Lecture 20

On the ugrad machine:

use mpich

Use the package from

"/cs/local/lib/pkg"

Use can also download and install it yourself from mpich.org

MPI is Simple

- Many parallel programs can be written using just these six functions, only two of which are non-trivial:
  - **MPI_Init**
  - **MPI_Finalize**
  - **MPI_Comm_size**
  - **MPI_Comm_rank**
  - **MPI_Send**
  - **MPI_Recv**

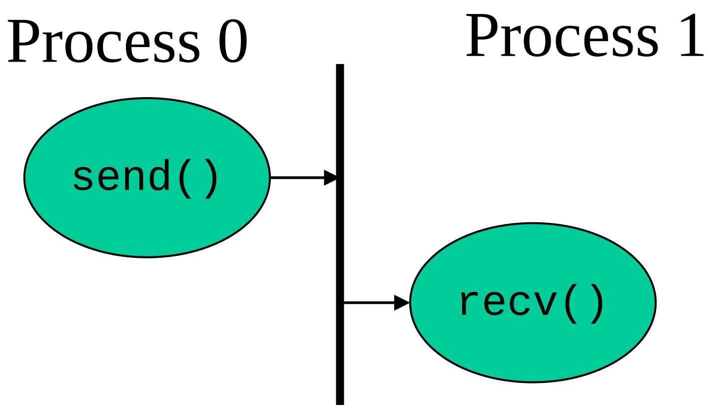
Simple Hello (C)

```
#include "mpi.h"
#include <stdio.h>

int main( int argc, char *argv[] )
{
    int rank, size;
    MPI_Init( &argc, &argv );
    MPI_Comm_rank( MPI_COMM_WORLD, &rank );
    MPI_Comm_size( MPI_COMM_WORLD, &size );
    printf( "I am %d of %d\n", rank, size );
    MPI_Finalize();
    return 0;
}
```

MPI Basic Send/Receive

- We need to fill in the details in



- Things that need specifying:
  - How will "data" be described?
  - How will processes be identified?
  - How will the receiver recognize/screen messages?
  - What will it mean for these operations to complete?

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MPI Basic (Blocking) Send

MPI_Send (start, count, datatype, dest, tag, comm)

- The message buffer is described by (**`start, count, datatype`**).
- The target process is specified by **`dest`**, which is the rank of the target process in the communicator specified by **`comm`**.
- When this function returns, the data has been delivered to the system and the buffer can be reused. The message may not have been received by the target process.

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MPI Basic (Blocking) Receive

MPI_Recv(start, count, datatype, source, tag, comm, status*)

- Waits until a matching (on **`source`** and **`tag`**) message is received from the system, and the buffer can be used.
- **`source`** is rank in communicator specified by **`comm`**, or **`MPI_ANY_SOURCE`**.
- **`status`** structure contains further information
- Receiving fewer than **`count`** occurrences of **`datatype`** is OK, but receiving more is an error.

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Identifying Processes

- MPI Communicator
  - Defines a *group* (set of ordered processes) and a *context* (a virtual network)
- Rank
  - Process number within the group
  - `MPI_ANY_SOURCE` will receive from any process
- Default communicator
  - `MPI_COMM_WORLD` the whole group

Identifying Messages

- An MPI Communicator defines a virtual network, `send/recv` pairs must use the same communicator
- `send/recv` routines have a *tag* (integer variable) argument that can be used to identify a message, or screen for a particular message.
  - `MPI_ANY_TAG` will receive a message with any tag

Identifying Data

- Data is described by a triple (address, type, count)
  - For `send`, this defines the message
  - For `recv`, this defines the size of the receive buffer
- Amount of data received, source, and tag available via *status* data structure
  - Useful if using `MPI_ANY_SOURCE`, `MPI_ANY_TAG`, or unsure of message size (must be smaller than buffer)

MPI Types

- Type may be recursively defined as:
  - An MPI predefined type
  - A contiguous array of types
  - An array of equally spaced blocks
  - An array of arbitrary spaced blocks
  - Arbitrary structure
- Each user-defined type constructed via an MPI routine, e.g. `MPI_TYPE_VECTOR`

MPI Predefined Types

C:	Fortran:
MPI_INT	MPI_INTEGER
MPI_FLOAT	MPI_REAL
MPI_DOUBLE	MPI_DOUBLE_PRECISION
MPI_CHAR	MPI_CHARACTER
MPI_UNSIGNED	MPI_LOGICAL
MPI_LONG	MPI_COMPLEX

Language Independent:

MPI_BYTE

MPI Types

- Explicit data description is useful:
  - Simplifies programming, e.g. send row/column of a matrix with a single call
  - Heterogeneous machines
  - May improve performance
    - Reduce memory-to-memory copies
    - Allow use of scatter/gather hardware
  - May hurt performance
    - User packing of data likely faster

Point-to-point Example

Process 0

```
#define TAG 999
float a[10];
int dest=1;
MPI_Send(a, 10,
MPI_FLOAT, dest, TAG,
MPI_COMM_WORLD);
```

Process 1

```
#define TAG 999
MPI_Status status;
int count;
float b[20];
int sender=0;
MPI_Recv(b, 20,
MPI_FLOAT, sender, TAG,
MPI_COMM_WORLD,
&status);
MPI_Get_count(&status,
MPI_FLOAT, &count);
```

MPI Basic (Standard) Send

MPI_Send (start, count, datatype, dest, tag, comm)

- The message buffer is described by (**`start, count, datatype`**).
- The target process is specified by **`dest`**, which is the rank of the target process in the communicator specified by **`comm`**.
- When this function returns, the data has been delivered to the system and the buffer can be reused. The message may not have been received by the target process.

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MPI Basic (Standard) Receive

MPI_Recv(start, count, datatype, source, tag, comm, status*)

- Waits until a matching (on **source** and **tag**) message is received from the system, and the buffer can be used.
- **source** is rank in communicator specified by **comm**, or **MPI_ANY_SOURCE**.
- **status** structure contains further information
- Receiving fewer than **count** occurrences of **datatype** is OK, but receiving more is an error.

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MPI Status Data Structure

- In C

```
MPI_Status status;
int recvd_tag, recvd_from, recvd_count;
recvd_tag = status.MPI_TAG;
recvd_from = status.MPI_SOURCE;
MPI_Get_count( &status, MPI_INT,
  &recvd_count);
```

MPI's Non-blocking Operations

- Non-blocking operations return (immediately) "request handles" that can be tested and waited on. (Posts a send/receive)

```
MPI_Request request;
MPI_Isend(start, count, datatype,
    dest, tag, comm, &request)
MPI_Irecv(start, count, datatype,
    dest, tag, comm, &request)
MPI_Wait(&request, &status)
```

- One can also test without waiting:

```
MPI_Test(request, &flag, status)
```

Example

```
#define MYTAG 123
  #define WORLD MPI_COMM_WORLD
  MPI_Request request;
  MPI_Status status;
Process 0:
  MPI_Irecv(B, 100, MPI_DOUBLE, 1, MYTAG, WORLD,
  &request)
  MPI_Send(A, 100, MPI_DOUBLE, 1, MYTAG, WORLD)
  MPI_Wait(&request, &status)
Process 1:
  MPI_Irecv(B, 100, MPI_DOUBLE, 0, MYTAG, WORLD,
  &request)
  MPI_Send(A, 100, MPI_DOUBLE, 0, MYTAG, WORLD)
  MPI_Wait(&request, &status)
```

Using Non-Blocking Send

Also possible to use non-blocking send:

- "status" argument to **MPI_Wait** doesn't return useful info here.

```
#define MYTAG 123
#define WORLD MPI_COMM_WORLD
MPI_Request request;
MPI_Status status;
p=1-me; /* calculates partner in exchange */
```

Process 0 and 1:

```
MPI_Isend(A, 100, MPI_DOUBLE, p, MYTAG, WORLD,
          &request)
MPI_Recv(B, 100, MPI_DOUBLE, p, MYTAG, WORLD,
                &status)
MPI_Wait(&request, &status)
```

Non-Blocking Gotchas

- Obvious caveats:
  - 1. You may not modify the buffer between Isend() and the corresponding Wait(). Results are undefined.
  - 2. You may not look at or modify the buffer between Irecv() and the corresponding Wait(). Results are undefined.
  - 3. You may not have two pending Irecv()s for the same buffer.
- Less obvious:
  - 4. You may not *look* at the buffer between Isend() and the corresponding Wait().
  - 5. You may not have two pending Isend()s for the same buffer.
- **Why the isend() restrictions?**
  - Restrictions give implementations more freedom, e.g.,
    - Heterogeneous computer with differing byte orders
    - Implementation swap bytes in the original buffer

Multiple Completions

- It is sometimes desirable to wait on multiple requests:

```
MPI_Waitall(count, array_of_requests,
   array_of_statuses)
MPI_Waitany(count, array_of_requests,
   &index, &status)
MPI_Waitsome(count, array_of_requests,
   array_of indices, array_of_statuses)
```

- There are corresponding versions of **`test`** for each of these.

Multiple completion

- Source of non-determinism (new issues fairness?), process what is ready first
- Latency hiding, parallel slack
- Still need to poll for completion, {do some work; check for comm}*
- Alternative: multiple threads or co-routine like support

MPI point to point routines

MPI_Send	Standard send
MPI_Recv	Standard receive
MPI_Bsend	Buffered send
MPI_Rsend	Ready send
MPI_Ssend	Synchronous send
MPI_Ibsend	Nonblocking, buffered send
MPI_Irecv	Nonblocking receive
MPI_Irsend	Nonblocking, ready send
MPI_Isend	Nonblocking send
MPI_Issend	Nonblocking synchronous send
MPI_Sendrecv	Exchange
MPI_Sendrecv_replace	Exchange, same buffer
MPI_Start	Persistent communication

Communication Modes

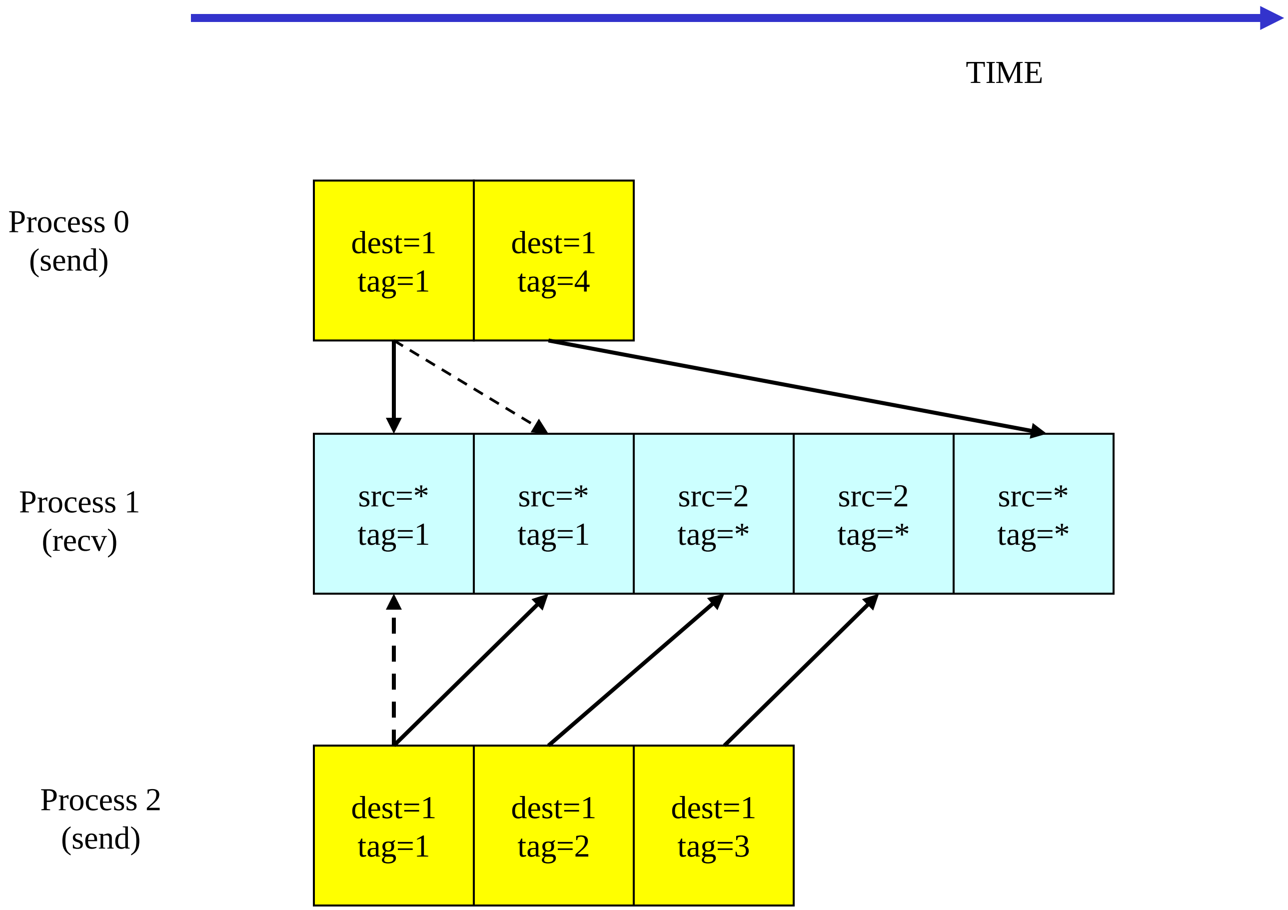
- Standard
  - Usual case (system decides)
  - **MPI_Send**, **MPI_Isend**
- Synchronous
  - The operation does not complete until a matching receive has started copying data into its receive buffer. (no buffers)
  - **MPI_Ssend**, **MPI_Issend**
- Ready
  - Matching receive already posted. (0-copy)
  - **MPI_Rsend**, **MPI_Irsend**
- Buffered
  - Completes after being copied into user provided buffers (Buffer_attach, Buffer_detach calls)
  - **MPI_Bsend**, **MPI_Ibsend**

Point to point with modes

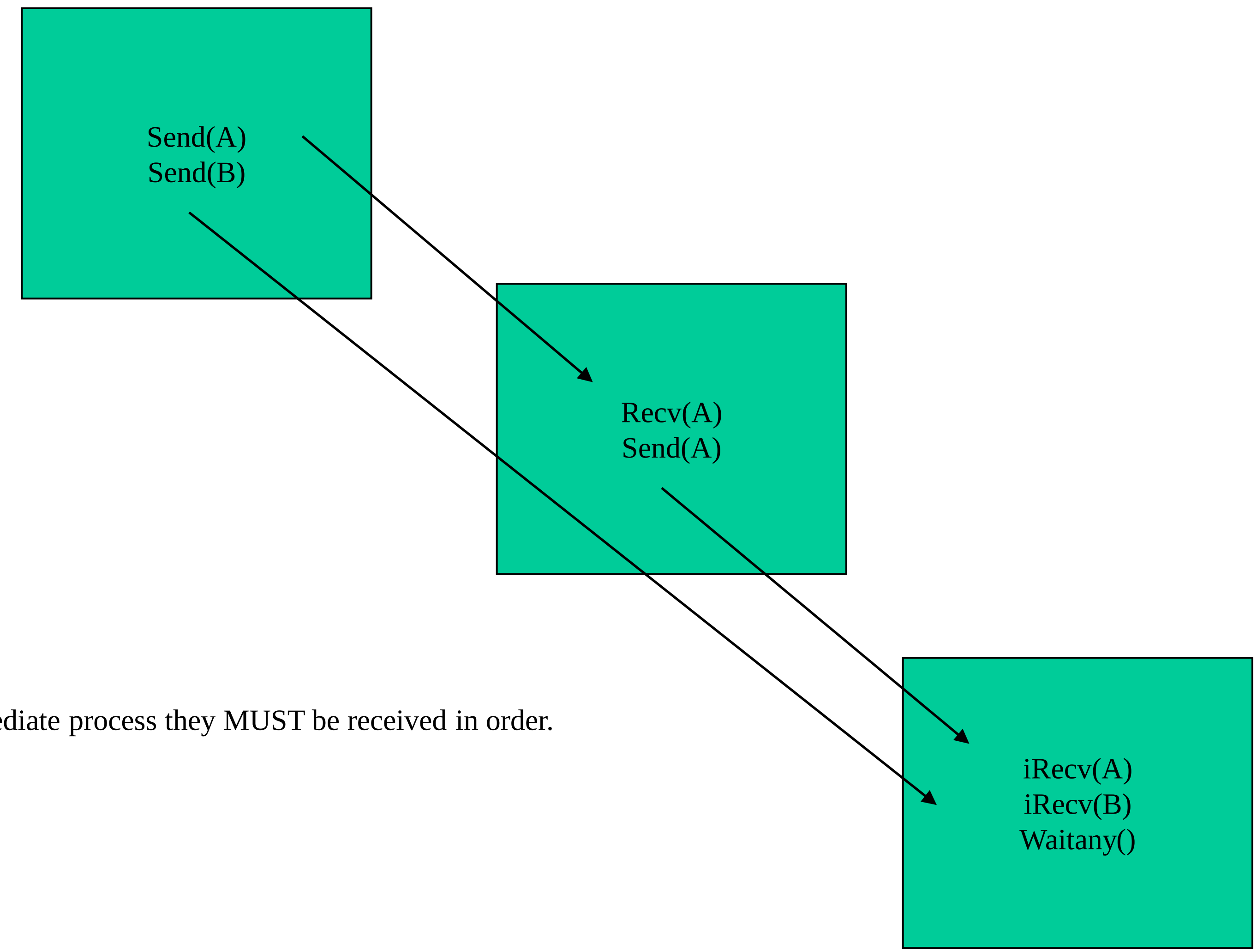
MPI_[SBR]send(start, count, datatype, dest, tag, comm)

There is only one mode for receive!

Messages matched in order



Message ordering



Without the intermediate process they MUST be received in order.

Sources of Deadlocks

- Send a large message from process 0 to process 1
  - If there is insufficient storage at the destination, the send must wait for the user to provide the memory space (through a receive)
- What happens with this code?

Process 0	Process 1
`Send(1)`	**`Send(0)`**
`Recv(1)`	**`Recv(0)`**

- This is called "unsafe" because it depends on the availability of system buffers

Some Solutions to the "unsafe" Problem

- Order the operations more carefully:

Process 0	Process 1
`Send(1)`	**`Recv(0)`**
`Recv(1)`	**`Send(0)`**

Supply receive buffer at same time as send:

Process 0	Process 1
`Sendrecv(1)`	**`Sendrecv(0)`**

More Solutions to the "unsafe" Problem

- Supply own space as buffer for send

Process 0	Process 1
`Bsend(1)`	**`Bsend(0)`**
`Recv(1)`	**`Recv(0)`**

Use non-blocking operations:

Process 0	Process 1
`Irecv(1)`	**`Irecv(0)`**
`Isend(1)`	**`Isend(0)`**
`Waitall`	**`Waitall`**