

LAM/MPI User's Guide

Version 7.0.6



The LAM/MPI Team
Open Systems Lab
<http://www.lam-mpi.org/>



pervasive**technology**labs
AT INDIANA UNIVERSITY

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Chapter 1

Don't Panic! (Who Should Read This Document?)

This document probably looks huge to new users. But don't panic! It is divided up into multiple, relatively independent sections that can be read and digested separately. Although this manual covers a lot of relevant material for all users, the following guidelines are suggested for various types of users. If you are:

- **New to MPI:** First, read Chapter 2 for an introduction to MPI and LAM/MPI. A good reference on MPI programming is also strongly recommended; there are several books available as well as excellent on-line tutorials (e.g., [3, 4, 5, 9]).

When you're comfortable with the concepts of MPI, move on to **New to LAM/MPI**.

- **New to LAM/MPI:** If you're familiar with MPI but unfamiliar with LAM/MPI, first read Chapter 4 for a mini-tutorial on getting started with LAM/MPI. You'll probably be familiar with many of the concepts described, and simply learn the LAM terminology and commands. Glance over and use as a reference Chapter 7 for the rest of the LAM/MPI commands. Chapter 11 contains some quick tips on common problems with LAM/MPI.

Assuming that you've already got MPI codes that you want to run under LAM/MPI, read Chapter 5 to see exactly what MPI-2 features LAM/MPI supports.

When you're comfortable with all this, move on to **Previous LAM user**.

- **Previous LAM user:** As a previous LAM user, you're probably already fairly familiar with all the LAM commands – their basic functionality hasn't changed much. However, many of them have grown new options and capabilities, particularly in the area of run-time tunable parameters. So be sure to read Chapters 6 to learn about LAM's System Services Interface (SSI), Chapters 8 and 9 (LAM and MPI SSI modules), and finally Chapter 12 (miscellaneous LAM/MPI information, features, etc.).

If you're curious to see a brief listing of new features in this release, see the release notes in Chapter 3. This isn't really necessary, but when you're kicking the tires of this version, it's a good way to ensure that you are aware of all the new features.

Finally, even for the seasoned MPI and LAM/MPI veteran, be sure to check out Chapter 10 for information about debugging MPI programs in parallel.

- **System administrator:** Unless you're also a parallel programmer, you're reading the wrong document. You should be reading the LAM/MPI Installation Guide [14] for detailed information on how to configure, compile, and install LAM/MPI.

Chapter 2

Introduction to LAM/MPI

This chapter provides a quick summary of the MPI standard and the LAM/MPI implementation of that standard.

2.1 About MPI

The Message Passing Interface (MPI) [2, 7], is a set of API functions enabling programmers to write high-performance parallel programs that pass messages between serial processes to make up an overall parallel job. MPI is the culmination of decades of research in parallel computing, and was created by the MPI Forum – an open group representing a wide cross-section of industry and academic interests. More information, including the both volumes of the official MPI standard, can be found at the main MPI Forum web site.¹

MPI is suitable for “big iron” parallel machines such as the IBM SP, SGI Origin, etc., but it also works in smaller environments such as a group of workstations. Since clusters of workstations are readily available at many institutions, it has become common to use them as a single parallel computing resource running MPI programs. The MPI standard was designed to support portability and platform independence. As a result, users can enjoy cross-platform development capability as well as transparent heterogeneous communication. For example, MPI codes which have been written on the RS-6000 architecture running AIX can be ported to a SPARC architecture running Solaris with little or no modifications.

2.2 About LAM/MPI

LAM/MPI is a high-performance, freely available, open source implementation of the MPI standard that is researched, developed, and maintained at the Open Systems Lab at Indiana University. LAM/MPI supports all of the MPI-1 Standard and much of the MPI-2 standard. More information about LAM/MPI, including all the source code and documentation, is available from the main LAM/MPI web site.²

LAM/MPI is not only a library that implements the mandated MPI API, but also the LAM run-time environment: a user-level, daemon-based run-time environment that provides many of the services required by MPI programs. Both major components of the LAM/MPI package are designed as component frameworks – extensible with small modules that are selectable (and configurable) at run-time. This component framework is known as the System Services Interface (SSI). The SSI component architectures are fully documented in [8, 10, 11, 12, 13, 14, 15].

¹<http://www.mpi-forum.org/>

²<http://www.lam-mpi.org/>

Chapter 3

Release Notes

This chapter contains release notes as they pertain to the run-time operation of LAM/MPI. The Installation Guide contains additional release notes on the configuration, compilation, and installation of LAM/MPI.

3.1 New Feature Overview

A full, high-level overview of all changes in the 7 series (and previous versions) can be found in the HISTORY file that is included in the LAM/MPI distribution.

Major new features specific to the 7 series include the following:

- LAM/MPI 7.0 is the first version to feature the System Services Interface (SSI). SSI is a “pluggable” framework that allows for a variety of run-time selectable modules to be used in MPI applications. For example, the selection of which network to use for MPI point-to-point message passing is now a run-time decision, not a compile-time decision.
- When used with supported back-end checkpoint/restart systems, LAM/MPI can checkpoint parallel MPI jobs (see Section 9.4, page 75 for more details).
- LAM/MPI supports the following underlying networks for MPI communication, including several run-time tunable-parameters for each (see Section 9.2, page 64 for more details):
 - TCP/IP, using direct peer-to-peer sockets
 - Myrinet, using the native gm message passing library
 - Shared memory, using either spin locks or semaphores
 - “LAM Daemon” mode, using LAM’s native run-time environment message passing
- LAM’s run-time environment can now be “natively” executed in the following environments (see Section 8.1, page 55 for more details):
 - BProc clusters
 - Globus grid environments (beta level support)
 - Traditional rsh / ssh-based clusters
 - OpenPBS/PBS Pro batch queue jobs

- Several collective algorithms have now been made “SMP-aware”, exhibiting better performance when enabled and executed on clusters of SMPs (see Section 9.3, page 72 for more details).
- Full support of the TotalView parallel debugger (see Section 10.2, page 81 for more details).
- Support for the MPI-2 portable MPI process startup command `mpiexec` (see Section 7.10, page 47 for more details).
- Full documentation for system administrators, users, and developers [8, 10, 11, 12, 13, 14, 15].
- Various MPI enhancements:
 - C++ bindings are provided for all supported MPI functionality.
 - Upgraded the included ROMIO package [16, 17] to version 1.2.5.1 for MPI I/O support.
 - Per MPI-2:4.8 free the `MPI_COMM_SELF` communicator at the beginning of `MPI_FINALIZE`, allowing user-specified functions to be automatically invoked.
 - Formal support for `MPI_THREAD_SINGLE`, `MPI_THREAD_FUNNELED`, and `MPI_THREAD_SERIALIZED`. `MPI_THREAD_MULTIPLE` is not supported (see Section 12.4, page 92 for more details).
 - Significantly increased the number of tags and communicators supported in most RPIs.
 - Enhanced scheduling capabilities for `MPI_COMM_SPAWN`.
- Various LAM run-time environment enhancements:
 - New `laminfo` command that provides detailed information about a given LAM/MPI installation.
 - Use `TMPDIR` environment variable for LAM’s session directory.
 - Restore the original `umask` when creating MPI processes.
 - Allow Fortran MPI processes to change how their name shows up in `mpitask`.
 - Better `SIGTERM` support in the LAM daemon; catch the signal and ensure that all sub-processes are killed and resources are released.
- Deprecated functionality (may disappear in future releases of LAM/MPI):
 - `LAMRSH` : The `LAMRSH` environment variable has been deprecated in favor of the `boot_rsh-agent` parameter to the `rsh` SSI boot module.
 - `LAM_MPI_SOCKET_SUFFIX` : The `LAM_MPI_SOCKET_SUFFIX` has been deprecated in favor of the `LAM_MPI_SESSION_SUFFIX` environment variable.

3.2 Platform-Specific Notes

3.2.1 Provided RPMs

If you install LAM/MPI via an official RPM from the LAM/MPI web site (or one of its mirrors), you may not have all the SSI modules that are described in Chapters 8 and 9. The modules that are shipped in 7.0.6 are listed in Table 3.1. If you need modules that are not provided in the RPMs, you will likely need to download and install the source LAM/MPI tarball.

This is for multiple reasons:

Boot	Collective	Checkpoint/Restart	RPI
globus rsh	lam_basic smp	<none>	crtcp lamd sysv tcp usysv

Table 3.1: SSI modules that are included in the official LAM/MPI RPMs.

- If provided as a binary, each SSI module may require a specific configuration (e.g., a specific version of the back-end software that it links to/interacts with). Since each SSI module is orthogonal to other modules, and since the back-end software systems that each SSI module interacts with may release new versions at any time, the number of combinations that would need to be provided is exponential. The logistics of attempting to provide pre-compiled binaries for all of these configurations is beyond the capability of the LAM Team. As a direct result, significant effort has gone into making building LAM/MPI from the source distribution as simple and all-inclusive as possible.
- Although LAM/MPI is free software (and freely distributable), some of the systems that its modules can interact with are not. The LAM Team cannot distribute modules that contain references to non-freely-distributable code.

The `laminfo` command can be used to see which SSI modules are available in your LAM/MPI installation.

3.2.2 Filesystem Issues

Case-insensitive filesystems. On systems with case-insensitive filesystems (such as Mac OS X with HFS+, or Linux with NTFS), the `mpicc` and `mpicc` commands will both refer to the same executable. This obviously makes distinguishing between the `mpicc` and `mpicc` wrapper compilers impossible. LAM will attempt to determine if you are building on a case-insensitive filesystem. If you are, the C++ wrapper compiler will be called `mpic++`. Otherwise, the C++ compiler will be called `mpicc` (although `mpic++` will also be available).

NFS-shared /tmp. The LAM per-session directory may not work properly when hosted in an NFS directory, and may cause problems when running MPI programs and/or supplementary LAM run-time environment commands. If using a local filesystem is not possible (e.g., on diskless workstations), the use of `tmpfs` or `tinyfs` is recommended. LAM's session directory will not grow large; it contains a small amount of meta data as well as known endpoints for Unix sockets to allow LAM/MPI programs to contact the local LAM run-time environment daemon.

AFS and tokens/permissions. AFS has some peculiarities, especially with file permissions when using `rsh/ssh`.

Many sites tend to install the AFS `rsh` replacement that passes tokens to the remote machine as the default `rsh`. Similarly, most modern versions of `ssh` have the ability to pass AFS tokens. Hence, if you are using the `rsh` boot module with `recon` or `lamboot`, your AFS token will be passed to the remote LAM daemon automatically. If your site does not install the AFS replacement `rsh` as the default, consult the documentation on `--with-rsh` to see how to set the path to the `rsh` that LAM will use.

Once you use the replacement `rsh` or an AFS-capable `ssh`, you should get a token on the target node when using the `rsh` boot module.¹ This means that your LAM daemons are running with your AFS token, and you should be able to run any program that you wish, including those that are not `system:anyuser` accessible. You will even be able to write into AFS directories where you have write permission (as you would expect).

Keep in mind, however, that AFS tokens have limited lives, and will eventually expire. This means that your LAM daemons (and user MPI programs) will lose their AFS permissions after some specified time unless you renew your token (with the `klog` command, for example) on the originating machine before the token runs out. This can play havoc with long-running MPI programs that periodically write out file results; if you lose your AFS token in the middle of a run, and your program tries to write out to a file, it will not have permission to, which may cause Bad Things to happen.

If you need to run long MPI jobs with LAM on AFS, it is usually advisable to ask your AFS administrator to increase your default token life time to a large value, such as 2 weeks.

3.2.3 Dynamic/Embedded Environments

In LAM/MPI version 7.0.6, the `gm` RPI includes the `ptmalloc` package as a substitute memory allocation mechanism (see Section 9.2.3, page 67 for more details). This can cause problems when running MPI processes as dynamically loaded modules. For example, when running a LAM/MPI program as a MEX function in a Matlab environment, normal Unix linker semantics create situations where both the default Unix and the `ptmalloc` memory management systems are used. This typically results in process failure.

Note that this *only* occurs when LAM/MPI processes are used in a dynamic environment and the `gm` RPI module is included in LAM/MPI on systems where `ptmalloc` is used (i.e., not Solaris). This appears to occur because of normal Unix semantics, and the only way to avoid it is to not use the `ptmalloc` package that is included in LAM for `gm` memory management. See the LAM/MPI Installation Guide for details on how to disable `ptmalloc`.

3.2.4 Linux

LAM/MPI is frequently used on Linux-based machines (IA-32 and otherwise). Although LAM/MPI is generally tested on Red Hat and Mandrake Linux systems using recent kernel versions, it should work on other Linux distributions as well.

Note that kernel versions 2.2.0 through 2.2.9 had some TCP/IP performance problems. It seems that version 2.2.10 fixed these problems; if you are using a Linux version between 2.2.0 and 2.2.9, LAM may exhibit poor TCP performance due to the Linux TCP/IP kernel bugs. We recommend that you upgrade to 2.2.10 (or the latest version). See <http://www.lam-mpi.org/linux/> for a full discussion of the problem.

3.2.5 Microsoft Windows^(TM)(Cygwin)

LAM/MPI does not yet support Microsoft Windows^(TM) or Cygwin environments.

3.2.6 Solaris

The `gm` RPI will fail to function properly on versions of Solaris older than Solaris 7.

¹If you are using a different boot module, you may experience problems with obtaining AFS tokens on remote nodes.

Chapter 4

Getting Started with LAM/MPI

This chapter provides a summary tutorial describing some of the high points of using LAM/MPI. It is not intended as a comprehensive guide; the finer details of some situations will not be explained. However, it is a good step-by-step guide for users who are new to MPI and/or LAM/MPI.

Using LAM/MPI is conceptually simple:

- Launch the LAM run-time environment (RTE)
- Repeat as necessary:
 - Compile MPI program(s)
 - Run MPI program(s)
- Shut down the LAM run-time environment

The tutorial below will describe each of these steps.

4.1 One-Time Setup

This section describes actions that usually only need to be performed once per user in order to setup LAM to function properly.

4.1.1 Setting the Path

One of the main requirements for LAM/MPI to function properly is for the LAM executables to be in your path. This step may vary from site to site; for example, the LAM executables may already be in your path – consult your local administrator to see if this is the case.

NOTE: If the LAM executables are already in your path, you can skip this step and proceed to Section 4.2.

In many cases, if your system does not already provide the LAM executables in your path, you can add them by editing your “dot” files that are executed automatically by the shell upon login (both interactive and non-interactive logins). Each shell has a different file to edit and corresponding syntax, so you’ll need to know which shell you are using. Tables 4.1 and 4.2 list several common shells and the associated files that are typically used. Consult the documentation for your shell for more information.

You’ll also need to know the directory where LAM was installed. For the purposes of this tutorial, we’ll assume that LAM is installed in `/usr/local/lam`. And to re-emphasize a critical point: these are only

Shell name	Interactive login startup file
sh (or Bash named “sh”)	<code>.profile</code>
csch	<code>.cschrc</code> followed by <code>.login</code>
tcsh	<code>.tcshrc</code> if it exists, <code>.cschrc</code> if it does not, followed by <code>.login</code>
bash	<code>.bash_profile</code> if it exists, or <code>.bash_login</code> if it exists, or <code>.profile</code> if it exists (in that order). Note that some Linux distributions automatically come with <code>.bash_profile</code> scripts for users that automatically execute <code>.bashrc</code> as well. Consult the <code>bash</code> manual page for more information.

Table 4.1: List of common shells and the corresponding environmental setup files commonly used with each for interactive startups (e.g., normal login). All files listed are assumed to be in the `$HOME` directory.

Shell name	Non-interactive login startup file
sh (or Bash named “sh”)	This shell does not execute any file automatically, so LAM will execute the <code>.profile</code> script before invoking LAM executables on remote nodes
csch	<code>.cschrc</code>
tcsh	<code>.tcshrc</code> if it exists, <code>.cschrc</code> if it does not
bash	<code>.bashrc</code> if it exists

Table 4.2: List of common shells and the corresponding environmental setup files commonly used with each for non-interactive startups (e.g., normal login). All files listed are assumed to be in the `$HOME` directory.

guidelines – the specifics may vary depending on your local setup. Consult your local system or network administrator for more details.

Once you have determined all three pieces of information (what shell you are using, what directory LAM was installed to, and what the appropriate “dot” file to edit), open the “dot” file in a text editor and follow the general directions listed below:

- For the Bash, Bourne, and Bourne-related shells, add the following lines:

```
PATH=/usr/local/lam/bin:$PATH
export PATH
```

- For the C shell and related shells (such as `tcsh`), add the following line:

```
set path = (/usr/local/lam/bin $path)
```

4.1.2 Finding the LAM Manual Pages

LAM includes manual pages for all supported MPI functions as well as all of the LAM executables. While this step *is not necessary* for correct MPI functionality, it can be helpful when looking for MPI or LAM-specific information.

Using Tables 4.1 and 4.2, find the right “dot” file to edit. Assuming again that LAM was installed to `/usr/local/lam`, open the appropriate “dot” file in a text editor and follow the general directions listed below:

- For the Bash, Bourne, and Bourne-related shells, add the following lines:

```
MANPATH=/usr/local/lam/man:$MANPATH
export MANPATH
```

- For the C shell and related shells (such as `tcsh`), add the following lines:

```
if ($?MANPATH == 0) then
  setenv MANPATH /usr/local/lam/man
else
  setenv MANPATH /usr/local/lam/man:$MANPATH
endif
```

4.2 System Services Interface (SSI)

LAM/MPI is built around a core of System Services Interface (SSI) plugin modules. SSI allows run-time selection of different underlying services within the LAM/MPI run-time environment, including tunable parameters that can affect the performance of MPI programs.

While this tutorial won’t go into much detail about SSI, just be aware that you’ll see mention of “SSI” in the text below. In a few places, the tutorial passes parameters to various SSI modules through either environment variables and/or the `-ssi` command line parameter to several LAM commands.

See other sections in this manual for a more complete description of SSI (Chapter 6, page 35), how it works, and what run-time parameters are available (Chapters 8 and 9, pages 55 and 63, respectively). Also, the `lamssi(7)`, `lamssi_boot(7)`, `lamssi_coll(7)`, `lamssi_cr(7)`, and `lamssi_rpi(7)` manual pages each provide additional information on LAM’s SSI mechanisms.

4.3 What Does Your LAM/MPI Installation Support?

LAM/MPI can be installed with a large number of configuration options. It depends on what choices your system/network administrator made when configuring and installing LAM/MPI. The `laminfo` command is provided to show the end-user with information about what the installed LAM/MPI supports. Running “`laminfo`” (with no arguments) prints a list of LAM’s capabilities, including all of its SSI modules.

Among other things, this shows what language bindings the installed LAM/MPI supports, what underlying network transports it supports, and what directory LAM was installed to. The `-parsable` option prints out all the same information, but in a conveniently machine-parsable format (suitable for using with scripts).

4.4 Booting the LAM Run-Time Environment

Before any MPI programs can be executed, the LAM run-time environment must be launched. This is typically called “booting LAM.” A successful boot process creates an instance of the LAM run-time environment commonly referred to as the “LAM universe.”

LAM’s run-time environment can be executed in many different environments. For example, it can be run interactively on a cluster of workstations (even on a single workstation, perhaps to simulate parallel execution for debugging and/or development). Or LAM can be run in production batch scheduled systems.

This example will focus on a traditional `rsh` / `ssh`-style workstation cluster (i.e., not under batch systems), where `rsh` or `ssh` is used to launch executables on remote workstations.

4.4.1 The Boot Schema File (a.k.a, “Hostfile”, “Machinefile”)

When using `rsh` or `ssh` to boot LAM, you will need a text file listing the hosts on which to launch the LAM run-time environment. This file is typically referred to as a “boot schema”, “hostfile”, or “machinefile.” For example:

```
# My boot schema
node1.cluster.example.com
node2.cluster.example.com
node3.cluster.example.com cpu=2
node4.cluster.example.com cpu=2
```

Four nodes are specified in the above example by listing their IP hostnames. Note also the “`cpu=2`” that follows the last two entries. This tells LAM that these machines each have two CPUs available for running MPI programs (e.g., `node3` and `node4` are two-way SMPs). It is important to note that the number of CPUs specified here has *no* correlation to the physical number of CPUs in the machine. It is simply a convenience mechanism telling LAM how many MPI processes we will typically launch on that node. The ramifications of the `cpu` key will be discussed later.

The location of this text file is irrelevant; for the purposes of this example, we’ll assume that it is named `hostfile` and is located in the current working directory.

4.4.2 The `lamboot` Command

The `lamboot` command is used to launch the LAM run-time environment. For each machine listed in the boot schema, the following conditions must be met for LAM’s run-time environment to be booted correctly:

- The machine must be reachable and operational.

- The user must be able to non-interactively execute arbitrary commands on the machine (e.g., without being prompted for a password).
- The LAM executables must be locatable on that machine, using the user's shell search path.
- The user must be able to write to the LAM session directory (usually somewhere under `/tmp`).
- The shell's start-up scripts must not print anything on standard error.
- All machines must be able to resolve the fully-qualified domain name (FQDN) of all the machines being booted (including itself).

Once all of these conditions are met, the `lamboot` command is used to launch the LAM run-time environment. For example:

```
shell$ lamboot -v -ssi boot rsh hostfile
```

```
LAM 7.0/MPI 2 C++/ROMIO - Indiana University
```

```
n0<1234> ssi:boot:base:linear: booting n0 (node1.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: booting n1 (node2.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: booting n2 (node3.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: booting n3 (node4.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: finished
```

The parameters passed to `lamboot` in the example above are as follows:

- `-v`: Make `lamboot` be slightly verbose.
- `-ssi boot rsh`: Ensure that LAM uses the `rsh/ssh` boot module to boot the LAM universe. Typically, LAM chooses the right boot module automatically (and therefore this parameter is not typically necessary), but to ensure that this tutorial does exactly what we want it to do, we use this parameter to absolutely ensure that LAM uses `rsh` or `ssh` to boot the universe.
- `hostfile`: Name of the boot schema file.

Common causes of failure with the `lamboot` command include (but are not limited to):

- User does not have permission to execute on the remote node. This typically involves setting up a `$HOME/.rhosts` file (if using `rsh`), or properly configured SSH keys (using `ssh`).
Setting up `.rhosts` and/or SSH keys for password-less remote logins are beyond the scope of this tutorial; consult local documentation for `rsh` and `ssh`, and/or internet tutorials on setting up SSH keys.¹
- The first time a user uses `ssh` to execute on a remote node, `ssh` typically prints a warning to the standard error. LAM will interpret this as a failure. If this happens, `lamboot` will complain that something unexpectedly appeared on `stderr`, and abort. The solution is to manually `ssh` to each node in the boot schema once in order to eliminate the `stderr` warning, and then try `lamboot` again.

¹As of this writing, a Google search for "ssh keys" turned up several decent tutorials; including any one of them here would significantly increase the length of this already-tremendously-long manual.

If you have having problems with `lamboot`, try using the `-d` option to `lamboot`, which will print enormous amounts of debugging output which can be helpful for determining what the problem is. Additionally, check the `lamboot(1)` man page as well as the LAM FAQ on the main LAM web site² under the section “Booting LAM” for more information.

4.4.3 The `lamnodes` Command

An easy way to see how many nodes and CPUs are in the current LAM universe is with the `lamnodes` command. For example, with the LAM universe that was created from the boot schema in Section 4.4.1, running the `lamnodes` command would result in the following output:

```
shell$ lamnodes
n0 node1.cluster.example.com:1:origin,this_node
n1 node2.cluster.example.com:1:
n2 node3.cluster.example.com:2:
n3 node4.cluster.example.com:2:
```

The “n” number on the far left is the LAM node number. For example, “n3” uniquely refers to `node4`. Also note the third column, which indicates how many CPUs are available for running processes on that node. In this example, there are a total of 6 CPUs available for running processes. This information is from the “cpu” key that was used in the hostfile, and is helpful for running parallel processes (see below).

Finally, the “origin” notation indicates which node `lamboot` was executed from. “this_node” obviously indicates which node `lamnodes` is running on.

4.5 Compiling MPI Programs

Note that it is *not* necessary to have LAM booted to compile MPI programs.

Compiling MPI programs can be a complicated process:

- The same compilers should be used to compile/link user MPI programs as were used to compile LAM itself.
- Depending on the specific installation configuration of LAM, a variety of `-I`, `-L`, and `-l` flags (and possibly others) may be necessary to compile and/or link a user MPI program.

LAM/MPI provides “wrapper” compilers to hide all of this complexity. These wrapper compilers simply add the correct compiler/linker flags and then invoke the underlying compiler to actually perform the compilation/link. As such, LAM’s wrapper compilers can be used just like “real” compilers.

The wrapper compilers are named `mpicc` (for C programs), `mpicc` and `mpic++` (for C++ programs), and `mpif77` (for Fortran programs). For example:

```
shell$ mpicc -g -c foo.c
shell$ mpicc -g -c bar.c
shell$ mpicc -g foo.o bar.o -o my_mpi_program
```

Note that no additional compiler and linker flags are required for correct MPI compilation or linking. The resulting `my_mpi_program` is ready to run in the LAM run-time environment. Similarly, the other two wrapper compilers can be used to compile MPI programs for their respective languages:

²<http://www.lam-mpi.org/faq/>

```
shell$ mpiCC -O c++_program.cc -o my_c++_mpi_program
shell$ mpif77 -O f77_program.f -o my_f77_mpi_program
```

Note, too, that any other compiler/linker flags can be passed through the wrapper compilers (such as `-g` and `-O`); they will simply be passed to the back-end compiler.

Finally, note that giving the `-showme` option to any of the wrapper compilers will show both the name of the back-end compiler that will be invoked, and also all the command line options that would have been passed for a given compile command. For example (line breaks added to fit in the documentation):

```
shell$ mpiCC -O c++_program.cc -o my_c++_program -showme
g++ -I/usr/local/lam/include -pthread -O c++_program.cc -o \
my_c++_program -L/usr/local/lam/lib -llammpio -llammpi++ -lpmpi \
-llamf77mpi -lmpi -llam -lutil -pthread
```

4.5.1 Sample MPI Program in C

The following is a simple “hello world” C program.

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

int main(int argc, char *argv[]) {
    int rank, size;

    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);

    printf("Hello, world! I am %d of %d\n", rank, size);

    MPI_Finalize();
    return 0;
}
```

This program can be saved in a text file and compiled with the `mpicc` wrapper compiler.

```
shell$ mpicc hello.c -o hello
```

4.5.2 Sample MPI Program in C++

The following is a simple “hello world” C++ program.

```
#include <iostream>
#include <mpi.h>

using namespace std;

int main(int argc, char *argv[]) {
```

```

int rank, size;

MPI::Init(argc, argv);
rank = MPI::COMM_WORLD.Get_rank();
size = MPI::COMM_WORLD.Get_size();

cout << "Hello, world! I am " << rank << " of " << size << endl;

MPI::Finalize();
return 0;
}

```

This program can be saved in a text file and compiled with the `mpiCC` wrapper compiler (or `mpic++` if on case-insensitive filesystems, such as Mac OS X's HFS+).

```

shell$ mpiCC hello.cc -o hello

```

4.5.3 Sample MPI Program in Fortran

The following is a simple “hello world” Fortran program.

```

program hello
include 'mpif.h'
integer rank, size, ierr

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)
stop
end

```

This program can be saved in a text file and compiled with the `mpif77` wrapper compiler.

```

shell$ mpif77 hello.f -o hello

```

4.6 Running MPI Programs

Once you have successfully established a LAM universe and compiled an MPI program, you can run MPI programs in parallel.

In this section, we will show how to run a Single Program, Multiple Data (SPMD) program. Specifically, we will run the `hello` program (from the previous section) in parallel. The `mpirun` and `mpiexec` commands are used for launching parallel MPI programs, and the `mpitask` commands can be used to provide crude debugging support. The `lamclean` command can be used to completely clean up a failed MPI program (e.g., if an error occurs).

4.6.1 The `mpirun` Command

The `mpirun` command has many different options that can be used to control the execution of a program in parallel. We'll explain only a few of them here.

The simplest way to launch the `hello` program across all CPUs listed in the boot schema is:

```
shell$ mpirun C hello
```

The `C` option means “launch one copy of `hello` on every CPU that was listed in the boot schema.” The `C` notation is therefore convenient shorthand notation for launching a set of processes across a group of SMPs.

Another method for running in parallel is:

```
shell$ mpirun N hello
```

The `N` option has a different meaning than `C` – it means “launch one copy of `hello` on every node in the LAM universe.” Hence, `N` disregards the CPU count. This can be useful for multi-threaded MPI programs.

Finally, to run an absolute number of processes (regardless of how many CPUs or nodes are in the LAM universe):

```
shell$ mpirun -np 4 hello
```

This runs 4 copies of `hello`. LAM will “schedule” how many copies of `hello` will be run in a round-robin fashion on each node by how many CPUs were listed in the boot schema file.³ For example, on the LAM universe that we have previously shown in this tutorial, the following would be launched:

- 1 `hello` would be launched on `n0` (named `node1`)
- 1 `hello` would be launched on `n1` (named `node2`)
- 2 `hello`s would be launched on `n2` (named `node3`)

Note that any number can be used – if a number is used that is greater than how many CPUs are in the LAM universe, LAM will “wrap around” and start scheduling starting with the first node again. For example, using `-np 10` would result in the following schedule:

- 2 `hello`s on `n0` (1 from the first pass, and then a second from the “wrap around”)
- 2 `hello`s on `n1` (1 from the first pass, and then a second from the “wrap around”)
- 4 `hello`s on `n2` (2 from the first pass, and then 2 more from the “wrap around”)
- 2 `hello`s on `n3`

The `mpirun(1)` man page contains much more information and `mpirun` and the options available. For example, `mpirun` also supports Multiple Program, Multiple Data (MPMD) programs, although it is not discussed here. Also see Section 7.12 (page 49) in this document.

³Note that the use of the word “schedule” does not imply that LAM has ties with the operating system for scheduling purposes (it doesn't). LAM “schedules” on a per-node basis; so selecting a process to run means that it has been assigned and launched on that node. The operating system is solely responsible for all process and kernel scheduling.

4.6.2 The `mpiexec` Command

The MPI-2 standard recommends the use of `mpiexec` for portable MPI process startup. In LAM/MPI, `mpiexec` is functionally similar to `mpirun`. Some options that are available to `mpirun` are not available to `mpiexec`, and vice-versa. The end result is typically the same, however – both will launch parallel MPI programs; which you should use is likely simply a personal choice.

That being said, `mpiexec` offers more convenient access in three cases:

- Running MPMD programs
- Running heterogeneous programs
- Running “one-shot” MPI programs (i.e., boot LAM, run the program, then halt LAM)

The general syntax for `mpiexec` is:

```
shell$ mpiexec <global_options> <cmd1> : <cmd2> : ...
```

Running MPMD Programs

For example, to run a manager/worker parallel program, where two different executables need to be launched (i.e., `manager` and `worker`, the following can be used:

```
shell$ mpiexec -n 1 manager : worker
```

This runs one copy of `manager` and one copy of `worker` for every CPU in the LAM universe.

Running Heterogeneous Programs

Since LAM is a heterogeneous MPI implementation, it supports running heterogeneous MPI programs. For example, this allows running a parallel job that spans a Sun SPARC machine and an IA-32 Linux machine (even though they are opposite endian machines). Although this can be somewhat complicated to setup (remember that you will first need to `lamboot` successfully, which essentially means that LAM must be correctly installed on both architectures), the `mpiexec` command can be helpful in actually running the resulting MPI job.

Note that you will need to have two MPI executables – one compiled for Solaris (e.g., `hello.solaris`) and one compiled for Linux (e.g., `hello.linux`). Assuming that these executables both reside in the same directory, and that directory is available on both nodes (or the executables can be found in the `PATH` on their respective machines), the following command can be used:

```
shell$ mpiexec -arch solaris hello.solaris : -arch linux hello.linux
```

This runs the `hello.solaris` command on all nodes in the LAM universe that have the string “solaris” anywhere in their architecture string, and `hello.linux` on all nodes that have “linux” in their architecture string. The architecture string of a given LAM installation can be found by running the `laminfo` command.

“One-Shot” MPI Programs

In some cases, it seems like extra work to boot a LAM universe, run a single MPI job, and then shut down the universe. Batch jobs are good examples of this – since only one job is going to be run, why does it take three commands? `mpiexec` provides a convenient way to run “one-shot” MPI jobs.

```
shell$ mpiexec -machinefile hostfile hello
```

This will invoke `lamboot` with the boot schema named “`hostfile`”, run the MPI program `hello` on all available CPUs in the resulting universe, and then shut down the universe with the `lamhalt` command (which we’ll discuss in Section 4.7, below).

4.6.3 The `mpitask` Command

The `mpitask` command is analogous to the sequential Unix command `ps`. It shows the current status of the MPI program(s) being executed in the LAM universe, and displays primitive information about what MPI function each process is currently executing (if any). Note that in normal practice, the `mpimsg` command only gives a snapshot of what messages are flowing between MPI processes, and therefore is usually only accurate at that single point in time. To really debug message passing traffic, use a tool such as message passing analyzer (e.g., XMPI), or a parallel debugger (e.g., TotalView).

`mpitask` can be run from any node in the LAM universe.

4.6.4 The `lamclean` Command

The `lamclean` command completely removed all running programs from the LAM universe. This can be useful if a parallel job crashes and/or leaves state in the LAM run-time environment (e.g., MPI-2 published names). It is usually run with no parameters:

```
shell$ lamclean
```

`lamclean` is typically only necessary when developing / debugging MPI applications – i.e., programs that hang, messages that are left around, etc. Correct MPI programs should terminate properly, clean up all their messages, unpublish MPI-2 names, etc.

4.7 Shutting Down the LAM Universe

When finished with the LAM universe, it should be shut down with the `lamhalt` command:

```
shell$ lamhalt
```

In most cases, this is sufficient to kill all running MPI processes and shut down the LAM universe.

However, in some rare conditions, `lamhalt` may fail. For example, if any of the nodes in the LAM universe crashed before running `lamhalt`, `lamhalt` will likely timeout and potentially not kill the entire LAM universe. In this case, you will need to use the `wipe` command to guarantee that the LAM universe has shut down properly:

```
shell$ wipe -v hostfile
```

where `hostfile` is the same boot schema that was used to boot LAM (i.e., all the same nodes are listed). `wipe` will forcibly kill all LAM/MPI processes and terminate the LAM universe. This is a slower process than `lamhalt`, and is typically not necessary.

Chapter 5

Supported MPI Functionality

This chapter discusses the exact levels of MPI functionality that is supported by LAM/MPI.

5.1 MPI-1 Support

LAM 7.0.6 has support for all MPI-1 functionality.

5.1.1 Language Bindings

LAM provides C, C++, and Fortran 77 bindings for all MPI-1 functions, types, and constants. Profiling support is available in all three languages (if LAM was configured and compiled with profiling support). The `laminfo` command can be used to see if profiling support was included in LAM/MPI.

5.1.2 MPI_CANCEL

`MPI_CANCEL` works properly for receives, but will almost never work on sends. `MPI_CANCEL` is most frequently used with unmatched `MPI_Irecv`'s that were made “in case” a matching message arrived. This simply entails removing the receive request from the local queue, and is fairly straightforward to implement.

Actually canceling a send operation is much more difficult because some meta information about a message is usually sent immediately. As such, the message is usually at least partially sent before an `MPI_CANCEL` is issued. Trying to chase down all the particular cases is a nightmare, to say the least.

As such, the LAM Team decided not to implement `MPI_CANCEL` on sends, and instead concentrate on other features.

But in true MPI Forum tradition, we would be happy to discuss any code that someone would like to submit that fully implements `MPI_CANCEL`.

5.2 MPI-2 Support

LAM 7.0.6 has support for many MPI-2 features. The main chapters of the MPI-2 standard are listed below, along with a summary of the support provided for each chapter.

5.2.1 Miscellany

Portable MPI Process Startup. The `mpiexec` command is now supported. Common examples include:

```

# Runs 4 copies of the MPI program my_mpi_program
shell$ mpiexec -n 4 my_mpi_program

# Runs my_linux_program on all available Linux machines, and runs
# my_solaris_program on all available Solaris machines
shell$ mpiexec -arch linux my_linux_program : -arch solaris my_solaris_program

# Boot the LAM run-time environment, run my_mpi_program on all
# available CPUs, and then shut down the LAM run-time environment.
shell$ mpiexec -machinefile hostfile my_mpi_program

```

See the `mpiexec(1)` man page for more details on supported options as well as more examples.

Passing NULL to MPI.INIT. Passing NULL as both arguments to `MPI.INIT` is fully supported.

Version Number. LAM 7.0.6 reports its MPI version as 1.2 through the function `MPI_GET_VERSION`.

Datatype Constructor MPI_TYPE_CREATE_INDEXED_BLOCK. The MPI function `MPI_TYPE_CREATE_INDEXED_BLOCK` is not supported by LAM/MPI.

Treatment of MPI.Status. Although LAM supports the constants `MPI_STATUS_IGNORE` and `MPI_STATUSES_IGNORE`, the function `MPI_REQUEST_GET_STATUS` is not provided.

Error class for invalid keyval. The error class for invalid keyvals, `MPI_ERR_KEYVAL`, is fully supported.

Committing committed datatype. Committing a committed datatype is fully supported; its end effect is a no-op.

Allowing user functions at process termination. Attaching attributes to `MPI_COMM_SELF` that have user-specified delete functions will now trigger these functions to be invoked as the first phase of `MPI_FINALIZE`. When these functions are run, MPI is still otherwise fully functional.

Determining whether MPI has finished. The function `MPI_FINALIZED` is fully supported.

The Info object. Full support for `MPI_Info` objects is provided. See Table 5.1.

Supported Functions		
<code>MPI_INFO_CREATE</code>	<code>MPI_INFO_FREE</code>	<code>MPI_INFO_GET_NTHKEY</code>
<code>MPI_INFO_DELETE</code>	<code>MPI_INFO_GET</code>	<code>MPI_INFO_GET_VALUELEN</code>
<code>MPI_INFO_DUP</code>	<code>MPI_INFO_GET_NKEYS</code>	<code>MPI_INFO_SET</code>

Table 5.1: Supported MPI-2 info functions.

Memory allocation. The `MPI_ALLOC_MEM` and `MPI_FREE_MEM` functions will return “special” memory that enable fast memory passing in RPIs that support it. These functions are simply wrappers to `malloc()` and `free()` (respectively) in RPI modules that do not take advantage of “special” memory. These functions can be used portably for potential performance gains.

Language interoperability. Inter-language interoperability is supported. It is possible to initialize LAM/MPI from either C or Fortran and mix MPI calls from both languages. Handle conversions for inter-language interoperability are fully supported. See Table 5.2.

Supported Functions	
<code>MPI_COMM_F2C</code>	<code>MPI_COMM_C2F</code>
<code>MPI_GROUP_F2C</code>	<code>MPI_GROUP_C2F</code>
<code>MPI_TYPE_F2C</code>	<code>MPI_TYPE_C2F</code>
<code>MPI_REQUEST_F2C</code>	<code>MPI_REQUEST_C2F</code>
<code>MPI_INFO_F2C</code>	<code>MPI_INFO_C2F</code>
<code>MPI_WIN_F2C</code>	<code>MPI_WIN_C2F</code>
<code>MPI_STATUS_F2C</code>	<code>MPI_STATUS_C2F</code>

Table 5.2: Supported MPI-2 handle conversion functions.

Error handlers. Communicator and window error handler functions are fully supported; this functionality is not yet supported for `MPI_File` handles. See Table 5.3

Supported Functions	
<code>MPI_COMM_CREATE_ERRHANDLER</code>	<code>MPI_WIN_CREATE_ERRHANDLER</code>
<code>MPI_COMM_GET_ERRHANDLER</code>	<code>MPI_WIN_GET_ERRHANDLER</code>
<code>MPI_COMM_SET_ERRHANDLER</code>	<code>MPI_WIN_SET_ERRHANDLER</code>

Table 5.3: Supported MPI-2 error handler functions.

New datatype manipulation functions. Several new datatype manipulation functions are provided. Table 5.4 lists the new functions.

Supported Functions	
<code>MPI_GET_ADDRESS</code>	<code>MPI_TYPE_CREATE_SUBARRAY</code>
<code>MPI_TYPE_CREATE_DARRAY</code>	<code>MPI_TYPE_CREATE_STRUCT</code>
<code>MPI_TYPE_CREATE_HINDEXED</code>	<code>MPI_TYPE_GET_EXTENT</code>
<code>MPI_TYPE_CREATE_HVECTOR</code>	<code>MPI_TYPE_GET_TRUE_EXTENT</code>
<code>MPI_TYPE_CREATE_RESIZED</code>	

Table 5.4: Supported MPI-2 new datatype manipulation functions.

New predefined datatypes. Support has been added for the `MPI_LONG_LONG_INT`, `MPI_UNSIGNED_LONG_LONG` and `MPI_WCHAR` basic datatypes.

Canonical MPI_PACK, MPI_UNPACK. Support is not provided for MPI_PACK_EXTERNAL, MPI_UNPACK_EXTERNAL, or MPI_PACK_EXTERNAL_SIZE.

5.2.2 Process Creation and Management

LAM/MPI supports all MPI-2 dynamic process management. Table 5.5 lists all the supported functions.

Supported Functions		
MPI_CLOSE_PORT	MPI_COMM_GET_PARENT	MPI_LOOKUP_NAME
MPI_COMM_ACCEPT	MPI_COMM_JOIN	MPI_OPEN_PORT
MPI_COMM_SPAWN	MPI_COMM_CONNECT	MPI_PUBLISH_NAME
MPI_COMM_DISCONNECT	MPI_COMM_SPAWN_MULTIPLE	MPI_UNPUBLISH_NAME

Table 5.5: Supported MPI-2 dynamic functions.

As requested by LAM users, MPI_COMM_SPAWN and MPI_COMM_SPAWN_MULTIPLE supports some MPI_Info keys for spawning MPMD applications and for more fine-grained control about where children processes are spawned. See the MPI_Comm_spawn(3) man page for more details.

These functions supersede the MPIL_COMM_SPAWN function that LAM/MPI introduced in version 6.2b. Hence, MPIL_COMM_SPAWN is no longer available.

5.2.3 One-Sided Communication

Support is provided for get/put/accumulate data transfer operations and for the post/wait/start/complete and fence synchronization operations. No support is provided for window locking.

The datatypes used in the get/put/accumulate operations are restricted to being basic datatypes or single level contiguous/vectors of basic datatypes.

The implementation of the one-sided operations is layered on top of the point-to-point functions, and will thus perform no better than them. Nevertheless it is hoped that providing this support will aid developers in developing and debugging codes using one-sided communication.

Table 5.6 lists the functions related to one-sided communication that have been implemented.

Supported Functions		
MPI_ACCUMULATE	MPI_WIN_CREATE	MPI_WIN_POST
MPI_GET	MPI_WIN_FENCE	MPI_WIN_START
MPI_PUT	MPI_WIN_FREE	MPI_WIN_WAIT
MPI_WIN_COMPLETE	MPI_WIN_GET_GROUP	

Table 5.6: Supported MPI-2 one-sided functions.

5.2.4 Extended Collective Operations

LAM 7.0.6 does not currently support MPI collective operations on intercommunicators. LAM also does not support the new collective operations MPI_EXSCAN or MPI_ALLTOALLW.

The “coll” System Services Interface (SSI) component type provides a framework to implement such algorithms; developers should see Section 9.3 (page 72) for details.

5.2.5 External Interfaces

The external interfaces chapter lists several different major topics. LAM's support for these topics is summarized in Table 5.7, and the exact list of functions that are supported is listed in 5.8.

Supported	Description
no	Generalized requests
no	Associating information with MPI_Status
yes	Naming objects
no	Error classes
no	Error codes
yes	Error handlers
yes	Decoding a datatype
yes	MPI and threads
yes	New attribute caching functions
yes	Duplicating a datatype

Table 5.7: Major topics in the MPI-2 chapter “External Interfaces”, and LAM's level of support.

Supported Functions		
MPI_COMM_SET_NAME	MPI_TYPE_SET_NAME	MPI_WIN_SET_NAME
MPI_COMM_GET_NAME	MPI_TYPE_GET_NAME	MPI_WIN_GET_NAME
MPI_COMM_CREATE_ERRHANDLER	MPI_WIN_CREATE_ERRHANDLER	
MPI_COMM_GET_ERRHANDLER	MPI_WIN_GET_ERRHANDLER	
MPI_COMM_SET_ERRHANDLER	MPI_WIN_SET_ERRHANDLER	
MPI_TYPE_GET_CONTENTS	MPI_INIT_THREAD	
MPI_TYPE_GET_ENVELOPE	MPI_QUERY_THREAD	
MPI_TYPE_GET_EXTENT	MPI_IS_THREAD_MAIN	
MPI_TYPE_GET_TRUE_EXTENT	MPI_TYPE_DUP	
MPI_COMM_CREATE_KEYVAL	MPI_TYPE_CREATE_KEYVAL	MPI_WIN_CREATE_KEYVAL
MPI_COMM_FREE_KEYVAL	MPI_TYPE_FREE_KEYVAL	MPI_WIN_FREE_KEYVAL
MPI_COMM_DELETE_ATTR	MPI_TYPE_DELETE_ATTR	MPI_WIN_DELETE_ATTR
MPI_COMM_GET_ATTR	MPI_TYPE_GET_ATTR	MPI_WIN_GET_ATTR
MPI_COMM_SET_ATTR	MPI_TYPE_SET_ATTR	MPI_WIN_SET_ATTR

Table 5.8: Supported MPI-2 external interface functions, grouped by function.

5.2.6 I/O

MPI-IO support is provided by including the ROMIO package from Argonne National Labs,¹ version 1.2.5.1. The LAM wrapper compilers (`mpicc`, `mpicc/mpic++`, and `mpif77`) will automatically provide all the necessary flags to compile and link programs that use ROMIO function calls.

Although the ROMIO group at Argonne has included support for LAM in their package, there are still a small number of things that the LAM Team had to do to make ROMIO compile and install properly with

¹<http://www.mcs.anl.gov/romio/>

LAM/MPI. As such, if you try to install the ROMIO package manually with LAM/MPI, you will experience some difficulties.

There are some important limitations to ROMIO that are discussed in the `romio/README` file. One limitation that is not currently listed in the ROMIO README file is that atomic file access will not work with AFS. This is because of file locking problems with AFS (i.e., AFS itself does not support file locking). The ROMIO test program `atomicity` will fail if you specify an output file on AFS.

Additionally, ROMIO does not support the following LAM functionality:

- LAM MPI-2 datatypes cannot be used with ROMIO; ROMIO makes the fundamental assumption that MPI-2 datatypes are built upon MPI-1 datatypes. LAM builds MPI-2 datatypes natively – ROMIO cannot presently handle this case.

This will hopefully be fixed in some future release of ROMIO. The ROMIO test programs `coll_test`, `fcoll_test`, `large_array`, and `coll_perf` will fail because they use the MPI-2 datatype `MPI_DARRAY`.

Please see the sections “ROMIO Users Mailing List” and “Reporting Bugs” in `romio/README` for how to submit questions and bug reports about ROMIO (that do not specifically pertain to LAM).

5.2.7 Language Bindings

LAM provides C, C++, and Fortran 77 bindings for all supported MPI-2 functions, types, and constants. LAM does not provide a Fortran 90 module. However, it is possible to use the Fortran 77 bindings with a Fortran 90 compiler by specifying the F90 compiler as your Fortran compiler when configuring/compiling LAM/MPI. See the LAM Installation Guide [14] for more details.

The C++ bindings include support for the C++ only `MPI::BOOL`, `MPI::COMPLEX`, `MPI::DOUBLE_COMPLEX`, and `MPI::LONG_DOUBLE_COMPLEX` datatypes.

Note that there are some issues with using MPI and Fortran 90 together. See the F90 / C++ chapter in the MPI-2 standard [2] for more information on using MPI with Fortran 90.

As mentioned in Section 5.1.1, profiling support is available in all three languages (if LAM was compiled with profiling support). The `laminfo` command can be used to see if profiling support was included in LAM/MPI.

Chapter 6

System Services Interface (SSI) Overview

The System Services Interface (SSI) makes up the core of LAM/MPI. It influences how many commands and MPI processes are executed. This chapter provides an overview of what SSI is and what users need to know about how to use it to maximize performance of MPI applications.

6.1 Types and Modules

SSI provides a component framework for the LAM run-time environment (RTE) and the MPI communications layer. Components are selected from each type at run-time and used to effect the LAM RTE and MPI library.

There are currently four types of components used by LAM/MPI:¹

- **boot**: Starting the LAM run-time environment, used mainly with the `lamboot` command.
- **coll**: MPI collective communications, only used within MPI processes.
- **cr**: Checkpoint/restart functionality, used both within LAM commands and MPI processes.
- **rpi**: MPI point-to-point communications, only used within MPI processes.

The LAM/MPI distribution includes instances of each component type referred to as modules. Each module is an implementation of the component type which can be selected and used at run-time to provide services to the LAM RTE and MPI communications layer. Chapters 8 and 9 list the modules that are available in the LAM/MPI distribution.

6.2 Terminology

Available The term “available” is used to describe a module that reports (at run-time) that it is able to run in the current environment. For example, an RPI module may check to see if supporting network hardware is present before reporting that it is available or not.

Chapters 8 and 9 list the modules that are included in the LAM/MPI distribution, and detail the requirements for each of them to indicate whether they are available or not.

Selected The term “selected” means that a module has been chosen to be used at run-time. Depending on the module type, zero or more modules may be selected.

¹More component types are expected to be added to LAM/MPI over time.

Scope Each module selection has a scope depending on the type of the module. “Scope” refers to the duration of the module’s selection. Table 6.1 lists the scopes for each module type.

Type	Scope description
<code>boot</code>	A module is selected at the beginning of <code>lamboot</code> (or <code>recon</code>) and is used for the duration of the LAM universe.
<code>coll</code>	A module is selected every time an MPI communicator is created (including <code>MPI_COMM_WORLD</code> and <code>MPI_COMM_SELF</code>). It remains in use until that communicator has been freed.
<code>cr</code>	Checkpoint/restart modules are selected at the beginning of an MPI job and remain in use until the job completes.
<code>rpi</code>	RPI modules are selected during <code>MPI_INIT</code> and remain in use until <code>MPI_FINALIZE</code> returns.

Table 6.1: SSI module types and their corresponding scopes.

6.3 SSI Parameters

One of the founding principles of SSI is to allow the passing of run-time parameters through the SSI framework. This allows both the selection of which modules will be used at run-time (by passing parameters to the SSI framework itself) as well as tuning run-time performance of individual modules (by passing parameters to each module). Although the specific usage of each SSI module parameter is defined by either the framework or the module that it is passed to, the value of most parameters will be resolved by the following:

1. If a valid value is provided via a run-time SSI parameter, use that.
2. Otherwise, attempt to calculate a meaningful value at run-time or use a compiled-in default value.²

As such, it is typically possible to set a parameter’s default value when LAM is configured/compiled, but use a different value at run time.

6.3.1 Naming Conventions

SSI parameter names are generally strings containing only letters and underscores, and can typically be broken down into three parts. For example, the parameter `boot_rsh_agent` can be broken into its three components:

- SSI module type: The first string of the name. In this case, it is `boot`.
- SSI module name: The second string of the name, corresponding to a specific SSI module. In this case, it is `rsh`.
- Parameter name: The last string in the name. It may be an arbitrary string, and include multiple underscores. In this case, it is `agent`.

²Note that many SSI modules provide configure flags to set compile-time defaults for “tweakable” parameters. See [14].

Although the parameter name is technically only the last part of the string, it is only proper to refer to it within its overall context. Hence, it is correct to say “the `boot_rsh_agent` parameter” as well as “the `agent` parameter to the `rsh` boot module”.

Note that the reserved string `base` may appear as a module name, referring to the fact that the parameter applies to all modules of a given type.

6.3.2 Setting Parameter Values

SSI parameters each have a unique name and can take a single string value. The parameter/value pairs can be passed by multiple different mechanisms. Depending on the target module and the specific parameter, mechanisms may include:

- Using command line flags when LAM was configured.
- Setting environment variables before invoking LAM commands.
- Using the `-ssi` command line switch to various LAM commands.
- Setting attributes on MPI communicators.

Users are most likely to utilize the latter three methods. Each is described in detail, below. Listings and explanations of available SSI parameters are provided in Chapters 8 and 9 (pages 55 and 63, respectively), categorized by SSI type and module.

Environment Variables

SSI parameters can be passed via environment variables prefixed with `LAM_MPI_SSI`. For example, selecting which RPI module to use in an MPI job can be accomplished by setting the environment variable `LAM_MPI_SSI_rpi` to a valid RPI module name (e.g., `tcp`).

Note that environment variables must be set *before* invoking the corresponding LAM/MPI commands that will use them.

`-ssi` Command Line Switch

LAM/MPI commands that interact with SSI modules accept the `-ssi` command line switch. This switch expects two parameters to follow: the name of the SSI parameter and its corresponding value. For example:

```
shell$ mpirun C -ssi rpi tcp my_mpi_program
```

runs the `my_mpi_program` on all available CPUs in the LAM universe using the `tcp` RPI module.

Communicator Attributes

Some SSI types accept SSI parameters via MPI communicator attributes (notably the MPI collective communication modules). These parameters follow the same rules and restrictions as normal MPI attributes. Note that for portability between 32 and 64 bit systems, care should be taken when setting and getting attribute values. The following is an example of portable attribute C code:

```
int flag, attribute_val;
void *set_attribute;
void **get_attribute;
```

```

MPI_Comm comm = MPI_COMM_WORLD;
int keyval = LAM_MPI_SSI_COLL_BASE_ASSOCIATIVE;

/* Set the value */
set_attribute = (void *) 1;
MPI_Comm_set_attr(comm, keyval, &set_attribute);

/* Get the value */
get_attribute = NULL;
MPI_Comm_get_attr(comm, keyval, &get_attribute, &flag);
if (flag == 1) {
    attribute_val = (int) *get_attribute;
    printf("Got the attribute value: %d\n", attribute_val);
}

```

Specifically, the following code is neither correct nor portable:

```

int flag, attribute_val;
MPI_Comm comm = MPI_COMM_WORLD;
int keyval = LAM_MPI_SSI_COLL_BASE_ASSOCIATIVE;

/* Set the value */
attribute_val = 1;
MPI_Comm_set_attr(comm, keyval, &attribute_val);

/* Get the value */
attribute_val = -1;
MPI_Comm_get_attr(comm, keyval, &attribute_val, &flag);
if (flag == 1)
    printf("Got the attribute value: %d\n", attribute_val);

```

6.4 Selecting Modules

As implied by the previous sections, modules are selected at run-time either by examining (in order) user-specified parameters, run-time calculations, and compiled-in defaults. The selection process involves a flexible negotiation phase which can be both tweaked and arbitrarily overridden by the user and system administrator.

6.4.1 Specifying Modules

Each SSI type has an implicit SSI parameter corresponding to the type name indicating which module(s) to be considered for selection. For example, to specify in that the `tcp` RPI module should be used, the SSI parameter `rpi` should be set to the value `tcp`. For example:

```

shell$ mpirun C -ssi rpi tcp my_mpi_program

```

The same is true for the other SSI types (`boot`, `cr`, and `coll`), with the exception that the `coll` type can be used to specify a comma-separated list of modules to be considered as each MPI communicator is created

(including `MPI_COMM_WORLD`). For example:

```
shell$ mpirun C -ssi coll smp,lam_basic my_mpi_program
```

indicates that the `smp` and `lam_basic` modules will potentially both be considered for selection for each MPI communicator.

6.4.2 Setting Priorities

Although typically not useful to individual users, system administrators may use priorities to set system-wide defaults that influence the module selection process in LAM/MPI jobs.

Each module has an associated priority which plays role in whether a module is selected or not. Specifically, if one or more modules of a given type are available for selection, the modules' priorities will be at least one of the factors used to determine which module will finally be selected. Priorities are in the range $[-1, 100]$, with -1 indicating that the module should not be considered for selection, and 100 being the highest priority. Ties will be broken arbitrarily by the SSI framework.

A module's priority can be set run-time through the normal SSI parameter mechanisms (i.e., environment variables or using the `-ssi` parameter). Every module has an implicit priority SSI parameter in the form `<type>_<module name>_priority`.

For example, a system administrator may set environment variables in system-wide shell setup files (e.g., `/etc/profile`, `/etc/bashrc`, or `/etc/csh.cshrc`) to change the default priorities.

6.4.3 Selection Algorithm

For each component type, the following general selection algorithm is used:

- A list of all available modules is created. If the user specified one or more modules for this type, only those modules are queried to see if they are available. Otherwise, all modules are queried.
- The module with the highest priority (and potentially meeting other selection criteria, depending on the module's type) will be selected.

Each SSI type may define its own additional selection rules. For example, the selection of `coll`, `cr`, and `rpi` modules may be inter-dependant, and depend on the supported MPI thread level. Chapter 9 (page 63) details the selection algorithm for MPI SSI modules.

Chapter 7

LAM/MPI Command Quick Reference

This section is intended to provide a quick reference of the major LAM/MPI commands. Each command also has its own manual page which typically provides more detail than this document.

7.1 The `lamboot` Command

The `lamboot` command is used to start the LAM run-time environment (RTE). `lamboot` is typically the first command used before any other LAM/MPI command (notable exceptions are the wrapper compilers, which do not require the LAM RTE, and `mpiexec` which can launch its own LAM universe). `lamboot` can use any of the available boot SSI modules; Section 8.1 details the requirements and operations of each of the boot SSI modules that are included in the LAM/MPI distribution.

Common arguments that are used with the `lamboot` command are:

- `-b`: When used with the `rsh` boot module, the “fast” boot algorithm is used which can noticeably speed up the execution time of `lamboot`. It can also be used where remote shell agents cannot provide output from remote nodes (e.g., in a Condor environment). Specifically, the “fast” algorithm assumes that the user’s shell on the remote node is the same as the shell on the node where `lamboot` was invoked.
- `-d`: Print debugging output. This will print a *lot* of output, and is typically only necessary if `lamboot` fails for an unknown reason. The output is forwarded to standard out as well as either `/tmp` or `syslog` facilities. The amount of data produced can fill these filesystems, leading to general system problems.
- `-l`: Use local hostname resolution instead of centralized lookups. This is useful in environments where the same hostname may resolve to different IP addresses on different nodes (e.g., clusters based on Finite Neighborhood Networks¹).
- `-s`: Close the `stdout` and `stderr` of the locally-launched LAM daemon (they are normally left open). This is necessary when invoking `lamboot` via a remote agent such as `rsh` or `ssh`.
- `-v`: Print verbose output. This is useful to show progress during `lamboot`’s progress. Unlike `-d`, `-v` does not forward output to a file or `syslog`.
- `-x`: Run the LAM RTE in fault-tolerant mode.

¹See <http://www.aggregate.org/> for more details.

- `<filename>`: The name of the boot schema file. Boot schemas, while they can be as simple as a list of hostnames, can contain additional information and are discussed in detail in Sections 4.4.1 and 8.1.1, pages 20 and 55, respectively.

Booting the LAM RTE is where most users (particularly first-time users) encounter problems. Each `boot` module has its own specific requirements and prerequisites for success. Although `lamboot` typically prints detailed messages when errors occur, users are strongly encouraged to read Section 8.1 for the details of the `boot` module that they will be using. Additionally, the `-d` switch should be used to examine exactly what is happening to determine the actual source of the problem – many problems with `lamboot` come from the operating system or the user’s shell setup; not from within LAM itself.

The most common `lamboot` example simply uses a hostfile to launch across an `rsh/ssh`-based cluster of nodes (the “`-ssi boot rsh`” is not technically necessary here, but it is specified to make this example correct in all environments):

```
shell$ lamboot -v -ssi boot rsh hostfile
```

```
LAM 7.0/MPI 2 C++/ROMIO – Indiana University
```

```
n0<1234> ssi:boot:base:linear: booting n0 (node1.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: booting n1 (node2.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: booting n2 (node3.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: booting n3 (node4.cluster.example.com)
```

```
n0<1234> ssi:boot:base:linear: finished
```

7.1.1 Multiple Sessions on the Same Node

In some cases (such as in batch-regulated environments), it is desirable to allow multiple universes owned by the same on the same node. The `TMPDIR`, `LAM_MPI_SESSION_PREFIX`, and `LAM_MPI_SESSION_SUFFIX` environment variables can be used to effect this behavior. The main issue is the location of LAM’s session directory; each node in a LAM universe has a session directory in a well-known location in the filesystem that identifies how to contact the LAM daemon on that node. Multiple LAM universes can simultaneously co-exist on the same node as long as they have different session directories.

LAM recognizes several batch environments and automatically adapts the session directory to be specific to a batch job. Hence, if the batch scheduler allocates multiple jobs from the same user to the same node, LAM will automatically do the “right thing” and ensure that the LAM universes from each job will not collide. Sections 12.7 and 12.8 (starting on page 94) discuss these issues in detail.

7.1.2 Avoiding Running on Specific Nodes

Once the LAM universe is booted, processes can be launched on any node. The `mpirun`, `mpiexec`, and `lamexec` commands are most commonly used to launch jobs in the universe, and are typically used with the `N` and `C` nomenclatures (see the description of `mpirun` in Section 7.12 for details on the `N` and `C` nomenclature) which launch jobs on all schedulable nodes and CPUs in the LAM universe, respectively. While finer-grained controls are available through `mpirun` (etc.), it can be convenient to simply mark some nodes as “non-schedulable,” and therefore avoid having `mpirun` (etc.) launch executables on those nodes when using `N` and `C` nomenclature.

For example, it may be convenient to boot a LAM universe that includes a controller node (e.g., a desktop workstation) and a set of worker nodes. In this case, it is desirable to mark the desktop workstation

as “non-scheduable” so that LAM will not launch executables there (by default). Consider the following boot schema:

```
# Mark my_workstation as “non-scheduable”
my_workstation.office.example.com schedule=no
# All the other nodes are, by default, scheduable
node1.cluster.example.com
node2.cluster.example.com
node3.cluster.example.com
node4.cluster.example.com
```

Booting with this schema allows the convenience of:

```
shell$ mpirun C my_mpi_program
```

which will only run `my_mpi_program` on the four cluster nodes (i.e., not the workstation). Note that this behavior *only* applies to the C and N designations; LAM will always allow execution on any node when using the nX or cX notation:

```
shell$ mpirun c0 C my_mpi_program
```

which will run `my_mpi_program` on all five nodes in the LAM universe.

7.2 The lamclean Command

The `lamclean` command is provided to clean up the LAM universe. It is typically only necessary when MPI processes terminate “badly,” and potentially leave resources allocated in the LAM universe (such as MPI-2 published names, processes, or shared memory). The `lamclean` command will kill *all* processes running in the LAM universe, and free *all* resources that were associated with them (including unpublishing MPI-2 dynamically published names).

7.3 The lamexec Command

The `lamexec` command is similar to `mpirun` but is used for non-MPI programs. For example:

```
shell$ lamexec N uptime
5:37pm up 21 days, 23:49, 5 users, load average: 0.31, 0.26, 0.25
5:37pm up 21 days, 23:49, 2 users, load average: 0.01, 0.00, 0.00
5:37pm up 21 days, 23:50, 3 users, load average: 0.01, 0.00, 0.00
5:37pm up 21 days, 23:50, 2 users, load average: 0.87, 0.81, 0.80
```

Most of the parameters and options that are available to `mpirun` are also available to `lamexec`. See the `mpirun` description in Section 7.12 for more details.

7.4 The lamgrow Command

The `lamgrow` command adds a single node to the LAM universe. It must use the same `boot` module that was used to initially boot the LAM universe. `lamgrow` must be run from a node already in the LAM universe. Common parameters include:

- `-v`: Verbose mode.
- `-d`: Debug mode; enables a *lot* of diagnostic output.
- `-n <nodeid>`: Assign the new host the node ID `nodeid`. `nodeid` must be an unused node ID. If `-n` is not specified, LAM will find the lowest node ID that is not being used.
- `-no-schedule`: Has the same effect as putting “`no_schedule=yes`” in the boot schema. This means that the C and N expansion used in `mpirun` and `lamexec` will not include this node.
- `-ssi <key> <value>`: Pass in SSI parameter `key` with the value `value`.
- `<hostname>`: The name of the host to expand the universe to.

For example, the following adds the node `blinky` to the existing LAM universe using the `rsh` boot module:

```
shell$ lamgrow -ssi boot rsh blinky.cluster.example.com
```

Note that `lamgrow` cannot grow a LAM universe that only contains one node that has an IP address of `127.0.0.1` (e.g., if `lamboot` was run with the default boot schema that only contains the name `localhost`). In this case, `lamgrow` will print an error and abort without adding the new node.

7.5 The `lamhalt` Command

The `lamhalt` command is used to shut down the LAM RTE. Typically, `lamhalt` can simply be run with no command line parameters and it will shut down the LAM RTE. Optionally, the `-v` or `-d` arguments can be used to make `lamhalt` be verbose or extremely verbose, respectively.

There are a small number of cases where `lamhalt` will fail. For example, if a LAM daemon becomes unresponsive (e.g., the daemon was killed), `lamhalt` may fail to shut down the entire LAM universe. It will eventually timeout and therefore complete in finite time, but you may want to use the last-resort `wipe` command (see Section 7.16).

7.6 The `laminfo` Command

The `laminfo` command can be used to query the capabilities of the LAM/MPI installation. Running `laminfo` with no parameters shows a prettyprint summary of information. Using the `-parsable` command line switch shows the same summary information, but in a format that should be relatively easy to parse with common unix tools such as `grep`, `cut`, `awk`, etc.

`laminfo` supports a variety of command line options to query for specific information. The `-h` option shows a complete listing of all options. Some of the most common options include:

- `-arch`: Show the architecture that LAM was configured for.
- `-path`: Paired with a second argument, display various paths relevant to the LAM/MPI installation. Valid second arguments include:
 - `prefix`: Main installation prefix
 - `bindir`: Where the LAM/MPI executables are located

- `libdir`: Where the LAM/MPI libraries are located
 - `incdir`: Where the LAM/MPI include files are located
 - `pkglibdir`: Where dynamic SSI modules are installed²
 - `sysconfdir`: Where the LAM/MPI help files are located
- `-version`: Paired with two addition options, display the version of either LAM/MPI or one or more SSI modules. The first argument identifies what to report the version of, and can be any of the following:
 - `lam`: Version of LAM/MPI
 - `boot`: Version of all boot modules
 - `boot:module`: Version of a specific boot module
 - `coll`: Version of all coll modules
 - `coll:module`: Version of a specific coll module
 - `cr`: Version of all cr modules
 - `cr:module`: Version of a specific cr module
 - `rpi`: Version of all rpi modules
 - `rpi:module`: Version of a specific rpi module

The second argument specifies the scope of the version number to display – whether to show the entire version number string, or just one component of it:

- `full`: Display the entire version number string
- `major`: Display the major version number
- `minor`: Display the minor version number
- `release`: Display the release version number
- `alpha`: Display the alpha version number
- `beta`: Display the beta version number
- `cvs`: Display the CVS version number³

Multiple options can be combined to query several attributes at once:

```
shell$ laminfo --parsable --arch --version lam major --version rpi tcp full
version:lam:7
ssi:boot:rsh:version:ssi:1.0
ssi:boot:rsh:version:api:1.0
ssi:boot:rsh:version:module:7.0
arch:i686-pc-linux-gnu
```

Note that three version numbers are returned for the `tcp` module. The first (`ssi`) indicates the overall SSI version that the module conforms to, the second (`api`) indicates what version of the `rpi` API the module conforms to, and the last (`module`) indicates the version of the module itself.

²Dynamic SSI modules are not supported in LAM/MPI 7.0, but will be supported in future versions.

³The value will either be 0 (not built from CVS), 1 (built from a cvs checkout) or a date encoded in the form YYYYMMDD (built from a nightly tarball on the given date)

7.7 The lamnodes Command

LAM was specifically designed to abstract away hostnames once `lamboot` has completed successfully. However, for various reasons (usually related to system-administration concerns, and/or for creating human-readable reports), it can be desirable to retrieve the hostnames of LAM nodes long after `lamboot`.

The command `lamnodes` can be used for this purpose. It accepts both the `N` and `C` syntax from `mpirun`, and will return the corresponding names of the specified nodes. For example:

```
shell$ lamnodes N
```

will return the node that each CPU is located on, the hostname of that node, the total number of CPUs on each, and any flags that are set on that node. Specific nodes can also be queried:

```
shell$ lamnodes n0,3
```

will return the node, hostname, number of CPUs, and flags on `n0` and `n3`.

Command line arguments can be used to customize the output of `lamnodes`. These include:

- `-c`: Suppress printing CPU counts
- `-i`: Print IP addresses instead of IP names
- `-n`: Suppress printing LAM node IDs

7.8 The lamshrink Command

The `lamshrink` command is used to remove a node from a LAM universe:

```
shell$ lamshrink n3
```

removes node `n3` from the LAM universe. Note that all nodes with ID's greater than 3 will not have their ID's reduced by one – `n3` simply becomes an empty slot in the LAM universe. `mpirun` and `lamexec` will still function correctly, even when used with `C` and `N` notation – they will simply skip the `n3` since there is no longer an operational node in that slot.

Note that the `lamgrow` command can optionally be used to fill the empty slot with a new node.

7.9 The mpicc, mpiCC / mpic++, and mpif77 Commands

Compiling MPI applications can be a complicated process because the list of compiler and linker flags required to successfully compile and link a LAM/MPI application not only can be quite long, it can change depending on the particular configuration that LAM was installed with. For example, if LAM includes native support for Myrinet hardware, the `-lpm` flag needs to be used when linking MPI executables.

To hide all this complexity, “wrapper” compilers are provided that handle all of this automatically. They are called “wrapper” compilers because all they do is add relevant compiler and linker flags to the command line before invoking the real back-end compiler to actually perform the compile/link. Most command line arguments are passed straight through to the back-end compiler without modification.

Therefore, to compile an MPI application, use the wrapper compilers exactly as you would use the real compiler. For example:

```
shell$ mpicc -O -c main.c
shell$ mpicc -O -c foo.c
shell$ mpicc -O -c bar.c
shell$ mpicc -O -o main main.o foo.o bar.o
```

This compiles three C source code files and links them together into a single executable. No additional `-I`, `-L`, or `-l` arguments are required.

The main exceptions to what flags are not passed through to the back-end compiler are:

- `-showme`: Used to show what the wrapper compiler would have executed. This is useful to see the full compile/link line would have been executed. For example (your output may differ from what is shown below, depending on your installed LAM/MPI configuration):

```
shell$ mpicc -O -c main.c -showme
gcc -I/usr/local/lam/include -pthread -O -c foo.c
```

The output line shown below is word wrapped in order to fit nicely in the document margins

```
shell$ mpicc -O -o main main.o foo.o bar.o -showme
gcc -I/usr/local/lam/include -pthread -O -o main main.o foo.o bar.o \
-L/usr/local/lam/lib -llammpio -lmpi -lamf77mpi -lmpi -llam -lutil \
-pthread
```

- `-lmpi`: When compiling a user MPI application, the `-lmpi` argument is used to indicate that MPI profiling support should be included. The wrapper compiler may alter the exact placement of this argument to ensure that proper linker dependency semantics are preserved.

It is *strongly* recommended to use the wrapper compilers for all compiling and linking of MPI applications.

7.9.1 Deprecated Names

Previous versions of LAM/MPI used the names `hcc`, `hcp`, and `hf77` for the wrapper compilers. While these command names still work (they are simply symbolic links to the real wrapper compilers `mpicc`, `mpicc/mpic++`, and `mpif77`, respectively), their use is deprecated.

7.10 The `mpiexec` Command

The `mpiexec` command is used to launch MPI programs. It is similar to, but slightly different than, `mpirun`.⁴ Although `mpiexec` is simply a wrapper around other LAM commands (including `lamboot`, `mpirun`, and `lamhalt`), it ties their functionality together and provides a unified interface for launching MPI processes. Specifically, `mpiexec` offers two features from command line flags that require multiple steps when using other LAM commands: launching MPMD MPI processes and launching MPI processes when there is no existing LAM universe.

⁴The reason that there are two methods to launch MPI executables is because the MPI-2 standard suggests the use of `mpiexec` and provides standardized command line arguments. Hence, even though LAM already had an `mpirun` command to launch MPI executables, `mpiexec` was added to comply with the standard.

7.10.1 General Syntax

The general form of `mpiexec` commands is:

```
mpiexec [global_args] local_args1 [: local_args2 [...]]
```

Global arguments are applied to all MPI processes that are launched. They must be specified before any local arguments. Common global arguments include:

- `-boot`: Boot the LAM RTE before launching the MPI processes.
- `-boot-args <args>`: Pass `<args>` to the back-end `lamboot`. Implies `-boot`.
- `-machinefile <filename>`: Specify `<filename>` as the boot schema to use when invoking the back-end `lamboot`. Implies `-boot`.
- `-ssi <key> <value>`: Pass the SSI `<key>` and `<value>` arguments to the back-end `mpirun` command.

Local arguments are specific to an individual MPI process that will be launched. They are specified along with the executable that will be launched. Common local arguments include:

- `-n <numprocs>`: Launch `<numprocs>` number of copies of this executable.
- `-arch <architecture>`: Launch the executable on nodes in the LAM universe that match this architecture. An architecture is determined to be a match if the `<architecture>` matches any subset of the GNU Autoconf architecture string on each of the target nodes (the `laminfo` command shows the GNU Autoconf configure string).
- `<other arguments>`: When `mpiexec` first encounters an argument that it doesn't recognize, the remainder of the arguments will be passed back to `mpirun` to actually start the process.

The following example launches four copies of the `my_mpi_program` executable in the LAM universe, using default scheduling patterns:

```
shell$ mpiexec -n 4 my_mpi_program
```

7.10.2 Launching MPMD Processes

The `:` separator can be used to launch multiple executables in the same MPI job. Specifically, each process will share a common `MPI_COMM_WORLD`. For example, the following launches a single manager process as well as a worker process for every CPU in the LAM universe:

```
shell$ mpiexec -n 1 manager : C worker
```

Paired with the `-arch` flag, this can be especially helpful in heterogeneous environments:

```
shell$ mpiexec -arch solaris sol_program : -arch linux linux_program
```

Even only “slightly heterogeneous” environments can run into problems with shared libraries, different compilers, etc. The `-arch` flag can be used to differentiate between different versions of the same operating system:

```
shell$ mpiexec -arch solaris2.8 sol2.8_program : -arch solaris2.9 sol2.9_program
```

7.10.3 Launching MPI Processes with No Established LAM Universe

The `-boot`, `-boot-args`, and `-machinefile` global arguments can be used to launch the LAM RTE, run the MPI process(es), and then take down the LAM RTE. This conveniently wraps up several LAM commands and provides “one-shot” execution of MPI processes. For example:

```
shell$ mpiexec -machinefile hostfile C my_mpi_program
```

Some boot SSI modules do not require a hostfile; specifying the `-boot` argument is sufficient in these cases:

```
shell$ mpiexec -boot C my_mpi_program
```

When `mpiexec` is used to boot the LAM RTE, it will do its best to take down the LAM RTE even if errors occur, either during the boot itself, or if an MPI process aborts (or the user hits Control-C).

7.11 The `mpimsg` Command (Deprecated)

The `mpimsg` command is deprecated. It is only useful in a small number of cases (specifically, when the `lamd` RPI module is used), and may disappear in future LAM/MPI releases.

7.12 The `mpirun` Command

The `mpirun` command is the main mechanism to launch MPI processes in parallel.

7.12.1 Simple Examples

Although `mpirun` supports many different modes of execution, most users will likely only need to use a few of its capabilities. It is common to launch either one process per node or one process per CPU in the LAM universe (CPU counts are established in the boot schema). The following two examples show these two cases:

```
# Launch one copy of my_mpi_program on every schedulable node in the LAM universe
shell$ mpirun N my_mpi_program
```

```
# Launch one copy of my_mpi_program on every schedulable CPU in the LAM universe
shell$ mpirun C my_mpi_program
```

The specific number of processes that are launched can be controlled with the `-np` switch:

```
# Launch four my_mpi_program processes
shell$ mpirun -np 4 my_mpi_program
```

The `-ssi` switch can be used to specify tunable parameters to MPI processes.

```
# Specify to use the usysv RPI module
shell$ mpirun -ssi rpi usysv C my_mpi_program
```

The available modules and their associated parameters are discussed in detail in Chapter 9.

Arbitrary user arguments can also be passed to the user program. `mpirun` will attempt to parse all options (looking for LAM options) until it finds a `--`. All arguments following `--` are directly passed to the MPI application.

```
# Pass three command line arguments to every instance of my_mpi_program
shell$ mpirun -ssi rpi usysv C my_mpi_program arg1 arg2 arg3
# Pass three command line arguments, escaped from parsing
shell$ mpirun -ssi rpi usysv C my_mpi_program -- arg1 arg2 arg3
```

7.12.2 Controlling Where Processes Are Launched

`mpirun` allows for fine-grained control of where to schedule launched processes. Note LAM uses the term “schedule” extensively to indicate which nodes processes are launched on. LAM does *not* influence operating system semantics for prioritizing processes or binding processes to specific CPUs. The boot schema file can be used to indicate how many CPUs are on a node, but this is only used for scheduling purposes. For a fuller description of CPU counts in boot schemas, see Sections 4.4.1 and 8.1.1 on pages 20 and 55, respectively.

LAM offers two main scheduling nomenclatures: by node and by CPU. For example `N` means “all schedulable nodes in the universe” (“schedulable” is defined in Section 7.1.2). Similarly, `C` means “all schedulable CPUs in the universe.”

More fine-grained control is also possible – nodes and CPUs can be individually identified, or identified by ranges. The syntax for these concepts is `n<range>` and `c<range>`, respectively. `<range>` can specify one or more elements by listing integers separated by commas and dashes. For example:

- `n3`: The node with an ID of 3.
- `c2`: The CPU with an ID of 2.
- `n2, 4`: The nodes with IDs of 2 and 4.
- `c2, 4-7`: The CPUs with IDs of 2, 4, 5, 6, and 7. Note that some of these CPUs may be on the same node(s).

Integers can range from 0 to the highest numbered node/CPU. Note that these nomenclatures can be mixed and matched on the `mpirun` command line:

```
shell$ mpirun n0 C manager-worker
```

will launch the `manager-worker` program on `n0` as well as on every schedulable CPU in the universe (yes, this means that `n0` will likely be over-subscribed).

When running on SMP nodes, it is preferable to use the `C/c<range>` nomenclature (with appropriate CPU counts in the boot schema) to the `N/n<range>` nomenclature because of how LAM will order ranks in `MPI_COMM_WORLD`. For example, consider a LAM universe of two four-way SMPs – `n0` and `n1` both have a CPU count of 4. Using the following:

```
shell$ mpirun C my_mpi_program
```

will launch eight copies of `my_mpi_program`, four on each node. LAM will place as many adjoining `MPI_COMM_WORLD` ranks on the same node as possible: `MPI_COMM_WORLD` ranks 0-3 will be scheduled on `n0` and `MPI_COMM_WORLD` ranks 4-7 will be scheduled on `n1`. Specifically, `C` schedules processes starting with `c0` and incrementing the CPU index number.

Note that unless otherwise specified, LAM schedules processes by CPU (vs. scheduling by node). For example, using `mpirun`’s `-np` switch to specify an absolute number of processes schedules on a per-CPU basis.

7.12.3 Per-Process Controls

`mpirun` allows for arbitrary, per-process controls such as launching MPMD jobs, passing different command line arguments to different `MPI_COMM_WORLD` ranks, etc. This is accomplished by creating a text file called an application schema that lists, one per line, the location, relevant flags, user executable, and command line arguments for each process. For example (lines beginning with “#” are comments):

```
# Start the manager on c0 with a specific set of command line options
c0 manager manager_arg1 manager_arg2 manager_arg3
# Start the workers on all available CPUs with different arguments
C worker worker_arg1 worker_arg2 worker_arg3
```

Note that the `-ssi` switch is *not* permissible in application schema files; `-ssi` flags are considered to be global to the entire MPI job, not specified per-process. Application schemas are described in more detail in the `appschema(5)` manual page.

7.12.4 Ability to Pass Environment Variables

All environment variables with names that begin with `LAM_MPI_` are automatically passed to remote nodes (unless disabled via the `-nx` option to `mpirun`). Additionally, the `-x` option enables exporting of specific environment variables to the remote nodes:

```
shell$ LAM_MPI_FOO='green eggs and ham'
shell$ export LAM_MPI_FOO
shell$ mpirun C -x DISPLAY,SEUSS=author samIam
```

This will launch the `samIam` application on all available CPUs. The `LAM_MPI_FOO`, `DISPLAY`, and `SEUSS` environment variables will be created each the process environment before the `smaIam` program is invoked.

Note that the parser for the `-x` option is currently not very sophisticated – it cannot even handle quoted values when defining new environment variables. Users are advised to set variables in the environment prior to invoking `mpirun`, and only use `-x` to export the variables to the remote nodes (not to define new variables), if possible.

7.12.5 Current Working Directory Behavior

Using the `-wd` option to `mpirun` allows specifying an arbitrary working directory for the launched processes. It can also be used in application schema files to specify working directories on specific nodes and/or for specific applications.

If the `-wd` option appears both in an application schema file and on the command line, the schema file directory will override the command line value. `-wd` is mutually exclusive with `-D`.

If neither `-wd` nor `-D` are specified, the local node will send the present working directory name from the `mpirun` process to each of the remote nodes. The remote nodes will then try to change to that directory. If they fail (e.g., if the directory does not exist on that node), they will start from the user’s home directory.

All directory changing occurs before the user’s program is invoked; it does not wait until `MPI_INIT` is called.

7.13 The `mpitask` Command

The `mpitask` command shows a list of the processes running in the LAM universe and a snapshot of their current MPI activity. It is usually invoked with no command line parameters, thereby showing summary details of all processes currently running. Since `mpitask` only provides a snapshot view, it is not advisable to use `mpitask` as a high-resolution debugger (see Chapter 10, page 81, for more details on debugging MPI programs). Instead, `mpitask` can be used to provide answers to high-level questions such as “Where is my program hung?” and “Is my program making progress?”

The following example shows an MPI program running on four nodes, sending a message of 524,288 integers around in a ring pattern. Process 0 is running (i.e., not in an MPI function), while the other three are blocked in `MPI_RECV`.

```
shell$ mpitask
TASK (G/L) FUNCTION PEER|ROOT TAG COMM COUNT DATATYPE
0 ring <running>
1/1 ring Recv 0/0 201 WORLD 524288 INT
2/2 ring Recv 1/1 201 WORLD 524288 INT
3/3 ring Recv 2/2 201 WORLD 524288 INT
```

7.14 The `recon` Command

The `recon` command is a quick test to see if the user’s environment is setup properly to boot the LAM RTE. It takes most of the same parameters as the `lamboot` command.

Although it does not boot the RTE, and does not definitively guarantee that `lamboot` will succeed, it is a good tool for testing while setting up first-time LAM/MPI users. `recon` will display a message when it has completed indicating whether it succeeded or failed.

7.15 The `tping` Command

The `tping` command can be used to verify the functionality of a LAM universe. It is used to send a ping message between the LAM daemons that constitute the LAM RTE.

It commonly takes two arguments: the set of nodes to ping (expressed in N notation) and how many times to ping them. Similar to the Unix `ping` command, if the number of times to ping is not specified, `tping` will continue until it is stopped (usually by the user hitting Control-C). The following example pings all nodes in the LAM universe three times:

```
shell$ tping N -c 3
1 byte from 3 remote nodes and 1 local node: 0.002 secs
1 byte from 3 remote nodes and 1 local node: 0.001 secs
1 byte from 3 remote nodes and 1 local node: 0.001 secs

3 messages, 3 bytes (0.003K), 0.005 secs (1.250K/sec)
roundtrip min/avg/max: 0.001/0.002/0.002
```

7.16 The wipe Command

The `wipe` command is used as a “last resort” command, and is typically only necessary if `lamhalt` fails. This usually only occurs in error conditions, such as if a node fails. The `wipe` command takes most of the same parameters as the `lamboot` command – it launches a process on each node in the boot schema to kill the LAM RTE on that node. Hence, it should be used with the same (or an equivalent) boot schema file as was used with `lamboot`.

Chapter 8

Available LAM Modules

There is currently only type of LAM module that is visible to users: `boot`, which is used to start the LAM run-time environment, most often through the `lamboot` command. The `lamboot` command itself is discussed in Section 7.1 (page 41); the discussion below focuses on the boot modules that make up the “back end” implementation of `lamboot`.

8.1 Booting the LAM Run-Time Environment

LAM provides a number of modules for starting the `lamd` control daemons. In most cases, the `lamds` are started using the `lamboot` command. In previous versions of LAM/MPI, `lamboot` could only use `rsh` or `ssh` for starting the LAM run-time environment on remote nodes. In LAM/MPI 7.0.6, it is possible to use a variety of mechanisms for this process startup. The following mechanisms are available in LAM/MPI 7.0.6:

- BProc
- Globus (beta-level support)
- `rsh` / `ssh`
- OpenPBS / PBS Pro (using the Task Management interface)

These mechanisms are discussed in detail below. Note that the sections below each assume that support for these modules have been compiled into LAM/MPI. The `laminfo` command can be used to determine exactly which modules are supported in your installation (see Section 7.6, page 44).

8.1.1 Boot Schema Files (a.k.a., “Hostfiles” or “Machinefiles”)

Before discussing any of the specific boot SSI modules, this section discusses the boot schema file, commonly referred to as a “hostfile” or a “machinefile”. Most (but not all) boot SSI modules require a boot schema, and the text below makes frequent mention of them. Hence, it is worth discussing them before getting into the details of each boot SSI.

A boot schema is a text file that, in its simplest form, simply lists every host that the LAM run-time environment will be invoked on. For example:

```
# This is my boot schema
inky.cluster.example.com
pinky.cluster.example.com
blinkly.cluster.example.com
clyde.cluster.example.com
```

Lines beginning with “#” are treated as comments and are ignored. Each non-blank, non-comment line must, at a minimum, list a host. Specifically, the first token on each line must specify a host (although the definition of how that host is specified may vary differ between boot modules).

However, each line can also specify arbitrary “key=value” pairs. A common global key is “cpu”. This key takes an integer value and indicates to LAM how many CPUs are available for LAM to use. If the key is not present, the value of 1 is assumed. This number does *not* need to reflect the physical number of CPUs – it can be smaller than, equal to, or greater than the number of physical CPUs in the machine. It is solely used as a shorthand notation for mpirun’s “C” notation, meaning “launch one process per CPU as specified in the boot schema file.” For example, in the following boot schema:

```
inky.cluster.example.com cpu=2
pinky.cluster.example.com cpu=4
blinkly.cluster.example.com cpu=4
# clyde doesn't mention a cpu count, and is therefore implicitly 1
clyde.cluster.example.com
```

issuing the command “mpirun C foo” would actually launch 11 copies of foo: 2 on inky, 4 on pinky, 4 on blinkly, and 1 on clyde.

Note that listing a host more than once has the same effect as incrementing the CPU count. The following boot schema has the same effect as the previous example (i.e., CPU counts of 2, 4, 4, and 1, respectively):

```
# inky has a CPU count of 2
inky.cluster.example.com
inky.cluster.example.com
# pinky has a CPU count of 4
pinky.cluster.example.com
pinky.cluster.example.com
pinky.cluster.example.com
pinky.cluster.example.com
# blinky has a CPU count of 4
blinkly.cluster.example.com
blinkly.cluster.example.com
blinkly.cluster.example.com
blinkly.cluster.example.com
# clyde only has 1 CPU
clyde.cluster.example.com
```

Other keys are defined on a per-boot-SSI-module, and are described below.

8.1.2 Minimum Requirements

In order to successfully launch a process on a remote node, several requirements must be met. Although each of the boot modules have different specific requirements, all of them share the following conditions for

successful operation:

1. Each target host must be reachable and operational.
2. The user must be able to execute arbitrary processes on the target.
3. The LAM executables must be locatable on that machine. This typically involves using: the shell's search path, the `LAMHOME` environment variable, or a boot-module-specific mechanism.
4. The user must be able to write to the LAM session directory (typically somewhere under `/tmp`; see Section 12.8, page 94).
5. All hosts must be able to resolve the fully-qualified domain name (FQDN) of all the machines being booted (including itself).
6. Unless there is only one host being booted, any host resolving to the IP address 127.0.0.1 cannot be included in the list of hosts.

If all of these conditions are not met, `lamboot` will fail.

8.1.3 Selecting a boot Module

Only one `boot` module will be selected; it will be used for the life of the LAM universe. As such, module priority values are the only factor used to determine which available module should be selected.

8.1.4 boot SSI Parameters

On many kinds of networks, LAM can know exactly which nodes should be making connections while booting the LAM run-time environment, and promiscuous connections (i.e., allowing any node to connect) are discouraged. However, this is not possible in some complex network configurations and promiscuous connections *must* be enabled.

By default, LAM's base `boot` SSI startup protocols disable promiscuous connections. However, this behavior can be overridden when LAM is configured and at run-time. If the SSI parameter `boot_base_promisc` set to an empty value, or set to the integer value 1, promiscuous connections will be accepted when than LAM RTE is booted.

8.1.5 The bproc Module

The Beowulf Distributed Process Space (BProc) is set of kernel modifications, utilities and libraries which allow a user to start processes on other machines in a Beowulf-style cluster. Remote processes started with this mechanism appear in the process table of the front-end machine in a cluster.

LAM/MPI functionality has been tested with BProc version 3.2.5. Prior versions had a bug that affected at least some LAM/MPI functionality. It is strongly recommended to upgrade to at least version 3.2.5 before attempting to use the LAM/MPI native BProc capabilities.

Minimum Requirements

Several of the minimum requirements listed in Section 8.1.2 will already be met in a BProc environment because BProc will copy `lamboot`'s entire environment (including the `PATH`) to the remote node. Hence, if `lamboot` is in the user's path on the local node, it will also [automatically] be in the user's path on the remote node.

However, one of the minimum requirements conditions (“The user must be able to execute arbitrary processes on the target”) deserves a BProc-specific clarification. BProc has its own internal permission system for determining if users are allowed to execute on specific nodes. The system is similar to the user/group/other mechanism typically used in many Unix filesystems. Hence, in order for a user to successfully `lamboot` on a BProc cluster, he/she must have BProc execute permissions on each of the target nodes. Consult the BProc documentation for more details.

Usage

In most situations, the `lamboot` command (and related commands) should automatically “know” to use the `bproc` boot SSI module when running on the BProc head node; no additional command line parameters or environment variables should be required. Specifically, when running in a BProc environment, the `bproc` module will report that it is available, and artificially inflate its priority relatively high in order to influence the boot module selection process. However, the BProc boot module can be forced by specifying the `boot` SSI parameter with the value of `bproc`.

Running `lamboot` on a BProc cluster is just like running `lamboot` in a “normal” cluster. Specifically, you provide a boot schema file (i.e., a list of nodes to boot on) and run `lamboot` with it. For example:

```
shell$ lamboot hostfile
```

Note that when using the `bproc` module, `lamboot` will only function properly from the head node. If you launch `lamboot` from a client node, it will likely either fail outright, or fall back to a different boot module (e.g., `rsh/ssh`).

It is suggested that the `hostfile` file contain hostnames in the style that BProc prefers – integer numbers. For example, `hostfile` may contain the following:

```
-1
0
1
2
3
```

which boots on the BProc front end node (-1) and four slave nodes (0, 1, 2, 3). Note that using IP hostnames will also work, but using integer numbers is recommended.

Tunable Parameters

Table 8.1 lists the SSI parameters that are available to the `bproc` module.

SSI parameter name	Default value	Description
<code>boot_bproc_priority</code>	50	Default priority level.

Table 8.1: SSI parameters for the `bproc` boot module.

Special Notes

After booting, LAM will, by default, not schedule to run MPI jobs on the BProc front end. Specifically, LAM implicitly sets the “no-schedule” attribute on the -1 node in a BProc cluster. See Section 7.1 (page 41) for more detail about this attribute and boot schemas in general.

8.1.6 The globus Module

LAM/MPI 7.0.6 includes beta support for Globus. Specifically, only limited types of execution are possible. The LAM Team would appreciate feedback from the Globus community on expanding Globus support in LAM/MPI.

Minimum Requirements

LAM/MPI jobs in Globus environment can only be started on nodes using the “fork” job manager for the Globus gatekeeper. Other job managers are not yet supported.

Usage

Starting the LAM run-time environment in Globus environment makes use of the Globus Resource Allocation Manager (GRAM) client `globus-job-run`. The Globus boot SSI module will never run automatically; it must always be specifically requested setting the `boot SSI` parameter to `globus`. Specifically, although the `globus` module will report itself available if `globus-job-run` can be found in the `PATH`, the default priority will be quite low, effectively ensuring that it will not be selected unless it is the only module available (which will only occur if the `boot` parameter is set to `globus`).

LAM needs to be able to find the Globus executables. This can be accomplished either by adding the appropriate directory to your path, or by setting the `GLOBUS_LOCATION` environment variable.

Additionally, the `LAM_MPI_SESSION_SUFFIX` environment variable should be set to a unique value. This ensures that this instance of the LAM universe does not conflict with any other, concurrent LAM universes that are running under the same username on nodes in the Globus environment. Although any value can be used for this variable, it is probably best to have some kind of organized format, such as `<your_username>-<some_long_random_number>`.

Next, create a boot schema to use with `lamboot`. Hosts are listed by their Globus contact strings (see the Globus manual for more information about contact strings). In cases where the Globus gatekeeper is running as a `inetd` service on the node, the contact string will simply be the hostname. If the contact string contains whitespace, the *entire* contact string must be enclosed in quotes (i.e., not just the values with whitespaces). For example, if your contact string is:

```
host1:port1:/O=xxx/OU=yyy/CN=aaa bbb ccc
```

Then you will need to have it listed as:

```
"host1:port1:/O=xxx/OU=yyy/CN=aaa bbb ccc"
```

The following will not work:

```
host1:port1:/O=xxx/OU=yyy/CN="aaa bbb ccc"
```

Each host in the boot schema must also have a “`lam_install_path`” key indicating the absolute directory where LAM/MPI is installed. This value is mandatory because you cannot rely on the `PATH` environment variable in Globus environment because users’ “dot” files are not executed in Globus jobs (and therefore the `PATH` environment variable is not provided). Other keys can be used as well; `lam_install_path` is the only mandatory key.

Here is a sample Globus boot schema:

```
# Globus boot schema
“inky.mycluster:12853:/O=MegaCorp/OU=Mine/CN=HPC Group” prefix=/opt/lam cpu=2
“pinky.yourcluster:3245:/O=MegaCorp/OU=Yours/CN=HPC Group” prefix=/opt/lam cpu=4
“blinky.hiscluster:23452:/O=MegaCorp/OU=His/CN=HPC Group” prefix=/opt/lam cpu=4
“clyde.hercluster:82342:/O=MegaCorp/OU=Hers/CN=HPC Group” prefix=/software/lam
```

Once you have this boot schema, the `lamboot` command can be used to launch it. Note, however, that unlike the other boot SSI modules, the Globus boot module will never be automatically selected by LAM – it must be selected manually with the `boot` SSI parameter with the value `globus`.

```
shell$ lamboot -ssi boot globus hostfile
```

Tunable Parameters

Table 8.2 lists the SSI parameters that are available to the `globus` module.

SSI parameter name	Default value	Description
<code>boot_globus_priority</code>	3	Default priority level.

Table 8.2: SSI parameters for the `globus` boot module.

8.1.7 The `rsh` Module (including `ssh`)

The `rsh/ssh` boot SSI module is typically the “least common denominator” boot module. When not in an otherwise “special” environment (such as a batch scheduler), the `rsh/ssh` boot module is typically used to start the LAM run-time environment.

Minimum Requirements

In addition to the minimum requirements listed in Section 8.1.2, the following additional conditions must also be met for a successful `lamboot` using the `rsh / ssh` boot module:

1. The user must be able to execute arbitrary commands on each target host without being prompted for a password.
2. The shell’s start-up script must not print anything on standard error. The user can take advantage of the fact that `rsh / ssh` will start the shell non-interactively. The start-up script can exit early in this case, before executing many commands relevant only to interactive sessions and likely to generate output.

Section 4 (page 17) provides a short tutorial on using the `rsh / ssh` boot module, including tips on setting up “dot” files, setting up password-less remote execution, etc.

Usage

Using `rsh`, `ssh`, or other remote-execution agent is probably the most common method for starting the LAM run-time execution environment. The boot schema typically lists the hostnames, CPU counts, and an optional username (if the user’s name is different on the remote machine). For example:

```
# rsh boot schema
inky.cluster.example.com cpu=2
pinky.cluster.example.com cpu=4
blinkyc.cluster.example.com cpu=4
clyde.cluster.example.com user=jsmith
```

The `rsh` / `ssh` boot module will usually run when no other boot module has been selected. It can, however, be manually selected, even when another module would typically [automatically] be selected by specifying the `boot` SSI parameter with the value of `rsh`. For example:

```
shell$ lamboot -ssi boot rsh hostfile
```

Tunable Parameters

Table 8.3 lists the SSI parameters that are available to the `rsh` module.

SSI parameter name	Default value	Description
<code>boot_rsh_agent</code>	From configure	Remote shell agent to use.
<code>boot_rsh_priority</code>	10	Default priority level.
<code>boot_rsh_username</code>	None	Username to use if different than login name.

Table 8.3: SSI parameters for the `rsh` boot module.

8.1.8 The `tm` Module (OpenPBS / PBS Pro)

Both OpenPBS and PBS Pro (both products of Altair Grid Technologies, LLC), contain support for the Task Management (TM) interface. When using TM, `rsh/ssh` is not necessary to launch jobs on remote nodes.

The advantages of using PBS's TM interface are:

- PBS can generate proper accounting information for all nodes in a parallel job.
- PBS can kill entire jobs properly when the job ends.
- `lamboot` executes significantly faster when using TM as compared to when it uses `rsh` / `ssh`.

Usage

When running in a PBS batch job, LAM should automatically detect that it should use the `tm` boot module – no extra command line parameters or environment variables should be necessary. Specifically, when running in a PBS job, the `tm` module will report that it is available, and artificially inflate its priority relatively high in order to influence the boot module selection process. However, the `tm` boot module can be forced by specifying the `boot` SSI parameter with the value of `tm`.

Unlike the `rsh/ssh` boot module, you do not need to specify a hostfile for the TM boot module. Instead, PBS itself provides a list of nodes (and associated CPU counts) to LAM. Using `lamboot` is therefore as simple as:

```
shell$ lamboot
```

The TM boot modules works in both interactive and non-interactive batch jobs.

Tunable Parameters

Table 8.4 lists the SSI parameters that are available to the `tm` module.

SSI parameter name	Default value	Description
<code>boot_tm_priority</code>	50	Default priority level.

Table 8.4: SSI parameters for the tm boot module.

Special Notes

Since the TM boot module is designed to work in PBS jobs, it will fail if the TM boot module is manually specified and LAM is not currently running in a PBS job.

The TM module does not start a shell on the remote node. Instead, the entire environment of `lamboot` is pushed to the remote nodes before starting the LAM run-time environment.

Also note that the Altair-provided client RPMs for PBS Pro do not include the `pbs_demux` command, which is necessary for proper execution of TM jobs. The solution is to copy the executable from the server RPMs to the client nodes.

Finally, TM does not provide a mechanism for path searching on the remote nodes, so the `lamd` executable is required to reside in the same location on each node to be booted.

Chapter 9

Available MPI Modules

There are multiple types of MPI modules:

1. `rpi`: MPI point-to-point communication, also known as the LAM Request Progression Interface (RPI).
2. `coll`: MPI collective communication.
3. `cr`: Checkpoint/restart support for MPI programs.

Each of these types, and the modules that are available in the default LAM distribution, are discussed in detail below.

9.1 MPI Module Selection Process

The modules used in an MPI process may be related or dependent upon external factors. For example, the `gm` RPI cannot be used for MPI point-to-point communication unless there is Myrinet hardware present in the node. The `blcr` checkpoint/restart module cannot be used unless thread support was included. And so on. As such, it is important for users to understand the module selection algorithm.

1. Set the thread level to be what was requested, either via `MPI_INIT_THREAD` or the environment variable `LAM_MPI_THREAD_LEVEL`.
2. Query relevant modules and make lists of the resulting available modules. “Relevant” means either a specific module (or set of modules) if the user specified them through SSI parameters, or all modules if not specified.
3. Eliminate all modules who do not support the current MPI thread level.
4. If no `rpi` modules remain, try a lower thread support level until all levels have been tried. If no thread support level can provide an `rpi` module, abort.
5. Select the highest priority `rpi` module. Reset the thread level (if necessary) to be at least the lower bound of thread levels that the selected `rpi` module supports.
6. Eliminate all `coll` and `cr` modules that cannot operate at the current thread level.
7. If no `coll` modules remain, abort. Final selection `coll` modules is discussed in Section [9.3.1](#) (page 73).
8. If no `cr` modules remain and checkpoint/restart support was specifically requested, abort. Otherwise, select the highest priority `cr` module.

9.2 MPI Point-to-point Communication (Request Progression Interface / RPI)

LAM provides multiple SSI modules for MPI point-to-point communication. Also known as the Request Progression Interface (RPI), these modules are used for all aspects of MPI point-to-point communication in an MPI application. Some of the modules require external hardware and/or software (e.g., the native Myrinet RPI module requires both Myrinet hardware and the GM message passing library). The `laminfo` command can be used to determine which RPI modules are available in a LAM installation.

Although one RPI module will likely be the default, the selection of which RPI module is used can be changed through the SSI parameter `rpi`. For example:

```
shell$ mpirun -ssi rpi tcp C my_mpi_program
```

runs the `my_mpi_program` executable on all available CPUs using the `tcp` RPI module, while:

```
shell$ mpirun -ssi rpi gm C my_mpi_program
```

runs the `my_mpi_program` executable on all available CPUs using the `gm` RPI module.

It should be noted that the choice of RPI usually does not affect the `boot` SSI module – hence, the `lamboot` command requirements on hostnames specified in the boot schema is not dependent upon the RPI. For example, if the `gm` RPI is selected, `lamboot` may still require TCP/IP hostnames in the boot schema, not Myrinet hostnames. Also note that selecting a particular module does not guarantee that it will be able to be used. For example, selecting the `gm` RPI module will still cause a run-time failure if there is no Myrinet hardware present.

The available modules are described in the sections below. Note that much of this information (particularly the tunable SSI parameters) is also available in the `lamssi_rpi(7)` manual page.

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9.2.1 Two Different Shared Memory RPI Modules

The `sysv` (Section 9.2.5, page 69) and the `usysv` (Section 9.2.7, page 71) modules differ only in the mechanism used to synchronize the transfer of messages via shared memory. The `sysv` module uses System V semaphores while the `usysv` module uses spin locks with back-off. Both modules use a small number of System V semaphores for synchronizing both the deallocation of shared structures and access to the shared pool.

The blocking nature of the `sysv` module should generally provide better performance than `usysv` on oversubscribed nodes (i.e., when the number of processes is greater than the number of available processors). System V semaphores will effectively force processes yield to other processes, allowing at least some degree of fair/regular scheduling. In non-oversubscribed environments (i.e., where the number of processes is less than or equal to the number of available processors), the `usysv` RPI should generally provide better performance than the `sysv` RPI because spin locks keep processors busy-waiting. This hopefully keeps the operating system from suspending or swapping out the processes, allowing them to react immediately when the lock becomes available.

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9.2.2 The `crtcp` Module (Checkpoint-able TCP Communication)

Module Summary

Name:	<code>crtcp</code>
Kind:	<code>rpi</code>
Default SSI priority:	25
Checkpoint / restart:	yes

The `crtcp` RPI module is almost identical to the `tcp` module, described in Section 9.2.6. TCP sockets are used for communication between MPI processes.

Overview

The following are the main differences between the `tcp` and `crtcp` RPI modules:

- The `crtcp` module can be checkpointed and restarted. It is currently the *only* RPI module in LAM/MPI that supports checkpoint/restart functionality.
- The `crtcp` module does not have the “fast” message passing optimization that is in the `tcp` module. As result, there is a small performance loss in certain types of MPI applications.

All other aspects of the `crtcp` module are the same as the `tcp` module.

Checkpoint/Restart Functionality

The `crtcp` module is designed to work in conjunction with a `cr` module to provide checkpoint/restart functionality. See Section 9.4 for a description of how LAM’s overall checkpoint/restart functionality is used.

The `crtcp` module’s checkpoint/restart functionality is invoked when the `cr` module indicates that it is time to perform a checkpoint. The `crtcp` then quiesces all “in-flight” MPI messages and then allows the checkpoint to be performed. Upon restart, TCP connections are re-formed, and message passing processing continues. No additional buffers or “rollback” mechanisms are required, nor is any special coding required in the user’s MPI application.

Tunable Parameters

The `crtcp` module has the same tunable parameter as the `tcp` module (maximum size of a short message), although it has a different name: `rpi_crtcp_short`.

SSI parameter name	Default value	Description
<code>rpi_crtcp_priority</code>	25	Default priority level.
<code>rpi_crtcp_short</code>	65535	Maximum length (in bytes) of a “short” message.

Table 9.1: SSI parameters for the `crtcp` RPI module.

9.2.3 The `gm` Module (Myrinet)

Module Summary

Name:	<code>gm</code>
Kind:	<code>rpi</code>
Default SSI priority:	50
Checkpoint / restart:	no

The `gm` RPI module is for native message passing over Myrinet networking hardware. The `gm` RPI provides low latency, high bandwidth message passing performance. As such, most users likely do not need to read the rest of this section.

Overview

In general, using the `gm` RPI module is just like using any other RPI module – MPI functions will simply use native GM message passing for their back-end message transport.

Although it is not required, users are strongly encouraged to use the `MPI_ALLOC_MEM` and `MPI_FREE_MEM` functions to allocate and free memory (instead of, for example, `malloc()` and `free()`).

Tunable Parameters

Table 9.2 shows the SSI parameters that may be changed at run-time; the text below explains each one in detail.

SSI parameter name	Default value	Description
<code>rpi_gm_maxport</code>	32	Maximum GM port number to check during <code>MPI_INIT</code> when looking for an available port.
<code>rpi_gm_nopin</code>	0	Whether to let LAM/MPI pin arbitrary buffers or not.
<code>rpi_gm_port</code>	-1	Specific GM port to use (-1 indicates none).
<code>rpi_gm_priority</code>	50	Default priority level.
<code>rpi_gm_shortmsglen</code>	8192	Maximum length (in bytes) of a “short” message.
<code>rpi_gm_tinymsglen</code>	1024	Maximum length (in bytes) of a “tiny” message.

Table 9.2: SSI parameters for the `gm` RPI module.

Port Allocation

It is usually unnecessary to specify which Myrinet/GM port to use. LAM/MPI will automatically attempt to acquire ports greater than 1.

By default, LAM will check for any available port between 1 and 8. If your Myrinet hardware has more than 8 possible ports, you can change the upper port number that LAM will check with the `rpi_gm_maxport` SSI parameter.

However, if you wish LAM to use a specific GM port number (and not check all the ports from [1, `maxport`]), you can tell LAM which port to use with the `rpi_gm_port` SSI parameter. Specifying which port to use has precedence over the port range check – if a specific port is indicated, LAM will try to use that and not check a range of ports. Specifying to use port “-1” (or not specifying to use a specific port) will tell LAM to check the range of ports to find any available port.

Note that in all cases, if LAM cannot acquire a valid port for every MPI process in the job, the entire job will be aborted.

Be wary of forcing a specific port to be used, particularly in conjunction with the MPI dynamic process calls (e.g., `MPI_COMM_SPAWN`). For example, attempting to spawn a child process on a node that already has an MPI process in the same job, LAM will try to use the same specific port, which will result in failure because the MPI process already on that node will have already claimed that port.

Adjusting Message Lengths

The `gm` RPI uses three different protocols for passing data between MPI processes: tiny, short, and long. Selection of which protocol to use is based solely on the length of the message. Tiny messages are sent

(along with tag and communicator information) in one transfer to the receiver. Short messages send two transfers: an “envelope” message (tag and communicator information) followed by the data of the message. Long messages use a rendezvous protocol – the envelope is sent to the destination, the receiver responds with an ACK (when it is ready), and then the sender sends another envelope followed by the data of the message.

The message lengths at which the different protocols are used can be changed with the SSI parameters `rpi_gm_tinymsglen` and `rpi_gm_shortmsglen`, which represent the maximum length of tiny and short messages, respectively. LAM defaults to 1,024 bytes and 8,192 bytes for the maximum lengths of tiny and short messages, respectively.

The maximum short message length *must* be larger than the maximum tiny length. If it is not, LAM will adjust the maximum short message length to be one more than the maximum tiny message length, effectively eliminating short messages – leaving only tiny and long.

It may be desirable to adjust these values for different kinds of applications and message passing patterns. The LAM Team would appreciate feedback on the performance of different values for real world applications.

Pinning Memory

The Myrinet native communication library (`gm`) can only communicate through “registered” or “pinned” memory. In most operating systems, LAM/MPI handles this automatically by pinning user-provided buffers when required. This allows for good message passing performance, especially when re-using buffers to send/receive multiple messages.

However, the `gm` library does not have the ability to pin arbitrary memory on Solaris systems – auxiliary buffers must be used. Although LAM/MPI controls all pinned memory, this has a detrimental effect on performance of large messages: LAM/MPI must copy all messages from the application-provided buffer to an auxiliary buffer before it can be sent (and vice versa for receiving messages). As such, users are strongly encouraged to use the `MPI_ALLOC_MEM` and `MPI_FREE_MEM` functions instead of `malloc()` and `free()`. Using these functions will allocate “pinned” memory such that LAM/MPI will not have to use auxiliary buffers and an extra memory copy.

The `rpi_gm_nopin` SSI parameter can be used to force Solaris-like behavior. On Solaris platforms, the default value is “1”, specifying to use auxiliary buffers as described above. On non-Solaris platforms, the default value is “0”, meaning that LAM/MPI will attempt to pin and send/receive directly from user buffers.

Note that since LAM/MPI manages all pinned memory, LAM/MPI must be aware of memory that is freed so that it can be properly unpinned before it is returned to the operating system. Hence, LAM/MPI must intercept calls to functions such as `sbrk()` and `munmap()` to effect this behavior. Since `gm` cannot pin arbitrary memory on Solaris, LAM/MPI does not need to intercept these calls on Solaris machines.

To this end, the `ptmalloc` memory allocation package¹ is included in LAM/MPI, and will automatically be included on platforms that support arbitrary pinning. `ptmalloc` allows LAM/MPI to intercept the relevant functions and ensure that memory is unpinned before returning it to the operating system. Use of `ptmalloc` will effectively overload all memory allocation functions (e.g., `malloc()`, `calloc()`, `free()`, etc.) for all applications that are linked against the LAM/MPI libraries (potentially regardless of whether they are using the `gm` RPI module or not). The `ptmalloc` package is thread safe and suitable for use in any application (it is the same memory allocations package that is included in the GNU Libc package).

¹<http://www.malloc.de/>

Memory Checking Debuggers

When running LAM’s gm RPI through a memory checking debugger (see Section 10.4), a number of “Read from unallocated” (RUA) and/or “Read from uninitialized” (RFU) errors may appear, originating from functions beginning with “gm_” or “lam_ssi_rpi_gm_”. These RUA/RFU errors are normal – they are not actually reads from unallocated sections of memory. The Myrinet hardware and gm kernel device driver handle some aspects of memory allocation, and therefore the operating system/debugging environment is not always aware of all valid memory. As a result, a memory checking debugger will often raise warnings, even though this is valid behavior.

Known Issues

As of LAM 7.0.6, the following issues still remain in the gm RPI module:

- Heterogeneity between big and little endian machines is not supported.
- The gm RPI is not supported with IMPI.
- Mixed shared memory / GM message passing is not yet supported; all message passing is through Myrinet / GM.
- XMPI tracing is not yet supported.
- The gm RPI module is designed to run in environments where the number of available processors is greater than or equal to the number of MPI processes on a given node. The gm RPI module will perform poorly (particularly in blocking MPI communication calls) if there are less processors than processes on a node.

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9.2.4 The lamd Module (Daemon-Based Communication)

Module Summary

Name:	lamd
Kind:	rpi
Default SSI priority:	10
Checkpoint / restart:	no

The lamd RPI module uses the LAM daemons for all interprocess communication. This allows for true asynchronous message passing (i.e., messages can progress even while the user’s program is executing), albeit at the cost of a significantly higher latency and lower bandwidth.

Overview

Rather than send messages directly from one MPI process to another, all messages are routed through the local LAM daemon, the remote LAM daemon (if the target process is on a different node), and then finally to the target MPI process. This potentially adds two hops to each MPI message.

Although the latency incurred can be significant, the lamd RPI can actually make message passing progress “in the background.” Specifically, since LAM/MPI is a single-threaded MPI implementation, it can typically only make progress passing messages when the user’s program is in an MPI function call. With the lamd RPI, since the messages are all routed through separate processes, message passing can actually occur when the user’s program is *not* in an MPI function call.

User programs that utilize latency-hiding techniques can exploit this asynchronous message passing behavior, and therefore actually achieve high performance despite of the high overhead associated with the lamd RPI.²

Tunable Parameters

The lamd module has only one tunable parameter: its priority.

SSI parameter name	Default value	Description
<code>rpi_lamd_priority</code>	10	Default priority level.

Table 9.3: SSI parameters for the lamd RPI module.

9.2.5 The sysv Module (Shared Memory Using System V Semaphores)

Module Summary

Name:	<code>sysv</code>
Kind:	<code>rpi</code>
Default SSI priority:	30
Checkpoint / restart:	<code>no</code>

The `sysv` RPI is the one of two combination shared-memory/TCP message passing modules. Shared memory is used for passing messages to processes on the same node; TCP sockets are used for passing messages to processes on other nodes. System V semaphores are used for synchronization of the shared memory pool.

Be sure to read Section 9.2.1 (page 64) on the difference between this module and the `usysv` module.

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Overview

Processes located on the same node communicate via shared memory. One System V shared segment shared by all processes on the same node. This segment is logically divided into three areas. The total size of the shared segment (in bytes) allocated on each node is:

$$(2 \times C) + (N \times (N - 1) \times (S + C)) + P$$

where C is the cache line size, N is the number of processes on the node, S is the maximum size of short messages, and P is the size of the pool for large messages,

The first area (of size $(2 \times C)$) is for the global pool lock. The `sysv` module allocates a semaphore set (of size 6) for each process pair communicating via shared memory. On some systems, the operating system may need to be reconfigured to allow for more semaphore sets if running tasks with many processes communicating via shared memory.

The second area is for “postboxes”, or short message passing. A postbox is used for communication one-way between two processes. Each postbox is the size of a short message plus the length of a cache line. There is enough space allocated for $(N \times (N - 1))$ postboxes. The maximum size of a short message is configurable with the `rpi_ssi_sysv_short` SSI parameter.

²Several users on the LAM/MPI mailing list have mentioned this specifically; even though the lamd RPI is slow, it provides *significantly* better performance because it can provide true asynchronous message passing.

The final area in the shared memory area (of size P) is used as a global pool from which space for long message transfers is allocated. Allocation from this pool is locked. The default lock mechanism is a System V semaphore but can be changed to a process-shared pthread mutex lock. The size of this pool is configurable with the `rpi_ssi_sysv_shmpoolsize` SSI parameter. LAM will try to determine P at configuration time if none is explicitly specified. Larger values should improve performance (especially when an application passes large messages) but will also increase the system resources used by each task.

Use of the Global Pool

When a message larger than $(2S)$ is sent, the transport sends S bytes with the first packet. When the acknowledgment is received, it allocates $(\text{messagelength} - S)$ bytes from the global pool to transfer the rest of the message.

To prevent a single large message transfer from monopolizing the global pool, allocations from the pool are actually restricted to a maximum of `rpi_ssi_sysv_shmmalloc` bytes. Even with this restriction, it is possible for the global pool to temporarily become exhausted. In this case, the transport will fall back to using the postbox area to transfer the message. Performance will be degraded, but the application will progress.

Tunable Parameters

Table 9.4 shows the SSI parameters that may be changed at run-time. Each of these parameters were discussed in the previous sections.

SSI parameter name	Default value	Description
<code>rpi_sysv_priority</code>	30	Default priority level.
<code>rpi_sysv_pollyield</code>	1	Whether or not to force the use of <code>yield()</code> to yield the processor.
<code>rpi_sysv_shmmalloc</code>	From configure	Maximum size of a large message atomic transfer. The default value is calculated when LAM is configured.
<code>rpi_sysv_shmpoolsize</code>	From configure	Size of the shared memory pool for large messages. The default value is calculated when LAM is configured.
<code>rpi_sysv_short</code>	8192	Maximum length (in bytes) of a “short” message for sending via shared memory (i.e., on-node). Directly affects the size of the allocated “postbox” shared memory area.
<code>rpi_tcp_short</code>	65535	Maximum length (in bytes) of a “short” message for sending via TCP sockets (i.e., off-node).

Table 9.4: SSI parameters for the sysv RPI module.

9.2.6 The tcp Module (TCP Communication)

Module Summary	
Name:	tcp
Kind:	rpi
Default SSI priority:	20
Checkpoint / restart:	no

The tcp RPI module uses TCP sockets for MPI point-to-point communication.

Tunable Parameters

Two different protocols are used to pass messages between processes: short and long. Short messages are sent eagerly and will not block unless the operating system blocks. Long messages use a rendezvous protocol; the body of the message is not sent until a matching MPI receive is posted. The crossover point between the short and long protocol defaults to 64KB, but can be changed with the `rpi_tcp_short` SSI parameter, an integer specifying the maximum size (in bytes) of a short message.

SSI parameter name	Default value	Description
<code>rpi_tcp_priority</code>	20	Default priority level.
<code>rpi_tcp_short</code>	65535	Maximum length (in bytes) of a “short” message.

Table 9.5: SSI parameters for the tcp RPI module.

9.2.7 The usysv Module (Shared Memory Using Spin Locks)

Module Summary	
Name:	usysv
Kind:	rpi
Default SSI priority:	40
Checkpoint / restart:	no

The usysv RPI is the one of two combination shared-memory/TCP message passing modules. Shared memory is used for passing messages to processes on the same node; TCP sockets are used for passing messages to processes on other nodes. Spin locks with back-off are used for synchronization of the shared memory pool (a System V semaphore or pthread mutex is also used for access to the per-node shared memory pool).

The nature of spin locks means that the usysv RPI will perform poorly when there are more processes than processors (particularly in blocking MPI communication calls). If no higher priority RPI modules are available (e.g., Myrinet/gm) and the user does not select a specific RPI module through the `rpi` SSI parameter, usysv may be selected as the default – even if there are more processes than processors. Users should keep this in mind; in such circumstances, it is probably better to manually select the `sysv` or `tcp` RPI modules.

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Overview

Aside from synchronization, the `usysv` RPI module is almost identical to the `sysv` module. The `usysv` module uses spin locks with back-off. When a process backs off, it attempts to yield the processor. If the configure script found a system-provided yield function,³ it is used. If no such function is found, then `select()` on `NULL` file descriptor sets with a timeout of 10us is used.

Tunable Parameters

Table 9.6 shows the SSI parameters that may be changed at run-time. Many of these parameters are identical to their `sysv` counterparts and are not re-described here.

SSI parameter name	Default value	Description
<code>rpi_tcp_short</code>	65535	Maximum length (in bytes) of a “short” message for sending via TCP sockets (i.e., off-node).
<code>rpi_usysv_pollyield</code>	1	Same as <code>sysv</code> counterpart.
<code>rpi_usysv_priority</code>	40	Default priority level.
<code>rpi_usysv_readlockpoll</code>	10,000	Number of iterations to spin before yielding the processing while waiting to read.
<code>rpi_usysv_shmmaxalloc</code>	From configure	Same as <code>sysv</code> counterpart.
<code>rpi_usysv_shmpoolsize</code>	From configure	Same as <code>sysv</code> counterpart.
<code>rpi_usysv_short</code>	8192	Same as <code>sysv</code> counterpart.
<code>rpi_usysv_writelockpoll</code>	10	Number of iterations to spin before yielding the processing while waiting to write.

Table 9.6: SSI parameters for the `usysv` RPI module.

9.3 MPI Collective Communication

MPI collective communication functions have their basic functionality outlined in the MPI standard. However, the implementation of this functionality can be optimized and/or implemented in different ways. As such, LAM provides modules for implementing the MPI collective routines that are targeted for different environments.

- Basic algorithms
- SMP-optimized algorithms

These modules are discussed in detail below. Note that the sections below each assume that support for these modules have been compiled into LAM/MPI. The `laminfo` command can be used to determine exactly which modules are supported in your installation (see Section 7.6, page 44).

³Such as `yield()` or `sched_yield()`.

9.3.1 Selecting a coll Module

coll modules are selected on a per-communicator basis. Most users will not need to override the coll selection mechanisms; the coll modules currently included in LAM/MPI usually select the best module for each communicator. However, mechanisms are provided to override which coll module will be selected on a given communicator.

When each communicator is created (including MPI_COMM_WORLD and MPI_COMM_SELF), all available coll modules are queried to see if they want to be selected. A coll module may therefore be in use by zero or more communicators at any given time. The final selection of which module will be used for a given communicator is based on priority; the module with the highest priority from the set of available modules will be used for all collective calls on that communicator.

Since the selection of which module to use is inherently dynamic and potentially different for each communicator, there are two levels of parameters specifying which modules should be used. The first level specifies the overall set of coll modules that will be available to *all* communicators; the second level is a per-communicator parameter indicating which specific module should be used.

The first level is provided with the coll SSI parameter. Its value is a comma-separated list of coll module names. If this parameter is supplied, only these modules will be queried at run time, effectively determining the set of modules available for selection on all communicators. If this parameter is not supplied, all coll modules will be queried.

The second level is provided with the MPI attribute LAM_MPI_SSI_COLL. This attribute can be set to the string name of a specific coll module on a parent communicator before a new communicator is created. If set, the attribute's value indicates the *only* module that will be queried. If this attribute is not set, all available modules are queried.

Note that no coordination is done between the SSI frameworks in each MPI process to ensure that the same modules are available and/or are selected for each communicator. Although `mpirun` allows different environment variables to be exported to each MPI process, and the value of an MPI attribute is local to each process, LAM's behavior is undefined if the same SSI parameters are not available in all MPI processes.

9.3.2 coll SSI Parameters

There are three parameters that apply to all coll modules. Depending on when their values are checked, they may be set by environment variables, command line switches, or attributes on MPI communicators.

- `coll_base_associative`: The MPI standard defines whether reduction operations are commutative or not, but makes no provisions for whether an operator is associative or not. This parameter, if defined to 1, asserts that all reduction operations on a communicator are assumed to be associative. If undefined or defined to 0, all reduction operations are assumed to be non-associative.

This parameter is examined during every reduction operation. See **Commutative and Associative Reduction Operators**, below.

- `coll_crossover`: If set, define the maximum number of processes that will be used with a linear algorithm. More than this number of processes may use some other kind of algorithm.

This parameter is only examined during MPI_INIT.

- `coll_reduce_crossover`: For reduction operations, the determination as to whether an algorithm should be linear or not is not based on the number of process, but rather by the number of bytes to be transferred by each process. If this parameter is set, it defines the maximum number of bytes

transferred by a single process with a linear algorithm. More than this number of bytes may result in some other kind of algorithm.

This parameter is only examined during `MPI_INIT`.

Commutative and Associative Reduction Operators

MPI-1 defines that all built-in reduction operators are commutative. User-defined reduction operators can specify whether they are commutative or not. The MPI standard makes no provisions for whether a reduction operation is associative or not. For some operators and datatypes, this distinction is largely irrelevant (e.g., find the maximum in a set of integers). However, for operations involving the combination of floating point numbers, associativity and commutativity matter. An *Advice to Implementors* note in MPI-1, section 4.9.1, 114:20, states:

It is strongly recommended that `MPI_REDUCE` be implemented so that the same result be obtained whenever the function is applied on the same arguments, appearing in the same order. Note that this may prevent optimizations that take advantage of the physical location of processors.

Some implementations of the reduction operations may specifically take advantage of data locality, and therefore assume that the reduction operator is associative. As such, LAM will always take the conservative approach to reduction operations and fall back to non-associative algorithms (e.g., `lam_basic`) for the reduction operations unless specifically told to use associative (SMP-optimized) algorithms by setting the SSI parameter `coll_base_associative` to 1.

9.3.3 The `lam_basic` Module

Module Summary

Name:	<code>lam_basic</code>
Kind:	<code>coll</code>
Default SSI priority:	0
Checkpoint / restart:	yes

The `lam_basic` module provides simplistic algorithms for each of the MPI collectives that are layered on top of point-to-point functionality.⁴ It can be used in any environment. Its priority is sufficiently low that it will be chosen if no other `coll` module is available.

Many of the algorithms are twofold: for N or less processes, linear algorithms are used. For more than N processes, binomial algorithms are used. No attempt is made to determine the locality of processes, however – the `lam_basic` module effectively assumes that there is equal latency between all processes. All reduction operations are performed in a strictly-defined order; associativity is not assumed.

No algorithms are implemented for intercommunicators; invoking a collective on an intercommunicator will result in a run-time MPI exception.

⁴The basic algorithms are the same that have been included in LAM/MPI since at least version 6.2.

9.3.4 The `smp` Module

Module Summary	
Name:	<code>smp</code>
Kind:	<code>coll</code>
Default SSI priority:	50
Checkpoint / restart:	yes

The `smp` module is geared towards SMP nodes in a LAN. Heavily inspired by the MagPie algorithms [6], the `smp` module determines the locality of processes before setting up a dynamic structure in which to perform the collective function. Although all communication is still layered on MPI point-to-point functions, the algorithms attempt to maximize the use of on-node communication before communicating with off-node processes. This results in lower overall latency for the collective operation.

The `smp` module assumes that there are only two levels of latency between all processes. As such, it will only allow itself to be available for selection when there are at least two nodes in a communicator and there are at least two processes on the same node.⁵

Only some of the collectives have been optimized for SMP environments. Table 9.7 shows which collective functions have been optimized, which were already optimal (from the `lam_basic` module), and which will eventually be optimized.

Special Notes

Since the goal of the SMP-optimized algorithms attempt to take advantage of data locality, it is strongly recommended to maximize the proximity of `MPI_COMM_WORLD` rank neighbors on each node. The C nomenclature to `mpirun` can ensure this automatically.

Also, as a result of the data-locality exploitation, the `coll_base_associative` parameter is highly relevant – if it is not set to 1, the `smp` module will fall back to the `lam_basic` reduction algorithms.

9.4 Checkpoint/Restart of MPI Jobs

LAM supports the ability to involuntarily checkpoint and restart parallel MPI jobs. Due to the asynchronous nature of the checkpoint/restart design, such jobs must run with a thread level of at least `MPI_THREAD_SERIALIZED`. This allows the checkpoint/restart framework to interrupt the user's job for a checkpoint regardless of whether it is performing message passing functions or not in the MPI communications layer.

LAM does not provide checkpoint/restart functionality itself; `cr` SSI modules are used to invoke back-end systems that save and restore checkpoints. The following notes apply to checkpointing parallel MPI jobs:

- No special code is required in MPI applications to take advantage of LAM/MPI's checkpoint/restart functionality, although some limitations may be imposed (depending on the back-end checkpointing system that is used).
- LAM's checkpoint/restart functionality *only* involves MPI processes; the LAM universe is not checkpointed. A LAM universe must be independently established before an MPI job can be restored.
- LAM does not yet support checkpointing/restarting MPI-2 applications. In particular, LAM's behavior is undefined when checkpointing MPI processes that invoke any non-local MPI-2 functionality (including dynamic functions and IO).

⁵As a direct result, `smp` will never be selected for `MPI_COMM_SELF`.

MPI function	Status
MPI_ALLGATHER	Not yet optimized for SMP environments; uses lam_basic algorithm instead.
MPI_ALLGATHERV	Not yet optimized for SMP environments; uses lam_basic algorithm instead.
MPI_ALLREDUCE	Optimized for SMP environments.
MPI_ALLTOALL	Identical to lam_basic algorithm; already optimized for SMP environments.
MPI_ALLTOALLV	Identical to lam_basic algorithm; already optimized for SMP environments.
MPI_ALLTOALLW	Not implemented.
MPI_BARRIER	Optimized for SMP environments.
MPI_BCAST	Optimized for SMP environments.
MPI_EXSCAN	Not implemented.
MPI_GATHER	Identical to lam_basic algorithm; already optimized for SMP environments.
MPI_GATHERV	Identical to lam_basic algorithm; already optimized for SMP environments.
MPI_REDUCE	Optimized for SMP environments.
MPI_REDUCE_SCATTER	Not yet optimized for SMP environments; uses lam_basic algorithm instead.
MPI_SCAN	Not yet optimized for SMP environments; uses lam_basic algorithm instead.
MPI_SCATTER	Identical to lam_basic algorithm; already optimized for SMP environments.
MPI_SCATTERV	Identical to lam_basic algorithm; already optimized for SMP environments.

Table 9.7: Listing of MPI collective functions indicating which have been optimized for SMP environments.

- Migration of restarted processes is available on a limited basis; the `crtcp` RPI will start up properly regardless of what nodes the MPI processes are re-started on, but other system-level resources may or may not be restarted properly (e.g., open files, shared memory, etc.).
- Checkpoints can only be performed after all processes have invoked `MPI_INIT` and before any process has invoked `MPI_FINALIZE`.

9.4.1 Selecting a `cr` Module

The `cr` framework coordinates with all other SSI modules to ensure that the entire MPI application is ready to be checkpointed before the back-end system is invoked. Specifically, for a parallel job to be able to checkpoint and restart, all the SSI modules that it uses must support checkpoint/restart capabilities.

All `coll` modules in the LAM/MPI distribution currently support checkpoint/restart capability because they are layered on MPI point-to-point functionality – as long as the RPI module being used supports checkpoint/restart, so do the `coll` modules. However, only one RPI module currently supports checkpoint/restart: `crtcp`. Attempting to checkpoint an MPI job when using any other `rpi` module will result in undefined behavior.

9.4.2 `cr` SSI Parameters

The `cr` SSI parameter can be used to specify which `cr` module should be used for an MPI job. An error will occur if a `cr` module is requested and an `rpi` or `coll` module cannot be found that supports checkpoint/restart functionality.

Additionally, the `cr_base_dir` SSI parameter can be used to specify the directory where checkpoint file(s) will be saved. If it is not set, and no default value was provided when LAM/MPI was configured (with the `--with-cr-file-dir` flag) the user's home directory is used.

9.4.3 The `blcr` Module

Module Summary	
Name:	<code>blcr</code>
Kind:	<code>cr</code>
Default SSI priority:	50
Checkpoint / restart:	yes

Berkeley Lab's Checkpoint/Restart (BLCR) [1] single-node checkpointer provides the capability for checkpointing and restarting processes under Linux. The `blcr` module, when used with checkpoint/restart SSI modules, will invoke the BLCR system to save and restore checkpoints.

Overview

The `blcr` module will only automatically be selected when the thread level is `MPI_THREAD_SERIALIZED` and all selected SSI modules support checkpoint/restart functionality (see the SSI module selection algorithm, Section 9.1, page 63). The `blcr` module can be specifically selected by setting the `cr` SSI parameter to the value `blcr`. Manually selecting the `blcr` module will force the MPI thread level to be at least `MPI_THREAD_SERIALIZED`.

Running a Checkpoint/Restart-Capable MPI Job

There are multiple ways to run a job with checkpoint/restart support:

- Use the `crtcp` RPI, and invoke `MPI_INIT_THREAD` with a requested thread level of `MPI_THREAD_SERIALIZED`. This will automatically make the `blcr` module available.

```
shell$ mpirun C -ssi rpi crtcp my_mpi_program
```

- Use the `crtcp` RPI and manually select the `blcr` module:

```
shell$ mpirun C -ssi rpi crtcp -ssi cr blcr my_mpi_program
```

T (7.0.5)

Depending on the location of the BLCR shared library, it may be necessary to use the `LD_LIBRARY_PATH` environment variable to specify where it can be found. Specifically, if the BLCR library is not in the default path searched by the linker, errors will occur at run time because it cannot be found. In such cases, adding the directory where the `libcr.so*` file(s) can be found to the `LD_LIBRARY_PATH` environment variable *on all nodes where the MPI application will execute* will solve the problem. Note that this may entail editing user's "dot" files to augment the `LD_LIBRARY_PATH` variable.⁶ For example:

```
# ...edit user's shell startup file to augment LD_LIBRARY_PATH...
```

```
shell$ lamboot hostfile
```

```
shell$ mpirun C -ssi rpi crtcp -ssi cr blcr my_mpi_program
```

Alternatively, the `-x` option to `mpirun` can be used to export the `LD_LIBRARY_PATH` environment variable to all MPI processes. For example (Bourne shell and derivatives):

```
shell$ LD_LIBRARY_PATH=/location/of/blcr/lib:$LD_LIBRARY_PATH
```

```
shell$ export LD_LIBRARY_PATH
```

```
shell$ mpirun C -ssi rpi crtcp -ssi cr blcr -x LD_LIBRARY_PATH my_mpi_program
```

For C shell and derivatives:

```
shell% setenv LD_LIBRARY_PATH /location/of/blcr/lib:$LD_LIBRARY_PATH
```

```
shell% mpirun C -ssi rpi crtcp -ssi cr blcr -x LD_LIBRARY_PATH my_mpi_program
```

⊥ (7.0.5)

Checkpointing and Restarting

Once a checkpoint-capable job is running, the BLCR command `cr_checkpoint` can be used to invoke a checkpoint. Running `cr_checkpoint` with the PID of `mpirun` will cause a context file to be created for `mpirun` as well as a context file for each running MPI process. Before it is checkpointed, `mpirun` will also create an application schema file to assist in restoring the MPI job. These files will all be created in the directory specified by LAM/MPI's configured default, the `cr_base_dir`, or the user's home directory if no default is specified.

The BLCR `cr_restart` command can then be invoked with the PID and context file generated from `mpirun`, which will restore the entire MPI job.

⁶Ensure to see Section 4.1.1 for details about which shell startup files should be edited. Also note that shell startup files are *only* read when starting the LAM universe. Hence, if you change values in shell startup files, you will likely need to re-invoke the `lamboot` command to put your changes into effect.

Tunable Parameters

There are no tunable parameters to the bcr cr module.

Known Issues

BLCR has its own limitations (e.g., BLCR does not yet support saving and restoring file descriptors); see the documentation included in BLCR for further information. Check the project's main web site⁷ to find out more about BLCR.

⁷<http://ftg.lbl.gov/>

Chapter 10

Debugging Parallel Programs

LAM/MPI supports multiple methods of debugging parallel programs. The following notes and observations generally apply to debugging in parallel:

- Note that most debuggers require that MPI applications were compiled with debugging support enabled. This typically entails adding `-g` to the compile and link lines when building your MPI application.
- Unless you specifically need it, it is not recommended to compile LAM with `-g`. This will allow you to treat MPI function calls as atomic instructions.
- Even when debugging in parallel, it is possible that not all MPI processes will execute exactly the same code. For example, “if” statements that are based upon a communicator’s rank of the calling process, or other location-specific information may cause different execution paths in each MPI process.

10.1 Naming MPI Objects

LAM/MPI supports the MPI-2 functions `MPI_<type>_SET_NAME` and `MPI_<type>_GET_NAME`, where `<type>` can be: `COMM`, `WIN`, or `TYPE`. Hence, you can associate relevant text names with communicators, windows, and datatypes (e.g., “6x13x12 molecule datatype”, “Local group reduction intracommunicator”, “Spawned worker intercommunicator”). The use of these functions is strongly encouraged while debugging MPI applications. Since they are constant-time, one-time setup functions, using these functions likely does not impact performance, and may be safe to use in production environments, too.

The rationale for using these functions is to allow LAM (and supported debuggers, profilers, and other MPI diagnostic tools) to display accurate information about MPI communicators, windows, and datatypes. For example, whenever a communicator name is available, LAM will use it in relevant error messages; when names are not available, communicators (and windows and types) are identified by index number, which – depending on the application – may vary between successive runs. The TotalView parallel debugger will also show communicator names (if available) when displaying the message queues.

10.2 TotalView Parallel Debugger

TotalView is a commercial debugger from Etnus that supports debugging MPI programs in parallel. That is, with supported MPI implementations, the TotalView debugger can automatically attach to one or more MPI processes in a parallel application.

LAM now supports basic debugging functionality with the TotalView debugger. Specifically, LAM supports TotalView attaching to one or more MPI processes, as well as viewing the MPI message queues in supported RPI modules.

This section provides some general tips and suggested use of TotalView with LAM/MPI. It is *not* intended to replace the TotalView documentation in any way. **Be sure to consult the TotalView documentation for more information and details than are provided here.**

Note: TotalView is licensed product provided by Etnus. You need to have TotalView installed properly before you can use it with LAM.¹

10.2.1 Attaching TotalView to MPI Processes

LAM/MPI does not need to be configured or compiled in any special way to allow TotalView to attach to MPI processes.

You can attach TotalView to MPI processes started by `mpirun` / `mpiexec` in following ways:

1. Use the `-tv` convenience argument when running `mpirun` or `mpiexec` (this is the preferred method):

```
shell$ mpirun -tv [...other mpirun arguments...]
```

For example:

```
shell$ mpirun -tv C my_mpi_program arg1 arg2 arg3
```

2. Directly launch `mpirun` in TotalView (you *cannot* launch `mpiexec` in TotalView):

```
shell$ totalview mpirun -a [...mpirun arguments...]
```

For example:

```
shell$ totalview mpirun -a C my_mpi_program arg1 arg2 arg3
```

Note the `-a` argument after `mpirun`. This is necessary to tell TotalView that arguments following “-a” belong to `mpirun` and not TotalView.

Also note that the `-tv` convenience argument to `mpirun` simply executes “`totalview mpirun -a . . .`”; so both methods are essentially identical.

TotalView can either attach to all MPI processes in `MPI_COMM_WORLD` or a subset of them. The controls for “partial attach” are in TotalView, not LAM. In TotalView 6.0.0 (analogous methods may work for earlier versions of TotalView – see the TotalView documentation for more details), you need to set the parallel launch preference to “ask.” In the root window menu:

1. Select File → Preferences
2. Select the Parallel tab
3. In the “When a job goes parallel” box, select “Ask what to do”
4. Click on OK

¹Refer to <http://www.etnus.com/> for more information about TotalView.

10.2.2 Suggested Use

Since TotalView support is started with the `mpirun` command, TotalView will, by default, start by debugging `mpirun` itself. While this may seem to be an annoying drawback, there are actually good reasons for this:

- While debugging the parallel program, if you need to re-run the program, you can simply re-run the application from within TotalView itself. There is no need to exit the debugger to run your parallel application again.
- TotalView can be configured to automatically skip displaying the `mpirun` code. Instead, TotalView will recognize the command named `mpirun` and start executing it immediately upon load. See below for details.

There are two ways to start debugging the MPI application:

1. The preferred method is to have a `$HOME/.tvdrvc` file that tells TotalView to skip past the `mpirun` code and automatically start the parallel program. Create or edit your `$HOME/.tvdrvc` file to include the following:

```
# Set a variable to say what the MPI "starter" program is
set starter_program mpirun

# Check if the newly loaded image is the starter program
# and start it immediately if it is.
proc auto_run_starter {loaded_id} {
    global starter_program
    set executable_name [TV::image get $loaded_id name]
    set file_component [file tail $executable_name]

    if {[string compare $file_component $starter_program] == 0} {
        puts "Automatically starting $file_component"
        dgo
    }
}

# Append this function to TotalView's image load callbacks so that
# TotalView run this program automatically.
dlappend TV::image_load_callbacks auto_run_starter
```

Note that when using this method, `mpirun` is actually running in the debugger while you are debugging your parallel application, even though it may not be obvious. Hence, when the MPI job completes, you'll be returned to viewing `mpirun` in the debugger. *This is normal* – all MPI processes have exited; the only process that remains is `mpirun`. If you click “Go” again, `mpirun` will launch the MPI job again.

2. Do not create the `$HOME/.tvdrvc` file with the “auto run” functionality described in the previous item, but instead simply click the “go” button when TotalView launches. This runs the `mpirun` command with the command line arguments, which will eventually launch the MPI programs and allow attachment to the MPI processes.

When TotalView initially attaches to an MPI process, you will see the code for `MPI_INIT` or one of its sub-functions (which will likely be assembly code, unless LAM itself was compiled with debugging information). You probably want to skip past the rest of `MPI_INIT`. In the Stack Trace window, click on function which called `MPI_INIT` (e.g., `main`) and set a breakpoint to line following call to `MPI_INIT`. Then click “Go”.

10.2.3 Limitations

The following limitations are currently imposed when debugging LAM/MPI jobs in TotalView:

1. Cannot attach to scripts: You cannot attach TotalView to MPI processes if they were launched by scripts instead of `mpirun`. Specifically, the following won't work:

```
shell$ mpirun -tv C script_to_launch_foo
```

But this will:

```
shell$ mpirun -tv C foo
```

For that reason, since `mpiexec` is a script, although the `-tv` switch works with `mpiexec` (because it will eventually invoke `mpirun`), you cannot launch `mpiexec` with TotalView.

2. TotalView needs to launch the TotalView server on all remote nodes in order to attach to remote processes.

The command that TotalView uses to launch remote executables might be different than what LAM/MPI uses. You may have to set this command explicitly and independently of LAM/MPI. For example, if your local environment has `rsh` disabled and only allows `ssh`, then you likely need to set the TotalView remote server launch command to “`ssh`”. You can set this internally in TotalView or with the `TVDSVRLAUNCHCMD` environment variable (see the TotalView documentation for more information on this).

3. The TotalView license must be able to be found on all nodes where you expect to attach the debugger.

Consult with your system administrator to ensure that this is setup properly. You may need to edit your “dot” files (e.g., `.profile`, `.bashrc`, `.cshrc`, etc.) to ensure that relevant environment variable settings exist on all nodes when you `lamboot`.

4. It is always a good idea to let `mpirun` finish before you rerun or exit TotalView.

5. TotalView will not be able to attach to MPI programs when you execute `mpirun` with `-s` option.

This is because TotalView will not get the source code of your program on nodes other than the source node. We advise you to either use a common filesystem or copy the source code and executable on all nodes when using TotalView with LAM so that you can avoid the use of `mpirun`'s `-s` flag.

10.2.4 Message Queue Debugging

The TotalView debugger can show the sending, receiving, and unexpected message queues for many parallel applications. Note the following:

- The MPI-2 function for naming communicators (`MPI_COMM_SET_NAME`) is strongly recommended when using the message queue debugging functionality. For example, `MPI_COMM_WORLD` and `MPI_COMM_SELF` are automatically named by LAM/MPI. Naming communicators makes it significantly easier to identify communicators of interest in the debugger.

Any communicator that is not named will be displayed as “--unnamed--”.

- Message queue debugging of applications is not currently supported for 64 bit executables. If you attempt to use the message queue debugging functionality on a 64 bit executable, TotalView will display a warning before disabling the message queue options.
- The lamd RPI does not support the message queue debugging functionality.
- LAM/MPI does not currently provide debugging support for dynamic processes (e.g., `MPI_COMM-SPAWN`).

10.3 Serial Debuggers

LAM also allows the use of one or more serial debuggers when debugging a parallel program.

10.3.1 Launching Debuggers

LAM allows the arbitrary execution of any executable in an MPI context as long as an MPI executable is eventually launched. For example, it is common to `mpirun` a debugger (or a script that launches a debugger on some nodes, and directly runs the application on other nodes) since the debugger will eventually launch the MPI process.

However, one must be careful when running programs on remote nodes that expect the use of `stdin` – `stdin` on remote nodes is redirected to `/dev/null`. For example, it is advantageous to export the `DISPLAY` environment variable, and run a shell script that invokes an `xterm` with “gdb” (for example) running in it on each node. For example:

```
shell$ mpirun C -x DISPLAY xterm-gdb.csh
```

Additionally, it may be desirable to only run the debugger on certain ranks in `MPI_COMM_WORLD`. For example, with parallel jobs that include tens or hundreds of MPI processes, it is really only feasible to attach debuggers to a small number of processes. In this case, a script may be helpful to launch debuggers for some ranks in `MPI_COMM_WORLD` and directly launch the application in others.

The LAM environment variable `LAMRANK` can be helpful in this situation. This variable is placed in the environment before the target application is executed. Hence, it is visible to shell scripts as well as the target MPI application. It is erroneous to alter the value of this variable.

Consider the following script:

```
#!/bin/csh -f

# Which debugger to run
set debugger=gdb

# On MPI_COMM_WORLD rank 0, launch the process in the debugger.
# Elsewhere, just launch the process directly.
if (“$LAMRANK” == “0”) then
```

```

echo Launching $debugger on MPI_COMM_WORLD rank $LAMRANK
$debugger $*
else
echo Launching MPI executable on MPI_COMM_WORLD rank $LAMRANK
$*
endif

# All done
exit 0

```

This script can be executed via `mpirun` to launch a debugger on `MPI_COMM_WORLD` rank 0, and directly launch the MPI process in all other cases.

10.3.2 Attaching Debuggers

In some cases, it is not possible or desirable to start debugging a parallel application immediately. For example, it may only be desirable to attach to certain MPI processes whose identity may not be known until run-time.

In this case, the technique of attaching to a running process can be used (this functionality is supported by many serial debuggers). Specifically, determine which MPI process you want to attach to. Then login to the node where it is running, and use the debugger’s “attach” functionality to latch on to the running process.

10.4 Memory-Checking Debuggers

Memory-checking debuggers are an invaluable tool when debugging software (even parallel software). They can provide detailed reports about memory leaks, bad memory accesses, duplicate/bad memory management calls, etc. Some memory-checking debuggers include (but are not limited to): the Solaris Forte debugger (including the `bcheck` command-line memory checker), the Purify software package, and the Valgrind software package.

LAM can be used with memory-checking debuggers. However, LAM should be compiled with special support for such debuggers. This is because in an attempt to optimize performance, there are many structures used internally to LAM that do not always have all memory positions initialized. For example, LAM’s internal `struct nmsg` is one of the underlying message constructs used to pass data between LAM processes. But since the `struct nmsg` is used in so many places, it is a generalized structure and contains fields that are not used in every situation.

By default, LAM only initializes relevant struct members before using a structure. Using a structure may involve sending the entire structure (including uninitialized members) to a remote host. This is not a problem for LAM the remote host will also ignore the irrelevant struct members (depending on the specific function being invoked). More to the point – LAM was designed this way to avoid setting variables that will not be used; this is a slight optimization in run-time performance. Memory-checking debuggers, however, will flag this behavior with “read from uninitialized” warnings.

The `--with-purify` option can be used with LAM’s `configure` script that will force LAM to zero out *all* memory before it is used. This will eliminate the “read from uninitialized” types of warnings that memory-checking debuggers will identify deep inside LAM. This option can only be specified when LAM is configured; it is not possible to enable or disable this behavior at run-time. Since this option invokes a slight overhead penalty in the run-time performance of LAM, it is not the default.

Chapter 11

Troubleshooting

Although LAM is a robust run-time environment, and its MPI layer is a mature software system, errors do occur. Particularly when using LAM/MPI for the first time, some of the initial, per-user setup can be confusing (e.g., setting up `.rhosts` or SSH keys for password-less remote logins). This section aims to identify a few common problems and solutions.

Much more information can be found on the LAM FAQ on the main LAM web site.¹

11.1 The LAM/MPI Mailing Lists

There are two mailing lists: one for LAM/MPI announcements, and another for questions and user discussion of LAM/MPI.

11.1.1 Announcements

This is a low-volume list that is used to announce new version of LAM/MPI, important patches, etc. To subscribe to the LAM announcement list, visit its list information page (you can also use that page to unsubscribe or change your subscription options):

<http://www.lam-mpi.org/mailman/listinfo.cgi/lam-announce>

11.1.2 General Discussion / User Questions

This list is used for general questions and discussion of LAM/MPI. User can post questions, comments, etc. to this list. Due to problems with spam, only subscribers are allowed to post to the list. To subscribe or unsubscribe from the list, visit the list information page:

<http://www.lam-mpi.org/mailman/listinfo.cgi/lam>

After you have subscribed (and received a confirmation e-mail), you can send mail to the list at the following address:

lam@lam-mpi.org

Be sure to include the following information in your e-mail:

¹<http://www.lam-mpi.org/faq/>

- The `config.log` file from the top-level LAM directory, if available (**please compress!**).
- The output of the `laminfo` command.
- A *detailed* description of what is failing. The more details that you provide, the better. E-mails saying “My application doesn’t work!” will inevitably be answered with requests for more information about *exactly what doesn’t work*; so please include as much detailed information in your initial e-mail as possible.

NOTE: People tend to only reply to the list; if you subscribe, post, and then unsubscribe from the list, you will likely miss replies.

Also please be aware that lam@lam-mpi.org is a list that goes to several hundred people around the world – it is not uncommon to move a high-volume exchange off the list, and only post the final resolution of the problem/bug fix to the list. This prevents exchanges like “Did you try X?”, “Yes, I tried X, and it did not work.”, “Did you try Y?”, etc. from cluttering up peoples’ inboxes.

11.2 LAM Run-Time Environment Problems

Some common problems with the LAM run-time environment are listed below.

11.2.1 Problems with the `lamboot` Command

Many first-time LAM users do not have their environment properly configured for LAM to boot properly. Refer to Section 4.4.2 for the list of conditions that LAM requires to boot properly. User problems with `lamboot` typically fall into one of the following categories:

- `rsh/ssh` is not setup properly for password-less logins to remote nodes.
Solution: Set up `rsh/ssh` properly for password-less remote logins. Consult local documentation or internet tutorials for how to setup `$HOME/.rhosts` and SSH keys. Note that the LAM Team **STRONGLY** discourages the use of `+ in .rhosts` or `host.equiv` files!
- `rsh/ssh` prints something on `stderr`.
Solution: Clean up system or user “dot” files so that nothing is printed on `stderr` during a remote login.
- A LAM daemon is unable to open a connection back to `lamboot`.
Solution: Many Linux distributions ship with firewalls enabled. LAM/MPI uses random TCP ports to communicate, and therefore firewall support must be either disabled or opened between machines that will be using LAM/MPI.
- LAM is unable to open a session directory.
Solution: LAM needs to use a per-user, per-session temporary directory, typically located under `/tmp` (see Section 12.8, page 94). LAM must be able to read/write in this session directory; check permissions in this tree.
- LAM is unable to find the current host in the boot schema.
Solution: LAM can only boot a universe that includes the current node. If the current node is not listed in the hostfile, or is not listed by a name that can be resolved and identified as the current node, `lamboot` (and friends) will abort.

- LAM is unable to resolve all names in the boot schema.

Solution: All names in the boot schema must be resolvable by the boot SSI module that is being used. This typically means that there end up being IP hostnames that must be resolved to IP addresses. Resolution can occur by any valid OS mechanism (e.g., through DNS, local file lookup, etc.). Note that the name “localhost” (or any address that resolves to 127.0.0.1) cannot be used in a boot schema that includes more than one host – otherwise the other nodes in the resulting LAM universe will not be able to contact that host.

11.3 MPI Problems

For the most part, LAM implements the MPI standard similarly to other MPI implementations. Hence, most MPI programmers are not too surprised by how LAM handles various errors, etc. However, there are some cases that LAM handles in its own unique fashion. In these cases LAM tries to display a helpful message discussing what happened.

Here’s some more background on a few of the messages:

- “One of the processes started by mpirun has exited with a nonzero exit code.”

This means that at least one MPI process has exited after invoking `MPI_INIT`, but before invoking `MPI_FINALIZE`. This is therefore an error, and LAM will abort the entire MPI application. The last line of the error message indicates the PID, node, and exit status of the failed process.

- “MPI.<function>: process in local group is dead (rank <N>, MPI_COMM_WORLD)”

This means that some MPI function tried to communicate with a peer MPI process and discovered that the peer process is dead. Common causes of this problem include attempting to communicate with processes that have failed (which, in some cases, won’t generate the “One of the processes started by mpirun has exited...” messages), or have already invoked `MPI_FINALIZE`. Communication should not be initiated that could involve processes that have already invoked `MPI_FINALIZE`. This may include using `MPI_ANY_SOURCE` or collectives on communicators that include processes that have already finalized.

Chapter 12

Miscellaneous

This chapter covers a variety of topics that don't conveniently fit into other chapters.

12.1 Singleton MPI Processes

It is possible to run an MPI process without the `mpirun` or `mpiexec` commands – simply run the program as one would normally launch a serial program:

```
shell$ my_mpi_program
```

Doing so will create an `MPI_COMM_WORLD` with a single process. This process can either run by itself, or spawn or connect to other MPI processes and become part of a larger MPI jobs using the MPI-2 dynamic function calls. A LAM RTE must be running on the local node, as with jobs started with `mpirun`.

12.2 MPI-2 I/O Support

MPI-2 I/O support is provided through the ROMIO package [16, 17]. Since support is provided through a third party package, its integration with LAM/MPI is not “complete.” Specifically, everywhere the MPI-2 standard specifies an argument of type `MPI_Request`, ROMIO's provided functions expect an argument of type `MPIO_Request`.

ROMIO includes its own documentation and listings of known issues and limitations. See the `README` file in the ROMIO directory in the LAM distribution.

12.3 Fortran Process Names

Since Fortran does not portably provide the executable name of the process (similar to the way that C programs get an array of `argv`), the `mpitask` command lists the name “LAM MPI Fortran program” by default for MPI programs that used the Fortran binding for `MPI_INIT` or `MPI_INIT_THREAD`.

The environment variable `LAM_MPI_PROCESS_NAME` can be used to override this behavior. Setting this environment variable before invoking `mpirun` will cause `mpitask` to list that name instead of the default title. This environment variable only works for processes that invoke the Fortran binding for `MPI_INIT` or `MPI_INIT_THREAD`.

12.4 MPI Thread Support

LAM currently implements support for `MPI_THREAD_SINGLE`, `MPI_THREAD_FUNNELED`, and `MPI_THREAD_SERIALIZED`. The constant `MPI_THREAD_MULTIPLE` is provided, although LAM will never return `MPI_THREAD_MULTIPLE` in the `provided` argument to `MPI_INIT_THREAD`.

LAM makes no distinction between `MPI_THREAD_SINGLE` and `MPI_THREAD_FUNNELED`. When `MPI_THREAD_SERIALIZED` is used, a global lock is used to ensure that only one thread is inside any MPI function at any time.

12.4.1 Thread Level

Selecting the thread level for an MPI job is best described in terms of the two parameters passed to `MPI_INIT_THREAD`: `requested` and `provided`. `requested` is the thread level that the user application requests, while `provided` is the thread level that LAM will run the application with.

- If `MPI_INIT` is used to initialize the job, `requested` will implicitly be `MPI_THREAD_SINGLE`. However, if the `LAM_MPI_THREAD_LEVEL` environment variable is set to one of the values in Table 12.1, the corresponding thread level will be used for `requested`.
- If `MPI_INIT_THREAD` is used to initialize the job, the `requested` thread level is the first thread level that the job will attempt to use. There is currently no way to specify lower or upper bounds to the thread level that LAM will use.

The resulting thread level is largely determined by the SSI modules that will be used in an MPI job; each module must be able to support the target thread level. A complex algorithm is used to attempt to find a thread level that is acceptable to all SSI modules. Generally, the algorithm starts at `requested` and works backwards towards `MPI_THREAD_SINGLE` looking for an acceptable level. However, any module may *increase* the thread level under test if it requires it. At the end of this process, if an acceptable thread level is not found, the MPI job will abort.

Value	Meaning
undefined	<code>MPI_THREAD_SINGLE</code>
0	<code>MPI_THREAD_SINGLE</code>
1	<code>MPI_THREAD_FUNNELED</code>
2	<code>MPI_THREAD_SERIALIZED</code>
3	<code>MPI_THREAD_MULTIPLE</code>

Table 12.1: Valid values for the `LAM_MPI_THREAD_LEVEL` environment variable.

Also note that certain SSI modules require higher thread support levels than others. For example, any checkpoint/restart SSI module will require a minimum of `MPI_THREAD_SERIALIZED`, and will attempt to adjust the thread level upwards as necessary (if that CR module will be used during the job).

Hence, using `MPI_INIT` to initialize an MPI job does not imply that the provided thread level will be `MPI_THREAD_SINGLE`.

12.5 MPI-2 Name Publishing

LAM supports the MPI-2 functions `MPI_PUBLISH_NAME` and `MPI_UNPUBLISH_NAME` for publishing and unpublishing names, respectively. Published names are stored within the LAM daemons, and are

therefore persistent, even when the MPI process that published them dies.

As such, it is important for correct MPI programs to unpublish their names before they terminate. However, if stale names are left in the LAM universe when an MPI process terminates, the `lamclean` command can be used to clean *all* names from the LAM RTE.

12.6 Interoperable MPI (IMPI) Support

The IMPI extensions are still considered experimental, and are disabled by default in LAM. They must be enabled when LAM is configured and built (see the Installation Guide file for details).

12.6.1 Purpose of IMPI

The Interoperable Message Passing Interface (IMPI) is a standardized protocol that enables different MPI implementations to communicate with each other. This allows users to run jobs that utilize different hardware, but still use the vendor-tuned MPI implementation on each machine. This would be helpful in situations where the job is too large to fit in one system, or when different portions of code are better suited for different MPI implementations.

IMPI defines only the protocols necessary between MPI implementations; vendors may still use their own high-performance protocols within their own implementations.

Terms that are used throughout the LAM / IMPI documentation include: IMPI clients, IMPI hosts, IMPI processes, and the IMPI server. See the IMPI section of the the LAM FAQ for definitions of these terms on the LAM web site.¹

For more information about IMPI and the IMPI Standard, see the main IMPI web site.²

Note that the IMPI standard only applies to MPI-1 functionality. Using non-local MPI-2 functions on communicators with ranks that live on another MPI implementation will result in undefined behavior (read: kaboom). For example, `MPI_COMM_SPAWN` will certainly fail, but `MPI_COMM_SET_NAME` works fine (because it is a local action).

12.6.2 Current IMPI functionality

LAM currently implements a subset of the IMPI functionality:

- Startup and shutdown
- All MPI-1 point-to-point functionality
- Some of the data-passing collectives: `MPI_ALLREDUCE`, `MPI_BARRIER`, `MPI_BCAST`, `MPI_REDUCE`

LAM does not implement the following on communicators with ranks that reside on another MPI implementation:

- `MPI_PROBE` and `MPI_IPROBE`
- `MPI_CANCEL`
- All data-passing collectives that are not listed above
- All communicator constructor/destructor collectives (e.g., `MPI_COMM_SPLIT`, etc.)

¹<http://www.lam-mpi.org/faq/>

²<http://impi.nist.gov/>

12.6.3 Running an IMPI Job

Running an IMPI job requires the use of an IMPI server. An open source, freely-available server is available.³

As described in the IMPI standard, the first step is to launch the IMPI server with the number of expected clients. The open source server from above requires at least one authentication mechanism to be specified (“none” or “key”). For simplicity, these instructions assume that the “none” mechanism will be used. Only one IMPI server needs to be launched per IMPI job, regardless of how many clients will connect. For this example, assume that there will be 2 IMPI clients; client 0 will be run in LAM/MPI, and client 1 will be run elsewhere.

```
shell$ export IMPI_AUTH_NONE=
shell$ impi_server -server 2 -auth 0
10.0.0.32:9283
```

The IMPI server must be left running for the duration of the IMPI job. The string that the IMPI server gives as output (“10.0.0.32:9283”, in this case) must be given to `mpirun` when starting the LAM process that will run in IMPI:

```
shell$ mpirun -client 0 10.0.0.32:9283 C my_mpi_program
```

This will run the MPI program in the local LAM universe and connect it to the IMPI server. From there, the IMPI protocols will take over and join this program to all other IMPI clients.

Note that LAM will launch an auxiliary “helper” MPI program named `impid` that will last for the duration of the IMPI job. It acts as a proxy to the other IMPI processes, and should not be manually killed. It will die on its own accord when the IMPI job is complete. If something goes wrong, it can be killed with the `lamclean` command, just like any other MPI process.

12.7 Batch Queueing System Support

LAM is now aware of some batch queueing systems. Support is currently included for PBS, LSF, and Clubmask-based systems. There is also a generic functionality that allows users of other batch queue systems to take advantages of this functionality.

- When running under a supported batch queue system, LAM will take precautions to isolate itself from other instances of LAM in concurrent batch jobs. That is, the multiple LAM instances from the same user can exist on the same machine when executing in batch. This allows a user to submit as many LAM jobs as necessary, and even if they end up running on the same nodes, a `lamclean` in one job will not kill MPI applications in another job.
- This behavior is *only* exhibited under a batch environment. Other batch systems can easily be supported – let the LAM Team know if you’d like to see support for others included. Manually setting the environment variable `LAM_MPI_SESSION_SUFFIX` on the node where `lamboot` is run achieves the same ends.

12.8 Location of LAM’s Session Directory

By default, LAM will create a temporary per-user session directory in the following directory:

³<http://www.osl.iu.edu/research/impi/>

`<tmpdir>/lam-<username>@<hostname>[-<session_suffix>]`

Each of the components is described below:

<tmpdir> : LAM will set the prefix used for the session directory based on the following search order:

1. The value of the `LAM_MPI_SESSION_PREFIX` environment variable
2. The value of the `TMPDIR` environment variable
3. `/tmp/`

It is important to note that (unlike `LAM_MPI_SESSION_SUFFIX`), the environment variables for determining `<tmpdir>` must be set on each node (although they do not necessarily have to be the same value). `<tmpdir>` must exist before `lamboot` is run, or `lamboot` will fail.

<username> : The user's name on that host.

<hostname> : The hostname.

<session_suffix> : LAM will set the suffix (if any) used for the session directory based on the following search order:

1. The value of the `LAM_MPI_SESSION_SUFFIX` environment variable.
2. If running under a supported batch system, a unique session ID (based on information from the batch system) will be used.

`LAM_MPI_SESSION_SUFFIX` and the batch information only need to be available on the node from which `lamboot` is run. `lamboot` will propagate the information to the other nodes.

12.9 Signal Catching

LAM MPI now catches the signals `SEGV`, `BUS`, `FPE`, and `ILL`. The signal handler terminates the application. This is useful in batch jobs to help ensure that `mpirun` returns if an application process dies. To disable the catching of signals use the `-nsigs` option to `mpirun`.

Bibliography

- [1] Jason Duell, Paul Hargrove, and Eric Roman. The Design and Implementation of Berkeley Lab's Linux Checkpoint/Restart, 2002.
- [2] Al Geist, William Gropp, Steve Huss-Lederman, Andrew Lumsdaine, Ewing Lusk, William Saphir, Tony Skjellum, and Marc Snir. MPI-2: Extending the Message-Passing Interface. In Luc Bouge, Pierre Fraigniaud, Anne Mignotte, and Yves Robert, editors, *Euro-Par '96 Parallel Processing*, number 1123 in Lecture Notes in Computer Science, pages 128–135. Springer Verlag, 1996.
- [3] William Gropp, Steven Huss-Lederman, Andrew Lumsdaine, Ewing Lusk, Bill Nitzberg, William Saphir, and Marc Snir. *MPI — The Complete Reference: Volume 2, the MPI-2 Extensions*. MIT Press, 1998.
- [4] William Gropp, Ewing Lusk, and Anthony Skjellum. *Using MPI: Portable Parallel Programming with the Message Passing Interface*. MIT Press, 1994.
- [5] William Gropp, Ewing Lusk, and Rajeev Thakur. *Using MPI-2: Advanced Features of the Message Passing Interface*. MIT Press, 1999.
- [6] Thilo Kielmann, Henri E. Bal, and Sergei Gorlatch. Bandwidth-efficient Collective Communication for Clustered Wide Area Systems. In *International Parallel and Distributed Processing Symposium (IPDPS 2000)*, pages 492–499, Cancun, Mexico, May 2000. IEEE.
- [7] Message Passing Interface Forum. MPI: A Message Passing Interface. In *Proc. of Supercomputing '93*, pages 878–883. IEEE Computer Society Press, November 1993.
- [8] Sriram Sankaran, Jeffrey M. Squyres, Brian Barrett, and Andrew Lumsdaine. Checkpoint-restart support system services interface (SSI) modules for LAM/MPI. Technical Report TR578, Indiana University, Computer Science Department, 2003.
- [9] Marc Snir, Steve W. Otto, Steve Huss-Lederman, David W. Walker, and Jack Dongarra. *MPI: The Complete Reference*. MIT Press, Cambridge, MA, 1996.
- [10] Jeffrey M. Squyres, Brian Barrett, and Andrew Lumsdaine. Boot system services interface (SSI) modules for LAM/MPI. Technical Report TR576, Indiana University, Computer Science Department, 2003.
- [11] Jeffrey M. Squyres, Brian Barrett, and Andrew Lumsdaine. MPI collective operations system services interface (SSI) modules for LAM/MPI. Technical Report TR577, Indiana University, Computer Science Department, 2003.

- [12] Jeffrey M. Squyres, Brian Barrett, and Andrew Lumsdaine. Request progression interface (RPI) system services interface (SSI) modules for LAM/MPI. Technical Report TR579, Indiana University, Computer Science Department, 2003.
- [13] Jeffrey M. Squyres, Brian Barrett, and Andrew Lumsdaine. The system services interface (SSI) to LAM/MPI. Technical Report TR575, Indiana University, Computer Science Department, 2003.
- [14] The LAM/MPI Team. *LAM/MPI Installation Guide*. Open Systems Laborator, Pervasive Technology Labs, Indiana University, Bloomington, IN, 7.0 edition, May 2003.
- [15] The LAM/MPI Team. *LAM/MPI User's Guide*. Open Systems Laborator, Pervasive Technology Labs, Indiana University, Bloomington, IN, 7.0 edition, May 2003.
- [16] Rajeev Thakur, William Gropp, and Ewing Lusk. Data sieving and collective I/O in ROMIO. In *Proceedings of the 7th Symposium on the Frontiers of Massively Parallel Computation*, pages 182–189. IEEE Computer Society Press, February 1999.
- [17] Rajeev Thakur, William Gropp, and Ewing Lusk. On implementing MPI-IO portably and with high performance. In *Proceedings of the 6th Workshop on I/O in Parallel and Distributed Systems*, pages 23–32. ACM Press, May 1999.

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