

# 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

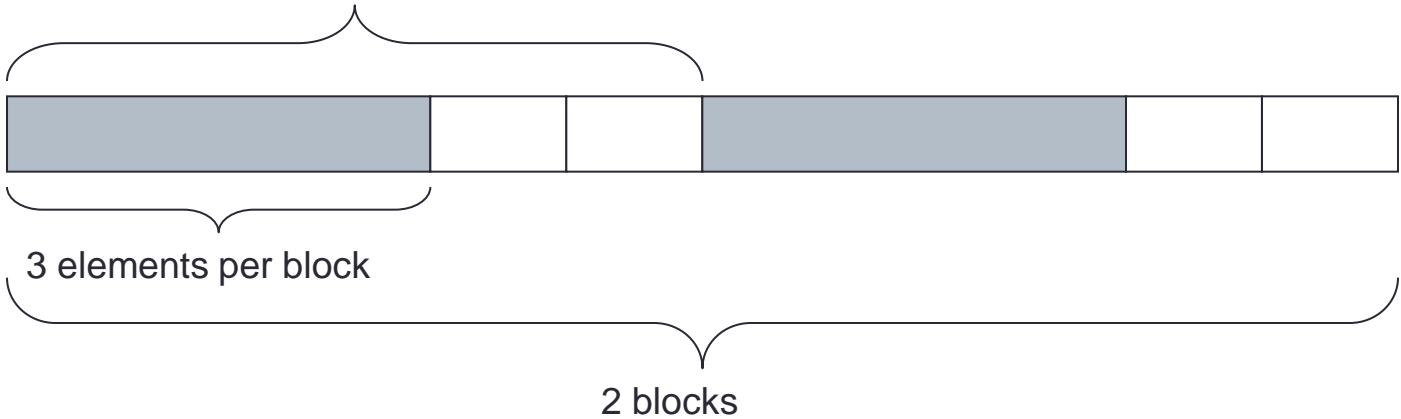
# Vector Datatype Example

Oldtype



5 element stride  
between blocks

Newtype



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

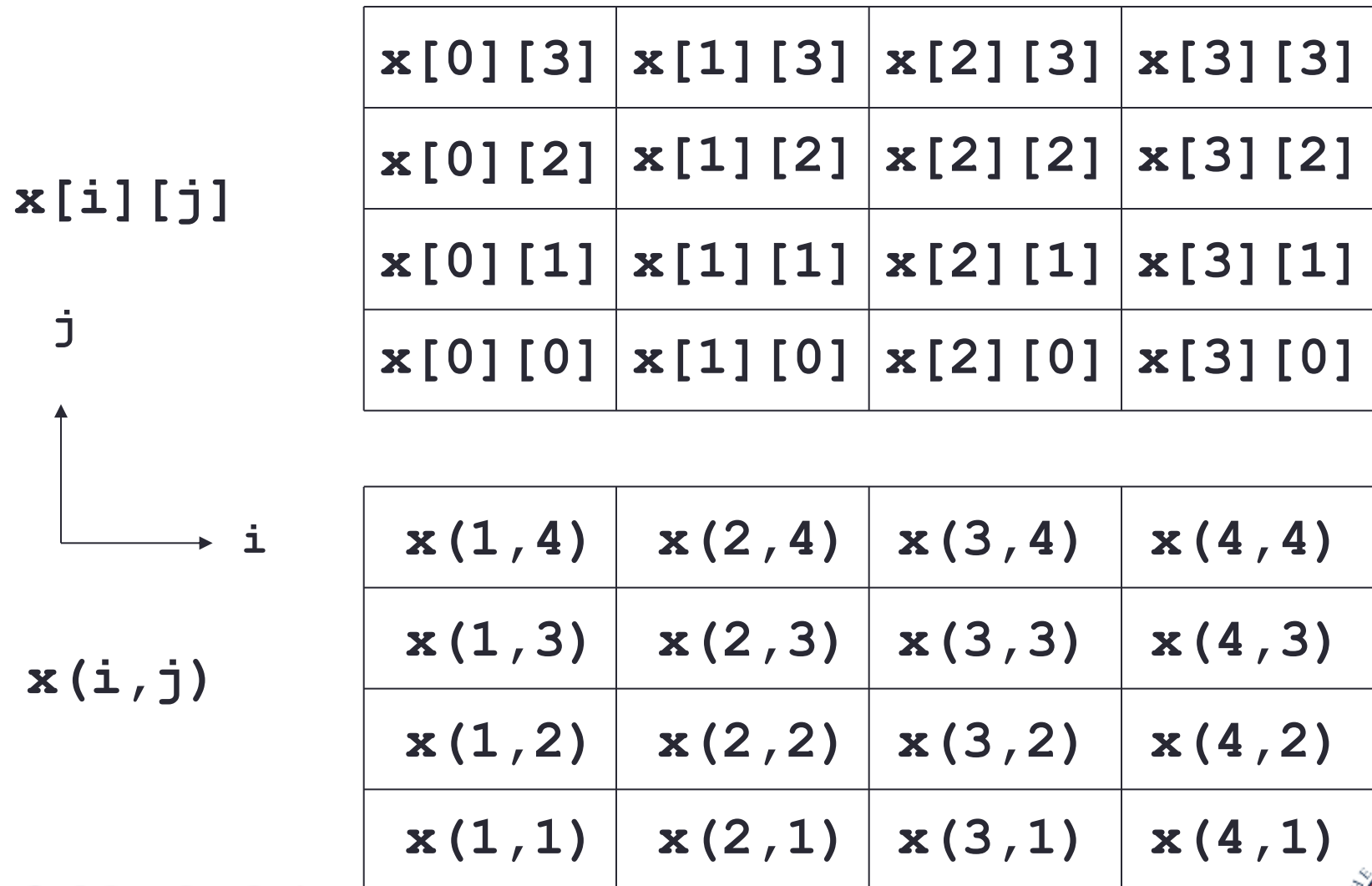
# What is a vector type?

- 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)



# 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

# Memory Layout

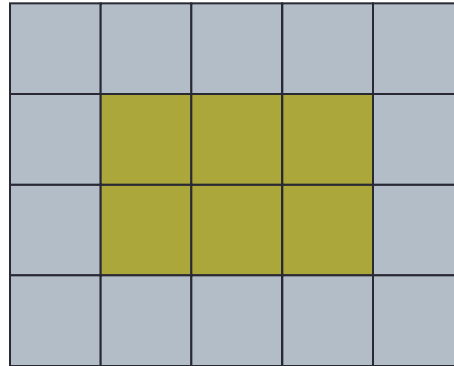
- You can choose to draw arrays however you like – how you draw them does not change reality!

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”

# C example

C: `x[5][4]`

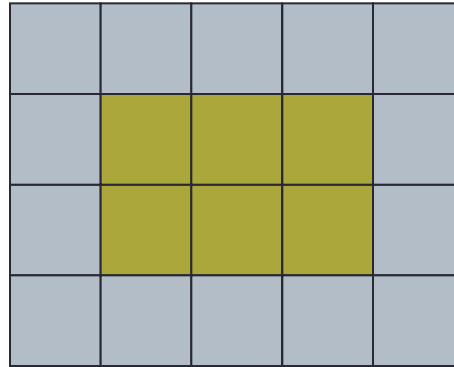


- A 3 x 2 subsection of a 5 x 4 array
  - three blocks of two elements separated by gaps of two



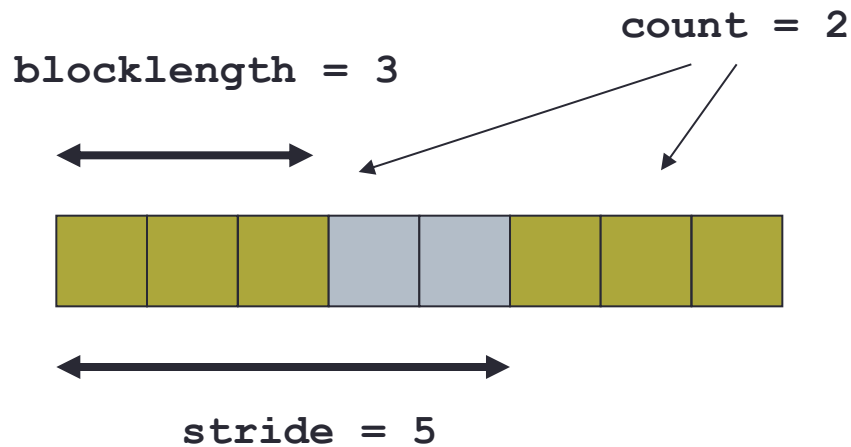
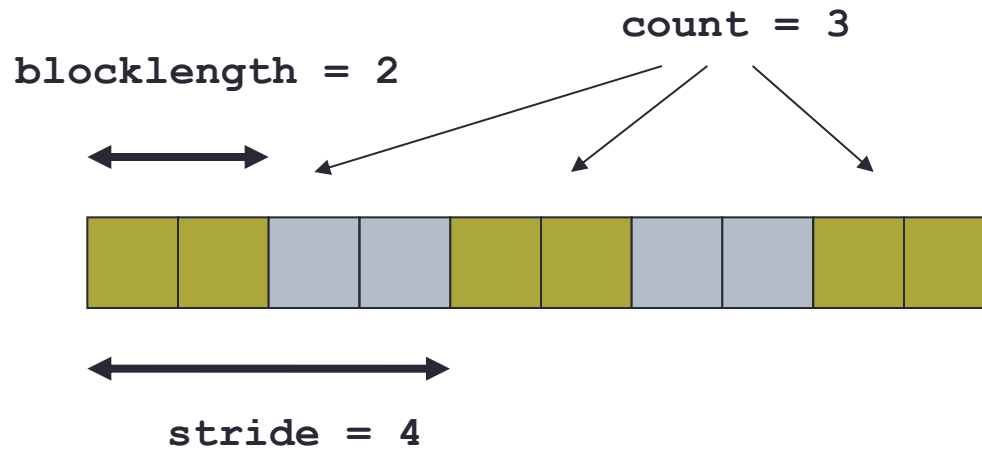
# Fortran example

F:  $x(5, 4)$



- 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

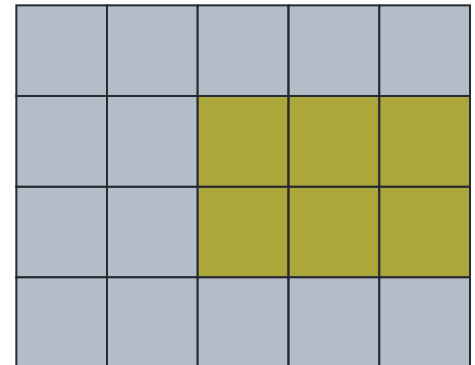
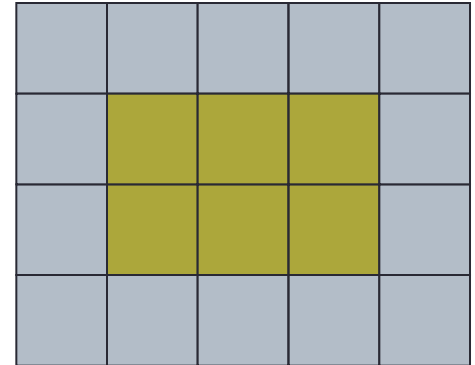
# Vectors in send routines

```
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

```
struct compound {          type compound
    int    ival;           integer           :: ival
    double dval[3];       double precision :: dval(3)
};                          end type compound
```

- 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 7.1 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 7.2
  - illustrates the use of **MPI\_Type\_vector**