TECHNISCHE UNIVERSITÄT DRESDEN

RWTH AACHEN UNIVERSITY

Center for Information Services and High Performance Computing (ZIH)

Session 2: MUST

Correctness Checking

Dr. Matthias S. Müller (RWTH Aachen University)
Tobias Hilbrich (Technische Universität Dresden)
Joachim Protze (RWTH Aachen University, LLNL)

Email:
mueller@itc.rwth-aachen.de
tobias.hilbrich@tu-dresden.de
protze@itc.rwth-aachen.de

ZIH
Center for Information Services & High Performance Computing

Content

- Motivation
- MPI usage errors
- Examples: Common MPI usage errors
  - Including MUST's error descriptions
- Correctness tools
- MUST usage

How many errors can you spot in this tiny example?

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

   MPI_Comm_rank (MPI_COMM_WORLD, &rank);
   MPI_Comm_size (MPI_COMM_WORLD, &size);

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INTEGER, &type);

   MPI_Recv (buf, 2, MPI_INT, size - rank, 123, MPI_COMM_WORLD, MPI_STATUS_IGNORE);

   MPI_Send (buf, 2, type, size - rank, 123, MPI_COMM_WORLD);

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

   return 0;
}
```

At least 8 issues in this code example

Content

- Motivation
- MPI usage errors
- Examples: Common MPI usage errors
    - Including MUST's error descriptions
- Correctness tools
- MUST usage

MPI usage errors

- MPI programming is error prone
- Bugs may manifest as:
  - Crashes
  - Hangs
  - Wrong results
  - Not at all! (Sleeping bugs)
- Tools help to detect these issues

MPI usage errors (2)

- Complications in MPI usage:
  - Non-blocking communication
  - Persistent communication
  - Complex collectives (e.g. Alltoallw)
  - Derived datatypes
  - Non-contiguous buffers
- Error Classes include:
  - Incorrect arguments
  - Resource errors
  - Buffer usage
  - Type matching
  - Deadlocks

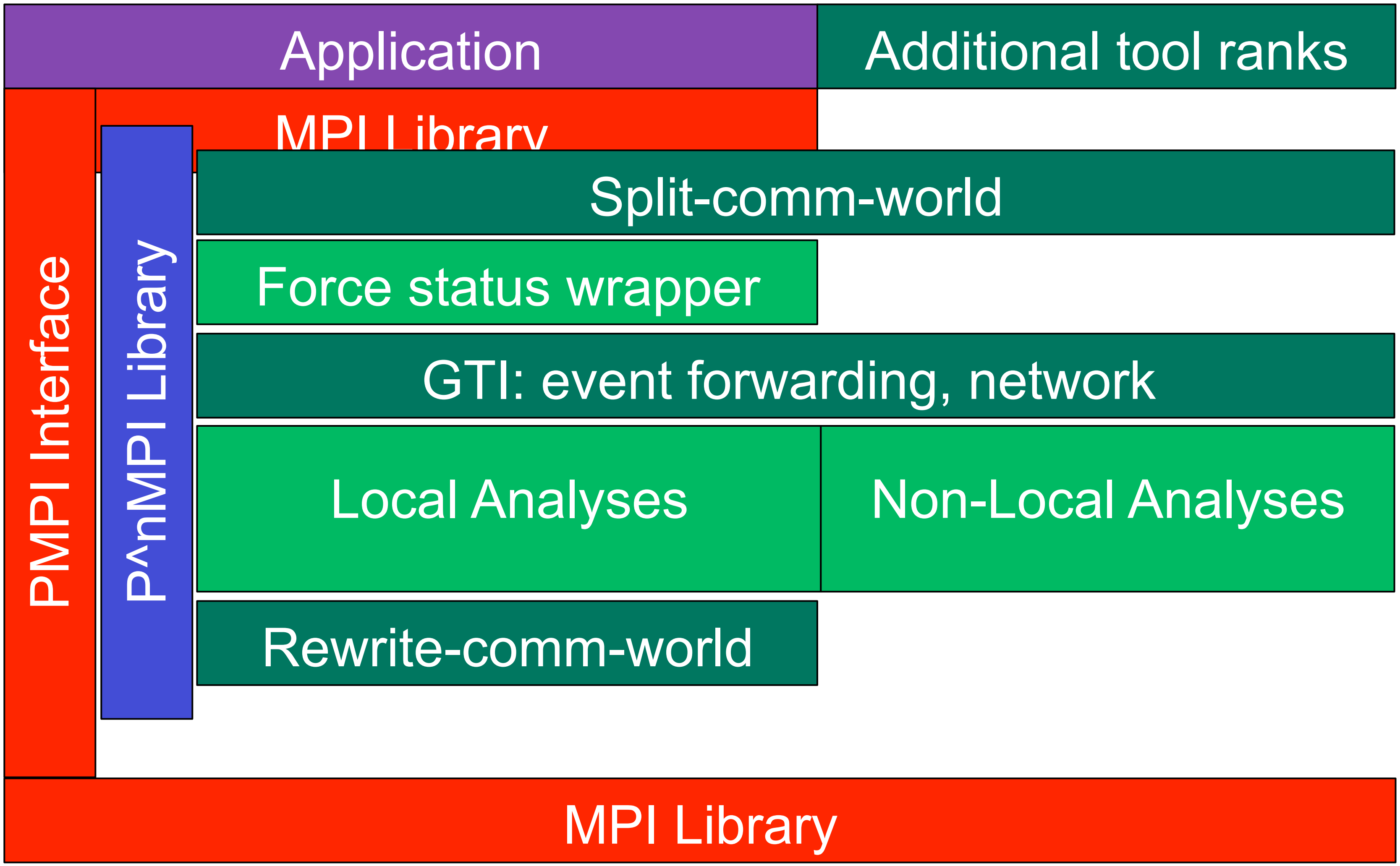
Content

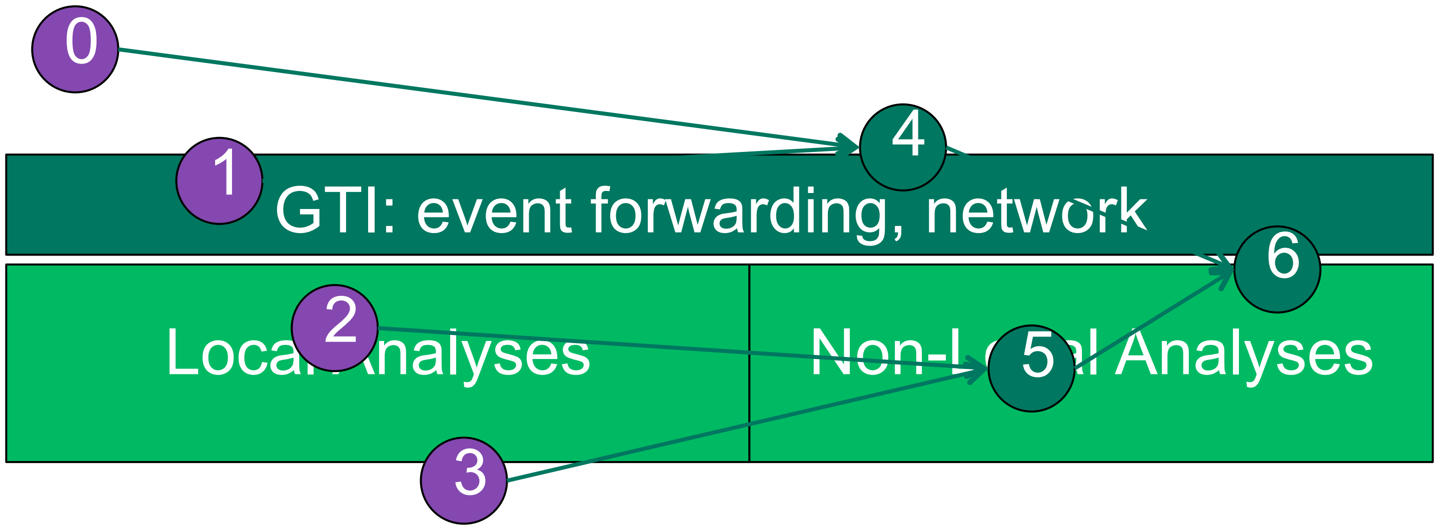
- Motivation
- MPI usage errors
- Examples: Common MPI usage errors
    - Including MUST's error descriptions
- Correctness tools
- MUST usage

Skipping some errors

- Missing MPI_Init:
  - Current release doesn't start to work, implementation in progress
- Missing MPI_Finalize:
  - Current release doesn't terminate all analyses, work in progress
- Src/dest rank out of range (size-rank): leads to crash, use crash save version of tool

MUST: Tool design

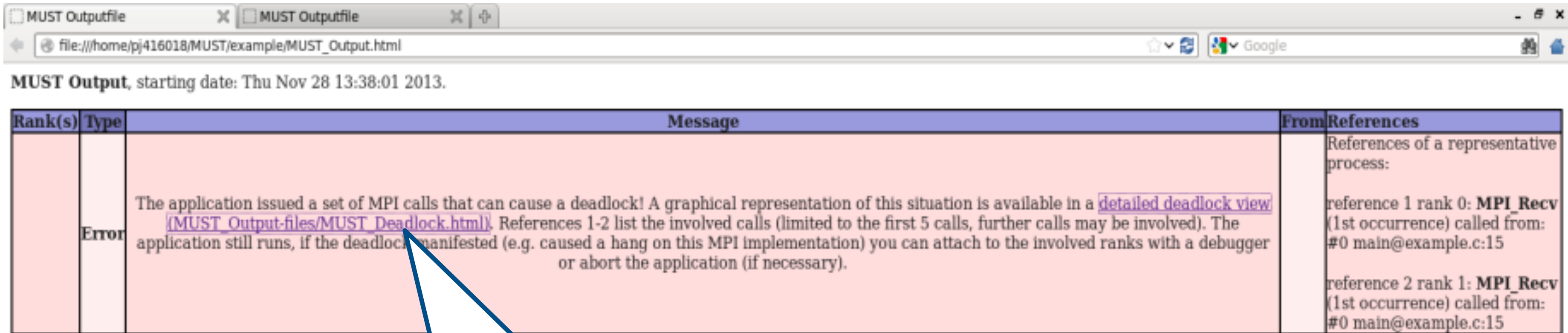



0
1
2
3
4
5
6
GTI: event forwarding, network
Analyses

Fixed some errors:

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INTEGER, &type);

   MPI_Recv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, MPI_STATUS_IGNORE);

   MPI_Send (buf, 2, type, size - rank - 1, 123, MPI_COMM_WORLD);

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

   MPI_Finalize ();

   return 0;
}
```

Must detects deadlocks



MUST Outputfile | MUST Outputfile

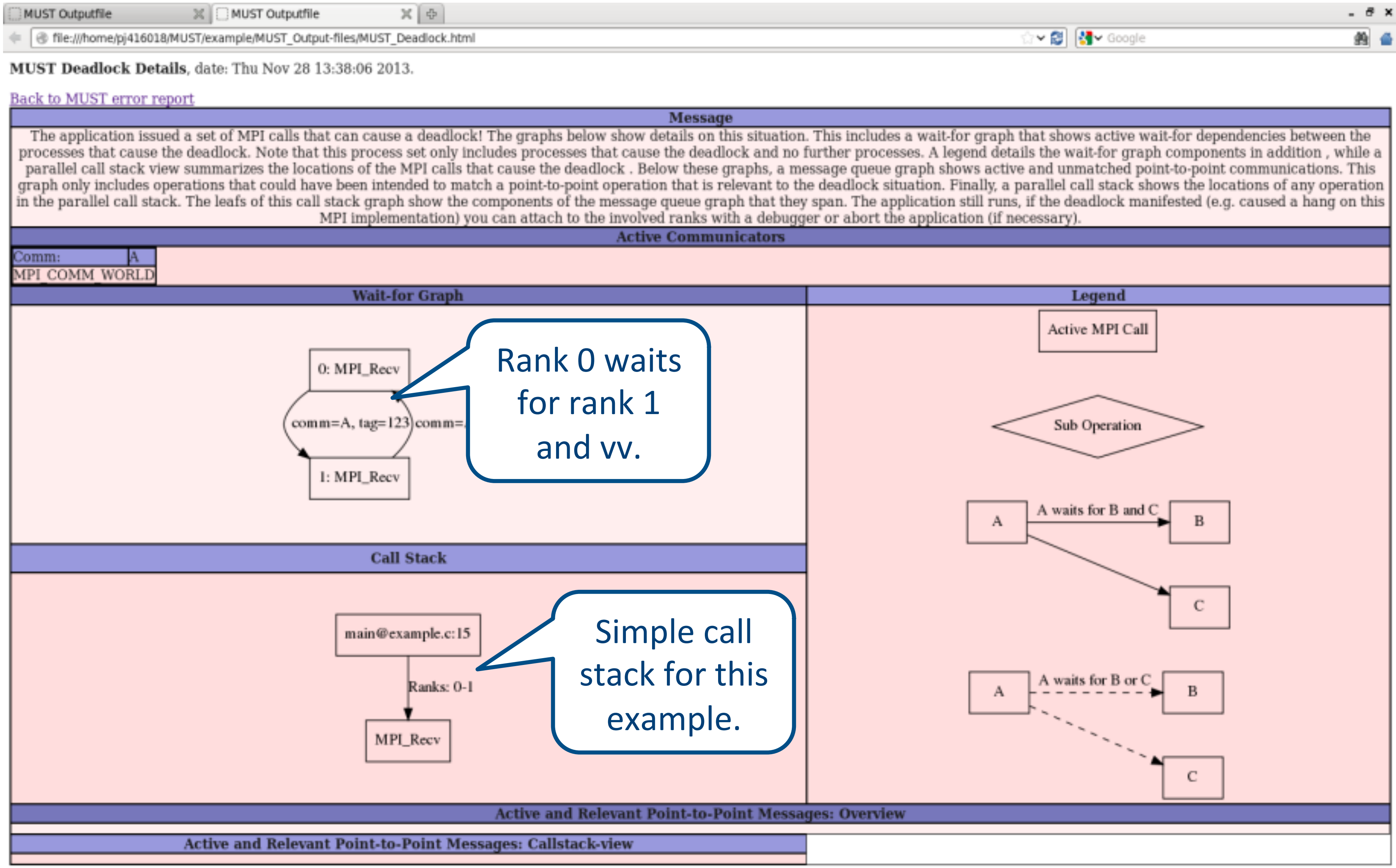
file:///home/pj416018/MUST/example/MUST_Output.html

MUST Output, starting date: Thu Nov 28 13:38:01 2013.

Rank(s)	Type	Message	From	References
	Error	The application issued a set of MPI calls that can cause a deadlock! A graphical representation of this situation is available in a detailed deadlock view (MUST_Output-files/MUST_Deadlock.html). References 1-2 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 or abort the application (if necessary).		References of a representative process: reference 1 rank 0: **MPI_Recv** (1st occurrence) called from: #0 main@example.c:15 reference 2 rank 1: **MPI_Recv** (1st occurrence) called from: #0 main@example.c:15

Click for graphical representation of the detected deadlock situation.

Graphical representation of deadlocks



Fix1: use asynchronous receive

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INTEGER, &type);

   MPI_Request request;
   MPI_Irecv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, &request);

   MPI_Send (buf, 2, type, size - rank - 1, 123, MPI_COMM_WORLD);

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

   MPI_Finalize ();

   return 0;
}
```

Use asynchronous receive: (MPI_Irecv)

MUST detects errors in handling datatypes

MUST Outputfile

file:///home/pj416018/MUST/example/MUST_Output.html

MUST Output, starting date: Thu Nov 28 13:50:48 2013.

Use of uncommited datatype: `type`

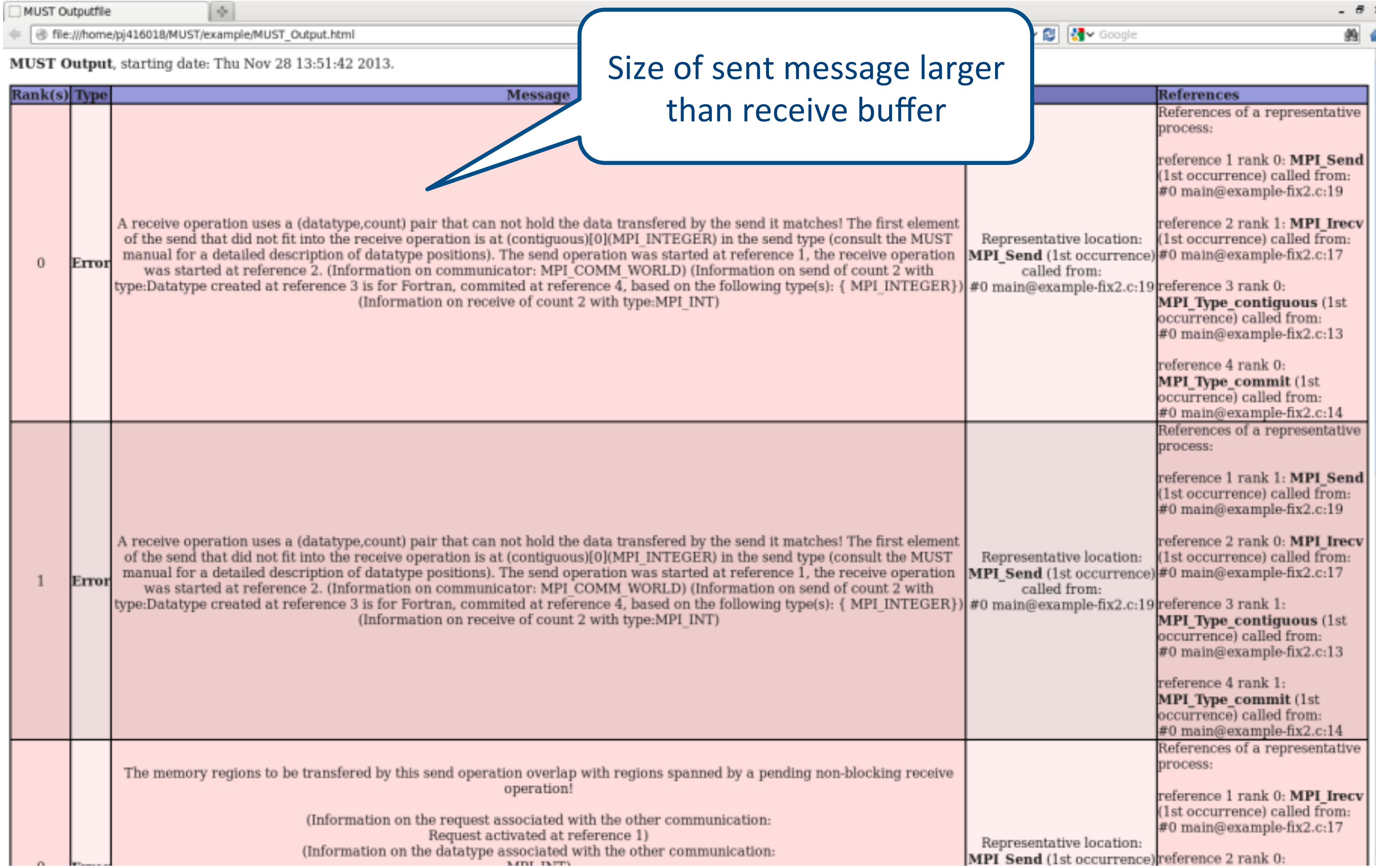
Rank(s)	Type	Message		References
0	Error	A receive operation uses a (datatype,count) pair that can not hold the data transfered by the send it matches! The first element of the send that did not fit into the receive operation is at (contiguous)[0](MPI_INTEGER) in the send type (consult the MUST manual 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) (Information on send of count 2 with type:Datatype created at reference 3 is for Fortran, based on the following type(s): { MPI_INTEGER}) (Information on receive of count 2 with type:MPI_INT)	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix1.c:18	References of a representative process: reference 1 rank 0: **MPI_Send** (1st occurrence) called from: #0 main@example-fix1.c:18 reference 2 rank 1: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix1.c:16 reference 3 rank 0: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix1.c:13
0-1	Error	Argument 3 (datatype) is not commited for transfer, call MPI_Type_commit before using the type for transfer! (Information on datatypeDatatype created at reference 1 is for Fortran, based on the following type(s): { MPI_INTEGER})	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix1.c:18	References of a representative process: reference 1 rank 1: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix1.c:13
0	Error	The memory regions to be transfered by this send operation overlap with regions spanned by a pending non-blocking receive operation! (Information on the request associated with the other communication: Request activated at reference 1) (Information on the datatype associated with the other communication: MPI_INT) The other communication overlaps with this communication at position:(MPI_INT) (Information on the datatype associated with this communication: Datatype created at reference 2 is for Fortran, based on the following type(s): { MPI_INTEGER}) This communication overlaps with the other communication at position:(contiguous)[0](MPI_INTEGER) A graphical representation of this situation is available in a detailed overlap view (MUST_Output-files/MUST_Overlap_0_0.html).	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix1.c:18	References of a representative process: reference 1 rank 0: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix1.c:16 reference 2 rank 0: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix1.c:13
1	Error	The memory regions to be transfered by this send operation overlap with regions spanned by a pending non-blocking receive operation! (Information on the request associated with the other communication: Request activated at reference 1) (Information on the datatype associated with the other communication: MPI_INT) The other communication overlaps with this communication at position:(MPI_INT) (Information on the datatype associated with this communication: Datatype created at reference 2 is for Fortran, based on the following type(s): { MPI_INTEGER}) This communication overlaps with the other communication at position:(contiguous)[0](MPI_INTEGER) A graphical representation of this situation is available in a detailed overlap view (MUST_Output-files/MUST_Overlap_1_0.html).	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix1.c:18	References of a representative process: reference 1 rank 1: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix1.c:16 reference 2 rank 1: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix1.c:13
				References of a representative process:

Fix2: use MPI_Type_commit

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INTEGER, &type);
   MPI_Type_commit (&type);

   MPI_Request request;
   MPI_Irecv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, &request);

   MPI_Send (buf, 2, type, size - rank - 1, 123, MPI_COMM_WORLD);

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

   MPI_Finalize ();

   return 0;
}
```

Commit the datatype before usage

MUST detects errors in transfer buffer sizes / types



MUST Outputfile

file:///home/pj416018/MUST/example/MUST_Output.html

MUST Output, starting date: Thu Nov 28 13:51:42 2013.

Rank(s)	Type	Message		References
0	**Error**	A receive operation uses a (datatype,count) pair that can not hold the data transfered by the send it matches! The first element of the send that did not fit into the receive operation is at (contiguous)[0](MPI_INTEGER) in the send 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) (Information on send of count 2 with type:Datatype created at reference 3 is for Fortran, commited at reference 4, based on the following type(s): { MPI_INTEGER}) (Information on receive of count 2 with type:MPI_INT)	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix2.c:19	References of a representative process: reference 1 rank 0: **MPI_Send** (1st occurrence) called from: #0 main@example-fix2.c:19 reference 2 rank 1: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix2.c:17 reference 3 rank 0: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix2.c:13 reference 4 rank 0: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix2.c:14
1	**Error**	A receive operation uses a (datatype,count) pair that can not hold the data transfered by the send it matches! The first element of the send that did not fit into the receive operation is at (contiguous)[0](MPI_INTEGER) in the send 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) (Information on send of count 2 with type:Datatype created at reference 3 is for Fortran, commited at reference 4, based on the following type(s): { MPI_INTEGER}) (Information on receive of count 2 with type:MPI_INT)	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix2.c:19	References of a representative process: reference 1 rank 1: **MPI_Send** (1st occurrence) called from: #0 main@example-fix2.c:19 reference 2 rank 0: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix2.c:17 reference 3 rank 1: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix2.c:13 reference 4 rank 1: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix2.c:14
		The memory regions to be transfered by this send operation overlap with regions spanned by a pending non-blocking receive operation! (Information on the request associated with the other communication: Request activated at reference 1) (Information on the datatype associated with the other communication:	Representative location: **MPI_Send** (1st occurrence)	References of a representative process: reference 1 rank 0: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix2.c:17 reference 2 rank 0:

Size of sent message larger than receive buffer

Fix3: use same message size for send and receive

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INTEGER, &type);
   MPI_Type_commit (&type);

   MPI_Request request;
   MPI_Irecv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, &request);

   MPI_Send (buf, 1, type, size - rank - 1, 123, MPI_COMM_WORLD);

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

   MPI_Finalize ();

   return 0;
}
```

Reduce the message size

MUST detects use of wrong argument values

MUST Outputfile

file:///home/pj416018/MUST/example/MUST_Output.html

Google

MUST Output, starting date: Mon Dec 2 13:11:12 2013.

Use of Fortran type in C, datatype mismatch between sender and receiver

Rank(s)	Type	Message		eferences
1	Error	A send and a receive operation use datatypes that do not match! Mismatch occurs at (contiguous)[0](MPI_INTEGER) in the send type and at (MPI_INT) in the receive type (consult the MUST manual for a detailed description of datatype positions). A graphical representation of this situation is available in a [detailed type mismatch view (MUST_Output-files/MUST_Typemismatch_1.html)](MUST_Output-files/MUST_Typemismatch_1.html). The send operation was started at reference 1, the receive operation was started at reference 2. (Information on communicator: MPI_COMM_WORLD) (Information on send of count 1 with type:Datatype created at reference 3 is for Fortran, commited at reference 4, based on the following type(s): { MPI_INTEGER}) (Information on receive of count 2 with type:MPI_INT)	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix3.c:19	eferences of a representative rocess: eference 1 rank 1: **PI_Send** (1st occurrence) called from: #0 main@example-fix3.c:19 reference 2 rank 0: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix3.c:17 reference 3 rank 1: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix3.c:13 reference 4 rank 1: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix3.c:14
0	Error	A send and a receive operation use datatypes that do not match! Mismatch occurs at (contiguous)[0](MPI_INTEGER) in the send type and at (MPI_INT) in the receive type (consult the MUST manual for a detailed description of datatype positions). A graphical representation of this situation is available in a [detailed type mismatch view (MUST_Output-files/MUST_Typemismatch_0.html)](MUST_Output-files/MUST_Typemismatch_0.html). The send operation was started at reference 1, the receive operation was started at reference 2. (Information on communicator: MPI_COMM_WORLD) (Information on send of count 1 with type:Datatype created at reference 3 is for Fortran, commited at reference 4, based on the following type(s): { MPI_INTEGER}) (Information on receive of count 2 with type:MPI_INT)	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix3.c:19	References of a representative process: reference 1 rank 0: **MPI_Send** (1st occurrence) called from: #0 main@example-fix3.c:19 reference 2 rank 1: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix3.c:17 reference 3 rank 0: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix3.c:13 reference 4 rank 0: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix3.c:14
		The memory regions to be transfered by this send operation overlap with regions spanned by a pending non-blocking receive operation!		References of a representative process: reference 1 rank 1:

Fix4: use C-datatype constants in C-code

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INT, &type);
   MPI_Type_commit (&type);

   MPI_Request request;
   MPI_Irecv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, &request);

   MPI_Send (buf, 1, type, size - rank - 1, 123, MPI_COMM_WORLD);

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

   MPI_Finalize ();

   return 0;
}
```

Use the integer datatype intended for usage in C

MUST detects data races in asynchronous communication

Data race between send and ascynchronous receive operation

MUST Outputfile

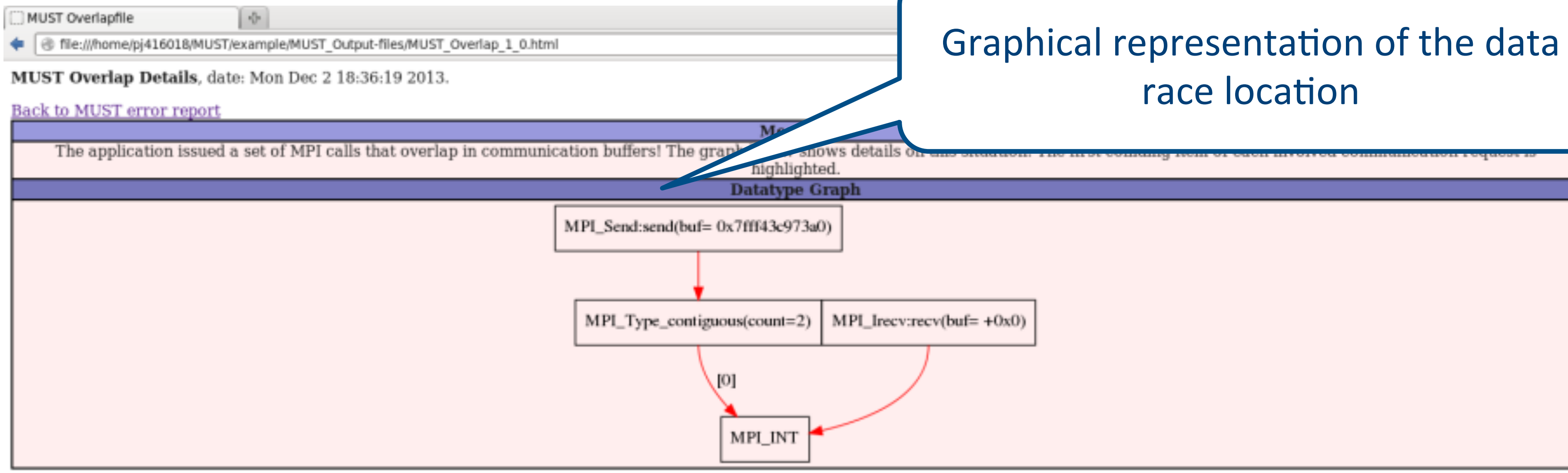
file:///home/pj416018/MUST/example/MUST_Output.html

MUST Output, starting date: Mon Dec 2 18:36:19 2013.

Rank(s)	Type	Message		
1	Error	The memory regions to be transfered by this send operation overlap with regi nned by a pending non-blocking receive operation! (Information on the request associated with the other communication: Request activated at reference 1) (Information on the datatype associated with the other communication: MPI_INT) The other communication overlaps with this communication at position:(MPI_INT) (Information on the datatype associated with this communication: Datatype created at reference 2 is for C, commited at reference 3, based on the following type(s): { MPI_INT}) This communication overlaps with the other communication at position:(contiguous)[0](MPI_INT) A graphical representation of this situation is available in a detailed overlap view (MUST_Output-files/MUST_Overlap_1_0.html).	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix4.c:19	References of a representative process: reference 1 rank 1: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix4.c:17 reference 2 rank 1: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix4.c:13 reference 3 rank 1: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix4.c:14
0-1	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}	Representative location: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix4.c:13	References of a representative process: reference 1 rank 1: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix4.c:13 reference 2 rank 1: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix4.c:14
0-1	Error	There are 1 requests 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 requests: -Request 1: Request activated at reference 1	Representative location: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix4.c:17	References of a representative process: reference 1 rank 1: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix4.c:17
0	Error	The memory regions to be transfered by this send operation overlap with regions spanned by a pending non-blocking receive operation! (Information on the request associated with the other communication: Request activated at reference 1) (Information on the datatype associated with the other communication: MPI_INT) The other communication overlaps with this communication at position:(MPI_INT) (Information on the datatype associated with this communication: Datatype created at reference 2 is for C, commited at reference 3, based on the following type(s): { MPI_INT}) This communication overlaps with the other communication at position:(contiguous)[0](MPI_INT) A graphical representation of this situation is available in a detailed overlap view (MUST_Output-files/MUST_Overlap_0_0.html).	Representative location: **MPI_Send** (1st occurrence) called from: #0 main@example-fix4.c:19	References of a representative process: reference 1 rank 0: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix4.c:17 reference 2 rank 0: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix4.c:13 reference 3 rank 0: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix4.c:14

MUST has completed successfully, end date: Mon Dec 2 18:36:20 2013.

Graphical representation of the race condition



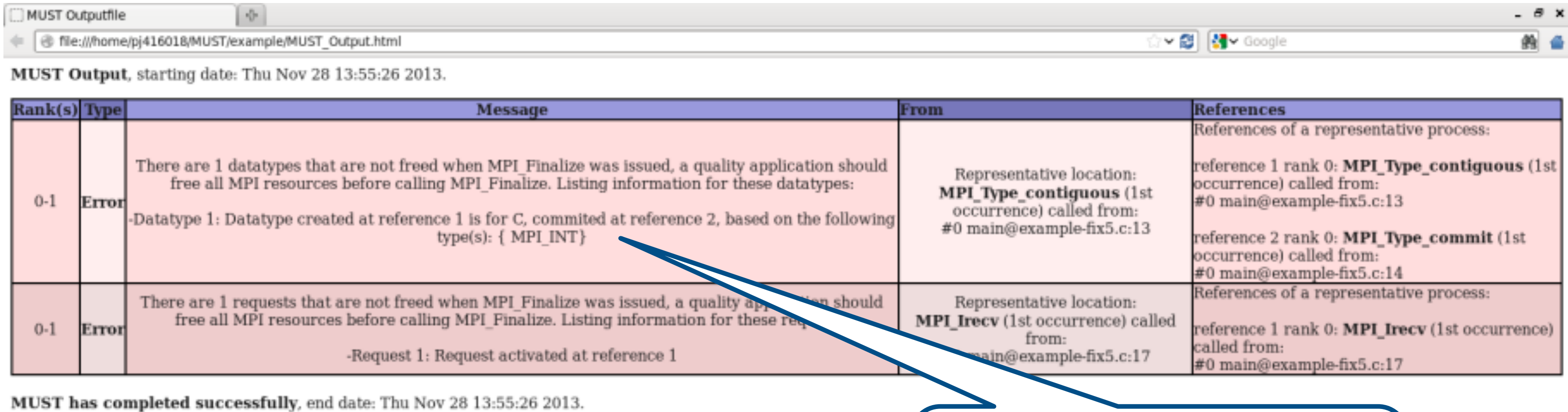
Graphical representation of the data race location

Fix5: use independent memory regions

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INTEGER, &type);
   MPI_Type_commit (&type);

   MPI_Request request;
   MPI_Irecv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, &request);

   MPI_Send (buf + 4, 1, type, size - rank - 1, 123, MPI_COMM_WORLD);

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

   MPI_Finalize ();

   return 0;
}
```

Offset points to independent memory

MUST detects leaks of user defined objects



MUST Outputfile

file:///home/pj416018/MUST/example/MUST_Output.html

MUST Output, starting date: Thu Nov 28 13:55:26 2013.

Rank(s)	Type	Message	From	References
0-1	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}	Representative location: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix5.c:13	References of a representative process: reference 1 rank 0: **MPI_Type_contiguous** (1st occurrence) called from: #0 main@example-fix5.c:13 reference 2 rank 0: **MPI_Type_commit** (1st occurrence) called from: #0 main@example-fix5.c:14
0-1	Error	There are 1 requests that are not freed when MPI_Finalize was issued, a quality ap[...]on should free all MPI resources before calling MPI_Finalize. Listing information for these req[...] -Request 1: Request activated at reference 1	Representative location: **MPI_Irecv** (1st occurrence) called from: [...]ain@example-fix5.c:17	References of a representative process: reference 1 rank 0: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix5.c:17

MUST has completed successfully, end date: Thu Nov 28 13:55:26 2013.

Leak of user defined datatype object

- User defined objects include
  - MPI_Comms (even by MPI_Comm_dup)
  - MPI_Datatypes
  - MPI_Groups

Fix6: Deallocate datatype object

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INT, &type);
   MPI_Type_commit (&type);

   MPI_Request request;
   MPI_Irecv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, &request);

   MPI_Send (buf + 4, 1, type, size - rank - 1, 123, MPI_COMM_WORLD);

   printf ("Hello, I am rank %d of %d.\n", rank, size);
   MPI_Type_free (&type);

   MPI_Finalize ();

   return 0;
}
```

Deallocate the created datatype

MUST detects unfinished asynchronous communication

MUST Outputfile

file:///home/pj416018/MUST/example/MUST_Output.html

MUST Output, starting date: Thu Nov 28 13:55:49 2013.

Rank(s)	Type	Message	From	References
0-1	**Error**	There are 1 requests 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 requests: -Request 1: Request activated at reference 1	Representative location: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix6.c:17	References of a representative process: reference 1 rank 0: **MPI_Irecv** (1st occurrence) called from: #0 main@example-fix6.c:17

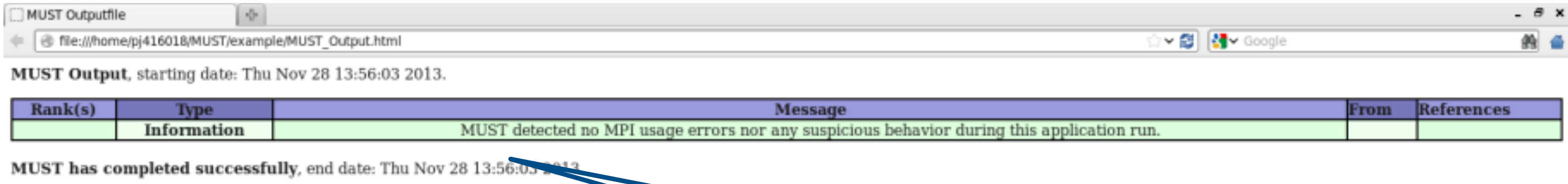
MUST has completed successfully, end date: Thu Nov 28 13:55:49 2013.

Remaining unfinished asynchronous receive

Fix8: use MPI_Wait to finish asynchronous communication

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

int main (int argc, char** argv)
{
   int rank, size, buf[8];

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

   MPI_Datatype type;
   MPI_Type_contiguous (2, MPI_INT, &type);
   MPI_Type_commit (&type);

   MPI_Request request;
   MPI_Irecv (buf, 2, MPI_INT, size - rank - 1, 123, MPI_COMM_WORLD, &request);

   MPI_Send (buf + 4, 1, type, size - rank - 1, 123, MPI_COMM_WORLD);

   MPI_Wait (&request, MPI_STATUS_IGNORE);

   printf ("Hello, I am rank %d of %d.\n", rank, size);
   MPI_Type_free (&type);

   MPI_Finalize ();

   return 0;
}
```

Finish the asynchronous communication


MUST Outputfile

file:///home/pj416018/MUST/example/MUST_Output.html

MUST Output, starting date: Thu Nov 28 13:56:03 2013.

Rank(s)	Type	Message	From	References
	Information	MUST detected no MPI usage errors nor any suspicious behavior during this application run.		

MUST has completed successfully, end date: Thu Nov 28 13:56:03 2013.

No further error detected

Hopefully this message applies to many applications

Content

- Motivation
- MPI usage errors
- Examples: Common MPI usage errors
    - Including MUST’s error descriptions
- Correctness tools
- MUST usage

Classes of Correctness Tools

- Debuggers:
  - Helpful to pinpoint any error
  - Finding the root cause may be very hard
  - Won’t detect sleeping errors
  - E.g.: gdb, TotalView, Alinea DDT
- Static Analysis:
  - Compilers and Source analyzers
  - Typically: type and expression errors
  - E.g.: MPI-Check
- Model checking:
  - Requires a model of your applications
  - State explosion possible
  - E.g.: MPI-Spin

Strategies of Correctness Tools

- Runtime error detection:
  - Inspect MPI calls at runtime
  - Limited to the timely interleaving that is observed
  - Causes overhead during application run
  - E.g.: Intel Trace Analyzer, Umpire, Marmot, MUST
- Formal verification:
  - Extension of runtime error detection
  - Explores ALL possible timely interleavings
  - Can detect potential deadlocks or type missmatches that would otherwise not occur in the presence of a tool
  - For non-deterministic applications exponential exploration space
  - E.g.: ISP

Content

- Motivation
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MUST Usage

1) Compile and link application as usual
   - Link against the shared version of the MPI lib (Usually default)
2) Replace “mpiexec” with “mustrun”
   - E.g.: *mustrun –np 4 myApp.exe input.txt output.txt*
3) Inspect “MUST_Output.html” in run directory
   - “MUST_Output/MUST_Deadlock.dot” exists in case of deadlock
   - Visualize with: *dot –Tps MUST_Deadlock.dot –o deadlock.ps*

- The mustrun script will use an extra process for non-local checks (Invisible to application)
- I.e.: “mustrun –np 4 …” will issue a “mpirun –np 5 …”
- Make sure to allocate the extra task in batch jobs

MUST - Features

- Local checks:
  - Integer validation
  - Integrity checks (pointers valid, etc.)
  - Operation, Request, Communicator, Datatype, Group usage
  - Resource leak detection
  - Memory overlap checks
- Non-local checks:
  - Collective verification
  - Lost message detection
  - Type matching (For P2P and collectives)
  - Deadlock detection (with root cause visualization)

MUST - Features: Scalability

- Local checks largely scalable
- Non-local checks:
    - Current default uses a central process
        - This process is an MPI task taken from the application
        - Limited scalability ~100 tasks (Depending on application)
    - Distributed analysis available (tested with 10k tasks)
        - Uses more extra tasks (10%-100%)
- Recommended: Logging to an HTML file
- Uses a scalable tool infrastructure
- Tool configuration happens at execution time