

Introduction to MPI

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Course Objectives & Assumptions

- Objectives
 - Teach basics of MPI-Programming
 - Share information related to running MPI programs on Stampede
- Assumptions
 - The audience has the basic understanding of C or Fortran programming
 - The audience has access to MPI installation either locally or remotely

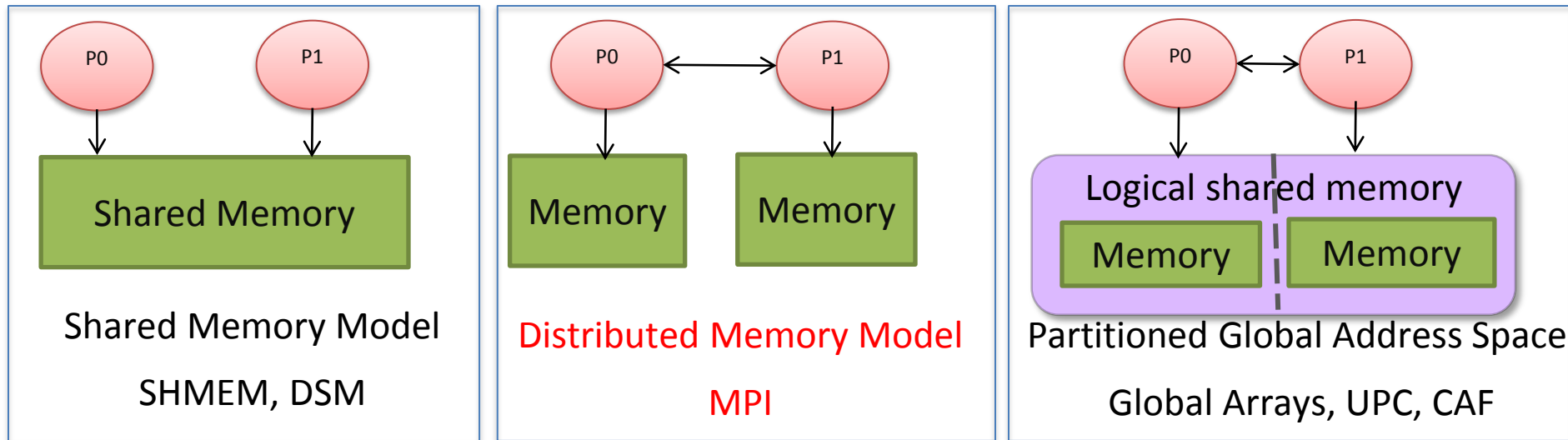
Content Overview

- Basic concepts related to MPI
- Environment Management MPI routines
- Compiling and running MPI programs
- Types of communication
 - Point-to-Point communication routines
 - Collective communication routines
- Examples
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Different Programming Models



- OpenMP falls under the category of Shared Memory Model
- MPI (Message Passing Interface) falls under the category of **Distributed Memory Model**

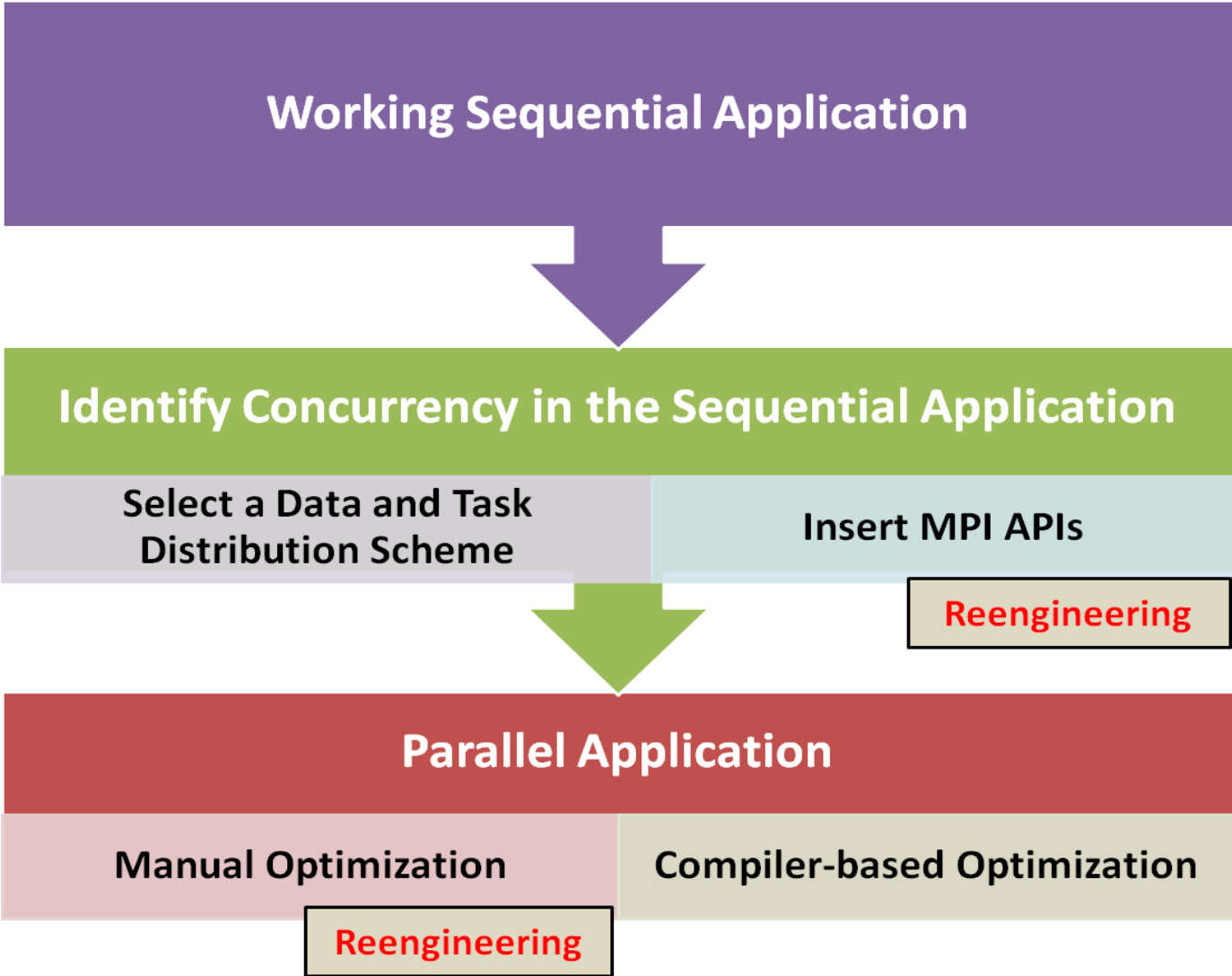
History of Message Passing Interface (MPI)

- Before 1989, no portable message passing library
 - Code on nCUBE/10 code doesn't work on Intel iPSC
- Standardization was needed
 - Efficiency, portability and flexibility was desired
- Result of this effort: MPI
 - MPI is a specification for message passing library that is standardized by MPI Forum
 - Multiple vendor-specific implementations (MPICH, OpenMPI)

Message Passing Interface (MPI)

- In summary, MPI is mainly used for programming systems with distributed memory
 - Where each process has a different address space
 - Processes need to communicate with each other
 - Synchronization
 - Data Exchange
 - Can also be used for shared memory and hybrid architectures
- MPI specifications have been defined for C, C++ and Fortran programs
- Evolution of MPI
 - MPI-1: 1992-1994 (100+ functions)
 - MPI-2: 1994-1996 (500+ functions)
 - MPI-3: 2008-2012

Explicit Parallelization with MPI (traditional way)



General Structure of MPI Programs

Process 0 (myProgram.c)

MPI include file

Declarations, prototypes, etc.

Program Begins

⋮

Initialize MPI environment

⋮

Do work & make message passing calls

⋮

Terminate MPI environment

⋮

Program Ends

Process 1 (myProgram.c)

MPI include file

Declarations, prototypes, etc.

Program Begins

⋮

Initialize MPI environment

⋮

Do work & make message passing calls

⋮

Terminate MPI environment

⋮

Program Ends

Serial code

Parallel code begins

Parallel code ends

Serial code

MPI Execution

- Each process runs a copy of the executable:
Single Program, Multiple Data (SPMD)
- Each process picks the portion of the work according to its rank
- Each process works independent of the other processes, except when communicating

Arguments for MPI Routine

(buffer, data count, data type, destination)

- **Buffer:** the name of a variable (including arrays and structures) that is to be sent/received. For C programs, this argument is passed by reference and usually must be prepended with an ampersand: **&var1**
- **Data Count:** number of data elements to be sent or received
- **Data Type:** could be elementary data type or derived
- **Destination:** the process where a message is to be delivered

Arguments for MPI Routine (source, tag, status, request)

- **Source:** indicates the process from which the message originated
- **Tag:** non-negative integer value to uniquely identify a message
- **Status:** for a receive operation, indicates the source and tag of a message
- **Request:** a unique “request number” issued by the system that can be used to check if a particular category of operation has completed or not (**more on this later**)

Concept of Communicators and Groups

`MPI_COMM_WORLD`



- Communicators and groups are objects that are used to define which collection of processes may communicate with each other
- Most MPI routines require a communicator as an argument
- **`MPI_COMM_WORLD`** is the predefined communicator that includes all MPI processes
- Multiple communicators and groups can be defined

Source: <https://computing.llnl.gov/tutorials/mpi/>

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Every MPI Program...

- Includes the MPI header file (`mpi.h`)
- Has a routine to initialize the MPI environment (`MPI_Init`)
- Has a routine to terminate the MPI environment (`MPI_Finalize`)

C	Fortran
<code>#include "mpi.h"</code>	<code>include 'mpif.h'</code>
<code>MPI_Xxx(. . .);</code>	<code>CALL MPI_XXX(. . ., ierr)</code> <code>Call mpi_xxx(. . ., ierr)</code>
<code>MPI_Init(NULL, NULL)</code> <code>MPI_Init(&argc, &argv)</code>	<code>MPI_INIT(ierr)</code>
<code>MPI_Finalize()</code>	<code>MPI_FINALIZE(ierr)</code>

Environment Management Routines (1)

- `MPI_Init` initializes the MPI execution environment, must be called before any other MPI routine is called, and is invoked only once in an MPI program
- `MPI_Finalize` terminates the MPI execution environment and must be called in the last
- `MPI_Comm_size` determines the number of processes (**size**) in a communicator (**comm**)
 - C: `MPI_Comm_size (comm, &size)`
 - Fortran: `MPI_COMM_SIZE (comm, size, ierr)`

Note: If `comm` is `MPI_COMM_WORLD`, then `size` is total number of processes in the program.

Environment Management Routines (2)

- `MPI_Comm_rank` determines the number of processes within a communicator, ranges from 0 to N-1
 - C: `MPI_Comm_rank (comm, &rank)`
 - Fortran: `MPI_COMM_RANK (comm, rank, ierr)`
- `MPI_Wtime` is a timer routine that returns elapsed wall clock time in seconds
 - C: `MPI_Wtime ()`
 - Fortran: `MPI_WTIME ()`

Serial Program: example1.c

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

```
int main() {
```

```
    printf("Wonderful Class!\n");
```

```
    return (0);
```

```
}
```

Compiling:

```
login3$ gcc -o example1 example1.c
```

Running:

```
login3$ ./example1
```

```
Wonderful Class!
```

Serial to Parallel: example1.c to mpiExample1.c

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

```
#include "mpi.h" ← Include the header file "mpi.h"
```

```
int main() {
```

```
    printf("Wonderful Class!\n");
```

```
    return (0);
```

```
}
```

Serial to Parallel: example1.c to mpiExample1.c

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

```
#include "mpi.h" <----- Include the header file "mpi.h"
```

```
int main(){
```

```
    MPI_Init(NULL, NULL); <----- Start up MPI
```

```
    printf("Wonderful Class!\n");
```

```
    return(0);
```

```
}
```

Notice the NULL value being passed to MPI_Init. We will come back to this later.

Serial to Parallel: example1.c to mpiExample1.c

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

```
#include "mpi.h" <----- Include the header file "mpi.h"
```

```
int main() {
```

```
    MPI_Init(NULL, NULL); <----- Start up MPI
```

```
    printf("Wonderful Class!\n");
```

```
    MPI_Finalize(); <----- Shut down MPI
```

```
    return (0);
```

```
}
```

Passing NULL to MPI_Init

- In MPI-1.1, an implementation is allowed to require that the arguments `argc` and `argv` that are passed to `main`, be also passed to `MPI_Init`
- In MPI-2 , conforming implementations are required to allow applications to pass NULL for both the `argc` and `argv` arguments of `main`

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Compiling `mpiExample1.c` on Stampede

- Only MPI-2 is available (MVAPICH2 and Intel MPI)
- Intel compiler available as a default option
- The GCC compiler module is also available but Intel is recommended
- Note: only 64-bit versions of the MPI libraries have been built on Stampede

Compiling mpiExample1.c on Stampede

- Compiling the example program

```
login1$ mpicc -o mpiExample1 mpiExample1.c
```

Compiler	Program	File Extension
mpicc	C	.c
mpicxx	C++	Intel: .C/c/cc/cpp/cxx/c++ PGI: .C/c/cc/cpp/cxx/
mpif90	F77/F90	.f, .for, .ftn, .f90, .f95, .fpp

Running mpiExample1.c

- To run your application on TACC resources
 - Please consult the userguide and write a job script (**myJob.sh**)
<http://www.tacc.utexas.edu/user-services/user-guides/stampede-user-guide>
 - Submit the job to the SLURM queue
login1\$ sbatch myJob.sh
 - Remember that Stampede has 16 cores per node. Also note that **tasks are same as MPI processes.**

Job Script for Stampede: myJob.sh

```
#!/bin/bash
#SBATCH -J myMPI                # Job Name
#SBATCH -o myMPI.o%j           # Name of the output file
#SBATCH -n 64                   # Requests 16 tasks/node, 64 cores total
#SBATCH -p normal               # Queue name normal
#SBATCH -t 01:30:00             # Run time (hh:mm:ss) - 1.5 hours
#SBATCH -A xxxxx                # Mention your account name (xxxxx)
set -x                           # Echo commands
ibrun ./mpiExample1             # Run the MPI executable
```

Note : `ibrun` is a wrapper for `mpirun/mpiexec` that is exclusive to TACC resources

Output from mpiExample1.c

```
login3$ cat myMPI.o2339942
...
TACC: Starting up job 2339942
TACC: Setting up parallel environment for MVAPICH ssh-based mpirun.
TACC: Setup complete. Running job script.
TACC: starting parallel tasks...
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
Wonderful Class!
...
TACC: Shutting down parallel environment.
TACC: Cleaning up after job: 2339942
TACC: Done.
```

Using Communicator: mpiExample2.c

```
1. #include <stdio.h>
2. #include "mpi.h"
3. int main(int argc, char* argv){
4.     int rank, size; <----- Extend the variable declaration
                           section
5.     MPI_Init(&argc, &argv); <----- Note argc and argv
6.     MPI_Comm_rank(MPI_COMM_WORLD, &rank); <----- Find process rank
7.     MPI_Comm_size(MPI_COMM_WORLD, &size); <----- Find out number
                                                of processes
8.     printf("Hello MPI World from process %d!", rank);
9.     MPI_Finalize();
10.    return 0;
11. }
```

↑
Using rank

Output from mpiExample2.c

TACC: Setup complete. Running job script.

TACC: starting parallel tasks...

Hello MPI World from process 45!

Hello MPI World from process 7!

Hello MPI World from process 10!

Hello MPI World from process 62!

Hello MPI World from process 27!

Hello MPI World from process 22!

Hello MPI World from process 33!

.....

TACC: Shutting down parallel environment.

TACC: Shutdown complete. Exiting.

TACC: Cleaning up after job: 2340827

TACC: Done

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Point-to-Point Communication

- Involve message passing between two different MPI processes
- One process performs a send operation and the other task performs a matching receive operation
- Most popular are blocking and non-blocking.
- There should be a matching receive routine for every send routine
 - If a send is not paired with a matching receive then the code will have a **deadlock**

Different Modes of Communication

- Synchronous (only send) **MPI_Ssend**
- Buffered (only send) **MPI_Bsend**
- "Ready" (send) **MPI_Rsend**
- Blocking (send and receive) ex: **MPI_Send**
- Non-blocking (send and receive) ex: **MPI_Isend**
- Combined (send/receive together) **MPI_Rendrecv**

Review: <http://www.mcs.anl.gov/research/projects/mpi/sendmode.html>

Point-to-Point Communication

Synchronous blocking send

MPI_Ssend :

Send a message and block until the application buffer in the sending task is free for reuse and the destination process has started to receive the message (MPI_Recv).

If both sends and receives are blocking operations then the use of the synchronous mode provides synchronous communication semantics: **a communication does not complete at either end before both processes rendez-vous at the communication**

Point-to-Point Communication

Buffered blocking send

MPI_Bsend :

Permits the programmer to allocate the required amount of buffer space into which data can be copied until it is delivered. Insulates against the problems associated with insufficient system buffer space. Routine returns after the data has been copied from application buffer space to the allocated send buffer.

Must be used with the MPI_Buffer_attach routine

Point-to-Point Communication

Blocking ready send

MPI_Rsend:

Should only be used if the programmer is certain that the matching receive has already been posted.

Point-to-Point Communication (blocking versus non-blocking)

- Blocking:
 - A blocking receive only "returns" after the data has arrived and is ready for use by the program
 - A blocking send routine returns after it is safe to modify the application buffer for reuse
- Non-blocking:
 - Non-blocking send and receive routines will return almost immediately
 - It is unsafe to modify the application buffer until you know for a fact that the requested non-blocking operation was actually performed

Point-to-Point Communication (blocking versus non-blocking)

- Blocking:
 - A blocking receive only "returns" after the data has arrived and is ready for use by the program
 - A blocking send routine returns after it is safe to modify the application buffer for reuse
- Non-blocking:
 - Non-blocking send and receive routines will return almost immediately
 - It is unsafe to modify the application buffer until you know for a fact that the requested non-blocking operation was actually performed

Point-to-Point Communication (blocking send)

```
MPI_Send(void *buf, int count, MPI_Datatype  
dType, int dest, int tag, MPI_Comm comm)
```

Argument	Description
buf	Initial address of the send buffer
count	Number of items to send
dType	MPI data type of items to send
dest	MPI rank or task that would receive the data
tag	Message ID
comm	MPI communicator where the exchange occurs

Some elementary data types: MPI_CHAR , MPI_SHORT , MPI_INT, MPI_LONG,
MPI_FLOAT , MPI_DOUBLE , ...

Point-to-Point Communication (blocking receive)

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

Argument	Description
buf	Initial address of receive buffer
count	Number of items to receive
dType	MPI data type of items to receive
source	MPI rank of task sending the data
tag	Message ID
comm	MPI communicator where the exchange occurs
status	Returns information on the message received, indicates the source of message and tag of the message

Point-to-Point Communication (blocking send and receive in code)

```
if (rank == 0) {  
    dest = 1;  
    source = 1;  
    MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag,  
                                                    MPI_COMM_WORLD);  
    MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag,  
                                                    MPI_COMM_WORLD, &Stat);  
} else if (rank == 1) {  
    dest = 0;  
    source = 0;  
    MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag,  
                                                    MPI_COMM_WORLD, &Stat);  
    MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag,  
                                                    MPI_COMM_WORLD);  
}
```

Point-to-Point Communication (this code will deadlock)

```
if (rank == 0) {
    dest = 1;
    source = 1;
    MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag,
            MPI_COMM_WORLD, &Stat);
    MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag,
            MPI_COMM_WORLD);
} else if (rank == 1) {
    dest = 0;
    source = 0;
    MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag,
            MPI_COMM_WORLD, &Stat);
    MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag,
            MPI_COMM_WORLD);
}
```

Point-to-Point Communication

(blocking but combined send & receive)

- Send and Receive stages use the same communicator, but have distinct tags
- Useful for communication patterns where each node both sends and receives messages (two-way communication)

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

- **Send arguments**
- **Receive arguments**
- **Common to both send and receive**

Point-to-Point Communication (non-blocking send & receive)

Non-blocking send	<code>MPI_Isend (buffer , count , type , dest , tag , comm , request)</code>
Non-blocking receive	<code>MPI_Irecv (buffer , count , type , source , tag , comm , request)</code>

- **MPI_Request** objects are used by non-blocking send & receive calls
 - In C, this argument is a pointer to a predefined structure named `MPI_Request`
 - The programmer uses this system assigned "handle" later (in a WAIT type routine) to determine completion of the non-blocking operation

Point-to-Point Communication (MPI_Wait)

- `MPI_Wait` is a blocking routine

```
MPI_Wait (&request, &status)
```

- It blocks until a specified non-blocking send or receive operation has completed
- Check `MPI_Waitany`, `MPI_Waitall`
- Also check `MPI_Test`

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Collective Communication

- Defined as communication between > 2 processes
 - One-to-many, many-to-one, many-to-many
- All processes within the communicator group call the same collective communication function with matching arguments
- Collective communication routines are blocking
- The size of data sent must exactly match the size of data received

Collective Communication (synchronization)

- `MPI_Barrier` creates a barrier synchronization in a group
 - Each task, when reaching the `MPI_Barrier` call, blocks until all tasks in the group reach the same `MPI_Barrier` call

`MPI_Barrier (comm)`

Collective Communication (data movement)

- `MPI_Bcast` broadcasts (sends) a message from the process designated as "root" to all other processes in the group

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

- `MPI_Scatter` distributes distinct messages from a single source task to each task in the group

`MPI_Scatter (&sendbuf, sendcnt, sendtype, &recvbuf, recvcnt, recvtype, root, comm)`

Collective Communication (data movement)

- `MPI_Gather` is reverse of `MPI_Scatter` and gathers distinct messages from each task in the group to a single destination task

```
MPI_Gather (&sendbuf, sendcnt, sendtype,  
&recvbuf, recvcount, recvtype, root, comm)
```

- `MPI_Allgather` gathers data from all tasks in a group and distributes to all tasks

```
MPI_Allgather (&sendbuf, sendcount,  
sendtype, &recvbuf, recvcount, recvtype, comm)
```

Collective Communication (collective computation)

- `MPI_Reduce` applies a reduction operation on all tasks in a group and places the result in one task

`MPI_Reduce (&sendbuf, &recvbuf, count, datatype, mpi_red_operation, root, comm)`

MPI Reduction Operation	Description
<code>MPI_MAX</code>	maximum
<code>MPI_MIN</code>	minimum
<code>MPI_SUM</code>	sum
<code>MPI_PROD</code>	product

Collective Communication (collective computation)

- `MPI_Allreduce` applies a reduction operation on all tasks in a group and passes the result to all tasks

```
MPI_Allreduce (&sendbuf, &recvbuf, count,  
datatype, mpi_red_operation, comm)
```

- Many more functions that the audience might want to explore on their own, example, `MPI_Reduce_scatter`, `MPI_All_to_all`, `MPI_Scatterv`, `MPI_Gatherv`, ...

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Sequential Program with a For-Loop:

example4.c

```
1.  #include <stdio.h>
2.  int main(int argc, char *argv[]) {
3.      int i, sum, upToVal;
4.      upToVal = 10000;
5.      sum = 0;
6.
7.      for(i=1; i<= upToVal; i++) {
8.          sum = sum + i;
9.      }
10.     printf("\nSum is %d\n", sum);
11.     return 0;
12. }
```

For-Loop & MPI_Reduce: mpiExample4.c (1)

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

3. int main(int argc, char *argv[]) {
4.     int i, sum, sumTotal, upToVal;
5.     int start, end, size, rank;

6.     upToVal = 10000;

7.     MPI_Init(&argc, &argv);
8.     MPI_Comm_size(MPI_COMM_WORLD, &size);
9.     MPI_Comm_rank(MPI_COMM_WORLD, &rank);

10.    start = rank * (upToVal / size) + 1;
11.    if (rank == (size - 1)) {
12.        end = upToVal;
13.    } else {
14.        end = start + (upToVal / size) - 1;
15.    }
```


For-Loop & MPI_Reduce: mpiExample4.c (2)

```
16.  sum = 0;
17.  sumTotal=0;
18.  for(i=start; i<= end; i++){
19.      sum = sum +i;
20.  }
21.  MPI_Reduce (&sum, &sumTotal, 1, MPI_INT, MPI_SUM, 0,
              MPI_COMM_WORLD );

22.  printf("\nRank: %d, sum: %d, sumTotal: %d\n", rank,
          sum, sumTotal);

23.  MPI_Finalize();
24.  return 0;
25. }
```

Output from mpiExample4.c

Rank: 6, sum: 10156875, sumTotal: 0

Rank: 4, sum: 7031875, sumTotal: 0

Rank: 7, sum: 11719375, sumTotal: 0

Rank: 5, sum: 8594375, sumTotal: 0

Rank: 3, sum: 5469375, sumTotal: 0

Rank: 2, sum: 3906875, sumTotal: 0

Rank: 1, sum: 2344375, sumTotal: 0

Rank: 0, sum: 781875, sumTotal: 50005000

MPI_Bcast Example: mpiExample7.c (1)

```
1. #include <stdio.h>
2. #include <mpi.h>

3. int main(int argc, char *argv[]){
4.     int i,rank,size;
5.     int root,count;
6.     int buffer[4];
7.     MPI_Status status;
8.     MPI_Request request;

9.     MPI_Init(&argc,&argv);
10.    MPI_Comm_size(MPI_COMM_WORLD,&size);
11.    MPI_Comm_rank(MPI_COMM_WORLD,&rank);
12.    root=0;
13.    count=4;
```

MPI_Bcast Example: mpiExample7.c (2)

```
14.  if(rank == root){
15.      for(i=0; i<count; i++){
16.          buffer[i]=i;
17.      }
18.  }
19.  MPI_Bcast(buffer, count, MPI_INT, root, MPI_COMM_WORLD);

20.  printf("Rank is: %d, Value at buffer[%d] is: %d \n",
          rank, count-1, buffer[count-1]);

21.  printf("\n");
22.  MPI_Finalize();
23.  return 0;
24. }
```

Output from mpiExample7.c

TACC: starting parallel tasks...

Rank is: 0, Value at buffer[4] is: 4

Rank is: 1, Value at buffer[4] is: 4

Rank is: 2, Value at buffer[4] is: 4

Rank is: 3, Value at buffer[4] is: 4

Rank is: 6, Value at buffer[4] is: 4

Rank is: 4, Value at buffer[4] is: 4

Rank is: 7, Value at buffer[4] is: 4

Rank is: 5, Value at buffer[4] is: 4

TACC: Shutting down parallel environment.

Note: Do not expect the output to be printed in any particular order. You might see jumbled up output.

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Summary of Key MPI Routines

C	Fortran
<code>MPI_Init (&argc,&argv)</code>	<code>MPI_INIT (ierr)</code>
<code>MPI_Comm_size (comm,&size)</code>	<code>MPI_COMM_SIZE (comm,size,ierr)</code>
<code>MPI_Comm_rank (comm,&rank)</code>	<code>MPI_COMM_RANK (comm,rank,ierr)</code>
<code>MPI_Finalize ()</code>	<code>MPI_FINALIZE (ierr)</code>
<code>MPI_Send(&buf,count,datatype,...)</code>	<code>MPI_SEND (buf,count,datatype,...)</code>
<code>MPI_Recv(&buf,count,datatype,...)</code>	<code>MPI_RECV (&buf,count,datatype,...)</code>
<code>MPI_Wtime ()</code>	<code>MPI_WTIME ()</code>

Words of Caution!

- Not all applications can be parallelized
 - Analyze and understand the data dependencies in your application
- Not all parallelization result in speed-up (parallel slowdown)
 - Too much communication could be an overkill!

Note:

Total Execution Time = Computation Time + Communication Time + I/O time

References

<https://computing.llnl.gov/tutorials/mpi/>

<http://www.mpi-forum.org>

<http://www.cs.usfca.edu/~peter/ppmpi/>

<http://www.mcs.anl.gov/research/projects/mpi/usingmpi/>

<http://geco.mines.edu/workshop/class2/examples/mpi/index.html>

For Fortran Users

Sample MPI code (F90)

```
program samplempi
  use mpi
  [other includes]

  integer :: ierr, np, rank
  [other declarations]

  call mpi_init(ierr)
  call mpi_comm_size(MPI_COMM_WORLD, np, ierr)
  call mpi_comm_rank(MPI_COMM_WORLD, rank, ierr)
  :
  [actual work goes here]
  :
  call mpi_finalize(ierr)
end program
```

Send/Recv Pairs in Code

- **Blocking Send & Blocking Recv**

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

- **Non-blocking Send & Blocking Recv**

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

Deadlock Example

! The following code contains a deadlock... can you spot it?

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

! Solution

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

Alternative Deadlock Solutions

! Solution using sendrecv

```
IF (rank==0) THEN
    CALL MPI_SENDRECV(sendbuf, count, MPI_REAL, 1, sendtag,
        recvbuf, count, MPI_REAL, 1, recvtag,
        MPI_COMM_WORLD, status, ierr)
ELSEIF (rank==1) THEN
    CALL MPI_SENDRECV(sendbuf, count, MPI_REAL, 0, sendtag,
        recvbuf, count, MPI_REAL, 0, recvtag,
        MPI_COMM_WORLD, status, ierr)
ENDIF
```

! Another possible solution (using all non-blocking calls)

```
IF (rank==0) THEN
    CALL MPI_ISEND(sendbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,req1,ierr)
    CALL MPI_IRECV(recvbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,req2,ierr)
ELSEIF (rank==1) THEN
    CALL MPI_ISEND(sendbuf,count,MPI_REAL,0,tag,MPI_COMM_WORLD,req1,ierr)
    CALL MPI_IRECV(recvbuf,count,MPI_REAL,1,tag,MPI_COMM_WORLD,req2,ierr)
ENDIF
CALL MPI_WAIT(req1, wait_status, ierr)
CALL MPI_WAIT(req2, wait_status, ierr)
```