COMP 322: Fundamentals of Parallel Programming

Lecture 31: Introduction to the Message Passing Interface (MPI) cont.

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Worksheet #30: MPI send and receive

In the space below, use the minimum amount of non-blocking communication to reach the print statement in line 10 (assume that the program is executed with two MPI processes).

```
1. int a[], b[];
2. ...
3. if (MPI.COMM_WORLD.rank() == 0) {
4.     MPI.COMM_WORLD.Isend(a, 0, 10, MPI.INT, 1, 1);
5.     MPI.COMM_WORLD.Send(b, 0, 10, MPI.INT, 1, 2);
6. }
7. else {
8.     Status s2 = MPI.COMM_WORLD.Recv(b, 0, 10, MPI.INT, 0, 2);
9.     Status s1 = MPI.COMM_WORLD.Recv(a, 0, 10, MPI_INT, 0, 1);
10.     System.out.println("a = " + a + " ; b = " + b);
11.}
12. …
```

MPI Matrix Multiply Example (Main)

```
if (myrank == 0) {
    // I'm the main process.
    a = new double[size * size];  // a = new double[size][size]
    b = new double[size * size];  // b = new double[size][size]
    c = new double[size * size];  // c = new double[size][size]

    // Initialize matrices.
    init( size );

    // Construct message components.
    averows = size / nprocs;
    extra = size % nprocs;
    offset[0] = 0;

    // Transfer matrices to each worker. Assume matching receives for Worker.
    for (int rank = 0; rank < nprocs; rank++) {
        rows[0] = ( rank < extra ) ? averows + 1 : averows;
        System.out.println( "Main process transmitting " + rows[0] + " rows to rank " + rank );
        if (rank != 0) {
            final double[] copy = new double[rows[0] * size];
            System.arraycopy(a, offset[0] * size, copy, 0, rows[0] * size);
            // TODO: send data to process rank with tag tagFromMain
            // using the temporary copy created above. Note that the length of a single row = size.
            // TODO: MPI.COMM_WORLD.send( . . .);
            // TODO: send correct elements in array b to process rank with tag tagFromMain
            // TODO MPI.COMM_WORLD.send( . . .);
        }
        offset[0] += rows[0];
    }…
```


MPI Matrix Multiply Example (Main)

```
if (myrank == 0) {
    // I'm the main process.
    a = new double[size * size];  // a = new double[size][size]
    b = new double[size * size];  // b = new double[size][size]
    c = new double[size * size];  // c = new double[size][size]

    // Initialize matrices.
    init( size );

    // Construct message components.
    averows = size / nprocs;
    extra = size % nprocs;
    offset[0] = 0;

    // Transfer matrices to each worker. Assume matching receives for Worker.
    for (int rank = 0; rank < nprocs; rank++) {
        rows[0] = ( rank < extra ) ? averows + 1 : averows;
        System.out.println( "Main process transmitting " + rows[0] + " rows to rank " + rank );
        if (rank != 0) {
           MPI.COMM_WORLD.send(offset, 0, 1, MPI.INT, rank, tagFromMain);
           MPI.COMM_WORLD.send(rows, 0, 1, MPI.INT, rank, tagFromMain);

           final double[] copy = new double[rows[0] * size];
           System.arraycopy(a, offset[0] * size, copy, 0, rows[0] * size);
                                    MPI.COMM_WORLD.send(copy, rows[0] * size, MPI.DOUBLE, rank, tagFromMain);
            MPI.COMM_WORLD.send(b, 0, size * size, MPI.DOUBLE, rank, tagFromMain);

        }
        offset[0] += rows[0];
    }…
```


MPI Matrix Multiply Example cont. (Main)

```
if (myrank == 0) {
    … //previous slide

   // Collect results from each worker. Assume matching sends from worker.
   for (int source = 1; source < nprocs; source++) {
        // TODO: receive date from process source with tag tagFromWorker
        // using the temporary copy created below (assume matching send from worker).
        final double[] copy = new double[…];
        System.arraycopy(copy, 0, c, …, …);
    }…
}
```


MPI Matrix Multiply Example cont. (Main)

```
if (myrank == 0) {
     … //previous slide

    // Collect results from each worker. Assume matching sends from worker.
   for (int source = 1; source < nprocs; source++) {
         MPI.COMM_WORLD.recv(offset, 0, 1, MPI.INT, source, tagFromWorker);
         MPI.COMM_WORLD.recv(rows, 0, 1, MPI.INT, source, tagFromWorker);
         final double[] copy = new double[rows[0] * size];
         MPI.COMM_WORLD.recv(copy, 0, rows[0] * size, MPI.DOUBLE, source, tagFromWorker);
         System.arraycopy(copy, 0, c, offset[0] * size, rows[0] * size);
     }…
 }
```


Collective Communications

- A popular feature of MPI is its family of collective communication operations.
- Each collective operation is defined over a communicator (most often, MPI.COMM_WORLD)
  - — Each collective operation contains an *implicit barrier*. The operation completes and execution continues when all processes in the communicator perform the *same* collective operation.
  - —A mismatch in operations results in *deadlock* e.g.,

    Process 0: .... MPI.Bcast(...) ....

    Process 1: .... MPI.Bcast(...) ....

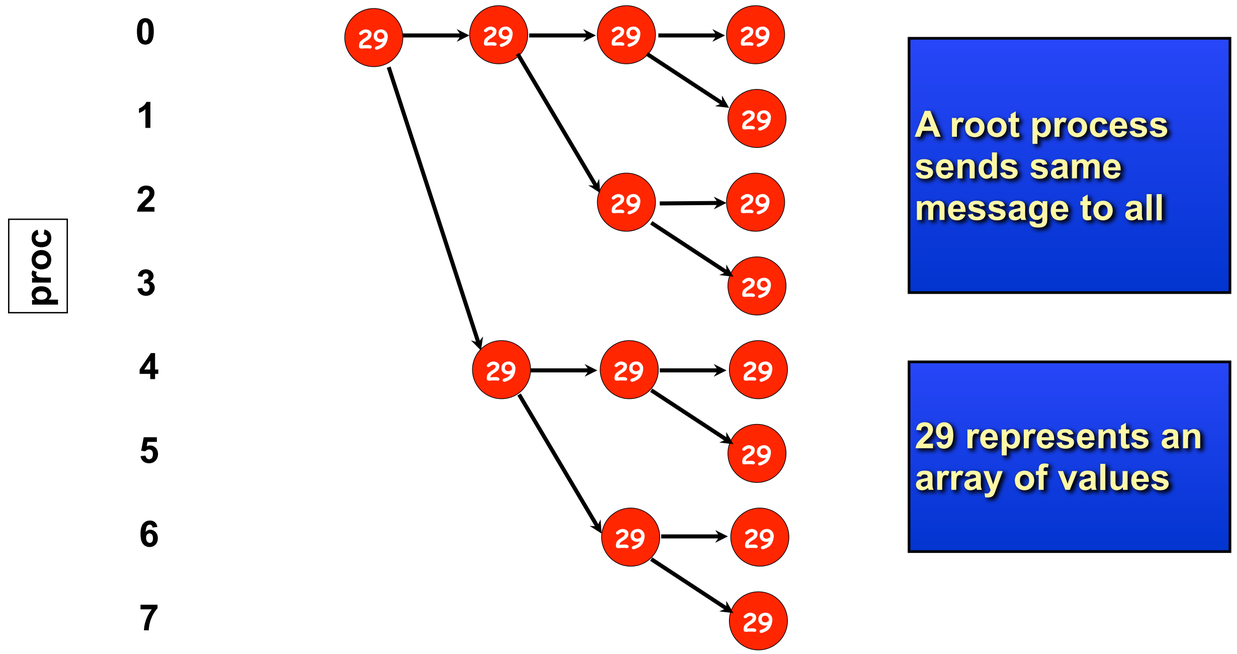
    Process 2: .... MPI.Gather(...) ….

- A simple example is the broadcast operation: all processes invoke the operation, all agreeing on one root process. Data is broadcast from that root.

  void Bcast(Object buf, int offset, int count, Datatype type, int root)

MPI Bcast

```
buf = new int[1]; if (rank==0) buf[0] = 29;
void Bcast(buf, 0, 1, MPI.INT, 0); // Executed by all processes
```



More Examples of Collective Operations

void Gather(Object sendbuf, int sendoffset, int sendcount, Datatype sendtype, Object recvbuf, int recvoffset, int recvcount, Datatype recvtype, int root)

- Each process sends the contents of its send buffer to the root process.

void Scatter(Object sendbuf, int sendoffset, int sendcount, Datatype sendtype, Object recvbuf, int recvoffset, int recvcount, Datatype recvtype, int root)

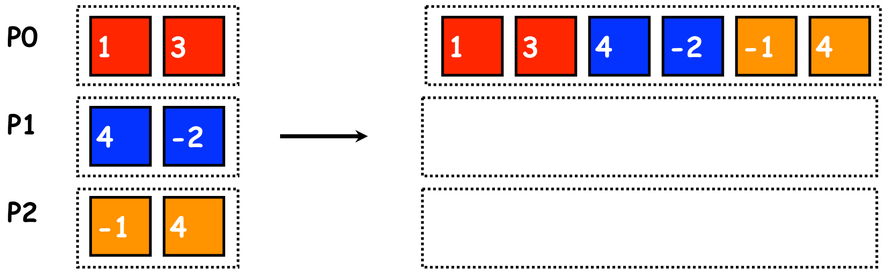
- Inverse of the operation Gather.

void Reduce(Object sendbuf, int sendoffset, Object recvbuf, int recvoffset, int count, Datatype datatype, Op op, int root)

- Combine elements in send buffer of each process using the reduce operation, and return the combined value in the receive buffer of the root process.

MPI Gather

- Use to copy an array of data from each process into a single array on a single process.
- Graphically:



- Note: only process 0 (P0) needs to supply storage for the output

void Gather(Object sendbuf, int sendoffset, int sendcount, Datatype sendtype, Object recvbuf, int recvoffset, int recvcount, Datatype recvtype, int root)

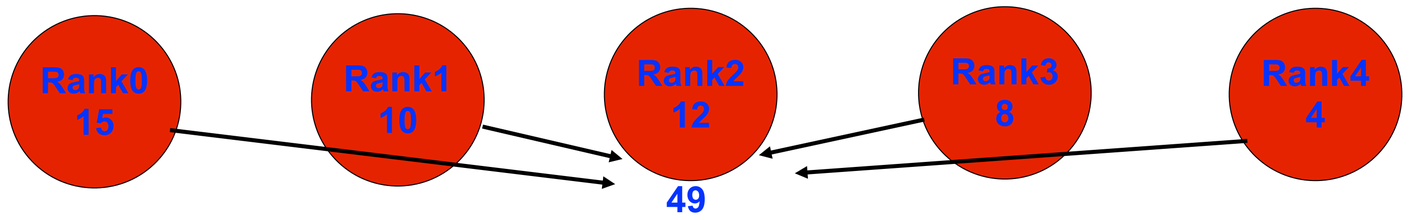
  - Each process sends the contents of its send buffer to the root process.

Predefined Reduction Operations

Operation	Meaning	Datatypes
`MPI_MAX`	Maximum	int, long, float, double
`MPI_MIN`	Minimum	int, long, float, double
`MPI_SUM`	Sum	int, long, float, double
`MPI_PROD`	Product	int, long, float, double
`MPI_LAND`	Logical AND	int, long
`MPI_BAND`	Bit-wise AND	byte, int, long
`MPI_LOR`	Logical OR	int, long
`MPI_BOR`	Bit-wise OR	byte, int, long
`MPI_LXOR`	Logical XOR	int, long
`MPI_BXOR`	Bit-wise XOR	byte, int, long
`MPI_MAXLOC`	max-min value-location	Data-pairs
`MPI_MINLOC`	min-min value-location	Data-pairs

MPI Reduce

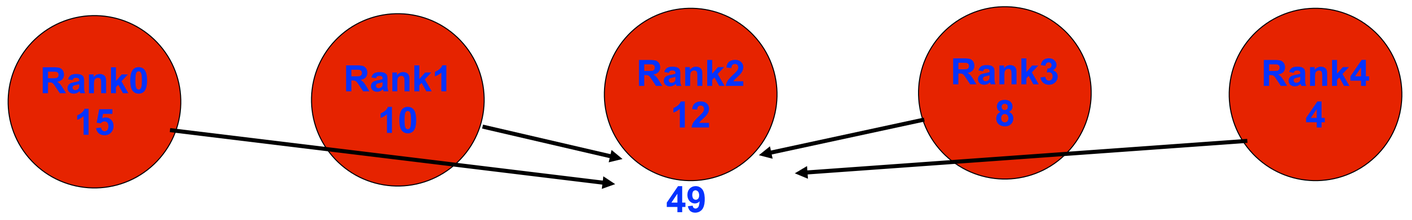
```
void MPI.COMM_WORLD.Reduce(
                Object    sendbuf  /* in */,
                int       sendoffset     /* in */,
                Object    recvbuf   /* out */,
                int       recvoffset     /* in */,
                int       count          /* in */,
                MPI.Datatype      datatype /* in */,
                MPI.Op    operator /* in */,
                int       root       /* in */ )
```



How would you write this using MPI Reduce with sendbuf size of 1?

MPI Reduce

```
void MPI.COMM_WORLD.Reduce(
                Object    sendbuf  /* in */,
                int       sendoffset     /* in */,
                Object    recvbuf   /* out */,
                int       recvoffset     /* in */,
                int       count          /* in */,
                MPI.Datatype      datatype /* in */,
                MPI.Op    operator /* in */,
                int       root       /* in */ )
```



MPI.COMM_WORLD.Reduce(msg, 0, result, 0, 1, MPI.INT, MPI.SUM, 2);

Announcements & Reminders

- Quiz for Unit 7 is today at 11:59pm

- HW 4 Checkpoint #1 is due by Monday April 19th at 11:59pm

Worksheet #31: MPI_Gather

In the space below, indicate what value should be provided instead of ??? in line 6, and how it should depend on myrank.

```
2.  MPI.Init(args) ;
3.   int myrank = MPI.COMM_WORLD.Rank() ;
4.   int numProcs = MPI.COMM_WORLD.Size() ;
5.   int size = ...;
6.   int[] sendbuf = new int[size];
7.   int[] recvbuf = new int[???];
8.   . . . // Each process initializes sendbuf
9.   MPI.COMM_WORLD.Gather(sendbuf, 0, size, MPI.INT,
10.                         recvbuf, 0, size, MPI.INT,
11.                        0/*root*/);
12.  . . .
13.  MPI.Finalize();
```