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Or it might simply use network connections, regardless

The programmer uses the same MPI functions to send messages whatever the underlying mechanism

MPI

One-to-one messaging

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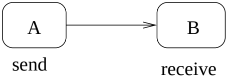
A basic use scenario is when one processor wants to send a message (some data) to another



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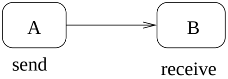

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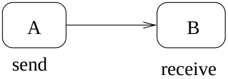

Simple message send

Processor A sends data (integers, floats, strings, etc.) to B

A can use a *send* function, while B uses a *receive* function

MPI

One-to-one messaging

```
int n[5];
...
if (myrank == 0) {
  MPI_Send(n, 5, MPI_INT, 1, 99, MPI_COMM_WORLD);
}
else if (myrank == 1) {
  MPI_Status stat;
  MPI_Recv(n, 5, MPI_INT, 0, 99, MPI_COMM_WORLD, &stat);
}
```

We suppose A has rank 0, B rank 1 in `WORLD`

MPI

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- `MPI_COMM_WORLD` The rank is within this communicator

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- `5` The number of items to read

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- `MPI_INT` The type of the items
- `0` The rank of the source

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- MPI_INT The type of the items
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- 99 The *tag* on the message you are waiting for: use MPI_ANY_TAG if you don't care
- MPI_COMM_WORLD The communicator
- stat A structure contains the status of the transfer, in particular the source and tag; and the error type in case of an error

MPI

Messaging Types

Types include
`MPI_CHAR`, `MPI_SHORT`, `MPI_INT`, `MPI_LONG`, `MPI_FLOAT`, `MPI_DOUBLE`, `MPI_BYTE`
among several others

`MPI_Send` and `MPI_Recv` are *blocking*, meaning `MPI_Send` waits until the data has been copied out of the buffer `n` into the messaging subsystem. The array `n` in A can be safely reused immediately after the `MPI_Send` call returns

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Naturally, `MPI_Recv` waits until the data is safely copied into its buffer

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For example, A won’t know when B actually gets the data; B doesn’t know when A sent the data

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Asynchronous messaging

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As messages take a significant time to be transmitted a send and a receive are certainly non-simultaneous

In comparison, in a shared memory system, once a value is written to a variable, that value is available essentially instantly everywhere (ignoring caching and speed of light issues!)

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And lots more

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If you find yourself using `MPI_Barrier`, think again!

MPI

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In order: if A sends message 1 then message 2 to B, then B will get message 1 before message 2: messages from one source to the same destination do not overtake each other

However, a message from A to B may be overtaken by a later message from C to B: there is no guarantee of order on messages from different sources (e.g., A to B is over the network, but C to B is in shared memory)

MPI

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A blocking receive with a tag will wait until a message with that tag arrives, even if other messages are ready waiting

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Multiple participant messaging

The above send and receive are point-to-point messages, namely one source and one destination

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MPI provides many more general kinds of messaging

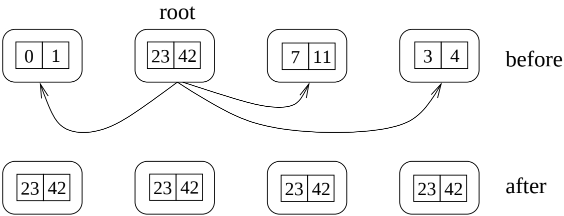
Point-to-point turns out to be much less useful than you might think

MPI

Broadcast:

```
MPI_Bcast(void* buffer, int count, MPI_Datatype datatype,
int root, MPI_Comm comm);
```

The buffer of data is sent from the process with rank `root` to *all* processes in the communicator



MPI broadcast

MPI

Note: all processes, including the receivers, should call `MPI_Bcast` with the same value for `root`

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The destination buffer can be different on each processor, but is typically the "same" buffer (in an SPMD sense)

MPI

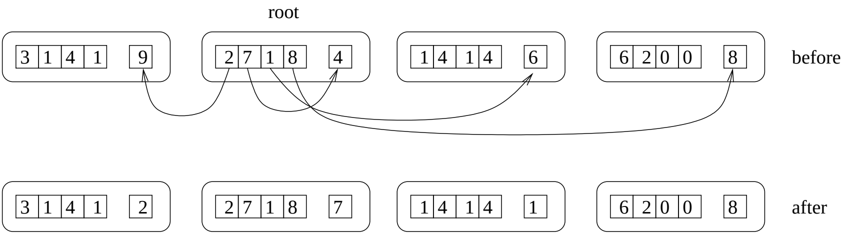
```
int n[2];
if (myrank == 1) {
  n[0] = 23;
  n[1] = 42;
}
...
MPI_Bcast(n, 2, MPI_INT, 1, MPI_COMM_WORLD);
```

All processes will now have the same values for their versions of `n`

MPI

```
MPI_Scatter(void* sendbuf,int sendcount, MPI_Datatype
sendtype, void* recvbuf, int recvcount, MPI_Datatype
recvtype, int root, MPI_Comm comm);
```

This takes the data `sendbuf`, an array, in processor with rank `root`, and sends `sendcount` items from the array to each other processor (and to itself) to end up in `recvbuf`



Scattering single values

MPI

The processor with rank 0 (in the specified communicator) gets the first `sendcount` items from `sendbuf`; processor 1 gets the next `sendcount` items; and so on

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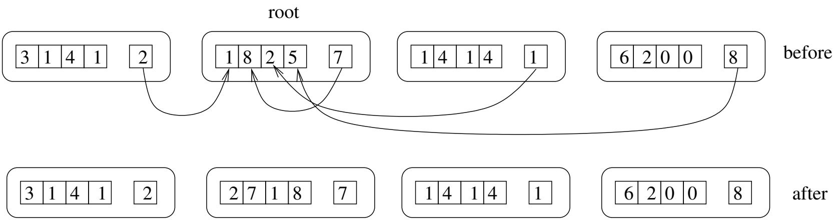
`recvcount` can be different from `sendcount`, but you had better be sure you understand what you are doing

Don't do that!

MPI

```
MPI_Gather(void* sendbuf, int sendcount, MPI_Datatype
sendtype, void* recvbuf, int recvcount, MPI_Datatype
recvtype, int root, MPI_Comm comm);
```

Takes `sendcount` elements of data `sendbuf` from each processor and puts them in the array `recvbuf` on processor `root`



Gathering single values

MPI

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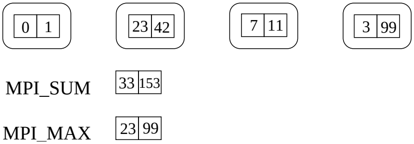
Type and counts can vary across processors

But don't do that

MPI

```
MPI_Reduce(void* sendbuf, void* recvbuf, int count,
MPI_Datatype datatype, MPI_Op op, int root, MPI_Comm comm);
```

Applies a reduction of operation `op` to each value in `sendbuf`, putting the result(s) into `recvbuf` on processor `root`



MPI reduce

MPI

Operations include
`MPI_MAX`, `MPI_MIN`, `MP_SUM`, `MPI_PROD`, `MPI_LAND` (logical AND), `MPI_LOR` (logical OR)
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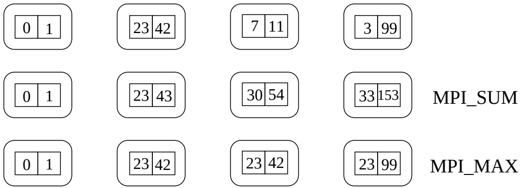
amongst others

You can also define your own reduction operators

MPI

```
MPI_Scan(void* sendbuf, void* recvbuf, int count,
MPI_Datatype datatype, MPI_Op op, MPI_Comm comm);
```

A *prefix scan* of the source `sendbuf`. Processor of rank *i* gets the reduction of values from processors 0 . . . *i* stored in its `recvbuf`



MPI scan

Prefix scans turn out to be a very useful tool in parallel algorithms

MPI

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For example, a `MPI_Bcast` of a large datastructure can be very slow

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For timing, `MPI_Wtime()` returns a “high precision” elapsed time in seconds on the calling processor

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This might be, say, 0.000001 (1 microsecond)

MPI

MPI also provides

- defining new MPI datatypes including arrays and structures;
- means of creating communicators;
- processor groups (communicators contain one or more groups);
- processor topologies (ways of arranging processors into particular geometric shapes that might fit a certain problem or hardware);
- more kinds of scatter/gather/reduce/scan;
- all-to-all broadcasts;
- and so on

MPI

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MPI scales very well to large systems

MPI

And, of course, you can mix shared and distributed memory: running shared memory OpenMP tasks communicating across nodes via MPI

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Don’t use OpenMP in the coursework: that should be pure MPI

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This the programmer’s problem: it’s a bug if you get it wrong

MPI

For example, you can still easily deadlock. Suppose A and B wish to exchange messages:

A	**B**
`MPI_Recv(...);`	`MPI_Recv(...);`
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Careful use of message tags helps structuring

As is common, MPI provides easy mechanism but no analysis

MPI

In fact, for this case, MPI provides `MPI_Sendrecv` which combines a send with a receive that is guaranteed not to deadlock

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And it can connect any pair of processes; is not limited to simple swapping between two processes. For example, A sends to B but receives from C; while B sends to C but receives from A; etc.