SINGULARIS LAB

Introduction to MPI

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Background on MPI

- MPI - Message Passing Interface
  - Library standard defined by a committee of vendors, implementers, and parallel programmers
  - Used to create parallel programs based on message passing
- 100% portable: one standard, many implementations
- Available on almost all parallel machines in C and Fortran
- Over 100 advanced routines but 6 basic

Key Concepts of MPI

- **Used to create parallel programs based on message passing**
  - **Normally the same program is running on several different processors**
  - **Processors communicate using message passing**
- **Typical methodology:**

```
start job on n processors
do i=1 to j
    each processor does some calculation
    pass messages between processor
end do
end job
```

Messages

- Simplest message: an array of data of one type.
- Predefined types correspond to commonly used types in a given language
  - MPI_FLOAT
  - MPI_DOUBLE
  - MPI_INT
- User can define more complex types and send packages.

Communicators

- Communicator
  - A collection of processors working on some part of a parallel job
  - Used as a parameter for most MPI calls
  - **MPI_COMM_WORLD** includes **all** of the processors in your job
  - Processors within a communicator are assigned numbers (ranks) 0 to n-1
  - Can create subsets of **MPI_COMM_WORLD**

Include files

- The MPI include file

  #include<mpi.h>
- Defines many constants used within MPI programs
- In C defines the interfaces for the functions
- Compilers know where to find the include files

Minimal MPI program

- Every MPI program needs these…

```
/* the mpi include file */
#include <mpi.h>
   int nPEs,ierr,iam;
/* Initialize MPI */
   ierr=MPI_Init(&argc, &argv);
/* How many processors (nPEs) are there?*/
   ierr=MPI_Comm_size(MPI_COMM_WORLD, &nPEs);
/* What processor am I (what is my rank)? */
   ierr=MPI_Comm_rank(MPI_COMM_WORLD, &iam);
...
   ierr=MPI_Finalize();
```

- In C MPI routines are functions and return an error value

Exercise 1 : Hello World

- Write a parallel “hello world” program
  - Initialize MPI
  - Have each processor print out “Hello, World” and its processor number (rank)
  - Quit MPI

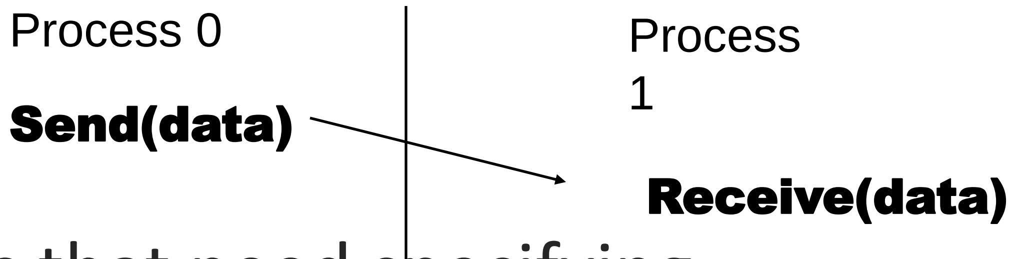
Solution 1: Hello World

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

int main( int argc, char *argv[] )
{
    int rank, size;
    MPI_Init( &argc, &argv );
    MPI_Comm_rank( MPI_COMM_WORLD, &rank );
    MPI_Comm_size( MPI_COMM_WORLD, &size );
    printf( "I am %d of %d\n", rank, size );
    MPI_Finalize();
    return 0;
}
```

MPI Basic Send/Receive

- We need to fill in the details in



Process 0

Send(data)

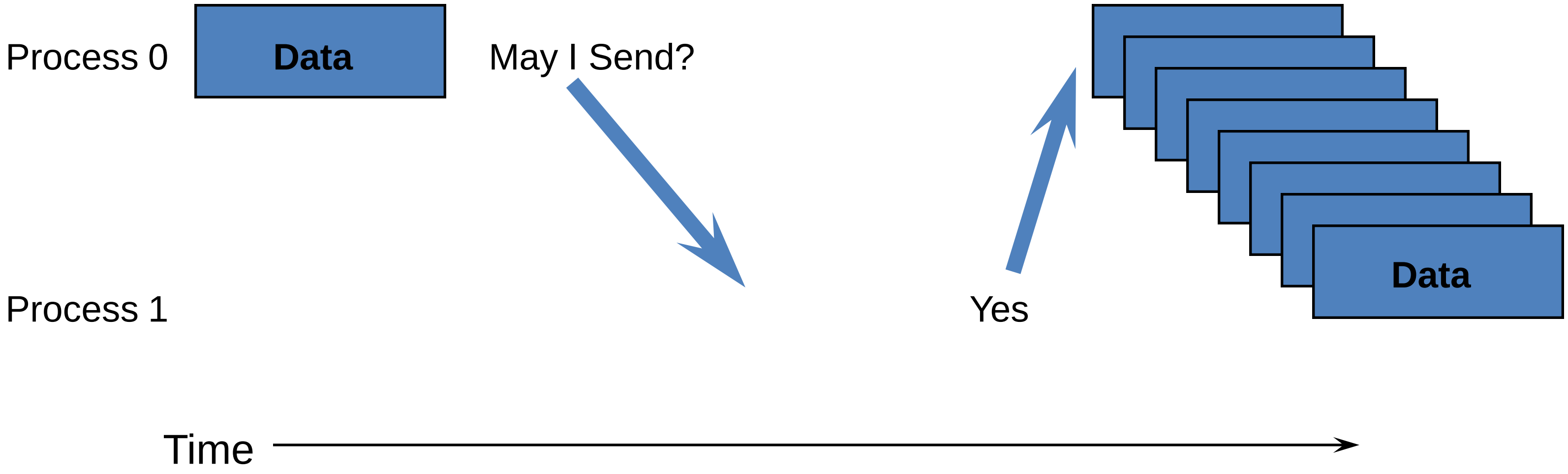
Process 1

Receive(data)

- Things that need specifying:
  - How will “data” be described?
  - How will processes be identified?
  - How will the receiver recognize/screen messages?
  - What will it mean for these operations to complete?

What is message passing?

- Data transfer plus synchronization



- Requires cooperation of sender and receiver
- Cooperation not always apparent in code

Some Basic Concepts

- Processes can be collected into *groups*.
- Each message is sent in a *context*, and must be received in the same context.
- A group and context together form a *communicator*.
- A process is identified by its *rank* in the group associated with a communicator.
- There is a default communicator whose group contains all initial processes, called **`MPI_COMM_WORLD`**.

Basic Communication

- Data values are transferred from one processor to another
  - One processor sends the data
  - Another receives the data
- Synchronous
  - Call does not return until the message is sent or received
- Asynchronous
  - Call indicates a start of send or receive, and another call is made to determine if finished

Synchronous Send

  - `MPI_Send(&buffer, count ,datatype, destination, tag,communicator);`

- Call blocks until message on the way

Synchronous Send

- **Buffer**: The data array to be sent
- **Count** : Length of data array (in elements, 1 for scalars)
- **Datatype** : Type of data, for example : MPI_DOUBLE_PRECISION, MPI_INT, etc
- **Destination** : Destination processor number (within given communicator)
- **Tag** : Message type (arbitrary integer)
- **Communicator** : Your set of processors
- **Ierr** : Error return (Fortran only)

Synchronous Receive

- C
  - `MPI_Recv(&buffer,count, datatype, source, tag, communicator, &status);`

  Call blocks the program until message is in *buffer*
- Status - contains information about incoming message
  - C
    - MPI_Status status;

Synchronous Receive

- **Buffer**: The data array to be received
- **Count** : Maximum length of data array (in elements, 1 for scalars)
- **Datatype** : Type of data, for example : MPI_DOUBLE_PRECISION, MPI_INT, etc
- **Source** : Source processor number (within given communicator)
- **Tag** : Message type (arbitrary integer)
- **Communicator** : Your set of processors
- **Status**: Information about message
- **Ierr** : Error return (Fortran only)

Exercise 2 : Basic Send and Receive

- Write a parallel program to send & receive data
  - Initialize MPI
  - Have processor 0 send an integer to processor 1
  - Have processor 1 receive an integer from processor 0
  - Both processors print the data
  - Quit MPI

Summary

- MPI is used to create parallel programs based on message passing
- Usually the same program is run on multiple processors
- The 6 basic calls in MPI are:
  - `MPI_INIT( ierr )`
  - `MPI_COMM_RANK( MPI_COMM_WORLD, myid, ierr )`
  - `MPI_COMM_SIZE( MPI_COMM_WORLD, numprocs, ierr )`
  - `MPI_Send(buffer, count,MPI_INTEGER,destination, tag, MPI_COMM_WORLD, ierr)`
  - `MPI_Recv(buffer, count, MPI_INTEGER,source,tag, MPI_COMM_WORLD, status,ierr)`
  - `call MPI_FINALIZE(ierr)`

MPI is Simple

- Many parallel programs can be written using just these six functions, only two of which are non-trivial:
  - `MPI_INIT`
  - `MPI_FINALIZE`
  - `MPI_COMM_SIZE`
  - `MPI_COMM_RANK`
  - `MPI_SEND`
  - `MPI_RECV`
- Point-to-point (send/recv) isn’t the only way...

Introduction to Collective Operations in MPI

- Collective operations are called by all processes in a communicator.
- **`MPI_BCAST`** distributes data from one process (the root) to all others in a communicator.
- **`MPI_REDUCE`** combines data from all processes in communicator and returns it to one process.
- In many numerical algorithms, **`SEND/RECEIVE`** can be replaced by **`BCAST/REDUCE`**, improving both simplicity and efficiency.

Collective Operations in MPI syntax

-
  ```
  int MPI_Reduce(
   const void *sendbuf,
   void *recvbuf,
   int count,
   MPI_Datatype datatype,
   MPI_Op op,             // op = MPI_MIN, MPI_MAX, MPI_SUM, …
   int root,              // rank to receive reduction in recvbuf
   MPI_Comm comm)
  ```

-
  ```
  int MPI_Bcast(
   void *buffer,
   int count,
   MPI_Datatype datatype,
   int root,              // rank sending data, others will receive
   MPI_Comm comm)
  ```

Example: PI

mpipi.cpp

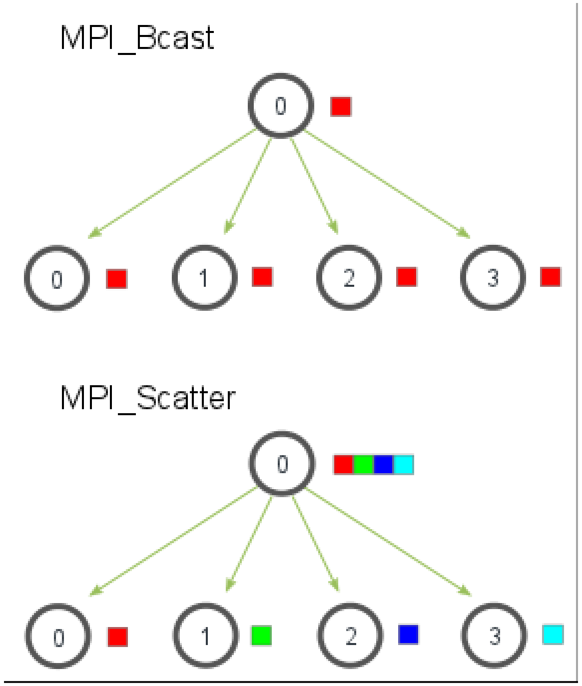
MPI_Bcast(…)

MPI_Reduce(…)

Alternative set of 6 Functions for Simplified MPI

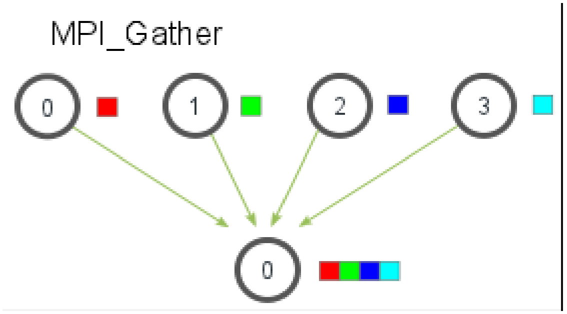
  - **`MPI_INIT`**
  - **`MPI_FINALIZE`**
  - **`MPI_COMM_SIZE`**
  - **`MPI_COMM_RANK`**
  - **`MPI_BCAST`**
  - **`MPI_REDUCE`**
- What else is needed (and why)?

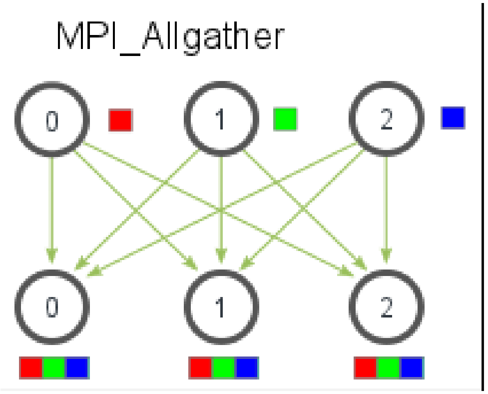
MPI_Scatter



```
MPI_Scatter(
void* send_data,
int send_count,
MPI_Datatype send_datatype,
void* recv_data,
int recv_count,
MPI_Datatype recv_datatype,
int root,
MPI_Comm communicator)
```

MPI_Gather





```
MPI_Gather(
void* send_data,
int send_count,
MPI_Datatype send_datatype,
void* recv_data,
int recv_count,
MPI_Datatype recv_datatype,
Int root,
MPI_Comm communicator)
```

AVG Example

mpiavg.cpp

MPI_Scatter(…)

MPI_Gather(…)

Sources of Deadlocks

- Send a large message from process 0 to process 1
  - If there is insufficient storage at the destination, the send must wait for the user to provide the memory space (through a receive)
- What happens with

Process 0	Process 1
`Send(1)`	**`Send(0)`**
`Recv(1)`	**`Recv(0)`**

- This is called “unsafe” because it depends on the availability of system buffers

Some Solutions to the “unsafe” Problem

- Order the operations more carefully:

Process 0	Process 1
`Send(1)`	**`Recv(0)`**
`Recv(1)`	**`Send(0)`**

- Use non-blocking operations:

Process 0	Process 1
`Isend(1)`	**`Isend(0)`**
`Irecv(1)`	**`Irecv(0)`**
`Waitall`	**`Waitall`**

When to use MPI

- Portability and Performance
- Irregular Data Structures
- Building Tools for Others
  - Libraries
- Need to Manage memory on a per processor basis

Summary

- MPI is required to scale parallel app among cluster nodes but also works on local multicore machine.
- The basic paradigm is to send and receive data.
- There are many implementations, on nearly all platforms.
- MPI subsets are easy to learn and use.
- Lots of MPI material is available.

Thanks for attention!

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