Introduction to MPI

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14 July 2010

Based on materials developed by CAC and TACC

Outline

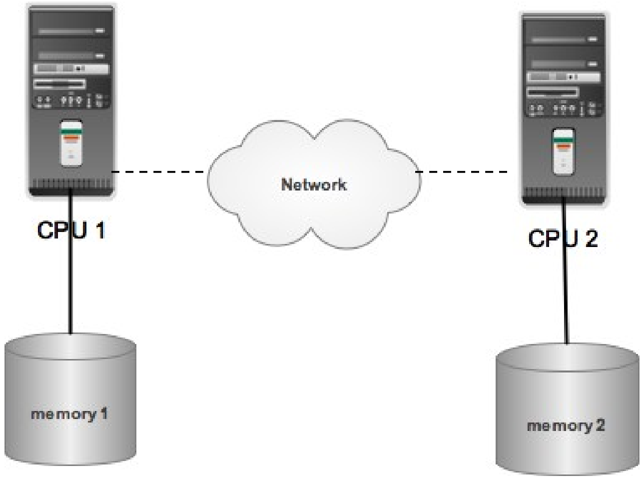
- Overview
- Basics
  - Hello World in MPI
  - Compiling and running MPI programs
- MPI Messages
- MPI Communicators
- Point-to-point communication
- Collective communication
- Releases
- MPI references and documentation

Overview | Introduction

- What is MPI? Message Passing Interface
- What is message passing?
  - Sending and receiving messages between tasks or processes
  - Can include performing operations on data in transit and synchronizing tasks
- Why send messages?
  - Clusters have distributed memory, i.e. each process has its own address space and no way to get at another's
- How do you send messages?
  - Programmer makes use of an Application Programming *Interface* (API) that specifies the functionality of high-level communication routines
  - Functions give access to a low-level *implementation* that takes care of sockets, buffering, data copying, message routing, etc.

Overview API for distributed memory parallelism

- Assumption: processes do not see each other's memory
- Communication speed is determined by some kind of network
  - Typical network = switch + cables + adapters + software stack…
- Key: the implementation of a message passing API (like MPI) can be optimized for any given network
  - Program gets the benefit
  - No code changes required
  - Works in shared memory, too



Overview | Why use MPI?

- MPI is a de facto standard
  - Public domain versions are easy to install
  - Vendor-optimized version are available on most hardware
- MPI is “tried and true”
  - MPI-1 was released in 1994, MPI-2 in 1996
- MPI applications can be fairly portable
- MPI is a good way to learn parallel programming
- MPI is expressive: it can be used for many different models of computation, therefore can be used with many different applications
- MPI code is efficient (though some think of it as the “assembly language of parallel processing”)

Basics

The basic outline of an MPI program follows these general steps:

- *Include the MPI header file --*
  #include <mpi.h> for basic definitions and types, implementation-specific.
- *Initialize communications --*
  MPI_INIT initializes the MPI environment
  MPI_COMM_SIZE returns the number of processes
  MPI_COMM_RANK returns this process's number (rank)
- *Communicate to share data between processes --*
  MPI_SEND sends a message
  MPI_RECV receives a message
- *Exit from the message-passing system --*
  MPI_FINALIZE

Basics Minimal Code Example

```
• #include <. . . .>
• #include "mpi.h"
• main(int argc, char **argv)
• {
•    char message[20];
•    int i, rank, size, type = 99;
•    MPI_Status status;
•    MPI_Init(&argc, &argv);
•    MPI_Comm_size(MPI_COMM_WORLD, &size);
•    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
•    if (rank == 0) {
•       strcpy(message, "Hello, world");
•       for (i = 1; i < size; i++)
•          MPI_Send(message, 13, MPI_CHAR, i, type, MPI_COMM_WORLD);
•    }
•    else
•       MPI_Recv(message, 20, MPI_CHAR, 0, type, MPI_COMM_WORLD, &status);
•    printf( "Message from process = %d : %.13s\n", rank,message);
•    MPI_Finalize();
• }
```

Basics | Initialize and Close Environment

```
#include <. . . .>
#include "mpi.h"
main(int argc, char **argv)
{
  char message[20];
  int i, rank, size, type = 99;
  MPI_Status status;
  MPI_Init(&argc, &argv);
  MPI_Comm_size(MPI_COMM_WORLD, &size);
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  if (rank == 0) {
    strcpy(message, "Hello, world");
    for (i = 1; i < size; i++)
      MPI_Send(message, 13, MPI_CHAR, i, type, MPI_COMM_WORLD);
  }
  else
    MPI_Recv(message, 20, MPI_CHAR, 0, type, MPI_COMM_WORLD, &status);
  printf( "Message from process = %d : %.13s\n", rank,message);
  MPI_Finalize();
}
```

Initialize MPI environment

An implementation may also use this call as a mechanism for making the usual argc and argv command-line arguments from “main” available to all tasks (C language only).

Close MPI environment

Basics — Query Environment

```
#include <. . . .>
#include "mpi.h"
main(int argc, char **argv)
{
  char message[20];
  int i, rank, size, type = 99;
  MPI_Status status;
  MPI_Init(&argc, &argv);
  MPI_Comm_size(MPI_COMM_WORLD, &size);
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  if (rank == 0) {
    strcpy(message, "Hello, world");
    for (i = 1; i < size; i++)
      MPI_Send(message, 13, MPI_CHAR, i, type, MPI_COMM_WORLD);
  }
  else
    MPI_Recv(message, 20, MPI_CHAR, 0, type, MPI_COMM_WORLD, &status);
  printf( "Message from process = %d : %.13s\n", rank,message);
  MPI_Finalize();
}
```

Returns number of Processes
This, like nearly all other MPI functions, must be called after MPI_Init and before MPI_Finalize. Input is the name of a communicator (MPI_COMM_WORLD is the default communicator) and output is the size of that communicator.

Returns this process' number, or rank
Input is again the name of a communicator and the output is the rank of this process in that communicator.

Basics | Pass Messages

```
#include <. . . .>
#include "mpi.h"
main(int argc, char **argv)
{
   char message[20];
   int i, rank, size, type = 99;
   MPI_Status status;
   MPI_Init(&argc, &argv);
   MPI_Comm_size(MPI_COMM_WORLD, &size);
   MPI_Comm_rank(MPI_COMM_WORLD, &rank);
   if (rank == 0) {
      strcpy(message, "Hello, world");
      for (i = 1; i< size; i++)
         MPI_Send(message, 13, MPI_CHAR, i, type, MPI_COMM_WORLD);
   }
   else
      MPI_Recv(message, 20, MPI_CHAR, 0, type, MPI_COMM_WORLD, &status);
   printf( "Message from process = %d : %.13s\n", rank,message);
   MPI_Finalize();
}
```

Send a message
Blocking send of data in the buffer.

Receive a message
Blocking receive of data into the buffer.

Basics | Compiling MPI programs

- Generally use a special compiler or compiler wrapper script
  - Not defined by the standard
  - Consult your implementation
  - Correctly handles include path, library path, and libraries
- MPICH-style (the most common)

  `mpicc -o foo foo.c`

  `mpif90 -o foo foo.f` (also mpif77)
- Some MPI specific compiler options

  `-mpilog` -- Generate log files of MPI calls

  `-mpitrace` -- Trace execution of MPI calls

  `-mpianim` -- Real-time animation of MPI (not available on all systems)
- Note: compiler/linker names are specific to MPICH. On IBM Power systems, they are *mpcc_r* and *mpxlf_r* respectively

Running MPI programs

- To run a simple MPI program using MPICH

```
mpirun -np 2 ./foo
mpiexec -np 2 ./foo
```

- Some MPI specific running options

  `-t` -- shows the commands that *mpirun* would execute

  `-help` -- shows all options for *mpirun*

- To run over Ranger's InfiniBand (as part of an SGE script)

```
ibrun ./foo
```

  – The scheduler handles the rest

- Note: *mpirun* and *mpiexec* are not part of MPI, but a similar command can be found in nearly all implementations
  – There are exceptions: on the IBM SP, for example, it is *poe*

Messages — 3 Parameters Describe the Data

```
MPI_Send( message, 13, MPI_CHAR, i,  type, MPI_COMM_WORLD  );

MPI_Recv( message, 20, MPI_CHAR, 0, type, MPI_COMM_WORLD, &status);
```

Type of data, should be same for send and receive
MPI_Datatype type

Number of elements (items, not bytes)
Recv number should be greater than or equal to amount sent
int count

Address where the data start
void data*

Messages — 3 Parameters Specify Routing

```
MPI_Send(  message, 13, MPI_CHAR, i,  type, MPI_COMM_WORLD );

MPI_Recv(  message, 20, MPI_CHAR, 0, type, MPI_COMM_WORLD, &status);
```

Identify process you're communicating with by rank number
int dest/src

Arbitrary tag number, must match up (receiver can specify MPI_ANY_TAG to indicate that any tag is acceptable)
int tag

Communicator specified for send and receive must match, no wildcards
MPI_Comm comm

Returns information on received message
MPI_Status status*

Messages | Fortran Notes

```
mpi_send (data, count, type, dest, tag, comm, ierr)
mpi_recv (data, count, type, src,  tag, comm, status, ierr)
```

- A few Fortran particulars
  - All Fortran arguments are passed by reference
  - *INTEGER ierr:* variable to store the error code (in C/C++ this is the return value of the function call)
- Wildcards are allowed
  - *src* can be the wildcard MPI_ANY_SOURCE
  - *tag* can be the wildcard MPI_ANY_TAG
  - *status* returns information on the source and tag, useful in conjunction with the above wildcards (receiving only)

MPI Communicators

- Communicators
  - Collections of processes that can communicate with each other
  - Most MPI routines require a communicator as an argument
  - Predefined communicator MPI_COMM_WORLD encompasses all tasks
  - New communicators can be defined; any number can co-exist
- Each communicator must be able to answer two questions
  - *How many processes exist in this communicator?*
  - MPI_Comm_size returns the answer, say, N_p
  - *Of these processes, which process (numerical rank) am I?*
  - MPI_Comm_rank returns the rank of the current process within the communicator, an integer between 0 and N_p-1 inclusive
  - Typically these functions are called just after MPI_Init

MPI_COMM C Example

```
#include <mpi.h>
main(int argc, char **argv){
   int np, mype, ierr;

   ierr = MPI_Init(&argc, &argv);
   ierr = MPI_Comm_size(MPI_COMM_WORLD, &np);
   ierr = MPI_Comm_rank(MPI_COMM_WORLD, &mype);
            :
   MPI_Finalize();
}
```

MPI_COMM C++ Example

```
#include “mpif.h”
[other includes]
int main(int argc, char *argv[]){
   int np,  mype,  ierr;
 [other declarations]
            :
          MPI::Init(argc, argv);
   np   = MPI::COMM_WORLD.Get_size();
   mype = MPI::COMM_WORLD.Get_rank();
            :
        [actual work goes here]
            :
          MPI::Finalize();
}
```

MPI_COMM Fortran Example

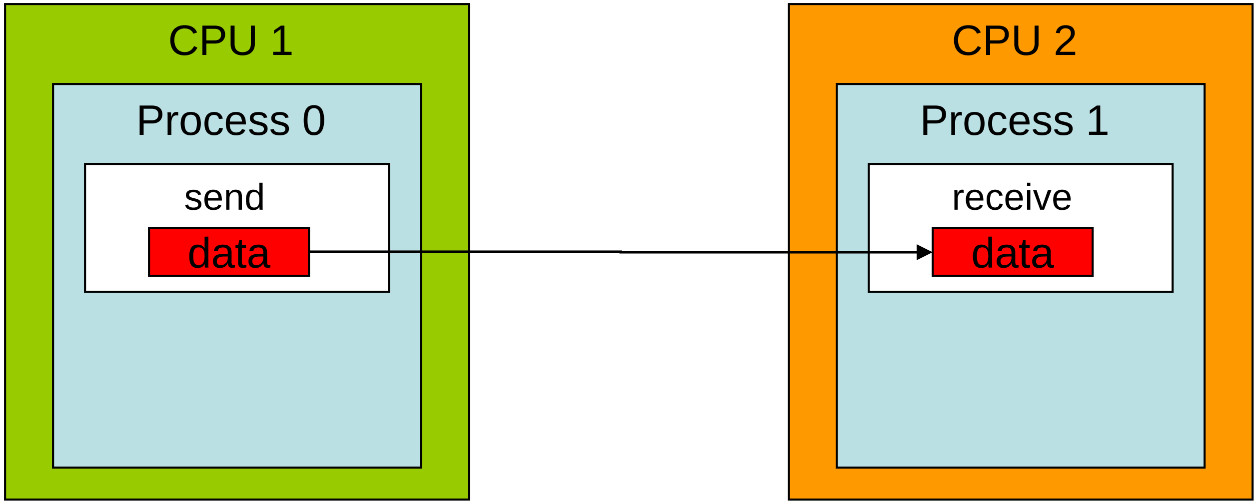
```
program param
  include ‘mpif.h’
  integer ierr, np, mype

  call mpi_init(ierr)
  call mpi_comm_size(MPI_COMM_WORLD, np  , ierr)
  call mpi_comm_rank(MPI_COMM_WORLD, mype, ierr)
          :
  call mpi_finalize(ierr)
end program
```

Point to Point Topics

- MPI_SEND and MPI_RECV
- Synchronous vs. buffered (asynchronous) communication
- Blocking send and receive
- Non-blocking send and receive
- Combined send/receive
- Deadlock, and how to avoid it

Point to Point Send and Recv: Simple

- Sending data ***from*** one point (process/task)
  to another point (process/task)
- One task sends while another receives



Point to Point | Send and Recv: So many choices

The communication mode indicates how the message should be sent.

Communication Mode	Blocking Routines	Non-Blocking Routines
Synchronous	MPI_Ssend	MPI_Issend
Ready	MPI_Rsend	MPI_Irsend
Buffered	MPI_Bsend	MPI_Ibsend
Standard	MPI_Send	MPI_Isend
	MPI_Recv	MPI_Irecv
	MPI_Sendrecv	
	MPI_Sendrecv_replace	

Note: the receive routine does not specify the communication mode -- it is simply blocking or non-blocking.

Point to Point Blocking vs Non-Blocking

A ***blocking*** send or receive call suspends execution of the process until the message buffer being sent/received is safe to use.

A ***non-blocking*** call initiates the communication process; the status of data transfer and the success of the communication must be verified independently by the programmer.

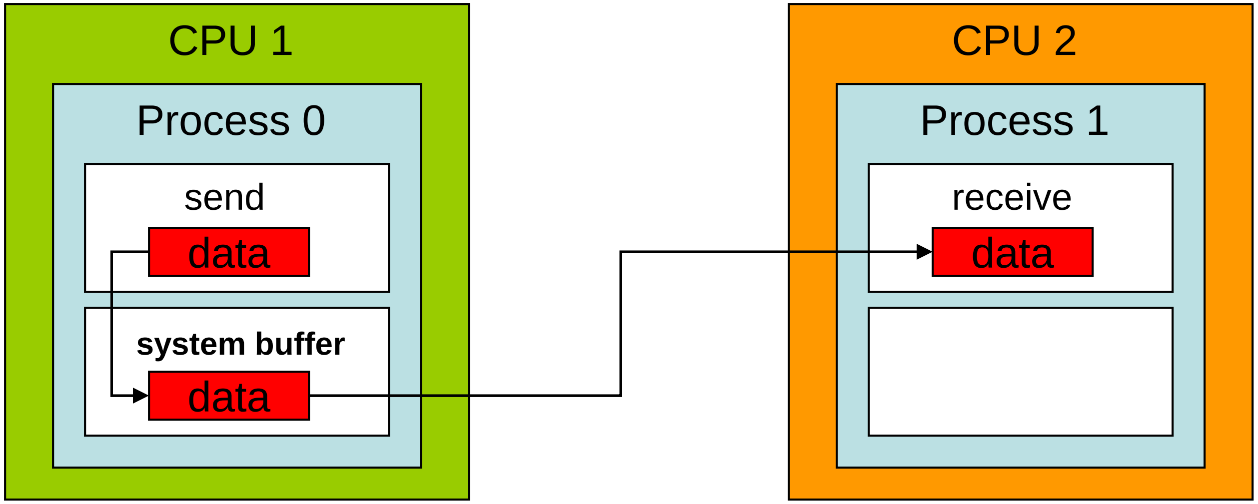
Point to Point Communication Modes

Mode	Pros	Cons
Synchronous – sending and receiving tasks must 'handshake'.	- Safest, therefore most portable - No need for extra buffer space - SEND/RECV order not critical	Synchronization overhead
Ready- assumes that a 'ready to receive' message has already been received.	- Lowest total overhead - No need for extra buffer space - Handshake not required	RECV *must* precede SEND
Buffered – move data to a buffer so process does not wait.	- Decouples SEND from RECV - no sync overhead on SEND - Programmer controls buffer size	Buffer copy overhead
Standard – defined by the implementer; meant to take advantage of the local system.	- Good for many cases - Compromise position	Your program may not be suitable

Point to Point Overhead

- **System overhead**
  cost of transferring data from the sender's message buffer onto the network, then from the network into the receiver's message buffer.
- **Synchronization overhead**
  time spent waiting for an event to occur on another task, e.g. waiting for a receive to be executed and for the handshake to arrive before the message can be transferred.
- **MPI_Send():** A blocking call which returns only when data has been sent from its buffer
- **MPI_Recv():** A blocking receive which returns only when data has been received onto its buffer
- Generally speaking, MPI communications operate in the "rendezvous protocol", which involves a handshake procedure in order to establish communication.

Point to Point Buffered send, MPI_Bsend



- Message contents are sent to a system-controlled block of memory
- Process 0 continues executing other tasks; when process 1 is ready to receive, the system simply copies the message from the system buffer into the appropriate memory location controlled by process
- Must be preceded with a call to MPI_Buffer_attach

Point to Point MPI_Sendrecv

```
MPI_Sendrecv(sendbuf, sendcount, sendtype, dest,
sendtag, recvbuf, recvcount, recvtype, source, recvtag,
comm, status)
```

- Useful for communication patterns where each of a pair of nodes both sends and receives a message (two-way communication).
- Executes a blocking send and a blocking receive operation
- Both operations use the same communicator, but have distinct tag arguments

Point to Point One-way blocking/non-blocking

- Blocking send, non-blocking recv

```
IF (rank==0) THEN
   CALL MPI_SEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,ie)
ELSEIF (rank==1) THEN
   CALL MPI_IRECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,req,ie)
   CALL MPI_WAIT(req,status,ie)
ENDIF
```

- Non-blocking send, non-blocking recv

```
IF (rank==0) THEN
   CALL MPI_ISEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,req,ie)
ELSEIF (rank==1) THEN
   CALL MPI_IRECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,req,ie)
ENDIF
CALL MPI_WAIT(req,status,ie)
```

Point to Point Two-way communication: deadlock!

- **Deadlock 1**

```
IF (rank==0) THEN
   CALL MPI_RECV(recvbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,status,ie)
   CALL MPI_SEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,ie)
ELSEIF (rank==1) THEN
   CALL MPI_RECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,status,ie)
   CALL MPI_SEND(sendbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,ie)
ENDIF
```

- **Deadlock 2**

```
IF (rank==0) THEN
   CALL MPI_SEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,ie)
   CALL MPI_RECV(recvbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,status,ie)
ELSEIF (rank==1) THEN
   CALL MPI_SEND(sendbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,ie)
   CALL MPI_RECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,status,ie)
ENDIF
```

Point to Point Two-way communication: solutions

- Solution 1

```
IF (rank==0) THEN
   CALL MPI_SEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,ie)
   CALL MPI_RECV(recvbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,status,ie)
ELSEIF (rank==1) THEN
   CALL MPI_RECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,status,ie)
   CALL MPI_SEND(sendbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,ie)
ENDIF
```

- Solution 2

```
IF (rank==0) THEN
   CALL MPI_SENDRECV(sendbuf,count,MPI_REAL,1,tag, &
                    recvbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,status,ie)
ELSEIF (rank==1) THEN
   CALL MPI_SENDRECV(sendbuf,count,MPI_REAL,0,tag, &
                    recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,status,ie)
ENDIF
```

Point to Point Solutions (continued)

- Solution 3

```
IF (rank==0) THEN
   CALL MPI_IRECV(recvbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,req,ie)
   CALL MPI_SEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,ie)
ELSEIF (rank==1) THEN
   CALL MPI_IRECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,req,ie)
   CALL MPI_SEND(sendbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,ie)
ENDIF
CALL MPI_WAIT(req,status)
```

- Solution 4

```
IF (rank==0) THEN
   CALL MPI_BSEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,ie)
   CALL MPI_RECV(recvbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,status,ie)
ELSEIF (rank==1) THEN
   CALL MPI_BSEND(sendbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,ie)
   CALL MPI_RECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,status,ie)
ENDIF
```

Point to Point | Two-way communications: summary

	CPU 0	CPU 1
Deadlock1	Recv/Send	Recv/Send
Deadlock2	Send/Recv	Send/Recv
Solution1	Send/Recv	Recv/Send
Solution2	SendRecv	SendRecv
Solution3	IRecv/Send, Wait	IRecv/Send, Wait
Solution4	BSend/Recv	BSend/Recv

Point to Point C Example

```
#include  "mpi.h"
main(int argc, char **argv){
int ipe, ierr; double a[2];
MPI_Status status;
MPI_Comm icomm = MPI_COMM_WORLD;
ierr = MPI_Init(&argc, &argv);
ierr = MPI_Comm_rank(icomm, &ipe);
ierr = MPI_Comm_size(icomm, &myworld);
if(ipe == 0){
    a[0] = mype; a[1] = mype+1;
    ierr = MPI_Send(a,2,MPI_DOUBLE, 1,9, icomm);
  }
else if (ipe == 1){
    ierr = MPI_Recv(a,2,MPI_DOUBLE, 0,9,icomm,&status);
    printf("PE %d, A array= %f %f\n",mype,a[0],a[1]);
  }
  MPI_Finalize();
}
```

Point to Point Fortran Example

```
program sr
   include "mpif.h"
   real*8,  dimension(2)                 :: A
   integer, dimension(MPI_STATUS_SIZE) :: istat
   icomm = MPI_COMM_WORLD
   call mpi_init(ierr)
   call mpi_comm_rank(icomm,mype,ierr)
   call mpi_comm_size(icomm,np  ,ierr);

   if(mype.eq.0) then
    a(1) = real(ipe); a(2) = real(ipe+1)
    call mpi_send(A,2,MPI_REAL8, 1,9,icomm, ierr)
   else if (mype.eq.1) then
    call mpi_recv(A,2,MPI_REAL8, 0,9,icomm, istat,ierr)
    print*,"PE ",mype,"received A array =",A
   endif

   call mpi_finalize(ierr)
end program
```

Collective Topics

- Overview
- Barriers
- Data Movement Operations
- Reduction Operations

Collective Overview

- What if one processor wants to send to everyone else?

```
if (mytid == 0 ) {
  for (tid=1; tid<ntids; tid++) {
    MPI_Send( (void*)a, /* target= */ tid, … );
  }
} else {
  MPI_Recv( (void*)a, 0, … );
}
```

- Implements a very naive, serial broadcast
- Too primitive
  - leaves no room for the OS / switch to optimize
  - leaves no room for more efficient algorithms
- Too slow: most receive calls will have a long wait for completion

Collective Overview

- Involve ALL processes within a communicator
- There are three basic types of collective communications:
  - Synchronization (MPI_Barrier)
  - Data movement (MPI_Bcast/Scatter/Gather/Allgather/AlltoAll)
  - Collective computation (MPI_Reduce/Allreduce/Scan)
- Programming considerations & restrictions
  - Blocking operation
  - No use of message tag argument
  - Collective operation within subsets of processes require separate grouping and new communicator
  - Can only be used with MPI predefined datatypes

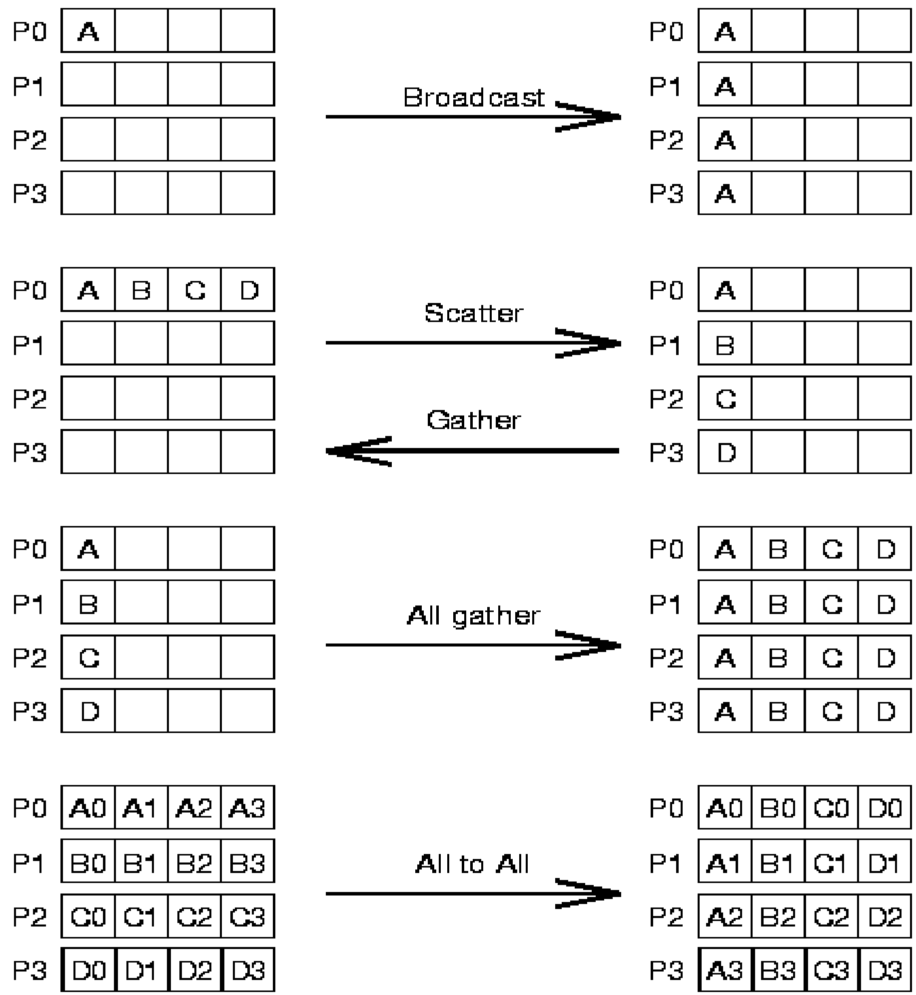
Collective | Barrier synchronization and broadcast

- *Barrier* blocks until all processes in comm have called it
- Useful when measuring communication/computation time
  - `mpi_barrier(comm, ierr)`
  - `MPI_Barrier(comm)`

- *Broadcast* sends data from root to all processes in comm
  - `mpi_bcast(data, count, type, root, comm, ierr)`
  - `MPI_Bcast(data, count, type, root, comm)`

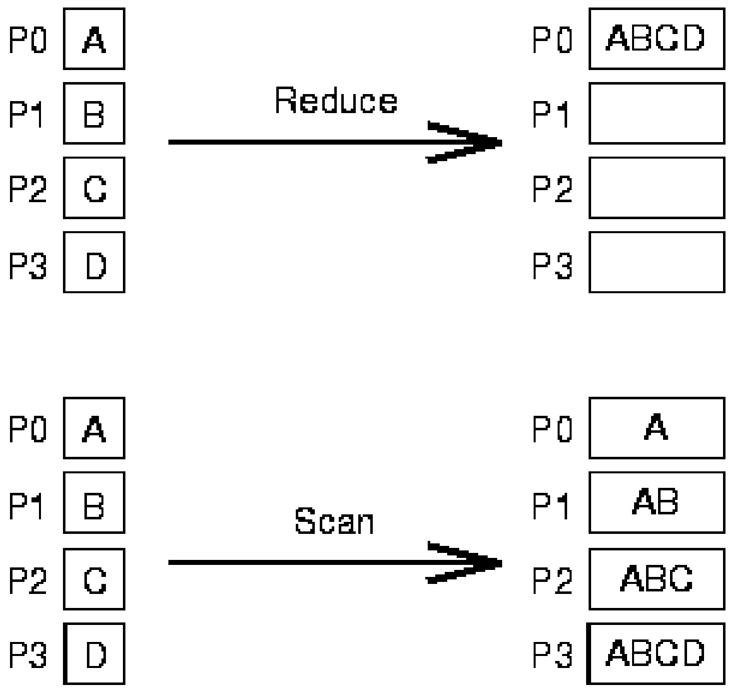
Collective Data movement

- Broadcast
- Scatter
- Gather
- Allgather
- Alltoall



Collective Reduction Operations

- Reduce
- Scan



Collective Reduction Operations

Name	Meaning
MPI_MAX	Maximum
MPI_MIN	Minimum
MPI_SUM	Sum
MPI_PROD	Product
MPI_LAND	Logical and
MPI_BAND	Bit-wise and
MPI_LOR	Logical or
MPI_BOR	Bit-wise or
MPI_LXOR	Logical xor
MPI_BXOR	Logical xor
MPI_MAXLOC	Max value and location
MPI_MINLOC	Min value and location

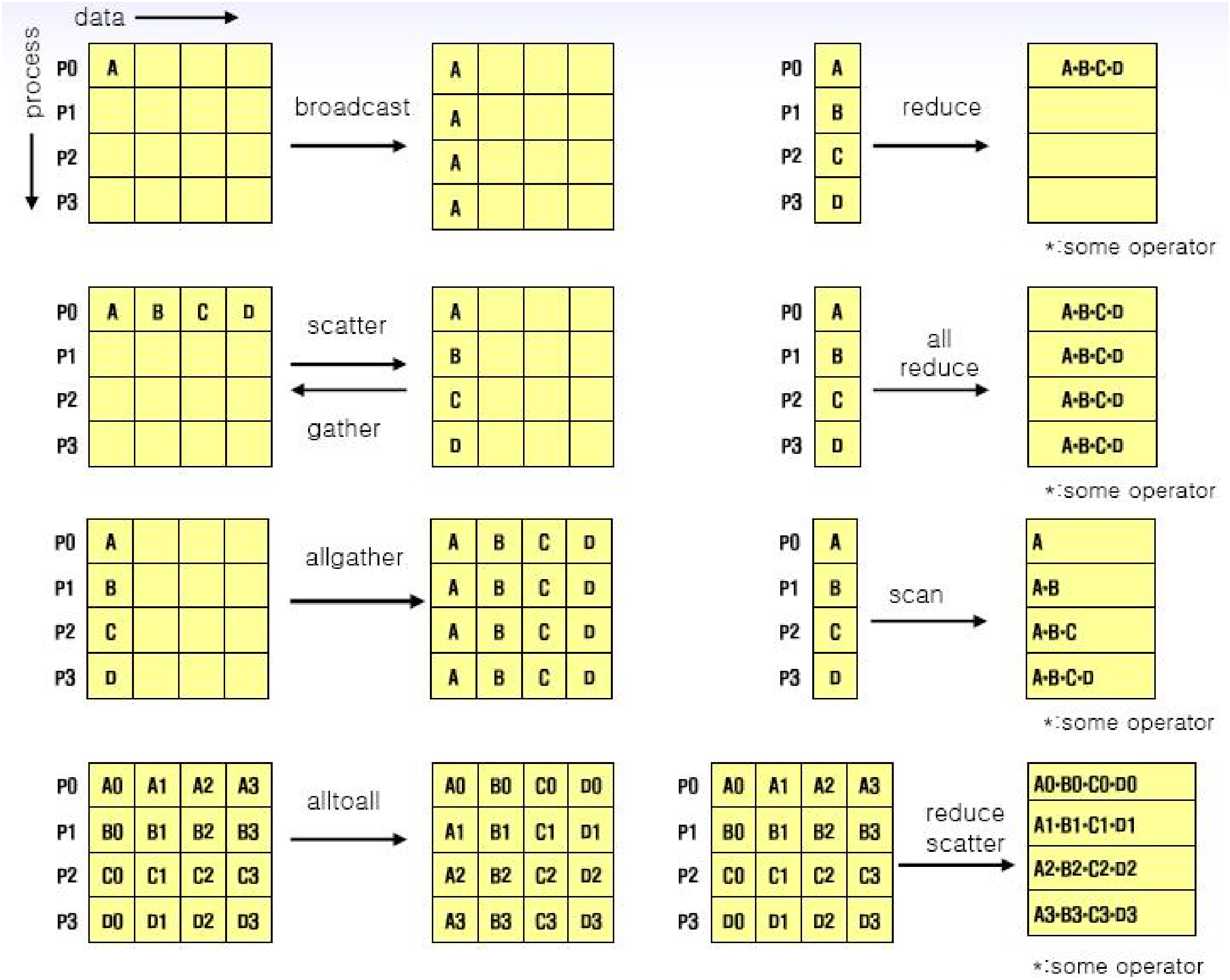
Collective C Example

```
#include <mpi.h>
#define WCOMM MPI_COMM_WORLD
main(int argc, char **argv){
  int npes, mype, ierr;
  double sum, val; int calc, knt=1;
  ierr = MPI_Init(&argc, &argv);
  ierr = MPI_Comm_size(WCOMM, &npes);
  ierr = MPI_Comm_rank(WCOMM, &mype);

  val = (double) mype;

  ierr=MPI_Allreduce(&val,&sum,knt,MPI_DOUBLE,MPI_SUM,WCOMM);

  calc=(npes-1 +npes%2)*(npes/2);
  printf(" PE: %d sum=%5.0f calc=%d\n",mype,sum,calc);
  ierr = MPI_Finalize();
}
```

Collective Fortran Example

```
program sum2all
include 'mpif.h'

  icomm = MPI_COMM_WORLD
  knt = 1
  call mpi_init(ierr)
  call mpi_comm_rank(icomm,mype,ierr)
  call mpi_comm_size(icomm,npes,ierr)
  val = dble(mype)

  call mpi_allreduce(val,sum,knt,MPI_REAL8,MPI_SUM,icomm,ierr)

  ncalc=(npes-1 + mod(npes,2))*(npes/2)
  print*,' pe#, sum, calc. sum = ',mype,sum,ncalc
  call mpi_finalize(ierr)

end program
```

Collective


data
process
P0
P1
P2
P3
broadcast
reduce
*:some operator
scatter
gather
all reduce
allgather
scan
alltoall
reduce scatter
A·B·C·D
A·B
A·B·C
A0·B0·C0·D0
A1·B1·C1·D1
A2·B2·C2·D2
A3·B3·C3·D3

MPI-1

- MPI-1 - Message Passing Interface (v. 1.2)
  - Library standard defined by committee of vendors, implementers, and parallel programmers
  - Used to create parallel SPMD codes based on explicit message passing
- Available on almost all parallel machines with C/C++ and Fortran bindings (and occasionally with other bindings)
- About 125 routines, total
  - 6 basic routines
  - The rest include routines of increasing generality and specificity

MPI-2

- Includes features left out of MPI-1
  - One-sided communications
  - Dynamic process control
  - More complicated collectives
  - Parallel I/O (MPI-IO)
- Implementations came along only gradually
  - Not quickly undertaken after the reference document was released (in 1997)
  - Now OpenMPI, MPICH2 (and its descendants), and the vendor implemenations are nearly complete or fully complete
- Most applications still rely on MPI-1, plus maybe MPI-IO

References

- MPI-1 and MPI-2 standards
  - http://www.mpi-forum.org/docs/mpi-11-html/mpi-report.html
  - http://www.mpi-forum.org/docs/mpi-20-html/mpi2-report.htm
  - http://www.mcs.anl.gov/mpi/ (other mirror sites)
- Freely available implementations
  - MPICH, http://www.mcs.anl.gov/mpi/mpich
  - LAM-MPI, http://www.lam-mpi.org/
- Books
  - *Using MPI*, by Gropp, Lusk, and Skjellum
  - *MPI Annotated Reference Manual,* by Marc Snir, *et al*
  - *Parallel Programming with MPI*, by Peter Pacheco
  - *Using MPI-2*, by Gropp, Lusk and Thakur
- Newsgroup: comp.parallel.mpi