UNIVERSITY of HOUSTON
CENTER FOR ADVANCED COMPUTING & DATA SYSTEMS

Introduction to Parallel Programming with MPI Part I

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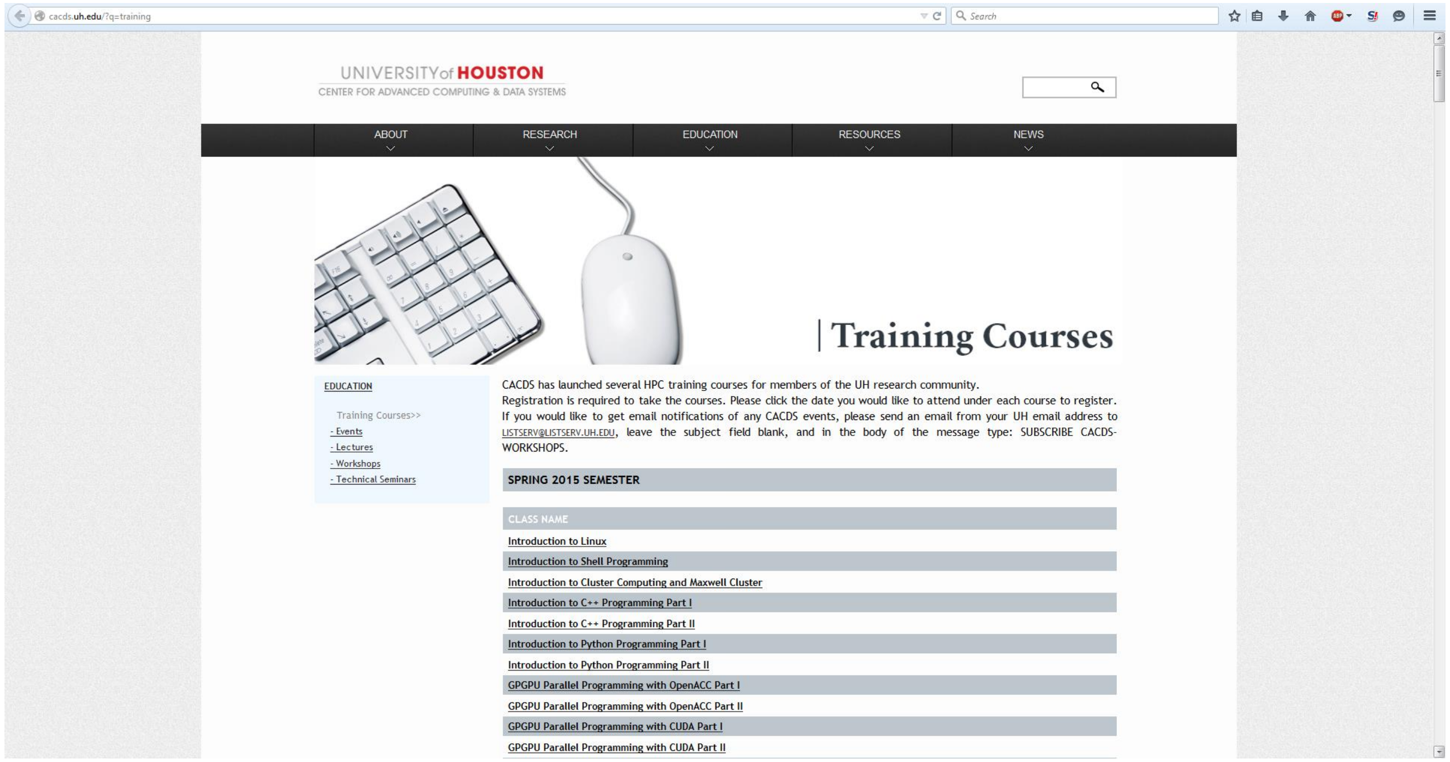

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- Log into your accounts
  - Username or login = hpc_user**X**
  - Where X = serial number 1 – 47 from the sign-in sheet
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Accessing Tutorial Materials

First login into the cluster:

TYPE AND EXECUTE COMMANDS IN Green!!!

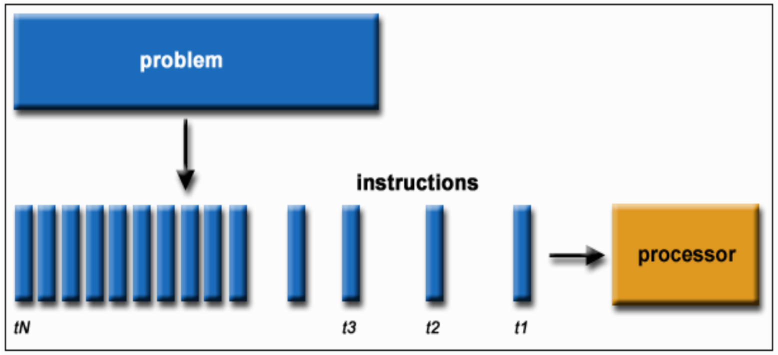
```
cd
cp /share/apps/tutorials/mpi_1.pdf  ~
cp /share/apps/tutorials/mpi_1.zip  ~
unzip mpi_1.zip
cd mpi_1
module add gcc openmpi
```

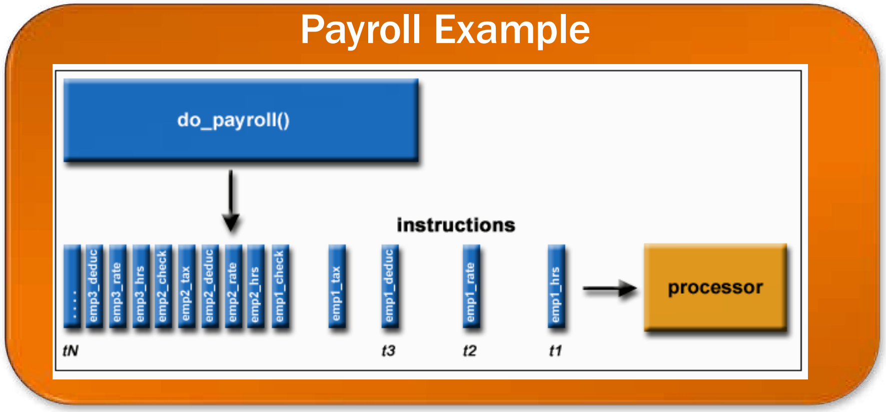
Overview

- Background
  - Parallel Computing
- Introduction
  - What is MPI?
- Using MPI in simple programs
  - What does a simple MPI program looks like?
  - How do I run an MPI program?
- Basic MPI routines
  - Examples and exercises
- Intermediate MPI
  - Examples and exercises

Background: Parallel Computing I

- Serial Computing:
  - Traditionally, software has been written for serial computation:
  - A problem is broken into a discrete series of instructions
  - Instructions are executed sequentially one after another
  - Executed on a single processor
  - Only one instruction may execute at any moment in time



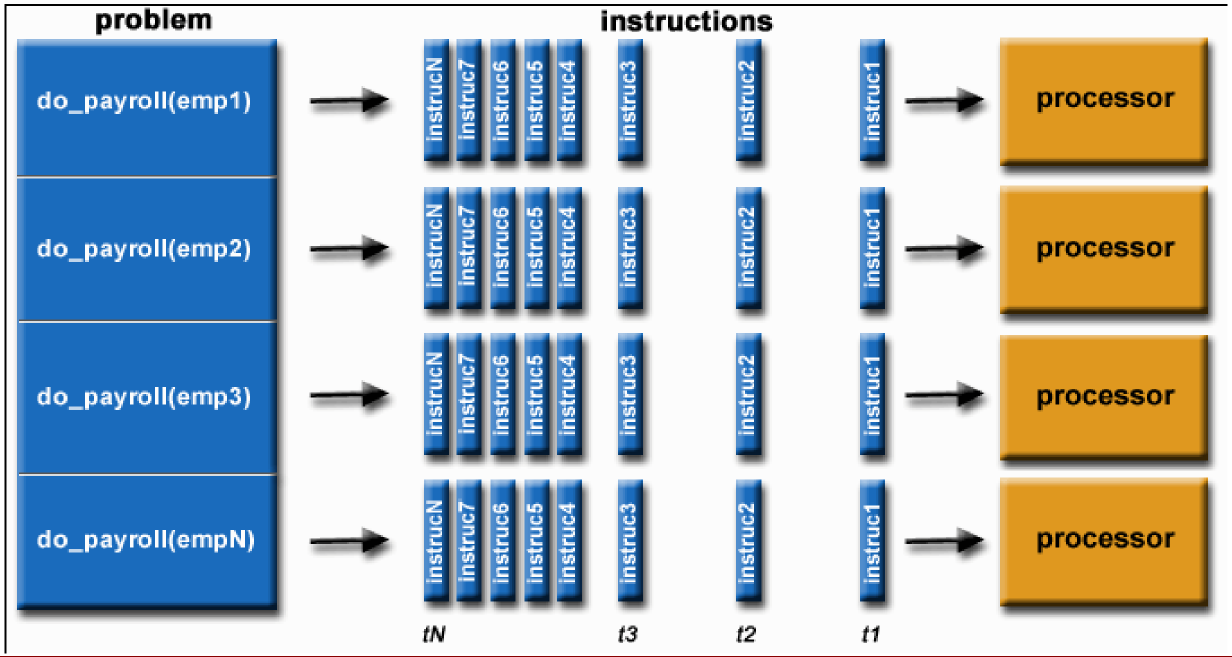


Background: Parallel Computing II

- Earlier CPU speeds kept doubling every 18 months (Moore's law)
- Would generate more heat than what can be economically dissipated from a CPU
- Thus Serial Computing is limited by the CPU speed
- Need for an alternate solution to reach ExaFLOPS of computations
  - Parallel Computing

Background: Parallel Computing III

- Parallel Computing is the simultaneous use of multiple compute resources to solve a computational problem:
  - A problem is broken into discrete parts that can be solved concurrently
  - Each part is further broken down to a series of instructions
  - Instructions from each part execute simultaneously on different processors
  - An overall control/coordination mechanism is employed

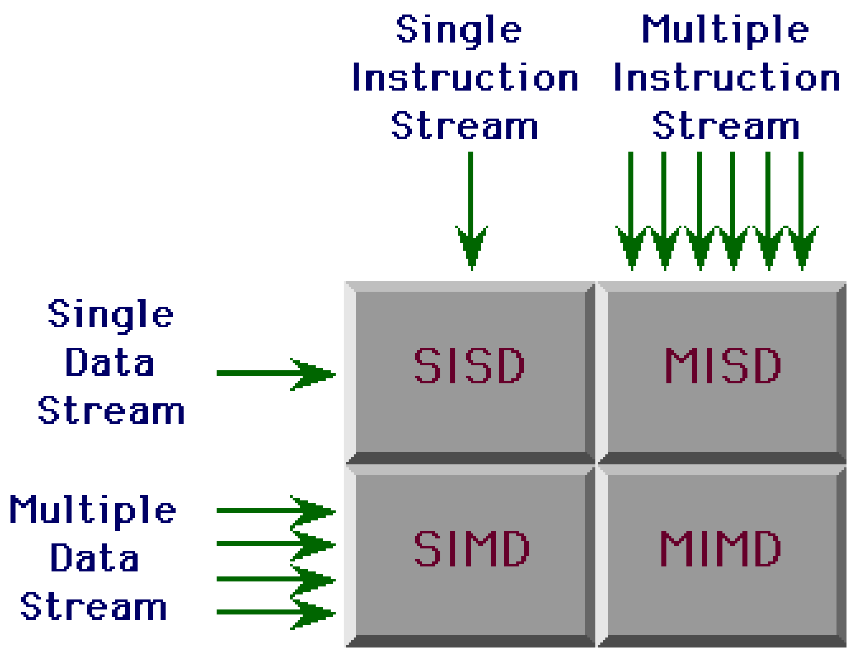


Background: Parallel Computing IV

- The computational problem should be able to:
  - Be broken apart into discrete pieces of work that can be solved simultaneously;
  - Execute multiple program instructions at any moment in time;
  - Be solved in less time with multiple compute resources than with a single compute resource.
- The compute resources are typically:
  - A single computer with multiple processors/cores
  - An arbitrary number of such computers connected by a network (i.e, distributed memory platforms)

Introduction: Types of parallel computing models

- Data Parallel - the same instructions are carried out simultaneously on multiple data items (SIMD)
- Task Parall   t data (MIMD)
- SPMD (sing   hronized at individual
- SPMD is eq   program can be made SI   ractical sense.)
- Message p   parallelism.
- High Perfor   SIMD interface



What is MPI?
Message Passing Interface I

- MPI (Message-Passing Interface) is a library of subroutines for handling communication and synchronization for programs running on parallel platforms.
- MPI addresses primarily the message-passing parallel programming model, in which data is moved from the address space of one process to that of another process through cooperative operations on each process.
- MPI targets distributed memory platforms, such as the UH Maxwell cluster, but it often delivers comparable performance on shared memory platforms also (such as the SGI UV).
- MPI programs usually follow a single program multiple data (SPMD) format.

What is MPI?
Message Passing Interface II

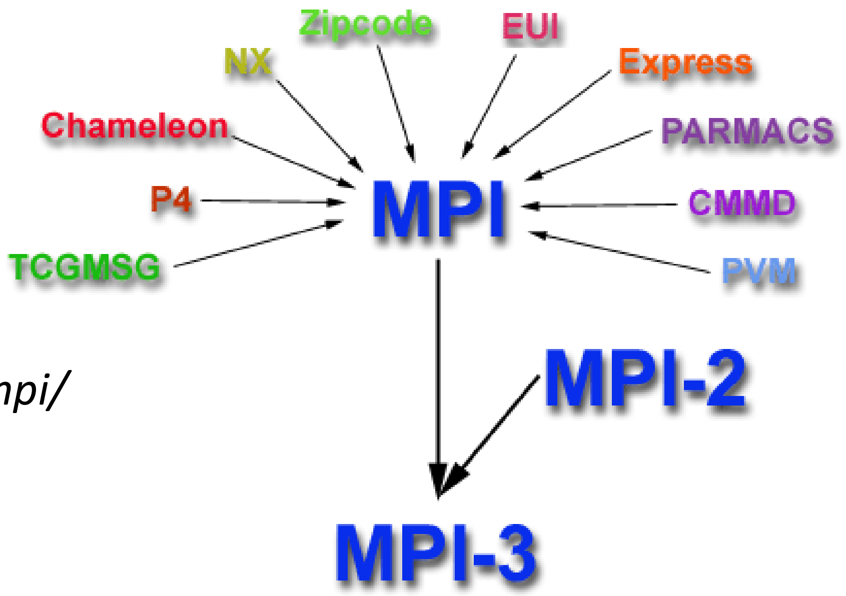
- MPI is not a language, and all MPI operations are expressed as functions, subroutines, or methods, according to the appropriate language bindings which, for C and Fortran, are part of the MPI standard.
  - The goal of the MPI is to develop a widely used standard for writing message-passing programs.
  - Establish a practical, portable, efficient, and flexible standard for message passing.
- http://www.mpi-forum.org/
- Currently on version 3.0 (September, 2013)

The Message-Passing Model

- A process is (traditionally) a program counter and address space.
- Processes may have multiple threads (program counters and associated stacks) sharing a single address space.
- MPI is for communication among processes, which have separate address spaces.
- Inter-process communication consists of
  - Synchronization
  - Movement of data from one process's address space to another's.

MPI Evolution

- 1980s: Distributed memory, parallel computing develops. Recognition of the need for a standard arose
- 1992: MPI1 draft proposal presented. Group adopts procedures and organization to form the MPI Forum with vendors, developers, academia and application scientists
- 1994: MPI-1.0 released
- 2008: MPI-2
- 2013: MPI-3.0



From: https://computing.llnl.gov/tutorials/mpi/

MPI 3.0 Standards

- MPI 3.0 includes support for
  - Point-to-point communication
  - Datatypes
  - Collective operations
  - Process groups
  - Communication contexts
  - Process topologies
  - Environmental management and inquiry
  - The Info object
  - Process creation and management
  - One-sided communication
  - External interfaces
  - Parallel file I/O
  - Language bindings for Fortran and C
  - Tool support

Why use MPI?

- MPI provides a powerful, efficient, and portable way to express parallel programs
- MPI was explicitly designed to enable libraries…
- ... which may eliminate the need for many users to learn (much of) MPI
- ***MPI's goal is not to make simple programs easy to write, but to make complex programs possible to write – Pavan Balaji***

A simple MPI program (C)

- Hello World

```
#include "mpi.h"
#include <stdio.h>
int main( int argc, char *argv[] )
{
MPI_Init( &argc, &argv );
printf( "Hello, world!\n" );
MPI_Finalize();
return 0;
}
```

A simple MPI program (Fortran)

- Hello World

```
program main
use MPI
Integer ierr
call MPI_INIT(ierr)
print *, 'Hello, world!'
call MPI_FINALIZE(ierr)
end
```

Running MPI program

- Given a program MY_MPI_PROGRAM.c where MPI is initialized and used:
- Load the MPI library

```
module load openmpi
```

- Compile with the appropriate MPI compiler wrapper
  - Fortran 77 Programs ===> mpif77
  - Fortran 90 Programs ===> mpif90
  - C Programs ===> mpicc
  - C++ Programs ===> mpic++ or mpiCC or mpicxx

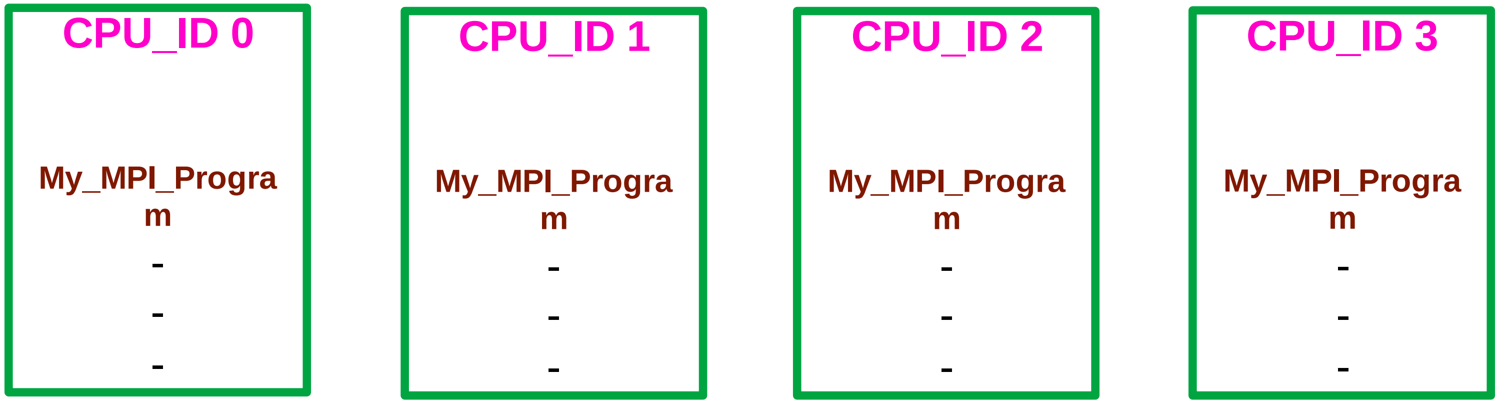
```
mpicc -o MY_MPI_PROGRAM MY_MPI_PROGRAM.c
```

- Run the executable using 4 processors:

```
mpirun –np 4 ./MY_MPI_PROGRAM
```

How MPI runs your application in parallel?

- MPI spawns an identical copy of MY_MPI_PROGRAM on each of the m requested processors.
  - e.g. If m=4, there will be four identical jobs running on four processors at the same time!



Understanding the Hello World program

- Open the program example1.c in vim editor or your choice of editor

```
#include "mpi.h"
#include <stdio.h>
int main( int argc, char *argv[] )
{
MPI_Init( &argc, &argv );
printf( "Hello, world!\n" );
MPI_Finalize();
return 0;
}
```

Load the MPI library, type:

```
module load openmpi
```

Compile, type:

```
mpicc example1.c -o hello
```

Run using:

```
mpirun -np 1 ./hello
```

number of processors

Result: `Hello world`

Understanding the Hello World program

Run with: `mpirun -np 2 ./hello`

Result:

```
Hello world
Hello world
```

```
#include "mpi.h"
#include <stdio.h>
int main( int argc, char *argv[] )
{
MPI_Init( &argc, &argv );
printf( "Hello, world!\n" );
MPI_Finalize();
return 0;
}
```

The program starts with just one *process*; the "master" process.

When `MPI_INIT()` executes, 1 additional process is created, called "worker". 2 processes in total.

Then each process executes their corresponding program: `printf("Hello,world!\n");`

This ends at `MPI_FINALIZE()` Control returns to the root process then.

Understanding the Hello World program

All MPI programs NEED these 3 commands to run:

C version

```
#include "mpi.h"
#include <stdio.h>
int main( int argc, char *argv[] )
{
MPI_Init( &argc, &argv );
printf( "Hello, world!\n" );
MPI_Finalize();
return 0;
}
```

- A template for an MPI program can be found in mpi_1 template.c

Understanding the Hello World program

All MPI programs NEED these 3 commands to run:

Fortran version

```
program hello
   include 'mpif.h'

integer :: ierr

   call MPI_INIT ( ierr )
   print *, "Hello world"
   call MPI_FINALIZE ( ierr )

end program hello
```

- A template for an MPI program can be found in mpi_1 template.f

Exercise 1

- Try compiling example1.cpp
- cd
- cd intro2mpi
- module load openmpi
- mpic++ example1.cpp -o example

- Now run the executable on 4 processors

```
mpirun -np 4 ./example
```

```
Output:
I am process 2 of 4 MPI processes
I am process 0 of 4 MPI processes
I am process 1 of 4 MPI processes
I am process 3 of 4 MPI processes
```

Assigning Work

- How can you assign different work to each processor, if all processors run the same program?
- The short answer:
    - MPI assigns a rank (an integer number) to each process to identify it.
    - The routine `MPI_COM_RANK` returns the rank of the calling process.
    - The routine `MPI_COM_SIZE` returns the size or number of processes in the communicator.
- These two parameters, size and rank, can then be used (through block if statements or otherwise) to differentiate the computations that each process will execute.

```
if (my_rank == 0)
    X = ....
    Y = ....
else
    Z1 = … Z2 = ...
```

The Longer Answer

- When MPI is initialized, it creates a communicator, consisting of a group of processes and their labels. This communicator is called,

  MPI_COMM_WORLD

- The number of processes (m) in this communicator is determined when we submit the MPI job:

  ```
  mpirun –np m MY_MPI_JOB
  ```

- Each process can probe for the value of m by calling the MPI routine

  MPI_COMM_SIZE

- Each process in the MPI_COMM_WORLD group is assigned a rank, an integer with incremental value between 0 and m-1. Each process can determine its own rank by calling the routine

  MPI_COMM_RANK

Template for MPI Programs in C
Template.c

```
#include <stdio.h>                                    /*–Include standard I/O C header file */

#include "mpi.h"                                      /*–Include the MPI header file */

int main( int argc, char* argv[])
{

    int myid, numprocs, itag;                         /*–Declare all variables and arrays. */

    MPI_Init(&argc,&argv);                            /* –> Required statement */

    MPI_Comm_rank(MPI_COMM_WORLD,                     /*–Who am I? — get my rank=myid */
    &myid);

    MPI_Comm_size(MPI_COMM_WORLD,                     /*–How many processes in the global group? */
    &numprocs);


    MPI_Finalize();                                   /*–Finalize MPI */
                                                      /* —> Required statement */
    return 0;
}
```

Template for MPI Programs in Fortran

```
program template

implicit none                                  ! highly recommended.  It will make
                                               ! debugging infinitely easier.

  include 'mpif.h'                             !–Include the mpi header file
                                               ! –> Required statement

 integer ierr, myid, numprocs,                 !–Declare all variables and arrays.
 itag
 integer irc

   call MPI_INIT( ierr )                       !–Initialize MPI
                                               ! –> Required statement

 call MPI_COMM_RANK( MPI_COMM_WORLD, myid, ierr )        !–Who am I? — get my rank=myid

 call MPI_COMM_SIZE( MPI_COMM_WORLD, numprocs, ierr )  !–How many processes in the global group?

 call MPI_FINALIZE(ierr)                       !–Finilize MPI
                                               ! —> Required statement

 stop
 end
```

Exercise 2

- Starting from template.c or template.f, write a program that uses a common value of x (e.g. x=5 in all processes) to compute:
  - $y=x^2$ in process 0
  - $y=x^3$ in process 1
  - $y=x^4$ in process 2
- and writes a statement from each process that identifies the process and reports the values of x and y from that process.

Exercise 2: Solution Using Three Processors

```
//program template
//!--Define new variables used
…….. int ip
float x,y
……
{MPI_COMM_RANK and MPI_COMM_SIZE CALLS......}

//!--Insert the calculations after the size (numprocs)
//! and rank (myid) are known.
//!--Set the value of x on all processes
x=5;

!--Define the value of y on each process .....
if(myid == 0)
y=pow(x,2);
else if (myid == 1)
y=pow(x,3);
else (myid == 2)
y=pow(x,4);

//!--...and print it.
printf(“On process %f, y= %f“,myid ,y);
```

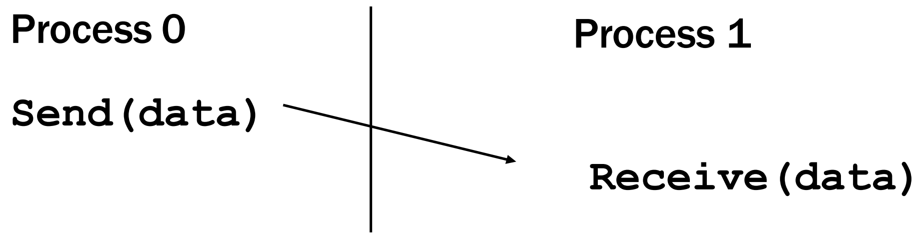
Exercise 2: Solution, a more concise version

```
//program template
.
.
//!--Define new variables used
 int ip;
 float x,y;
   .
   .
 {MPI_COMM_RANK and MPI_COMM_SIZE CALLS......}

//!--Insert the calculations after the size (numprocs)
//!  and rank (myid) are known.

//!--Set the value of x on all processes
  x=5;

//!--Define the value of y on each process and print it.
  y=pow(x,(2+myid));
   printf("On process %f, y= %f",myid ,y);
         .
         .
```

Results from Exercise 2

Cooperative operations for communication

- The message-passing approach makes the exchange of data *cooperative*.
- Data is explicitly *sent* by one process and *received* by another.
- An advantage is that any change in the receiving process's memory is made with the receiver's explicit participation.
- Communication and synchronization are combined.



Communication

- MPI is designed to manage codes running on distributed memory platforms. Thus data residing on other processes is accessed through MPI calls.
- Although MPI includes a large number of communication routines, most applications require only a handful of them.
- A minimal set of routines that most parallel codes run with are:

MPI_INIT

MPI_COMM_SIZE

MPI_COMM_RANK

MPI_SEND

MPI_RECV

MPI_FINALIZE

- Point to point and collective communications

Point to Point Communications

- MPI_Send and MPI_Recv perform "point to point" communications.
- The two routines work together to complete a transfer of data from one process to another.
- One process posts a send operation, and the target process posts a receive for the data being transferred.

e.g. (pseudocode)

```
  if (my_rank == 0)
   &    MPI_SEND(.......,1,..)

   if (my_rank == 1)
   &    MPI_RECV(.......,0,.....)
```

Blocking MPI Send routine

MPI_Send(buf, count, datatype, dest, tag, comm)

buf =initial address of send buffer (choice)

count =number of entries to send (integer)

datatype=datatype of each message entry (handle)

dest =rank of destination (integer)

tag =message tag

comm =communicator (handle)

ierr =return error code (integer) only for fortran

some datatype available handles:

MPI_SHORT
MPI_INT
MPI_LONG
MPI_FLOAT
MPI_DOUBLE
MPI_CHAR
MPI_C_COMPLEX
MPI_BYTE
MPI_PACKED

Blocking MPI Receive routine

MPI_Recv (buf, count, datatype, source, tag, comm, status)

OUT	buf initial address of receive buffer (choice)
IN	count number of elements in receive buffer (non-negative
IN	integer)
IN	datatype datatype of each receive buffer element (handle)
IN	source rank of source or MPI_ANY_SOURCE (integer)
IN	tag message tag or MPI_ANY_TAG (integer)
OUT	comm communicator (handle)
	status status object (Status)

Any routine that calls MPI_RECV, should declare the status array

- integer status(MPI_STATUS_SIZE)
- The status array contains information on the received message, such as its tag, source, error code. The number of entries received can also be obtained from this array.

C implementation/signature

- int MPI_Recv(void* buf, int count, MPI_Datatype datatype, int source, int tag, MPI_Comm comm, MPI_Status *status)

EXAMPLE 2: Point to Point Communication

```
 ….
    int   i,  dest,   numprocs, my_rank,  source;

    MPI_Status status;
        float x[5],  y[5];    //Buffers for copy and receive
        int     count   =5;

/* --the common calling arguments */

    int    tag     = 2;
/*---process 0 send data to process 1 (dest=1) */
    if (my_rank == 0) {
      for (i=1;i<=5; i++) {
         x[i-1]=(float) i;
      }
       dest    = 1;
       MPI_Send( &x[0], count,  MPI_FLOAT,  dest,  tag,   MPI_COMM_WORLD);
    }

/*---process 1 receives data from process 0 (source=0) */
    if (my_rank == 1) {
   /* float y=0.; */
      int source=0;

      MPI_Recv(&y[0],  count, MPI_FLOAT,  source,  tag, MPI_COMM_WORLD, &status);

   printf("At process %d y= %.1f %.1f %.1f %.1f %.1f \n", my_rank,y[0],
            y[1],y[2],y[3],y[4]);
    }
…..
    return 0;
   }
```

The full program can be copied from example2.c or example2.f

The Message Envelope

How does an MPI process select which message to receive if more than one message has been sent to it?

Each message carries verification information with it called the **message envelope**.

The message envelope consists of the following:

source
destination
tag
communicator

A message is received only if the arguments in the posted receive call agree with the message envelope of an incoming message.

Exercise 3

- Using the program in exercise 2, send all values of y to process 0 and compute the average of y at process 0.
- Print the result, including the process rank from where it is being printed.

Solution of Exercise 3

```
  int tag;                    MPI_Status status;
  float  x, y, buff;
     .....
     ......
    {CALCULATION OF Y ON THE DIFFT. PROCESSES}
     .
/*–Average the values of y*/
    tag=1;
    if (myid == 0) {
     for (int  ip=0; ip < numprocs; ip++) {
       MPI_Recv(buff, 1, MPI_REAL, ip, tag,  MPI_COMM_WORLD, status);
       y+=buff;
      }
     y=y/float(numprocs);
    printf (“The average value of y is %d”, y );
    else
    MPI_Send(y  , 1, MPI_FLOAT, 0, tag, &MPI_COMM_WORLD);
.......
```

Wildcards

- What if I want to receive a message regardless of its source and/or tag?
====> Replace the source and/or tag entry on the MPI_RECV call with a wildcard:

- Ignore source by using the MPI_ANY_SOURCE
wildcard:
MPI_Recv(buf, count, datatype, & MPI_ANY_SOURCE, tag, comm, status)

- Ignore tag by using the MPI_ANY_TAG
wildcard:
MPI_Recv(buf, count, datatype, &source, MPI_ANY_TAG, comm, status)

- Ignore tag and
source:
MPI_Recv(buf, count, datatype, &MPI_ANY_SOURCE, MPI_ANY_TAG, comm, status)

- *WILDCARDS SHOULD ONLY BE USED WHEN ABSOLUTELY NECESSARY!*

Blocking vs Non-Blocking Communications

- MPI_Send and MPI_Recv are **blocking** communications routines.

- What does it mean for MPI_Send to be a **blocking** routine?
  - Once a call to MPI_SEND is posted by a process, the call does not return control to the calling program or routine, until the buffer containing the data to be copied unto the receiving process can be safely overwritten (This insures that the message being sent is not "corrupted" before the sending is complete)

- What does it mean for MPI_Recv to be a **blocking** routine?
  - The call does not return control to the calling program until the data to be received has in fact been received.

Avoiding 'Hung' Processes

A "Hung" condition occurs when one or more processes reach a call to an MPI blocked receive routine, but the message never arrives. The process will wait indefinitely and no error message will be generated. (The same will happen with a blocked send message that is never completed).

A "Hung" condition can occur when two processes exchange messages, if the exchange is not programmed carefully.

First: an example of an exchange that will never "hang":
Can you tell why? (If not compare to the example on next page).

```
//–Exchange messages
   if (myid == 0) {
     MPI_Send(a,1,MPI_FLOAT,1,tag,MPI_COMM_WORLD);
     MPI_Recv(b,1,MPI_FLOAT,1,tag,MPI_COMM_WORLD,
     &status);
  }
   else if (myid == 1) {
      MPI_Recv(a,1,MPI_FLOAT,0,tag,MPI_COMM_WORLD,  &
      status);
      MPI_Send(b,1,MPI_FLOAT,0,tag,MPI_COMM_WORLD);
   }
```

The code above is an excerpt from **example3_a.c**
Please verify that this code will run to completion without a problem

Example of a Hanging Program

- Suppose that the order of the send and receive calls are modified as follows

```
//!--Exchange messages
    if (myid == 0) {
        MPI_Recv(b,1,MPI_FLOAT,1,tag,MPI_COMM_WORLD, &        status );
        MPI_Send(a,1,MPI_FLOAT,1,tag,MPI_COMM_WORLD );
    }
    else if (myid == 1) {                                     status );
         MPI_Recv(a,1,MPI_FLOAT,0,tag,MPI_COMM_WORLD, &
         MPI_Send(b,1,MPI_FLOAT,0,tag,MPI_COMM_WORLD );
     }
```

- The code above is an excerpt from example3_a.c
- Will this program run as well as example3_a?
- Why?

Example of a Hanging Program: Why?

The program in example3_c.c will not run at all, it will hang!
(that is, it will never complete and give no error diagnostic – other that running out of time).

Here is why:

1. Each of processes 0 and 1 calls a blocking MPI_Recv routine and expects to receive a message from the other process.
2. Neither process will continue on to the next statement until the information has been received (or is at least safely on its way).
3. At this point neither process has actually SENT any message to the other process.
4. **Thus both processes will wait indefinitely for a message that will never come....**

Example of a Program that MIGHT hang

- The following order of the send and receive calls will work on some platforms but not others.
- IT IS NOT RECOMMENDED!

```
//!–Exchange messages if (myid == 0) {
    MPI_Send(a,1,MPI_FLOAT,1,tag,MPI_COMM_WORLD);
    MPI_Recv(b,1,MPI_FLOAT,1,tag,MPI_COMM_WORLD, & status);
    }
    else if (myid == 1) {
     MPI_Send(b,1,MPI_FLOAT,0,tag,MPI_COMM_WORLD);
     MPI_Recv(a,1,MPI_FLOAT,0,tag,MPI_COMM_WORLD,&status);
    }
```

- The full program can be found in **example3_b.c**
- A safe alternative is to use the **MPI_SENDRECV** routine instead.

MPI_SENDRECV

MPI_SendRecv(sendbuf, sendcount, sendtype, & dest, sendtag, recvbuf, recvcount, recvtype,
&source, recvtag, comm, status)

- sendbuf =initial address of send buffer (choice)
-
- sendcount = # of entries to send (integer)
-
- sendtype =type of entries in send buffer (handle)
-
- dest =rank of destination (integer)
-
- sendtag =send tag (integer)
-
- recvbuf =initial address of receive buffer (choice)
-
- recvcount=max. num. of entries to receive (integer)
-
- recvtype =type of entries in receive buffer (handle)
-
- source =rank of source (integer)
-
- recvtag =receive tag (integer)
-
- status =return status(integer)
-
- comm =communicator
- (handle)

Example 4 : Using MPI_SendRecv I

Example 4:

Shows the use of the SendRecv MPI call replacing a pair of consecutive send and receive calls originating from a single process. Note that the communications here are the same as in example3_b, except that the SendRecv insures that no deadlock or hangup occurs.

- Here is an excerpt from example 4,
- //–Exchange messages

```
tag1=1;
tag2=2;
if (myid == 0)  {
MPI_SendRecv (a, 1 , MPI_FLOAT, 1, tag1, & b, 1, MPI_FLOAT, 1, tag2, & MPI_COMM_WORLD,
status); }
else if (myid == 1) {
  MPI_SendRecv(b,1,MPI_FLOAT,0,tag2,  &a,1,MPI_FLOAT,0,tag1, &MPI_COMM_WORLD, status );
 }
```

See example4.c

Example 5: Using MPI_SendRecv II

- MPI_SENDRECV is compatible with simple MPI_SEND and MPI_RECV routines. Here is an example that illustrates the point.
- Example 5
- Process 0 sends a to process 1 and receives b from process 2:

```
MPI_COMM    comm;           comm =MPI_COMM_WORLD;
tag1=1;     tag2=2;
if     (myid == 0)
    MPI_SendRecv(a,1,MPI_FLOAT,1,tag1, &       b,1,MPI_FLOAT,2,tag2, & comm, status);
else if (myid==1)
    MPI_Recv(a,1,MPI_FLOAT,0,tag1, &comm, status);
else if (myid==2)
    MPI_Send(b,1,MPI_FLOAT,0,tag2,&comm);
```

- (See example5.c)

Non-Blocking Communications

The most common non-blocking point-to-point MPI communication routines are:

MPI_ISend(buf, count, datatype, dest, tag, comm, request)

MPI_IRecv(buf, count, datatype, source, tag, comm, request)

- **buf** =initial address of send buffer (choice)
- **count** =number of entries to send/receive (integer)
- **datatype**=datatype of each entry (handle)
- **dest** =rank of destination process (integer)
- **source** =rank of source process(integer)
- **tag** =message tag
- **comm** =communicator (handle)
- **request** =request handle (handle)

Blocking vs Non-Blocking I

- **What is the difference between MPI_ISend and MPI_Send?**
  - MPI_ISend returns control to the calling routine immediately after posting the send call, before it is safe to overwrite (or use) the buffer being sent.
  - (MPI_IRecv and MPI_Recv differ in a similar way)

- **What is the advantage of using non-blocking communication routines?**
  - Performance can be improved by allowing computations that do not involve the buffer being sent (or received) to proceed simultaneously with the communication.

- **How can the communicated buffer be re-used safely?**
  - The MPI_ISend (and MPI_IRecv) return a handle: the request argument. The MPI_Wait routine can later
    be called in order to "complete" the request communication. MPI_Wait blocks computation until the request in question is complete and it is safe to re-use the buffer.

Blocking vs Non-Blocking II

The non-blocking routines MPI_ISend and MPI_IRecv are similar to their blocking couterparts, MPI_Send and MPI_Recv.

- The difference between them is that non-blocking communications return control to the calling routine BEFORE it is safe to re-use the buffer being sent or received.
- This allows the program to proceed with computations not involving the communication buffer, while the communication completes.
- Before the program is to use the sent/received buffer, a call to MPI_Wait is necessary.
- MPI_Wait is a blocking routine. It does not return control to the calling routine until it is safe to re-use the buffer.

Non-Blocking an example

(Pseudocode)

Post a non-blocking send of variable a.

MPI_ISend(a,.........,REQUEST1,...)

While the communication of a takes place, compute the values of b, c, and d (which do not involve a).

```
b=x2
c=y3
d=b+c
```

Block computation until it is safe to use a again.

MPI_Wait(REQUEST1,status)

Use a on the computation of e, modify a, etc.

```
e=a+b
a=d
```

Collective MPI Routines

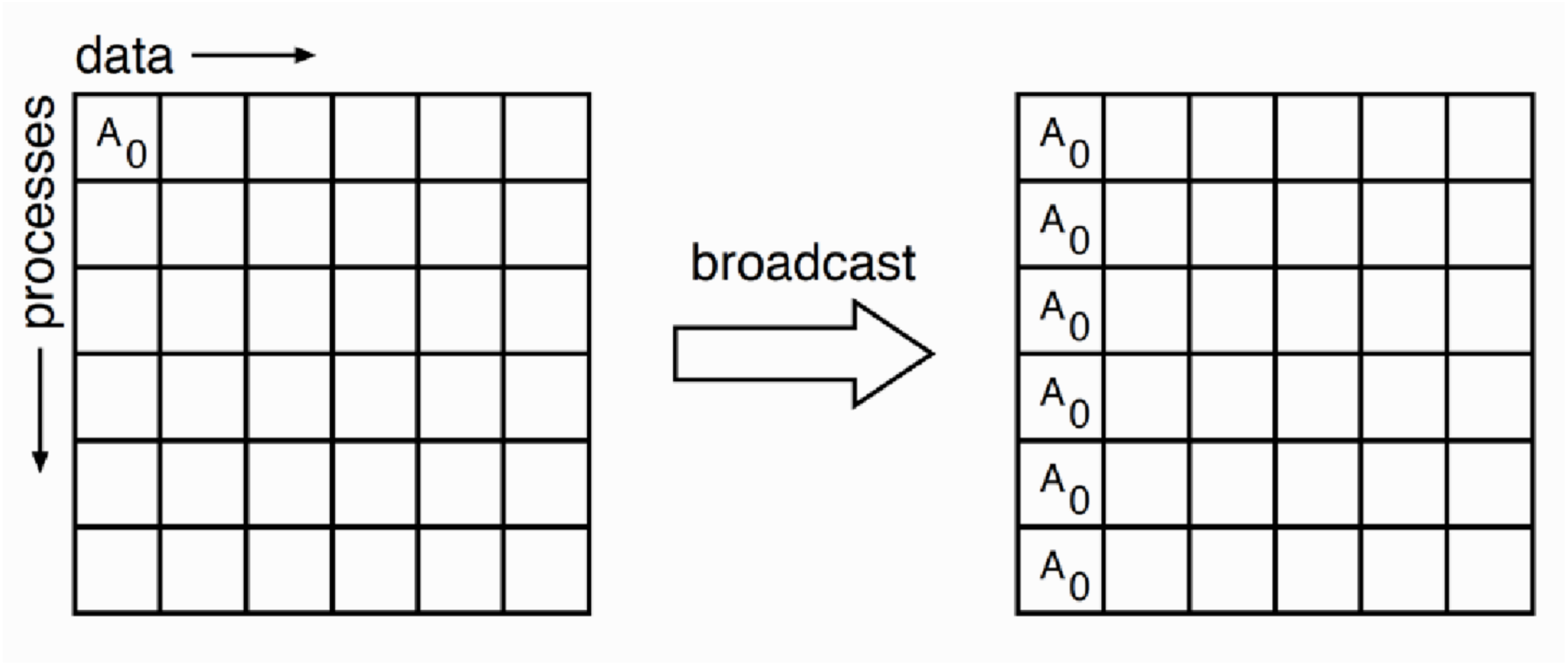
Collective MPI routines involve simultaneous communications among all the processors within a communicator group.

The communication involves a group or groups of processes.

3 types of collective communications:

- Barrier synchronization
- Global communications: *Broadcast, Gather, Scatter*
- Global Reduction Operations: *Sum, Max, Min*

Broadcast



Broadcast Routine

One of the most commonly used collective routines.

- The root process broadcasts the data in buffer to all the processes in the communicator.

- All processes must call MPI_BCAST with the same root value.

```
MPI_Bcast(buffer, count, datatype, root, comm)
```

buffer	= initial address of buffer (choice)
count	= number of entries in buffer (integer)
datatype	= datatype of buffer (handle)
root	= rank of broadcasting process (integer)
comm	= communicator (handle)

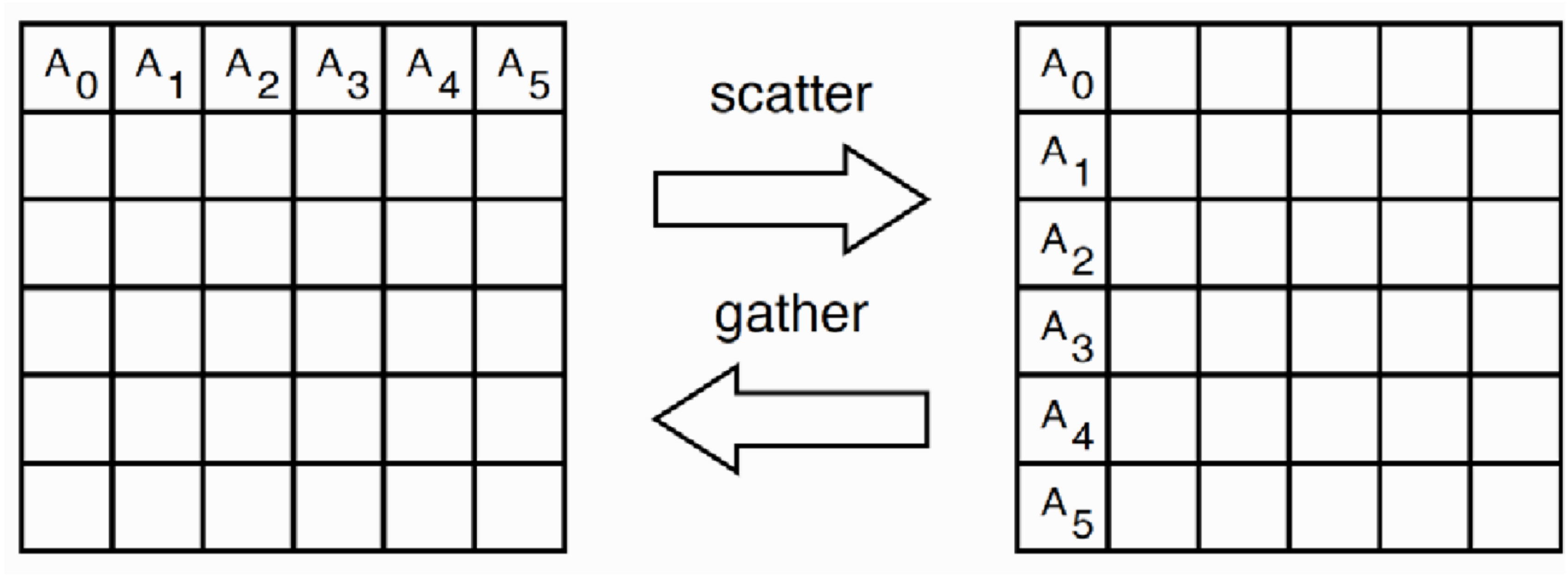
Exercise 4: Using Broadcast

- Modify the code for exercise 2 so that the value of x is defined ONLY on processor 0. Add the necessary code to broadcast the value of x to all the other processors.

Solution to Exercise 4

```
//Partial solution.
.
//!–Define new variables used
   int  ip;
   float  x, y;
      .
      .
   {MPI_COMM_RANK and MPI_COMM_SIZE
   CALLS......}
//!–Insert the calculations after the size and rank
//!  are known.

//!–Set the value of x on process 0.
      if (myid == 0)    x=5;

//!–Broadcast the value of x to all processes.
      MPI_Bcast( x, 1, MPI_FLOAT, 0,MPI_COMM_WORLD
      );
!–Define the value of y on each process and print it.
 for (ip=0; ip<numprocs;ip++)
 {
    if(myid == ip-1)
    {
           y = pow(x,(2+myid));
           printf("On process %f, y= %f",myid,  y);
    }
   }
      .
      .
```

Scatter and Gather



MPI_Scatter

Sends data from one process to all other processes in a communicator

```
MPI_Scatter(sendbuf, sendcount, sendtype, recvbuf,
   recvcount, recvtype, root, comm)
```

IN sendbuf	= address of send buffer (choice, significant only at root)
IN sendcount	= number of elements sent to each process (non-negative integer, signficant only at root)
IN sendtype	= data type of send buffer elements (significant only at root) (handle)
OUT recvbuf	= address of receive buffer (choice)
IN recvcount	= number of elements in receive buffer (non-negative integer)
IN recvtype	= data type of receive buffer elements (handle)
IN root	= rank of sending process (integer)
IN comm	= communicator (handle)

```
int MPI_Scatter(const void* sendbuf, int sendcount,
   MPI_Datatype sendtype, void* recvbuf, int recvcount,
   MPI_Datatype recvtype, int root, MPI_Comm comm)
```

Scatter Example I

```
/*Scatter sets of 100 ints from the root to each process in the group*/
....
MPI_Comm comm;
int gsize,*sendbuf;
int root, rbuf[100];
...
MPI_Comm_size(comm, &gsize);
sendbuf = (int *)malloc(gsize*100*sizeof(int));
...
MPI_Scatter(sendbuf, 100, MPI_INT, rbuf, 100, MPI_INT, root, comm);
```

Scatter Example II

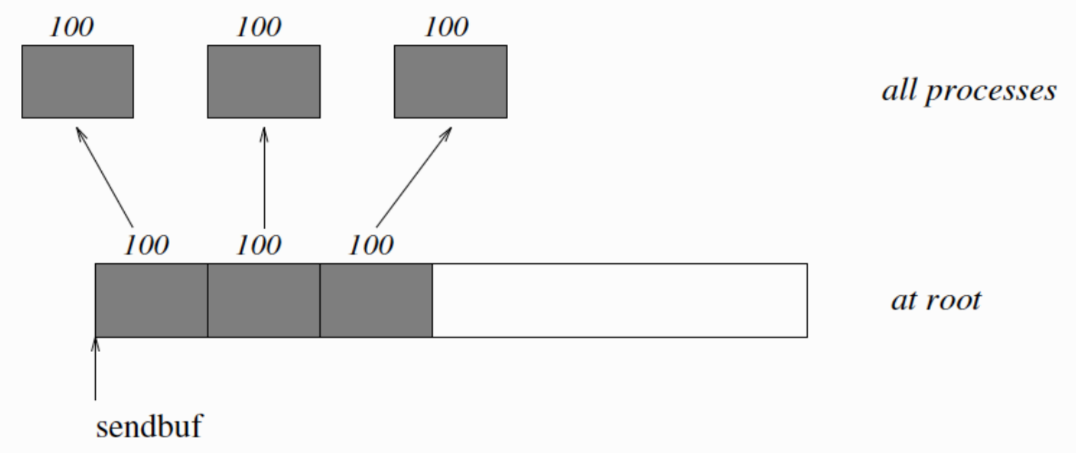


Figure 5.9: The root process scatters sets of 100 `ints` to each process in the group.

MPI_Gather

Gathers together values from a group of processes

MPI_Gather(sendbuf, sendcount, sendtype, recvbuf, recvcount, recvtype, root, comm)

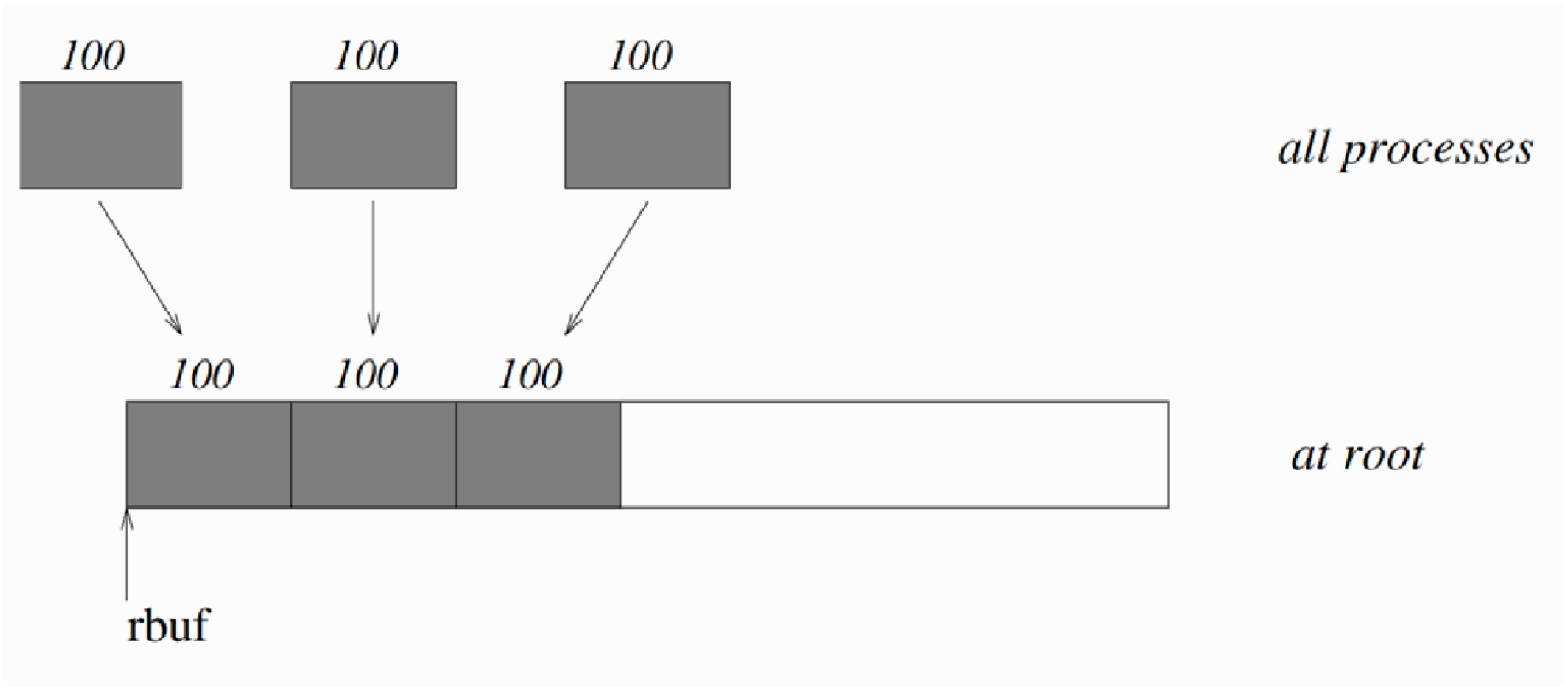
- IN sendbuf starting address of send buffer (choice)
- IN sendcount number of elements in send buffer (non-negative integer)
- IN sendtype data type of send buffer elements (handle)
- OUT recvbuf address of receive buffer (choice, significant only at root)
- IN recvcount number of elements for any single receive (non-negative integer, significant only at root)
- IN recvtype data type of recv buffer elements (significant only at root) (handle)
- IN root rank of receiving process (integer)
- IN comm communicator (handle)

int MPI_Gather(const void* sendbuf, int sendcount, MPI_Datatype sendtype, void* recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)

Gather Example I

```
….
MPI_Comm comm;
int gsize, sendarray[100];
int root, *rbuf;
…
MPI_Comm_size(comm, &gsize);
rbuf = (int *)malloc(gsize*100*sizeof(int));
MPI_Gather(sendarray, 100, MPI_INT, rbuf, 100, MPI_INT, root,
comm);
```

Gather Example II



The root process gathers 100 ints from each process in the group.

Summary

- The parallel computing community has cooperated on the development of a standard for message-passing libraries.
- MPI subsets are easy to learn and use.
- Lots of MPI learning material are available.

MPI Part 2 (3/27/2015)

- Reductions
- Communicators and groups
- One sided communications
- Hybrid Programming with Shared Memory
- …..

Acknowledgement

- Jerry Ebalunode
  - CACDS@UH
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  - CACDS@UH
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References

- The Standard itself:
  - at http://www.mpi-forum.org
- General MPI reference:
  - http://www.mpi-forum.org/docs/mpi-3.0/mpi30-report.pdf
- Tutorials
  - https://computing.llnl.gov/tutorials/mpi/
- Books:
  - *Using MPI: Portable Parallel Programming with the Message-Passing Interface*, by Gropp, Lusk, and Skjellum, MIT Press, 1994.
  - *MPI: The Complete Reference,* by Snir, Otto, Huss-Lederman, Walker, and Dongarra, MIT Press, 1996.
  - *Designing and Building Parallel Programs*, by Ian Foster, Addison-Wesley, 1995.
  - *Parallel Programming with MPI*, by Peter Pacheco, Morgan-Kaufmann, 1997. *MPI:*
  - *The Complete Reference Vol 1 and 2,*MIT Press, 1998(Fall).
- Other information on Web:
  - at http://www.mcs.anl.gov/mpi
  - pointers to lots of stuff, including other talks and tutorials, a FAQ, other MPI pages

Thank you

- Please fill the course assessment forms, *just click the home icon in your browser*

- Email yourselves the **slides & example programs** from
  /home/hpc_userXX/mpif90.zip

- Upper menu > System > **Log Out** hpc_user...

Upcoming training events at CACDS

Intro to MPI parallel computing II, 3/27, 10am, PGH 200

Visualization with Paraview I, 3/24, 2pm, PGH 235
Visualization with Paraview II, 3/27, 2pm, PGH 235

Intro to high performance numerical libraries, 3/31, 10am, PGH 200
GPGPU parallel programming with OpenACC I, 3/31, 2pm, PGH 235