MPI: Terminology and Examples

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Review

It is recommended to first review the slides on Parallel Computing and OpenMP. They cover some key terms that will be used in these slides.

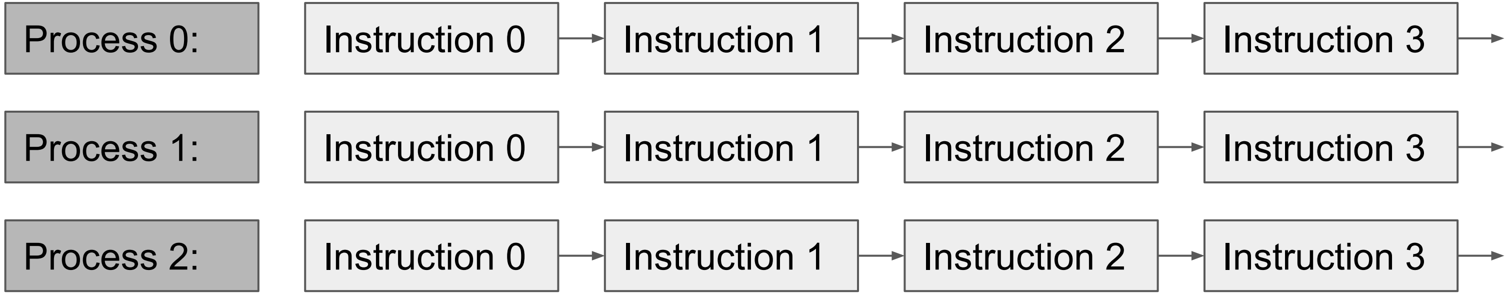
MPI

- Standard for distributed memory parallelism.
- Allows for multiple nodes (or just multiple cores) to run a program in parallel.
- Stands for Message Passing Interface (more on that on the next slide).
- Utilizes function calls as opposed to compiler directives.
- Syntax example: send a message:

```
MPI_Send(&buffer, count, MPI_INT, destination, tag,
    MPI_COMM_WORLD);
```

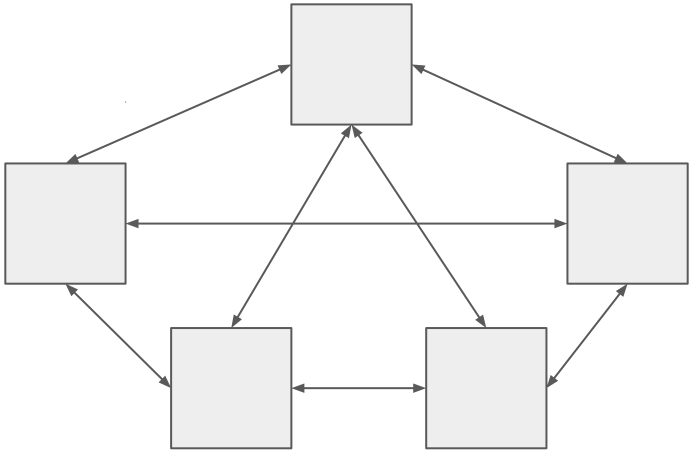
Key Term: **Process**

- MPI entity that can use a core to execute instructions.
- Does NOT share memory with other processes.
- Can send and receive messages to and from other processes (hence Message Passing Interface).
- Each process executes a copy of the same program.



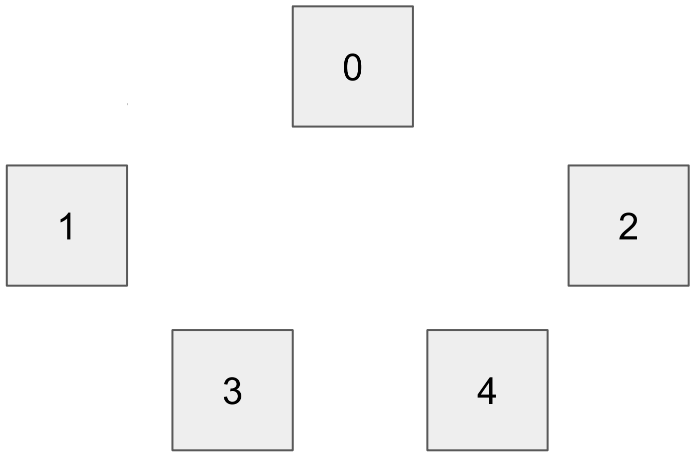
Key Term: **Communicator**

- A collection of MPI processes that can send and receive messages to and from each other.
- Normally this is all of the processes, and there is a constant defined for it, `MPI_COMM_WORLD`.



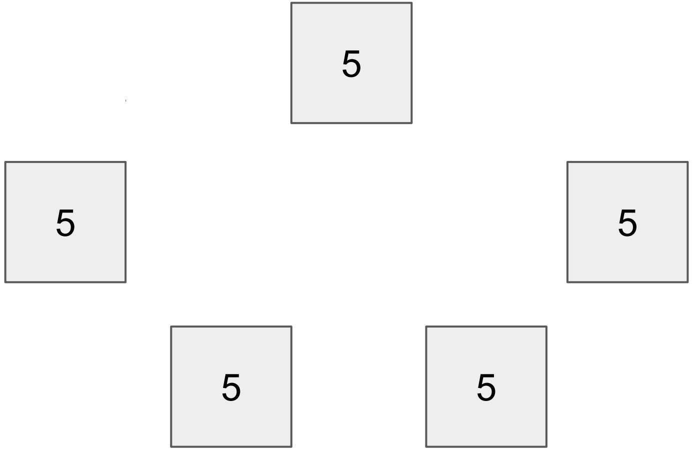
Key Term: **Rank**

- Unique identifier for each process in the communicator.
- Usually an integer starting at 0 and counting upwards.



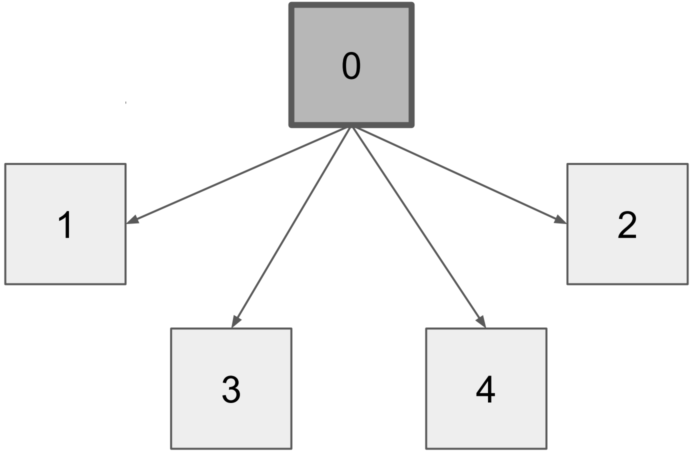
Key Term: **Size**

- Number of processes in a communicator.
- Same for all processes in the communicator.



Key Term: **Boss/Master**

- Optional, single process in the communicator with different tasks to do than the others.
- Sometimes assigns work to the other processes (hence **boss**).
- Usually rank 0.



MPI Program Execution

- Each process executes a copy of the same program with a different value for the rank.
- If only certain processes should do certain instructions, use the rank to distinguish these.
- Example:

```
if (rank == BOSS) {
  /* send work */
}
else {
  /* receive work */
}
```

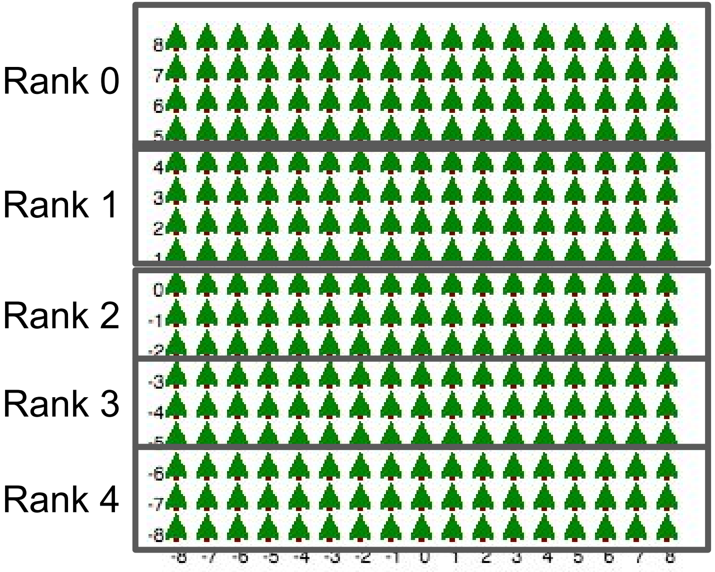
The 6 Basic MPI Routines

1. Initialize the communicator.
2. Set my rank.
3. Set the size.
4. Send a message.
5. Receive a message.
6. Finalize the communicator.

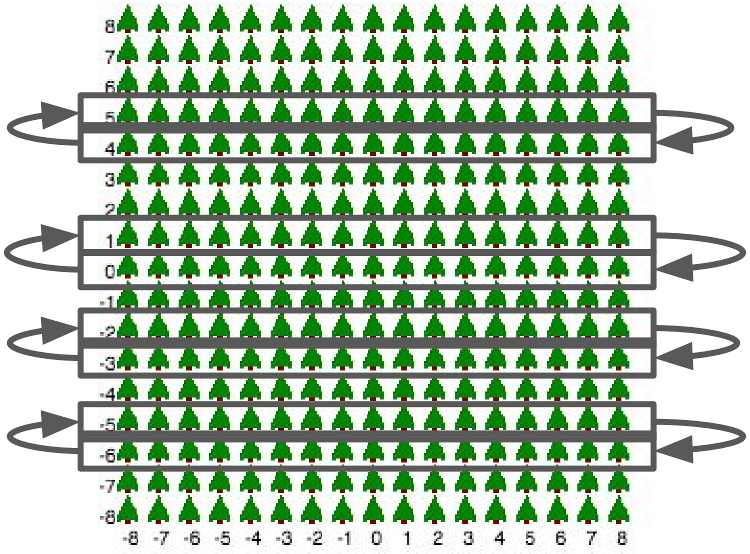
MPI Algorithm for Forest Fire Model

- Same basic model as OpenMP version, with a few extra tasks (shown below in blue).
- Data
  - **Trees** (for checking trees)
  - **NewTrees** (for changing trees)
- Tasks
  - **DistributeRows**: Each process assigns itself some of the rows of the forest.
  - **InitData**: One of the processes lights the center tree on fire.
  - For each time step:
    - **ContinueBurning**: For trees already burning that haven't burnt out, burn another step.
    - **CommunicateBoundaries**: Each process communicates tree data to its neighbor processes.
    - **BurnNew**: For trees next to a burning neighbors, catch on fire with some probability.
    - **AdvanceTime**: Copy NewTrees into Trees.

MPI Algorithm for Forest Fire Model



DistributeRows

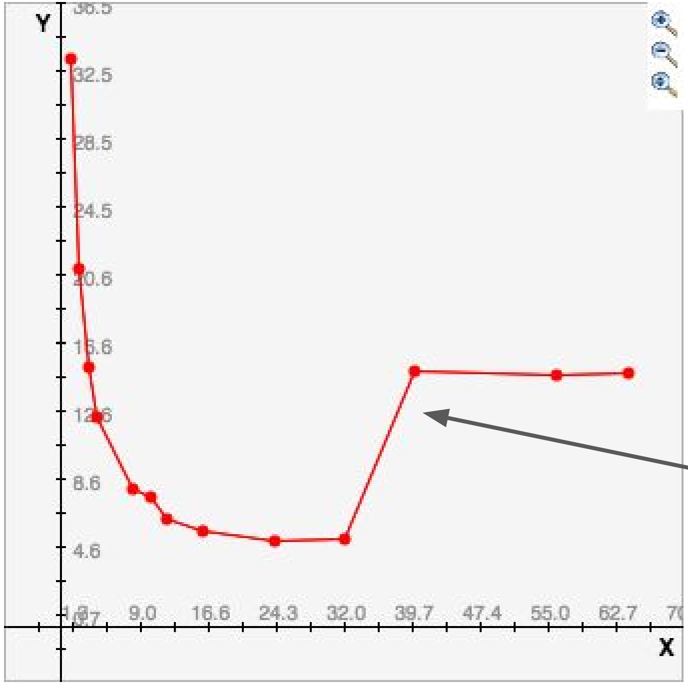


CommunicateBoundaries

Differences with OpenMP

- Processes instead of threads.
- Memory is distributed, not shared.
- For a process to read a value in another process' memory, a message has to be sent and received.
- No need for locks, because one process cannot read another process' memory directly.
- Requires writing more code (not just sticking directives above `for` loops).
- Allows a program to be scaled across more than 1 node.

Strong Scaling of MPI Forest Fire

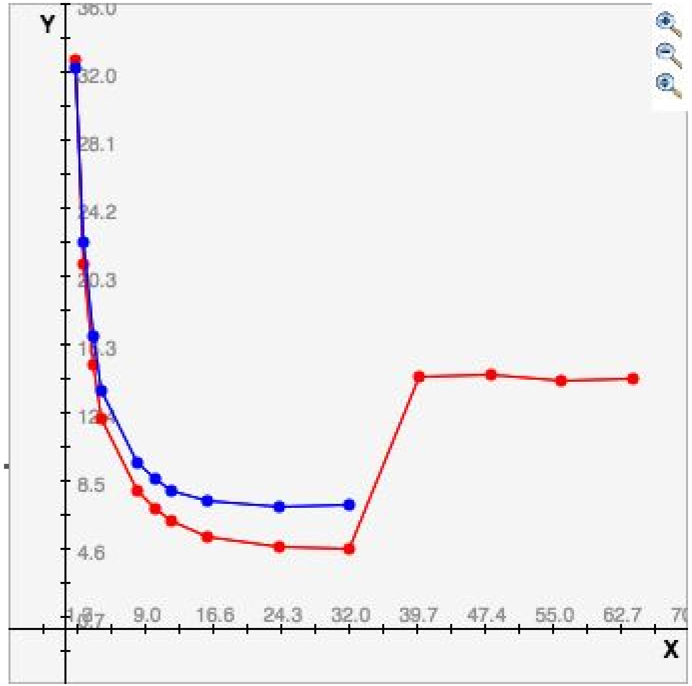


Jump from using 1 node to using 2 nodes : same flat line with extra time for inter-node communication

Strong Scaling Comparison of OpenMP and MPI

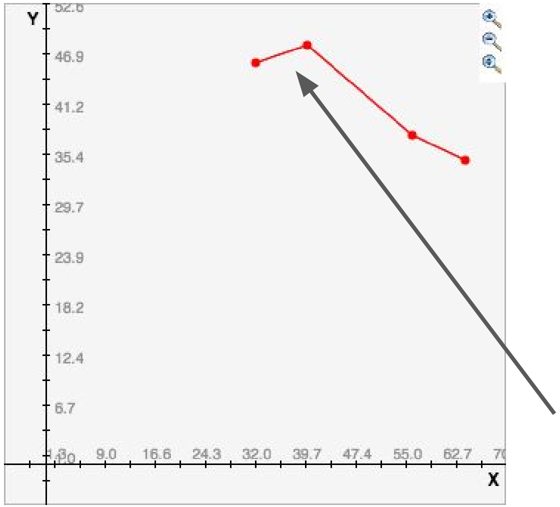
- MPI: Red
- OpenMP: Blue

- Note: not every MPI program is faster than its OpenMP counterpart, though that is the case here.



Strong Scaling with a Bigger Problem Size

- Before the problem size was 1300 rows, columns, and time steps.
- Now the problem size is 4000 rows, columns, and time steps.
- Just looking at process counts of 32, 40, 56, and 64, we see a slight slowdown from 32 to 40, but then a continual speedup.
- OpenMP is unable to scale beyond 1 node (32 cores for Blue Waters), so it cannot achieve the speed of 64 MPI processes for this problem size.

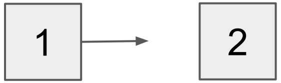


Jump from using 1 node
to using 2 nodes

MPI Example Communication: **Send**

- One process sends a buffer of data to another process.
- Forest fire example: process 1 sends its bottom row of trees to process 2.
- C syntax:

```
MPI_Send(SendBuf, /* buffer */
 NColsPlusBounds, /* count */
         MPI_INT, /* type */
               2, /* rank of receiver */
               0, /* message tag */
 MPI_COMM_WORLD); /* communicator */
```



MPI Example Communication: **Receive**

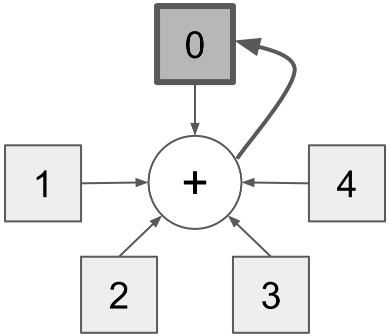
- One process receives a buffer of data from another process.
- Forest fire example: process 2 receives its top row of trees from process 1.
- C syntax:

```
MPI_Recv(RecvBuf, /* buffer */
 NColsPlusBounds, /* count */
         MPI_INT, /* type */
               1, /* rank of sender */
               0, /* message tag */
  MPI_COMM_WORLD, /* communicator */
        &status); /* struct with info about sent message */
```

MPI Example Communication: **Reduce**

- All processes contribute a buffer of data.
- An operation is performed on the data (e.g. sum, min, max).
- One process receives the result.
- Forest fire example: sum the number of burned trees.
- C syntax:

```
MPI_Reduce(&NBurnedTrees, /* send buffer */
                      &i, /* receive buffer */
                       1, /* count */
                 MPI_INT, /* type */
                 MPI_SUM, /* operation */
                       0, /* rank of receiver */
          MPI_COMM_WORLD); /* communicator */
```



MPI Example Communication: **Broadcast**

- One process sends a buffer of data to all processes (including itself).
- All processes replace their copy of the buffer with the sender's copy.
- Forest fire example: boss broadcasts whether input parameters are valid.
- C syntax:

```
MPI_Bcast(&AreParamsValid, /* buffer */
                        1, /* count */
                  MPI_INT, /* type */
                        0, /* rank of sender */
           MPI_COMM_WORLD); /* communicator */
```