MPI

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Young Won Lim
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Please send corrections (or suggestions) to youngwlim@hotmail.com.

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The Butterfly Swap Operations

Communicators and Groups defines
collection of processes that may communicate with each other.

Need to specify a communicator as an argument.

MPI_COMM_WORLD - predefined communicator
that includes all of your MPI processes.

Within a communicator, every process has its own unique, integer identifier,
called rank or “task ID”.

Used to specify the source and destination.
Also can be used in conditional statements.

MPI_Alltoall

MPI_Alltoall - Sends data from all to all processes

```
int MPI_Alltoall( void *sendbuf, int sendcount, MPI_Datatype sendtype,
                  void *recvbuf, int recvcnt, MPI_Datatype recvtype, MPI_Comm comm )
```

INPUT PARAMETERS

- **sendbuf** - starting address of send buffer (choice)
- **sendcounts** - integer array equal to the group size specifying the number of elements to send to each processor
- **sendtype** - data type of send buffer elements (handle)
- **recvcounts** - integer array equal to the group size specifying the maximum number of elements that can be received from each processor
- **recvtype** - data type of receive buffer elements (handle)
- **comm** - communicator (handle)

OUTPUT PARAMETERS

- **recvbuf** - address of receive buffer (choice)

MPI_Alltoallv

MPI_Alltoallv - Sends data from all to all processes, with a displacement

int MPI_Alltoallv (void *sendbuf, int *sendcnts, int *sdispls, MPI_Datatype sendtype,
void *recvbuf, int *recvcnts, int *rdispls, MPI_Datatype recvtype, MPI_Comm comm)

INPUT PARAMETERS

sendbuf - starting address of send buffer (choice)
sendcounts - integer array equal to the group size specifying the number of elements to send to each processor
sdispls - integer array (of length group size). Entry j specifies the displacement (relative to sendbuf from which to take the outgoing data destined for process j
sendtype - data type of send buffer elements (handle)
recvcounts - integer array equal to the group size specifying the maximum number of elements that can be received from each processor
rdispls - integer array (of length group size). Entry i specifies the displacement (relative to recvbuf at which to place the incoming data from process
recvtype - data type of receive buffer elements (handle)
comm - communicator (handle)

OUTPUT PARAMETERS

recvbuf - address of receive buffer (choice)

MPI_Alltoallv

Alltoallv
flexibility in that the location of send data is specified by sdispls
and the location of the placement of receive data is specified by rdispls.

The **jth block** sent from **process i** is received
by **process j** and is placed in the **ith block**.

Need not be all the same size block

sendcount[j], sendtype at **process i**
recvcount[i], recvtype at **process j**.

The amount of data sent must be equal to the amount of data received,
pairwise between every pair of processes.

Distinct type maps between sender and receiver are still allowed.

MPI_Alltoallw

ALLTOALLW in MPI-2.

Can specify separately count, displacement, and datatype.

The displacement of blocks is specified in bytes.

Can be seen as a generalization several MPI functions depending on the input arguments.

Communication Parameters

Point to point communication

Simple latency / bandwidth model

Not good for ping-pong benchmark data

MPI message transfer is complex

Message Envelope

supplementary information such as

length, sender, tag, etc

Eager Protocol

Rendezvous Protocol

Eager Protocol

For short messages

The message itself + supplementary information (message envelope)
may be sent and stored at the receiver side
without receiver's intervention

A matching receiver operation may not be needed
But afterward, the message in the intermediate buffer
must be copied to the receive buffer

+Synchronization overhead is reduced
- May require large amount of preallocated buffer space
- Flooding a process with many eager messages may overflow → contention

Rendezvous Protocol

For large messages

Buffering the data is impossible

The message envelope is immediately stored at the receiver
The actual message transfer blocks until the user’s receive buffer is available

Extra data copy could be avoided,
improving effective bandwidth,
but sender and receiver must synchronize.

Communication Modes

Blocking	**Immediate**
Standard	**Standard**
Buffered	**Buffered**
Synchronous	**Synchronous**
Ready	**Ready**

Blocking

does not return until
the message data and envelope have been safely stored away
so that the sender is free to access and overwrite the send buffer.

The message might be copied directly into the matching receive buffer,
or it might be copied into a temporary system buffer.

Message buffering decouples the send and receive operations.

A blocking send can complete
as soon as the message was buffered,
even if no matching receive has been executed by the receiver.

On the other hand, message buffering can be expensive,
as it entails additional memory-to-memory copying,
and it requires the allocation of memory for buffering.

MPI offers the choice of several communication modes that allow one to control the choice of the communication protocol.

Standard Communication Mode

It is up to MPI to decide whether outgoing messages will be buffered.

1) MPI may buffer outgoing messages.
→ the send call may complete before a matching receive is invoked.

2) Buffer space may be unavailable, or
MPI may choose not to buffer outgoing messages, for performance reasons.
→ the send call will not complete until a matching receive has been posted,
and the data has been moved to the receiver.

Thus, a send in standard mode can be started
whether or not a matching receive has been posted.
It may complete before a matching receive is posted.

The standard mode send is non-local: successful completion of the send operation may depend on the occurrence of a matching receive.

Buffered Communication Mode

A buffered mode send operation can be started
whether or not a matching receive has been posted.

It may complete before a matching receive is posted.

However, unlike the standard send, this operation is **local**,
and its completion does not depend on the occurrence of a matching receive.

Thus, if a send is executed and no matching receive is posted,
then MPI must buffer the outgoing message,
so as to allow the send call to complete.

An error will occur if there is insufficient buffer space.
The amount of available buffer space is controlled by the user.

Buffer allocation by the user may be required
for the buffered mode to be effective.

Synchronous Communication Mode

A send that uses the synchronous mode can be started
whether or not a matching receive was posted.

However, the send will complete successfully
only if a matching receive is posted,
and the receive operation has started
to receive the message sent by the synchronous send.

Thus, the completion of a synchronous send
not only indicates that the send buffer can be reused,
but also indicates that the receiver has reached a certain point in its execution,
namely that it has started executing the matching receive.

If both sends and receives are blocking operations
then the use of the synchronous mode provides
synchronous communication semantics:
a communication does not complete at either end
before both processes rendezvous at the communication.

A send executed in this mode is non-local.

Ready Communication Mode

A send that uses the ready communication mode may be started only if the matching receive is already posted. Otherwise, the operation is erroneous and its outcome is undefined.

On some systems, this allows the removal of a hand-shake operation that is otherwise required and results in improved performance.

The completion of the send operation does not depend on the status of a matching receive, and merely indicates that the send buffer can be reused.

A send operation that uses the ready mode has the same semantics as a standard send operation, or a synchronous send operation;

it is merely that the sender provides additional information to the system (namely that a matching receive is already posted), that can save some overhead.

In a correct program, therefore, a ready send could be replaced by a standard send with no effect on the behavior of the program other than performance.

NonBlocking Communication (1)

overlapping communication and computation
light-weight threads vs nonblocking communication.

A nonblocking send (receive) start call initiates the send (receive) operation, but does not complete it.

The send (receive) start call will return
before the message was copied out of (into) the send (receiver) buffer.

A separate send (receive) complete call
is needed to complete the communication, i.e., to verify that the data
has been copied out of the send buffer (received into the receive buffer) .

With suitable hardware, the transfer of data out of the sender (receiver) memory may proceed concurrently with computations done at the sender (receiver) after the send (receive) was initiated and before it completed.

The use of nonblocking receives may also avoid
system buffering and memory-to-memory copying,
as information is provided early on the location of the receive buffer.

NonBlocking Communication (2)

Nonblocking send start calls can use the same four modes as blocking sends:
standard, buffered, synchronous and ready.

Sends of all modes, ready excepted, can be started whether or not a matching receive has been posted ;
a nonblocking ready send can be started only if a matching receive is posted.

In all cases, the send start call is local:
it returns immediately, irrespective of the status of other processes.

If the call causes some system resource to be exhausted, then it will fail and return an error code. Quality implementations of MPI should ensure that this happens only in ``pathological'' cases. That is, an MPI implementation should be able to support a large number of pending nonblocking operations.

The send-complete call returns when data has been copied out of the send buffer. It may carry additional meaning, depending on the send mode.

NonBlocking Communication (3)

If the send mode is **synchronous**, then the send can complete only if a matching receive has started. That is, a receive has been posted, and has been matched with the send. In this case, the send-complete call is non-local. Note that a synchronous, nonblocking send may complete, if matched by a nonblocking receive, before the receive complete call occurs. (It can complete as soon as the sender ``knows'' the transfer will complete, but before the receiver ``knows'' the transfer will complete.)

If the send mode is **buffered** then the message must be buffered if there is no pending receive. In this case, the send-complete call is local, and must succeed irrespective of the status of a matching receive.

If the send mode is **standard** then the send-complete call may return before a matching receive occurred, if the message is buffered. On the other hand, the send-complete may not complete until a matching receive occurred, and the message was copied into the receive buffer.

Nonblocking sends can be matched with blocking receives, and vice-versa.

Send Modes (1)

MPI_Send
MPI_Send will not return until you can use the send buffer.
It may or may not block
(it is allowed to buffer, either on the sender or receiver side,
or to wait for the matching receive).

MPI_Bsend
May buffer;
returns immediately and you can use the send buffer.
A late add-on to the MPI specification.
Should be used only when absolutely necessary.

MPI_Ssend
will not return until matching receive posted

MPI_Rsend
May be used ONLY if matching receive already posted.
User responsible for writing a correct program.

Send Modes (2)

MPI_Isend

Nonblocking send. But not necessarily asynchronous.
You can NOT reuse the send buffer until either a successful, wait/test or you KNOW that the message has been received (see MPI_Request_free).
Note also that while the I refers to immediate, there is no performance requirement on MPI_Isend. An immediate send must return to the user without requiring a matching receive at the destination. An implementation is free to send the data to the destination before returning, as long as the send call does not block waiting for a matching receive.
Different strategies of when to send the data offer different performance advantages and disadvantages that will depend on the application.

MPI_Ibsend

buffered nonblocking

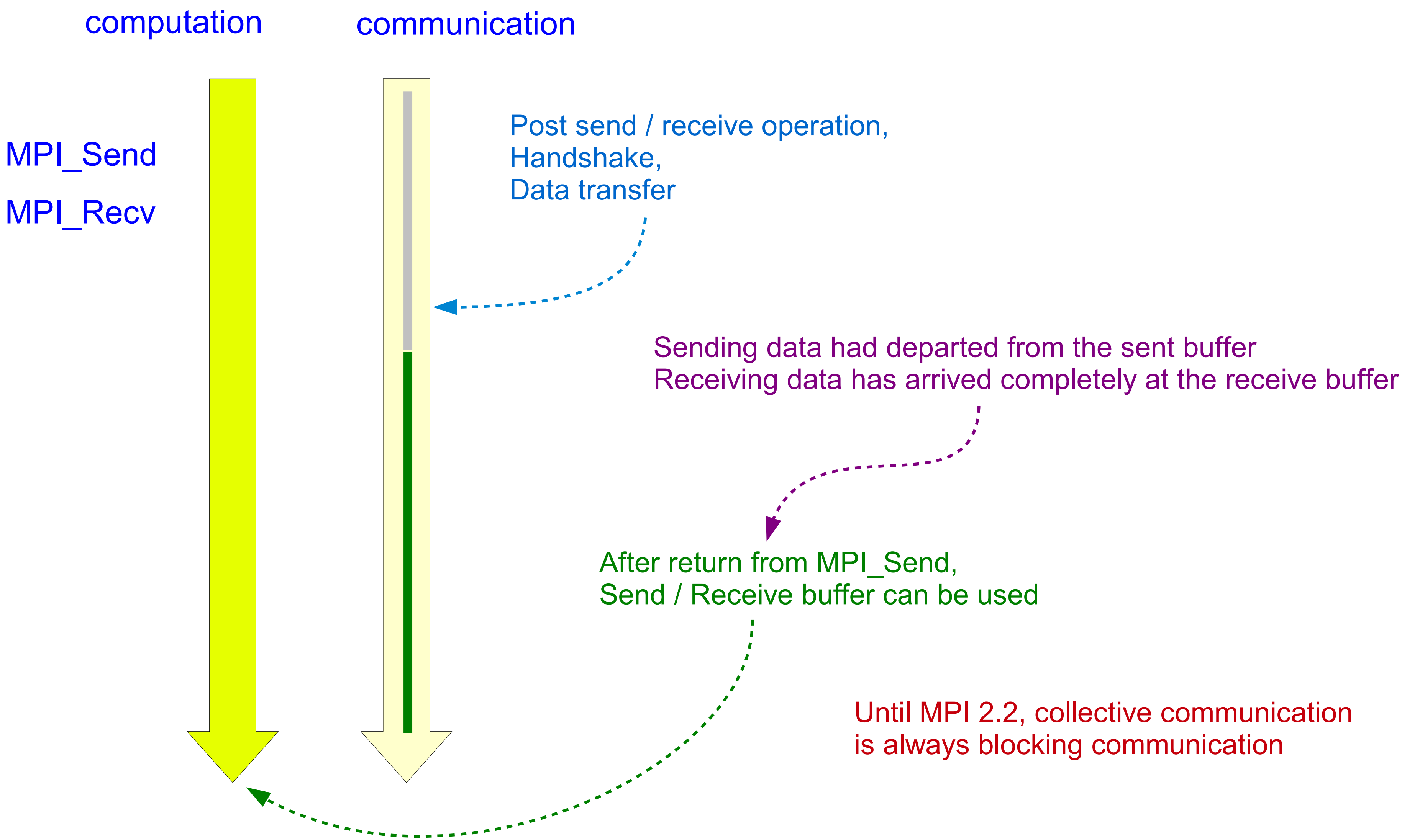
MPI_Issend

Synchronous nonblocking. Note that a Wait/Test will complete only when the matching receive is posted.

MPI_Irsend

As with MPI_Rsend, but nonblocking.

Blocking Communication



computation

communication

MPI_Send

MPI_Recv

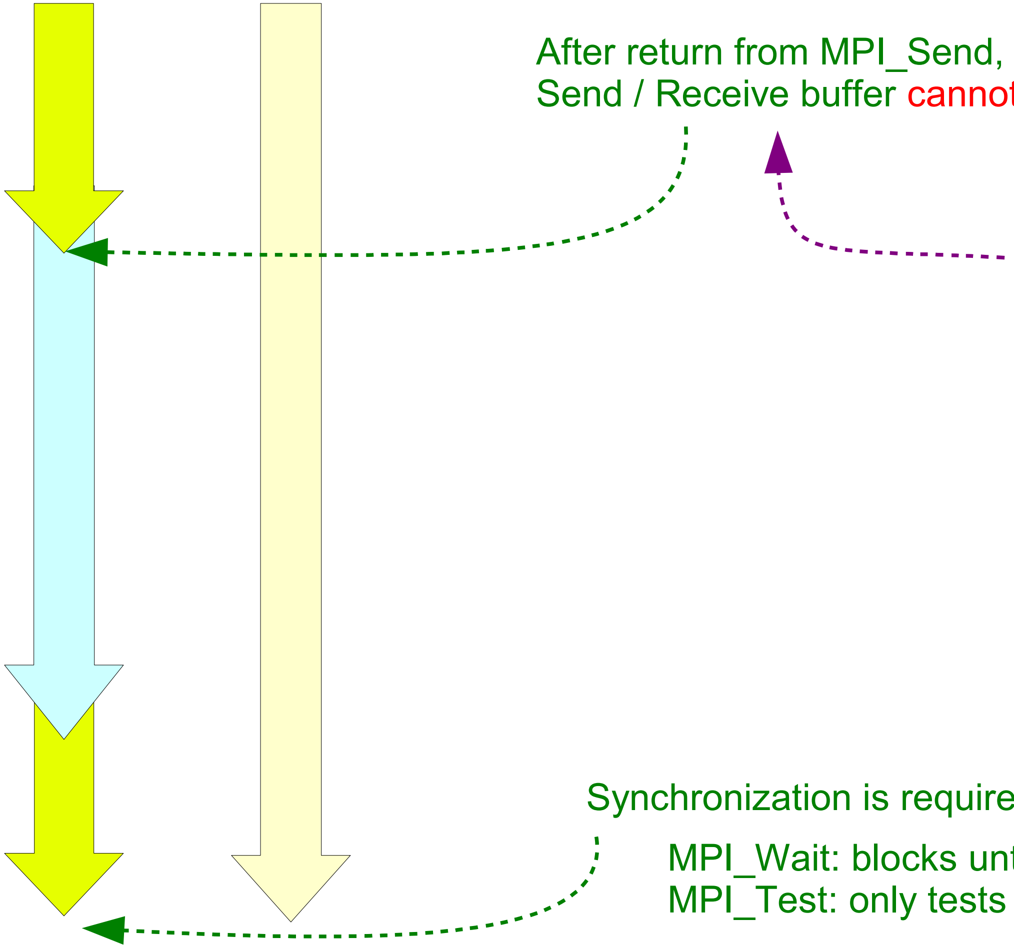
Post send / receive operation,
Handshake,
Data transfer

Sending data had departed from the sent buffer
Receiving data has arrived completely at the receive buffer

After return from MPI_Send,
Send / Receive buffer can be used

Until MPI 2.2, collective communication
is always blocking communication

Non-Blocking Communication (1)



computation

communication

MPI_Isend

MPI_Irecv

Can do other useful computation unless it access the buffer

MPI_Wait

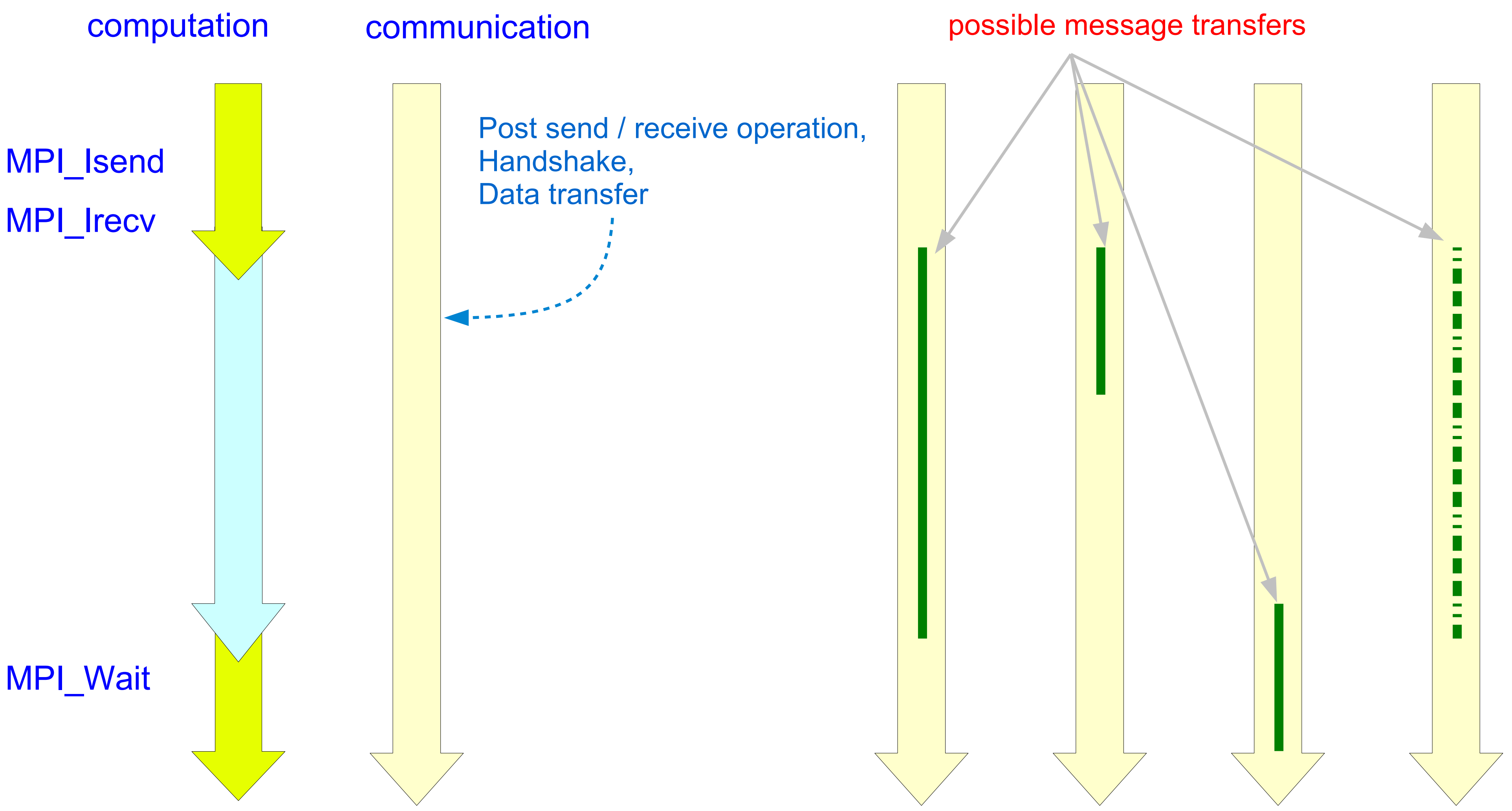
After return from MPI_Send,
Send / Receive buffer cannot be used

MPI_Isend, MPI_Irecv <u>merely initiates</u> a message transmission and <u>returns</u> immediately to the user.

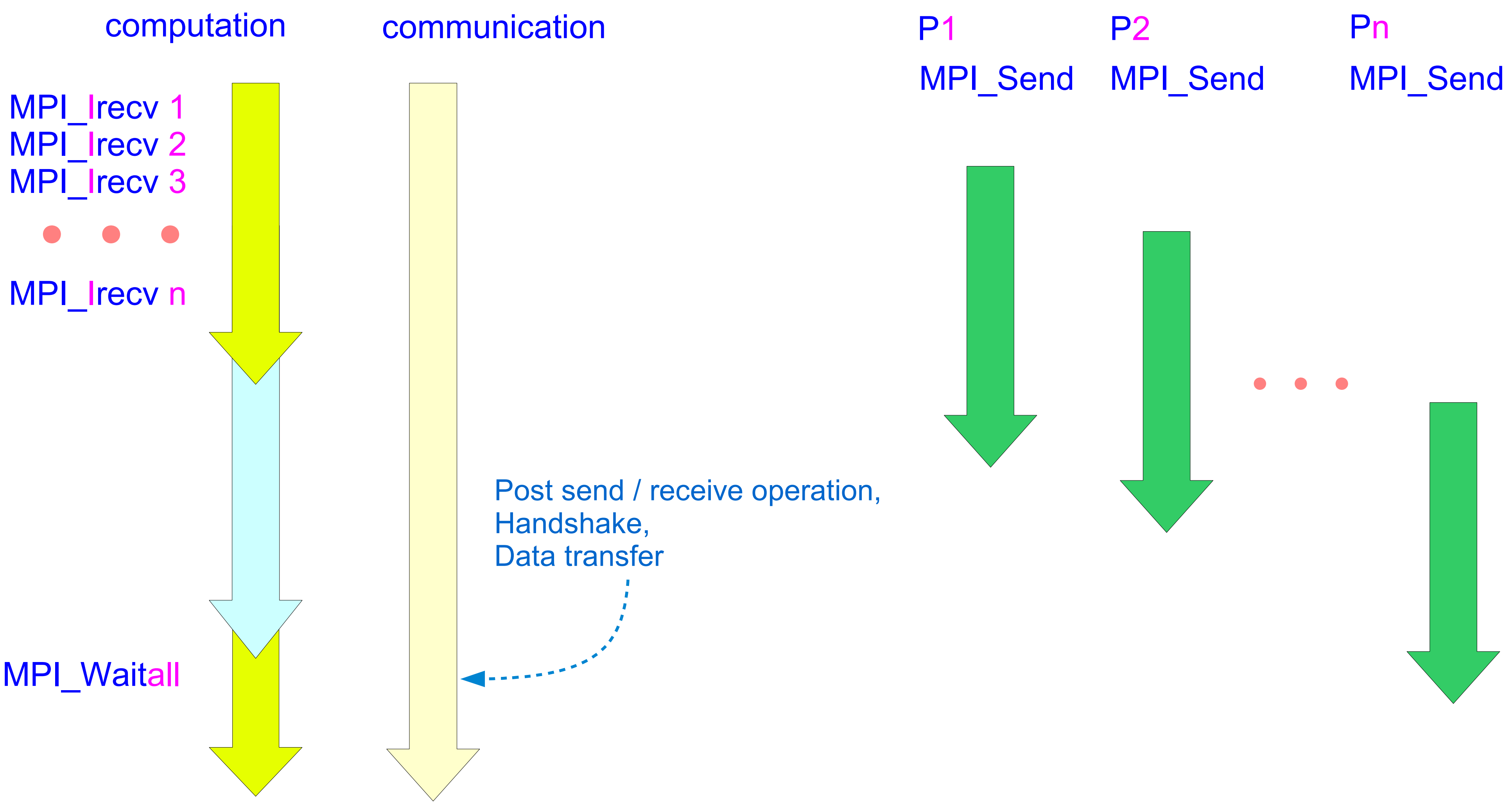
Synchronization is required

MPI_Wait: blocks until the buffer is available
MPI_Test: only tests for completion and returns flag

Non-Blocking Communication (2)



Multiple Request



computation

communication

MPI_Irecv 1
MPI_Irecv 2
MPI_Irecv 3

● ● ●

MPI_Irecv n

MPI_Waitall

Post send / receive operation,
Handshake,
Data transfer

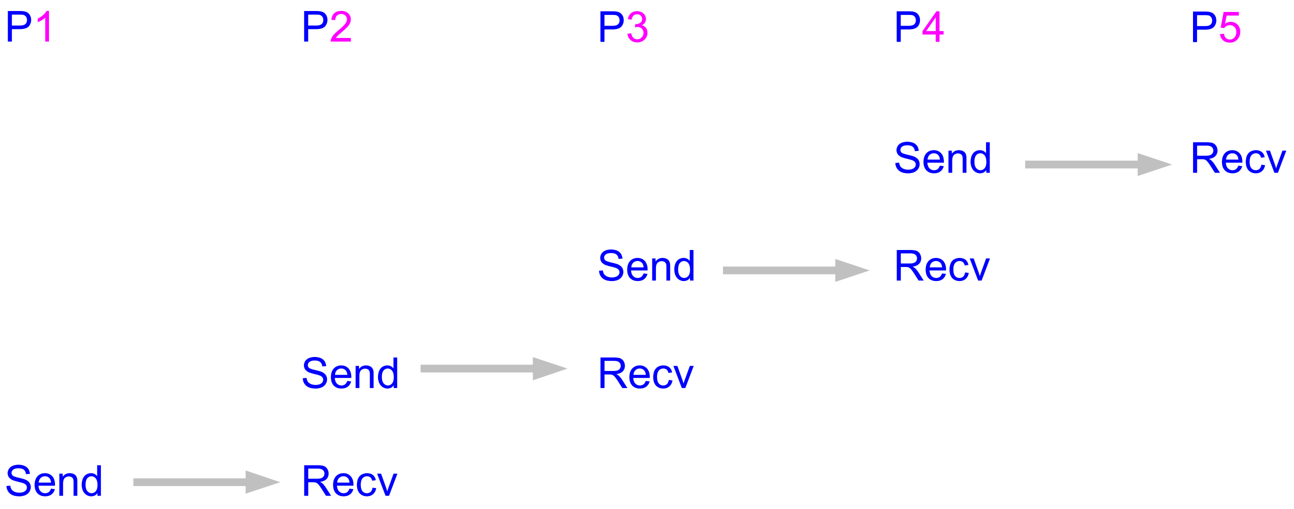
P1
MPI_Send

P2
MPI_Send

Pn
MPI_Send

● ● ●

Implicit Serialization and Synchronization



P1 P2 P3 P4 P5

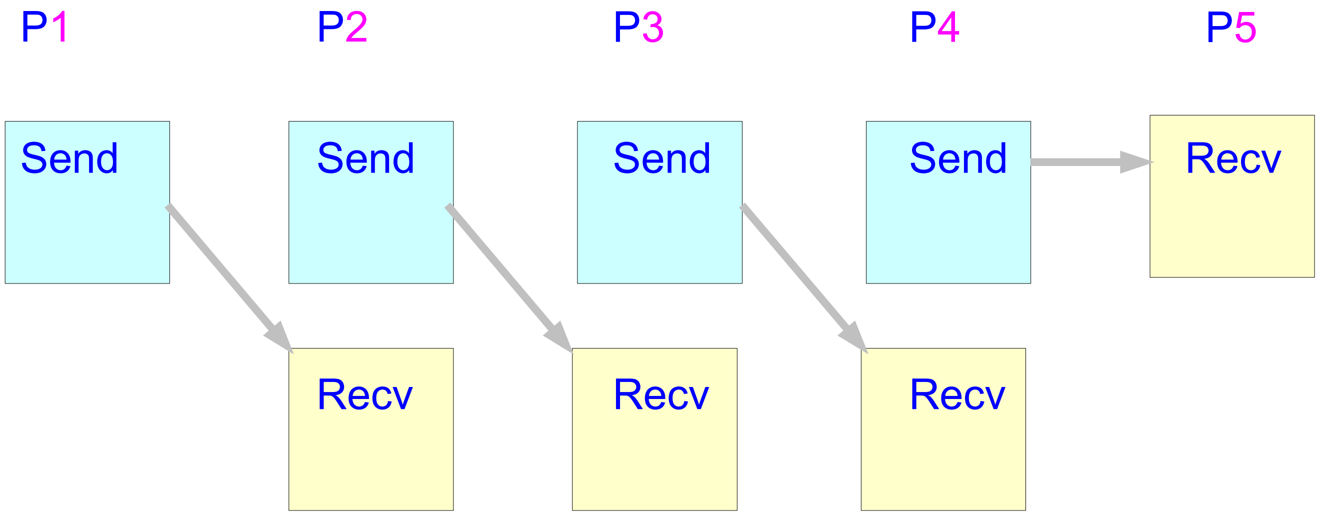
Send → Recv

Send → Recv

Send → Recv

Send → Recv

Implicit Serialization and Synchronization

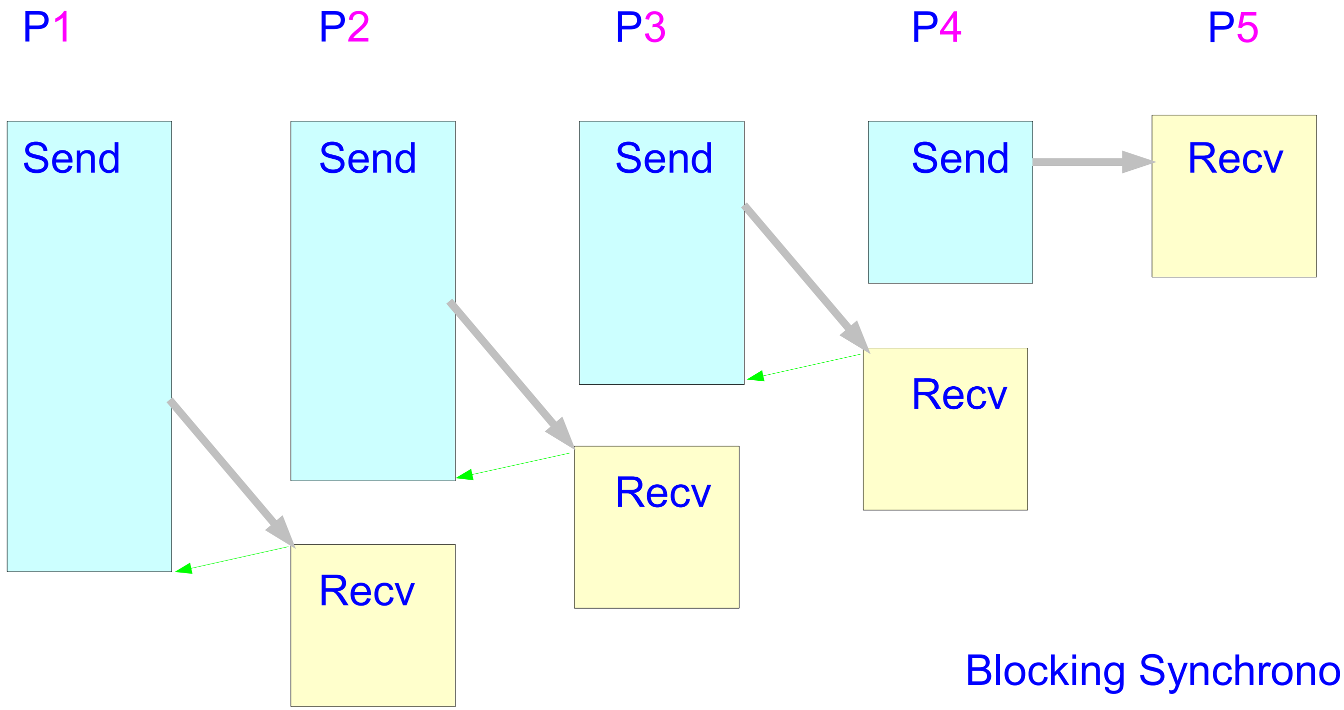


Blocking but not Synchronous Send

Blocking Recv

Eager Delivery
Not Synchronous – enables a send to end
<u>before</u> the corresponding recv is posted

Implicit Serialization and Synchronization

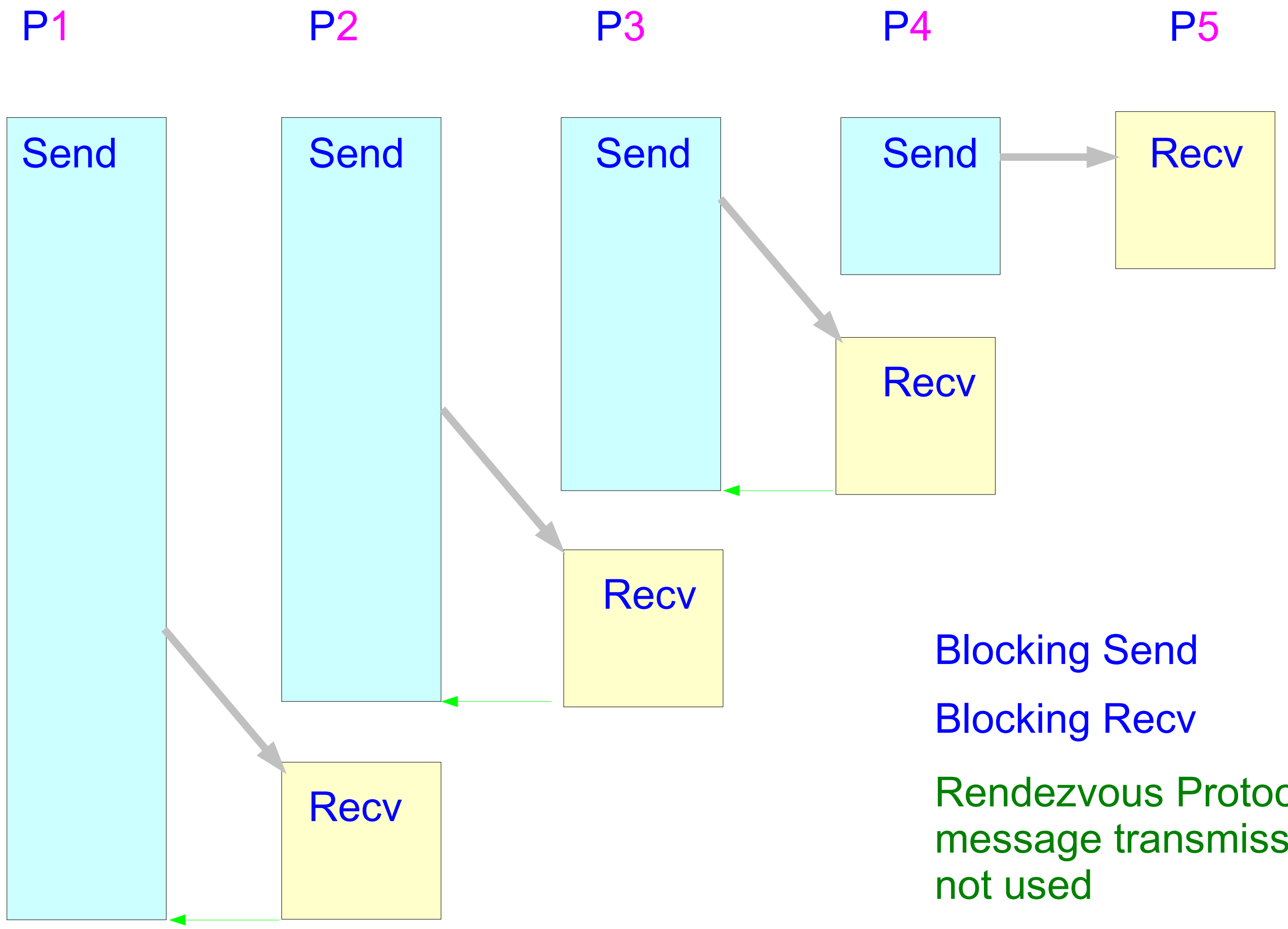


Blocking Synchronous Send

Blocking Recv

Eager Delivery
Synchronous – forces a send finish only after it's matching recv is posted

Implicit Serialization and Synchronization



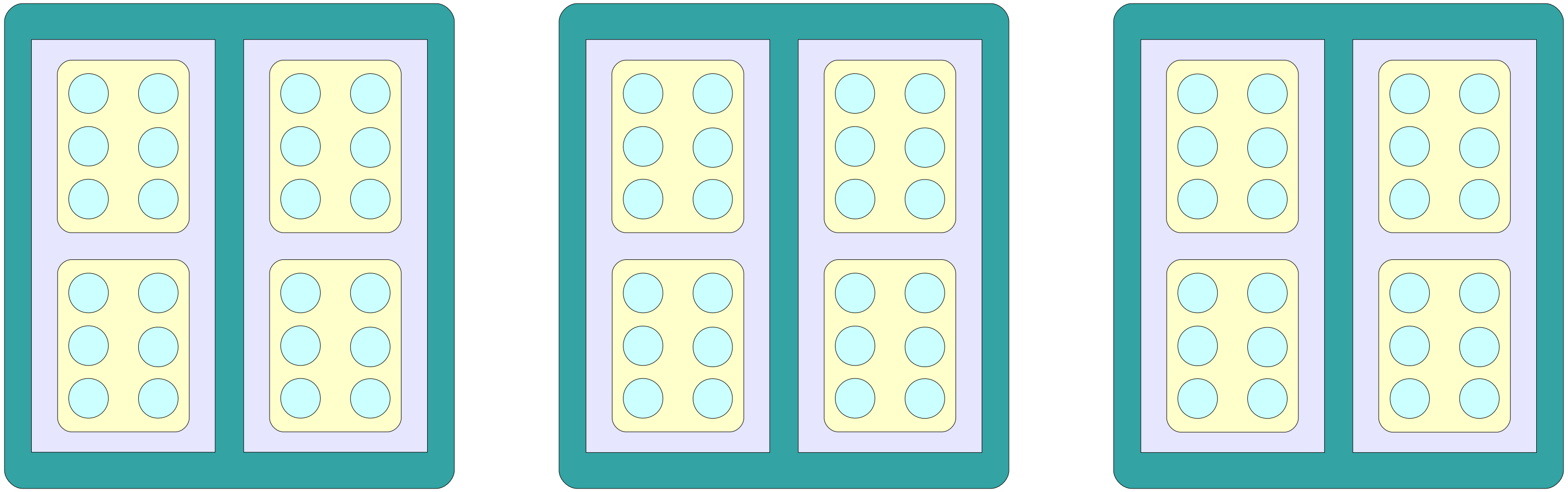
Blocking Send

Blocking Recv

Rendezvous Protocol – forces a serial message transmission because buffering is not used

Rank Reorder

PE 0, 1, 2, 3, 4, 5, 6, ….



Ex) MPICH on CrayPAT

MPICH_RANK_REORDER_METHOD

ROUND-ROBIN	One rank per node, wrap around
	Sequential ranks are placed on the next node
SMP-STYLE	Fill up one node before going to next
	All cores from all nodes are allocated in a sequential order
FOLDED RANK	One rank per node, wrap back

Rank

MPI_Comm_size : Determines the size of the group associated with a communicator

MPI_Comm_rank : Determines the rank of the calling process in the communicator

MPI_Cart_create : Makes a new communicator to which **topology information** has been attached

MPI_Dims_create : Creates a division of processors in a cartesian grid

MPI_Cart_coords : Determines **process coords** in cartesian topology given rank in group

MPI_Cart_rank : Determines **process rank** in communicator given Cartesian location

MPI_Cart_shift : Returns the **shifted source and destination ranks**, given a shift Direction and amount

Rank

int **MPI_Comm_size** (MPI_Comm comm, int *size)

int **MPI_Comm_rank** (MPI_Comm comm, int *rank)

int **MPI_Cart_create** (MPI_Comm comm_old, int ndims, int *dims, int *periods,
int reorder, MPI_Comm *comm_cart)

Int **MPI_Dims_create** (int nnodes, int ndims, int *dims)

int **MPI_Cart_coords** (MPI_Comm comm, int rank, int maxdims, int *coords)

int **MPI_Cart_rank** (MPI_Comm comm, int *coords, int *rank)

int **MPI_Cart_shift** (MPI_Comm comm, int direction, int displ, int *source, int *dest)

Rank

```
int MPI_Cart_create (MPI_Comm comm_old, int ndims, int *dims, int *periods,
                                   int reorder, MPI_Comm *comm_cart)

MPI_Cart_create (MPI_COMM_WORLD,                  // standard communicator
                              2,                                  // two dimensions
```

Nonblocking s. Asynchronous Communication

Nonblocking :

implies that the message buffer cannot be used
after the call has returned from the MPI library.

It depends on the implementation
whether data transfer (MPI progress) takes place
outside MPI while user code is being executed

```
T = MPI_Wtime()

      MPI_Irecv(...);
      do_work( delay );
      MPI_Wait(...);

T = MPI_Wtime() - T;
```

If MPI_Irecv() triggers a truly asynchronous data transfer,

the measured overall time will stay constant with increasing delay until the delay equals the message transfer time. Beyond this point, there will be a linear rise in execution time.

If MPI progress occurs only inside the MPI library
(which means, in this example, within MPI_Wait()),

the time for data transfer and the time for executing do_work() will always add up
and there will be linear rise of overall execution time starting from zero delay

Nonblocking s. Asynchronous Communication

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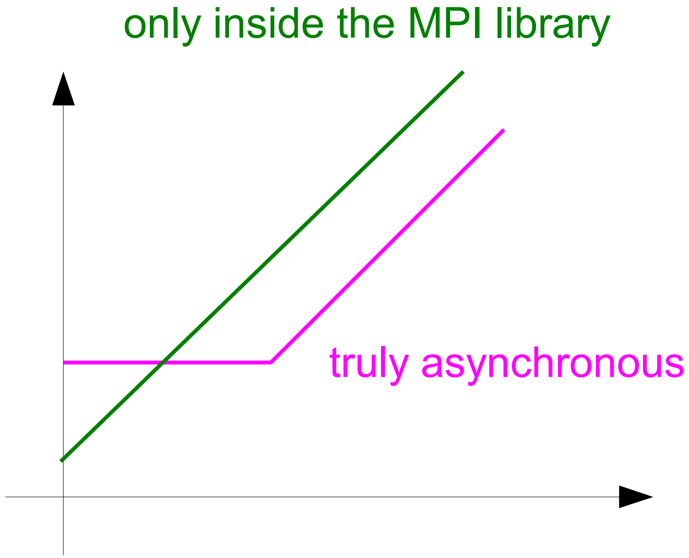


Intranode point-to-point communication (1)

Cray XT5 system

One XT5 node
– 2 AMD Opteron chips
With a 2MB quad-core L3 group each
These nodes are connected via 3D torus network

Different Level of
point-to-point communication characteristics

Intranode intrasocket : inside an L3 group
Intranode intersocket : between core on different sockets
Internode : between different nodes

Internode ↔ Intranode : large difference
Intersocket ↔ Intrasocket : similar

Intranode point-to-point communication (2)

False Assumption:
Any intranode MPI communication is infinitely fast.

Depends on the MPI implementation

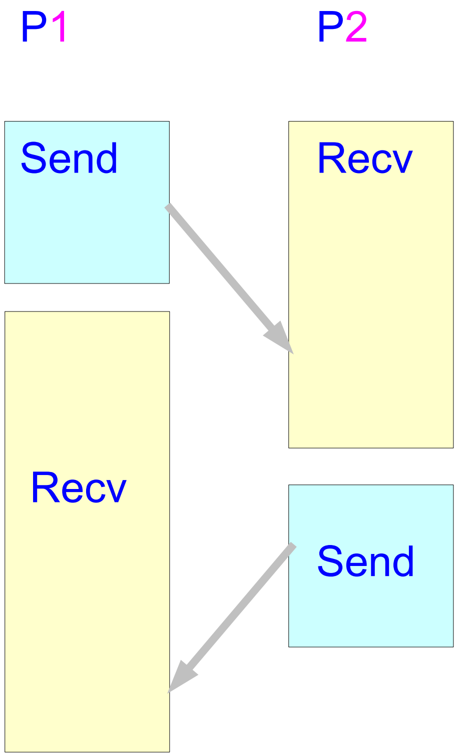
When the MPI library is not aware of intranode communication, relatively slow network protocols are used instead of memory-to-memory copies

Nontemporal stores or cache line zero
Depending on message size and cache sizes
Large message / No shared cache : avoid the write allocate

Single copy (simple block copy command)
From send buf to recv buf
(synchronizing randezvous protocol)
Intermediate buffer (additional copy)

Hardware support for intranode memory-to-memory copy

Ping-Pong Benchmark (1)



Message Size

$$T = T_l + \frac{N}{B}$$

Latency Max Bandwidth

$$B_{eff} = \frac{N}{T} = \frac{N}{T_l + N/B}$$

A multicore processor with a shared cache
- fit into the cache

IMB (Intel Benchmarks)

Ping-Pong Benchmark (2)

$$T = T_l + \frac{N}{B}$$

Small sized message : latency dominating

$$T \approx T_l$$

$$B_{eff} = \frac{N}{T} = \frac{N}{T_l + N/B}$$

Large sized message : effective bandwidth saturating

$$B_{eff} \approx B$$

Measured latency with N=0

May be inaccurate because of the followings:

All protocols have some overhead (headers)

Some protocols have min message size > 1 byte

Involves multiple software layers (added latencies)

May not have optimized low-latency I/O

Different buffering algorithms at a certain message size

Extremely large message must be split into smaller chunks

Ping-Pong Benchmark (3)

$$T = T_l + \frac{N}{B}$$

$$B_{eff} = \frac{N}{T} = \frac{N}{T_l + N/B} = \frac{B}{2}$$

$$T_l = \frac{N_{1/2}}{B} \qquad B T_l = N_{1/2}$$

$$B_{eff}(B, T_l) = \frac{N}{T_l + N/B}$$

$$B_{eff}(\beta B, T_l) = \frac{N}{T_l + N/\beta B}$$

$$\frac{B_{eff}(\beta B, T_l)}{B_{eff}(B, T_l)} = \frac{T_l + N/B}{T_l + N/\beta B} = \frac{1 + N/B T_l}{1 + N/\beta B T_l} = \frac{1 + N/N_{1/2}}{1 + N/\beta N_{1/2}}$$

Whether an increase in maximum network bandwidth by a factor of β is really beneficial for all messages?

Message Aggregation

References

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