Parallel programming

MPI 2

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Today's topic

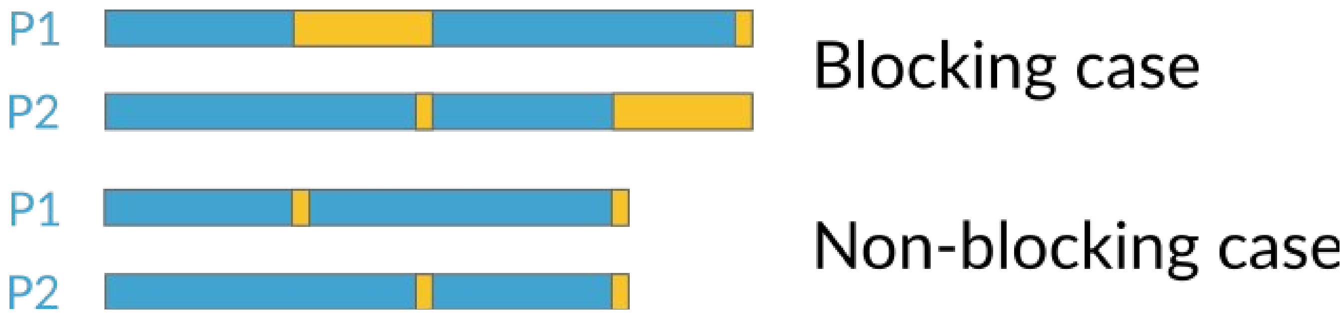
- From previous seminar we know
  - General principle of MPI
  - Synchronous communication (point to point, collective)
- Questions:
  - What if we want to avoid IDLE times of point to point communication?
  - Is there any way how to create our own data types?
  - Can we create any network topology from lectures?
  - What if we don't know the size of message?

Synchronous communication

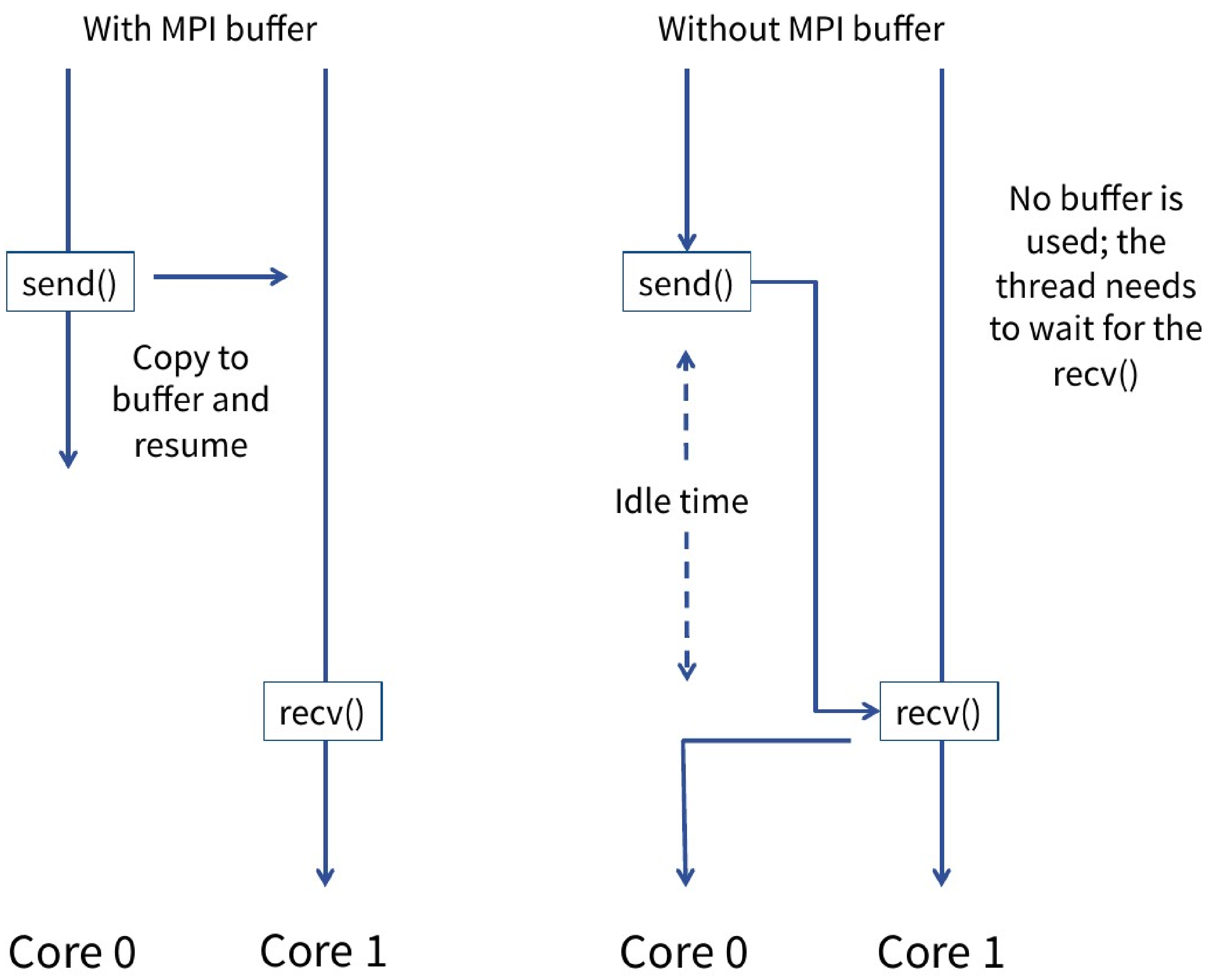
- For the moment, we have only seen **blocking** point-to-point communication
  - After sending a message process has to wait **(delay)**
  - Process waits until it receives the message **(delay)**
- Both send and receive operations using buffers
  - Send waits until the data are copied from the buffer
  - Receive waits until the data are copied to the buffer
- Waiting for the calls causes IDLE times in communication
- On the other hand buffer can be used right after the operation

Asynchronous communication

- Copying to/from the buffer (yellow color) is usually much slower than own computation of the process (blue color)
- We can continue in own computation, and when we want to use buffer again, we can check, if the copying is finished
  - **Check** if the communication operation is finished



Non-blocking and Blocking



MPI Isend

- ```
  int MPI_Isend(void* buf,
                int count,
                MPI_Datatype datatype,
                int dest,
                int tag,
                MPI_Comm comm,
                MPI_Request *request)
  ```
- All parameters are the same as of function **`MPI_Send`** except:
  - **`request`** -> MPI request object (stores information about the communication operation)
- An **`MPI_Isend`** creates a **send request** and returns a **request** object
- It may or may not have sent the message, or buffered it. The caller is responsible for **not changing the buffer** until after waiting upon the resulting request object
  ```

MPI Irecv

```
int MPI_Irecv(void* buf,
              int count,
              MPI_Datatype datatype,
              int source,
              int tag,
              MPI_Comm comm,
              MPI_Request *request)
```

- All parameters are the same as of function MPI_Recv except:
  - `request` -> MPI request object (stores information about the communication operation)
  - See that MPI_Status is missing
- An MPI_Irecv creates a receive request and returns a receive request in an MPI_Request object.
- The caller is responsible for **not changing the buffer** until after waiting upon the resulting request object

Checking if communication is finished

- **`int MPI_Wait(MPI_Request *request,`**
  `                MPI_Status *status)`
- An **`MPI_Wait`** call waits for completion of the operation that created the request object passed to it
  - For a send, the semantics of the sending mode have been fulfilled
  - For a receive, the buffer is now valid for use
  - Implicit for blocking send and receive operations
- **`int MPI_Test(MPI_Request *request,`**
  `                int *flag,`
  `                MPI_Status *status)`
- An **`MPI_Test`** call returns immediately a **flag** value indicating whether a corresponding MPI_Wait would return immediately
  - Flag is 1 if request has been completed
  - Flag is 0 if request has not been completed
  - Useful for **bussy waiting** loops

Task

`AsyncSendAndReceive.cpp`

- Write a program which sends short message “IDKFA” in **non-blocking way** from one process to another one and prints the result.

```
 _______
< IDKFA >
 -------
        \   ^__^
         \  (oo)\_______
            (__)\       )\/\
                ||----w |
                ||     ||
```

Custom types

- As you might have noticed, all datatypes in MPI communications are atomic types
- Sometimes, it might be useful to create higher-level structures
  - MPI allows us to do that in the form of **derived** or custom datatypes
- A datatype can be defined easily by specifying a sequence of couples. Each couple represent a block (type, displacement).
  - Type could be atomic or also derived
  - Displacement indicates the offset in bytes in memory
- There are multiple types how to create or use own datatypes in MPI
  - One way is to serialize your datatypes into a **byte array** and send it as **`MPI_BYTE`** array
  - You can also create your own **`MPI_Datatype`**

MPI Structures

- ```
  int MPI_Type_create_struct(int count,
                             const int *block_length,
                             const MPI_Aint *displacement,
                             const MPI_Datatype *types,
                             MPI_Datatype *new_type)
  ```
  - **`count`** -> number of elements
  - **`block_length`** -> number of contiguous elements of that type
  - **`displacement`** -> array of address offsets in the custom datatype (Aint = address integer)
  - **`types`** -> array of all the different sub-types we are going to use in the custom type
  - **`new_type`** -> resulting datatype
- We can create our own MPI structure, when we know all datatypes in original structure and their offsets
- Creation of structure must be followed by **`MPI_Type_Commit`**
- When you are working with structure consist of same datatypes you can represent your structure as a vector using **`MPI_Type_contiguous`**
- See **`CustomTypeDemo.cpp`**
  ```

Custom operation in MPI

- **`MPI_Reduce`** is a collective operation for data reduction using specific reduce operation
- **`MPI_Reduce`** supports custom operations to perform reductions other than basic mathematical operations
- Custom operations are user-defined and allow **flexibility in data reduction**
- Custom operations enable performing operations **on user-defined data types**

Custom operation in MPI

-
```
int MPI_Op_create(MPI_User_function *user_fn,
                  int commute,
                  MPI_Op *op)
```
  - **`user_fn`** -> User-defined function for the operation
  - **`commute`** -> A flag indicating commutativity
  - **`op`** -> **`MPI_Op`** object for storing the created operation
- A custom reduction operation is a user-defined function for reducing data
  - It can be applied with **`MPI_Reduce`** to combine data from multiple processes
- **`MPI_Op_create`** is a function in MPI for creating custom reduction **`MPI_Op`** operations
- See **`CustomOperationDemo.cpp`**

Task

`BestStudent.cpp`

- Write a program for finding best student at school
  - Use provided struct `Student` and `find_best_student` function
  - Create custom **`MPI_Datatype`** Student based on struct `Student`
  - Create custom **`MPI_Op`** for data reduction
  - Scatter student data generated by process 0
  - Each process finds its best student using `find_best_student` function
  - Use **`MPI_Reduce`** to get best student at process 0
  - Print the best student
  - Follow the provided guidelines

Probing incoming communications

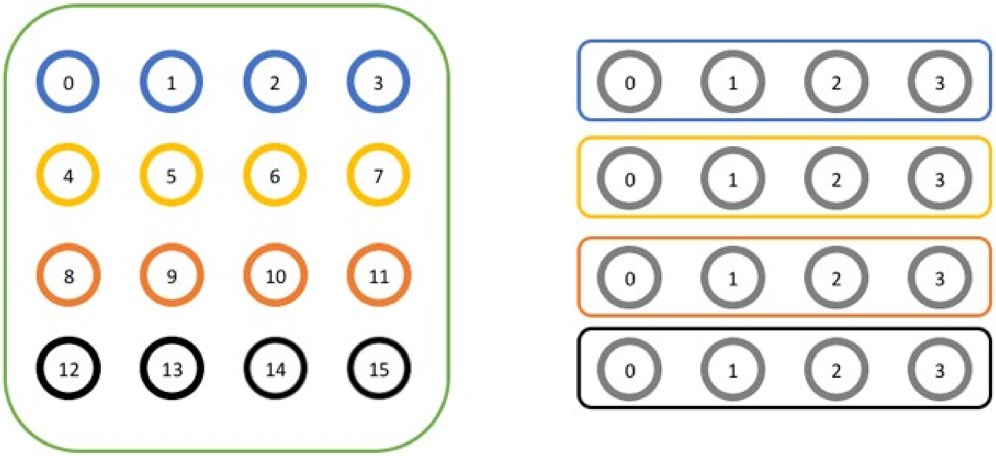
- The amount of data can be really big -> optimizing the size of the messages sent have a real influence on the performance of the system
  1. **Try to group as many data as possible in one communication**
  2. **Try to send the exact amount of data you are storing in your buffer and no more**
- **Probing** the message = asking MPI to give you the size of the message
  - Information of the message is stored in **`MPI_Status`**
  - Getting the count of elements we are about to receive
  - Getting the **ID** and **tags** of the processes we are receiving from
    - We can use **`MPI_ANY_SOURCE`** and **`MPI_ANY_TAG`**
- Probing only informs that the process is ready to receive a communication
  - Use **`MPI_Get_Count`** on the received status to retrieve the information we want

MPI_Probe and MPI_Iprobe


- ```
  int MPI_Probe(int source,
                int tag,
                MPI_Comm comm,
                MPI_Status *status)
  ```
- ```
  int MPI_Iprobe(int source,
                 int tag,
                 MPI_Comm comm,
                 int *flag,
                 MPI_Status *status)
  ```
- Allow checking of incoming messages
- The user can then decide how to receive them, based on the information returned by the probe in the status variable.
- See **`ProbeMessageDemo.cpp`**

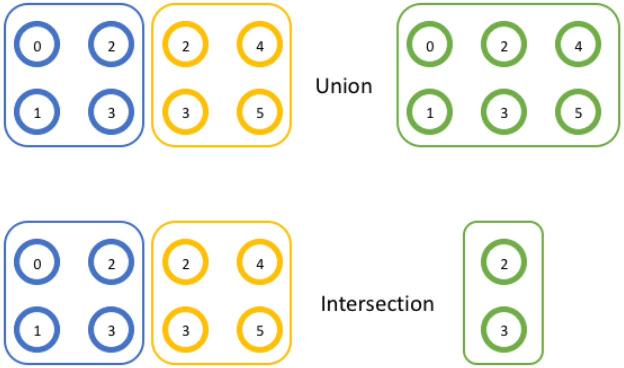
Communicator Management

- At the start of an MPI program all its processes belong to the communicator **`MPI_COMM_WORLD`**
- In many application we want to partition processes into **n subgroups** forming separate communicators (intra-communicator)
- Intra-communicator
  - Set of all processes which share that communicator
  - Collective and point to point communications can be performed with an intra-communicator



MPI Groups

- Group is set of processes inside the communicator
- MPI uses these groups in the same way that set theory generally works
  - MPI provides Union and Intersection operations on groups
- **`int MPI_Comm_group(MPI_Comm comm, MPI_Group* group)`**
  - Creates new **`MPI_Group`** group in communicator **`MPI_Comm comm`**
- **`int MPI_Group_incl(MPI_Group group, int n, const int *ranks, MPI_Group* newgroup)`**
  - Contains the processes in group with ranks contained in ranks, which is of size n
- **`int MPI_Group_union(MPI_Group group1, MPI_Group group2, MPI_Group* newgroup)`**
  - Newgroup -> Union of group1 and group2
- **`int MPI_Group_intersection(MPI_Group group1, MPI_Group group2, MPI_Group* newgroup)`**
  - Newgroup -> Intersection of group1 and group2



Communicator Constructor

- `int MPI_Comm_create_group(MPI_Comm comm, MPI_Group group, int tag, MPI_Comm * newcomm)`

```
int MPI_Comm_create_group(MPI_Comm comm,
                          MPI_Group group,
                          int tag,
                          MPI_Comm * newcomm)
```

  - **comm** -> communicator (handle)
  - **group** -> group, which is a subset of the group of comm (handle)
  - **tag** -> safe tag unused by other communication
  - **newcomm** -> new communicator (handle)
- Requires that comm is an intra-communicator
- Returns a new intra-communicator, **newcomm**, for which the group argument defines the communication group
- No cached information propagates from **comm** to **newcomm**
- Each process must provide a group argument that is a subgroup of the group associated with **comm**

Communicator Splitting

- ```
  int MPI_Comm_split(MPI_Comm comm,
                     int color,
                     int key,
                     MPI_Comm *newcomm)
  ```
  - **`comm`** -> Communicator
  - **`color`** -> control of subset assignment
  - **`key`** -> control of rank assignment
  - **`newcomm`** -> new communicator
- Partitions the group associated with comm into disjoint subgroups, one for each value of color
- Within each subgroup, the processes are ranked in the order defined by the value of the argument key
- See **`CommunicatorDemo.cpp`**
  ```