An Introduction to MPI Programming

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Topics

- **Introduction**
- **Initialising MPI & basic concepts**
- **Compiling and running a parallel program on the Cray**
- **Practical : “Hello World” MPI program**
- **Synchronisation**
- **Practical**
- **Data types and tags**
- **Basic sends and receives**
- **Practical**
- **Collective communications**
- **Reduction Operations**
- **MPI References**

Introduction (1 of 4)

- **Message Passing evolved in the late 1980's**
- **Cray was dominate in supercomputing**
  - **with very expensive shared-memory vector processors**
- **Many companies tried new approaches to HPC**
- **Workstation and PC Technology was spreading rapidly**
- **"The Attack of the Killer Micros"**
- **Message Passing was a way to link them together**
  - **many different flavours PVM, PARMACS, CHIMP, OCCAM**
- **Cray recognised the need to change**
  - **switched to MPP using cheap DEC Alpha microprocessors (T3D/T3E)**
- **But application developers needed portable software**

Introduction (2 of 4)

- **Message Passing Interface (MPI)**
  - The MPI Forum was a combination of end users and vendors (1992)
  - defined a standard set of library calls in 1994
  - Portable across different computer platforms
  - Fortran and C Interfaces
- **Used by multiple tasks to send and receive data**
  - Working together to solve a problem
  - Data is decomposed (split) into multiple parts
  - Each task handles a separate part on its own processor
  - Message passing to resolve data dependencies
- **Works within a node and across Distributed Memory Nodes**
- **Can scale to thousands of processors**
  - Subject to constraints of Amdahl's Law

Introduction (3 of 4)

- **The MPI standard is large**
  - **Well over 100 routines in MPI version 1**
  - **Result of trying to cater for many different flavours of message passing and a diverse range of computer architectures**
  - **And an additional 100+ in MPI version 2 (1997)**
  - **And many more additions in MPI version 3 (2012)**
  - **MPI version 1 works whatever version of MPI you have**
- **Many sophisticated features**
  - **Designed for both homogenous and heterogeneous environments**
- **But most people only use a small subset**
  - **IFS was initially parallelised using Parmacs**
  - **This was replaced by about 10 MPI (version 1) routines**
    - **Hidden within “MPL” library**

Introduction (4 of 4)

- **This course will look at just a few basic routines**
  - **Fortran Interface Only**
  - **MPI version 1.2**
  - **SPMD (Single Program Multiple Data)**
  - **As used at ECMWF in IFS**
- **A mass of useful material on the Web**
  - **MPI standard**
    - **Lots of useful information about MPI's behaviour & implementation**
    - **http://www.mpi-forum.org/docs/mpi-1.1/mpi-11-html/mpi-report.html**
  - **Open MPI documentation**
    - **A nice easy guide to the API (contains MPI v2 too), including Fortran interface**
    - **http://www.open-mpi.org/doc/v1.10/**

SPMD

- **The SPMD model is by far the most common**
  - **Single Program Multiple Data**
  - **One program executes multiple times simultaneously**
  - **The problem is divided across the multiple copies**
  - **Each work on a subset of the data**
- **MPMD**
  - **Multi Program Multiple Data**
  - **Different executable on different processors**
  - **Useful for coupled models for example**
  - **Part of the MPI 2 standard**
  - **Not currently used by IFS**
  - **Can be mimicked in SPMD mode**
    - **Top level branch deciding which “program” (subroutine) this task will run**

Some definitions

- **Task**
  - one running instance (copy) of a program
  - Equivalent to a UNIX process
  - Basic unit of an MPI parallel execution
  - May run on one processor
    - Or across many if OpenMP is used as well (threads)
    - Or many tasks on one processor (not a good idea!)
- **Master**
  - the master task is the first task in a parallel program : TaskID=0
- **Slave**
  - all other tasks in a parallel program
  - Nothing intrinsically different between master/slave – but the parallel program may treat them differently

The simplest MPI program.....

- **Lets start with “hello world”**
- **Introduces**
  - **4 essential housekeeping routines**
  - **the “`use mpi`” statement**
  - **the concept of Communicators**

```
program hello

implicit none

print *,"Hello world"

end
```

Hello World with MPI

```
program hello

implicit none
use mpi
integer:: ierror,ntasks,mytask

call MPI_INIT(ierror)
call MPI_COMM_SIZE(MPI_COMM_WORLD, ntasks, ierror)
call MPI_COMM_RANK(MPI_COMM_WORLD, mytask, ierror)

print *,"Hello world from task ",mytask," of ",ntasks

call MPI_FINALIZE(ierror)

end
```

use mpi : The MPI header file

```
use mpi
```

- **The MPI header file**
- **Always include in any routine calling an MPI function**
- **Contains declarations for constants used by MPI**
- **May contain interface blocks, so compiler will tell you if you make an obvious error in arguments to MPI library**
  - **This is not mandated by the standard so you shouldn't rely on it. You may want to test Cray's mpi to see if it does!**
- **In Fortran77 use "`include 'mpif.h'`" instead**

Hello World with MPI

```
program hello

implicit none
use mpi
integer:: ierror,ntasks,mytask

call MPI_INIT(ierror)
call MPI_COMM_SIZE(MPI_COMM_WORLD, ntasks, ierror)
call MPI_COMM_RANK(MPI_COMM_WORLD, mytask, ierror)

print *,"Hello world from task ",mytask," of ",ntasks

call MPI_FINALIZE(ierror)

end
```

MPI_INIT

```
integer:: ierror
call MPI_INIT(ierror)
```

- **Initializes the MPI environment**
- **Expect a return code of zero for ierror**
  - **If an error occurs the MPI layer will normally abort the job**
  - **best practise would check for non zero codes**
  - **we will ignore for clarity – but see later slides for `MPI_ABORT`**
- **On the Cray all tasks execute the code before `MPI_INIT`**
  - **this is an implementation dependent feature**
  - **try not to do anything that alters the state of the system before this, eg. I/O**

Hello World with MPI

```
program hello

implicit none
use mpi
integer:: ierror,ntasks,mytask

call MPI_INIT(ierror)
call MPI_COMM_SIZE(MPI_COMM_WORLD, ntasks, ierror)
call MPI_COMM_RANK(MPI_COMM_WORLD, mytask, ierror)

print *,"Hello world from task ",mytask," of ",ntasks

call MPI_FINALIZE(ierror)

end
```

MPI_COMM_WORLD

- **An MPI communicator**
- **Constant integer value from "`use mpi`"**
- **`MPI_COMM_WORLD` means all tasks**
  - **many MPI programs only use `MPI_COMM_WORLD`**
  - **All our examples only use `MPI_COMM_WORLD`**
- **Communicators define sets or groups of tasks**
  - **dividing programs into subsets of tasks often not necessary**
  - **IFS also creates and uses some additional communicators**
    - **useful when doing collective communications**
    - **Useful if you want to dedicate a subset of tasks to a special job (eg. I/O server)**
  - **advanced topic**

Hello World with MPI

```
program hello

implicit none
use mpi
integer:: ierror,ntasks,mytask

call MPI_INIT(ierror)
call MPI_COMM_SIZE(MPI_COMM_WORLD, ntasks, ierror)
call MPI_COMM_RANK(MPI_COMM_WORLD, mytask, ierror)

print *,"Hello world from task ",mytask," of ",ntasks

call MPI_FINALIZE(ierror)

end
```

MPI_COMM_SIZE

```
integer:: ierror,ntasks
call MPI_COMM_SIZE(MPI_COMM_WORLD, ntasks, ierror)
```

- **Returns the number of parallel tasks in the variable "ntasks"**
  - **the number of tasks is defined from the aprun command which starts the parallel executable**
- **Value can be used to help decompose the problem**
  - **in conjunction with Fortran allocatable/automatic arrays**
  - **avoid the need to recompile for different processor numbers**

Hello World with MPI

```
program hello

implicit none
use mpi
integer:: ierror,ntasks,mytask

call MPI_INIT(ierror)
call MPI_COMM_SIZE(MPI_COMM_WORLD, ntasks, ierror)
call MPI_COMM_RANK(MPI_COMM_WORLD, mytask, ierror)

print *,"Hello world from task ",mytask," of ",ntasks

call MPI_FINALIZE(ierror)

end
```

MPI_COMM_RANK

```
integer:: ierror, mytask
call MPI_COMM_RANK(MPI_COMM_WORLD, mytask, ierror)
```

- **Returns the rank of the task in `mytask`**
  - **In the range `0` to `ntasks-1`**
    - **Easy to make mistakes with this as Fortran arrays normally run `1:n`**
  - **Used as a task identifier when sending/receiving messages**

Hello World with MPI

```
program hello

implicit none
use mpi
integer:: ierror,ntasks,mytask

call MPI_INIT(ierror)
call MPI_COMM_SIZE(MPI_COMM_WORLD, ntasks, ierror)
call MPI_COMM_RANK(MPI_COMM_WORLD, mytask, ierror)

print *,"Hello world from task ",mytask," of ",ntasks

call MPI_FINALIZE(ierror)

end
```

MPI_FINALIZE

```
integer:: ierror
call MPI_FINALIZE(ierror)
```

- **Tell the MPI layer that we have finished**
- **Any MPI call after this is an error**
  - **Like MPI_INIT, the MPI standard does not mandate what happens after an MPI_FINALIZE – cannot guarantee that all tasks still execute after this point**
- **Does not stop the program – at least one (probably all!) tasks will continue to run**

MPI_ABORT

```
integer:: ierror
call MPI_ABORT(MPI_COMM_WORLD,ierror)
```

- **Causes all tasks to abort**
- **Even if only one task makes call**

PBSPro and MPI

- **Many varied ways of defining your requirements**
- **For the exercises we'll keep it as simple as possible**
  - **Create an interactive shell in which you can run parallel jobs in up to one node (48 hyperthreaded CPUs)**
  - **You won't need to wait every time you run an executable!**
  - **Don't forget to log out when you're finished!**
  - **Not recommended for regular use!**

```
$ ssh cca  # or ccb
```

queue "np"

one node

```
$ qsub -q np -I -l EC_nodes=1 -l EC_hyperthreads=2
```

interactive

Use hyperthreading

Compiling an MPI Program

- **Very easy using modules**
  - **Automatically adds all the flags/libraries required for MPI**

```
$ module load PrgEnv-cray    # Use Cray compilers
      or
$ module load PrgEnv-intel   # Use Intel compilers
      or
$ module load PrgEnv-gnu     # Use Gnu compilers

----

$ ftn hello.f90              # produces a.out
$ ftn -c hello.f90           # produces hello.o
      or
      and
$ ftn hello.o -o hello.exe   # produces hello.exe
```

Running an MPI Program

- **aprun**
  - **Details and many options covered in other lectures**
  - **Here we will use a very simple form**
  - **Run from the MOM node (where your interactive shell is running), launches the parallel executable on the parallel (ESM) node(s)**

```
$ aprun –n 4 <executable>
```

First Practical

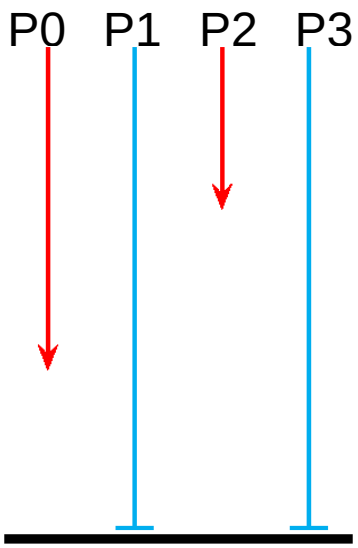
- **Copy all the practical exercises to your account on cca or ccb:**
  - `cd $HOME`
  - `mkdir mpi_course ; cd mpi_course`
  - `cp –r ~trx/mpi.2016/* .`
- **Exercise1a**
  - **Run your own Hello World program with MPI**
- **See the README for details**

MPI_BARRIER

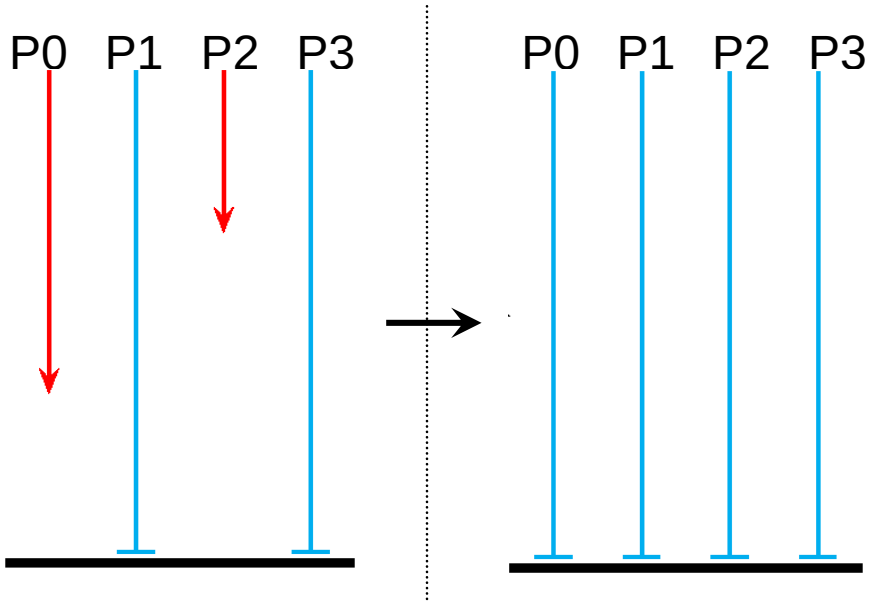
```
integer:: ierror
call MPI_BARRIER(MPI_COMM_WORLD,ierror)
```

- **Forces all tasks (in a communicator group) to synchronise (wait for each other)**

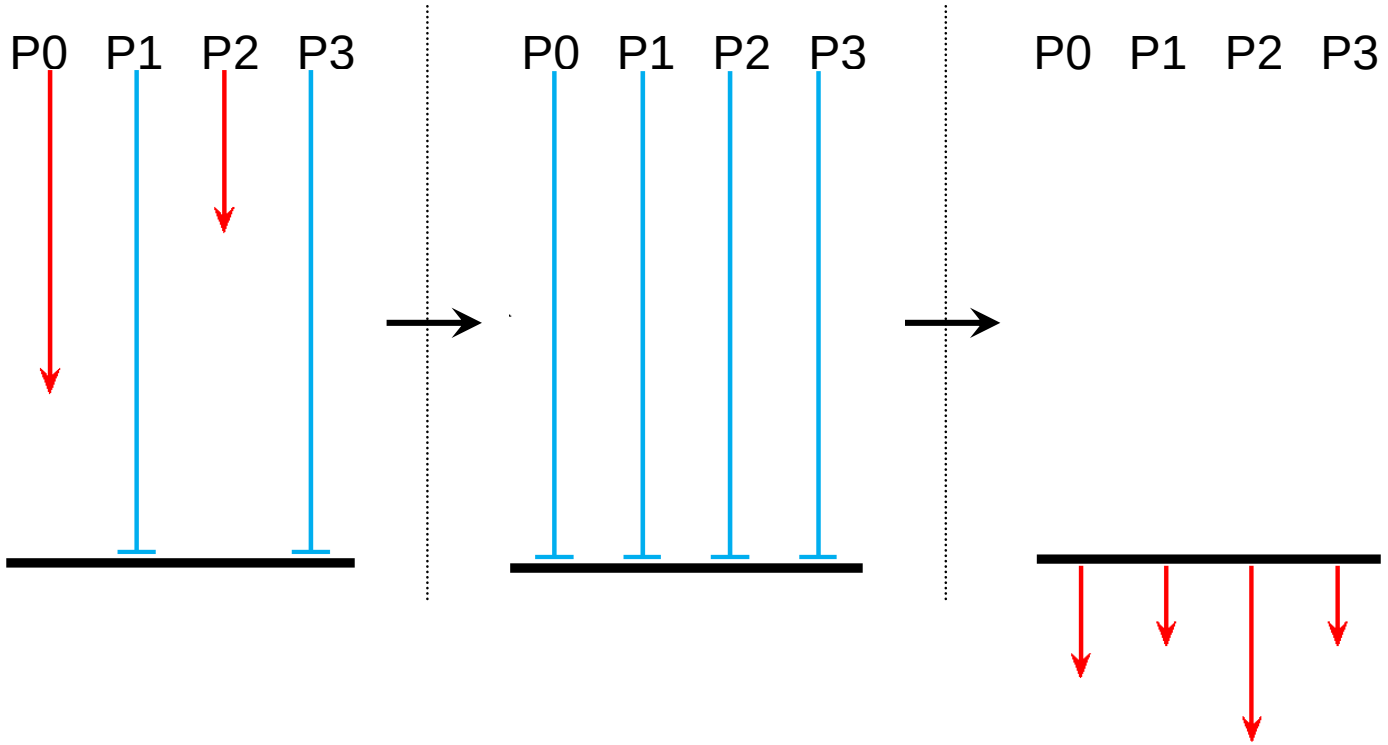
MPI_BARRIER



MPI_BARRIER



MPI_BARRIER



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MPI_BARRIER

- **Possible uses:**
  - for timing points
  - to improve output of prints
    - can be used to force ordering of events
  - to separate different communications phases
- **A task waits in the barrier until every task has reached it**
- **Then all tasks exit the call together at the same time**
- **Deadlock if one task does not reach the barrier**
  - `MPI_BARRIER` will wait until the task reaches its cpu limit
- **What happens if different tasks call `MPI_BARRIER` in different parts of the code?**
  - Could be desired behaviour, or it could be highly confusing bug!

Second Practical

- **Forcing the ordering of output**
- **Exercise 1b – see the README file for more details…**

Basic Sends and Receives

- **`MPI_SEND`**
  - sends a message from one task to another
- **`MPI_RECV`**
  - receives a message from another task
- **A message is just data with some form of identification**
  - think of it as an email – the body and some headers
    - To: Where the message should be sent to
    - Subject: Some description of the contents (in MPI, a “tag”)
    - Body: The data itself (can be any size), various Fortran types
- **You program the logic to send and receive messages**
  - the sender and receiver are working together
  - every send must have a corresponding receive

MPI Datatypes

- **MPI can send variables of any Fortran type**
  - `integer, real, real*8, logical,.....`
  - **it needs to know the type**
- **There are predefined constants used to identify types**
  - `MPI_INTEGER, MPI_REAL, MPI_REAL8, MPI_LOGICAL.....`
  - **Defined by "`use mpi`"**
- **Also user defined data types**
  - **MPI allows you create types created out of basic Fortran types (rather like a Fortran 90 structure)**
  - **Allows strided (non contiguous) data to be communicated**
  - **advanced topic not covered here**

MPI Tags

- **All messages are given an integer TAG value**
  - **standard says maximum value is at least 32768 (2^31)**
  - **`CALL MPI_Comm_get_attr (MPI_COMM_WORLD,MPI_TAG_UB, maxtag, flag, error)`**
- **This helps to identify a message (like an email's "subject")**
- **Particularly useful when sending multiple messages**
- **You decide what tag values to use**
  - **Good idea (helps spot problems) to use separate ranges of tags in different communication areas, eg:**
    - **1000, 1001, 1002..... in routine a**
    - **2000, 2001, 2002.... in routine b**

MPI_SEND

```
FORTRAN_TYPE:: sbuf
integer:: count, dest, tag, ierror
call MPI_SEND( sbuf, count, MPI_TYPE, dest, tag, &
               MPI_COMM_WORLD, ierror)
```

SBUF	**the array being sent**	**input**
COUNT	**the number of elements to send**	**input**
MPI_TYPE	**type of SBUF eg MPI_REAL**	**input**
DEST	**the task id of the receiver**	**input**
TAG	**the message identifier**	**input**

MPI_RECV

```
FORTRAN_TYPE:: rbuf
integer:: count, source, tag, status(MPI_STATUS_SIZE),ierror
call MPI_RECV( rbuf, count, MPI_TYPE, source, tag, &
               MPI_COMM_WORLD, status, ierror)
```

RBUF	**the array being received**	**output**
COUNT	**the length of RBUF**	**input**
MPI_TYPE	**type of RBUF eg MPI_REAL**	**input**
SOURCE	**the task id of the sender**	**input**
TAG	**the message identifier**	**input**
STATUS	**information about the message**	**output**

More on MPI_RECV

- **`MPI_RECV` will block (wait) until the message arrives**
  - **if message never sent then deadlock**
    - **task will wait until it reaches cpu time limit, and then dies**
- **Order in which messages are received**
  - **For a given pair of processors using the same communicator, the MPI standard guarantees the messages will be received in the same order they were sent**
- **This means you need to be careful**
  - **If you are receiving multiple messages from the same task, you MUST do the `MPI_RECVs` in the same order as the `MPI_SENDs`**
  - **Otherwise the first `MPI_RECV` will wait forever, and eventually die**
  - ***What happens if you don't know the ordering of the `MPI_SENDs`?***

How to be less specific on MPI_RECV

- **The source and tag can be more open**
  - `MPI_ANY_SOURCE` means receive from any sender
  - `MPI_ANY_TAG` means receive any tag
  - Useful in more complex communication patterns
  - Used to receive messages in a more random order
  - helps smooth out load imbalance
  - May require over-allocation of receive buffer
- **But how do we know what message we've received?**
  - `status(MPI_SOURCE)` will contain the actual sender
  - `status(MPI_TAG)` will contain the actual tag

An example : task 0 sends a message to task 1

```
subroutine transfer(values,len,mytask)
implicit none
use mpi
integer:: mytask,len,source,dest,tag,ierror,status(MPI_STATUS_SIZE)
real::    values(len)
tag = 12345
if(mytask.eq.0) then
   dest = 1
   call MPI_SEND(values,len,MPI_REAL,dest,tag,MPI_COMM_WORLD,ierror)
elseif(mytask.eq.1) then
   source = 0
   call MPI_RECV(values,len,MPI_REAL,source,tag,MPI_COMM_WORLD,status,ierror)
endif
end
```

Third Practical

- **Sending and receiving a message**
- **Exercise 1c – see the README file for more details…**

Collective Communications (1)

- **SEND/RECV is pairwise communication**
- **Often we want to do more complex communication patterns**
- **For example**
  - **Send the same message from one task to many other tasks**
  - **Receive messages from many tasks onto many other tasks**
- **We could write this with `MPI_SEND` & `MPI_RECV`**
  - **How?**
  - **Why not?**

Collective Communications

- **MPI contains many Collective Communications routines**
  - called by all tasks (in a communicator group) together
  - replace multiple send/receive calls
  - easier to code and understand
  - can be more efficient
  - the MPI library may optimise the data transfers
- **We will look at `MPI_BCAST` and `MPI_GATHER`**
- **Other routines will be summarised**
- **The diagrams are schematic**
  - Help to conceptualise the data movement
  - The MPI library and machine hardware may actually be doing a more complex (and hopefully efficient!) communication pattern
- **IFS uses a few collective routines, sometimes we hand code our own**

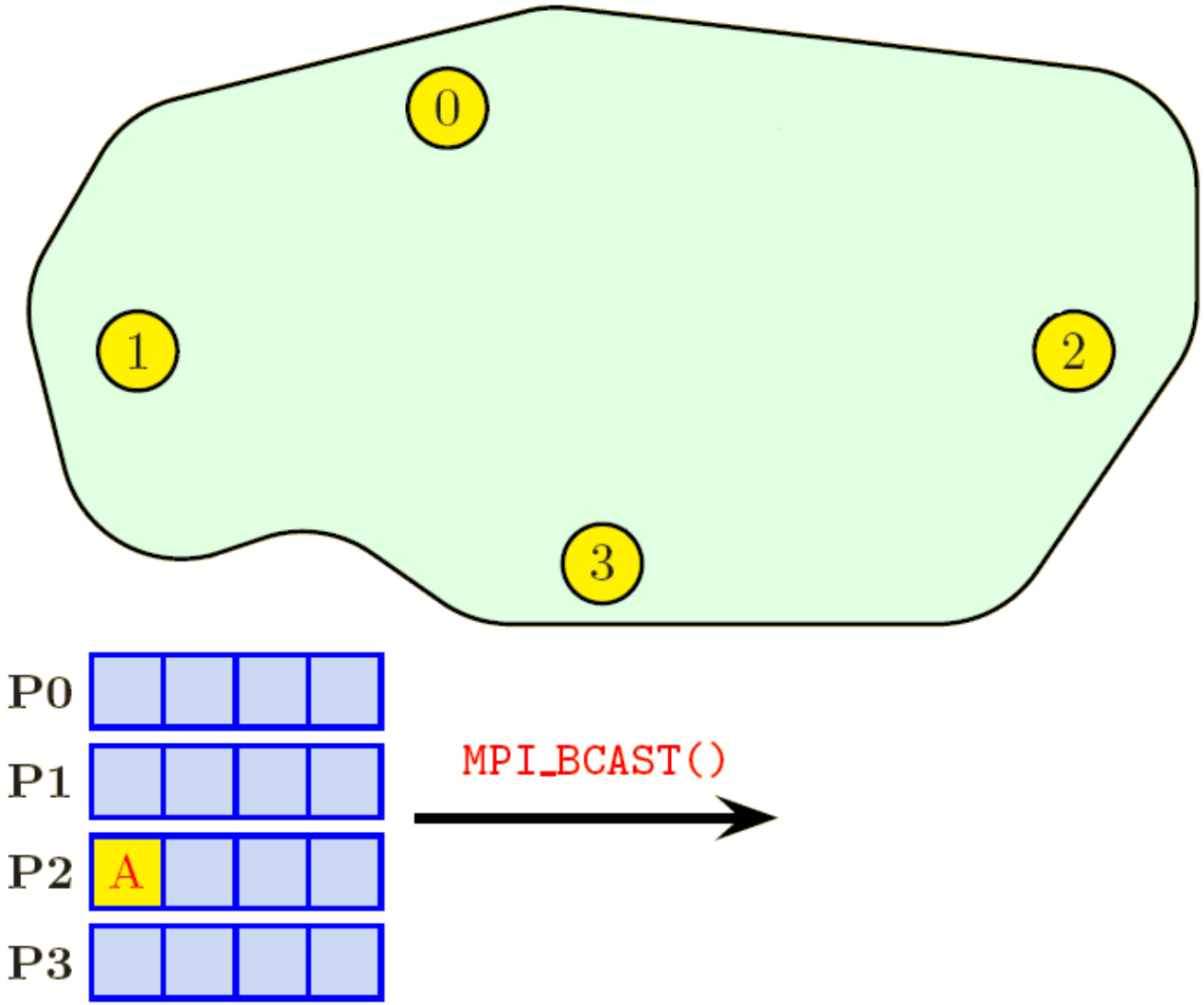
MPI_BCAST

```
FORTRAN_TYPE:: buff
integer:: count, root, ierror
call MPI_BCAST( buff,count,MPI_TYPE,root,MPI_COMM_WORLD,ierror)
```

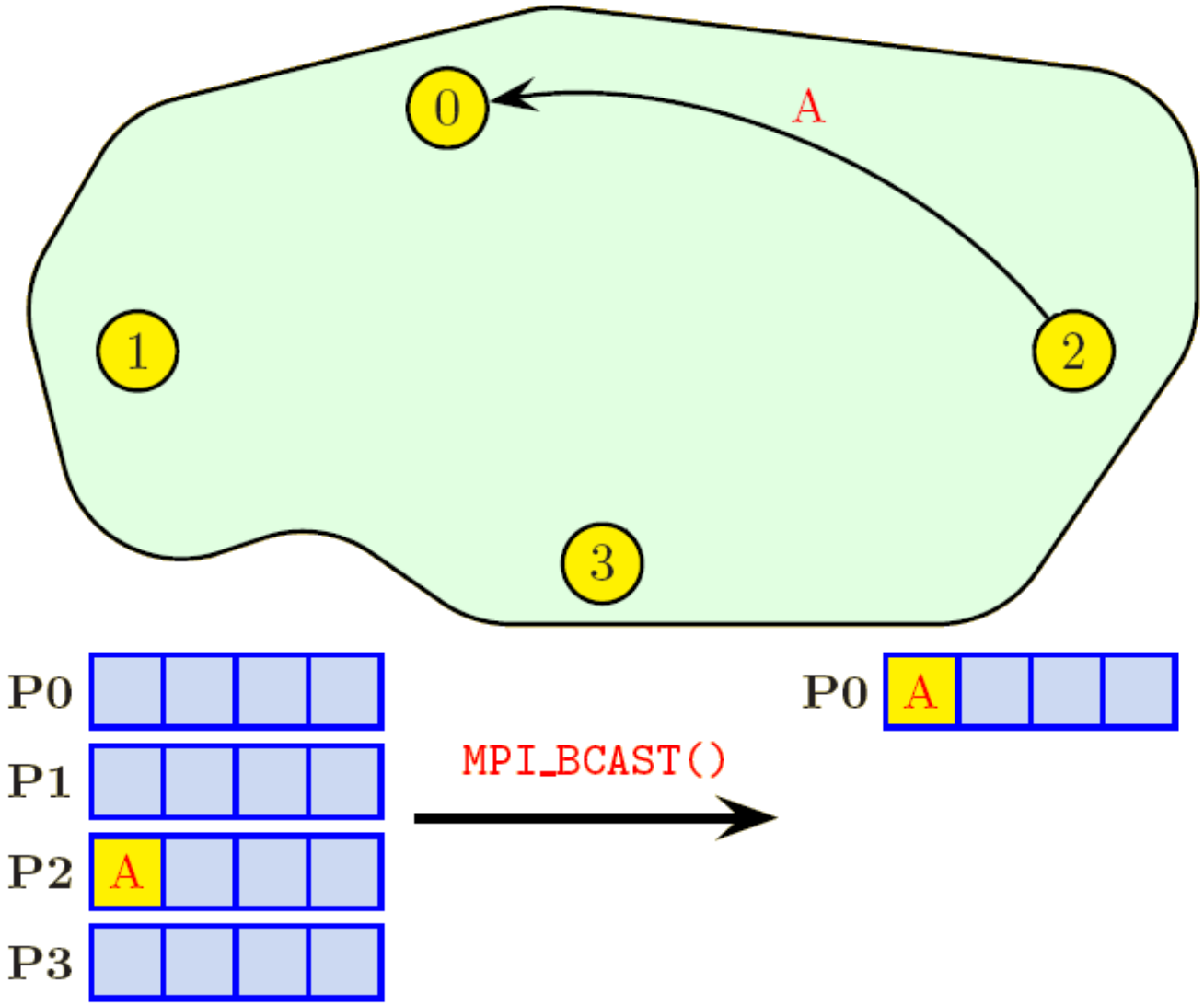
• **ROOT**	**task doing broadcast**	**input**
• **BUFF**	**array being broadcast**	**input/output**
• **COUNT**	**the number of elements**	**input**
• ***MPI_TYPE***	**the kind of variable**	**input**

The contents of `buff` are sent from task id `root` to all other tasks. Each task receives the full array. Equivalent to putting `MPI_SEND` in a loop and matching `MPI_RECVs`

MPI_BCAST



MPI_BCAST



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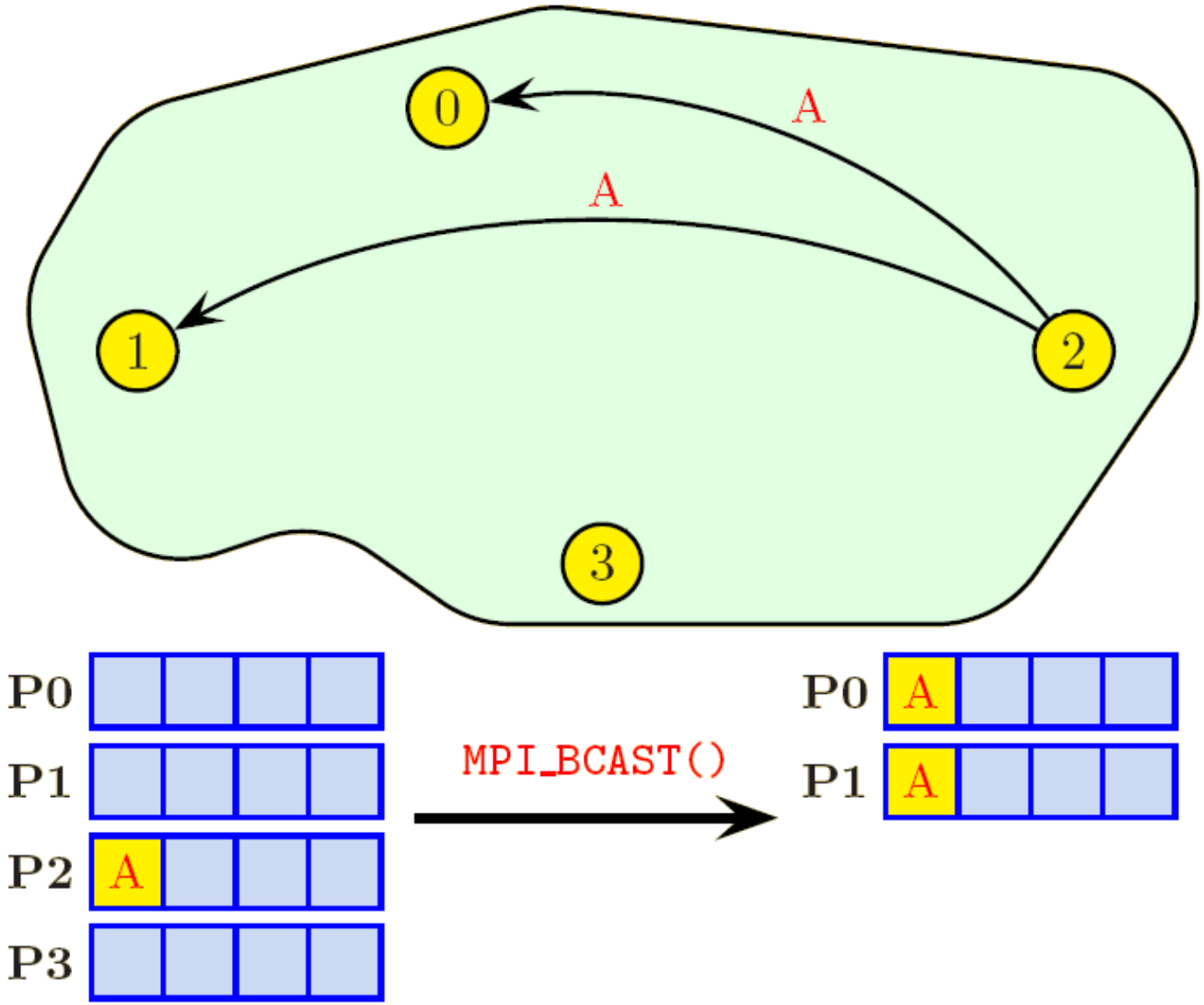
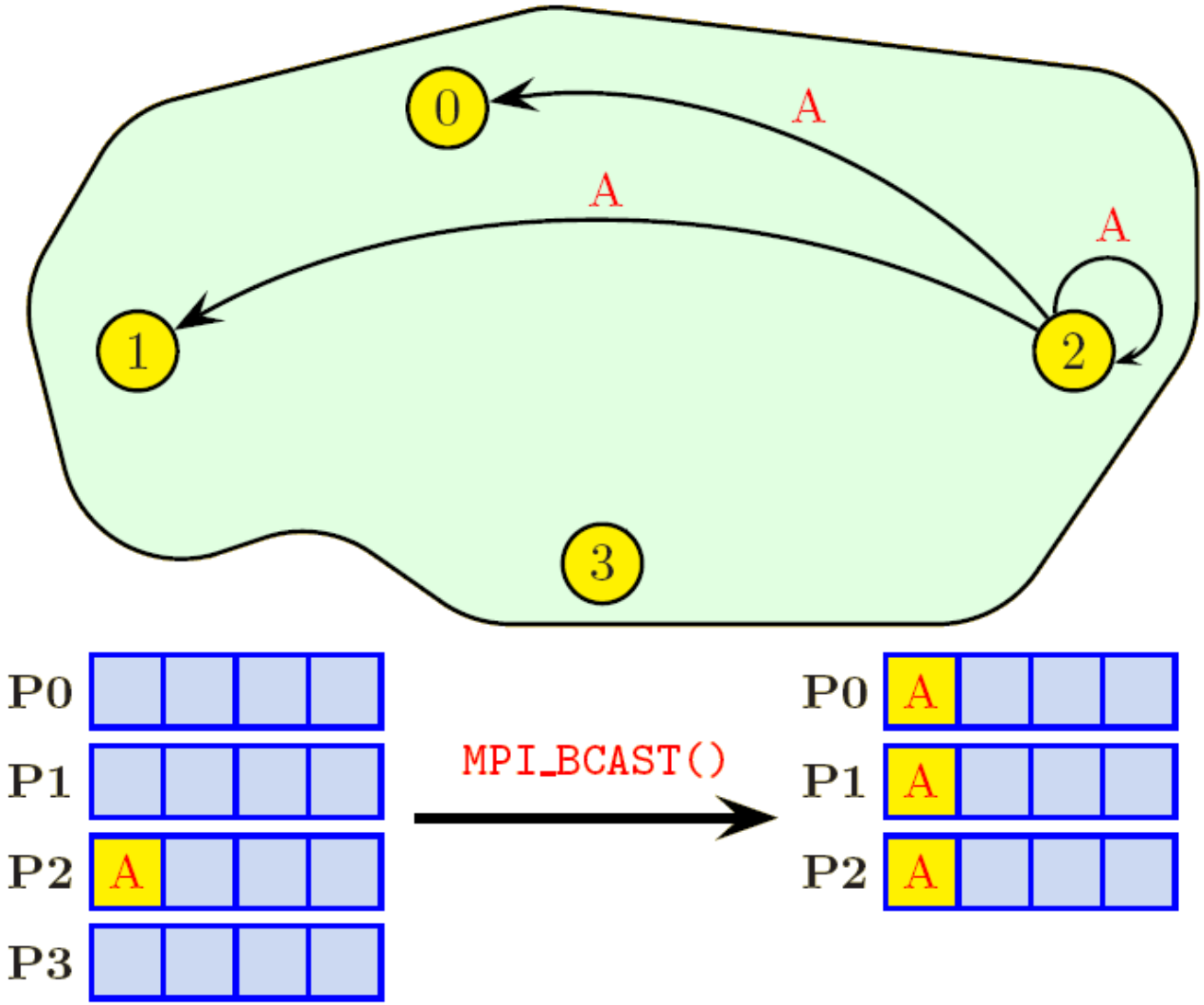
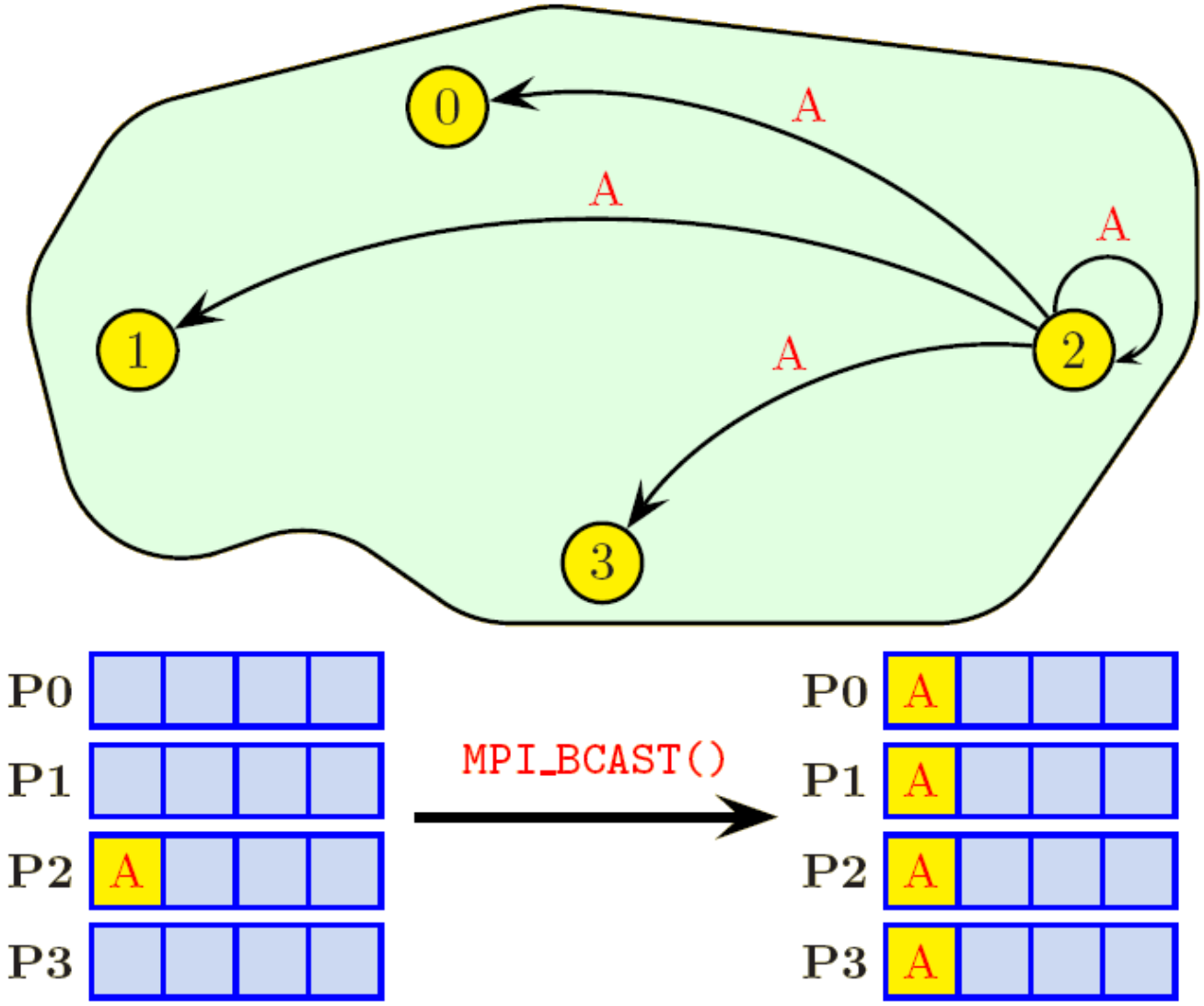


MPI_BCAST



MPI_BCAST



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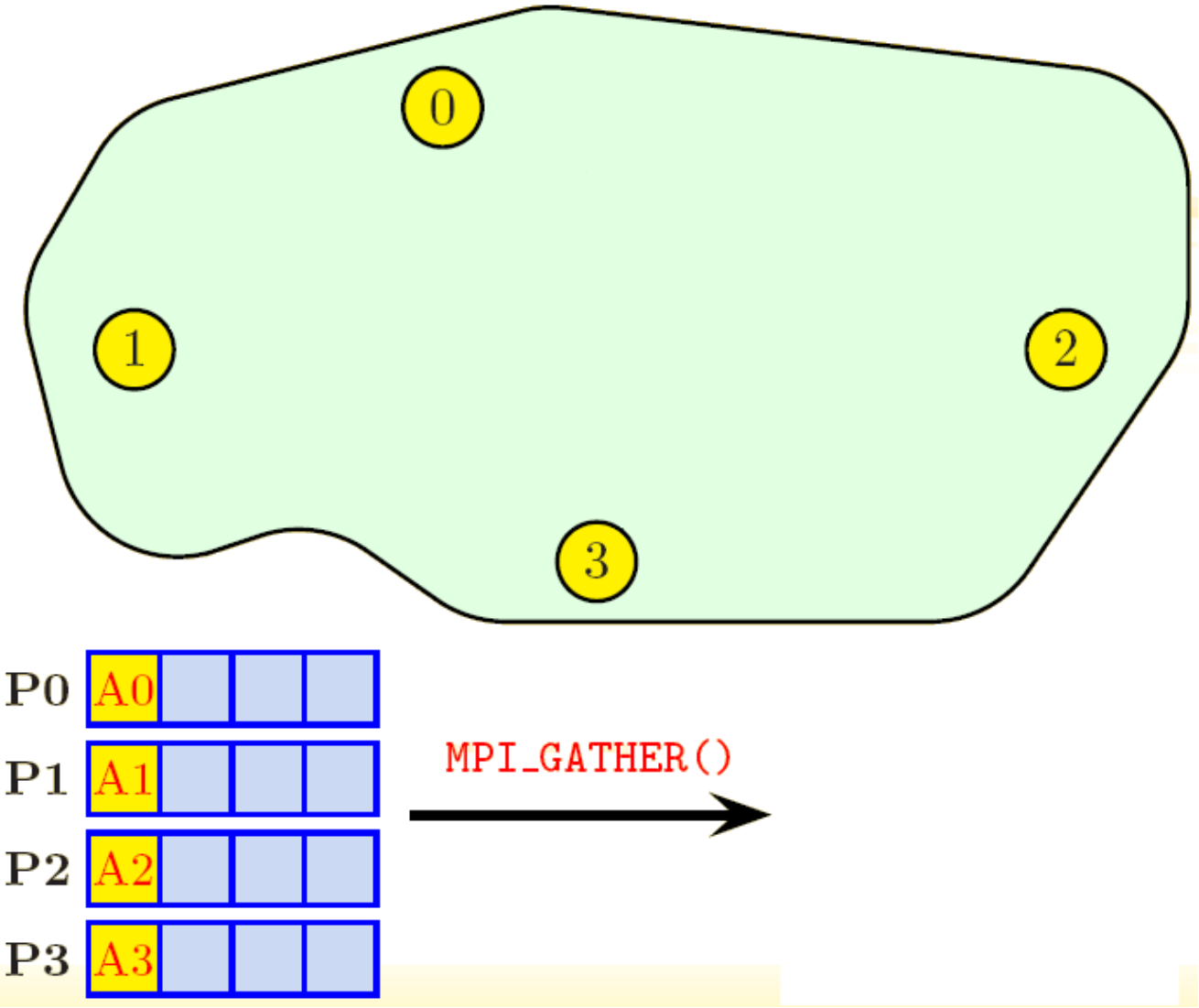
MPI_GATHER

```
FORTRAN_TYPE:: sbuff, rbuff
integer:: count, root, ierror
call MPI_GATHER( sbuff,scount,MPI_TYPE, &
                 rbuff,rcount,MPI_TYPE,root,MPI_COMM_WORLD,ierror)
```

ROOT	**task doing gather**	**input**
SBUFF	**array being sent**	**input**
RBUFF	**array being received**	**output**
[S/R]COUNT	**number of items to/from each task**	**input**

The contents of `sbuff` are sent from every task to task id `root` and received (concatenated in rank order) in array `rbuff`. Could also be done by putting `MPI_RECV` in a loop.

MPI_GATHER



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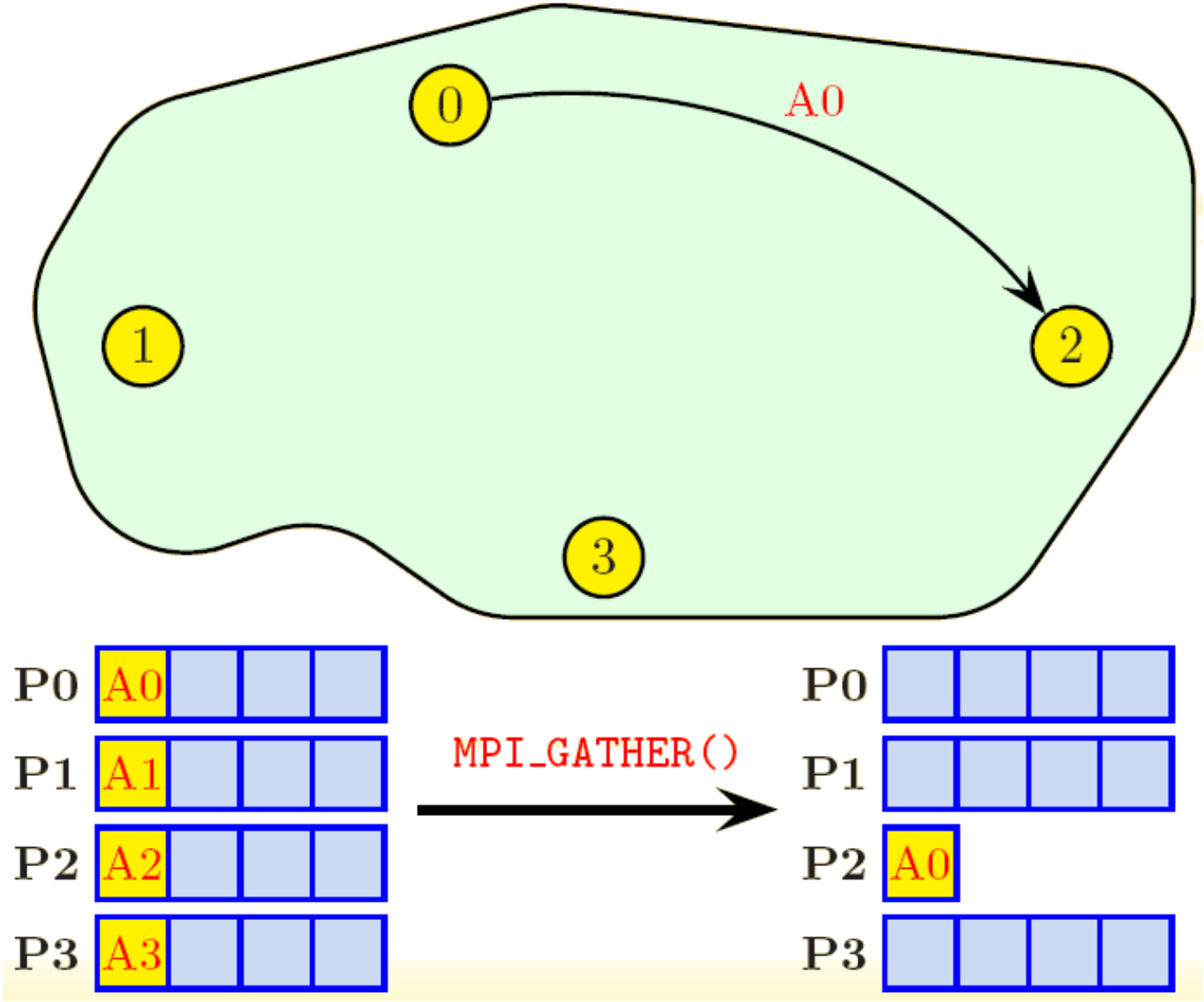

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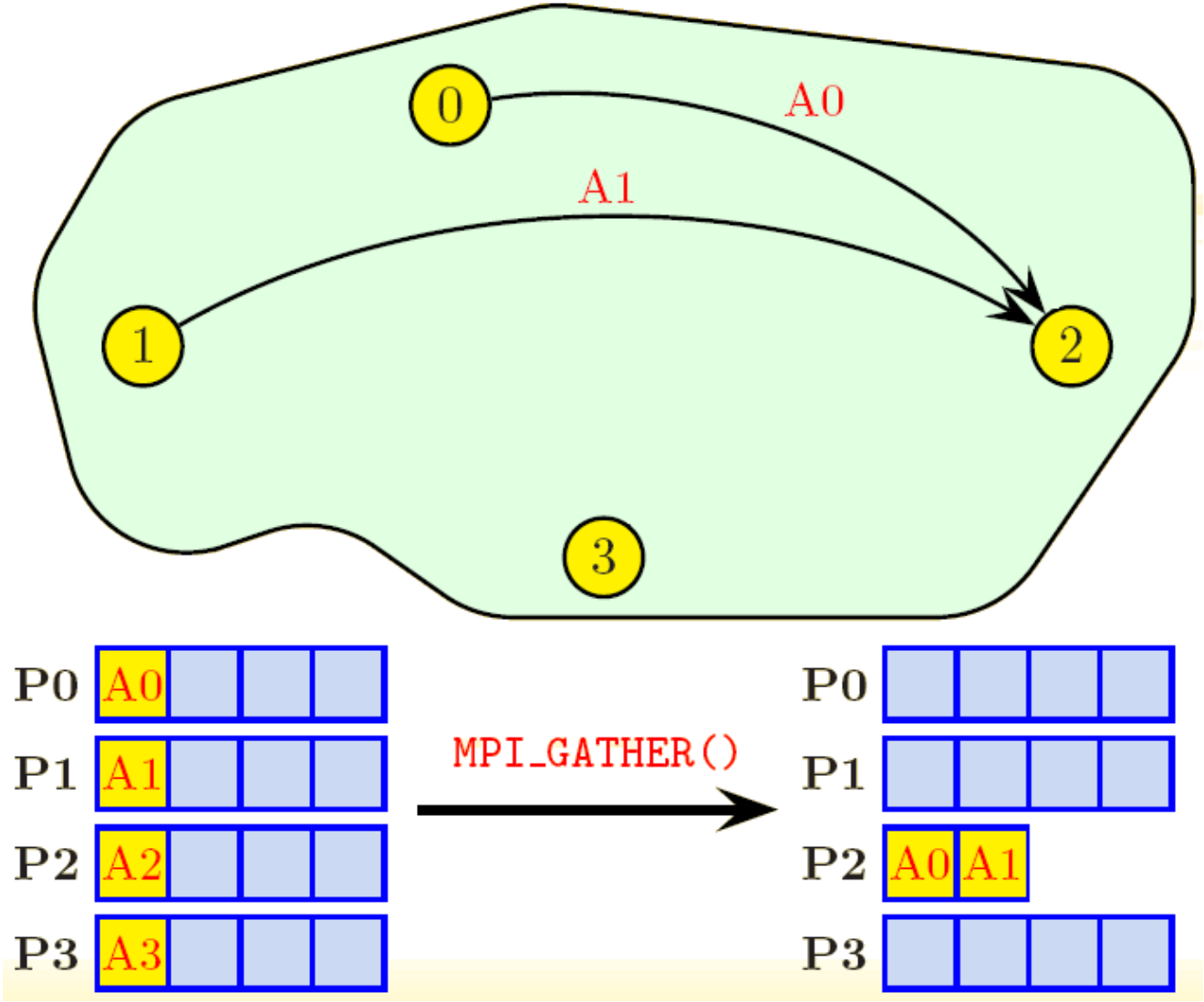
MPI_GATHER



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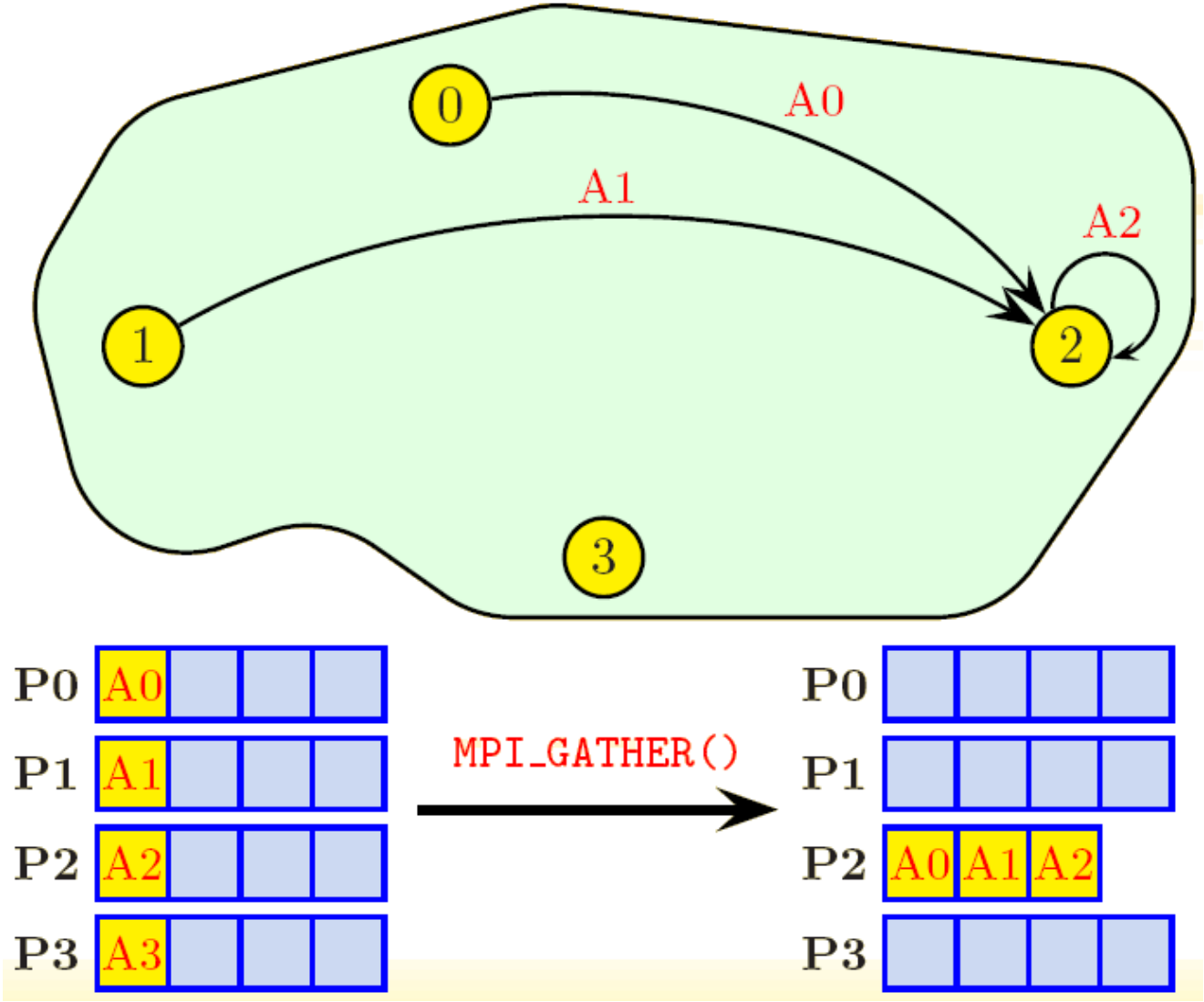
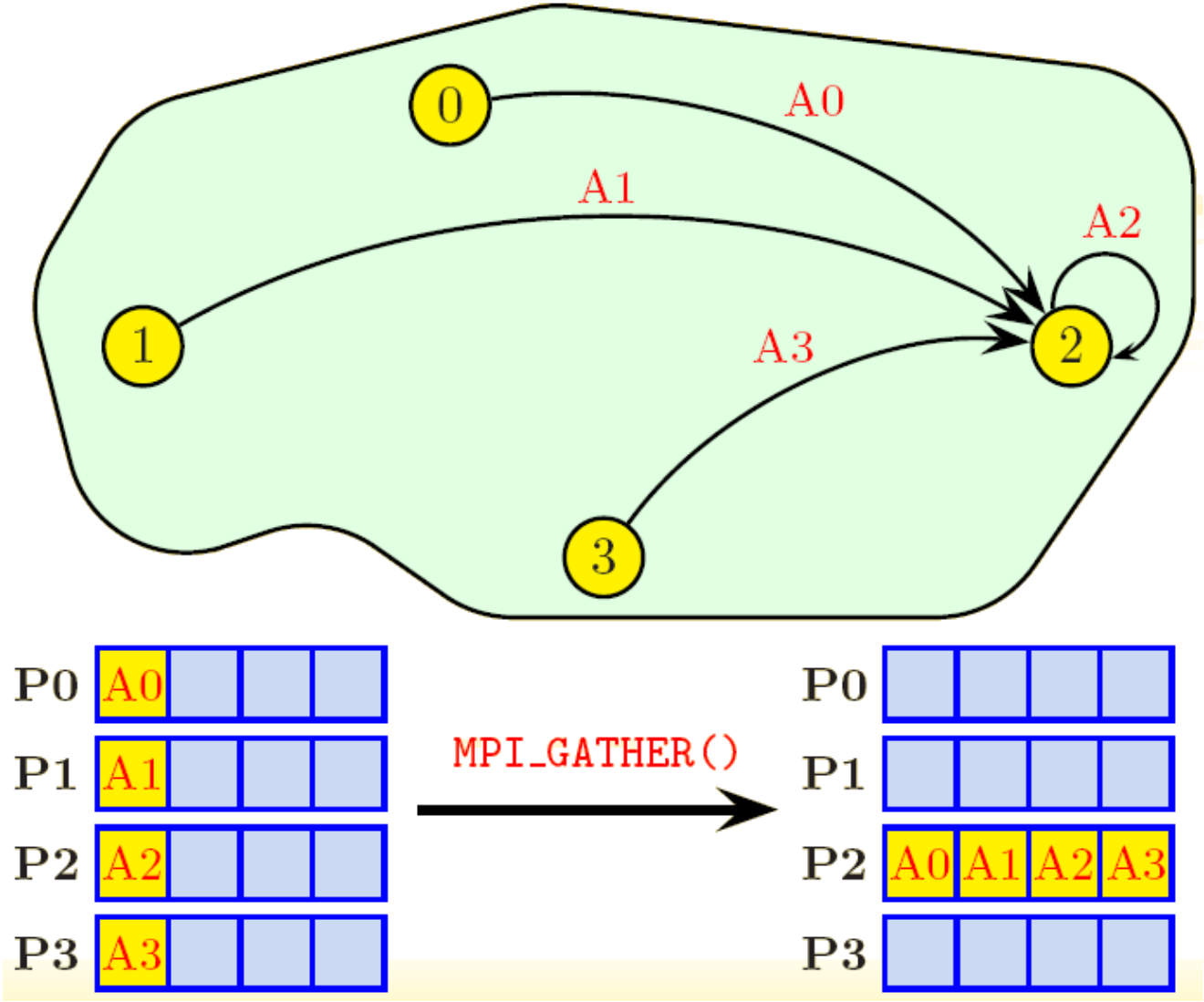


MPI_GATHER



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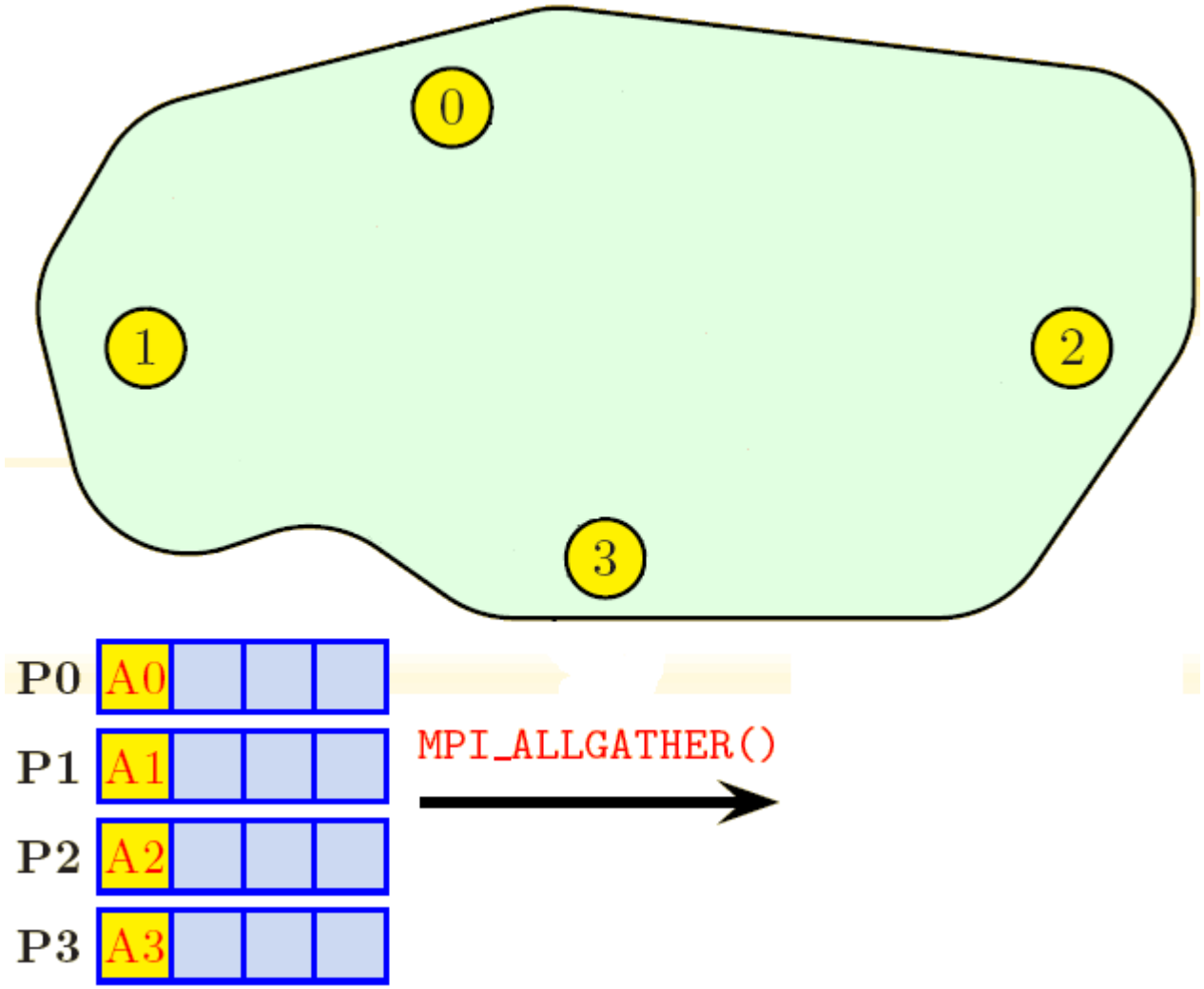
Gather Routines

- **`MPI_ALLGATHER`**
  - gather arrays of equal length into one array on all tasks
  - Equivalent to doing `MPI_GATHER` followed by `MPI_BCAST`
- **`MPI_GATHERV`**
  - gather arrays of different lengths into one array on one task
- **`MPI_ALLGATHERV`**
  - gather arrays of different lengths into one array on all tasks
- **Where do you think these may be useful?**

MPI_ALLGATHER



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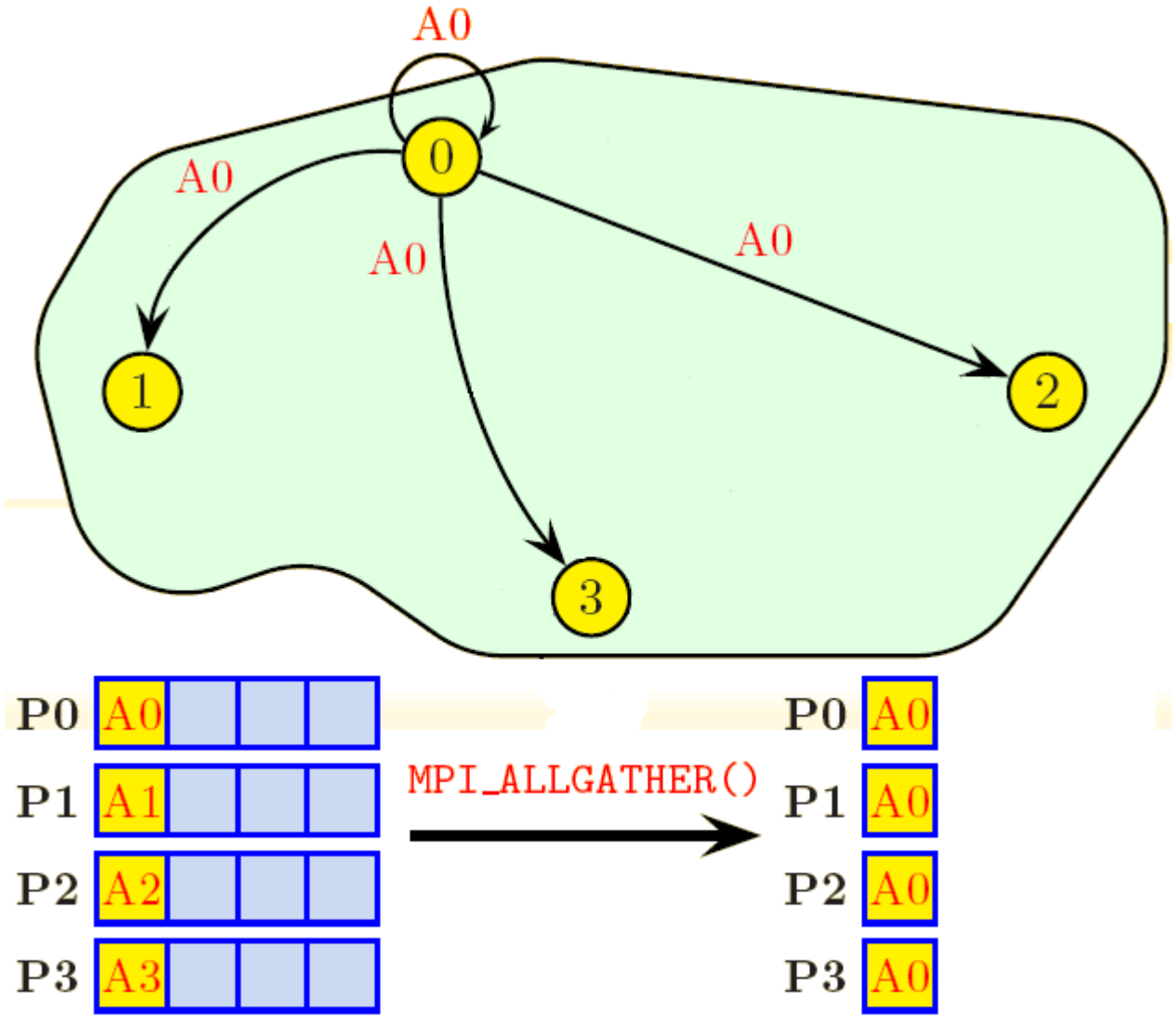
MPI_ALLGATHER



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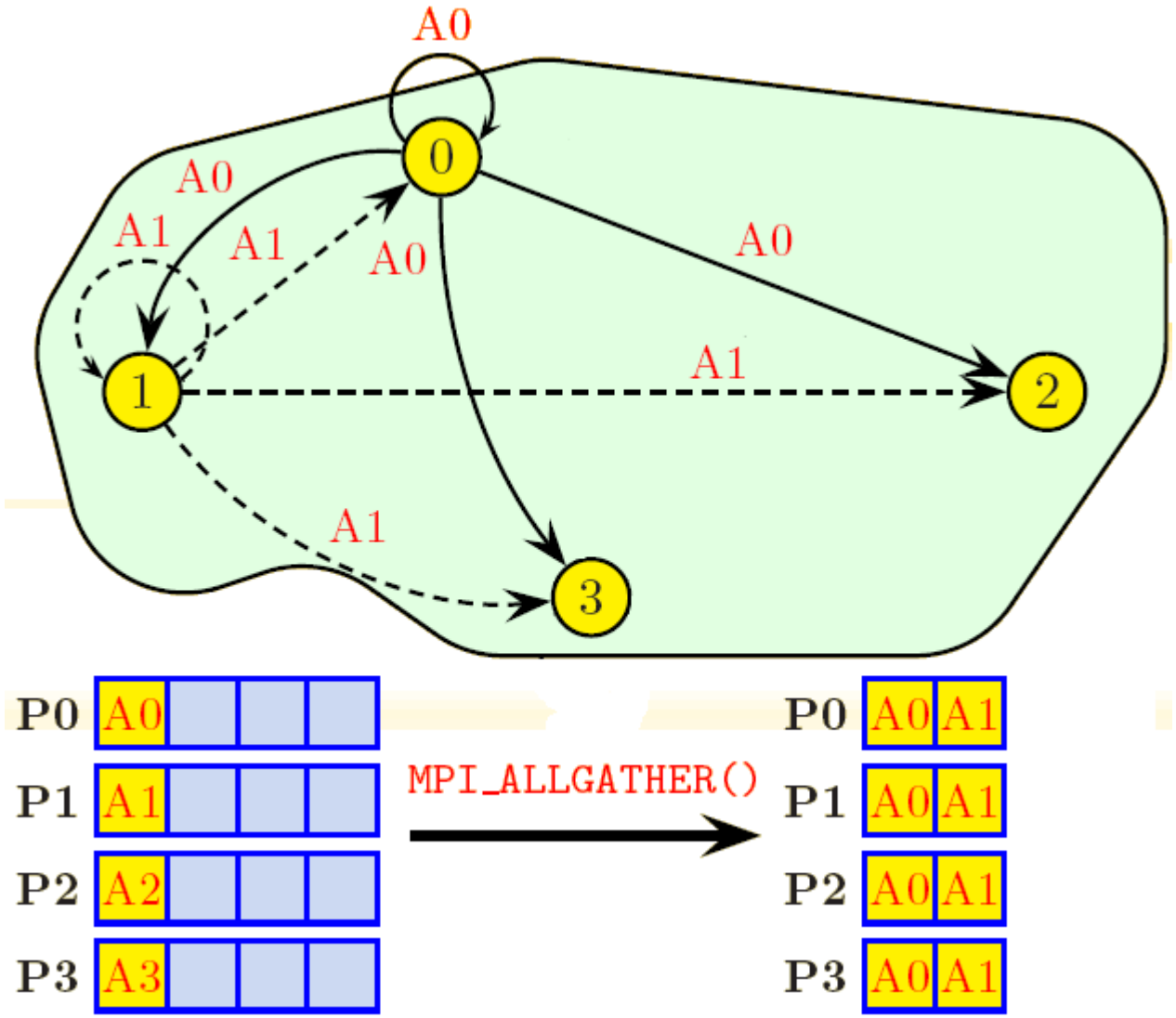
MPI_ALLGATHER



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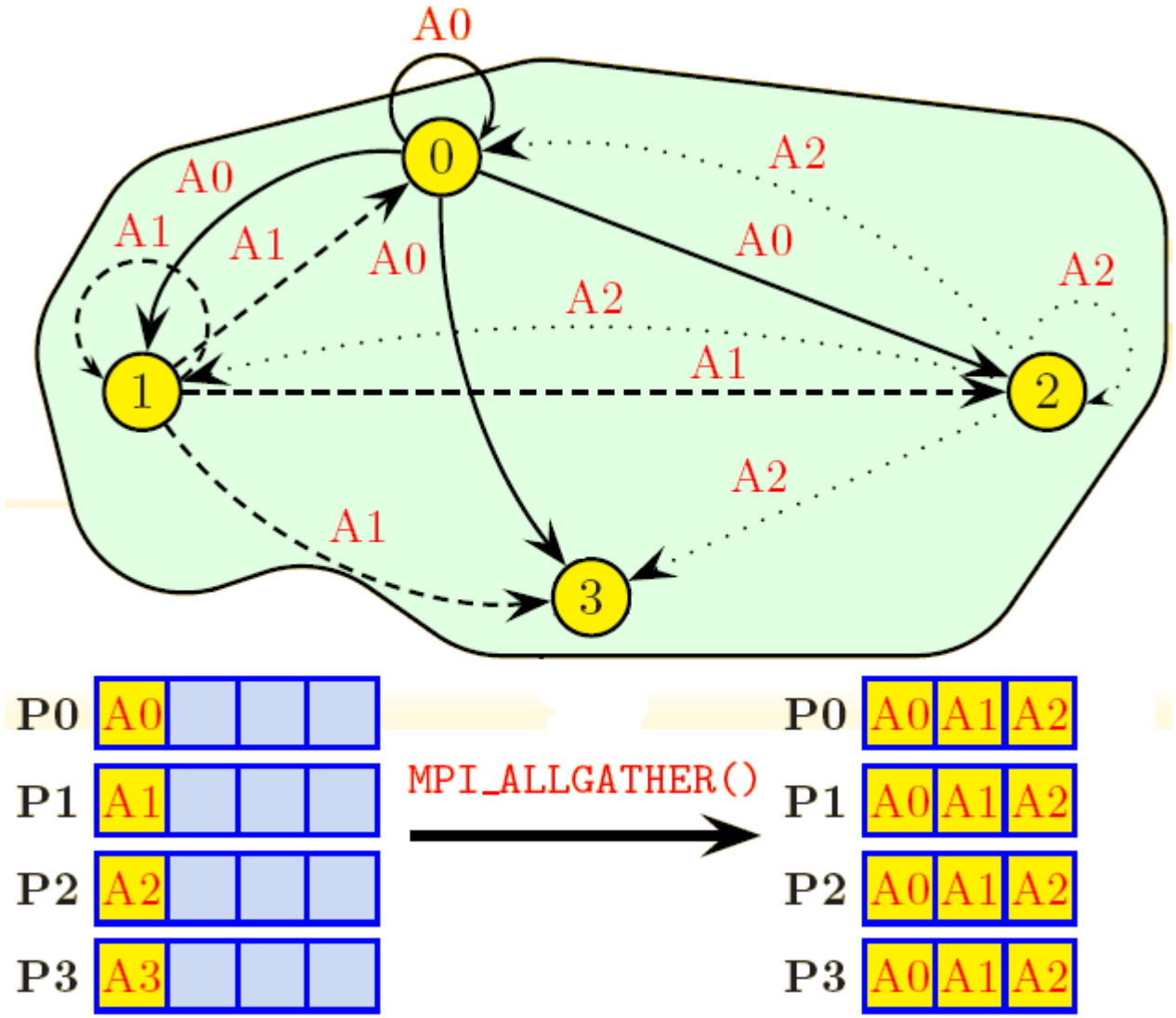
MPI_ALLGATHER



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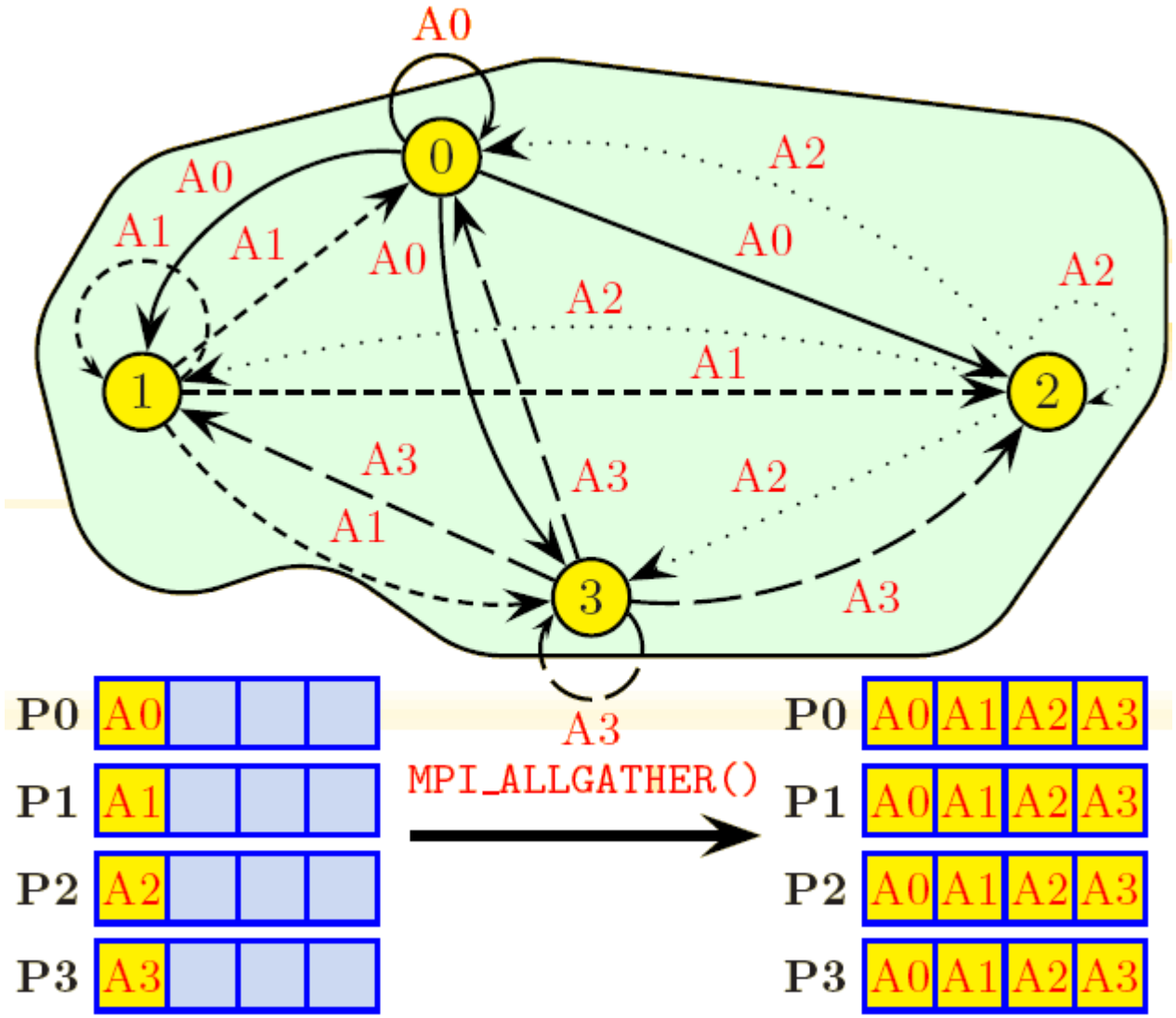
MPI_ALLGATHER



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Scatter Routines

- **`MPI_SCATTER`**
  - **divide one array on one task equally amongst all tasks**
  - **each task receives the same amount of data**

- **`MPI_SCATTERV`**
  - **divide one array on one task unequally amongst all tasks**
  - **each task can receive a different amount of data**

- **Where do you think they might be useful?**

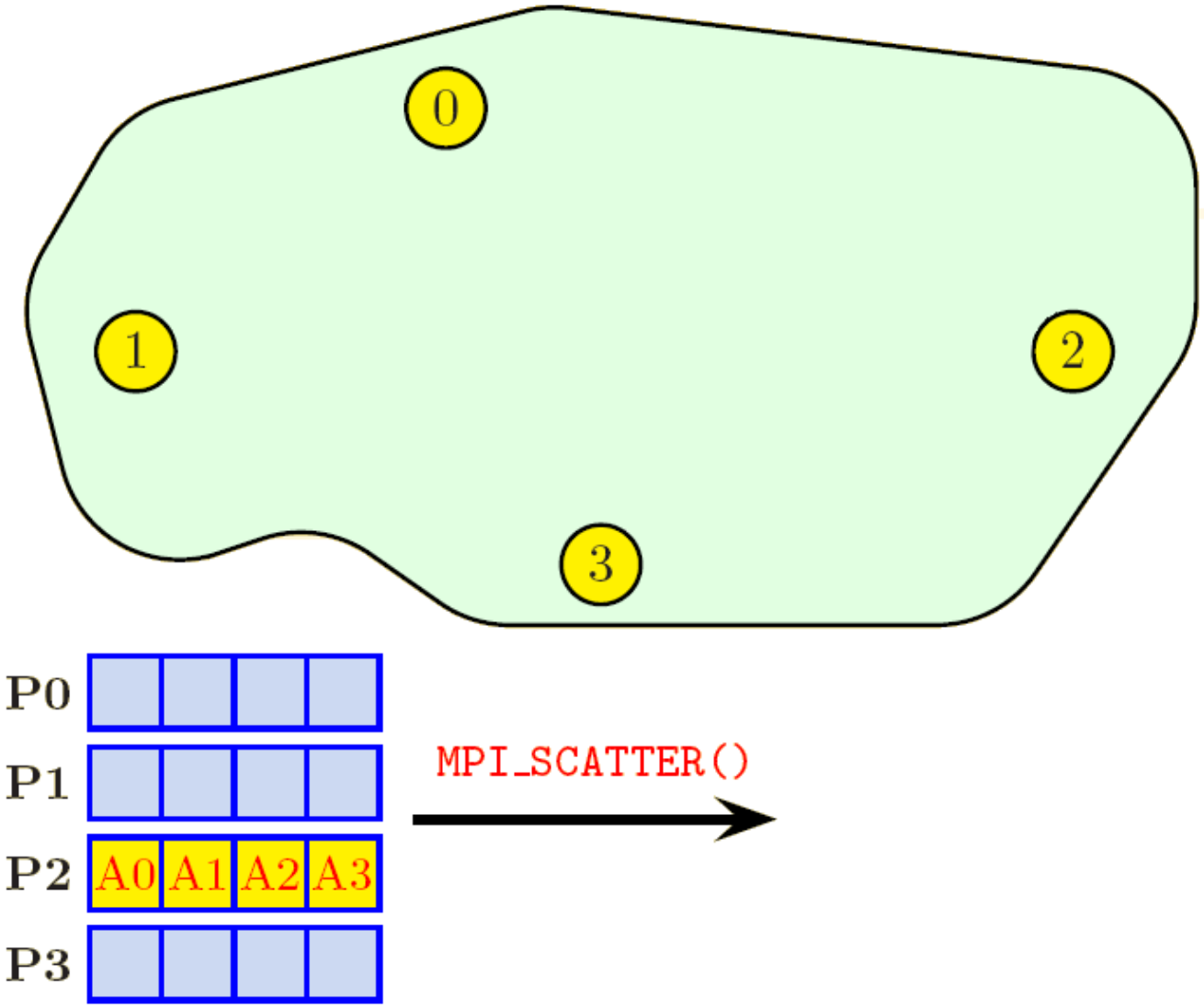
MPI_SCATTER

```
FORTRAN_TYPE:: sbuff, rbuff
integer:: count, root, ierror
call MPI_SCATTER( sbuff,scount,MPI_TYPE, &
                  rbuff,rcount,MPI_TYPE,root,MPI_COMM_WORLD,ierror)
```

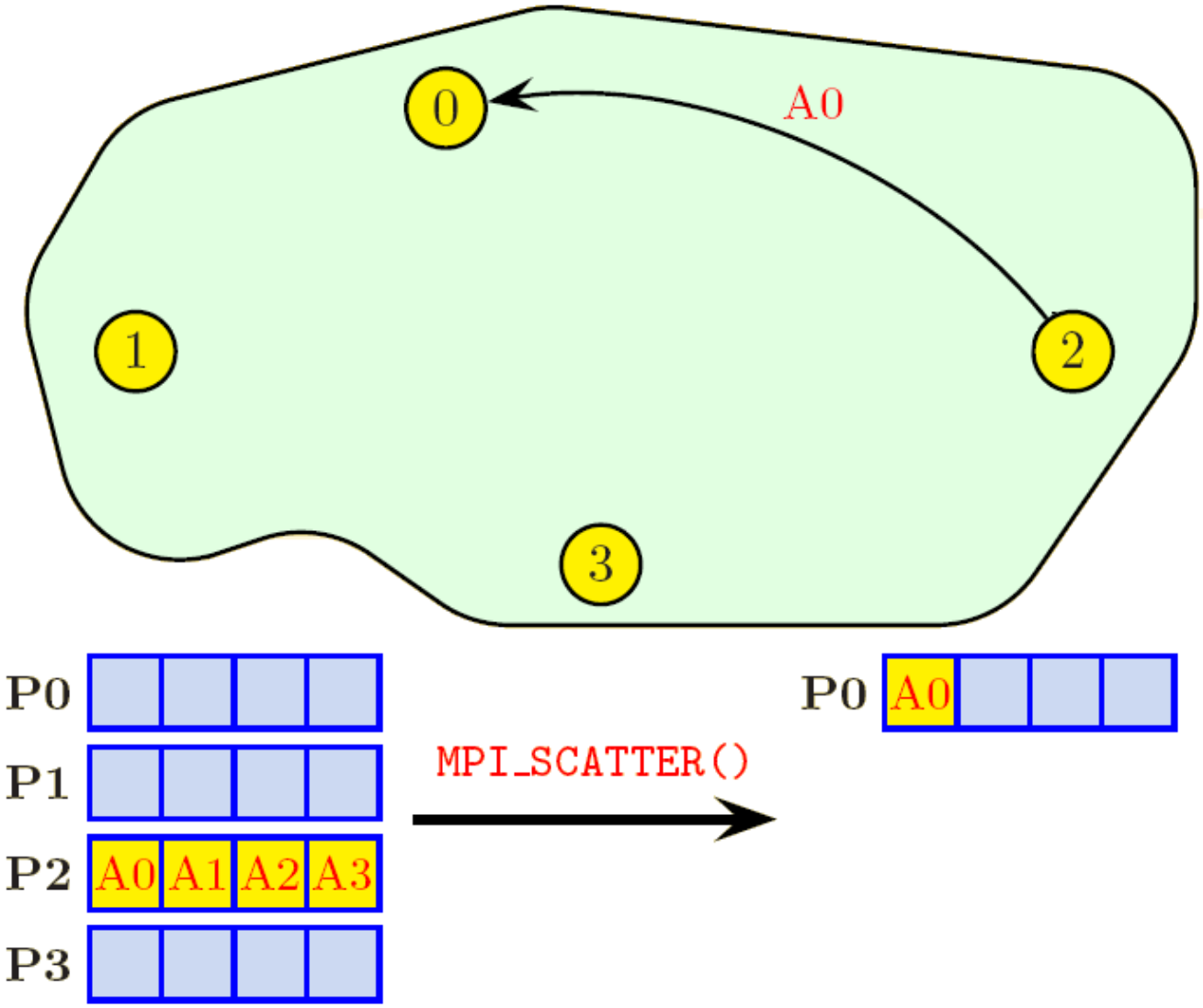
- **ROOT** — **task doing scatter** — **input**
- **SBUFF** — **array being sent** — **input**
- **RBUFF** — **array being received** — **output**
- **[S/R]COUNT** — **number of items to/from each task** — **input**

The contents of `sbuff` on task id `root` are equally split and each task receives its part in array `rbuff`. Could also be done by putting `MPI_SEND` in a loop.

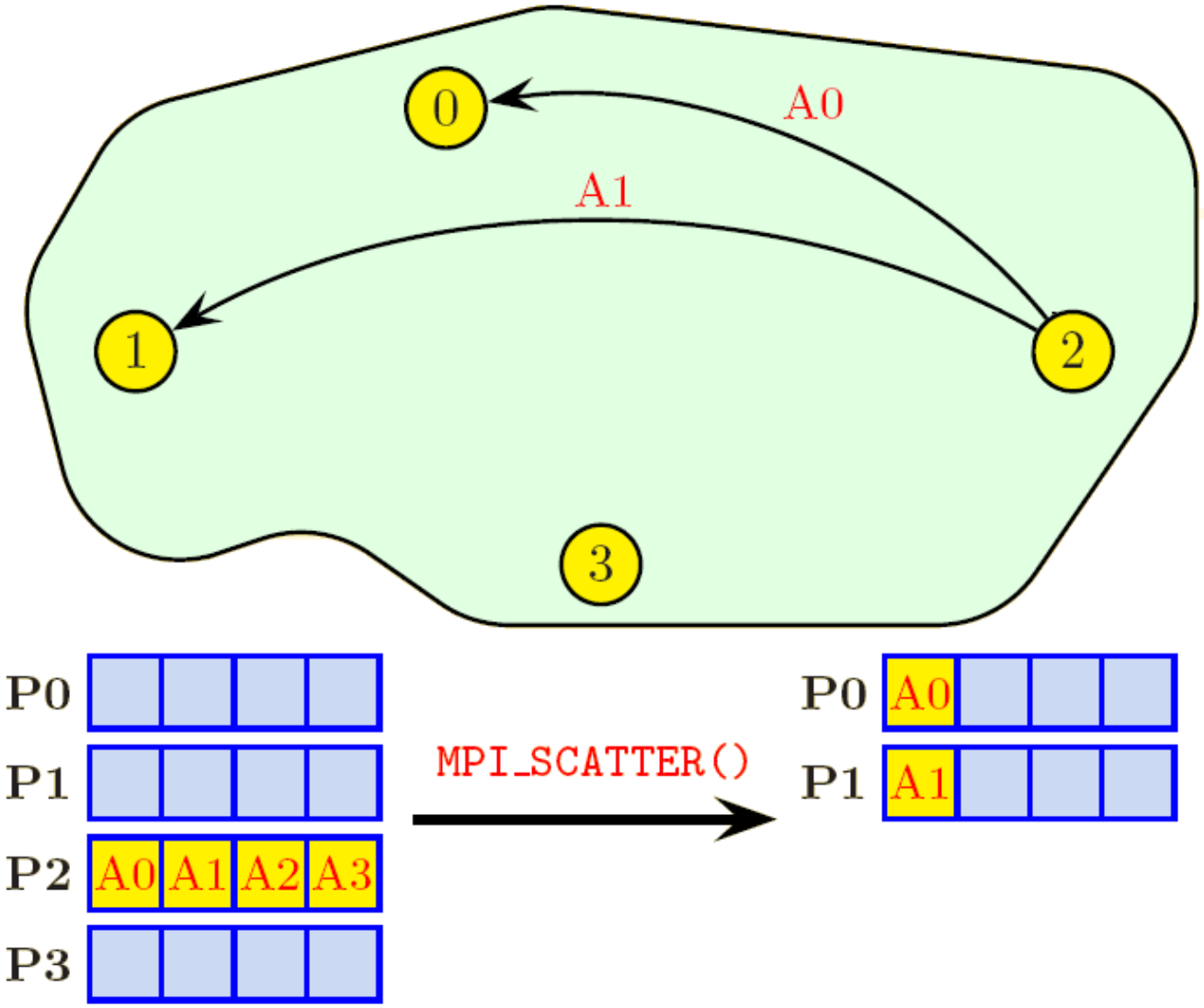
MPI_SCATTER



MPI_SCATTER



MPI_SCATTER



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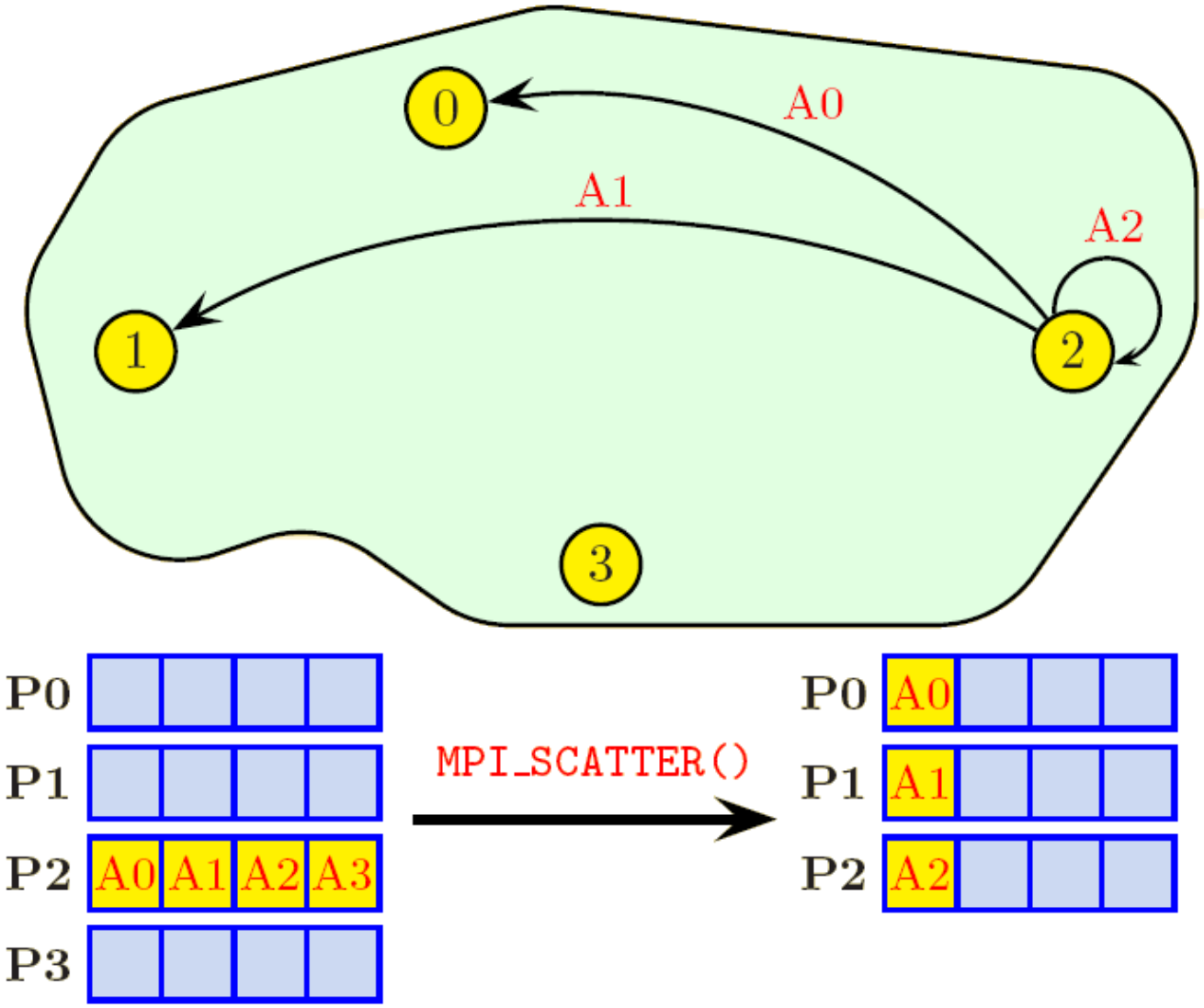
MPI_SCATTER



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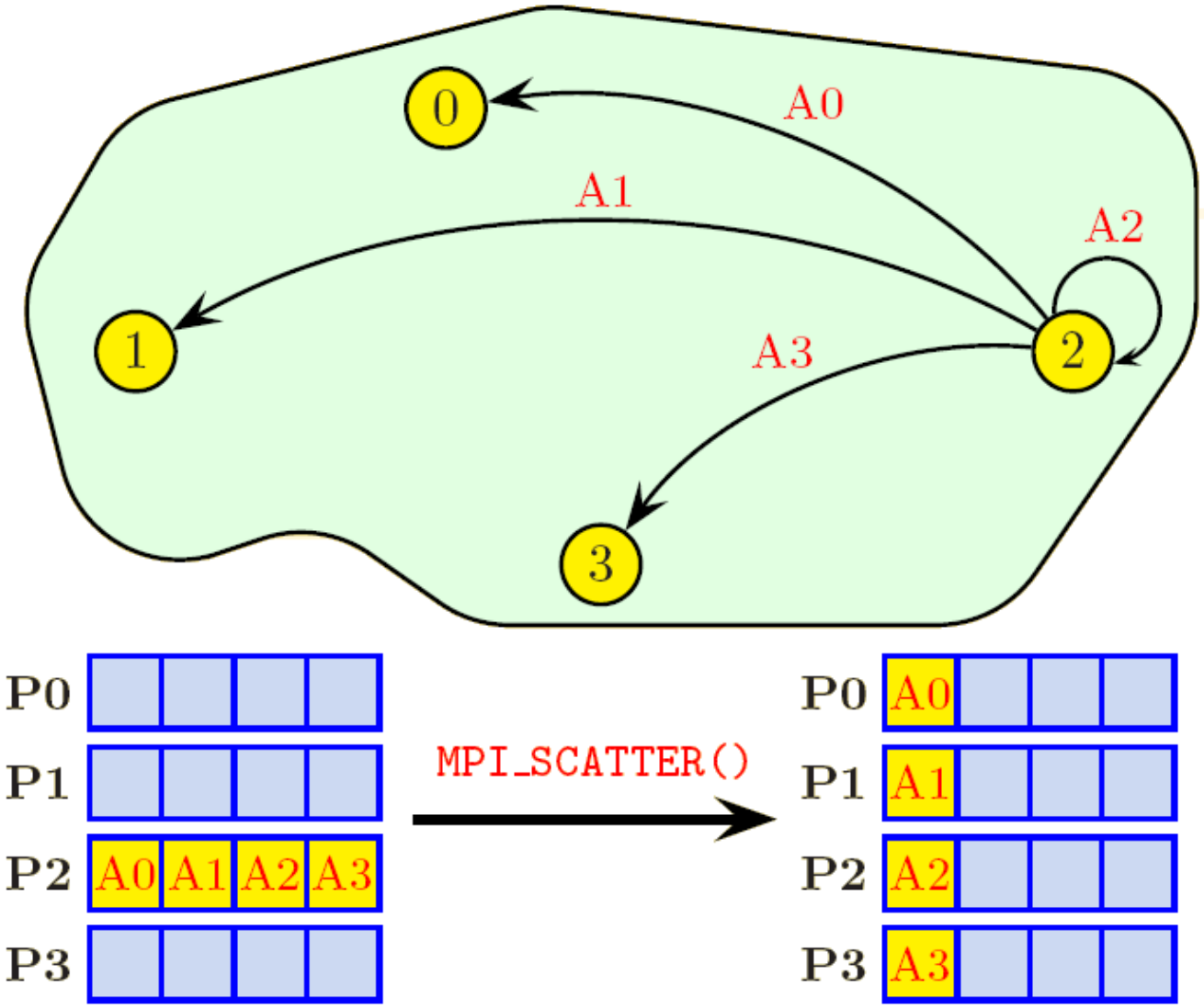
MPI_SCATTER



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All to All Routines

- **`MPI_ALLTOALL`**
  - **every task sends equal length parts of an array to all other tasks**
  - **every task receives equal parts from all other tasks**
  - **transpose of data over the tasks**

- **`MPI_ALLTOALLV`**
  - **as above but parts are different lengths**

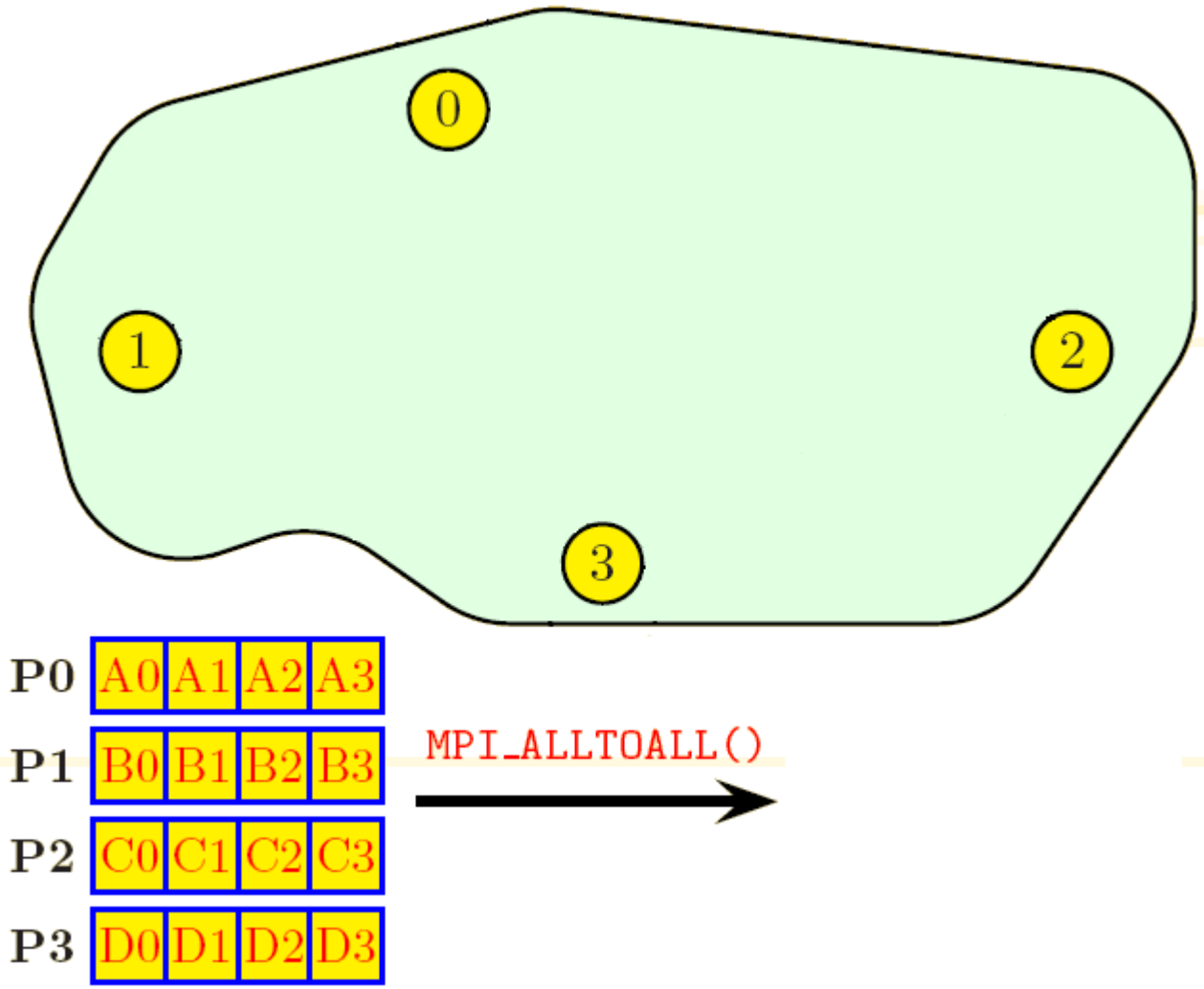
MPI_ALLTOALL

```
FORTRAN_TYPE:: sbuff, rbuff
integer:: count, root, ierror
call MPI_SCATTER( sbuff,scount,MPI_TYPE, &
                  rbuff,rcount,MPI_TYPE,MPI_COMM_WORLD,ierror)
```

- **SBUFF** — **array being sent** — **input**
- **RBUFF** — **array being received** — **output**
- **[S/R]COUNT** — **number of items to/from each task** — **input**

The contents of `sbuff` on each task are equally split and each task receives an equal part into array `rbuff`. Could also be done by putting `MPI_SEND/MPI_RECV` in a loop.

MPI_ALLTOALL



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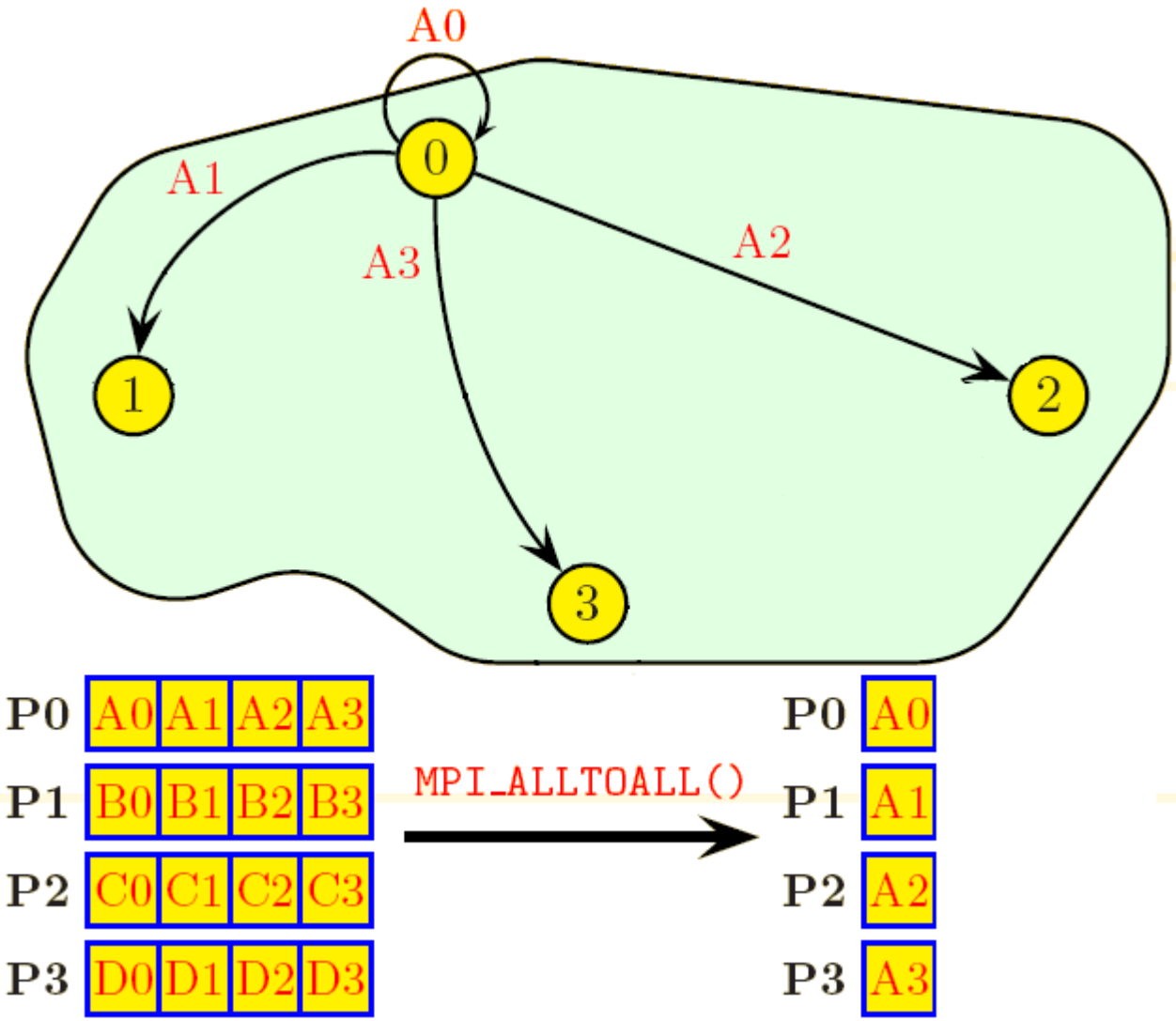
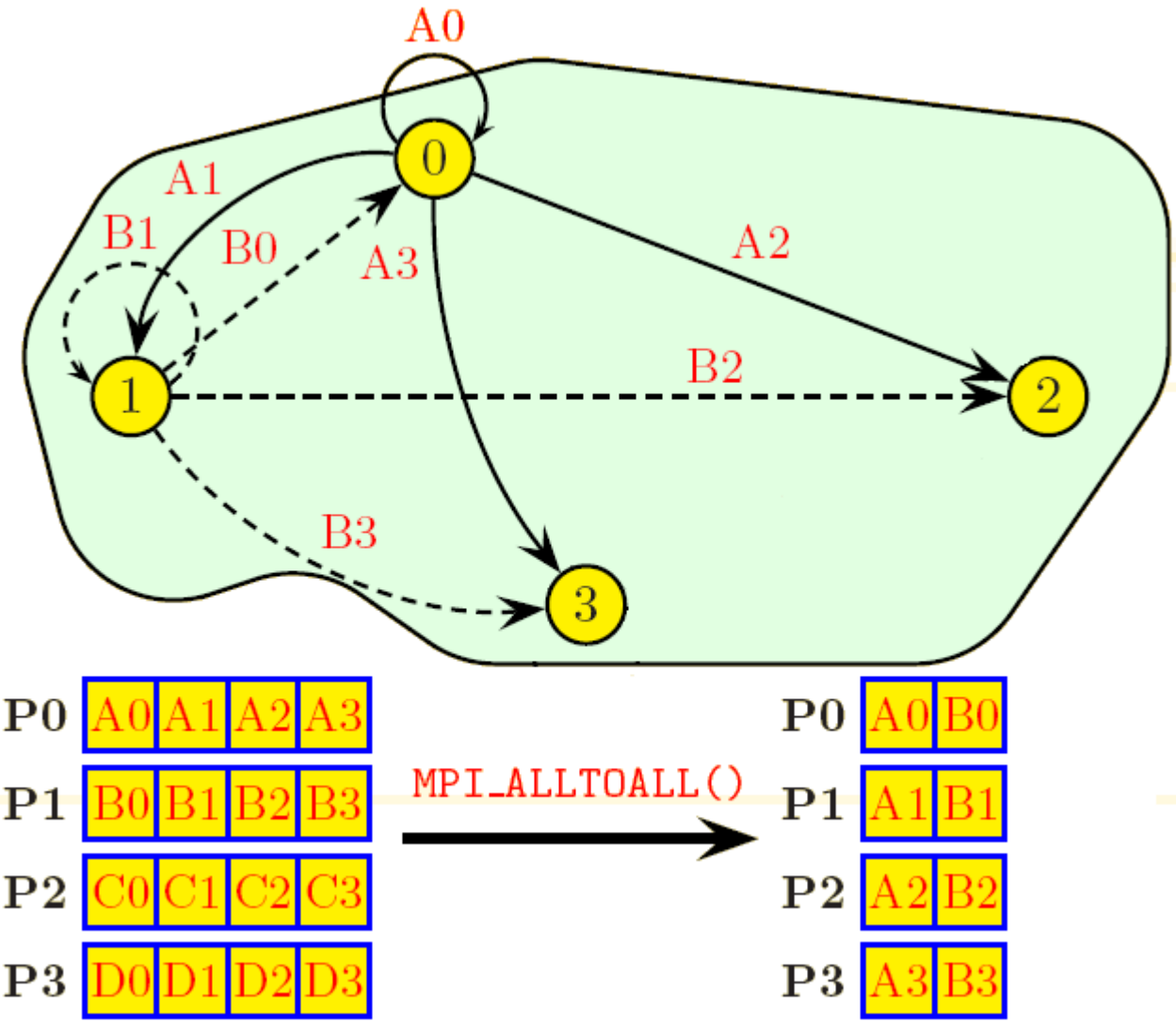
MPI_ALLTOALL



IDRIS-CNRS

MPI_ALLTOALL



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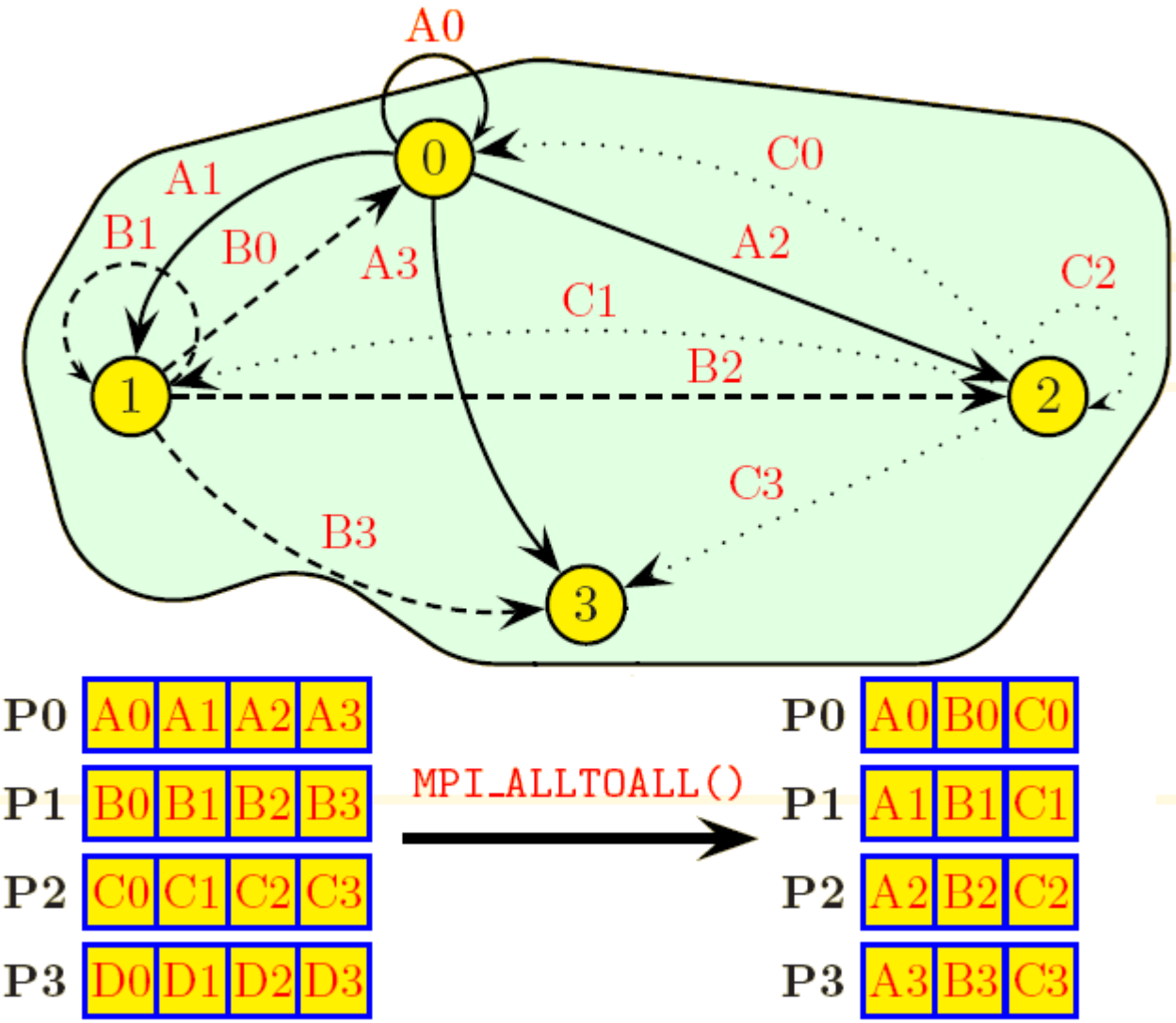
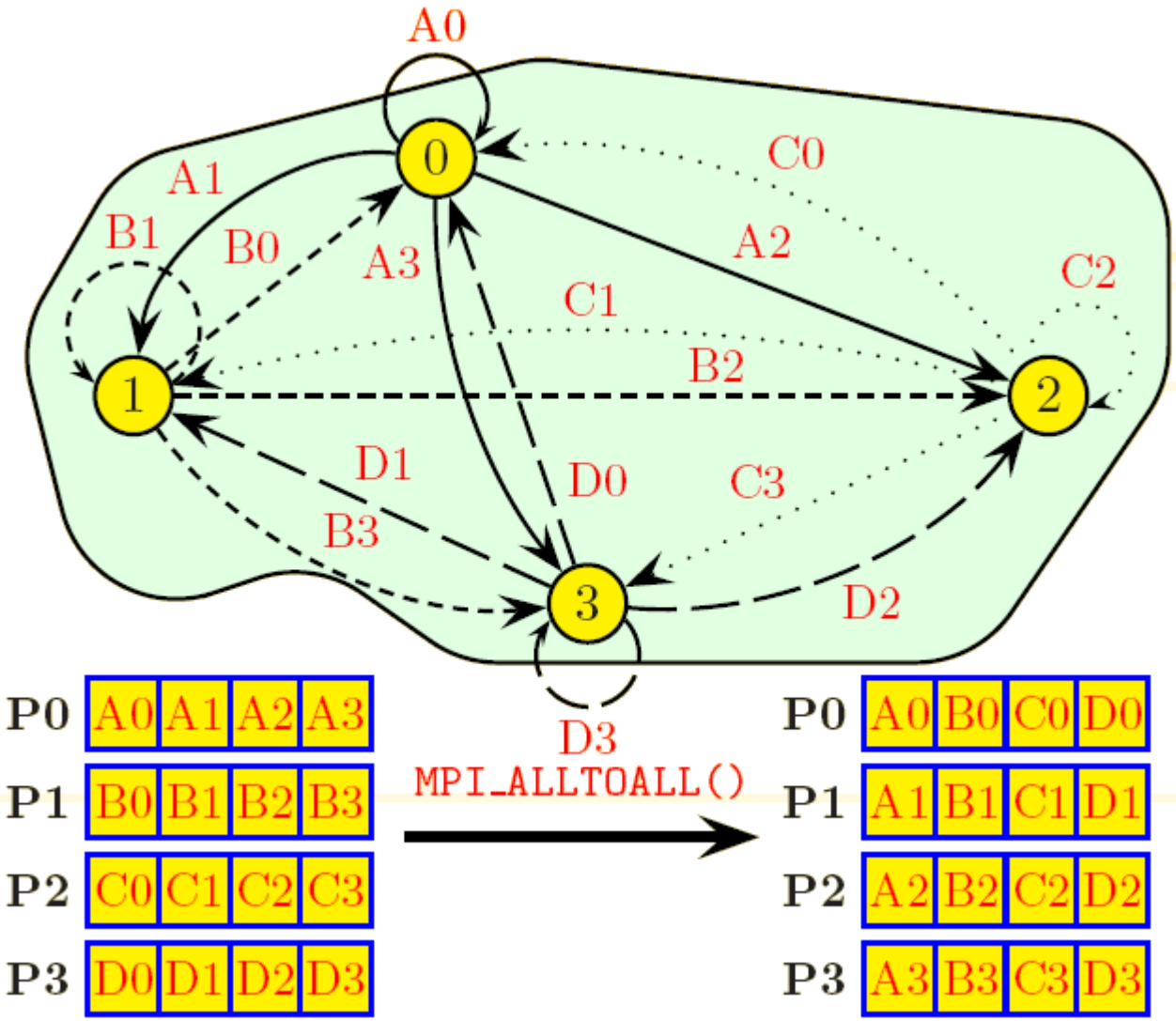
MPI_ALLTOALL



IDRIS-CNRS

MPI_ALLTOALL



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Reduction routines

- **Perform both communications and simple maths**
  - **Global sum, min, max, ...**
- **Beware reproducibility**
  - **MPI makes no guarantee of reproducibility**
    - **Eg. Summing an array of real numbers from each task**
    - **May be summed in a different order each time**
  - **You may need to write your own order preserving summation if reproducibility is important to you.**
- **`MPI_REDUCE`**
  - **every task sends data and result is computed on the "root" task**
- **`MPI_ALLREDUCE`**
  - **every task sends, result is computed and broadcast back to all tasks. Equivalent to `MPI_REDUCE` followed by `MPI_BCAST`**

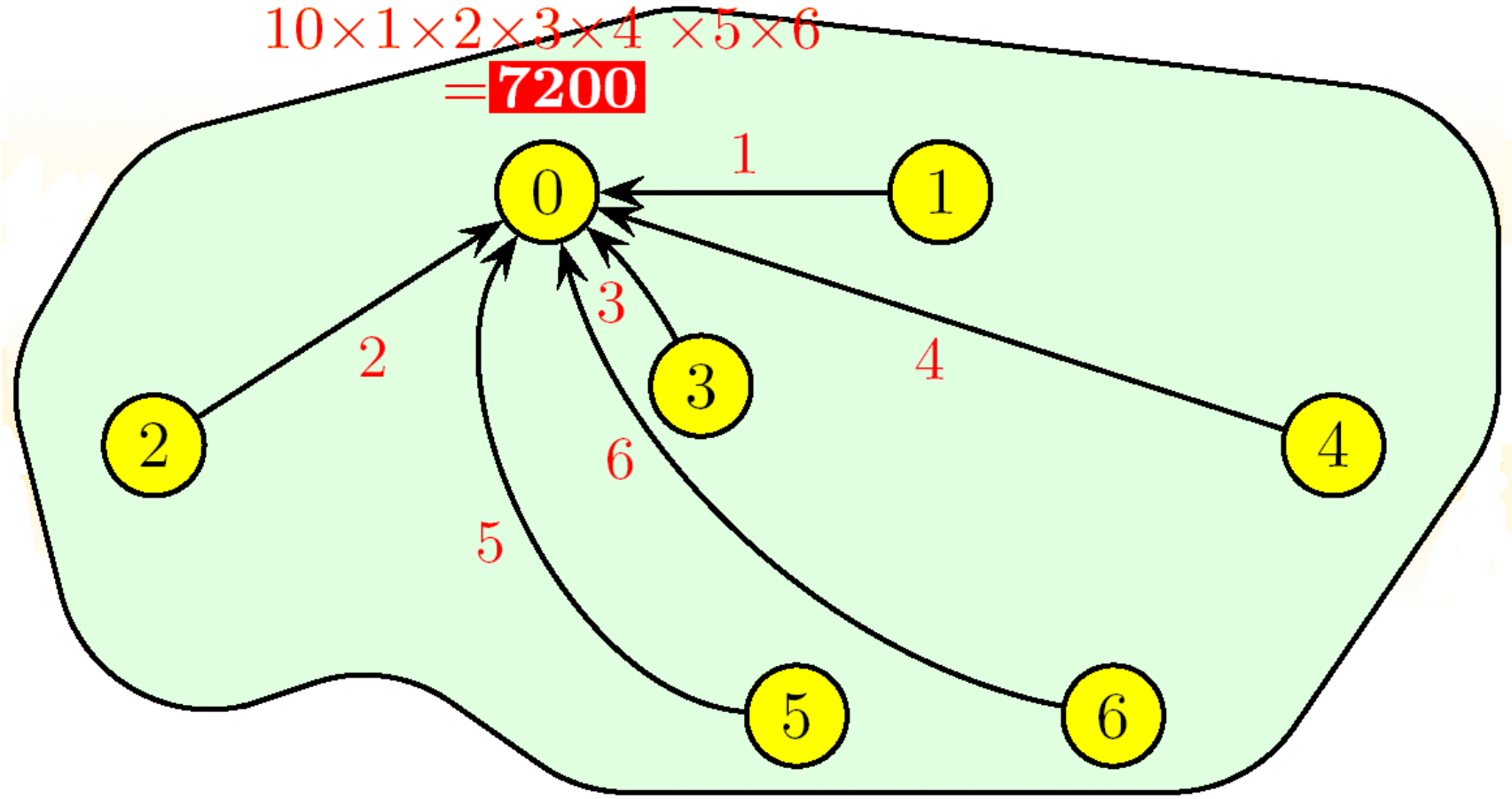
MPI_REDUCE

```
FORTRAN_TYPE:: sbuff, rbuff
integer:: count, root, ierror
call MPI_REDUCE( sbuff,rbuff,count,MPI_TYPE,OP_TYPE, &
                 root,MPI_COMM_WORLD,ierror)
```

- **SBUFF** — **array to be reduced** — **input**
- **RBUFF** — **result of reduction** — **output**
- **COUNT** — **number of items to be reduced** — **input**

The contents of `sbuff` from all tasks are reduced according to `OP_TYPE` and the result is sent to RBUFF task `root`. `OP_TYPE` can be `MPI_MAX`, `MPI_MIN`, `MPI_SUM`, `MPI_IPROD`, `MPI_IAND`, `MPI_BAND`, `MPI_IOR`, `MPI_BOR`, `MPI_LXOR`, `MPI_BXOR`, `MPI_MAXLOC`, `MPI_MINLOC`

MPI_REDUCE



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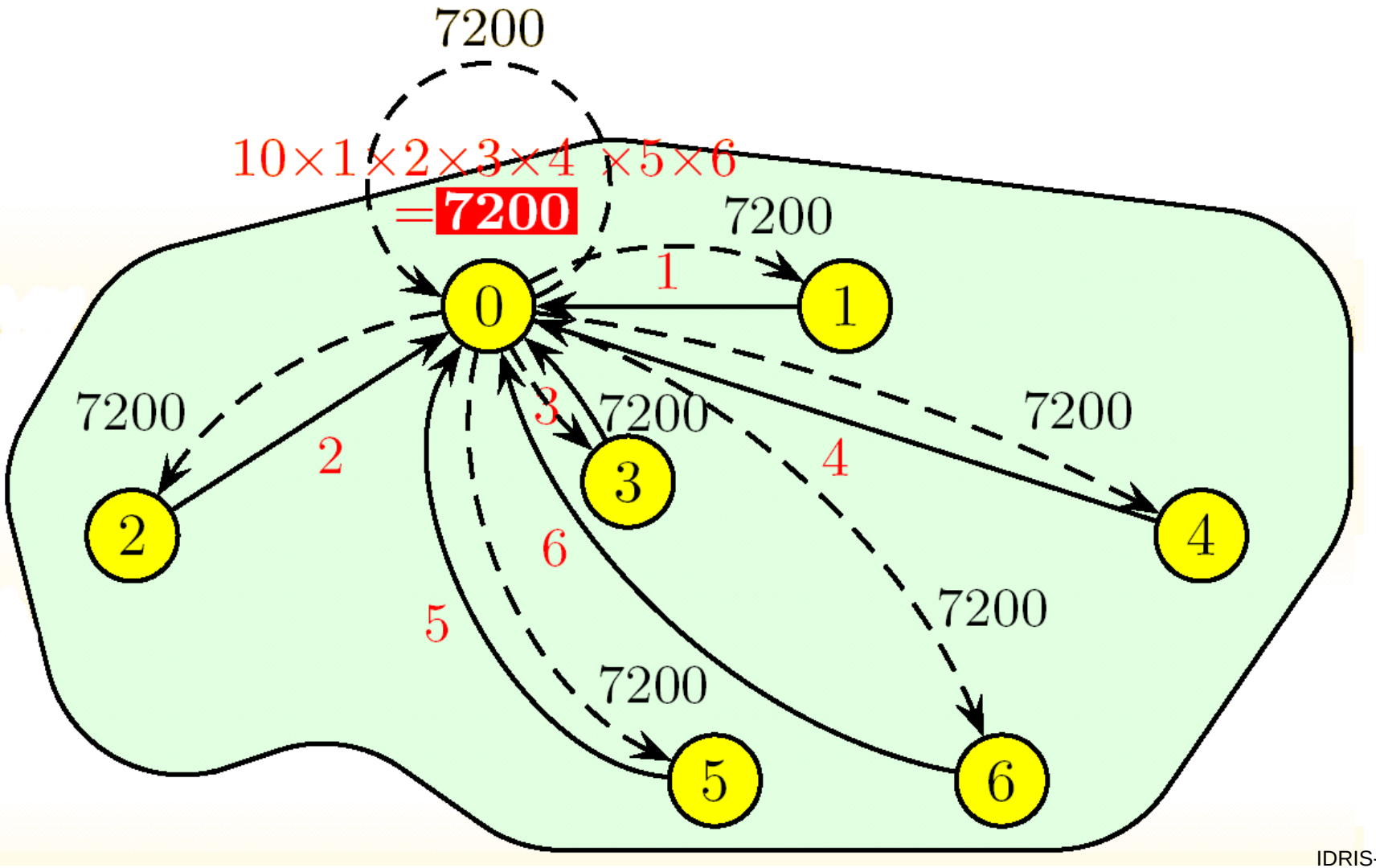
MPI_ALLREDUCE



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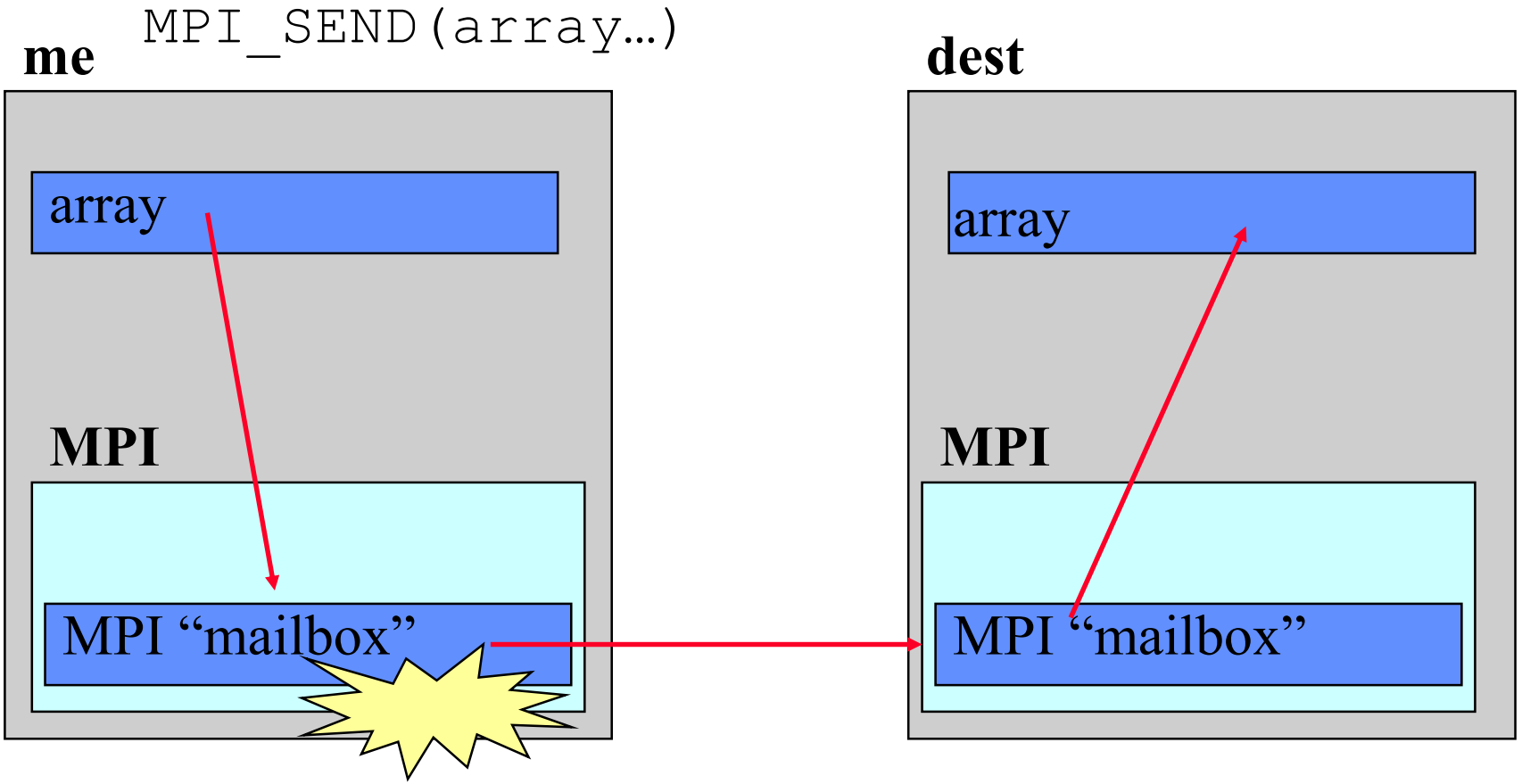
Back to “simple” send & receives

- **What happens after you do MPI_SEND?**
  - **When does the next instruction get executed?**
- **What happens after you do MPI_RECV?**
  - **When does the next instruction get executed?**

Blocking v Non-blocking communication

- **Blocking communication**
  - **Call to MPI "sending" routine does not return until the "send" buffer (array) is safe to use again**
    - **This does not necessarily mean the data has been sent and received by the remote task (although it might!)**
  - **Call to MPI "receiving" routine does not return until the "receive" buffer has received all the data in the incoming message**
- **Non-blocking communication**
  - **Call to MPI routine returns immediately**
  - **Further MPI calls are required to check the progress of the communication**
  - **Allows other work to be done during communication**
- **Cray's `MPI_SEND` can sometimes be blocking and sometimes non-blocking!**

MPI_SEND : Eager protocol

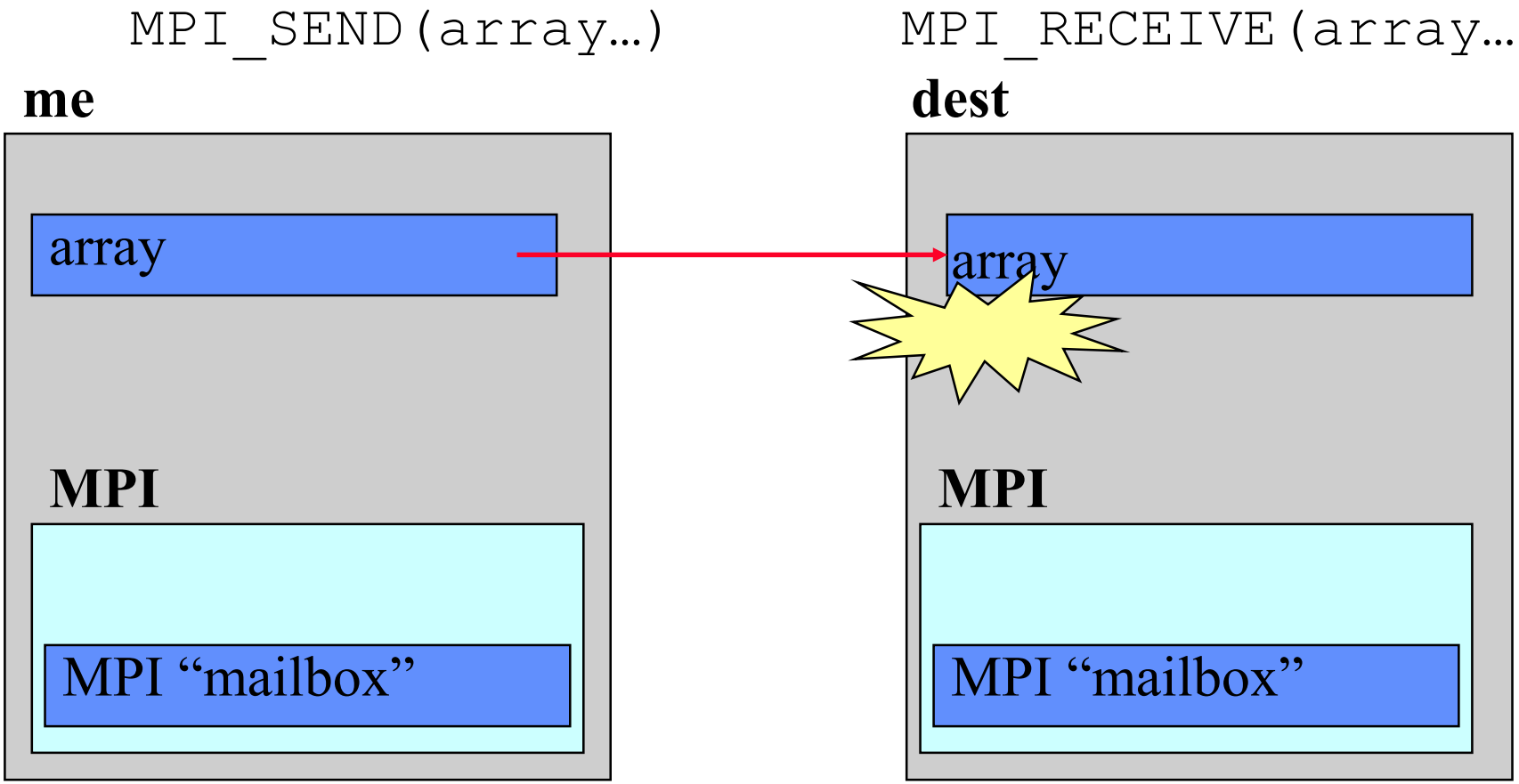


MPI_SEND completes when “array” is copied into “mailbox” on the sending task

MPI_SEND : Eager protocol

- **The MPI layer has copied the data elsewhere**
  - **using internal buffer/mailbox space on the sending task**
- **`MPI_SEND` returns as soon as the message has been copied**
  - **The message is then "in transit" but not necessarily in the receivers array**
- **Used for short messages**
  - **By default "short" is 8192 bytes (8Kb) on the Cray**
  - **Can be modified by envioronment vairable**
    - **`$ export MPICH_GNI_MAX_EAGER_MSG_SIZE=X` *(bytes)***
    - **Maximum permitted value 131072 bytes (128Kb)**
- **No need to worry if the remote task has done an "`MPI_RECEIVE`"**

MPI_SEND : Rendezvous protocol



`MPI_SEND` completes when "array" is copied into "array" on the receiving task

MPI_SEND : Rendezvous protocol

- **`MPI_SEND` does not return until the message has been successfully received by the remote task**
- **Used for long messages**
  - **By default "long" is >8192 bytes on the Cray**
- **Need to ensure that remote task is doing an "`MPI_RECEIVE`" otherwise we may deadlock…**
  - **Easily done!**
  - **eg. ping-pong example – 2 tasks exchanging messages…**

```
if(me .eq.0) then
  other=1
else
  other=0
endif

call MPI_SEND(sbuff,n,MPI_REAL8,other,tag,MPI_COMM_WORLD,ierror)
call MPI_RECV(rbuff,n,MPI_REAL8,other,tag,MPI_COMM_WORLD,stat,ierror)
```

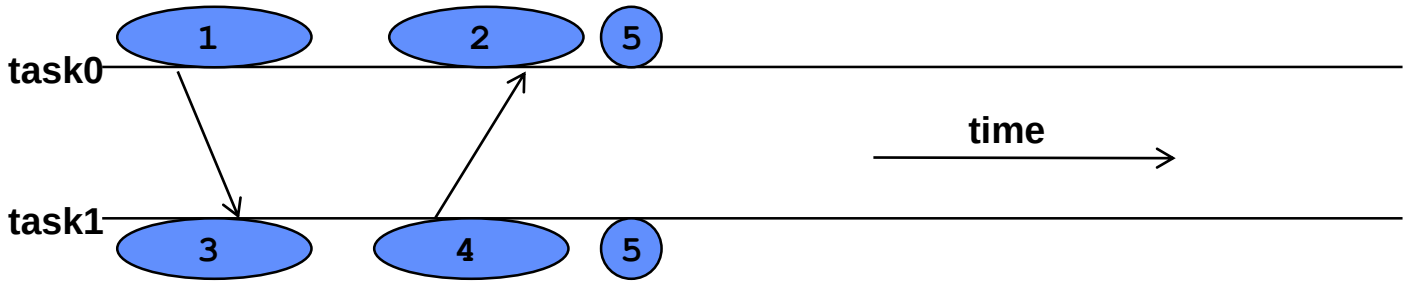
Solutions to Send/Send deadlocks

- **My advice – avoid `MPI_SEND/MPI_RECV`!**
  - **Behaviour is implementation dependent – code may work, but then stop working when message size changes or move to another platform**
- **Pair up sends and receives (next slide shows how…)**
  - **But this is not very efficient**
- **use `MPI_SENDRECV`**
  - **Hopefully more efficient**
- **use a buffered send (like the eager protocol, but user space buffering)**
  - **`MPI_BSEND`**
- **use asynchronous sends/receives (recommended)**
  - **`MPI_ISEND` or `MPI_IRECV`**

Paired Sends and Receives

- **More complex code, and close synchronisation**
- **Less efficient**
  - **task 1 has to wait until it has received message from task 0 before it can send its message**

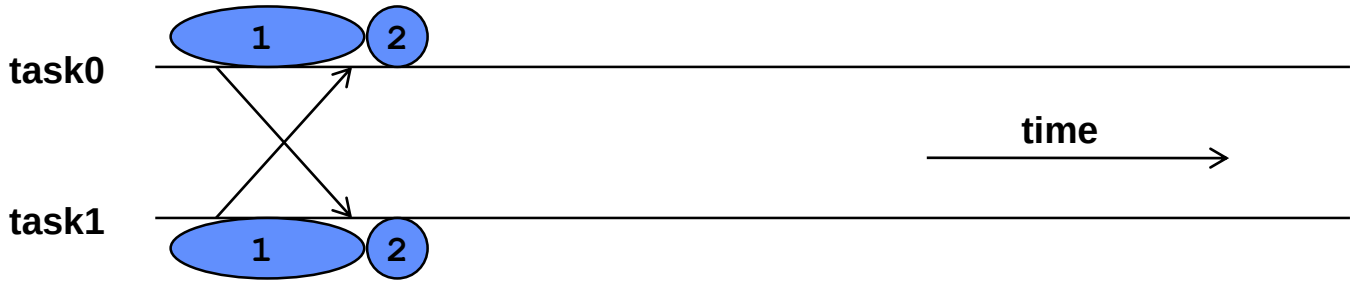
```
if (me .eq. 0) then
  other=1
1 call MPI_SEND(sbuff,n,MPI_REAL8,other,tag,MPI_COMM_WORLD,ierror)
2 call MPI_RECV(rbuff,n,MPI_REAL8,other,tag,MPI_COMM_WORLD,stat,ierror)
else
  other=0
3 call MPI_RECV(rbuff,n,MPI_REAL8,other,tag,MPI_COMM_WORLD,stat,ierror)
4 call MPI_SEND(sbuff,n,MPI_REAL8,other,tag,MPI_COMM_WORLD,ierror)
endif
5
```



MPI_SENDRECV

- **Simpler to code & hopefully more efficient**
- **Still implies close synchronisation**

1
```
call MPI_SENDRECV(sbuff,n,MPI_REAL8,other,1, &
                  rbuff,n,MPI_REAL8,other,1, &
                  MPI_COMM_WORLD,stat,ierror)
```
2



MPI_BSEND

- **This performs a send using an additional buffer**
  - **the buffer is allocated by the program via `MPI_BUFFER_ATTACH`**
  - **done once as part of the program initialisation**
  - **`MPI_BSEND` completes as soon as message is copied into buffer**
- **Typically quick to implement**
  - **add the `MPI_BUFFER_ATTACH` call**
    - **how big to make the buffer?**
  - **change `MPI_SEND` to `MPI_BSEND` everywhere**
- **But introduces additional memory copy**
  - **extra overhead**
  - **not recommended for production codes**
  - **One day your buffer won't be big enough!**

MPI_IRECV / MPI_ISEND

- **Uses Non Blocking Communications**
- **“I” stands for immediate**
  - **the call returns immediately**
- **Routines return without completing the operation**
  - **the operations run asynchronously (in the background)**
  - **Must NOT reuse the buffer (send/receive array) until safe to do so**
- **Later test that the operation completed**
  - **via an integer identification handle passed to `MPI_WAIT`**

```
call MPI_IRECV(rbuff,n,MPI_REAL8,other,1,MPI_COMM_WORLD,request,ierror)
call MPI_SEND (sbuff,n,MPI_REAL8,other,1,MPI_COMM_WORLD,ierror)
call MPI_WAIT(request,stat,ierr)
```

- **Alternatively could have used `MPI_ISEND` and `MPI_RECV`**

Non Blocking Communications

- **Routines include**
  - `MPI_ISEND`
  - `MPI_IRECV`
  - `MPI_WAIT`
  - `MPI_WAITALL`
    - **Waits for a number of outstanding communications to complete**

Final Practical

- **exercise2**
- **A “simple” numerical model**
- **See the README for details**
- **See copies of MPI standard for details of arguments required for various MPI routines you might want to use.**
- **Ask if you need help or don’t understand anything!**