MPI Refresher

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An aside on parallelization

- Shared memory parallelism
  - CUDA (single GPU), OpenMP
- All threads run on the same compute node (the same GPU)
- All threads can access a common memory
- Data exchange via shared memory spaces

- Distributed memory parallelism
  - MPI, PGAS
- Processes can run on different compute nodes
- Each process works on its own memory
- Data exchange via explicit communication between ranks

An aside on parallelization

- MPI and OpenMP are standardized
  - MPI 4.1 (11/2023) – 1166 pages
  - OpenMP 5.2 (11/2021) – 669 pages

- Implementation is separated
  - Open MPI, MPICH, MVAPICH
  - Intel MPI, CRAY MPICH, IBM MPI, …
  - OpenMP support in various compilers[1]
  - Implemented specification version may vary

- Roots in CPU-only applications, extensions for GPUs

[1] https://www.openmp.org/resources/openmp-compilers-tools/

From CUDA to MPI

- CUDA
- Each CUDA thread executes the kernel body
- Threads can be identified by their thread and block IDs
- Without synchronization, all ranks execute asynchronously

- MPI
- Each MPI rank executes the whole application
- Ranks can be identified by their rank IDs
- Without synchronization, all ranks execute asynchronously

MPI Hello World

- Hello world example

```
#include <mpi.h>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);









    MPI_Finalize();
}
```

MPI Hello World

- Hello world example

```
#include <mpi.h>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int rank, numRanks;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &numRanks);




    MPI_Finalize();
}
```

MPI Hello World

- Hello world example

```
#include <mpi.h>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int rank, numRanks;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &numRanks);

    std::cout << "Hello from rank " << rank << " of " << numRanks << std::endl;

    MPI_Finalize();
}
```

MPI Hello World

- Compile with

```
mpicxx -O3 mpi-hello-world.cpp \
       -o mpi-hello-world
```

- Run with

```
mpirun –n 4 ./mpi-hello-world
```

- Could print

```
Hello from rank 0 of 4
Hello from rank 1 of 4
Hello from rank 2 of 4
Hello from rank 3 of 4
```

- But could also print

```
Hello from rank 2 of 4
Hello from rank 3 of 4
Hello from rank 1 of 4
Hello from rank 0 of 4
```

Communication

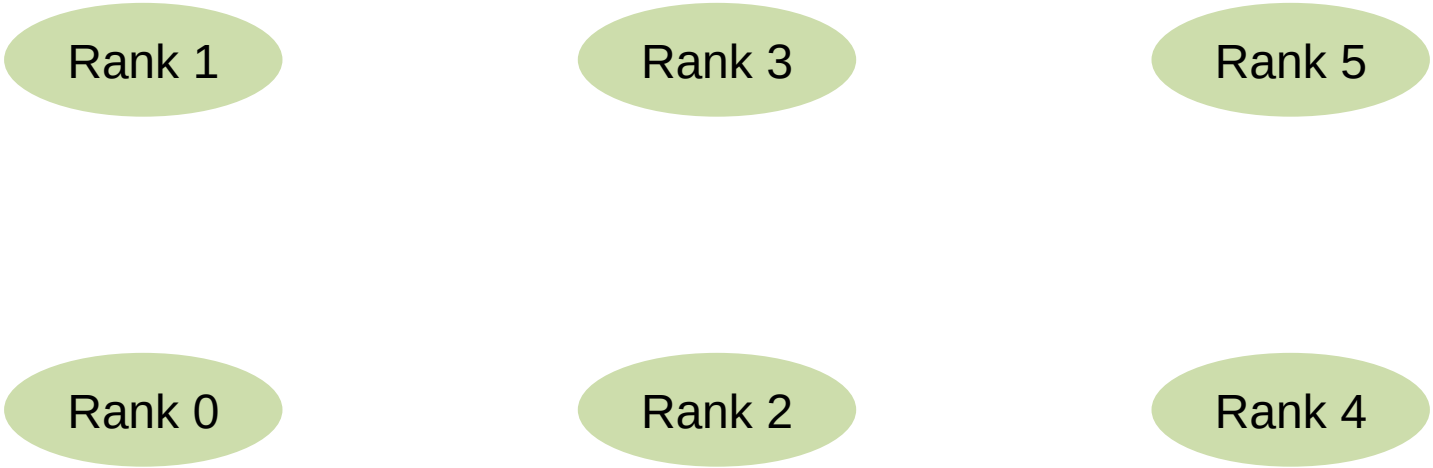
- Communication between ranks via point-to-point and collective operations
- Point-to-point: send and receive messages between two ranks, e.g.

```
MPI_Send
MPI_Recv
```

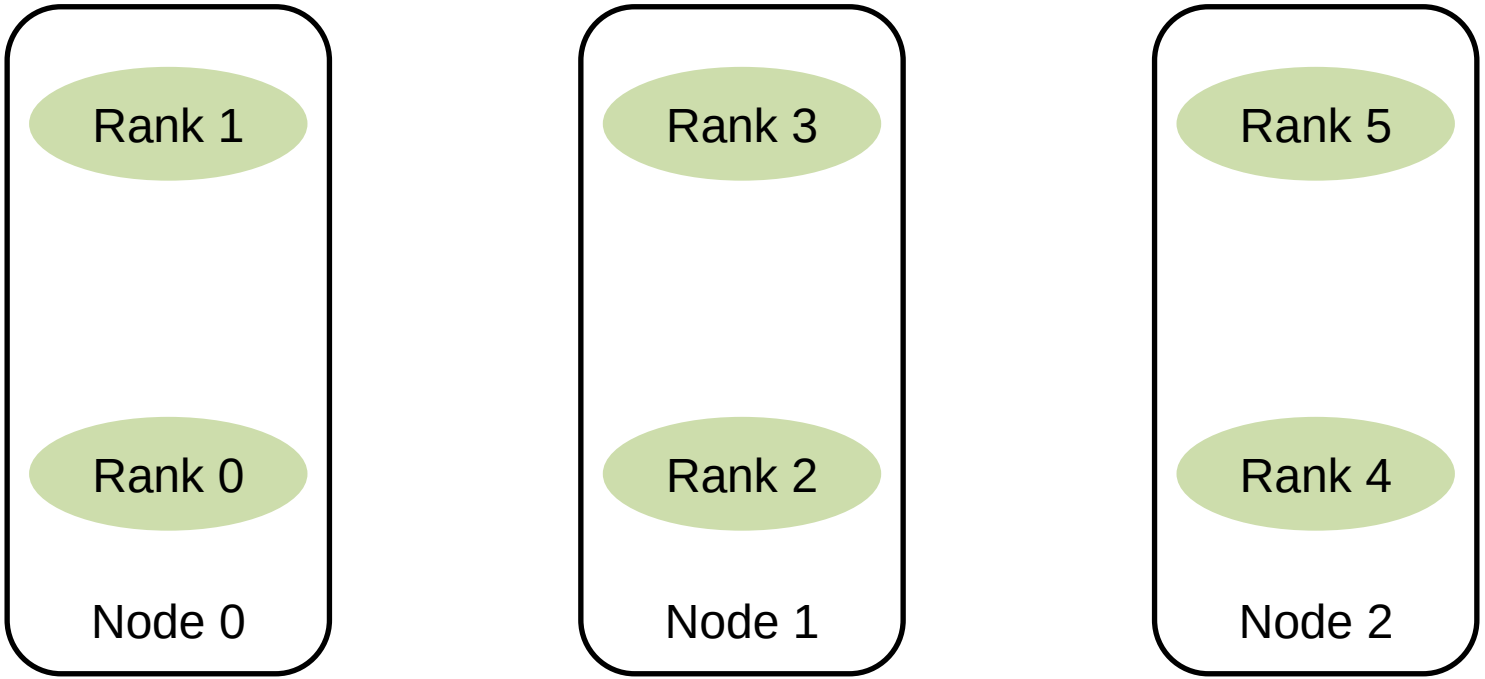
- Collective: all ranks participate in the same operation, e.g.

```
MPI_Barrier
MPI_Reduce
MPI_Bcast
```

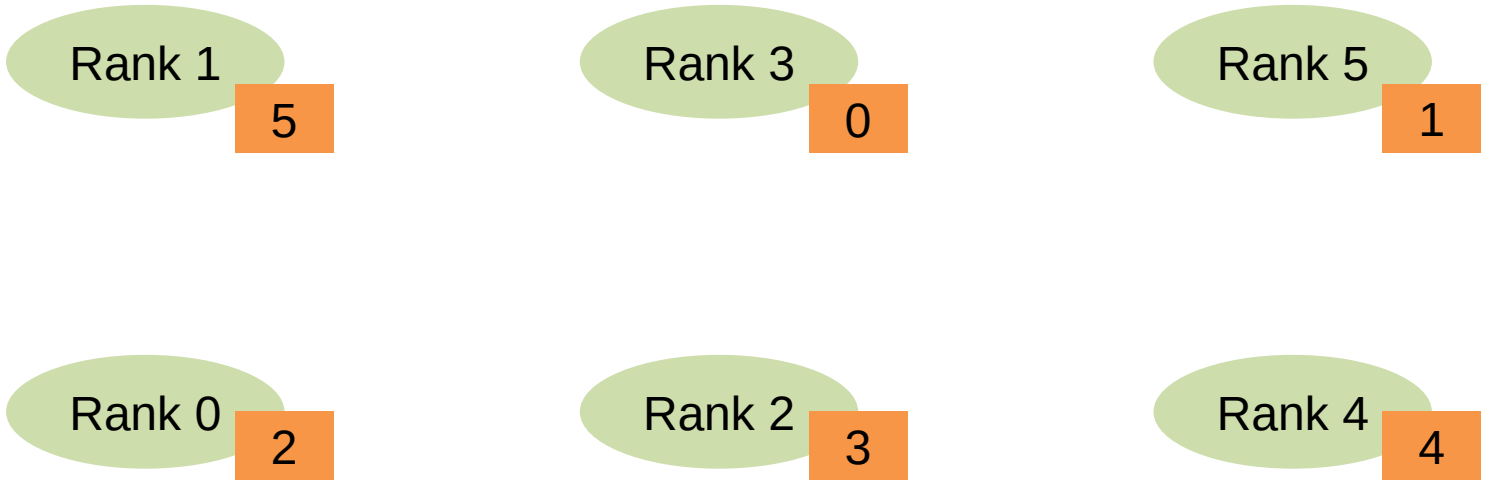
Example



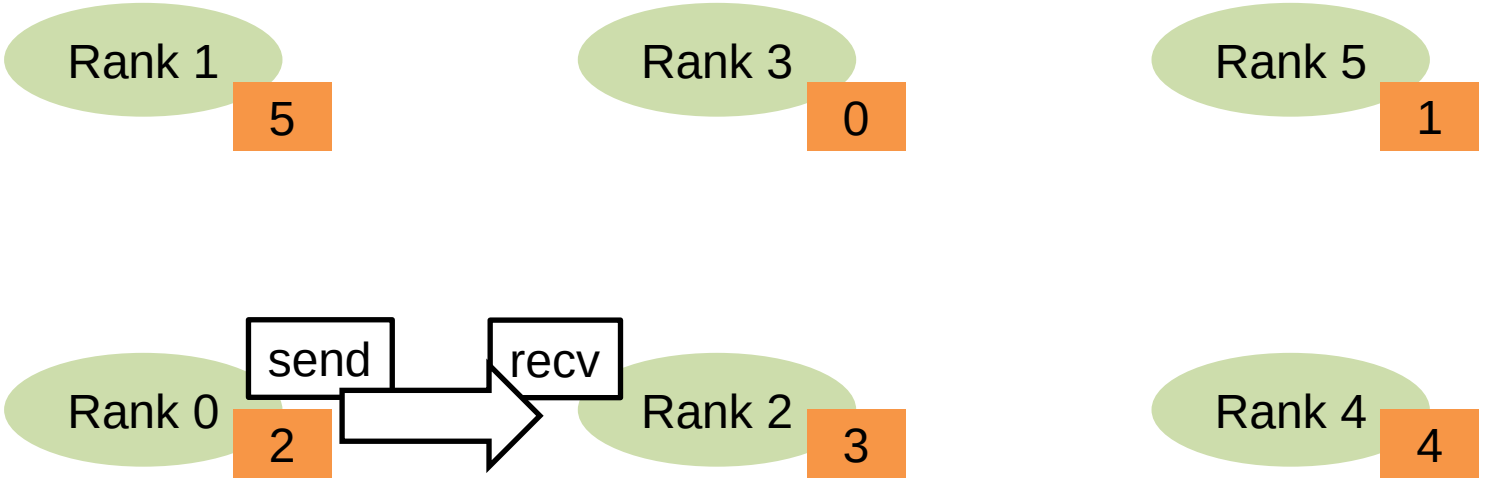
Example Node Mapping



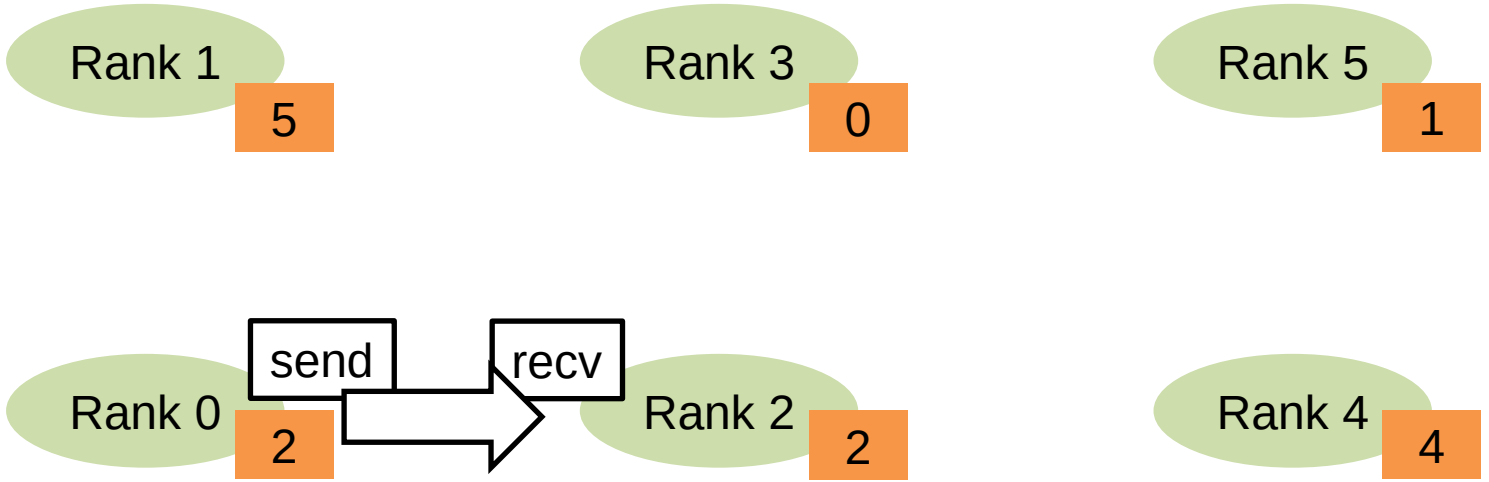
Example with Values



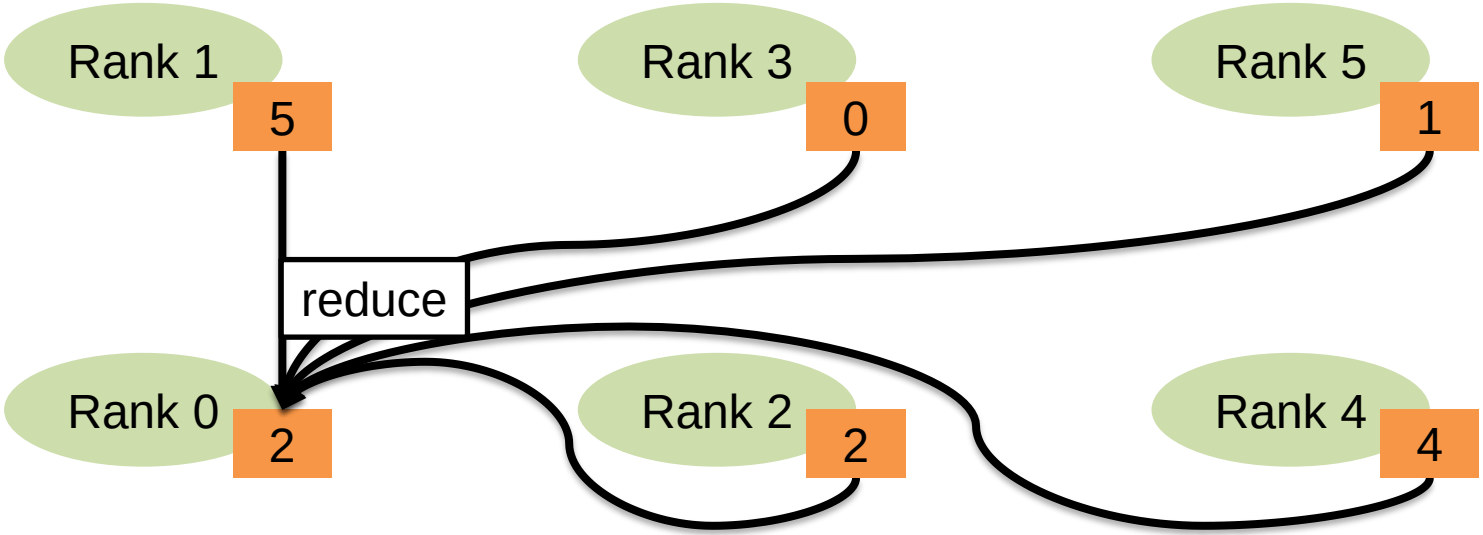
MPI Send/ Recv



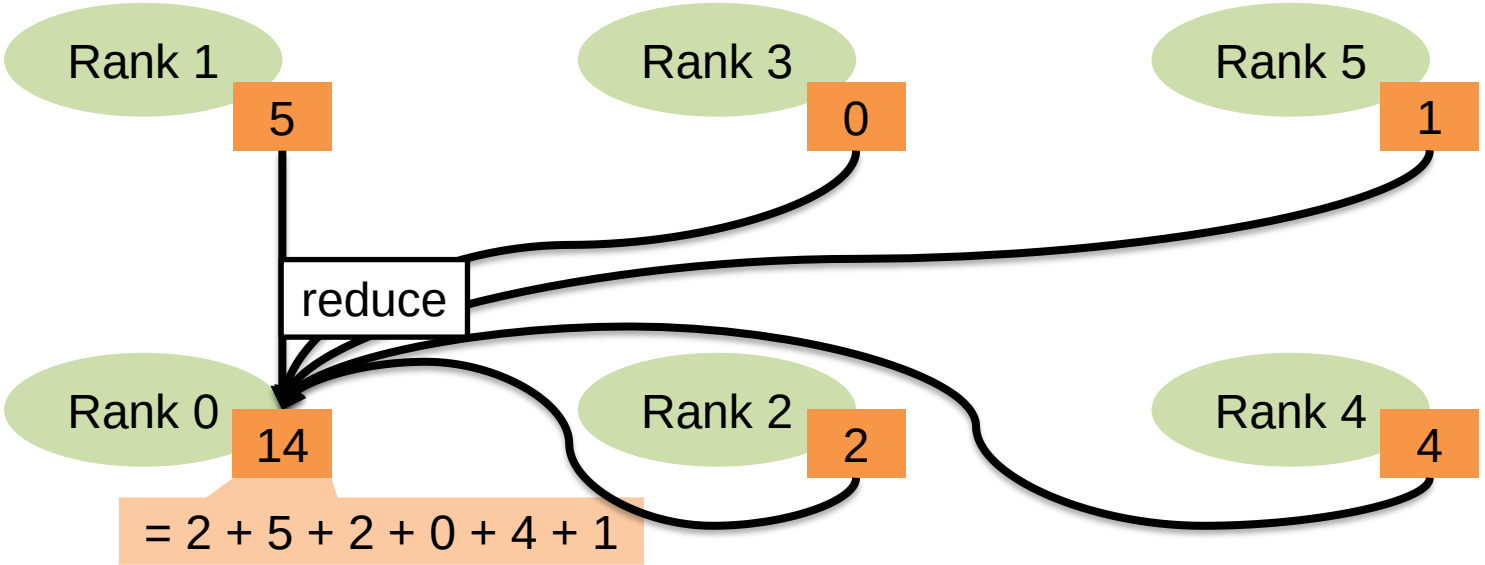
MPI Send/ Recv



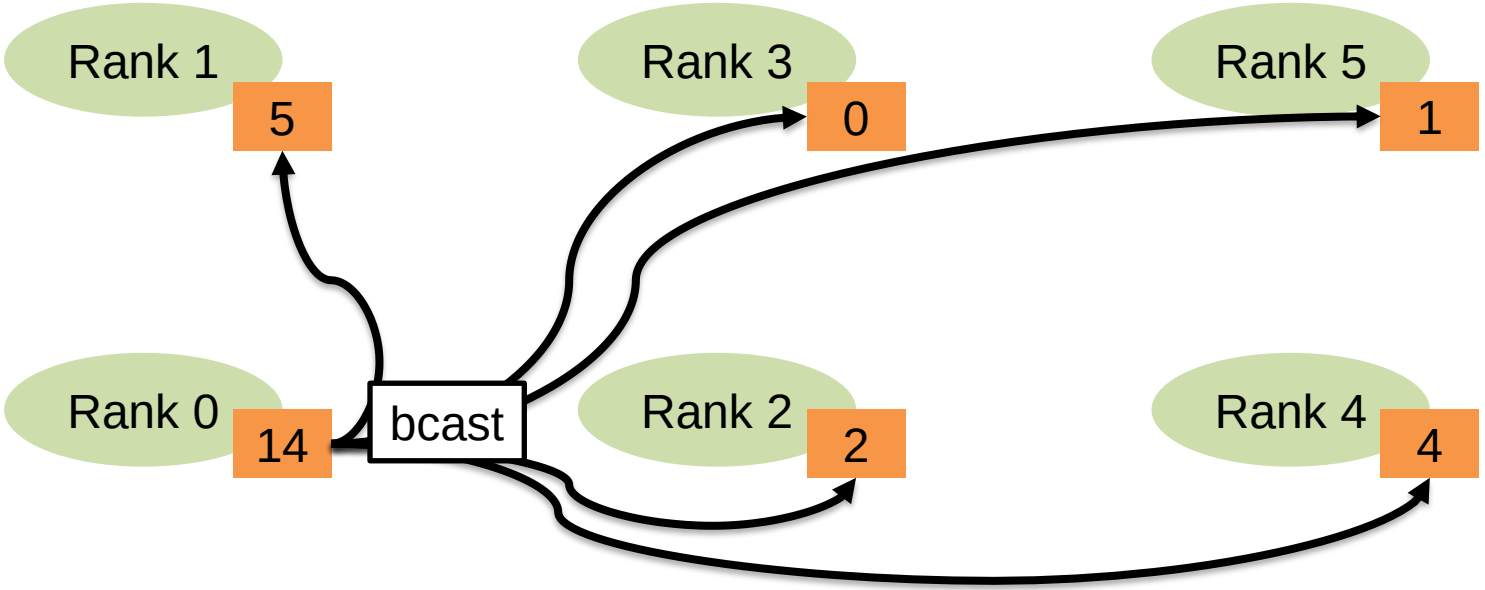
MPI Reduce



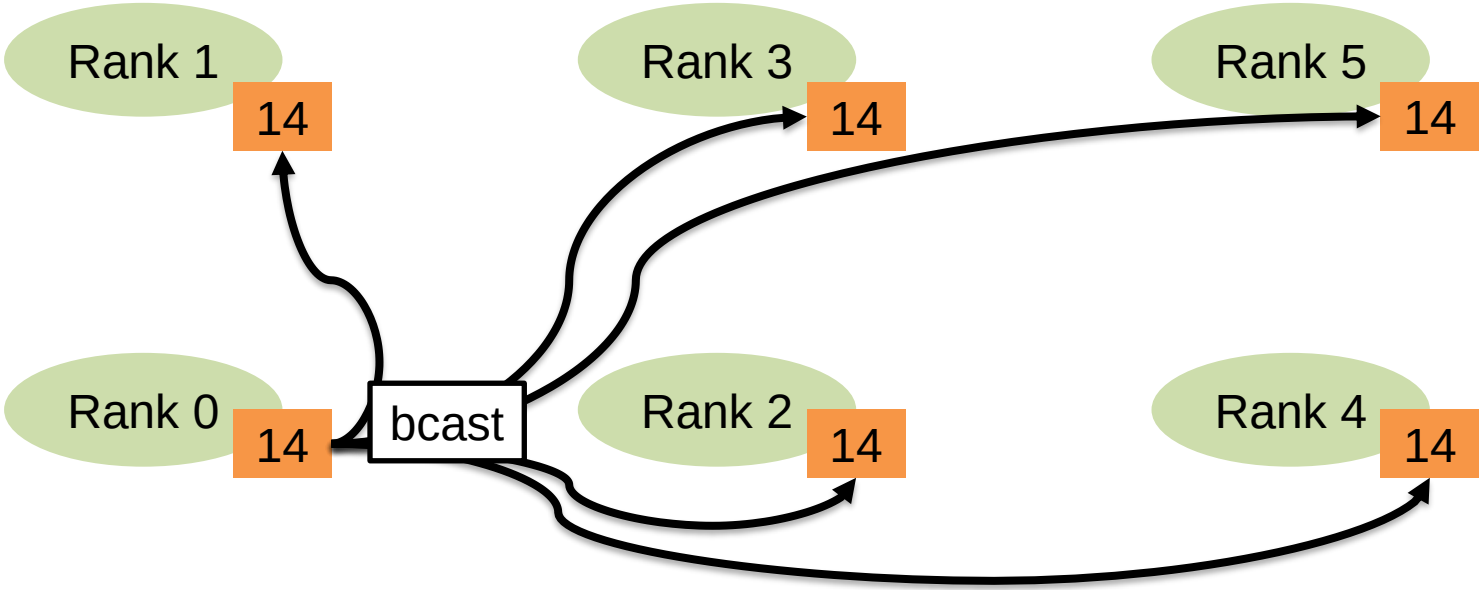
MPI Reduce



MPI Broadcast



MPI Broadcast



Communication

- Communication between ranks via point-to-point and collective operations
- Point-to-point: send and receive messages between two ranks, e.g.

```
MPI_Send(&sendData, count, MPI_DOUBLE, dest, tag, MPI_COMM_WORLD);
MPI_Recv(&recvData, count, MPI_DOUBLE, src,  tag, MPI_COMM_WORLD, &mpiStatus);
```

- Collective: all ranks participate in the same operation, e.g.

```
MPI_Barrier(MPI_COMM_WORLD);
MPI_Reduce(&sendData, &recvData, count, MPI_DOUBLE, MPI_SUM, root, MPI_COMM_WORLD);
MPI_Bcast(&data, count, MPI_DOUBLE, root, MPI_COMM_WORLD);
```

Beyond First Steps

- Other collective operations
  - MPI_Gather, MPI_Scatter, MPI_Scan, …
  - MPI_Allreduce, MPI_Allgather, …
- Non-blocking communication
  - MPI_Isend, MPI_Irecv, MPI_Ireduce, …
  - MPI_Test, MPI_Wait, …
- One-sided communication
  - MPI_Get, MPI_Put, …
- Custom (sub-) communicators
  - MPI_Cart_create, MPI_Dims_create, …
- MPI I/O, Error handling, timing/ profiling, …

CUDA-Aware MPI