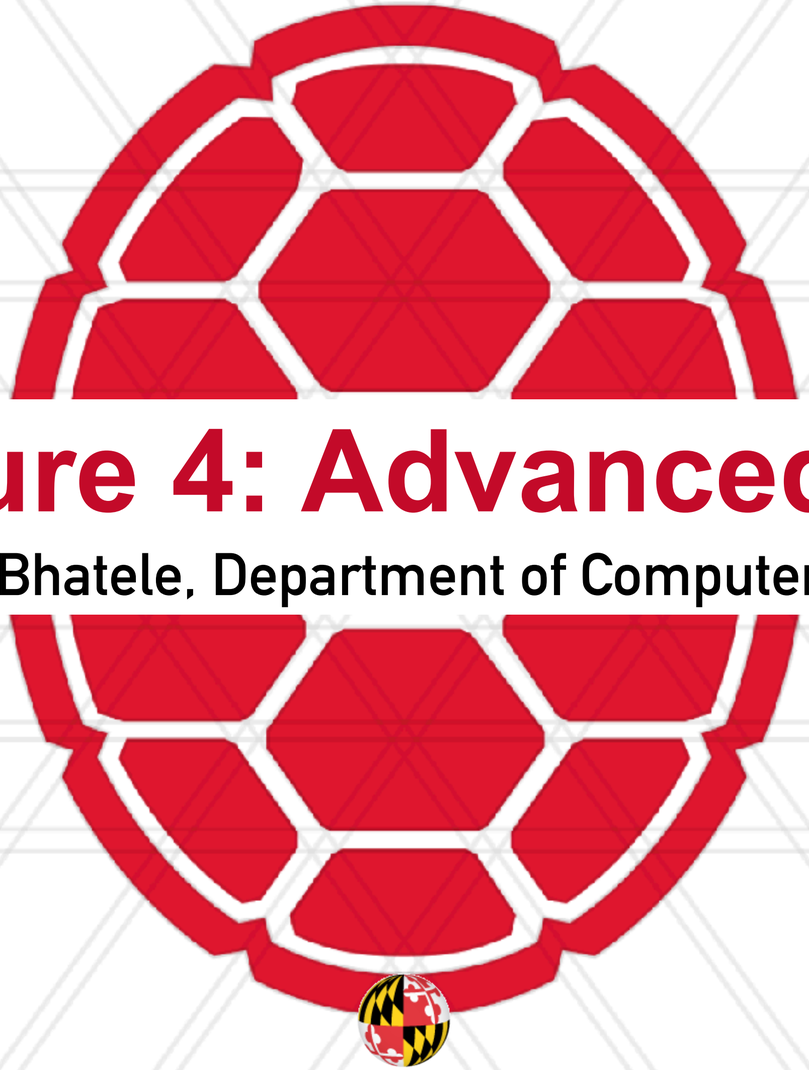
High Performance Computing Systems (CMSC714)



Lecture 4: Advanced MPI

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Announcements

- Paper reading assignments will start from the Feb 11 lecture
- Assignment 1 on MPI will be posted on Feb 8 before 11:59 pm AoE and will be due on Feb 22 11:59 pm AoE

Summary of last lecture

- Parallel architectures and programming models
- Message passing and MPI
- Basic MPI routines:
  - MPI_Init, MPI_Finalize
  - MPI_Comm_rank, MPI_Comm_size
  - MPI_Send, MPI_Recv
- Delivery order: only guaranteed between a pair of processes

Non-blocking point-to-point calls

- MPI_Isend and MPI_Irecv
- Two parts:
  - post the operation
  - Wait for results: need to call MPI_Wait or MPI_Test
- Can help with overlapping computation with communication

MPI_Isend

```
int MPI_Isend( const void *buf, int count, MPI_Datatype datatype,
int dest, int tag, MPI_Comm comm, MPI_Request *request )
```

`buf`: address of send buffer

`count`: number of elements in send buffer

`datatype`: datatype of each send buffer element

`dest`: rank of destination process

`tag`: message tag

`comm`: communicator

`request`: communication request

MPI_Irecv

```
int MPI_Irecv( void *buf, int count, MPI_Datatype datatype, int
source, int tag, MPI_Comm comm, MPI_Request *request )
```

`buf`: address of receive buffer

`count`: maximum number of elements in receive buffer

`datatype`: datatype of each receive buffer element

`source`: rank of source process

`tag`: message tag

`comm`: communicator

`request`: communication request

MPI_Wait

```
int MPI_Wait( MPI_Request *request, MPI_Status *status )
```

`request`: communication request

status: status object

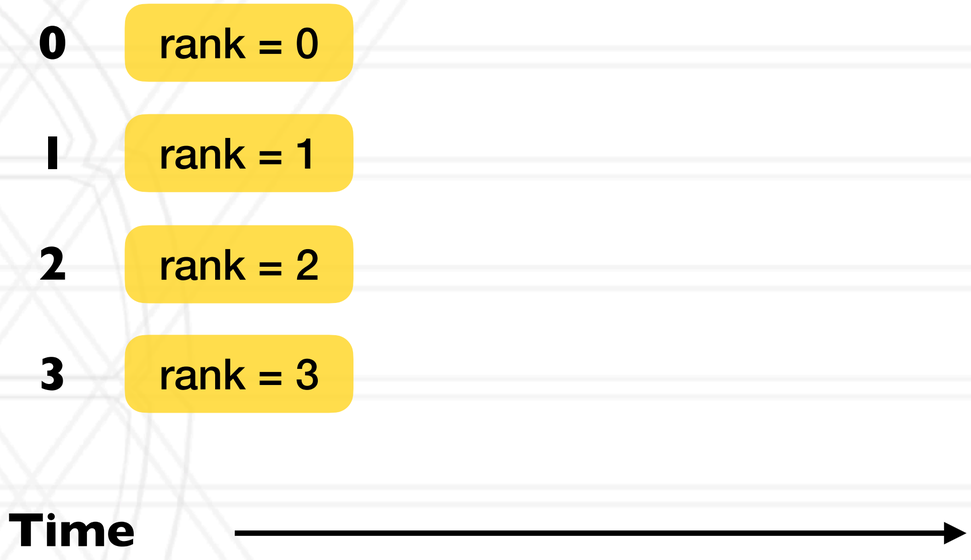
- Status object can provide information about:
  - Source process for a message: status.source
  - Message tag: status.tag
  - Number of elements: `MPI_Get_count( MPI_Status *status, MPI_Datatype datatype, int count)`

Non-blocking send/receive in MPI

```
int main(int  argc, char *argv) {
  ...

  MPI_Request req;
  MPI_Status stat;
  if (rank == 0) {
    data = 7;
    MPI_Isend(&data, 1, MPI_INT, 1, 0, MPI_COMM_WORLD, &req);
  } else if (rank == 1) {
    MPI_Irecv(&data, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, &req);

    ...
    MPI_Wait(&req, &stat);
    printf("Process 1 received data %d from process 0\n", data);
  }

  ...
}
```

Example program

```
int main(int  argc, char *argv) {
  ...
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  ...
  if (rank % 2 == 0) {
    data = rank;
    MPI_Isend(&data, 1, MPI_INT, rank+1, 0, ...);
  } else {
    data = rank * 2;
    MPI_Irecv(&data, 1, MPI_INT, rank-1, 0, ...);

    ...
    MPI_Wait(&req, &stat);
    printf("Process %d received data %d\n”, data);
  }
  ...
}
```



Example program

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  ...
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  ...
  if (rank % 2 == 0) {
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  }
  ...
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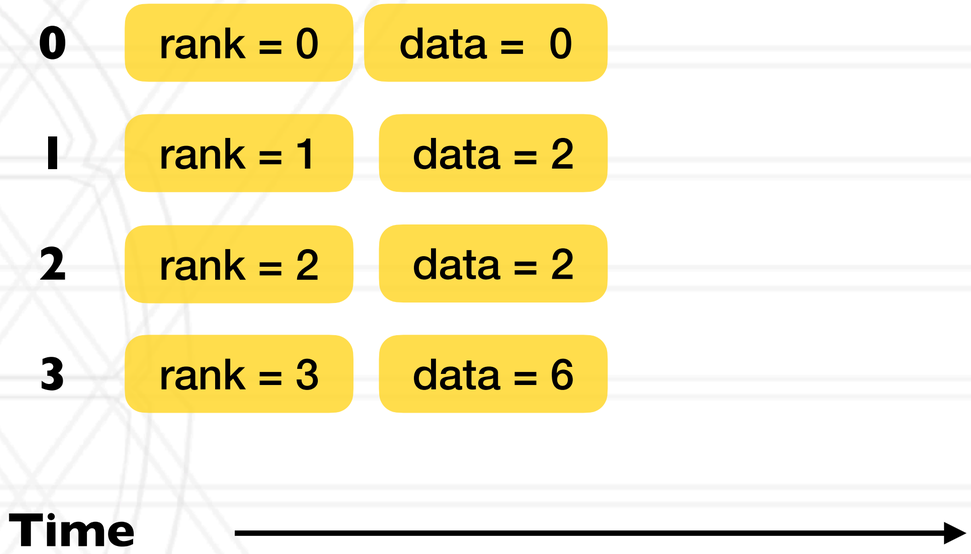
```



Example program

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    ...
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  }
  ...
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```

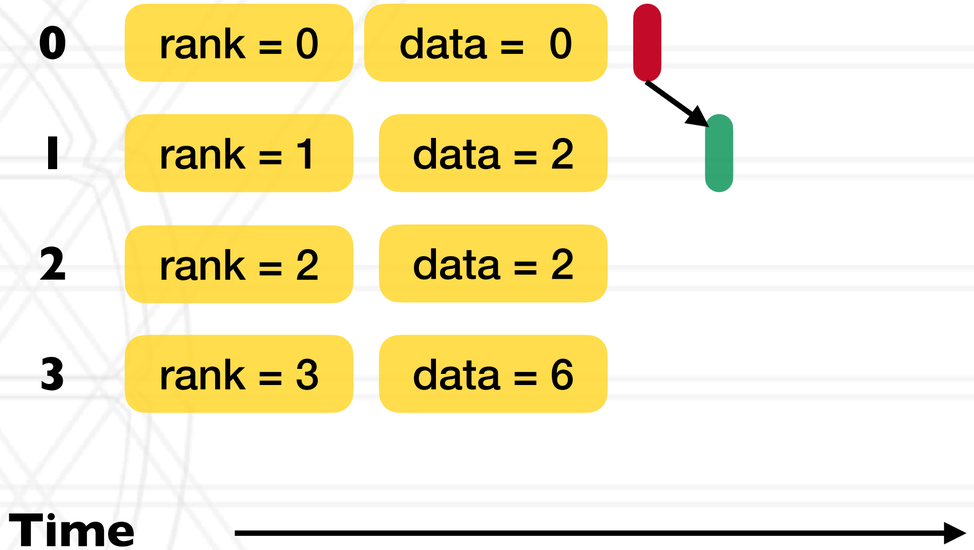

Example program

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    ...
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  }
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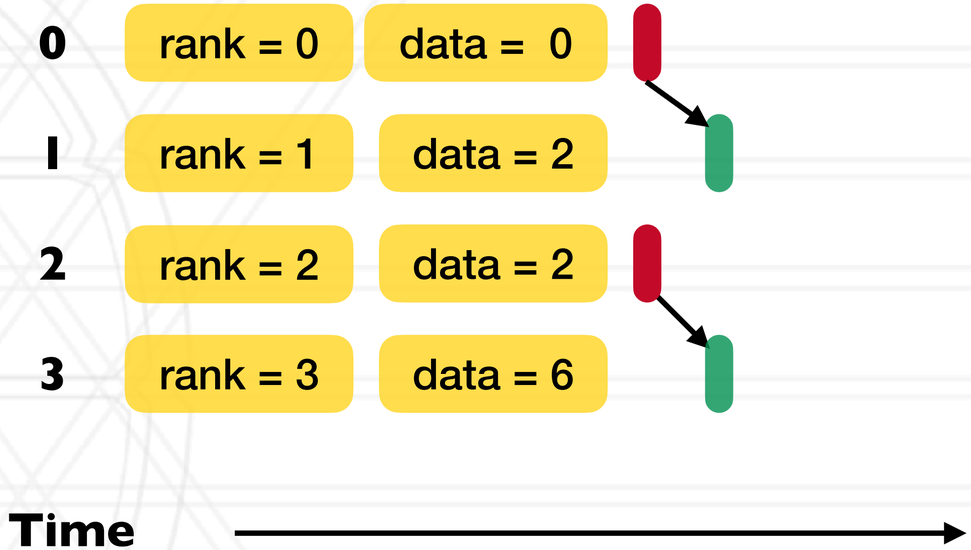
}
```



Example program

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    ...
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    printf("Process %d received data %d\n”, data);
  }
  ...
}
```
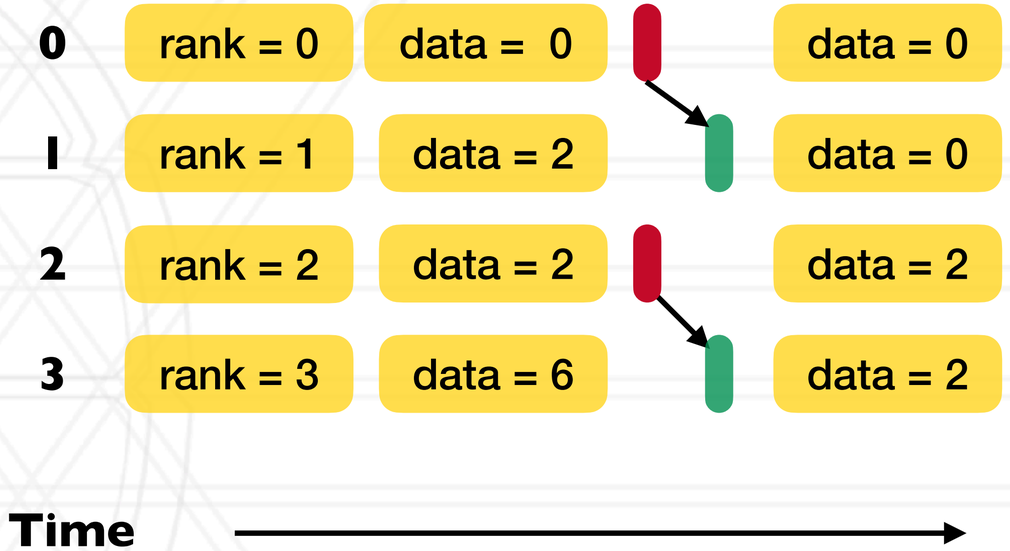
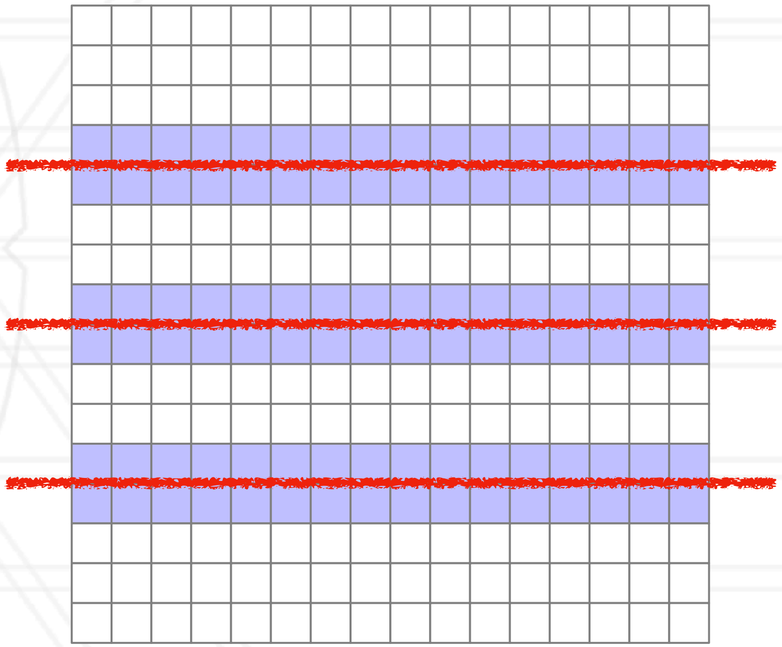



Other calls

- `int MPI_Test( MPI_Request *request, int *flag, MPI_Status *status )`
- `int MPI_Waitall( int count, MPI_Request array_of_requests[], MPI_Status *array_of_statuses[] )`
- `MPI_Waitany`
- `MPI_Waitsome`

2D stencil computation

```
int main(int  argc, char *argv) {
  ...

  MPI_Comm_rank(MPI_COMM_WORLD, &rank);

  MPI_Irecv(&data1, 16, MPI_DOUBLE, (rank-1)%4, 0, ...);
  MPI_Irecv(&data2, 16, MPI_DOUBLE, (rank+1)%4, 0, ...);


  MPI_Isend(&data3, 16, MPI_DOUBLE, (rank-1)%4, 0, ...);
  MPI_Isend(&data4, 16, MPI_DOUBLE, (rank+1)%4, 0, ...);


  MPI_Waitall(...);

  ...
}
```



Collective operations

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- `int MPI_Barrier( MPI_Comm comm)`
  - Blocks until all processes in the communicator have reached this routine

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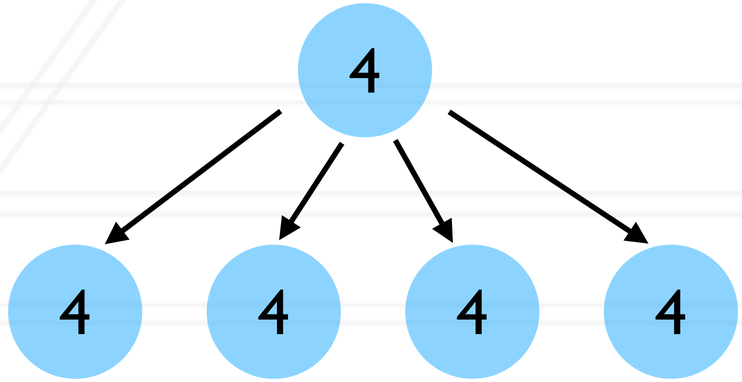
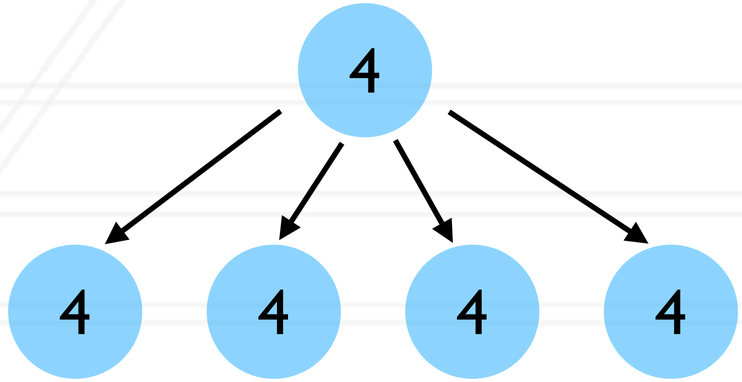
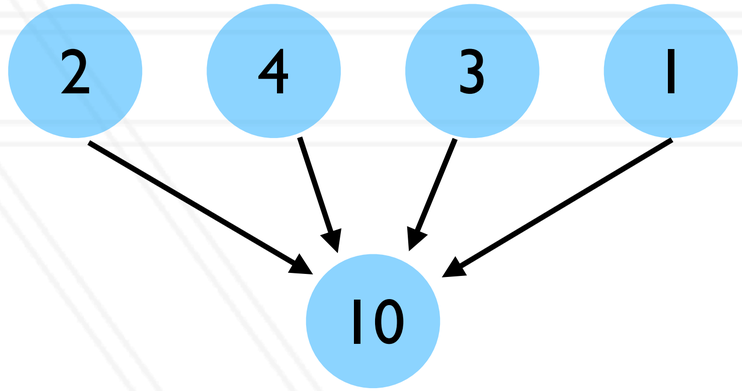
- `int MPI_Bcast( void *buffer, int count, MPI_Datatype datatype, int root, MPI_Comm comm )`
  - Send data from root to all processes



Collective operations

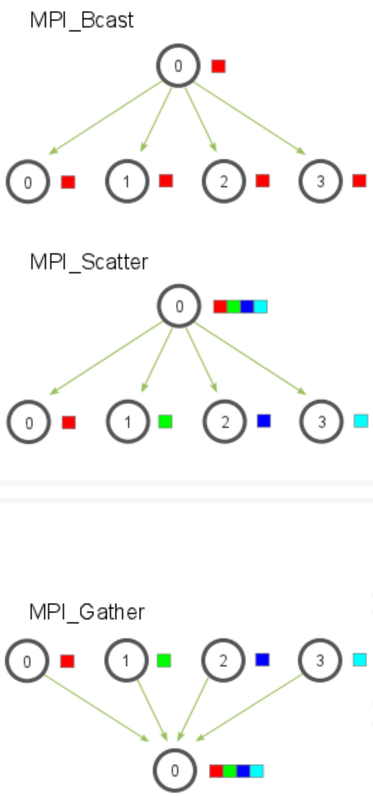
- `int MPI_Barrier( MPI_Comm comm)`
  - Blocks until all processes in the communicator have reached this routine
- `int MPI_Bcast( void *buffer, int count, MPI_Datatype datatype, int root, MPI_Comm comm )`
  - Send data from root to all processes
- `int MPI_Reduce( const void *sendbuf, void *recvbuf, int count, MPI_Datatype datatype, MPI_Op op, int root, MPI_Comm comm )`
  - Reduce data from all processes to the root





Collective operations

- `int MPI_Scatter( const void *sendbuf, int sendcount, MPI_Datatype sendtype, void *recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)`
  - Send data from root to all processes
- `int MPI_Gather( const void *sendbuf, int sendcount, MPI_Datatype sendtype, void *recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)`
  - Gather data from all processes to the root
- MPI_Scan



https://mpitutorial.com/tutorials/mpi-scatter-gather-and-allgather/zh_cn/

Other MPI calls

- MPI_Wtime
  - Returns elapsed time

```
{
  double starttime, endtime;
  starttime = MPI_Wtime();

  ....  code region to be timed  ...

  endtime = MPI_Wtime();
  printf("Time %f seconds\n",endtime-starttime);
}
```

Calculate the value of $\pi = \int_0^1 \frac{4}{1+x^2}$

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

    n = 10000;

    h   = 1.0 / (double) n;
    sum = 0.0;

    for (i = 1; i <= n; i += 1) {
        x = h * ((double)i - 0.5);
        sum += (4.0 / (1.0 + x * x));
    }
    pi = h * sum;

    ...
}
```

Calculate the value of $\pi = \int_0^1 \frac{4}{1+x^2}$

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

    n = 10000;
    MPI_Bcast(&n, 1, MPI_INT, 0, MPI_COMM_WORLD);

    h   = 1.0 / (double) n;
    sum = 0.0;

    for (i = myrank + 1; i <= n; i += numranks) {
        x = h * ((double)i - 0.5);
        sum += (4.0 / (1.0 + x * x));
    }
    pi = h * sum;

    MPI_Reduce(&pi, &globalpi, 1, MPI_DOUBLE, MPI_SUM, 0, MPI_COMM_WORLD);

    ...
}
```

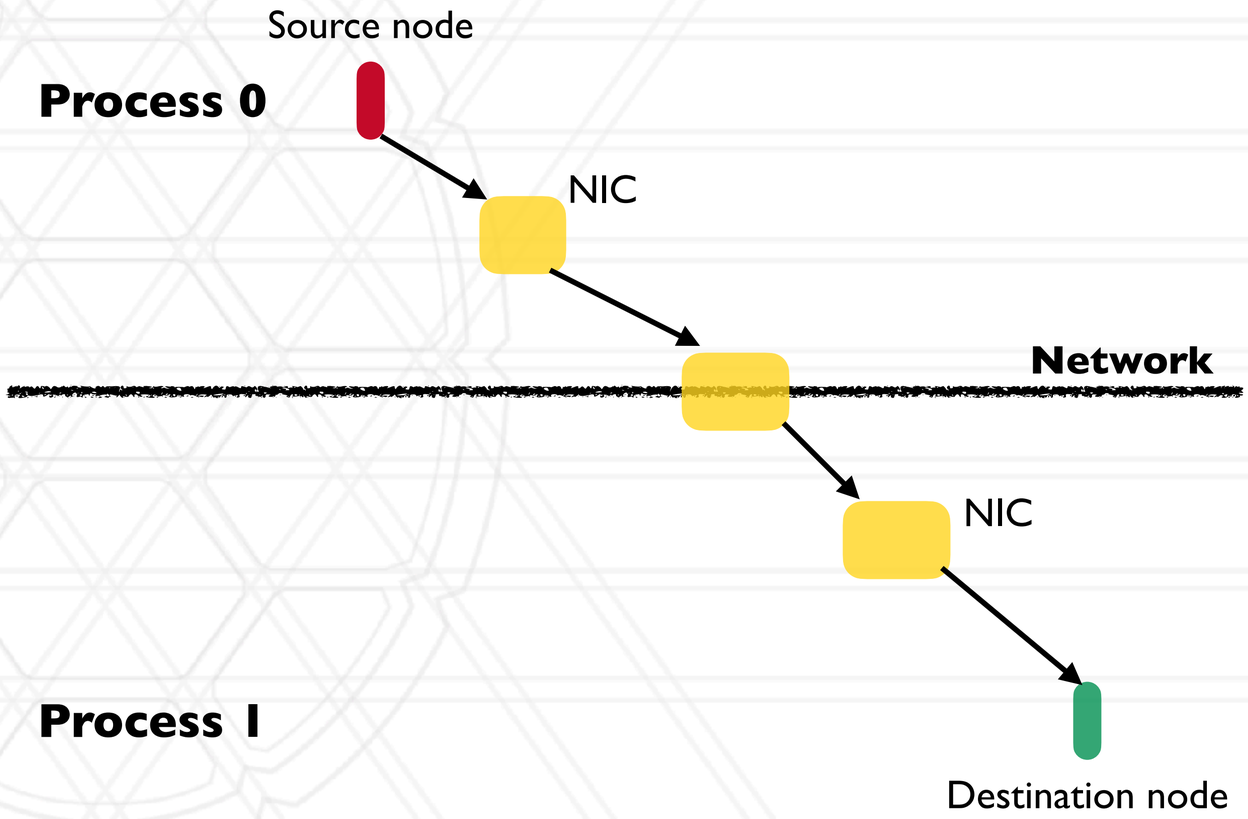
Other MPI send modes

- Basic mode:
  - MPI_Send
- Buffered mode:
  - MPI_Bsend
  - Use MPI_Buffer_attach to provide space for buffering
- Synchronous mode
  - MPI_Ssend
- Ready mode
  - MPI_Rsend

https://www.mcs.anl.gov/research/projects/mpi/sendmode.html

Protocols for sending message

- Eager
  - Message sent assuming destination can store
- Rendezvous
  - Message only sent after handshake (receiving ack) with destination
- Short
  - Data sent with the message envelope



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