DATA SCIENCE &
SCIENTIFIC COMPUTING

L05: MPI programming (2)

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Collective operations

- Collective routines provide a higher-level way to organize a parallel program
- Each process executes the same communication operations
- MPI provides a rich set of collective operations…

Collective operations

- Communications involving group of processes in a communicator.
- Groups and communicators can be constructed “by hand” or using topology routines.
- Tags are not used; different communicators deliver similar functionality.
- No non-blocking collective operations.
- Three classes of operations: synchronization, data movement, collective computation.

MPI_Barrier

Stop processes until all processes within a communicator reach the barrier

Almost never required in a parallel program Occasionally useful in measuring performance and load balancing

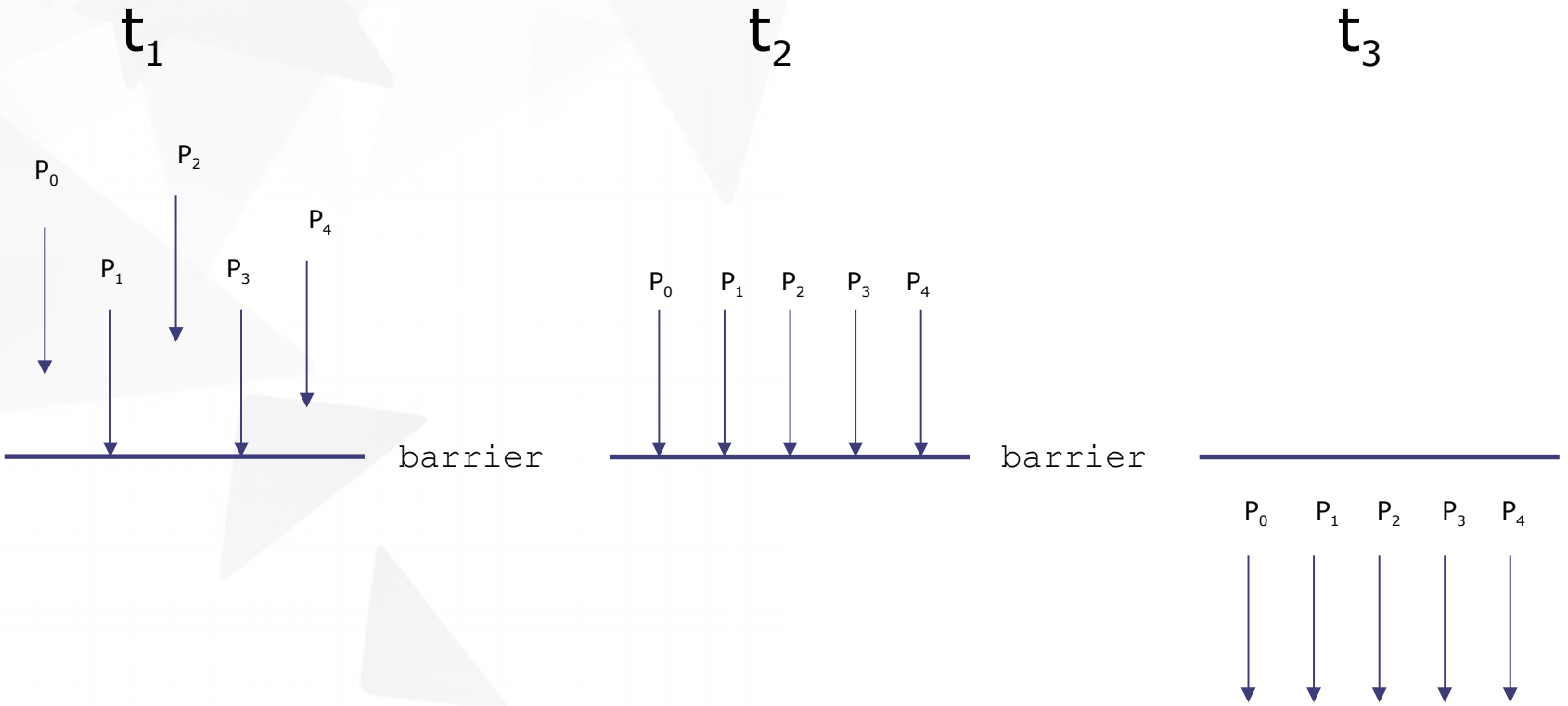
Fortran:

```
CALL MPI_BARRIER( comm, ierr)
```

C:

```
int MPI_Barrier(MPI_Comm comm)
```

Barrier



Broadcast (MPI_BCAST)

One-to-all communication: same data sent from root process to all others in the communicator

Fortran:

```
INTEGER count, type, root, comm, ierr
CALL MPI_BCAST(buf, count, type, root, comm, ierr)
```

Buf array of type **type**

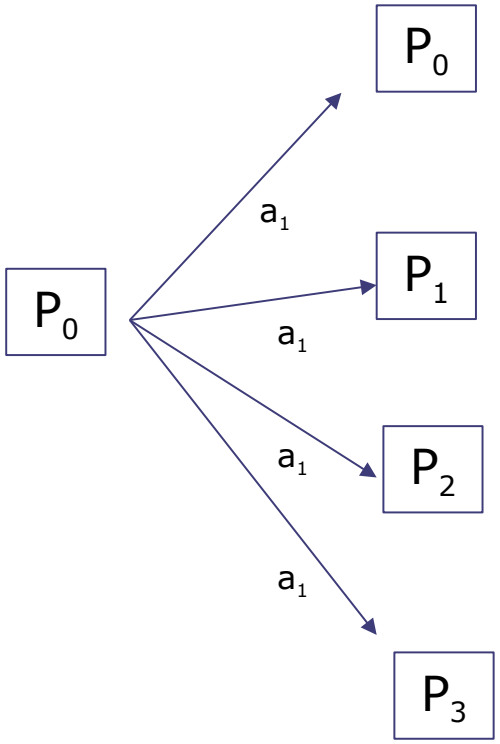
C:

```
int MPI_Bcast(void *buf, int count, MPI_Datatype
  datatype, int root, MPI_Comm comm)
```

All processes must specify same **root**, **rank** and **comm**

Broadcast

```
PROGRAM broad_cast
 INCLUDE 'mpif.h'
 INTEGER ierr, myid, nproc, root
 INTEGER status(MPI_STATUS_SIZE)
 REAL A(2)
 CALL MPI_INIT(ierr)
 CALL MPI_COMM_SIZE(MPI_COMM_WORLD, nproc, ierr)
 CALL MPI_COMM_RANK(MPI_COMM_WORLD, myid, ierr)
 root = 0
 IF( myid .EQ. 0 ) THEN
   a(1) = 2.0
   a(2) = 4.0
 END IF
 CALL MPI_BCAST(a, 2, MPI_REAL, 0, MPI_COMM_WORLD, ierr)
 WRITE(6,*) myid, ': a(1)=', a(1), 'a(2)=', a(2)
 CALL MPI_FINALIZE(ierr)
 END
```



Reduction

The reduction operation allow to:

- Collect data from each process
- Reduce the data to a single value
- Store the result on the root processes
- Store the result on all processes

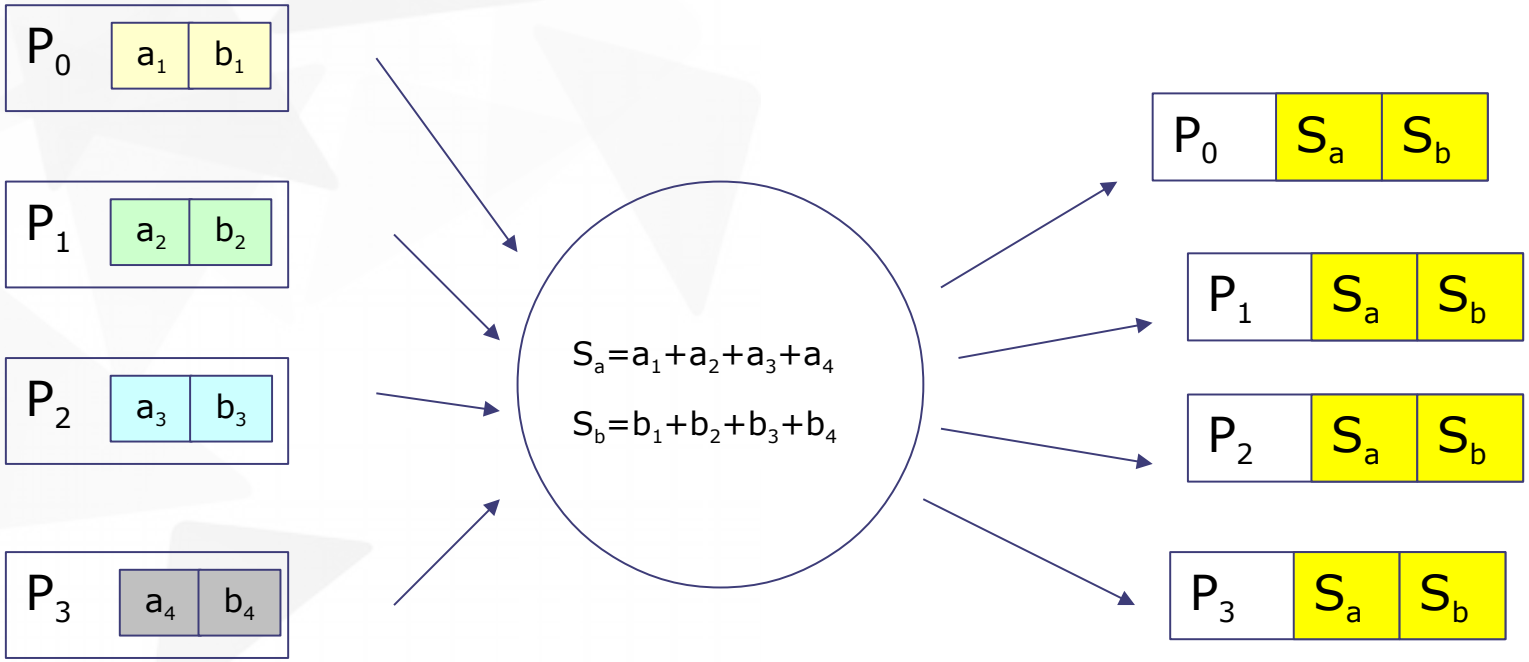
MPI_Reduce and MPI_Allreduce

C:

```
int MPI_Reduce(void * snd_buf, void * rcv_buf, int count,
   MPI_Datatype type, MPI_Op op, int root, MPI_Comm comm)

int MPI_Allreduce(void * snd_buf, void * rcv_buf, int count,
   MPI_Datatype type, MPI_Op op, MPI_Comm comm)
```

Reduce, Parallel Sum



Reduction function works with arrays

other operation: product, min, max, and, ….

Internally is usually implemented with a binary tree

MPI_REDUCE and MPI_ALLREDUCE

Fortran:

MPI_REDUCE(snd_buf,rcv_buf,count,type,op,root,comm,ierr)

`snd_buf`	input array of type `type` containing local values.
`rcv_buf`	output array of type `type` containing global results
`count`	`(INTEGER)` number of element of `snd_buf` and `rcv_buf`
`type (INTEGER)`	MPI type of `snd_buf` and `rcv_buf`
`op`	`(INTEGER)` parallel operation to be performed
`root (INTEGER)`	MPI id of the process storing the result
`comm (INTEGER)`	communicator of processes involved in the operation
`ierr (INTEGER)`	output, error code (if `ierr=0` no error occours)

MPI_ALLREDUCE(snd_buf,rcv_buf,count,type,op,comm,ierr)

The argument `root` is missing, the result is stored to all processes.

Predefined Reduction Operations

MPI op	Function
MPI_MAX	Maximum
MPI_MIN	Minimum
MPI_SUM	Sum
MPI_PROD	Product
MPI_LAND	Logical AND
MPI_BAND	Bitwise AND
MPI_LOR	Logical OR
MPI_BOR	Bitwise OR
MPI_LXOR	Logical exclusive OR
MPI_BXOR	Bitwise exclusive OR
MPI_MAXLOC	Maximum and location
MPI_MINLOC	Minimum and location

Reduce, example

```
PROGRAM reduce
  INCLUDE 'mpif.h'
  INTEGER ierr, myid, nproc, root
  INTEGER status(MPI_STATUS_SIZE)
  REAL A(2), res(2)
  CALL MPI_INIT(ierr)
  CALL MPI_COMM_SIZE(MPI_COMM_WORLD, nproc, ierr)
  CALL MPI_COMM_RANK(MPI_COMM_WORLD, myid, ierr)
  root = 0
  a(1) = 2.0
  a(2) = 4.0
  CALL MPI_REDUCE(a, res, 2, MPI_REAL, MPI_SUM, root,
 &  MPI_COMM_WORLD, ierr)
  IF( myid .EQ. 0 ) THEN
    WRITE(6,*) myid, ': res(1)=', res(1), 'res(2)=', res(2)
  END IF
  CALL MPI_FINALIZE(ierr)
  END
```

MPI_Scatter

One-to-all communication: different data sent from root process to all others in the communicator

Fortran:

sender receiver

```
CALL MPI_SCATTER(sndbuf, sndcount, sndtype, rcvbuf, rcvcount, rcvtype,
   root, comm, ierr)
```

Arguments definition are like other MPI subroutine

sndcount is the number of elements sent to each process, not the size of **sndbuf**, that should be **sndcount** times the number of process in the communicator

The sender arguments are significant only at root

MPI_Gather

One-to-all communication: different data collected by the root process, from all others processes in the communicator. Is the opposite of Scatter

Fortran:

```
CALL MPI_GATHER(sndbuf, sndcount, sndtype, rcvbuf, rcvcount, rcvtype,
   root, comm, ierr)
```

sender

receiver

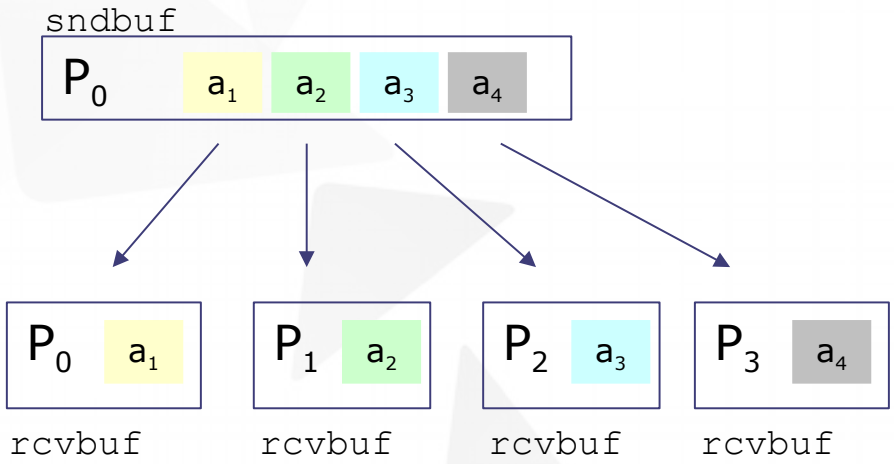
Arguments definition are like other MPI subroutine

rcvcount is the number of elements collected from each process, not the size of **rcvbuf**, that should be **rcvcount** times the number of process in the communicator

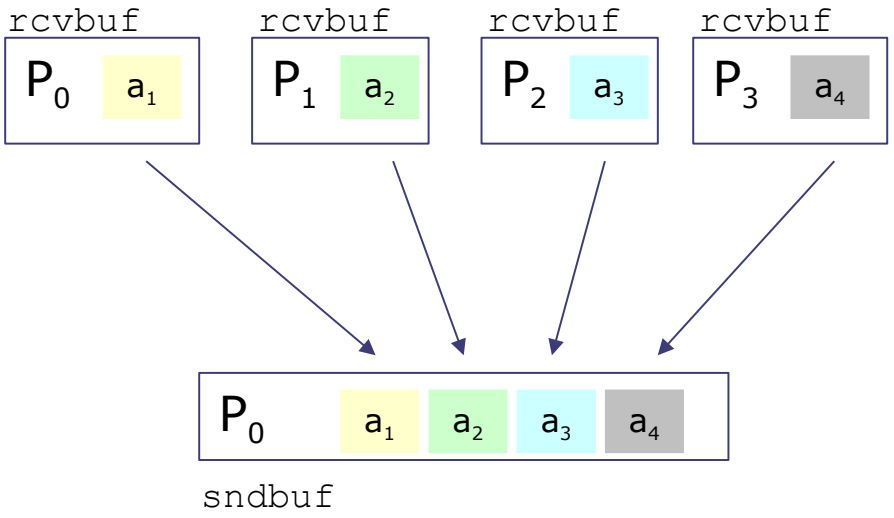
The receiver arguments are significant only at root

Scatter/Gather

Scatter



Gather



Scatter/Gather examples

scatter

```
 PROGRAM scatter
 INCLUDE 'mpif.h'
 INTEGER ierr, myid, nproc, nsnd, I, root
 INTEGER status(MPI_STATUS_SIZE)
 REAL A(16), B(2)
 CALL MPI_INIT(ierr)
 CALL MPI_COMM_SIZE(MPI_COMM_WORLD, nproc, ierr)
 CALL MPI_COMM_RANK(MPI_COMM_WORLD, myid, ierr)
 root = 0
 IF( myid .eq. root ) THEN
   DO i = 1, 16
     a(i) = REAL(i)
   END DO
 END IF
 nsnd = 2
 CALL MPI_SCATTER(a, nsnd, MPI_REAL, b, nsnd,
& MPI_REAL, root, MPI_COMM_WORLD, ierr)
 WRITE(6,*) myid, ': b(1)=', b(1), 'b(2)=', b(2)
 CALL MPI_FINALIZE(ierr)
 END
```

gather

```
 PROGRAM gather
 INCLUDE 'mpif.h'
 INTEGER ierr, myid, nproc, nsnd, I, root
 INTEGER status(MPI_STATUS_SIZE)
 REAL A(16), B(2)
 CALL MPI_INIT(ierr)
 CALL MPI_COMM_SIZE(MPI_COMM_WORLD, nproc, ierr)
 CALL MPI_COMM_RANK(MPI_COMM_WORLD, myid, ierr)
 root = 0
 b(1) = REAL( myid )
 b(2) = REAL( myid )
 nsnd = 2
 CALL MPI_GATHER(b, nsnd, MPI_REAL, a, nsnd,
&  MPI_REAL, root MPI_COMM_WORLD, ierr)
 IF( myid .eq. root ) THEN
   DO i = 1, (nsnd*nproc)
     WRITE(6,*) myid, ': a(i)=', a(i)
   END DO
 END IF
 CALL MPI_FINALIZE(ierr)
 END
```

Exercise:

- Modify pi_mpi.c to use collective operation instead of naive communication algorithm