MPI
derived datatypes

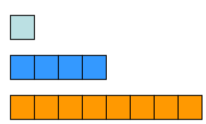
Edgar Gabriel

Derived Datatypes

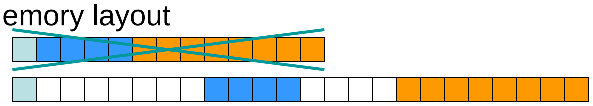
- Basic idea: interface to describe memory layout of user data structures

e.g. a structure in C

```
typedef struct {
  char     a;
  int      b;
  double   c;
} mystruct;
```

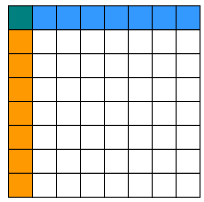


Memory layout

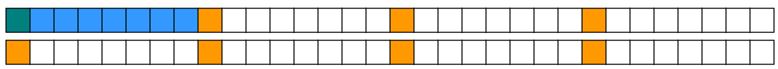


Derived Datatype examples

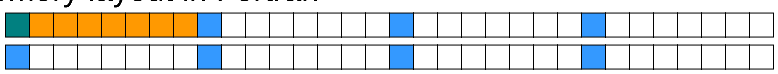
- E.g. describing a column or a row of a matrix



- Memory layout in C

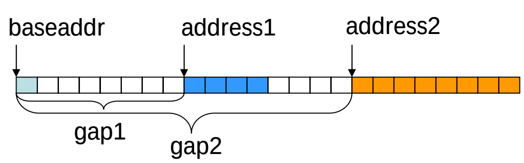


- Memory layout in Fortran



How to describe non-contiguous data structures

```
typedef struct {
   char       a;
   int        b;
   double     c;
} mystruct;
```



- using a list-I/O interface, e.g. <address, size>

```
<baseaddr, sizeof(char)>
<address1, sizeof(int)>
<address2, sizeof(double)>
```

- or

```
<baseaddr,      sizeof(char)>
<baseaddr+gap1, sizeof(int)>
<baseaddr+gap2, sizeof(double)>
```

…or in MPI terminology…

- a list of <address, count, datatype> sequences

```
<baseaddr,      1, MPI_CHAR>
<baseaddr+gap1, 1, MPI_INT>
<baseaddr+gap2, 1, MPI_DOUBLE>
```

- …leading to the following interface…

```
MPI_Type_struct (int count, int blocklength[],
    MPI_Aint displacements[], MPI_Datatype datatypes[],
    MPI_Datatype *newtype );
```

MPI-2

```
MPI_Type_create_struct (int count, int blocklength[],
    MPI_Aint displacements[], MPI_Datatype datatypes[],
    MPI_Datatype *newtype );
```

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MPI_Type_struct/MPI_Type_create_struct

- MPI_Aint:
  - Is an MPI Address integer
  - An integer being able to store a memory address
- Displacements are considered to be relative offsets
  - ⇒ displacement[0] = 0 in most cases!
  - ⇒ Displacements are not required to be positive, distinct or in increasing order

- How to determine the address of an element

```
MPI_Address (void *element, MPI_Aint *address);
```

MPI-2

```
MPI_Get_address (void *element, MPI_Aint *address);
```

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Addresses in MPI

- Why not use the & operator in C ?
  - ANSI C does NOT require that the value of the pointer returned by & is the absolute address of the object!
  - Might lead to problems in segmented memory space
  - Usually not a problem
- In Fortran: all data elements passed to a single MPI_Type_struct call have to be in the same `common` -block

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Type map vs. Type signature

- Type signature is the sequence of basic datatypes used in a derived datatype, e.g.

  `typesig(mystruct) = {char, int, double}`
- Type map is sequence of basic datatypes + sequence of displacements

  `typemap(mystruct) = {(char,0),(int,8),(double,16)}`
- Type matching rule of MPI: type signature of sender and receiver has to match
  - Including the count argument in Send and Recv operation (e.g. unroll the description)
  - Receiver must not define overlapping datatypes
  - The message need not fill the whole receive buffer

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Committing and freeing a datatype

- If you want to use a datatype for communication or in an MPI-I/O operation, you have to commit it first

```
MPI_Type_commit (MPI_Datatype *datatype);
```

- Need not commit a datatype, if just used to create more complex derived datatypes

```
MPI_Type_free (MPI_Datatype *datatype);
```

- It is illegal to free any predefined datatypes

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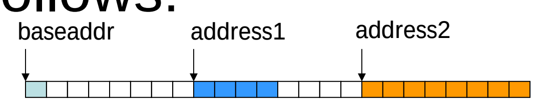
Our previous example looks like follows:




```
mystruct mydata;

MPI_Address ( &mydata,   &baseaddr);
MPI_Address ( &mydata.b, &addr1);
MPI_Address ( &mydata.c, &addr2);

displ[0] = 0;
displ[1] = addr1 – baseaddr;
displ[2] = addr2 – baseaddr;

dtype[0] = MPI_CHAR;              blength[0] = 1;
dtype[1] = MPI_INT;               blength[1] = 1;
dtype[2] = MPI_DOUBLE;            blength[2] = 1;

MPI_Type_struct ( 3, blength, displ, dtype, &newtype );
MPI_Type_commit ( &newtype );
```

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Basically we are done…

- With MPI_Type_struct we can describe any pattern in the memory
- Why other MPI datatype constructors ?
  - Because description of some datatypes can become rather complex
  - For convenience

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MPI_Type_contiguous

```
MPI_Type_contiguous ( int count, MPI_Datatype datatype,
                      MPI_Datatype *newtype );
```

- `count` elements of the same datatype forming a contiguous chunk in the memory

```
int myvec[4];
MPI_Type_contiguous ( 4, MPI_INT, &mybrandnewdatatype);
MPI_Type_commit ( &mybrandnewdatatype );
MPI_Send ( myvec, 1, mybrandnewdatatype, … );
```

- Input datatype can be a derived datatype
  - End of one element of the derived datatype has to be exactly at the beginning of the next element of the derived datatype

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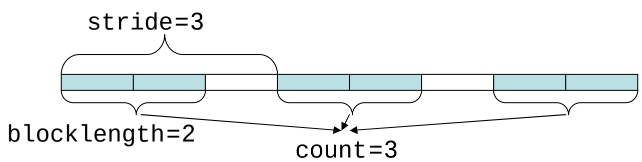
MPI_Type_vector

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

- `count` blocks of `blocklength` elements of the same datatype
- Between the start of each block there are `stride` elements of the same datatype



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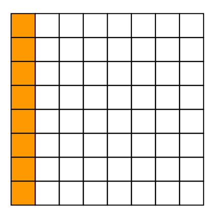
Example using MPI_Type_vector

- Describe a column of a 2-D matrix in C



```
dtype   = MPI_DOUBLE;
stride  = 8;
blength = 1;
count   = 8;

MPI_Type_vector (count,blength,stride,dtype,&newtype);
MPI_Type_commit (&newtype);
```

- Which column you are really sending depends on the pointer which you pass to the according MPI_Send routine!

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MPI_Type_hvector

```
MPI_Type_hvector( int count, int blocklength,
        MPI_Aint stride, MPI_Datatype datatype,
        MPI_Datatype *newtype );
```

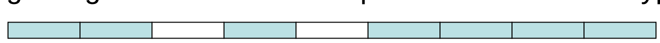
```
MPI_Type_create_hvector( int count, int blocklength,
        MPI_Aint stride, MPI_Datatype datatype,
        MPI_Datatype *newtype );
```

- Identical to MPI_Type_vector, except that the stride is given in bytes rather than in number of elements

MPI_Type_indexed

```
MPI_Type_indexed( int count, int blocklengths[],
        int displacements[], MPI_Datatype datatype,
        MPI_Datatype *newtype );
```

- The number of elements per block do not have to be identical
- `displacements` gives the distance from the ‘base’ to the beginning of the block in multiples of the used datatype



```
count = 3     blocklengths[0] = 2 displacements[0] = 0
              blocklengths[1] = 1 displacements[1] = 3
              blocklengths[2] = 4 displacements[2] = 5
```

MPI_Type_hindexed

```
MPI_Type_hindexed( int count, int blocklengths[],
      MPI_Aint displacements[], MPI_Datatype datatype,
      MPI_Datatype *newtype );
MPI_Type_create_hindexed( int count, int blocklengths[],
      MPI_Aint displacements[], MPI_Datatype datatype,
      MPI_Datatype *newtype );
```

- Identical to MPI_Type_indexed, except that the displacements are given in bytes and not in multiples of the datatypes

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Duplicating a datatype

```
MPI_Type_dup(MPI_Datatype datatype,MPI_Datatype *newtype);
```

- Mainly useful for library developers, e.g. datatype ownership
- The new datatype has the same ‘committed’ state as the previous datatype
  - If datatype has already been committed, newtype is committed as well

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MPI_Type_create_subarray

```
MPI_Type_create_subarray (int ndims, int sizes[],
      int subsizes[], int starts[], int order,
      MPI_Datatype datatype,MPI_Datatype *newtype);
```

- Define sub-matrices of n-dimensional data
- `sizes[]`: dimension of the entire matrix
- `subsizes[]`: dimensions of the submatrix described by the derived data type
- `starts[]`: array describing the beginning of the submatrices
- Order: `MPI_ORDER_C` for row-major order or `MPI_ORDER_FORTRAN` for column-major data

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Example

Dimension 1

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64

Dimension 0

```
ndims =2
sizes[0]    = 8;    sizes[1] = 8;
subsizes[0]= 4; subsizes[1] = 2
starts[0]   = 2;   starts[1] = 4;
MPI_Type_create_subarray ( ndims, sizes, subsizes,
                    starts, MPI_ORDER_C, &newtype);
```

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More datatype constructors

```
MPI_Type_create_darray(int size, int rank, int
  ndims,    int gsizes[], int distribs[], int
  dargs[],  int psizes[], int order, MPI_Datatype
  datatype,      MPI_Datatype *newtype);
```

- Describe HPF-like data distributions

```
MPI_Type_create_indexed_block( int count,
      int blocklength, int displs[],
      MPI_Datatype datatype, MPI_Datatype
  *newtype );
```

- Further simplification of MPI_Type_indexed

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Portable vs. non-portable datatypes

- Any data type constructors using byte-offsets are considered non-portable
  – Might rely on data alignment rules given on various platforms
- Non-portable datatype constructors:
  – `MPI_Type_struct`
  – `MPI_Type_hvector/MPI_Type_create_hvector`
  – `MPI_Type_hindexed/MPI_Type_create_hindexed`
- Non-portable datatypes are not allowed to be used in
  – one-sided operations
  – parallel File I/O operations

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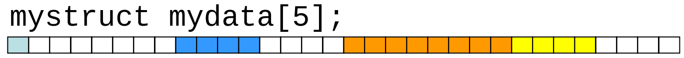
A problem with the specification up to now

```
typedef struct {
  char     a;
  int      b;
  double   c;
  float    d;
} mystruct;
mystruct mydata[5];
```



- …but just want to send b and c of the structure, however multiple elements of `mystruct`

…simple description…

```
MPI_Address ( &(mydata[0],   &baseaddr);
MPI_Address ( &(mydata[0].b, &addr1);
MPI_Address ( &(mydata[0].c, &addr2);

displ[0] = addr1 - baseaddr;
displ[1] = addr2 – baseaddr;

dtype[0] = MPI_INT;        blength[0] = 1;
dtype[1] = MPI_DOUBLE;     blength[1] = 1;

MPI_Type_struct ( 2, blength, displ, dtype, &newtype );
MPI_Type_commit ( &newtype );
```

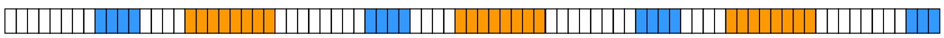
If we use this datatype….

- it is ok if we send one element

  `MPI_Send ( mydata, 1, newtype,…);`
- If we send more elements, all data at the receiver will be wrong, except for the first element

  `MPI_Send ( mydata, 5, newtype, …);`
- Memory layout

- What we send is



- What we wanted to do is

…so what we missed …

- …was to tell MPI where the next element of the structure starts
  - or in other words: we did not tell MPI where the begin and the end of the structure is

- Two ‘marker’ datatypes introduced in MPI
  - `MPI_LB:` lower bound of a structure
  - `MPI_UB:` upper bound of a structure

Correct description of the structure would be

```
MPI_Address ( &(mydata[0]),   &baseaddr);
MPI_Address ( &(mydata[0].b), &addr1);
MPI_Address ( &(mydata[0].c), &addr2);
MPI_Address ( &(mydata[1]),   &addr3);

displ[0] = 0;
displ[1] = addr1 - baseaddr;
displ[2] = addr2 – baseaddr;
displ[3] = addr3 – baseaddr;

dtype[0] = MPI_LB;        blength[0] = 1;
dtype[1] = MPI_INT;       blength[1] = 1;
dtype[2] = MPI_DOUBLE;    blength[2] = 1;
dtype[3] = MPI_UB;        blength[3] = 1;

MPI_Type_struct ( 4, blength, displ, dtype, &newtype );
```

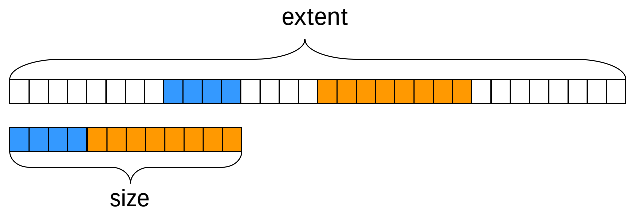

Determining upper- and lower bound

- Two functions to extract the upper and the lower bound of a datatype

```
MPI_Type_ub ( MPI_Datatype dat, MPI_Aint *ub );
MPI_Type_lb ( MPI_Datatype dat, MPI_Aint *lb );
```

extent vs. size of a datatype

```
MPI_Type_extent ( MPI_Datatype dat, MPI_Aint *ext);
MPI_Type_size ( MPI_Datatype dat, int *size );
```



extent := upper bound – lower bound;

size = amount of bytes really transferred

The MPI-2 view of the same problem (I)

- Problem with the way MPI-1 treats this problem: upper and lower bound can become messy, if you have derived datatype consisting of derived datatype consisting of derived datatype consisting of… and each of them has MPI_UB and MPI_LB set
- No way to erase upper and lower bound markers once they are set

- MPI-2 solution: reset the extent of the datatype

```
MPI_Type_create_resized ( MPI_Datatype datatype,
    MPI_Aint lb, MPI_Aint extent, MPI_Datatype
    *newtype );
```

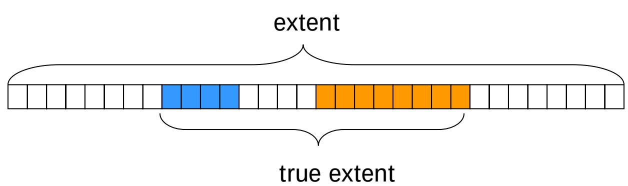
  – Erases all previous lb und ub markers

MPI-2 view of the same problem (II)

```
MPI_Type_get_true_extent ( MPI_Datatype dat,
      MPI_Aint *lb, MPI_Aint *extent );
```

The true extent

- Extent of the datatype ignoring UB and LB markers: all gaps in the middle are still considered, gaps at the beginning and at the end are removed
- E.g. required for intermediate buffering



Decoding MPI datatypes

- An important question for library developers:
  - Given a datatype handle, can I determine how it was created
  - Given a datatype handle, can I determine what memory layout it describes ?
- MPI-1: no
- MPI-2: yes ☺

MPI_Type_get_envelope

```
MPI_Type_get_envelope ( MPI_Datatype datatype,
        int *num_integers, int *num_addresses,
        int *num_datatypes, int *combiner );
```

- The `combiner` field returns how the datatype was created, e.g.
  - `MPI_COMBINER_NAMED:` basic datatype
  - `MPI_COMBINER_CONTIGUOS:` MPI_Type_contiguous
  - `MPI_COMBINER_VECTOR:` MPI_Type_vector
  - `MPI_COMBINER_INDEXED:` MPI_Type_indexed
  - `MPI_COMBINER_STRUCT:` MPI_Type_struct
- The other fields indicate how large the integer-array, the datatype-array, and the address-array has to be for the following call to `MPI_Type_get_contents`

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MPI_Type_get_contents

```
MPI_Type_get_contents ( MPI_Datatype datatype, int
        max_integer, int max_addresses, int max_datatypes,
        int *integers, int *addresses, MPI_Datatype *dts);
```

- Call is erroneous for a predefined datatypes
- If returned data types are derived datatypes, then objects are duplicates of the original derived datatypes. User has to free them using `MPI_Type_free`
- The values in the integer, addresses and datatype arrays are depending on the original datatype constructor
- Type decoding functions available for MPICH 1.2.5 or MPICH2 or LAM7.0.x

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Examples using MPI_Type_get_contents

- e.g. for MPI_Type_struct

```
count              integers[0]
blocklengths[]     integers[1] – integers[integers[0]]
displacements[]    addresses[0]–addresses[integers[0]-1]
datatypes[]        dts[0] – dts[integers[0]-1]
```

- e.g. for MPI_Type_contiguous

```
count              integers[0]
datatype           dts[0]
```

- For the complete list, see the MPI-2 specification

The Info-object

- General mechanism in MPI-2 to pass hints to the MPI library
- Used in
  - Dynamic processes management
  - One-sided operations
  - Parallel File I/O
- An Info-object is a pair of (`key`, `value`)
- `Key` and `value` are both character strings
- Separate functions introduced by MPI, since many languages do not have good support for handling character strings

The Info-object cont.

- `Key` and `value` are case-sensitive
- A `key` may just have one `value` attached to it
- If an implementation does not recognize a `key`, it will ignore it
- Maximum length for key: `MPI_MAX_INFO_KEY`
- Maximum length for value: `MPI_MAX_INFO_VAL`

Handling Info-objects

- Create a new Info object
```
MPI_Info_create ( MPI_Info *info );
```
- Add a (key, value) pair
  – Overrides previous value, if key already known
```
MPI_Info_set ( MPI_Info info, char *key, char *val);
```
- Delete a (key, value) pair
```
MPI_Info_delete ( MPI_Info info, char *key);
```
- Determine a value for a certain key
  – Flag indicates, whether key was recognized
```
MPI_Info_get ( MPI_Info info, char *key, int valuelen,
     char *val, int *flag);
```
- Destroy an Info object
```
MPI_Info_free ( MPI_Info *info);
```