# MPI Communication
# Point-to-Point (P2P)

Luca Tornatore - I.N.A.F.

DATA SCIENCE & ARTIFICIAL INTELLIGENCE

SCIENTIFIC & DATA-INTENSIVE COMPUTING

**2024-2025 @ Università di Trieste**

# Outline

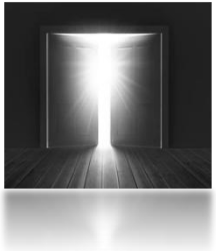
Intro to MPI

Point-to-Point Communications

Collective Communications

few JEDI things

# Outline



Intro to MPI

Point-to-Point Communications

Collective Communications

few JEDI things

# Building blocks: Send and Receive

The very basic building block of a message-passing interface is, obviously, the capability of sending and receiving messages between two tasks:

```
int MPI_Send( const void *buf,
              int count,
              MPI_Datatype,
              int dest,
              int tag,
              MPI_Comm comm )
```

The begin of the memory region to be sent

The size of the message

The rank of the receiver

Tag your messages to distinguish them

Specify the communicator

# Building blocks: Send and Receive

The very basic building block of a message-passing interface is, obviously, the capability of sending and receiving messages between two tasks:

```
int MPI_Recv( const void *,
              int count,
              MPI_Datatype,
              int source,
              int tag,
              MPI_Comm comm,
              MPI_Status &status)
```

The begin of the memory region to be sent

The ***maximum*** size of the message

The rank of the receiver

Tag your messages to distinguish them

Specify the communicator

Return details about the message

# NOTICE

In the following slides we will describe many MPI calls, in their fundamental traits.

Please, refer to the man pages for a thorough description and for all the possibile output values in specific cases

# Building blocks: Send and Receive

```
int MPI_Send( const void *buf,
              int count,
              MPI_Datatype,
              int dest,
              int tag,
              MPI_Comm comm )
```

```
int MPI_Recv( const void *buf,
              int count,
              MPI_Datatype,
              int dest,
              int tag,
              MPI_Comm comm,
              MPI_Status &status)
```

Then, the messages consists of a **body**

`buf`
`count`
`datatype`

and of an **envelop**

`dest`
`tag`
`comm`

# Building blocks: Send and Receive

| MPI DataType | C DataType |
|---|---|
| MPI_CHAR | char |
| MPI_BYTE | unsigned char |
| MPI_(UNSIGNED)_SHORT | (unsigned) short int |
| MPI_(UNSIGNED)_INT | (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_PACKED | |

## example

```
int N;
if ( Myrank == 0 )
      MPI_Send( &N, 1, MPI_INT, 1, 0, MPI_COMM_WORLD );

else if ( Myrank == 1 ) {
      MPI_Recv( &N, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, MPI_STATUS_IGNORE );
```

NOTE: **`MPI_STATUS_IGNORE`** is always valid instead of putting an `MPI_Status` varible's address as last argument of `MPI_Recv`

# Building blocks: Send and Receive

## example

How can I send more “things” of differente type?

```
typedef struct {
        int    i, j;
        double d, f;
        char   s[4]; } my_data;

unsigned int length = N*sizeof(my_data);
if ( Myrank == 0 )
      MPI_Send( data, length, MPI_BYTE, 1, 0, MPI_COMM_WORLD );

else if ( Myrank == 1 ) {
      MPI_Recv( data, length, MPI_BYTE, 0, 0, MPI_COMM_WORLD,
                MPI_STATUS_IGNORE );
```

# Building blocks: Send and Receive

## What are the tag useful for ?

It makes easier to distinguish between two similar messages and avoid errors

```
if ( Myrank == 0 ) {
      MPI_Send( myname, 100, MPI_BYTE, 1, 0, MPI_COMM_WORLD );
      MPI_Send( mysurnasme, 100, MPI_BYTE, 1, 1, MPI_COMM_WORLD ); }

  else if ( Myrank == 1 ) {
      MPI_Recv( myname, 100, MPI_BYTE, 0, 0, MPI_COMM_WORLD,
                                                MPI_STATUS_IGNORE );
      MPI_Recv( mysurname, 100, MPI_BYTE, 0, 1, MPI_COMM_WORLD,
                                                MPI_STATUS_IGNORE );   }
```

Note: We'll see more on how the messages are ordered

# Building blocks: Send and Receive

## Why the MPI_Status in MPI_Recv ?

- **The `MPI_Recv`'s argument count provides the *maximum* number of elements that the call expects to receive.** If the message exceeds that count, an error is thrown.
  Hence, you do not know whether `MPI_Recv` has got n ≤count elements.

- Valid values for the source and tag arguments are **`MPI_ANY_SOURCE`** and **`MPI_ANY_TAG`**, so that the task could receive messages from anybody and with any tag.

- However, it may be that, once received, you need to know who was the sender, which was the tag and what is the size of the received message.
  You recover these data with

  ```
  status.TAG, status.MPI_SOURCE
  ```

  and by calling

  ```
  MPI_Get_count (  &status, MPI_type_used, &count )
  ```

  where you must use the same type than in the `Recv`, and you get how many data in `count`

# Building blocks: Send and Receive

## How to get the size of the received message with `MPI_Get_count`

Getting the size of the received message

**The `MPI_Recv`'s argument count provides the *maximum* number of elements that the call expects to receive.** If the message exceeds that count, an error is thrown.

Hence, in general you do not know whether `MPI_Recv` has got n ≤count elements.

```
if ( Me == 0 )
  {
    MPI_Send( data, Ndata, MPI_BYTE, 1, TAG_DATA, MPI_COMM_WORLD );
    printf("Task %d has sent %d data: %d %d, ... %d!i\n",
           Me, Ndata, data[0], data[1], data[Ndata-1] );
  }
else
  {
    MPI_Status status;
    int        Nrecv;

    MPI_Recv( data, Ndata, MPI_BYTE, 0, TAG_DATA, MPI_COMM_WORLD, &status );

    MPI_Get_count ( &status, MPI_BYTE, &Nrecv );
    printf("Task %d has received %d data: %d %d, ... %d\n",
           Me, Nrecv, data[0], data[1], data[Nrecv-1] );

  }
```

get_count.c

## How to check whether a message is arriving

You may want to know whether a message is arriving, from who and how large *before to actually get it.*

```
MPI_Status status;

 // Probe for an incoming message from whatever process and whatever tag
MPI_Probe(MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &status);

source = status.MPI_SOURCE;
tag    = status.MPI_TAG;
MPI_Get_count(&status, MPI_BYTE, &number_amount);
char *buffer = (char*)malloc( number_amount );
MPI_Recv( buffer, number_amount, MPI_BYTE, source, tag, MPI_COMM_WORLD, &status)
...
 // Probe for an incoming message from process zero with a precise tag

MPI_Probe(0, really_this_tag, MPI_COMM_WORLD, &status);
...
```

probe.c

## Safety first

Let's consider `probe.c`

```
MPI_Send( data, N, MPI_INT, 1, TAG_DATA, MPI_COMM_WORLD );
...
modify( data );
```

`data` is the memory region that contains the data that have been sent by the `MPI_Send`.

At what point in the future it is safe to modify the memory region involved in a `MPI_Send` ?

In other words, **how can we be sure that the communication has ended and the data have all been received?**

## Safety first

**how can we be sure that the communication has ended and the data have all been received?**

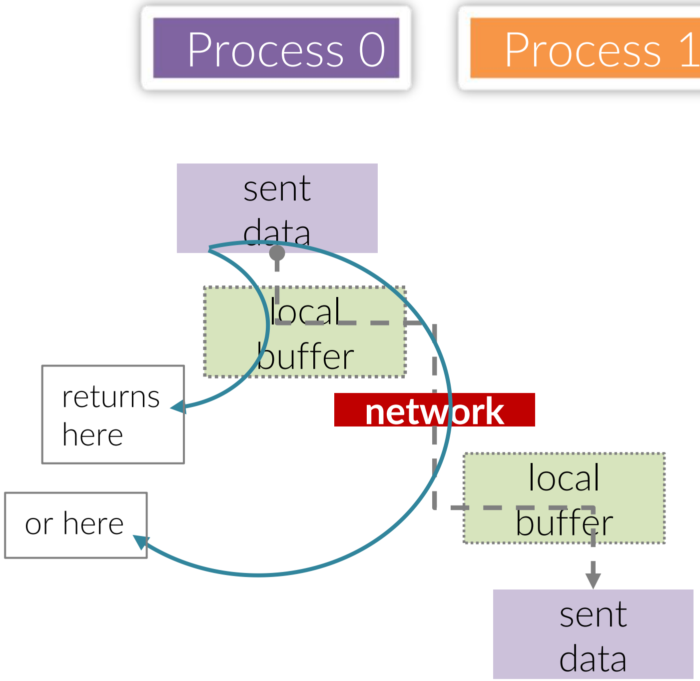
The MPI standard prescribes that **`MPI_Send` returns when it is safe to modify the send buffer**.

So, whenever `MPI_Send` returns, it is safe to act on the memory region that has been sent.

However, this leads us to a more general discussion.

# MPI Communication protocols

## Eager protocol




MPI implementation may apply different communication protocols, depending on the message size.

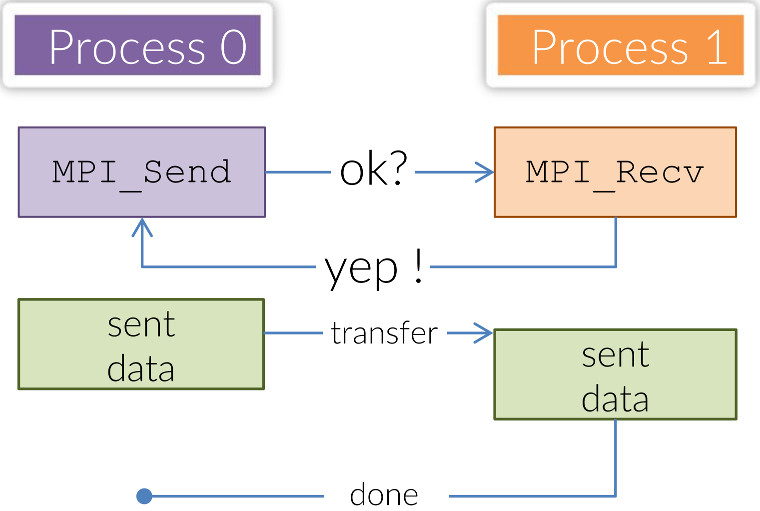
In the eager protocol, `MPI_Send` returns before that the data actully reach the destination. More correctly, it returns without *knowing* whether that happened already or not.

The MPI library copies the sent data on local buffer, either on the sender size or the receiver size. The actual transfer will complete afterwards and the `MPI_Send` returns.

This protocol is normally applied for **small sizes**

# MPI Communication protocols

## Rendezvous protocol




In the rendezvous protocol, the sender first asks the agreement to the receiver.

Once it gets the acknowledgment, the data tranfer starts.
At the end of it, the `MPI_Send` (and the `MPI_Recv`) returns.

This protocol is normally applied for large messages, for which the bufferization would require too much memory.

## Safety first

As a matter of fact, then, `MPI_Recv` does not complete until the buffer is full and `MPI_Send` does not complete until the buffer is empty.

As such, the completion of `MPI_Send/MPI_recv` depends on the size of the message and the size of the buffer provided by MPI.

This in general may lead to potentially dangerous situations, such as **deadlocks** or **unsafe code**, which appears to run smoothly just because of the system’s bufferization.

# Unsafe code

```
if ( Me == 0 )
  {
    MPI_Send( data_to_send, N, MPI_BYTE, !Me, DATA_FIRST, MPI_COMM_WORLD );
    MPI_Recv( data_to_recv, N, MPI_BYTE, !Me, DATA_SECND, MPI_COMM_WORLD, MPI_STATUS_IGNORE );
  }
else
  {
    MPI_Send( data_to_send, N, MPI_BYTE, !Me, DATA_FIRST, MPI_COMM_WORLD );
    MPI_Recv( data_to_recv, N, MPI_BYTE, !Me, DATA_SECND, MPI_COMM_WORLD, MPI_STATUS_IGNORE );
  }
```

This exchange may run smoothly due to system's bufferization.

However, as the message size grows, it will incur in a deadlock.

```
char myname[10], myname2[10];

if ( Me == 0 )
  {
    MPI_Send( myname, 100, MPI_BYTE, 1, NAME, MPI_COMM_WORLD );
    MPI_Send( myname2, 100, MPI_BYTE, SURNAME, 0, MPI_COMM_WORLD );
  }
else
  {
    MPI_Recv( myname2, 100, MPI_BYTE, 0, SURNAME, MPI_COMM_WORLD,
              MPI_STATUS_IGNORE );

    MPI_Recv( myname, 100, MPI_BYTE, 0, NAME, MPI_COMM_WORLD,
              MPI_STATUS_IGNORE );
  }
```

This exchange may run smoothly due to system's bufferization.

However, using MPI_Ssend instead of Send will surely result in a deadlock

( ... did you noticed that the Recv of the two messages are in opposite order than the Send ? )

potential_deadlock.c

# Unsafe code

Code that rely on the system's bufferization to run correctly are called *unsafe*

Solutions to cure or, better, to avoid the unsafe situations are:

- designing more carefully the communication pattern
- checking the runnability by substituting `MPI_Send` with `MPI_Ssend`
- using `MPI_Sendrecv`
- supplying explicitly buffer with `MPI_Bsend`
- non-blovking operations

# Unsafe code & Deadlocks

The order of the Send / Recv must be crafted so that a Send is matched by Recv, with the same **source, tags and communicator.**

The mismatches lead to unsafe code or deadlocks, because the function will not return and the code hangs.

*a communication is made of the message data plus the envelop which assemble all the information needed to convey the message to the recipient.*

Due to system's bufferization in the *eager* protocol, some of these patterns may be run apparently smoothly, while hanging for larger data size or on different systems.

**Code that rely on the system's bufferization to run correctly are called *unsafe*.**

# Unsafe code & Deadlocks

deadlock

```
if (Rank == 0) {
  Recv ( from 1 );
  Send ( to 1 ); }
if (Rank == 1) {
  Recv ( from 0 );
  Send ( to 0 ); }
```

```
if (Rank == 0) {
  Recv ( from 1 );
  Send ( to 2 ); }
else if (Rank == 1) {
  Recv ( from 2 );
  Send ( to 1 ); }
else if (Rank == 2 ) {
  Recv ( from 0 );
  Send ( to 0 ); }
```

unsafe

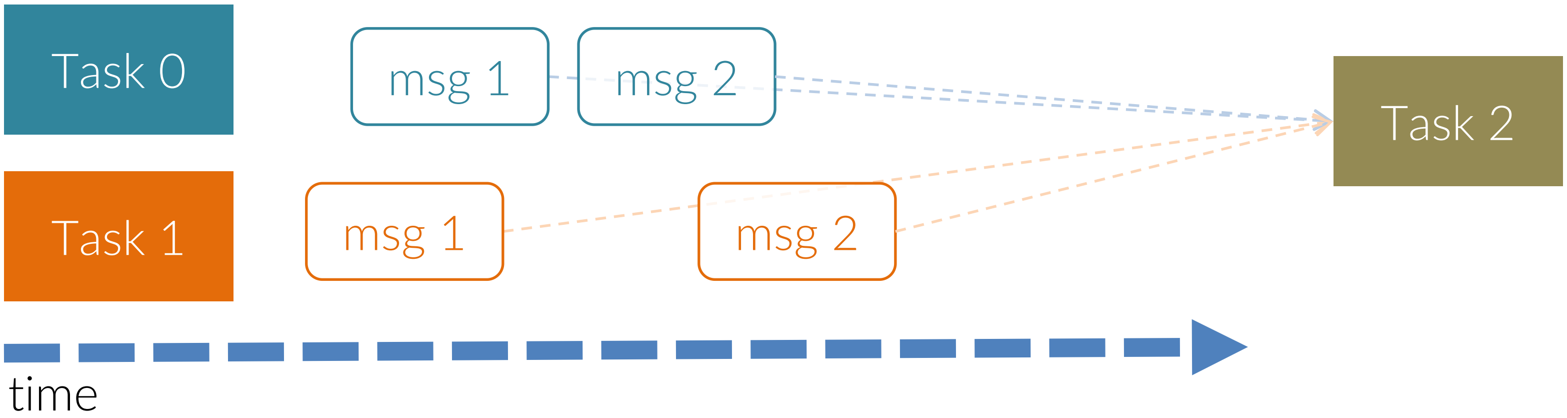
```
if (Rank == 0) {
  Send ( from 1 );
  Recv ( from 1 ); }
if (Rank == 1) {
  Send ( to 0 );
  Recv ( from 0 ); }
```

safe

```
if (Rank == 0) {
  Recv ( from 1 );
  Send ( to 1 ); }
if (Rank == 1) {
  Send ( to 0 );
  Recv ( from 0 ); }
```

# Ordering of communications

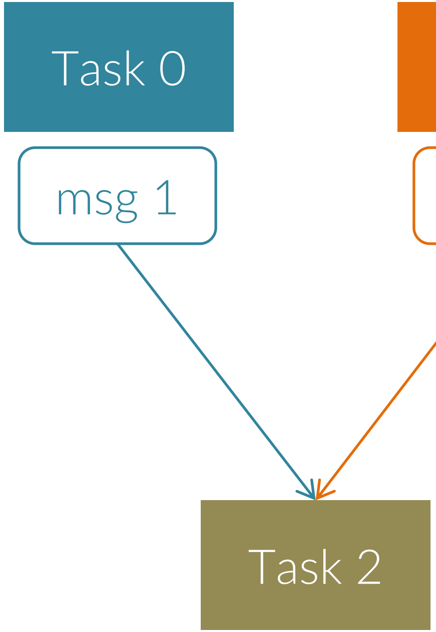
MPI does not ensure any ordering of messages from different sources




- Messages from the same source to the same target with same tags are ensured to arrive in issuing order (msg1, msg2 and msg 1, msg 2 respectively).
- Messages to the same target from different sources are *not* ensured to arrive in *any order* (not even if with the same tag).

# Fairness

MPI does not ensure any fairness in case of message starvation




If two messages from two sources match a `Recv` on a task ( two `Send` with same size, same tag, same comm; one `Recv` with that size, `ANY_SOURCE` and either the same tag or `ANY_TAG` ) then it is undefined which one will be received.

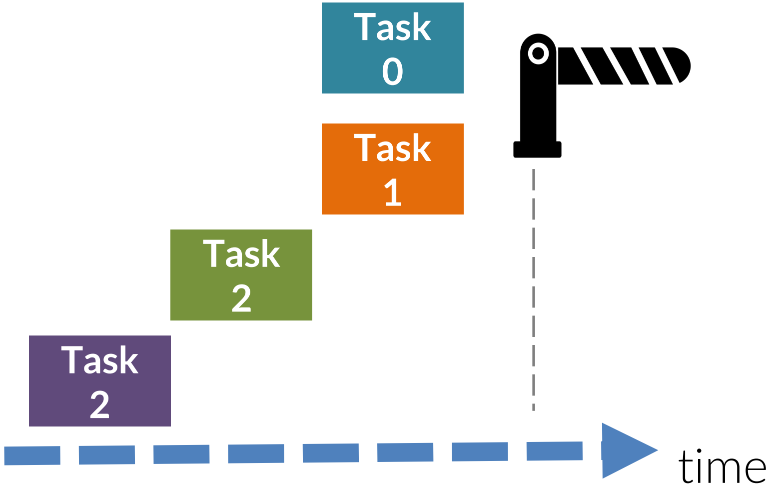
# The most violent sync: the barrier

The MPI_Barrier ensures a synchronization among the MPI threads

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

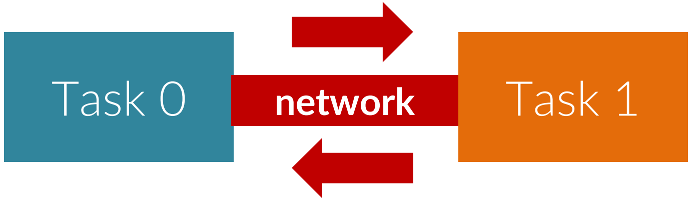
It is a **collective call**, we'll see more about that tomorrow.

The call completes when all the MPI ranks in the group have entered the barrier.



# First exercises: Ping-Pong test

The aim is to estimate the latency time and the bandwidth of the network between two nodes




Modelling the communication time as

$t_{comm}$ = **λ** + size / bw

where  is the latency, bw is the bandwidth and **λ** size is the message size,

by exchanging messages of different size we should be able to infer both **λ** and bw.

# First exercises: Ping-Pong test

1) > Rank 0 sends a msg to Rank 1, with tag 01
   > Rank 1 waits in Recv

2) > Rank 1 sends a msg to Rank 0, with tag 10
   > Rank 0 waits in Recv

3) repeat N times (2×N messages), time each exchange and accumulate the timings.
You may use either the timer that you know or `MPI_Wtime()`

# Different P2P communication modes

| mode | routine | notes |
|---|---|---|
| standard | `MPI_Send` | Safe to modify data once returns. Equiv. to synchronous or asynchronous mode (uses sys buffers) depending on msg. size and implementation choices |
| synchronous | `MPI_Ssend` | Completes when the receive has started.<br>Unsafe communication patterns will deadlock ➨ a way to probe your code. |
| asynchrounous or "buffered" | `MPI_Bsend` | Completes after the buffer has been copied.<br>Needs an explicit buffer. |
| ready | `MPI_Rsend` | Mandatory that the matching receive has already been posted. May be the fastest solution, but it is quite problematic |
| *all* | `MPI_Recv` | One `Recv` serves 'em all |

# Ssend

```
int MPI_Ssend (const void *buf, int count, MPI_Datatype datatype,
               int dest, int tag, MPI_Comm comm)
```

`MPI_Ssend` has the same signature of `MPI_Send`.
The only difference is that `MPI_Ssend` always apply the synchronous (i.e. the rendez-vous) protocol, and hence it returns when the actual data sending starts.
That is the reason why it can be used to spot unsafa communication patterns.

# Bsend

```
int MPI_Bsend(const void *buf, int count, MPI_Datatype datatype,
              int dest, int tag, MPI_Comm comm)
```

MPI_Bsend has the same signature of MPI_Send.
The difference is that MPI_Bsend uses a buffer that must have been "attached" previously and is "detached" afterwards.

# Bsend

**`int MPI_Bsend(const void *buf, int count, MPI_Datatype datatype, int dest, int tag, MPI_Comm comm)`**

```c
buffer_size = sizeof(int)*data_size + (Ntasks-1)*MPI_BSEND_OVERHEAD;
mybuffer    = (int*)malloc(buffer_size);

// attach the bufer
//
MPI_Buffer_attach( (void*)&mybuffer, buffer_size );

for ( int j = 0; j < Ntasks; j++ )
  if ( j != Myrank )
    MPI_Bsend( data, data_size, MPI_INT, j, j, myCOMM_WORLD );

// at this point, since Bsend has returned, the data have
// been copied into the buffer mybuffer

MPI_Buffer_detach( mybuffer, &buffer_size );
```

1) allocate room for the buffer. Clearly its size must be  the max data size that will be sent. Note that **MPI_BSEND_OVERHEAD** bytes must be added per every call posted

2) notify to MPI that that area is the buffer to be used. That is said “to attach”

3) when all the Bsends issued that use that buffer have completed, the buffer can be “detached”

4) the detach will not return until the send has been completed

buffered_send.c

# Rsend

```
int MPI_Rsend(const void *buf, int count, MPI_Datatype datatype,
              int dest, int tag, MPI_Comm comm)
```

`MPI_Rsend` has the same signature of `MPI_Send`.
The difference is that `MPI_Rsend` requires that the matchinf `MPI_Recv` was already posted because it skips all the protocols and immediately starts the communication. It may be really performant but it must be used with ***extreme caution***.
A typical pattern:

```
Requester   Server
MPI_Irecv
MPI_Send     MPI_Recv
             MPI_Rsend
MPI_Wait
```

rsend.c

# Send & Receive

```
int MPI_Sendrecv( void *sendbuf, int sendcount, MPI_Datatype sendtype,
                  int dest, int sendtag,
                  void *recvbuf, int recvcount, MPI_Datatype recvtype,
                  int source, int recvtag,
                  MPI_Comm comm, MPI_Status &status);

int MPI_Sendrecv_replace (
                  void *buf, int count, MPI_Datatype type,
                  int dest, int sendtag,
                  MPI_Comm comm, MPI_Status &status);
```

Quite often there is a combined Send&Recv pattern between pairs of processes, for instance when performing domanin decomposition when an all-to-all exchange take place, or a "shift" on a chain of procs. MPI_Sendrecv offers this combined call that execute exactly that pattern.
With the the `_replace` variant, the same amount of data is sent form a buffer / received on the same buffer.

# Non-Blocking communications

Until now we have considered p2p communication functions that do not return until some conditions are met (either the copy of the data into a buffer or the actaul delivery of the data to the recipient, in case of the sender, or the actual arrival of the data into thei local destination in case of the receiver).

As such, the caller is *blocked* into the call and can not perform any other operation.
Those functions are consequently identified as **blocking functions.**

If what follows the Send/Recv depends on the fact that the operations mentioned above actually completed, then the usage of those functions reflects an actual dependency and there is little to be done.

However, if there are other instructions that could be executed while waiting that the data arrive at destination, by using blocking functions we are loosing parallelism.

# Non-Blocking communications

To obviate to this issue, MPI offers the **non-blocking functions**, i.e. a set of functions that return immediately.

However, their return does not mean that the communication has completed but only that it has been posted on an internal queue system that will execute it at some point in the future.

To assess, at any moment, whether the communication has been executed, MPI provides dedicated routines:

```
MPI_Test ( MPI_Request *, int *flag, MPI_Status *)
MPI_Wait ( MPI_Request *, MPI_Status *)
MPI_Waitall (int count, MPI_Request array_of_req[],
             MPI_Status array_of_st[] )
```

# Non-Blocking communications

## General non-blocking syntax

```
int MPI_Isend( void *buf, int count, MPI_Datatype dtype,
               int dest, int tag, MPI_Comm comm,
               MPI_Request *request );

int MPI_Irecv( void *buf, int count, MPI_Datatype datatype,
               int source, int tag, MPI_Comm comm,
               MPI_Request *request );
```

The request variable is used to handle the status of the `MPI_Isend` operation posted.
At any point after the call, the status can be determined by the immediately-returning call

## General non-blocking syntax

The `request` variable is used to handle the status of the `MPI_Isend` or `MPI_Irecv` operation posted.
At any point after the call, the status can be determined by the immediately-returning call

```
int MPI_Test( MPI_Request *request, int *flag, MPI_Status *status );
```

A call to MPI_Test returns flag = true if the operation identified by request is complete. In such a case, the status object is set to contain information on the completed operation; if the communication object was created by a nonblocking send or receive, then it is deallocated and the request handle is set to MPI_REQUEST_NULL. The call returns flag = false, otherwise. In this case, the value of the status object is undefined. MPI_Test is a local operation.

which sets the `flag` variable to 0 ("not completed") or 1 ("completed")
In case the `status` variable is not needed, `MPI_STATUS_IGNORE` is a viable option (look in the man page how to inspect the `status` varialbe).

# Non-Blocking communications

## General non-blocking syntax

The `request` variable is used to handle the status of the `MPI_Isend` or `MPI_Recv` operation posted.
As well, the completion of a Isen call can be determined by the blocking call

```
int MPI_Wait( MPI_Request *request, MPI_Status *status );
```

A call to MPI_Wait returns when the operation identified by request is complete. If the communication object associated with this request was created by a nonblocking send or receive call, then the object is deallocated by the call to MPI_Wait and the request handle is set to MPI_REQUEST_NULL.

In case the `status` variable is not needed, `MPI_STATUS_IGNORE` is a viable option (look in the man page how to inspect the `status` varialbe).

# Non-Blocking communications

To assess, at any moment, whether the communication has been executed, MPI provides dedicated routines:

for one communication:

```
MPI_Test ( MPI_Request *, int *flag, MPI_Status *)
MPI_Wait ( MPI_Request *, MPI_Status *)
```

for many communications:

```
MPI_Testall (int count,
             MPI_Request array_of_req[],
             int flags[],
             MPI_Status array_of_st[] )
```

- `count`: how many communications we are testing
- `array_of_req[]`: the `count`-long array of requests
- `flags[]`: the `count`-long array of flags to be returned
- `array_of_st[]`: the `count`-long array of status (may be IGNORE)

```
MPI_Waitall (int count, MPI_Request array_of_req[], MPI_Status array_of_st[] )
```

# Non-Blocking communications

for many communications:

```
MPI_Testall / MPI_Waitall
MPI_Testany / MPI_Waitany
MPI_Testsome / MPI_Waitsome
```

```
MPI_Testany (int count, MPI_Request array_of_requests[],
             int *index, int *flag, MPI_Status *status)
```

**flag** will be true if any of the communications succeeded; **index** will contain its index.

```
MPI_Testsome (int incount, MPI_Request array_of_requests[],
              int *outcount, int array_of_idx[], MPI_Status array_of_st[])
```

**outcount** contains how many cmmunications succeeded; **array_of_idx** contains the indices of the operations that completed

# Non-Blocking communications

for many communications:

```
MPI_Testall / MPI_Waitall
MPI_Testany / MPI_Waitany
MPI_Testsome / MPI_Waitsome
```

```
MPI_Waitany (int count, MPI_Request array_of_requests[],
            int *index, MPI_Status *status)
```

Returns as soon as a communication in the pool completes; `index` will contain its index.

```
MPI_Waitsome (int incount, MPI_Request array_of_requests[],
              int *outcount, int array_of_idx[], MPI_Status array_of_st[])
```

`outcount` contains how many comunications succeeded; `array_of_idx` contains the indices of the operations that completed in the first `outcount` entries

# Different P2P communication modes

| mode | Blocking routine | Non-blocking routine |
|---|---|---|
| standard | `MPI_Send` | `MPI_Isend` |
| synchronous | `MPI_Ssend` | `MPI_Issend` |
| asynchrounous or “buffered” | `MPI_Bsend` | `MPI_Ibsend` |
| ready | `MPI_Rsend` | `MPI_Irsend` |
| *all* | `MPI_Recv` | `MPI_Irecv` |

All the sending routines have a correspondent non-blocking version

# Non-Blocking communications

## Example of non-blocking communications usage: overlapping comm. & computation

```
MPI_Recv ( data_bunch, from prev_proc );
int flag_send = 1;

while ( data_bunch != no_data )
  {
      int         flag_recv;
      MPI_Request req_recv, req_send;

      MPI_Irecv ( next_data_bunch, &req_recv);
      process ( data_bunch );

      do {
           if ( flag_send )
               MPI_Isend ( data_bunch, to_next_proc, &req_send );
            else
               MPI_Test( &req_send, &flag, MPI_STATUS_IGNORE )
         } while ( flag == 0 )

      MPI_Test( req_recv, &flag, MPI_STATUS_IGNORE);
      while ( flag != true ) {
          do_something_else();
          MPI_Test( req_recv, flag); }
  }
```

Non-blocking communications avoid to get stuck in non-returning communication when the involved processes are not synchronized.

If there are other independent tasks that the processes can perform, the non-blocking can bu used instead. Quite often it is possilbe to re-design the workflow so that the communications are “pre-emptively” issued while some calculations is performed on a previous data bunch.

# that’s all, have fun