

HPC.NRW

MPI in Small Bites

PPCES 2025

HPC.NRW Competence Network



EDIH
Rheinland



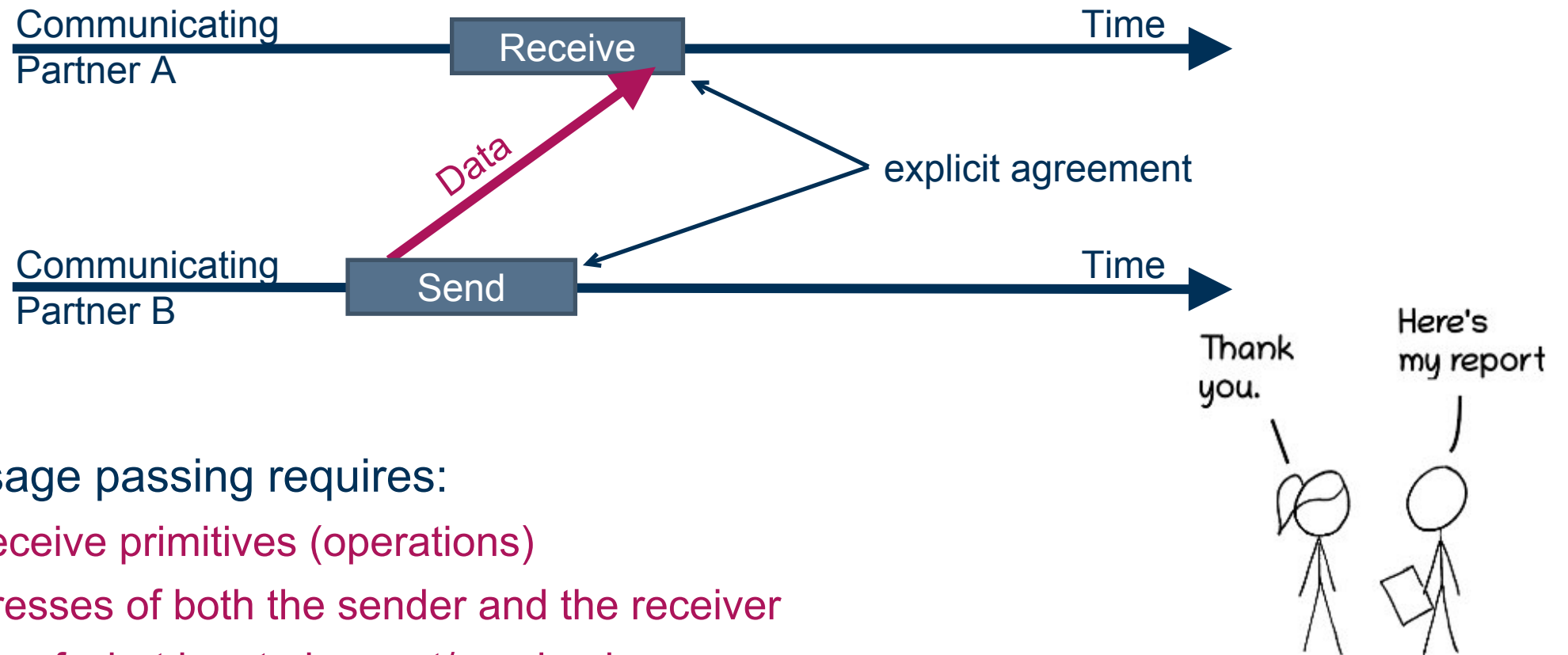
THE COMPETENCE NETWORK FOR HIGH PERFORMANCE COMPUTING IN
NRW

Blocking Point-to-Point Communication

HPC.NRW Competence Network

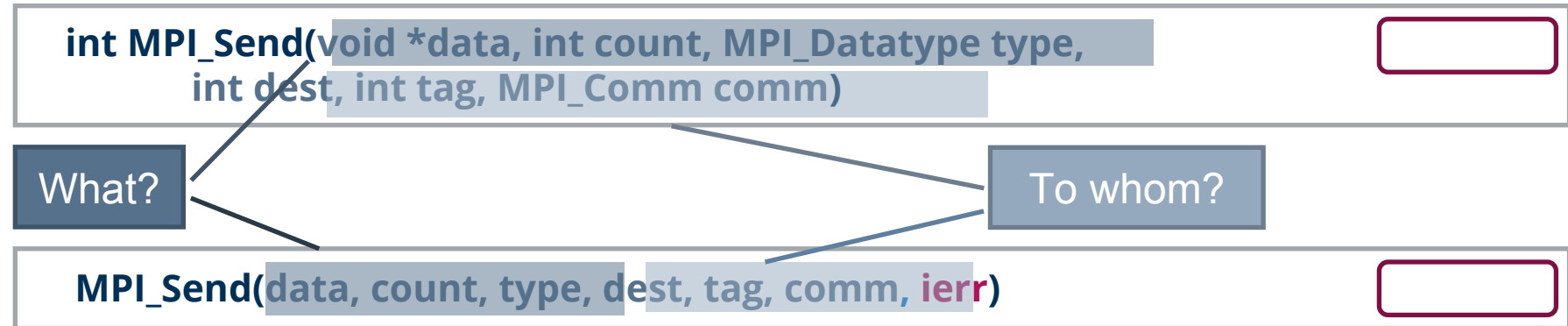
MPI in Small Bites

- The goal is to enable communication between processes that share no memory space



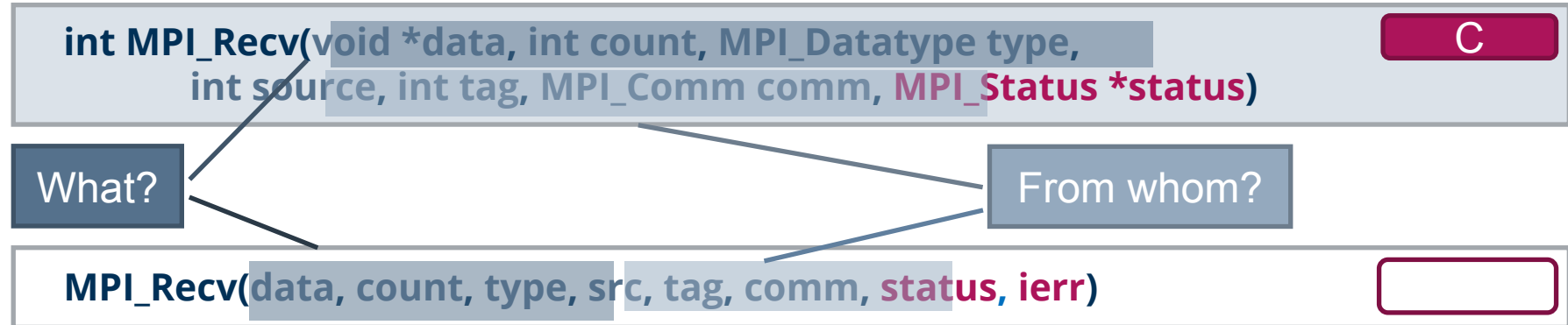
- Explicit message passing requires:
 - Send and receive primitives (operations)
 - Known addresses of both the sender and the receiver
 - Specification of what has to be sent/received

- Sending a message:



- **data:** location in memory of the data to be sent
- **count:** number of elements of type to be sent
- **type:** handle of the *MPI datatype* of the buffer content
- **dest:** rank of the receiver
- **tag:** additional identification of the message
ranges from 0 to MPI_TAG_UB (implementation dependant, but not less than 32767)
- **comm:** communication context (communicator handle)

- Receiving a message:



- **data:** location of the receive buffer
- **count:** size of the receive buffer in data elements
- **type:** Handle of the MPI datatype of the data elements
- **source:** rank of the sender or **MPI_ANY_SOURCE** (wildcard)
- **tag:** message tag or **MPI_ANY_TAG** (wildcard)
- **comm:** communication context
- **status:** status of the receive operation or **MPI_STATUS_IGNORE**

- 1. Provide dynamic identification of all peers
 - Who am I and who else is also working on this problem?
- 2. Provide robust mechanisms to exchange data
 - Whom to send data to / From whom to receive the data?
 - How much data?
 - What kind of data?
 - Has the data arrived?
- 3. Provide synchronisation mechanisms
 - Have all processes reached same point in the program execution flow?
- 4. Provide methods to launch and control a set of processes
 - How do we start multiple processes and get them to work together?
- 5. Portability

Only local completion information available.



- Message matching is performed using the **message envelope**
- Send operation

```
int MPI_Send (void *data, int count, MPI_Datatype type,  
int dest, int tag, MPI_Comm comm)
```

Message Envelope

	Sender	Receiver
Source	Implicit	Explicit, wildcard possible (MPI_ANY_SOURCE)
Destination	Explicit	Implicit
Tag	Explicit	Explicit, wildcard possible (MPI_ANY_TAG)
Communicator	Explicit	Explicit

- Receive operation

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

- Correct reception of MPI messages is also dependent on the data type.

- Recall:

```
MPI_Send (void *data, int count, MPI_Datatype type,  
          int dest, int tag, MPI_Comm comm)
```

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

- Type signatures must match
 - May not be verified by MPI library (source for unpredictable errors!)
- One send operation is matched with one receive operation
 - Messages **do not** aggregate (no single receive for multiple sends)
 - Messages **do not** separate (no multiple receives for a single send)

- The receive buffer must be able to fit the entire message
 - send count \leq receive count **OK** (check effective message length with status)
 - send count $>$ receive count **ERROR** (message truncation)
- Message size inquiry:
 - `MPI_Get_count (MPI_Status *status, MPI_Datatype datatype, int *count)`
 - Number of integral elements of type **datatype** in the message reference by **status**
 - If message size not divisible by size of given datatype size: **MPI_UNDEFINED**

- The MPI status object contains information about the message

C

```
MPI_Status status;  
...  
status.MPI_SOURCE // message source rank  
status.MPI_TAG    // message tag  
status.MPI_ERROR  // receive status code
```

Fortran

```
INTEGER, DIMENSION(MPI_STATUS_SIZE) :: status  
...  
status(MPI_SOURCE) ! message source rank  
status(MPI_TAG)    ! message tag  
status(MPI_ERROR) ! receive status code
```

Fortran 2008

```
TYPE(MPI_Status) :: status  
...  
status%MPI_SOURCE ! message source rank  
status%MPI_TAG    ! message tag  
status%MPI_ERROR  ! receive status code
```

Checking for Message Availability (no threads)

- Checking for message: `MPI_Probe(int source, int tag, MPI_Comm comm, MPI_Status *status)`
 - Do **NOT** use with multiple communicating threads (alternatives covered in a separate part)
 - Message is **not received**, separate call to **MPI_Recv** needed
 - Message envelope and size stored in **status** object

```
MPI_Probe(MPI_ANY_SOURCE, MPI_ANY_TAG, comm, &status);
```

- Checks for **any** message in the given communicator (wildcards)
- Receive **must** use specific values from **status** to receive the inquired message

```
MPI_Status status;
```

```
MPI_Probe(MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD,  
&status);
```

```
... allocate buffer of message size ...
```

```
MPI_Recv(buffer, message size, MPI_INT, MPI_ANY_SOURCE, 0,  
MPI_COMM_WORLD, &status);
```

Incorrect program

Checking for Message Availability (no threads)

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```
MPI_Status status;
```

```
MPI_Probe(MPI_ANY_SOURCE, 0, MPI_COMM_WORLD,  
&status);
```

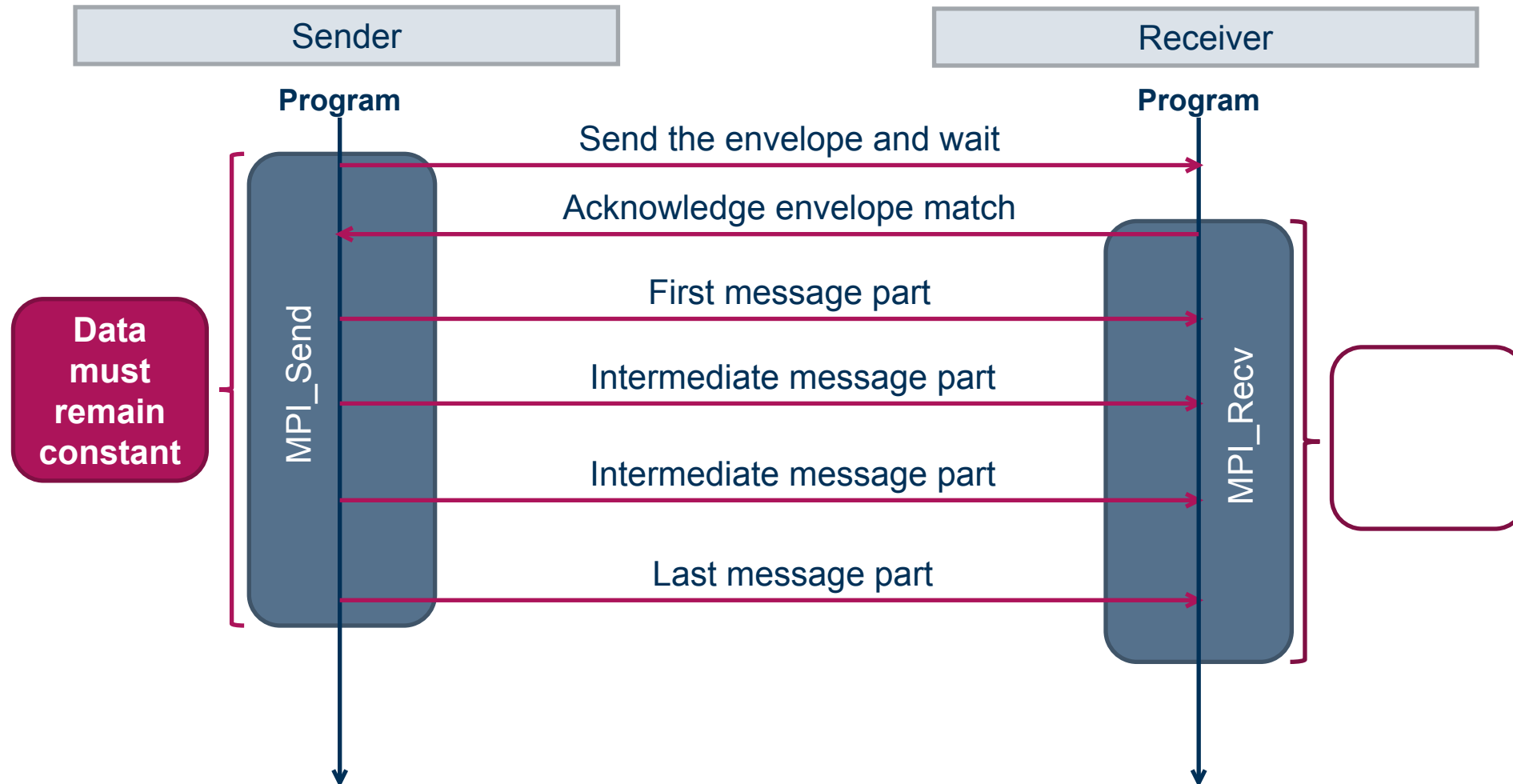
```
... allocate buffer based on message size ...
```

```
MPI_Recv(buffer, size, MPI_INT, status.MPI_SOURCE, 0,  
MPI_COMM_WORLD, &status);
```

Use envelope
data from status.

- MPI operations complete locally once the message buffer is no longer in use by the MPI library and is thus free for reuse
- Send operations complete:
 - once the message is constructed **and**
 - placed completely onto the network **or**
 - buffered completely (by MPI, the OS, the network, ...)
- Receive operations complete:
 - once the entire message has arrived and has been placed into the buffer
- Blocking MPI procedures only return once the corresponding operation has completed
 - **MPI_Send** and **MPI_Recv** are blocking

Blocking send (w/o buffering) and receive calls:



MPI Point-to-Point Send Modes

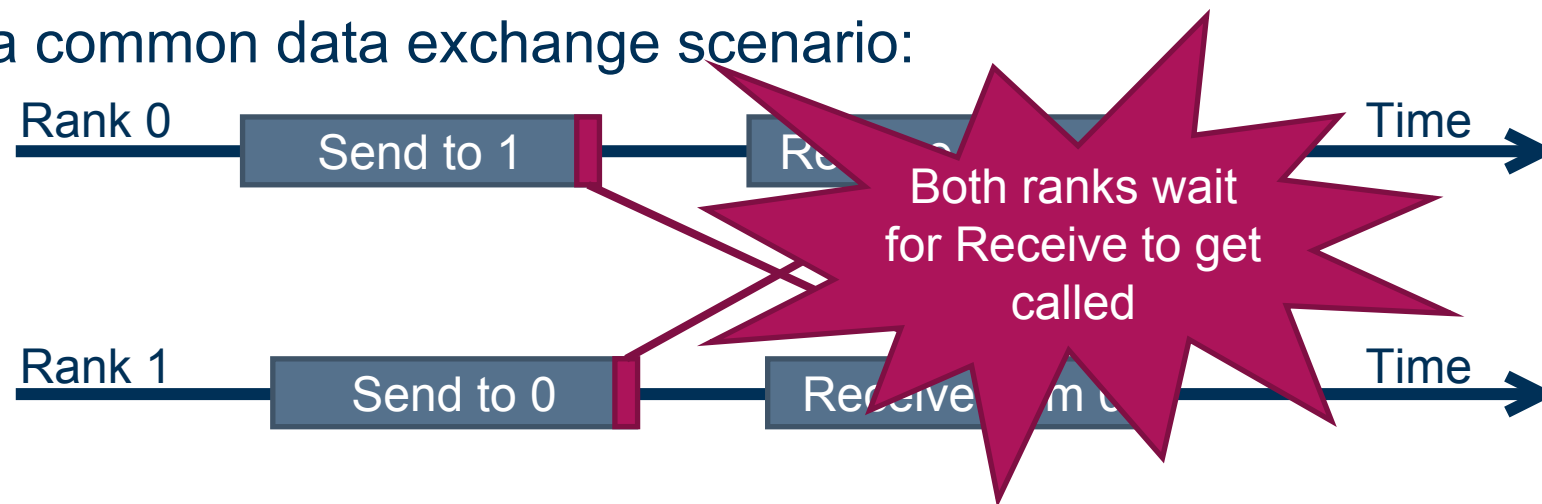
	Call	Semantics
Buffered / Asynchronous	MPI_Bsend	Uses extra (user-provided) buffer space to copy the message buffer and returns to the user. Message transfer may happen at a later point using the buffer.
Rendezvous / Synchronous	MPI_Ssend	Explicitly waits for the receiver to start the receive process
Standard	MPI_Send	May follow buffered (library-internal buffer) or synchronous semantics depending on implementation, input, and/or runtime situation
Ready	MPI_Rsend	Sender assumes the receive to be posted on remote process

MPI Point-to-Point Send Modes

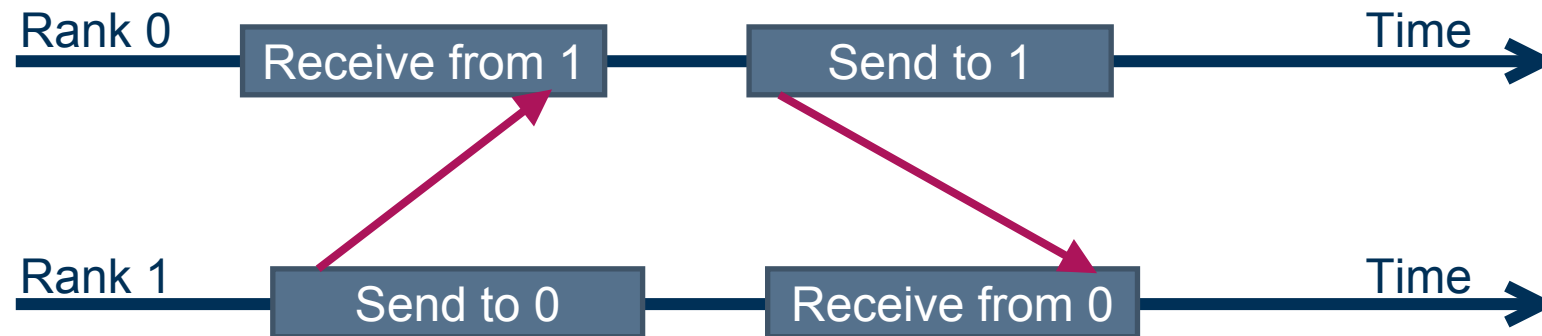
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Ready	MPI_Rsend	Sender assumes the receive to be posted on remote process

Try to avoid! Needed guarantees hard to ensure, and often no benefit observable.

- Both MPI_Send and MPI_Recv calls are blocking:
 - Standard send operation has two (implementation specific) modes of operation:
 - Buffering the message → Asynchronous completion
 - Waiting for the receiver to start receiving → Synchronous completion
 - **Never rely on any implementation-specific behaviour!**
- Deadlock in a common data exchange scenario:



- Both MPI_Send and MPI_Recv calls are blocking:
 - Standard send operation has two (implementation specific) modes of operation:
 - Buffering the message → Asynchronous completion
 - Waiting for the receiver to start receiving → Synchronous completion
 - **Never rely on any implementation-specific behaviour!**
- Deadlock prevention in a common data exchange scenario:



```
MPI_Sendrecv (void *senddata, int sendcount, MPI_Datatype sendtype,  
int dest, int sendtag, void *recvdata, int recvcount,  
MPI_Datatype recvtype, int source, int recvtag,  
MPI_Comm comm, MPI_Status *status)
```

- Sends one message and receives one message (in any order) without deadlocking (unless unmatched)
- Send and receive buffers **must not overlap!**

```
MPI_Sendrecv_replace (void *data, int count, MPI_Datatype datatype,  
int dest, int sendtag, int source, int recvtag,  
MPI_Comm comm, MPI_Status *status)
```

- Using the same memory location, elements count and datatype for both operations
- Often slower than MPI_Sendrecv

- Order is preserved for point-to-point operations
 - in a given communicator
 - between any pair of processes
- Probe/receive returns the earliest matching message
- Order is **not** guaranteed for
 - Messages sent within different communicators
 - Messages arriving from different senders
 - Messages sent from different threads even with identical envelopes (logically concurrent)

- Communication primitives for data exchange between two processes
- Blocking communication returns on **local** completion
 - An operation is locally complete when arguments to MPI can be re-used / deallocated
- Message order guaranteed between two processes on the same communicator
- Different send modes exist to tweak communication pattern
 - Use 'standard' send (MPI_Send) if unsure or unless another mode is explicitly needed
- Use other means than 'buffered' mode to avoid deadlock (avoid the extra copy)
 - Combined send-receive calls
 - Explicit communication patterns (may reduce maintainability and impact performance)
 - Non-blocking communication (covered in another part)