Possible Malleability Support in MPI 5:

What Does it Mean for (MPI) Tools?

Martin Schulz

Chair for Computer Architecture and Parallel Systems
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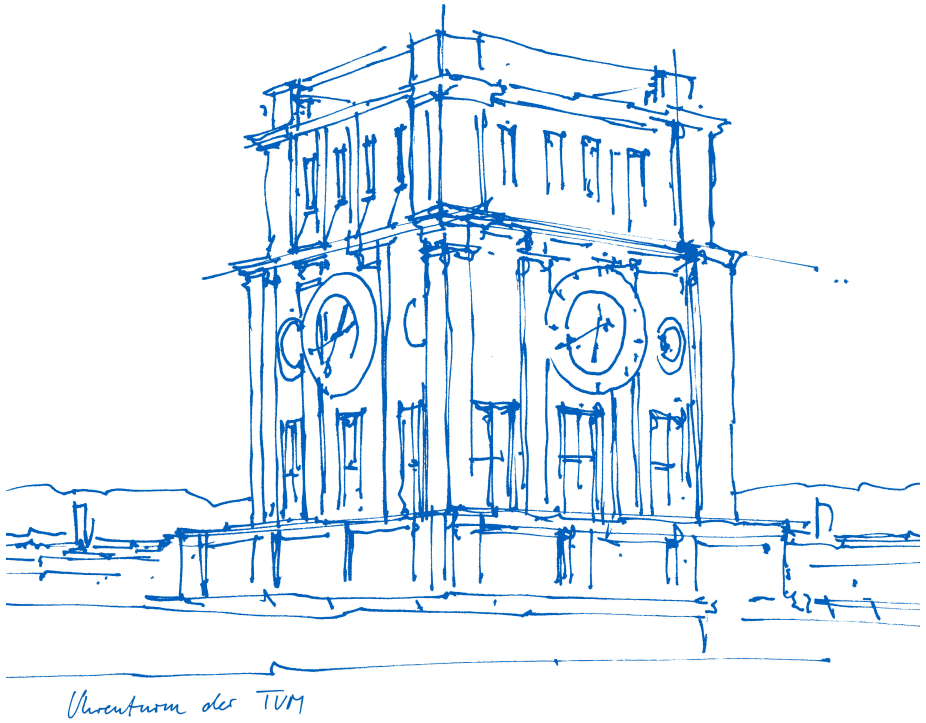
Scalable Tools Workshop 2022

Monday June 20th, 2022



Possible Malleability Support in MPI 5 (and all the other stuff the MPI Forum is cooking up):

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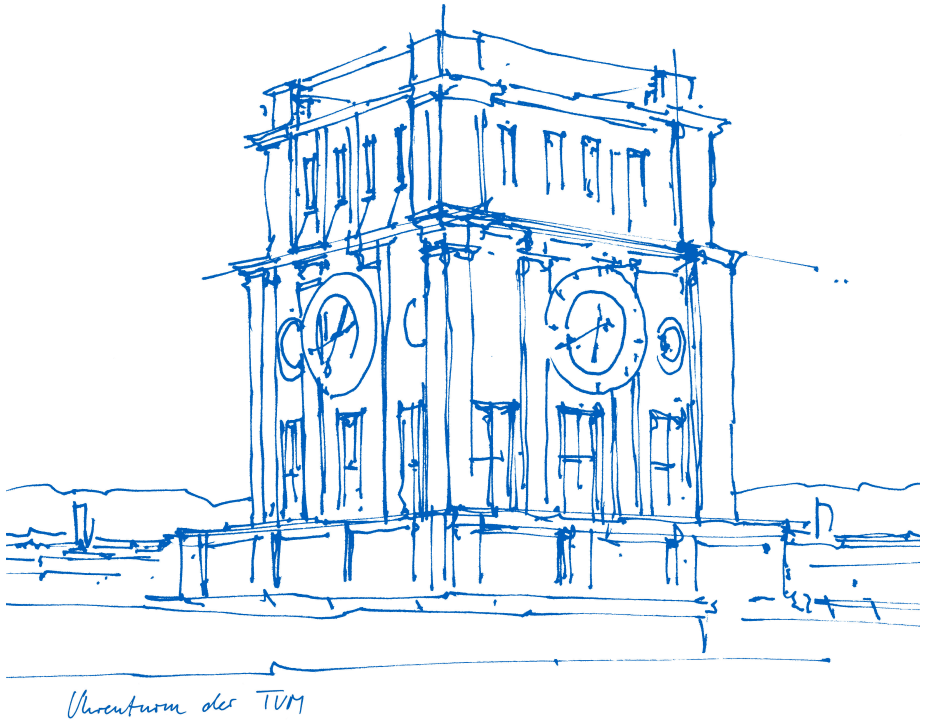


Overview of (some) items in MPI that will affect tools

MPI 4.0 introduced MPI Sessions

- Dynamic initialization and finalization
- Resource isolation

Plans for MPI 5.0 include support for malleability

- Based on the MPI Sessions model
- Changing resource availability and usage on the fly

Other MPI features

- Fault tolerance
- Partitioned communication and accelerator bindings
- Continuations

Finally, perhaps some good news: QMPI

MPI Sessions

Instead of MPI_Init / MPI_COMM_WORLD:

1. Get local access to the MPI library

   Get a Session Handle

2. Query the underlying run-time system

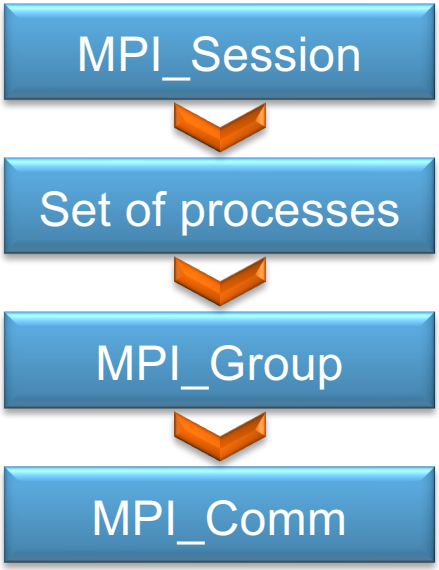
   Get a "set" of processes

3. Determine the processes you want

   Create an MPI_Group

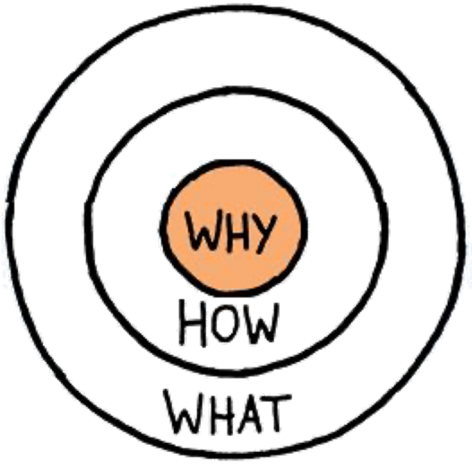
4. Create a communicator with just those processes

   Create an MPI_Comm



Never mix handles derived from two sessions in any call!

MPI Sessions



What does this do?

- Deliver runtime information to the MPI library
- Enable resource isolation between sessions
- Eliminate the static resource MPI_COMM_WORLD

Where do Process Sets Come From?

- Two predefined sets: **`mpi://WORLD`** and **`mpi://SELF`**
- Runtimes can provide system configurations, like **`location://rack/17`**
- Users can specify process sets, like **`app://ocean`**

Intended Usage Patterns

- Scalable initialization on subsets of processes
- Separate library initialization
- Separation of application components (ice, ocean, atmosphere, …)

Consequences

No MPI_COMM_WORLD (potentially, ever)

- Applications do not have to call MPI_Init
  - No longer the first call that can be intercepted
  - More calls allowed before MPI_Init
- Applications can call MPI_Session_init multiple times
  - Every session can have different process sets
  - Even mpi://WORLD can be different

Tools need to track all Session initializations and finalizations

- May have to deal with re-initializations
- Can only rely on communicators derived from particular process sets
- Have to obey the rule of not mixing handles from multiple sessions
- Will be hard to impossible to create a global communicator

Advantages: Tools can utilize separate/isolated sessions themselves

PMPI and MPI Sessions

MPI Session calls can be tracked with PMPI

- Standard interception possible
- Can influence thread levels, if needed

Currently: single PMPI tool stack across all MPI Sessions

- Tools need to keep track of session handles and associations
  - Forum is considering a query Session ID procedure – helpful?
- Tool invocations may not make sense in the calling context

Is this the right model?

- Or should there be a tool(stack) per session
  - If so, how to specify the tool?
  - How to name/associate the sessions?
- Or should there for be a different model?

- Do we need other routines?

Malleability on top of MPI Sessions

Enables path from the runtime to the application

- Runtime can add new process sets in a session (possibly with versioning)
- New sessions can have new process set lists (arguments at session start)

MPI Forum working on APIs to provide handshake

- Detection of new resources
- Negotiations for and acceptance of new resources

Connection to fault tolerance proposals

- Set of sessions from multiple processes can form a transitive “bubble”
- Bubbles can be seen as inherent fault domains (connection to FT)

Should maintain MPI look & feel

EuroHPC Time-X: Weather and climate [1]

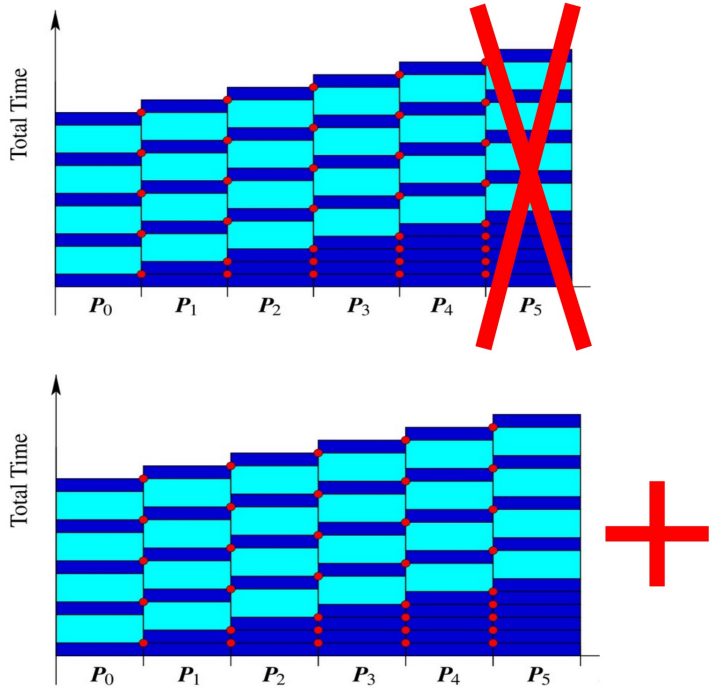
Exploit malleable MPI to support varying resources ‘for parallel-in-time applications

- Vary number of parallel steps
- Based on efficiency predictions
- Based on resource availability

Key design points

- Who triggers malleability?
- Cost model

Each column represents a parallel-in-time simulation instance for a particular time interval



Support removing time-parallel simulation instances (top) or adding them (bottom)

EU Grant #955701
BMBF #16HPC050

Impact of Malleability

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Resource Change: Add {1,13}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Resource Change: Add {6}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Resource Change: Remove {1,4}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Resource Change: Add {15}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Resource Change: Remove {5,12,13}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Resource Change: Add {1,213}

- Resources can come and go
- Final set can be completely different than starting
- But: negotiation routines can be intercepted

From: Jan Fecht, TUM – published at HPCMALL 2022

Example API

Resource Changes

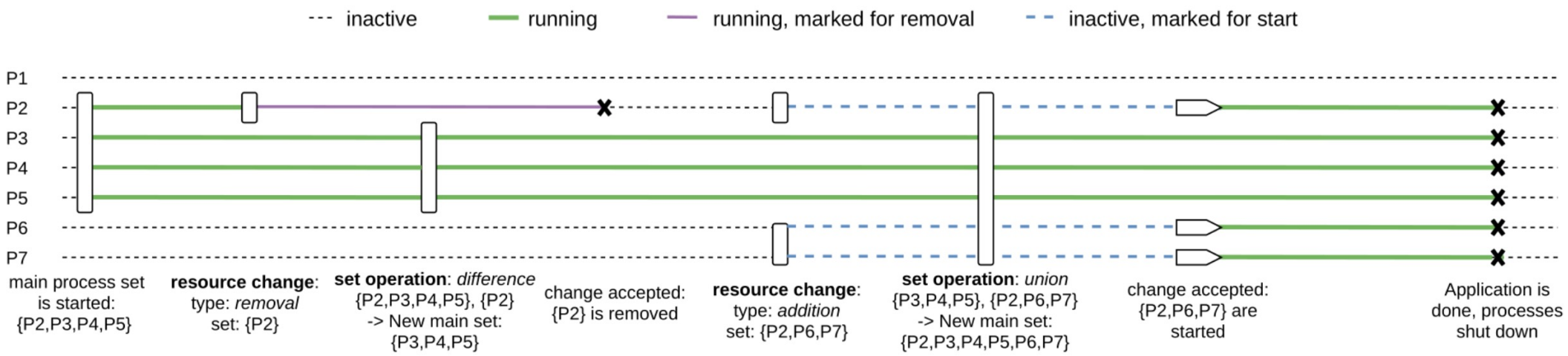
- Resource Change = **new process set** + **resource change type**
- The application:
  1. **polls** for a resource change
  2. does **load balancing**
  3. **accepts** the resource change
- Optional **info object** for passing information to new processes

```
int MPIDYNRES_RC_get(
    MPI_Session session,
    MPIDYNRES_RC_type *o_rc_type,
    char o_diff_pset_name[],
    MPIDYNRES_RC_tag *o_tag,
    MPI_Info *o_info
);
```

```
int MPIDYNRES_RC_accept(
    MPI_Session session,
    MPIDYNRES_RC_tag i_tag,
    MPI_Info i_info
);
```

From: Jan Fecht, TUM – published at HPCMALL 2022

Example for Malleability



Creation of new Psets

- New routines are an option for this

Processes come and go

- Need to intercept “adjustment phase”
- Need to see if application accepts the changes

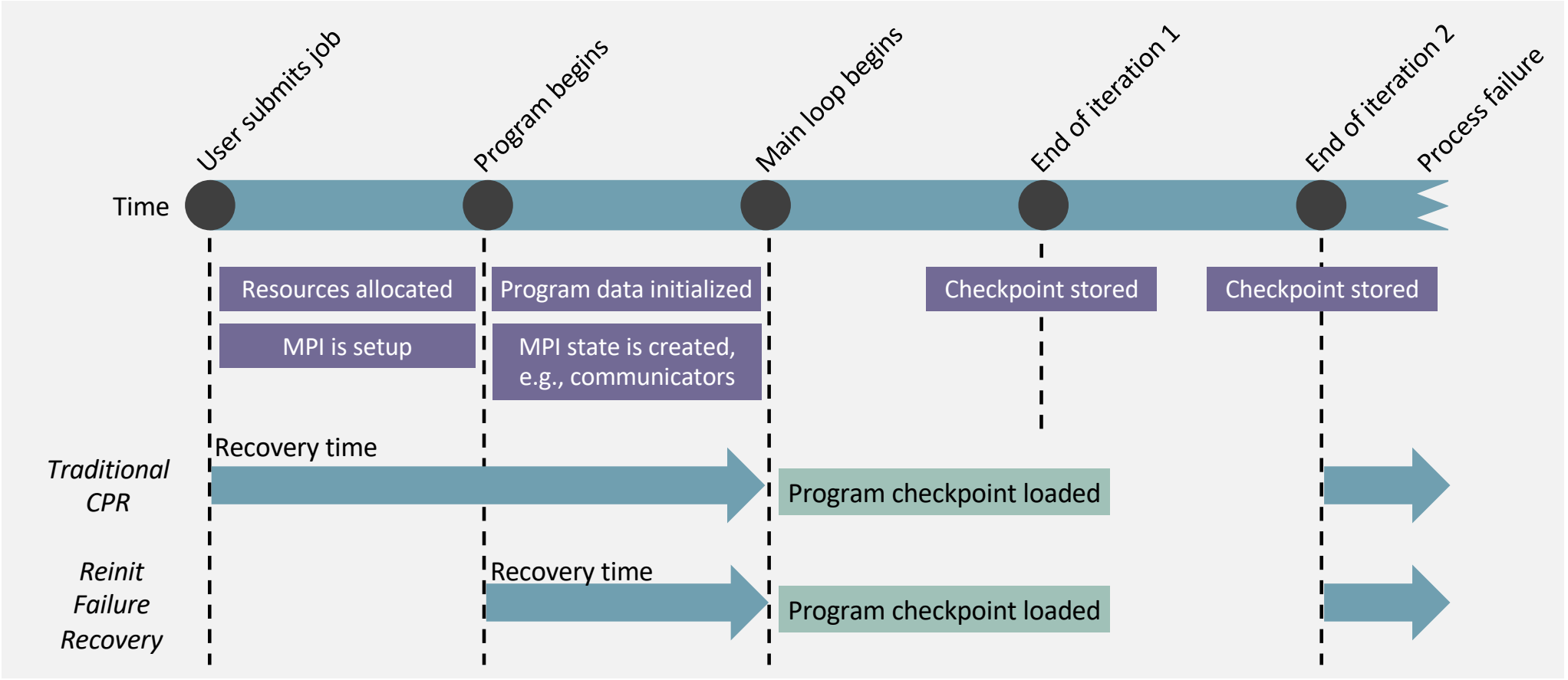
From: Jan Fecht, TUM – published at HPCMALL 2022

A different view on Malleability: Fault Tolerance

MPI Forum is making a push (again) for fault tolerance

- Multiple options/models on the table, tools will have to track that
- Implicitly changes to set of processes of applications
- Already changes to error handling to allow for continued execution

Coarse-grained Recovery (Reinit)



From: Ignacio Laguna, LLNL

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- Multiple options/models on the table, tools will have to track that
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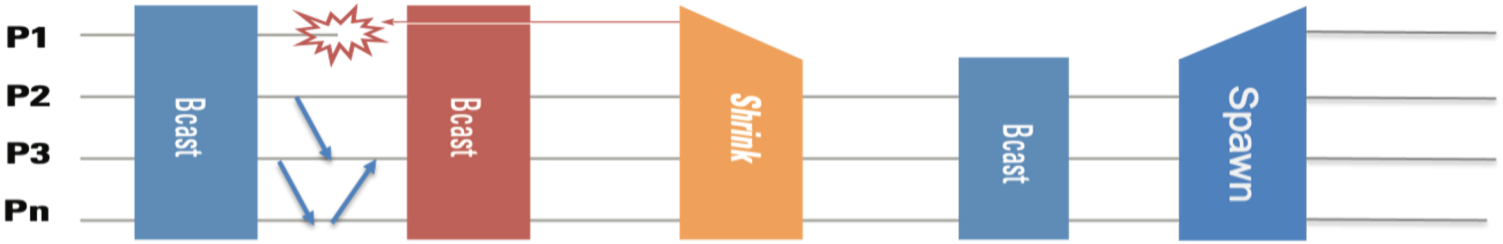
Option 1: Coarse-Grained Recovery (“Reinit” proposal)

- On failure in the system, automatic jump to start of main / No finalize
- Processes will be re-used so that data can be maintained
- But some processes may be restarted from scratch
- All MPI state is lost and has to be rebuilt (including tool state!)

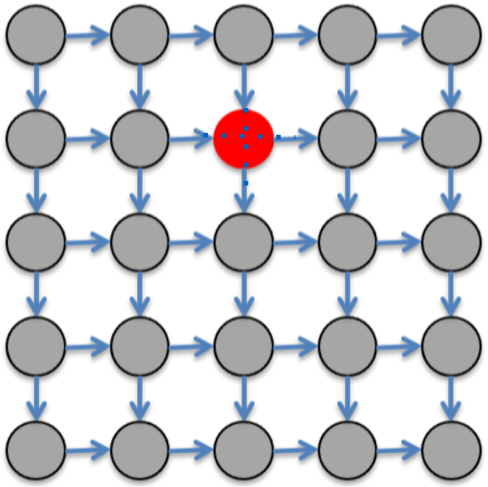
ULFM MPI Crash Recovery



- Some applications can **continue** w/o recovery
- Some applications are **malleable**
  - Shrink creates a new, smaller communicator on which collectives work
- Some applications are *not* **malleable**
  - Spawn can recreate a "same size" communicator
  - It is easy to reorder the ranks according to the original ordering
  - Pre-made code snippets available

- Failure Notification
- Error Propagation
- Error Recovery
- Respawn of nodes
- Dataset restoration

Not all recovery strategies require all of these features,
that's why the interface should split notification, propagation and recovery.



Who should be notified of a failure?
What is the scope of a failure?
What actions should be taken?

- Adds **3 error codes** and **5 functions to manage process crash**
  - **Error codes:** interrupt operations that may block due to process crash
  - MPI_COMM_FAILURE_ACK / GET_ACKED: continued operation with ANY-SOURCE RECV and observation known failures
  - MPI_COMM_REVOKE lets applications interrupt operations on a communicator
  - MPI_COMM_AGREE: synchronize failure knowledge in the application
  - MPI_COMM_SHRINK: create a communicator excluding failed processes
  - More info on the MPI Forum ticket #20: https://github.com/mpi-forum/mpi-issues/issues/20

From: Aurelien Bouteiller, UTK

A different view on Malleability: Fault Tolerance

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Option 2: Fine-Grained Recovery (“ULFM” proposal)

- Contiued, but limited operation after failure
- Tools would have to follow same limitations (and not change the state!)
- Communicator can be revoked, shrunk and deleted/replaced
- Mechanisms built on top of ULFM may need PMPI

And Now to Something Completely Different!

Partitioned Communication (MPI 4.0)

```
MPI_Psend_init(..., &request);
for (...) {
  MPI_Start(&request);
  #pragma omp parallel
  {
                kernel(..., request);
  }
  MPI_Wait(&request);
}
MPI_Request_free(&request);
```

```
Thread:

kernel(..., MPI_Request request) {
  int i = my_partition[my_id];
  /* Compute and fill partition i then mark ready: */
  MPI_Pready(i, request);
}
```

Next steps:

- Collective versions for partitioned communication

Current extension proposals focus on accelerators

- Optimizations to ensure buffers are “ready”
- Bindings should allow exection from the accelerator

Accelerator Bindings for MPI Partitioned APIs

CUDA and SYCL Language Bindings Under Exploration

```
int MPI_Psend_init(const void *buf, int partitions, MPI_Count count,
                   MPI_Datatype datatype, int dest, int tag, MPI_Comm comm, MPI_Info info,
                   MPI_Request *request)

int MPI_Precv_init(void *buf, int partitions, MPI_Count count,
                   MPI_Datatype datatype, int source, int tag, MPI_Comm comm, MPI_Info info,
                   MPI_Request *request)

int MPI_[start,wait][_all](...)
```

Keep host only

Add device bindings

```
__device__ int MPI_Pready(int partition, MPI_Request request)

__device__ int MPI_Pready_range(int partition_low, int partition_high, MPI_Request request)

__device__ int MPI_Pready_list(int length, const int array_of_partitions[], MPI_Request request)

__device__ int MPI_Parrived(MPI_Request request, int partition, int *flag)
```

Interception options unclear

- Does PMPI work on this and, if so, how? Do we need it?
- How would this impact tools for other functions (e.g., RMA Put/Get)?

From: Work by Jim Dinan, NVIDIA and Maria Garzaran, Intel

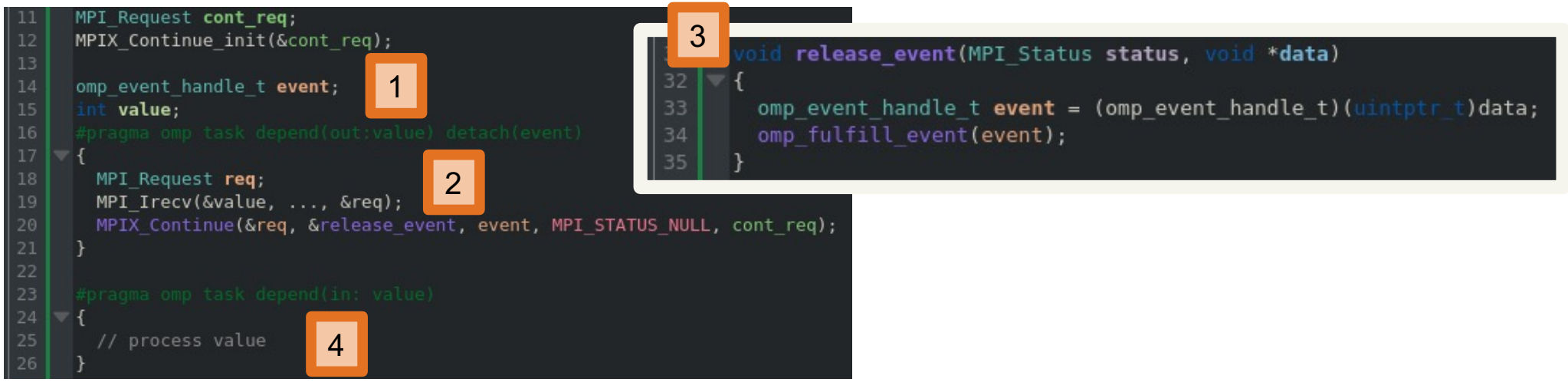
MPI Continuations

Opening Up MPI for Hybrid Runtimes

Several Proposals for Continuations

- Treat the completion of an MPI operation as continuation of some activity
- Ability to couple with OpenMP events and dependencies

Proposal for Thread Continuations



"Callback-based completion notification using MPI Continuations,"
Joseph Schuchart, Christoph Niethammer, José Gracia, George Bosilca, Parallel Computing, 2021.

"MPI Detach - Asynchronous Local Completion,"
Joachim Protze, Marc-André Hermanns, Ali Demiralp, Matthias S. Müller, Torsten Kuhlen. EuroMPI '20.

MPI Continuations

Opening Up MPI for Hybrid Runtimes

Several Proposals for Continuations

- Treat the completion of an MPI operation as continuation of some activity
- Ability to couple with OpenMP events and dependencies

Consequences for Tools

- Must track MPI and OpenMP
- Request tracking needs new approach
- May need wrapping of callback function (limitations tbd.)

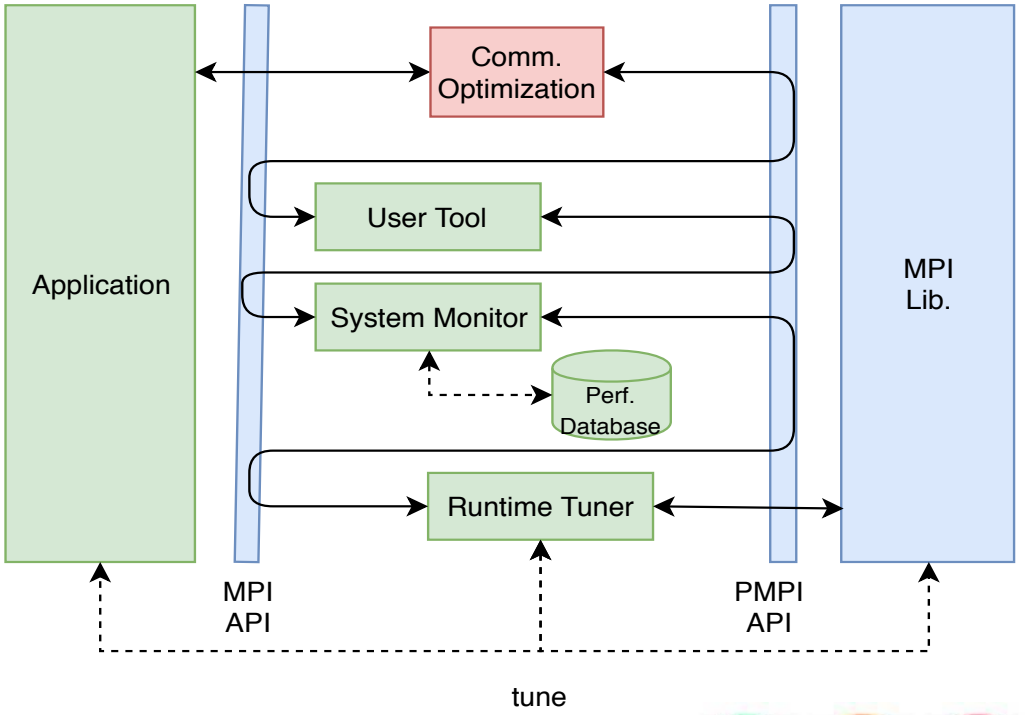
Good News (hopefully ☺): QMPI is Making Progress

Replacement idea for PMPI

- Multiple intercepts
- Runtime loading
- Options for user vs. system tools

Status

- Initial PMPI prototype
  (works on any MPI)
- Text proposal almost complete
- Prototype in MPICH available
- Open questions
  - Tool specification at runtime
  - How to deal with PMPI in transition period
  - Long term: dynamic tool loading



From: Bengisu Elis, TUM – published at EuroMPI 2019, MPICH Implementation by Wesley Bland when at Intel (now Meta)

MPI is Changing and Tools will Need to Adapt

Sessions change process tracking

- No global process set is guaranteed
- Process sets can change

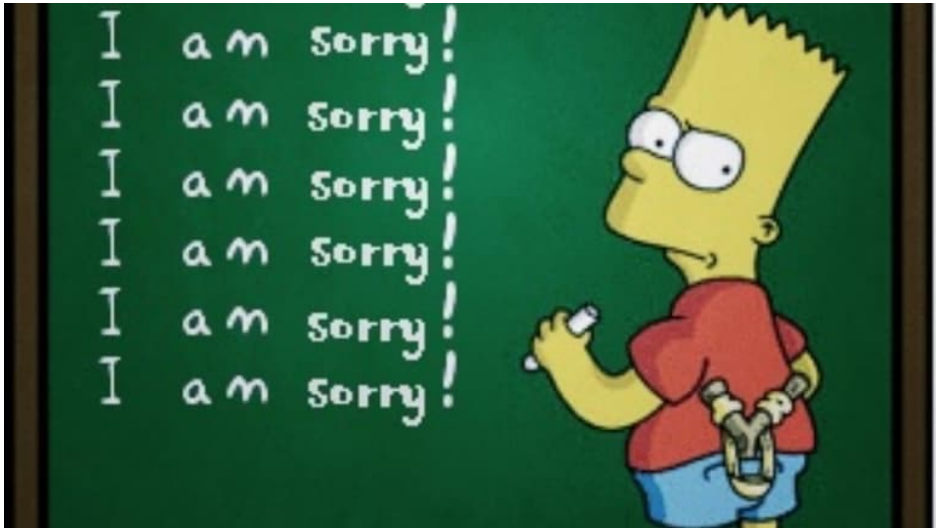
Malleability → Dynamic Tools

- Track process sets even within sessions
- Capture negotiations with runtime
- Match adjustment phases of apps
- Fault tolerance complicates things

Other new features likely on the way

- Accelerator bindings
  (especially for partitioned communication)
- Push towards hybrid runtimes

QMPI is making progress



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