

Derived Datatypes



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MPI Datatypes

- Basic types
- Derived types
 - vectors
 - structs
 - others

Basic datatypes

```
int x[10];  
INTEGER:: x(10);  
  
// send all 10 values  
MPI_Send(x, 10, MPI_INT, ...);  
MPI_SEND(x, 10, MPI_INTEGER, ...)
```



```
// send first 4 values  
MPI_Send(&x[0], 4, ...);  
MPI_SEND(x(1), 4, ...)
```



```
// send 5th, 6th, 7th, 8th  
MPI_Send(&x[4], 4, ...);  
MPI_SEND(x(5), 4, ...)
```



```
// ??  
struct mystruct x[10];  
type(mytype) :: x(10)
```



Motivation

- Send / Recv calls need a datatype argument
 - pre-defined values exist for pre-defined language types
 - e.g. `real <-> MPI_REAL; int <-> MPI_INT`
- What about types defined by a program?
 - e.g. structures (in C) or user-defined types (Fortran)
- **Send / Recv** calls take a count parameter
 - what about data that isn't contiguous in memory?
 - e.g. subsections of 2D arrays

Approach

- Can define new types in MPI
 - user calls setup routines to describe new data type to MPI
 - remember, MPI is a library and NOT a compiler!
 - MPI returns a new data type handle
 - store this value in a variable, e.g. **MPI_MY_NEWTYPE**
- Derived types have same status as pre-defined
 - can use in any message-passing call
- Some care needed for reduction operations
 - user must also define a new **MPI_Op** appropriate to the new data type to tell MPI how to combine them

Defining types

- All derived types stored by MPI as a list of basic types and displacements (in bytes)
 - for a structure, types may be different
 - for an array subsection, types will be the same
- User can define new derived types in terms of both basic types and other derived types

Derived Data types - Type

basic datatype 0	displacement of datatype 0
basic datatype 1	displacement of datatype 1
...	...
basic datatype n-1	displacement of datatype n-1

Contiguous Data

- 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:

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

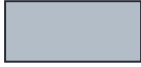
```
INTEGER COUNT, OLDTYPE, NEWTYPE, IERROR
```

Use of contiguous

- May make program clearer to read
- Imagine sending a block of 4 integers
 - use `MPI_Ssend` with `MPI_INT` / `MPI_INTEGER` and `count = 4`
- Or ...
 - define a new contiguous type of 4 integers called `BLOCK4`
 - use `MPI_Ssend` with `type=BLOCK4` and `count = 1`
- May also be useful intermediate stage in building more complicated types
 - i.e. later used in definition of another derived type

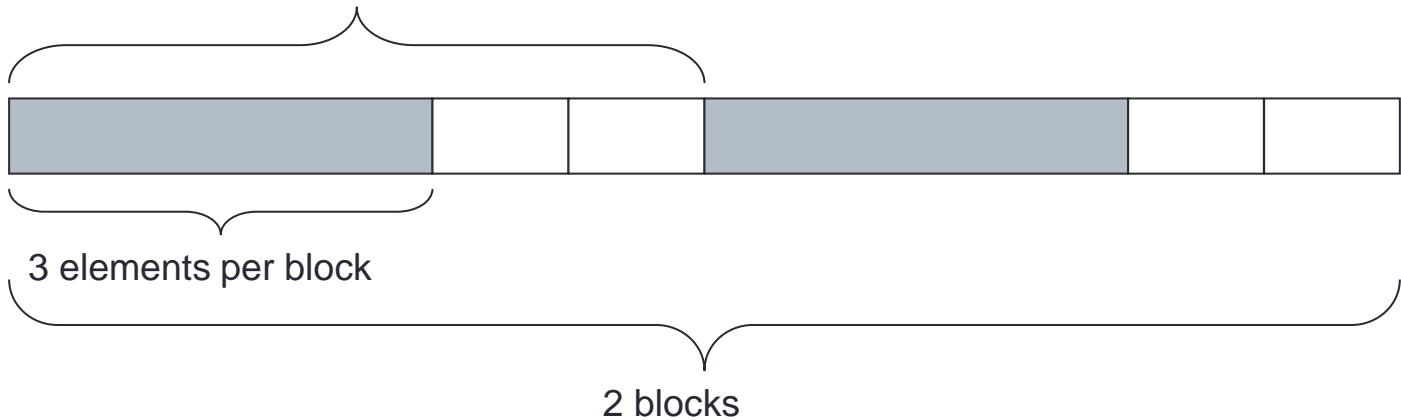
Vector Datatype Example

Oldtype



5 element stride
between blocks

Newtype



- $\text{count} = 2$
- $\text{stride} = 5$
- $\text{blocklength} = 3$

What is a vector type?

- Why is a pattern with blocks and gaps useful?

A vector type corresponds to a subsection of a 2D array

- Think about how arrays are stored in memory
 - unfortunately, different conventions for C and Fortran!
 - must use statically allocated arrays in C because dynamically allocated arrays (using `malloc`) have no defined storage format
 - In Fortran, can use either static or allocatable arrays

Coordinate System (how I draw arrays)

$x[i][j]$

j



i

$x(i, j)$

$x[0][3]$	$x[1][3]$	$x[2][3]$	$x[3][3]$
$x[0][2]$	$x[1][2]$	$x[2][2]$	$x[3][2]$
$x[0][1]$	$x[1][1]$	$x[2][1]$	$x[3][1]$
$x[0][0]$	$x[1][0]$	$x[2][0]$	$x[3][0]$

$x(1, 4)$	$x(2, 4)$	$x(3, 4)$	$x(4, 4)$
$x(1, 3)$	$x(2, 3)$	$x(3, 3)$	$x(4, 3)$
$x(1, 2)$	$x(2, 2)$	$x(3, 2)$	$x(4, 2)$
$x(1, 1)$	$x(2, 1)$	$x(3, 1)$	$x(4, 1)$

Memory Layout

- You can choose to draw arrays however you like – how you draw them does not change reality!

First index i	Second index j	Format
right	up	coordinates
down	right	matrix
right	down	graphics (scan lines)

- Regardless of how you draw them, the layout in memory is:
 - $x[i][j]$ is followed by $x[i][j+1]$ (in C)
 - $x(i, j)$ is followed by $x(i+1, j)$ (in Fortran)
 - if you create arrays with malloc in C/C++ things are more complicated ...
- Depending on how you draw them, this can appear “row major” or “column major”

Array Layout in Memory

C: $\mathbf{x}[16]$

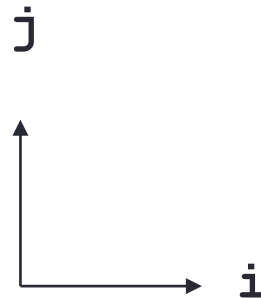
F: $\mathbf{x}(16)$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----

C: $\mathbf{x}[4][4]$

F: $\mathbf{x}(4, 4)$

4	8	12	16
3	7	11	15
2	6	10	14
1	5	9	13

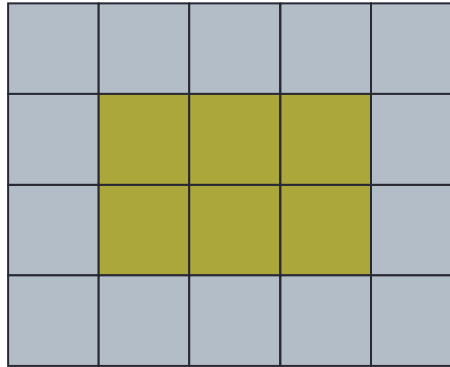


13	14	15	16
9	10	11	12
5	6	7	8
1	2	3	4

- Data is contiguous in memory
 - different conventions for mapping 2D to 1D arrays in C and Fortran

C example

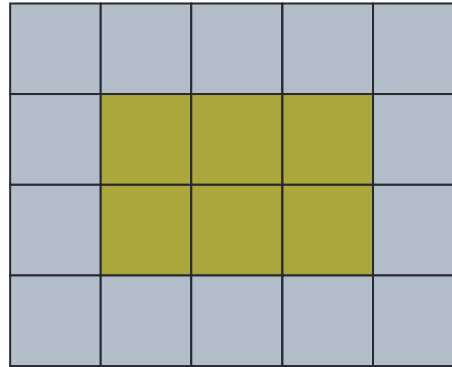
C: **x**[5][4]



- A 3 x 2 subsection of a 5 x 4 array
 - three blocks of two elements separated by gaps of two

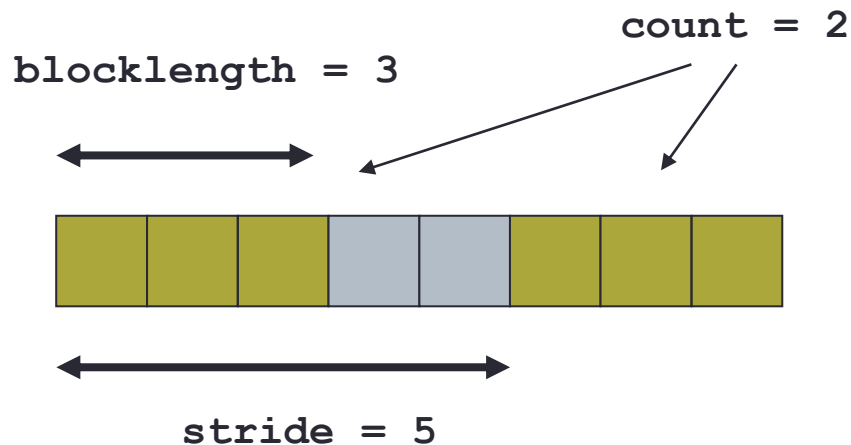
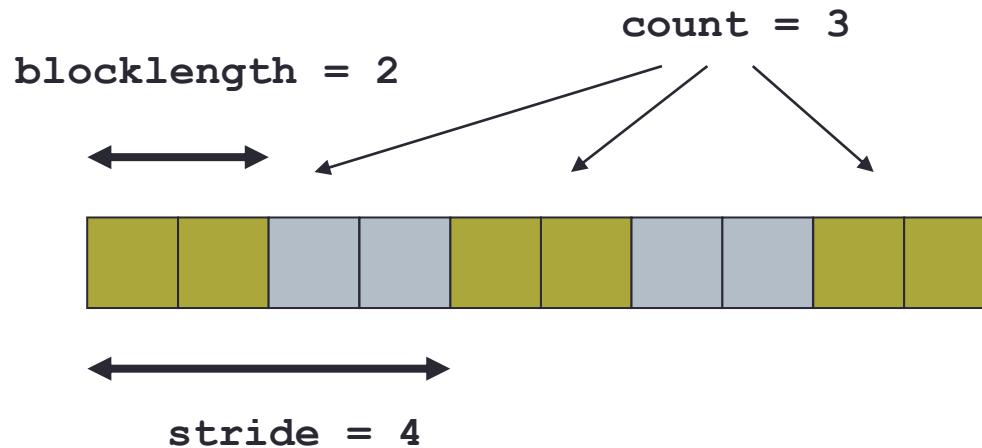
Fortran example

F: $\mathbf{x}(5, 4)$



- A 3 x 2 subsection of a 5 x 4 array
 - two blocks of three elements separated by gaps of two

Equivalent Vector Datatypes



Constructing a Vector Datatype

- C:

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

- Fortran:

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

Sending a vector

- Have defined a **3x2** subsection of a **5x4** array
 - but not defined WHICH subsection
 - is it the bottom left-hand corner? top-right?
- Data that is sent depends on what buffer you pass to the send routines
 - pass the address of the first element that should be sent

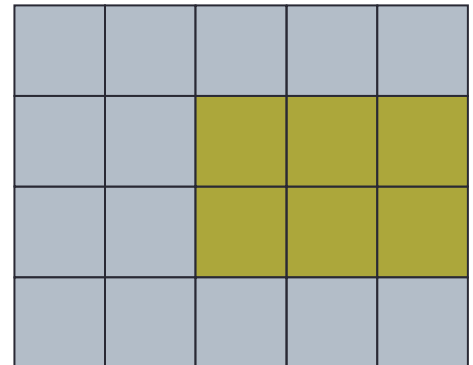
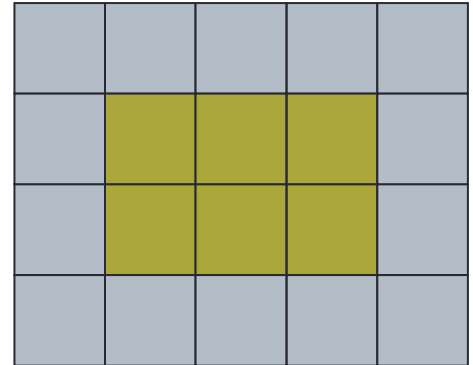
Vectors in send routines

```
MPI_Ssend(&x[1][1], 1, vector3x2, ...);
```

```
MPI_SSEND(x(2,2) , 1, vector3x2, ...)
```

```
MPI_Ssend(&x[2][1], 1, vector3x2, ...);
```

```
MPI_SSEND(x(3,2) , 1, vector3x2, ...)
```



Extent of a Datatype

- May be useful to find out how big a derived type is
 - extent is distance from start of first to end of last data entry
 - can use these routines to compute extents of basic types too
 - answer is returned in bytes

- C:

```
int MPI_Type_get_extent (MPI_Datatype datatype,  
                        MPI_Aint *extent)
```

- Fortran:

```
MPI_TYPE_GET_EXTENT( DATATYPE, EXTENT, IERROR)  
INTEGER DATATYPE, EXTENT, IERROR
```

Structures

- Can define compound objects in C and Fortran

<pre>struct compound { int ival; double dval[3]; };</pre>	<pre>type compound integer :: ival double precision :: dval(3) end type compound</pre>
--	---

- Storage format NOT defined by the language
 - different compilers do different things
 - e.g. insert arbitrary padding between successive elements
 - need to tell MPI the byte displacements of every element

Constructing a Struct Datatype

- C:

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

- Fortran:

```
MPI_TYPE_CREATE_STRUCT (COUNT,  
    ARRAY_OF_BLOCKLENGTHS,  
    ARRAY_OF_DISPLACEMENTS,  
    ARRAY_OF_TYPES, NEWTYPE, IERROR)
```


Struct Datatype Example

- `count = 2`
- `array_of_blocklengths[0] = 1`
- `array_of_types[0] = MPI_INT`
- `array_of_blocklengths[1] = 3`
- `array_of_types[1] = MPI_DOUBLE`
- But how do we compute the displacements?
 - need to create a compound variable in our program
 - explicitly compute memory addresses of every member
 - subtract addresses to get displacements from origin

Address of a Variable

- C:

```
int MPI_Get_address (void *location,  
                    MPI_Aint *address);
```

- Fortran:

```
MPI_GET_ADDRESS (LOCATION, ADDRESS, IERROR)
```

```
<type> LOCATION (*)
```

```
INTEGER (KIND=MPI_ADDRESS_KIND) ADDRESS
```

```
INTEGER IERROR
```

Committing a datatype

- Once a datatype has been constructed, it needs to be committed before it is used in a message-passing call
- This is done using **MPI_TYPE_COMMIT**

- C:

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

- Fortran:

```
MPI_TYPE_COMMIT (DATATYPE, IERROR)  
INTEGER DATATYPE, IERROR
```

Exercise

Derived Datatypes

- See Exercise 8 on the sheet
- Modify the passing-around-a-ring exercise.
- Calculate two separate sums:
 - rank integer sum, as before
 - rank floating point sum
- Use a **struct datatype** for this.
- If you are a Fortran programmer unfamiliar with Fortran derived types then jump to exercise 8.2
 - illustrates the use of **MPI_Type_vector**