new cluster, is useful to ensure that the appropriate network drivers are installed and that the network hardware is functioning properly. If any machine has defective network cards or cables, this test can also be useful for identifying which machine has the problem.

To compile the program, set the `MPI_ROOT` environment variable to the location of HP-MPI. The default is "C:\Program Files (x86)\Hewlett-Packard\HP-MPI" for 64-bit systems, and "C:\Program Files\Hewlett-Packard\HP-MPI" for 32-bit systems. This may already be set by the HP-MPI install.

Open a command window for the compiler you plan on using. This will include all libraries and compilers in path, and compile the program using the **mpicc** wrappers:

```
> "%MPI_ROOT%\bin\mpicc" -mpi64 /out:pp.exe ^
"%MPI_ROOT%\help\ping_ping_ring.c"
```

Use the startup that is appropriate for your cluster. Your situation should resemble one of the following:

If running on Windows CCS using automatic scheduling:

Submit the command to the scheduler, but include the total number of processes needed on the nodes as the `-np` command. This is **NOT** the rank count when used in this fashion. Also include the `-nodex` flag to indicate only one rank/node.

Assume we have 4 CPUs/nodes in this cluster. The command would be:

```
> "%MPI_ROOT%\bin\mpirun" -ccp -np 12 -IBAL -nodex -prot ^
ping_ping_ring.exe
```

```
> "%MPI_ROOT%\bin\mpirun" -ccp -np 12 -IBAL -nodex -prot ^
ping_ping_ring.exe 10000
```

In each case above, the first **mpirun** uses 0 bytes per message and is checking latency. The second **mpirun** uses 1000000 bytes per message and is checking bandwidth.

```
#include <stdio.h>
#include <stdlib.h>
#ifndef _WIN32
#include <unistd.h>
#endif
#include <string.h>
#include <math.h>
#include <mpi.h>


#define NLOOPS     1000
#define ALIGN      4096

#define SEND(t)    MPI_Send(buf, nbytes, MPI_CHAR, partner, (t), \
                  MPI_COMM_WORLD)
#define RECV(t)   MPI_Recv(buf, nbytes, MPI_CHAR, partner, (t), \
                  MPI_COMM_WORLD, &status)
#ifdef CHECK
#   define SETBUF()for (j=0; j<nbytes; j++) { \
                   buf[j] = (char) (j + i); \
             }

#   define CLRBUF()memset(buf, 0, nbytes)
#   define CHKBUF()for (j = 0; j < nbytes; j++) { \
                   if (buf[j] != (char) (j + i)) { \
                        printf("error: buf[%d] = %d, " \
                             "not %d\n", \
                             j, buf[j], j + i); \
                       break; \

                   } \

             }

#else
#   define SETBUF()
#   define CLRBUF()
#   define CHKBUF()
#endif

int
main(argc, argv)

int               argc;
char             *argv[];

{
     int          i;
#ifdef CHECK
     int          j;

#endif
     double            start, stop;
     intn         bytes = 0;
```

```
        int         rank, size;
        int         root;
        int         partner;
        MPI_Status  status;
        char        *buf, *obuf;
        char        myhost[MPI_MAX_PROCESSOR_NAME];
        int         len;
        char        str[1024];

        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &size);
        MPI_Get_processor_name(myhost, &len);

        if (size < 2) {
           if ( ! rank) printf("rping: must have two+ processes\n");
           MPI_Finalize();
           exit(0);

        }

        nbytes = (argc > 1) ? atoi(argv[1]) : 0;
        if (nbytes < 0) nbytes = 0;

/*
 * Page-align buffers and displace them in the cache to avoid
        collisions.
 */
        buf = (char *) malloc(nbytes + 524288 + (ALIGN - 1));
        obuf = buf;
        if (buf == 0) {
              MPI_Abort(MPI_COMM_WORLD, MPI_ERR_BUFFER);
              exit(1);
        }

        buf = (char *) ((((unsigned long) buf) + (ALIGN - 1)) &
           ~(ALIGN - 1));
        if (rank > 0) buf += 524288;
        memset(buf, 0, nbytes);
/*
 * Ping-pong.
 */
         for (root=0; root<size; root++) {
               if (rank == root) {
                   partner = (root + 1) % size;
                   sprintf(str, "[%d:%s] ping-pong %d bytes ...\n",
                        root, myhost, nbytes);
/*
 * warm-up loop
 */

                    for (i = 0; i < 5; i++) {
                          SEND(1);
                          RECV(1);
                 }

/*
 * timing loop
 */
```

```
                 start = MPI_Wtime();
                for (i = 0; i < NLOOPS; i++) {
                     SETBUF();
                     SEND(1000 + i);
                     CLRBUF();
                     RECV(2000 + i);
                    CHKBUF();
                }
                stop = MPI_Wtime();

                sprintf(&str[strlen(str)],
                     "%d bytes: %.2f usec/msg\n", nbytes,
                     (stop - start) / NLOOPS / 2 * 1024 * 1024);
                if (nbytes > 0) {
                     sprintf(&str[strlen(str)],
                         "%d bytes: %.2f MB/sec\n", nbytes,
                         nbytes / (1024. * 1024.) /
                        ((stop - start) / NLOOPS / 2));
                }
                fflush(stdout);
          } else if (rank == (root+1)%size) {
/*
 * warm-up loop
 */
                partner = root;
                for (i = 0; i < 5; i++) {
                     RECV(1);
                     SEND(1);
                }
               for (i = 0; i < NLOOPS; i++) {
                    CLRBUF();
                    RECV(1000 + i);
                    CHKBUF();
                    SETBUF();
                    SEND(2000 + i);
                }
          }

          MPI_Bcast(str, 1024, MPI_CHAR, root, MPI_COMM_WORLD);
          if (rank == 0) {
                 printf("%s", str);
          }
    }

    free(obuf);
    MPI_Finalize();
    exit(0);

}
```

ping_pong_ring.c output

Example output might look like:

```
Host 0 -- ip 172.16.159.3 -- ranks 0
Host 1 -- ip 172.16.150.23 -- ranks 1
Host 2 -- ip 172.16.150.24 -- ranks 2

host | 0    1    2
=====|================
   0 : SHM  IBAL IBAL
   1 : IBAL SHM  IBAL
   2 : IBAL IBAL SHM

[0:mpiccp3] ping-pong 1000000 bytes ...
1000000 bytes: 1089.29 usec/msg
1000000 bytes: 918.03 MB/sec
[1:mpiccp4] ping-pong 1000000 bytes ...
1000000 bytes: 1091.99 usec/msg
1000000 bytes: 915.76 MB/sec
[2:mpiccp5] ping-pong 1000000 bytes ...
1000000 bytes: 1084.63 usec/msg
1000000 bytes: 921.97 MB/sec
```

The table showing SHM/IBAL is printed because of the `-prot` option (print protocol) specified in the **`mpirun`** command.

It could show any of the following settings:
  IBAL: IBAL on InfiniBand
  TCP: TCP/IP
  MPID: daemon communication mode
  SHM: shared memory (intra host only)

If one or more hosts show considerably worse performance than another, it can often indicate a bad card or cable.

If the run aborts with some kind of error message, it is possible that HP-MPI incorrectly determined which interconnect was available.

compute_pi.f

This Fortran 77 example computes pi by integrating f(x) = 4/(1 + x^2). Each process:

- Receives the number of intervals used in the approximation
- Calculates the areas of its rectangles
- Synchronizes for a global summation

Process 0 prints the result of the calculation.

```
program main

      include 'mpif.h'

      double precision PI25DT
      parameter(PI25DT = 3.141592653589793238462643d0)

      double precision  mypi, pi, h, sum, x, f, a
      integer n, myid, numprocs, i, ierr
C
C Function to integrate
C
      f(a) = 4.d0 / (1.d0 + a*a)
      call MPI_INIT(ierr)
      call MPI_COMM_RANK(MPI_COMM_WORLD, myid, ierr)
      call MPI_COMM_SIZE(MPI_COMM_WORLD, numprocs, ierr)
      print *, "Process ", myid, " of ", numprocs, " is alive"

      sizetype = 1
      sumtype = 2

      if (myid .eq. 0) then
              n = 100
      endif

      call MPI_BCAST(n, 1, MPI_INTEGER, 0, MPI_COMM_WORLD, ierr)
C
C Calculate the interval size.
C
      h = 1.0d0 / n
      sum  = 0.0d0

      do 20 i = myid + 1, n, numprocs
              x = h * (dble(i) - 0.5d0)
              sum = sum + f(x)
 20   continue


      mypi = h * sum
```

```
C
C Collect all the partial sums.
C
      call MPI_REDUCE(mypi, pi, 1, MPI_DOUBLE_PRECISION,
     +                MPI_SUM, 0, MPI_COMM_WORLD, ierr)
C
C Process 0 prints the result.
C
      if (myid .eq. 0) then
              write(6, 97) pi, abs(pi - PI25DT)
 97           format('  pi is approximately: ', F18.16,
     +               '  Error is: ', F18.16)
      endif

      call MPI_FINALIZE(ierr)

      stop
      end
```

compute_pi output

The output from running the compute_pi executable is shown below. The application was run with -np = 10.

```
Process  0 of  10 is alive
Process  1 of  10 is alive
Process  2 of  10 is alive
Process  3 of  10 is alive
Process  4 of  10 is alive
Process  5 of  10 is alive
Process  6 of  10 is alive
Process  7 of  10 is alive
Process  8 of  10 is alive
Process  9 of  10 is alive
pi is approximately: 3.1416009869231249
Error is: 0.0000083333333318
```

master_worker.f90

In this Fortran 90 example, a master task initiates (numtasks - 1) number of worker tasks. The master distributes an equal portion of an array to each worker task. Each worker task receives its portion of the array and sets the value of each element to (the element's index + 1). Each worker task then sends its portion of the modified array back to the master.

```
program array_manipulation
  include 'mpif.h'

  integer (kind=4) :: status(MPI_STATUS_SIZE)
  integer (kind=4), parameter :: ARRAYSIZE = 10000, MASTER = 0
  integer (kind=4) :: numtasks, numworkers, taskid, dest, index,
i
  integer (kind=4) :: arraymsg, indexmsg, source, chunksize,
int4, real4
  real (kind=4) :: data(ARRAYSIZE), result(ARRAYSIZE)
  integer (kind=4) :: numfail, ierr

  call MPI_Init(ierr)
  call MPI_Comm_rank(MPI_COMM_WORLD, taskid, ierr)
  call MPI_Comm_size(MPI_COMM_WORLD, numtasks, ierr)
  numworkers = numtasks - 1
  chunksize = (ARRAYSIZE / numworkers)
  arraymsg = 1
  indexmsg = 2
  int4 = 4
  real4 = 4
  numfail = 0

! ******************************** Master task
******************************
  if (taskid .eq. MASTER) then
     data = 0.0
     index = 1
     do dest = 1, numworkers
        call MPI_Send(index, 1, MPI_INTEGER, dest, 0,
MPI_COMM_WORLD, ierr)
        call MPI_Send(data(index), chunksize, MPI_REAL, dest, 0,
&
             MPI_COMM_WORLD, ierr)
        index = index + chunksize
     end do

     do i = 1, numworkers
        source = i
        call MPI_Recv(index, 1, MPI_INTEGER, source, 1,
MPI_COMM_WORLD, &
             status, ierr)
        call MPI_Recv(result(index), chunksize, MPI_REAL, source,
1, &
             MPI_COMM_WORLD, status, ierr)
     end do

     do i = 1, numworkers*chunksize
        if (result(i) .ne. (i+1)) then
           print *, 'element ', i, ' expecting ', (i+1), ' actual
is ', result(i)
           numfail = numfail + 1
        endif
     enddo

     if (numfail .ne. 0) then
        print *, 'out of ', ARRAYSIZE, ' elements, ', numfail, '
wrong answers'
     else
        print *, 'correct results!'
     endif
  end if

! ******************************* Worker task
*******************************
  if (taskid .gt. MASTER) then
     call MPI_Recv(index, 1, MPI_INTEGER, MASTER, 0,
MPI_COMM_WORLD, &
          status, ierr)
     call MPI_Recv(result(index), chunksize, MPI_REAL, MASTER, 0,
&
          MPI_COMM_WORLD, status, ierr)

     do i = index, index + chunksize - 1
        result(i) = i + 1
     end do

     call MPI_Send(index, 1, MPI_INTEGER, MASTER, 1,
MPI_COMM_WORLD, ierr)
     call MPI_Send(result(index), chunksize, MPI_REAL, MASTER, 1,
&
          MPI_COMM_WORLD, ierr)
  end if

  call MPI_Finalize(ierr)

end program array_manipulation
```

master_worker output

The output from running the master_worker executable is shown below. The application was run with -np = 2.

```
correct results!
```

cart.C

This C++ program generates a virtual topology. The class Node represents a node in a 2-D torus. Each process is assigned a node or nothing. Each node holds integer data, and the shift operation exchanges the data with its neighbors. Thus, north-east-south-west shifting returns the initial data.

```
#include <stdio.h>
#include <mpi.h>

#define NDIMS   2

typedef enum { NORTH, SOUTH, EAST, WEST } Direction;

// A node in 2-D torus
class Node {
private:
  MPI_Comm      comm;
  int           dims[NDIMS], coords[NDIMS];
  int           grank, lrank;
  int           data;
public:
  Node(void);
  ~Node(void);
  void profile(void);
  void print(void);
  void shift(Direction);
};

// A constructor
Node::Node(void)
{
  int i, nnodes, periods[NDIMS];

  // Create a balanced distribution
  MPI_Comm_size(MPI_COMM_WORLD, &nnodes);
  for (i = 0; i < NDIMS; i++) { dims[i] = 0; }
  MPI_Dims_create(nnodes, NDIMS, dims);

  // Establish a cartesian topology communicator
  for (i = 0; i < NDIMS; i++) { periods[i] = 1; }
  MPI_Cart_create(MPI_COMM_WORLD, NDIMS, dims, periods, 1,
&comm);

 // Initialize the data
  MPI_Comm_rank(MPI_COMM_WORLD, &grank);
  if (comm == MPI_COMM_NULL) {
    lrank = MPI_PROC_NULL;
    data = -1;
  } else {
    MPI_Comm_rank(comm, &lrank);
```

```
      data = lrank;
      MPI_Cart_coords(comm, lrank, NDIMS, coords);
    }
  }

  // A destructor
  Node::~Node(void)
  {
    if (comm != MPI_COMM_NULL) {
      MPI_Comm_free(&comm);
    }
  }

  // Shift function
  void Node::shift(Direction dir)
  {
    if (comm == MPI_COMM_NULL) { return; }

    int direction, disp, src, dest;

    if (dir == NORTH) {
      direction = 0; disp = -1;
    } else if (dir == SOUTH) {
      direction = 0; disp = 1;
    } else if (dir == EAST) {
      direction = 1; disp = 1;
    } else {
      direction = 1; disp = -1;
    }
    MPI_Cart_shift(comm, direction, disp, &src, &dest);
    MPI_Status stat;
    MPI_Sendrecv_replace(&data, 1, MPI_INT, dest, 0, src, 0, comm,
  &stat);
  }
  // Synchronize and print the data being held

  void Node::print(void)
  {
    if (comm != MPI_COMM_NULL) {
      MPI_Barrier(comm);
      if (lrank == 0) { puts(""); } // line feed
      MPI_Barrier(comm);
      printf("(%d, %d) holds %d\n", coords[0], coords[1], data);
    }
  }

  // Print object's profile
  void Node::profile(void)
  {
    // Non-member does nothing
    if (comm == MPI_COMM_NULL) { return; }

    // Print "Dimensions" at first
    if (lrank == 0) {
      printf("Dimensions: (%d, %d)\n", dims[0], dims[1]);
    }
    MPI_Barrier(comm);

    // Each process prints its profile
    printf("global rank %d: cartesian rank %d, coordinate (%d,
  %d)\n",
           grank, lrank, coords[0], coords[1]);
  }

  // Program body
  //
  // Define a torus topology and demonstrate shift operations.
  //

  void body(void)
  {
    Node node;

    node.profile();

    node.print();

    node.shift(NORTH);
    node.print();
    node.shift(EAST);
    node.print();
    node.shift(SOUTH);
    node.print();
    node.shift(WEST);
    node.print();
  }
  //
  // Main program---it is probably a good programming practice to
  call
  //   MPI_Init() and MPI_Finalize() here.
  //
  int main(int argc, char **argv)
  {
    MPI_Init(&argc, &argv);
    body();
    MPI_Finalize();
  }
```

cart output

The output from running the cart executable is shown below. The application was run with `-np` = 4.

```
Dimensions: (2, 2)
global rank 0: cartesian rank 0, coordinate (0, 0)
global rank 1: cartesian rank 1, coordinate (0, 1)
global rank 3: cartesian rank 3, coordinate (1, 1)
global rank 2: cartesian rank 2, coordinate (1, 0)

(0, 0) holds 0
(1, 0) holds 2
```

```
(1, 1) holds 3
(0, 1) holds 1

(0, 0) holds 2
(1, 0) holds 0
(0, 1) holds 3
(1, 1) holds 1

(0, 0) holds 3
(0, 1) holds 2
(1, 0) holds 1
(1, 1) holds 0

(0, 0) holds 1
(1, 0) holds 3
(0, 1) holds 0
(1, 1) holds 2

(0, 0) holds 0
(1, 0) holds 2
(0, 1) holds 1
(1, 1) holds 3
```

communicator.c

This C example shows how to make a copy of the default communicator `MPI_COMM_WORLD` using `MPI_Comm_dup`.

```
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>

int
main(argc, argv)

int                     argc;
char                    *argv[];

{
        int             rank, size, data;
        MPI_Status      status;
        MPI_Comm        libcomm;

        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &size);

        if (size != 2) {
                if ( ! rank) printf("communicator: must have two
processes\n");
                MPI_Finalize();
                exit(0);
        }

        MPI_Comm_dup(MPI_COMM_WORLD, &libcomm);

        if (rank == 0) {
                data = 12345;
                MPI_Send(&data, 1, MPI_INT, 1, 5,
MPI_COMM_WORLD);
                data = 6789;
                MPI_Send(&data, 1, MPI_INT, 1, 5, libcomm);
        } else {
                MPI_Recv(&data, 1, MPI_INT, 0, 5, libcomm,
&status);
                printf("received libcomm data = %d\n", data);
                MPI_Recv(&data, 1, MPI_INT, 0, 5, MPI_COMM_WORLD,
&status);
                printf("received data = %d\n", data);
        }

        MPI_Comm_free(&libcomm);
        MPI_Finalize();
        return(0);
}
```

communicator output

The output from running the communicator executable is shown below. The application was run with `-np` = 2.

```
received libcomm data = 6789
received data = 12345
```

multi_par.f

The Alternating Direction Iterative (ADI) method is often used to solve differential equations. In this example, multi_par.f, a compiler that supports OPENMP directives is required in order to achieve multi-level parallelism.

multi_par.f implements the following logic for a 2-dimensional compute region:

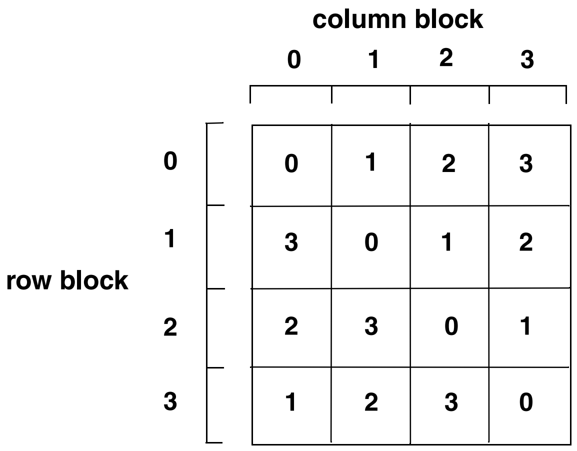
```
DO J=1,JMAX
  DO I=2,IMAX
    A(I,J)=A(I,J)+A(I-1,J)
  ENDDO
ENDDO

DO J=2,JMAX
  DO I=1,IMAX
    A(I,J)=A(I,J)+A(I,J-1)
  ENDDO
ENDDO
```

There are loop carried dependencies on the first dimension (array's row) in the first innermost DO loop and the second dimension (array's column) in the second outermost DO loop.

A simple method for parallelizing the fist outer-loop implies a partitioning of the array in column blocks, while another for the second outer-loop implies a partitioning of the array in row blocks.

With message-passing programming, such a method will require massive data exchange among processes because of the partitioning change. "Twisted data layout" partitioning is better in this case because the partitioning used for the parallelization of the first outer-loop can accommodate the other of the second outer-loop. The partitioning of the array is shown in Figure A-1.

Figure A-1 **Array partitioning**



In this sample program, the rank *n* process is assigned to the partition *n* at distribution initialization. Because these partitions are not contiguous-memory regions, MPI's derived datatype is used to define the partition layout to the MPI system.

Each process starts with computing summations in row-wise fashion. For example, the rank 2 process starts with the block that is on the 0th-row block and 2nd-column block (denoted as [0,2]).

The block computed in the second step is [1,3]. Computing the first row elements in this block requires the last row elements in the [0,3] block (computed in the first step in the rank 3 process). Thus, the rank 2 process receives the data from the rank 3 process at the beginning of the second step. Note that the rank 2 process also sends the last row elements of the [0,2] block to the rank 1 process that computes [1,2] in the second step. By repeating these steps, all processes finish summations in row-wise fashion (the first outer-loop in the illustrated program).

The second outer-loop (the summations in column-wise fashion) is done in the same manner. For example, at the beginning of the second step for the column-wise summations, the rank 2 process receives data from the rank 1 process that computed the [3,0] block. The rank 2 process also sends the last column of the [2,0] block to the rank 3 process. Note that each process keeps the same blocks for both of the outer-loop computations.

This approach is good for distributed memory architectures on which repartitioning requires massive data communications that are expensive. However, on shared memory architectures, the partitioning of the compute region does not imply data distribution. The row- and column-block partitioning method requires just one synchronization at the end of each outer loop.

For distributed shared-memory architectures, the mix of the two methods can be effective. The sample program implements the twisted-data layout method with MPI and the row- and column-block partitioning method with OPENMP thread directives. In the first case, the data dependency is easily satisfied as each thread computes down a different set of columns. In the second case we still want to compute down the columns for cache reasons, but to satisfy the data dependency, each thread computes a different portion of the same column and the threads work left to right across the rows together.

```
      implicit none
      include 'mpif.h'
      integer nrow                    ! # of rows
      integer ncol                    ! # of columns
      parameter(nrow=1000,ncol=1000)
      double precision array(nrow,ncol) ! compute region
      integer blk                     ! block iteration counter
      integer rb                      ! row block number
      integer cb                      ! column block number
      integer nrb                     ! next row block number
      integer ncb                     ! next column block
number
      integer rbs(:)                  ! row block start
subscripts
      integer rbe(:)                  ! row block end
subscripts
      integer cbs(:)                  ! column block start
subscripts
      integer cbe(:)                  ! column block end
subscripts
      integer rdtype(:)               ! row block communication
datatypes
      integer cdtype(:)               ! column block
communication datatypes
      integer twdtype(:)              ! twisted distribution
```

```
datatypes
      integer ablen(:)                    ! array of block lengths
      integer adisp(:)                    ! array of displacements
      integer adtype(:)                   ! array of datatypes
      allocatable
rbs,rbe,cbs,cbe,rdtype,cdtype,twdtype,ablen,adisp,
     *     adtype
      integer rank                        ! rank iteration counter
      integer comm_size                   ! number of MPI processes
      integer comm_rank                   ! sequential ID of MPI
process
      integer ierr                        ! MPI error code
      integer mstat(mpi_status_size)      ! MPI function status
      integer src                         ! source rank
      integer dest                        ! destination rank
      integer dsize                       ! size of double
precision in bytes
double precision startt,endt,elapsed ! time keepers
external compcolumn,comprow       ! subroutines execute in
threads

c
c     MPI initialization
c
      call mpi_init(ierr)
      call mpi_comm_size(mpi_comm_world,comm_size,ierr)
      call mpi_comm_rank(mpi_comm_world,comm_rank,ierr)

c
c     Data initialization and start up
c
      if (comm_rank.eq.0) then
         write(6,*) 'Initializing',nrow,' x',ncol,' array...'
         call getdata(nrow,ncol,array)
         write(6,*) 'Start computation'
      endif
      call mpi_barrier(MPI_COMM_WORLD,ierr)
      startt=mpi_wtime()
c
c     Compose MPI datatypes for row/column send-receive
c
c     Note that the numbers from rbs(i) to rbe(i) are the indices
c     of the rows belonging to the i'th block of rows.  These
indices
c     specify a portion (the i'th portion) of a column and the
c     datatype rdtype(i) is created as an MPI contiguous datatype
c     to refer to the i'th portion of a column.  Note this is a
c     contiguous datatype because fortran arrays are stored
c     column-wise.
c
c     For a range of columns to specify portions of rows, the
situation
c     is similar:  the numbers from cbs(j) to cbe(j) are the
indices
c     of the columns belonging to the j'th block of columns.
These
```

```
c     indices specify a portion (the j'th portion) of a row, and
the
c     datatype cdtype(j) is created as an MPI vector datatype to
refer
c     to the j'th portion of a row.  Note this a vector datatype
c     because adjacent elements in a row are actually spaced nrow
c     elements apart in memory.
c

allocate(rbs(0:comm_size-1),rbe(0:comm_size-1),cbs(0:comm_size-1)
,
     *     cbe(0:comm_size-1),rdtype(0:comm_size-1),
     *     cdtype(0:comm_size-1),twdtype(0:comm_size-1))
      do blk=0,comm_size-1
         call blockasgn(1,nrow,comm_size,blk,rbs(blk),rbe(blk))
         call mpi_type_contiguous(rbe(blk)-rbs(blk)+1,
     *        mpi_double_precision,rdtype(blk),ierr)
         call mpi_type_commit(rdtype(blk),ierr)
         call blockasgn(1,ncol,comm_size,blk,cbs(blk),cbe(blk))
         call mpi_type_vector(cbe(blk)-cbs(blk)+1,1,nrow,
     *        mpi_double_precision,cdtype(blk),ierr)
         call mpi_type_commit(cdtype(blk),ierr)
      enddo



c     Compose MPI datatypes for gather/scatter
c
c     Each block of the partitioning is defined as a set of fixed
length
c     vectors.  Each process'es partition is defined as a struct
of such
c     blocks.
c
      allocate(adtype(0:comm_size-1),adisp(0:comm_size-1),
     *     ablen(0:comm_size-1))
      call mpi_type_extent(mpi_double_precision,dsize,ierr)
      do rank=0,comm_size-1
         do rb=0,comm_size-1
            cb=mod(rb+rank,comm_size)
            call
mpi_type_vector(cbe(cb)-cbs(cb)+1,rbe(rb)-rbs(rb)+1,
     *           nrow,mpi_double_precision,adtype(rb),ierr)
            call mpi_type_commit(adtype(rb),ierr)
            adisp(rb)=((rbs(rb)-1)+(cbs(cb)-1)*nrow)*dsize
            ablen(rb)=1
         enddo
         call mpi_type_struct(comm_size,ablen,adisp,adtype,
     *        twdtype(rank),ierr)
         call mpi_type_commit(twdtype(rank),ierr)
         do rb=0,comm_size-1
            call mpi_type_free(adtype(rb),ierr)
         enddo
      enddo
      deallocate(adtype,adisp,ablen)
```

```
c     Scatter initial data with using derived datatypes defined
above
c     for the partitioning.  MPI_send() and MPI_recv() will find
out the
c     layout of the data from those datatypes.  This saves
application
c     programs to manually pack/unpack the data, and more
importantly,
c     gives opportunities to the MPI system for optimal
communication
c     strategies.
c
      if (comm_rank.eq.0) then
         do dest=1,comm_size-1
            call
mpi_send(array,1,twdtype(dest),dest,0,mpi_comm_world,
     *           ierr)
         enddo
      else
         call
mpi_recv(array,1,twdtype(comm_rank),0,0,mpi_comm_world,
     *        mstat,ierr)
      endif

c
c     Computation
c
c     Sum up in each column.
c     Each MPI process, or a rank, computes blocks that it is
assigned.
c     The column block number is assigned in the variable 'cb'.
The
c     starting and ending subscripts of the column block 'cb' are
c     stored in 'cbs(cb)' and 'cbe(cb)', respectively.  The row
block
c     number is assigned in the variable 'rb'.  The starting and
ending
c     subscripts of the row block 'rb' are stored in 'rbs(rb)'
and
c     'rbe(rb)', respectively, as well.
      src=mod(comm_rank+1,comm_size)
      dest=mod(comm_rank-1+comm_size,comm_size)
      ncb=comm_rank
      do rb=0,comm_size-1
         cb=ncb
c
c     Compute a block.  The function will go thread-parallel if
the
c     compiler supports OPENMP directives.
c
         call compcolumn(nrow,ncol,array,
     *                   rbs(rb),rbe(rb),cbs(cb),cbe(cb))
         if (rb.lt.comm_size-1) then
c
c     Send the last row of the block to the rank that is to
compute the
```

```
c     block next to the computed block.  Receive the last row of
the
c     block that the next block being computed depends on.
c
            nrb=rb+1
            ncb=mod(nrb+comm_rank,comm_size)
            call
mpi_sendrecv(array(rbe(rb),cbs(cb)),1,cdtype(cb),dest,
     *
0,array(rbs(nrb)-1,cbs(ncb)),1,cdtype(ncb),src,0,
     *           mpi_comm_world,mstat,ierr)
         endif
      enddo
c
c     Sum up in each row.
c     The same logic as the loop above except rows and columns
are
c     switched.
c
      src=mod(comm_rank-1+comm_size,comm_size)
      dest=mod(comm_rank+1,comm_size)
      do cb=0,comm_size-1
         rb=mod(cb-comm_rank+comm_size,comm_size)
         call comprow(nrow,ncol,array,
     *              rbs(rb),rbe(rb),cbs(cb),cbe(cb))
         if (cb.lt.comm_size-1) then
            ncb=cb+1
            nrb=mod(ncb-comm_rank+comm_size,comm_size)
            call
mpi_sendrecv(array(rbs(rb),cbe(cb)),1,rdtype(rb),dest,
     *
0,array(rbs(nrb),cbs(ncb)-1),1,rdtype(nrb),src,0,
     *           mpi_comm_world,mstat,ierr)
         endif
      enddo
c
c     Gather computation results
c
      call mpi_barrier(MPI_COMM_WORLD,ierr)
      endt=mpi_wtime()

      if (comm_rank.eq.0) then
         do src=1,comm_size-1
            call
mpi_recv(array,1,twdtype(src),src,0,mpi_comm_world,
     *           mstat,ierr)
         enddo

elapsed=endt-startt
         write(6,*) 'Computation took',elapsed,' seconds'
      else
         call
mpi_send(array,1,twdtype(comm_rank),0,0,mpi_comm_world,
     *        ierr)
      endif
c
```

```
c     Dump to a file
c
c      if (comm_rank.eq.0) then
c         print*,'Dumping to adi.out...'
c         open(8,file='adi.out')
c         write(8,*) array
c         close(8,status='keep')
c      endif
c
c     Free the resources
c
      do rank=0,comm_size-1
         call mpi_type_free(twdtype(rank),ierr)
      enddo
      do blk=0,comm_size-1
         call mpi_type_free(rdtype(blk),ierr)
         call mpi_type_free(cdtype(blk),ierr)
      enddo
      deallocate(rbs,rbe,cbs,cbe,rdtype,cdtype,twdtype)
c
c     Finalize the MPI system
c
      call mpi_finalize(ierr)
      end
c**************************************************************
*********
      subroutine
blockasgn(subs,sube,blockcnt,nth,blocks,blocke)
c
c     This subroutine:
c     is given a range of subscript and the total number of
blocks in
c     which the range is to be divided, assigns a subrange to
the caller
c     that is n-th member of the blocks.
c
      implicit none
      integer subs             ! (in)      subscript start
      integer sube             ! (in)      subscript end
      integer blockcnt         ! (in)      block count
      integer nth              ! (in)      my block (begin from
0)
      integer blocks           ! (out)     assigned block start
subscript
      integer blocke           ! (out)     assigned block end
subscript
c
      integer d1,m1
c
      d1=(sube-subs+1)/blockcnt
      m1=mod(sube-subs+1,blockcnt)
      blocks=nth*d1+subs+min(nth,m1)
      blocke=blocks+d1-1
      if(m1.gt.nth)blocke=blocke+1
      end
c
```

```
c*************************************************************
*********
      subroutine compcolumn(nrow,ncol,array,rbs,rbe,cbs,cbe)
c
c     This subroutine:
c     does summations of columns in a thread.
c
      implicit none

      integer nrow                           ! # of rows
      integer ncol                           ! # of columns
      double precision array(nrow,ncol)      ! compute region
      integer rbs                            ! row block start
subscript
      integer rbe                            ! row block end
subscript
      integer cbs                            ! column block start
subscript
      integer cbe                            ! column block end
subscript

c
c     Local variables
c
      integer i,j

c
c     The OPENMP directive below allows the compiler to split
the
c    values for "j" between a number of threads.  By making i
and j
c     private, each thread works on its own range of columns
"j",
c     and works down each column at its own pace "i".
c
c     Note no data dependency problems arise by having the
threads all
c     working on different columns simultaneously.
c

C$OMP PARALLEL DO PRIVATE(i,j)
      do j=cbs,cbe
         do i=max(2,rbs),rbe
            array(i,j)=array(i-1,j)+array(i,j)
         enddo
      enddo
C$OMP END PARALLEL DO
      end

c*************************************************************
*********
      subroutine comprow(nrow,ncol,array,rbs,rbe,cbs,cbe)
c
c     This subroutine:
c     does summations of rows in a thread.
c
```

```
      implicit none

      integer nrow                          ! # of rows
      integer ncol                          ! # of columns
      double precision array(nrow,ncol)     ! compute region
      integer rbs                           ! row block start
subscript
      integer rbe                           ! row block end
subscript
      integer cbs                           ! column block start
subscript
      integer cbe                           ! column block end
subscript

c
c     Local variables
c
      integer i,j

c
c     The OPENMP directives below allow the compiler to split
the
c     values for "i" between a number of threads, while "j"
moves
c     forward lock-step between the threads.  By making j
shared
c     and i private, all the threads work on the same column
"j" at
c     any given time, but they each work on a different
portion "i"
c     of that column.
c
c     This is not as efficient as found in the compcolumn
subroutine,
c     but is necessary due to data dependencies.
c


C$OMP PARALLEL PRIVATE(i)
      do j=max(2,cbs),cbe
C$OMP DO
         do i=rbs,rbe
            array(i,j)=array(i,j-1)+array(i,j)
         enddo
C$OMP END DO
      enddo
C$OMP END PARALLEL

      end
c
c***************************************************************
*********
       subroutine getdata(nrow,ncol,array)
c
c     Enter dummy data
c
```

```
      integer nrow,ncol
      double precision array(nrow,ncol)
c
      do j=1,ncol
         do i=1,nrow
            array(i,j)=(j-1.0)*ncol+i
         enddo
      enddo
      end
```

multi_par.f output

The output from running the multi_par.f executable is shown below. The application was run with `-np1`.

```
Initializing 1000  x 1000  array...
Start computation
Computation took 4.088211059570312E-02  seconds
```

io.c

In this C example, each process writes to a separate file called iodata*x*, where *x represents each process rank in turn.* Then, the data in iodata*x* is read back.

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <mpi.h>

#define SIZE (65536)
#define FILENAME "iodata"

/*Each process writes to separate files and reads them back. The
file name is “iodata” and the process rank is appended to it.*/

main(argc, argv)

     int argc;
     char **argv;

{
        int *buf, i, rank, nints, len, flag;
        char *filename;
        MPI_File fh;
        MPI_Status status;

        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);

        buf = (int *) malloc(SIZE);
        nints = SIZE/sizeof(int);
        for (i=0; i<nints; i++) buf[i] = rank*100000 + i;

        /* each process opens a separate file called
FILENAME.'myrank' */

        filename = (char *) malloc(strlen(FILENAME) + 10);
        sprintf(filename, "%s.%d", FILENAME, rank);

        MPI_File_open(MPI_COMM_SELF, filename,
                      MPI_MODE_CREATE | MPI_MODE_RDWR,
                      MPI_INFO_NULL, &fh);

        MPI_File_set_view(fh, (MPI_Offset)0, MPI_INT, MPI_INT,
"native",
                          MPI_INFO_NULL);
        MPI_File_write(fh, buf, nints, MPI_INT, &status);
        MPI_File_close(&fh);

        /* reopen the file and read the data back */
        for (i=0; i<nints; i++) buf[i] = 0;
        MPI_File_open(MPI_COMM_SELF, filename,
                      MPI_MODE_CREATE | MPI_MODE_RDWR,
                      MPI_INFO_NULL, &fh);
        MPI_File_set_view(fh, (MPI_Offset)0, MPI_INT, MPI_INT,
"native",
                          MPI_INFO_NULL);
        MPI_File_read(fh, buf, nints, MPI_INT, &status);
        MPI_File_close(&fh);

        /* check if the data read is correct */
        flag = 0;
        for (i=0; i<nints; i++)
                if (buf[i] != (rank*100000 + i)) {
                        printf("Process %d: error, read %d,
should be %d\n",
                               rank, buf[i], rank*100000+i);
                        flag = 1;
                }

        if (!flag) {
                printf("Process %d: data read back is correct\n",
rank);
                MPI_File_delete(filename, MPI_INFO_NULL);
        }

        free(buf);
        free(filename);

        MPI_Finalize();
        exit(0);
}
```

io output

The output from running the io executable is shown below. The application was run with `-np` = 4.

```
Process 0: data read back is correct
Process 1: data read back is correct
Process 2: data read back is correct
Process 3: data read back is correct
```

thread_safe.c

In this C example, N clients loop MAX_WORK times. As part of a single work item, a client must request service from one of Nservers at random. Each server keeps a count of the requests handled and prints a log of the requests to stdout. Once all the clients are done working, the servers are shutdown.

```
#include <stdio.h>
#include <mpi.h>
#include <pthread.h>

#define MAX_WORK        40
#define SERVER_TAG      88
#define CLIENT_TAG      99
#define REQ_SHUTDOWN    -1

static int service_cnt = 0;

int process_request(request)
int request;
{
      if (request != REQ_SHUTDOWN) service_cnt++;
      return request;
}

void* server(args)
void *args;

{
        int rank, request;
        MPI_Status status;
        rank = *((int*)args);

        while (1) {
                MPI_Recv(&request, 1, MPI_INT, MPI_ANY_SOURCE,
                         SERVER_TAG, MPI_COMM_WORLD, &status);

                if (process_request(request) == REQ_SHUTDOWN)
                    break;

                    MPI_Send(&rank, 1, MPI_INT,
status.MPI_SOURCE,
                             CLIENT_TAG, MPI_COMM_WORLD);

                printf("server [%d]: processed request %d for
client %d\n",
                       rank, request, status.MPI_SOURCE);
       }

       printf("server [%d]: total service requests: %d\n", rank,
service_cnt);
```

```
       return (void*) 0;
}

void client(rank, size)
int rank;
int size;

{
        int w, server, ack;
        MPI_Status status;

        for (w = 0; w < MAX_WORK; w++) {
               server = rand()%size;

        MPI_Sendrecv(&rank, 1, MPI_INT, server, SERVER_TAG, &ack,
                     1,MPI_INT,server,CLIENT_TAG,MPI_COMM_WORLD,
&status);

        if (ack != server) {
                   printf("server failed to process my
request\n");
                   MPI_Abort(MPI_COMM_WORLD, MPI_ERR_OTHER);
                }
        }
}

void shutdown_servers(rank)
int rank;

{
         int request_shutdown = REQ_SHUTDOWN;
         MPI_Barrier(MPI_COMM_WORLD);
         MPI_Send(&request_shutdown, 1, MPI_INT, rank,
SERVER_TAG, MPI_COMM_WORLD);
}

main(argc, argv)
int argc;
char *argv[];

{
        int rank, size, rtn;
        pthread_t mtid;
        MPI_Status      status;
        int my_value, his_value;

        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &size);

        rtn = pthread_create(&mtid, 0, server, (void*)&rank);
        if (rtn != 0) {
                printf("pthread_create failed\n");
                MPI_Abort(MPI_COMM_WORLD, MPI_ERR_OTHER);
        }
        client(rank, size);
        shutdown_servers(rank);

        rtn = pthread_join(mtid, 0);
        if (rtn != 0) {
                printf("pthread_join failed\n");
                MPI_Abort(MPI_COMM_WORLD, MPI_ERR_OTHER);
        }

        MPI_Finalize();
        exit(0);
}
```

thread_safe output

The output from running the thread_safe executable is shown below. The application was run with `-np` = 2.

```
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [1]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [1]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [0]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [1]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [1]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [1]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [1]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [0]: processed request 0 for client 0
server [0]: processed request 1 for client 1
server [0]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [1]: processed request 0 for client 0
server [1]: processed request 0 for client 0
server [1]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [1]: processed request 0 for client 0
server [0]: processed request 0 for client 0
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [1]: processed request 1 for client 1
server [0]: processed request 1 for client 1
server [0]: total service requests: 38
server [1]: total service requests: 42
```

sort.C

This program does a simple integer sort in parallel. The sort input is built using the "rand" random number generator. The program is self-checking and can run with any number of ranks.

```
#define NUM_OF_ENTRIES_PER_RANK100

#include <stdio.h>
#include <stdlib.h>
#include <iostream.h>
#include <mpi.h>

#include <limits.h>

#include <iostream.h>
#include <fstream.h>


//
// Class declarations.
//



class Entry {
private:
 int value;

public:

  Entry()
         { value = 0; }

  Entry(int x)
         { value = x; }

  Entry(const Entry &e)
         { value = e.getValue(); }

  Entry& operator= (const Entry &e)
         { value = e.getValue(); return (*this); }

  int getValue() const { return value; }

  int operator> (const Entry &e) const
         { return (value > e.getValue()); }
};


class BlockOfEntries {
private:
  Entry **entries;
  int numOfEntries;

public:
  BlockOfEntries(int *numOfEntries_p, int offset);
  ~BlockOfEntries();
  int getnumOfEntries()
       { return numOfEntries; }
  void setLeftShadow(const Entry &e)
       { *(entries[0]) = e; }
  void setRightShadow(const Entry &e)
       { *(entries[numOfEntries-1]) = e; }

  const Entry& getLeftEnd()
       { return *(entries[1]); }
  const Entry& getRightEnd()
       { return *(entries[numOfEntries-2]); }

  void singleStepOddEntries();
  void singleStepEvenEntries();
  void verifyEntries(int myRank, int baseLine);
  void printEntries(int myRank);
};



//
// Class member definitions.
//
const Entry MAXENTRY(INT_MAX);
const Entry MINENTRY(INT_MIN);



//
//BlockOfEntries::BlockOfEntries
//
//Function:- create the block of entries.
//
BlockOfEntries::BlockOfEntries(int *numOfEntries_p, int
myRank)


{
//
// Initialize the random number generator's seed based on the
caller's rank;
// thus, each rank should (but might not) get different random
values.
//



  srand((unsigned int) myRank);

  numOfEntries = NUM_OF_ENTRIES_PER_RANK;
  *numOfEntries_p = numOfEntries;


//
// Add in the left and right shadow entries.
//

  numOfEntries += 2;



//
// Allocate space for the entries and use rand to initialize
the values.
//



  entries = new Entry *[numOfEntries];
  for(int i = 1; i < numOfEntries-1; i++) {
        entries[i] = new Entry;
       *(entries[i]) = (rand()%1000) * ((rand()%2 == 0)? 1 :
-1);
}



//
// Initialize the shadow entries.
//
    entries[0] = new Entry(MINENTRY);
    entries[numOfEntries-1] = new Entry(MAXENTRY);
}



//
//BlockOfEntries::~BlockOfEntries
//
//Function:- delete the block of entries.
//
BlockOfEntries::~BlockOfEntries()

{
  for(int i = 1; i < numOfEntries-1; i++) {
          delete entries[i];
  }
  delete entries[0];
  delete entries[numOfEntries-1];
  delete [] entries;
}



//
```

```
//BlockOfEntries::singleStepOddEntries
//
//Function: - Adjust the odd entries.
//
void
BlockOfEntries::singleStepOddEntries()


{
for(int i = 0; i < numOfEntries-1; i += 2) {
       if (*(entries[i]) > *(entries[i+1]) ) {
       Entry *temp = entries[i+1];
       entries[i+1] = entries[i];
       entries[i] = temp;
    }
  }
}



//
//BlockOfEntries::singleStepEvenEntries
//
//Function: - Adjust the even entries.
//
void
BlockOfEntries::singleStepEvenEntries()


{

   for(int i = 1; i < numOfEntries-2; i += 2) {
        if (*(entries[i]) > *(entries[i+1]) ) {
        Entry *temp = entries[i+1];
        entries[i+1] = entries[i];
        entries[i] = temp;
    }
  }
}



//
//BlockOfEntries::verifyEntries
//
//Function: - Verify that the block of entries for rank myRank
//  is sorted and each entry value is greater than
//  or equal to argument baseLine.
//


void
BlockOfEntries::verifyEntries(int myRank, int baseLine)


{
  for(int i = 1; i < numOfEntries-2; i++) {
       if (entries[i]->getValue() < baseLine) {
           cout << "Rank " << myRank
                   << " wrong answer i = " << i
                   << " baseLine = " << baseLine
                   << " value = " << entries[i]->getValue()
                  << endl;
           MPI_Abort(MPI_COMM_WORLD, MPI_ERR_OTHER);
       }


       if (*(entries[i]) > *(entries[i+1]) ) {
            cout << "Rank " << myRank
                 << " wrong answer i = " << i
                 << " value[i] = "
                 << entries[i]->getValue()
                 << " value[i+1] = "
                 << entries[i+1]->getValue()
                 << endl;
           MPI_Abort(MPI_COMM_WORLD, MPI_ERR_OTHER);
        }
    }
}



//
//BlockOfEntries::printEntries
//
//Function: - Print myRank's entries to stdout.
//
void
BlockOfEntries::printEntries(int myRank)
{
    cout << endl;
    cout << "Rank " << myRank << endl;
    for(int i = 1; i < numOfEntries-1; i++)
          cout << entries[i]->getValue() << endl;
}



int
main(int argc, char **argv)



{
    int  myRank, numRanks;


MPI_Init(&argc, &argv);

MPI_Comm_rank(MPI_COMM_WORLD, &myRank);
MPI_Comm_size(MPI_COMM_WORLD, &numRanks);
```

```
//
// Have each rank build its block of entries for the global
sort.
//

   int numEntries;
   BlockOfEntries *aBlock = new BlockOfEntries(&numEntries,
           myRank);


//
// Compute the total number of entries and sort them.
//

       numEntries *= numRanks;
       for(int j = 0; j < numEntries / 2; j++) {


//
// Synchronize and then update the shadow entries.
//

       MPI_Barrier(MPI_COMM_WORLD);

       int recvVal, sendVal;
       MPI_Request sortRequest;
       MPI_Status status;

//
// Everyone except numRanks-1 posts a receive for the right's
   rightShadow.
//

      if (myRank != (numRanks-1)) {
           MPI_Irecv(&recvVal, 1, MPI_INT, myRank+1,
                      MPI_ANY_TAG, MPI_COMM_WORLD,
                     &sortRequest);
      }



//
// Everyone except 0 sends its leftEnd to the left.
//


     if (myRank != 0) {
           sendVal = aBlock->getLeftEnd().getValue();
           MPI_Send(&sendVal, 1, MPI_INT,
                    myRank-1, 1, MPI_COMM_WORLD);
      }

      if (myRank != (numRanks-1)) {
```

```
                MPI_Wait(&sortRequest, &status);
                aBlock->setRightShadow(Entry(recvVal));
            }


//
// Everyone except 0 posts for the left's leftShadow.
//

            if (myRank != 0) {
                MPI_Irecv(&recvVal, 1, MPI_INT, myRank-1,
                        MPI_ANY_TAG, MPI_COMM_WORLD,
                        &sortRequest);
            }


//
// Everyone except numRanks-1 sends its rightEnd right.
//

            if (myRank != (numRanks-1)) {
                sendVal = aBlock->getRightEnd().getValue();
                MPI_Send(&sendVal, 1, MPI_INT,
                              myRank+1, 1, MPI_COMM_WORLD);
            }


            if (myRank != 0) {
                MPI_Wait(&sortRequest, &status);
                aBlock->setLeftShadow(Entry(recvVal));
            }


//
// Have each rank fix up its entries.
//

            aBlock->singleStepOddEntries();
            aBlock->singleStepEvenEntries();
        }


//
//  Print and verify the result.
//

        if (myRank == 0) {
            intsendVal;

            aBlock->printEntries(myRank);
            aBlock->verifyEntries(myRank, INT_MIN);

            sendVal = aBlock->getRightEnd().getValue();
            if (numRanks > 1)
                MPI_Send(&sendVal, 1, MPI_INT, 1, 2,
MPI_COMM_WORLD);
```

```
   } else {
      int          recvVal;
      MPI_Status  Status;
      MPI_Recv(&recvVal, 1, MPI_INT, myRank-1, 2,
                  MPI_COMM_WORLD, &Status);
      aBlock->printEntries(myRank);
      aBlock->verifyEntries(myRank, recvVal);
      if (myRank != numRanks-1) {
            recvVal = aBlock->getRightEnd().getValue();
            MPI_Send(&recvVal, 1, MPI_INT, myRank+1, 2,
                        MPI_COMM_WORLD);
      }
   }


   delete aBlock;
   MPI_Finalize();
   exit(0);
}
```

sort.C output

The output from running the sort executable is shown below. The application was run with -np4.

```
Rank 0
-998
-996
-996
-993

...
-567
-563
-544
-543

Rank 1
-535
-528
-528

...
-90
-90
-84
-84

Rank 2
-78
-70
-69
-69
```

```
...
383
383
386
386

Rank 3
386
393
393
397

...
950
965
987
987
```

compute_pi_spawn.f

This example computes pi by integrating f(x) = 4/(1 + x**2) using MPI_Spawn. It starts with one process and spawns a new world that does the computation along with the original process. Each newly spawned process receives the # of intervals used, calculates the areas of its rectangles, and synchronizes for a global summation. The original process 0 prints the result and the time it took.

```
  program mainprog
  include 'mpif.h'
  double precision PI25DT
  parameter(PI25DT = 3.141592653589793238462643d0)
  double precision  mypi, pi, h, sum, x, f, a
  integer n, myid, numprocs, i, ierr
  integer parenticomm, spawnicomm, mergedcomm, high
C
C Function to integrate
C
  f(a) = 4.d0 / (1.d0 + a*a)
\
  call MPI_INIT(ierr)
  call MPI_COMM_RANK(MPI_COMM_WORLD, myid, ierr)
  call MPI_COMM_SIZE(MPI_COMM_WORLD, numprocs, ierr)
  call MPI_COMM_GET_PARENT(parenticomm, ierr)
  if (parenticomm .eq. MPI_COMM_NULL) then
       print *, "Original Process ", myid, " of ", numprocs,
  +              " is alive"
      call MPI_COMM_SPAWN("./compute_pi_spawn", MPI_ARGV_NULL, 3,
  +              MPI_INFO_NULL, 0, MPI_COMM_WORLD, spawnicomm,
  +              MPI_ERRCODES_IGNORE, ierr)
      call MPI_INTERCOMM_MERGE(spawnicomm, 0, mergedcomm, ierr)
      call MPI_COMM_FREE(spawnicomm, ierr)
  else
       print *, "Spawned Process ", myid, " of ", numprocs,
  +              " is alive"
      call MPI_INTERCOMM_MERGE(parenticomm, 1, mergedcomm, ierr)
      call MPI_COMM_FREE(parenticomm, ierr)
  endif
  call MPI_COMM_RANK(mergedcomm, myid, ierr)
  call MPI_COMM_SIZE(mergedcomm, numprocs, ierr)
  print *, "Process ", myid, " of ", numprocs,
  +              " in merged comm is alive"

  sizetype = 1
  sumtype = 2
  if (myid .eq. 0) then
         n = 100
  endif
  call MPI_BCAST(n, 1, MPI_INTEGER, 0, mergedcomm, ierr)
C
```

```
C Calculate the interval size.
C
  h = 1.0d0 / n
  sum  = 0.0d0
  do 20 i = myid + 1, n, numprocs
      x = h * (dble(i) - 0.5d0)
      sum = sum + f(x)
20   continue
  mypi = h * sum
C
C Collect all the partial sums.
C
  call MPI_REDUCE(mypi, pi, 1, MPI_DOUBLE_PRECISION,
  +                MPI_SUM, 0, mergedcomm, ierr)
C
C Process 0 prints the result.
C
  if (myid .eq. 0) then
        write(6, 97) pi, abs(pi - PI25DT)
97           format('  pi is approximately: ', F18.16,
  +                '  Error is: ', F18.16)
  endif
  call MPI_COMM_FREE(mergedcomm, ierr)
  call MPI_FINALIZE(ierr)
  stop
  end
```

compute_pi_spawn.f output

The output from running the compute_pi_spawn executable is shown below. The application was run with -np1 and with the `-spawn` option.

```
Original Process  0 of  1 is alive
Spawned Process  0 of  3 is alive
Spawned Process  2 of  3 is alive
Spawned Process  1 of  3 is alive
Process  0 of  4 in merged comm is alive
Process  2 of  4 in merged comm is alive
Process  3 of  4 in merged comm is alive
Process  1 of  4 in merged comm is alive
pi is approximately: 3.1416009869231254
Error is: 0.0000083333333323
```

B Standard-flexibility in HP-MPI

HP-MPI implementation of standard flexibility

HP-MPI contains a full MPI-2 standard implementation. There are items in the MPI standard for which the standard allows flexibility in implementation. This appendix identifies HP-MPI's implementation of many of these standard-flexible issues.

Table B-1 displays references to sections in the MPI standard that identify flexibility in the implementation of an issue. Accompanying each reference is HP-MPI's implementation of that issue.

Table B-1 HP-MPI implementation of standard-flexible issues

Reference in MPI standard	HP-MPI's implementation
MPI implementations are required to define the behavior of MPI_Abort (at least for a `comm` of `MPI_COMM_WORLD`). MPI implementations may ignore the `comm` argument and act as if `comm` was `MPI_COMM_WORLD`. *See MPI-1.2 Section* 7.5.	MPI_Abort kills the application. `comm` is ignored, uses `MPI_COMM_WORLD`.
An implementation must document the implementation of different language bindings of the MPI interface if they are layered on top of each other. *See MPI-1.2 Section* 8.1.	Fortran is layered on top of C and profile entry points are given for both languages.
MPI does not mandate what an MPI process is. MPI does not specify the execution model for each process; a process can be sequential or multithreaded. *See MPI-1.2 Section* 2.6.	MPI processes are UNIX or Win32 Console processes and can be multithreaded.

Table B-1 HP-MPI implementation of standard-flexible issues (Continued)

Reference in MPI standard	HP-MPI's implementation
MPI does not provide mechanisms to specify the initial allocation of processes to an MPI computation and their initial binding to physical processes. *See MPI-1.2 Section* 2.6.	HP-MPI provides the `mpirun -np #` utility and appfiles as well as startup integrated with other job schedulers and launchers. Refer to the relevant sections in this guide.
MPI does not mandate that any I/O service be provided, but does suggest behavior to ensure portability if it is provided. *See MPI-1.2 Section* 2.8.	Each process in HP-MPI applications can read and write data to an external drive. Refer to "External input and output" on page 193 for details.
The value returned for `MPI_HOST` gets the rank of the host process in the group associated with `MPI_COMM_WORLD`. `MPI_PROC_NULL` is returned if there is no host. MPI does not specify what it means for a process to be a host, nor does it specify that a `HOST` exists.	HP-MPI always sets the value of `MPI_HOST` to `MPI_PROC_NULL`.
MPI provides `MPI_GET_PROCESSOR_NAME` to return the name of the processor on which it was called at the moment of the call. *See MPI-1.2 Section* 7.1.1.	If you do not specify a host name to use, the hostname returned is that of `gethostname`. If you specify a host name using the `-h` option to `mpirun`, HP-MPI returns that host name.
The current MPI definition does not require messages to carry data type information. Type information might be added to messages to allow the system to detect mismatches. *See MPI-1.2 Section* 3.3.2.	The default HP-MPI library does not carry this information due to overload, but the HP-MPI diagnostic library (DLIB) does. To link with the diagnostic library, use `-ldmpi` on the link line.

Table B-1 HP-MPI implementation of standard-flexible issues (Continued)

Reference in MPI standard	HP-MPI's implementation
Vendors may write optimized collective routines matched to their architectures or a complete library of collective communication routines can be written using MPI point-to-point routines and a few auxiliary functions. *See MPI-1.2 Section* 4.1.	Use HP-MPI's collective routines instead of implementing your own with point-to-point routines. HP-MPI's collective routines are optimized to use shared memory where possible for performance.
Error handlers in MPI take as arguments the communicator in use and the error code to be returned by the MPI routine that raised the error. An error handler can also take "stdargs" arguments whose number and meaning is implementation dependent. *See MPI-1.2 Section* 7.2 and *MPI-2.0 Section* 4.12.6.	To ensure portability, HP-MPI's implementation does not take "stdargs". For example in C, the user routine should be a C function of type `MPI_handler_function`, defined as: void (MPI_Handler_function) (MPI_Comm *, int *);
MPI implementors may place a barrier inside `MPI_FINALIZE`. *See MPI-2.0 Section* 3.2.2.	HP-MPI's `MPI_FINALIZE` behaves as a barrier function such that the return from `MPI_FINALIZE` is delayed until all potential future cancellations are processed.
MPI defines minimal requirements for thread-compliant MPI implementations and MPI can be implemented in environments where threads are not supported. *See MPI-2.0 Section* 8.7.	HP-MPI provides a thread-compliant library (lmtmpi). Use `-lmtmpi` on the link line to use the libmtmpi. Refer to "Thread-compliant library" on page 54 for more information.

Table B-1 **HP-MPI implementation of standard-flexible issues (Continued)**

Reference in MPI standard	HP-MPI's implementation
The format for specifying the filename in `MPI_FILE_OPEN` is implementation dependent. An implementation may require that filename include a string specifying additional information about the file. *See MPI-2.0 Section* 9.2.1.	HP-MPI I/O supports a subset of the MPI-2 standard using ROMIO, a portable implementation developed at Argonne National Laboratory. No additional file information is necessary in your filename string.

C mpirun using implied prun or srun

Implied prun

HP-MPI provides an implied `prun` mode. The implied `prun` mode allows the user to omit the `-prun` argument from the `mpirun` command line with the use of the environment variable `MPI_USEPRUN`.

Set the environment variable:

```
% setenv MPI_USEPRUN 1
```

HP-MPI will insert the `-prun` argument.

The following arguments are considered to be `prun` arguments:

- `-n -N -m -w -x`
- `-e MPI_WORKDIR=/path` will be translated to the `prun` argument `--chdir=/path`
- any argument that starts with `--` and is not followed by a space
- `-np` will be translated to `-n`
- `-prun` will be accepted without warning.

The implied `prun` mode allows the use of HP-MPI appfiles. Currently, an appfile must be homogenous in its arguments with the exception of `-h` and `-np`. The `-h` and `-np` arguments within the appfile are discarded. All other arguments are promoted to the `mpirun` command line. Additionally, arguments following `--` are also processed.

Additional environment variables provided:

- `MPI_PRUNOPTIONS`

  Allows additional `prun` options to be specified such as `--label`.

  ```
  % setenv MPI_PRUNOPTIONS <option>
  ```

- `MPI_USEPRUN_IGNORE_ARGS`

  Provides an easy way to modify the arguments contained in an appfile by supplying a list of space-separated arguments that `mpirun` should ignore.

  ```
  % setenv MPI_USEPRUN_IGNORE_ARGS <option>
  ```

`prun` arguments:

- `-n, --ntasks=ntasks`

  Specify the number of processes to run.

- `-N, --nodes=nnodes`

  Request that nnodes nodes be allocated to this job.

- `-m, --distribution=(block|cyclic)`

  Specify an alternate distribution method for remote processes.

- `-w, --nodelist=`*`host1,host2,...`* `or` *`filename`*

  Request a specific list of hosts.

- `-x, --exclude=`*`host1,host2,...`* `or` *`filename`*

  Request that a specific list of hosts not be included in the resources allocated to this job.

- `-l, --label`

  Prepend task number to lines of stdout/err.

For more information on `prun` arguments, refer to the `prun` man page.

Using the `-prun` argument from the `mpirun` command line is still supported.

Implied srun

HP-MPI also provides an implied `srun` mode. The implied `srun` mode allows the user to omit the `-srun` argument from the `mpirun` command line with the use of the environment variable `MPI_USESRUN`.

Set the environment variable:

```
% setenv MPI_USESRUN 1
```

HP-MPI will insert the `-srun` argument.

The following arguments are considered to be `srun` arguments:

- `-n -N -m -w -x`
- any argument that starts with `--` and is not followed by a space
- `-np` will be translated to `-n`
- `-srun` will be accepted without warning.

The implied `srun` mode allows the use of HP-MPI appfiles. Currently, an appfile must be homogenous in its arguments with the exception of `-h` and `-np`. The `-h` and `-np` arguments within the appfile are discarded. All other arguments are promoted to the `mpirun` command line. Additionally, arguments following `--` are also processed.

Additional environment variables provided:

- `MPI_SRUNOPTIONS`

  Allows additional `srun` options to be specified such as `--label`.

  ```
  % setenv MPI_SRUNOPTIONS <option>
  ```

- `MPI_USESRUN_IGNORE_ARGS`

  Provides an easy way to modify the arguments contained in an appfile by supplying a list of space-separated arguments that `mpirun` should ignore.

  ```
  % setenv MPI_USESRUN_IGNORE_ARGS <option>
  ```

  In the example below, the appfile contains a reference to `-stdio=bnone` which is filtered out because it is set in the ignore list.

  ```
  % setenv MPI_USESRUN_VERBOSE 1
  ```

```
% setenv MPI_USESRUN_IGNORE_ARGS -stdio=bnone

% setenv MPI_USESRUN 1

% setenv MPI_SRUNOPTION --label

% bsub -I -n4 -ext "SLURM[nodes=4]" \
$MPI_ROOT/bin/mpirun -stdio=bnone -f appfile \
-- pingpong
```

```
Job <369848> is submitted to default queue <normal>.
<<Waiting for dispatch ...>>
<<Starting on lsfhost.localdomain>>
/opt/hpmpi/bin/mpirun
unset
MPI_USESRUN;/opt/hpmpi/bin/mpirun
-srun  ./pallas.x -npmin 4 pingpong
```

`srun` arguments:

- `-n, --ntasks=ntasks`

  Specify the number of processes to run.

- `-N, --nodes=nnodes`

  Request that nnodes nodes be allocated to this job.

- `-m, --distribution=(block|cyclic)`

  Specify an alternate distribution method for remote processes.

- `-w, --nodelist=`*`host1,host2,...`* `or` *`filename`*

  Request a specific list of hosts.

- `-x, --exclude=`*`host1,host2,...`* `or` *`filename`*

  Request that a specific list of hosts not be included in the resources allocated to this job.

- `-l, --label`

  Prepend task number to lines of stdout/err.

For more information on `srun` arguments, refer to the `srun` man page.

The following is an example using the implied `srun` mode. Note how the contents of the appfile are passed along except for `-np` and `-h` which are discarded. Also note how some arguments are pulled from the appfile and others after the --.

Here is the appfile:

-np 1 -h foo -e MPI_FLAGS=T ./pallas.x -npmin 4

% **setenv MPI_SRUNOPTION "--label"**

these are required to use the new feature:

% **setenv MPI_USESRUN 1**

```
 % bsub -I -n4 $MPI_ROOT/bin/mpirun -f appfile -- sendrecv

Job <2547> is submitted to default queue <normal>.
<<Waiting for dispatch ...>>
<<Starting on localhost>>
0: #---------------------------------------------------
0: #    PALLAS MPI Benchmark Suite V2.2, MPI-1 part
0: #---------------------------------------------------
0: # Date        : Thu Feb 24 14:24:56 2005
0: # Machine     : ia64# System      : Linux
0: # Release     : 2.4.21-15.11hp.XCsmp
0: # Version     : #1 SMP Mon Oct 25 02:21:29 EDT 2004
0:
0: #
0: # Minimum message length in bytes:   0
0: # Maximum message length in bytes:   8388608
0: #
0: # MPI_Datatype                   :   MPI_BYTE
0: # MPI_Datatype for reductions    :   MPI_FLOAT
0: # MPI_Op                         :   MPI_SUM
0: #
0: #
0:
0: # List of Benchmarks to run:
0:
0: # Sendrecv
0:
0: #-------------------------------------------------------------
0: # Benchmarking Sendrecv
0: # ( #processes = 4 )
0: #-------------------------------------------------------------
0: #bytes #repetitions  t_min      t_max      t_avg    Mbytes/sec
0: 0         1000       35.28      35.40      35.34        0.00
0: 1         1000       42.40      42.43      42.41        0.04
0: 2         1000       41.60      41.69      41.64        0.09
0: 4         1000       41.82      41.91      41.86        0.18
0: 8         1000       41.46      41.49      41.48        0.37
0: 16        1000       41.19      41.27      41.21        0.74
0: 32        1000       41.44      41.54      41.51        1.47
0: 64        1000       42.08      42.17      42.12        2.89
0: 128       1000       42.60      42.70      42.64        5.72
0: 256       1000       45.05      45.08      45.07       10.83
0: 512       1000       47.74      47.84      47.79       20.41
0: 1024      1000       53.47      53.57      53.54       36.46
0: 2048      1000       74.50      74.59      74.55       52.37
0: 4096      1000      101.24     101.46     101.37       77.00
0: 8192      1000      165.85     166.11     166.00       94.06
```

```
0: 16384    1000      293.30      293.64      293.49      106.42
0: 32768    1000      714.84      715.38      715.05       87.37
0: 65536     640     1215.00     1216.45     1215.55      102.76
0: 131072    320     2397.04     2401.92     2399.05      104.08
0: 262144    160     4805.58     4826.59     4815.46      103.59
0: 524288     80     9978.35    10017.87     9996.31       99.82
0: 1048576    40    19612.90    19748.18    19680.29      101.28
0: 2097152    20    36719.25    37786.09    37253.01      105.86
0: 4194304    10    67806.51    67920.30    67873.05      117.79
0: 8388608     5   135050.20   135244.61   135159.04      118.30
0: #=======================================================
0: #
0: #  Thanks for using PMB2.2
0: #
0: #  The Pallas team kindly requests that you
0: #  give us as much feedback for PMB as possible.
0: #
0: #  It would be very helpful when you sent the
0: #  output tables of your run(s) of PMB to
0: #
0: #              #######################
0: #              #                     #
0: #              #   pmb@pallas.com    #
0: #              #                     #
0: #              #######################
0: #
0: #  You might also add
0: #
0: #  - personal information (institution, motivation
0: #                            for using PMB)
0: #  - basic information about the machine you used
0: #    (number of CPUs, processor type e.t.c.)
0: #
0: #=======================================================
0: MPI Rank        User (seconds)      System (seconds)
0:     0                    4.95                  2.36
0:     1                    5.16                  1.17
0:     2                    4.82                  2.43
0:     3                    5.20                  1.18
0:              ----------------      ----------------
0: Total:                  20.12                  7.13
```

`srun` is supported on XC systems with SLURM.

Using the `-srun` argument from the `mpirun` command line is still supported.

D Frequently asked questions

This section describes frequently asked HP-MPI questions. The following category of issues are addressed:

- General

- Installation and setup
- Building applications
- Performance problems
- Network specific
- Windows specific

General

QUESTION: Where can I get the latest version of HP-MPI?

ANSWER: External customers can go to www.hp.com/go/mpi. HP Independent Software Vendors (ISVs) can go to http://www.software.hp.com/kiosk.

QUESTION: Where can I get a license for HP-MPI?

ANSWER: First, determine if a license is necessary. A license is not necessary if you are running on HP-UX or an HP XC system. Licenses are not necessary for supported ISV applications. Currently supported ISV applications are:

- Acusim Software (AcuSolve)
- ADINA R&D, Inc. (ADINA)
- ANSYS, Inc. (ANSYS CFX)
- ABAQUS, Inc. (ABAQUS)
- Accelrys (CASTEP, DMol3, Discover, MesoDyn, ONETEP, GULP)
- Allied Engineering Corp. (ADVC)
- AVL (FIRE, SWIFT)
- CD-adapco (STAR-CD)
- ESI Group (PAM-CRASH, PAM-FLOW)
- Exa Corp. (PowerFLOW)
- Fluent (FLUENT)
- LSTC (LS-DYNA)
- MAGMA (MAGMASOFT)
- Mecalog Group (RADIOSS)
- Metacomp Technologies (Metacomp)
- MSC Software (Marc, Nastran)
- Ricardo (VECTIS)
- Roxar (Roxar)

- TNO (TASS)
- UGS (NX Nastran)
- University of Birmingham (Molpro)
- University of Texas (AMLS)

You must have a sufficiently new version of these applications to ensure the ISV licensing mechanism is used.

In all other cases, a license is required. If you do need a license, then follow the instructions you received with your purchase. Go to http://licensing.hp.com and enter the information received with your order.

QUESTION: Can I use HP-MPI in my C++ application?

ANSWER: Yes, HP-MPI currently provides C++ classes for the MPI bindings.The classes provided are an inlined interface class to the MPI C bindings. Although most of the classes are inlined, a small portion is a pre-built library. This library is g++ ABI compatible. Because some C++ compilers are not g++ ABI compatible, we provide the source files and instructions on how to build this library with your C++ compiler if necessary. For more information, see “C++ bindings (for HP-UX and Linux)” on page 46.

QUESTION: How can I tell what version of HP-MPI I’m using?

ANSWER: Try one of the following:

- `% ` **`mpirun -version`**
- (on HP-UX) `% ` **`swlist -l product|grep "HPMPI"`**
- (on Linux) `% ` **`rpm -qa|grep "hpmpi"`**

For Windows, see the Windows FAQ section.

QUESTION: What Linux versions does HP-MPI support?

ANSWER: RedHat Enterprise Linux AS 2.1, 3.0, 4.0, and SuSE SLES 9, and 9.1, 9.2, 9.3, and 10.0 are officially supported. Other versions may work, but are not tested and officially supported.

QUESTION: What is MPI_ROOT that I see referenced in the documentation?

ANSWER: `MPI_ROOT` is an environment variable that HP-MPI (`mpirun`) uses to determine where HP-MPI is installed and therefore which executables and libraries to use. It is particularly helpful when you have multiple versions of HP-MPI installed on a system. A typical invocation of HP-MPI on systems with multiple `MPI_ROOT`s installed is:

```
% setenv MPI_ROOT /scratch/test-hp-mpi-2.2.5/
```

```
% $MPI_ROOT/bin/mpirun ...
```

Or

```
% export MPI_ROOT=/scratch/test-hp-mpi-2.2.5
```

```
% $MPI_ROOT/bin/mpirun ...
```

If you only have one copy of HP-MPI installed on the system and it is in `/opt/hpmpi` or `/opt/mpi`, then you do not need to set `MPI_ROOT`.

For Windows, see the Windows FAQ section.

QUESTION: Can you confirm that HP-MPI is include-file-compatible with MPICH?

ANSWER: HP-MPI can be used in what we refer to as MPICH compatibility mode. In general, object files built with HP-MPI's MPICH mode can be used in an MPICH application, and conversely object files built under MPICH can be linked into an HP-MPI application using MPICH mode. However, using MPICH compatibility mode to produce a single executable to run under both MPICH and HP_MPI will be more problematic and is not recommended. Refer to "MPICH object compatibility for HP-UX and Linux" on page 59 for more information.

Installation and setup

QUESTION: Do I need a license to run HP-MPI?

ANSWER: A license is not necessary if you are running on HP-UX or an HP XC system. Licenses are not necessary for supported ISV applications. See "General" on page 277 for a list of currently supported ISV applications.

In all other cases, a license is required. If you do need a license, then follow the instructions you received with your purchase. Go to http://licensing.hp.com and enter the information received with your order.

QUESTION: How are the ranks launched? (Or, why do I get the message "remshd: Login incorrect" or "Permission denied"?)

ANSWER: There are a number of ways that HP-MPI can launch the ranks, but some way must be made available:

- Allow passwordless `rsh` access by setting up `hosts.equiv` and/or `.rhost` files to allow the `mpirun` machine to `rsh` into the execution nodes.
- Allow passwordless `ssh` access from the `mpirun` machine to the execution nodes and set the environment variable `MPI_REMSH` to the full path of `ssh`.
- Use SLURM (`srun`) by using the `-srun` option to `mpirun`.
- Under Quadrics, use RMS (`prun`) by using the `-prun` option to `mpirun`.

For Windows, see the Windows FAQ section.

QUESTION: How can I verify that HP-MPI is installed and functioning optimally on my system?

ANSWER: A simple `hello_world` test is available in `$MPI_ROOT/help/hello_world.c` that can validate basic launching and connectivity. Other more involved tests are there as well, including a simple `ping_pong_ring.c` test to ensure that you are getting the bandwidth and latency you expect. Refer to "ping_pong_ring.c (HP-UX and Linux)" on page 211 for details.

QUESTION: Can I have multiple versions of HP-MPI installed and how can I switch between them?

ANSWER: You can install multiple HP-MPI's and they can be installed anywhere, as long as they are in the same place on each host you plan to run on. You can switch between them by setting `MPI_ROOT`. See "General" on page 277 for more information on `MPI_ROOT`.

QUESTION: How do I install in a non-standard location?

ANSWER: Two possibilities are:

```
% rpm --prefix=/wherever/you/want -ivh hpmpi-XXXXX.XXX.rpm
```

Or, you can basically "untar" an rpm using:

```
% rpm2cpio hpmpi-XXXXX.XXX.rpm|cpio -id
```

For Windows, see the Windows FAQ section.

QUESTION: How do I install a permanent license for HP-MPI?

ANSWER: You can install the permanent license on the server it was generated for by running **`lmgrd -c`** ***`<full path to license file>`***.

Building applications

QUESTION: Which compilers does HP-MPI work with?

ANSWER: HP-MPI works well with all compilers. We explicitly test with gcc, Intel, PathScale, and Portland, as well as HP-UX compilers. HP-MPI strives not to introduce compiler dependencies.

For Windows, see the Windows FAQ section.

QUESTION: What MPI libraries do I need to link with when I build?

ANSWER: We recommend using the `mpicc`, `mpif90`, and `mpi77` scripts in `$MPI_ROOT/bin` to build. If you absolutely do not want to build with these scripts, we recommend using them with the `-show` option to see what they are doing and use that as a starting point for doing your build. The `-show` option will just print out the command it would use to build with. Because these scripts are readable, you can examine them to understand what gets linked in and when.

For Windows, see the Windows FAQ section.

QUESTION: How do I specifically build a 32-bit application on a 64-bit architecture?

ANSWER: On Linux, HP-MPI contains additional libraries in a 32-bit directory for 32-bit builds.

```
$MPI_ROOT/lib/linux_ia32
```

Use the `-mpi32` flag to mpicc to ensure that the 32-bit libraries are used. In addition, your specific compiler may require a flag to indicate a 32-bit compilation.

For example:

On an Opteron system using gcc, you need to tell gcc to generate 32-bit via the flag `-m32`. In addition, the `-mpi32` is used to ensure 32-bit libraries are selected.

```
% setenv MPI_ROOT /opt/hpmpi

% setenv MPI_CC gcc

% $MPI_ROOT/bin/mpicc hello_world.c -mpi32 -m32

% file a.out
```

```
a.out: ELF 32-bit LSB executable, Intel 80386, version 1 (SYSV),
for GNU/Linux 2.2, dynamically linked (uses shared libraries),
not stripped
```

For more information on running 32-bit applications, see “Network specific” on page 286.

For Windows, see the Windows FAQ section.

Performance problems

QUESTION: How does HP-MPI clean up when something goes wrong?

ANSWER: HP-MPI uses several mechanisms to clean up job files. Note that all processes in your application must call `MPI_Finalize`.

- When a correct HP-MPI program (that is, one that calls `MPI_Finalize`) exits successfully, the root host deletes the job file.
- If you use `mpirun`, it deletes the job file when the application terminates, whether successfully or not.
- When an application calls `MPI_Abort`, `MPI_Abort` deletes the job file.
- If you use `mpijob -j` to get more information on a job, and the processes of that job have all exited, `mpijob` issues a warning that the job has completed, and deletes the job file.

QUESTION: My MPI application hangs at MPI_Send. Why?

ANSWER: Deadlock situations can occur when your code uses standard send operations and assumes buffering behavior for standard communication mode. You should not assume message buffering between processes because the MPI standard does not mandate a buffering strategy. HP-MPI does sometimes use buffering for `MPI_Send` and `MPI_Rsend`, but it is dependent on message size and at the discretion of the implementation.

QUESTION: How can I tell if the deadlock is because my code depends on buffering?

ANSWER: To quickly determine whether the problem is due to your code being dependent on buffering, set the `z` option for `MPI_FLAGS`. `MPI_FLAGS` modifies the general behavior of HP-MPI, and in this case converts `MPI_Send` and `MPI_Rsend` calls in your code to `MPI_Ssend`, without you having to rewrite your code. `MPI_Ssend` guarantees synchronous send semantics, that is, a send can be started whether or not a matching receive is posted. However, the send completes successfully only if a matching receive is posted and the receive operation has started to receive the message sent by the synchronous send.

If your application still hangs after you convert `MPI_Send` and `MPI_Rsend` calls to `MPI_Ssend`, you know that your code is written to depend on buffering. You should rewrite it so that `MPI_Send` and `MPI_Rsend` do not depend on buffering.

Alternatively, use non-blocking communication calls to initiate send operations. A non-blocking send-start call returns before the message is copied out of the send buffer, but a separate send-complete call is needed to complete the operation. Refer also to “Sending and receiving messages” on page 7 for information about blocking and non-blocking communication. Refer to “MPI_FLAGS” on page 120 for information about `MPI_FLAGS` options.

QUESTION: How do I turn on MPI collection of message lengths? I want an overview of MPI message lengths being sent within the application.

ANSWER: The information is available through HP-MPI’s instrumentation feature. Basically, including **`-i`** ***`<filename>`*** on the `mpirun` command line will create <*`filename`*> with a report that includes number and sizes of messages sent between ranks. Refer to “Creating an instrumentation profile” on page 159 for more information.

Network specific

QUESTION: What extra software do I need to allow HP-MPI to run on my InfiniBand hardware?

ANSWER: On HP-UX, download the IB4X-00 driver from the software depot at http://www.hp.com/go/softwaredepot. Configure `/etc/privgroup`. (See “ITAPI” on page 87). Otherwise, consult your interconnect vendor.

QUESTION: I get an error when I run my 32-bit executable on my AMD64 or Intel(R)64 system.

```
dlopen for MPI_ICLIB_IBV__IBV_MAIN could not open libs in list
libibverbs.so:
libibverbs.so: cannot open shared object file: No such file or
directory
x: Rank 0:0: MPI_Init: ibv_resolve_entrypoints() failed
x: Rank 0:0: MPI_Init: Can't initialize RDMA device
x: Rank 0:0: MPI_Init: MPI BUG: Cannot initialize RDMA protocol
dlopen for MPI_ICLIB_IBV__IBV_MAIN could not open libs in list
libibverbs.so:
libibverbs.so: cannot open shared object file: No such file or
directory
x: Rank 0:1: MPI_Init: ibv_resolve_entrypoints() failed
x: Rank 0:1: MPI_Init: Can't initialize RDMA device
x: Rank 0:1: MPI_Init: MPI BUG: Cannot initialize RDMA protocol
MPI Application
rank 0 exited before MPI_Init() with status 1 MPI Application
rank 1 exited before MPI_Init() with status 1
```

ANSWER: Note that not all messages that say "Can’t initialize RDMA device" are caused by this problem. This message can show up when running a 32-bit executable on a 64-bit Linux machine. The 64-bit daemon used by HP-MPI cannot determine the bitness of the executable and thereby uses incomplete information to determine the availability of high performance interconnects. To work around the problem, use flags (`-TCP`, `-VAPI`, etc.) to explicitly specify the network to use. Or, with HP-MPI 2.1.1 and later, use the `-mpi32` flag to `mpirun`.

QUESTION: Where does HP-MPI look for the shared libraries for the high-performance networks it supports?

ANSWER: For detailed information on high-performance networks, see “Interconnect support” on page 82.

QUESTION: How can I control which interconnect is used for running my application?

ANSWER: The environment variable `MPI_IC_ORDER` instructs HP-MPI to search in a specific order for the presence of an interconnect. The contents are a colon separated list. For a list of the default contents, see "Interconnect support" on page 82.

Or, mpirun command line options can be used which take higher precedence than `MPI_IC_ORDER`. Lowercase selections imply to use if detected, otherwise keep searching. Uppercase selections demand the interconnect option be used, and if it cannot be selected the application will terminate with an error. For a list of command line options, see Table 3-3 on page 83.

An additional issue is how to select a subnet when TCP/IP is used and multiple TCP/IP subnets are available between the nodes. This can be controlled by using the `-netaddr` option to `mpirun`. For example:

```
% mpirun -TCP -netaddr 192.168.1.1 -f appfile
```

This will cause TCP/IP to be used over the subnet associated with the network interface with IP address 192.168.1.1.

For more detailed information and examples, see "Interconnect support" on page 82.

For Windows, see the Windows FAQ section.

Windows specific

QUESTION: What versions of Windows does HP-MPI support?

ANSWER: HP-MPI for Windows V1.0 supports Windows CCS. HP-MPI for Windows V1.1 supports Windows 2003 and Windows XP multinode runs with the HP-MPI Remote Launch service running on the nodes. This service is provided with V1.1. The service is not required to run in an SMP mode.

QUESTION: What is MPI_ROOT that I see referenced in the documentation?

ANSWER: `MPI_ROOT` is an environment variable that HP-MPI (**`mpirun`**) uses to determine where HP-MPI is installed and therefore which executables and libraries to use. It is particularly helpful when you have multiple versions of HP-MPI installed on a system. A typical invocation of HP-MPI on systems with multiple `MPI_ROOT`s installed is:

```
>set MPI_ROOT=\\nodex\share\test-hp-mpi-2.2.5
>"%MPI_ROOT%\bin\mpirun" ...
```

When HP-MPI is installed in Windows, it will automatically set `MPI_ROOT` for the system to the default location. The default install location differs between 32- and 64-bit Windows.

For 32-bit Windows, the default is:
C:\Program Files \Hewlett-Packard\HP-MPI

For 64-bit Windows, the default is:
C:\Program Files (x86)\Hewlett-Packard\HP-MPI

QUESTION: How are ranks launched on Windows?

ANSWER: On Windows CCS, ranks are launched by scheduling HP-MPI tasks to the existing job. These tasks are used to launch the remote ranks. Because CPUs need to be available to schedule these tasks, the initial **`mpirun`** task submitted must only use a single task in the job allocation.

For additional options, refer to the release note for your specific version.

QUESTION: How do I install in a non-standard location on Windows?

ANSWER: To install HP-MPI on Windows, double-click the **`setup.exe`**, and follow the instructions. One of the initial windows is the **`Select Directory`** window, which indicates where to install HP-MPI.

If you are installing using command line flags, use **`/DIR="<path>"`** to change the default location.

QUESTION: Which compilers does HP-MPI for Windows work with?

ANSWER: HP-MPI works well with all compilers. We explicitly test with Visual Studio, Intel, and Portland compilers. HP-MPI strives not to introduce compiler dependencies.

QUESTION: What libraries do I need to link with when I build?

ANSWER: We recommend using the **`mpicc`** and **`mpif90`** scripts in **`%MPI_ROOT%\bin`** to build. If you absolutely do not want to build with these scripts, we recommend using them with the `-show` option to see what they are doing and use that as a starting point for doing your build.

The `-show` option will print out the command to be used for the build and not execute. Because these scripts are readable, you can examine them to understand what gets linked in and when.

If you are building a project using Visual Studio IDE, we recommend adding the provided **`HPMPI.vsprops`** (for 32-bit applications) or **`HPMPI64.vsprops`** (for 64-bit applications) to the property pages by using Visual Studio's Property Manager. Add this property page for each MPI project in your solution.

QUESTION: How do I specifically build a 32-bit application on a 64-bit architecture?

ANSWER: On windows, open the appropriate compiler command window to get the correct 32-bit or 64-bit compilers. When using **`mpicc`** or **`mpif90`** scripts, include the `-mpi32` or `-mpi64` flag to link in the correct MPI libraries.

QUESTION: How can I control which interconnect is used for running my application?

ANSWER: The default protocol on Windows is TCP. Windows currently does not have automatic interconnect selection. To use InfiniBand, you have two choices: WSD or IBAL.

WSD uses the same protocol as TCP. You must select the appropriate IP subnet, specifically the IPoIB subnet for the InfiniBand drivers.

To select the desired subnet, use the `-netaddr` flag. For example:

```
R:\> mpirun -TCP -netaddr 192.168.1.1 -ccp -np 12 rank.exe
```

This will force TCP/IP to be used over the subnet associated with the network interface with IP address 192.168.1.1.

To use the low-level InfiniBand protocol, use the `-IBAL` flag instead of `-TCP`. For example:

```
R:\> mpirun -IBAL -netaddr 192.168.1.1 -ccp -np 12 rank.exe
```

The use of `-netaddr` is not required when using `-IBAL`, but HP-MPI still uses this subnet for administration traffic. By default, it will use the TCP subnet available first in the binding order. This can be found and changed by going to the **`Network Connections->Advanced Settings`** windows.

IBAL is the desired protocol when using InfiniBand. IBAL performance for both latency and bandwidth is considerably better than WSD.

For more information, see "Interconnect support" on page 82.

QUESTION: When I use 'mpirun -ccp -np 2 -nodex rank.exe' I only get one node, not two. Why?

ANSWER: When using the automatic job submittal feature of **`mpirun`**, the `-np` *`X`* is used to request the number of CPUs for the scheduled job. This is usually equal to the number of ranks.

But when using `-nodex` to indicate only one rank/node, the actual number of CPUs for the job is greater than the number of ranks. Because compute nodes can have different CPUs on each node, and **`mpirun`** cannot determine the number of CPUs required until the nodes are allocated to the job, the user must provide the total number of CPUs desired for the job. Then the `-nodex` flag will limit the number of ranks scheduled to just one/node.

In other words, `-np` *`X`* is the number of CPUs for the job, and `-nodex` is telling **`mpirun`** to only use one CPU/node.

QUESTION: What is a UNC path?

ANSWER: A Universal Naming Convention (UNC) path is a path that is visible as a network share on all nodes. The basic format is

\\node-name\exported-share-folder\paths

UNC paths are usually required because mapped drives may not be consistent from node to node, and many times don't get established for all logon tokens.

QUESTION: I am using mpirun automatic job submittal to schedule my job while in C:\tmp, but the job won't run. Why?

ANSWER: The automatic job submittal will set the current working directory for the job to the current directory. (Equivalent to using **`-e MPI_WORKDIR=<path>`**.) Because the remote compute nodes cannot access the local disks, they need a UNC path for the current directory.

HP-MPI can convert the local drive to a UNC path if the local drive is a mapped network drive. So running from the mapped drive instead of the local disk allows HP-MPI to set a working directory to a visible UNC path on remote nodes.

QUESTION: I run a batch script before my MPI job, but it fails. Why?

ANSWER: Batch files run in a command window. When the batch file starts, Windows will first start a command window and try to set the directory to the 'working directory' indicated by the job. This is usually a UNC path so all remote nodes can see this directory. But command windows cannot change directory to a UNC path.

One option is to use VBScript instead of .bat files for scripting tasks.

Glossary

application In the context of HP-MPI, an application is one or more executable programs that communicate with each other via MPI calls.

asynchronous Communication in which sending and receiving processes place no constraints on each other in terms of completion. The communication operation between the two processes may also overlap with computation.

bandwidth Data transmission capacity of a communications channel. The greater a channel's bandwidth, the more information it can carry per unit of time.

barrier Collective operation used to synchronize the execution of processes. `MPI_Barrier` blocks the calling process until all receiving processes have called it. This is a useful approach for separating two stages of a computation so messages from each stage are not overlapped.

blocking receive Communication in which the receiving process does not return until its data buffer contains the data transferred by the sending process.

blocking send Communication in which the sending process does not return until its associated data buffer is available for reuse. The data transferred can be copied directly into the matching receive buffer or a temporary system buffer.

broadcast One-to-many collective operation where the root process sends a message to all other processes in the communicator including itself.

buffered send mode Form of blocking send where the sending process returns when the message is buffered in application-supplied space or when the message is received.

buffering Amount or act of copying that a system uses to avoid deadlocks. A large amount of buffering can adversely affect performance and make MPI applications less portable and predictable.

cluster Group of computers linked together with an interconnect and software that functions collectively as a parallel machine.

collective communication Communication that involves sending or receiving messages among a group of processes at the same time. The communication can be one-to-many, many-to-one, or many-to-many. The main collective routines are `MPI_Bcast`, `MPI_Gather`, and `MPI_Scatter`.

communicator Global object that groups application processes together. Processes in a communicator can communicate with each other or with processes in another group. Conceptually, communicators define a communication context and a static group of processes within that context.

context Internal abstraction used to define a safe communication space for processes. Within a communicator, context separates point-to-point and collective communications.

data-parallel model Design model where data is partitioned and distributed to each process in an application. Operations are performed on each set of data in parallel and intermediate results are exchanged between processes until a problem is solved.

derived data types User-defined structures that specify a sequence of basic data types and integer displacements for noncontiguous data. You create derived data types through the use of type-constructor functions that describe the layout of sets of primitive types in memory. Derived types may contain arrays as well as combinations of other primitive data types.

determinism A behavior describing repeatability in observed parameters. The order of a set of events does not vary from run to run.

domain decomposition Breaking down an MPI application's computational space into regular data structures such that all computation on these structures is identical and performed in parallel.

executable A binary file containing a program (in machine language) which is ready to be executed (run).

explicit parallelism Programming style that requires you to specify parallel constructs directly. Using the MPI library is an example of explicit parallelism.

functional decomposition Breaking down an MPI application's computational space into separate tasks such that all computation on these tasks is performed in parallel.

gather Many-to-one collective operation where each process (including the root) sends the contents of its send buffer to the root.

granularity Measure of the work done between synchronization points. Fine-grained applications focus on execution at the instruction level of a program. Such applications are load balanced but suffer from a low computation/communication ratio. Coarse-grained applications focus on execution at the program level where multiple programs may be executed in parallel.

group Set of tasks that can be used to organize MPI applications. Multiple groups are useful for solving problems in linear algebra and domain decomposition.

intercommunicators Communicators that allow only processes in two different groups to exchange data.

intracommunicators Communicators that allow processes within the same group to exchange data.

instrumentation Cumulative statistical information collected and stored in ASCII format. Instrumentation is the recommended method for collecting profiling data.

latency Time between the initiation of the data transfer in the sending process and the arrival of the first byte in the receiving process.

load balancing Measure of how evenly the work load is distributed among an application's processes. When an application is perfectly balanced, all processes share the total work load and complete at the same time.

locality Degree to which computations performed by a processor depend only upon local data. Locality is measured in several ways including the ratio of local to nonlocal data accesses.

locality domain (ldom) Consists of a related collection of processors, memory, and peripheral resources that compose a fundamental building block of the system. All processors and peripheral devices in a given locality domain have equal latency to the memory contained within that locality domain.

mapped drive In a network, drive mappings reference remote drives, and you have the option of assigning the letter of your choice. For example, on your local machine you might map S: to refer to drive C: on a server. Each time S: is referenced on the local machine, the drive on the server is substituted behind the scenes. The mapping may also be set up to refer only to a specific folder on the remote machine, not the entire drive.

message bin A message bin stores messages according to message length. You can define a message bin by defining the byte range of the message to be stored in the bin—use the MPI_INSTR environment variable.

message-passing model Model in which processes communicate with each other by sending and receiving messages. Applications based on message passing are nondeterministic by default. However, when one process sends two or more messages to another, the transfer is deterministic as the messages are always received in the order sent.

MIMD Multiple instruction multiple data. Category of applications in which many instruction streams are applied concurrently to multiple data sets.

MPI Message-passing interface. Set of library routines used to design scalable parallel applications. These routines provide a wide range of operations that include computation, communication, and synchronization. MPI-2 is the current standard supported by major vendors.

MPMD Multiple data multiple program. Implementations of HP-MPI that use two or more separate executables to construct an application. This design style can be used to simplify the application source and reduce the size of spawned processes. Each process may run a different executable.

multilevel parallelism Refers to multithreaded processes that call MPI routines to perform computations. This approach is beneficial for problems that can be decomposed into logical parts for parallel execution (for example, a looping construct that spawns multiple threads to perform a computation and then joins after the computation is complete).

multihost A mode of operation for an MPI application where a cluster is used to carry out a parallel application run.

nonblocking receive Communication in which the receiving process returns before a message is stored in the receive buffer. Nonblocking receives are useful when communication and computation can be effectively overlapped in an MPI application. Use of nonblocking receives may also avoid system buffering and memory-to-memory copying.

nonblocking send Communication in which the sending process returns before a message is stored in the send buffer.

Nonblocking sends are useful when communication and computation can be effectively overlapped in an MPI application.

non–determinism A behavior describing non-repeatable parameters. A property of computations which may have more than one result. The order of a set of events depends on run time conditions and so varies from run to run.

parallel efficiency An increase in speed in the execution of a parallel application.

point-to-point communication Communication where data transfer involves sending and receiving messages between two processes. This is the simplest form of data transfer in a message-passing model.

polling Mechanism to handle asynchronous events by actively checking to determine if an event has occurred.

process Address space together with a program counter, a set of registers, and a stack. Processes can be single threaded or multithreaded. Single-threaded processes can only perform one task at a time. Multithreaded processes can perform multiple tasks concurrently as when overlapping computation and communication.

race condition Situation in which multiple processes vie for the same resource and receive it in an unpredictable manner. Race conditions can lead to cases where applications do not run correctly from one invocation to the next.

rank Integer between zero and (number of processes - 1) that defines the order of a process in a communicator. Determining the rank of a process is important when solving problems where a master process partitions and distributes work to slave processes. The slaves perform some computation and return the result to the master as the solution.

ready send mode Form of blocking send where the sending process cannot start until a matching receive is posted. The sending process returns immediately.

reduction Binary operations (such as addition and multiplication) applied globally to all processes in a communicator. These operations are only valid on numeric data and are always associative but may or may not be commutative.

scalable Ability to deliver an increase in application performance proportional to an increase in hardware resources (normally, adding more processors).

scatter One-to-many operation where the root's send buffer is partitioned into n segments and distributed to all processes such that the ith process receives the ith segment. n represents the total number of processes in the communicator.

send modes Point-to-point communication in which messages are passed using one of four different types of blocking sends. The four send modes include standard mode (`MPI_Send`), buffered mode (`MPI_Bsend`), synchronous mode (`MPI_Ssend`), and ready mode (`MPI_Rsend`). The modes are all invoked in a similar manner and all pass the same arguments.

shared memory model Model in which each process can access a shared address space. Concurrent accesses to shared memory are controlled by synchronization primitives.

SIMD Single instruction multiple data. Category of applications in which homogeneous processes execute the same instructions on their own data.

SMP Symmetric multiprocessor. A multiprocess computer in which all the processors have equal access to all machine resources. Symmetric multiprocessors have no manager or worker processes.

spin-yield Refers to an HP-MPI facility that allows you to specify the number of milliseconds a process should block (spin) waiting for a message before yielding the CPU to another process. Specify a spin-yield value in the MPI_FLAGS environment variable.

SPMD Single program multiple data. Implementations of HP-MPI where an application is completely contained in a single executable. SPMD applications begin with the invocation of a single process called the master. The master then spawns some number of identical child processes. The master and the children all run the same executable.

standard send mode Form of blocking send where the sending process returns when the system can buffer the message or when the message is received.

stride Constant amount of memory space between data elements where the elements are stored noncontiguously. Strided data are sent and received using derived data types.

synchronization Bringing multiple processes to the same point in their execution before any can continue. For example, `MPI_Barrier` is a collective routine that blocks the calling process until all receiving processes have called it. This is a useful approach for separating two stages of a computation so messages from each stage are not overlapped.

synchronous send mode Form of blocking send where the sending process returns only if a matching receive is posted and the receiving process has started to receive the message.

tag Integer label assigned to a message when it is sent. Message tags are one of the synchronization variables used to ensure that a message is delivered to the correct receiving process.

task Uniquely addressable thread of execution.

thread Smallest notion of execution in a process. All MPI processes have one or more threads. Multithreaded processes have one address space but each process thread contains its own counter, registers, and stack. This allows rapid context switching because threads require little or no memory management.

thread-compliant An implementation where an MPI process may be multithreaded. If it is, each thread can issue MPI calls. However, the threads themselves are not separately addressable.

trace Information collected during program execution that you can use to analyze your application. You can collect trace information and store it in a file for later use or analyze it directly when running your application interactively.

UNC A Universal Naming Convention (UNC) path is a path that is visible as a network share on all nodes. The basic format is \\node-name\exported-share-folder

\paths. UNC paths are usually required because mapped drives may not be consistent from node to node, and many times don’t get established for all logon tokens.

yield See spin-yield.