aiXcelerate 2019

Runtime Correctness Checking Tools

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MPI runtime correctness checking

How many errors can you spot in this tiny example?

```c
#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;
}
```

No MPI_Init before first MPI-call
Fortran type in C
Recv-recv deadlock
Rank0: src=size (out of range)
Type not committed before use
Type not freed before end of main
Send 4 int, recv 2 int: truncation
No MPI_Finalize before end of main

MPI usage errors

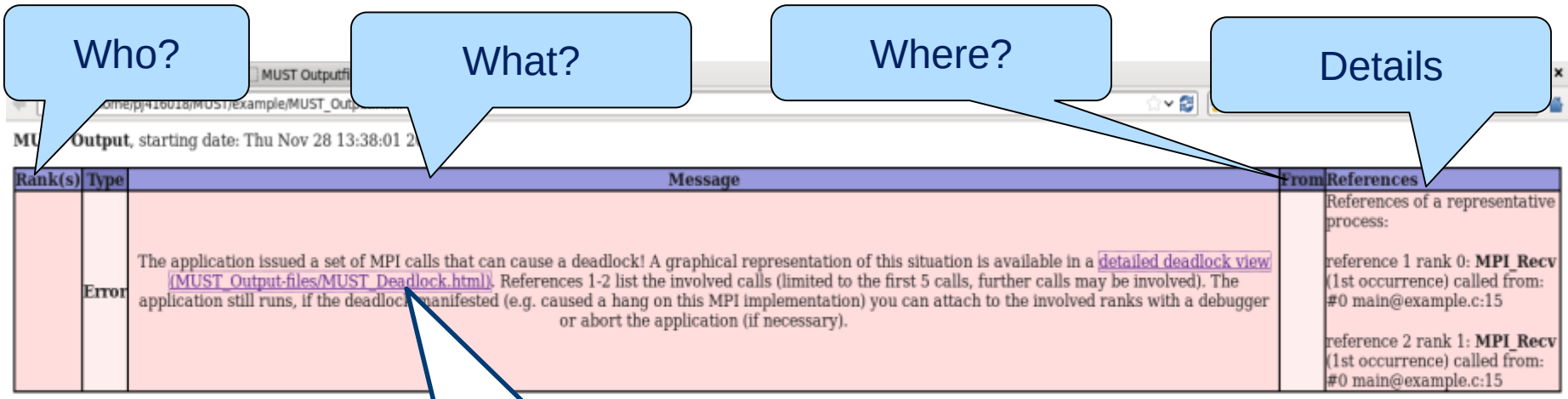
- MPI programming is error prone
- Bugs may manifest as:
  - Crashes
  - Hangs
  - Wrong results
  - Not at all! (Sleeping bugs)
- Tools help to detect these issues

MPI usage errors (2)

- Complications in MPI usage:
  - Non-blocking communication
  - Persistent communication
  - Complex collectives (e.g. Alltoallw)
  - Derived datatypes
  - Non-contiguous buffers

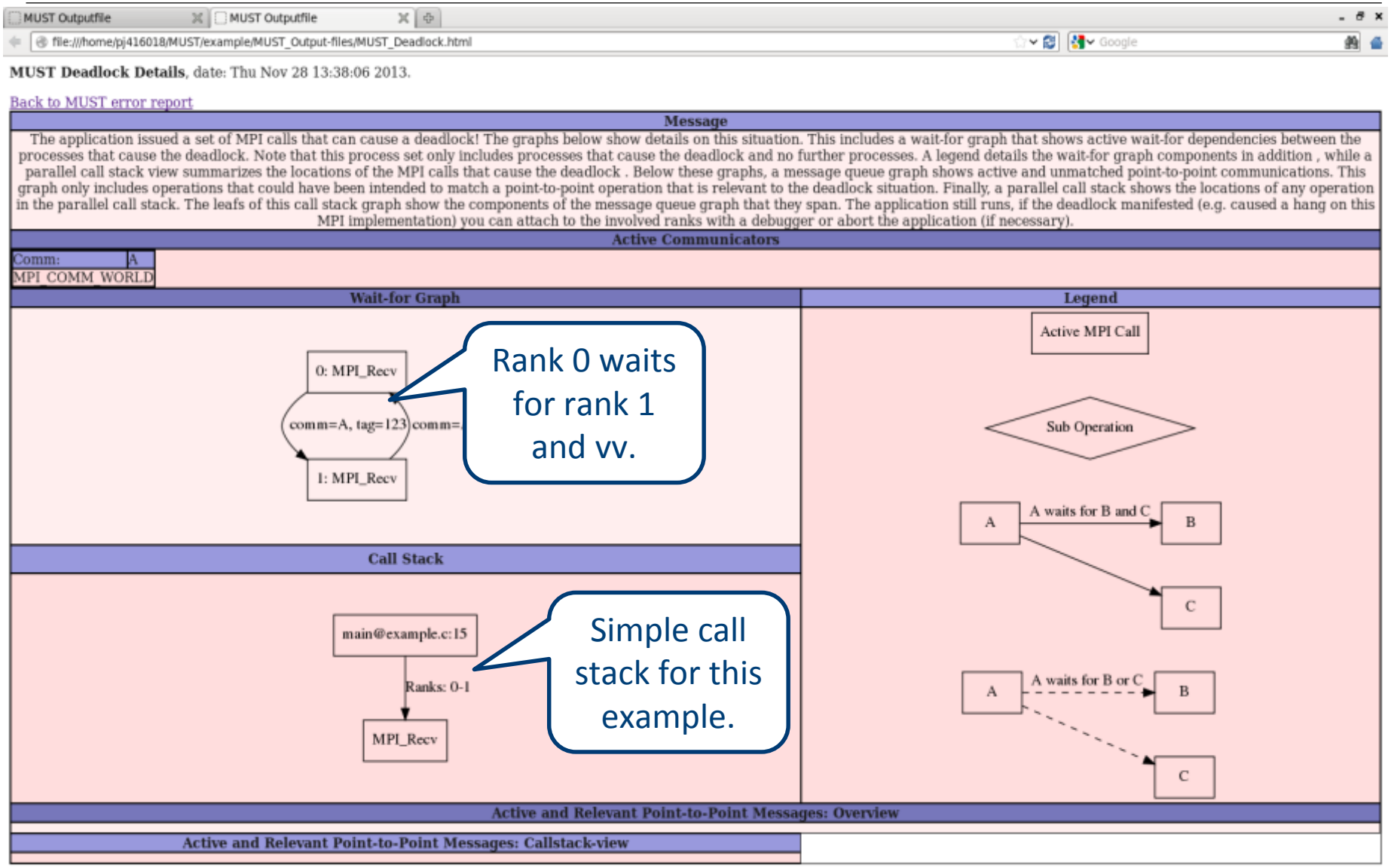
- Error Classes include:
  - Incorrect arguments
  - Resource errors
  - Buffer usage
  - Type matching
  - Deadlocks

Must detects deadlocks

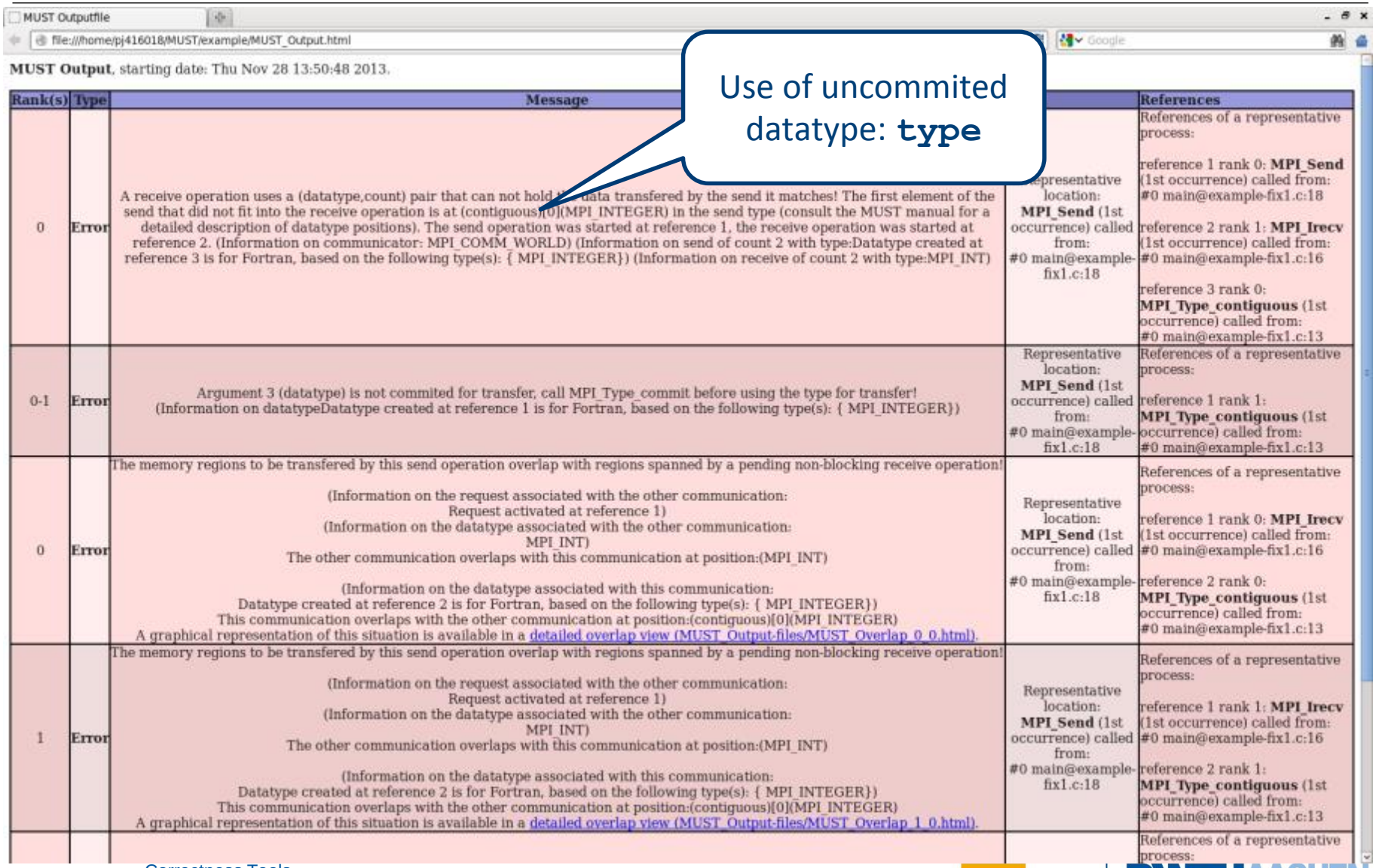


Click for graphical representation of the detected deadlock situation.

Graphical representation of deadlocks

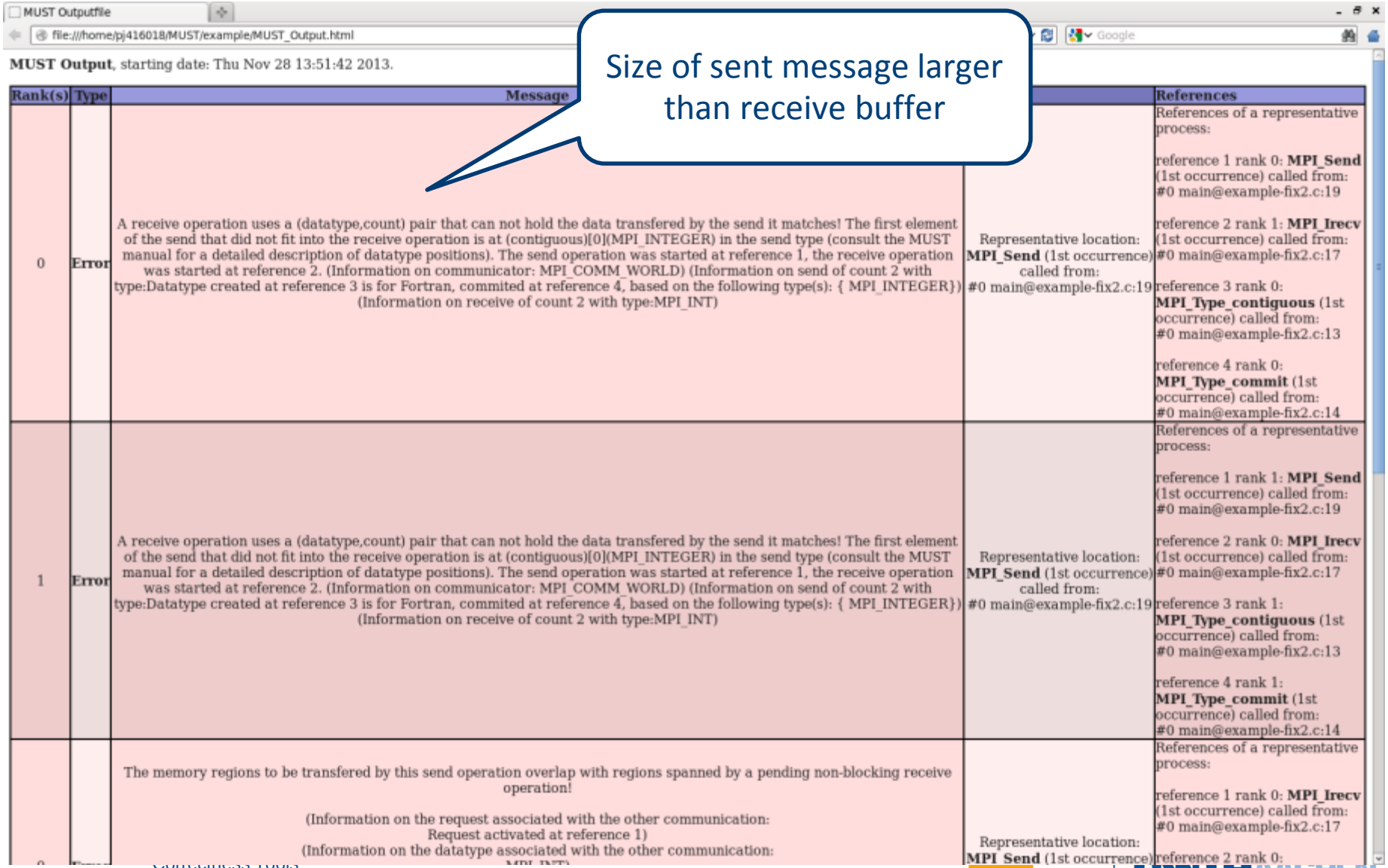


MUST detects errors in handling datatypes

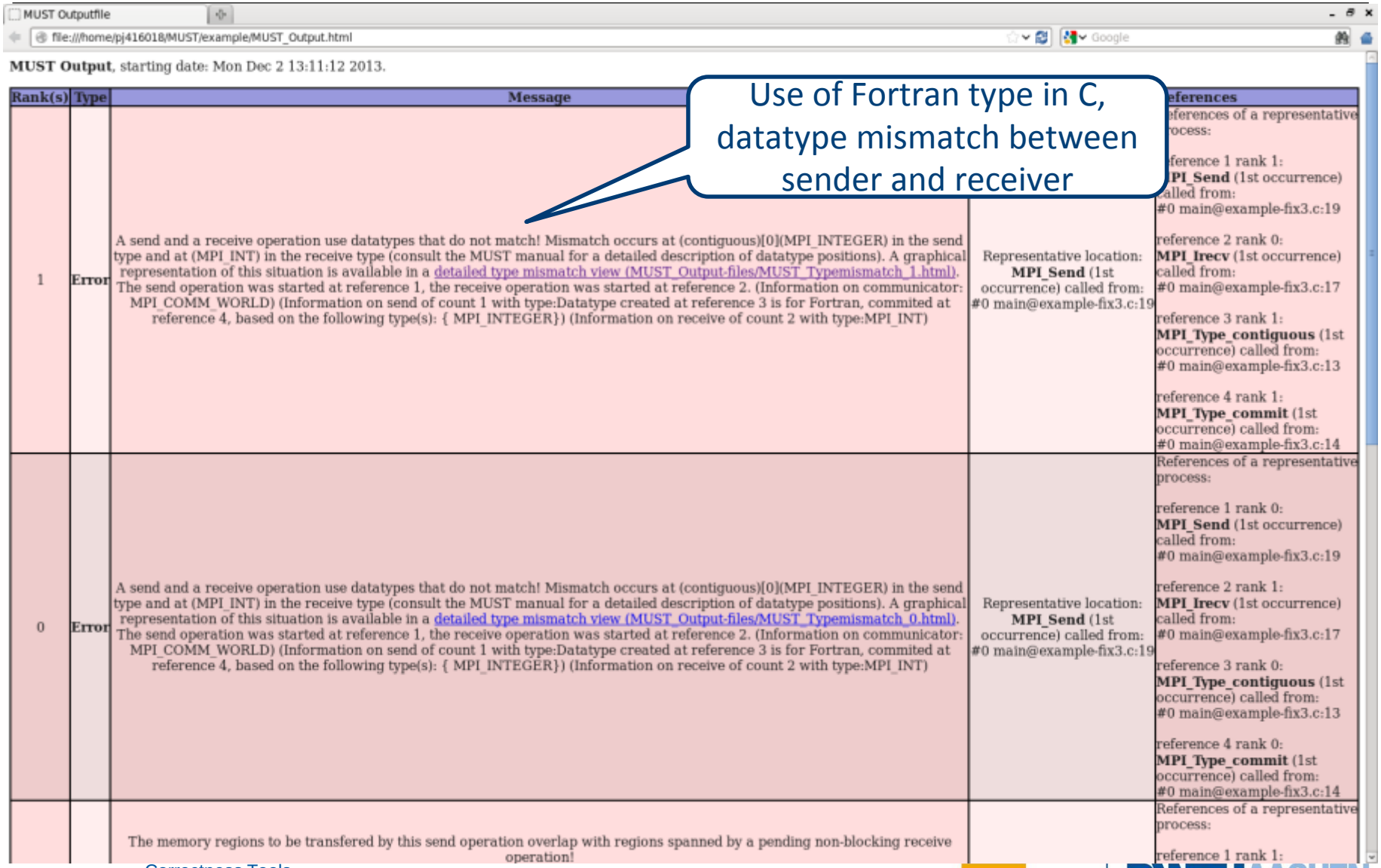


Rank(s)	Type	Message		References
0	Error	A receive operation uses a (datatype,count) pair that can not hold the data transfered by the send it matches! The first element of the send that did not fit into the receive operation is at (contiguous)[0](MPI_INTEGER) in the send type (consult the MUST manual 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)	epresentative 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:

MUST detects errors in transfer buffer sizes / types



MUST detects use of wrong argument values



Sometimes fixing one defect introduces several new ones

```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_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;
}
```

Deadlock was fixed by non-blocking recv

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MUST detects data races in asynchronous communication

MUST Outputfile

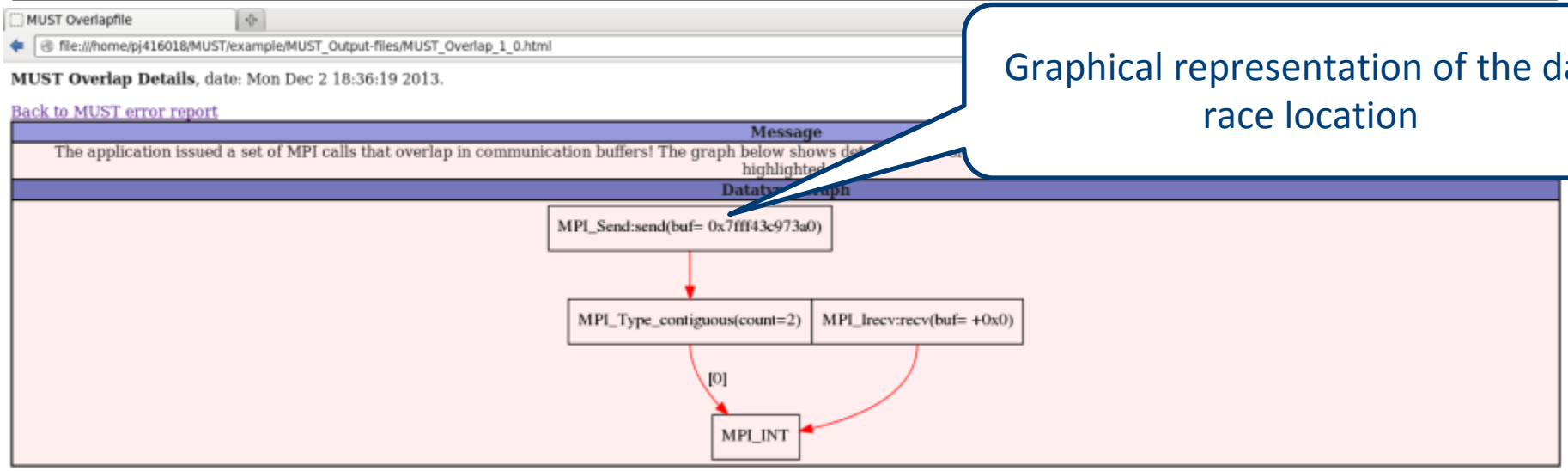
file:///home/pj416018/MUST/example/MUST_Output.html

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

Data race between send and ascynchronous receive operation

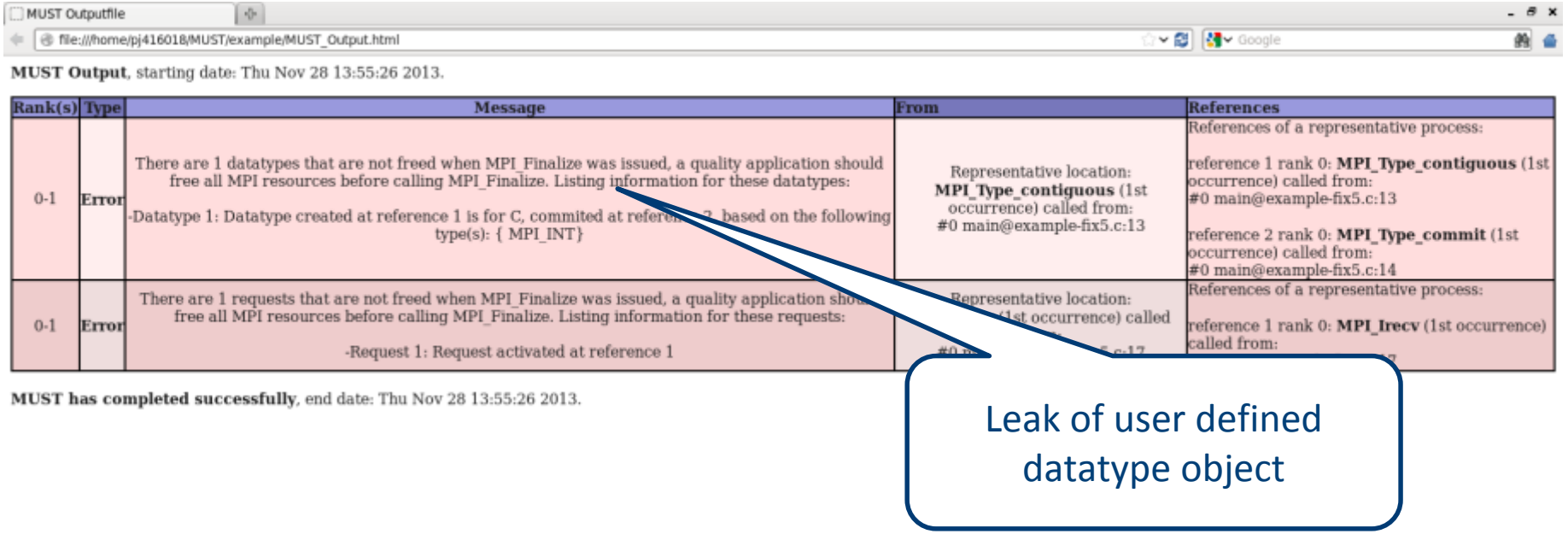
Rank(s)	Type	Message		
1	Error	The memory regions to be transfered by this send operation overlap with regi… …ned by a pend… non-blocking receive operation! (Information on the request associated with the other communication: Request activated at reference 1) (Information on the datatype associated with 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

Graphical representation of the race condition

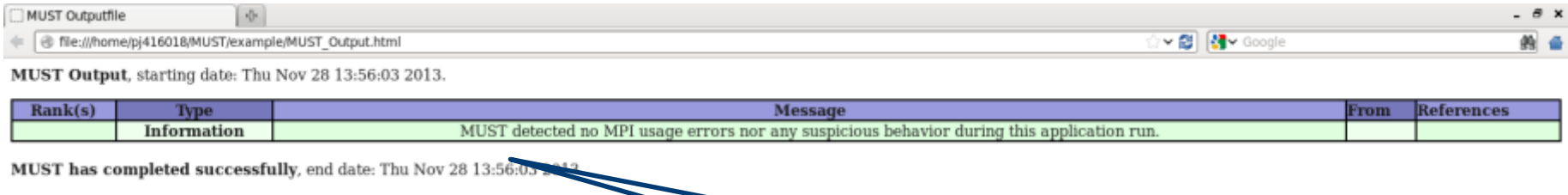


Graphical representation of the data race location

MUST detects leaks of user defined objects



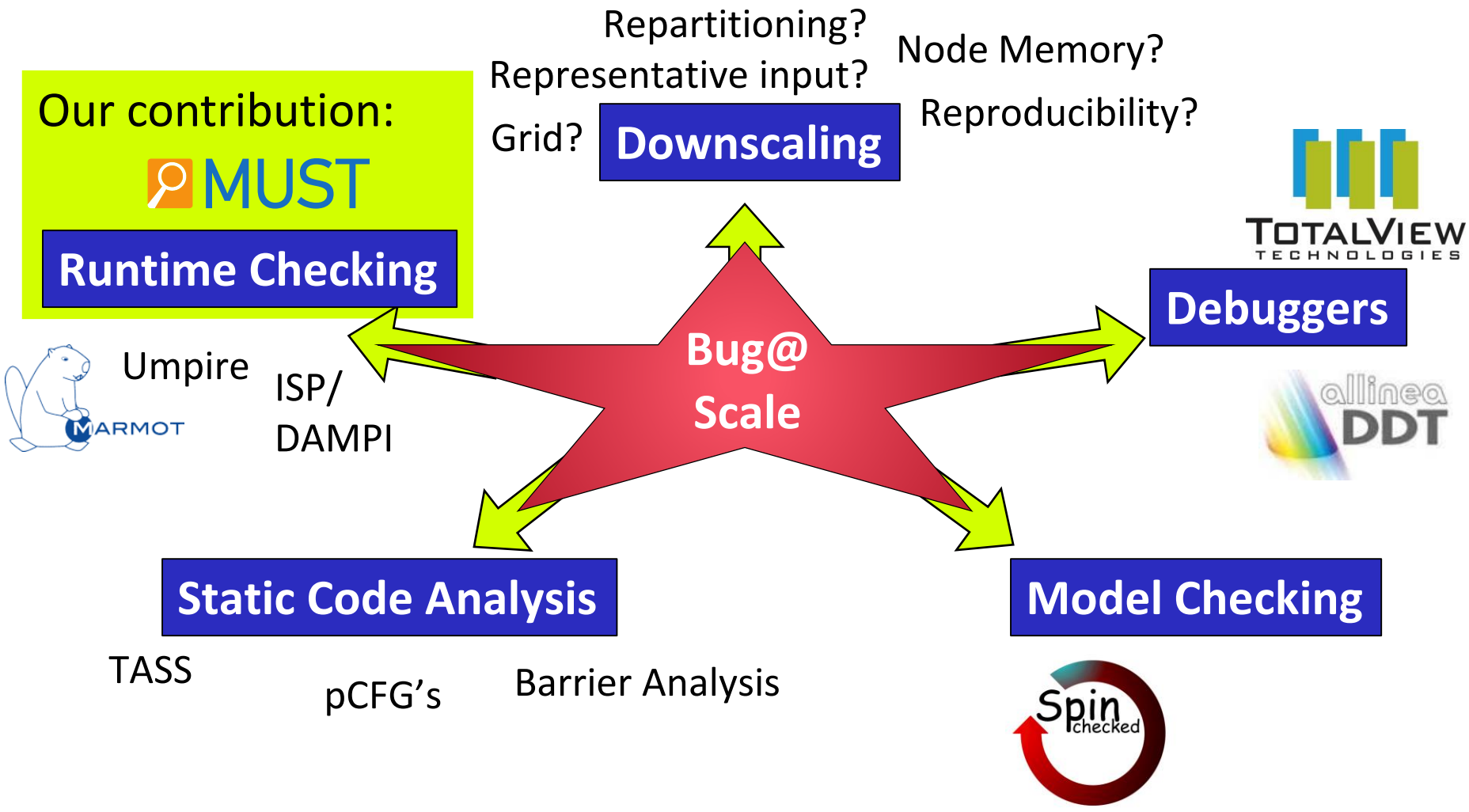
- User defined objects include
  - MPI_Comms (even by MPI_Comm_dup)
  - MPI_Datatypes
  - MPI_Groups



No further error detected

Hopefully this message applies to many applications

Approaches to Remove Bugs (Selection)



MUST – Basic Usage

- Load MUST module:

```
% module load DEV-TOOLS must
```

- Apply MUST with an mpiexec wrapper, that's it:

```
% $MPICC source.c -o exe
% $MPIRUN -np 4 ./exe
```

- Replace:

```
% $MPICC -g source.c -o exe
% mustrun --must:mpiexec $MPIRUN -np 4 ./exe
```

or:

```
% mustrun -np 4 ./exe
```

- After run: inspect "MUST_Output.html"

MUST - Advanced usage

- MUST scales with application to 10000's processes
  - Use --must:fanin
- Read help:
  - % mustrun --help
- Read documentation:
  - http://www.itc.rwth-aachen.de/must/
- MUST is available for download (BSD license):
  - http://www.itc.rwth-aachen.de/must/
- Feedback via email:
  - must-feedback@lists.rwth-aachen.de

Hands-On

MUST - Handson

```
$ module load DEV-TOOLS must
$ module list
Currently Loaded Modulefiles:
 1) DEVELOP    3) intelmpi/2018  5) must/1.6-rc3
 2) intel/19.0    4) DEV-TOOLS

$ cd tealeaf/MUST/
$ make mustrun -j8 COMPILER=INTEL

$ konqueror MUST_Output.html
```

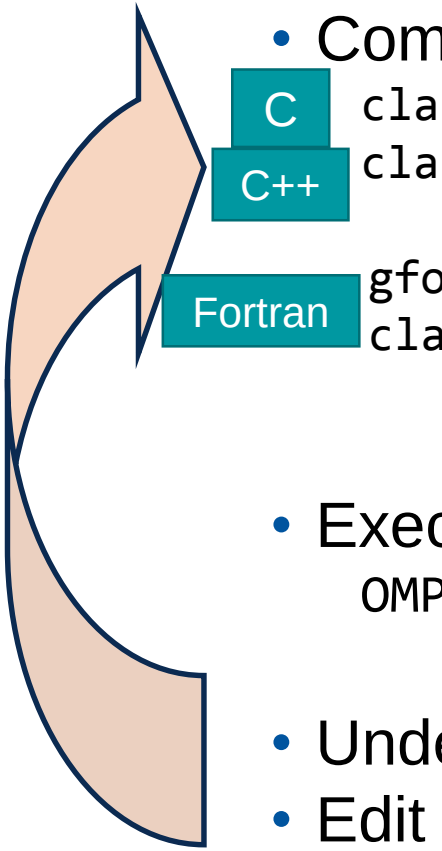
OpenMP runtime correctness checking

OpenMP Correctness checking: ThreadSanitizer – Overview

- Correctness checking for threaded applications
- Integrated in clang and gcc compiler
- Low runtime overhead: 2x – 15x
- Used to find data races in browsers like Chrome and Firefox

OpenMP Correctness checking: ThreadSanitizer – Usage

```
module load clang/9.0 gcc/7
```



- Compile the program with clang compiler:

```
clang -fsanitize=thread -fopenmp -g myprog.c -o myprog
clang++ -fsanitize=thread -fopenmp -g myprog.cpp
        -o myprog
gfortran -fsanitize=thread -fopenmp -g myprog.f -c
clang -fsanitize=thread -fopenmp -lgfortran myprog.o
        -o myprog
```

- Execute:

```
OMP_NUM_THREADS=4 ./myprog
```

- Understand and correct the detected threading errors
- Edit the source code
- Repeat until no errors reported

OpenMP Correctness checking: ThreadSanitizer – Result Summary

```
 1 #include <stdio.h>
 2
 3 int main(int argc, char **argv) {
 4     int a = 0;
 5     #pragma omp parallel
 6     {
 7         if (a < 100) {
 8             #pragma omp critical
 9             a++;
10         }
11     }
12 }
```

WARNING: ThreadSanitizer: data race

Read of size 4 at 0x7fffffffdcdc by thread T2:

#0 .omp_outlined. race.c:7 (race+0x0000004a6dce)

#1 __kmp_invoke_microtask <null> (libomp_tsan.so)

Previous write of size 4 at 0x7fffffffdcdc by main thread:

#0 .omp_outlined. race.c:9 (race+0x0000004a6e2c)

#1 __kmp_invoke_microtask <null> (libomp_tsan.so)

Archer - Handson

```
$ module switch intel clang/9.0
$ module load gcc/7
$ module list
Currently Loaded Modulefiles:
 1) DEVELOP  2) clang/7.0 3) intelmpi/2018 4) gcc/7

$ cd tealeaf/Archer/
$ make run -j8 COMPILER=LLVM

SUMMARY: ThreadSanitizer: data race
../TeaLeaf_ref/generate_chunk_kernel.f90:99

SUMMARY: ThreadSanitizer: data race
../TeaLeaf_ref/generate_chunk_kernel.f90:100
```

Thank you for your attention