



# *Computação em Larga Escala*

*Message Passing Interface (MPI) 1*

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## *Summary*

- *Collective communication*
  - *Broadcast*
  - *Scatter*
  - *Gather*
  - *Reduce*
- *Suggested reading*

DETI

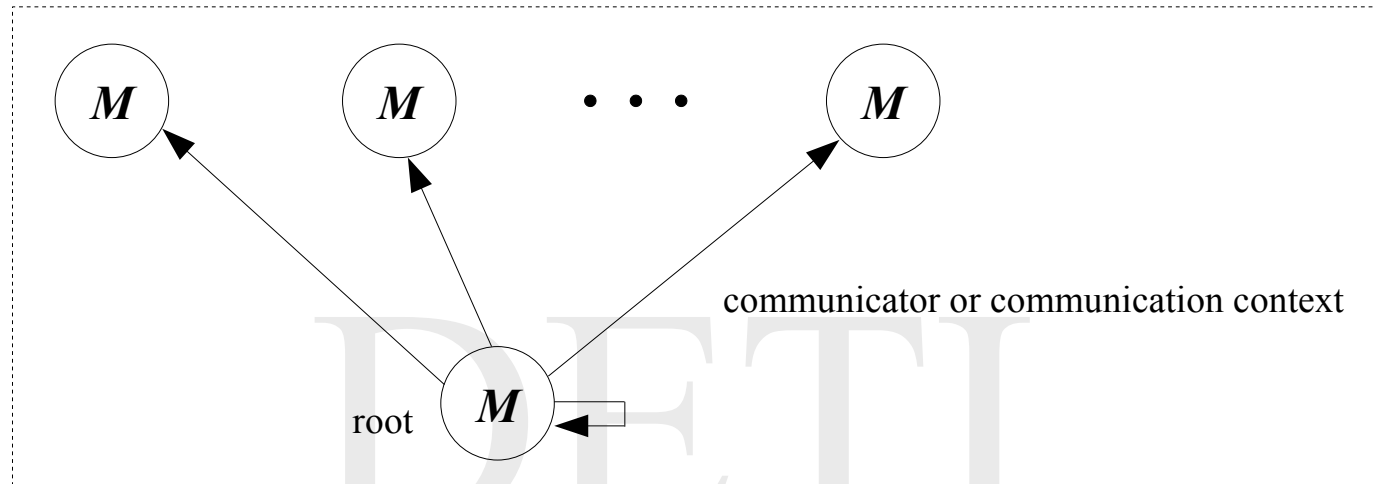
## *Collective communication*

*Collective communication* addresses the case where multiple processes, organized in a group, or groups of participating processes, exchange messages.

There are several types of collective communication

- **broadcast** – a message is sent from a *root* process (the calling process of the communication group) to all the processes (belonging to the communication group), itself included
- **scatter** – specific messages of similar type are sent from a *root* process (the calling process of the communication group) to all the processes (belonging to the communication group), itself included
- **gather** – specific messages of similar type are sent from all the processes (belonging to the communication group) to a *root* process (the calling process of the communication group).

## Broadcast - 1



- the message  $M$  is sent from the process with rank  $root$  to all the processes of the communication group, itself included
- in the standard case, *broadcast* is a blocking operation, that is, the processes block until the message is effectively received
- the *broadcast* operation can be thought of as the process with rank  $root$  to perform a *send* and all the processes in the group to perform next a *receive*

## ***Broadcast - 2***

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

**buf** - pointer to the memory region where the information content of the message is, or will be, stored

**count** - number of elements of the array which represents the information content of the message

**datatype** - MPI information data type

**root** - rank of the root process

**comm** - identification of the communication context (process group)

## ***Broadcast - 3***

```
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

int main (int argc, char *argv[])
{
    int rank;
    char *data = malloc ((strlen ("I, 0, am the leader!") + 1) * sizeof (char));
    int len = strlen ("I, 0, am the leader!") + 1;

    MPI_Init (&argc, &argv);
    MPI_Comm_rank (MPI_COMM_WORLD, &rank);
    if (rank == 0)
    {
        data = "I, 0, am the leader!";
        printf ("Broadcast message: %s \n", data);
    }
    MPI_Bcast(data, len, MPI_CHAR, 0, MPI_COMM_WORLD);
    printf ("I, %d, received the message: %s \n", rank, data);
    MPI_Finalize ();
    return EXIT_SUCCESS;
}
```

## ***Broadcast - 4***

```
[ruib@ruib-laptop basic]$ mpicc -Wall -o broadCast broadCast.c
```

```
[ruib@ruib-laptop basic]$ mpiexec -n 10 ./broadCast
```

```
Broadcast message: I, 0, am the leader!
```

```
I, 0, received the message: I, 0, am the leader!
```

```
I, 1, received the message: I, 0, am the leader!
```

```
I, 4, received the message: I, 0, am the leader!
```

```
I, 5, received the message: I, 0, am the leader!
```

```
I, 6, received the message: I, 0, am the leader!
```

```
I, 7, received the message: I, 0, am the leader!
```

```
I, 2, received the message: I, 0, am the leader!
```

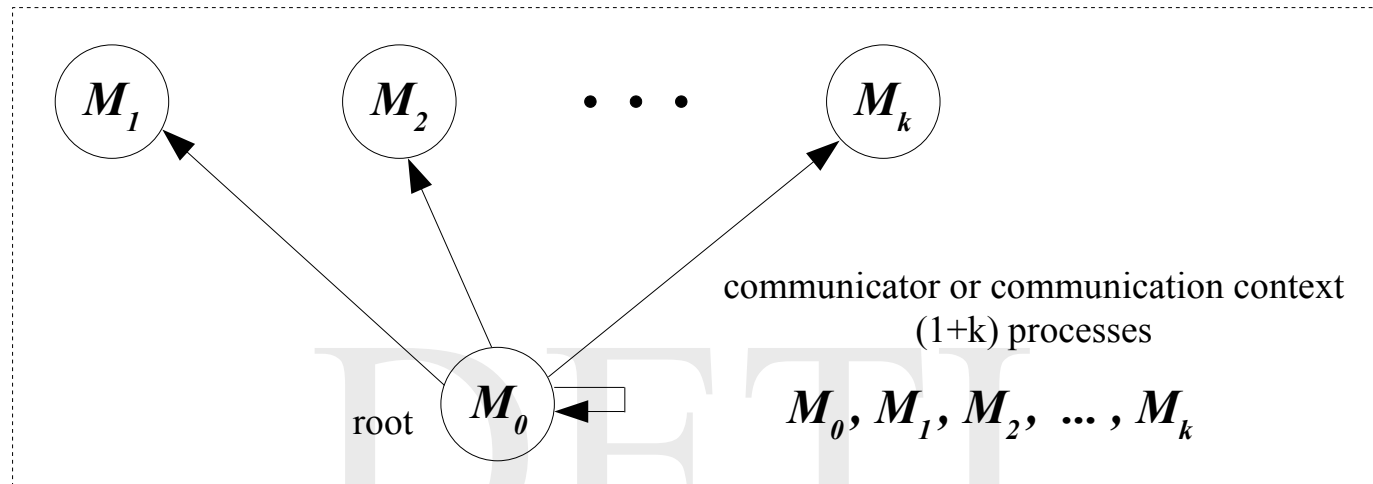
```
I, 3, received the message: I, 0, am the leader!
```

```
I, 8, received the message: I, 0, am the leader!
```

```
I, 9, received the message: I, 0, am the leader!
```

```
[ruib@ruib-laptop basic]$
```

## *Scatter - 1*



- a collection of  $k+1$  similar messages  $M_0, M_1, M_2, \dots, M_k$ , where  $k+1$  is the group size, are sent from the process with rank *root* to all the processes of the communication group, itself included
- in the standard case, *scatter* is a blocking operation, that is, the processes block until the message is effectively received
- the *scatter* operation can be thought of as the process with rank *root* to perform a *send* and all the processes in the group to perform next a *receive*



## *Scatter - 2*

```
int MPI_Scatter (void *sendbuf, int sendcount, MPI_Datatype sendtype,  
                void *recvbuf, int recvcount, MPI_Datatype recvtype, int root,  
                MPI_Comm comm);  
  
int MPI_Scatterv (void *sendbuf, int *sendcounts, int *displs, MPI_Datatype sendtype,  
                 void *recvbuf, int recvcount, MPI_Datatype recvtype, int root,  
                 MPI_Comm comm);
```

**sendbuf** - pointer to the memory region where the information content of the multiple messages to be sent are stored (significant only at root)

**sendcount** - number of elements sent to each process (significant only at root)

**sendcounts** - array with the number of elements sent to each process (significant only at root)

**displs** - array with the displacements (relative to the beginning of sendbuf) from which to take the sent data to each process

**sendtype** - MPI data type of send buffer elements (significant only at root)

**recvbuf** - pointer to the memory region where the information content of the received message is to be stored

**recvcount** - maximum number of elements received by each process

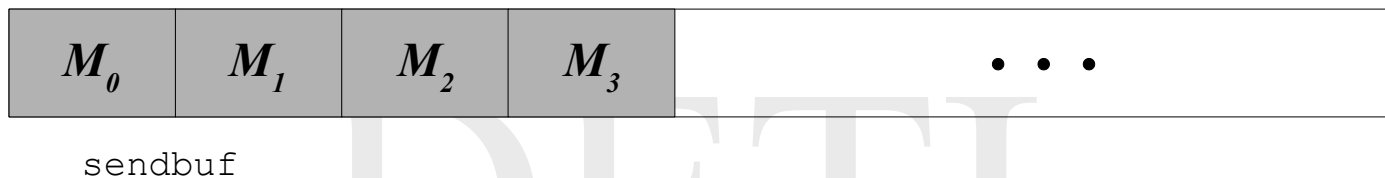
**recvtype** - MPI data type of receive buffer elements

**root** - rank of the root process

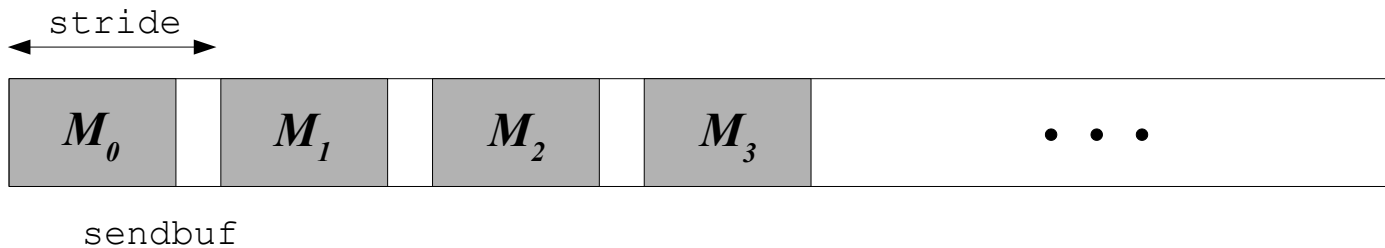
**comm** - identification of the communication context (process group)

## *Scatter - 3*

In `MPI_Scatter`, all messages to be sent have the same length and are stored contiguously in the sent buffer.



In `MPI_Scatterv`, all messages to be sent may have different lengths and may not be stored contiguously in the sent buffer.



## Scatter - 4

```
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>

int main (int argc, char *argv[])
{
    int rank, size, i;
    int *sendData = NULL, *recData;

    MPI_Init (&argc, &argv);
    MPI_Comm_rank (MPI_COMM_WORLD, &rank);
    MPI_Comm_size (MPI_COMM_WORLD, &size);
    recData = malloc (10 * sizeof (int));
    if (rank == 0)
    {
        sendData = malloc (10 * size * sizeof (int));
        printf ("Data to be scattered\n");
        for (i = 0; i < 10 * size; i++)
        {
            sendData[i] = i;
            printf ("%d ", sendData[i]);
        }
        printf ("\n");
    }
    MPI_Scatter (sendData, 10, MPI_INT, recData, 10, MPI_INT, 0, MPI_COMM_WORLD);
    printf ("Received data by process %d: ", rank);
    for (i = 0; i < 10; i++)
        printf ("%2d ", recData[i]);
    printf ("\n");
    MPI_Finalize ();
    return EXIT_SUCCESS;
}
```

## *Scatter - 5*

```
[ruib@ruib-laptop basic]$ mpicc -Wall -o scatter1 scatter1.c
```

```
[ruib@ruib-laptop basic]$ mpiexec -n 4 ./scatter1
```

```
Data to be scattered
```

```
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26  
27 28 29 30 31 32 33 34 35 36 37 38 39
```

```
Received data by process 0: 0 1 2 3 4 5 6 7 8 9
```

```
Received data by process 2: 20 21 22 23 24 25 26 27 28 29
```

```
Received data by process 3: 30 31 32 33 34 35 36 37 38 39
```

```
Received data by process 1: 10 11 12 13 14 15 16 17 18 19
```

```
[ruib@ruib-laptop basic]$
```

## Scatter - 6

```
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>

int main (int argc, char *argv[])
{
    int rank, size;
    int *sendData = NULL, *recData, *sendCount, *disp, recCount;
    int i;

    MPI_Init (&argc, &argv);
    MPI_Comm_rank (MPI_COMM_WORLD, &rank);
    MPI_Comm_size (MPI_COMM_WORLD, &size);
    recData = malloc (10 * sizeof (int));
    sendCount = malloc (size * sizeof (int));
    disp = malloc (size * sizeof (int));
    for (i = 0; i < size; i++)
    { sendCount[i] = (i < 3) ? 2 * (i + 1) : 10;
      disp[i] = 20 * i;
    }
    if (rank == 0)
    { sendData = malloc (20 * size * sizeof (int));
      printf ("Data to be scattered\n");
      for (i = 0; i < 20 * size; i++)
      { sendData[i] = i;
        printf ("%2d ", sendData[i]);
      }
      printf ("\n");
    }
    recCount = (rank < 3) ? 2 * (rank + 1) : 10;
    MPI_Scatterv (sendData, sendCount, disp, MPI_INT, recData, recCount, MPI_INT, 0,
                 MPI_COMM_WORLD);
    printf ("Received data by process %d: ", rank);
    for (i = 0; i < recCount; i++)
        printf ("%2d ", recData[i]);
    printf ("\n");
    MPI_Finalize ();

    return EXIT_SUCCESS;
}
```

## *Scatter - 7*

```
[ruib@ruib-laptop basic]$ mpicc -Wall -o scatter2 scatter2.c
```

```
[ruib@ruib-laptop basic]$ mpiexec -n 4 ./scatter2
```

```
Data to be scattered
```

```
 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22  
23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45  
46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68  
69 70 71 72 73 74 75 76 77 78 79
```

```
Received data by process 0:  0  1
```

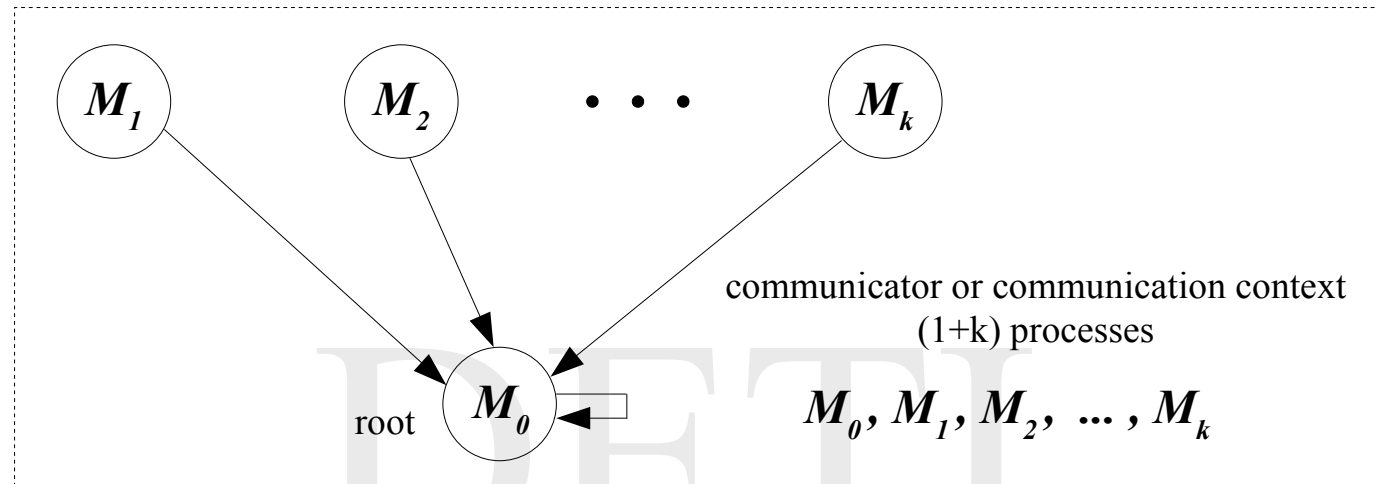
```
Received data by process 3: 60 61 62 63 64 65 66 67 68 69
```

```
Received data by process 1: 20 21 22 23
```

```
Received data by process 2: 40 41 42 43 44 45
```

```
[ruib@ruib-laptop basic]$
```

## *Gather - 1*



- a collection of  $k+1$  similar messages  $M_0, M_1, M_2, \dots, M_k$ , where  $k+1$  is the group size, are sent from all the processes of the communication group, *root* included, to the process with rank *root*
- in the standard case, *gather* is a blocking operation, that is, the process with rank *root* blocks until all the messages are effectively received
- the *gather* operation can be thought of as all the processes in the group to perform a *send* and the process with rank *root* to perform next a *receive*

## *Gather - 2*

```
int MPI_Gather (void *sendbuf, int sendcount, MPI_Datatype sendtype,  
               void *recvbuf, int recvcount, MPI_Datatype recvtype, int root,  
               MPI_Comm comm);  
  
int MPI_Gatherv (void *sendbuf, int sendcount, MPI_Datatype sendtype, void *recvbuf,  
                 int *recvcounts, int *displs, MPI_Datatype recvtype, int root,  
                 MPI_Comm comm);
```

**sendbuf** - pointer to the memory region where the information content of the message to be sent is stored

**sendcount** - number of elements sent by each process

**sendtype** - MPI data type of send buffer elements

**recvbuf** - pointer to the memory region where the information content of the received messages are to be stored (significant only at root)

**recvcount** - maximum number of elements received from each process (significant only at root)

**recvcounts** - array with the number of elements received from each process (significant only at root)

**displs** - array with the displacements (relative to the beginning of recvbuf) from which to store the sent data from each process (significant only at root)

**recvtype** - MPI data type of receive buffer elements (significant only at root)

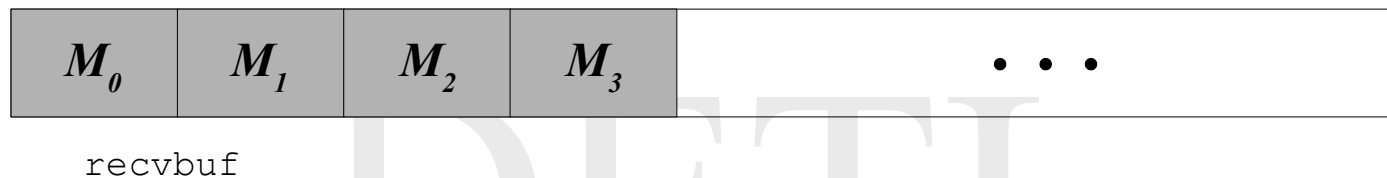
**root** - rank of the root process

**comm** - identification of the communication context (process group)

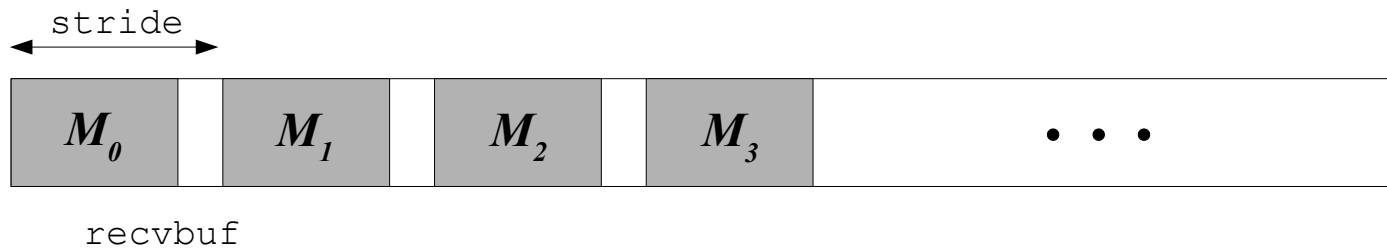


## *Gather - 3*

In `MPI_Gather`, all messages to be received have the same length and are stored contiguously in the receive buffer.



In `MPI_Gatherv`, all messages to be received may have different lengths and may not be stored contiguously in the received buffer.



## *Gather - 4*

```
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>

int main (int argc, char *argv[])
{
    int rank, size, i;
    int *sendData, *recData;

    MPI_Init (&argc, &argv);
    MPI_Comm_rank (MPI_COMM_WORLD, &rank);
    MPI_Comm_size (MPI_COMM_WORLD, &size);
    sendData = malloc (10 * sizeof (int));
    recData = malloc (10 * size * sizeof (int));
    printf ("Data to be sent by process %d: ", rank);
    for (i = 0; i < 10; i++)
    { sendData[i] = 10 * rank + i;
      printf ("%d ", sendData[i]);
    }
    printf ("\n");
    MPI_Gather (sendData, 10, MPI_INT, recData, 10, MPI_INT, 0, MPI_COMM_WORLD);
    if (rank == 0)
    { printf ("Gathered data\n");
      for (i = 0; i < 10 * size; i++)
          printf ("%d ", recData[i]);
      printf ("\n");
    }
    MPI_Finalize ();
    return EXIT_SUCCESS;
}
```

## *Gather - 5*

```
[ruib@ruib-laptop basic]$ mpicc -Wall -o gather1 gather1.c
```

```
[ruib@ruib-laptop basic]$ mpiexec -n 4 ./gather1
```

```
Data to be sent by process 0:  0  1  2  3  4  5  6  7  8  9
```

```
Data to be sent by process 3: 30 31 32 33 34 35 36 37 38 39
```

```
Data to be sent by process 1: 10 11 12 13 14 15 16 17 18 19
```

```
Data to be sent by process 2: 20 21 22 23 24 25 26 27 28 29
```

```
Gathered data
```

```
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26  
27 28 29 30 31 32 33 34 35 36 37 38 39
```

```
[ruib@ruib-laptop basic]$
```

## Gather - 6

```
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>

int main (int argc, char *argv[])
{
    int rank, size;
    int *sendData, sendCount, *recData, *recCount, *disp, offset;
    int i;

    MPI_Init (&argc, &argv);
    MPI_Comm_rank (MPI_COMM_WORLD, &rank);
    MPI_Comm_size (MPI_COMM_WORLD, &size);
    recCount = malloc (size * sizeof (int));
    disp = malloc (size * sizeof (int));
    offset = 0;
    for (i = 0; i < size; i++)
    { recCount[i] = (i < 3) ? 2 * (i + 1) : 10;
      disp[i] = offset;
      offset += recCount[i];
    }
    sendData = malloc (recCount[rank] * sizeof (int));
    recData = malloc (offset * size * sizeof (int));
    printf ("Data to be sent by process %d: ", rank);
    sendCount = (rank < 3) ? 2 * (rank + 1) : 10;
    for (i = 0; i < sendCount; i++)
    { sendData[i] = 10 * rank + i;
      printf ("%2d ", sendData[i]);
    }
    printf ("\n");
    MPI_Gatherv (sendData, sendCount, MPI_INT, recData, recCount, disp, MPI_INT, 0,
                 MPI_COMM_WORLD);
    if (rank == 0)
    { printf ("Gathered data\n");
      for (i = 0; i < offset; i++)
          printf ("%d ", recData[i]);
      printf ("\n");
    }
    MPI_Finalize ();
    return EXIT_SUCCESS;
}
```

## *Gather - 7*

```
[ruib@ruib-laptop basic]$ mpicc -Wall -o gather2 gather2.c
```

```
[ruib@ruib-laptop basic]$ mpiexec -n 4 ./gather2
```

```
Data to be sent by process 1: 10 11 12 13
```

```
Data to be sent by process 3: 30 31 32 33 34 35 36 37 38 39
```

```
Data to be sent by process 2: 20 21 22 23 24 25
```

```
Data to be sent by process 0: 0 1
```

```
Gathered data
```

```
0 1 10 11 12 13 20 21 22 23 24 25 30 31 32 33 34 35 36 37 38 39
```

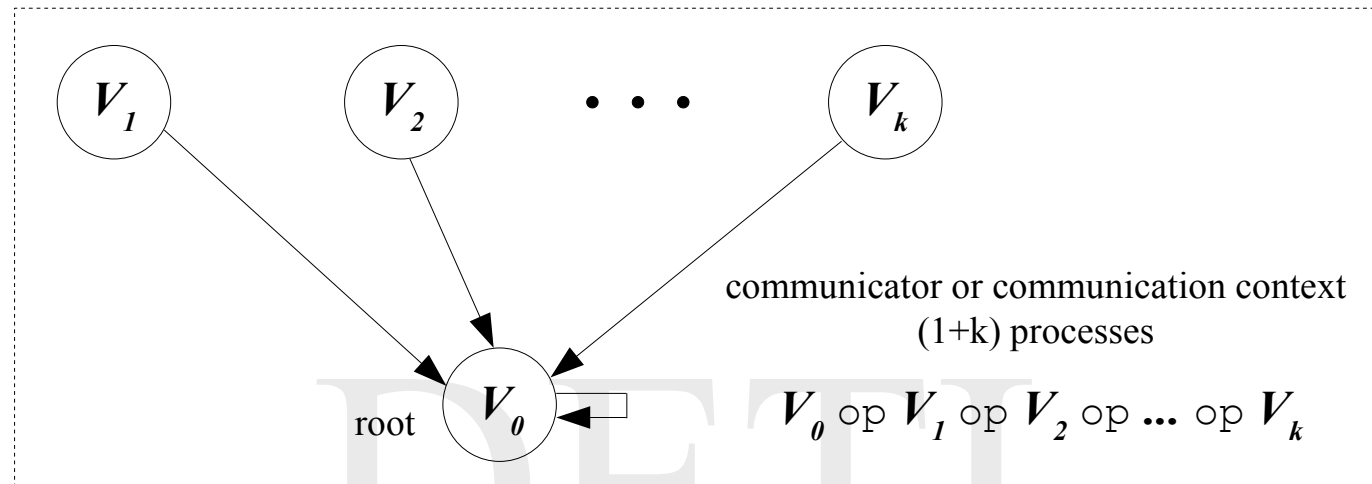
```
[ruib@ruib-laptop basic]$
```

## *Reduce - 1*

A further type of collective communication is

- *reduce* – allows one to perform a global calculation by aggregating (reducing) the values of a variable from all the processes (belonging to the communication group) using a commutative binary operator and sending the result to the *root* process (the calling process of the communication group).

## Reduce - 2



- a collection of  $k+1$  similar value arrays  $V_0, V_1, V_2, \dots, V_k$ , where  $k+1$  is the group size, are sent from all the processes of the communication group to the process with rank *root* and are computed together, element by element, through the application of a commutative binary operator
- in the standard case, *reduce* is a blocking operation, that is, the process with rank *root* blocks until the computation is effectively concluded
- the *reduce* operation can be thought of as all the processes in the group to perform a *send* and the process with rank *root* to perform next a *receive*

## *Reduce - 3*

### MPI predefined reduction operations

MPI operation	Meaning
MPI_MAX	maximum value
MPI_MIN	minimum value
MPI_SUM	sum of values
MPI_PROD	product of values
MPI_LAND	logical and of values
MPI_BAND	bitwise and of values
MPI_LOR	logical or of values
MPI_BOR	bitwise or of values
MPI_LXOR	logical x-or of values
MPI_BXOR	bitwise x-or of values



## *Reduce - 4*

```
int MPI_Reduce (void *sendbuf, void *recvbuf, int count, MPI_Datatype datatype,  
               MPI_Op op, int root, MPI_Comm comm);
```

**sendbuf** - pointer to the memory region where the information content of the message is stored

**recvbuf** - pointer to the memory region where the information content of the message will be stored (significant only at root)

**count** - number of elements of the array which represents the information content of the messages to be sent

**datatype** - MPI information data type

**op** - reduce operation

**root** - rank of the root process

**comm** - identification of the communication context (process group)

## *Reduce - 5*

```
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main (int argc, char *argv[])
{
    int rank, size;
    int val, maxVal;

    MPI_Init (&argc, &argv);
    MPI_Comm_rank (MPI_COMM_WORLD, &rank);
    MPI_Comm_size (MPI_COMM_WORLD, &size);
    srand (getpid ());
    val = ((double) rand () / RAND_MAX) * 1000;
    printf ("Value generated by process %d = %d \n", rank, val);
    MPI_Reduce (&val, &maxVal, 1, MPI_INT, MPI_MAX, 0, MPI_COMM_WORLD);
    if (rank == 0)
        printf ("Largest value = %d\n", maxVal);
    MPI_Finalize ();
    return EXIT_SUCCESS;
}
```

## *Reduce - 6*

```
[ruib@ruib-laptop basic2]$ mpicc -Wall -o reduce reduce.c
```

```
[ruib@ruib-laptop basic2]$ mpiexec -n 10 ./reduce
```

```
Value generated by process 1 = 393
```

```
Value generated by process 2 = 755
```

```
Value generated by process 3 = 115
```

```
Value generated by process 5 = 328
```

```
Value generated by process 0 = 540
```

```
Value generated by process 4 = 478
```

```
Value generated by process 6 = 688
```

```
Value generated by process 7 = 546
```

```
Value generated by process 8 = 908
```

```
Value generated by process 9 = 270
```

```
Largest value = 908
```

```
[ruib@ruib-laptop basic2]$
```

## *Suggested reading*

- *Introduction to HPC with MPI for Data Science*, Nielsson F., Springer International, 2016
  - Chapter 2: *Introduction to MPI: The Message Passing Interface*
- *MPI: A Message-Passing Interface Standard (Version 3.1)*, Message Passing Interface Forum, 2015