Distributed and Parallel Systems Group
University of Innsbruck

Simone Pellegrini, **Radu Prodan** and Thomas Fahringer

A Lightweight C++ Interface to MPI

Message Passing Interface

- MPI is a relatively old standard
  - MPI 1.0 was introduced in 1994
- Designed upon an abstraction level which is the **lowest common denominator** across C,C++ and Fortran
  - i.e. functions calls, pointers, data types, etc…
- MPI standard evolved over 17 years by solely adding new primitives
  - MPI 3.0 will contain several hundreds routines
  - Abstraction level stays the same

Evolution of Languages

- MPI did not keep the pace with the evolution of languages in the last 17 years
  - Objects Oriented Programming in **Fortran 2000**
  - C++ Templates and template meta-programming
  - Lambdas and variadic templates in **C++11**
- HPC community is also slowly adopting C++

MPI C++ Bindings Deprecated

- MPI committee deprecated the C++ binding in MPI 2.3
  - They will be removed in MPI 3.0
- Why?
  - Poor overall integration in the C++ environment (e.g. with the standard template library STL)
  - Level of abstraction far lower than typical C++ libraries
  - C bindings are preferred even in C++ applications
  - Weaken type safety when mapping common C++ constructs to MPI

Outline

- Overview of existing MPI C++ bindings
  - Boost.MPI
- Introduction of MPP (MPI C++) interface
  - MPI endpoints as streams
  - Integration with user and legacy data types
- Performance evaluation
  - Interface overhead
  - **QUAD_MPI** real case scenario

MPI Running Example

```
if ( rank==0 ) {
    MPI_Send ((const int[1]) { 2 }, 1, MPI_INT, 1,
                                                  0, MPI_COMM_WORLD );

    std::array<float,2>& val = { 3.14f, 2.95f };
    MPI_Send (&val.front(), val.size(), MPI_FLOAT, 1,
                                                  0, MPI_COMM_WORLD);

} else if (rank == 1) {
    int n;
    MPI_Recv (&n, 1, MPI_INT, 0,
                          0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);

    std::vector<float> values(n);
    MPI_Recv (&values.front(), n, MPI_FLOAT, 0,
                          0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
}
```

What we don't like?

- 60% of MPI routines parameters can be either
  - **Inferred** by the compiler (**type** and **size** of sent/received data)
  - **Defaulted** (**tag** = 0, **comm** = MPI_COMM_WORLD, **status** = MPI_STATUS_IGNORE)

- Send/Recv both requires a **void*** which
  - **Weaken** type safety
  - Transfer **constant values** (a.k.a. **R-Values**) inefficient
    - Unless c99's compounds literals are used as in line 1
  - Miss an integration with C++ references

Outline

- Overview of existing MPI C++ bindings
  - Boost.MPI
- Introduction of MPP (MPI C++) interface
  - MPI endpoints as streams
  - Integration with user and legacy data types
- Performance evaluation
  - Estimate the interface overhead
  - **QUAD_MPI** real case scenario

Boost.MPI

Rank

Tag

Body

```
if ( world.rank() == 0 ) {
    world.send( 1, 1, 2 );
    world.send( 1, 0, { 3.14f, 2.95f } );

} else if (world.rank() == 1) {
    int n;
    world.recv(0, 1, n);
    std::vector<float>& values(n);
    world.recv(0, 0, values);
}
```

Communicator

Support for references

Boost.MPI: Summary

- Advantages
  - Much easier to read (less syntax)
  - Type and size of the transmitted data is inferred
  - Includes support for C++ references

- Disadvantages
  - No **default parameters**
  - MPI endpoints not handled as streams using the insertion **<<** and extraction **>> C++ stream operations**
    - Communication statements cannot be combined, e.g.
    - cout << "Hello" << "world"
  - Use of **software serialization** for transmitting user data types with poor performance
    - No integration with **MPI_Datatype**s

Outline

- Overview of existing MPI C++ bindings
  - Boost.MPI
- Introduction of MPP (MPI C++) interface
  - MPI endpoints as streams
  - Integration with user and legacy data types
- Performance evaluation
  - Estimate the interface overhead
  - **QUAD_MPI** real case scenario

MPP: MPI C++ Interface

- Interface to MPI smoothly integrated into the C++ programming language
  - Combines concepts of object-oriented programming and templates

- **<u>Key features</u>**:
  - **Header only** interface
  - Reduce the number of parameters MPI routines and infer as much as possible at compile-time
  - Improved integration with user and legacy data types with **safer type checking**
  - Use **compiler optimizations** to reduce overhead
    - e.g. function inlining, constant propagation
  - Focus on **point-to-point** communications

Running Example in MPP

```
using namespace mpi;

if ( comm::world.rank() == 0 ) {
    comm::world(1) << 2 << { 3.14f, 2.95f };

} else if ( mpi::world.rank() == 1 ) {
    int n;
    comm::world(0) >> n;
    std::vector<float>& values(n);
    comm::world(0) >> values;
}
```

Communicator

Rank

Support for references

MPP Features

- Concept of **endpoint**
  - **mpi::endpoint comm::operator() (int rank);**
  - Can be used as input/output stream using the insertion **<<** and extraction **>>** operators (lines 3-4)

- Infer **type** and **size** of the transmitted data and perform **type checking**

- Message **tag** is optional
  - By default messages are sent with a **tag 0** (lines 3,9)
  - User can provide a different value, if needed (lines 4,7)

Asynchronous Communications

- **Future pattern** utilized for simplifying the use of asynchronous communications

```
float real;
mpi::request<float>&& req =
                        mpi::comm::world(mpi::any) > real;
// ... do something else ...
use( req.get() );
```

- **T& request::get()** blocks for the communication to complete and directly returns a reference to received value

User and Legacy Data types

- A good MPI interface must be capable of dealing with non-primitive data types
- Boost.MPI
  - Generic but **inefficient** approach based on software serialization
- **MPI_Datatypes:** MPI's mechanism to deal with user-defined types
  - **Very efficient**, but cumbersome to use, **unknown** to most programmers
  - Programmers need to manually specify the **starting address** of the object in memory and its **layout**
    - The number of elements that compose the type
    - For each element **recursively**, the displacement from the starting address of the container type and their MPI_Datatype

User Data Types in MPP

- We support sending user/legacy data types in MPP via the **type traits** design pattern

- For any new data type the programmer specifies via a C++ template specialization class:
  - How to determine its **starting memory address**
  - The **number of elements** composing the type
  - **Type of elements**

Type Traits to Handle STL Vectors

```
template <class T>
struct mpi_type_traits<std::vector<T>> {
        static inline const T* get_addr( const std::vector<T>& vec ) {
                { return mpi_type_traits<T>::get_addr(vec.front()); }
        static inline const size_t get_size( const std::vector<T>& vec )
                { return vec.size(); }
        static inline MPI_Datatype get_type( const std::vector<T>& )
                { return mpi_type_traits<T>::get_type( T() ); }
};
```

```
vector<int> v =  { 2, 3, 5, 7, 11, 13, 17, 19 };
comm::world(1) << v

typedef mpi_type_traits<vector<int>> vect_traits;
MPI_Ssend( vect_traits::get_addr(v), vect_traits::get_size(v),
                                                vect_traits::get_type(v), ... );
```

Outline

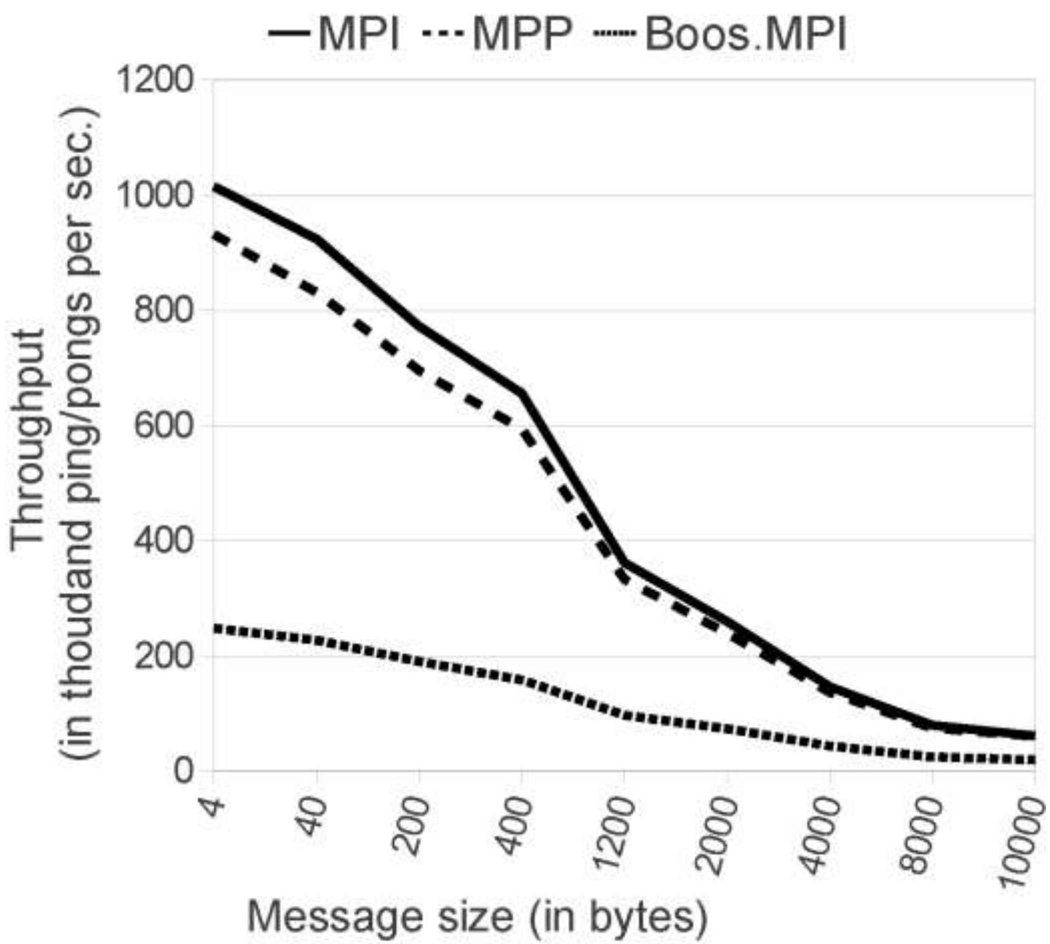
- Overview of existing MPI C++ bindings
  - Boost.MPI
- Introduction of our MPP (MPI C++) interface
  - Endpoints as streams
  - Integration with user and legacy data types
- Performance evaluation
  - Estimate the interface overhead
  - **QUAD_MPI** real case scenario

Library Overhead

- 3 interfaces
  - Standard MPI C bindings
  - Boost.MPI
  - MPP
- The MPI library utilized is the same, i.e. **Open MPI 1.4.2**
- 2 micro-benchmarks to measure
  - **Throughput**
  - **User data type overhead**

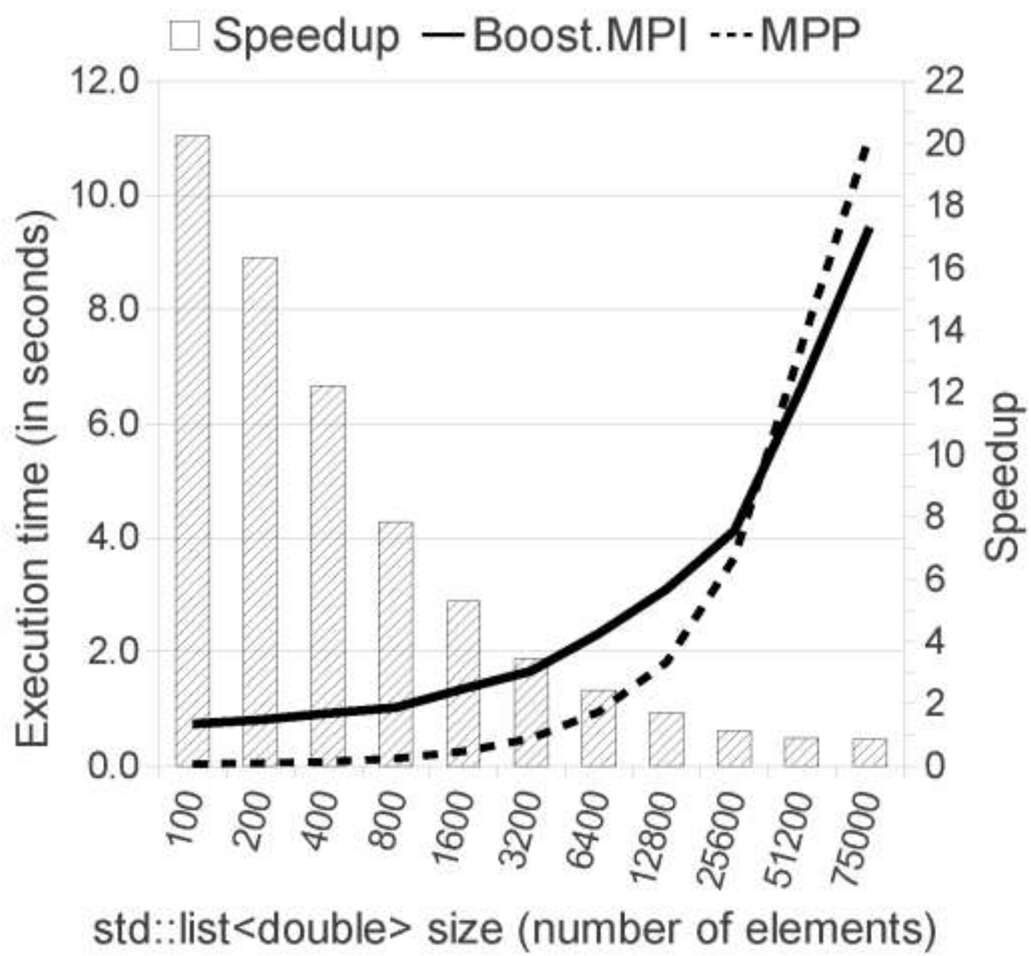
Throughput

- Simple **ping-pong** application using **shared memory** communication
  - **--mca btl sm** flag
  - Minimize communication
  - Emphasize library overhead



std::list<double> Linked List

- Ping-pong application
- Processes allocated on different nodes
- Infiniband interconnection

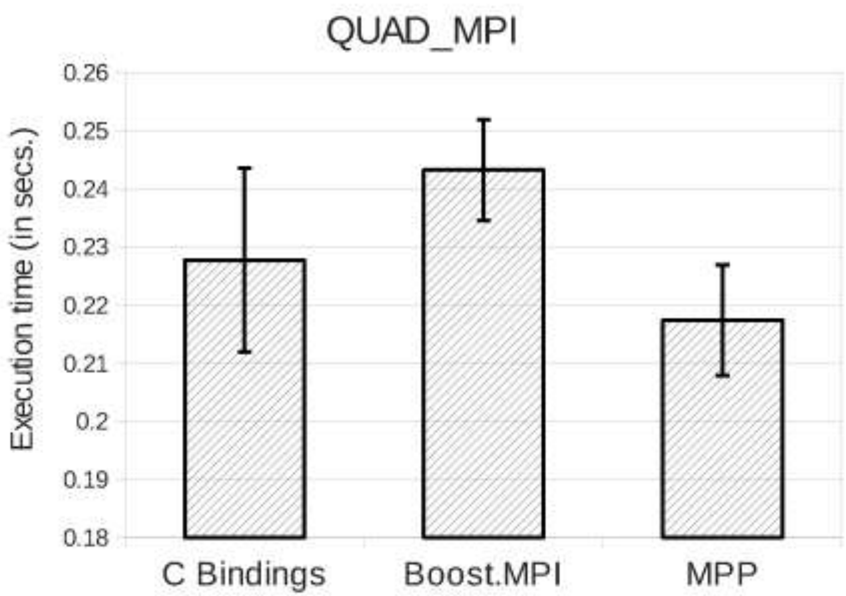


QUAD_MPI

- Integral approximation using the quadrature rule
  - Rank 0 assigns a sub-range [A,B) of the problem to other P-1 processes
  - P processes compute in parallel the partial results for [A,B)
  - Result is aggregated via reduction

- MPP reduces the input code by 30% in terms of number of characters

- MPP has better performance due to elimination of temporary variable assignments



Conclusions and Future Work

- Lightweight C++ interface to MPI
- Higher abstraction level
  - C++ stream operators for send/receive operations
  - Infer data type and size with improved type checking
  - Integrations with MPI_Datatypes instead of serialization with improved performance
- Missing features
  - Integration of **collective communications**
  - Simplify utilization of other cumbersome features of the MPI library (e.g. dynamic processes, topologies)

Thanks for your Attention

Questions?