Introduction to Parallel Programming

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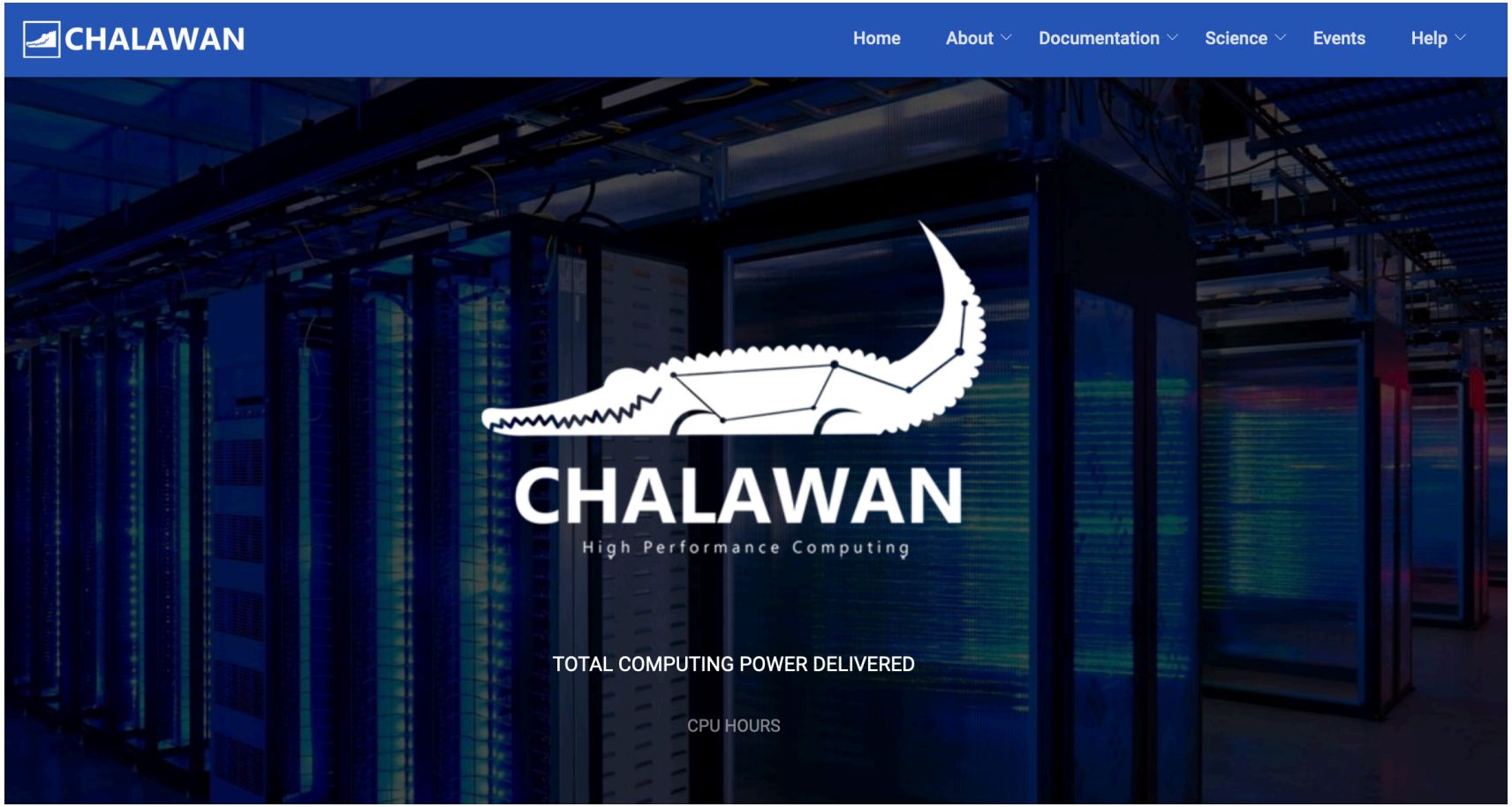
Distributed Memory System

```
[POLLUX:~] $ lscpu
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
CPU(s):                28
On-line CPU(s) list:   0-27
Thread(s) per core:    1
Core(s) per socket:    14
Socket(s):             2
NUMA node(s):          2
Vendor ID:             GenuineIntel
CPU family:            6
Model:                 85
Model name:            Intel(R) Xeon(R) Gold 6132 CPU @ 2.60GHz
Stepping:              4
CPU MHz:               2600.000
BogoMIPS:              5200.00
Virtualization:        VT-x
L1d cache:             32K
L1i cache:             32K
L2 cache:              1024K
L3 cache:              19712K
NUMA node0 CPU(s):     0,2,4,6,8,10,12,14,16,18,20,22,24,26
NUMA node1 CPU(s):     1,3,5,7,9,11,13,15,17,19,21,23,25,27
```

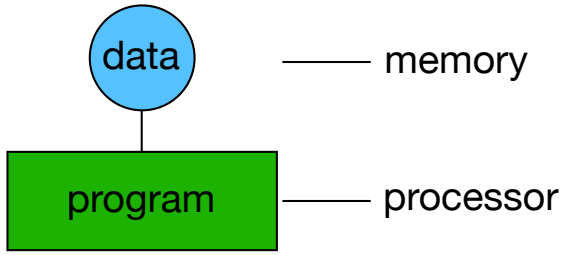
Chalawan Cluster

http://chalawan.narit.or.th/

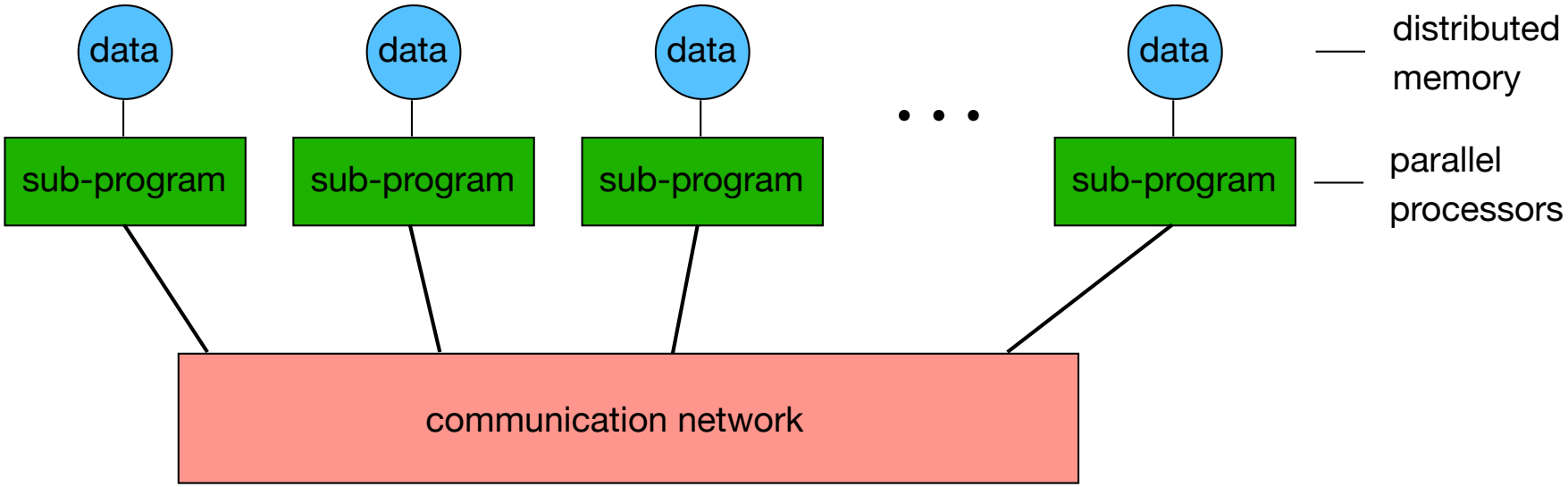


The Message-Passing Programming Paradigm

- **Sequential Programming Paradigm**

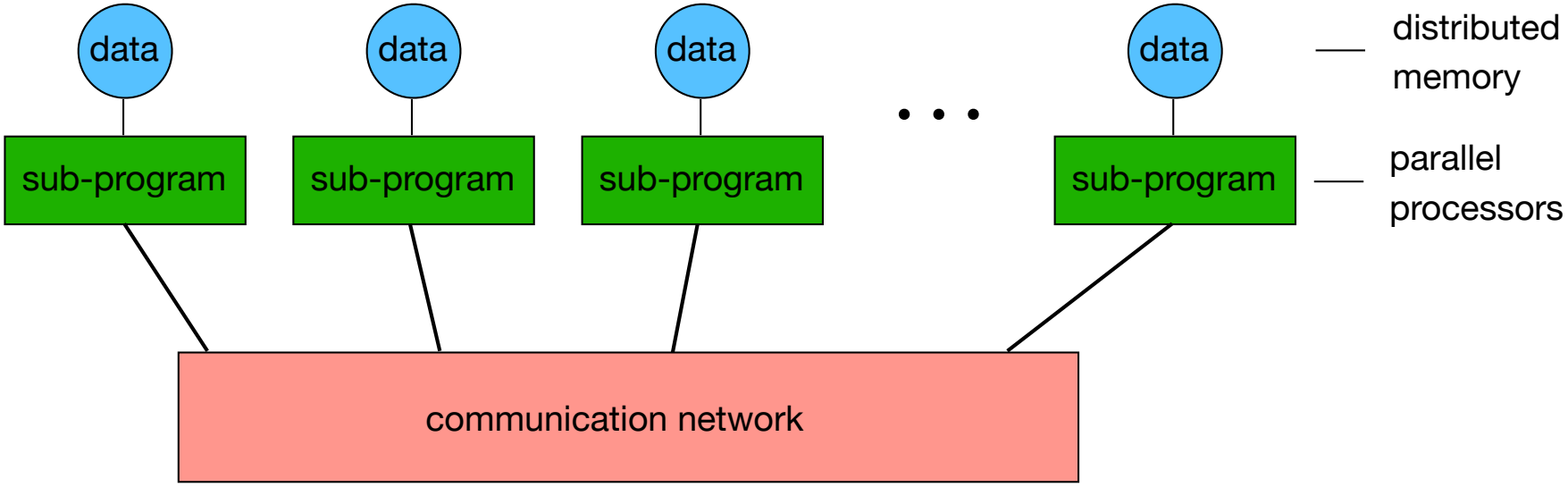


- **Message-Passing Programming Paradigm**



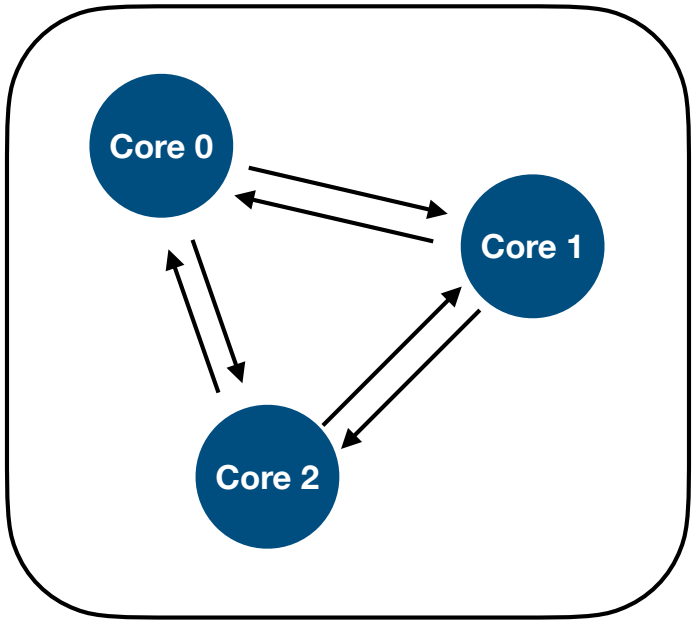
The Message-Passing Programming Paradigm

- Each processor in a message passing program
  - written in a conventional sequential language, e.g., C/C++, Fortran, or Python
  - typically the same on each processor (SPMD)
  - the variables of each sub-program have
  - communicate via
    - **the same name**
    - **but different locations (distributed memory) and different data!**
    - **i.e. all variables are private**
  - communicate via special send & receive routines (***message passing***)

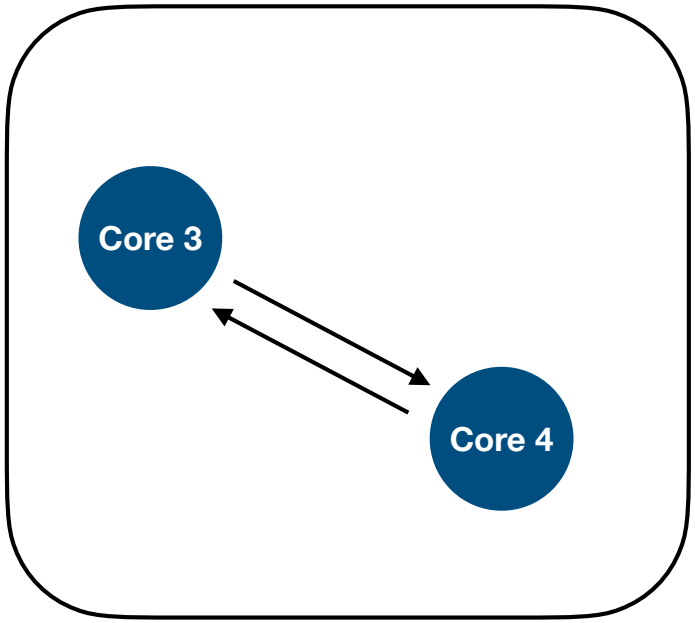


Communicators

A **communicator** is a group of cores that can communicate to one another. Each cores is independent and can run its own process.



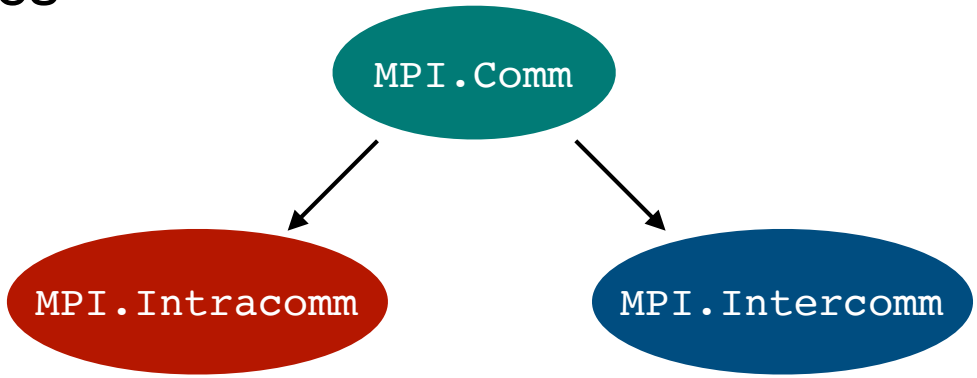
Communicator A



Communicator B

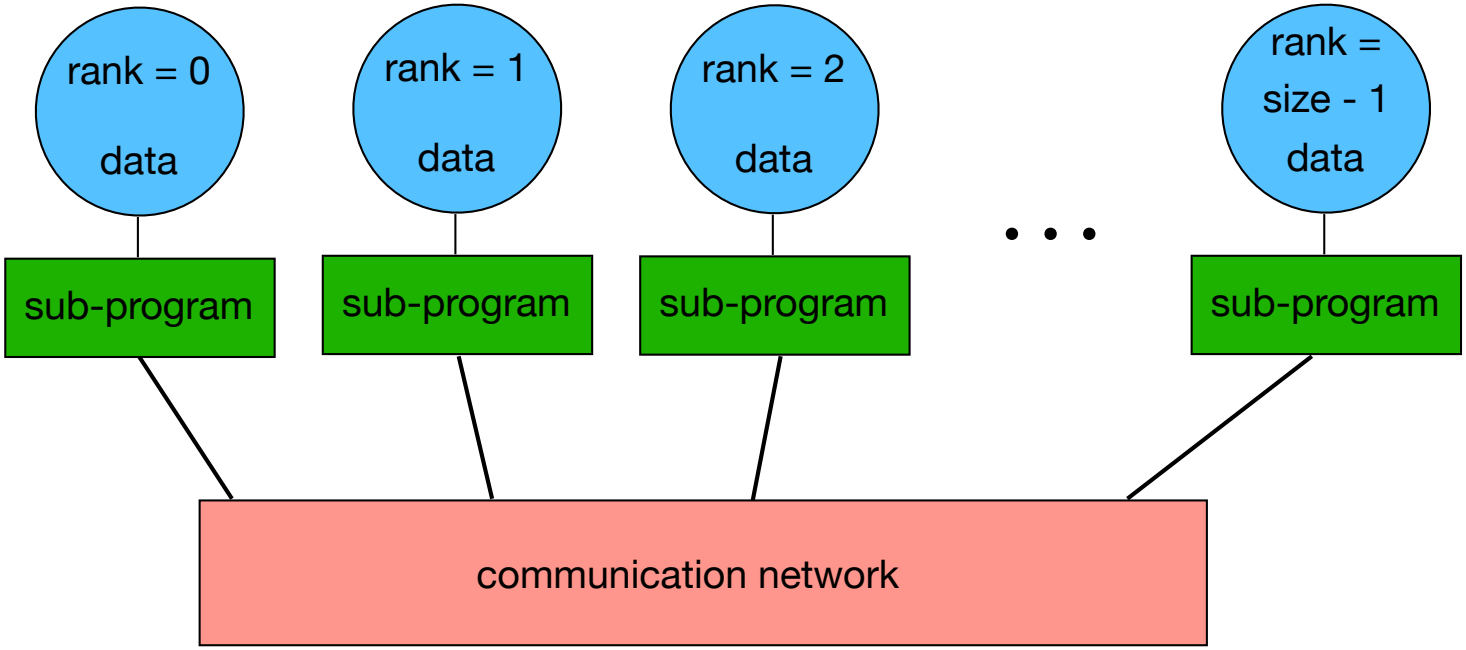
Communicators

- In *MPI for Python*, `MPI.Comm` is the base class of communicators.
- `MPI.Intracomm` is a sub-class of `MPI.Comm` mainly used for local nodes. **`MPI.COMM_WORLD`** and **`MPI.COMM_SELF`** are pre-defined instances of `MPI.Intracomm`.
- `MPI.Intercomm` is also a sub-class of `MPI.Comm` mainly used for remote nodes



Data and Work Distribution

- The value of **rank** is returned by special library routine.
- The system of **size** processes is started by special MPI initialization.
- All distribution decision are based on rank
- i.e., which process work on which data



See MPI/ex00_mpi_greeting.py

Point-to-point Communications

- Simplest form of message passing.
- One process (core) sends a message to another. Another process (core) will receive the message

`MPI.Comm.Send`

`MPI.Comm.Recv`

```
MPI.Comm.Send(buf, dest, tag=0)
```

```
MPI.Comm.Recv(buf, source=ANY_SOURCE, tag=ANY_TAG,
              status=None)
```

See MPI/ex01_mpi_send_recv0.py

MPI DataType

- When sending an array of data, the type of MPI needs to know the type of data.
- Sometime the data type has to be specified in the data buffer.

`MPI.CHAR`	`MPI.LONG`
`MPI.BYTE`	`MPI.FLOAT`
`MPI.SHORT`	`MPI.DOUBLE`
`MPI.INT`	`MPI.COMPLEX`

See MPI/ex02_mpi_send_recv1.py

MPI for Python object

- On top of Standard MPI commands, `mpi4py` has commands for generic Python objects using all lowercases.
- Python objects are serialized / deserialized using `pickle` module

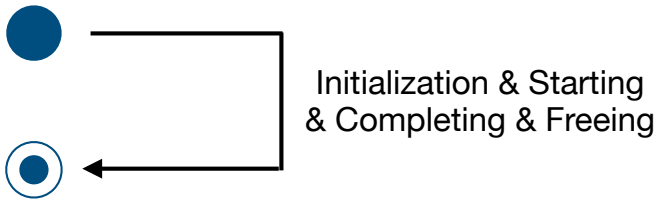
```
MPI.Comm.send(object, dest, tag=0)
```

```
MPI.Comm.recv(object, source=ANY_SOURCE, tag=ANY_TAG,
              status=None)
```

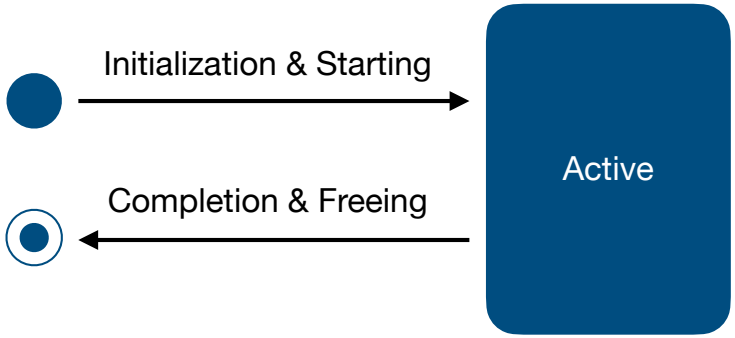
See MPI/ex03_mpi_send_recv2.py

MPI Operations

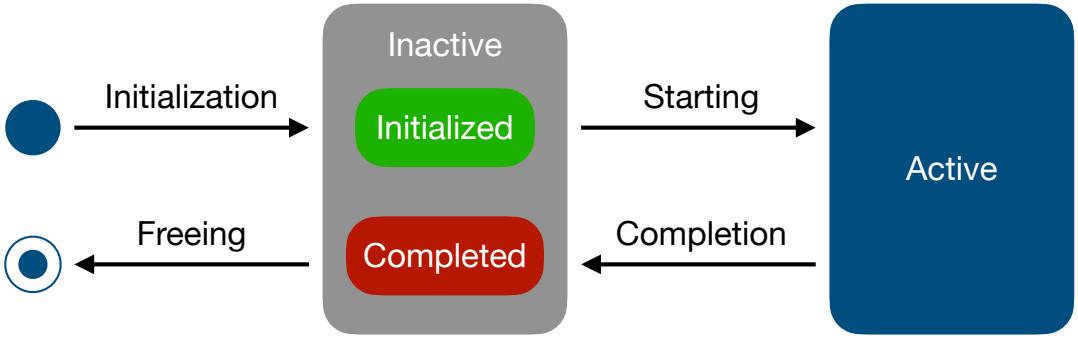
- **Blocking**
  Initialization & Starting & Completion & Freeing



- **Non-blocking**
  Initialization & Starting
  Completion & Freeing



- **Persistent**
  Initialization
  Starting
  Completion
  Freeing



See MPI/ex04_send_recv3.py

MPI Send Communication Modes

`MPI_Send` has 4 modes of communication while `MPI_Recv` has only 1 mode.
Both can be blocking or non-blocking.

- **Standard**
  The MPI library decide whether or not the non-local buffered the outgoing data.
- **Buffered (Asynchronous)**
  The MPI library decide to use buffer for outgoing data if no matching receiver has been posted.
- **Synchronous**
  The outgoing data buffer can be reused once the receiving process starting receiving the data.
- **Ready**
  The outgoing data buffer can be reused once the receiving process has been posted.

MPI Send Variants

Communication Mode	Blocking	Non-blocking	Persistent
Standard	`MPI.Comm.Send` `MPI.Comm.send`	`MPI.Comm.Isend` `MPI.Comm.isend`	`MPI.Comm.Send_init`
Buffered (Asynchronous)	`MPI.Comm.Bsend` `MPI.Comm.bsend`	`MPI.Comm.Ibsend` `MPI.Comm.ibsend`	`MPI.Comm.Bsend_init`
Synchronous	`MPI.Comm.Ssend` `MPI.Comm.ssend`	`MPI.Comm.Isend` `MPI.Comm.isend`	`MPI.Comm.Ssend_init`
Ready	`MPI.Comm.Rsend`	`MPI.Comm.Irsend`	`MPI.Comm.Rsend_init`

for generic Python objects

MPI Recv Variants

Communication Mode	Blocking	Non-blocking	Persistent
Standard	`MPI.Comm.Recv` `MPI.Comm.recv`	`MPI.Comm.Irecv` `MPI.Comm.irecv`	`MPI.Comm.Recv_Init`

for generic Python objects

MPI Sendrecv Variants

- The **send-receive** operation combine in one operation the sending of a message to one destination and the receiving of another message, from another process

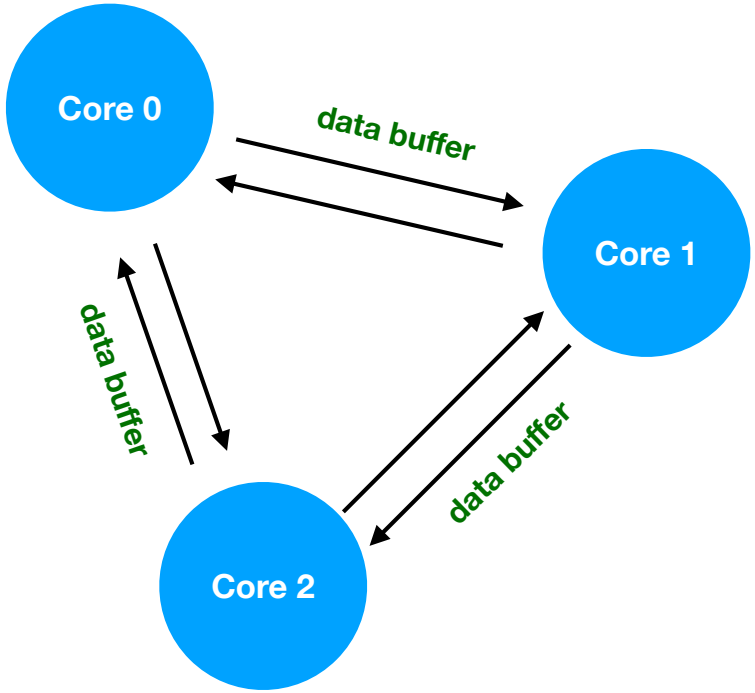
Communication Mode	Blocking

Standard	`MPI.Comm.Sendrecv`
	`MPI.Comm.Sendrecv_replace`
	`MPI.Comm.sendrecv`

See MPI/ex05_mpi_send_recv4.py

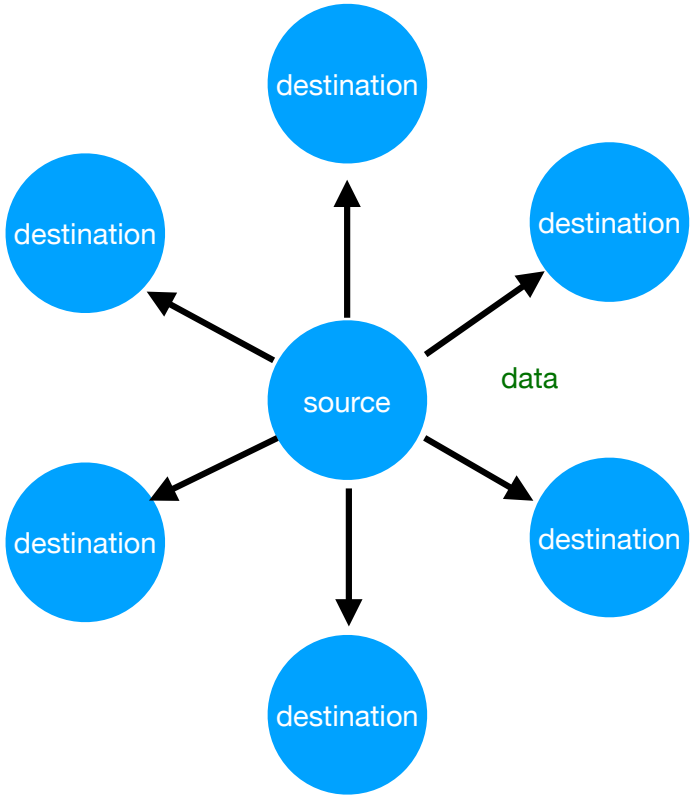
Collective Communication

- Collective communication routines are higher level routines.
- Several processes are involved at a time



Broadcast

- A one-to-many communication.
- All core receive the same copy of the data
- Not very efficient if we have only one communication channel.




```
MPI.Comm.Bcast(buf, root=0)
```

MPI Bcast Variants

Communication Mode	Blocking	Non-blocking
Standard	`MPI.Comm.Bcast` `MPI.Comm.bcast`	`MPI.Comm.Ibcast`

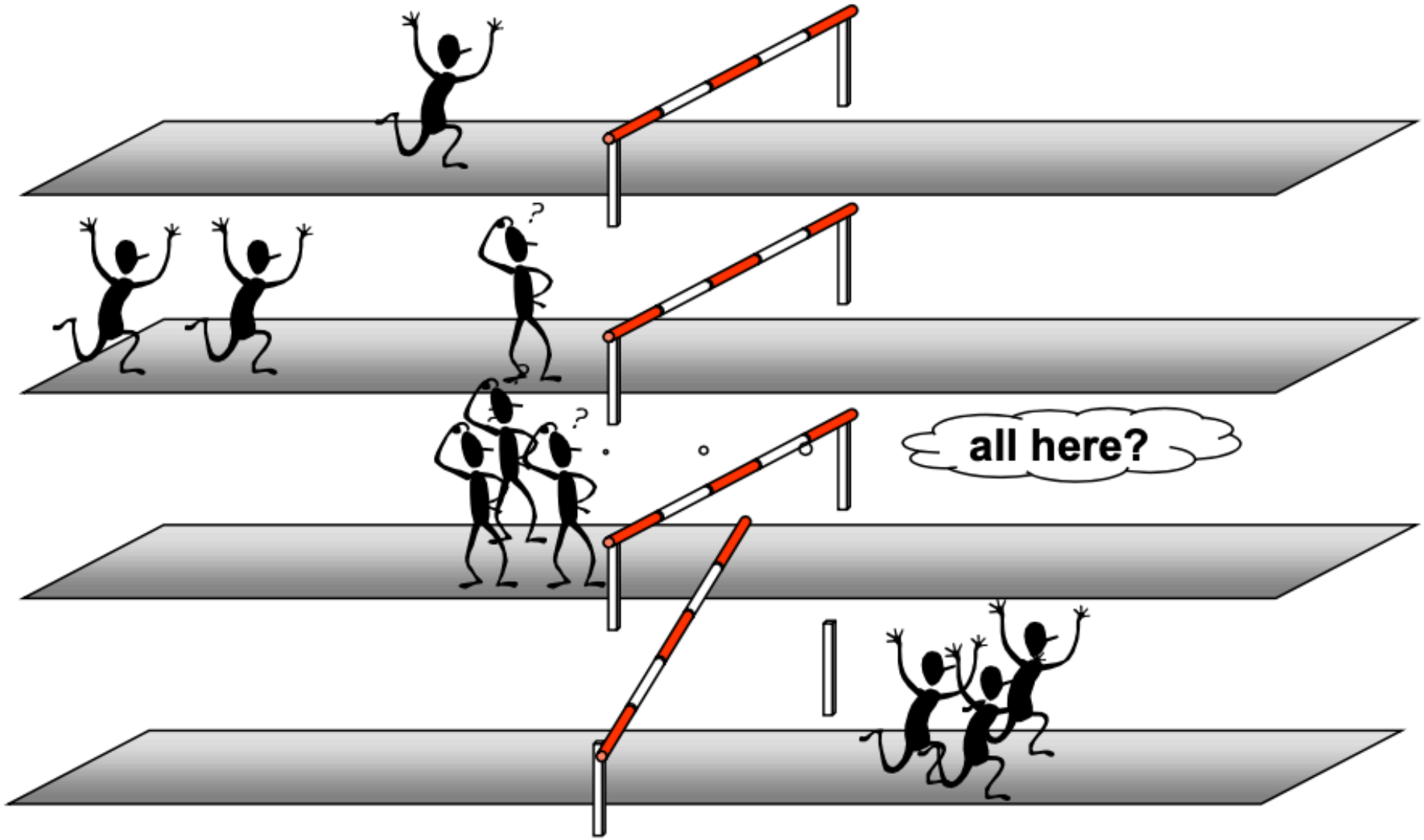
```
MPI.Comm.Ibcast(buf, root=0)
```

```
MPI.Comm.bcast(object, root=0)
```

See MPI/ex06_mpi_bcast.py

Barrier

- Synchronize processes



MPI Barrier Variants

Communication Mode	Blocking	Non-blocking
Standard	`MPI.Comm.Barrier` `MPI.Comm.barrier`	`MPI.Comm.Ibarrier`

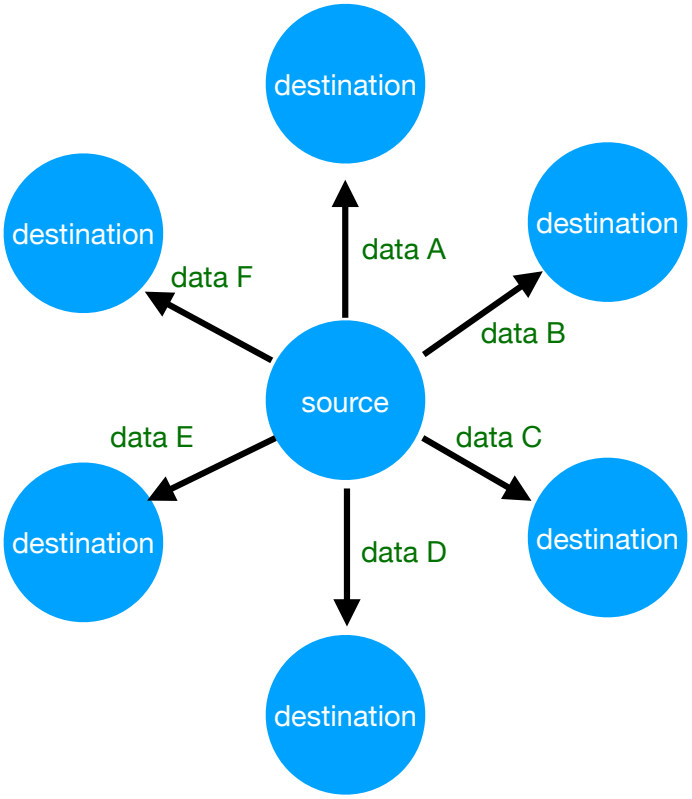
```
MPI.Comm.Barrier()
```

```
MPI.Comm.Ibarrier()
```

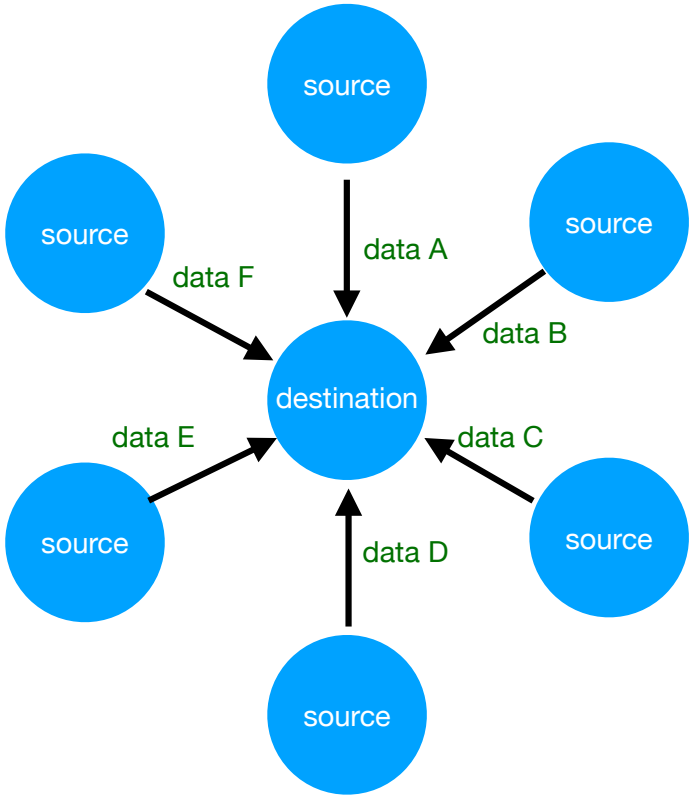
```
MPI.Comm.barrier()
```

Scatter and Gather

- Split the data equally to all other processes.



Scatter

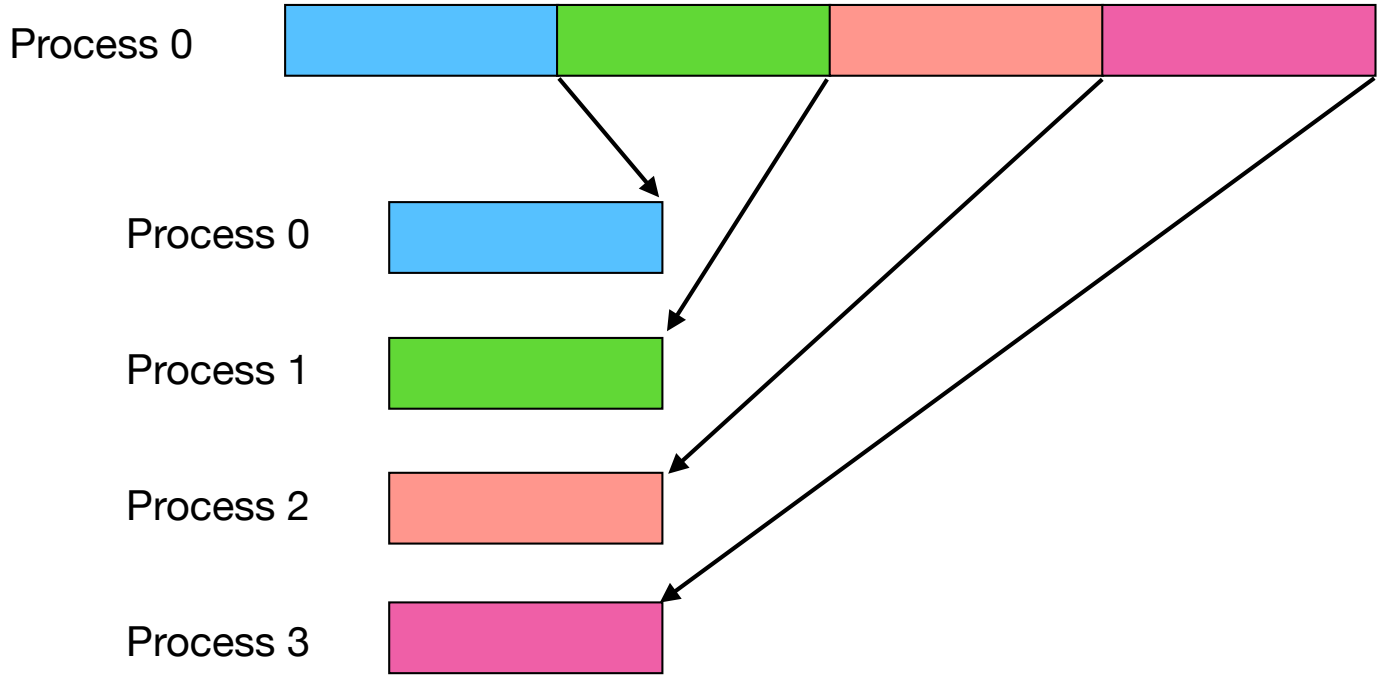


Gather

See MPI/ex07_mpi_scatter_gather.py

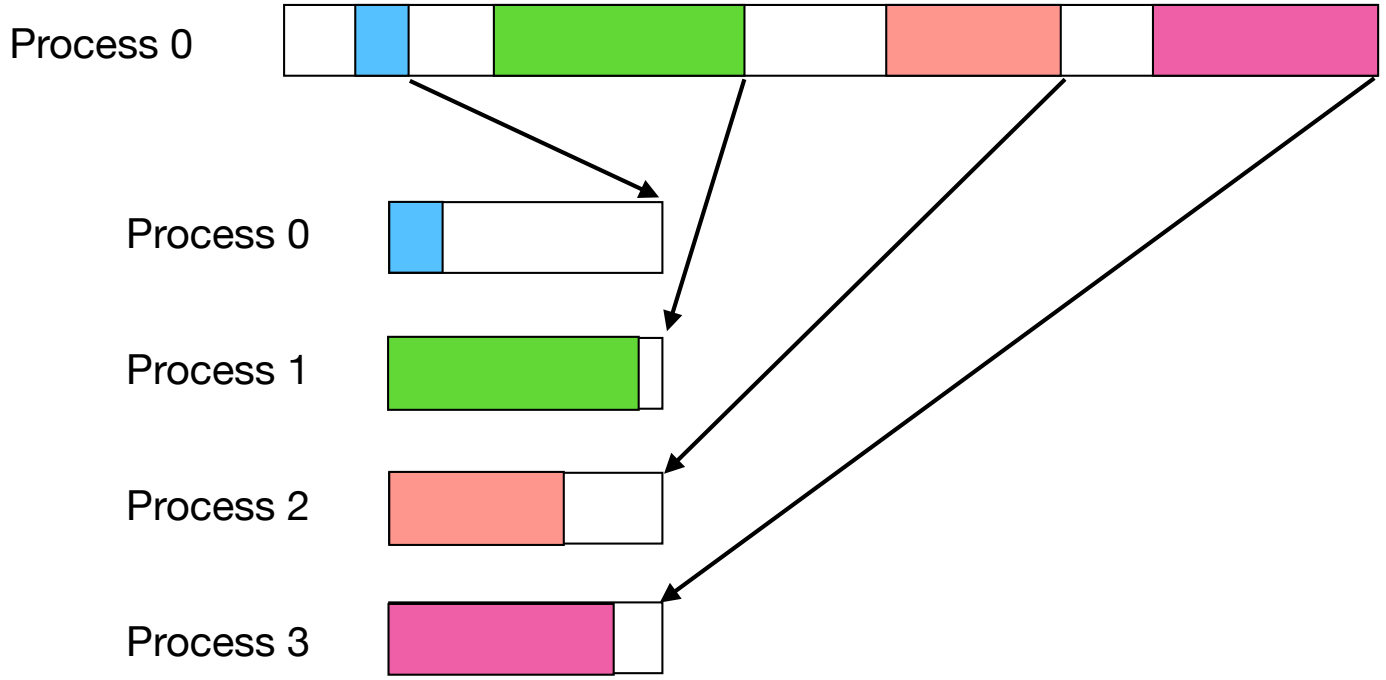
Scatter and Gather

- Scatter (Gather) requires contiguous data and uniform data size



Scatter and Gather (Vector data)

- Scatterv (Gatherv) allows gaps between messages in source data
- Irregular message size are allowed.
- Data can be distributed to processes in any order



See MPI/ex08_mpi_scatterv_gatherv.py

MPI Scatter / Gather Variants

Communication Mode	Blocking	Non-blocking

Standard	`MPI.Comm.Scatter`
	`MPI.Comm.Scatterv`
	`MPI.Comm.scatter`
		`MPI.Comm.Iscatter`
		`MPI.Comm.Iscatterv`

Communication Mode	Blocking	Non-blocking

Standard	`MPI.Comm.Gather`
	`MPI.Comm.Gatherv`
	`MPI.Comm.gather`
		`MPI.Comm.Igather`
		`MPI.Comm.Igahterv`

Allgather and Allgatherv

- Gathers data from all members of a group and sends the data to all members of the group.
- The Allgather (Allgatherv) function is similar to the MPI_Gather function, except that it sends the data to all processes instead of only to the root.

See MPI/ex09_allgather.py

MPI Allgather Variants

Communication Mode	Blocking	Non-blocking

Standard	`MPI.Comm.Allgather`
	`MPI.Comm.Allgatherv`
	`MPI.Comm.allgather`
		`MPI.Comm.Iallgather`
		`MPI.Comm.Iallgatherv`

```
MPI.Comm.Allgather(sendbuff, recvbuff)
```

```
MPI.Comm.Allgatherv(sendbuff, recvbuff)
```

```
MPI.Comm.allgather(sendobj)
```

All to all

- Gathers data from and scatters data to all members of a group.
- The **Alltoall** is an extension **Allgather** function.
- Each process sends distinct data to each of the receivers. The *j*th block that is sent from process *i* is received by process *j* and is placed in the *i*th block of the receive buffer.

All to all Variants

Communication Mode	Blocking	Non-blocking

Standard	`MPI.Comm.Alltoall`
	`MPI.Comm.Alltoallv`
	`MPI.Comm.Alltoallw`
	`MPI.Comm.alltoall`
		`MPI.Comm.Ialltoall`
		`MPI.Comm.Ialltoallv`
		`MPI.Comm.Ialltoallw`

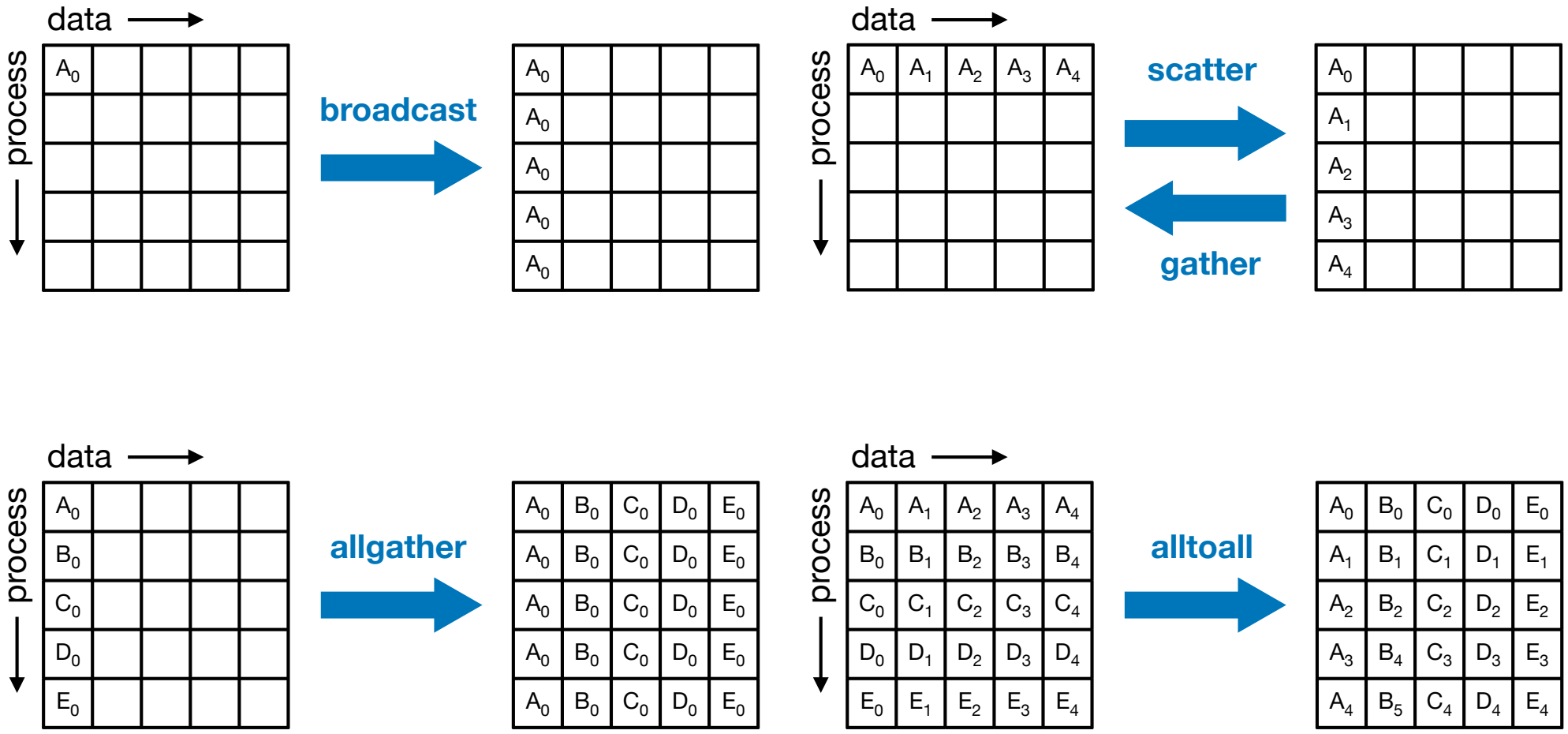
```
MPI.Comm.Alltoall(sendbuff, recvbuff)
```

```
MPI.Comm.Alltoallv(sendbuff, recvbuff)
```

```
MPI.Comm.alltoall(sendobj)
```

See MPI/ex10_alltoall.py

Summary of Collective Communication



Reduce / Allreduce

- Performs a global reduce operation across all members of a group.

Communication Mode	Blocking	Non-blocking

Standard	`MPI.Comm.Reduce`
	`MPI.Comm.Allreduce`
	`MPI.Comm.reduce`
	`MPI.Comm.allreduce`
		`MPI.Comm.Ireduce`
		`MPI.Comm.Iallreduce`

```
MPI.Comm.Reduce(sendbuff, recvbuff, op=MPI.SUM, root=0)
```

See MPI/ex11_reduce.py

MPI Operation Object

- Use with Reduce / Allreduce to perform reduction operation

`MPI.MAX`	Returns the maximum element
`MPI.MIN`	Returns the minimum element
`MPI.SUM`	Sums the elements
`MPI.PROD`	Multiplies all elements

Reduce_scatter

- Performs a global reduce operation across all members of a group and scatter the result.

Communication Mode	Blocking	Non-blocking
Standard	`MPI.Comm.Reduce_scatter` `MPI.Comm.Reduce_scatter_block`	`MPI.Comm.Ireduce_scatter` `MPI.Comm.Ireduce_scatter_block`

```
MPI.Comm.Reduce_scatter(sendbuff, recvbuff, recvcounts=None,
                        op=SUM)
```

```
MPI.Comm.Reduce_scatter_block(sendbuff, recvbuff, op=SUM)
```

See MPI/ex12_reduce_scatter.py