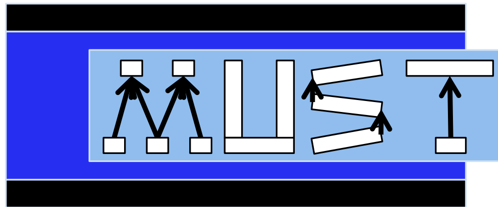
MUST

MPI Runtime Error Detection Tool



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1 Introduction

MUST detects usage errors of the Message Passing Interface (MPI) and reports them to the user. As MPI calls are complex and usage errors common, this functionality is extremely helpful for application developers that want to develop correct MPI applications. This includes errors that already manifest as segmentation faults or incorrect results as well as many errors that are not visible to the application developer or do not manifest on a certain system or MPI implementation.

To detect errors, MUST intercepts the MPI calls that are issued by the target application and evaluates their arguments. The two main usage scenarios for MUST arise during application development and during porting. When a developer adds new MPI communication calls, MUST can detect newly introduced errors, especially also some that may not manifest in an application crash. Further, before porting an application to a new system, MUST can detect violations to the MPI standard that might manifest on the target system. MUST reports errors in a log file that can be investigated once the execution of the target executable finishes (irrespective of whether the application crashed or not).

2 Installation

The MUST software consists of three individual packages:

- P^nMPI
- GTI
- MUST

The P^nMPI package provides base infrastructure for the MUST software and intercepts MPI calls of the target application. GTI provides tool infrastructure, while the MUST package contains the actual correctness checks.

Each MUST installation is build with a certain compiler and MPI library. It should only be used for applications that are built with the same pair of compiler and MPI library. This is necessary as the behavior of MUST may differ depending on the MPI library. Compilers may be mixed if they are binary compatible.

All three packages require CMake for configuration, it is freely available at `http://www.cmake.org/`. You can execute *which cmake* to determine whether a CMake installation is available. If not, contact your system administrator or install your a local version, which requires no root privileges. We suggest to use CMake version 2.8 or later (use *cmake --version*).

Further, in order to augment the MUST output with call stack information, which is very helpful for pinpointing errors, it is possible to utilize Dyninst. In that case MUST uses the Stackwalker API from Dyninst to read and print

stacktraces for errors. As the installation of Dyninst is often non-trivial we suggest this for more experienced users or administrators only. Section 6 presents the necessary steps for such an installation.

2.1 P^{n}MPI

P^{n}MPI can be build as follows:

```
tar -xf pnmpi.tar
cd pnmpi
mkdir BUILD
cd BUILD
CC=<C-COMPILER> CXX=<C++-COMPILER> FC=<F90-COMPILER> \
cmake ../ \
     -DCMAKE_INSTALL_PREFIX=<PNMPI-INSTALLATION-DIR> \
     -DCMAKE_BUILD_TYPE=Release
make
make install
```

The CMake call will determine your MPI installation in order to configure P^{n}MPI correctly. If this should fail – or multiple MPIs are available – you can tip the configuration by specifying *-DMPI_C_COMPLIER=<FILE-PATH-TO-MPICC>* as well as *-DMPI_CXX_COMPLIER=<FILE-PATH-TO-MPICXX>* and *-DMPI_Fortran_COMPLIER=<FILE-PATH-TO-MPIF90>* as additional arguments to the *cmake* command. More advanced users can fine tune the detection by specifying additional variables, consult the comments in *cmake-modules/FindMPI.cmake*.

Further, P^{n}MPI will require a Python installation of version 2.7 or later.

2.2 GTI

GTI can be build as follows:

```
tar -xf gti.tar
cd gti
mkdir BUILD
cd BUILD
CC=<C-COMPILER> CXX=<C++-COMPILER> FC=<F90-COMPILER> \
cmake ../ \
      -DCMAKE_INSTALL_PREFIX=<GTI-INSTALLATION-DIR> \
      -DCMAKE_BUILD_TYPE=Release \
      -DPnMPI_HOME=<PNMPI-INSTALLATION-DIR>
make
make install
```

If you specified extra arguments for the MPI detection when installing P^{n}MPI, you must also add these arguments for the *cmake* call of the GTI configuration. Further, GTI will require developer headers for *libxml2* that should be available on most systems.

2.3 MUST

MUST is built as follows:

```
tar -xf must.tar
cd must
mkdir BUILD
cd BUILD
CC=<C-COMPILER> CXX=<C++-COMPILER> FC=<F90-COMPILER> \
cmake ../ \
     -DCMAKE_INSTALL_PREFIX=<MUST-INSTALLATION-DIR> \
     -DCMAKE_BUILD_TYPE=Release \
     -DGTI_HOME=<GTI-INSTALLATION-DIR>
make
make install
```

The installation of MUST relies almost completely on the settings specified when installing GTI. Usually no extra arguments are needed. You can specify *-DENABLE_TESTS=On* to activate the test suite that is included in MUST.

2.4 Environmentals

You must add *<MUST-INSTALLATION-DIR>/bin* to your *PATH* variable to allow convenient usage of MUST. Further, you should make sure that you load the version of CMake that was used to build MUST.

3 Usage

The following two steps allow you to use MUST:

- Replace the *mpiexec* command with *mustrun* to execute your application;
- Inspect the result file of the run.

3.1 Execution

The actual execution of an application with MUST is done by replacing the *mpiexec* command with *mustrun*. It performs a code generation step to adapt the MUST tool to your application and will run your application with MUST afterwards. It uses a default set of correctness checks and a communication system where one MPI process is used to drive some of MUST's correctness checks. So when submitting a batch job, you should be sure to allocate resources for one additional task. Further, when calling *mustrun* you need to have access to the compilers and MPI utilities that where used to build MUST itself.

A regular *mpiexec* command like:

```
mpiexec -np 4 application.exe
```

Is replaced with:

`mustrun -np 4 application.exe`

It will execute your application with 4 tasks, but requires one additional task, i.e. it will actually invoke *mpiexec* with *-np 5*.

If your machine provides no compilers in batch jobs, you can prepare a run as follows:

`mustrun --must:mode prepare -np 4 application.exe`

In your batch job you would then just execute:

`mustrun --must:mode run -np 4 application.exe`

The *mustrun* tool provides further switches to modify its behavior, call *mustrun --must:help* for a summary. On many machines the *mpiexec* command can differ on batch jobs, add *--must:mpiexec <MPIEXEC>* to the *mustrun* command to override the default. If you encounter errors during execution, please submit error reports where you use *--must:verbose* as an argument to *mustrun*.

3.2 Results

MUST stores its results in an HTML file named *MUST_Output.html*. It contains information on all detected issues including information on where the error occurred.

4 Example

As an example consider the following application that contains three MPI usage errors:

```
1  #include <stdio.h>
2  #include <mpi.h>
3
4  int main (int argc, char** argv)
5  {
6      int rank,
7          size,
8          sBuf[2] = {1,2},
9          rBuf[2];
10     MPI_Status status;
11     MPI_Datatype newType;
12
13     MPI_Init(&argc,&argv);
14     MPI_Comm_rank (MPI_COMM_WORLD, &rank);
15     MPI_Comm_size (MPI_COMM_WORLD, &size);
16
17     //Enough tasks ?
18       if (size < 2)
19       {
20           printf ("This test needs at least 2 processes!\n");
21           MPI_Finalize();
22           return 1;
23       }
24
```

```
25          //Say hello
26          printf ("Hello, I am rank %d of %d processes.\n", rank, size);
27
28          //1) Create a datatype
29          MPI_Type_contiguous (2, MPI_INT, &newType);
30          MPI_Type_commit (&newType);
31
32          //2) Use MPI_Sendrecv to perform a ring communication
33          MPI_Sendrecv (
34                  sBuf, 1, newType, (rank+1)%size, 123,
35                  rBuf, sizeof(int)*2, MPI_BYTE, (rank-1+size) % size, 123,
36                  MPI_COMM_WORLD, &status);
37
38          //3) Use MPI_Send and MPI_Recv to perform a ring communication
39          MPI_Send (sBuf, 1, newType, (rank+1)%size, 456, MPI_COMM_WORLD);
40          MPI_Recv (rBuf, sizeof(int)*2, MPI_BYTE, (rank-1+size) % size,
                456, MPI_COMM_WORLD, &status);
41
42          //Say bye bye
43          printf ("Signing off, rank %d.\n", rank);
44
45      MPI_Finalize ();
46
47      return 0;
48  }
49
50  /*EOF*/
```

4.1 Execution with MUST

A user could set up the environment for MUST, build the application, and run the it with the following commands:

```
#Set up environment
export PATH=<MUST-INSTALLATION-DIR>/bin:$PATH

#Compile and link, we rely on the ld-preload mechanism
mpicc example.c -o example.exe -g

#Run with 4 processes, will need resources for 5 tasks!
mustrun -np 4 example.exe
```

4.2 Output File

The output of the run with MUST will be stored in a file named *MUST_Output.html*. For this application MUST will detect three different errors that are:

- A type mismatch (Table 2)
- A send-send deadlock (Table 4)
- A leaked datatype (Table 6)

Table 2 shows the first error that MUST detects. The error results from the usage of non-matching datatypes, which are an `MPI_INT` and an `MPI_BYTE` of the

MUST Output, date: Thu Aug 25 09:04:01 2011.

Rank	Type	Message	Form	References
0	**Error**	A send and a receive operation use datatypes that do not match! Miss-match occurs at (CONTIGUOUS)[0](MPI_INT) in the send type and at (MPI_BYTE) in the receive type (consult the MUST manual for a detailed description of datatype positions). The send operation was started at reference 1, the receive operation was started at reference 2. (Information on communicator: MPI_COMM_WORLD) (Informationon send of count 1 with type: Datatype created at reference 3 is for C, commited at reference 4, based on the following type(s): MPI_INT) (Information on receive of count 8 with type:MPI_BYTE)	call MPI_Sendrecv	reference 1: call MPI_Sendrecv @rank 3 reference 2: call MPI_Sendrecv @rank 0 reference 3: call MPI_Type_contiguous @rank 3 reference 4: call MPI_Type_commit @rank 3

Table 2: Type miss-match error report from MUST.

same size as the integer value. This is not allowed according to the MPI standard. A correct application would use `MPI_INT` for both the send and receive call.
The example shows the specification of the location in the datatype that mismatches. The location `(CONTIGUOUS)[0](MPI_INT)` means that the used datatype is of contiguous kind, the mismatch is within the first child of the contiguous type which is defined to be a base type namely `MPI_INT`.
As another example `(VECTOR)[1][2](MPI_CHAR)` would address the third entry of the second block of a vector with basetype `MPI_CHAR`.

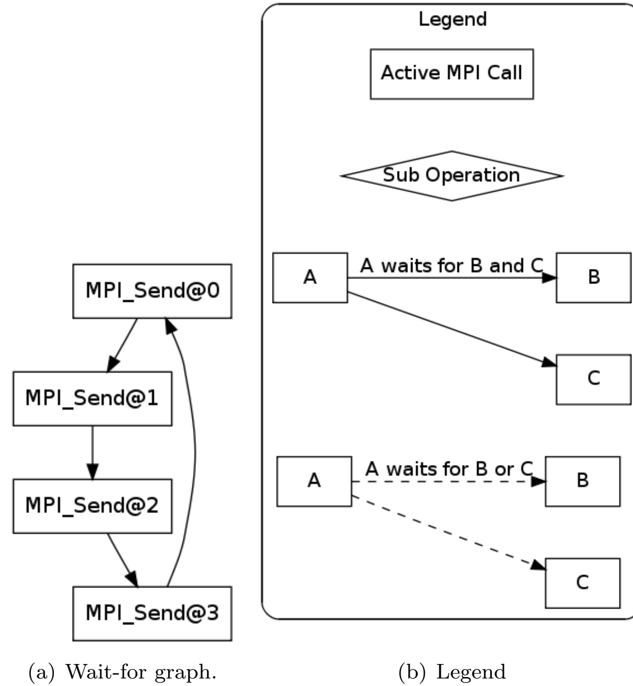
MUST Output, date: Thu Aug 25 09:04:01 2011.

Rank	Type	Message	Form	References
	Error	The application issued a set of MPI calls that can cause a deadlock! A graphical representation of this situation is available in the file named "MUST_Deadlock.dot". Use the dot tool of the graphviz package to visualize it, e.g. issue "dot -Tps MUST_Deadlock.dot -o deadlock.ps". The graph shows the nodes that form the root cause of the deadlock, any other active MPI calls have been removed. A legend is available in the dot format in the file named "MUST_DeadlockLegend.dot", further information on these graphs is available in the MUST manual. References 1-4 list the involved calls (limited to the first 5 calls, further calls may be involved). The application still runs, if the deadlock manifested (e.g. caused a hang on this MPI implementation) you can attach to the involved ranks with a debugger.		reference 1: call MPI_Send@rank 0 reference 2: call MPI_Send@rank 1 reference 3: call MPI_Send@rank 2 reference 4: call MPI_Send@rank 3

Table 4: Send-send deadlock report from MUST.

The second error results from the application calling send calls that can lead to deadlock (Table 4). Each task issues one call to `MPI_Send` while no matching

receive is available. This can cause deadlock, however, as such calls would be buffered for most MPI implementations this is a deadlock that only manifests for some message sizes or MPI implementations.



(a) Wait-for graph. (b) Legend

Figure 1: Visualization of the send-send deadlock from Table 4.

If MUST detects a deadlock it provides a visualization for its core, i.e. the set of MPI calls of which at least one call has to be modified or replaced. It stores a wait-for graph representation of this core in a file named *MUST_Deadlock.dot*. This file uses the DOT language of the *Graphviz* package. You can visualize it by issuing *dot -Tps MUST_Deadlock.dot -o deadlock.ps* and opening *deadlock.ps* with the post script viewer of your choice (DOT also supports additional output formats). Figure 1 presents this visualization for the send-send deadlock in the example. It also shows the legend that is provided in *MUST_DeadlockLegend.dot*. The wait-for graph shows that all the `MPI_Send` calls are causing a cyclic wait-for condition. If MUST was configured with Dyninst (Section 6), it will also print a parallel call stack in a file called *MUST_DeadlockCallStack.dot*.

Finally, MUST detects that the application leaks MPI resources when calling `MPI_Finalize`, which is a not freed datatype in this case. Applications should free all such resources before invoking `MPI_Finalize`, as leaks are easier to detect in such cases.

MUST Output, date: Thu Aug 25 09:04:01 2011.

Rank	Type	Message	Form	References
	Error	There are 1 datatypes that are not freed when MPI_Finalize was issued, a quality application should free all MPI resources before calling MPI_Finalize. Listing information for these datatypes: -Datatype 1: Datatype created at reference 1 is for C, commited at reference 2, based on the following type(s): MPI_INT		reference 1: call MPI_Type_contiguous @rank 0 reference 2: call MPI_Type_commit @rank 0

Table 6: Resource leak report from MUST.

5 Included Checks

MUST currently provides correctness checks for the following classes of errors:

- Constants and integer values
- Communicator usage
- Datatype usage
- Group usage
- Operation usage
- Request usage
- Leak checks (MPI resources not freed before calling `MPI_Finalize`)
- Type miss-matches
- Overlapping buffers passed to MPI
- Deadlocks resulting from MPI calls

6 Optional: MUST Installation with Dyninst

In order to install MUST with Dyninst support a full Dyninst installation or a separate installation of the Dyninst Stackwalker API is needed. This usually requires an installation of libdwarf. Installation instructions for these can be found on the Dyninst website[1]. We suggest to install libdwarf as a shared library (*--enable-shared* during its configure).

After a successful installation of the Stackwalker API it is necessary to configure MUST to use this installation. Use the following CMake variables:

- **-DUSE_CALLPATH=On** Enables the feature
- **-DCALLPATH_STACKWALKER_HOME=** Should point to the directory used for Stackwalker API installation (i.e. prefix given to its configure)
- **-DCALLPATH_STACKWALKER_PLATFORM=** Usually *x86_64-unknown-linux2.4* depends on your platform
- **-DCALLPATH_STACKWALKER_EXTRA_LIBRARIES=** Additional libaries that are needed, if libdwarf was built statically you will need to add an absolute filepath to this lib here

Afterwards run *make* and *make install* to build and install MUST. When running MUST no additional steps are needed. However, the stackwalker library will only be able to extract source file names and line numbers if the application was built with the debugging flag *-g*. Otherwise, it will list symbol addresses and library names instead.

Note that MUST expects that the shared libraries for the Stackwalker API and libdwarf (if built as a shared library) are in the `LD_LIBRARY_PATH`.

7 Troubleshooting

The following lists currently known problems or issues and potential workarounds.

7.1 Issues with Ld-Preload

In order to use MUST, your application must be linked against the core library of P^nMPI. Per default MUST will add this library at execution time by using the ld-preload mechanism. If this causes issues you can use the following command to manually link the P^nMPI library:

```
mpicc source.c -L<PNMPI-INSTALLATION-DIR>/lib  \
        -lpnmpi -o application.exe
```

Important: if you manually link against the MPI library, you must add the P^nMPI library first and the MPI library afterwards.

[1] http://www.dyninst.org/

8 Copyright and Contact

MUST is distributed under a BSD style license, for details see the file LICENSE.txt in its package. Also, MUST uses parts of the callpath library from LLNL, its also uses a BSD style license, which can be found in the file modules/Callpath/LICENSE. Further, MUST uses parts of LLNL's adept utils which have a BSD style license too, it is listed in the respective source files.

Contact *tobias.hilbrich@tu-dresden.de* for bug reports, feedback, and feature requests.