ANL/MCS-TM-ANL-96/6

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

by

William Gropp and Ewing Lusk

MATHEMATICS AND
COMPUTER SCIENCE
DIVISION

Contents

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 computing environments. This paper describes how to build and run MPI programs using the mpich implementation of MPI.

1 Introduction

mpich is a freely available implementation of the MPI standard that runs on a wide variety of systems. This document assumes that mpich has already been installed; if not, you should first read *Installation Guide to* mpich*, a Portable Implementation of MPI.* For concreteness, this document assumes that the mpich implementation is installed into '/usr/local/mpi' and that you have added '/usr/local/mpi/bin' to your path. If mpich is installed somewhere else, you should make the appropriate changes.

In addition, you need to know what systems mpich has been built and installed for. You need to know the *architecture* and the *device*. The architecture indicates the kind of processor; examples are sun4 and intelnx. The device indicates how mpich performs communication between processes; examples are ch_p4 and ch_nx. The libraries and special commands for each architecture/device pair are provided in the directory '/usr/local/mpi/lib/<architecture>/<device>'. For example, the directory for the sun4 architecture and ch_p4 device is in '/usr/local/mpi/lib/sun4/ch_p4'. This directory should also be in your path (or you should use the full path for some commands; we'll indicate which).

This approach makes it easy to have mpich available for several different parallel machines. For example, you might have a workstation cluster version and a massively parallel version.

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. These commands are mpicc for C programs and mpif77 for Fortran programs.

2.1 The mpicc and mpif77 commands

The mpich implementation provides two commands for compiling and linking C (mpicc) and Fortran (mpif77) 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 [6]. This is a program to compile or link MPI programs. 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 or Fortran compiler. For example,

```
    mpicc -c foo.c
    mpif77 -c foo.f
```

and

```
    mpicc -o foo foo.o
    mpif77 -o foo foo.o
```

Commands for the linker may include additional libraries. For example, to use some routines from the MPE library, enter

```
    mpicc -o foo foo.o -lmpe
```

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

```
    mpicc -o foo foo.c
    mpif77 -o foo foo.f
```

may also be used. Note that just as for regular C programs, you may need to specify the math library with '`-lm`':

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

These commands are set up for a specific architecture and `mpich` device and are located in the directory that contains the MPI libraries. For example, if the architecture is `sun4` and the device is `ch_p4`, these commands may be found in '`/usr/local/mpi/lib/sun4/ch_p4`' (assuming that `mpich` is installed in '`/usr/local/mpi`').

2.2 Running with mpirun

To run an MPI program, use the `mpirun` command, which is located in '`/usr/local/mpi/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).

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.

2.3 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/mpi/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 two basic types of parallel environments: parallel computers and clusters of workstations. Naturally, a parallel computer (usually) provides an integrated, relatively easy way of running parallel programs. Clusters of workstations and other computers, 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.

3.1 Difference between workstation clusters and MPPs

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 3.3 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/mpi/bin/machines`'. 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` and `ch_nexus` devices. There are some differences between them that will be noted; however, most options are the same for both devices.

3.2 Checking your machines list

Use the script '`tstmachines`' in '`/usr/local/mpi/lib/<arch>/<device>`' 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 `bin/tstmachines` is the name of the architecture; this is the same name as the extension on the machines file. For example,

```
    /usr/local/mpi/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/mpi/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 ...
```

3.3 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/mpi/lib/<arch>/<device>`'[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/mpi/bin/machines/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
```

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. (There are command line arguments to `mpirun` that can be used instead of these environment variables; `mpirun -help` will give you more information.)

The `ch_nexus` device requires that you specify these settings in a resource database (.rdb) file. This allows you to run the secure servers on different ports on each machine, or if your username is different on the machines you are interested in running on. The .rdb file should look like:

[1]The Nexus secure server was built from the p4 server, but has added some new functionality that it relies on to start user programs. If you plan on using the secure server with the `ch_nexus` device, use the one distributed with the nexus distribution ('`/usr/local/nexus/bin/sserver`')

```
<host> ss_port=<portnumber> ss_login=<username>
```

where `<host>` is the name of the machine running the secure server, `<portnumber>` is the port that the server was started on, and `<username>` is your username on that machine. You may omit the `ss_login` parameter if your username is the same on both machines.

For example, if you wish to use the server on pelican using port 1234 and tern using port 9876, and also on wren using port 16000 with the username "guest", your .rdb file would look like:

```
pelican ss_port=1234
tern ss_port=9876
wren ss_port=16000 ss_login=guest
```

`mpirun` can be notified of this file with the "`-nexusdb` filename" option.

3.4 Heterogeneous networks and closer control

A heterogeneous network 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. The `mpirun` command may be told to use all of these with

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

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
```

3.4.1 P4 procgroup files

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.

The `ch_nexus` device uses a similar flag:

```
mpirun -nexuspg startupfile myprog
```

The format for the startupfile will also be explained 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. [2]

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:

[2]This is only a benefit with the `ch_p4` device. Nexus is currently developing a shared memory module that should be available in its next release

```
    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
```

3.4.2 Nexus startup files

The startup files for the `ch_nexus` device are somewhat different, but easy to understand (For a full explaination, see the Nexus User's Guide at http://www.mcs.anl.gov/nexus/uguide_3.0/index.html). The information contained in a `ch_p4` pgfile is a subset of the items in a Nexus resouce database ('`.rdb`') file. The startup file will list the nodes you wish to run on:

```
    sun1
    sun2
    sun3
    hp1
```

This starts the executable on each of the machines listed. To start more than one node on a machine, the following syntax is used:

```
    sun1,2
    sun2
    hp1,1
```

This example will start 3 nodes on sun1, 1 on sun2, and 2 on hp1. The .rdb file will specify any other pieces of information you may need. If the executables for the machines are in different locations, you would use the `startup_dir` attribute:

```
    sun1 startup_dir=/users/jones
    sun2 startup_dir=/users/jones
    sun3 startup_dir=/users/jones
    hp1 startup_dir=/home/mbj
```

To indicate that the executables have different names, you would use the `startup_exe` attribute:

```
sun1 startup_exe=myprog
sun2 startup_exe=myprog
sun3 startup_exe=myprog
hp1 startup_exe=a.out
```

These attributes can be used in conjuction with each other, as well. This provides the added benefit that one can start the program to read/write data files in different directories from the executable. The following example uses a \ as a line continuation character (much like a Makefile would) for readability:

```
sun1 \
    startup_dir=/users/jones/sun1 \
    startup_exe=/users/jones/myprog
sun2 \
    startup_dir=/users/jones/sun2 \
    startup_exe=/users/jones/myprog
sun3 \
    startup_dir=/users/jones/sun3 \
    startup_exe=/users/jones/myprog
hp1 \
    startup_dir=/home/mbj/data \
    startup_dir=/home/mbj/a.out
```

The `rsh_login` attribute is used whenever your login name differs on one machine from the machine you are starting on:

```
sun1 rsh_login=jones
sun2 rsh_login=jones
sun3 rsh_login=jones
hp1 rsh_login=mbj
```

This attribute can be used in conjunction with any other .rdb attribute (just like `startup_dir` and `startup_exe` were used together). At this time, shared memory is not supported in Nexus, but an alpha level module has been developed and is being tested. Please contact nexus@mcs.anl.gov for current status on the module. For a list of other attributes, see the Nexus User's Guide mentioned earlier.

3.4.3 Using special switches

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/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
```

Using ch_nexus, if you wish to send TCP over an alternate host name, you would use the tcp_interface attribute for the .rdb file:

```
host1 tcp_interface=host1-atm
host2 tcp_interface=host2-atm
```

3.5 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 -t 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.

3.5.1 IBM SPx

Using mpirun with the IBM SP1 and SP2 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_eui device) or for running P4 (if using the ch_p4 device).

3.5.2 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.

3.6 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 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.

3.7 The Convex Exemplar SPP

The Convex Exemplar version has been specially tuned by Convex Computer Corporation to take advantage of the specific architecture of the Exemplar. In particular, most of the collective communication library has been reimplemented using shared memory algorithms; the result is a significant decrease in latency over implementations layered on top of point-to-point functions.

The environment variable `MPI_GLOBMEMSIZE`, mentioned above, specifies the size of the shared memory region on *each* hypernode rather than the total amount of shared memory. On the Exemplar, its default value is 16MB.

A Convex-specific environment variable is `MPI_TOPOLOGY`. If you specify

```
setenv MPI_TOPOLOGY <i>,<j>,<k>,<l>,...
```

where the sum of the arguments equals the number of processes specified with `-np` on the `mpirun` command line, then the specified number of processes is started on each hypernode. Use of this environment variable is optional; the default behavior (keeping the processes on the same hypernode as much as possible) is usually more beneficial.

4 Sample MPI programs

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

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`).

mpich/examples/contrib/nuclei This is the closest thing to a real scientific application that we have now; it has not been tested recently. It is the application described at the end of Chapter 3 of the *Using MPI* book.

Additional examples from the book *Using MPI* [3] are available by anonymous ftp and through the World Wide Web at ftp://info.mcs.anl.gov/pub/mpi/using/.

5 The MPE library of useful extensions

It is anticipated that `mpich` will continue to accumulate extension routines of various kinds. Some of them may ultimately become part of an extended MPI Standard. In the meantime, 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`.
- 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

You can create customized logfiles for viewing with `upshot` by calls to the various `mpe` logging routines. For details, see the `mpe` man pages. A profiling library exists that automatically logs all calls to MPI functions. To find out how to link with a profiling library that produces log files automatically, see Section 5.4.

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

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

5.1.1 Parallel X Graphics

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.

5.1.2 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.)

5.2 Profiling libraries

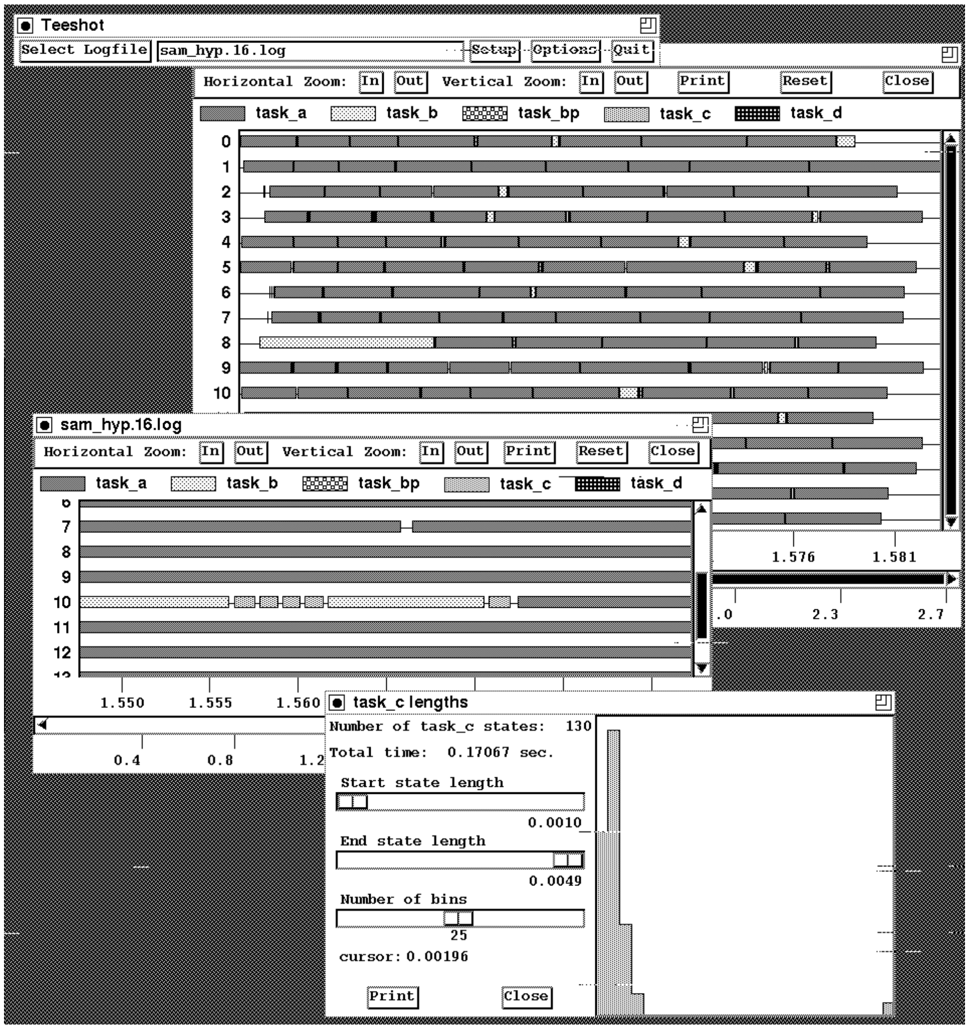
The MPI profiling interface provides a convenient way for you to add performance analysis tools to any MPI implementation. We demonstrate this mechanism in `mpich`, and give you a running start, by supplying three profiling libraries with the `mpich` distribution.

5.2.1 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`.

5.2.2 Logfile creation and upshot

The second profiling library generates *logfiles*, which are files of timestamped events. During execution, calls to `MPI_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. You can analyze the logfile produced at the end with a variety of tools. One that we use is called Upshot, which is a derivative of Upshot [5], written in Tcl/Tk. A screen dump of Upshot in use is shown in Figure 1. It shows parallel time lines with process states, like one of the



Number of task_c states: 130
Total time: 0.17067 sec.
Start state length 0.0010
End state length 0.0049
Number of bins 25
cursor: 0.00196

Figure 1: A screendump from `upshot`

paraGraph [4]. The view can be zoomed in or out, horizontally or vertically, centered on any point in the display chosen with the mouse. In Figure 1, 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.

5.2.3 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.

5.3 Accessing the profiling libraries

If the MPE libraries have been built, it is very easy to access the profiling libraries. The easiest way is the use the `mpicc` and `mpif77` commands. If you are using the makefile templates and `mpireconfig` instead, then using the profiling libraries is also simple. The sample makefiles contain the makefile variable `PROFLIB`; by making with different values of this symbol, different profiling effects can be accomplished. In the following examples, we list the libraries that must be *added* to the list of libraries *before* the '`-lmpi`' library.

-ltmpi -lpmpi 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.

-llmpi -lpmpi -lm Generate an upshot-style log file of all MPI calls. The name of the output file is `executablename_profile.log`. For example, if the program is `sendrecv`, the generated log file is `sendrecv_profile.log`.

-lampi -lmpe -lm -lX11 -lpmpi Produce 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`).

In Fortran, it is necessary to include the library '`-lfmpi`' 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 '`-lfmpi -llmpi -lpmpi -lm`'.

5.4 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/profiling/wrappergen` or Appendix A.

Examples of how to write wrapper templates are located in the `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 `profiling/examples` directory.

5.5 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 5.4. 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 (-lpmpi)> \
  <standard mpi library (-lmpi)>
  ```

To simplify it, some sample makefile sections have been created in '`mpich/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/$(ARCH)/$(COMM) $(PROF_LIB) -lmpi
   ```

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)/profiling/lib/Makefile.logging
   ```

   (or

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

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

5.6 Examining event logs with `upshot`

The original `upshot` was written in C and distributed several years ago [5]. To go with `mpich`, it has been completely rewritten by Ed Karrels to provide more robustness and flexibility. The current version resides in the directory `profiling/upshot`, and there is a symbolic link to the executable in `mpich/bin`. A newer version, currently under development but functional, providing less functionality but greater speed on large log files, is in `profiling/nupshot`.

6 Debugging MPI programs

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 `xterm`s 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.

-mpichdebug Generate detailed information on each operation; this is useful only to experts.

-mpiqueue Describe the state of the queues when `MPI_Finalize` is called. Can be used to find lost messages.

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

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

6.4 p4 arguments for 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
```

6.5 Debugging for Nexus

The `ch_nexus` device will allow you to take advantage of any Nexus debugging facilities only if you link against the debug version of both `mpich` and Nexus. Since `configure -device=ch_nexus` does not create a debug version of the `mpich` library, the person who installed the `ch_nexus` device should contact geisler@mcs.anl.gov for instructions on how to do this.

If the debug version already exists at your site, and you have linked your program against it, you can pass the following parameters to your program using `mpirun`:

- `-Dnexus` This command sets the trace level (0-9) 0 will give you nothing, and 9 will give you more than you can effectively use. Suggested values are 2 or 3.
- `-debug_display` This command gives the X windows screen name that the debugger should be displayed on. One debugger will start for each node (except the starting node). Use the `go` command to start your program with the right parameters.
- `-debug_command` This command tells where to find the script to start up a debugger for each node. This should be generated automatically with `configure -device=ch_nexus` in either '`/usr/local/mpi/bin/rundbx`' or '`/usr/local/mpi/bin/rungdb`'.

So, to run a program at trace level 3, one would enter:

```
mpirun -np 2 program -mpi -Dnexus 3
```

Be sure to include the -mpi BEFORE any of the debugging flags. See the debugging section of the Nexus User's Guide for more details on how to debug `ch_nexus` programs.

6.6 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.

6.7 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.

6.8 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).

6.9 Attaching 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
```

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. These tools are not available yet, but will be released soon.

6.11 Contents of the library files

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

libmpi.a MPI library (`MPI_Xxxx`)

libpmpi.a Profiling version (`PMPI_Xxxx`)

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 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 [2]
  - As postscript for ftp: at `info.mcs.anl.gov` in `pub/mpi/mpi-report.ps`.
  - As hypertext on the World Wide Web: `http://www.mcs.anl.gov/mpi`
  - As a journal article: in the Fall 1994 issue of the Journal of Supercomputing Applications [7]
- 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*, by Gropp, Lusk, and Skjellum [3].
  - *MPI: The Complete Reference*, by Snir, et al.
- 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 by `ftp`:
  - `mpich` is available by anonymous `ftp` from `info.mcs.anl.gov` in the directory `pub/mpi/mpich`, file `mpich.tar.Z`.
  - LAM is available by anonymous `ftp` from `tbag.osc.edu` in the directory `pub/lam`.
  - The CHIMP version of MPI is available by anonymous `ftp` from `ftp.epcc.ed.ac.uk` in the directory `pub/chimp/release`.
- Test code repository (new):
  - `ftp//:info.mcs.anl.gov/pub/mpi/mpi-test`

8 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., 1.0.11)
- 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` or `util/tstmachines`.

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.

8.1 Problems compiling or linking Fortran programs

8.1.1 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 -lmpi
   invalid option -L/usr/local/mpich/lib/sun4/ch_p4
   ld: -lmpi: 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/libmpi.a
   ```

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 -lmpi
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
```

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.

8.2 Problems linking C programs

8.2.1 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.

8.2.2 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 -lmpi
       -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.

8.2.3 HPUX

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

   ```
   cc -o pgm pgm.o -L/usr/local/mpi/lib/hpux/ch_p4 -lmpi  -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.

8.3 Problems starting programs

8.3.1 General

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

   ```
    mpirun -np 2 cpi
   ```

   either I get an error message or the program hands.

   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/mpi/bin/mpirun
```

3. **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.

4. **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).

   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
   ```

5. **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`).

6. **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.

8.3.2 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.
   ```

   when using the `ch_p4` or `chameleon` 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 3.3). 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 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.

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 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.

5. **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 build 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
```

In general, you should select the mpirun in '`lib/<architecture>/<device>`' directory over the one in the '`bin`' directory.

6. **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/sun4`' early in my search path; I could use

```
     cd /home/gropp/bin/sun4
     ln -s /usr/bin/rsh  rsh
```

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

7. **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.

8. **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`.

9. **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 administrators correct the problem (often one of an inconsistent set of `rsh/rshd` programs).

10. **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.

11. **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`').

    (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 case `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.

12. **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 creates 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_eui` or `ch_mpl` device; the cause is the same but it originates within the IBM MPL library.

13. **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.

14. **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.

8.3.3 Intel Paragon

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

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

8.3.4 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).

2. **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).

8.3.5 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 SPx, 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/homempich/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 AMD) 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 SPx, 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 the MPICH implementation is using.

4. **Q:** When trying to run on an IBM SP2, 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.

8.4 Programs fail at startup

8.4.1 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; 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`.

8.4.2 Workstation Networks

1. **Q:** I can run programs using a small number of processes, but one 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 seems to limit 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.

8.5 Programs fail after starting

8.5.1 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 fixed precision datatypes 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. If `mpich` is configured with the `-use_rndv` option and rebuilt, `mpich` will use a "rendevous" method to deliver messages.

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.

8.5.2 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.

8.6 Trouble with Input and Output

8.6.1 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 );
   ```

8.6.2 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 (\); this will cause the output to be flushed but will also put the user's input on the next line.

8.6.3 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.

8.7 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.

8.7.1 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/mpi/bin/upshot
   ```

8.7.2 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`, 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)

    Special Options for Nexus device:

    -nexuspg filename
            Use the given Nexus startup file instead of creating one.
            Overrides -np and -nolocal, selects -leave_pg

    -nexusdb filename
            Use the given Nexus resource database.

    Special Options for Workstation Clusters:

    -e      Use execer to start the program on workstation
```

```
        clusters
-pg     Use a procgroup file to start the p4 programs, not execer
        (default)
-leave_pg
        Don't delete the P4 procgroup file after running
-p4pg filename
        Use the given p4 procgroup file instead of creating one.
        Overrides -np and -nolocal, selects -leave_pg.
-tcppg filename
        Use the given tcp procgroup file instead of creating one.
        Overrides -np and -nolocal, selects -leave_pg.
-p4ssport num
        Use the p4 secure server with port number num to start the
        programs.  If num is 0, use the value of the
        environment variable MPI_P4SSPORT.  Using the server can
        speed up process startup.  If MPI_USEP4SSPORT as well as
        MPI_P4SSPORT are set, then that has the effect of giving
        mpirun the -p4ssport 0 parameters.

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` 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.

Acknowledgments

The work described in this report has benefited from conversations with and use by a large number of people. We also thank those that have helped in the implementation of MPICH, particularly Patrick Bridges and Edward Karrels. Particular thanks goes to Nathan Doss and Anthony Skjellum for valuable help in the implementation and development of MPICH.

References

[1] Ralph Butler and Ewing Lusk. User's guide to the `p4` parallel programming system. Technical Report ANL-92/17, Argonne National Laboratory, 1992.

[2] Message Passing Interface Forum. MPI: A message-passing interface standard. Computer Science Dept. Technical Report CS-94-230, University of Tennessee, Knoxville, TN, 1994.

[3] William Gropp, Ewing Lusk, and Anthony Skjellum. *Using MPI: Portable Parallel Programming with the Message Passing Interface.* MIT Press, 1994.

[4] M. T. Heath. Recent developments and case studies in performance visualization using ParaGraph. In G. Haring and G. Kotsis, editors, *Performance Measurement and Visualization of Parallel Systems*, pages 175–200, Amsterdam, The Netherlands, 1993. Elsevier Science Publishers.

[5] Virginia Herrarte and Ewing Lusk. Studying parallel program behavior with `upshot`. Technical Report ANL–91/15, Argonne National Laboratory, Argonne, IL 60439, 1991.

[6] Edward Karrels and Ewing Lusk. Performance analysis of MPI programs. In Jack Dongarra and Bernard Tourancheau, editors, *Proceedings of the Workshop on Environments and Tools For Parallel Scientific Computing.* SIAM Publications, 1994.

[7] Message Passing Interface Forum. MPI: A message-passing interface standard. *International Journal of Supercomputer Applications*, 8(3/4), 1994.