MUST system applied to high level language approach in MYX project

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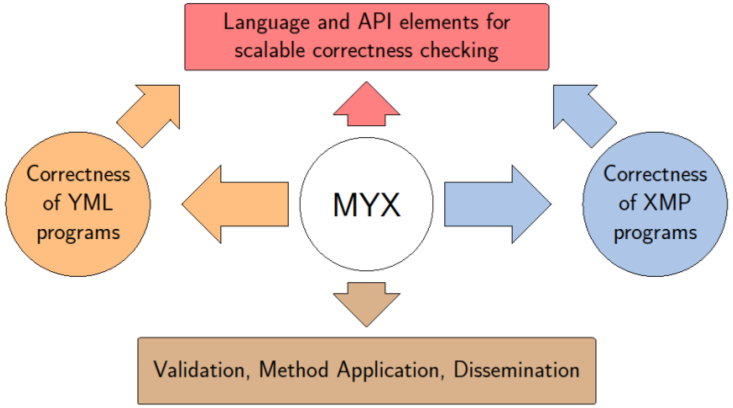
MYX Project Consortium

- MUST Correctness Checking for YML and XMP Programs.
- International collaboration among Germany (DFG), Japan (JST), and France (ANR).
- Part of the Priority Programme "Software for Exascale Computing" (SPPEXA) in German.

- Partner from Germany (project coordinator)
  - RWTH Aachen, IT Center and Institute for High Performance Computing
  - Prof. Matthias S. Mueller, Joachim Protze, Christian Terboven
- Partner from Japan
  - University of Tsukuba, Center for Computational Sciences, and Advanced Institute of Computational Science, RIKEN
  - Prof. Taisuke Boku, Hitoshi Murai, Miwako Tsuji
- Partner from France
  - Maison de la Simulation
  - Prof. Serge Petiton. Prof. Nahid Emad

MYX Project

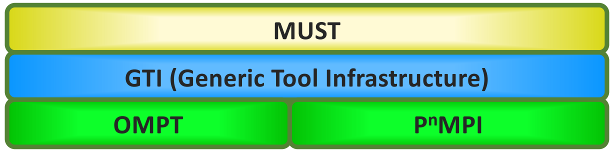
- Background
  - Errors in programs will increase in highly-parallel and complicated exascale computing.
  - Automatic correctness checking of programs is important.
- Goals
  - higher productivity by scalable correctness checking
  - targets: YML and/or XcalableMP (XMP)
- Components
  - MUST: a correctness checking tool
  - YML: a workflow language
  - XMP: a PGAS language

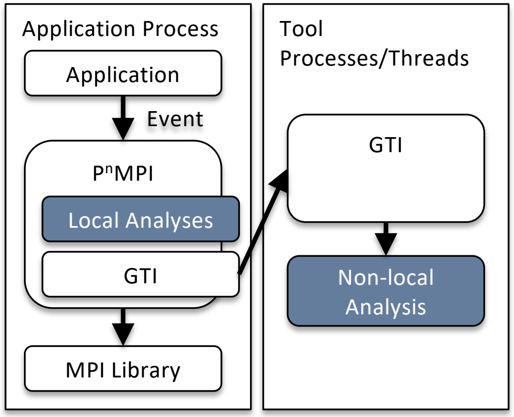

Language and API elements for scalable correctness checking
Correctness of YML programs
MYX
Correctness of XMP programs
Validation, Method Application, Dissemination

MUST

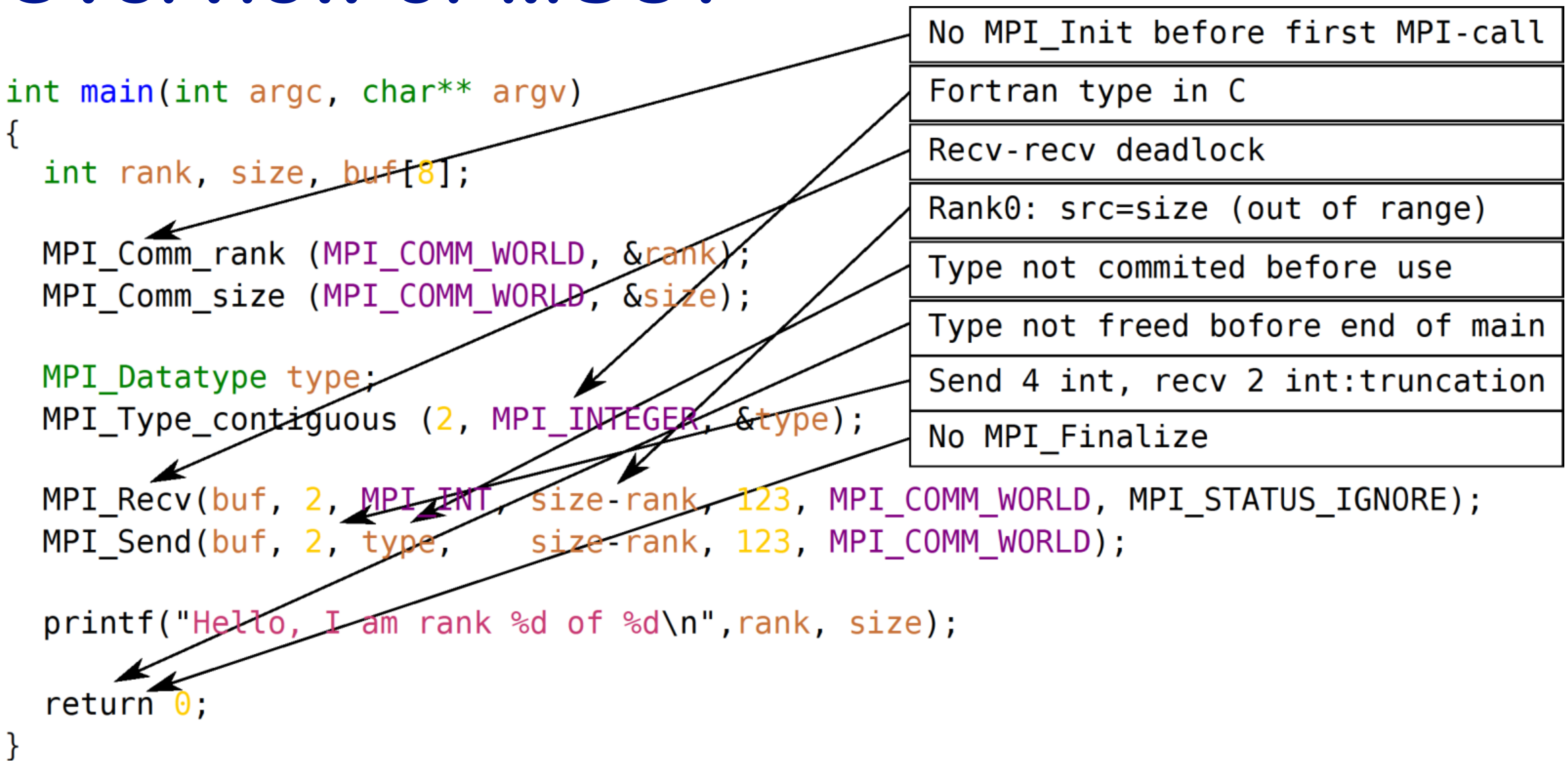
- Correctness checking tool developed by RWTH Aachen
  - can detect local and global errors in MPI/OpenMP programs.
- The latest version supports checking MPI one-sided comms.

MUST software stack





Overview of MUST



```
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 commited before use

Type not freed bofore end of main

Send 4 int, recv 2 int:truncation

No MPI_Finalize

What's XcalableMP ?

www.xcalablemp.org

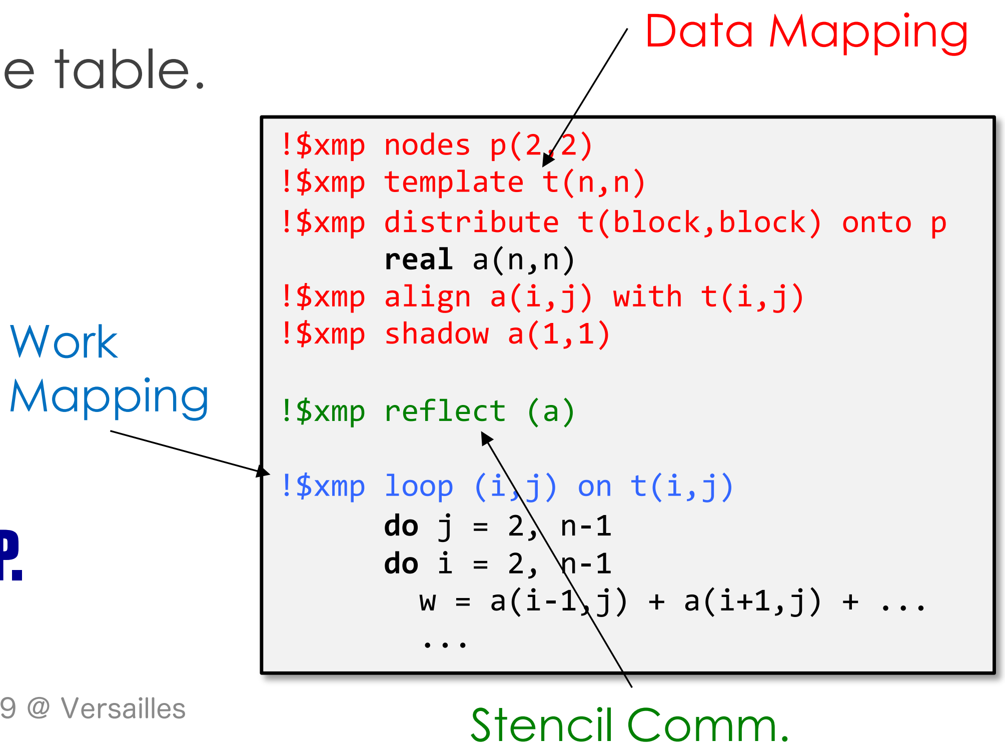
Directive-based PGAS extension for Fortran & C

- Proposed by *XMP Spec. WG* of PC Cluster Consortium.
- Ver. 1.4 spec. is available.
- Now ver. 2.0 (incl. C++ support) on the table.
- Adopted by Post-K Projects.

Supports two parallelization models:

- Global-view (based on HPF-like data/work mapping directives)
- Local-view (based on coarray)

Allows mixture with MPI and/or OpenMP.



Data Mapping

Work Mapping

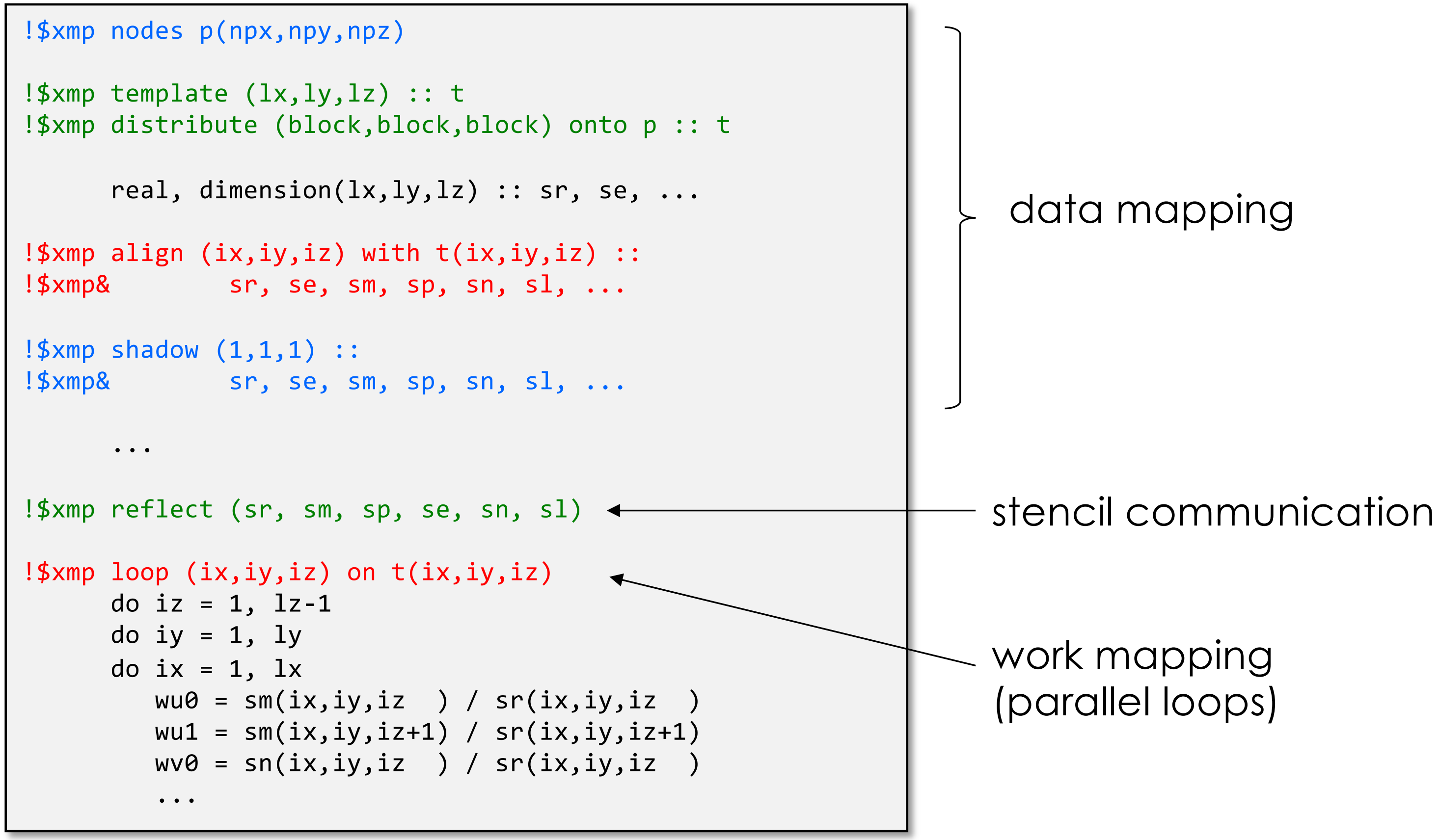
Stencil Comm.

```
!$xmp nodes p(2,2)
!$xmp template t(n,n)
!$xmp distribute t(block,block) onto p
      real a(n,n)
!$xmp align a(i,j) with t(i,j)
!$xmp shadow a(1,1)

!$xmp reflect (a)

!$xmp loop (i,j) on t(i,j)
      do j = 2, n-1
      do i = 2, n-1
        w = a(i-1,j) + a(i+1,j) + ...
        ...
```

Example of a Global-view XMP Program

```
real, dimension(lx,ly,lz) :: sr, se, ...







...




do iz = 1, lz-1
do iy = 1, ly
do ix = 1, lx
   wu0 = sm(ix,iy,iz  ) / sr(ix,iy,iz  )
   wu1 = sm(ix,iy,iz+1) / sr(ix,iy,iz+1)
   wv0 = sn(ix,iy,iz  ) / sr(ix,iy,iz  )
   ...
```

Example of a Global-view XMP Program



```
!$xmp nodes p(npx,npy,npz)

!$xmp template (lx,ly,lz) :: t
!$xmp distribute (block,block,block) onto p :: t

      real, dimension(lx,ly,lz) :: sr, se, ...

!$xmp align (ix,iy,iz) with t(ix,iy,iz) ::
!$xmp&        sr, se, sm, sp, sn, sl, ...

!$xmp shadow (1,1,1) ::
!$xmp&        sr, se, sm, sp, sn, sl, ...

      ...

!$xmp reflect (sr, sm, sp, se, sn, sl)

!$xmp loop (ix,iy,iz) on t(ix,iy,iz)
      do iz = 1, lz-1
      do iy = 1, ly
      do ix = 1, lx
         wu0 = sm(ix,iy,iz  ) / sr(ix,iy,iz  )
         wu1 = sm(ix,iy,iz+1) / sr(ix,iy,iz+1)
         wv0 = sn(ix,iy,iz  ) / sr(ix,iy,iz  )
         ...
```

data mapping

stencil communication

work mapping
(parallel loops)

Local-view Programming in XMP

- *Coarray*, a PGAS feature of Fortran 2008, is available in XMP/C as well as in XMP/Fortran.
- Basic idea: data declared as *coarray* can be accessed by remote nodes.

XMP/Fortran

```
1 real a(1024)[*], b(1024)
2 a(512:1024)[1] = b(1:512)
3 sync all
```

XMP/C

```
1 float a[1024]:[*], b[1024];
2 a[512:512]:[0] = b[0:512];
3 xmp_sync_all(NULL);
```

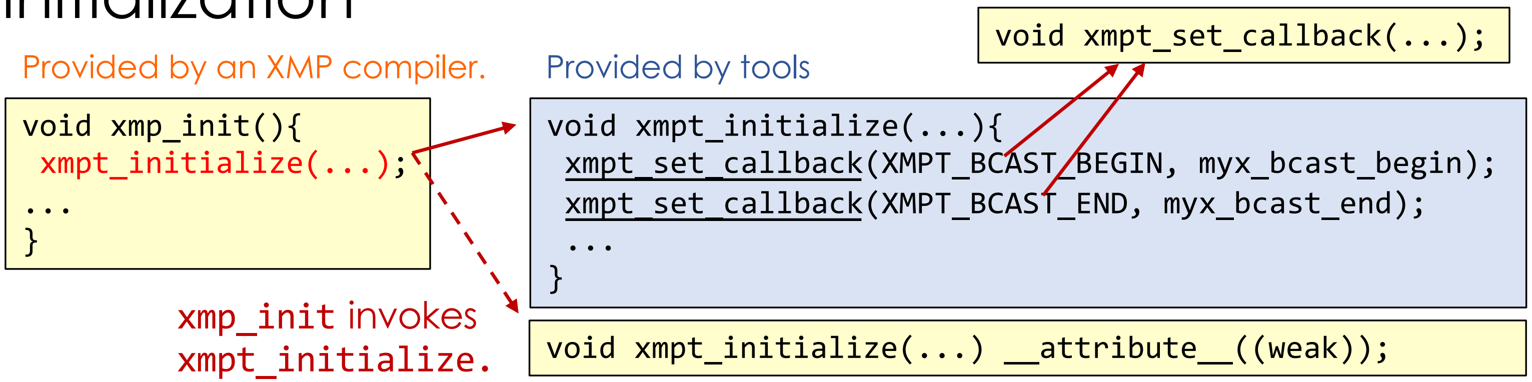
1. An array `a` is declared as a coarray.
2. A local array section `b(1:512)` is put to a remote array section `a(512:1024)` on image 1.
3. A memory fence and barrier synchronization is performed.

XMPT Tool Interface

- ... is a tool API of XMP.
- Objective:
  - providing a more generic tool API of XMP.
- Basic ideas inspired by OMPT
  - event- and callback-based
- Planned targets:
  - *Score-P* / *Scalasca* (JSC)
  - *Extrae* (BSC)
  - *MUST* correctness checking tool (this project)
  - etc.

Basic Design of XMPT

- At initialization



Callbacks are registered through `xmpt_set_callback.`

```
void xmpt_set_callback(...);
```

Provided by an XMP compiler.

```
void xmp_init(){
 xmpt_initialize(...);
...
}
```

xmp_init invokes xmpt_initialize.

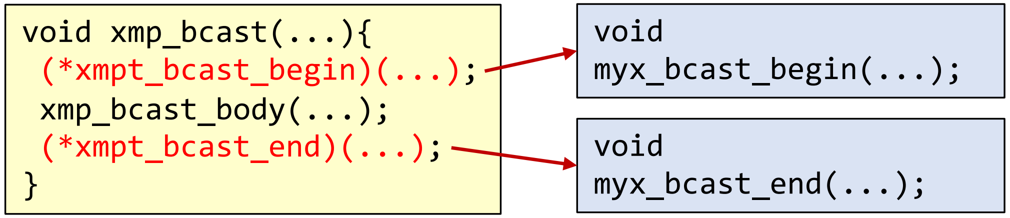
Provided by tools

```
void xmpt_initialize(...){
 xmpt_set_callback(XMPT_BCAST_BEGIN, myx_bcast_begin);
 xmpt_set_callback(XMPT_BCAST_END, myx_bcast_end);
 ...
}
```

```
void xmpt_initialize(...) __attribute__((weak));
```

- At each event

The registered callbacks are invoked.



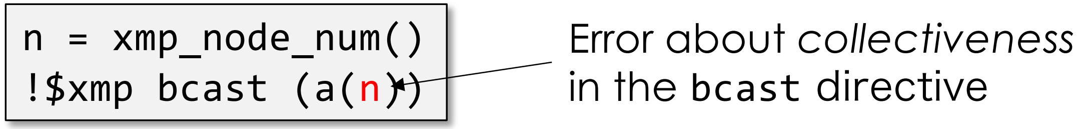
```
void xmp_bcast(...){
 (*xmpt_bcast_begin)(...);
 xmp_bcast_body(...);
 (*xmpt_bcast_end)(...);
}
```

```
void
myx_bcast_begin(...);
```

```
void
myx_bcast_end(...);
```

Correctness Checking of XMP Programs

- Errors in global directives



```
n = xmp_node_num()
!$xmp bcast (a(n))
```

Error about *collectiveness* in the `bcast` directive

- Data race of coarrays
  - XMPT events are defined for coarray accesses & syncs. as well as XMP directives.
  - MYX could detect it.

A data race may occur when a coarray is accessed in unordered segments in different images.

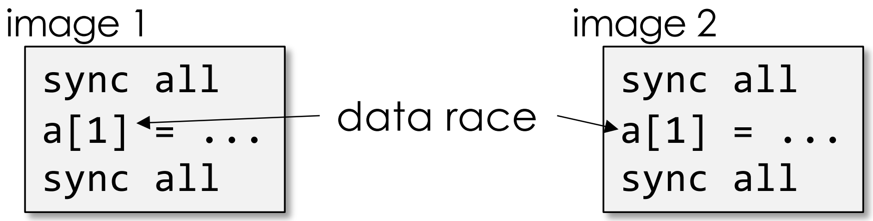


image 1

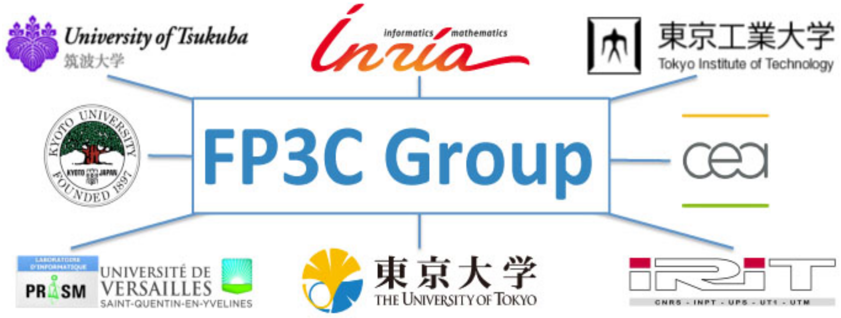
```
sync all
a[1] = ...
sync all
```

image 2

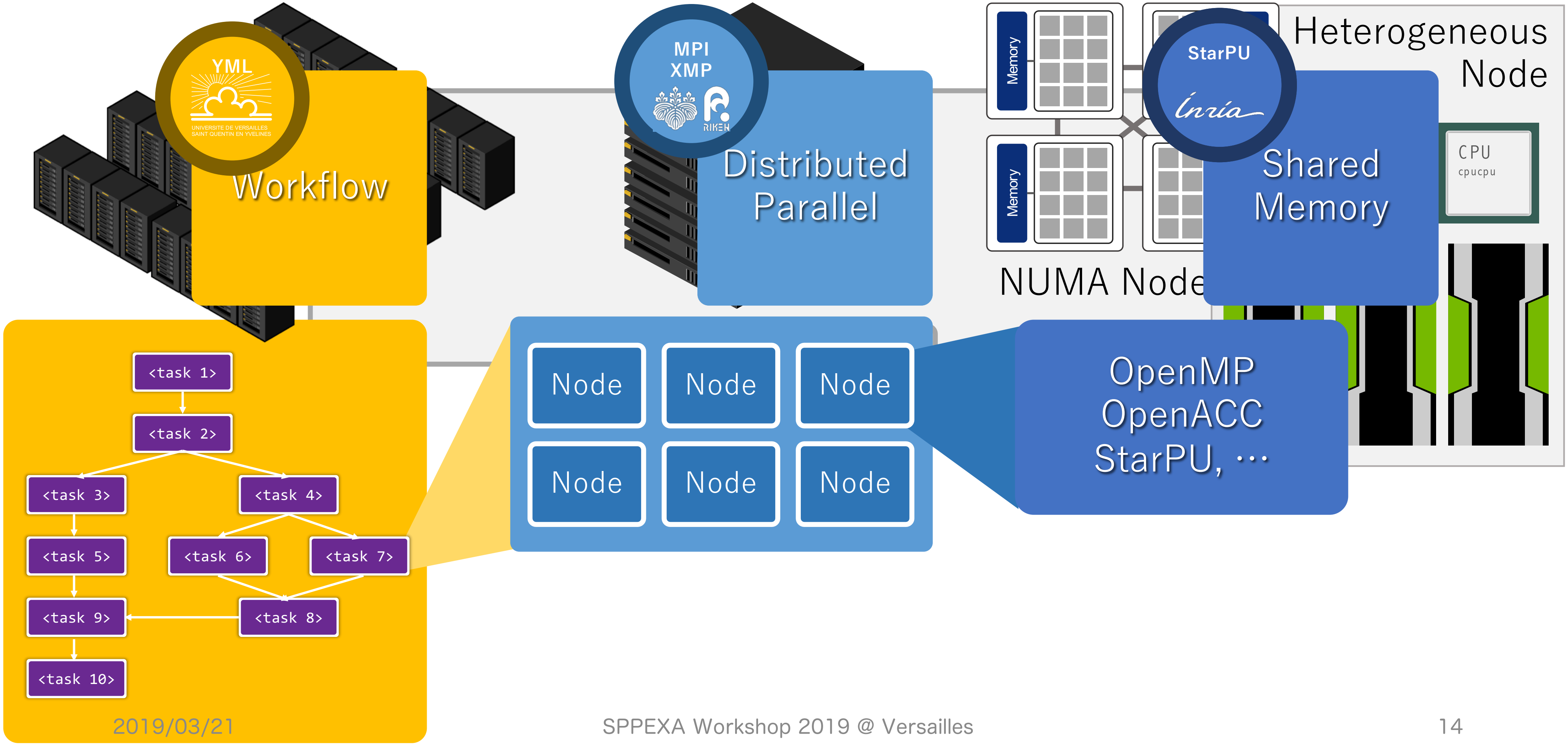
```
sync all
a[1] = ...
sync all
```

XMP+YML and FP3C project

- FP3C: Framework and Programming for Post Petascale Computing
  - a collaborative project between Japan and France
  - September. 2010 – March. 2014
- Various research fields and their integration
  - Programming model and programming language design
  - Runtime libraries
  - Accelerator
  - Algorithm and mathematical libraries
  - etc…

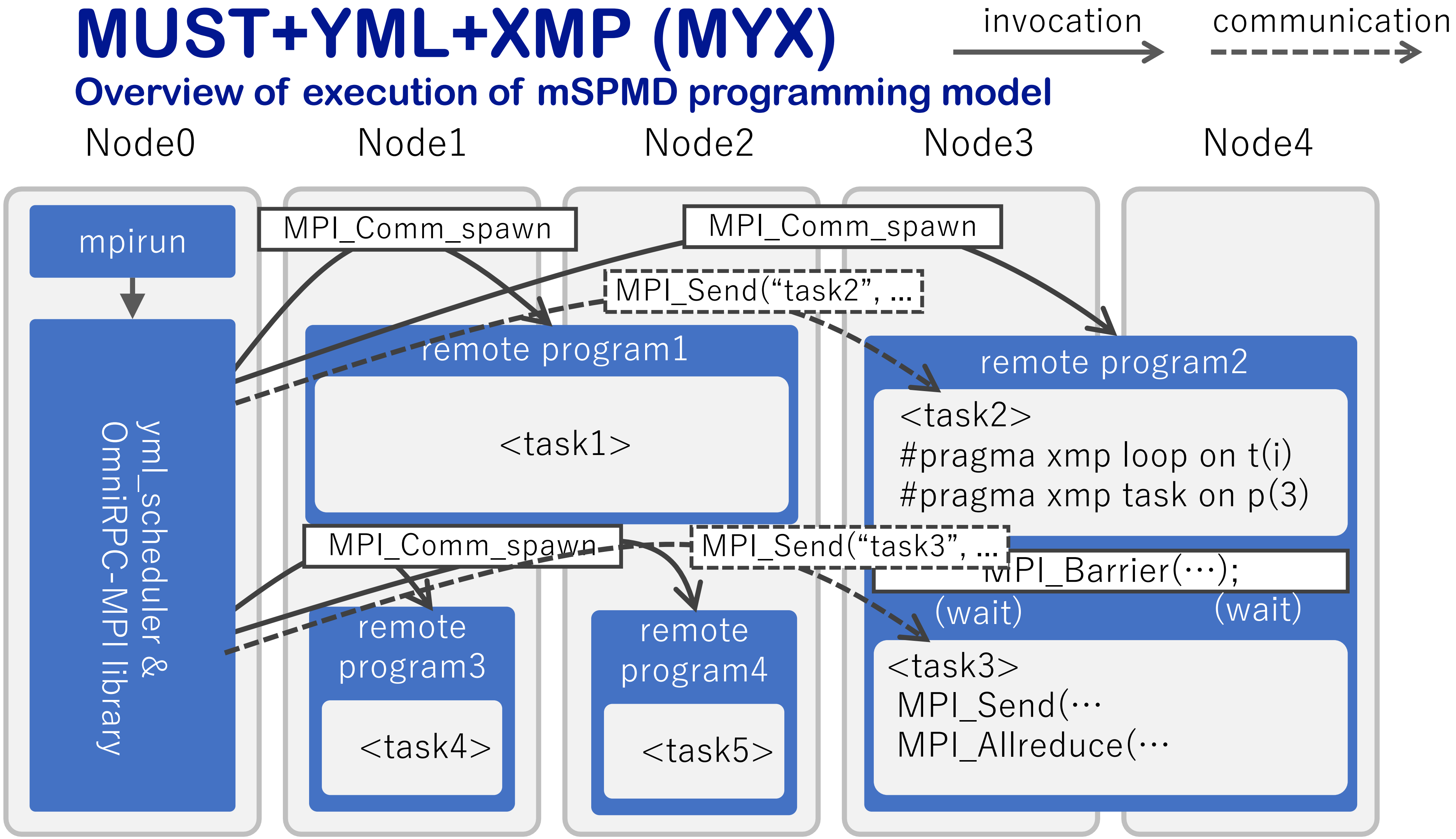


Multi SPMD (mSPMD) Programming Model



MUST+YML+XMP (MYX)

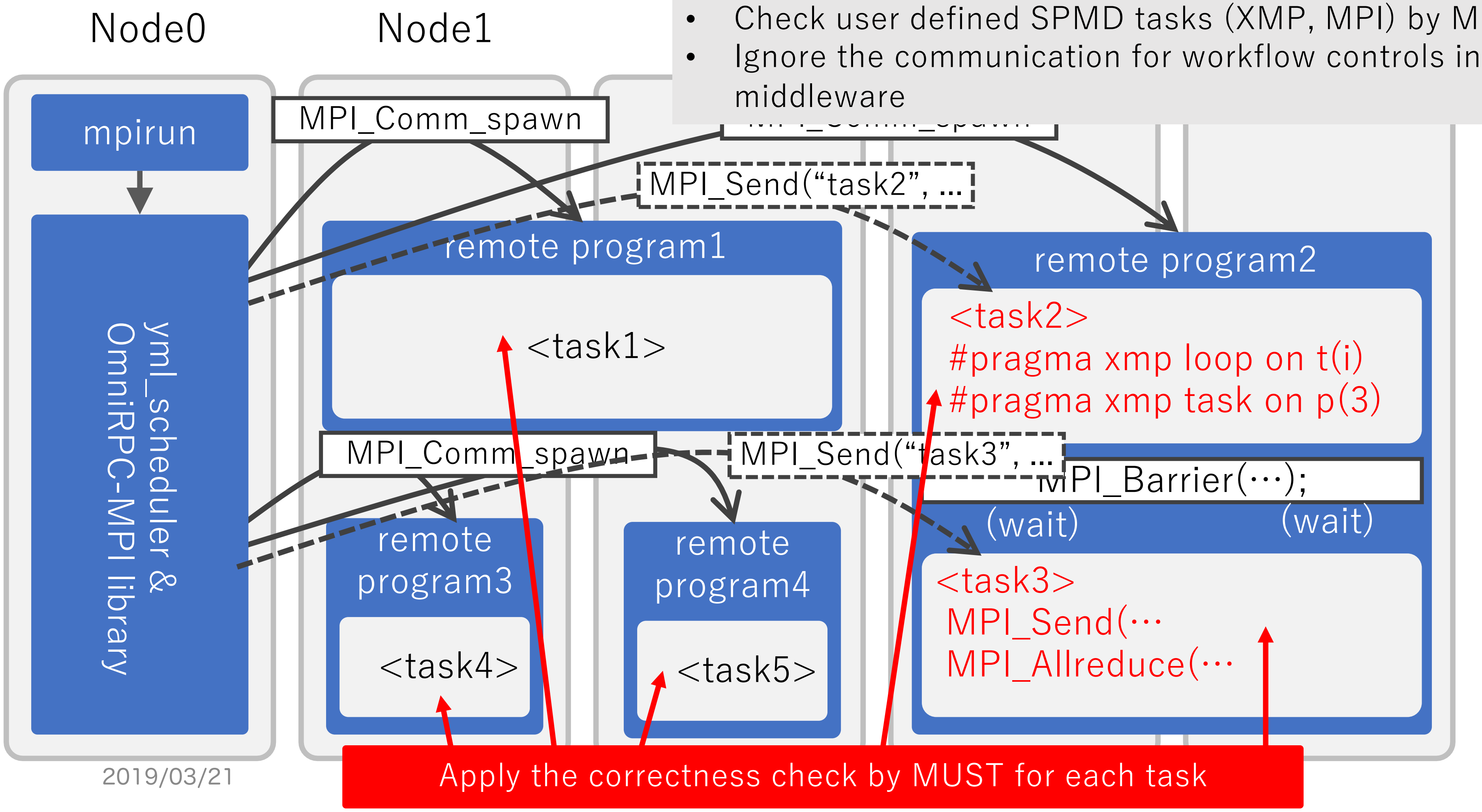
Overview of execution of mSPMD programming model



MUST+YML+XMP (MYX)

Target of correctness check in execution of mSPMD programming model

- Check user defined SPMD tasks (XMP, MPI) by MUST
- Ignore the communication for workflow controls in the middleware



Apply the correctness check by MUST for each task

MUST+YML+XMP (MYX): Implementation

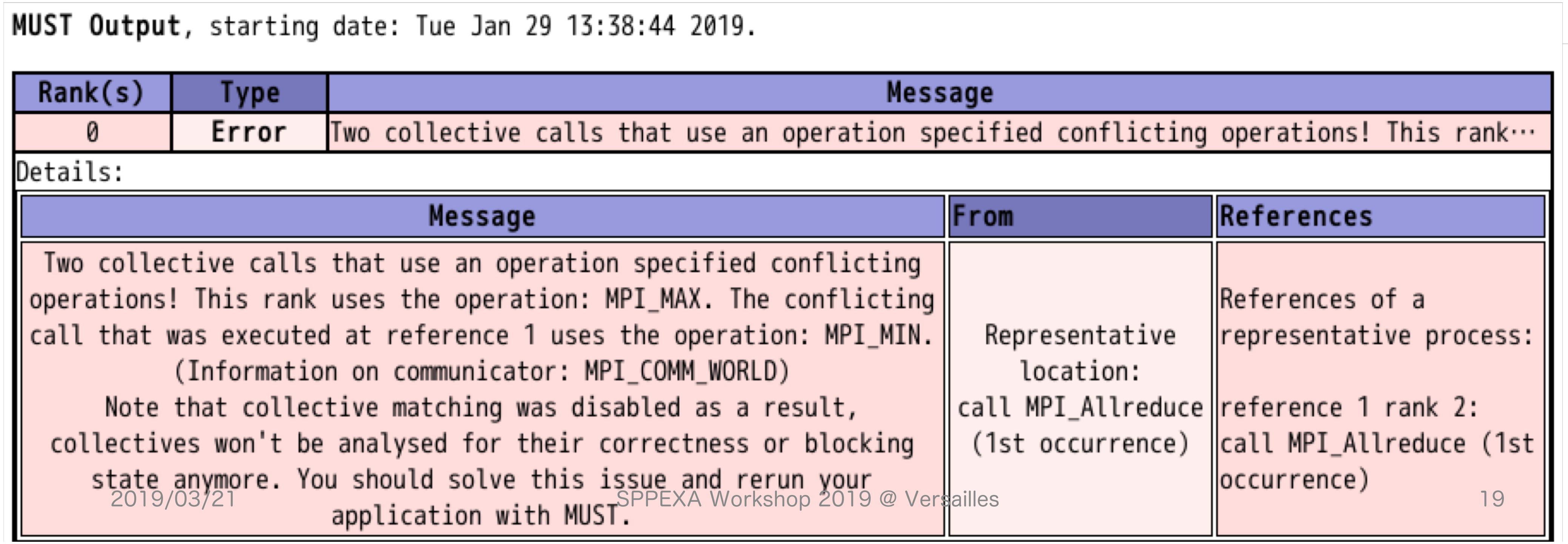
- MUST+MPI / MUST+XMP : to check a single SPMD program
  - **mustrun** –np *n* application.exe
  - prepare a dedicated dynamic library for the application.exe, set the environmental variables
  - mpirun –np (*n*+*1*) application.exe: 1 process should be kept for the MUST analysis
- MUST+YML+MPI/XMP: to check multiple SPMD program
  - Instead of mustrun (mpirun), MPI_Comm_spawn is used to invoke remote SPMD programs in mSPMD
  - extend the middleware of workflow scheduler and the remote program generator in mSPMD
    - MPI_* functions in the workflow control are replaced with PMPI_* functions
    - MPI_Comm_spwan("prog", **n**, …) → PMPI_Comm_spwan("prog", **n+1**, …)
  - preparation steps performed within the mustrun script before mpirun should be performed before starting a workflow
    - set the environmental variables required by MUST manually (Originally, they are set by the mustrun scprit)
    - prepare a dedicated dynamic library to analyze each remote program

Experiments

- Repeat simple communications w/ a nd w/o error s in each task of themSPMD Programming Model
  - investigate the results when MUST is applied, or when MUST is not applied
  - investigate the overhead
- Experimental environment
  - Intel Xeon CUP E5-2680 v3 @ 2.5GHz (24 core)
  - DDR4-2133 Reg ECC (2GBx6)
  - flat-MPI (up to 24 processes)
- Configurations:
  - each task runs on 4 processes, 4 tasks are executed simultaneously
  - each task runs on 10 processes, 2 tasks are executed simultaneously

Result

	mSPMD w/ MUST		mSPMD wo MUST
Reduction・correct	complete		complete
Reduction・incorrect	terminated	reported	terminated
Pingpong・correct	complete		complete
Pingpong・incorrect	complete	reported	complete



MUST Output, starting date: Tue Jan 29 13:38:44 2019.

Rank(s)	Type	Message
0	Error	Two collective calls that use an operation specified conflicting operations! This rank…

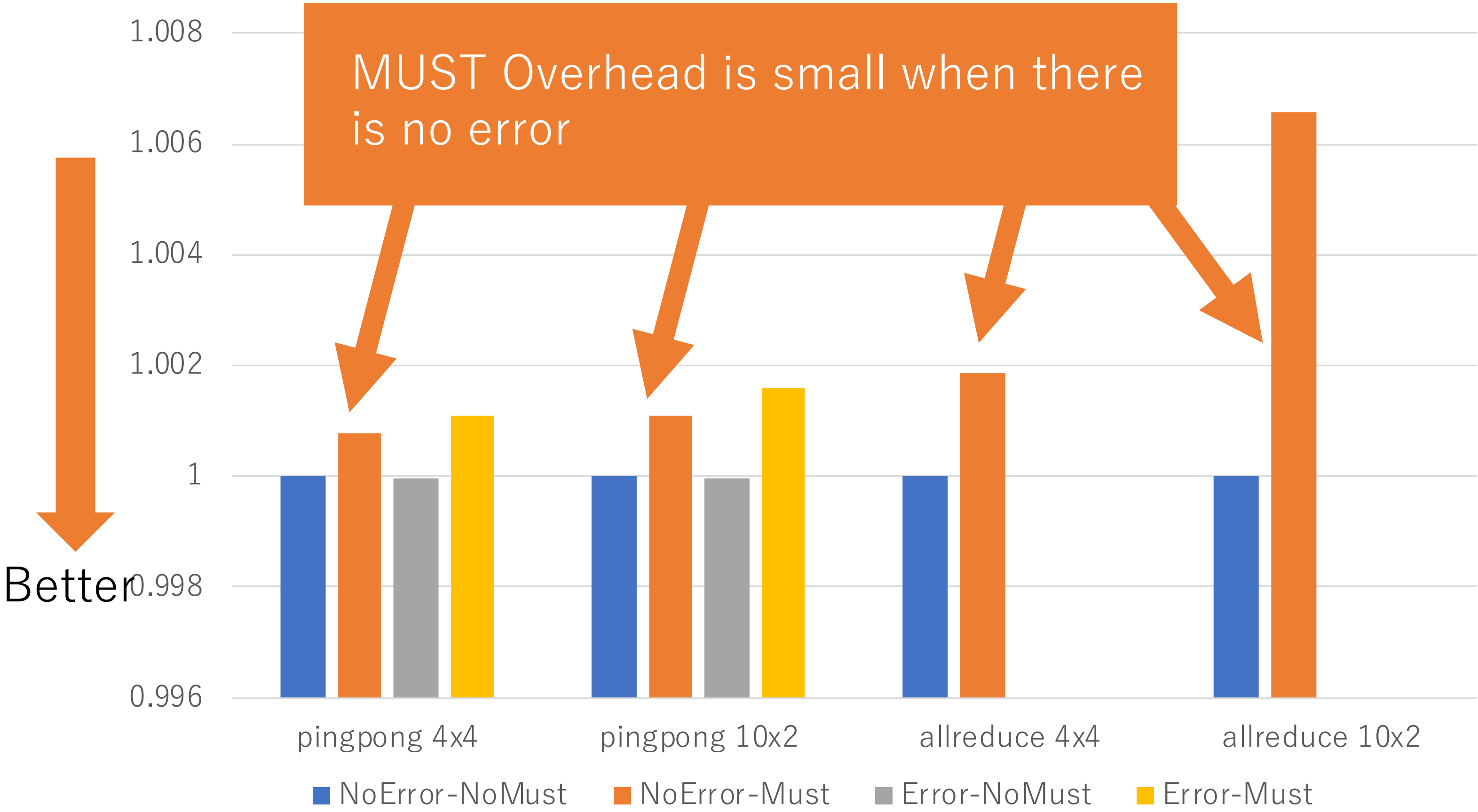
Details:

Message	From	References
Two collective calls that use an operation specified conflicting operations! This rank uses the operation: MPI_MAX. The conflicting call that was executed at reference 1 uses the operation: MPI_MIN. (Information on communicator: MPI_COMM_WORLD) Note that collective matching was disabled as a result, collectives won't be analysed for their correctness or blocking state anymore. You should solve this issue and rerun your application with MUST.	Representative location: call MPI_Allreduce (1st occurrence)	References of a representative process: reference 1 rank 2: call MPI_Allreduce (1st occurrence)

Experiments (overhead)

- MPI-pingpong w/ and w/o an error, w/ and w/o MUST
- MPI-allreduce w/ and w/o an error, w/ and w/o MUST
- Relative execution time

based on the case that is w/o error, w/o MUST


MUST Overhead is small when there is no error

Conclusion

- MYX: an international collaborative project for higher productivity in exascale computing. Runtime correctness check by MUST for multi SPMD Programming Model by YML+XMP
  - MUST is a correctness checking tool.
  - YML is a workflow language (to be presented by Miwako)
  - XMP is a directive-based PGAS extension for Fortran & C supporting the global- and local-view programming.
- XMP+MUST
  - XMP provides an interfere, XMPT, for performance tools
  - MUST uses the XMPT and check the correctness of XMP
- XMP+YML
  - Tasks written in XMP of a workflow managed by YML
- MUST+YML+XMP
  - The task generator and middleware in mSPMD have been extended

  ⇒ Scalable, reliable programming model with high productively

  Scalable : Combination of multiple-SPMDs by YML and XMP

  Reliable : Fault-detection and recovery are supported

  High Productively : XMP, YML are easier than C+MPI

  MUST and XMPT provide a debug tool for SPMD