Introduction to MPI

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Introduction to MPI

Credits

http://www.mpi-forum.org/
https://computing.llnl.gov/tutorials/mpi/#What
http://www.idris.fr/data/cours/parallel/mpi/choix_doc.html
Programming Model training from R. Dolbeau & G.-E. Moulard (Atos)
Formations CED – Du calcul parallèle au massivement parallèle

Plan

- Introduction
- Environment
- Data type
- Point-to-point communications
- Collective communications
- Questions

Introduction

1. Reminders about parallelism
2. Parallel programming model

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1. Goals of Parallel Programming

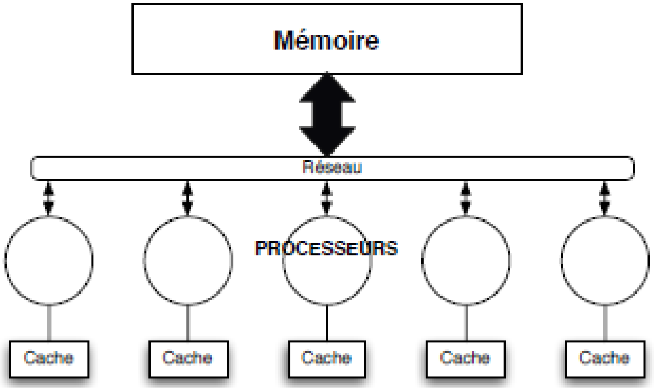
- **Parallelizing?**
  - « Reorganizing » the problem to process simultaneously data and computations while using a number of computing ressources

- **Why?**
  - Improve **performance** => computing faster
  - Process a **bigger volume of data** => using memory of several computing nodes

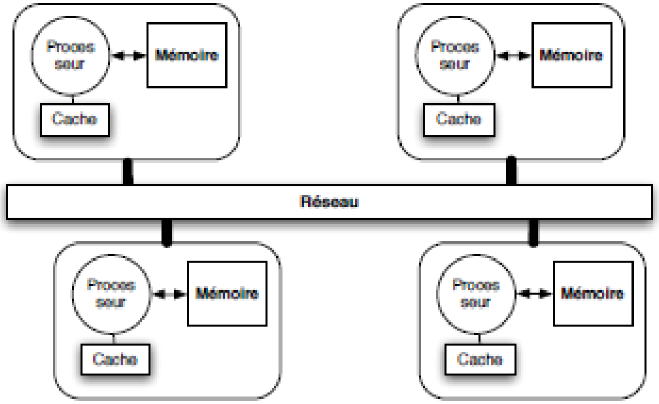
- **Important points:**
  - Knowing hardware **architecture**
  - Choosing a **programming model**: **MPI**, OpenMP, hybrid programming…

1. Architectures

- **Shared memory computer**
  – Several processors sharing the same global memory space via a fast interconnect



- **Distributed memory computer**
  – Each node with its own memory
  – Each node reaches other nodes memory via the network (call to communications routines)



- **Hybrid computer**
  – Most common case: a set of shared memory computers (eventually equipped with coprocessors or accelarators) linked by a network

1. What Matters

- From developer point of view, architecture = network of processors
  - CPU => **computing power**. Determine the FLOPS (FLoating-point Operations Per Second).
  - Several levels of memory => several levels of parallelism. Critical points: **size of memories** & IO speed.
  - Communication network => limiting factor: **bandwidth**.

- **Parallel programming**: use of a software layer to handle ressources processing and access => **MPI**

2. MPI: Message Passing Interface

- High level API for message passing
- Designed for **Performance, scalability and portability**
- Currently, it's the third major release:
  - 1995: v1.2 (MPI-1)
  - 1997: v2.0 (MPI-2)
  - 2008: v2.1
  - 2009: v2.2
  - 2012: v3.0 (**MPI-3**)
  - 2015: v3.1
- An API with different implementations
  - Some with specific extensions…
  - ... which can break the portability of an application

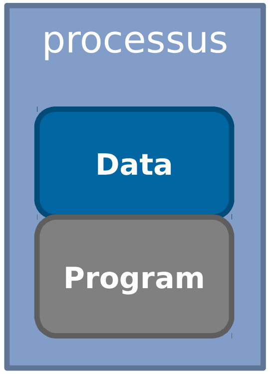
2. MPI Implementations

- Open source implementation
  - MPICH (MPI-1)
  - MPICH2 (MPI-2)
  - OpenMPI (1.8.3 includes most of MPI-3)
  - LAM/MPI

- Manufacturer implementation's
  - HP MPI
  - Intel MPI
  - BullxMPI

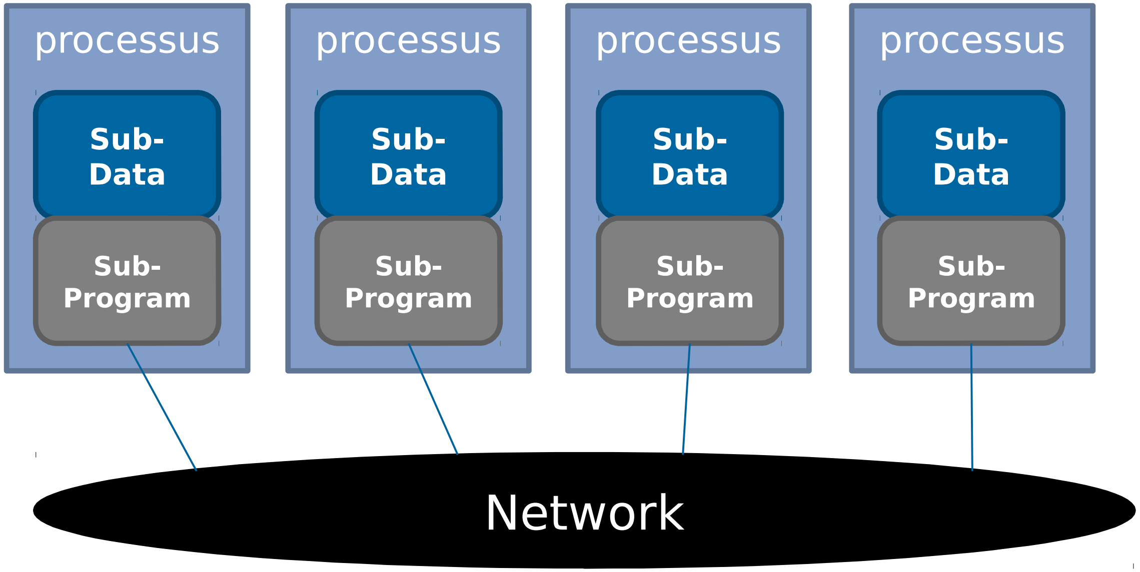
2. Sequential Programming Model

- The program is executed by a single process.
- This process runs on a single physical processor of the machine.
- All data (Variables and Constants) are allocated in the memory assigned for the process.
- Does not allow to exploit modern machines with several physical processors distributed on several node
  - Limited in term of computing power
  - Limited in term of problem size (1 node)



2. Programming Model by Message Passing

- A program is divided into sub-programs each executed by a process.
- The processes communicate by the interconnection network by sending or receiving messages
  - Possibility to exploit whole platform.



2. Key Notions

- Key notions: process, message, synchronization
  - “Virtual” process ≠ processor / physical core. Processes can execute on different or identical processors / cores.
  - Each process has its **own variables** and does not access directly to the **variables of other processes**.
  - Data sharing between processes is done by **explicit send & receives of messages**.
  - Processes **synchronization**.

2. Programmation MPI

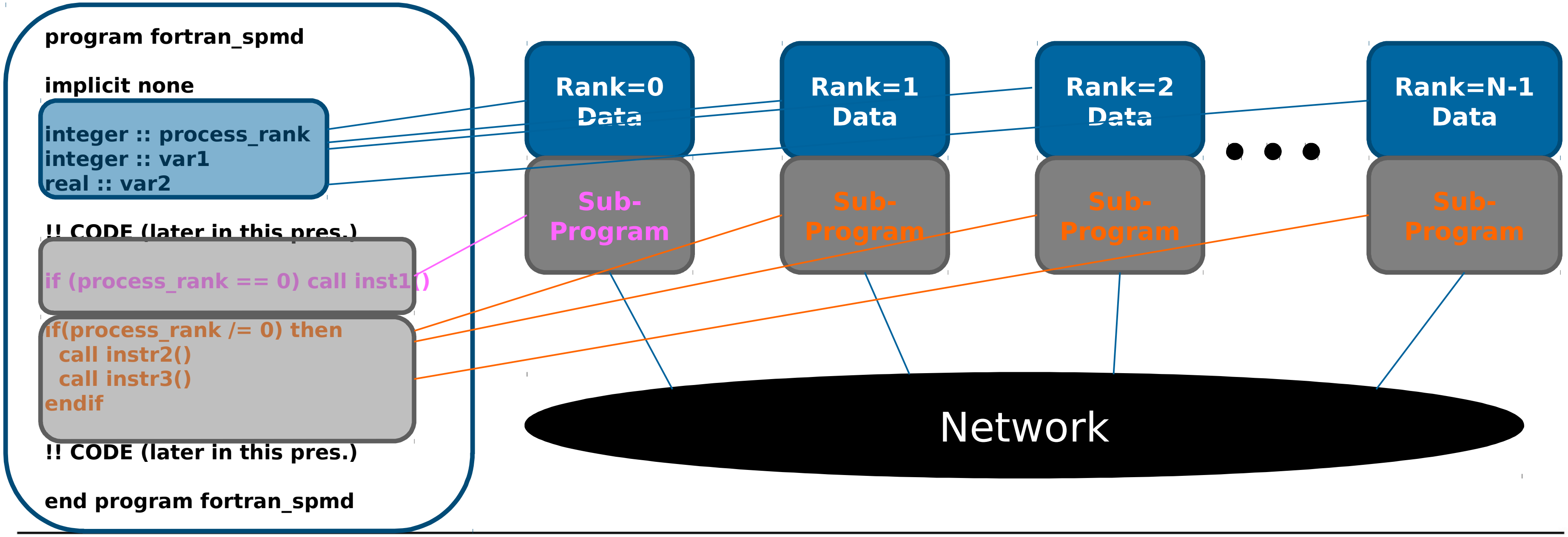
- In an MPI program each process runs a sub-program
  - Written in a classical language (**C**, C++, **Fortran**, Python, ...)
  - Can be different depending of the process
  - Most often, the same sub-program for all process (SPMD – Single Program Multiple Data)
    - Not required by the model, MPMD (Multiple Program Multiple Data) is also possible

- Variables of each sub-program:
  - Can have the **same name** (SPMD)
  - **Different memory locations and different values** (Distributed memory)
  - **Private to the sub-program**

- The sub-programs use routines for **sending and receiving messages** to communicate

2. Work and Data Distribution in MPI

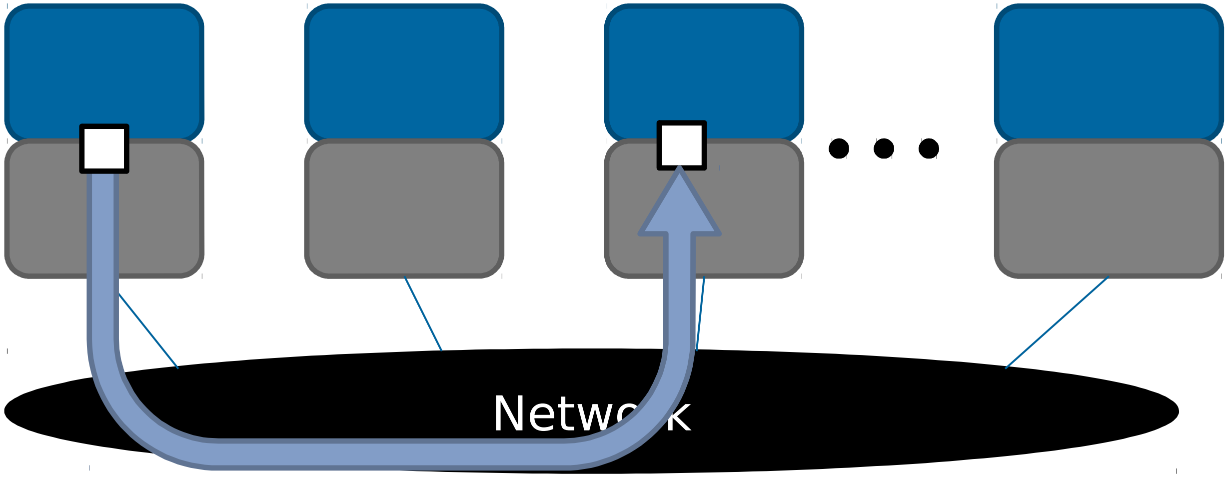
- Create a system of N independent processes
- Each process has a unique ID: **Rank [0:N-1]**
- Data and work distribution is based on **rank**



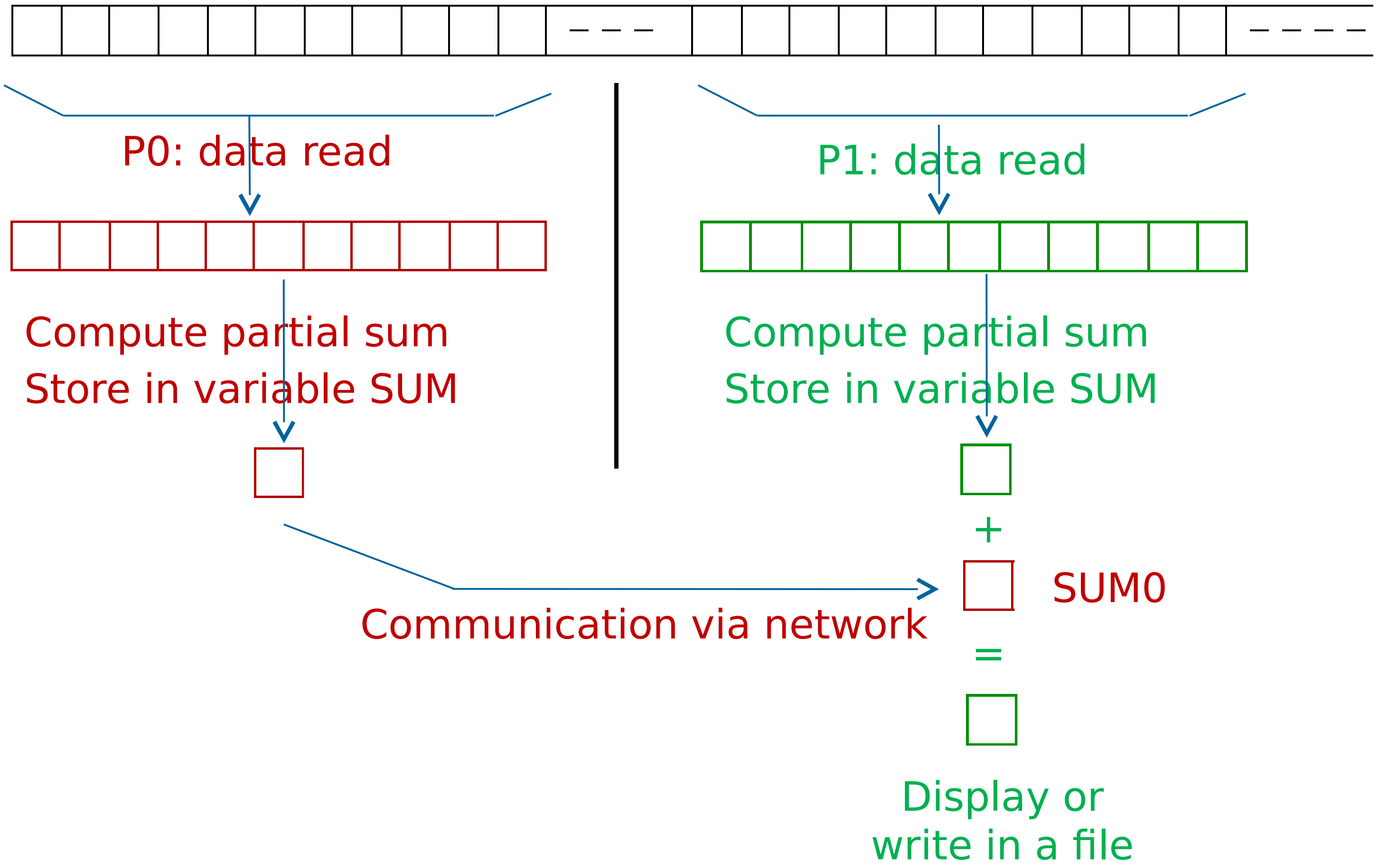
2. Messages

- Messages are blocks of data exchanged by sub-programs.

- For message sending and receiving, different information are required
  - The rank of sender/receiver
  - data location
  - data type
  - data size



2. A First Simple Example



Bases

1. Environment
2. Communicator
3. Environmental Management

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1. Generality

- Compilation unit containing MPI routines must:
  - C/C++: **include** mpi header file "**mpi.h**"
  - Fortran: **use** "**MPI**" module
    - Introduced in MPI-2, else use "mpi.h"
- The prefix "MPI_" is **reserved** for MPI routines and macros.
- MPI routines in C/C++ & Fortran have the same format:
  - "MPI" prefix and the first letter are in capital letter
    - MPI_Xxxx_xxx_xxx()

1. Initialization of MPI Program

- In MPI program, the function **MPI_Init** must be the first one called by each sub-program

  – C/C++:

```
int MPI_Init(int *argc, char **argv)
```

  – Fortran:

```
MPI_Init(mpierror)
```

- Initializes the **environment** of MPI execution (communicator ...)

1. Termination of a MPI Program

- Each sub-program must call **MPI_Finalize** before the end of the program

  – C/C++:

```
int MPI_Finalize()
```

  – Fortran:

```
MPI_Finalize(mpierror)
```

- In case where it's necessary to stop the program before the normal end, use **MPI_Abort** function:
  – For example if memory allocation required by a process fails

2. Communicators

- A **communicator** is composed of a MPI process group.

- At the initialization of MPI program, a communicator with all MPI processes is created: **MPI_COMM_WORLD**
  - this is a global communicator.

- Each MPI process is identified by its **rank** within a communicator:
  - identifier between 0 and (number of processes in the communicator – 1)

- A process can belong to several communicators and has an associated rank (identifier) for each of these communicators

- Two MPI processes must be in the same communicator to be able to communicate together.

2. Communicator: Size and Rank

- **MPI_Comm_size** function provides the number of MPI processes in the communicator
  - C/C++: **int MPI_Comm_size**(MPI_Comm comm, int *size)
  - Fortran **MPI_Comm_size**(comm, size, mpierror)

- **MPI_Comm_rank** function provides the rank of the process in the communicator:
  - C/C++: **int MPI_Comm_rank**(MPI_Comm comm, int*rank)
  - Fortran: **MPI_Comm_rank**(comm, rank, mpierror)

2. Basic Example in C

```
#include <mpi.h>

int main(int argc, char *argv[])
{
/* The basic MPI Program */
int mpierror, mpisize, mpirank;

mpierror=MPI_Init(&argc, &argv);

mpierror=MPI_Comm_size(MPI_COMM_WORLD, &mpisize);
mpierror=MPI_Comm_rank(MPI_COMM_WORLD, &mpirank);

/* Do work here */

mpierror=MPI_Finalize();

return 0;
}
```

2. Basic Example in Fortran

```
program firstmpi
! The basic MPI Program
use MPI

integer :: mpierror, mpisize, mpirank

call MPI_Init(mpierror)

call MPI_Comm_size(MPI_COMM_WORLD, mpisize, mpierror)
call MPI_Comm_rank(MPI_COMM_WORLD, mpirank, mpierror)

! Do work here

call MPI_Finalize(mpierror)

end program firstmpi
```

2. TP: MPI101

- Execute the TP (in C)
  - Batch environment "SLURM"
  - ./build.sh, ./run.sh

<u>Compilation:</u>

```
icc -c mpi101.c
icc -lmpi mpi101.o -o mpi101

mpiicc -o mpi101
```

- Modify number of processes

```
srun --mpi=pmi2 -J TPMPI -N 1 -n 2 -p E52697v2 ./mpi101
```

- `--mpi=pmi2`: enables interaction between Slurm and MPI
- `-J TPMPI`: Job Name
- `-N 1`: number of node asked
- `-n 2`: Number of processes
- `-p E52697v2`: Partition Name (group of machine)

3. MPI Environmental Management

- MPI_Get_processor_name
  - Gets the processor name; format is implementation dependent
- MPI_Get_version
  - Gets version and sub-version of MPI
- MPI_Initialized
  - Gets if MPI_Init was called; for example, useful for libraries
- MPI_Wtime
  - Gets the time in seconds since an arbitrary point in the past
    - if MPI_WTIME_IS_GLOBAL is true (1), the value is synchronized for all processes
- MPI_Wtick
  - Gets the precision in second of MPI_Wtime

3. TP: MPI101 phase 2

- Display the name of the machine using the MPI function
- Modify the number of nodes to run the program

MPI_Get_processor_name

Gets the name of the processor

Synopsis

```
int MPI_Get_processor_name( char *name, int *resultlen )
```

Output Parameters

name A unique specifier for the actual (as opposed to virtual) node. This must be an array of size at least MPI_MAX_PROCESSOR_NAME.
resultlen Length (in characters) of the name

3. TP: MPI101 phase 2 (solution)

```
#include <mpi.h>
int main(int argc, char *argv[])
{
/* The basic MPI Program */
int mpierror, mpisize, mpirank;
mpierror=MPI_Init(&argc, &argv);
mpierror=MPI_Comm_size(MPI_COMM_WORLD, &mpisize);
mpierror=MPI_Comm_rank(MPI_COMM_WORLD, &mpirank);
/* Do work here */
{
        char temp[MPI_MAX_PROCESSOR_NAME];
        int resultlen;
        int  r = MPI_Get_processor_name(temp, &resultlen);
        printf("I am %d out of %d running on %s\n", mpirank, mpisize, temp);
}
mpierror=MPI_Finalize();
return 0;
}
```

Data Type

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Data Type

- For portability reasons, MPI predefined **elementary data types**.

- Using elementary data types to build more complex types (**derived data types**)
  - Not tackled in this training

- MPI implementations can provide more elementary data types:
  - These types are in "mpi.h” header file.
  - They can prevent portability

Data Type

- Predefined data types in Fortran:

TYPE MPI	TYPE FORTRAN
MPI_INTEGER	INTEGER
MPI_REAL	REAL
MPI_DOUBLE_PRECISION	DOUBLE_PRECISION
MPI_COMPLEX	COMPLEX
MPI_LOGICAL	LOGICAL
MPI_CHARACTER	CHARACTER(1)
MPI_BYTE	
MPI_PACKED	

Data Type

- Predefined data types in C:

TYPE MPI	TYPE C
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 MPI_LONG_LONG	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_WCHAR	wchar_t (treated as printable character)

Data Type

- Predefined data types in C (end):

TYPE MPI	TYPE C
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double
MPI_C_BOOL	_Bool
MPI_INT8_T MPI_INT16_T MPI_INT32_T MPI_INT64_T	int8_t int16_t int32_t int64_t
MPI_UINT8_T MPI_UINT16_T MPI_UINT32_T MPI_UINT64_T	uint8_t uint16_t uint32_t uint64_t
MPI_C_COMPLEX MPI_C_FLOAT_COMPLEX	Float _Complex
MPI_C_DOUBLE_COMPLEX	double _Complex
MPI_C_LONG_DOUBLE_COMPLEX	long double _Complex
MPI_BYTE	
MPI_PACKED	

Point to Point Communications

1. Description
2. Contents
3. Execution
4. Optimizations

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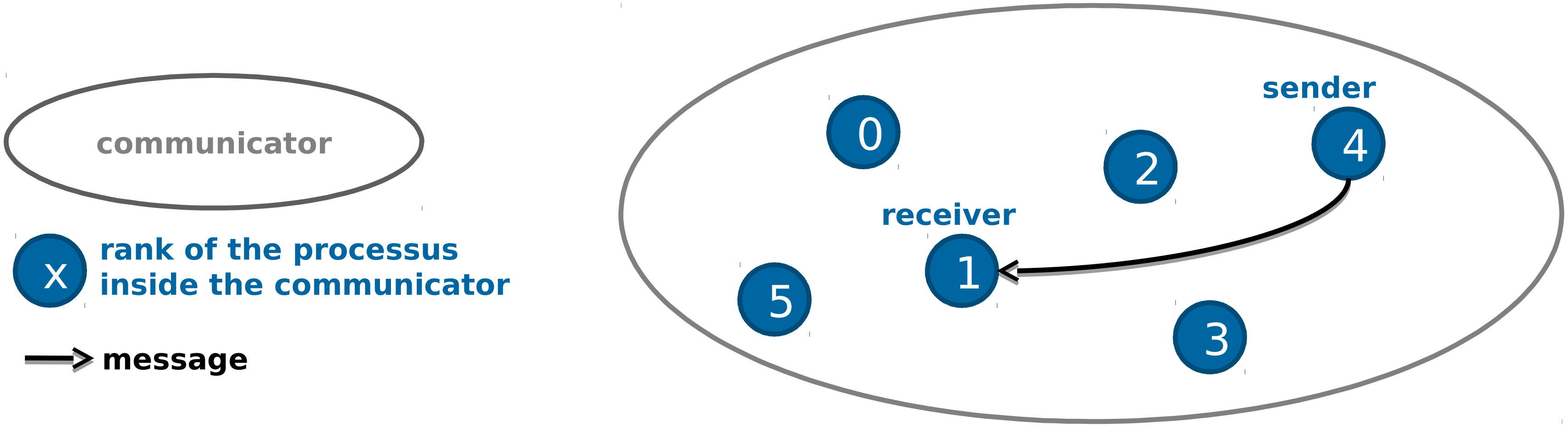
1. Principle

- A point to point communication is a communication between **two** MPI processes.
- One process is the **sender**: it sends the message.
- The other is the **receiver** or recipient: it waits the message of the senders.
- The sender and the receiver are identified by their rank.



1. Blocking Communications

- A **blocking send** blocks the process until the memory space used for the message can be re-written without any modification of the message.

- A blocking send can be **synchronous**
  - It waits for an acknowledgment of receipt.

- A blocking send can be **asynchronous**
  - If system memory space is used to send the message.

- A **blocking reception** blocks the process until data are received and ready to be used by the system.

1. Non-Blocking Communication

- **Non-blocking send and reception** return almost immediately:
  - no wait for communication event (copy in the system memory space or acknowledgement of receipt)

- They aim to **overlap** communications time and computing time.

- User can not know the exact moment when a sending or a receiving has effectively been done.

- **Synchronization routines** help ensure the sending or receiving of message.

- It is unsafe to modify the memory space used for data sending or receiving without being ensured of the end of a sending or receiving.

1. Modes

- **4 modes of send** for point to point communications:
  - Standard (MPI implementation dependant)
  - Buffered (copy in a buffer ; the send is done later, asynchroneously ; no need to wait receiving) => should probably give better results, but requires copy in memory
  - Synchronous (with receiving ; the program takes back the hand when the send is complete)
  - Ready (started only if the matching receive is already posted)
- Each mode has blocking and non-blocking implementation:

	Mode	Blocking	Non-blocking
Send	Standard	MPI_Send	MPI_Isend
	Buffered	MPI_Bsend	MPI_Ibsend
	Synchronous	MPI_Ssend	MPI_Issend
	Ready	MPI_Rsend	MPI_Irsend
Receive		MPI_Recv	MPI_Irecv

2. Parameters (1/2)

- Parameters of point to point communication:
  - **buffer**: memory address of the data or reception buffer
  - **count**: number of elements in send buffer or the maximum of elements to receive
  - **type**: data type
  - **comm**: communicator used
  - **dest**: rank of destination
  - **source**: rank of source
    - use *MPI_ANY_SOURCE* to receive a message from any source

2. Parameters (2/2)

- **tag**: a nonzero integer given by the programmer to identify a message
  - use *MPI_ANY_TAG* to receive a message without knowing the tag.

- **request**: used to associate non-blocking communication operations (Isend and Irecv) with an (MPI_request type) object used for synchronization.

- **status**: a variable containing additional information about the receive operation after it completes
  - *MPI_Status* type
  - contains the rank of the sender, the tag of the message, the error of the message.
  - Instead, we have to find out the length of the message with *MPI_Get_count*
  - which can be ignored with *MPI_STATUS_IGNORE* or *MPI_STATUSES_IGNORE*

2. Message Envelope & Body

- The envelope (description of the “context”) of message contains:
  - Identities of the sender and the receiver (ranks)
  - The tag
  - The communicator

- A receiving operation works with a send operation only if the envelopes match.

- Communication with the fictive process of rank *MPI_PROC_NULL* has no effect.

- The body of the message contains:
  - A buffer with data inside
  - The type of the data
  - Their size

2. Send Operations

- Standard blocking send

```
int MPI_Send(buffer, count, type, dest, tag, comm, status)
```

- Synchronous blocking send:

```
int MPI_Ssend(buffer, count, type, dest, tag, comm)
```

- Standard non-blocking send:

```
int MPI_Isend(buffer, count, type, dest, tag, comm, request)
```

2. Reception Operations

- Blocking reception :

```
int MPI_Recv(buffer, count, type, source, tag, comm, status)
```

  - return only when *buffer* contains the message

- Non-blocking reception

```
int MPI_Irecv(buffer, count, type, source, tag, comm, request)
```

  - return immediately

2. A Simple Example

```fortran
program basic_sendrecv

implicit none

use MPI

integer :: source, dest, tag, error, buffer, nb_elements
integer(MPI_STATUS_SIZE) :: status

source = 0
dest = 1
tag = 21
nb_elements = 1

!! MPI INITIALIZATION

if (rank_process == source) then
  buffer = 12
  call MPI_SEND(buffer, nb_elements, MPI_INTEGER, dest, tag, MPI_COMM_WORLD, error)
  print *, "I am process of rank ", rank_process, " , buffer =  ", buffer
else if (rank_process == dest) then
  buffer = 0
  print *, "I am process of rank ", rank_process, " , buffer =  ", buffer
  call MPI_RECV(buffer, nb_elements, MPI_INTEGER, source, tag, MPI_COMM_WORLD, status, error)
  print *, "I am process of rank ", rank_process, " , buffer =  ", buffer
endif

!! MPI FINALIZE

end program basic_sendrecv
```

```
>> I am process of rank 1, buffer = 0
>> I am process of rank 0, buffer = 12
>> I am process of rank 1, buffer = 12
```

3. Executing Features

- During a point to point communication, the send & the receive are 2 different operations, eventually asynchronous, done by 2 different processes.

- It raises questions:
  - What happens if no reception corresponds to the send?
  - Can we use variables send/received without impact on the message?
  - How to take back hand and do something else during the send or receive of the message?
  - …

- One important notion to be defined: **completion**.

3. Completion

- Of the reception: the message is arrived and the variable copied in local memory and can be used by the processor receiver.
- Of the send: the send variable (i.e. the matching memory zone) can be used safely, on read or write, in the sense that a modification of this variable by the processor sending will no more impact on the reception of the other processor.
- => Completion ≈ variables send/received can be used without risk
- A non-blocking send does not guarantee completion!

3. Sending Process

1. Beginning of the communication (**posting** of the send)
2. Then 2 situations possible:
   - Copy in a buffer. The send will be done later, asynchroneously. No need to wait the reception.
   - Synchronisation with reception: the routine is waiting that the process receiving is ready and that the transfer has begun. Program takes back control only when the send is complete.

► « Bufferization » will probably give better performance but requires a copy in memory (sending or receiving side, amongst the implementation). To note that the size of the buffers is necessarily limited.

3. Receiving Process

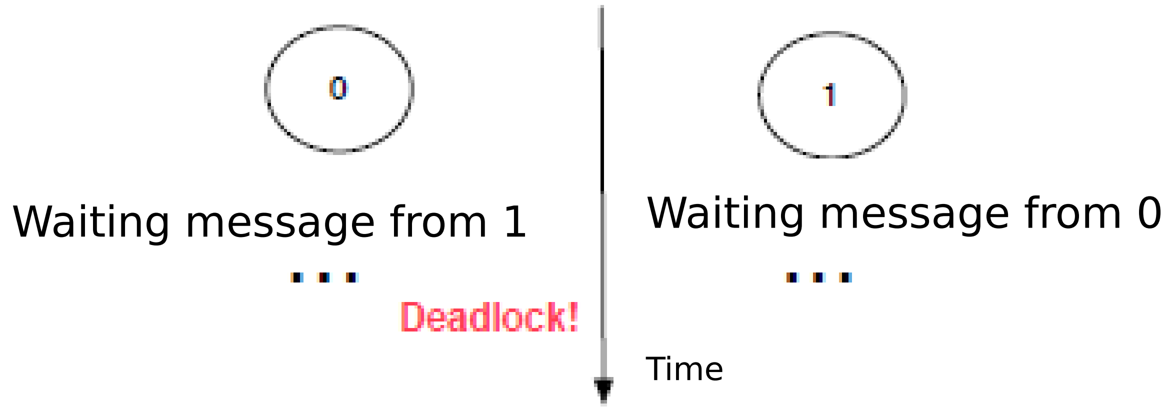
1. Initialization of the reception (**posting**): verification in the stack of the waiting messages if an envelop corresponds to the one asked by the SEND_RECV
2. Transfer of data received in the memory zone dedicated by the SEND_RECV.

- **Warning**: data type is not checked by the SEND_RECV.

- **Warning 2**: In « standard » mode, using MPI_SEND and MPI_RECV is safe from the data access point of view, nevertheless a bad management in the code of the synchronization and the blocking behaviour may lead to **deadlocks**.

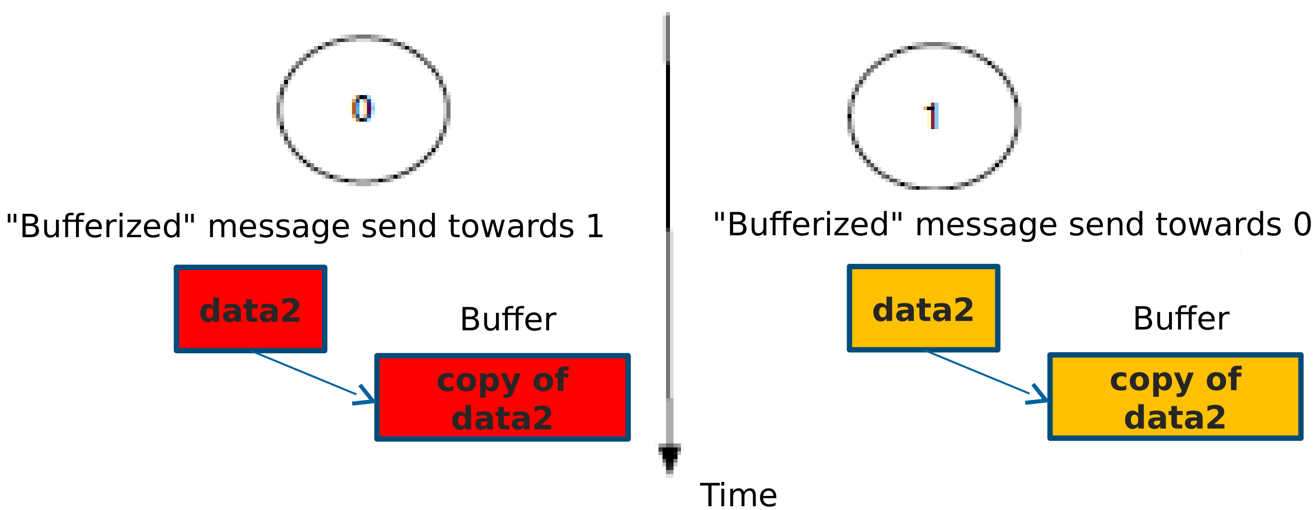
3. A First Example of Deadlock

```
if (rank_process == 0) then
  ! Reception of 10 MPI_REAL in data coming from 1 with tag "tag1"
  call MPI_RECV(data, 10, MPI_REAL, 1, tag1, MPI_COMM_WORLD, status, error)
  ! Send of 10 MPI_REAL of data2 towards 1 with the tag "tag2"
  call MPI_SEND(data2, 10, MPI_REAL, 1, tag2, MPI_COMM_WORLD, error)
else if (rank_process == 1) then
  ! Reception of 10 MPI_REAL in data coming from 0 with tag "tag2"
  call MPI_RECV(data, 10, MPI_REAL, 0, tag2, MPI_COMM_WORLD, status, error)
  ! Send of 10 MPI_REAL of data2 towards 0 with the tag "tag1"
  call MPI_SEND(data2, 10, MPI_REAL, 0, tag1, MPI_COMM_WORLD, error)
endif
```



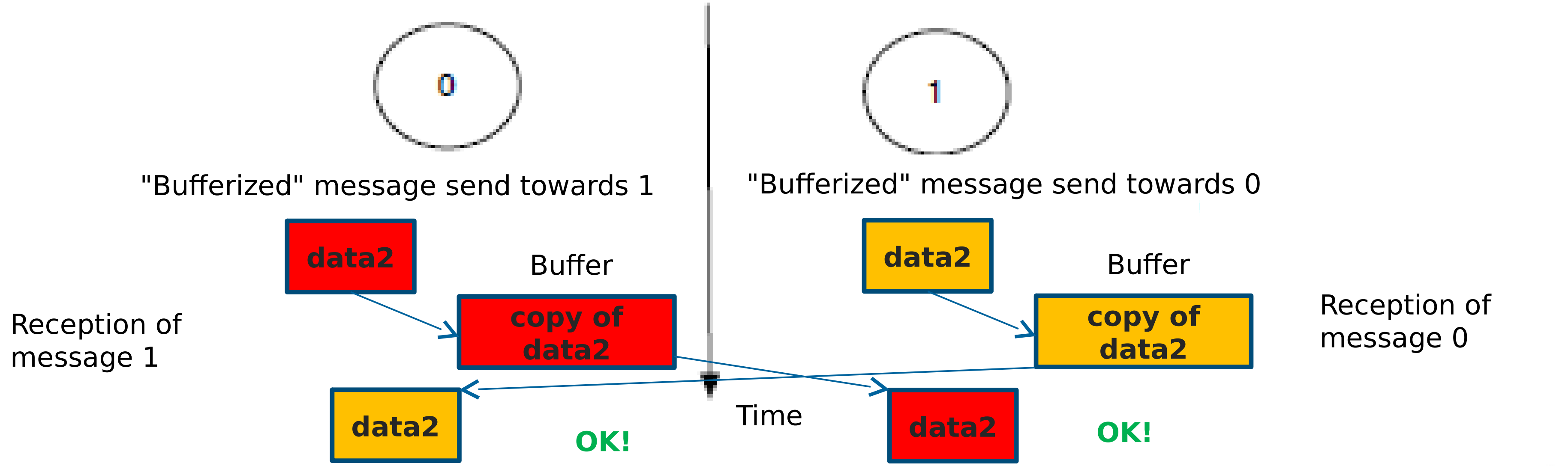
3. A Second Example of Deadlock

```
if (rank_process == 0) then
  ! Send of 10 MPI_REAL of data2 towards 1 with the tag "tag2"
  call MPI_SEND(data2, 10, MPI_REAL, 1, tag2, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 1 with tag "tag1"
  call MPI_RECV(data, 10, MPI_REAL, 1, tag1, MPI_COMM_WORLD, status, error)
else if (rank_process == 1) then
  ! Send of 10 MPI_REAL of data2 towards 0 with the tag "tag1"
  call MPI_SEND(data2, 10, MPI_REAL, 0, tag1, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 0 with tag "tag2"
  call MPI_RECV(data, 10, MPI_REAL, 0, tag2, MPI_COMM_WORLD, status, error)
endif
```



3. A Second Example of Deadlock

```
if (rank_process == 0) then
  ! Send of 10 MPI_REAL of data2 towards 1 with the tag "tag2"
  call MPI_SEND(data2, 10, MPI_REAL, 1, tag2, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 1 with tag "tag1"
  call MPI_RECV(data, 10, MPI_REAL, 1, tag1, MPI_COMM_WORLD, status, error)
else if (rank_process == 1) then
  ! Send of 10 MPI_REAL of data2 towards 0 with the tag "tag1"
  call MPI_SEND(data2, 10, MPI_REAL, 0, tag1, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 0 with tag "tag2"
  call MPI_RECV(data, 10, MPI_REAL, 0, tag2, MPI_COMM_WORLD, status, error)
endif
```



3. A Second Example of Deadlock

```
if (rank_process == 0) then
  ! Send of 10 MPI_REAL of data2 towards 1 with the tag "tag2"
  call MPI_SEND(data2, 10, MPI_REAL, 1, tag2, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 1 with tag "tag1"
  call MPI_RECV(data, 10, MPI_REAL, 1, tag1, MPI_COMM_WORLD, status, error)
else if (rank_process == 1) then
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  call MPI_SEND(data2, 10, MPI_REAL, 0, tag1, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 0 with tag "tag2"
  call MPI_RECV(data, 10, MPI_REAL, 0, tag2, MPI_COMM_WORLD, status, error)
endif
```
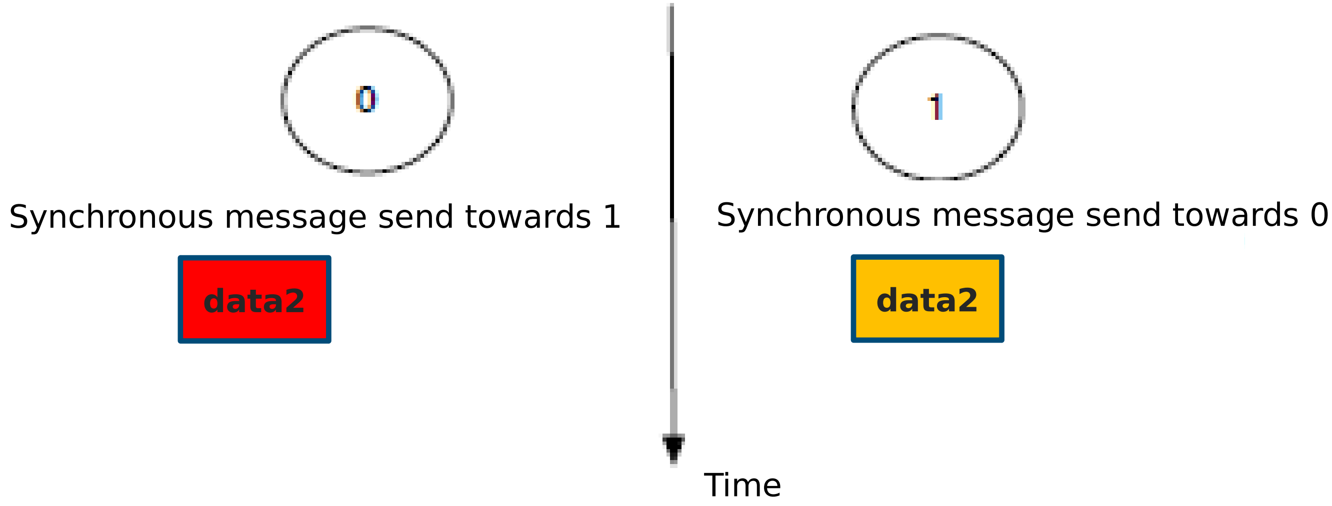
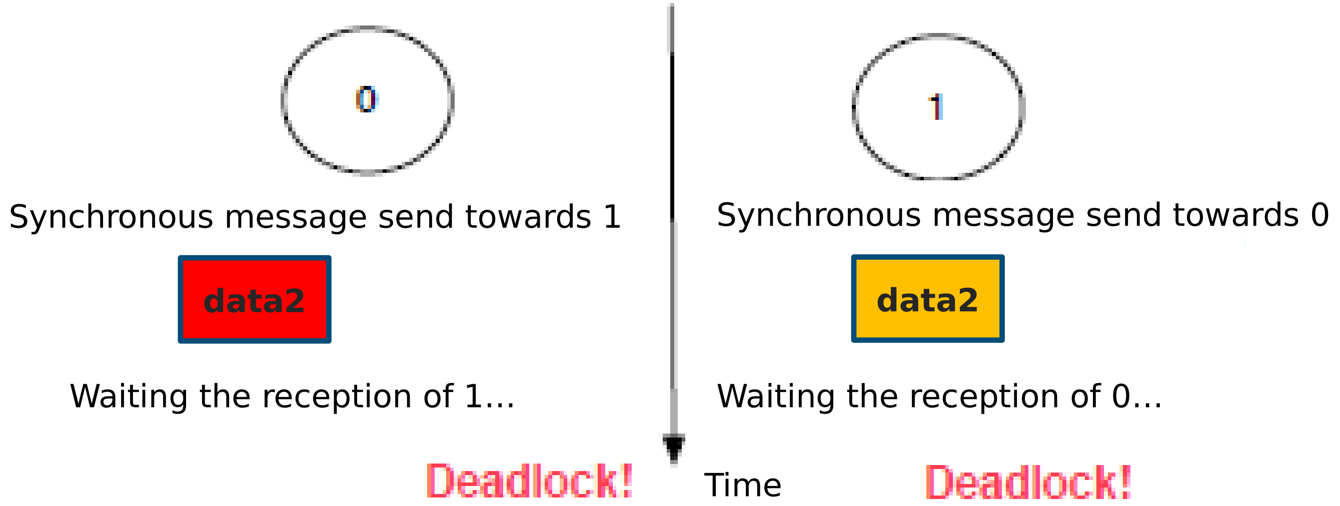



3. A Second Example of Deadlock

```
if (rank_process == 0) then
  ! Send of 10 MPI_REAL of data2 towards 1 with the tag "tag2"
  call MPI_SEND(data2, 10, MPI_REAL, 1, tag2, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 1 with tag "tag1"
  call MPI_RECV(data, 10, MPI_REAL, 1, tag1, MPI_COMM_WORLD, status, error)
else if (rank_process == 1) then
  ! Send of 10 MPI_REAL of data2 towards 0 with the tag "tag1"
  call MPI_SEND(data2, 10, MPI_REAL, 0, tag1, MPI_COMM_WORLD, error)
  ! Reception of 10 MPI_REAL in data coming from 0 with tag "tag2"
  call MPI_RECV(data, 10, MPI_REAL, 0, tag2, MPI_COMM_WORLD, status, error)
endif
```



3. Complements

- It exists routines allowing to perform a send and a receive at one time:

MPI_SENDRECV(data_send, nb_elem_send, type_send, dest, tag_send,
data_recv, nb_elem_recv, type_recv, src, tag_recv,
comm, status, error)

MPI_SENDRECV_REPLACE(data, nb_elem, type, dest, tag_send,
src, tag_recv, comm, status, error)

  - Warning: in the first case, data_send & data_recv must be different. In the second case, the variable send is replaced by the one received.

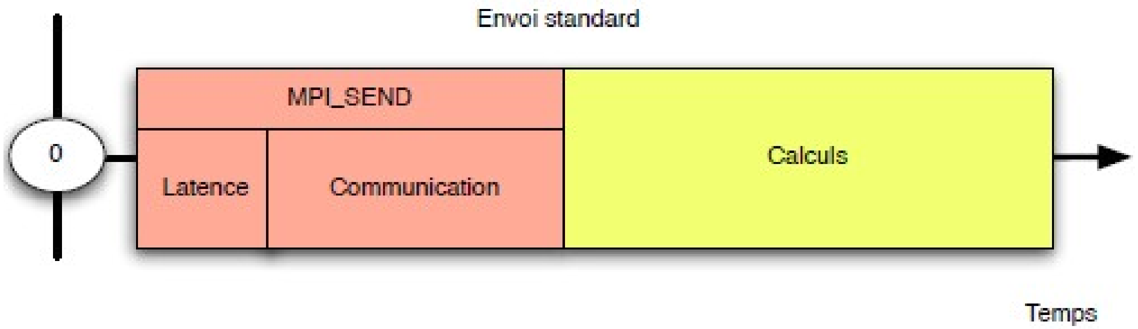
int **MPI_Probe**(int source, int tag, MPI_Comm comm, MPI_Status *status)

- envelop.

4. Performance of a MPI Computation (1/2)

- What are decisive factors?
  - System architecture and network between cores and nodes.
  - MPI implementation.
  - The code: choice of algorithms, memory management, communication/computing ratio in the code, load balancing…
- Time sharing during the execution of a MPI program
  - Latency: time to begin an exchange ≈ time needed to send an empty message
  - Communications
  - Computations

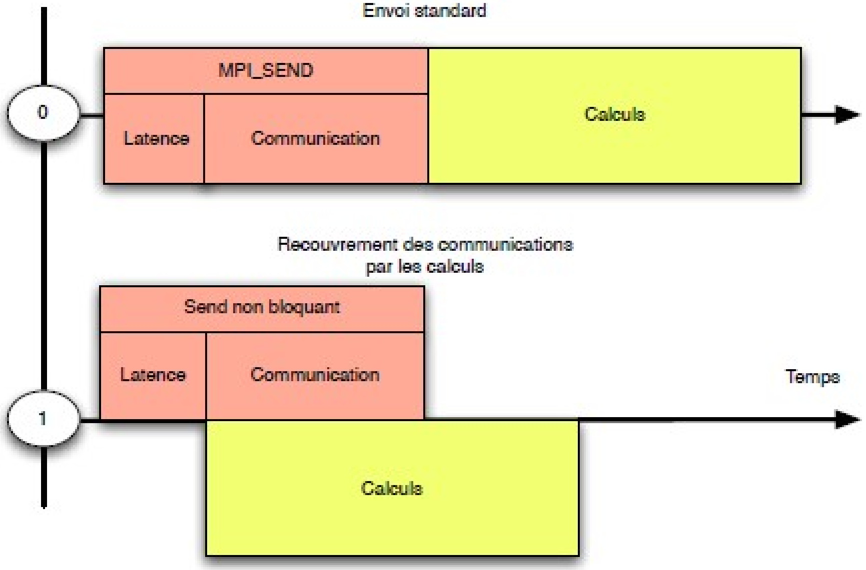
Example:



4. Performance of a MPI Computation (2/2)

- How to improve the implementation?
  - Use the good algorithms…
  - Use specialized libraries (fftw, scalapack…).
  - Overlap communications with computations.
  - Change communication mode.
  - Balance load between different processes.

Example:



4. Non-blocking Communications (1/2)

- How? To not wait the completion to give back control.

- Non-blocking send (MPI_ISEND): as soon as the message is posted, the program takes back control over the processor source.
- Non-blocking receive (MPI_IRECV): as soon as the reception is posted, the program takes back the hand.

=> The program can do something else during data transfers: overlap communications with computations.

Warning: The program takes back control before that the reception or the send is complete. As a consequence the variable send/received is not usable immediately.

4. Non-blocking Communications (2/2)

- How to know if the reception or the send is finished? To not wait the completion to give back control?
- MPI_WAIT

```
call MPI_ISEND(data, nb_elements, type, dest, tag, comm, request, error)
!! ...
call MPI_WAIT(request, status, error)
```

MPI_WAIT is **blocking** and gives back control as soon as the reception or the send has completed.

- MPI_TEST

```
logical flag
!! ...
call MPI_ISEND(data, nb_elements, type, dest, tag, comm, request, error)
!! ...
call MPI_WAIT(request, status, error)
```

MPI_TEST is **non-blocking** and sends back a boolean that is true if the send or the reception has completed.

Collective Communications

1. Description
2. Vector Version
3. Reduction

17-10-2016

1. Collective Communications

- A collective communication allows to realize in one call a set of point to point communications.

- A collective communication implies **all** processes of a communicator.

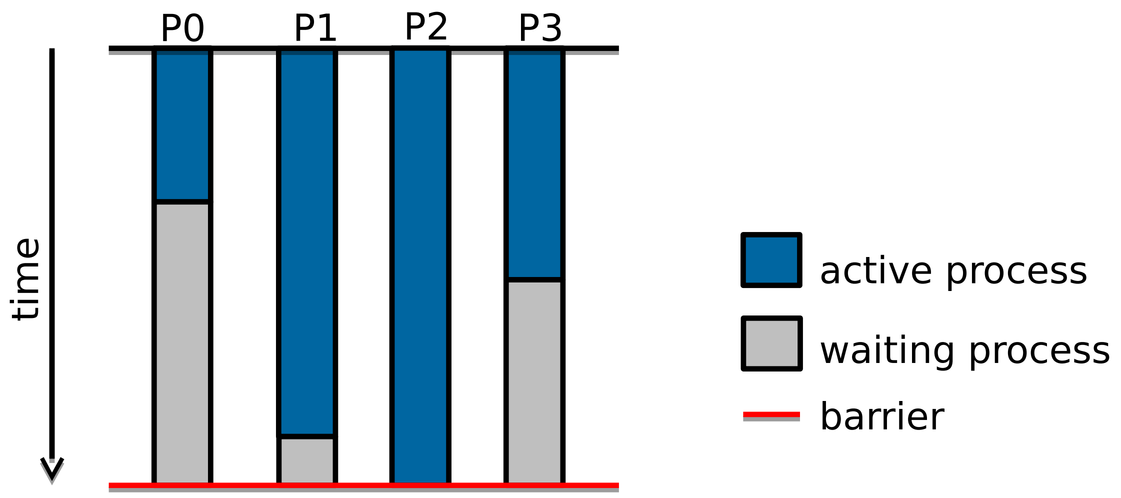
- 3 types of collective operations:
  - synchronization
  - data transfer
  - global reduction operation

- No tag needed

1. Global Synchronization

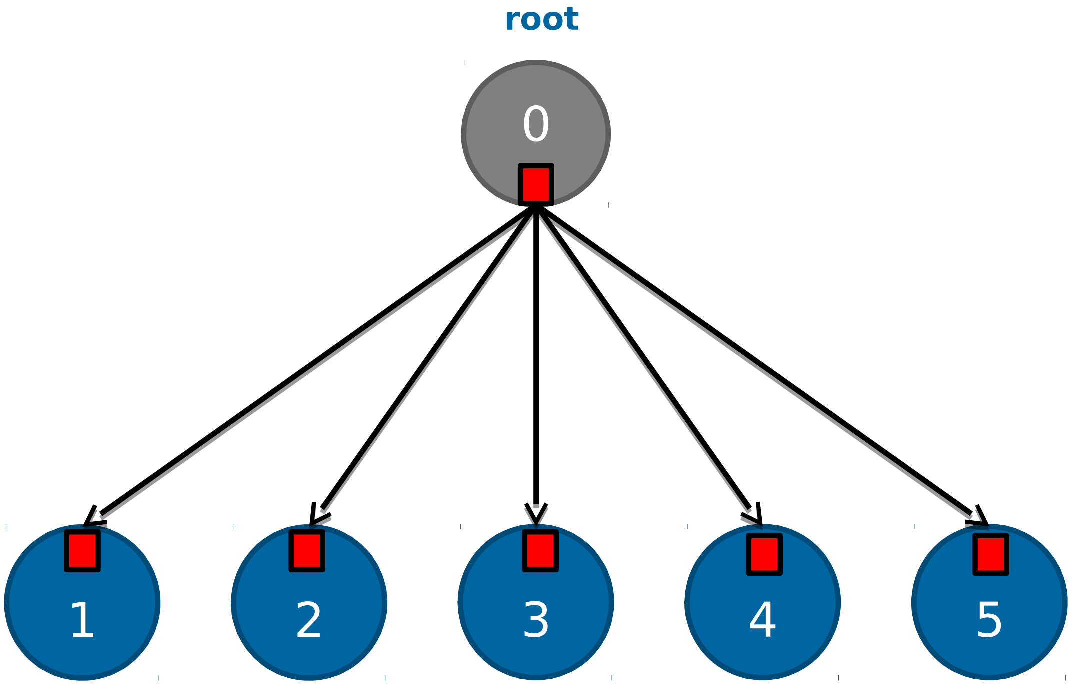
```
int MPI_Barrier(MPI_Comm comm)
```

- Barrier synchronization across all members of a *comm.*
- Blocks the caller until all group members have called it
- Returns at any process only after all processes in *comm* have entered the call.



1. Broadcast (1/2)

int **MPI_Bcast**(&buffer, count, datatype, root, comm)

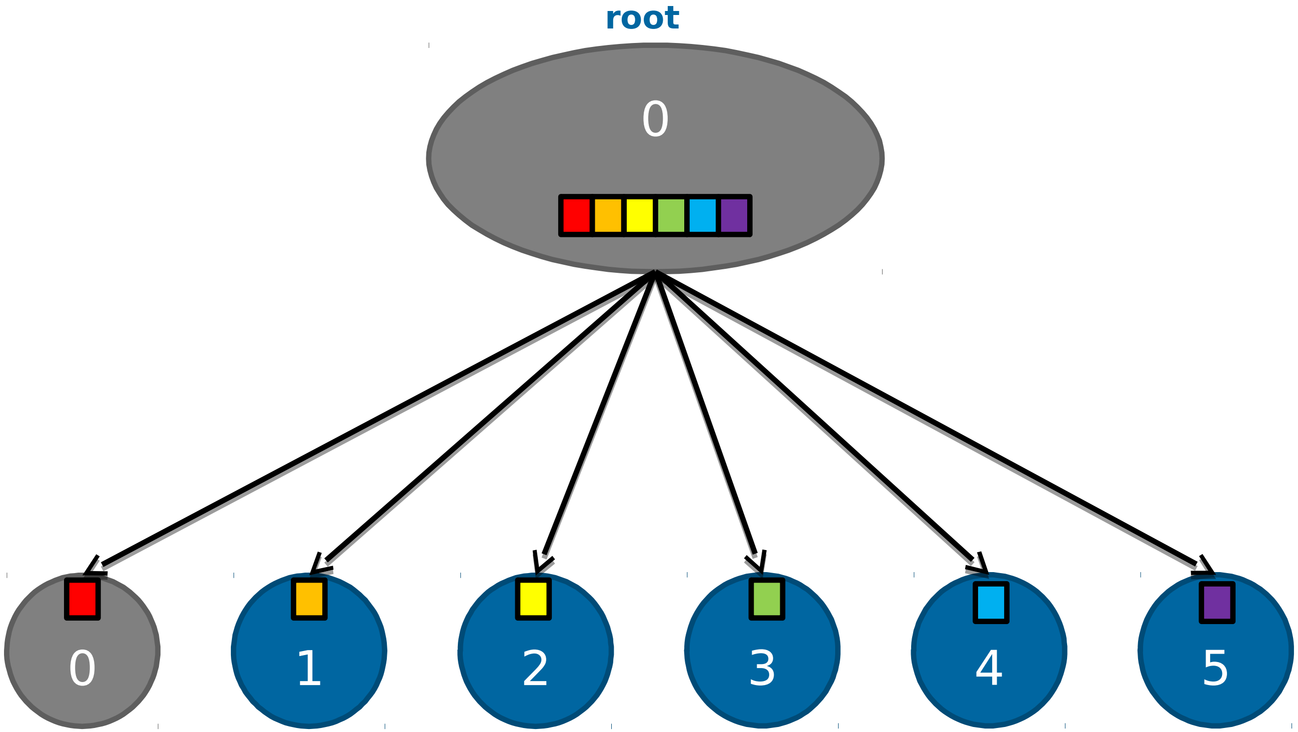


1. Broadcast (2/2)

- *root* sends data to all process in the communicator
- Others processes wait to receive the data
- Equivalent to:
  - *root* calls *MPI_Send* to all processes
  - others process call *MPI_Recv*

1. Scatter (1/2)

int **MPI_Scatter**(&sendbuf, sendcnt, sendtype,
&recvbuf, recvcnt, recvtype, root, comm)



1. Scatter (2/2)

- Each process receives a part of the data sent by *root* according to their rank:

- The message is split into n equal segments, the i-th segment is sent to the i-th process of *comm*.

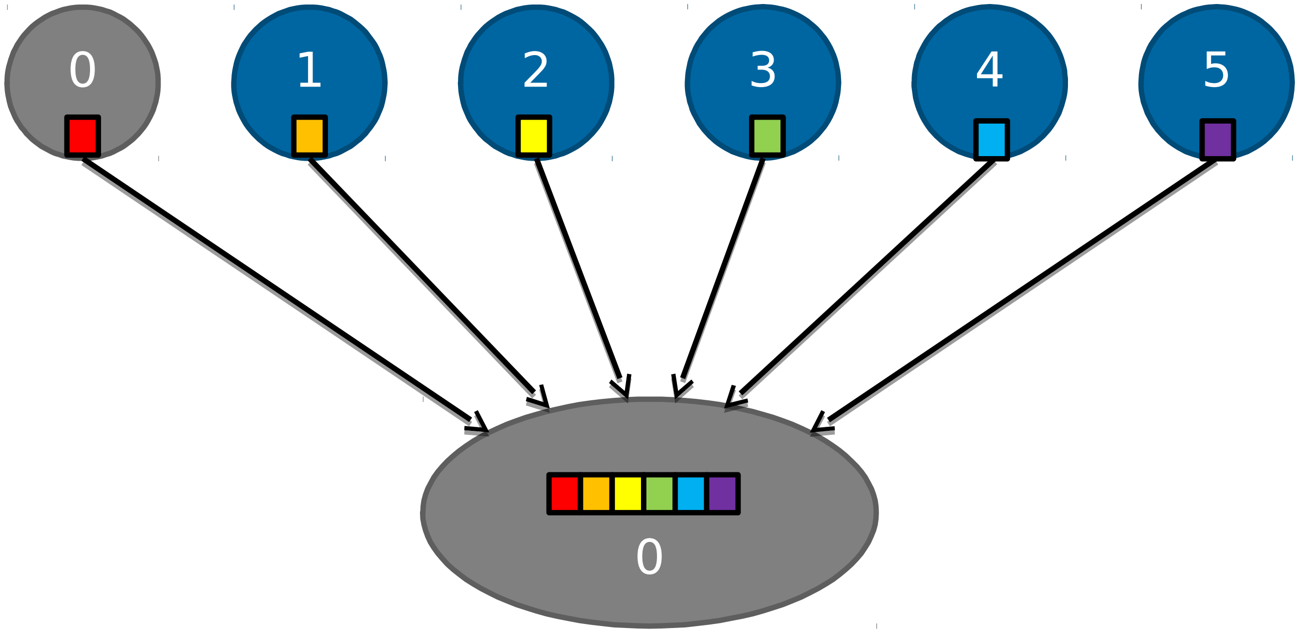
- Equivalent to :
  - *root* sends to each process of rank *i* a part of data:
    - MPI_Send(&(sendbuf + i * sendcnt * extent(sendtype), sendcnt, sendtype, i, ...)
  - Each process receives:
    - MPI_Recv(&recvbuf, recvcnt, recvtype, root, ...)

- Only *root* uses *sendbuf*, *sendcnt* and *sendtype* arguments.

- *root* can use *MPI_IN_PLACE* to receive data :
  - *root* sends no data to itself

1. Gather (1/2)

```
int MPI_Gather(&sendbuf, sendcnt, sendtype,
               &recvbuf, recvcount, recvtype, root, comm)
```



1. Gather (2/2)

- Each process (*root* process included) sends the contents of its send buffer to the root process.

- The *root* process receives the messages and stores them in rank order.

- Equivalent to :
  - each of the n processes (including the root process) executes a call to:

    MPI_Send(&sendbuf, sendcnt, sendtype, root, ...)
  - and the root executes n calls to:

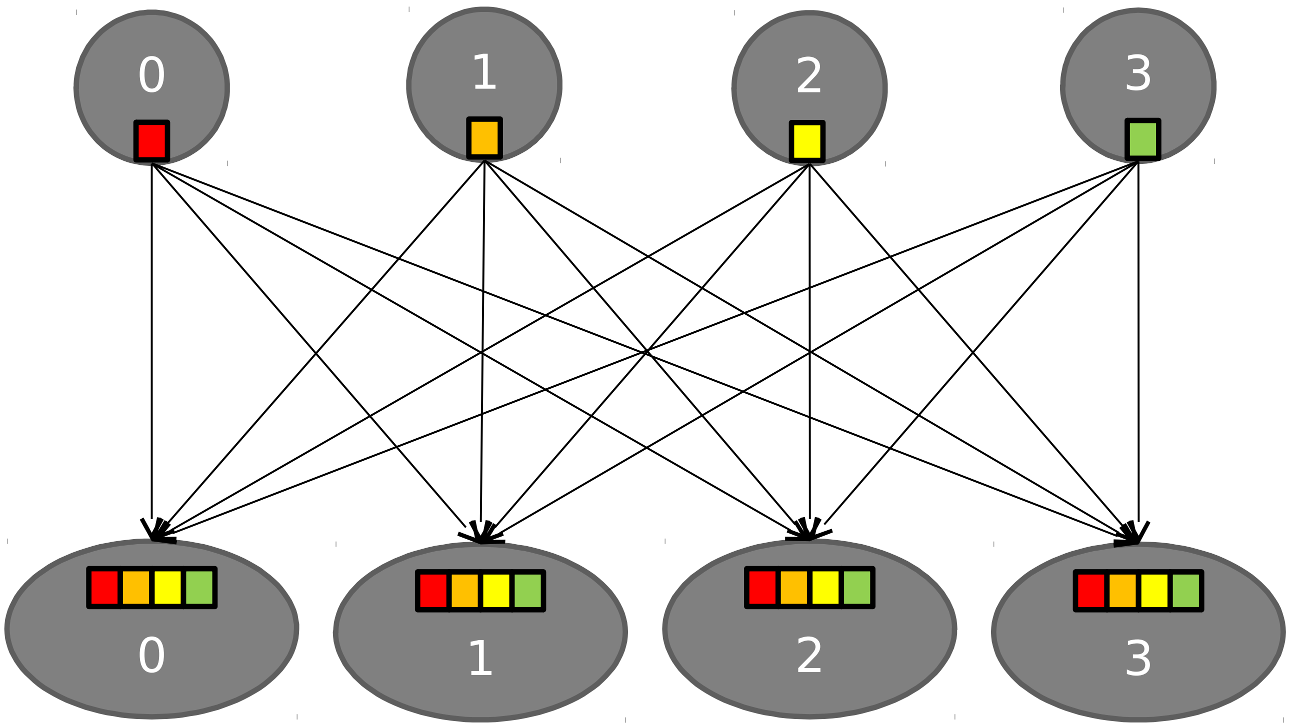
    MPI_Recv(&(recvbuf + i * recvcnt * extent(recvtype)), recvcnt, recvtype, i, ...)

- *root* can use *MPI_IN_PLACE* as send buffer:
  - *root* sends no data to itself

- The *recvbuf*, *recvtype* and *recvcnt* arguments are ignored for all non-root processes.

1. Allgather (1/2)

int MPI_Allgather(&sendbuf, sendcount, sendtype,
&recvbuf, recvcount, recvtype, comm)



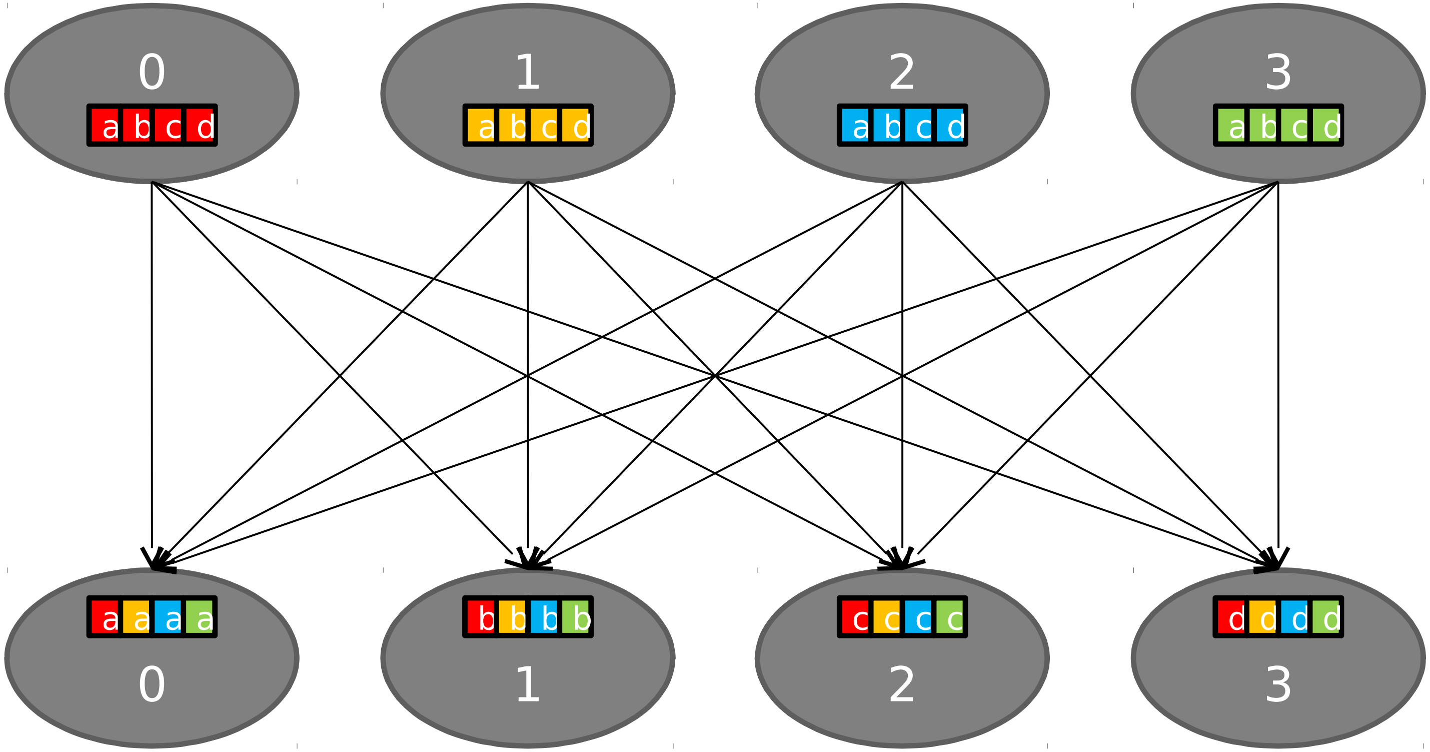
1. Allgather (2/2)

- MPI_ALLGATHER can be thought of as MPI_GATHER, but where all processes receive the result, instead of just the root.

- All processes can use "MPI_IN_PLACE" in the parameter *sendbuf* ,
  - process sends no data to itself

1. All-to-All Scatter/Gather(1/2)

int MPI_Alltoall(&sendbuf, sendcount, sendtype,
&recvbuf, recvcount, recvtype, comm)



1. All-to-All Scatter/Gather(2/2)

- It is an extension of MPI_ALLGATHER to the case where each process sends distinct data to each of the receivers.

- Equivalent to
  - each process executes a send to each process (itself included)

    MPI_Send(&(sendbuf + i * sendcnt * extent(sendtype), sendcnt, sendtype, i, ...)
  - and a receive from every other process with a call to,

    MPI_Recv(&(recvbuf + i * recvcnt * extent(recvtype)), recvcnt, recvtype, i, ...)

- All processes can use MPI_IN_PLACE in the parameter *sendbuf* ,
  - the data to be sent is taken from the recvbuf…
  - …and replaced by the received data

2. Vector Versions of the Collective

- Operation of collective vector (name of operation with "**v”** suffix)
  - MPI_Scatterv
  - MPI_Gatherv
  - MPI_Allgatherv
  - MPI_Alltoallv (et MPI_Alltoallw)

- Allows a varying count of data from each process, since *recvcounts* is now an array

2. Vector Version of Scatter (1/3)

```
int MPI_Scatterv(const void* sendbuf, const int sendcounts[],
                 const int displs[], MPI_Datatype sendtype,
                 void* recvbuf, int recvcount, MPI_Datatype recvtype,
                 int root, MPI_Comm comm)
```

- Vector version of MPI_Scatter
  - *sendcounts*: integer array (of length group size) specifying the number of elements to send to each *rank*
  - *displs*: integer array (of length group size). Entry *i* specifies the displacement (relative to *sendbuf*) from which to take the outgoing data to process *i*
- The send buffer is ignored for all non-root processes.

2. Vector Version of Scatter (2/3)

- Equivalent to:
  - the outcome is as if the root executes n send operations,

```
MPI_Send( &(sendbuf + displs[i] * extent(sendtype), sendcounts[i], sendtype, i, ...)
```

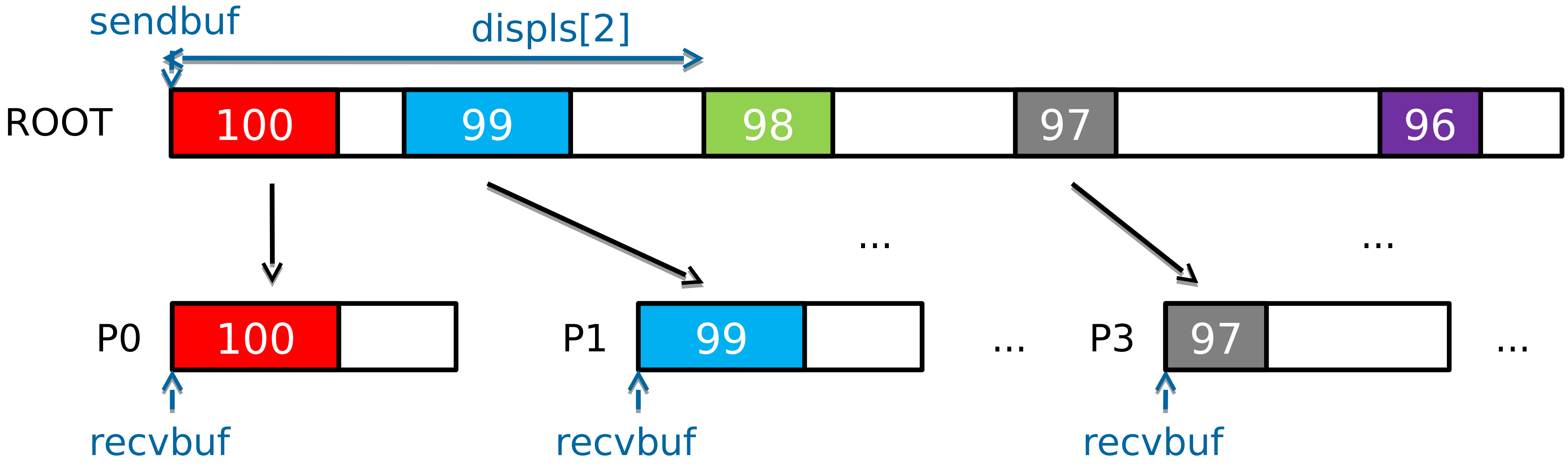
  - and each process executes a receive

```
MPI_Recv( &recvbuf, recvcount, recvtype, root, ...)
```

- *root* can use MPI_IN_PLACE as *recvbuf*:
  - root sends no data to itself

2. Vector Version of Scatter (3/3)

```
...
for (i=0; i<gsize; ++i) {
  displs[i] = i*stride;
  scounts[i] = 100-i;
}
MPI_Scatterv(sendbuf, scounts, displs, MPI_INT, recvbuf, 100-i, MPI_INT, root, comm);
```



2. TP: Example of vector version of collective communication

- The first process (rank=0) send an array to all process.
  - The size of the array depending of the rank of the receiver.
    (sends 1 element to rank=1, 2 elements to rank=2 …)

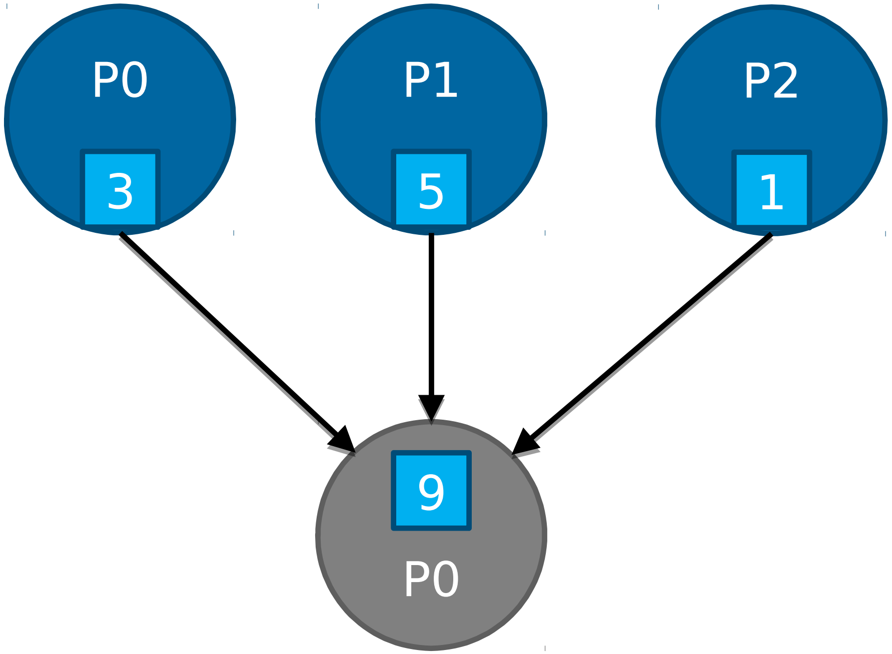
2. TP: Example of vector version of collective communication (solution)

```
int *scounts = malloc(sizeof(int)* mpisize);
int *displs = malloc(sizeof(int)* mpisize);
for (i = 0 ; i < mpisize ; i++)
  scounts[i] = i;
displs[0] = 0;
for (i = 1 ; i < mpisize ; i++)
  displs[i] = displs[i-1] + scounts[i-1];

 MPI_Scatterv(array, scounts, displs, MPI_INT,
                  array, mpirank, MPI_INT, 0, MPI_COMM_WORLD);
```

3. Reduction (1/6)

- Performs a global reduce operation (for example sum, maximum, and logical and) across all members of a group

- Example with *SUM* operation



3. Reduction (2/6)

- Predefined Reduction Operations

Name	Meaning
MPI_MAX	Maximum
MPI_MIN	Minimum
MPI_SUM	Sum
MPI_PROD	Product
MPI_LAND	logical and
MPI_BAND	bit-wise and
MPI_LOR	logical or
MPI_BOR	bit-wise or
MPI_LXOR	logical exclusive or (xor)
MPI_BXOR	bit-wise exclusive or (xor)
MPI_MAXLOC	max value and location
MPI_MINLOC	Min value and location

3. Reduction (3/6)

int **MPI_Reduce**(const void* sendbuf, void* recvbuf, int count, MPI_Datatype datatype,
MPI_Op op, int root, MPI_Comm comm)

- MPI_REDUCE combines the elements provided in the input buffer *sendbuf* of each process in the communicator *comm*, using the operation *op*.
- Returns the combined value in the output buffer of the process with rank root
- Example

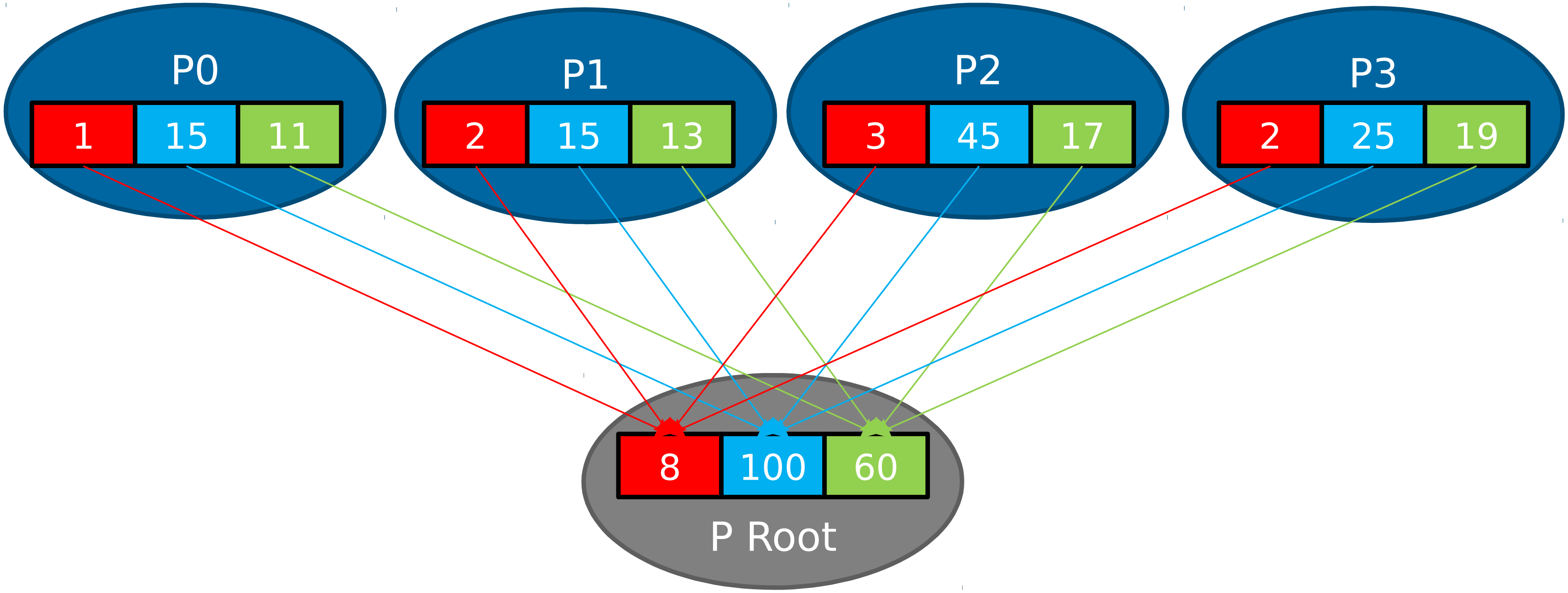
MPI_Reduce(&sendbuf, &recvbuf, 2, MPI_INT, MPI_MAX, 0, comm)

  – recvbuf[0] = max(all of sendbuf[0])
  – recvbuf[1] = max(all of sendbuf[1])

3. Reduction (4/6)

- Another example:

MPI_Reduce(&sendbuf, &recvbuf, 3, MPI_INT, MPI_SUM, 0, comm)

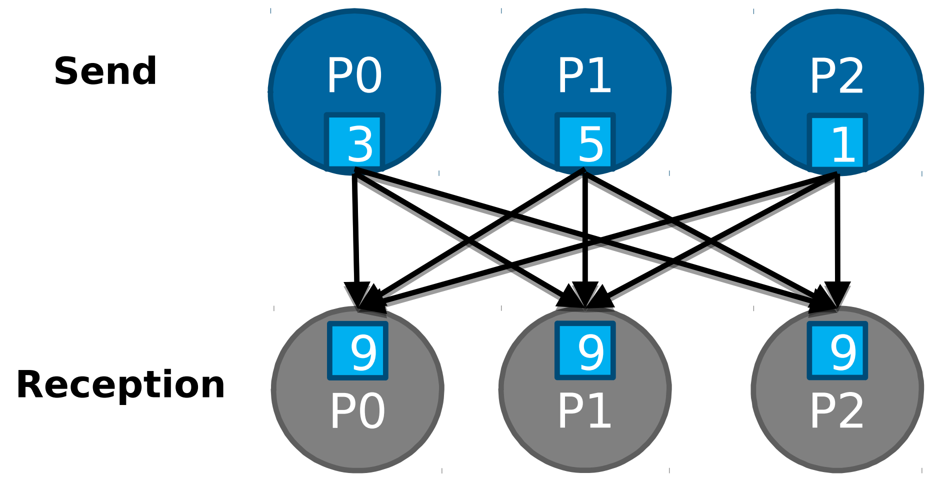


3. Reduction (5/6)

int **MPI_Allreduce**(const void* sendbuf, void* recvbuf, int count,
MPI_Datatype datatype, MPI_Op op, MPI_Comm comm)

- A variant of the reduce operations where the result is returned to all processes in a group.

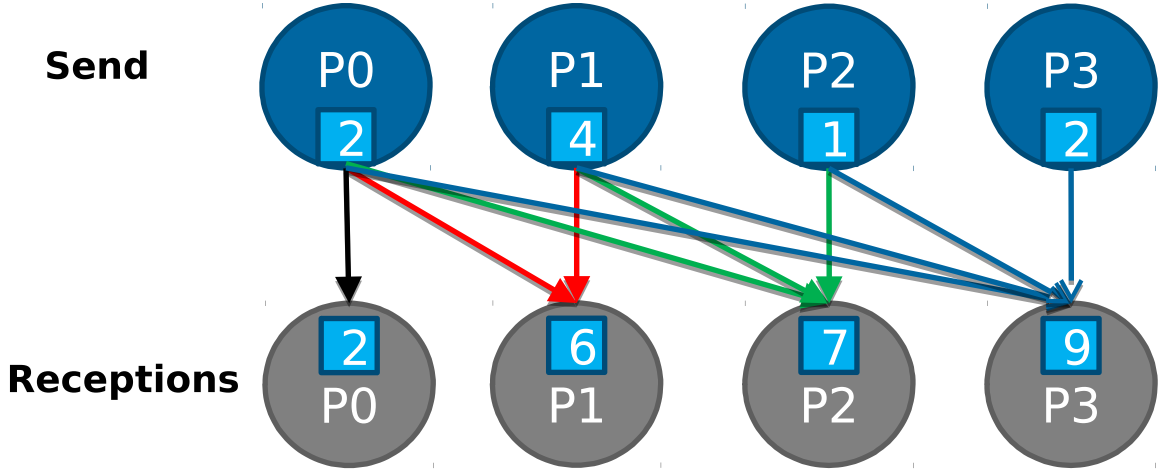
- Example with *SUM* operation



3. Reduction (6/6)

int **MPI_Scan**(const void* sendbuf, void* recvbuf, int count,
MPI_Datatype datatype, MPI_Op op, MPI_Comm comm)

- The operation returns, in the receive buffer of the process with rank i, the reduction of the values in the send buffers of processes with ranks 0,. . .,i
- Example with *SUM* operation



3. User Defined Reduction

- Just to mention that thanks to the following routines, the user can define its own reduction operations.

int **MPI_Op_create**(MPI_User_function* user_fct, int commute, MPI_Op* op)

int **MPI_Op_free**(MPI_Op* op)

void **MPI_User_function**(void* invec, void* inoutvec, int *len, MPI_Datatype *datatype)

Questions?

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Thanks

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