Advanced MPI

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Announcements

- 1st extra credit: Scribe for lectures
  - 5% of course grade
- Detailed instructions: https://www.cs.umd.edu/class/spring2024/cmsc416/scribing.shtml

Any downsides to using blocking calls?

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- Performance: the receiver blocks for a message and cannot do anything else while waiting for a message

Non-blocking point-to-point calls

- Most important routines: MPI_Isend and MPI_Irecv
- Two parts to a non-blocking operation:
  - Posting: post the non-blocking operation
  - Completion: wait for its results at a later point in the program — done via calls to MPI_Wait or MPI_Test
- Can help facilitate overlap of computation with communication

MPI_Isend: Non-blocking pt2pt send

```
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: Non-blocking pt2pt receive

```
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: blocking call

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

`request`: communication request

status: status object

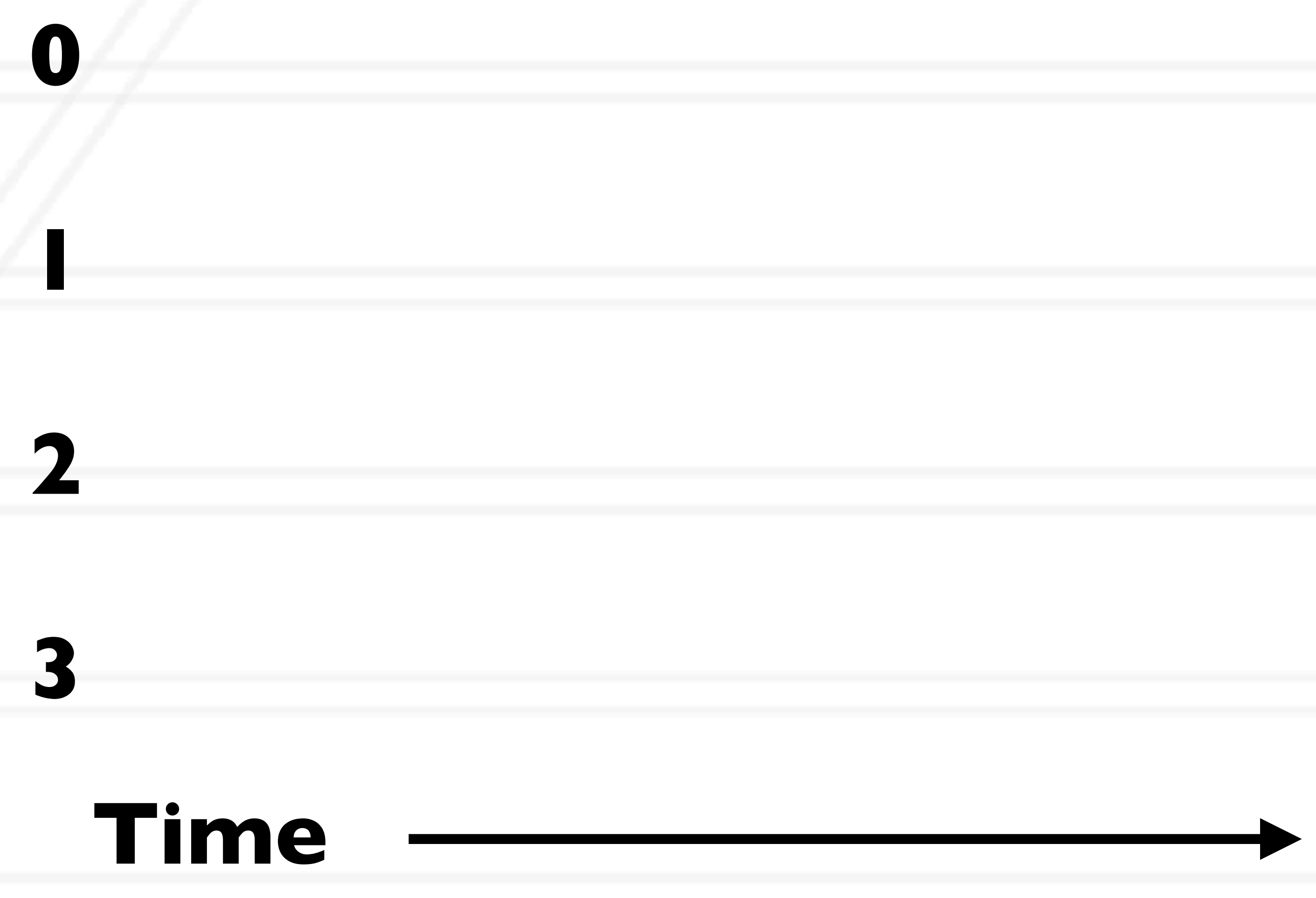
Request object is an opaque object in MPI "system" memory associated with a particular communication operation. It links the posting to the completion.

- Status object can provide information about:
  - count: number of received entries
  - MPI_SOURCE: source of the message
  - MPI_TAG: tag value of the message
  - MPI_ERROR: error associated with the message
- If you don't want to inspect it, you can use `MPI_STATUS_IGNORE`

Using non-blocking send/recv

```
int main(int argc, char *argv[]) {
  ...
  MPI_Comm_rank(MPI_COMM_WORLD, &myrank);
  MPI_Request req;
  MPI_Status stat;
  ...
  if (myrank % 2 == 0) {
    data = myrank;
    MPI_Isend(&data, 1, MPI_INT, myrank+1, 0, ..., &req);
  } else {
    data = myrank * 2;
    MPI_Irecv(&data, 1, MPI_INT, myrank-1, 0, ..., &req);

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



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  }
  ...
}
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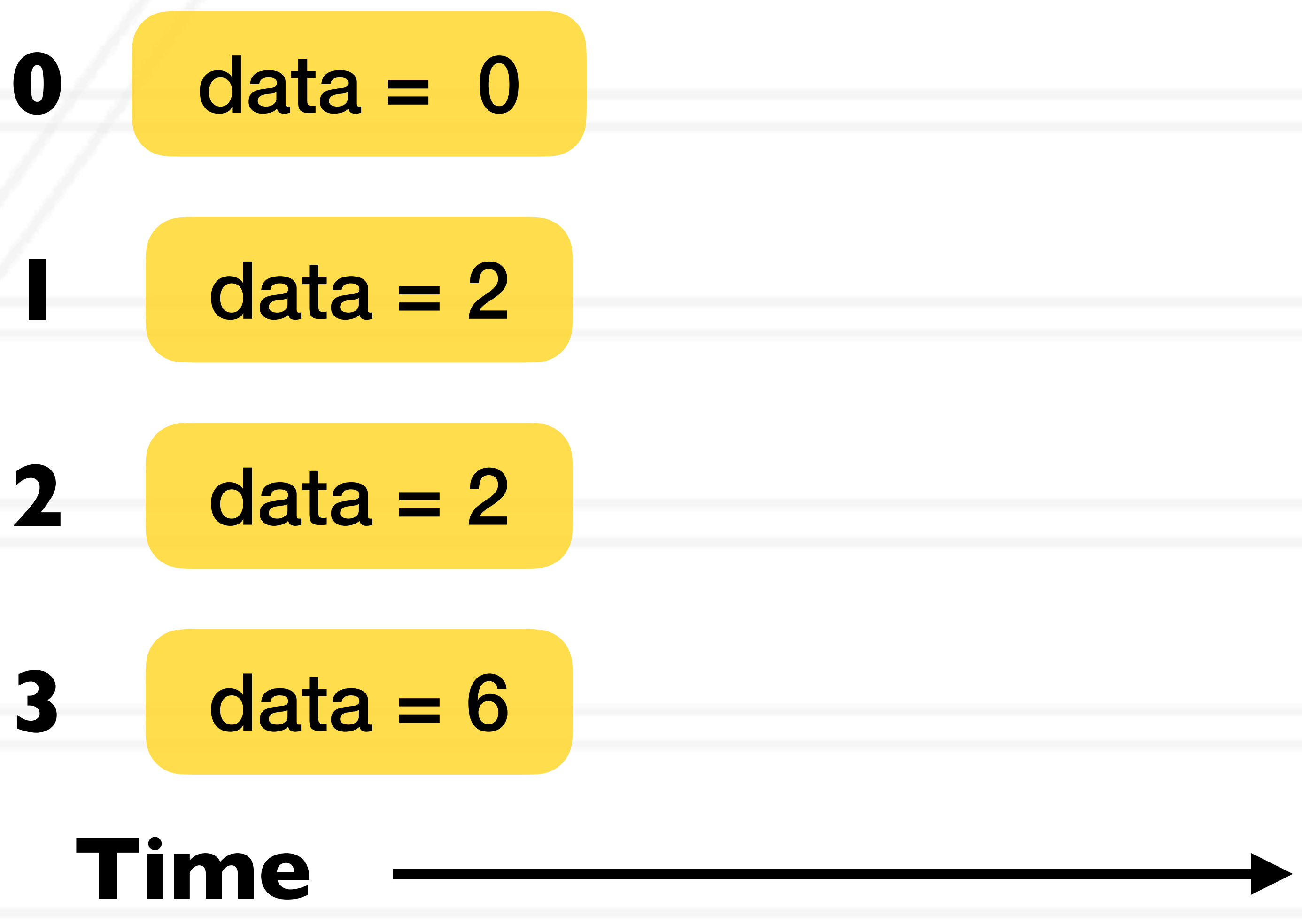

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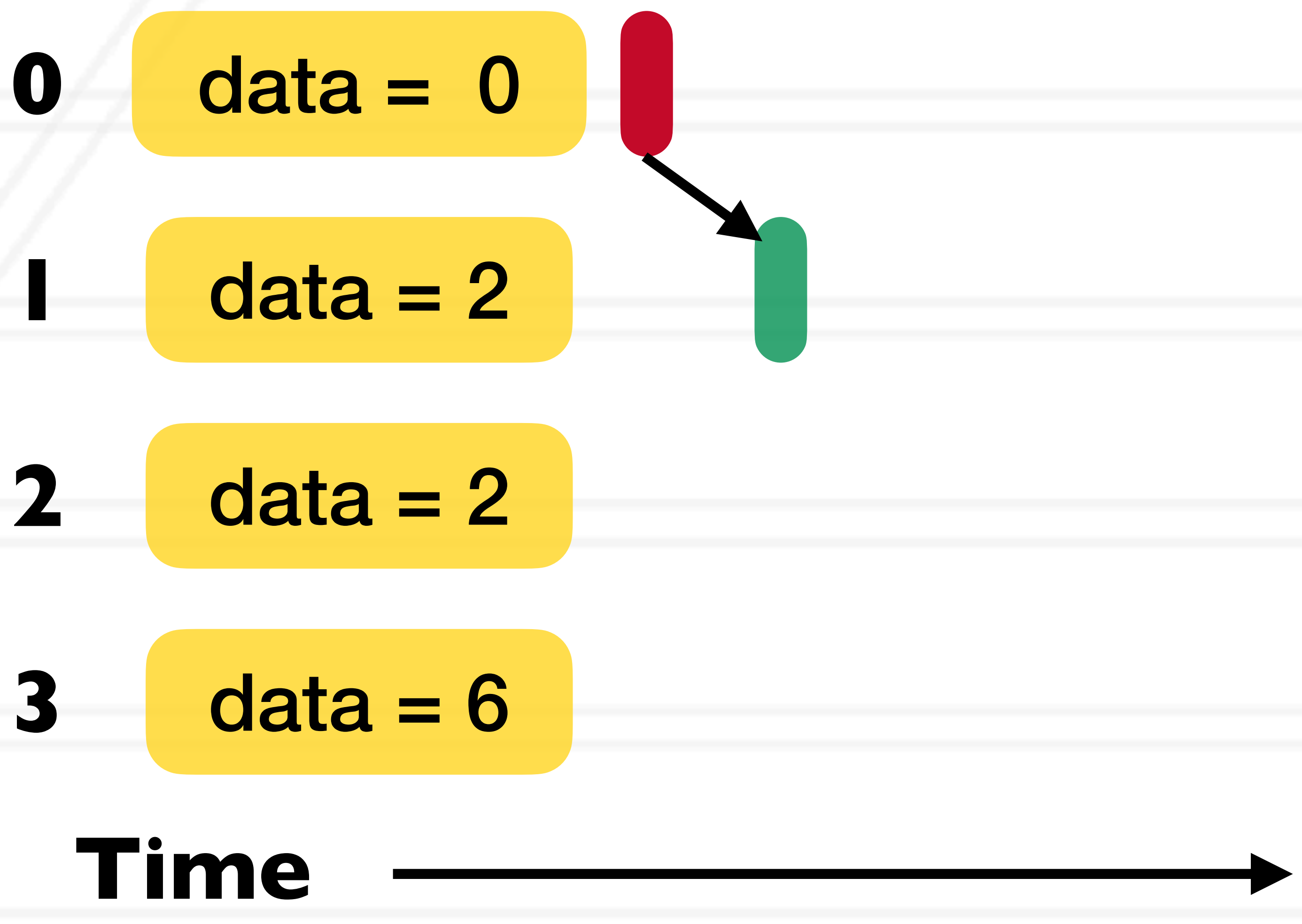

Using non-blocking send/recv

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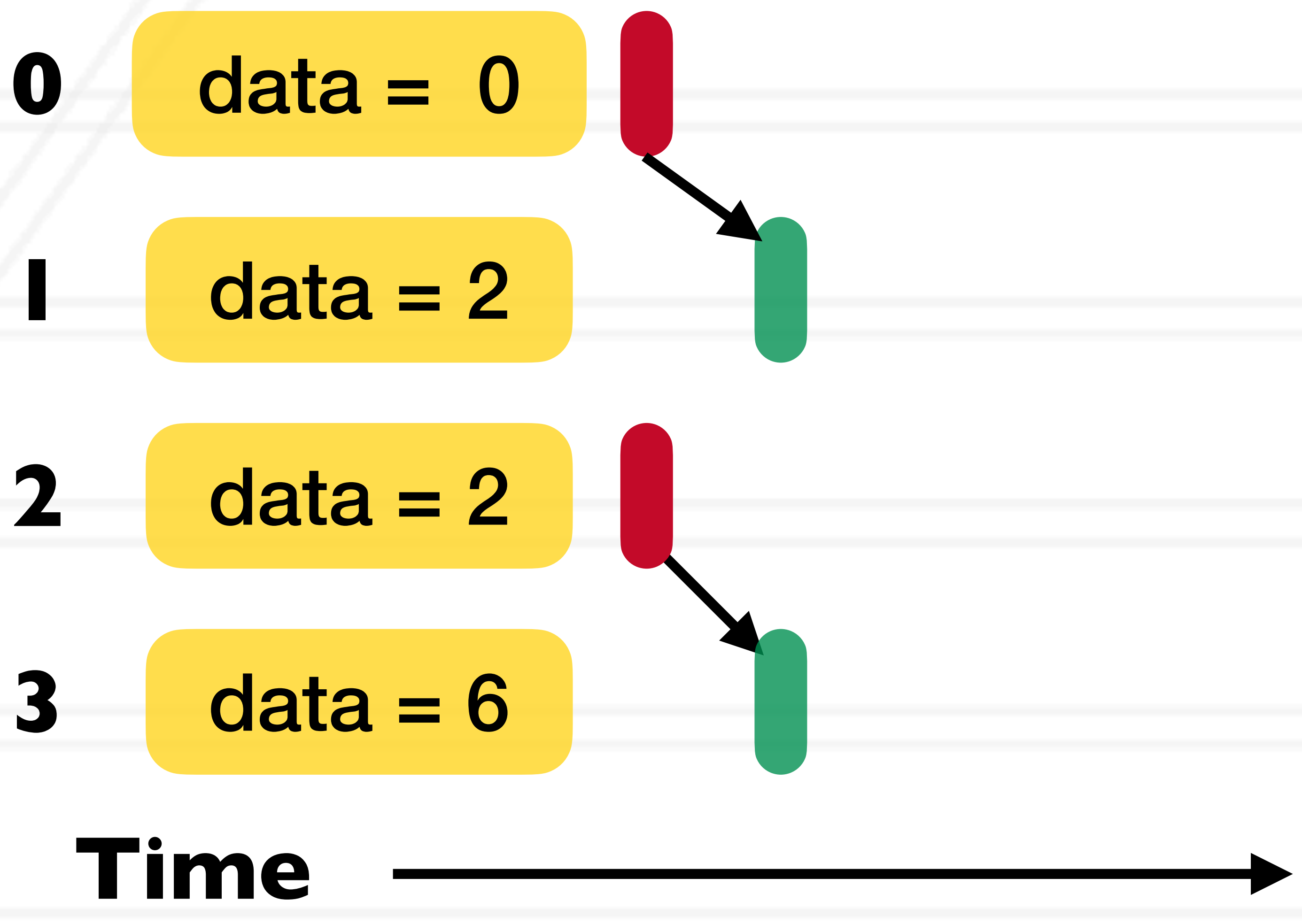
```



Using non-blocking send/recv

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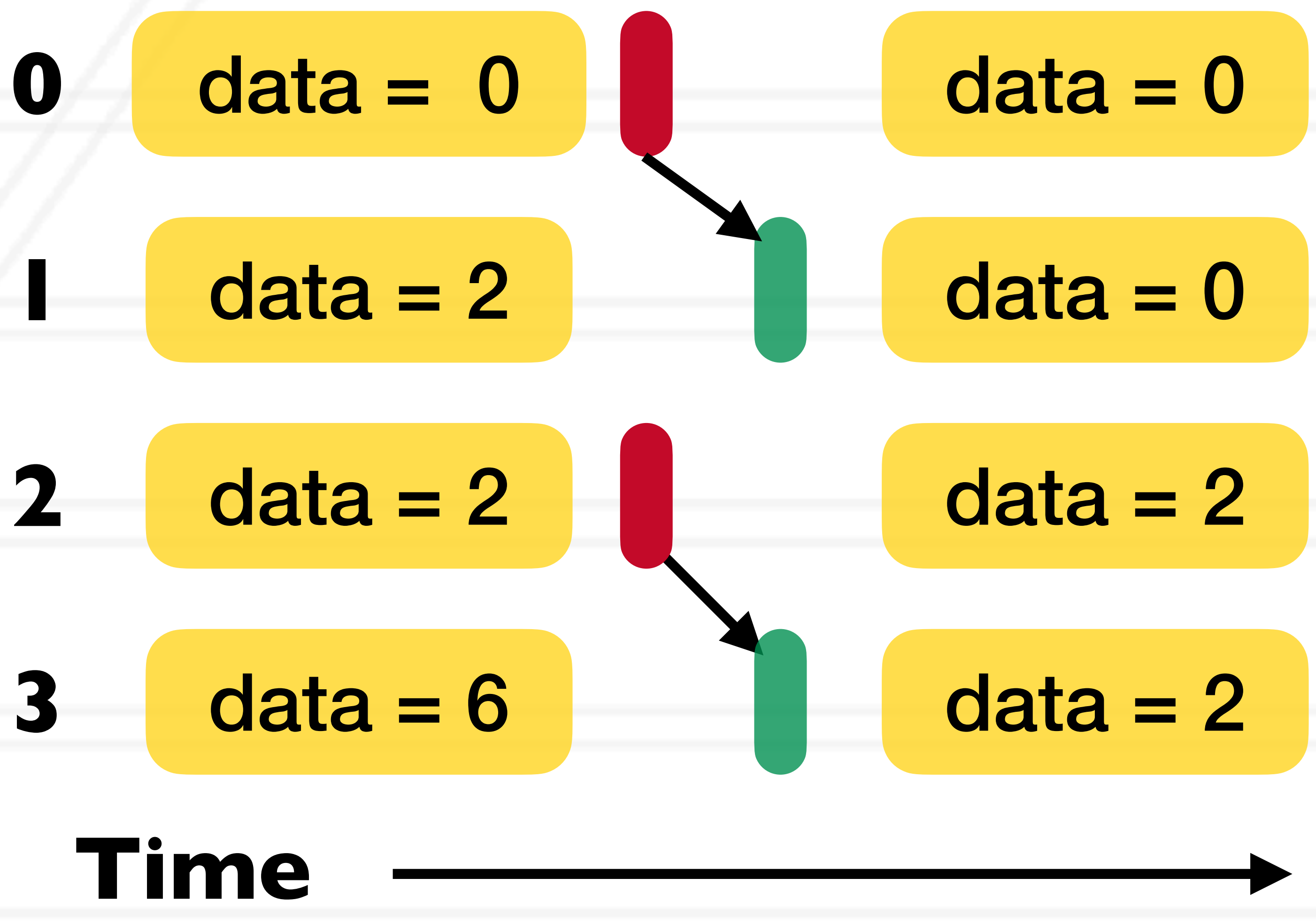
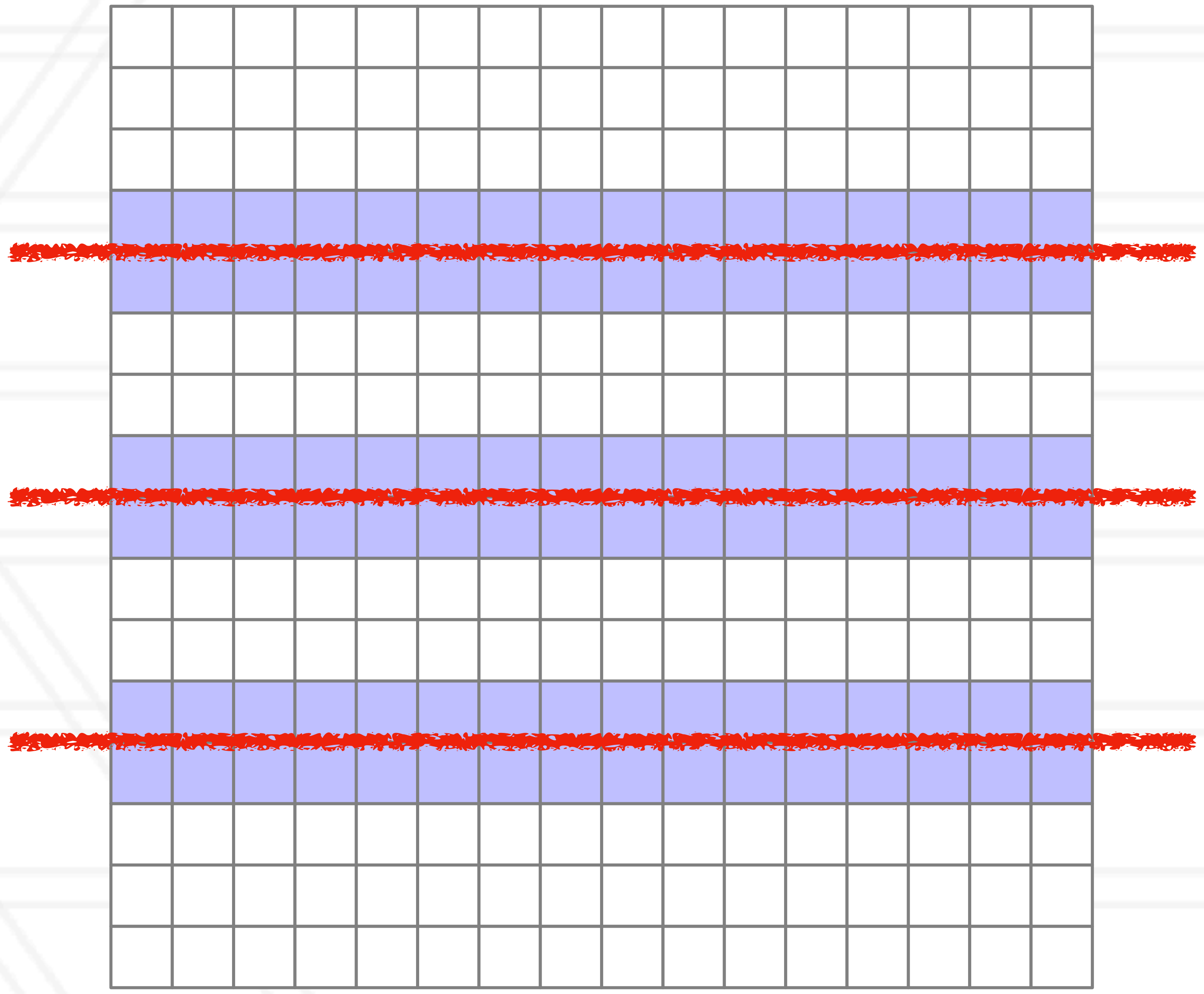
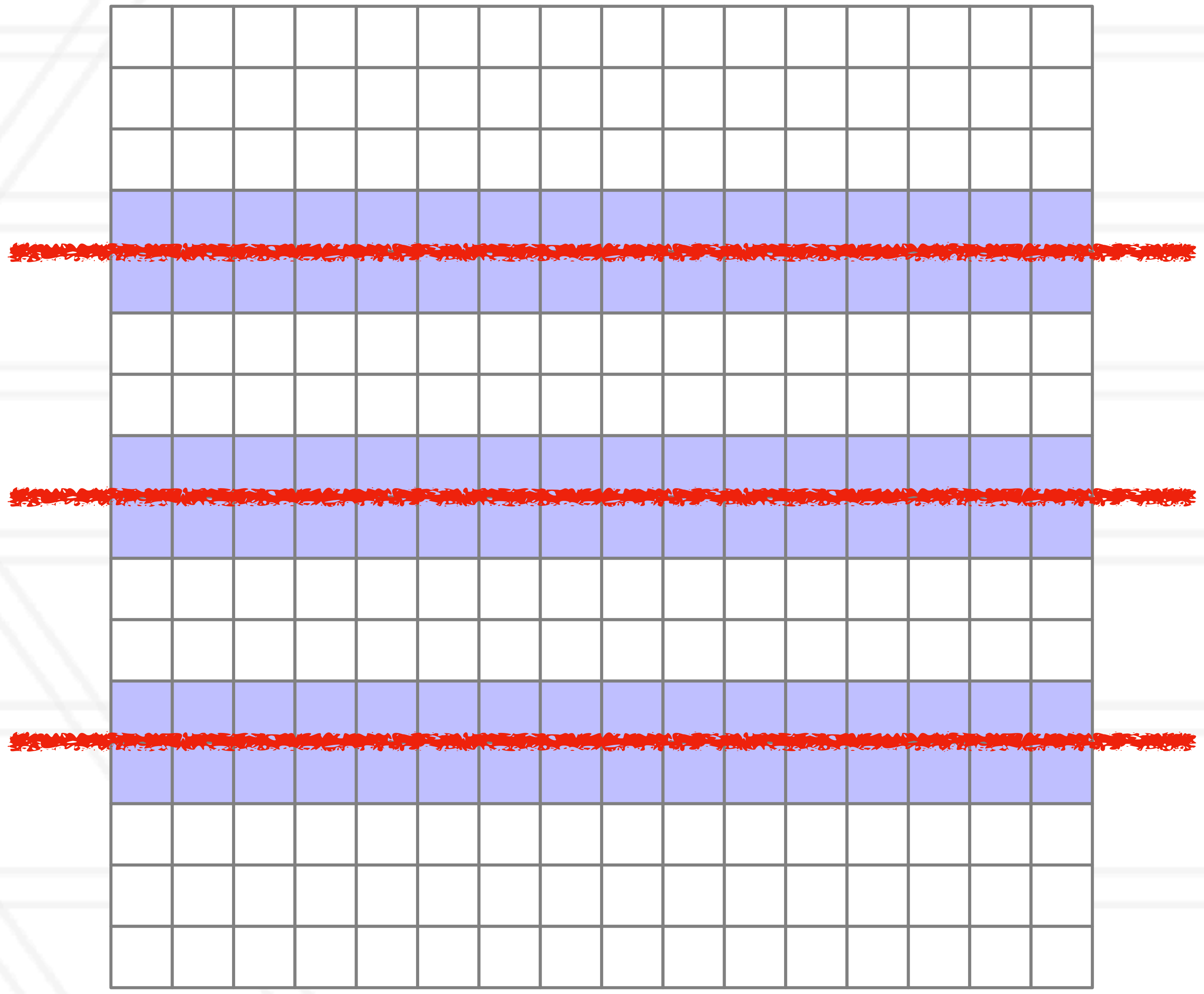



2D stencil computation



2D stencil computation

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

  MPI_Comm_rank(MPI_COMM_WORLD, &myrank);

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

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


  MPI_Waitall(…);

  compute();

  ...
}
```



Other MPI calls

- `int MPI_Test( MPI_Request *request, int *flag, MPI_Status *status )`
  - `flag` is set to true if the operation has completed
- `int MPI_Waitall( int count, MPI_Request array_of_requests[], MPI_Status *array_of_statuses[] )`
  - Waits for all given MPI requests to complete
- `MPI_Waitany`
  - Waits for any specified MPI request to complete

Collective operations

- All processes in the communicator participate in the operation

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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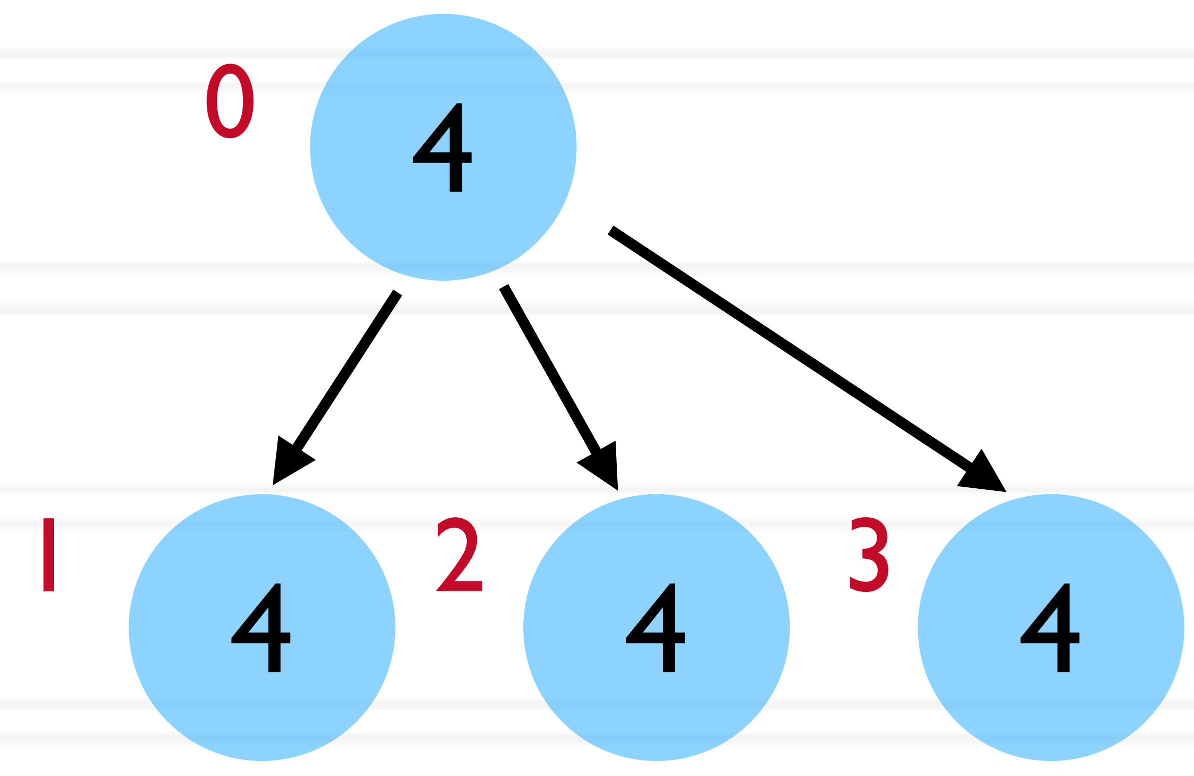
- `int MPI_Barrier( MPI_Comm comm)`
  - Blocks until all processes in the communicator have reached this routine
- `int MPI_Bcast( void *buffer, int count, MPI_Datatype datatype, int root, MPI_Comm comm )`
  - Send data from root to all processes of the communicator
  - Buffer represents what is being sent on root but where things will be written on other processes



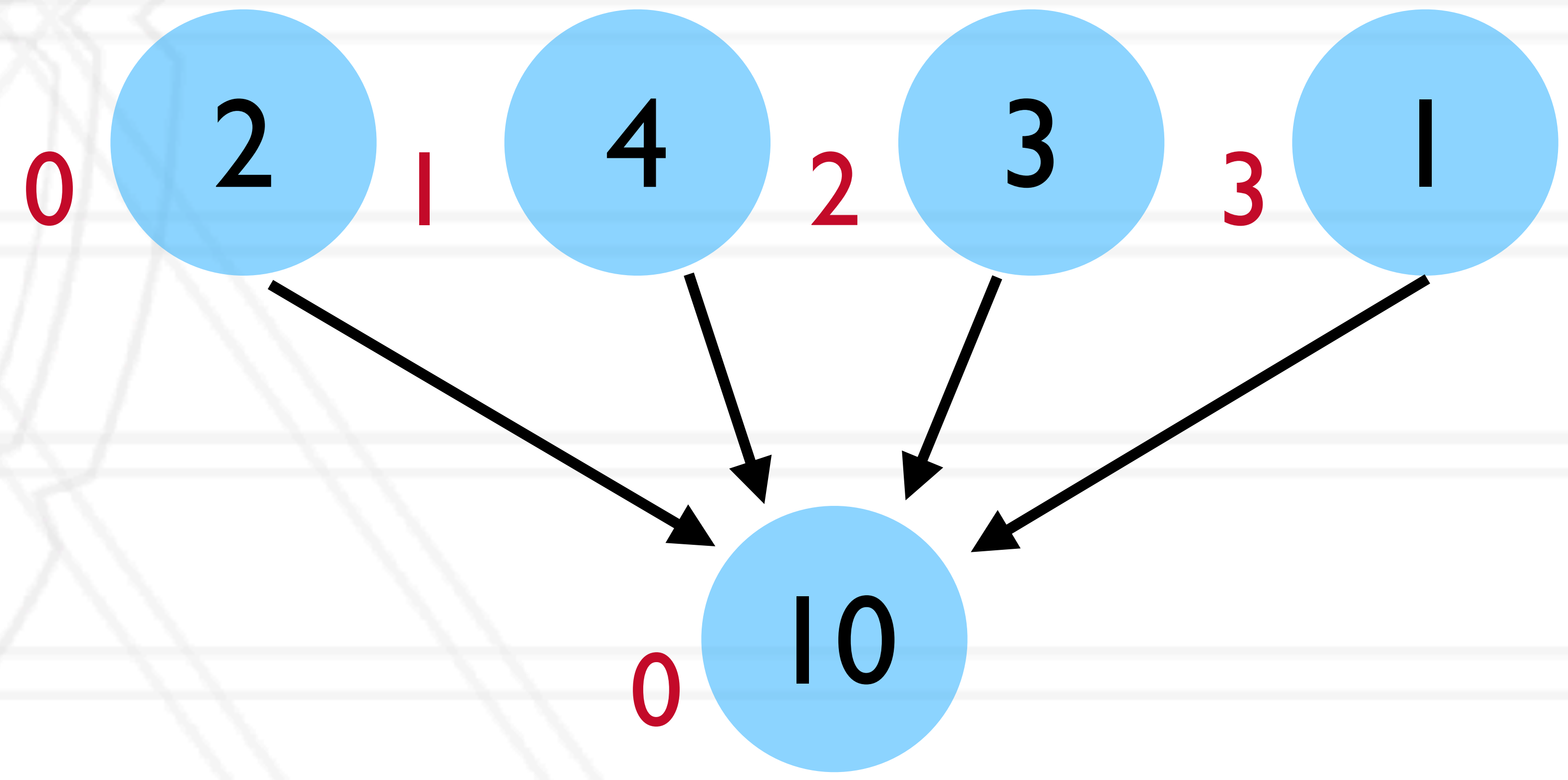
Collective operations

Collective operations

- `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
  - sendbuf should be valid on all processes
  - Recvbuf only needs to exist on root

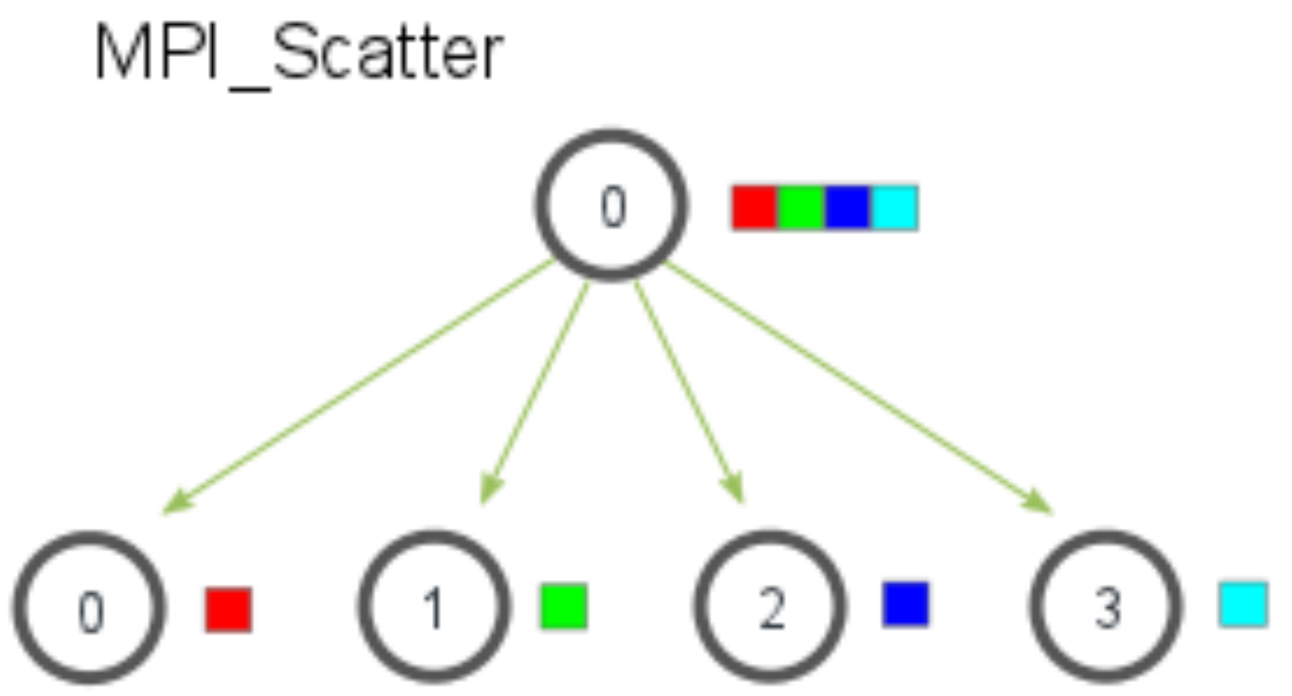
Collective operations

- `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
  - sendbuf should be valid on all processes
  - Recvbuf only needs to exist on root
- MPI_Allreduce
  - Can be used to send the result back to **all** processes

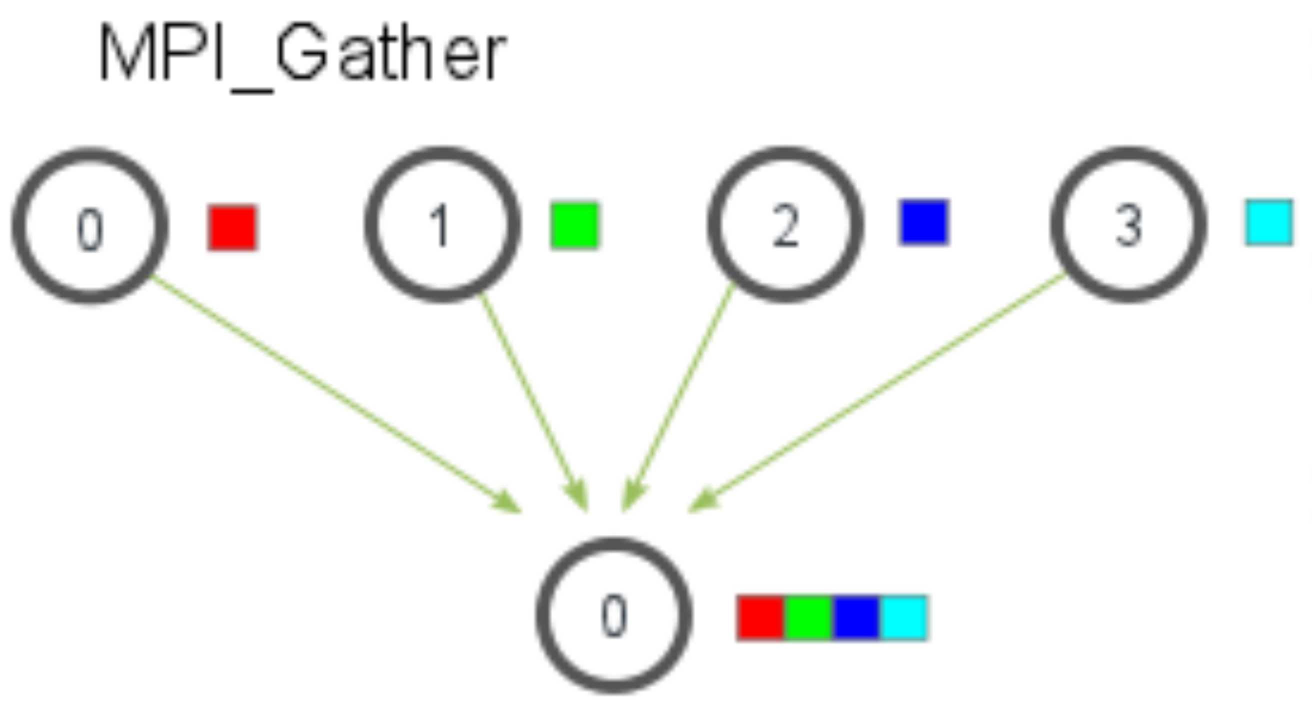


Collective operations

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



- `MPI_Scan`: Computes prefix sum

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

Other MPI calls

- double MPI_Wtime (void)
    - Returns elapsed time in seconds since an arbitrary time in the past

```
{
  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 $\pi = \int_0^1 \frac{4}{1+x^2}$

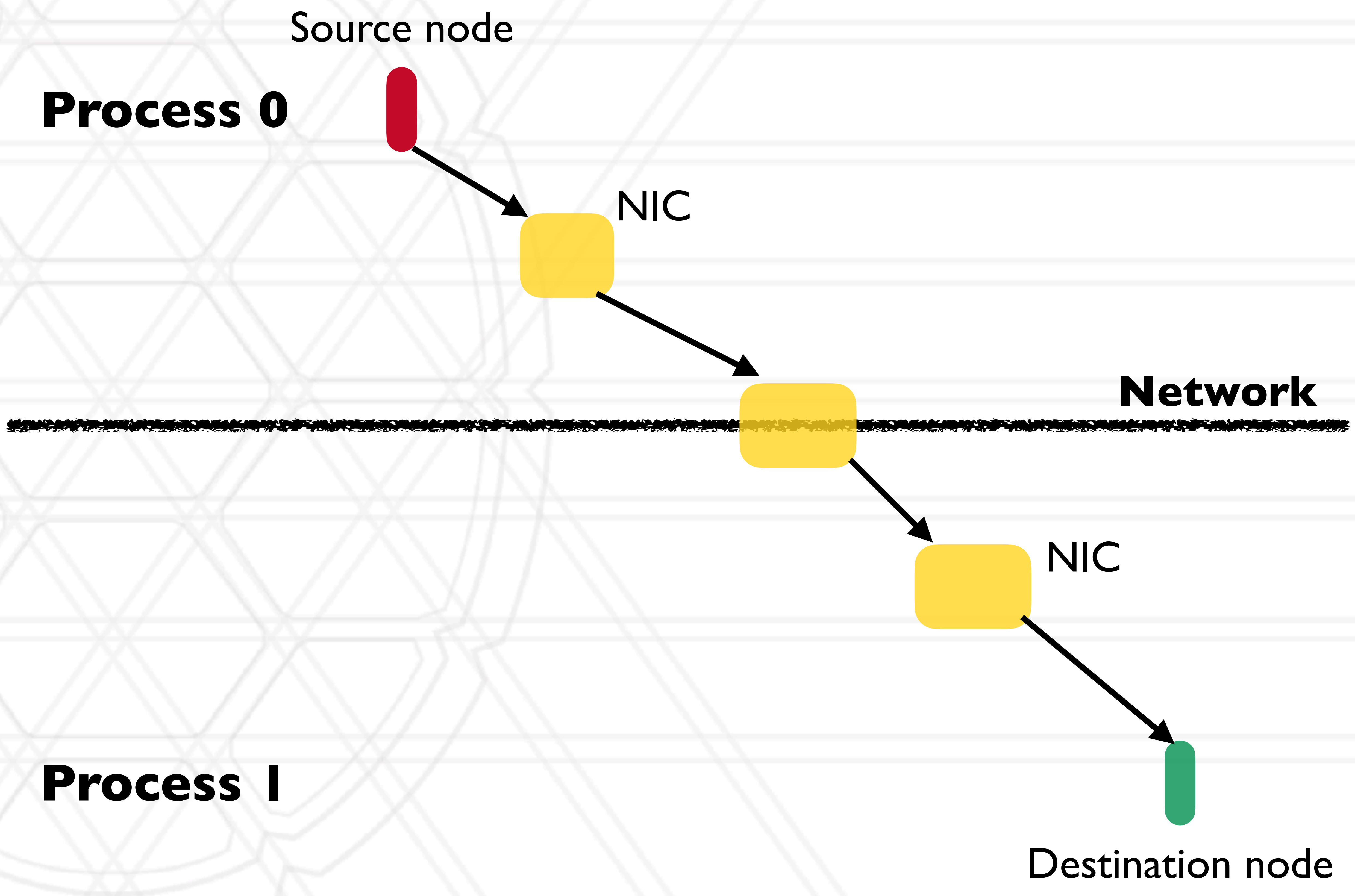
```
int main(int argc, char *argv[])
{
    ...

    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 += numpes) {
        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);

    ...
}
```

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



Other MPI send modes

- Basic mode: `MPI_Send`
- Buffered mode: `MPI_Bsend` — returns immediately and send buffer can be reused
  - Use `MPI_Buffer_attach` to provide space for buffering
- Synchronous mode: `MPI_Ssend` — will not return until matching receive is posted
- Ready mode: MPI_Rsend — may be used ONLY if matching receive is already posted
- Non-blocking versions of all of the above also exist

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

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