Institute of Computer Science
Department of Mathematics and Computer Science

Freie Universität Berlin

Algorithms and Programming IV

MPI Group Communication and MPI-2

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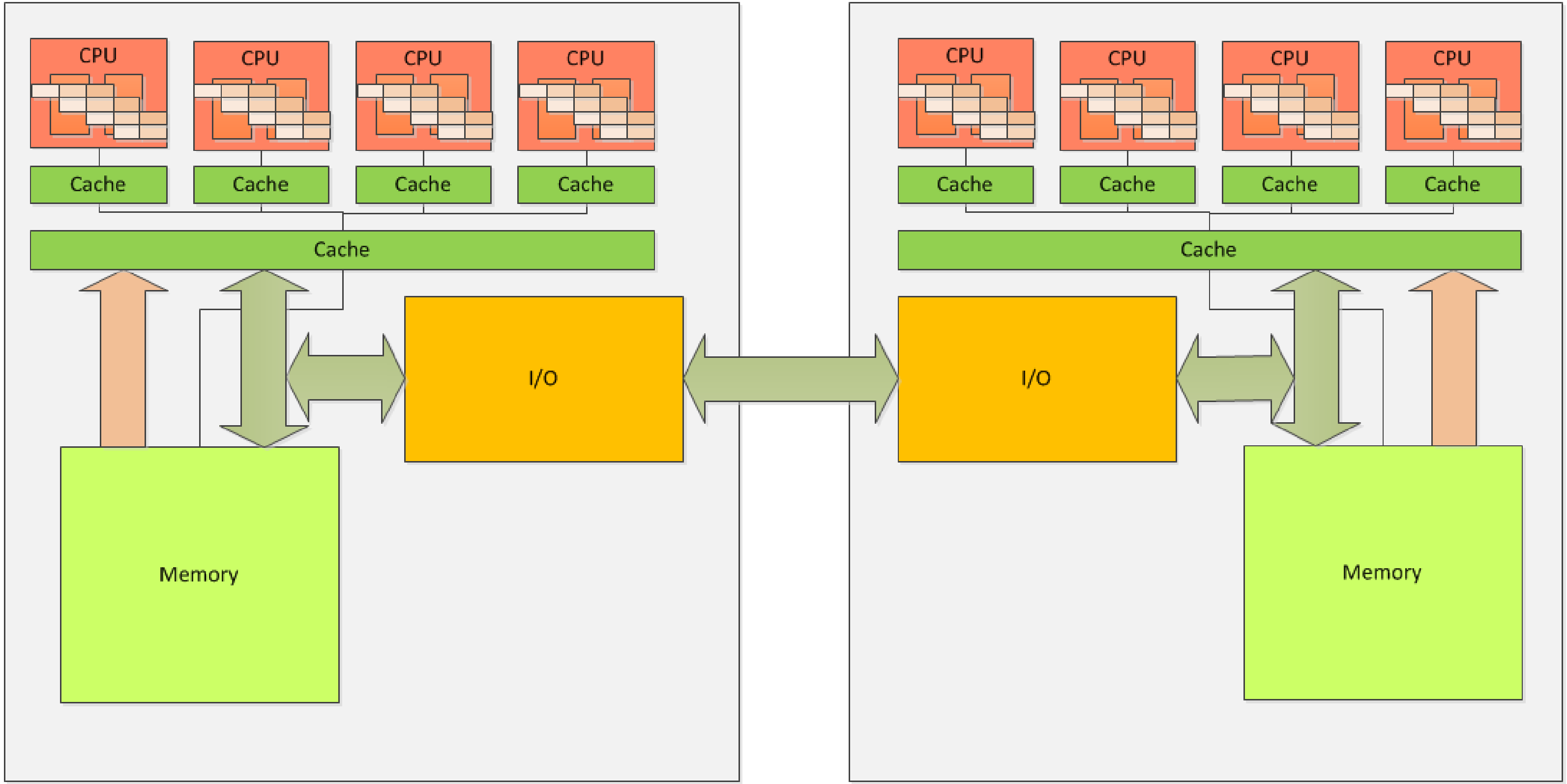
Objectives of Today‘s Lecture

- Introduction to MPI group communication
- Introduction to MPI-2

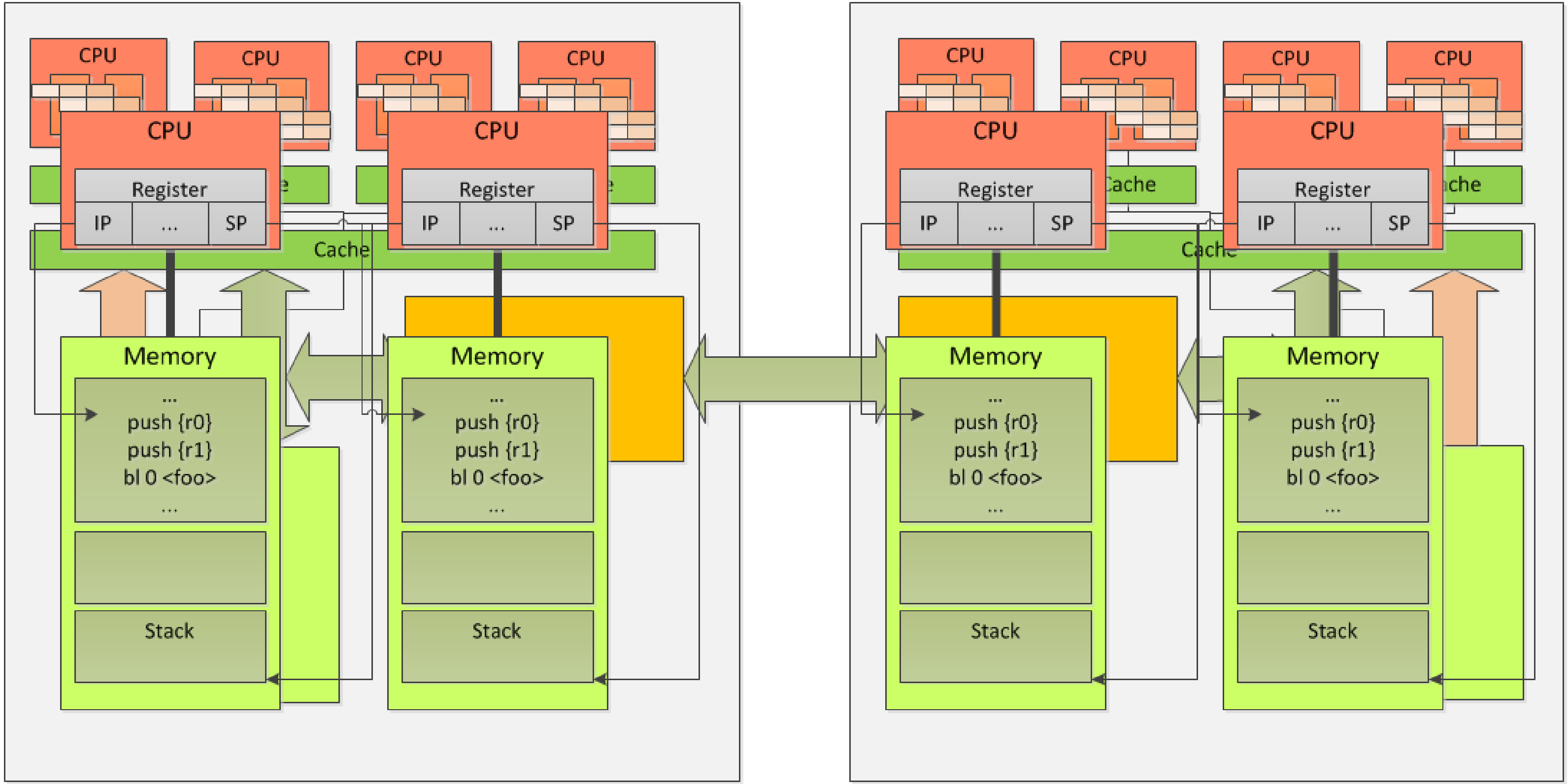
Concepts of Non-sequential and Distributed Programming

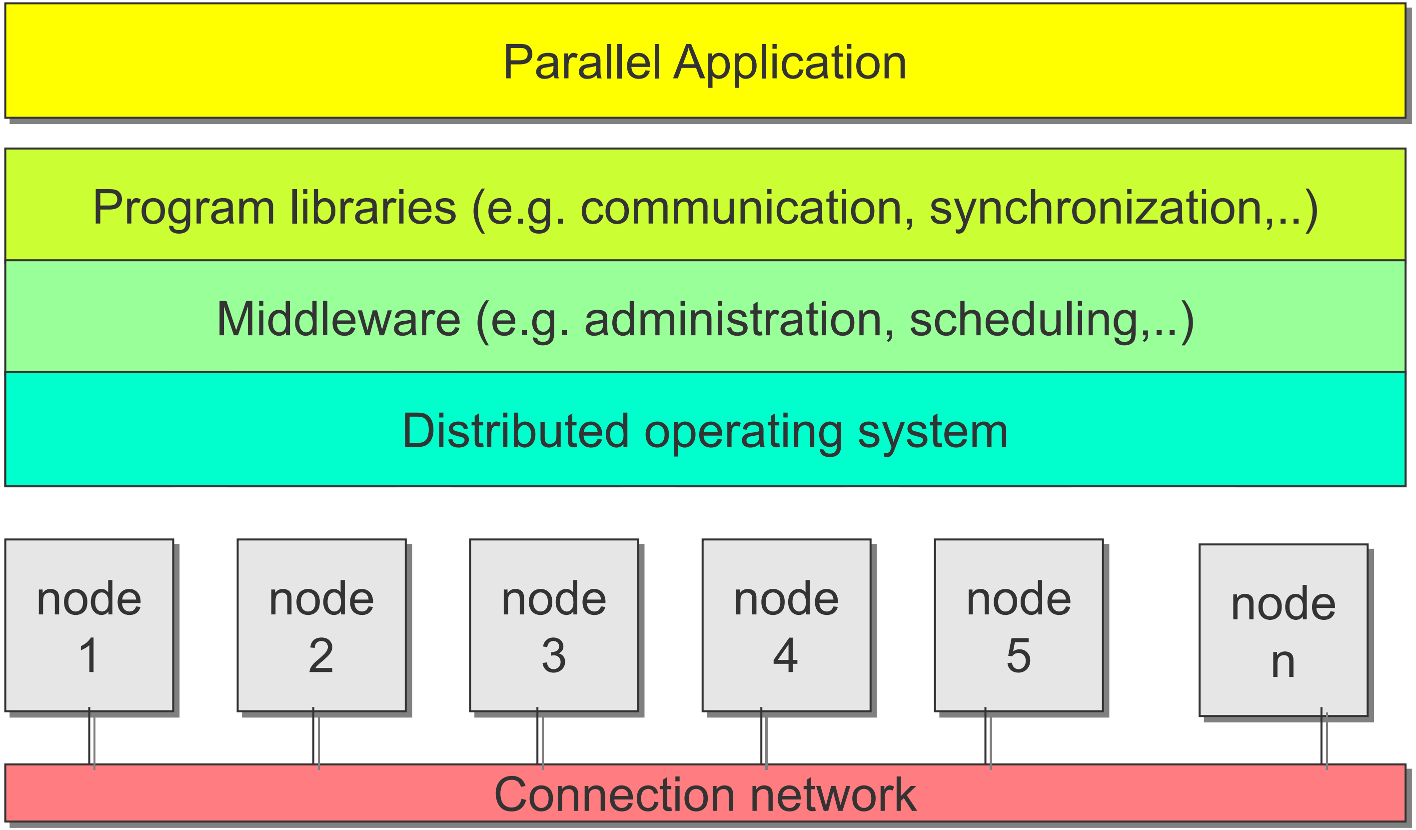
MPI GROUP COMMUNICATION

Machine Model



Machine and Execution Model




Parallel Application
Program libraries (e.g. communication, synchronization,..)
Middleware (e.g. administration, scheduling,..)
Distributed operating system
node 1
node 2
node 3
node 4
node 5
node n
Connection network

MPI_Bcast

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

- (Blocking) broadcast operation to send (`root == my_rank`) or receive (`root != my_rank`) a message to all participating processes of the communicator `comm`.
- The broadcast message must be received by all processes with `MPI_Bcast()`.
- In case several messages were sent the sequence of these will be preserved.

MPI_Bcast

- `buffer` – pointer to the buffer in which the message to be sent is located,
- `count` – number of elements of type datatype to be sent,
- `datatype` – type of elements to be sent, all elements of a message must have the same type,
- `root` – rank of the sending process,
- `comm` – communicator that describes the group of processes that can exchange messages.

MPI_Reduce

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

- Merging the content of different messages in a global reduction operation (accumulation operation) `op` to be stored in a single value in `recvbuf`.
- All processes of the of the communicator `comm` have to send messages for the reduce operation.
- The root process `root` must provide the receive buffer `recvbuf`.

MPI_Reduce

- `sendbuf` – pointer to the buffer in which the message to be sent is located
- `recvbuf` – pointer to the buffer in which the messages are stored when received.
- `count` – number of elements of type datatype to be sent
- `datatype` – type of elements to be sent, all elements of a message must have the same type
- `op` – reduction operation
- `root` – rank of the receiving process
- `comm` – communicator that describes the group of processes that can exchange messages

MPI_Reduce – Operations

MPI_Reduce operations	Description
MPI_MAX	Returns the maximum element
MPI_MIN	Returns the minimum element
MPI_SUM	Sums the elements
MPI_PROD	Multiplies all elements
MPI_LAND	Performs a *logical and* across the elements
MPI_BAND	Performs a *bitwise and* across the bits of the elements
MPI_LOR	Performs a *logical or* across the elements
MPI_BOR	Performs a *bitwise or* across the bits of the elements
MPI_LXOR	Performs a *logical exclusive or* across the elements
MPI_BXOR	Performs a bitw. *exclusive or* across the bits of the elements
MPI_MAXLOC	Returns the max. value and the rank of the proc. that owns it
MPI_MINLOC	Returns the min. value and the rank of the proc. that owns it

MPI_Op_create

```
int MPI_Op_create ( MPI_User_function *function,
                    int commute,
                    MPI_Op *op);
```

- To define a special reduce operation to be used with `MPI_Reduce()`.

MPI_Op_create

- `function` – pointer to the function to be applied to the corresponding operation,
- `commute` – specifies whether the operation is commutative (`commute = 1`) or not (`commute = 0`),
- `op` – data type of the operation to be applied.

Extended MPI Datatypes

MPI datentyp	Combination of C datentypes
MPI_FLOAT_INT	(float, int)
MPI_DOUBLE_INT	(double, int)
MPI_LONG_INT	(long, int)
MPI_SHORT_INT	(short, int)
MPI_LONG_DOUBLE_INT	(long double, int)
MPI_2INT	(int, int)

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MPI_Type_create_struct

```
int MPI_Type_create_struct (
        int count,
        int array_of_blocklengths[],
        const MPI_Aint array_of_displacements[],
        const MPI_Datatype array_of_types[],
        MPI_Datatype *new_type);
```

- Generation of a new structured data type as a combination of MPI basic types.

MPI_Type_create_struct

- `count` – number of elements in the following arrays,
- `array_of_blocklengths`
  – specifies the number of elements in each block,
- `array_of_displacements`
  – specifies the number of bytes to move each block,
- `array_of_types`
  – specifies the MPI type of the elements of each block,
- `new_type` – new data type.

MPI_Type_contiguous

```
int MPI_Type_contiguous (
                    int count,
                    MPI_Datatype old_type,
                    MPI_Datatype *new_type);
```

– Creates a contiguous datatype out of an existing datatype.

MPI_Type_commit

```
int MPI_Type_commit (
                    MPI_Datatype *data_type);
```

− Commits a datatype to be used by the MPI environment.

```c
// https://www.open-mpi.org/doc/v1.8/man3/MPI_Op_create.3.php

typedef struct {
  double real,imag;
} Complex;

// the user-defined function
void myProd( Complex *in, Complex *inout,
             int *len, MPI_Datatype *dptr)
{
  int i;
  Complex c;

  for (i=0; i< *len; ++i) {
    c.real = inout->real*in->real -
             inout->imag*in->imag;
    c.imag = inout->real*in->imag +
             inout->imag*in->real;
    *inout = c;
    in++; inout++;
  }
}
```

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```c
// and, to call it...
...
  // each proc has an array of 100 Compl.
  Complex a[100], answer[100];
  MPI_Op myOp;
  MPI_Datatype ctype;

  // At this point, the answer, which
  // consists of 100 Complexes,
  // resides on root
```

source code: 12-00.c

```c
// https://www.open-mpi.org/doc/v1.8/man3/MPI_Op_create.3.php

typedef struct {
  double real,imag;
} Complex;

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void myProd( Complex *in, Complex *inout,
             int *len, MPI_Datatype *dptr)
{
  int i;
  Complex c;

  for (i=0; i< *len; ++i) {
    c.real = inout->real*in->real -
             inout->imag*in->imag;
    c.imag = inout->real*in->imag +
             inout->imag*in->real;
    *inout = c;
    in++; inout++;
  }
}
```

```c
// and, to call it...
...
  // each proc has an array of 100 Compl.
  Complex a[100], answer[100];
  MPI_Op myOp;
  MPI_Datatype ctype;

  // define type Complex for MPI
  MPI_Type_contiguous( 2, MPI_DOUBLE,
            &ctype );

  // At this point, the answer, which
  // consists of 100 Complexes,
  // resides on root
```

source code: 12-00.c

```c
// https://www.open-mpi.org/doc/v1.8/man3/MPI_Op_create.3.php

typedef struct {
  double real,imag;
} Complex;

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void myProd( Complex *in, Complex *inout,
         int *len, MPI_Datatype *dptr)
{
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  for (i=0; i< *len; ++i) {
    c.real = inout->real*in->real -
         inout->imag*in->imag;
    c.imag = inout->real*in->imag +
         inout->imag*in->real;
    *inout = c;
    in++; inout++;
  }
}
```

```c
// and, to call it...
...
  // each proc has an array of 100 Compl.
  Complex a[100], answer[100];
  MPI_Op myOp;
  MPI_Datatype ctype;

  // define type Complex for MPI
  MPI_Type_contiguous( 2, MPI_DOUBLE,
          &ctype );
  MPI_Type_commit( &ctype );



  // At this point, the answer, which
  // consists of 100 Complexes,
  // resides on root
```

source code: 12-00.c

```c
// https://www.open-mpi.org/doc/v1.8/man3/MPI_Op_create.3.php

typedef struct {
  double real,imag;
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// the user-defined function
void myProd( Complex *in, Complex *inout,
             int *len, MPI_Datatype *dptr)
{
  int i;
  Complex c;

  for (i=0; i< *len; ++i) {
    c.real = inout->real*in->real -
             inout->imag*in->imag;
    c.imag = inout->real*in->imag +
             inout->imag*in->real;
    *inout = c;
    in++; inout++;
  }
}
```

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```c
// and, to call it...
...
  // each proc has an array of 100 Compl.
  Complex a[100], answer[100];
  MPI_Op myOp;
  MPI_Datatype ctype;

  // define type Complex for MPI
  MPI_Type_contiguous( 2, MPI_DOUBLE,
          &ctype );
  MPI_Type_commit( &ctype );

  // create the complex-product user-op
  MPI_Op_create( myProd, True, &myOp );

  // At this point, the answer, which
  // consists of 100 Complexes,
  // resides on root
```

source code: 12-00.c

```
// https://www.open-mpi.org/doc/v1.8/man3/MPI_Op_create.3.php

typedef struct {
  double real,imag;
} Complex;

// the user-defined function
void myProd( Complex *in, Complex *inout,
             int *len, MPI_Datatype *dptr)
{
  int i;
  Complex c;

  for (i=0; i< *len; ++i) {
    c.real = inout->real*in->real -
             inout->imag*in->imag;
    c.imag = inout->real*in->imag +
             inout->imag*in->real;
    *inout = c;
    in++; inout++;
  }
}
```



```
// and, to call it...
...
  // each proc has an array of 100 Compl.
  Complex a[100], answer[100];
  MPI_Op myOp;
  MPI_Datatype ctype;

  // define type Complex for MPI
  MPI_Type_contiguous( 2, MPI_DOUBLE,
            &ctype );
  MPI_Type_commit( &ctype );

  // create the complex-product user-op
  MPI_Op_create( myProd, True, &myOp );

  MPI_Reduce( a, answer, 100, ctype,
            myOp, root, comm );

  // At this point, the answer, which
  // consists of 100 Complexes,
  // resides on root
```

source code: 12-00.c

```c
// https://www.open-mpi.org/doc/v1.8/man3/MPI_Op_create.3.php

typedef struct {
  double real,imag;
} Complex;

// the user-defined function
void myProd( Complex *in, Complex *inout,
             int *len, MPI_Datatype *dptr)
{
  int i;
  Complex c;

  for (i=0; i< *len; ++i) {
    c.real = inout->real*in->real -
             inout->imag*in->imag;
    c.imag = inout->real*in->imag +
             inout->imag*in->real;
    *inout = c;
    in++; inout++;
  }
}
```

```c
// and, to call it...
...
  // each proc has an array of 100 Compl.
  Complex a[100], answer[100];
  MPI_Op myOp;
  MPI_Datatype ctype;

  // define type Complex for MPI
  MPI_Type_contiguous( 2, MPI_DOUBLE,
          &ctype );
  MPI_Type_commit( &ctype );

  // create the complex-product user-op
  MPI_Op_create( myProd, True, &myOp );

  MPI_Reduce( a, answer, 100, ctype,
          myOp, root, comm );

  // At this point, the answer, which
  // consists of 100 Complexes,
  // resides on root
```

source code: 12-00.c

MPI_Gather

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

- Gathers together values from a group of processes of the communicator `comm` (without reduction operation).
- The elements are stored in order of the numbers of the processes involved.

MPI_Gather

- `sendbuf` – pointer to the buffer in which the message to be sent is located,
- `sendcount` – number of elements of type datatype to be sent,
- `sendtype` – type of elements to be sent,
- `recvbuf` – pointer to the buffer in which the messages are stored when received,
- `recvcount` – number of elements of type datatype to be received,
- `recvtype` – type of elements to be sent, all elements of a message must have the same type,
- `root` – rank of the receiving process,
- `comm` – communicator that describes the group of processes that can exchange messages.

MPI_Gatherv

```
int MPI_Gatherv (    void *sendbuf, int sendcount,
                     MPI_Datatype sendtype,
                     void *recvbuf, const int recvcounts[],
                     const int displs[],
                     MPI_Datatype recvtype,
                     int root,
                     MPI_Comm comm);
```

- Gathers together values out of messages with different size from a group of processes of the communicator `comm`.
- The root process specifies the number (`recvcounts`) and position of the storage within the receive buffer (`displs`).

MPI_Scatter

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

- Distribution of individual data (same size) by messages to all the processes of the communicator `comm`.
- The data is distributed and sent according to the numbers of the target processes.

MPI_Scatter

- `sendbuf` – pointer to the buffer containing the data to be sent,
- `sendcount` – number of elements of type datatype to be sent,
- `sendtype` – type of elements to be sent,
- `recvbuf` – pointer to the buffer in which the message is stored when received,
- `recvcount` – number of elements of type datatype to be received,
- `recvtype` – type of elements to be sent, all elements of a message must have the same type,
- `root` – rank of the receiving process,
- `comm` – communicator that describes the group of processes that can exchange messages.

MPI_Scatterv

```
int MPI_Scatterv (  void *sendbuf,
                    const int sendcounts[],
                    const int displs[],
                    MPI_Datatype sendtype,
                    void *recvbuf,
                    int recvcount,
                    MPI_Datatype recvtype,
                    int root,
                    MPI_Comm comm);
```

– Distribution of individual data of different sizes by messages to all the processes of the communicator `comm`.

MPI_Allgather

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

- Gathers together data from messages from all processes of the communicator `comm` and distribute it to all involved processes.
- The elements are stored in the order of the numbers of the processes involved.

MPI_Allgather

- `sendbuf` – pointer to the buffer containing the data to be sent,
- `sendcount` – number of elements of type datatype to be sent,
- `sendtype` – type of elements to be sent,
- `recvbuf` – pointer to the buffer in which the message is stored when received,
- `recvcount` – number of elements of type datatype to be received,
- `recvtype` – type of elements to be sent, all elements of a message must have the same type,
- `comm` – communicator that describes the group of processes that can exchange messages.

MPI_Allgatherv

```
int MPI_Allgatherv (void *sendbuf,
                    int sendcount,
                    MPI_Datatype sendtype,
                    void *recvbuf,
                    const int recvcounts[],
                    const int displs[],
                    MPI_Datatype recvtype,
                    MPI_Comm comm);
```

– Gathering of individual messages from all processes of the communicator `comm` (without reduction operation) and distribution to all involved processes.

MPI_Allreduce

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

- Merging the content of different messages in a global reduction operation (accumulation operation) `op` and distributes the result back to all processes of the communicator `comm`.

MPI_Allreduce

- `sendbuf` – pointer to the buffer containing the data to be sent,
- `recvbuf` – pointer to the buffer in which the message is stored when received,
- `count` – number of elements of type datatype to be received,
- `datatype` – type of elements to be sent, all elements of a message must have the same type,
- `op` – reduction operation,
- `comm` – communicator that describes the group of processes that can exchange messages.

```c
// part of simple MPI program with MPI_Allreduce
// to multiply a matrix and a vector
// Rauber, Ruenger: Parallele und vert. Prg.

int m, local_m, n, p;
float a[MAX_N][MAX_LOC_M], local_b[MAX_LOC_M];
float c[MAX_N], sum[MAX_N];

local_m = m / p;
for (i = 0; i < n; i++) {
  sum[i] = 0;
  for (j = 0; j < local_m; j++)
    sum[i] = sum[i] + a[i][j] * local_b[j];
}
MPI_Allreduce (sum, c, n, MPI_FLOAT, MPI_SUM, comm);
```

source code: 12-01.c

MPI_Alltoall

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

– Total exchange of (individual) messages of equal size of all processes of the communicator `comm` (without reduction operation).

MPI_Alltoall

- `sendbuf` – pointer to the buffer containing the data to be sent,
- `sendcount` – number of elements of type datatype to be sent,
- `sendtype` – type of elements to be sent,
- `recvbuf` – pointer to the buffer in which the message is stored when received,
- `recvcount` – number of elements of type datatype to be received,
- `recvtype` – type of elements to be sent, all elements of a message must have the same type,
- `comm` – communicator that describes the group of processes that can exchange messages.

MPI_Alltoallv

```
int MPI_Alltoallv ( void *sendbuf,
                    const int sendcounts[],
                    const int sdispls[],
                    MPI_Datatype sendtype,
                    void *recvbuf,
                    const int recvcounts[],
                    const int rdispls[],
                    MPI_Datatype recvtype,
                    MPI_Comm comm);
```

– Total exchange of (individual) messages with different size of all processes of the communicator `comm` (without reduction operation).

MPI_Comm_group

```
int MPI_Comm_group (MPI_Comm comm,
                    MPI_Group *group);
```

– Returns all processes assigned to the communicator `comm` in the group data structure `group`.

MPI_Group_union

```
int MPI_Group_union (        MPI_Group group1,
                             MPI_Group group2,
                             MPI_Group *new_group);
```

- Merges the processes of the groups `group1` and `group2` into a group `new_group`.

MPI_Group_intersection

```
int MPI_Group_intersection (      MPI_Group group1,
                                  MPI_Group group2,
                                  MPI_Group *new_group);
```

− Produces a new group `new_group` as the intersection of the processes of the groups `group1` and `group2`.

MPI_Group_difference

```
int MPI_Group_difference ( MPI_Group group1,
                           MPI_Group group2,
                           MPI_Group *new_group);
```

– Makes a new group `new_group` from the difference of the groups `group1` and `group2`.

MPI_Group_incl

```
int MPI_Group_incl (MPI_Group group,
                    int p,
                    const int ranks[],
                    MPI_Group *new_group);
```

- Creates a new group `new_group` from the processes of an existing group `group` by taking only the `p` processes listed in `ranks`.

MPI_Group_excl

```
int MPI_Group_excl (MPI_Group group,
                    int p,
                    const int ranks[],
                    MPI_Group *new_group);
```

- Creates a new group `new_group` from the processes of an existing group `group` by not adopting the `p` processes listed in `ranks`.

MPI_Group_compare

```
int MPI_Group_compare (     MPI_Group group1,
                            MPI_Group group2,
                            int *res);
```

- Compares two groups and stores the result in `res`.
- For groups with the same processes in the same order `MPI_IDENT` is returned, for groups with the same processes in different orders `MPI_SIMILAR` and for different groups `MPI_UNEQUAL`.

MPI_Group_free

```
int MPI_Group_free (MPI_Group *group);
```

- Releases the data structure holding the group `group`.

MPI_Comm_create

```
int MPI_Comm_create (        MPI_Comm comm,
                             MPI_Group group,
                             MPI_Comm new_comm);
```

– Creates a new communicator `new_comm`, which addresses the processes of the group `group`, from the existing communicator `comm`.

MPI_Comm_compare

```
int MPI_Comm_compare (      MPI_Comm comm1,
                            MPI_Comm comm2,
                            int *res);
```

- Compares the two communicators `comm1` and `comm2` and stores the result in `res`.
- If `comm1` and `comm2` point to the same data structure, `MPI_IDENT` is returned. If there are different communicators with the same processes in the same order `MPI_CONGRUENT` is returned, if there are communicators with the same processes in different orders `MPI_SIMILAR` and if there are different communicators `MPI_UNEQUAL` is returned.

MPI_Comm_dup

```
int MPI_Comm_dup (  MPI_Comm comm,
                    MPI_Comm new_comm);
```

- Creates a new communicator `new_comm` with the same processes in the same order as the communicator `comm`.

MPI_Comm_split

```
int MPI_Comm_split (MPI_Comm comm,
                    int color,
                    int key,
                    MPI_Comm *new_comm);
```

- Split the processes of the communicator `comm` according to the values `color` in the order `key` and return the communicator in which the corresponding process is found.
- If a process has not set the value `color`, it will not be found in any of the created communicators.

MPI_Comm_free

```
int MPI_Comm_free ( MPI_Comm *comm);
```

- Releases the communicator `comm` after all message transmissions performed with this communicator have been completed.

MPI_Wtime

```
double MPI_Wtime (  void);
```

- Returns the time in seconds after a certain time. The elapsed processing time can be determined from the difference between second calls.

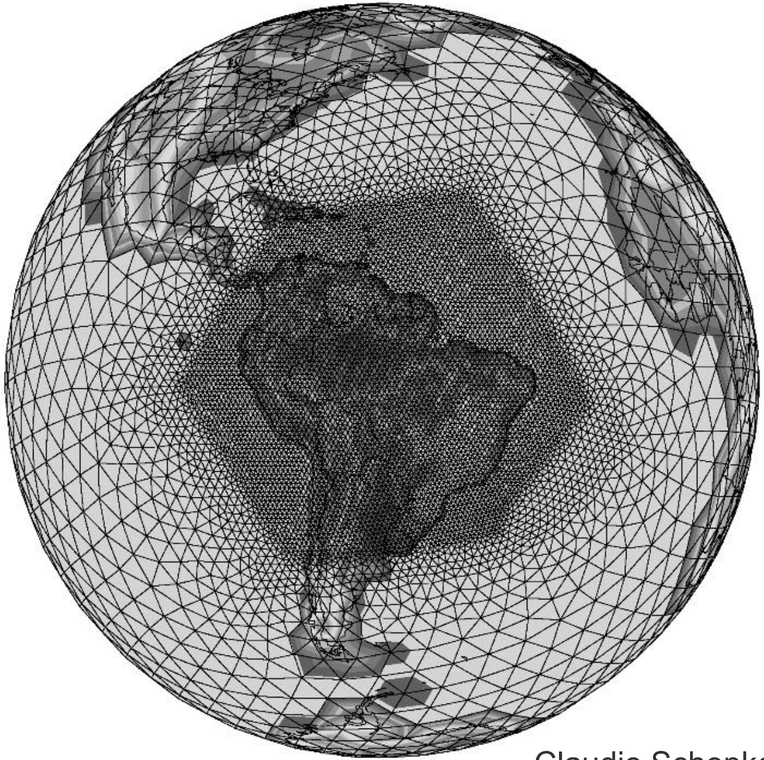
Concepts of Non-sequential and Distributed Programming

MPI-2

MPI-2

- MPI-2 is an extension of the MPI standard.
- It introduces new functions to support
  - memory transfers,
  - dynamic process management,
  - input/output operations.

- In particular, applications with very high resource requirements will be programmed with dynamic process generation and dynamic runtime behavior.



Claudio Schepke

MPI_Comm_spawn

```
int MPI_Comm_spawn (const char *command,
                    char *argv[],
                    int maxprocs,
                    MPI_Info info,
                    int root,
                    MPI_Comm comm,
                    MPI_Comm *intercomm,
                    int array_of_errcodes[]);
```

- Creates a number of `maxprocs` new MPI processes that execute the `command` program. The child processes still have to call `MPI_Init()` for execution.

MPI_Comm_spawn

- The parameters for `MPI_Comm_spawn` are:
  - `command` – program executed by the child processes,
  - `argv` – arguments passed to the child processes,
  - `maxprocs` – number of child processes to be created,
  - `info` – process information or `MPI_INFO_NULL`, to transfer the administration to the runtime system,
  - `root` – rank of the parent process,
  - `comm` – communicator of the parent process,
  - `intercomm` – communicator, the group of child processes,
  - `array_of_errcodes` – error code per child process.

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MPI_Comm_get_parent

```
int MPI_Comm_get_parent (  MPI_Comm *parent);
```

- Returns the communicator of the parent process in `parent`.

MPI_Comm_spawn_multiple

```
int MPI_Comm_spawn_multiple (    int count,
                                 const char *commands[],
                                 char **argv[],
                                 int maxprocs[],
                                 MPI_Info infos[],
                                 int root,
                                 MPI_Comm comm,
                                 MPI_Comm *intercomm,
                                 int array_of_errcodes[]);
```

- Starts `count` many `command` programs, each with `maxprocs` many processes.
- It creates one communicator for all child processes.

MPI_Comm_spawn_multiple

- `count` – number of programs to be started,
- `command` – program executed by the child processes,
- `argv` – arguments passed to the child processes,
- `maxprocs` – number of child processes to be created,
- `info` – process information or `MPI_INFO_NULL`, to transfer the administration to the runtime system,
- `root` – rank of the parent process,
- `comm` – communicator of the parent process,
- `intercomm` – communicator, the group of child processes,
- `array_of_errcodes` – error code per child process.

Concepts of Non-sequential and Distributed Programming

NEXT LECTURE

Institute of Computer Science
Department of Mathematics and Computer Science

Freie Universität Berlin

Design and Implementation of Parallel Applications

APL IV: Concepts of Non-sequential and Distributed Programming (Summer Term 2023)