Derived Datatypes

- MPI datatypes
- Procedure
- Datatype construction
- Type maps
- Contiguous datatype*
- Vector datatype*
- Extent of a datatype
- Structure datatype*
- Committing a datatype
- Exercises

*includes sample C and Fortran programs

MPI datatypes

- Basic types
- Derived types
  - Constructed from existing types (basic and derived)
  - Used in MPI communication routines to transfer high-level, extensive data entities
- Examples:
  - Sub-arrays or “unatural” array memory striding
  - C structures and Fortran common blocks
  - Large set of general variables
- Alternative to repeated sends of basic types
  - Slow, clumsy and error prone

Procedure

- **Construct** new datatype using MPI routines:
  - `MPI_Type_contiguous`, `MPI_Type_vector`, `MPI_Type_struct`, `MPI_Type_indexed`, `MPI_Type_hvector`, `MPI_Type_hindexed`
- **Commit** (creates a formal description of the buffer required for this new type):
  - `MPI_Type_Commit`
- **Use** new datatype in sends/receives, etc…
- **Free** datatype after use to reclaim storage:

```
call MPI_Type_Free(newtype, ierr)
```

`MPI_Type_free(type)` (`type` set to `MPI_DATATYPE_NULL`)

Datatype construction

- Datatype specified by its **type map**
  - Like a stencil laid over memory

- Displacements are offsets (in bytes) from the starting memory address of the desired data
  - `MPI_Type_extent` function can be used to get size (in bytes) of datatypes
  - extent: distance, in bytes, from beginning to end of type

Type maps

Basic datatype 0	Displacement of datatype 0
Basic datatype 1	Displacement of datatype 1
…	…
Basic datatype n-1	Displacement of datatype n-1

Contiguous datatype

- The simplest derived datatype consists of a number of contiguous items of the same datatype

C:

```
int MPI_Type_contiguous (int count,
          MPI_datatype oldtype,MPI_Datatype *newtype)
```

Fortran:

```
CALL MPI_TYPE_CONTIGUOUS(COUNT,OLDTYPE,NEWTYPE,IERROR)

INTEGER COUNT, OLDTYPE, NEWTYPE, IERROR
```

Sample Program #2 - C

```
#include <stdio.h>
#include<mpi.h>
/* Run with four processes */
 int main(int argc, char *argv[]) {
    int rank;
    MPI_Status status;
    struct {
     int x;
     int y;
     int z;
    } point;
    MPI_Datatype ptype;
    MPI_Init(&argc,&argv);
    MPI_Comm_rank(MPI_COMM_WORLD,&rank);
    MPI_Type_contiguous(3,MPI_INT,&ptype);
    MPI_Type_commit(&ptype);
    if(rank==3){
       point.x=15; point.y=23; point.z=6;
       MPI_Send(&point,1,ptype,1,52,MPI_COMM_WORLD);
    } else if(rank==1) {
       MPI_Recv(&point,1,ptype,3,52,MPI_COMM_WORLD,&status);
       printf("P:%d received coords are (%d,%d,%d)
   \n",rank,point.x,point.y,point.z);
    }
    MPI_Finalize();
 }
```

```
Program Output:
P:1 received coords are (15,23,6)
```

Sample Program #2 - Fortran

```
      PROGRAM contiguous
C Run with four processes
      INCLUDE 'mpif.h'
      INTEGER err, rank, size
      integer status(MPI_STATUS_SIZE)
      integer x,y,z
      common/point/x,y,z
      integer ptype
      CALL MPI_INIT(err)
      CALL MPI_COMM_RANK(MPI_COMM_WORLD,rank,err)
      CALL MPI_COMM_SIZE(MPI_COMM_WORLD,size,err)
      call MPI_TYPE_CONTIGUOUS(3,MPI_INTEGER,ptype,err)
      call MPI_TYPE_COMMIT(ptype,err)
      print *,rank,size
      if(rank.eq.3) then
         x=15
         y=23
         z=6
         call MPI_SEND(x,1,ptype,1,30,MPI_COMM_WORLD,err)
        else if(rank.eq.1)then
         call MPI_RECV(x,1,ptype,3,30,MPI_COMM_WORLD,status,err)
         print *,'P:',rank,' coords are ',x,y,z
        end if
      CALL MPI_FINALIZE(err)
      END
```

```
Program Output
P:1 coords are 15, 23, 6
```

Vector datatype

- User completely specifies memory locations defining the **vector**

C:

```
int MPI_Type_vector(int count, int blocklength, int stride,
MPI_Datatype oldtype, MPI_Datatype *newtype)
```

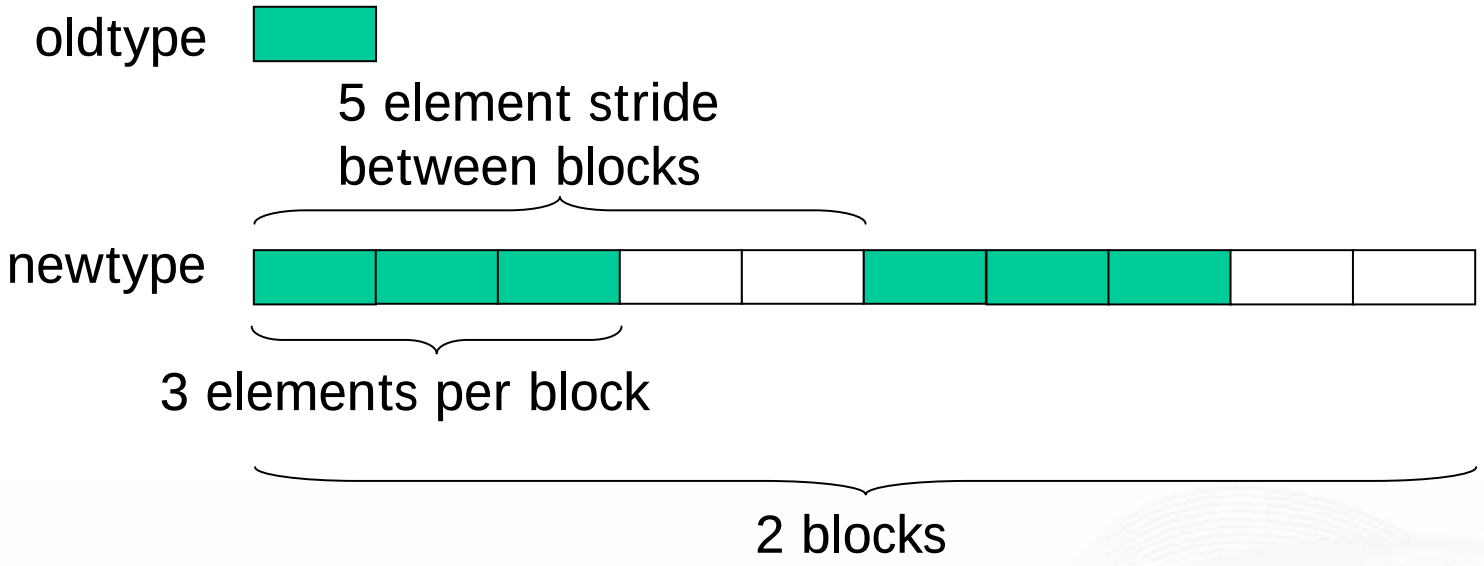
Fortran:

```
CALL MPI_TYPE_VECTOR(COUNT, BLOCKLENGTH, STRIDE,
                     OLDTYPE, NEWTYPE, IERROR)
```

- *newtype* has *count* blocks each consisting of *blocklength* copies of *oldtype*

- Displacement between blocks is set by *stride*

Vector datatype example



- `count` = 2
- `stride` = 5
- `blocklength` = 3

Sample Program #3 - C

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

 int main(int argc, char *argv[]) {
    int rank,i,j;
    MPI_Status status;
    double x[4][8];
    MPI_Datatype coltype;
    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD,&rank);
    MPI_Type_vector(4,1,8,MPI_DOUBLE,&coltype);
    MPI_Type_commit(&coltype);
    if(rank==3){
      for(i=0;i<4;++i)
       for(j=0;j<8;++j) x[i][j]=pow(10.0,i+1)+j;
      MPI_Send(&x[0][7],1,coltype,1,52,MPI_COMM_WORLD);
    } else if(rank==1) {
       MPI_Recv(&x[0][2],1,coltype,3,52,MPI_COMM_WORLD,&status);
       for(i=0;i<4;++i)printf("P:%d my x[%d][2]=%1f\n",rank,i,x[i][2]);
    }
    MPI_Finalize();
 }
```

```
        Program Output
P:1 my x[0][2]=17.000000
P:1 my x[1][2]=107.000000
P:1 my x[2][2]=1007.000000
P:1 my x[3][2]=10007.000000
```

Sample Program #3 - Fortran

```
      PROGRAM vector
C Run with four processes
      INCLUDE 'mpif.h'
      INTEGER err, rank, size
      integer status(MPI_STATUS_SIZE)
      real x(4,8)
      integer rowtype
      CALL MPI_INIT(err)
      CALL MPI_COMM_RANK(MPI_COMM_WORLD,rank,err)
      CALL MPI_COMM_SIZE(MPI_COMM_WORLD,size,err)
      call MPI_TYPE_VECTOR(8,1,4,MPI_REAL,rowtype,err)
      call MPI_TYPE_COMMIT(rowtype,err)
      if(rank.eq.3) then
        do i=1,4
         do j=1,8
          x(i,j)=10.0**i+j
         end do
        enddo
         call MPI_SEND(x(2,1),1,rowtype,1,30,MPI_COMM_WORLD,err)
        else if(rank.eq.1)then
         call MPI_RECV(x(4,1),1,rowtype,3,30,MPI_COMM_WORLD,status,err)
         print *,'P:',rank,' the 4th row of x is'
         do i=1,8
          print*,x(4,i)
         end do
        end if
      CALL MPI_FINALIZE(err)
      END
```

```
        Program Output
 P:1 the 4th row of x is
 101.
 102.
 103.
 104.
 105.
 106.
 107.
 108.
```

Extent of a datatype

- Handy utility function for datatype construction

- Extent defined to be the memory span (in bytes) of a datatype

C:

```
MPI_Type_extent (MPI_Datatype datatype, MPI_Aint* extent)
```

Fortran:

```
CALL MPI_TYPE_EXTENT (DATATYPE, EXTENT, IERROR)

INTEGER  DATATYPE, EXTENT, IERROR
```

Structure datatype

- Use for variables comprising heterogeneous datatypes
  - C structures
  - Fortran common blocks
- This is the most general derived datatype

C:

```
int MPI_Type_struct (int count, int *array_of_blocklengths,
            MPI_Aint *array_of_displacements,
            MPI_Datatype *array_of_types,
            MPI_Datatype *newtype)
```

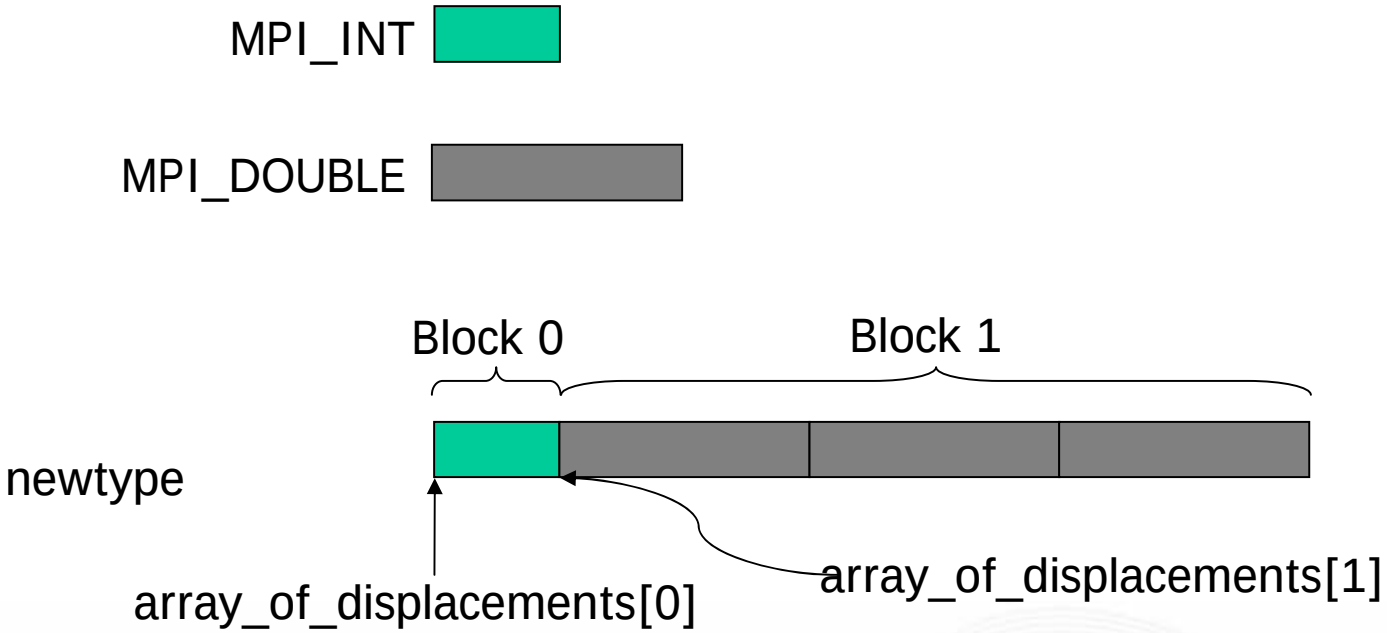
Fortran:

```
CALL MPI_TYPE_STRUCT(COUNT,ARRAY_OF_BLOCKLENGTHS,
            ARRAY_OF_DISPLACEMENTS,ARRAY_OF_TYPES,
            NEWTYPE,IERROR)
```

Structure datatype (cont.)

- *`newtype`* consists of `count` blocks where the *i*th block is `array_of_blocklengths[i]` copies of the type `array_of_types[i]`. The displacement of the *i*th block (in bytes) is given by `array_of_displacements[i]`.

Struct datatype example



- `count = 2`
- `array_of_blocklengths = {1,3}`
- `array_of_types = {MPI_INT, MPI_DOUBLE}`
- `array_of_displacements = {0, extent(MPI_INT)}`

Sample Program #4 - C

```
#include <stdio.h>
#include<mpi.h>
int main(int argc, char *argv[]) {
 int rank,i;
 MPI_Status status;
 struct {
    int num;
    float x;
    double data[4];
 } a;
 int blocklengths[3]={1,1,4};
 MPI_Datatype types[3]={MPI_INT, MPI_FLOAT, MPI_DOUBLE};
 MPI_Aint displacements[3];
 MPI_Datatype restype;
 MPI_Aint intex, floatex;
 MPI_Init(&argc, &argv);
 MPI_Comm_rank(MPI_COMM_WORLD, &rank);
 MPI_Type_extent(MPI_INT, &intex);MPI_Type_extent(MPI_FLOAT, &floatex);
 displacements[0] = (MPI_Aint) 0; displacemtnts[1] = intex;
 displacements[2] = intex+floatex;
 MPI_Type_struct(3, blocklengths, displacements, types, &restype);
```

Sample Program #4 - C (cont.)

```
...
   MPI_Type_commit(&restype);
   if (rank==3){
      a.num=6; a.x=3.14; for(i=0;i 4;++i) a.data[i]=(double) i;
      MPI_Send(&a,1,restype,1,52,MPI_COMM_WORLD);
   } else if(rank==1) {
      MPI_Recv(&a,1,restype,3,52,MPI_COMM_WORLD,&status);
      printf("P:%d my a is %d %f %lf %lf %lf %lf\n",

      rank,a.num,a.x,a.data[0],a.data[1],a.data[2],a.data[3]);
    }
    MPI_Finalize();
}
```

Program output

```
P:1 my a is 6 3.140000 0.000000 1.000000 2.000000 3.000002
```

Sample Program #4 - Fortran

```
PROGRAM structure
INCLUDE 'mpif.h'
INTEGER err, rank, size
integer status(MPI_STATUS_SIZE)
integer num
real x
complex data(4)
common /result/num,x,data
integer blocklengths(3)
data blocklengths/1,1,4/
integer displacements(3)
integer types(3),restype
data types/MPI_INTEGER,MPI_REAL,MPI_COMPLEX/
integer intex,realex
CALL MPI_INIT(err)
CALL MPI_COMM_RANK(MPI_COMM_WORLD,rank,err)
CALL MPI_COMM_SIZE(MPI_COMM_WORLD,size,err)
call MPI_TYPE_EXTENT(MPI_INTEGER,intex,err)
call MPI_TYPE_EXTENT(MPI_REAL,realex,err)
displacements(1)=0
displacements(2)=intex
displacements(3)=intex+realex
```

Sample Program #4 - Fortran (cont.)

```
 call MPI_TYPE_STRUCT(3,blocklengths, displacements,types,
&                     restype,err)
 call MPI_TYPE_COMMIT(restype,err)
 if(rank.eq.3) then
   num=6
   x=3.14
   do i=1,4
    data(i)=cmplx(i,i)
   end do
   call MPI_SEND(num,1,restype,1,30,MPI_COMM_WORLD,err)
  else if(rank.eq.1)then
   call MPI_RECV(num,1,restype,3,30,MPI_COMM_WORLD,status,err)
   print*,'P:',rank,' I got'
   print*,num
   print*,x
   print*,data
  end if
 CALL MPI_FINALIZE(err)
 END
```

Program Output

```
P:1 I got
6
3.1400001
(1.,1.), (2.,2.), (3.,3.), (4.,4.)
```

Committing a datatype

- Once constructed, datatype must be committed (MPI_TYPE_COMMIT) before it is used
- Creates a formal description of a communication buffer and makes it ready for use

C:

```
int MPI_Type_commit (MPI_Datatype *datatype)
```

Fortran:

```
CALL MPI_TYPE_COMMIT (DATATYPE, IERROR)
```

Class Exercise: "Structured" Ring

- Modify the calculating ring exercise
- Calculate two separate sums:
  - rank integer sum, as before
  - rank floating point sum
- Use an MPI structure datatype in this problem

Extra Exercise: Matrix Block

- Write an MPI program in which two processes exchange a sub-array (corner, boundary, etc) of a two-dimensional array. How does the time taken for one message vary as a function of sub-array size?