GWDG – Kurs
Parallel Programming with MPI

Point-to-Point Communication

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Learning Objectives

- MPI Functions for Message Passing:

  `MPI_SEND, MPI_RECV, MPI_ISEND, MPI_IRECV, MPI_PROBE, MPI_WAIT, MPI_TEST`

- The Difference between Blocking and Non_Blocking Message Passing
- Avoiding Deadlocks in Message Passing

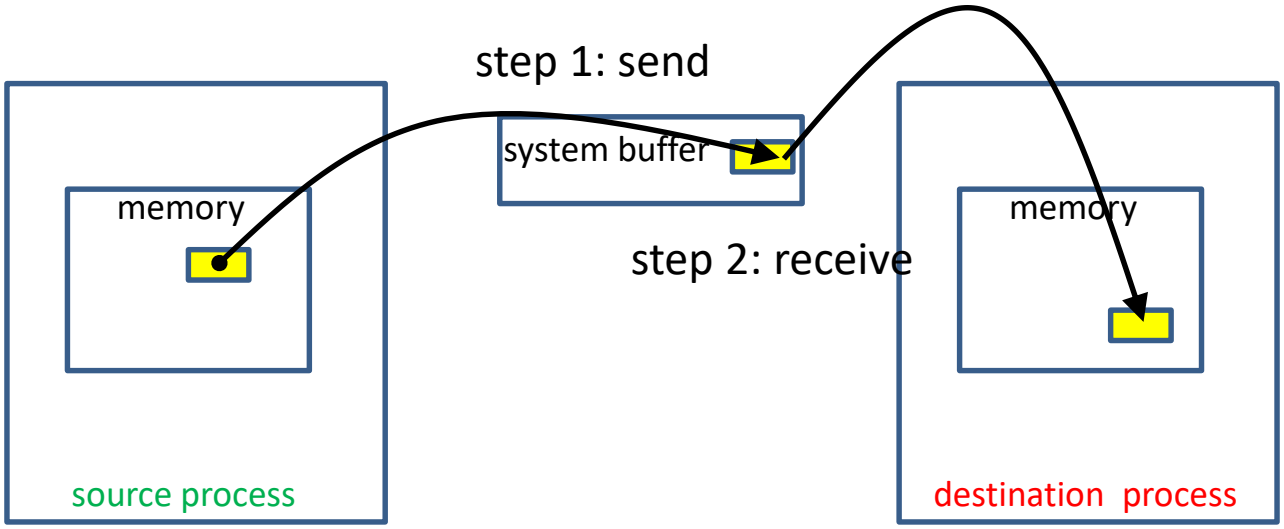
Outline

- Message Passing in MPI
- Content of Messages: Data and Envelope
- Basic Functions for Blocking Message Passing:
  `MPI_SEND, MPI_RECV`
- Distinguish Messages to be Received:
  `MPI_ANY_..., MPI_STATUS, MPI_PROBE`
- Semantic of Blocking Message Passing
  Buffered vs. Synchronous Send
- Non-Blocking Message Passing:
  Why and How, Request Objects
- Basic Functions for Non-Blocking Message Passing:
  `MPI_ISEND, MPI_IRECV, MPI_WAIT, MPI_TEST`
- Semantic of Non-Blocking Message Passing

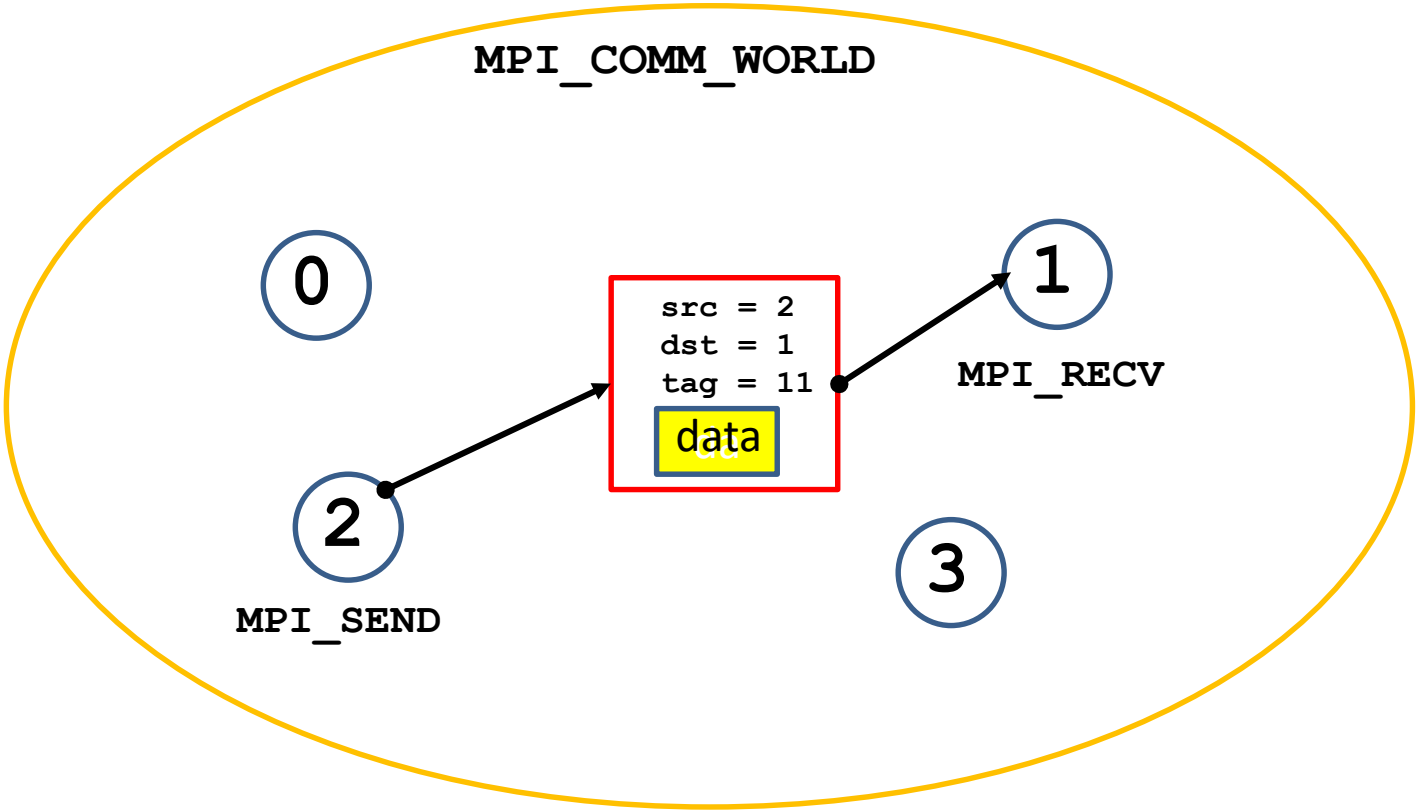
Message Passing

Basic mechanism of the message passing programming model:
Transfer a message between two processes in **two steps**:

1. On the source process: Sending the message from memory to the destination process
2. On the destination process: Receiving the message from the source process to memory



MPI Setup for Message Passing



MPI specification: Message Content

A MPI message contains:

a number of elements of the **same** datatype.

MPI datatypes:

- basic datatype
  basic C types are different from basic Fortran types
- derived datatypes
  derived datatypes can be built up from basic or recursively from derived datatypes.
- datatype handles are used to describe the data layout of a datatype in memory.

Basic MPI-Datatypes: Fortran

MPI datatype	Fortran datatype
MPI_INTEGER	INTEGER
MPI_REAL	REAL
MPI_DOUBLE_PRECISION	DOUBLE PRECISION
MPI_LOGICAL	LOGICAL
MPI_CHARACTER	CHARACTER
MPI_COMPLEX	COMPLEX

Basic MPI Datatypes: C

MPI datatype	C datatype
MPI_INT	signed int
MPI_LONG	signed long int
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double
MPI_CHAR	char
MPI_UNSIGNED	unsigned int
MPI_UNSIGNED_LONG	unsigned long int
MPI_UNSIGNED_SHORT	unsigned short int
MPI_UNSIGNED_CHAR	unsigned char

Basic MPI-datatypes: mpi4py

MPI datatype	correspond to C datatype
MPI.INT	signed int
MPI.LONG	signed long int
MPI.FLOAT	float
MPI.DOUBLE	double
MPI.LONG_DOUBLE	long double
MPI.CHAR	char

MPI specification: Message Envelope

Each MPI message content is accompanied by a message envelope, which contains additional information necessary or useful for the data transfer:

- the communicator, to which source and destination processes belong,
- the ranks of message-source and message-destination processes in this communicator,
- an identifier (tag), which can be used to differentiate between messages.

> The message tag must be specified by the user as an integer in the range [0, UB], where the value of the implementation dependent upper bound UB is equal to the MPI constant MPI_TAG_UB. The MPI standard requires UB to be at least 32767.

Blocking Send Operation: MPI_SEND

C:

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

Fortran:

```
MPI_SEND(buf, count, datatype, dest, tag,
         comm, ierr)
<type> buf(*)
INTEGER count, datatype, dest, tag, comm, ierr
```

Blocking Send Operation: MPI_SEND

mpi4py:

`comm.send(obj, dest, tag = 0 )`

`obj` : Python object; **`dest:`** integer , **`tag`**: integer, optional (default: 0)

The Python object contains all information about number and types of data-elements

`comm.Send(ar, dest, tag = 0 )`

`ar` : NumPy array; **`dest:`** integer , **`tag`**: integer, optional (default: 0)

The NumPy array contains information about number and types of its elements.

A section of the array can be selected by specifying:

`ar[startindex:stopindex]`

Blocking Receive Operation: MPI_RECV

C:

```
int MPI_Recv(void *buf, int count,
             MPI_Datatype datatype,
             int src, int tag, MPI_Comm comm,
             MPI_Status *status)
```

Fortran:

```
MPI_RECV(buf, count, datatype, src, tag,
         comm, status, ierr)
<type> buf(*)
INTEGER count, datatype, src, tag, comm, ierr
INTEGER status(MPI_STATUS_SIZE)
```

Blocking Receive Operation: MPI_RECV

mpi4py:

```
obj = comm.recv(buf=None, source= MPI.ANY_SOURCE,
                          tag= MPI.ANY_TAG, status=None)
```

obj : python object, **source**, **tag**: integer

status:**MPI.status() or None**

```
comm.Recv(ar, source= MPI.ANY_SOURCE,
          tag= MPI.ANY_TAG, status=None)
```

ar : numpy array; **dest**, **tag**: integer

status:**MPI.status() or None**

MPI_RECV Restriction

The size of data to be recieved must be equal or greater than the size of the pending message:

`recvcount*size(recvtype)` must be equal or greater than **`sendcount*size(sendtype)`**

otherwise the program stops with an error

„Wild Cards“ for **MPI_RECV**

MPI_RECV copies a pending message into the memory of the calling process, starting at address ***buf*** **--**

if the source and tag attributes of the message envelope conform with the source and tag arguments in the call to MPI_RECV.

With “wild card” arguments for source and/or for tag a pending message will be received regardless of its attributed source and/or tag values.

C, Fortran : **MPI_ANY_SOURCE, MPI_ANY_TAG**

mpi4py **MPI.ANY_SOURCE, MPI.ANY_TAG**

The **`status`** argument in **`MPI_RECV`**

The actual source and tag of the received message, and its actual size can be retrieved from the data-structure **`status`** returned as an argument in the call to MPI_RECV.

If the information from status is not needed, the argument can be ignored, saving memory space for this data structure and the processing cost to produce its content.

C, Fortran: use **`MPI_STATUS_IGNORE`** as **`status`** argument

mpi4py: use **`status = None`** or omit the **`status`** argument

Retrieving Message Properties from the Status Argument `stat`

	C	Fortran	mpi4py
type of **`stat`**	`MPI_Status stat`	`integer stat(MPI_STATUS_SIZE)`	`stat = MPI.Status()`
source	`stat.MPI_SOURCE`	`stat(MPI_SOURCE)`	`stat.Get_source()`
tag	`stat.MPI_TAG`	`stat(MPI_TAG)`	`stat.Get_tag()`
error	`stat.MPI_ERROR`	`stat(MPI_ERROR)`	`stat.Get_error()`
count	`MPI_Get_count (&stat,datatype,&count)`	`call MPI_GET_COUNT (stat,datatype,count,ierr)`	`stat.Get_elements (datatype)`
size	`---`	`---`	`stat.Get_size()`

Probing a Message before Receiving

The properties of a pending message can be retrieved with the MPI_PROBE routine before actually copying the message to memory with MPI_RECV.

C:

```
MPI_Probe(source, tag, comm, &status);
```

Fortran:

```
call MPI_PROBE(source, tag, comm, status, ierr)
```

mpi4py:

```
res = comm.Probe(source=ANY_SOURCE, tag=ANY_TAG,
                 status=None)
```

res : Literal **(True)**

source and **tag** can be wild cards!

Probing the information in status can be used to

- adjust the count of elements to be received to the size of the message
- select messages from particular sources / with particular tags .

Semantics of Blocking Point-to-Point Communication

A call to MPI_SEND is **blocking**:

- It completes, if the message data from the send buffer are copied to another location and therefore the send buffer can be safely reused.
  - It is **local** , if the message data are copied to a temporary buffer in the source or destination process: it can complete before a matching MPI_RECV has been called in the destination process.
  - It is **non-local**, if the message data are copied directly to the receive buffer of a matching MPI_RECV call: it can complete only after a matching MPI_RECV has been called in the destination process.
- The choice between buffered and direct sending the message with MPI_SEND is **implementation dependent**

A call to MPI_RECV is **blocking**:

- It completes, if the data from a matching message are completely copied into the receive buffer.
  - It is always **non-local** : it can complete only after a matching MPI_SEND has been called in the source process.

Explicit Modi for blocking Send

MPI provides three additional send routines with prescribed behavior:

Buffered Send: **MPI_BSEND(sbuf,...**

A user defined temporary buffer **`temp`** must be provided with a call to

MPI_BUFFER_ATTACH(temp,size)

Is **local**: it completes, when **`sbuf`** has been copied to **`temp`** in the sending process

Low latency / low bandwidth (additional data copying)

Synchronous Send: **MPI_SSEND(sbuf,...**

Is **non-local:** it returns, when **`sbuf`** has been copied to **`rbuf`** in the memory of the destination process

High latency (establishing communication channel) / high bandwidth

Ready Send: **MPI_RSEND(sbuf,...**

Is **non-local**: it fails unless a matching MPI_RECV has been called in the destination process.

Standard Send: **MPI_SEND(sbuf,...**

Buffered for short, synchronous for long messages

Best of two worlds / but danger of deadlock

Syntax for Buffered Send

Fortran:

```
call MPI_BUFFER_ATTACH(temp, bsize, ierr)
call MPI_BSEND( sendbuf, count, datatype, ...
call MPI_BUFFER_DETACH(temp, bsize, ierr)
```

bsize is the size in Bytes of the temporary buffer to be attached.

The temporary buffer space **temp** must be declared to contain at least **bsize** Bytes.

bsize >= # Bytes for the send buffer + MPI_BSEND_OVERHEAD

where MPI_BSEND_OVERHEAD, is a predefined upper bound of Bytes used for administration of buffered send.

Syntax for Buffered Send

C:

```
MPI_Buffer_attach(void* temp, int bsize);
MPI_Bsend( void* sendbuf, int count, ...);
MPI_Buffer_detach(void* temp_ptr, int* bsize);
```

bsize is the size in Bytes of the temporary buffer to be attached.

The temporary buffer space with address pointer **temp** must be declared to contain at least **bsize** Bytes,

temp_ptr is the pointer to the address in memory, where the value of the address pointer **temp** is stored.

bsize >= # Bytes for the send buffer + MPI_BSEND_OVERHEAD

where MPI_BSEND_OVERHEAD, is a predefined upper bound of Bytes used for administration of buffered send.

Syntax for Buffered Send

mpi4py:

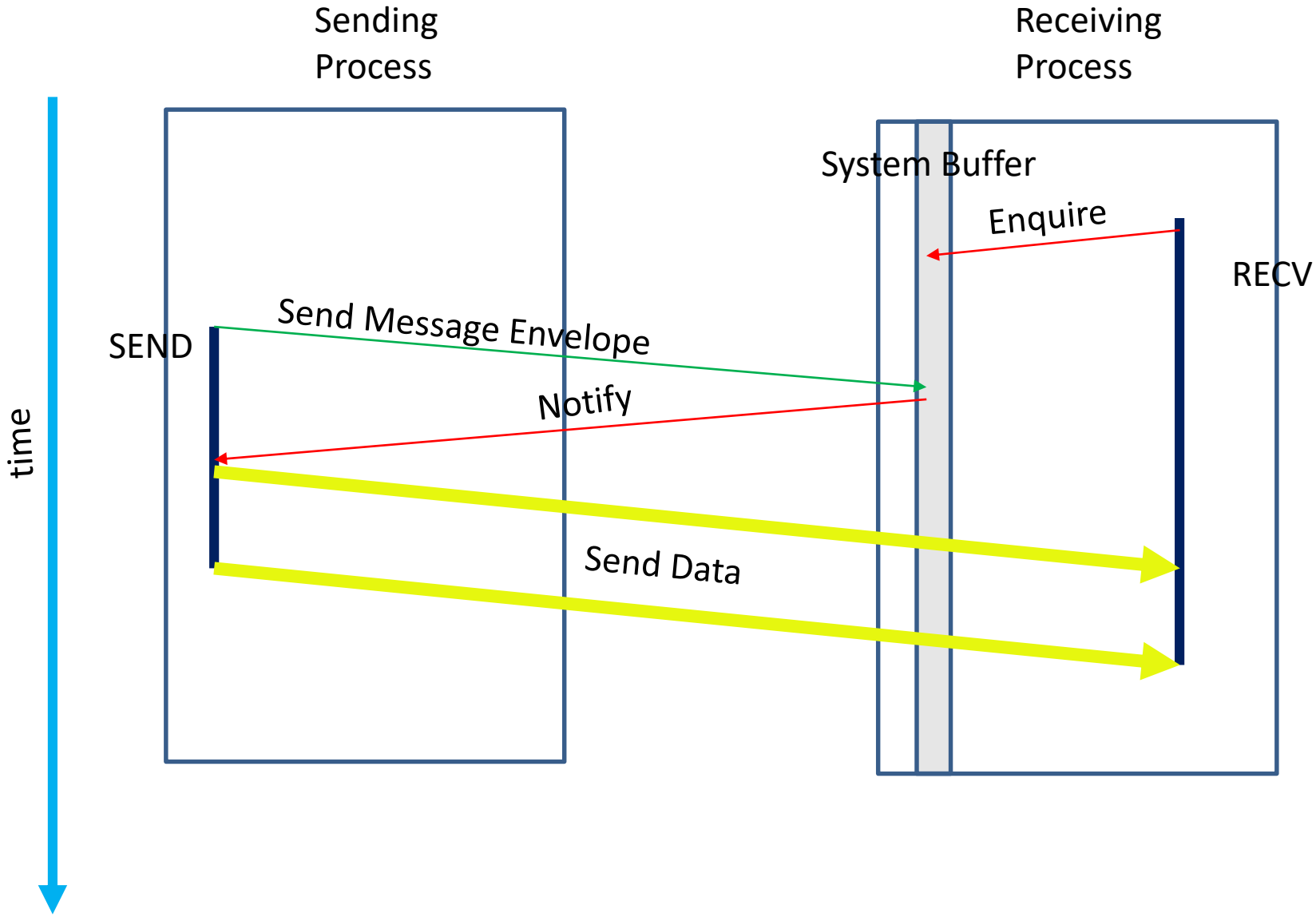
```
sendbuf = numpy.ones(nl,dtype = np.float64)
ntemp = nl + MPI.BSEND_OVERHEAD/8
temp = np.empty(ntemp,dtype = np.float64)

MPI.Attach_buffer(temp)
comm.Bsend(sendbuf,dest,tag=0)
MPI.Detach_buffer()
```

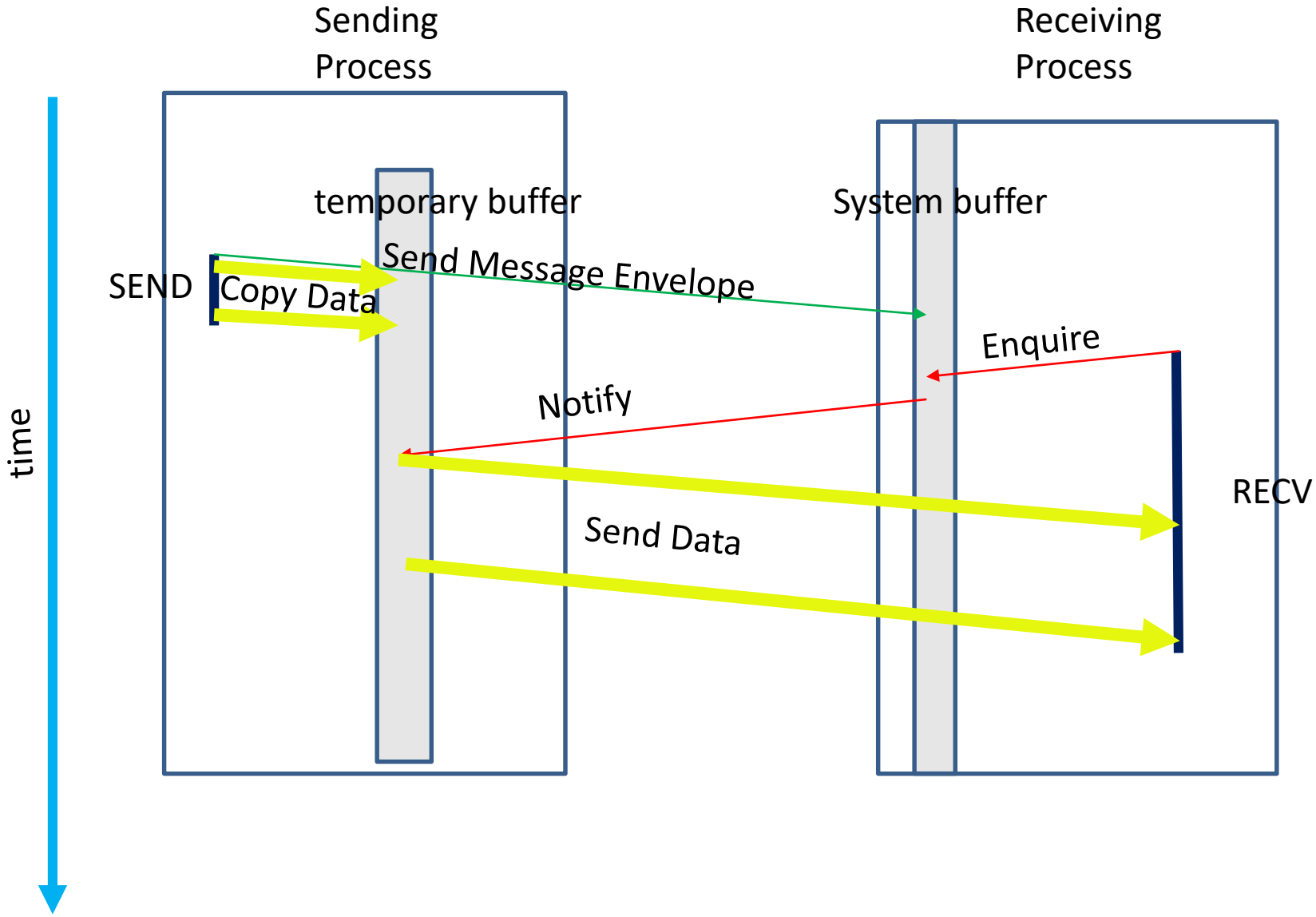
#Bytes of temp = # Bytes for the send buffer + **MPI.BSEND_OVERHEAD**

where MPI.BSEND_OVERHEAD, is a predefined upper bound of Bytes used for administration of buffered send.

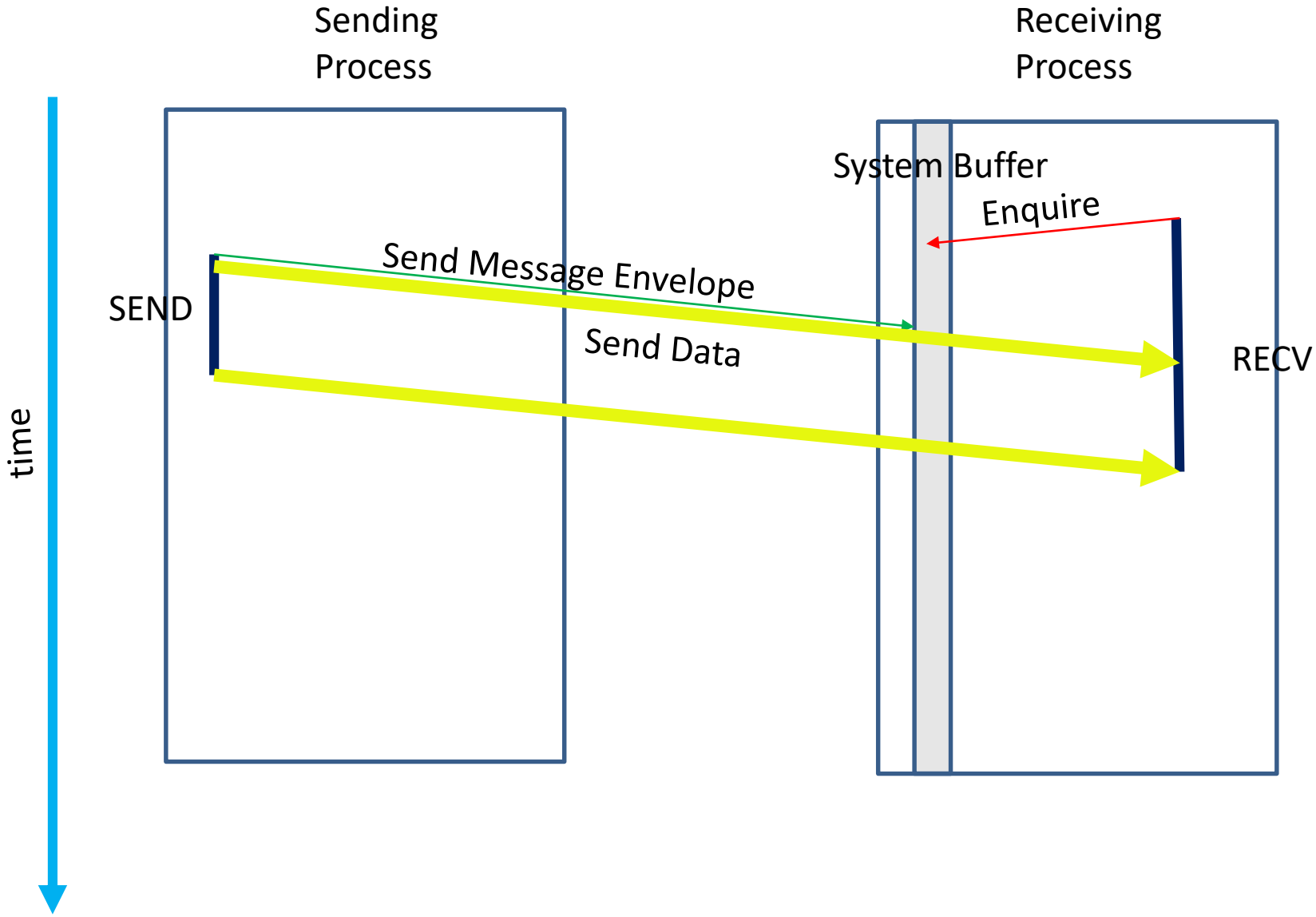
Synchronous Send



Buffered Send



Ready Send


Sending Process
Receiving Process
System Buffer
Enquire
Send Message Envelope
SEND
Send Data
RECV
time

Message Order Preservation

Rule for multiple messages on the same connection,

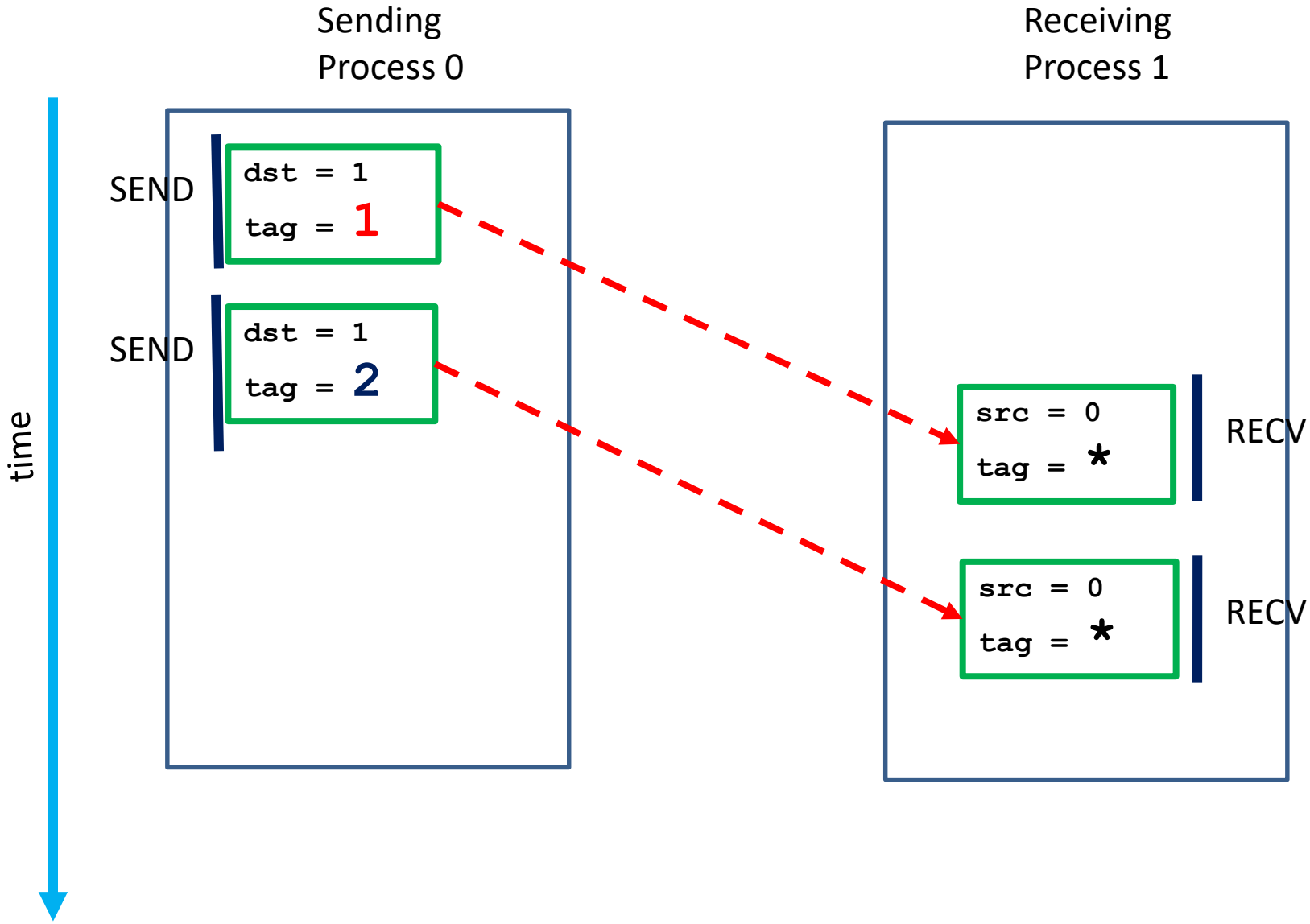
i.e. same communicator, source, and destination rank:

- If several receives match multiple messages, then the sending order is preserved.

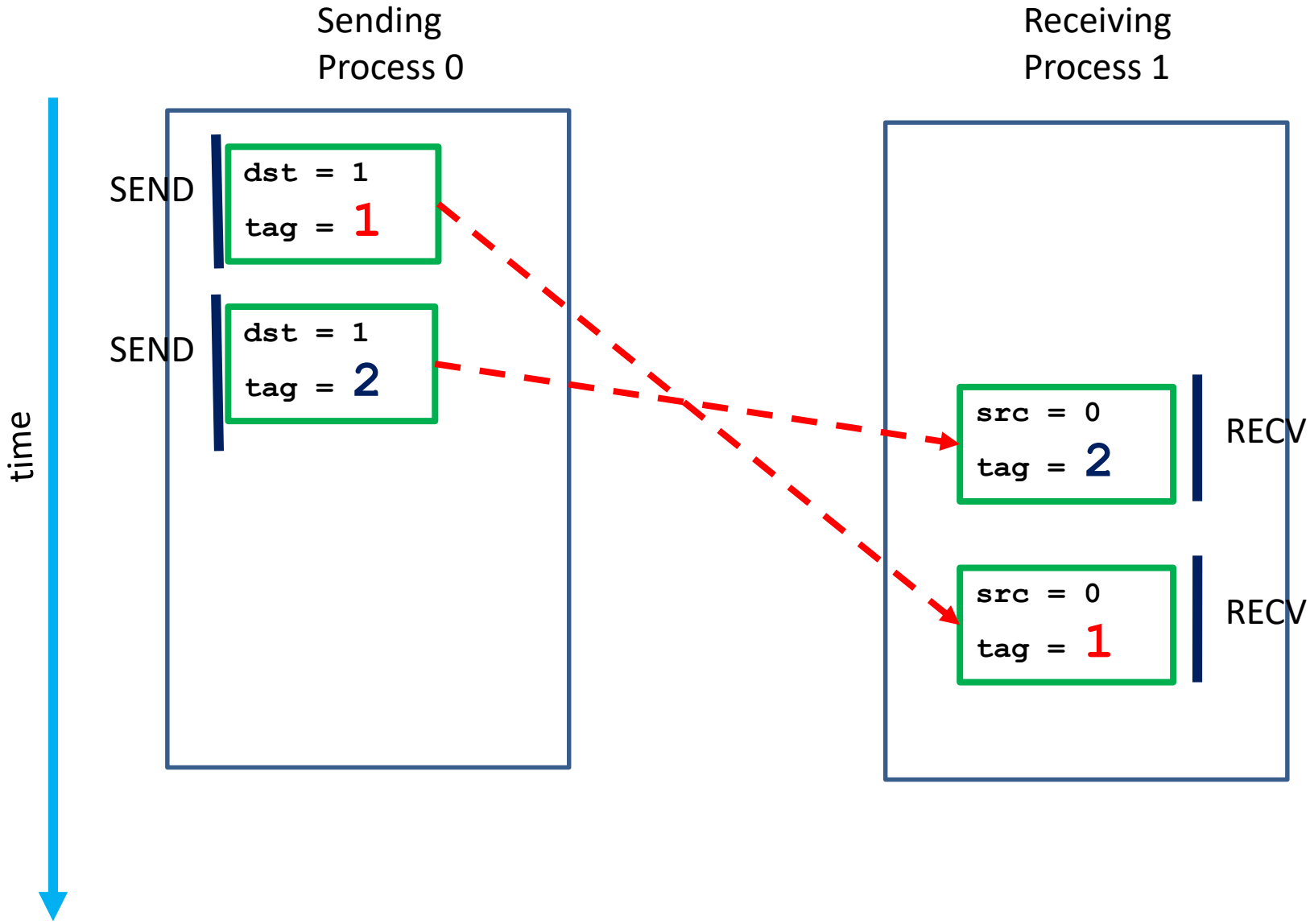
Messages do not overtake each other.

- This is true even for non-synchronous sends.

Receives Match Both Sends



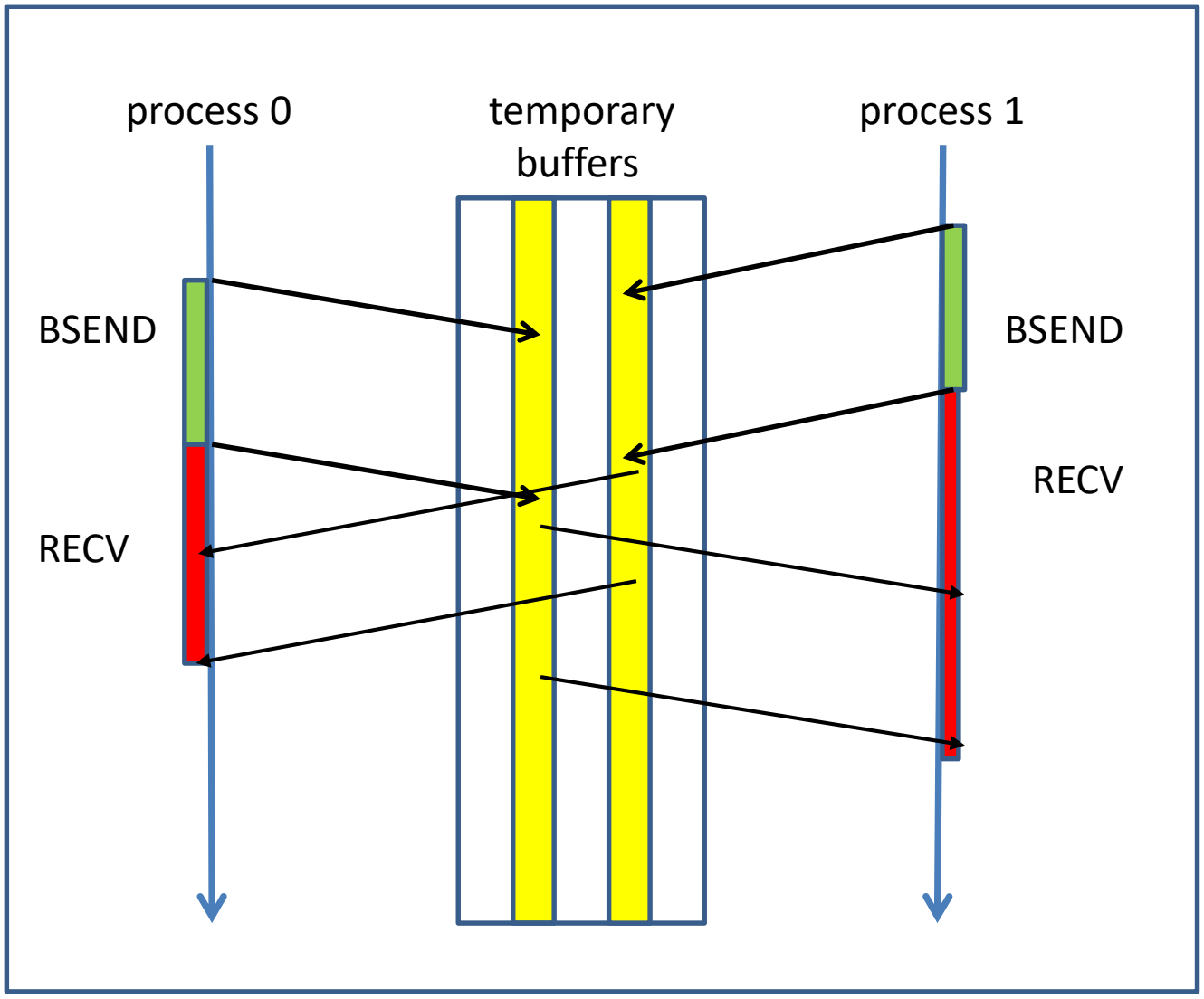
Each Receive Matches One Send



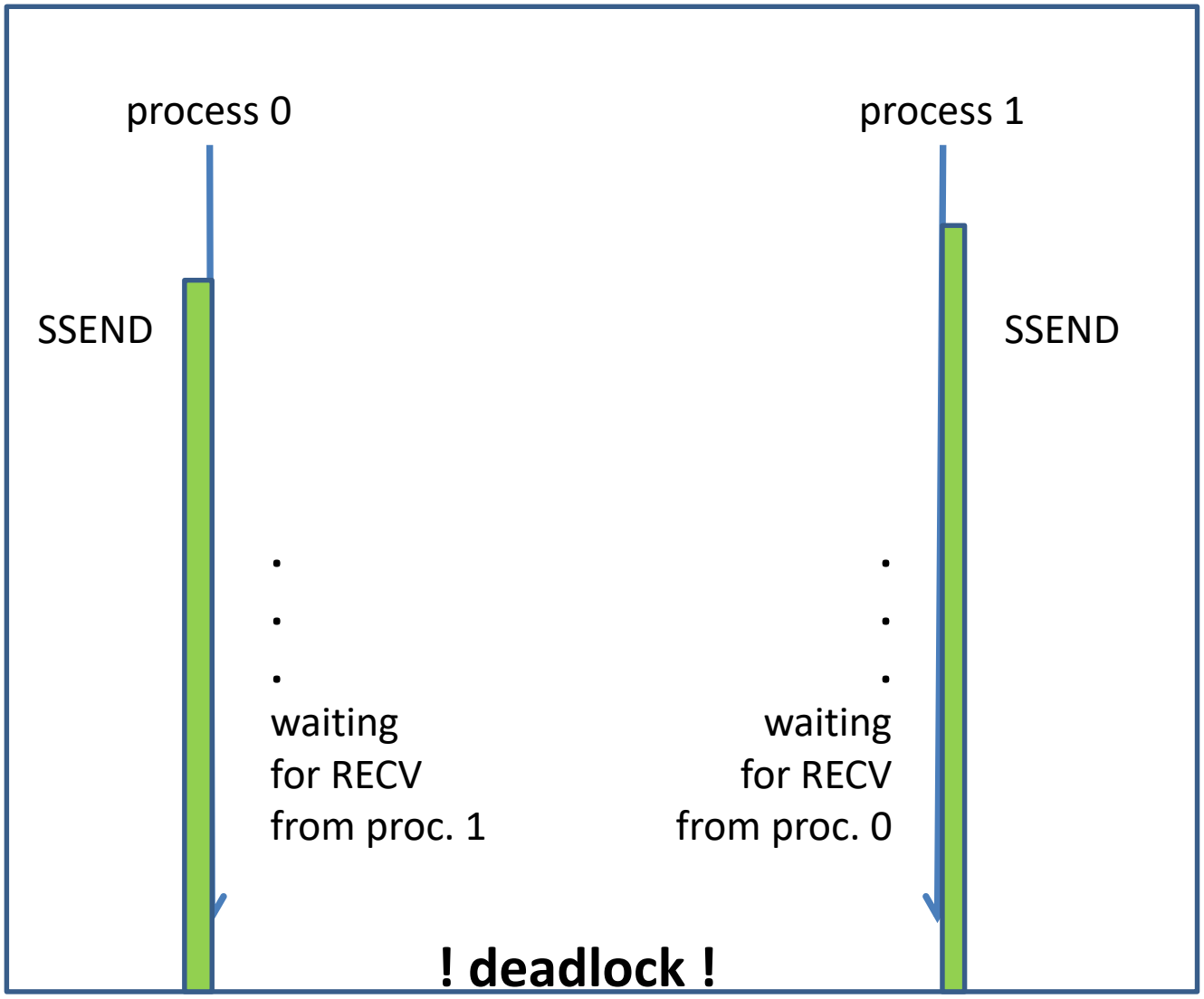
Message Exchange

```
CALL MPI_COMM_RANK(comm, rank, ierr)
IF (rank.EQ.0) THEN
    CALL MPI_SEND(sendbuf, count, MPI_REAL, 1, tag,
                  comm, ierr)
    CALL MPI_RECV(recvbuf, count, MPI_REAL, 1, tag,
                  comm, status, ierr)
ELSE IF (rank.EQ.1) THEN
    CALL MPI_SEND(sendbuf, count, MPI_REAL, 0, tag,
                  comm, ierr)
    CALL MPI_RECV(recvbuf, count, MPI_REAL, 0, tag,
                  comm, status, ierr)
END IF
```

Message Exchange with Buffered SEND



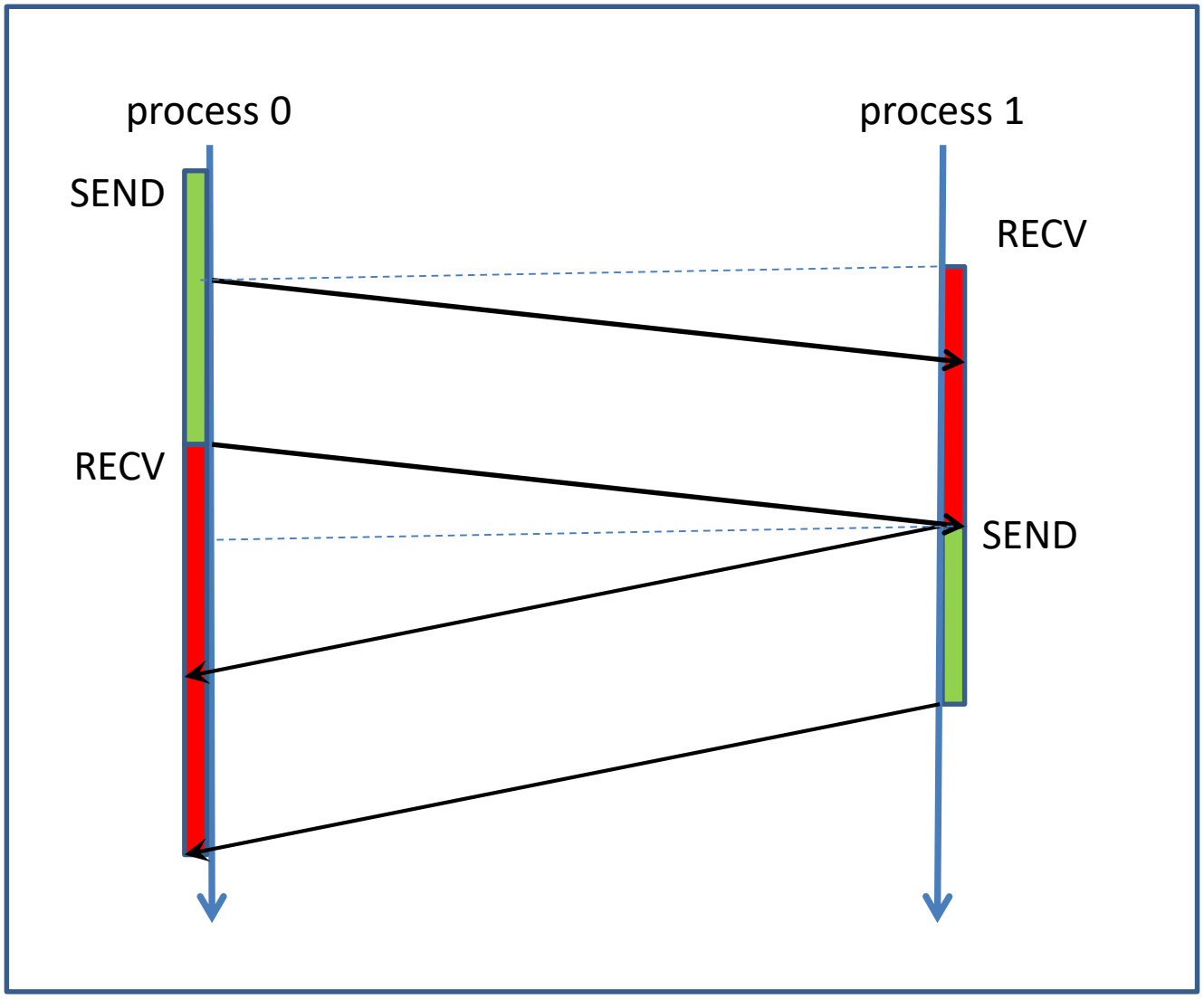
Message Exchange with Synchronous SEND



No Deadlock with Reversed Order

```
CALL MPI_COMM_RANK(comm, rank, ierr)
IF (rank.EQ.0) THEN
    CALL MPI_SEND(sendbuf, count, MPI_REAL, 1, tag,
                  comm, ierr)
    CALL MPI_RECV(recvbuf, count, MPI_REAL, 1, tag,
                  comm, status, ierr)
ELSE IF (rank.EQ.1) THEN
    CALL MPI_RECV(recvbuf, count, MPI_REAL, 0, tag,
                  comm, status, ierr)
    CALL MPI_SEND(sendbuf, count, MPI_REAL, 0, tag,
                  comm, ierr)
END IF
```

Message Exchange without Deadlock



Message Exchange with MPI_SENDRECV

```
CALL MPI_COMM_RANK(comm, rank, ierr)
IF (rank.EQ.0) THEN
      ipn = 1
ELSE IF (rank.EQ.1) THEN
      ipn = 0
END IF
call MPI_SENDRECV( sendbuf, count, MPI_REAL, ipn, tag
                 , recvbuf, count, MPI_REAL, ipn, tag
                 , comm, status, ierr )
```

Non-Blocking Point-to-Point Communication

Blocking vs. Non-Blocking

Blocking

Calls to blocking point-to point send and receive routines return after completion of the intended data movement:

- The message passing is completed in the sending process, when the data from the send buffer are copied to a different place (either to a temporary buffer or to the receive buffer in the receiving process)
- The message passing is completed in the receiving process, when the data from the send buffer are stored in the receive buffer.

Non-Blocking

Calls to non-blocking routines return immidiately.
Completion of the communication must be monitored by MPI routines for testing or waiting for completion.

- User responsibility:
  data in send or receive buffer are not to be used until the completion ot the transaction has been assured

WHY Non-Blocking Communication

- **Overlap** communication and working with data not involved in the communication
- **Break** deadlocks and serialization
- **Avoid** temporary buffering of messages

HOW Non-Blocking Communication

Split communication into two operations

1. **Posting**: initiate non-blocking communication routine
   - returns **i**mmediately
   - routine name starting with MPI_**I** …

   compute and communicate data
   not involved in the posted routine

2. **Waiting**: monitor the progress of the posted communication
   - MPI_WAIT blocks until completion of the communication
   - MPI_TEST returns the status of the communication

The Request Object

A **request object** is used to identify a non-blocking communication

A **request handle** refering to the **request object** generated with the call to **`MPI_I`**… is returned in an argument in the calling sequence
The **request handle** argument in the MPI_WAIT and MPI_TEST routines identifies the specific communication process to be monitored

Nonblocking Communication

Nonblocking communication calls **cooperate** with blocking communication calls:

A message sent by MPI_ISEND can be received by MPI_RECV

A message sent by MPI_SEND can be received by MPI_IRECV

Syntax for Non-Blocking SEND

C:

```
int MPI_Isend(void *buf, int count, MPI_Datatype datatype,
          int dest, int tag, MPI_Comm comm, MPI_Request *req)
```

Fortran:

```
MPI_ISEND(buf, count, datatype, dest, tag, comm, req, ierr)
       <type> buf(*)
       INTEGER count, datatype, dest, tag, comm, req, ierr
```

mpi4 py:

```
req=comm.isend(buf,dest,tag=0)
       buf : any Python object
req=comm.Isend(buf,dest,tag=0)
       buf : buffer-like object, e.g. numpy-array
```

Syntax for Non-Blocking RECV

C:

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

Fortran:

```
MPI_IRECV(buf, count, datatype, source, tag, comm, req, ierr)
        <type> buf(*)
        INTEGER count, datatype, source, tag, comm, req, ierr
```

mpi4 py:

```
req=comm.irecv(buf=None, source=ANY_SOURCE, tag=ANY_TAG)
        buf : optional
req=comm.Irecv(buf, source=ANY_SOURCE, tag=ANY_TAG)
        buf : buffer-like object, e.g. numpy-array
```

No status argument for posting a nonblocking receive

Waiting for Completion

C:

```
int  MPI_Wait( MPI_Request *req
               , MPI_Status *status )
```

Fortran:

```
MPI_WAIT(req, status, ierr)
INTEGER req, status(MPI_STATUS_SIZE), ierror
```

mpi4py:

```
buf=MPI.Request.wait(req, status=None) or
buf=req.wait(status=None)
       buf: any Python object

MPI.Request.Wait(req, status=None) or
req.Wait(status=None)
```

- WAIT is blocking until the operation, which created **`req`**, has completed.
- If **`req`** was created by **`IRECV`**, **`status`** contains information about sender, tag and length of the message; if it was created by **`ISEND`**, **`status`** is undefined

Testing for Completion

C:

```
int MPI_Test( MPI_Request *req, int *flag
              , MPI_Status *status )
```

Fortran:

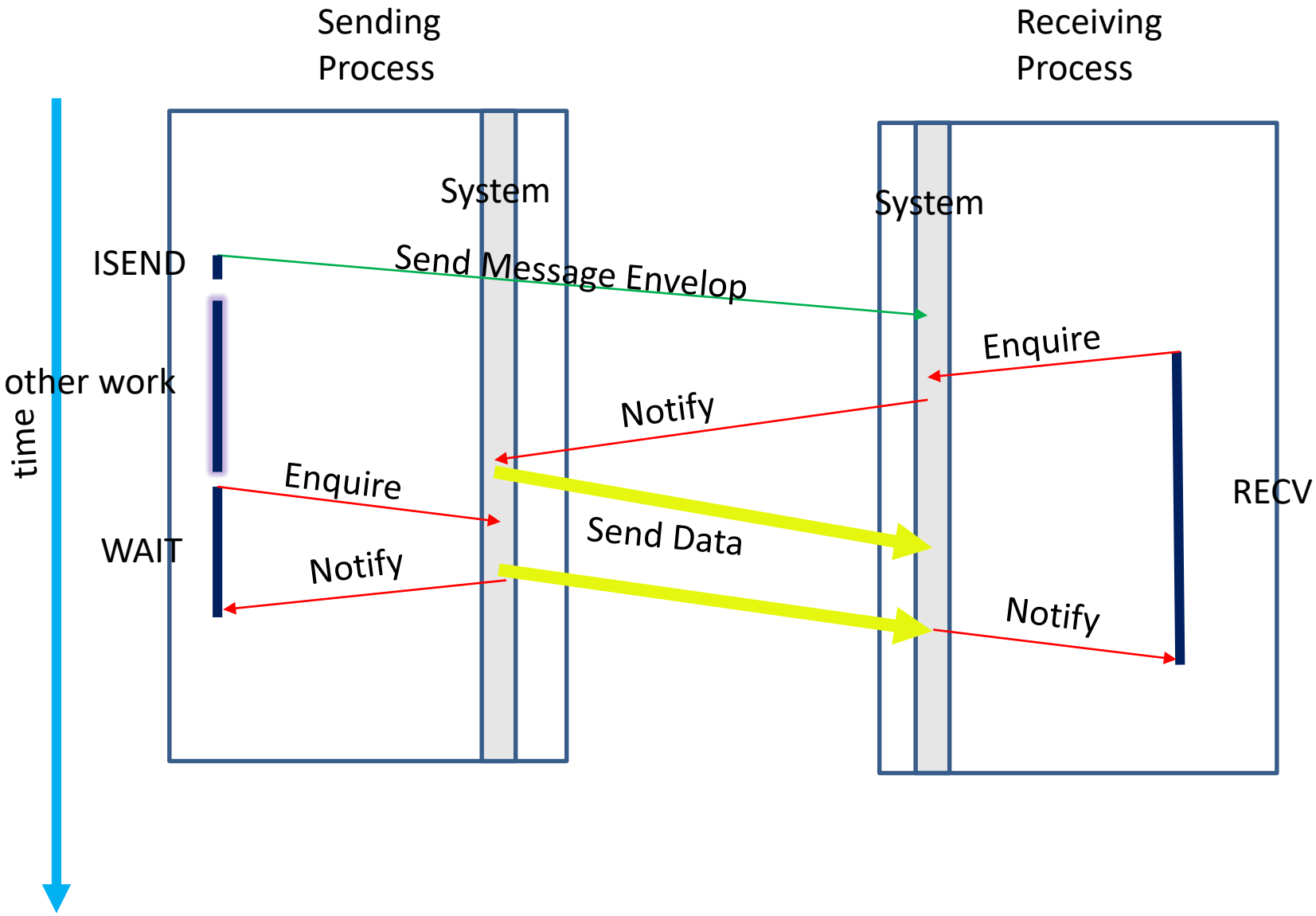
```
MPI_TEST(req, flag, status, ierr)
     INTEGER req, status(MPI_STATUS_SIZE), ierror
     LOGICAL flag
```

mpi4py:

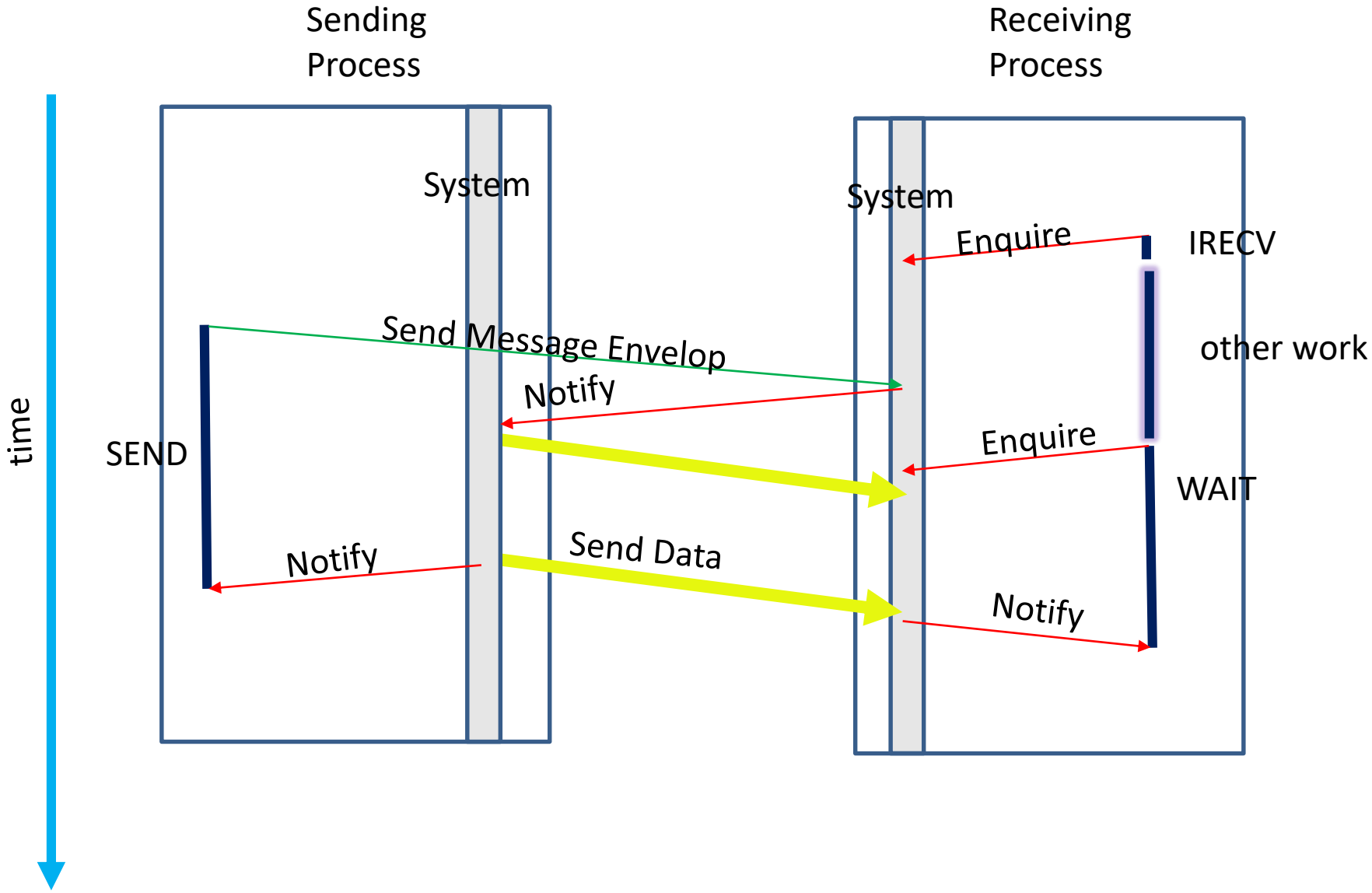
```
flag = MPI.Request.Test(req, status=None)
[flag,obj] = MPI.Request.test(req, status=None)
```

- TEST is non-blocking.
- returns **`flag=true (1 for C)`**, if the operation, which created **`request`**, has completed.
- returns **`flag=false (0 for C)`**, if the operation, which created **`request`**, has not yet completed.
- If the operation has completed, **`status`** is as in **`MPI_WAIT`**

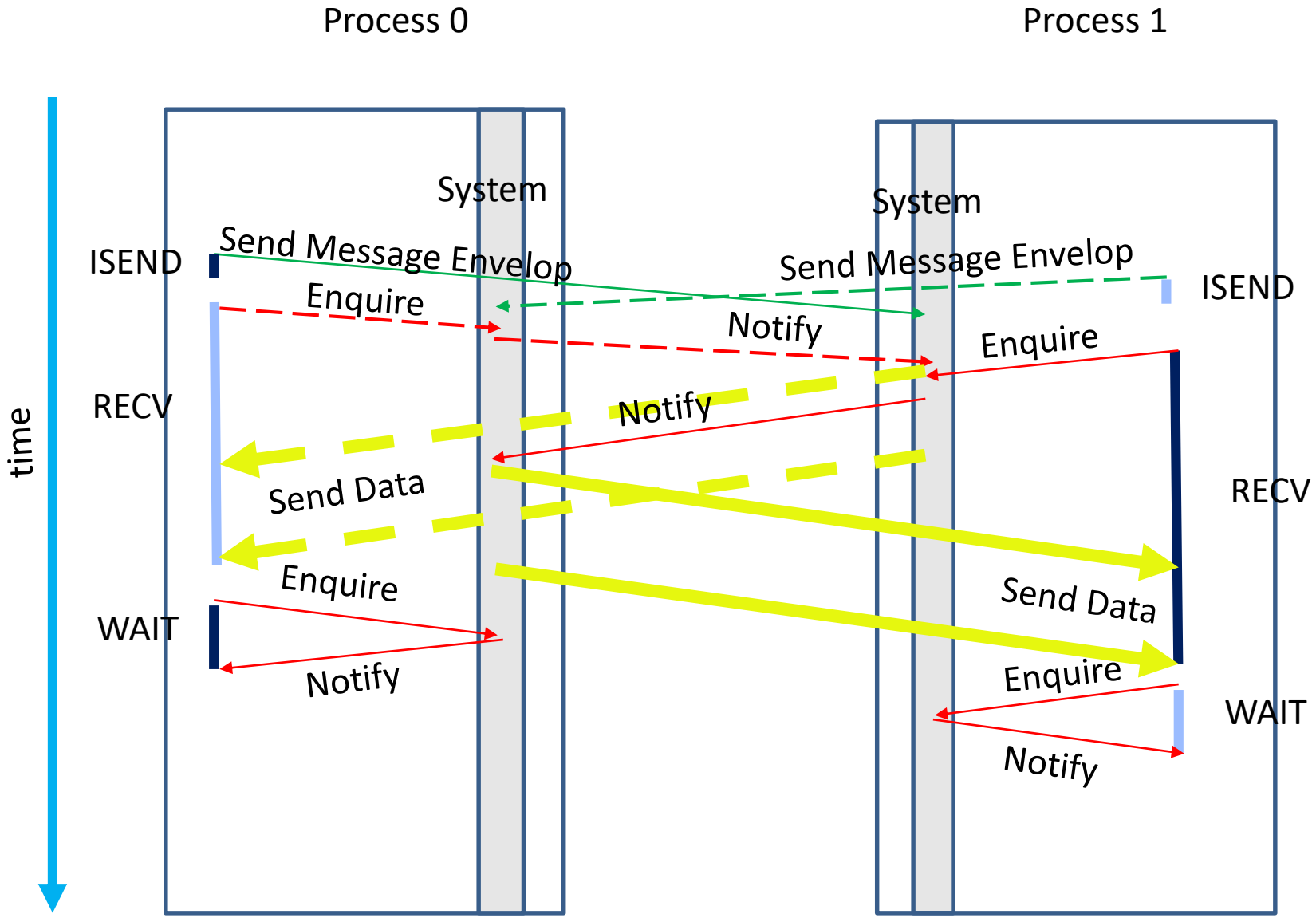
ISEND


Sending Process
Receiving Process
System
System
ISEND
Send Message Envelop
Enquire
other work
Notify
time
Enquire
RECV
WAIT
Send Data
Notify
Notify

IRECV


Sending Process
Receiving Process
System
System
Enquire
IRECV
Send Message Envelop
other work
Notify
SEND
Enquire
WAIT
Notify
Send Data
Notify
time

Message Exchange with ISEND



Summary for python Syntax

Communcation of **buffer-like object** (e.g. numpy-array) :

:

Blocking send `comm.Send(buf,dest,tag)`

Blocking receive `comm.Recv(buf,source,tag)`

Communicated object buf	**as parameter in Send**
	as parameter in Recv

Nonblocking send `req=comm.Isend(buf,dest,tag)`

Nonblocking receive `req=comm.Irecv(buf,source,tag)`

Wait for completion `MPI.Request.Wait(req,status)`

Test *for completion* `flag=MPI.Request.Test(req,status)`

Communicated object buf	**as parameter in Isend**
	as parameter in Irecv

Summary for python Syntax

Communcation of **general python object** :

Blocking send `comm.send(buf,dest,tag)`

Blocking receive `buf=comm.recv(source,tag)`

Communicated object buf as parameter in	**send**
as return value in	**recv**

Nonblocking send `req=comm.isend(buf,dest,tag)`

Nonblocking receive `req=comm.irecv(source,tag)`

Wait for completion `buf=MPI.Request.wait(req,status)`

Test *for completion* `[flag,buf]=MPI.Request.test(req,status)`

Communicated object buf as parameter in	**isend**
as return value in	**wait or test**