
The MPI Message-passing Standard Practical use and implementation (II)

SPD Course

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MPI communication semantics



- Message order is not guaranteed,
 - Only communications with same envelope are non-overtaking
- Different communicators do not allow message exchange
 - Unless you consider termination by error and deadlocks forms of communication
- No fairness provided
 - You have to code priorities yourself
 - Implementations *may* be fair, but you can't count on that
- Resources are limited
 - E.g. Do not assume buffers are always available, allocate them explicitly
 - E.g. You shall free structures and objects you are not going to use again
 - The limits are often within the library implementation, hard to discover in advance...

Point to point and communication buffers



- All communication primitives in MPI assume to work with communication buffers
 - How the buffer is used is implementation dependent, but you can specify many constraint
- The structure of the buffer
 - depends on your data structures
 - depends on your MPI implementation
 - depends on your machine hardware and on related optimizations
 - shall never depend on your programming language
- The MPI Datatype abstractions aims at that

Primitive Data types (C bindings)



MPI_CHAR char
(treated as printable character)
MPI_SHORT signed short int
MPI_INT signed int
MPI_LONG signed long int
MPI_LONG_LONG_INT
signed long long int
MPI_LONG_LONG (as a synonym)
signed long long int
MPI_SIGNED_CHAR signed char
(treated as integral value)
MPI_UNSIGNED_CHAR unsigned char
(treated as integral value)
MPI_UNSIGNED_SHORT
unsigned short int
MPI_UNSIGNED unsigned int
MPI_UNSIGNED_LONG
unsigned long int
MPI_UNSIGNED_LONG_LONG
unsigned long long int
MPI_FLOAT float
MPI_DOUBLE double

MPI_LONG_DOUBLE long double
MPI_WCHAR wchar_t
(ISO C standard, see <stddef.h>)
(treated as printable character)
MPI_C_BOOL _Bool

Many special bit-sized types

MPI_INT8_T int8_t
MPI_INT16_T int16_t
MPI_INT32_T int32_t
MPI_INT64_T int64_t
MPI_UINT8_T uint8_t
MPI_UINT16_T uint16_t
MPI_UINT32_T uint32_t
MPI_UINT64_T uint64_t

MPI_C_COMPLEX float _Complex
MPI_C_FLOAT_COMPLEX
(as a synonym) float _Complex
MPI_C_DOUBLE_COMPLEX
double _Complex
MPI_C_LONG_DOUBLE_COMPLEX
long double _Complex

MPI_BYTE
MPI_PACKED

Datatype role in MPI

- Datatype
 - a descriptor used by the MPI implementation
 - holds information concerning a given kind of data structure
- Datatypes are opaque objects
 - Some are constant (**PRIMITIVE** datatypes)
 - More are user-defined (**DERIVED** datatypes)
 - to be explicitly defined before use, and destroyed after
- Defining/using a datatype **does not** allocate the data structure itself:
 - Allocation done by the host languages
 - Datatypes provide explicit memory layout information to MPI, more than the host language

Conversion and packing



- Data type information is essential to allow packing and unpacking of data within/from communication buffers
- MPI is a linked library → MPI datatypes provide type information to the runtime
- Data types known to MPI can be converted during communication
- For *derived* datatypes, more complex issues related to memory layout

MPI_SEND

MPI_SEND(buf, count, datatype, dest, tag, comm)

- IN buf initial address of send buffer
- IN count number of elements in send buffer
(non-negative integer, **in datatypes**)
- IN datatype datatype of each send buffer element
(handle)
- IN dest rank of destination
- IN tag message tag
- IN comm communicator (handle)

- *The amount of transferred data is not fixed*

MPI_RECV

MPI_RECV (buf, count, datatype, source, tag, comm, status)

- OUT buf initial address of receive buffer
- IN count number of elements in receive buffer (non-negative integer, **in datatypes**)
- IN datatype datatype of each receive buffer element (handle)
- IN source rank of source or **MPI_ANY_SOURCE**
- IN tag message tag or **MPI_ANY_TAG**
- IN comm communicator (handle)
- OUT status status object (Status)

- *The amount of received data is not fixed and can exceed the receiver's buffer size*

Return status

- `MPI_Status`
structure filled in by many operations
 - not an opaque object, an ordinary C struct
 - special value `MPI_IGNORE_STATUS` (beware!!)
 - known fields: `MPI_SOURCE`, `MPI_TAG`, useful for wildcard `Recv`, as well as `MPI_ERROR`
 - additional fields are allowed, but are not defined by the standard or made openly accessible
 - Example: the actual *count* of received objects
- `MPI_Get_count(MPI_Status *status, MPI_Datatype datatype, int *count)`
 - MPI primitive used to retrieve the number of elements actually received

The NULL process



- `MPI_PROC_NULL`
 - Rank of a fictional process
 - Valid in every communicator and point-to-point
 - Communication will always succeed
 - A receive will always receive no data and not modify its buffer

Derived datatypes

- Abstract definition
 - Type map and type signature
- Program Definition
 - MPI constructors
- Local nature
 - They are not shared
 - In communications, type **signatures** and **type maps** for the data type used are checked
 - Need to be consolidated before use in communication primitives (MPI_Commit)

MPI TYPE CONSTRUCTORS



- Typemap & typesignatures
- Rules for matching Datatypes
- Size and extent
- Contiguous
- Vector
 - Count, blocklen, stride example
 - Row, column, diagonals (exercises)
 - Multiple rows
 - Stride<blocklen, negative strides
- Examples: composing datatypes
- Hvector
- Indexed
- Hindexed
- Standard send and recv: any_tag, any_source
- Send has modes, recv can be asymmetric, both can be incomplete

Typemaps and type signatures

- A datatype is defined by its memory layout
 - as a list of basic types and displacements

- Typemap

$$TM = \{(type_0, disp_0), \dots, (type_{n-1}, disp_{n-1})\}$$

- Type signature

$$TS = \{(type_0), \dots, (type_{n-1})\}$$

- Each $type_i$ is a basic type with a known size
- Size = the sum of sizes of all $type_i$
- Extent = the distance between the earliest and the latest byte occupied by a datatype
- Rules for matching Datatypes

Typemaps and type signatures

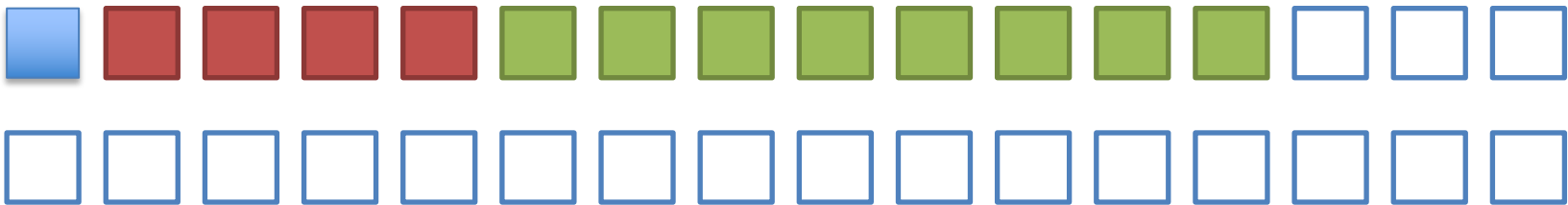
- Type map

$$TM = \{(\text{byte}, 0), (\text{int}, 1), (\text{double}, 5)\}$$

- Type signature

$$TS = \{(\text{byte}), (\text{int}), (\text{double})\}$$

- Size = $1 + 4 + 8 = 13$
 - Note that we are assuming a 32 bit architecture here!
- Extent = 13



Typemaps and type signatures

- Your compiler will likely add aligning constraints to basic types: let's assume ints are word aligned, and doubles are double-word aligned

- Type map

$$TM = \{(\text{byte}, 0), (\text{int}, 4), (\text{double}, 8)\}$$

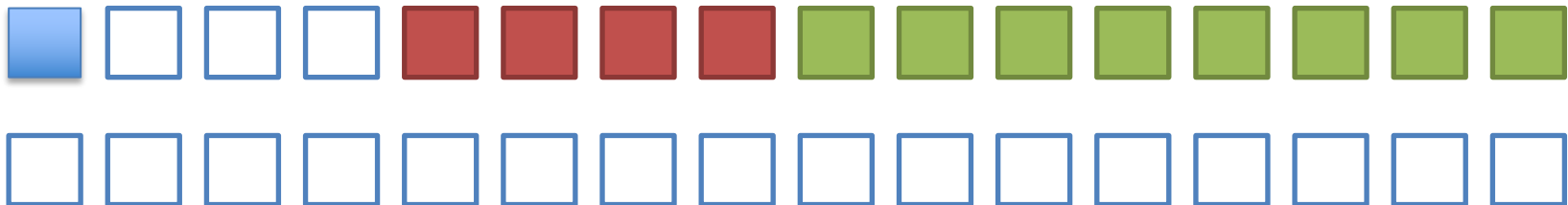
- Type signature

$$TS = \{(\text{byte}), (\text{int}), (\text{double})\}$$

- Size = 1+4+8 = 13

- Extent = 16

- You need the padding for code execution, but you want to leave padding out of communication buffers
 - E.g. when sending large arrays of structures
 - Data packing and unpacking is automated in MPI



Matching rules for datatypes

- Typemaps are essential for **packing** into the communication buffer, and **unpacking**
- datatype in a send / recv couple must match
 - Datatypes are local to the process
 - Datatype descriptors (typemaps) **may** be passed among processes by MPI routines (but that's not mandatory per the standard)
 - What really counts is the **type signature**
 - Do not “break” primitive types
 - “holes” in the data are dealt with by pack /unpack
- Datatype typemaps can have repeats
 - Disallowed on the receiver side!

Datatypes: shake before use!

- Before looking at the the core primitive for defining new derived datatypes, remember
- `MPI_TYPE_COMMIT(datatype)`
 - Mandatory before every actual use of a datatype!
 - Consolidates the datatype definition, making it permanent
 - Enables the new datatype for use in all non-datatype defining MPI primitives
 - e.g. commit before a point to point or a collective
 - May compile internal information needed to the MPI library runtime
 - e.g. : optimized routines for data packing & unpacking
- `MPI_TYPE_FREE(datatype)`
 - Free library memory used by a datatype that is no longer needed
 - Be sure that the datatype is not currently in use!

Contiguous Datatype



```
int MPI_Type_contiguous(int count,  
    MPI_Datatype oldtype,  
    MPI_Datatype *newtype)
```

- Create a plain array of identical elements
- No extra space between elements
- Overall size is count* number of elements

Contiguous Datatype

```
MPI_Datatype mytype;
MPI_Type_contiguous( 4, MPI_INT, &mytype);
MPI_Type_commit(mytype)
```

- Type map

$$TM = \{(\mathbf{int}, 0), (\mathbf{int}, 4), (\mathbf{int}, 8), (\mathbf{int}, 12),\}$$

- Type signature

$$TS = \{(\mathbf{int}), (\mathbf{int}), (\mathbf{int}), (\mathbf{int})\}$$

- Size = 16
- Extent = 16



Vector Datatype

```
int MPI_Type_vector(int count, int blocklength,  
int stride, MPI_Datatype oldtype,  
MPI_Datatype *newtype)
```

- Create a spaced array (a series of contiguous blocks with space in between)
- Count = number of blocks
- Blocklength = number of items in each block
- Stride = distance between *the start* of each block
- The size unit is the size of the inner datatype

Vector Datatype

```
MPI_Datatype mytype;
MPI_Type_vector( 4, 2, 4, MPI_BYTE, &mytype);
MPI_Type_commit(mytype)
```

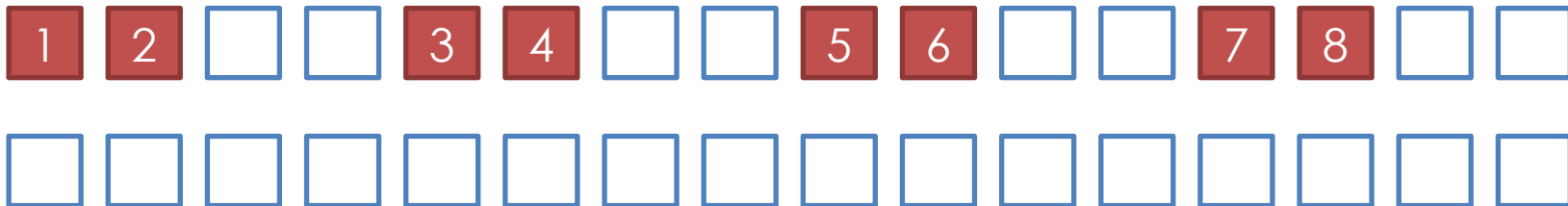
- Type map

$$TM = \{(\text{byte}, 0), (\text{byte}, 1), (\text{byte}, 4), (\text{byte}, 5), (\text{byte}, 8), (\text{byte}, 9), (\text{byte}, 12), (\text{byte}, 13)\}$$

- Type signature

$$TS = \{(\text{byte}), (\text{byte}), (\text{byte}), (\text{byte}), (\text{byte}), (\text{byte}), (\text{byte}), (\text{byte})\}$$

- Size = 8
- Extent = 13



Vector Datatype



- What if stride is less than the blocklength?
- What if the stride is zero?

Hvector datatype

```
int MPI_Type_create_hvector(  
    int count, int blocklength, MPI_Aint stride,  
    MPI_Datatype oldtype, MPI_Datatype  
    *newtype)
```

- Create a vector of block with arbitrary alignment
- Same as the vector but:
 - The stride is an offset in **bytes** between each block starts
- Many other datatypes have an “H version” where some parameters are in byte units

HVector Datatype

```
MPI_Datatype mytype;
MPI_Type_hvector( 3, 2, 9, MPI_INT, &mytype);
MPI_Type_commit(mytype)
```

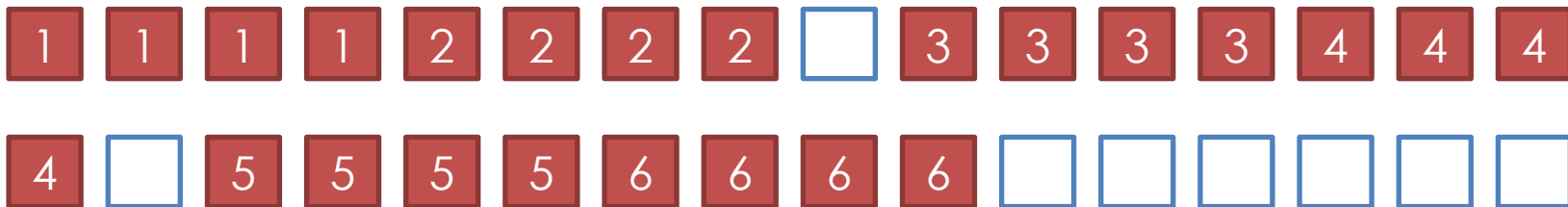
- Type map

$$TM = \{(\mathbf{int}, 0), (\mathbf{int}, 4), (\mathbf{int}, 9), (\mathbf{int}, 13), (\mathbf{int}, 18), (\mathbf{int}, 22)\}$$

- Type signature

$$TS = \{(\mathbf{int}), (\mathbf{int}), (\mathbf{int}), (\mathbf{int}), (\mathbf{int}), (\mathbf{int})\}$$

- Size = 24
- Extent = 26



Indexed datatype

```
int MPI_Type_indexed(  
    int count, int *array_of_blocklengths,  
    int *array_of_displacements,  
  
    MPI_Datatype oldtype, MPI_Datatype *newtype)
```

- Blocks of different sizes
- Count is a number of blocks
- Length and position (w.r.t. structure start!) are specified for each block
- All in units of the inner datatype
- Some uses for this datatype: triangular matrixes, arrays of contiguous lists, reordering data structure blocks (e.g. matrix rows) as we communicate

Hindexed Datatype

```
int MPI_Type_create_hindexed(  
    int count, int array_of_blocklengths[],  
    MPI_Aint array_of_displacements[],  
    MPI_Datatype oldtype, MPI_Datatype  
    *newtype)
```

- Same as Indexed, but block positions are given in bytes
- Enhanced flexibility in memory layout

Struct Datatype

**MPI_TYPE_CREATE_STRUCT (count,
array_of_blocklengths, array_of_displacements,
array_of_types, newtype)**

IN count number of blocks (non-negative integer)

- also number of entries in arrays array_of_types,
array_of_displacements and array_of_blocklengths

IN array_of_blocklength elements in each block
(array of non-negative integer)

IN array_of_displacements byte displacement of
each block (array of integer)

IN array_of_types type of elements in each block
(array of handles to datatype objects)

OUT newtype new datatype (handle)

Struct Datatype

```
typedef struct {
    int a; char b[2]; double c
}
```

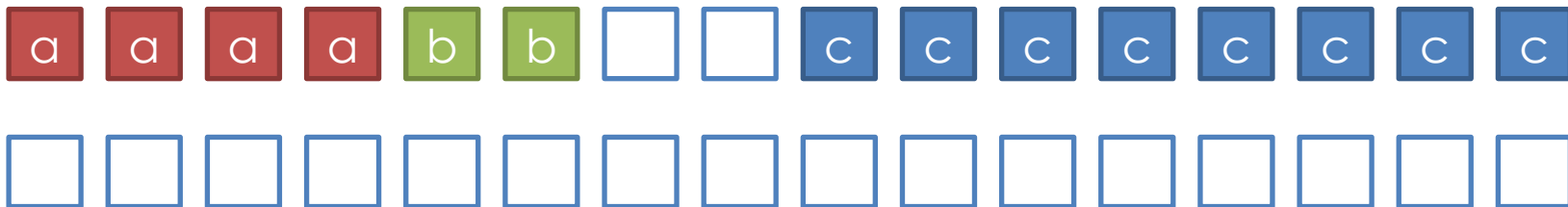
- Assuming 32 bit words, double-word aligned doubles etc...
- Type map

$$TM = \{(\text{int}, 0), (\text{char}, 5), (\text{char}, 6), (\text{double}, 8)\}$$

- Type signature

$$TS = \{(\text{int}), (\text{char}), (\text{char}), (\text{double})\}$$

- Size = 14
- Extent = 16



MPI TYPE CONSTRUCTORS

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- Rules for matching Datatypes
- Size and extent
- Contiguous
- Vector
 - Count, blocklen, stride example
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 - Multiple rows
 - Stride<blocklen, e.g. negative offsets
- Examples: composing datatypes
- Hvector
- Indexed
- Hindexed
- Struct
- A simple tool to display MPI typemaps : MPIMap
<http://computation.llnl.gov/casc/mpimap/>

Exercises

- Start preparing for the lab sessions
 - Install a version of MPI which works on your O.S.
 - OpenMPI (active development)
 - LAM MPI (same team, only maintained)
 - MPICH (active development)
 - Check out details that have been skipped in the lessons (read man pages and the docs)
 - How to run programs, how to specify the mapping of processes on machines (Usually it is a file listing all available machines)
 - How to check a process rank, act on the rank
 - Read the first chapters of the Wilkinson-Allen
 - Write a minimal program that runs and initializes MPI, run it with $NP>3$
 - Write at least a simple program that uses `MPI_Comm_World`, has a small fixed number of processes and communications and run it on your laptop
 - E.g. a trivial ping-pong program with 2 processes

Reference Texts

- MPI standard Relevant Material for 2nd lesson
 - Chapter 3:
 - section 3.2 (blocking send and recv with details)
 - section 3.3 (datatype matching rules and meaning of conversion in MPI)
 - Chapter 4: sections with the specific datatype constructors discussed