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User's Guide for `mpich`, a Portable Implementation of MPI Version 1.2.0

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Contents

This *User's Guide* corresponds to Version 1.2.0 of `mpich`. It was processed by LaTeX on December 2, 1999.

Abstract

MPI (Message-Passing Interface) is a standard specification for message-passing libraries. mpich is a portable implementation of the full MPI specification for a wide variety of parallel and distributed computing environments. This paper describes how to build and run MPI programs using the mpich implementation of MPI.

Version 1.2.0 of mpich is primarily a bug fix and increased portability release, particularly for LINUX-based clusters. Features that are new in 1.2.0 are:

- Full MPI 1.2 compliance, *including* cancel of sends
- IMPI (Interoperable MPI [2]) style flow control.
- A Windows NT version is now available as open source. The installation and use for this version is different; this manual covers only the Unix version of mpich.
- Support for SMP-clusters in mpirun.
- A Fortran 90 MPI module (actually two, see Section 2.1.1).
- Support for MPI_INIT_THREAD (but only for MPI_THREAD_SINGLE)
- Support for VPATH-style installations, along with a installation process and choice of directory names that is closer to the GNU-recommended approach
- A new, scalable log file format, SLOG, for use with the MPE logging tools. SLOG files can be read by a new version of Jumpshot which is included with this release.
- Update ROMIO
- A new device for networked clusters, similar to the p4 device but based on daemons and thus supporting a number of new convenience features, including fast startup. See Section 3.2 for details.

Features that were new in 1.1.1 are:

- The ROMIO subsystem implements a large part of the MPI-2 standard for parallel I/O. For details on what types of file systems runs on and current limitations, see the Romio documentation in romio/doc.
- The MPI-2 standard C++ bindings are available for the MPI-1 functions.
- A new device, Globus, is available. See Section 3.3.
- A new program visualization program, called Jumpshot, is available as an alternative to the upshot and nupshot programs.

1 Introduction

`Mpich` is a freely available implementation of the MPI standard that runs on a wide variety of systems. The details of the `mpich` implementation are described in [8]; related papers include [6] and [7]. This document assumes that `mpich` has already been installed; if not, you should first read *Installation Guide to* `mpich`*, a Portable Implementation of MPI* [5]. For concreteness, this document assumes that the `mpich` implementation is installed into '`/usr/local/mpich`' and that you have added '`/usr/local/mpich/bin`' to your path. If `mpich` is installed somewhere else, you should make the appropriate changes. If `mpich` has been built for several different architectures and/or communiation mechanisms (called *devices* in `mpich`), you must choose the directories appropriately; check with whoever installed `mpich` at your site.

2 Linking and running programs

`mpich` provides tools that simplify creating MPI executables. Because `mpich` programs may require special libraries and compile options, you should use the commands that `mpich` provides for compiling and linking programs.

2.1 Scripts to Compile and Link Applications

The `mpich` implementation provides four commands for compiling and linking C (`mpicc`), Fortran 77 (`mpif77`), C++ (`mpiCC`), and Fortran 90 (`mpif90`) programs.

You may use these commands *instead of* the '`Makefile.in`' versions, particularly for programs contained in a small number of files. In addition, they have a simple interface to the profiling and visualization libraries described in [14]. In addition, the following special options are supported:

-mpilog Build version that generates MPE log files.

-mpitrace Build version that generates traces.

-mpianim Build version that generates real-time animation.

-show Show the commands that would be used without actually running them.

Use these commands just like the usual C, Fortran 77, C++, or Fortran compilers. For example,

```
mpicc -c foo.c
mpif77 -c foo.f
mpiCC -c foo.C
mpif90 -c foo.f
```

and

```
mpicc -o foo foo.o
mpif77 -o foo foo.o
mpiCC -o foo foo.o
mpif90 -o foo foo.o
```

Commands for the linker may include additional libraries. For example, to use routines from the C math library library, use

```
mpicc -o foo foo.o -lm
```

Combining compilation and linking in a single command, as shown here,

```
mpicc -o foo foo.c
mpif77 -o foo foo.f
mpiCC -o foo foo.C
mpif90 -o foo foo.f
```

may also be used.

Note that while the suffixes `.c` for C programs and `.f` for Fortran-77 programs are standard, there is no consensus for the suffixes for C++ and Fortran-90 programs. The ones shown here are accepted by many but not all systems.

2.1.1 Fortran 90 and the MPI module

When `mpich` was configured, the installation process normally looks for a Fortran 90 compiler, and if it finds one, builds two different versions of an MPI module. One moudle includes only the MPI routines that do not take "choice" arguments; the other includes all MPI routines. A choice argument is an argument that can take any datatype; typically, these are the buffers in MPI communication routines such as `MPI_Send` and `MPI_Recv`. The two different modules can be accessed with the `-nochoice` and `-choice` option to `mpif90` respectively. The choice version of the module supports a limited set of datatypes (numeric scalars and numeric one- and two-dimensional arrays). This is an experimental feature; please send mail to `mpi-bugs@mcs.anl.gov` if you have any trouble. Neither of these modules offer full "extended Fortran support" as defined in the MPI-2 standard.

2.2 Compiling and Linking without the Scripts

In some cases, it is not possible to use the scripts supplied by `mpich` for compiling and linking programs. For example, another tool may have its own compilation scripts. In this case, you can use `-compile_info` and `-link_info` to have the `mpich` compilation scripts indicate the compiler flags and linking libraries that are required for correct operation of the `mpich` routines. For example, when using the `ch_shmem` device on Solaris systems, the library `thread` (`-lthread`) must be linked with the application. If the `thread` library is not provided, the application will still link, but essential routines will be replaced with dummy versions contained within the Solaris C library, causing the application to fail.

2.3 Running with mpirun

To run an MPI program, use the `mpirun` command, which is located in '`/usr/local/mpich/bin`' . For almost all systems, you can use the command

```
mpirun -np 4 a.out
```

to run the program '`a.out`' on four processors. The command `mpirun -help` gives you a complete list of options, which may also be found in Appendix B.

On exit, `mpirun` returns a status of zero unless `mpirun` detected a problem, in which case it returns a non-zero status (currently, all are one, but this may change in the future).

2.3.1 SMP Clusters

When using a cluster of symmetrix multiprocessors (SMPs) with the `ch_p4` device (configured with `-comm=shared`, you can control the number of processes that communicate with shared memory on each SMP node. First, you need to modify the machines file (see Section 3.1) to indicate the number of processes that should be started on each host. Normally this number should be no greater than the number of processors; on SMPs with large numbers of processors, the number should be one less than the number of processors in order to leave one processor for the operating system. The format is simple: each line of the machines file specifies a hostname, optionally followed by a colon (`:`) and the number of processes to allow. For example, the file containing the lines

```
mercury
venus
earth
mars:2
jupiter:15
```

specifies three single process machines (`mercury`, `venus`, and `earth`), a 2 process machine (`mars`), and a 15 process machine (`jupiter`).

By default, `mpirun` will only use on process on each machine (more precisely, it will not use shared memory to communicate between processes). By setting the environment variable `MPI_MAX_CLUSTER_SIZE` to a positive integer value, `mpirun` will use upto that many processes, sharing memory for communication, on a host. For example, if `MPI_MAX_CLUSTER_SIZE` had the value 4, then `mpirun -np 9` with the above machine file create one process on each of `mercury`, `venus`, and `earth`, 2 on `mars` (2 because the machines file specifies that `mars` may have 2 processes sharing memory) and 4 on `jupiter` (because `jupiter` may have 15 processes and only 4 more are needed). If 10 processes were needed, `mpirun` would start over from the beginning of the machines file, creating an additional process on `mercury`; the value of `MPI_MAX_CLUSTER_SIZE` prevents `mpirun` from starting a fifth process sharing memory on `jupiter`.

2.3.2 Multiple Architectures

When using the p4 device in workstation clusters, multiple architectures may be handled by giving multiple `-arch` and `-np` arguments. For example, to run a program on 2 sun4s and 3 rs6000s, with the local machine being a sun4, use

```
mpirun -arch sun4 -np 2 -arch rs6000 -np 3 program
```

This assumes that program will run on both architectures. If different executables are needed, the string '%a' will be replaced with the arch name. For example, if the programs are `program.sun4` and `program.rs6000`, then the command is

```
mpirun -arch sun4 -np 2 -arch rs6000 -np 3 program.%a
```

If instead the execuables are in different directories; for example, '`/tmp/me/sun4`' and '`/tmp/me/rs6000`', then the command is

```
mpirun -arch sun4 -np 2 -arch rs6000 -np 3 /tmp/me/%a/program
```

It is important to specify the architecture with `-arch` *before* specifying the number of processors. Also, the *first* `arch` command must refer to the processor on which the job will be started. Specifically, if `-nolocal` is not specified, then the first `-arch` must refer to the processor from which mpirun is running.

When running on multiple machines using the globus device, `mpirun` is also used, but different techniques are used to control how executables are selected. See Section 3.3 for details.

2.4 More detailed control

For more control over the process of compiling and linking programs for `mpich`, you should use a '`Makefile`'. Rather than modify your '`Makefile`' for each system, you can use a makefile template and use the command '`mpireconfig`' to convert the makefile template into a valid '`Makefile`'. To do this, start with the file '`Makefile.in`' in '`/usr/local/mpich/examples`'. Modify this '`Makefile.in`' for your program and then enter

```
mpireconfig Makefile
```

(not `mpireconfig Makefile.in`). This creates a '`Makefile`' from '`Makefile.in`'. Then enter:

```
make
```

3 Special features of different systems

MPI makes it relatively easy to write portable parallel programs. However, one thing that MPI does not standardize is the environment within which the parallel program is running. There are three basic types of parallel environments: parallel computers, clusters of workstations, and integrated distributed environments, which we will call "computational grids", that include parallel computers and workstations, and that may span multiple sites. Naturally, a parallel computer (usually) provides an integrated, relatively easy way of running parallel programs. Clusters of workstations and grid environments, on the other hand, usually have no standard way of running a parallel program and will require some additional setup. The `mpich` implementation is designed to hide these differences behind the `mpirun` script; however, if you need special features or options or if you are having problems running your programs, you will need to understand the differences between these systems. In the following, we describe the special features that apply for workstation clusters, grids (as supported by the globus device), and certain parallel computers.

3.1 Workstation clusters

Most massively parallel processors (MPPs) provide a way to start a program on a requested number of processors; `mpirun` makes use of the appropriate command whenever possible. In contrast, workstation clusters require that each process in a parallel job be started individually, though programs to help start these processes exist (see 3.1.3 below). Because workstation clusters are not already organized as an MPP, additional information is required to make use of them. `mpich` should be installed with a list of participating workstations in the file '`machines.<arch>`' in the directory '`/usr/local/mpich/share`'. This file is used by `mpirun` to choose processors to run on. (Using heterogeneous clusters is discussed below.) The rest of this section discusses some of the details of this process, and how you can check for problems. These instructions apply to only the `ch_p4` device.

3.1.1 Checking your machines list

Use the script '`tstmachines`' in '`/usr/local/mpich/sbin`' to ensure that you can use all of the machines that you have listed. This script performs an `rsh` and a short directory listing; this tests that you both have access to the node and that a program in the current directory is visible on the remote node. If there are any problems, they will be listed. These problems *must* be fixed before proceeding.

The only argument to `tstmachines` is the name of the architecture; this is the same name as the extension on the machines file. For example,

```
/usr/local/mpich/bin/tstmachines sun4
```

tests that a program in the current directory can be executed by all of the machines in the `sun4` machines list. This program is silent if all is well; if you want to see what it is doing, use the `-v` (for verbose) argument:

```
/usr/local/mpich/bin/tstmachines -v sun4
```

The output from this command might look like

```
Trying true on host1.uoffoo.edu ...
Trying true on host2.uoffoo.edu ...
Trying ls on host1.uoffoo.edu ...
Trying ls on host2.uoffoo.edu ...
Trying user program on host1.uoffoo.edu ...
Trying user program on host2.uoffoo.edu ...
```

If `tstmachines` finds a problem, it will suggest possible reasons and solutions.

3.1.2 Using the Secure Shell

The *Installation Guide* explains how to set up your environment so that the `ch_p4` device on networks will use the secure shell `ssh` instead of `rsh`. This is useful on networks where for security reasons the use of `rsh` is discouraged or disallowed.

3.1.3 Using the Secure Server

Because each workstation in a cluster (usually) requires that a new user log into it, and because this process can be very time-consuming, `mpich` provides a program that may be used to speed this process. This is the *secure server*, and is located in '`serv_p4`' in the directory '`/usr/local/mpich/bin`' [1]. The script '`chp4_servs`' in the same directory may be used to start '`serv_p4`' on those workstations that you can `rsh` programs on. You can also start the server by hand and allow it to run in the background; this is appropriate on machines that do not accept `rsh` connections but on which you have accounts.

Before you start this server, check to see if the secure server has been installed for general use; if so, the same server can be used by everyone. In this mode, root access is required to install the server. If the server has not been installed, then you can install it for your own use without needing any special privileges with

```
chp4_servs -port=1234
```

This starts the secure server on all of the machines listed in the file '`/usr/local/mpich/share/machines.<arch>`'.

The port number, provided with the option `-port=`, must be different from any other port in use on the workstations.

To make use of the secure server for the `ch_p4` device, add the following definitions to your environment:

```
setenv MPI_USEP4SSPORT yes
setenv MPI_P4SSPORT 1234
```

[1] The `globus` device does not use the secure server. It uses a security model implemented using the GSS API. See section 3.3 Security and the `globus` device

The value of MPI_P4SSPORT must be the port with which you started the secure server. When these environment variables are set, mpirun attempts to use the secure server to start programs that use the ch_p4 device. (The command line argument -p4ssport to mpirun may be used instead of these environment variables; mpirun -help will give you more information.)

3.1.4 Heterogeneous networks and the ch_p4 device

A heterogeneous network of workstations is one in which the machines connected by the network have different architectures and/or operating systems. For example, a network may contain 3 Sun SPARC (sun4) workstations and 3 SGI IRIX workstations, all of which communicate via the TCP/IP protocol. The mpirun command may be told to use all of these with

```
mpirun -arch sun4 -np 3 -arch IRIX -np 3 program.%a
```

While the ch_p4 device supports communication between workstations in heterogeneous TCP/IP networks, it does not allow the coupling of multiple multicomputers. To support such a configuration, you should use the globus device. See the following section for details.

The special program name program.%a allows you to specify the different executables for the program, since a Sun executable won't run on an SGI workstation and vice versa. The %a is replaced with the architecture name; in this example, program.sun4 runs on the Suns and program.IRIX runs on the SGI IRIX workstations. You can also put the programs into different directories; for example,

```
mpirun -arch sun4 -np 3 -arch IRIX -np 3 /tmp/%a/program
```

For even more control over how jobs get started, we need to look at how mpirun starts a parallel program on a workstation cluster. Each time mpirun runs, it constructs and uses a new file of machine names for just that run, using the machines file as input. (The new file is called PIyyyy, where yyyy is the process identifier.) If you specify -keep_pg on your mpirun invocation, you can use this information to see where mpirun ran your last few jobs. You can construct this file yourself and specify it as an argument to mpirun. To do this for ch_p4, use

```
mpirun -p4pg pgfile myprog
```

where pfile is the name of the file. The file format is defined below.

This is necessary when you want closer control over the hosts you run on, or when mpirun cannot construct it automatically. Such is the case when

- You want to run on a different set of machines than those listed in the machines file.
- You want to run different executables on different hosts (your program is not SPMD).
- You want to run on a heterogeneous network, which requires different executables.

- You want to run all the processes on the same workstation, simulating parallelism by time-sharing one machine.
- You want to run on a network of shared-memory multiprocessors and need to specify the number of processes that will share memory on each machine.

The format of a `ch_p4` procgroup file is a set of lines of the form

```
<hostname>  <#procs>  <progname>  [<login>]
```

An example of such a file, where the command is being issued from host `sun1`, might be

```
sun1   0  /users/jones/myprog
sun2   1  /users/jones/myprog
sun3   1  /users/jones/myprog
hp1    1  /home/mbj/myprog    mbj
```

The above file specifies four processes, one on each of three suns and one on another workstation where the user's account name is different. Note the `0` in the first line. It is there to indicate that no *other* processes are to be started on host `sun1` than the one started by the user by his command.

You might want to run all the processes on your own machine, as a test. You can do this by repeating its name in the file:

```
sun1 0 /users/jones/myprog
sun1 1 /users/jones/myprog
sun1 1 /users/jones/myprog
```

This will run three processes on `sun1`, communicating via sockets.

To run on a shared-memory multiprocessor, with 10 processes, you would use a file like:

```
sgimp  9  /u/me/prog
```

Note that this is for 10 processes, one of them started by the user directly, and the other nine specified in this file. This requires that `mpich` was configured with the option `-comm=shared`; see the installation manual for more information.

If you are logged into host `gyrfalcon` and want to start a job with one process on `gyrfalcon` and three processes on `alaska`, where the `alaska` processes communicate through shared memory, you would use

```
local    0  /home/jbg/main
alaska   3  /afs/u/graphics
```

It is not possible to provide different command line argument to different MPI processes.

3.1.5 Environment Variables used by P4

There are several enviroment variables that can be used to tune the performance of the `ch_p4` device. Note that these environment variables must be defined for all processes that are created, not just the process that you are launching MPI programs from (i.e., setting these variables should be part of your '`.login`' or '`.cshrc`' startup files).

`P4_SOCKBUFSIZE`. Specifies the socket buffer size in bytes. Increasing this value can improve performance on some system. However, under LINUX, particularly LINUX systems with the TCP patches, increasing this can increase the probability the `mpich` will hang.

`P4_WINSHIFT`. This is another socket parameter that is supported on only a few platforms. We recommend leaving it alone.

`P4_GLOBMEMSIZE`. This is the amount of memory in bytes reserved for communication with shared memory (when `mpich` is configured with `-comm=shared`). Increase this if you get error messages about `p4_shmalloc` returning `NULL`.

3.1.6 Using special interconnects

In some installations, certain hosts can be connected in multiple ways. For example, the "normal" Ethernet may be supplemented by a high-speed FDDI ring. Usually, alternate host names are used to identify the high-speed connection. All you need to do is put these alternate names in your `machines.xxxx` file. In this case, it is important not to use the form `local 0` but to use the name of the local host. For example, if hosts `host1` and `host2` have ATM connected to `host1-atm` and `host2-atm` respectively, the correct `ch_p4` procgroup file to connect them (running the program '`/home/me/a.out`') is

```
host1-atm 0 /home/me/a.out
host2-atm 1 /home/me/a.out
```

3.1.7 Using Shared Libraries

Shared libraries can help reduce the size of an executable. This is particularly valuable on clusters of workstations, where the executable must normally be copied over a network to each machine that is to execute the parallel program. However, there are some practical problems in using shared libraries; this section discusses some of them and how to solve most of those problems. Currently, shared libraries are not supported from C++.

In order to build shared libraries for `mpich`, you must have configured and built `mpich` with the `--enable-sharedlib` option. Because each Unix system and in fact each compiler uses a different and often incompatible set of options for creating shared objects and libraries, `mpich` may not be able to determine the correct options. Currently, `mpich` understands Solaris, GNU `gcc` (on most platforms, including LINUX and Solaris), and IRIX. Information on building shared libraries on other platforms should be sent to `mpi-bugs@mcs.anl.gov`.

Once the shared libraries are built, you must tell the mpich compilation and linking commands to use shared libraries (the reason that shared libraries are not the default will become clear below). You can do this either with the command line option -shlib or by setting the environment variable MPICH_USE_SHLIB to yes. For example,

```
mpicc -o cpi -shlib cpi.c
```

or

```
setenv MPICH_USE_SHLIB yes
mpicc -o cpi cpi.c
```

Using the environment variable MPICH_USE_SHLIB allows you to control whether shared libraries are used without changing the compilation commands; this can be very useful for projects that use makefiles.

Running a program built with shared libraries can be tricky. Some (most?) systems *do not remember* where the shared library was found when the executable was linked! Instead, they depend on finding the shared library in either a default location (such as '/lib') or in a directory specified by an environment variable such as LD_LIBRARY_PATH or by a command line argument such as -R or -rpath (more on this below). The mpich configure tests for this and will report whether an executable built with shared libraries remembers the location of the libraries. It also attemps to use a compiler command line argument to force the executable to remember the location of the shared library.

If you need to set an environment variable to indicate where the mpich shared libraries are, you need to ensure that both the process that you run mpirun from and any processes that mpirun starts gets the enviroment variable. The easiest way to do this is to set the environment variable within your '.cshrc' (for csh or tcsh users) or '.profile' (for sh and ksh users) file.

However, setting the environment variable within your startup scripts can cause problems if you use several different systems. For example, you may have a single '.cshrc' file that you use with both an SGI (IRIX) and Solaris system. You do not want to set the LD_LIBRARY_PATH to point the SGI at the Solaris version of the mpich shared libraries[2]. Instead, you would like to set the environment variable before running mpirun:

```
setenv LD_LIBRARY_PATH ${LD_LIBRARY_PATH}:/usr/local/mpich/lib/shared
mpirun -np 4 cpi
```

Unfortunately, this won't always work. Depending on the method that mpirun and mpich use to start the processes, the environment variable may not be sent to the new process. This will cause the program to fail with a message like

```
    ld.so.1: /home/me/cpi: fatal: libpmpich.so.1.0: open failed: No such
    file or directory
Killed
```

[2]You can make '.cshrc' check for the kind of system that you are running on and pick the paths appropriately. This isn't as flexible as the approach of setting the environment variable from the running shell.

To work around this problem, you should use the (new) secure server (Section 3.1.3). This server is built with

```
make serv_p4
```

and can be installed on all machines in the machines file for the current architecture with

```
chp4_servs -port=1234
```

The new secure server propagates *all* environment variables to the remote process, and ensures that the environment in which that process (containing your MPI program) contains all environment variables that start with `LD_` (just in case the system uses `LD_SEARCH_PATH` or some other name for finding shared libraries).

An alternative to using `LD_LIBRARY_PATH` and the secure server is to add an option to the link command that provides the path to use in searching for shared libraries. Unfortunately, the option that you would like is "append this directory to the search path" (such as you get with `-L`). Instead, many compilers provide only "replace the search path with this path."[3] For example, some compilers allow `-Rpath:path:...:path` to specify a replacement path. Thus, if both `mpich` and the user provide library search paths with `-R`, one of the search paths will be lost. Eventually, `mpicc` and friends can check for `-R` options and create a unified version, but they currently do not do this. You can, however, provide a complete search path yourself if your compiler supports an option such as `-R`.

The preceeding may sound like a lot of effort to go to, and in some ways it is. For large clusters, however, the effort will be worth it: programs will start faster and more reliably.

3.2 Fast Startup with the Multipurpose Daemon and the ch_p4mpd Device

3.2.1 Goals

The goal of the multipurpose daemon (`mpd` and the associated `ch_p4mpd` device) is to make `mpirun` behave like a single program even as it starts multiple processes to execute an MPI job. We will refer to the *mpirun* process and the *MPI* processes. Such behavior includes

- fast, scalable startup of MPI (and even non-MPI) processes. For those accustomed to using the `ch_p4` device on TCP networks, this will be the most immediately noticeable change. Job startup is now `much` faster.
- collection of `stdout` and `stderr` from the MPI processes to the `stdout` and `stderr` of the mpirun process.
- delivery of `mpirun`'s `stdin` to the `stdin` of MPI process 0.
- delivery of signals from the mpirun process to the MPI processes. This means that it is easy to kill, suspend, and resume your parallel job just as if it were a single process, with `cntl-C`, `cntl-Z`, and `bg` and `fg` commands

[3] Even though the linker may provide the "append to search path" form.

- delivery of command-line arguments to all MPI processes
- copying of the PATH environment from the environment in which mpirun is executed to the environments in which the MPI processes are executed
- use of an optional argument to provide other environment variables
- use of a further optional argument to specify where the MPI processes will run (see below).

3.2.2 Introduction

The ch_p4 device relies by default on rsh for process startup on remote machines. The need for authentication at job startup time, combined with the sequential process by which contact information is collected from each remote machine and broadcast back to all machines, makes job startup unscalably slow, especially for large numbers of processes.

With Version 1.2.0 of mpich, we introduce a new method of process startup based on daemons. This mechanism, which requires configuration with a new device, has not yet been widely enough tested to become the default for clusters, but we anticipate that it eventually will become so, and therefore release it now in order that users may experiment with it. It has been built and tested on Solaris and Linux environments; others may require some fiddling with the configure script in mpich/mpid/mpd, which is where the source for the daemon code resides. It is not yet possible to install it automatically with make install, but it can be installed by hand or used from the directory where it is built, which is mpich/mpid/mpd.

The basic idea is to establish, ahead of job-startup time, a network of daemons on the machines where MPI processes will run, and also on the machine on which mpirun will be executed. Then job startup commands (and other commands) will contact the local daemon and use the pre-existing daemons to start processes. Much of the initial synchronization done by the ch_p4 device is eliminated, since the daemons can be used at run time to aid in establishing communication between processes.

To use the new startup mechanism, you must

- configure with the new device:

  ```
  configure -device=ch_p4mpd
  ```

- make as usual:

  ```
  make
  ```

- go to the MPICH/mpid/mpd directory, where the daemons code is located and the daemons are built, or else put this directory in your PATH.
- start the daemons:

  The daemons can be started by hand on the remote machines using the port numbers advertised by the daemons as they come up:

– On fire:

```
fire% mpd &
[2] 23792
[fire_55681]: MPD starting
fire%
```

– On soot:

```
soot% mpd -h fire -p 55681 &
[1] 6629
[soot_35836]: MPD starting
soot%
```

The mpd's are identified by a host and port number.

If the daemons do not advertize themselves, one can find the host and port by using the mpdtrace command:

– On fire:

```
fire% mpd &
fire% mpdtrace
mpdtrace: fire_55681:  lhs=fire_55681  rhs=fire_55681  rhs2=fire_55681
fire%
```

– On soot:

```
soot% mpd -h fire -p 55681 &
soot% mpdtrace
mpdtrace: fire_55681:  lhs=soot_33239  rhs=soot_33239  rhs2=fire_55681
mpdtrace: soot_33239:  lhs=fire_55681  rhs=fire_55681  rhs2=soot_33239
soot%
```

What mpidtrace is showing is the ring of mpd's, by hostname and port that can be used to introduce another mpd into the ring. The left and right neighbor of each mpd in the ring is shown as lhs and rhs respectively. rhs2 shows the daemon two steps away to the right (which in this case is the daemon itself).

There is also a pair of scripts in the mpich/mpid/mpd directory that can help:

```
localmpds <number>
```

will start <number> mpds on the local machine. This is only really useful for testing. Usually you would do

```
mpd &
```

to start one mpd on the local machine. Then other mpd's can be started on remote machines via rsh, if that is available:

```
remotempds <hostfile>
```

where <hostfile> contains the names of the other machines to start the mpd's on. It is a simple list of hostnames only, unlike the format of the MACHINES files used by the ch_p4 device, which can contain comments and other symbols.

- Finally, start jobs with the `mpirun` command.
- If you don't start the daemons first, `mpirun` will attempt to start them for you, on the machines listed in the `mpd.hosts` file in the `mpd` directory. This file is initialized at configure time with five copies of the machine you are building on, but you can edit it. Be sure that the `mpich/bin` directory is in your path if you use this method.

You can kill the daemons with the `mpdallexit` command.

3.2.3 Examples

Here are a few examples of usage of the `mpirun` that is built when the MPICH is configured and built with the `ch_p4mpd` device.

- Run the `cpi` example

  ```
  mpirun -np 16 /home/you/mpich/examples/basic/cpi
  ```

  If you put `/home/you/mpich/examples/basic` in your path, with

  ```
  setenv PATH ${PATH}:/home/you/mpich/examples/basic
  ```

  then you can just do

  ```
  mpirun -np 16 cpi
  ```

- Run the `fpi` program, which prompts for a number of intervals to use.

  ```
  mpirun -np 32 fpi
  ```

  The streams `stdin`, `stdout`, and `stderr` will be mapped back to your `mpirun` process, even if the MPI process with rank 0 is executed on a remote machine.

- Use arguments and environment variables.

  ```
  mpirun -np 32 myprog arg1 arg2 -MPDENV- MPE_LOG_FORMAT=SLOG \
              GLOBMEMSIZE=16000000
  ```

  The argumnet `-MPDENV-` is a *fence*. All arguments after it are handled by `mpirun` rather than the application program.

- Specify where the first process is to run. By default, MPI processes are spawned by by consecutive `mpd`'s in the rung, starting with the one *after* the local one (the one running on the same machine as the `mpirun` process. Thus if you are logged into `dion` and there are `mpd`'s running `dion` and on `belmont1`, `belmont2`, ..., `belmont64`, and you type

  ```
  mpirun -np 32 cpi
  ```

your processes will run on `belmont1`, `belmont2`, ..., `belmont32`. ;You can force your MPI processes to start elsewhere by giving `mpirun` its optional starting location arguments. If you type

```
mpirun -np 32 cpi -MPDLOC- belmont33
```

then your job will run on `belmont33`, `belmont34`, ..., `belmont64`.

This provides an extremely preliminary and crude way for `mpirun` to choose locations for MPI processes. In the long run we intend to use the `mpd` project as an environment for exploring the interfaces among job schedules, process managers, parallel application programs (particularly in the dynamic environment of MPI-2), and user commands.

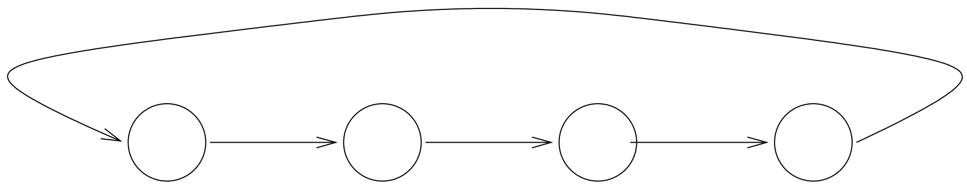
- Find out what hosts your `mpd`'s are running on:

  ```
  mpirun -np 32 hostname | sort | uniq
  ```

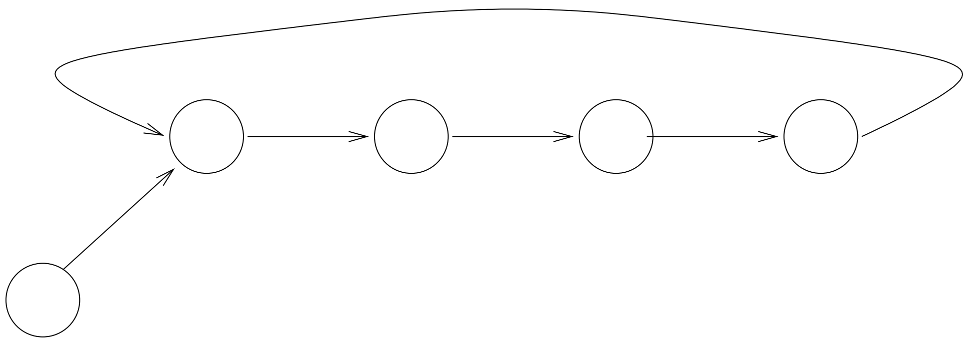
  This will run 32 instances of `hostname` assuming `/bin` is in your path, regardless of how many `mpd`'s there are. The other processes will be wrapped around the ring of `mpd`'s.

3.2.4 How the Daemons Work

Once the daemons are started they are connected in a ring: A "console" process (`mpirun`,



`mpdtrace`, `mpdallexit`, etc.) can connect to any mpd, which it does by using a Unix named socket set up in `/tmp` by the local mpd. If it is an `mpirun` process, it requests that a number



of processes be started, starting at the machine given by `-MPDLOC-` as described above. The location defaults to the mpd `next` in the ring after the one contacted by the console. Then the following events take place.

- The mpd's fork that number of `manager` processes (the executable is called `mpdman` and is located in the `mpich/mpid/mpd` directory). The managers are forked consecutively by the mpd's around the ring, wrapping around if necessary.
- The managers form themselves into a ring, and fork the application processes, called *clients.*
- The console disconnects from the mpd and reconnects to the first manager. `stdin` from `mpirun` is delivered to the client of manager 0.
- The managers intercept standard I/O fro the clients, and deliver command-line arguments and the environment variables that were specified on the `mpirun` command. The sockets carrying `stdout` and `sdterr` form a tree with manager 0 at the root.

At this point the situation looks something like Figure 1. When the clients need to contact

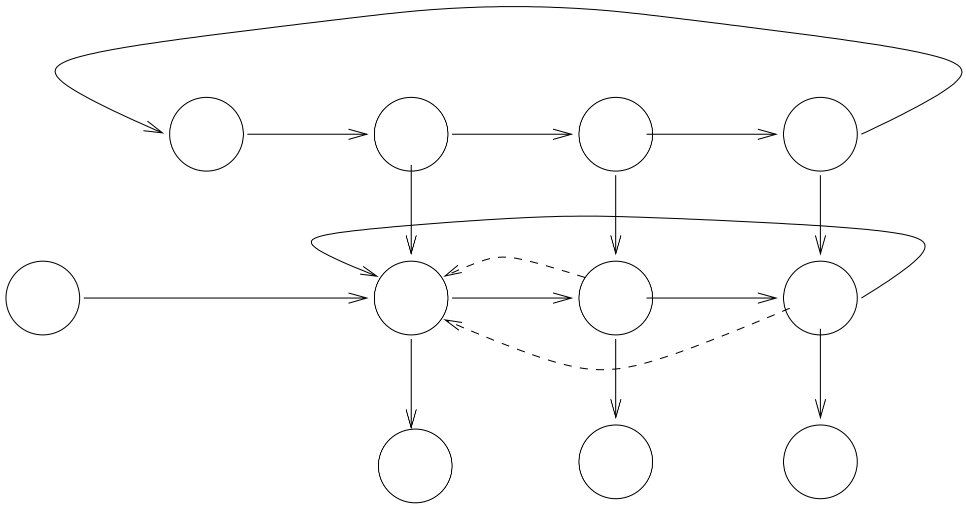


Figure 1: Mpds with console, managers, and clients

each other, they use the managers to find the appropriate `p4 listener`. The `mpirun` process can be suspended, in which case it and the clients are suspended, but the mpd's and managers remain executing, so that they can unsuspend the clients when `mpirun` is unsuspended. Killing the `mpirun` process kills the clients and managers.

The same ring of mpd's can be used to run multiple jobs from multiple consoles at the same time. At this time there still needs to be a separate ring of mpd's for each user.

3.3 Computational Grids: the `globus` device

The globus device (see `http://www.globus.org/mpi`) supports the execution of MPI programs on "computational grids" that may include parallel computers and workstations, and that may span multiple sites. In such grid environments, different sites may support different security mechanisms and different process creation mechanisms. The globus device hides these low-level details from you, allowing you to start programs with `mpirun` as on MPPs and workstation clusters. The globus device also provides other convenient features, such as remote access to files and executable staging. These features are provided by using services supplied by the Globus toolkit: see `http://www.globus.org` for details.

The Globus device requires that special servers be running on the computers where processes are to be created. In our discussion of how to use the globus device, we assume that we are using the globus device on GUSTO, an international network of resources on which the various Globus servers are already installed and running. If possible, we recommend that you use the globus device in this environment. If you wish to use the globus device in other situations, please send email to `developers@globus.org`. Details of how to run MPI programs using the Globus device on the GUSTO environment are in Appendix C.

3.4 MPPs

Each MPP is slightly different, and even systems from the same vendor may have different ways for running jobs at different installations. The `mpirun` program attempts to adapt to this, but you may find that it does not handle your installation. One step that you can take is to use the `-show` or `-t` (for test) option to `mpirun`. This shows how `mpirun` would start your MPI program without actually doing so. Often, you can use this information, along with the instructions for starting programs at your site, to discover how to start the program. Please let us know (`mpi-bugs@mcs.anl.gov`) about any special needs.

3.4.1 IBM SP

Using `mpirun` with the IBM SP computers can be tricky, because there are so many different (and often mutually exclusive) ways of running programs on them. The `mpirun` distributed with `mpich` works on systems using the Argonne scheduler (sometimes called EASY) and with systems using the default resource manager values (i.e., those not requiring the user to choose an `RMPOOL`). If you have trouble running an `mpich` program, try following the rules at your installation for running an MPL or POE program (if using the `ch_mpl` device) or for running p4 (if using the `ch_p4` device).

3.4.2 Intel Paragon

Using `mpirun` with an Intel Paragon can be tricky, because there are so many different (and often mutually exclusive) ways of running programs. The `mpirun` distributed with `mpich` works with Paragons that provide a default compute partition. There are some options, `-paragon...`, for selecting other forms. For example, `-paragonpn compute1` specifies the pre-existing partition named `compute1` to run on.

3.5 Symmetric Multiprocessors (SMPs)

On many of the shared-memory implementations (device `ch_shmem`, `mpich` reserves some shared memory in which messages are transferred back and forth. By default, `mpich` reserves roughly four **CHECK** MBytes of shared memory. You can change this with the environment variable `MPI_GLOBMEMSIZE`. For example, to make it 8 MB, enter

```
setenv MPI_GLOBMEMSIZE 8388608
```

Large messages are transfered in pieces, so `MPI_GLOBMEMSIZE` does not limit the maximum message size but increasing it may improve performance.

By default, MPICH limits the number of processes for the `ch_shmem` device to 32, unless it determines at configure time that the machine has more processors. You can override this limit by setting the environment variable `PROCESSOR_COUNT` to the maximum number of processes that you will want to run, and then reconfigure and remake `mpich`.

4 Sample MPI programs

The `mpich` distribution contains a variety of sample programs, which are located in the `mpich` source tree.

mpich/examples/basic contains a few short programs in Fortran, C, and C++ for testing the simplest features of MPI.

mpich/examples/test contains multiple test directories for the various parts of MPI. Enter "make testing" in this directory to run our suite of function tests.

mpich/examples/test/lederman tests created by Steve Huss-Lederman of SRC. See the README in that directory.

mpich/examples/perftest Performance benchmarking programs. See the script `runmpptest` for information on how to run the benchmarks. These are relatively sophisticated.

mpich/mpe/contrib/mandel A Mandelbrot program that uses the MPE graphics package that comes with mpich. It should work with any other MPI implementation as well, but we have not tested it. This is a good demo program if you have a fast X server and not too many processes.

mpich/mpe/contrib/mastermind A program for solving the Mastermind puzzle in parallel. It can use graphics (`gmm`) or not (`mm`).

Additional examples from the book *Using MPI* [9] are available by anonymous ftp and through the World Wide Web at `ftp://info.mcs.anl.gov/pub/mpi/using/`. At the web site `ftp://info.mcs.anl.gov/pub/mpi` can also be found tutorial material containing other examples.

5 The MPE library of useful extensions

It is anticipated that `mpich` will continue to accumulate extension routines of various kinds. We keep them in a library we call `mpe`, for MultiProcessing Environment.

Currently the main components of the mpe library are

- A set of routines for creating logfiles for examination by upshot, nupshot or Jumpshot.
- A shared-display parallel X graphics library.
- Routines for sequentializing a section of code being executed in parallel.
- Debugger setup routines.

5.1 Creating logfiles

MPE provides several ways to generate logfiles that describe the progress of a computation. These logfiles can be viewed with upshot, nupshot, or Jumpshot. In addition, you can customize these logfiles to add application-specific information.

The easiest way to generate logfiles is to link your program with a special MPE library that uses the profiling feature of MPI to intercept all MPI calls in an application. To find out how to link with a profiling library that produces log files automatically, see Section 5.8.

You can create customized logfiles for viewing with upshot or Jumpshot by calls to the various mpe logging routines. For details, see the mpe man pages. An example is shown in Section 5.4.3.

To be added in later editions of this *User's Guide*:

- All mpe logging routines
- Format of logfiles
- An example logfile

5.2 Parallel X Graphics

MPE provides a set of routines that allows you to display simple graphics with the X Window System. In addition, there are routines for input, such as getting a region defined by using the mouse. A sample of the available graphics routines are shown in Table 1. For arguments, see the man pages.

You can find an example of the use of the mpe graphics library in the directory mpich/mpe/contrib/mandel. Enter

```
make
mpirun -np 4 pmandel
```

to see a parallel Mandelbrot calculation algorithm that exploits several features of the mpe graphics library.

	Control Routines
`MPE_Open_graphics`	(collectively) opens an X display
`MPE_Close_graphics`	Closes a X11 graphics device
`MPE_Update`	Updates an X11 display
	Output Routines
`MPE_Draw_point`	Draws a point on an X display
`MPE_Draw_points`	Draws points on an X display
`MPE_Draw_line`	Draws a line on an X11 display
`MPE_Draw_circle`	Draws a circle
`MPE_Fill_rectangle`	Draws a filled rectangle on an X11 display
`MPE_Draw_logic`	Sets logical operation for new pixels
`MPE_Line_thickness`	Sets thickness of lines
`MPE_Make_color_array`	Makes an array of color indices
`MPE_Num_colors`	Gets the number of available colors
`MPE_Add_RGB_color`	Add a new color
	Input Routines
`MPE_Get_mouse_press`	Get current coordinates of the mouse
`MPE_Get_drag_region`	Get a rectangular region

Table 1: MPE graphics routines.

5.3 Other `mpe` routines

Sometimes during the execution of a parallel program, you need to ensure that only a few (often just one) processor at a time is doing something. The routines `MPE_Seq_begin` and `MPE_Seq_end` allow you to create a "sequential section" in a parallel program.

The MPI standard makes it easy for users to define the routine to be called when an error is detected by MPI. Often, what you'd like to happen is to have the program start a debugger so that you can diagnose the problem immediately. In some environments, the error handler in `MPE_Errors_call_dbx_in_xterm` allows you to do just that. In addition, you can compile the `mpe` library with debugging code included. (See the `-mpedbg` configure option.)

5.4 Profiling libraries

The MPI profiling interface provides a convenient way for you to add performance analysis tools to any MPI implementation. We demonstrate this mechanism in `mpich`, and give you a running start, by supplying three profiling libraries with the `mpich` distribution. MPE users may build and use these libraries with any MPI implementation.

5.4.1 Accumulation of time spent in MPI routines

The first profiling library is simple. The profiling version of each `MPI_Xxx` routine calls `PMPI_Wtime` (which delivers a time stamp) before and after each call to the corresponding

PMPI_Xxx routine. Times are accumulated in each process and written out, one file per process, in the profiling version of MPI_Finalize. The files are then available for use in either a global or process-by-process report. This version does not take into account nested calls, which occur when MPI_Bcast, for instance, is implemented in terms of MPI_Send and MPI_Recv.

5.4.2 Logfile creation

The second profiling library generates *logfiles*, which are files of timestamped events. During execution, calls to MPE_Log_event are made to store events of certain types in memory, and these memory buffers are collected and merged in parallel during MPI_Finalize. During execution, MPI_Pcontrol can be used to suspend and restart logging operations. (By default, logging is on. Invoking MPI_Pcontrol(0) turns it off; MPI_Pcontrol(1) turns it back on again.) The calls to MPE_Log_event are made automatically for each MPI call. You can analyze the logfile produced at the end with a variety of tools; these are described in Sections 5.5 and 5.6.

5.4.3 Customizing logfiles

In addition to using the predefined MPE logging libraries, you can insert your own calls to the logging routines to define and log states. States may be nested, allowing you to define a state describing a user routine that contains several MPI calls, and display both the user defined state and the MPI operations contained within it. The routines MPE_Describe_state and MPE_Log_event are used to describe user-defined states. The routine MPE_Log_get_event_number may be used to get unique event numbers (this is important if you are writing a library that uses the MPE logging routines).

```
MPE_Describe_state( 1001, 1002, "Amult", "bluegreen" );
...
MyAmult( Matrix m, Vector v )
{
    /* Log the start event along with the size of the matrix */
    MPE_Log_event( 1001, m->n, (char *)0 );
    ... amult code, including MPI calls ...
    MPE_Log_event( 1002, 0, (char *)0 );
}
```

The log file generated by this code will have the MPI routines within the routine MyAmult indicated by a containing bluegreen rectangle.

If you are not using the MPE logging library, you will also need to use MPE_Init_log and MPE_Finish_log.

5.4.4 Real-time animation

The third library does a simple form of real-time program animation. The MPE graphics library contains routines that allow a set of processes to share an X display that is not associated with any one specific process. Our prototype uses this capability to draw arrows that represent message traffic as the program runs.

5.5 upshot and nupshot

One tool that we use is called `upshot`, which is a derivative of Upshot [13], written in Tcl/Tk. A screen dump of Upshot in use is shown in Figure 2. It shows parallel time lines

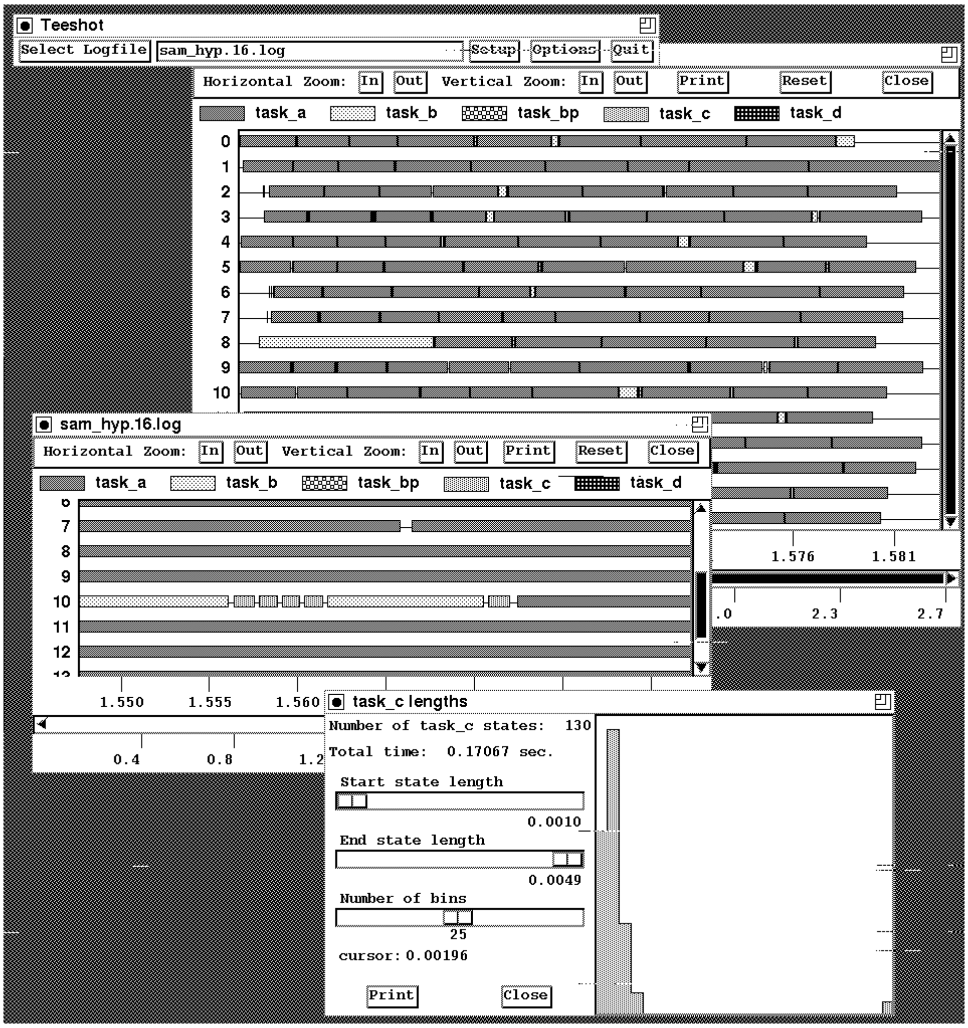


Figure 2: A screendump from `upshot`

with process states, like one of the paraGraph [12]. The view can be zoomed in or out, horizontally or vertically, centered on any point in the display chosen with the mouse. In Figure 2, the middle window has resulted from zooming in on the upper window at a chosen point to show more detail. The window at the bottom of the screen show a histogram of state durations, with several adjustable parameters.

`Nupshot` is a version of `upshot` that is faster but requires an older version of Tcl/tk.

5.6 Jumpshot

Another tool that is new and is now available is called `Jumpshot`, which has evolved from Upshot and Nupshot. `Jumpshot`, which is written in Java, is a graphical visualization tool for interpreting binary clog tracefiles which displays them onto a canvas object, such as the one depicted in Figure 3.

5.6.1 Description of Options

- Jumpshot Window
  - **File**

    New Frame Opens a new jumpshot window

    Select Logfile Opens up a window that allows you to select a logfile to view

    Exit Quit jumpshot
  - **Display** Select the type of display jumpshot should show.
  - **System** Select the look and feel of choice. Certain look and feel may not be supported. Enable or disable tool tips. Tool tips are small descriptions that become visible when user places mouse over some region like a button, window, etc.
  - **Help**

    Manual Opens a window containing this section

    About Gives a short description of jumpshot
  - **Logfile** Contains name of loaded logfile
  - **Display** Display loaded logfile
- Display Window
  - **In, Out, Reset** These buttons are used to zoom in and out horizontally.
  - **Print** Clicking on this button will bring up the `Print Dialog` window where you will be able to choose printer-related options and print display of this window.
  - **Options** Clicking on this button will bring up the `Options` window.
  - **Process #s** Double clicking on process #s will bring up the `Adjust Process` window
  - **Scroll Bar** Use to move forward or backward in time
  - **Keyboard Keys**

    Z or z Lock Zoom at point where the mouse is positioned.

    T or t Set a time marker at point where the mouse is positioned.

Mouse Button Clicking of any mouse button on a specific state instance on the display will bring `State Info` window which displays information on that state instance. Clicking on this window will dispose of it. Clicking of any mouse button on the circle at origin of a message will open up a window containing information on that message. Clicking on this window will dispose of it.

- Options Window
  - **Line Display** Turn off/on the zoom lock line and elapsed time line. These are the vertical lines that you see in the Display Window.
  - **Display Options** Add/Cut time lines or mountain ranges to/from the display window
  - **Zoom & Time** Zoom Factor: Length of display is multiplied by this value when you zoom in. Length of display is divided by this value when you zoom out. From and To are starting and ending times in viewport respectively. To change these values edit and press enter.
  - **Nesting** Nest Factor: Measure of difference between heights of successive nested levels. The larger the value, the larger the difference. To change the value, edit and press enter. DO OPTIMAL NESTING: Calculates most appropriate nest factor and implements it.
- Adjust Process Window
  This window contains options used to manipulate processes.
  - **Scrollbar** The scrollbar is used to move the current process forward and backward in time.
  - **Forward/Backward** This button is used to determine the direction in which the current process is to be moved.
  - **Reset** This causes the process to take up its original position in time.
  - **Display** This checkbox controls the display status of the selected process. A process can be selected from the `AVAILABLE` list.
  - **Swap** This causes the selected process to be swapped with the current process.
  - **Delete** The selected process is deleted. The deleted process is removed from the `AVAILABLE` list and placed in the `DELETED` list.
  - **Insert** This causes the selected process from the `DELETED` list to be placed just above the selected process from the `AVAILABLE` list.
- Process States
  Initially below the Display Window, the process states region contains buttons for each state and message. This region can be attached to any of the 4 sides of the Display Window. It can also be torn away from the Display Window and made to form its own window.
  - **All States On** Turn on all possible states
  - **ALL States Off** Turn off all possible states
  - [**State**] Clicking on any state will produce a histogram window for that state.

- **checkbox** Use this to enable/disable this state's display.

- State Histogram Window
  This window contains information on an associated state. The histogram given is the plot of the number of state instances (y-axis) versus duration in seconds (x-axis).

5.6.2 Known Bugs in Jumpshot

1. If the Process States region is torn away from the Display Window, it forms its own window. If the Display Window is closed, the Process States window will not close. To close it, you will have to click on the close icon present on the window (provided by windows manager). This happens due to a bug in JToolBar, which is an object in Java.

2. As the size of the logfile increases, `jumpshot's` performance decreases, and can ultimately result in `jumpshot` hanging while it is reading in the logfile. It is hard to determine at what point `jumpshot` will hang, but we have seen it with files as small as 10MB. There is a current research effort that will result in the ability to make `jumpshot` significantly more scalable. The SLOG (scalable log file) format supports scalable logging of data.

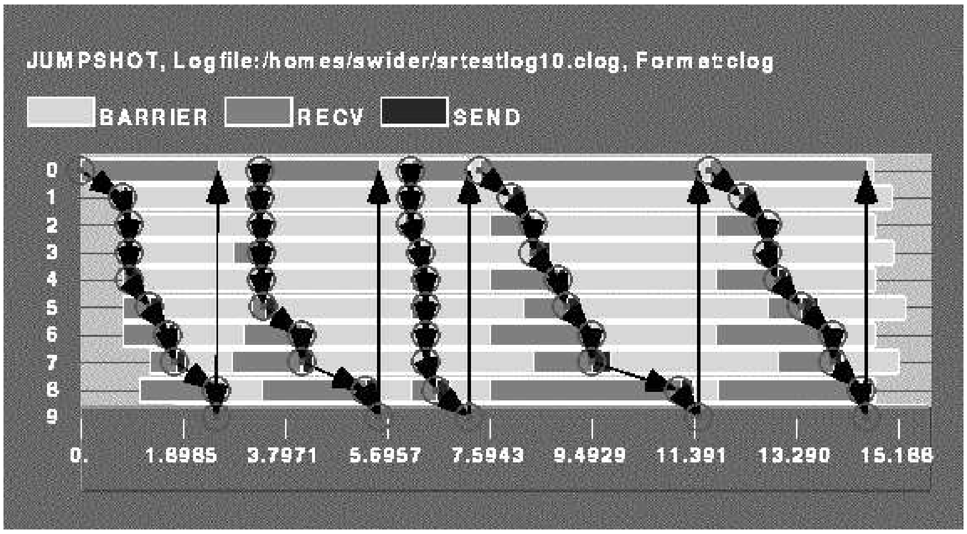


Figure 3: Jumpshot Display

5.7 SLOG and Jumpshot-3

The SLOG log file format allows one to visualize a big logfile, in the GB range, which was not possible in previous log file format, CLOG/ALOG. The new logfile format can be used in the current MPICH profiling library system, MPE.

5.7.1 Use of SLOG

The MPE libraries include all the necessary SLOG definitions. After the program is compiled and linked with the MPE libraries. e.g.

```
mpicc -mpilog -o cpi cpi.c
```

The previous command allows one to profile all the MPI calls in MPICH.

If one wants to profile some user-defined calls using the

```
MPE_Log_get_event_number()/MPE_Describe_state()/MPE_Log_event()
```

calls. For example, `mpich/mpe/contrib/test/cpilog.c` and `mpich/mpe/contrib/test/fpi.f` can be compiled with the following commands.

```
mpif77 -mpilog -o fpilog fpi.f
mpicc -mpilog -o cpilog cpilog.c -Impich/mpe
```

Where -Impich/mpe is for include files, mpe.h

There are 2 ways to generate an slog file:

```
1, Automatic slogfile generation : set the environmental variable,
   MPE_LOG_FORMAT, to SLOG

   In csh/tcsh: setenv MPE_LOG_FORMAT SLOG

   For ch_p4 and ch_shmem device, run with the usual mpirun command.
       mpirun -np N cpilog

   But for ch_p4mpd device, run with following command
       mpirun -np N cpilog -MPDENV- MPE_LOG_FORMAT=SLOG

2, CLOG to SLOG converter : cd to ~mpich/mpe, then do
   "make clog2slog" which will create the converter, clog2slog.

   Since the default logfile format for MPE is clog.  So one can
   do profiling as usual, i.e. generate a clog file.  If clog file
   generated is big, like above 4 MB.  One would like to convert it
   to a slogfile which is much more efficiently handled by jumpshot-3.

       $(MPICH)/mpe/clog2slog cpilog.clog

   which would generate a file called cpilog.slog.  The converter also
   provides some additional flexibility that is not available in automatic
   slogfile generation.  Namely, one can modify the frame size and other
   internals used in slogfile.  Do "clog2slog" at the command line for
   more details.
```

5.8 Accessing the profiling libraries

If the MPE libraries have been built, it is very easy to access the profiling libraries. The configure in the `mpe` directory determines the link path necessary for each profiling library (which varies slightly for each MPI implementation). This information is placed in the following variables:

PROF_LIB The path needed to link with the mpe library only. The link path is `-lmpe -lpmpich` or `-lmpe -lpmpi` depending on the MPI implementation.

LOG_LIB The path needed to link with the logging library. The logging library will log all MPI calls and generate a CLOG file (which can be viewed with `jumpshot`) or an ALOG file (which can be viewed with `upshot`). If a CLOG file is preferred, be sure to set MPE_LOG_FORMAT to CLOG. The link path is `-llmpi $PROF_LIB`.

TRACE_LIB The path needed to link with the tracing library. The tracing library will trace all MPI calls. Each MPI call is preceded by a line that contains the rank in `MPI_COMM_WORLD` of the calling process, and followed by another line indicating that the call has completed. Most send and receive routines also indicate the values of count, tag, and partner (destination for sends, source for receives). Output is to standard output. The link path is `-ltmpi $PROF_LIB`.

ANIM_LIB The path needed to link with the animation library. The animation library produces a real-time animation of the program. This requires the MPE graphics, and uses X11 Window System operations. You may need to provide a specific path for the X11 libraries (instead of `-lX11`). The link path is `-lampi $PROF_LIB -lX11`.

These variables are substituted in the Makefile in the '`mpe/contrib/test`' directory. As part of the `make` process, a small C program '`cpi`' is linked with each profiling library. The result of each link test will be written as part of the make output. If the link test is successful, then these link paths should be used for your programs as well.

If the MPI implementation being used is MPICH, then adding `-mpilog` to your link line will automatically link your program with the `mpe` and logging libraries (`-llmpi -lmpe`). You will also need to add `-lpmpich` to your link line to link with the MPI profiling interface.

The configure in the `mpe` directory also determines the link path necessary to link Fortran programs with the logging library (which varies slightly for each MPI implementation). This path is stored in the variable `FLIB_PATH` and substituted in the Makefile in the '`mpe/test`' directory. A small Fortran program '`fpi`' is linked using this path during the `make` process and the result is written to the make output. If successful, then this path should also be used with your Fortran programs.

If the MPI implementation being used is MPICH, it is necessary to include the library '`-lfmpich`' ahead of the profiling libraries. This allows C routines to be used for implementing the profiling libraries for use by both C and Fortran programs. For example, to generate log files in a Fortran program, the library list is `-lfmpich -llmpich -lmpe -lpmpich`.

If the MPI implementation being used is not MPICH, it is necessary to include the file '`mpe_proff.o`' (sample MPI Fortran profiling library) ahead of the profiling libraries.

This is not necessary with MPICH since the library '`-lfmpich`' is included on the link line. It should be noted here that there has not been extensive testing with profiling Fortran programs using MPI implementations other than MPICH.

It is possible to combine automatic logging with manual logging. Automatic logging will log all MPI calls and is achieved by linking with $LOG_LIB. Manual logging is achieved by the user inserting calls to the `MPE` routines around MPI calls. This way, only the chosen MPI calls will be logged. However, if a combination of these two types of logging is preferred, then the user must omit the call to `MPE_Finish_log`. Because all MPI calls will be logged, `MPI_Finalize` will call `MPE_Finish_log`.

5.9 Automatic generation of profiling libraries

For each of these libraries, the process of building the library was very similar. First, profiling versions of `MPI_Init` and `MPI_Finalize` must be written. The profiling versions of the other MPI routines are similar in style. The code in each looks like

```
int MPI_Xxx( . . . )
{
       do something for profiling library
    retcode = PMPI_Xxx( . . . );
       do something else for profiling library
    return retcode;
}
```

We generate these routines by writing the "do something" parts only once, in schematic form, and then wrapping them around the `PMPI_` calls automatically. It is thus easy to generate profiling libraries. See the `README` file in `mpich/mpe/profiling/wrappergen` or Appendix A.

Examples of how to write wrapper templates are located in the `mpe/profiling/lib` subdirectory. There you will find the source code (the `.w` files) for creating the three profiling libraries described above. An example `Makefile` for trying these out is located in the `mpe/profiling/examples` directory.

5.10 Tools for Profiling Library Management

The sample profiling wrappers for `mpich` are distributed as wrapper definition code. The wrapper definition code is run through the `wrappergen` utility to generate C code (see Section 5.9. Any number of wrapper definitions can be used together, so any level of profiling wrapper nesting is possible when using wrappergen.

A few sample wrapper definitions are provided with `mpich`:

timing Use `MPI_Wtime()` to keep track of the total number of calls to each MPI function, and the time spent within that function. This simply checks the timer before and after the function call. It does not subtract time spent in calls to other functions.

logging Create logfile of all pt2pt function calls.

vismess Pop up an X window that gives a simple visualization of all messages that are passed.

allprof All of the above. This shows how several profiling libraries may be combined.

Note: These wrappers do not use any mpich-specific features besides the MPE graphics and logging used by 'vismess' and 'logging', respectively. They should work on any MPI implementation.

You can incorporate them manually into your application, which involves three changes to the building of your application:

- Generate the source code for the desired wrapper(s) with wrappergen. This can be a one-time task.
- Compile the code for the wrapper(s). Be sure to supply the needed compile-line parameters. 'vismess' and 'logging' require the MPE library ('`-lmpe`'), and the 'vismess' wrapper definition requires MPE_GRAPHICS.
- Link the compiled wrapper code, the profiling version of the mpi library, and any other necessary libraries ('vismess' requires X) into your application. The required order is:

```
$(CLINKER)   <application object files...> \
<wrapper object code> \
<other necessary libraries (-lmpe)> \
<profiling mpi library (-lpmpich)> \
<standard mpi library (-lmpi)>
```

To simplify it, some sample makefile sections have been created in '`mpich/mpe/profiling/lib`':

```
Makefile.timing - timing wrappers
Makefile.logging - logging wrappers
Makefile.vismess - animated messages wrappers
Makefile.allprof - timing, logging, and vismess
```

To use these Makefile fragments:

1. (optional) Add `$(PROF_OBJ)` to your application's dependency list:

   ```
   myapp:  myapp.o $(PROF_OBJ)
   ```

2. Add `$(PROF_FLG)` to your compile line `CFLAGS`:

   ```
   CFLAGS = -O $(PROF_FLG)
   ```

3. Add `$(PROF_LIB)` to your link line, after your application's object code, but before the main MPI library:

   ```
   $(CLINKER) myapp.o -L$(MPIR_HOME)/lib $(PROF_LIB) -lmpich
   ```

4. (optional) Add `$(PROF_CLN)` to your clean target:

   ```
   rm -f *.o *~ myapp $(PROF_CLN)
   ```

5. Include the desired Makefile fragment in your makefile:

   ```
   include $(MPIR_HOME)/mpe/profiling/lib/Makefile.logging
   ```

   (or

   ```
   #include $(MPIR_HOME)/mpe/profiling/lib/Makefile.logging
   ```

   if you are using the wildly incompatible BSD 4.4-derived make)

6 Debugging MPI programs with built-in tools

Debugging of parallel programs is notoriously difficult, and we do not have a magical solution to this problem. Nonetheless, we have built into `mpich` a few features that may be of use in debugging MPI programs.

6.1 Error handlers

The MPI Standard specifies a mechanism for installing one's own error handler, and specifies the behavior of two predefined ones, `MPI_ERRORS_RETURN` and `MPI_ERRORS_ARE_FATAL`. As part of the `mpe` library, we include two other error handlers to facilitate the use of `dbx` in debugging MPI programs.

```
MPE_Errors_call_dbx_in_xterm
MPE_Signals_call_debugger
```

These error handlers are located in the `mpe` directory. A configure option (`-mpedbg`) includes these error handlers into the regular MPI libraries, and allows the command-line argument `-mpedbg` to make `MPE_Errors_call_dbx_in_xterm` the default error handler (instead of `MPI_ERRORS_ARE_FATAL`).

6.2 Command-line arguments for `mpirun`

`mpirun` provides some help in starting programs with a debugger.

```
mpirun -dbx -np 2 program
```

starts `program` on two machines, with the local one running under the `dbx` debugger. The option `-gdb` selects the `gdb` debugger instead. The option `-xxgdb` allows you to use the `xxgdb` (X Window GUI interface to `gdb`).

6.3 MPI arguments for the application program

These are currently undocumented, and some require configure options to have been specified (like `-mpipktsize` and `-chmemdebug`). The `-mpiversion` option is useful for finding out how your installation of `mpich` was configured and exactly what version it is.

-mpedbg If an error occurs, start `xterms` attached to the process that generated the error. Requires the `mpich` be configured with `-mpedbg` and works on only some workstations systems.

-mpiversion Print out the version and configuration arguements for the `mpich` implementation being used.

These arguments are provided to the program, not to `mpirun`. That is,

```
mpirun -np 2 a.out -mpiversion
```

6.4 p4 Arguments for the ch_p4 Device

When using the `ch_p4` device, a number of command-line arguments may be used to control the behavior of the program.

6.4.1 p4 Debugging

If your configuration of `mpich` used `-device=ch_p4`, then some of the `p4` debugging capabilities are available to you. The most useful of these are the command line arguments to the application program. Thus

```
mpirun -np 10 myprog -p4dbg 20 -p4rdbg 20
```

results in program tracing information at a level of 20 being written to `stdout` during execution. For more information about what is printed at what levels, see the `p4` Users' Guide [1].

If one specifies `-p4norem` on the command line, `mpirun` will not actually start the processes. The master process prints a message suggesting how the user can do it. The point of this option is to enable the user to start the remote processes under his favorite debugger, for instance. The option only makes sense when processes are being started remotely, such as on a workstation network. Note that this is an argument to the *program*, not to `mpirun`. For example, to run `myprog` this way, use

```
mpirun -np 4 myprog -p4norem
```

6.4.2 Setting the Working Directory for the p4 Device

By default, the working directory for processes running remotely with `ch_p4` device is the same as that of the executable. To specify the working directly, use `-p4wdir` as follows:

```
mpirun -np 4 myprog -p4wdir myrundir
```

6.5 Command-line arguments for the application program

Arguments on the command line that follow the application program name and are not directed to the `mpich` system (don't begin with `-mpi` or `-p4`) are passed through to all processes of the application program. For example, if you execute

```
mpirun -echo -np 4 myprog -mpiversion -p4dbg 10 x y z
```

then `-echo -np 4` is interpreted by `mpirun` (echo actions of `mpirun` and run four processes), `-mpiversion` is interpreted by `mpich` (each process prints configuration information), `-p4dbg 10` is interpreted by the p4 device if your version was configured with `-device=ch_p4` (sets p4 debugging level to 10), and `x y z` are passed through to the application program. In addition, `MPI_Init` strips out non-application arguments, so that after the call to `MPI_Init` in your C program, the argument vector `argv` contains only

```
myprog x y z
```

and your program can process its own command-line arguments in the normal way.

It is not possible to provide different command-line arguments for the different processes.

6.6 Starting jobs with a debugger

The `-dbx` option to `mpirun` causes processes to be run under the control of the `dbx` debugger. This depends on cooperation between `dbx` and `mpich` and does not always work; if it does not, you will know immediately. If it does work, it is often the simplest way to debug MPI programs. Similiarly, the argument `-gdb` makes use of the GNU debugger.

For example, enter

```
mpirun -dbx or mpirun -gdb a.out
```

In some cases, you will have to wait until the program completes and then type `run` to run the program again. Also, `mpirun` relies on the `-sr` argument to `dbx` (this tells `dbx` to read initial commands from a file). If your `dbx` does not support that feature, `mpirun` will fail to start your program under the debugger.

6.7 Starting the debugger when an error occurs

Enter

```
mpirun ... a.out -mpedbg
```

(requires `mpich` built with `-mpedbg` option; do `-mpiversion` and look for `-mpedbg` option).

6.8 Attaching a debugger to a running program

On workstation clusters, you can often attach a debugger to a running process. For example, the debugger `dbx` often accepts a process id (pid) which you can get by using the `ps` command. The form is either

```
dbx a.out pid
```

or

```
dbx -pid pid a.out
```

One can also attach the TotalView debugger to a running program (See Section 7.3 below).

6.9 Signals

In general, users should avoid using signals with MPI programs. The manual page for `MPI_Init` describes the signals that are used by the MPI implementation; these should not be changed by the user.

In a few cases, you can change the signal *before* calling `MPI_Init`. In those cases, your signal handler will be called after the MPICH implementation acts on the signal. For example, if you want to change the behavior of `SIGSEGV` to print a message, you can establish such a signal handler before calling `MPI_Init`. With devices such as the `ch_p4` device that handle `SIGSEGV`, this will cause your signal handler to be called after MPICH processes it.

6.10 Related tools

The *Scalable Unix Tools* (SUT) is a collection for managing workstation networks as a MPP. These include programs for looking at all of the processes in a cluster and performing operations on them (such as attaching the debugger to every process you own that is running a particular program). This is not part of MPI but can be very useful in working with workstation clusters. An MPI version of these tools is under development.

6.11 Contents of the library files

The directory containing the MPI library file (‘`libmpich.a`’) contains a few additional files. These are summarized here

libmpich.a MPI library (`MPI_Xxxx`)

libfmpich.a Only the Fortran interfaces to the MPI routines.

libpmpich.a Profiling version (`PMPI_Xxxx`). If weak symbols are supported by the system, this file may be a link to `libmpich.a`.

libf90mpich.a Support for MPI module for Fortran 90.

libf90mpichnc.a Support for the "no-choice" subset MPI module.

libmpe.a MPE graphics, logging, and other extensions (`PMPE_Xxxx`)

libmpe_nompi.a MPE graphics without MPI

mpe_prof.o Sample profiling library (C)

mpe_proff.o Sample profiling library (Fortran)

7 Debugging MPI programs with TotalView

TotalView © is a powerful, commercial-grade, portable debugger for parallel and multi-threaded programs, available from Etnus (`http://www.etnus.com/toolworks`**CHECK**). TotalView understands multiple MPI implementations, including `mpich`. By "understand" is meant that if you have TotalView installed on your system, it is easy to start your `mpich` program under the control of TotalView, even if you are running on multiple machines, manage your processes both collectively and individually through TotalView's convenient GUI, and even examine internal `mpich` data structures to look at message queues [3]. The general operation model of TotalView will be familiar to users of command-line-based debuggers such as `gdb` or `dbx`.

7.1 Preparing `mpich` for TotalView debugging

See the *Installation Guide* for instructions on configuring `mpich` so that TotalView can display message queues.

7.2 Starting an `mpich` program under TotalView control

To start a parallel program under TotalView control, simply add '`-tv`' to your `mpirun` arguments:

```
mpirun -tv -np 4 cpi
```

TotalView will come up and you can start the program by typing '`G`'. A window will come up asking whether you want to stop processes as they execute `MPI_Init`. You may find it more convenient to say "no" and instead to set your own breakpoint after `MPI_Init` (See Section 7.4.) This way when the process stops it will be on a line in your program instead of somewhere inside `MPI_Init`.

7.3 Attaching to a running program

TotalView can attach to a running MPI program, which is particularly useful if you suspect that your code has deadlocked. To do this start TotalView with no arguments, and then press '`N`' in the root window. This will bring up a list of the processes that you can attach to. When you dive through the initial `mpich` process in this window TotalView will also acquire all of the other `mpich` processes (even if they are not local). (See the TotalView manual for more details of this process.)

7.4 Debugging with TotalView

You can set breakpoints by clicking in the left margin on a line number. Most of the TotalView GUI is self-explanatory. You select things with the left mouse button, bring up an action menu with the middle button, and "dive" into functions, variables, structures, processes, etc., with the right button. Pressing `cntl-?` in any TotalView window brings up help relevant to that window. In the initial TotalView window it brings up general help. The full documentation (The TotalView *User's Guide*) is available at `http://www.etnus.com/tw/tvdemo37.htm`**CHECK**.

You switch from viewing one process to the next with the arrow buttons at the top-right corner of the main window, or by explicitly selecting (left button) a process in the root window to re-focus an existing window onto that process, or by diving (right button) through a process in the root window to open a new window for the selected process. All the keyboard shortcuts for commands are listed in the menu that is attached to the middle button. The commands are mostly the familiar ones. The special one for MPI is the '`m`' command, which displays message queues associated with the process.

Note also that if you use the MPI-2 function `MPI_Comm_set_name` on a communicator, TotalView will display this name whenever showing information about the communicator, making it easier to understand which communicator is which.

7.5 Summary

TotalView is a very powerful, flexible debugger for parallel and multithreaded programs. It has many capabilities beyond those described here, which are just enough to get you started. For more details, see the *TotalView User's Guide*, and particularly the section on `mpich`.

8 Other MPI Documentation

Information about MPI is available from a variety of sources. Some of these, particularly WWW pages, include pointers to other resources.

- The Standard itself:
  - As a Technical report: U. of T. report [4]
  - As postscript for ftp: at `ftp.mcs.anl.gov` in `pub/mpi/mpi-report.ps`.
  - As hypertext on the World Wide Web: `http://www.mpi-forum.org`
  - As a journal article: in the Fall 1994 issue of the Journal of Supercomputing Applications [15]

- MPI Forum discussions
  - The MPI Forum email discussions and both current and earlier versions of the Standard are available from `netlib`.
- Books:
  - *Using MPI: Portable Parallel Programming with the Message-Passing Interface, Second Edition*, by Gropp, Lusk, and Skjellum [10].
  - *Using MPI-2: Advanced Features of the Message-Passing Interface*, by Gropp, Lusk, and Thakur [11]
  - *MPI: The Complete Reference, Second Edition*, by Snir, et al. [17].
  - *Parallel Programming with MPI*, by Peter S. Pacheco. [16]
- Newsgroup:
  - `comp.parallel.mpi`
- Mailing lists:
  - `mpi-comm@cs.utk.edu`: The MPI Forum discussion list.
  - `mpi-impl@mcs.anl.gov`: The implementors' discussion list.
  - `mpi-bugs@mcs.anl.gov`: The address to report problems with `mpich` to.
- Implementations available from the web:
  - `mpich` is available from `http://www.mcs.anl.gov/mpi/mpich` or by anonymous `ftp` from `ftp.mcs.anl.gov` in the directory `pub/mpi/mpich`, file `mpich.tar.gz`.
  - LAM is available from `http://www.mpi.nd.edu/lam`**CHECK** or by anonymous `ftp` from `http://www.mpi.nd.edu/lam/`.
- Test code repository (new):
  - `ftp://ftp.mcs.anl.gov/pub/mpi/mpi-test`

9 In Case of Trouble

This section describes some commonly encountered problems and their solutions. It also describes machine-dependent considerations. Send any problem that you can not solve by checking this section to `mpi-bugs@mcs.anl.gov`.

Please include:

- The version of `mpich` (e.g., 1.2.0)
- The output of running your program with the `-mpiversion` argument (e.g., `mpirun -np 1 a.out -mpiversion`)
- The output of

```
uname -a
```

for your system. If you are on an SGI system, also

```
hinv
```

- If the problem is with a script like configure or mpirun, run the script with the `-echo` argument (e.g., `mpirun -echo -np 4 a.out`).
- If you are using a network of workstations, also send the output of `bin/tstmachines` **CHECK not sbin**[4].

Each section is organized in question and answer format, with questions that relate to more than one environment (workstation, operating system, etc.) first, followed by questions that are specific to a particular environment. Problems with workstation clusters are collected together as well.

9.1 Problems compiling or linking Fortran programs

9.1.1 General

1. **Q:** When linking the test program, the following message is generated:

   ```
   f77 -g -o secondf secondf.o -L/usr/local/mpich/lib/sun4/ch_p4 -lmpich
   invalid option -L/usr/local/mpich/lib/sun4/ch_p4
   ld: -lmpich: No such file or directory
   ```

   A: This `f77` program does not accept the `-L` command to set the library search path. Some systems provide a shell script for `f77` that is very limited in its abilities. To work around this, use the full library path instead of the `-L` option:

   ```
   f77 -g -o secondf secondf.o /usr/local/mpich/lib/sun4/ch_p4/libmpich.a
   ```

   As of the `mpich` 1.2.0 release, the `mpich` configure attempts to find the correct option for indicating library paths to the Fortran compiler. If you find that the `mpich` configure has made an error, please submit a bug report to `mpi-bugs@mcs.anl.gov`.

2. **Q:** When linking Fortran programs, I get undefined symbols such as

   ```
   f77  -c secondf.f
   secondf.f:
    MAIN main:
   f77  -o secondf secondf.o -L/home/mpich/lib/solaris/ch_shmem -lmpich
   Undefined                       first referenced
    symbol                             in file
   getdomainname
   /home/mpich/lib/solaris/ch_shmem/libmpi .a(shmempriv.o)
   ld: fatal: Symbol referencing errors. No output written to secondf
   ```

[4] `tstmachines` is not supported in the `globus` device

There is no problem with C programs.

A: This means that your C compiler is providing libraries for you that your Fortran compiler is not providing. Find the option for the C compiler and for the Fortran compilers that indicate which library files are being used (alternately, you may find an option such as `-dryrun` that shows what commands are being used by the compiler). Build a simple C and Fortran program and compare the libraries used (usually on the `ld` command line). Try the ones that are present for the C compiler and missing for the Fortran compiler.

3. **Q:** When trying to run `configure`, I get error messages like

```
./configure: syntax error at line 20: `(' unexpected
```

A: You have an obsolete version of the Bourne shell (`sh`). MPICH requires that the `sh` shell support shell procedures; this has been standard in most Bourne shells for years. To fix this, you might consider (a) getting an update from your vendor or (b) installing one of the many publically available sh-shell replacements.

9.2 Problems Linking C Programs

9.2.1 General

1. **Q:** When linking programs, I get messages about `__builtin_saveregs` being undefined.

A: You may have a system on which C and Fortran routines are incompatible (for example, using `gcc` and the vendor's Fortran compiler). If you do not plan to use Fortran, the easiest fix is to rebuild with the `-nof77` option to configure.

You should also look into making your C compiler compatible with your Fortran compiler. One possibility is use `f2c` to convert Fortran to C, then use the C compiler to compile everything. If you take this route, remember that *every* Fortran routine has to be compiled using `f2c` and the C compiler.

9.2.2 Sun Solaris

1. **Q:** When linking on Solaris, I get an error like this:

```
cc -g -o testtypes testtypes.o -L/usr/local/mpich/lib/solaris/ch_p4 -lmpich
       -lsocket -lnsl -lthread
ld: warning: symbol `_defaultstkcache' has differing sizes:
       (file /usr/lib/libthread.so value=0x20; file /usr/lib/libaio.so
       value=0x8);
       /usr/lib/libthread.so definition taken
```

A: This is a bug in Solaris 2.3 that is fixed in Solaris 2.4. There may be a patch for Solaris 2.3; contact Sun for more information.

9.2.3 HPUX

1. **Q:** When linking on HPUX, I get an error like this:

   ```
   cc -o pgm pgm.o -L/usr/local/mpich/lib/hpux/ch_p4 -lmpich  -lm
   /bin/ld: Unsatisfied symbols:
   sigrelse (code)
   sigset (code)
   sighold (code)
   *** Error code 1
   ```

   A: You need to add the link option `-lV3`. The p4 device uses the System V signals on the HP; these are provided in the '`V3`' library.

9.2.4 LINUX

1. **Q:** When linking a Fortran program, I get

   ```
   Linking:
   foo.o(.data+0x0): undefined reference to 'pmpi_wtime_'
   ```

   A: This is a bug in the `pgf77` compiler (which is itself a workaround for a bug in the LINUX `ld` command). You can fix it by either adding -lpmpich to the link line or modifying the '`mpif.h`' to remove the `external pmpi_wtime, pmpi_wtick` statement.

The `mpich` configure attempts to determine if `pmpi_wtime` and `pmpi_wtick` can be declared in '`mpif.h`' and removes them if there is a problem. If this happens and you use `pmpi_wtime` or `pmpi_wtick` in your program, you will need to declare them as functions returning `double precision` values.

9.3 Problems starting programs

9.3.1 General

1. **Q:** When trying to start a program with

   ```
   mpirun -np 2 cpi
   ```

   either I get an error message or the program hangs.

   A: On Intel Paragons and IBM SP1 and SP2, there are many mutually exclusive ways to run parallel programs; each site can pick the approach(es) that it allows. The script `mpirun` tries one of the more common methods, but may make the wrong choice. Use the `-v` or `-t` option to `mpirun` to see how it is trying to run the program, and then compare this with the site-specific instructions for using your system. You may need to adapt the code in `mpirun` to meet your needs.

2. **Q:** When trying to run a program with, e.g., `mpirun -np 4 cpi`, I get

   ```
   usage : mpirun [options] <executable> [<dstnodes>] [-- <args>]
   ```

   or

   ```
   mpirun [options] <schema>
   ```

   A: You have a command named `mpirun` in your path ahead of the `mpich` version. Execute the command

   ```
   which mpirun
   ```

   to see which command named `mpirun` was actually found. The fix is to either change the order of directories in your path to put the `mpich` version of `mpirun` first, or to define an alias for `mpirun` that uses an absolute path. For example, in the csh shell, you might do

   ```
   alias mpirun /usr/local/mpich/bin/mpirun
   ```

3. **Q:** When trying to start a large number of processes on a workstation network, I get the message

   ```
   p4_error: latest msg from perror: Too many open files
   ```

   A: There is a limitation on the number of open file descriptors. On some systems you can increase this limit yourself; on others you must have help from your system administrator. You could experiment with the secure server, but it is not a complete solution. We are working now on a more scalable startup mechanism for the next release.

4. **Q:** When I issue the command:

   ```
   mpirun -dbx -np 1 foo
   ```

   `dbx` does start up but this message appears:

   ```
   dbx version 3.19 Nov  3 1994 19:59:46
   Unexpected argument ignored: -sr
   /scr/MPI/me/PId8704 is not an executable
   ```

   A: Your version of `dbx` does not support the `-sr` argument; this is needed to give `dbx` the initial commands to execute. You will not be able to use `mpirun` with the `-dbx` argument. Try using `-gdb` or `-xxgdb` instead of `-dbx` if you have the GNU debugger. Another excellent debugging option is to use TotalView.

5. **Q:** When attempting to run cpilog I get the following message:

   ```
   ld.so.1: cpilog: fatal: libX11.so.4: can't open file: errno 2
   ```

A: The X11 version that configure found isn't properly installed. This is a common problem with Sun/Solaris systems. One possibility is that your Solaris machines are running slightly different versions. You can try forcing static linking (-Bstatic on SunOS).

Alternately, consider adding these lines to your '`.login`' (assuming C shell):

```
setenv OPENWINHOME /usr/openwin
setenv LD_LIBRARY_PATH /opt/SUNWspro/lib:/usr/openwin/lib
```

(you may want to check with your system administrator first to make sure that the paths are correct for your system). Make sure that you add them *before* any line like

```
if ($?USER == 0 || $?prompt == 0) exit
```

6. **Q:** My program fails when it tries to write to a file.

   A: If you opened the file *before* calling `MPI_INIT`, the behavior of MPI (not just `mpich`) is undefined. On the `ch_p4` version, only process zero (in `MPI_COMM_WORLD`) will have the file open; the other processes will not have opened the file. Move the operations that open files and interact with the outside world to after `MPI_INIT` (and before `MPI_FINALIZE`).

7. **Q:** Programs seem to take forever to start.

   A: This can be caused by any of several problems. On systems with dynamically-linked executables, this can be caused by problems with the file system suddenly getting requests from many processors for the dynamically-linked parts of the executable (this has been measured as a problem with some DFS implementations). You can try statically linking your application.

   On workstation networks, long startup times can be due to the time used to start remote processes; see the discussion on the secure server in Section 3.1.3.

9.3.2 Workstation Networks

1. **Q:** When I use `mpirun`, I get the message `Permission denied`.

   A: If you see something like this

```
% mpirun -np 2 cpi
Permission denied.
```

or

```
% mpirun -np 2 cpi
socket: protocol failure in circuit setup
```

when using the `ch_p4` device, it probably means that you do not have permission to use `rsh` to start processes. The script `tstmachines` can be used to test this. For example, if the architecture type (the `-arch` argument to configure) is `sun4`, then try

```
tstmachines sun4
```

If this fails, then you may need a '`.rhosts`' or '`/etc/hosts.equiv`' file (you may need to see your system administrator) or you may need to use the p4 server (see Section 3.1.3). Another possible problem is the choice of the remote shell program; some systems have several. Check with your systems administrator about which version of `rsh` or `remsh` you should be using. If you must use `ssh`, see the section on using `ssh` in the *Installation Manual*.

If your system allows a '`.rhosts`' file, do the following:

(a) Create a file '`.rhosts`' in your home directory

(b) Change the protection on it to user read/write only: `chmod og-rwx .rhosts`.

(c) Add one line to the '`.rhosts`' file for each processor that you want to use. The format is

```
host username
```

For example, if your username is `doe` and you want to user machines `a.our.org` and `b.our.org`, your '`.rhosts`' file should contain

```
a.our.org doe
b.our.org doe
```

Note the use of fully qualified host names (some systems require this).

On networks where the use of .rhosts files is not allowed, (such as the one in MCS at Argonne), you should use the p4 server to run on machines that are not trusted by the machine that you are initiating the job from.

Finally, you may need to use a non-standard `rsh` command within MPICH. MPICH must be reconfigured with `-rsh=command_name`, and perhaps also with `-rshnol` if the remote shell command does not support the `-l` argument. Systems using Kerberos and/or AFS may need this. See the section in the *Installation Guide* on using the secure shell `ssh`, for example.

An alternate source of the "Permission denied." message is that you have used the su command to change your effective user id. On some systems the `ch_p4` device will not work in this situation. Log in normally and try again.

2. **Q:** When I use `mpirun`, I get the message `Try again`.

   A: If you see something like this

```
% mpirun -np 2 cpi
Try again.
```

it means that you were unable to start a remote job with the remote shell command on some machine, even though you would normally be able to. This may mean that the destination machine is very busy, out of memory, or out of processes. The man page for `rshd` may give you more information.

The only fix for this is to have your system administrator look into the machine that is generating this message.

3. **Q:** When running the workstation version (`-device=ch_p4`), I get error messages of the form

   ```
   stty: TCGETS: Operation not supported on socket
   ```

   or

   ```
   stty: tcgetattr: Permission denied
   ```

   or

   ```
   stty: Can't assign requested address
   ```

   A: This means that one your login startup scripts (i.e., '`.login`' and '`.cshrc`' or '`.profile`') contains an unguarded use of the `stty` or `tset` program. For C shell users, one typical fix is to check for the variables `TERM` or `PROMPT` to be initialized. For example,

   ```
   if ($?TERM) then
       eval `tset -s -e^\? -k^U -Q -I $TERM`
   endif
   ```

   Another solution is to see if it is appropriate to add

   ```
   if ($?USER == 0 || $?prompt == 0) exit
   ```

   near the top of your '`.cshrc`' file (but *after* any code that sets up the runtime environment, such as library paths (e.g., `LD_LIBRARY_PATH`)).

4. **Q:** When running the workstation version (`-device=ch_p4`) and running either the `tstmachines` script to check the machines file or the MPICH tests, I get messages about unexpected output or differences from the expected output. I also get extra output when I run programs. MPI programs do seem to work, however.

   A: This means that one your login startup scripts (i.e., '`.login`' and '`.cshrc`' or '`.profile`' or '`.bashrc`') contains an unguarded use of some program that generates output, such as `fortune` or even `echo`. For C shell users, one typical fix is to check for the variables `TERM` or `PROMPT` to be initialized. For example,

   ```
   if ($?TERM) then
       fortune
   endif
   ```

   Another solution is to see if it is appropriate to add

   ```
   if ($?USER == 0 || $?prompt == 0) exit
   ```

   near the top of your '`.cshrc`' file (but *after* any code that sets up the runtime environment, such as library paths (e.g., `LD_LIBRARY_PATH`)).

5. **Q:** When using `mpirun` I get strange output like

   ```
   arch: No such file or directory
   ```

   A: This is usually a problem in your '`.cshrc`' file. Try the shell command

   ```
   which hostname
   ```

   If you see the same strange output, then your problem is in your '`.cshrc`' file.

6. **Q:** When I try to run my program, I get

   ```
   p0_4652:  p4_error: open error on procgroup file (procgroup): 0
   ```

   A: This indicates that the `mpirun` program did not create the expected input to run the program. The most likely reason is that the mpirun command is trying to run a program built with device `ch_p4` (workstation networks) as shared memory or some special system.

   Try the following:

   Run the program using mpirun and the `-t` argument:

   ```
   mpirun -t -np 1 foo
   ```

   This should show what mpirun would do (`-t` is for testing). Or you can use the `-echo` argument to see exactly what mpirun is doing:

   ```
   mpirun -echo -np 1 foo
   ```

   Depending on the choice made by the installer of mpich, you should select the device-specific version of mpirun over a "generic" version. For mpich installations that have been built in-place with the regular defaults, the mpirun to use can be found in '`build/<architecture>/<device>/bin`'.

7. **Q:** When trying to run a program I get this message:

   ```
   icy%  mpirun -np 2 cpi -mpiversion
   icy: icy: No such file or directory
   ```

   A: Your problem is that '`/usr/lib/rsh`' is not the remote shell program. Try the following:

   ```
   which rsh
   ls /usr/*/rsh
   ```

   You probably have '`/usr/lib`' in your path ahead of '`/usr/ucb`' or '`/usr/bin`'. This picks the 'restricted' shell instead of the 'remote' shell. The easiest fix is to just remove '`/usr/lib`' from your path (few people need it); alternately, you can move it to after the directory that contains the 'remote' shell rsh.

   Another choice would be to add a link in a directory earlier in the search path to the remote shell. For example, I have '`/home/gropp/bin/solaris`' early in my search path; I could use

```
cd /home/gropp/bin/solaris
ln -s /usr/bin/rsh  rsh
```

there (assuming '/usr/bin/rsh' is the remote shell).

8. **Q:** When trying to run a program I get this message:

   ```
   trying normal rsh
   ```

   A: You are using a version of the remote shell program that does not support the `-l` argument. Reconfigure with `-rshnol` and rebuild MPICH. You may suffer some loss of functionality if you try to run on systems where you have different user names. You might also try using `ssh`.

9. **Q:** When I run my program, I get messages like

   ```
   | ld.so: warning: /usr/lib/libc.so.1.8 has older revision than expected 9
   ```

   A: You are trying to run on another machine with an out-dated version of the basic C library. For some reason, some manufacturers do not make the shared libraries compatible between minor (or even maintenance) releases of their software. You need to have you system administrator bring the machines to the same software level.

   One temporary fix that you can use is to add the link-time option to force static linking instead of dynamic linking. For some Sun workstations, the option is `-Bstatic`.

10. **Q:** Programs never get started. Even `tstmachines` hangs.

    A: Check first that `rsh` works at all. For example, if you have workstations `w1` and `w2`, and you are running on `w1`, try

    ```
    rsh w2 true
    ```

    This should complete quickly. If it does not, try

    ```
    rsh w1 true
    ```

    (that is, use `rsh` to run `true` on the system that you are running on). If you get `permission denied`, see the help on that. If you get

    ```
    krcmd: No ticket file (tf_util)
    rsh: warning, using standard rsh: can't provide Kerberos auth data.
    ```

    then your system has a faulty installation of `rsh`. Some FreeBSD systems have been observed with this problem. Have your system administrator correct the problem (often one of an inconsistent set of `rsh/rshd` programs).

11. **Q:** When running the workstation version (`-device=ch_p4`), I get error messages of the form

    ```
    more slaves than message queues
    ```

A: This means that you are trying to run `mpich` in one mode when it was configured for another. In particular, you are specifying in your p4 procgroup file that several processes are to shared memory on a particular machine by either putting a number greater than 0 on the first line (where it signifies number of local processes besides the original one), or a number greater than 1 on any of the succeeding lines (where it indicates the total number of processes sharing memory on that machine). You should either change your procgroup file to specify only one process on line, or reconfigure `mpich` with

```
configure -device=ch_p4 -comm=shared
```

which will reconfigure the p4 device so that multiple processes can share memory on each host. The reason this is not the default is that with this configuration you will see busy waiting on each workstation, as the device goes back and forth between selecting on a socket and checking the internal shared-memory queue.

12. **Q:** My programs seem to hang in `MPI_Init`.

    A: There are a number of ways that this can happen:

    (a) One of the workstations you selected to run on is dead (try '`tstmachines`' [5]).

    (b) You linked with the FSU pthreads package; this has been reported to cause problems, particularly with the system `select` call that is part of Unix and is used by `mpich`.

    Another is if you use the library '`-ldxml`' (extended math library) on Digital Alpha systems. This has been observed to cause `MPI_Init` to hang. No workaround is known at this time; contact Digital for a fix if you need to use MPI and '`-ldxml`' together.

    The root of this problem is that the `ch_p4` device uses `SIG_USR1`, and so any library that also uses this signal can interfere with the operation of `mpich` if it is using `ch_p4`. You can rebuild `mpich` to use a different signal by using the configure argument `-listener_sig=SIGNAL_NAME` and remaking `mpich`.

13. **Q:** My program (using device `ch_p4`) fails with

```
p0_2005:  p4_error: fork_p4: fork failed: -1
          p4_error: latest msg from perror: Error 0
```

A: The executable size of your program may be too large. When a `ch_p4` or `ch_tcp` device program starts, it may create a copy of itself to handle certain communication tasks. Because of the way in which the code is organized, this (at least temporarily) is a full copy of your original program and occupies the same amount of space. Thus, if your program is over half as large as the maximum space available, you wil get this error. On SGI systems, you can use the command `size` to get the size of the executable and `swap -l` to get the available space. Note that `size` gives you the size in bytes and `swap -l` gives you the size in 512-byte blocks. Other systems may offer similar commands.

A similar problem can happen on IBM SPx using the `ch_mpl` device; the cause is the same but it originates within the IBM MPL library.

[5] '`tstmachines`' is not supported in the `globus` device

14. **Q:** Sometimes, I get the error

    ```
    Exec format error. Wrong Architecture.
    ```

    A: You are probably using NFS (Network File System). NFS can fail to keep files updated in a timely way; this problem can be caused by creating an executable on one machine and then attempting to use it from another. Usually, NFS catches up with the existence of the new file within a few minutes. You can also try using the `sync` command. `mpirun` in fact tries to run the `sync` command, but on many systems, `sync` is only advisory and will not guarentee that the file system has been made consistent.

15. **Q:** There seem to be two copies of my program running on each node. This doubles the memory requirement of my application. Is this normal?

    A: Yes, this is normal. In the `ch_p4` implementation, the second process is used to dynamically establish connections to other processes. With Version 1.1.1 of MPICH, this functionality can be placed in a separate thread on many architectures, and this second process will not be seen. To enable this, pass the option `-threaded_listener` to the '`configure`' in '`mpid/ch_p4/p4`'. You can do this my using `-p4_opts=-threaded_listener` on the `configure` command line for mpich.

16. **Q:** `MPI_Abort` sometimes doesn't work. Why?

    A: Currently (Version 1.2.0) a process detects that another process has aborted only when it tries to receive a message, and the aborting process is one that it has communicated with in the past. Thus it is porssible for a process busy with computation not to notice that one of its peers has issued an `MPI_Abort`, although for many common communication patterns this does not present a problem. This will be fixed in a future release.

9.3.3 Intel Paragon

1. **Q:** How do I run jobs with `mpirun` under NQS on my Paragon?

    A: Give `mpirun` the argument `-paragontype nqs`.

9.3.4 IBM RS6000

1. **Q:** When trying to run on an IBM RS6000 with the `ch_p4` device, I got

    ```
    % mpirun -np 2 cpi
    Could not load program /home/me/mpich/examples/basic/cpi
    Could not load library libC.a[shr.o]
    Error was: No such file or directory
    ```

    A: This means that MPICH was built with the `xlC` compiler but that some of the machines in your '`util/machines/machines.rs6000`' file do not have `xlC` installed. Either install `xlC` or rebuild MPICH to use another compiler (either `xlc` or `gcc`; `gcc` has the advantage of never having any licensing restrictions).

9.3.5 IBM SP

1. **Q:** When starting my program on an IBM SP, I get this:

   ```
   $ mpirun -np 2 hello
   ERROR: 0031-124  Couldn't allocate nodes for parallel execution.  Exiting ...
   ERROR: 0031-603  Resource Manager allocation for task: 0, node:
   me1.myuniv
   .edu, rc = JM_PARTIONCREATIONFAILURE
   ERROR: 0031-635  Non-zero status -1 returned from pm_mgr_init
   ```

   A: This means that either `mpirun` is trying to start jobs on your SP in a way different than your installation supports or that there has been a failure in the IBM software that manages the parallel jobs (all of these error messages are from the IBM `poe` command that `mpirun` uses to start the MPI job). Contact your system administrator for help in fixing this situation. You system administrator can use

   ```
   dsh -av "ps aux | egrep -i 'poe|pmd|jmd'"
   ```

   from the control workstation to search for stray IBM POE jobs that can cause this behavior. The files `/tmp/jmd_err` on the individual nodes may also contain useful diagnostic information.

2. **Q:** When trying to run on an IBM SP, I get the message from `mpirun`:

   ```
   ERROR: 0031-214  pmd: chdir </a/user/gamma/home/mpich/examples/basic>
   ERROR: 0031-214  pmd: chdir </a/user/gamma/home/mpich/examples/basic>
   ```

   A: These are messages from tbe IBM system, not from `mpirun`. They may be caused by an incompatibility between POE, the automounter (especially the AMD automounter) and the shell, especially if you are using a shell other than `ksh`. There is no good solution; IBM often recommends changing your shell to `ksh`!

3. **Q:** When I tried to run my program on an IBM SP, I got

   ```
   ERROR : Cannot locate message catalog (pepoe.cat) using current NLSPATH
   INFO  : If NLSPATH is set correctly and catalog exists, check LANG or
   LC_MESSAGES variables
   (C) Opening of "pepoe.cat" message catalog failed
   ```

   (and other variations that mention NLSPATH and "message catalog").

   A: This is a problem in your system; contact your support staff. Have them look at (a) value of NLSPATH, (b) links from '`/usr/lib/nls/msg/prime`' to the appropriate language directory. The messages are not from MPICH; they are from the IBM POE/MPL code the MPICH implementation is using.

4. **Q:** When trying to run on an IBM SP, I get this message:

   ```
   ERROR: 0031-124  Less than 2 nodes available from pool 0
   ```

A: This means that the IBM POE/MPL system could not allocate the requested nodes when you tried to run your program; most likely, someone else was using the system. You can try to use the environment variables `MP_RETRY` and `MP_RETRYCOUNT` to cause the job to wait until the nodes become available. Use `man poe` to get more information.

5. **Q:** When running on an IBM SP, my job generates the message

   ```
   Message number 0031-254 not found in Message Catalog.
   ```

   and then dies.

   A: If your user name is eight characters long, you may be experiencing a bug in the IBM POE environment. The only fix at the time this was written was to use an account whose user name was seven characters or less. Ask your IBM representative about PMR 4017X (poe with userids of length eight fails) and the associated APAR IX56566.

9.4 Programs fail at startup

9.4.1 General

1. **Q:** With some systems, you might see

   ```
   /lib/dld.sl: Bind-on-reference call failed
   /lib/dld.sl: Invalid argument
   ```

   (This example is from HP-UX), or

   ```
   ld.so: libc.so.2: not found
   ```

   (This example is from SunOS 4.1; similar things happen on other systems).

   A: The problem here is that your program is using shared libraries, and the libraries are not available on some of the machines that you are running on. To fix this, relink your program without the shared libraries. To do this, add the appropriate command-line options to the link step. For example, for the HP system that produced the errors above, the fix is to use `-Wl,-Bimmediate` to the link step. For SunOS, the appropriate option is `-Bstatic`.

9.4.2 Workstation Networks

1. **Q:** I can run programs using a small number of processes, but once I ask for more than 4–8 processes, I do not get output from all of my processes, and the programs never finish.

   A: We have seen this problem with installations using AFS. The remote shell program, `rsh`, supplied with some AFS systems limits the number of jobs that can use standard output. This seems to prevent some of the processes from exiting as well, causing the job to hang. There are four possible fixes:

(a) Use a different `rsh` command. You can probably do this by putting the directory containing the non-AFS version first in your `PATH`. This option may not be available to you, depending on your system. At one site, the non-AFS version was in '`/bin/rsh`'.

(b) Use the secure server (`serv_p4`). See the discussion in the Users Guide.

(c) Redirect all standard output to a file. The MPE routine `MPE_IO_Stdout_to_file` may be used to do this.

(d) Get a fixed `rsh` command. The likely source of the problem is an incorrect usage of the `select` system call in the `rsh` command. If the code is doing something like

```
int mask;
mask |= 1 << fd;
select( fd+1, &mask, ... );
```

instead of

```
fd_set mask;
FD_SET(fd,&mask);
select( fd+1, &mask, ... );
```

then the code is incorrect (the `select` call changed to allow more than 32 file descriptors many years ago, and the `rsh` program (or programmer!) hasn't changed with the times).

A fourth possiblity is to get an AFS version of `rsh` that fixes this bug. As we are not running AFS ourselves, we do not know whether such a fix is available.

2. **Q:** Not all processes start.

   A: This can happen when using the `ch_p4` device and a system that has extremely small limits on the number of remote shells you can have. Some systems using "Kerberos" (a network security package) allow only three or four remote shells; on these systems, the size of `MPI_COMM_WORLD` will be limited to the same number (plus one if you are using the local host).

   The only way around this is to try the secure server; this is documented in the `mpich` installation guide. Note that you will have to start the servers "by hand" since the `chp4_servs` script uses remote shell to start the servers.

9.5 Programs fail after starting

9.5.1 General

1. **Q:** I use `MPI_Allreduce`, and I get different answers depending on the number of processes I'm using.

   A: The MPI collective routines may make use of associativity to achieve better parallelism. For example, an

```
MPI_Allreduce( &in, &out, MPI_DOUBLE, 1, ... );
```

might compute

$$(((((((a+b)+c)+d)+e)+f)+g)+h)$$

or it might compute

$$((a+b)+(c+d))+((e+f)+(g+h)),$$

where $a, b, \ldots$ are the values of `in` on each of eight processes. These expressions are equivalent for integers, reals, and other familar objects from mathematics but are *not* equivalent for datatypes, such as floating point, used in computers. The association that MPI uses will depend on the number of processes, thus, you may not get exactly the same result when you use different numbers of processes. Note that you are not getting a wrong result, just a different one (most programs assume the arithmetic operations are associative).

2. **Q:** I get the message

   ```
   No more memory for storing unexpected messages
   ```

   when running my program.

   A: `mpich` has been configured to "aggressively" deliver messages. This is appropriate for certain types of parallel programs, and can deliver higher performance. However, it can cause applications to run out of memory when messages are delivered faster than they are processed. The `mpich` implementation does attempt to control such memory usage, but there are still a few more steps to take in the `mpich` implementation. As a work-around, you can introduce synchronous sends or barriers into your code. The need for these will be eliminated in a future `mpich` release; the 1.2.0 release is much more careful about its memory use.

3. **Q:** My Fortran program fails with a BUS error.

   A: The C compiler that MPICH was built with and the Fortran compiler that you are using have different alignment rules for things like `DOUBLE PRECISION`. For example, the GNU C compiler `gcc` may assume that all `double`s are aligned on eight-byte boundaries, but the Fortran language requires only that `DOUBLE PRECISION` align with `INTEGER`s, which may be four-byte aligned.

   There is no good fix. Consider rebuilding MPICH with a C compiler that supports weaker data alignment rules. Some Fortran compilers will allow you to force eight-byte alignment for `DOUBLE PRECISION` (for example, `-dalign` or `-f` on some Sun Fortran compilers); note though that this may break some correct Fortran programs that exploit Fortran's storage association rules.

   Some versions of `gcc` may support `-munaligned-doubles`; `mpich` should be rebuilt with this option if you are using `gcc`, version 2.7 or later.

4. **Q:** I'm using `fork` to create a new process, or I'm creating a new thread, and my code fails.

   A: The `mpich` implementation is not thread safe and does not support either fork or the creation of new processes. Note that the MPI specification is thread safe, but implementations are not required to be thread safe. At this writing, few implementations are thread-safe, primarily because this reduces the performance of the MPI implementation (you at least need to check to see if you need a thread lock, actually getting and releasing the lock is even more expensive).

The `mpich` implementation supports the `MPI_Init_thread` call; with this call, new in MPI-2, you can find out what level of thread support the MPI implementation supports. As of version 1.2.0 of `mpich`, only `MPI_THREAD_SINGLE` is supported. Future versions of `mpich` will support `MPI_THREAD_MULTIPLE`.

Q: C++ programs execute global destructors (or constructors) more times than expected. For example:

```
class Z {
public:
  Z()  { cerr << "*Z" << endl; }
  ~Z() { cerr << "+Z" << endl; }
};

Z z;

int main(int argc, char **argv) {
  MPI_Init(&argc, &argv);
  MPI_Finalize();
}
```

when running with the `ch_p4` device on two processes executes the destructor twice for each process.

A: The number of processes running before `MPI_Init` or after `MPI_Finalize` is not defined by the MPI standard; you can not rely on any specific behavior. In the `ch_p4` case, a new process is `fork`ed to handle connection requests; it terminates with the end of the program.

9.5.2 HPUX

1. **Q:** My Fortran programs seem to fail with `SIGSEGV` when running on HP workstations. **A:** Try compiling and linking the Fortran programs with the option `+T`. This *may* be necessary to make the Fortran environment correctly handle interrupts used by `mpich` to create connections to other processes.

9.5.3 ch_shmem device

1. **Q:** My program sometimes hangs when using the `ch_shmem` device. **A:** Make sure that you are linking with *all* of the correct libraries. If you are not using `mpicc`, try using `mpicc` to link your application. The reason for this is that correct operation of the shared-memory version may depend on additional, system-provided libraries. For example, under Solaris, the thread library must used, otherwise, non-functional versions of the mutex routines critical to the correct functioning of the MPI implementation are taken from '`libc`' instead.

9.5.4 LINUX

1. **Q:** Processes fail with messages like

   ```
   p0_1835:  p4_error: Found a dead connection while looking for messages: 1
   ```

   A: What is happening is that the TCP implementation on this platform is deciding that the connection has "failed" when it really hasn't. The current MPICH implementation assumes that the TCP implementation will not close connections and has no code to reanimate failed connections. Future versions of MPICH will work around this problem.

   In addition, some users have found that the single processor kernel is more stable than the SMP kernel.

9.6 Trouble with Input and Output

9.6.1 General

1. **Q:** I want output from `printf` to appear immediately.

   A: This is really a feature of your C and/or Fortran runtime system. For C, consider

   ```
   setbuf( stdout, (char *)0 );
   ```

9.6.2 IBM SP

1. **Q:** I have code that prompts the user and then reads from standard input. On IBM SPx systems, the prompt does not appear until *after* the user answers the prompt!

   A: This is a feature of the IBM POE system. There is a POE routine, `mpc_flush(1)`, that you can use to flush the output. Read the man page on this routine; it is synchronizing over the entire job and cannot be used unless all processes in `MPI_COMM_WORLD` call it. Alternately, you can always end output with the newline character (`\n`); this will cause the output to be flushed but will also put the user's input on the next line.

9.6.3 Workstation Networks

1. **Q:** I want standard output (`stdout`) from each process to go to a different file.

   A: `mpich` has no built-in way to do this. In fact, it prides itself on gathering the stdouts for you. You can do one of the following:

   (a) Use Unix built-in commands for redirecting `stdout` from inside your program (`dup2`, etc.). The MPE routine `MPE_IO_Stdout_to_file`, in '`mpe/mpe_io.c`', shows one way to do this. Note that in Fortran, the approach of using `dup2` will work only if the Fortran `PRINT` writes to `stdout`. This is common but by no means universal.

(b) Write explicitly to files instead of to `stdout` (use `fprintf` instead of `printf`, etc.). You can create the file name from the process's rank. This is the most portable way.

9.7 Upshot and Nupshot

The `upshot` and `nupshot` programs require specific versions of the `tcl` and `tk` languages. This section describes only problems that may occur once these tools have been successfully built.

9.7.1 General

1. **Q:** When I try to run `upshot` or `nupshot`, I get

   ```
   No display name and no $DISPLAY environment variables
   ```

   A: Your problem is with your X environment. Upshot is an X program. If your workstation name is '`foobar.kscg.gov.tw`', then before running any X program, you need to do

   ```
   setenv DISPLAY foobar.kscg.gov.tw:0
   ```

   If you are running on some other system and displaying on foobar, you might need to do

   ```
   xhost +othermachine
   ```

   on foobar, or even

   ```
   xhost +
   ```

   which gives all other machines permission to write on foobar's display.

   If you do not have an X display (you are logged in from a Windows machine without an X capability) then you cannot use `upshot`.

2. **Q:** When trying to run `upshot`, I get

   ```
   upshot: Command not found.
   ```

   A: First, check that `upshot` is in your path. You can use the command

   ```
   which upshot
   ```

   to do this.

   If it is in your path, the problem may be that the name of the `wish` interpreter is too long for your Unix system. Look at the first line of the '`upshot`' file. It should be something like

```
#! /usr/local/bin/wish -f
```

If it is something like

```
#! /usr/local/tcl7.4-tk4.2/bin/wish -f
```

this may be too long of a name (some Unix systems restrict this first line to a mere 32 characters). To fix this, you'll need to put a link to 'wish' somewhere where the name will be short enough. Alternately, you can start upshot with

```
/usr/local/tcl7.4-tk4.2/bin/wish -f /usr/local/mpich/bin/upshot
```

9.7.2 HP-UX

1. **Q:** When trying to run upshot under HP-UX, I get error messages like

   ```
   set: Variable name must begin with a letter.
   ```

   or

   ```
   upshot: syntax error at line 35: '(' unexpected
   ```

   A: Your version of HP-UX limits the shell names for very short strings. Upshot is a program that is executed by the wish shell, and for some reason HP-UX is both refusing to execute in this shell and then trying to execute the upshot program using your current shell (e.g., 'sh' or 'csh'), instead of issuing a sensible error message about the command name being too long. There are two possible fixes:

   (a) Add a link with a much shorter name, for example

   ```
   ln -s /usr/local/tk3.6/bin/wish /usr/local/bin/wish
   ```

   Then edit the upshot script to use this shorter name instead. This may require root access, depending on where you put the link.

   (b) Create a regular shell program containing the lines

   ```
   #! /bin/sh
   /usr/local/tk3.6/bin/wish -f /usr/local/mpi/bin/upshot
   ```

   (with the appropriate names for both the 'wish' and 'upshot' executables).

   Also, file a bug report with HP. At the very least, the error message here is wrong; also, there is no reason to restrict general shell choices (as opposed to login shells).

Appendices

A Automatic generation of profiling libraries

The profiling wrapper generator (wrappergen) has been designed to complement the MPI profiling interface. It allows the user to write any number of 'meta' wrappers which can be applied to any number of MPI functions. Wrappers can be in separate files, and can nest properly, so that more than one layer of profiling may exist on indiividual functions.

Wrappergen needs three sources of input:

1. A list of functions for which to generate wrappers.
2. Declarations for the functions that are to be profiled. For speed and parsing simplicity, a special format has been used. See the file '`proto`'.
3. Wrapper definitions.

The list of functions is simply a file of whitespace-separated function names. If omitted, any `forallfn` or `fnall` macros will expand for every function in the declaration file.

A.1 Writing wrapper definitions

Wrapper definitions themselves consist of C code with special macros. Each macro is surrounded by the {{ }} escape sequence. The following macros are recognized by wrappergen:

`{{fileno}}`

An integral index representing which wrapper file the macro came from. This is useful when declaring file-global variables to prevent name collisions. It is suggested that all identifiers declared outside functions end with `_{{fileno}}`. For example:

```
static double overhead_time_{{fileno}};
```

might expand to:

```
static double overhead_time_0;
```

(end of example).

```
{{forallfn <function name escape> <function A> <function B> ... }}
   ...
{{endforallfn}}
```

The code between `{{forallfn}}` and `{{endforallfn}}` is copied once for every function profiled, except for the functions listed, replacing the escape string specified by `<function name escape>` with the name of each function. For example:

```
{{forallfn fn_name}}static int {{fn_name}}_ncalls_{{fileno}};
{{endforallfn}}
```

might expand to:

```
static int MPI_Send_ncalls_1;
static int MPI_Recv_ncalls_1;
static int MPI_Bcast_ncalls_1;
```

(end of example)

```
{{foreachfn <function name escape> <function A> <function B> ... }}
  ...
{{endforeachfn}}
```

`{{foreachfn}}` is the same as `{{forallfn}}` except that wrappers are written only the functions named explicitly. For example:

```
{{forallfn fn_name mpi_send mpi_recv}}
   static int {{fn_name}}_ncalls_{{fileno}};
{{endforallfn}}
```

might expand to:

```
static int MPI_Send_ncalls_2;
static int MPI_Recv_ncalls_2;
```

(end of example)

```
{{fnall <function name escape> <function A> <function B> ... }}
  ...
  {{callfn}}
  ...
{{endfnall}}
```

`{{fnall}}` defines a wrapper to be used on all functions except the functions named. Wrappergen will expand into a full function definition in traditional C format. The `{{callfn}}` macro tells wrappergen where to insert the call to the function that is being profiled. There must be exactly one instance of the `{{callfn}}` macro in each wrapper definition. The macro specified by `<function name escape>` will be replaced by the name of each function.

Within a wrapper definition, extra macros are recognized.

```
{{vardecl <type> <arg> <arg> ... }}
```

Use `vardecl` to declare variables within a wrapper definition. If nested macros request variables through vardecl with the same names, wrappergen will create unique names by adding consecutive integers to the end of the requested name (var, var1, var2, ...) until a unique name is created. It is unwise to declare variables manually in a wrapper definition, as variable names may clash with other wrappers, and the variable declarations may occur later in the code than statements from other wrappers, which is illegal in classical and ANSI C.

`{{<varname>}}`

If a variable is declared through `vardecl`, the requested name for that variable (which may be different from the uniquified form that will appear in the final code) becomes a temporary macro that will expand to the uniquified form. For example,

```
{{vardecl int i d}}
```

may expand to:

```
int i, d3;
```

(end of example)

`{{<argname>}}`

Suggested but not neccessary, a macro consisting of the name of one of the arguments to the function being profiled will be expanded to the name of the corresponding argument. This macro option serves little purpose other than asserting that the function being profilied does indeed have an argument with the given name.

`{{<argnum>}}`

Arguments to the function being profiled may also be referenced by number, starting with 0 and increasing.

`{{returnVal}}`

`ReturnVal` expands to the variable that is used to hold the return value of the function being profiled.

`{{callfn}}`

`callfn` expands to the call of the function being profiled. With nested wrapper definitions, this also represents the point at which to insert the code for any inner nested functions. The nesting order is determined by the order in which the wrappers are encountered by wrappergen. For example, if the two files '`prof1.w`' and '`prof2.w`' each contain two wrappers for `MPI_Send`, the profiling code produced when using both files will be of the form:

```
int MPI_Send( args...)
arg declarations...
{
   /*pre-callfn code from wrapper 1 from prof1.w */
   /*pre-callfn code from wrapper 2 from prof1.w */
   /*pre-callfn code from wrapper 1 from prof2.w */
   /*pre-callfn code from wrapper 2 from prof2.w */

   returnVal = MPI_Send( args... );
```

```
    /*post-callfn code from wrapper 2 from prof2.w */
    /*post-callfn code from wrapper 1 from prof2.w */
    /*post-callfn code from wrapper 2 from prof1.w */
    /*post-callfn code from wrapper 1 from prof1.w */

    return returnVal;
  }
```

```
{{fn <function name escape>  <function A> <function B> ... }}
  ...
  {{callfn}}
  ...
{{endfnall}}
```

fn is identical to fnall except that it only generates wrappers for functions named explicitly. For example:

```
{{fn this_fn MPI_Send}}
  {{vardecl int i}}
  {{callfn}}
  printf( "Call to {{this_fn}}.\n" );
  printf( "{{i}} was not used.\n" );
  printf( "The first argument to {{this_fn}} is {{0}}\n" );
{{endfn}}
```

will expand to:

```
int  MPI_Send( buf, count, datatype, dest, tag, comm )
void * buf;
int count;
MPI_Datatype datatype;
int dest;
int tag;
MPI_Comm comm;
{
  int  returnVal;
  int i;
  returnVal = PMPI_Send( buf, count, datatype, dest, tag, comm );
  printf( "Call to MPI_Send.\n" );
  printf( "i was not used.\n" );
  printf( "The first argument to MPI_Send is buf\n" );
  return returnVal;
}
```

A sample wrapper file is in 'sample.w' and the corresponding output file is in 'sample.out'.

B Options for mpirun

The options for mpirun[6], as shown by mpirun -help, are

```
mpirun [mpirun_options...] <progname> [options...]

  mpirun_options:
    -arch <architecture>
            specify the architecture (must have matching machines.<arch>
            file in ${MPIR_HOME}/bin/machines) if using the execer
    -h      This help
    -machine <machine name>
            use startup procedure for <machine name>
    -machinefile <machine-file name>
            Take the list of possible machines to run on from the
            file <machine-file name>
    -np <np>
            specify the number of processors to run on
    -nolocal
            don't run on the local machine (only works for
            p4 and ch_p4 jobs)
    -stdin filename
            Use filename as the standard input for the program.  This
            is needed for programs that must be run as batch jobs, such
            as some IBM SP systems and Intel Paragons using NQS (see
            -paragontype below).
    -t      Testing - do not actually run, just print what would be
            executed
    -v      Verbose - throw in some comments
    -dbx    Start the first process under dbx where possible
    -gdb    Start the first process under gdb where possible
    -xxgdb  Start the first process under xxgdb where possible
             (on the Meiko, selecting either -dbx or -gdb starts prun
             under totalview instead)

    Options for the globus device:

    With the exception of -h, these are the only mpirun options supported
    by the globus device.

    -machinefile <machine-file name>
            Take the list of possible machines to run on from the
            file <machine-file name>
    -np <np>
            specify the number of processors to run on
```

[6] Not all the options are supported by the globus device. See the section "Options for the globus device" in this appendix.

```
-leave_pg
        Don't delete the globus RSL file after running
-globusargs dumprsl | {stage, nostage}
        dumprsl - display the RSL string that would have been
                  used to submit the job.  using this option
                  does not run the job.
        {stage, nostage} - stage takes the executable named on
                           the mpirun command and transfers it
                           to all the executable machines
                           (~/.gass_cache) and removes it
                           after executing.
                           this only works when all the executable
                           machines are binary compatible.
                           the default value is nostage.
        when specifying more than one value to -globusargs, you
        must surrond them all with double quotation marks, e.g.,
        -globusargs "dumprsl stage"
-globusrsl <globus-rsl-file name>
        <globus-rsl-file name> must contain a Globus RSL
        string.  When using this option all other mpirun options
        are ignored and -leave_pg is implied.


Special Options for Batch Environments:

-mvhome Move the executable to the home directory.  This
        is needed when all file systems are not cross-mounted
        Currently only used by anlspx
-mvback files
        Move the indicated files back to the current directory.
        Needed only when using -mvhome; has no effect otherwise.
-maxtime min
        Maximum job run time in minutes.  Currently used only
        by anlspx.  Default value is $max_time minutes.
-nopoll Do not use a polling-mode communication.
        Available only on IBM SPx.
-mem value
       This is the per node memory request (in Mbytes).  Needed for some
       CM-5s. ( Default $max_mem. )

-cpu time
       This is the the hard cpu limit used for some CM-5s in
       minutes. (Default $maxtime minutes.)

Special Options for IBM SP2:

-cac name
        CAC for ANL scheduler.  Currently used only by anlspx.
```

```
          If not provided will choose some valid CAC.

    Special Options for Intel Paragon:

    -paragontype name
           Selects one of default, mkpart, NQS, depending on how you want
           to submit jobs to a Paragon.

    -paragonname name
           Remote shells to name to run the job (using the -sz method) on
           a Paragon.

    -paragonpn name
           Name of partition to run on in a Paragon (using the -pn name
           command-line argument)
```

On exit, `mpirun` returns a status of zero unless `mpirun` detected a problem, in which case it returns a non-zero status (currently, all are one, but this may change in the future).

Multiple architectures may be handled by giving multiple `-arch`[7] and `-np` arguments. For example, to run a program on 2 sun4s and 3 rs6000s, with the local machine being a sun4, use

```
mpirun -arch sun4 -np 2 -arch rs6000 -np 3 program
```

This assumes that program will run on both architectures. If different executables are needed, the string '%a' will be replaced with the arch name. For example, if the programs are `program.sun4` and `program.rs6000`, then the command is

```
mpirun -arch sun4 -np 2 -arch rs6000 -np 3 program.%a
```

If instead the executables are in different directories; for example, '`/tmp/me/sun4`' and '`/tmp/me/rs6000`', then the command is

```
mpirun -arch sun4 -np 2 -arch rs6000 -np 3 /tmp/me/%a/program
```

It is important to specify the architecture with `-arch` *before* specifying the number of processors. Also, the *first* `arch` command must refer to the processor on which the job will be started. Specifically, if `-nolocal` is *not* specified, then the first `-arch` must refer to the processor from which mpirun is running.

C MPI, Globus, and GUSTO

In the section we describe how to run MPI programs using the MPICH Globus device in the GUSTO distributed computing environment.

[7] `-arch` is not supported by the `globus` device.

C.1 Using the globus device on GUSTO

Three features of the GUSTO environment make the use of the globus device particularly easy:

- The public-key-based implementation of Globus security services are used; this allows you to log on just once and then access resources at a variety of GUSTO sites. (However, you must first set up your Globus security environment: see below).
- Globus process creation servers called Globus Resource Allocation Managers (GRAMs) or simply *resource managers* already exist on the various GUSTO resources.
- You have access to a Lightweight Directory Access Protocol (LDAP) database called the *Metacomputing Directory Service (MDS)* where information describing Globus installations is stored. We shall see how this is used below.

Perform the following experiment to verify that your machine has the Globus client software installed and configured to use GUSTO. Use the following `ldapsearch` command to query MDS for the names of all GUSTO resource managers:[8],

```
% <globusinstalldir>/bin/ldapsearch "mn=*" | grep ^mn
```

which should result in something similar to this

```
mn=bolas.isi.edu-fork@globus.org, ou=ISI, o=University of Southern California, o=Globus, c=US
mn=bolas.isi.edu-fork@globus.org
mn=fr1n12.mhpcc.edu-fork@globus.org, o=Maui High Performance Computing Center, o=Globus, c=US
mn=fr1n12.mhpcc.edu-fork@globus.org
mn=fr37n13.mhpcc.edu-fork@globus.org, o=Maui High Performance Computing Center, o=Globus, c=US
mn=fr37n13.mhpcc.edu-fork@globus.org
mn=sif.ncsa.uiuc.edu-lsf@globus.org, o=NCSA, o=Globus, c=US
mn=sif.ncsa.uiuc.edu-lsf@globus.org
mn=pitcairn.mcs.anl.gov-fork@globus.org, ou=MCS, o=Argonne National Laboratory, o=Globus, c=US
mn=pitcairn.mcs.anl.gov-fork@globus.org
```

C.1.1 Setting up security for GUSTO

Because GUSTO uses public key security, you must spend a few minutes setting up your security environment before you can start using the globus device on GUSTO. This entails obtaining a private key from the GUSTO certificate authority (CA) and setting up some local configuration information. This process is somewhat complex but only has to be performed once. See `http://www.globus.org/security/tutorial.html` for a more detailed discussion of these topics.

1. Set your `GLOBUS_DIR` environment variable to point to the top level Globus directory:

   ```
   % setenv GLOBUS_DIR <globusinstalldir>
   ```

[8] Complete instructions regarding how to use `ldapsearch` to query MDS can be found at `http://www.globus.org`.

2. Augment your path to include the bin directories for both Globus and the SSL libraries, which must also be installed to use the globus device on GUSTO (see `http://www.globus.org` for details). These are

```
$GLOBUS_DIR/bin
<sslinstalldir>/bin
```

3. Make a directory in which to store your certificate and key:

```
% mkdir ~/cert
% cd ~/cert
```

4. Run the SSL certreq program to generate your certificate request and private key:

```
% certreq
```

Something like this will appear upon your screen. It may take a few seconds to finish generating the private key.

```
Using configuration from
/soft/pub/packages/SSLeay-0.8.1/etc/ssleay.globus.cnf
Generating a 1024 bit RSA private key
...............................+++++
.....................+++++
writing new private key to 'newkey.pem'
Enter PEM pass phrase:
```

At this point, you should enter in a pass phrase. A pass phrase is basically a password, except that it can be longer (64 characters) and can include spaces. It will immediately ask you to re-enter your password, for verification. The subsequent screen output will be:

```
Verifying password - Enter PEM pass phrase:
-----
You are about to be asked to enter information that will be
incorporated
into your certificate request.
What you are about to enter is what is called a Distinguished Name
or a DN.
There are quite a few fields but you can leave some blank
For some fields there will be a default value,
If you enter '.', the field will be left blank.
-----
Country Name (2 letter code) [US]:
```

You can press return to answer any question with the default value (within the brackets []). Otherwise, enter the appropriate information. The next few questions are as follows:

```
Main Organization [Globus]:
Home Globus Site [Argonne National Laboratory]:
Organizational Unit Name (eg, section) [MCS]:
name (eg, Globus id without the @globus.org) []:
```

For name, enter your old "globusid", which tended to be your username or last name, (e.g., smartin, wsmith, foster).

The next questions pertain to optional information not currently being used by the authentication program. You may simply hit return to all further questions. The screen output will be:

```
Please enter the following 'extra' attributes
to be sent with your certificate request
A challenge password []:
An optional company name []:
Private key is in newkey.pem
Request is in newreq.pem
E-Mail the newreq.pem file to Globus CA:
ca@globus.org
```

At this point, you are done with the certreq script. It will return you to the UNIX prompt, having created 2 new files in your directory, `newkey.pem` and `newreq.pem`.

5. Mail the newreq.pem file to the GUSTO CA:

   `% mail ca@globus.org < newreq.pem`

   You should receive a response from the CA with your signed certificate.

6. Store the certificate received from the GUSTO CA (including the

   ```
   ----BEGIN CERTIFICATE----
   ```

   and

   ```
   ----END CERTIFICATE----
   ```

   delimiters) in the file `~/cert/newcert.pem`.

7. Set protection modes on the files in `~/cert`:

   ```
   % chmod 444 newcert.pem
   % chmod 400 newkey.pem
   ```

   These protections are essential if you are to insure the security and integrity of your private key and certificate. Basically they ensure that the certificate is world readable but unalterable, while the private key file is readable only by you, the user, and also unalterable.

8. Use the `setenv` command to set the environment variables used to locate your certificate file, private key, and trusted certificates:

```
% cd
% setenv X509_CERT_DIR $GLOBUS_DIR/share
% setenv X509_USER_CERT cert/newcert.pem
% setenv X509_USER_KEY cert/newkey.pem
% setenv X509_USER_PROXY cert/newproxy.pem
```

The first of these commands indicates the directory containing the trusted certificate; the second the filename of the file containing your certificate; the third the filename of the file containing your private key; and the fourth the filename in which your temporary proxy certificate and key should be stored.

9. Enable access to the resources that you wish to use. Before you can use any GUSTO resource, you must (a) have an account on those resources, and (b) have any entry in an access control list called a `globusmap` file associated with the resource. You must email the Globus administrator of each resource in question.

C.1.2 Authenticating yourself to GUSTO

Now that you have set up your Globus security environment, you are ready to run some MPI programs. As a first step, we authenticate ourselves ("log on") to GUSTO by running the command `cinit`. This command creates a *temporary credential*, which allows you to use GUSTO resources for a certain amount of time. This credential is stored in a file, the name of which must be recorded in the environment variable `X509_USER_PROXY`. Hence, we might type:

```
% setenv X509_USER_PROXY /tmp/my_temporary_cert
% cinit -out $X509_USER_PROXY
```

The temporary credential is valid for a default period of time, typically 12 hours. You can change this period by using the `-hours` flag on the `cinit` command, for example:

```
% setenv X509_USER_PROXY /tmp/my_temporary_cert
% cinit -hours 6 -out $X509_USER_PROXY
```

You may acquire a new security credential at any time. If you acquire a new credential before a previous one expires, the new credential simply overwrites the old one. **Attempting to start an MPI application in the presence of an expired security credential will result in failure.**

C.1.3 Using `mpirun` on GUSTO

Before typing your first `mpirun` command you must identify the computers on which you wish to run your application. This is done by listing the *manager names* associated with these computers in a `machines` file on your Globus client. For example, the following `machines` file

```
ico16.mcs.anl.gov-easymcs@globus.org 10
sp023e.sp.uh.edu-loadleveler@globus.org 5
```

names managers associated with two IBM SPs, one at Argonne and the other at the University of Houston. Assuming the `machines` file and executable `myapp` are in your current directory, you can then start your application as follows:

```
% mpirun -np 15 -globusargs stage myapp
```

This command loads `myapp` on 10 nodes on the Argonne SP, transfers a copy of `myapp` to the Houston SP (`-globusargs stage`), and loads `myapp` on 5 nodes there. (The number of nodes to create on each machine are specified by the counts appearing at the end of each line in the `machines` file.) Issues of authentication and the submission of appropriate requests to the Argonne and Houston SP schedulers are handled automatically. All 15 nodes behave as a single MPI application, i.e., a single `MPI_COMM_WORLD` with nodes ranked 0 through 14. Standard output and standard error are routed back to the originating node. Hence, the behavior is identical to that of an MPI program running on a single 15-node parallel computer.

Determining resource manager names. This example assumes that you know the resource manager names for the computers on which you want to run. To learn the manager name for a particular machine[9], e.g., `pitcairn.mcs.anl.gov`, use the `ldapsearch` command introduced earlier:

```
yukon% ldapsearch "hn=pitcairn.mcs.anl.gov" | grep ^mn
mn=pitcairn.mcs.anl.gov-fork@globus.org, ou=MCS, o=Argonne National Laboratory,
o=Globus, c=US
mn=pitcairn.mcs.anl.gov-fork@globus.org
```

which returns two different names for the one GRAM running on `pitcairn.mcs.anl.gov`. The first, longer name is called the *distinguished name*; we are only interested in the second, shorter name, `pitcairn.mcs.anl.gov-fork@globus.org`.

To find all the manager names at a particular location, e.g., Argonne National Laboratory,

```
ldapsearch "mn=*" mn | grep ^mn | grep "anl.gov"
mn=pitcairn.mcs.anl.gov-fork@globus.org, ou=MCS, o=Argonne National Laboratory,
o=Globus, c=US
mn=pitcairn.mcs.anl.gov-fork@globus.org
mn=ico16.mcs.anl.gov-fork@globus.org, ou=MCS, o=Argonne National Laboratory, o=G
lobus, c=US
mn=ico16.mcs.anl.gov-fork@globus.org
mn=ico16.mcs.anl.gov-easymcs@globus.org, ou=MCS, o=Argonne National Laboratory,
o=Globus, c=US
mn=ico16.mcs.anl.gov-easymcs@globus.org
```

[9] Although a single machine typically has one GRAM, multiple GRAMs may run on a single machine.

Specifying node counts. The optional numbers appearing at the end of each line in a `machines` file (default value = 1) are used to determine the maximum number of nodes to create on each machine. Hence, given the `machines` file above, the command `mpirun -np 8` would start just 8 nodes on the Argonne SP. `mpirun` "wraps around" the `machines` file, so `-np 18` would create 10 nodes on the Argonne SP, 5 nodes at Houston, and a further 3 nodes at Argonne. These three groups of nodes comprise three distinct "subjobs." This distinction is important because communication within a subjob can be very different from communication between subjobs, particularly on MPPs such as the IBM SP. Communication between subjobs is always done using TCP/IP. Communication within a subjob is done using the fastest protocol available, for example IBM's MPL.

Staging. In the above example, we used the `-globusargs stage` option to request that our application be staged to the computers on which we wanted to run. Staging works here because the computers in question are binary compatible. If even one of the platforms listed in the `machines` file is not binary compatible then you may not use the `-globusargs stage` option. Instead, you must either stage executables manually, prior to running the program, or use the more flexible staging commands described in C.1.4 below.

If you wanted to run an application on a cluster of binary compatible workstations (one process on each) that all share the same filesystem, then staging is not required. In this case you write a `machines` file listing the Globus servers in your cluster, e.g.,

```
pitcairn.mcs.anl.gov-fork@globus.org
tuva.mcs.anl.gov-fork@globus.org
```

and omit the `-globusargs stage` option from the `mpirun` command:

```
% mpirun -np 2 myapp
```

Locating the `machines` file. The `mpirun` command determines which `machines` file to use as follows:

1. If a `-machinefile <machinefilename>` argument is specified on the `mpirun` command, it uses that; otherwise,
2. it looks for a file `machines` in the directory in which you typed `mpirun`; and finally,
3. it looks for a `machines` file in `<mpidir>/lib/<arch>/globus` where `<mpidir>` is the directory where you built MPICH and `<arch>` is the architecture MPICH was built on, e.g., `solaris`, `IRIX64`, ...

If none of these information are provided, then `mpirun` fails.

C.1.4 Advanced features of the globus device

As noted above, the `-globusargs stage` command does not support staging when machines are not binary compatible. In this situation, we must currently use something called a

Resource Specification Language (RSL) request to specify the executable filename for each machine. This technique is very flexible, but rather complex; work is currently underway to simplify the manner in which these issues are addressed.

The easiest way to learn how to write your own RSL request is to study the one generated for you by mpirun. Consider the example where we wanted to run an application on a cluster of workstations. Recall our `machines` file looked like this:

```
pitcairn.mcs.anl.gov-fork@globus.org
tuva.mcs.anl.gov-fork@globus.org
```

To view the RSL request generated in this situation, *without* actually launching the program, we type the following `mpirun` command:

```
% mpirun -globusargs dumprsl -np 2 myapp 123 456
```

which produces the following output:

```
+
( &(resourceManagerContact="pitcairn.mcs.anl.gov:8711:pitcairn.mcs.anl.gov-f
ork@globus.org")
   (count=1)
   (label="subjob 0")
   (arguments=" 123 456")
   (directory=/homes/karonis/MPI/mpich.yukon/mpich/lib/IRIX64/globus)
   (executable=/homes/karonis/MPI/mpich.yukon/mpich/lib/IRIX64/globus/myapp)
)
( &(resourceManagerContact="tuva.mcs.anl.gov:8711:tuva.mcs.anl.gov-fork@glob
us.org")
   (count=1)
   (label="subjob 1")
   (arguments=" 123 456")
   (directory=/homes/karonis/MPI/mpich.yukon/mpich/lib/IRIX64/globus)
   (executable=/homes/karonis/MPI/mpich.yukon/mpich/lib/IRIX64/globus/myapp)
)
```

This RSL specification specifies such things as the "contact string" for the GRAMs that we will be using, the number of nodes that we want to create, a unique label for each subjob, our home directory, and the name of the executable that we will be using.

We can write a custom RSL request by simply modifying the request obtained above. For example, if we want to use a different executable on the two different machines, we can simply change the executable name. Once we have made this change, we use the `-globusrsl` option to supply this modified request to `mpirun`:

```
% mpirun -globusrsl <myrslrequestfile>
```

where `<myrslrequestfile>` is the filename of your RSL reqeust. You do not specify any other arguments to `mpirun` (e.g., `-np`, executable, command line arguments, etc.), and even the `machines` file is ignored, as all required information is contained in the RSL request.

RSL is a flexible language capable of doing much more than has been presented here. For example, it can be used to stage executables and to set environment variables on remote computers before starting execution. A full description of the language can be found at `http://www.globus.org`.

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