NHR FAU

Friedrich-Alexander-Universität Erlangen-Nürnberg

Introduction to Parallel Programming with MPI

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Blocking Collective Communication

Collectives in MPI

Collectives: operations including all ranks of a communicator

All ranks must call the function!

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- Nonblocking variants (since MPI 3.0):
  buffer can be used after completion (`MPI_Wait*`/`MPI_Test*`)

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- Blocking variants: buffer can be reused after return
- Nonblocking variants (since MPI 3.0):
  buffer can be used after completion (`MPI_Wait*`/`MPI_Test*`)

- May or may not synchronize the processes
- Cannot interfere with point-to-point communication
  - Completely separate modes of operation!

Collectives in MPI

- Rules for all collectives
  - Data type matching
  - No tags
  - Count must be exact, i.e., there is only one message length, buffer must be large enough

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  - Synchronization (barrier)
  - Data movement (broadcast, scatter, gather, all-to-all)
  - Collective computation (reduction, scan)
  - Combinations of data movement and computation (reduction + broadcast)

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- Types:
  - Synchronization (barrier)
  - Data movement (broadcast, scatter, gather, all-to-all)
  - Collective computation (reduction, scan)
  - Combinations of data movement and computation (reduction + broadcast)
- General assumption: MPI does a better job at collectives than you trying to emulate them with a collection of point-to-point calls

Barrier

- Explicit synchronization of all ranks from specified communicator

```
MPI_Barrier(comm);
```

- Ranks only return from call after every rank has called the function

- `MPI_Barrier`: rarely needed
  - Debugging

Barrier

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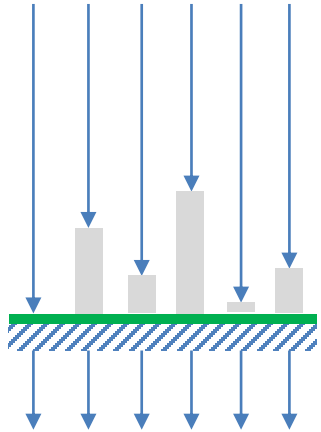
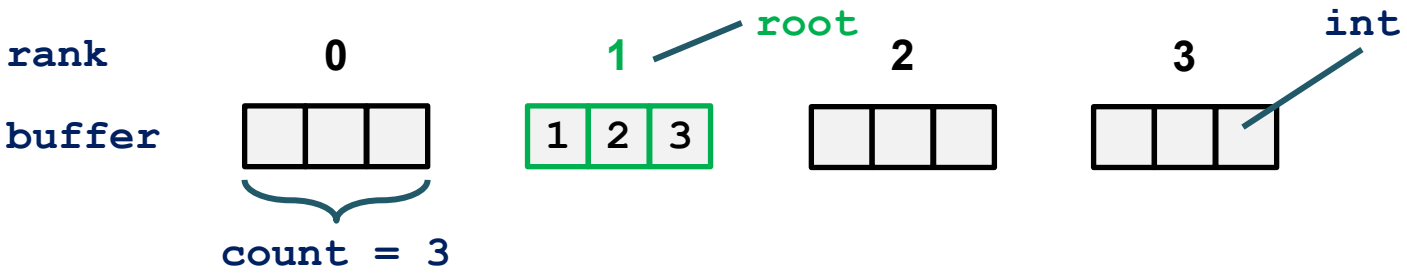


Broadcast

- Send buffer contents from one rank (“**root**”) to all ranks

```
MPI_Bcast(buf, count, datatype, int root, comm);
```

- no restrictions on which rank is root – often rank 0



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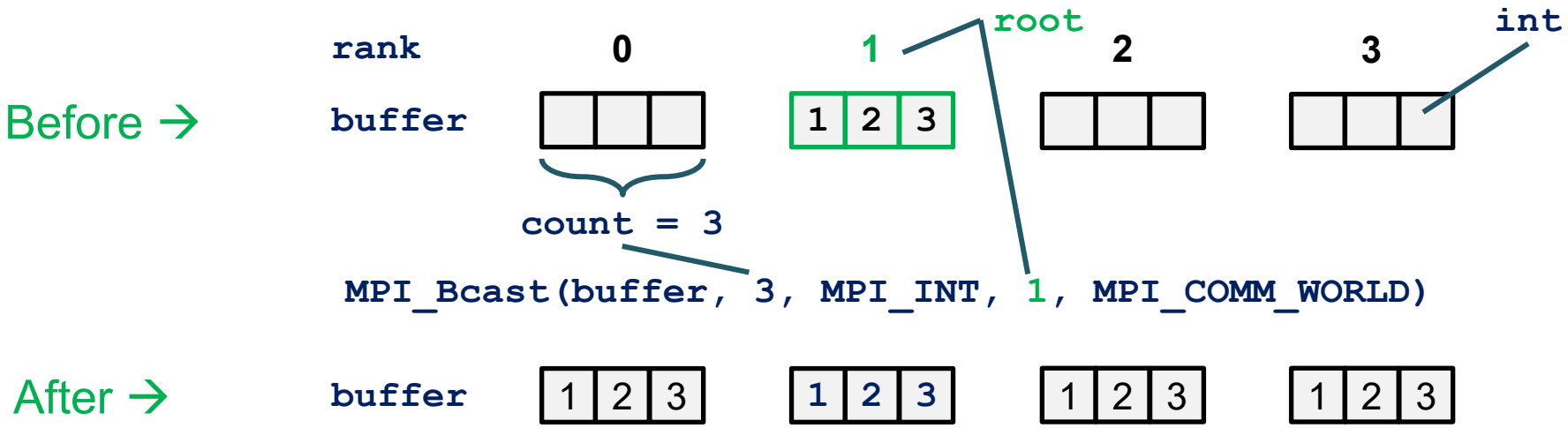
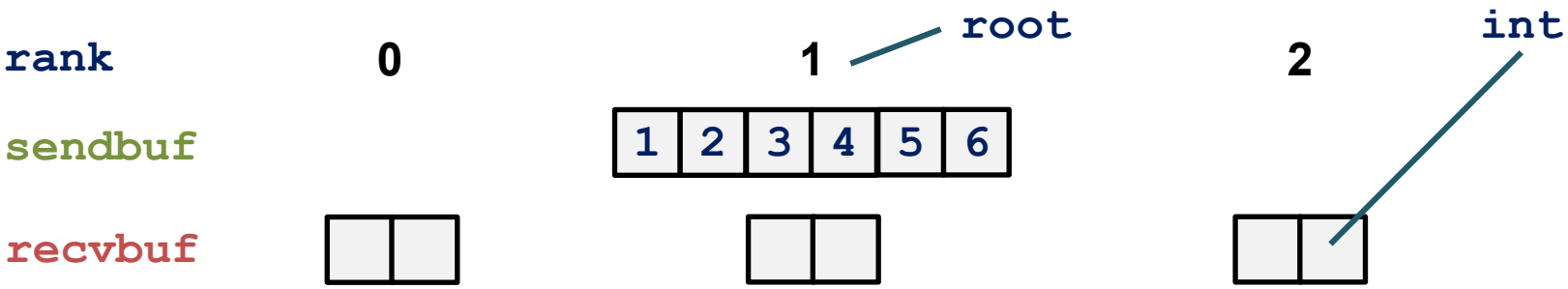
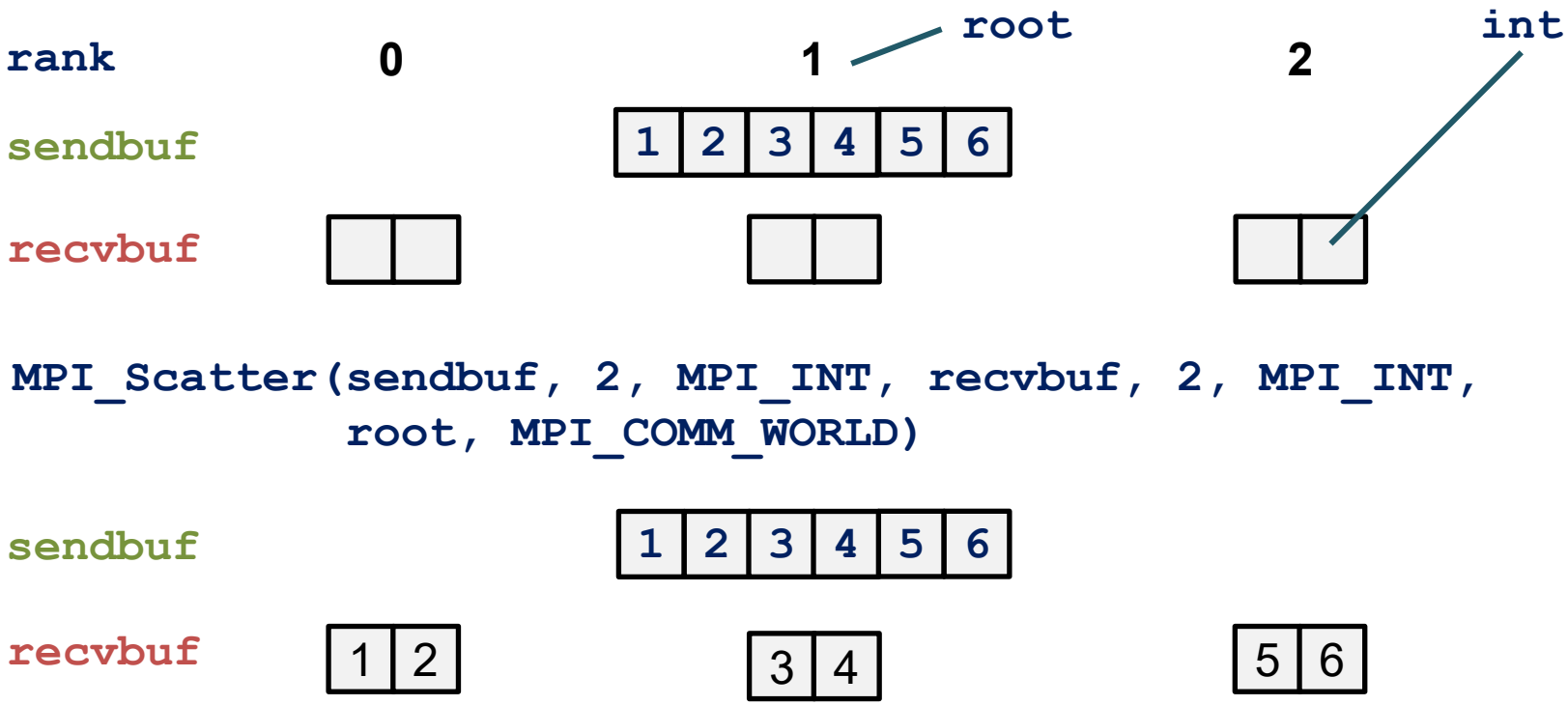


Scatter




```
MPI_Scatter(sendbuf, 2, MPI_INT, recvbuf, 2, MPI_INT,
            root, MPI_COMM_WORLD)
```

Scatter


rank
0
1
2
root
int
sendbuf
1 2 3 4 5 6
recvbuf
MPI_Scatter(sendbuf, 2, MPI_INT, recvbuf, 2, MPI_INT,
root, MPI_COMM_WORLD)
sendbuf
1 2 3 4 5 6
recvbuf
1 2
3 4
5 6

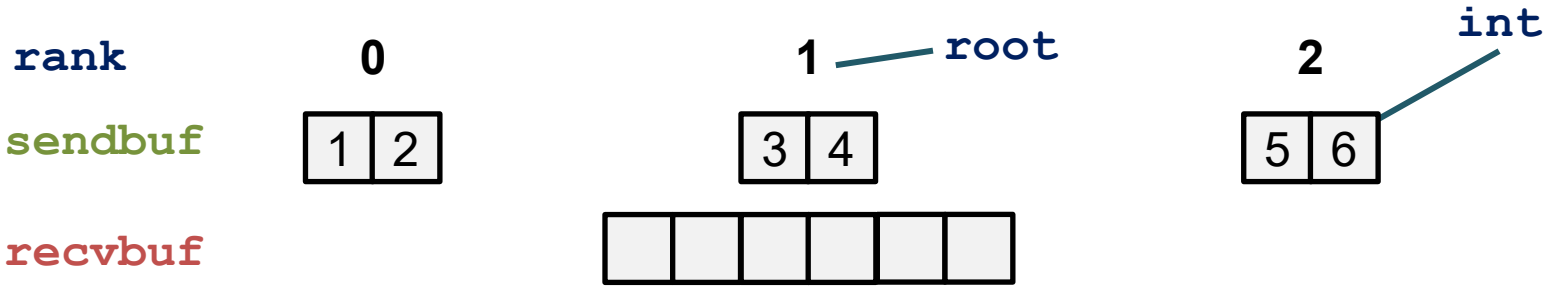
Scatter

- Send every i-th chunk of an array to the i-th rank

```
MPI_Scatter(sendbuf, sendcount, sendtype,
            recvbuf, recvcount, recvtype,
            root, comm);
```

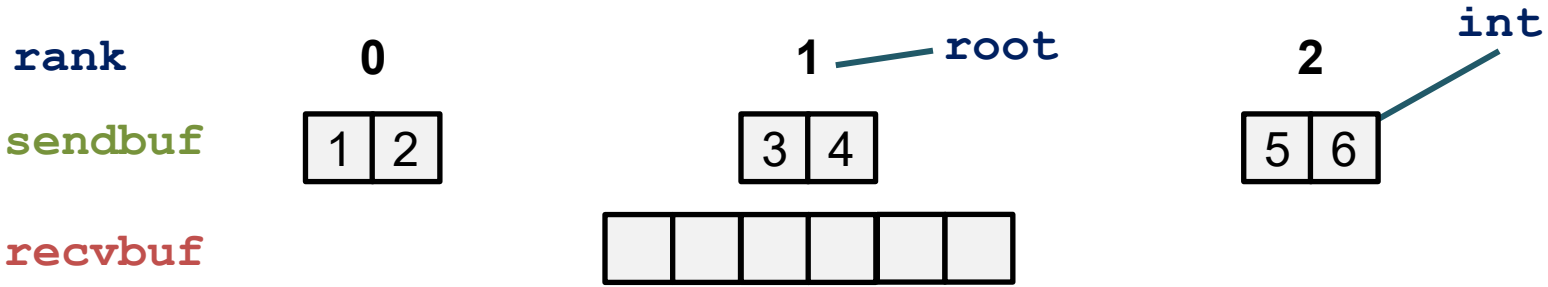
- Root and comm must be the same on all processes
- Type signature of send and receive variables must match
- Usually, **`sendcount`** = **`recvcount`** because **`sendtype = recvtype`**
  - This is the length of the chunk
- **`sendbuf`** is ignored on non-root ranks because there is nothing to send

Gather




```
MPI_Gather(sendbuf, 2, MPI_INT, recvbuf, 2, MPI_INT,
           root, MPI_COMM_WORLD)
```

Gather




```
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```
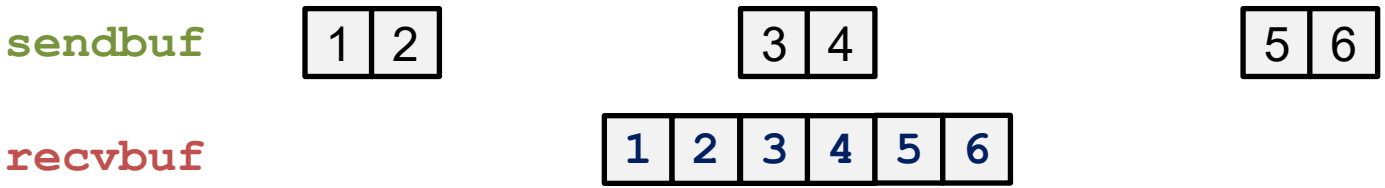



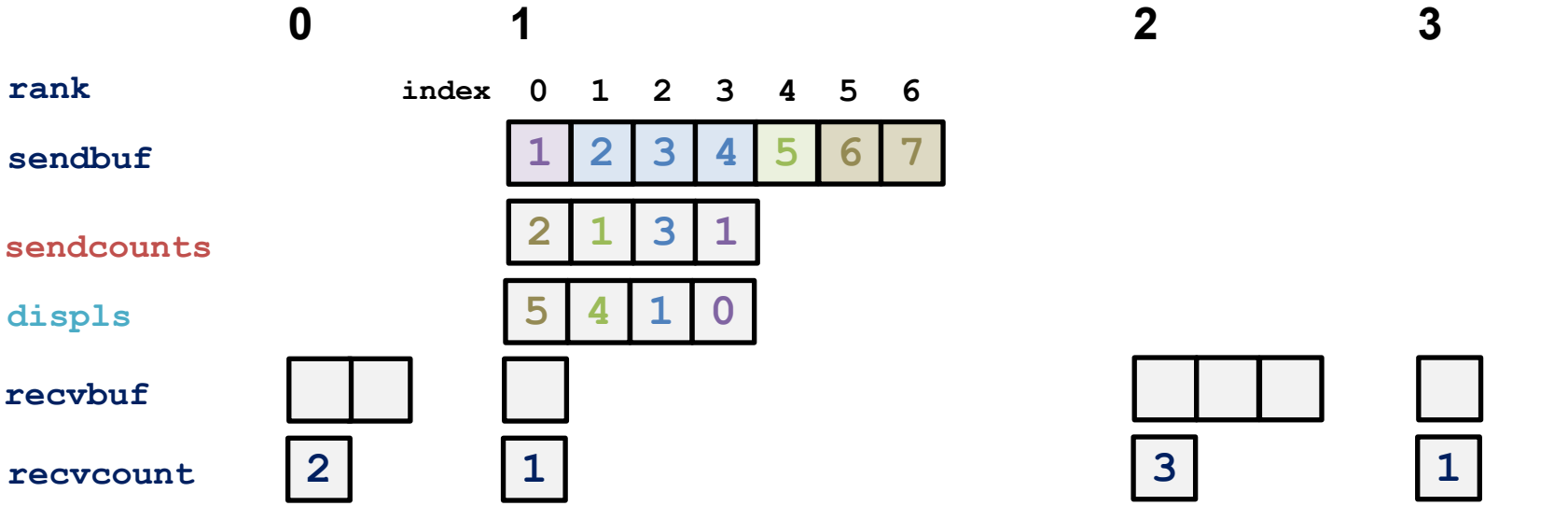
Gather

- Receive a message from each rank and place i-th rank's message at i-th position in receive buffer

```
MPI_Gather(sendbuf, sendcount, sendtype,
           recvbuf, recvcount, recvtype,
           root, comm)
```

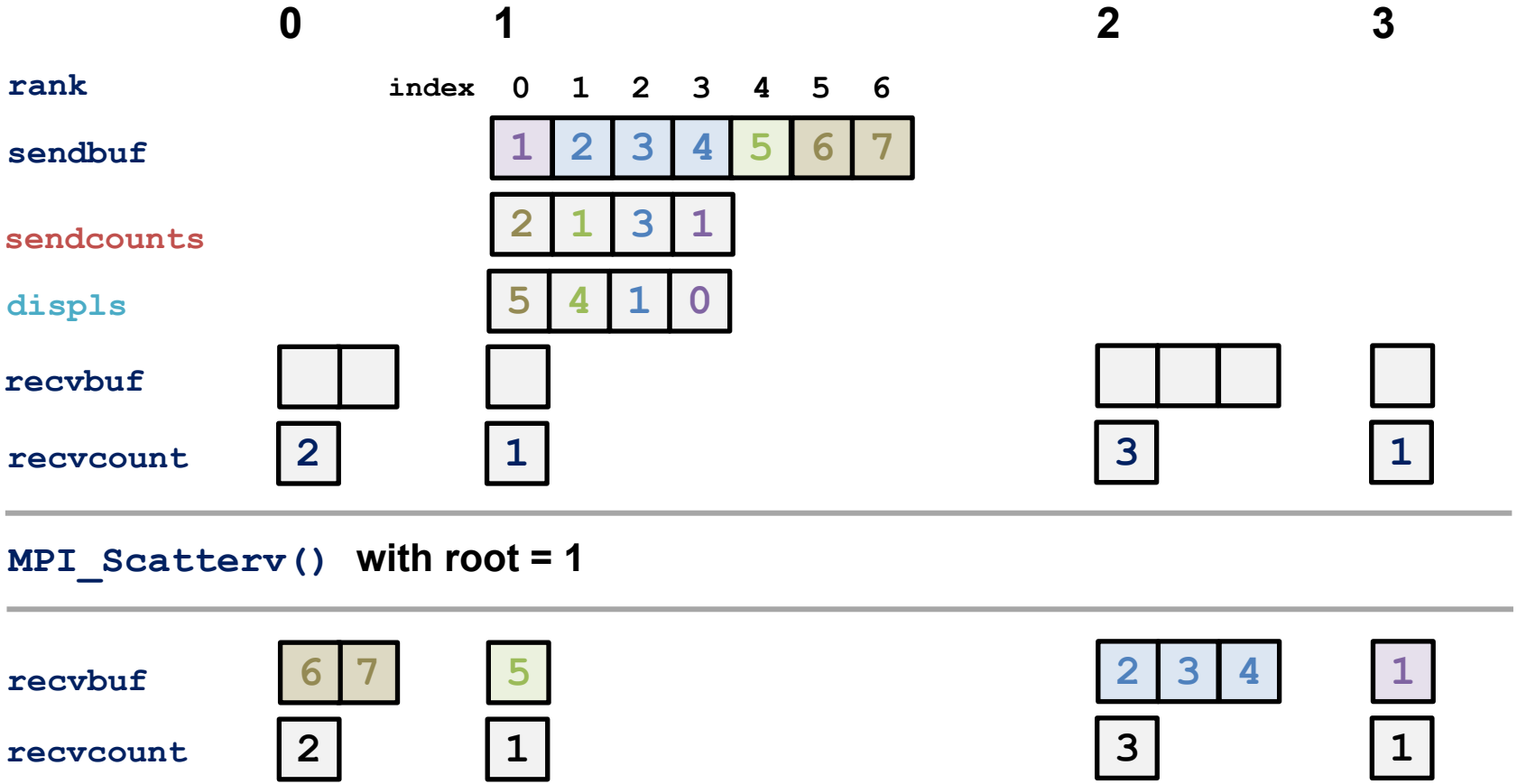
- Root and comm must be the same on all processes
- Type signature of send and receive variables must match
- Usually, **`sendcount`** = **`recvcount`** because **`sendtype = recvtype`**
- **`recvbuf`** is ignored on non-root ranks because there is nothing to receive

Scatterv



`MPI_Scatterv()` **with root = 1**

Scatterv


0
1
2
3
rank
index 0 1 2 3 4 5 6
sendbuf 1 2 3 4 5 6 7
sendcounts 2 1 3 1
displs 5 4 1 0
recvbuf
recvcount 2 1 3 1
MPI_Scatterv() with root = 1
recvbuf 6 7 5 2 3 4 1
recvcount 2 1 3 1

Scatterv: more flexible scatter

- Send chunks of different sizes to different ranks

```
MPI_Scatterv(
    sendbuf, int sendcounts[], int displs[], sendtype,
    recvbuf, recvcount, recvtype, root, comm)
```

`sendcounts[]`: array specifying the number of elements to send to each rank: send **`sendcounts[i]`** elements to rank **`i`**

`displs[]`: integer array specifying the displacements in **`sendbuf`** from which to take the outgoing data to each rank, specified in number of elements

Gatherv: more flexible gather

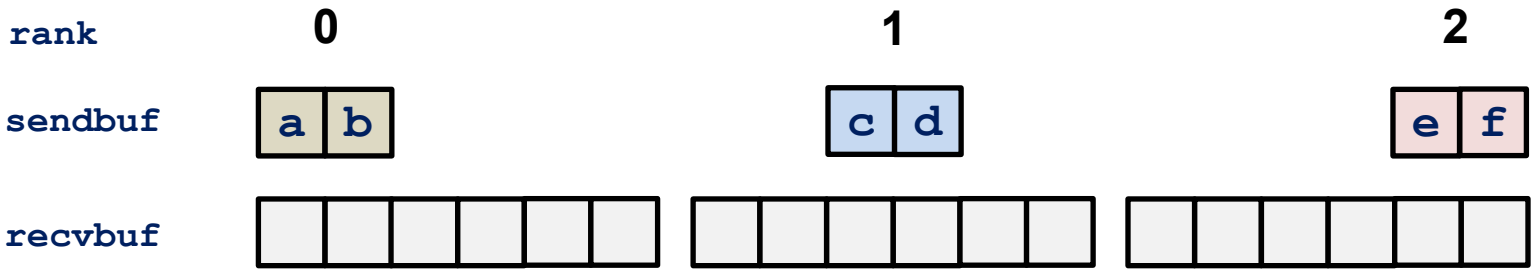
- Receive segments of different sizes from different ranks

```
MPI_Gatherv(
    sendbuf, sendcount, sendtype,
    recvbuf, int recvcounts[], int displs[], recvtype,
    root, comm)
```

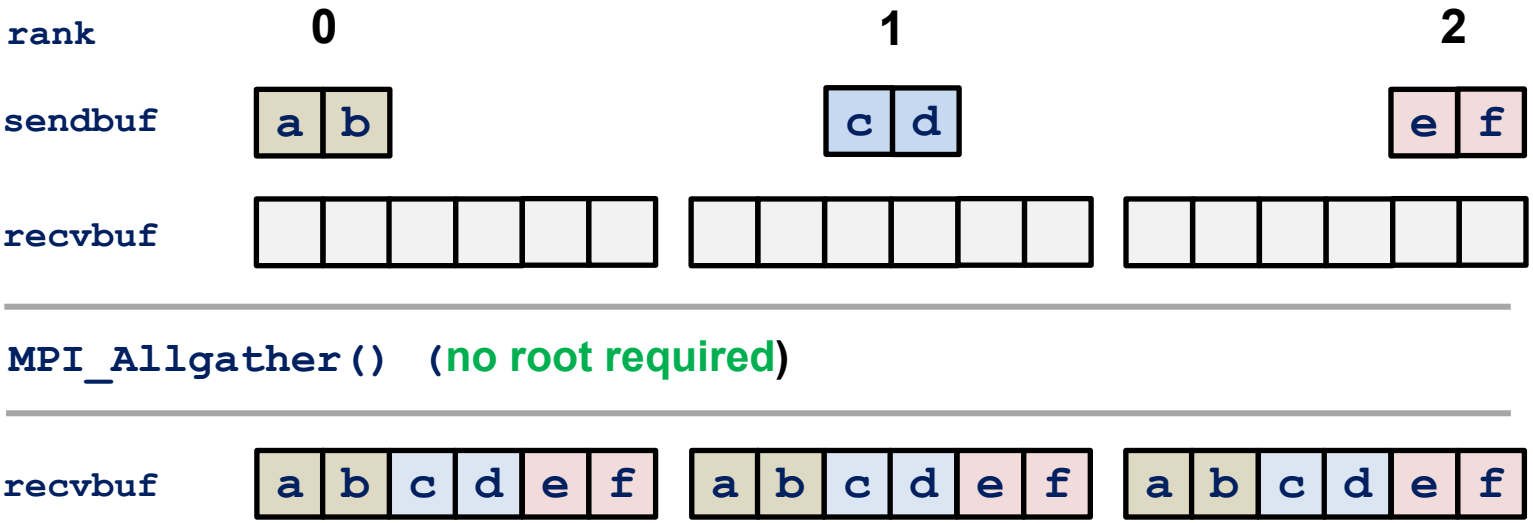
`recvcounts[]`: array specifying the number of elements to receive from each rank: receive **`recvcounts[i]`** elements from rank **`i`**

`displs[]`: integer array specifying the displacements where received data from specific rank is put in **`recvbuf`**, in units of elements:

Allgather



Allgather



In this example: `sendcount=recvcount=2`

Allgather

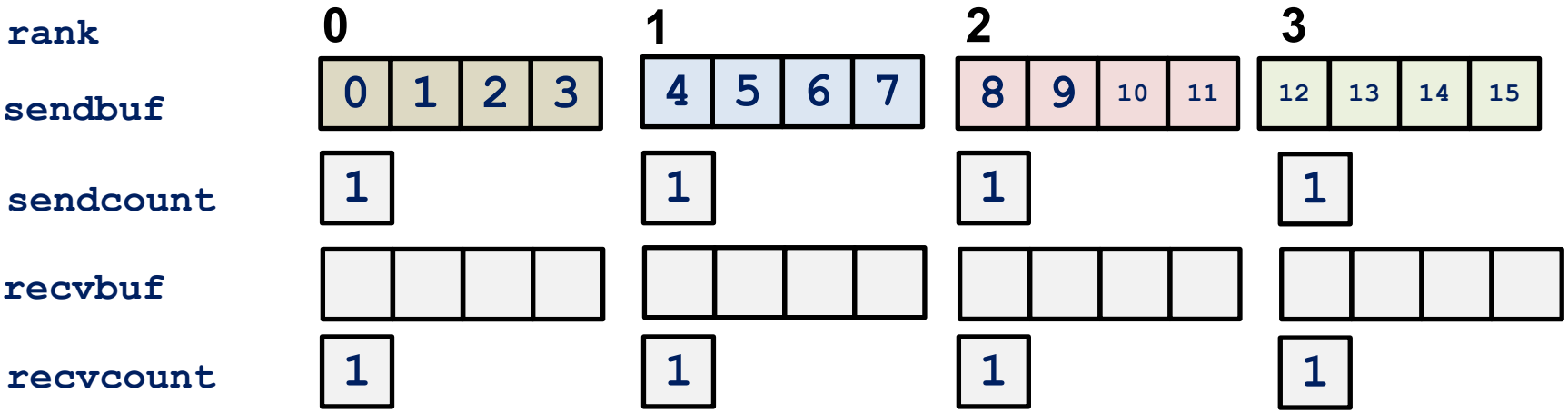
- Combination of gather and broadcast

```
MPI_Allgather(sendbuf, sendcount, sendtype,
              recvbuf, recvcount, recvtype,
              comm);
```

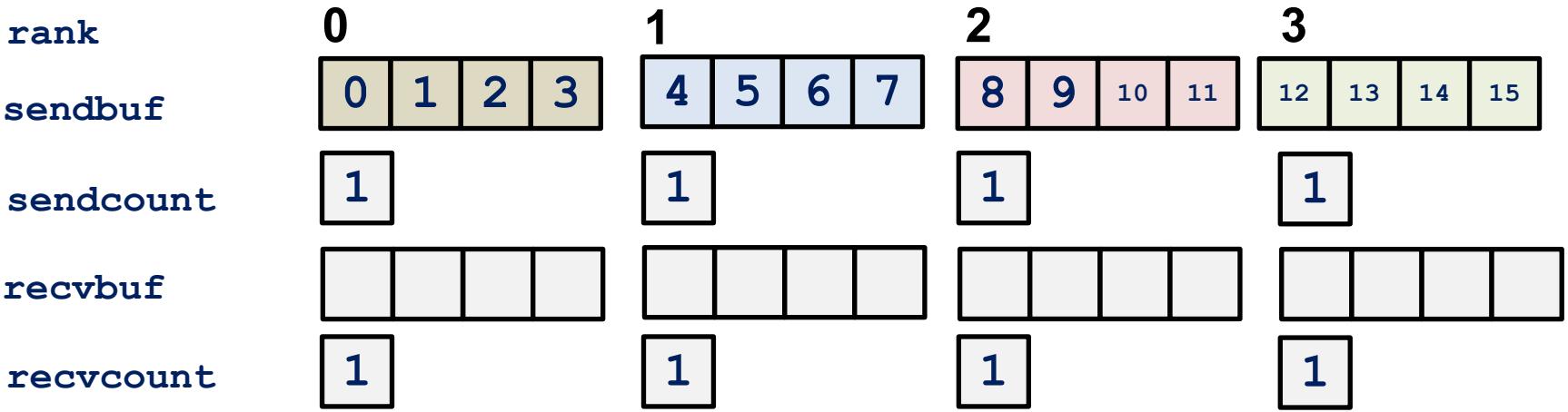
- Also available: `MPI_Allgatherv()` (cf. `MPI_Gatherv()`)

- Why not just use gather followed by a broadcast instead?
  - MPI library has more options for optimization
  - General assumption: Combined collectives are faster than using separate ones

Alltoall


rank
0
1
2
3
sendbuf
0 1 2 3
4 5 6 7
8 9 10 11
12 13 14 15
sendcount
1
1
1
1
recvbuf
recvcount
1
1
1
1

Alltoall



`MPI_Alltoall()` (no root required)

Alltoall

- **MPI_Alltoall**: For all ranks, send i-th chunk to i-th rank

```
MPI_Alltoall(sendbuf, sendcount, sendtype,
             recvbuf, recvcount, recvtype,
             comm)
```

- **MPI_Alltoallv**: Allows different number of elements to be send/received by each rank

- **MPI_Alltoallw**: Allows also different data types and displacements in bytes

Summary of MPI Collective Communications

- MPI (blocking) collectives
  - All ranks in communicator must call the function
- Communication and synchronization
  - Barrier, broadcast, scatter, gather, and combinations thereof
- In-place buffer specification `MPI_IN_PLACE`
  - Save some space if needed

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Answer: b., because they are completely separate modes of operation.

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Answer: b., it is necessary.

Quiz:

4. To send an identical piece of data to all other processes in a communicator, which collective call should be used?
   a. `MPI_Gather`
   b. `MPI_Bcast`
   c. `MPI_Scatter`
   d. `MPI_Alltoall`

Quiz:

4. To send an identical piece of data to all other processes in a communicator, which collective call should be used?

   a. `MPI_Gather`

   b. `MPI_Bcast`

   c. `MPI_Scatter`

   d. `MPI_Alltoall`

Answer: b.

Quiz:

4. To send an identical piece of data to all other processes in a communicator, which collective call should be used?
   a. `MPI_Gather`
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   c. `MPI_Scatter`
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Answer: b.

5. Which of the following collective calls is similar to the process of transposing a matrix in mathematics?
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   b. `MPI_Bcast`
   c. `MPI_Scatter`
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Answer: d.