SLING

Advanced MPI

Parallel File I/O

EURO

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Acknowledgments

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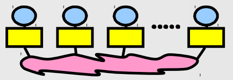
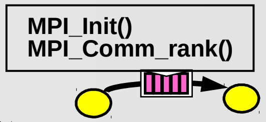
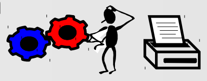
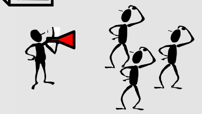
Chap.13 Parallel File I/O

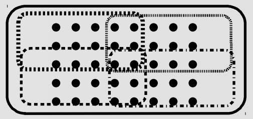
Parallel File I/O

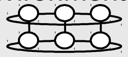


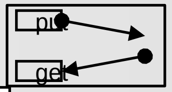


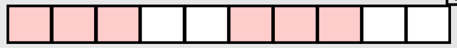


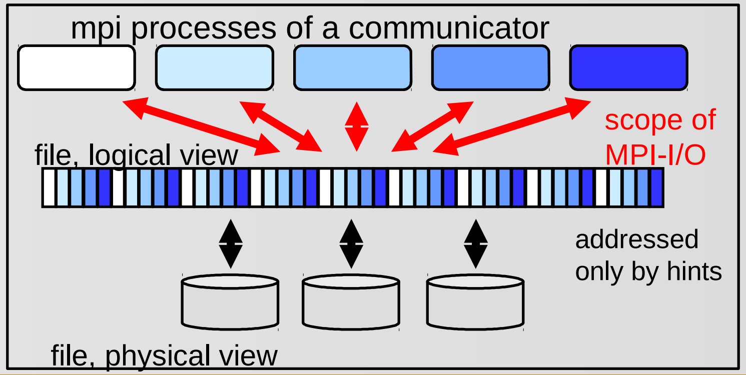












Outline

Motivation, I.

- Many parallel applications need
  - coordinated parallel access to a file by a group of processes
  - simultaneous access
  - all processes may read/write many (small) non-contiguous pieces of the file,
    i.e. the data may be distributed amongst the processes according to a partitioning scheme
  - all processes may read the same data
- Efficient collective I/O based on
  - fast physical I/O by several processors, e.g. striped
  - distributing (small) pieces by fast message passing

Motivation, II.

- Analogy: writing / reading a file is like
  sending/receiving a message
- Handling parallel I/O needs

handling groups of processes	->	MPI topologies and groups
collective operations	->	file handle defined like communicators
nonblocking operations to overlap computation & I/O	->	MPI_I..., MPI_Wait, ... new **split** collective interface
non-contiguous access	->	MPI derived datatypes

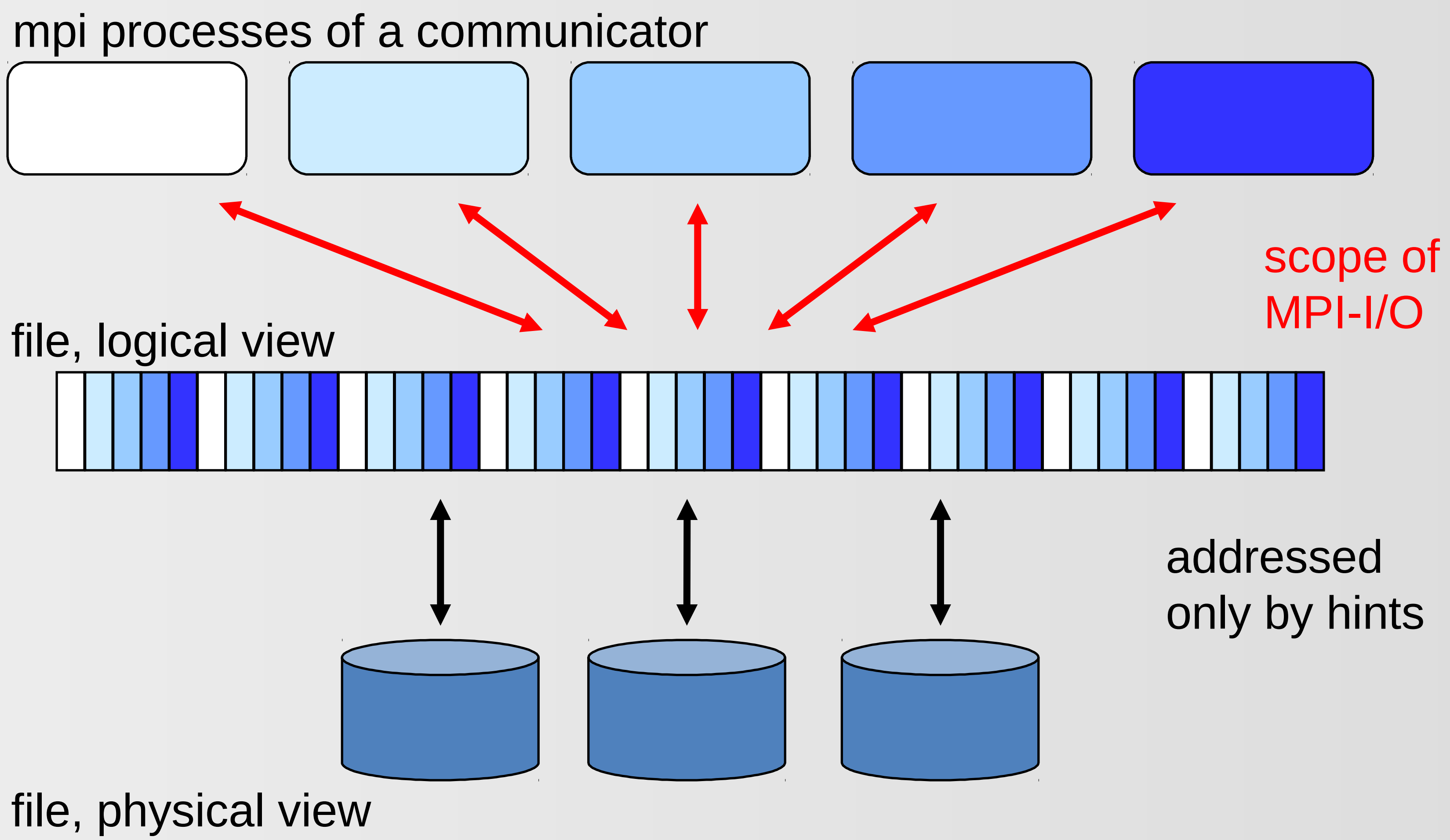
MPI-I/O Features

- Provides a high-level interface to support
  - data file partitioning among processes
  - transfer global data between memory and files (collective I/O)
  - asynchronous transfers
  - strided access
- MPI derived datatypes used to specify common data access patterns for maximum flexibility and expressiveness

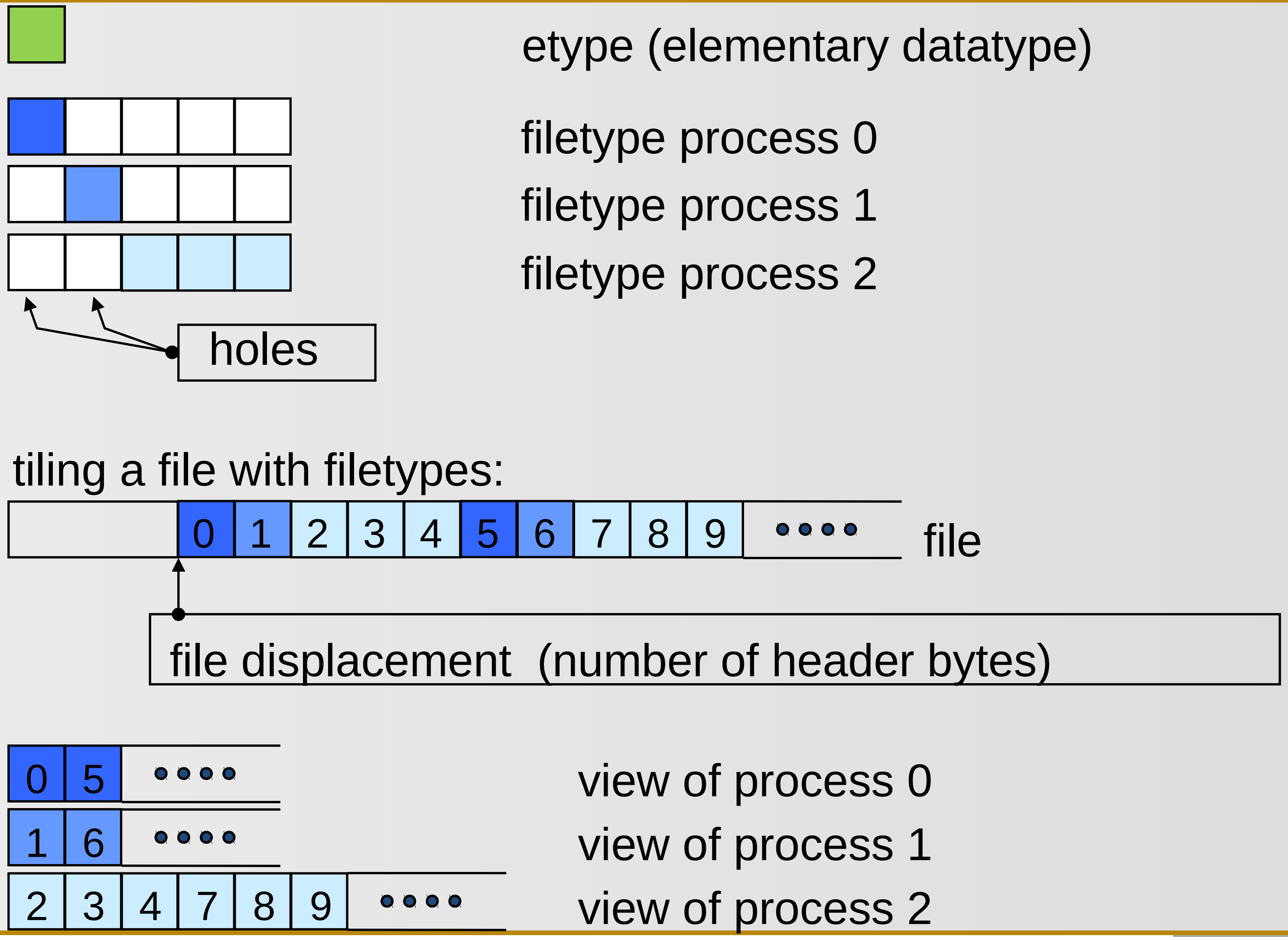
MPI-I/O Principles

- MPI file contains elements of a single MPI datatype (etype)
- partitioning the file among processes with an access template (filetype)
- all file accesses transfer to/from a contiguous or
  non-contiguous user buffer (MPI datatype)
- nonblocking / blocking and collective / individual read / write routines
- individual and shared file pointers, explicit offsets
- binary I/O
- automatic data conversion in heterog. systems
- file interoperability with external representation

Logical view / Physical view



Definitions



Comments on Definitions

file	- an ordered collection of typed data items
etypes	- is the unit of data access and positioning / offsets
	- can be any basic or derived datatype (with non-negative, monotonically non-decreasing, non-absolute displacem.)
	- generally contiguous, but need not be
	- typically same at all processes
filetypes	- the basis for partitioning a file among processes
	- defines a template for accessing the file
	- different at each process
	- the etype or derived from etype (displacements: non-negative, monoton. non-decreasing, non-abs., <u>multiples of etype extent</u>)
view	- each process has its own view, defined by: a displacement, an etype, and a filetype.
	- The filetype is repeated, starting at **displacement**
offset	- position relative to current view, in units of etype

Opening an MPI File

- MPI_FILE_OPEN is collective over **`comm`**
- filename's namespace is implementation-dependent!
- filename must reference the same file on all processes
- process-local files can be opened by passing MPI_COMM_SELF as **`comm`**
- returns a file handle *fh*
  [*represents the file, the process group of* **`comm`**, *and the current view*]

```
MPI_FILE_OPEN(comm, filename, amode, info, fh)
```

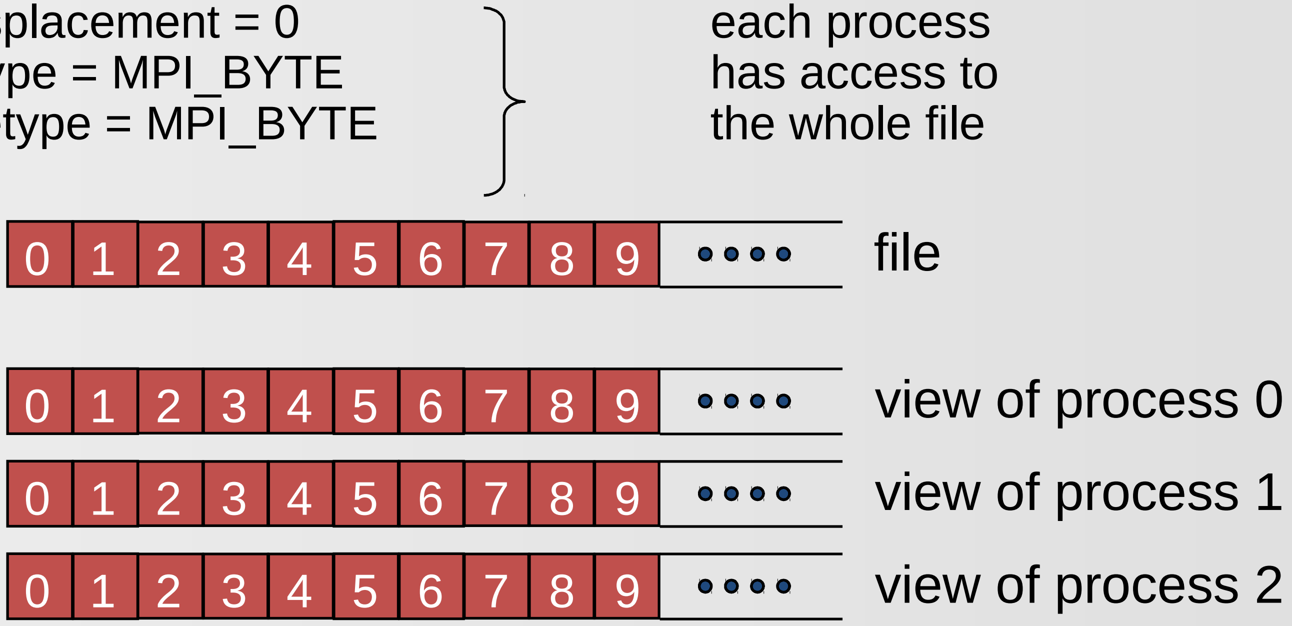
Fortran C/C++ language bindings – see MPI Standard

Default View

MPI_FILE_OPEN(comm, filename, amode, info, *fh*)

- Default:
  - displacement = 0
  - etype = MPI_BYTE
  - filetype = MPI_BYTE

each process
has access to
the whole file



- Sequence of MPI_BYTE matches with any datatype
  (see MPI-3.0, Section 13.6.5 on page 544 / MPI-3.1, Section 13.6.6 on page 549)
- Binary I/O (no ASCII text I/O)

Access Modes

- same value of **amode** on all processes in MPI_FILE_OPEN
- Bit vector OR of integer constants (Fortran 77: +)
  - MPI_MODE_RDONLY - read only
  - MPI_MODE_RDWR - reading and writing
  - MPI_MODE_WRONLY - write only
  - MPI_MODE_CREATE - create if file doesn’t exist
  - MPI_MODE_EXCL - error creating a file that exists
  - MPI_MODE_DELETE_ON_CLOSE - delete on close
  - MPI_MODE_UNIQUE_OPEN - file not opened concurrently
  - MPI_MODE_SEQUENTIAL - file only accessed sequentially: mandatory for sequential stream files (pipes, tapes, ...)
  - MPI_MODE_APPEND - all file pointers set to end of file [*caution: reset to zero by any subsequent MPI_FILE_SET_VIEW*]

File Info: Reserved Hints

- Argument in MPI_FILE_OPEN, MPI_FILE_SET_VIEW, MPI_FILE_SET_INFO
- reserved key values:
  - collective buffering
    - “collective_buffering”: specifies whether the application may benefit from collective buffering
    - “cb_block_size”: data access in chunks of this size
    - “cb_buffer_size”: on each node, usually a multiple of block size
    - “cb_nodes”: number of nodes used for collective buffering
  - disk striping (only relevant in MPI_FILE_OPEN)
    - “striping_factor”: number of I/O devices used for striping
    - “striping_unit”: length of a chunk on a device (in bytes)
- MPI_INFO_NULL may be passed

Closing and Deleting a File

- Close: collective

```
MPI_FILE_CLOSE(fh)
```

- Delete:
  - automatically by MPI_FILE_CLOSE

    if **`amode=MPI_DELETE_ON_CLOSE | …`**

    was specified in MPI_FILE_OPEN
  - deleting a file that is not currently opened:

```
MPI_FILE_DELETE(filename, info)
```

[*same implementation-dependent rules as in MPI_FILE_OPEN*]

Writing with Explicit Offsets

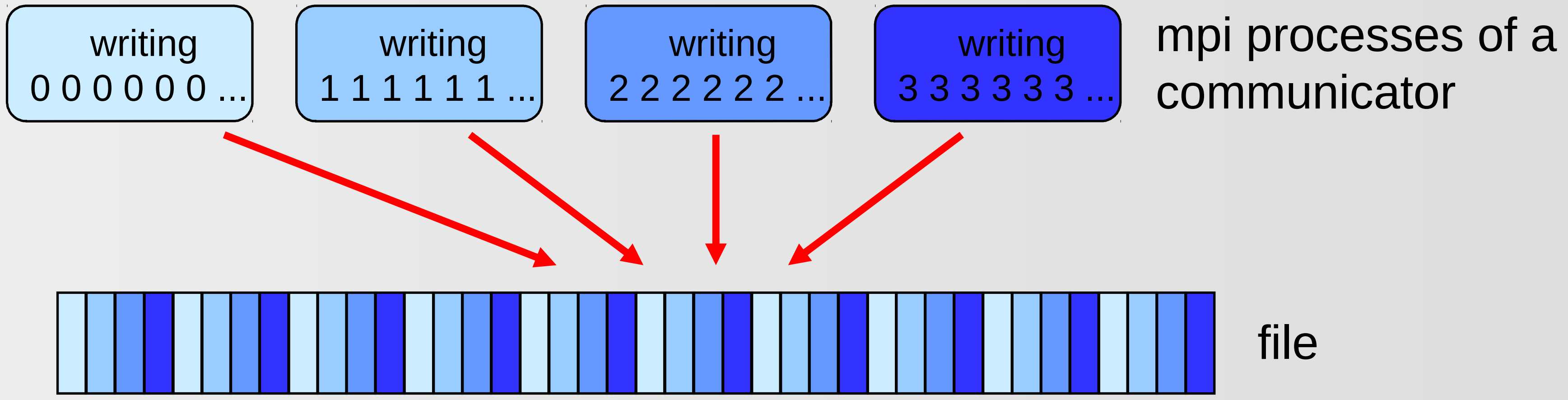
MPI_FILE_WRITE_AT(fh,offset,buf,count,datatype,*status*)

- writes **`count`** elements of **`datatype`** from memory **`buf`** to the file
- starting **`offset`** **`*`** units of **`etype`**
  from begin of view
- the elements are stored into the locations of the current view
- the sequence of basic datatypes of **`datatype`**
  (= signature of **`datatype`**)
  must match
  contiguous copies of the **`etype`** of the current view

MPI–IO Exercise 1: Four processes write a file in parallel

- each process should write its rank (as one character) ten times

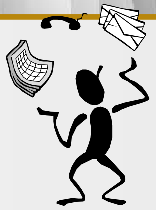
  to the offsets = my_rank + i * size_of_MPI_COMM_WORLD, i=0..9
- Result: “0123012301230123012301230123012301230123“
- Each process uses the default view



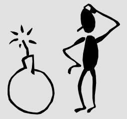
- please, use skeleton:

```
cp ~/MPI/tasks/C/Ch13/mpi_io_exa1_skel.c  my_exa1.c
cp ~/MPI/tasks/F_30/Ch13/mpi_io_exa1_skel_30.f90   my_exa1_30.f90
```

During the Exercise



Please **stay here in the main room** while you do this exercise



And have fun with this short exercise

Please do not look at the solution before you finished this exercise,

otherwise,

90% of your learning outcome may be lost

As soon as you finished the exercise,

please **go to your breakout room**

and continue your discussions with your fellow learners:

Who of you uses NetCDF or HDF5?

As far as I know, both use MPI-I/O.

Outline – Block 2

File Views

- Provides a visible and accessible set of data from an open file
- A separate view of the file is seen by each process through triple := (displacement, etype, filetype)
- User can change a view during the execution of the program - but collective operation
- A linear byte stream, represented by the triple

  (0, MPI_BYTE, MPI_BYTE), is the default view

Set/Get File View

- Set view
  - changes the process’s view of the data
  - local and shared file pointers are reset to zero
  - collective operation
  - etype and filetype must be committed
  - datarep argument is a string that specifies the format in which data is written to a file: “native”, “internal”, “external32”, or user-defined
  - same etype extent and same datarep on all processes
- Get view
  - returns the process’s view of the data

```
MPI_FILE_SET_VIEW(fh, disp, etype, filetype, datarep, info)
MPI_FILE_GET_VIEW(fh, disp, etype, filetype, datarep)
```

Data Representation, I.

- “native”
  - data stored in file identical to memory
  - on homogeneous systems no loss in precision or I/O performance due to type conversions
  - on heterogeneous systems loss of interoperability
  - no guarantee that MPI files accessible from C/Fortran

- “internal”
  - data stored in implementation specific format
  - can be used with homogeneous or heterogeneous environments
  - implementation will perform type conversions if necessary
  - no guarantee that MPI files accessible from C/Fortran

Data Representation, II.

- “external32”
  - follows standardized representation (IEEE)
  - all input/output operations are converted from/to the “external32” representation
  - files can be exported/imported between different MPI environments
  - due to type conversions from (to) native to (from) “external32” data precision and I/O performance may be lost
  - “internal” may be implemented as equal to “external32”
  - can be read/written also by non-MPI programs

- user-defined

No information about the default,
i.e., datarep without MPI_File_set_view() is not defined

Fileview examples with SUBARRAY and DARRAY

- Task
  - reading a global matrix from a file
  - storing a subarray into a local array on each process
  - according to a given distribution scheme

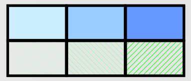
Example with Subarray, I.

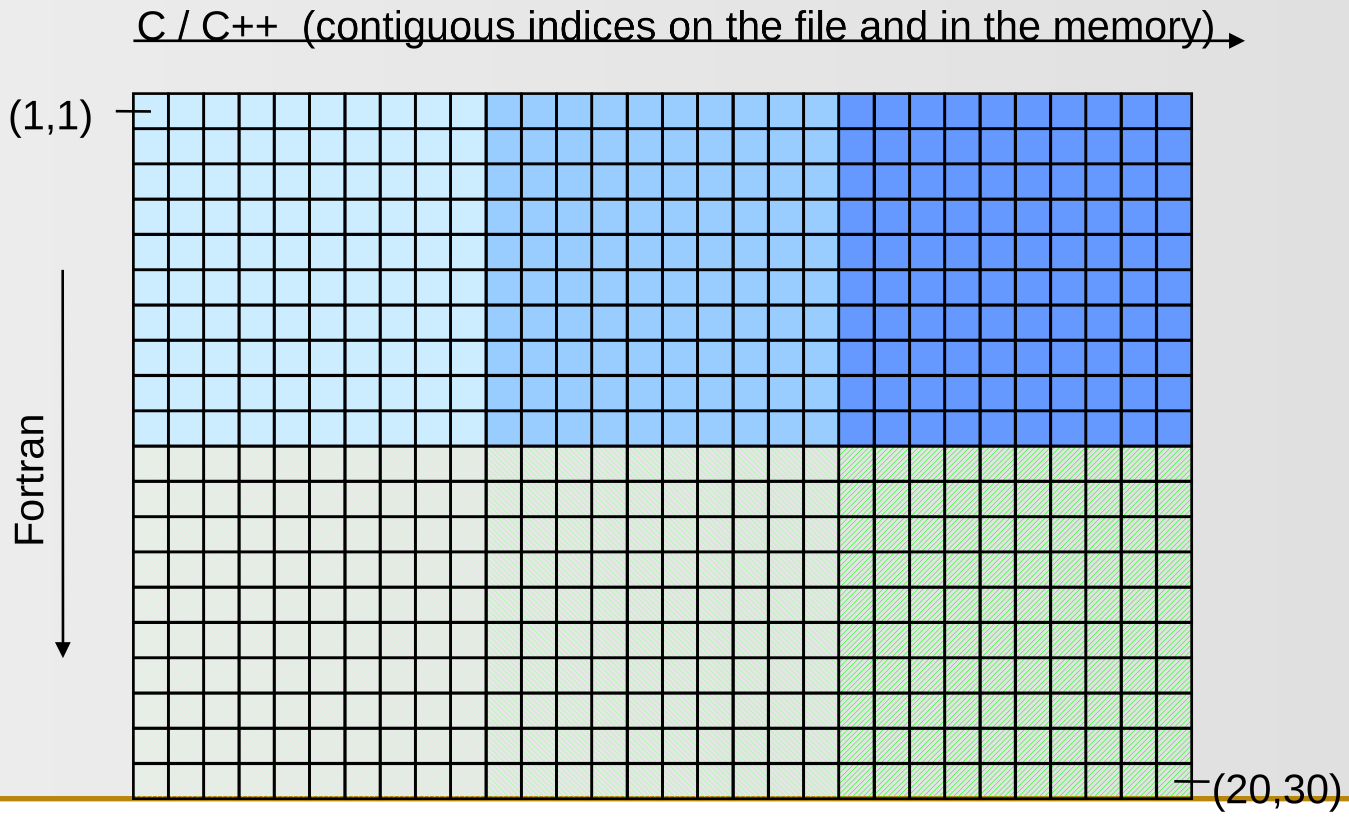
- 2-dimensional distribution scheme: (BLOCK,BLOCK)
- garray on the file 20x30:
  - Contiguous indices is language dependent:
  - in Fortran: (1,1), (2,1), (3,1), ... , (1,10), (2,20), (3,10), ..., (20,30)
  - in C/C++: [0][0], [0][1], [0][2], ... , [10][0], [10][1], [10][2], ..., [19][29]
- larray = local array in each MPI process

  = subarray of the global array
- same ordering on file (garray) and in memory (larray)

Example with Subarray, II. — Distribution

- Process topology: 2x3
- global array on the file: 20x30
- distributed on local arrays in each processor: 10x10





Example with Subarray, III. — Reading the file

```
!!!!  real garray(20,30)                              ! these HPF-like comment lines !
!!!!  PROCESSORS   procs(2,  3)                       ! explain the data distribution   !
!!!!  DISTRIBUTE garray(BLOCK,BLOCK) onto procs ! used in this MPI program         !
      real larray(10,10) ; integer (kind=MPI_OFFSET_KIND) disp,offset; disp=0; offset=0

      ndims=2 ; psizes(1)=2 ; period(1)=.false. ; psizes(2)=3 ; period(2)=.false.
      call MPI_CART_CREATE(MPI_COMM_WORLD, ndims, psizes, period,
                                                      .TRUE., comm, ierror)
      call MPI_COMM_RANK(comm, rank, ierror)
      call MPI_CART_COORDS(comm, rank, ndims, coords, ierror)

      gsizes(1)=20 ;  lsizes(1)= 10 ;  starts(1)=coords(1)*lsizes(1)
      gsizes(2)=30 ;  lsizes(2)= 10 ;  starts(2)=coords(2)*lsizes(2)
      call MPI_TYPE_CREATE_SUBARRAY(ndims, gsizes, lsizes, starts,
                        MPI_ORDER_FORTRAN, MPI_REAL, subarray_type, ierror)
      call MPI_TYPE_COMMIT(subarray_type , ierror)

      call MPI_FILE_OPEN(comm, 'exa_subarray_testfile', MPI_MODE_CREATE +
                              MPI_MODE_RDWR, MPI_INFO_NULL, fh, ierror)
      call MPI_FILE_SET_VIEW (fh, disp, MPI_REAL, subarray_type, 'native',
                                    MPI_INFO_NULL, ierror)
      call MPI_FILE_READ_AT_ALL(fh, offset, larray, lsizes(1)*lsizes(2), MPI_REAL,
                                   status, ierror)
```

Example with Subarray, IV.

- All MPI coordinates and indices start with 0,

  even in Fortran, i.e. with MPI_ORDER_FORTRAN

- MPI indices (here **`starts`**) may differ ( ) from Fortran indices

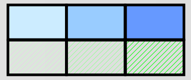
- Block distribution on 2*3 processes:

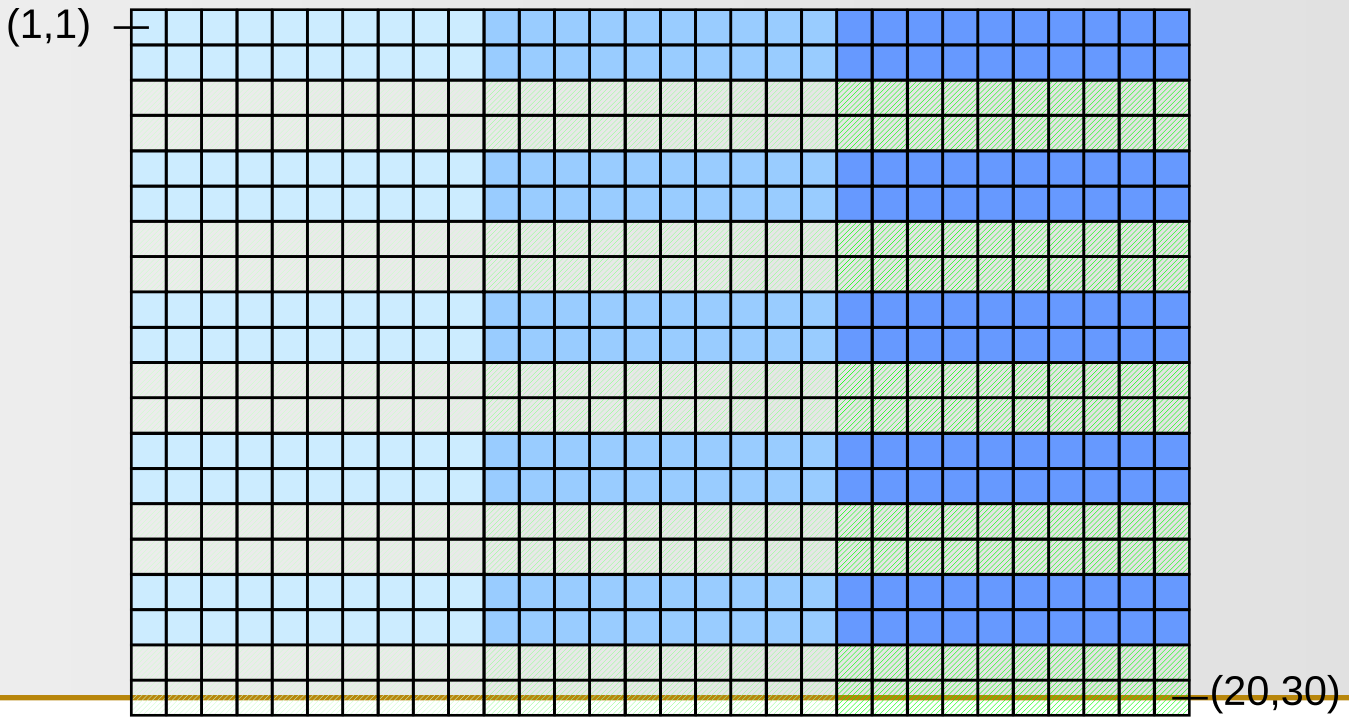
rank = 0
coords = (0, 0)
starts = (0, 0)
garray(1:10, 1:10)
= larray (1:10, 1:10)
	rank = 1
	coords = (0, 1)
	starts = (0, 10)
	garray(1:10, 11:20)
	= larray (1:10, 1:10)
		rank = 2
		coords = (0, 2)
		starts = (0, 20)
		garray(1:10, 21:30)
		= larray (1:10, 1:10)

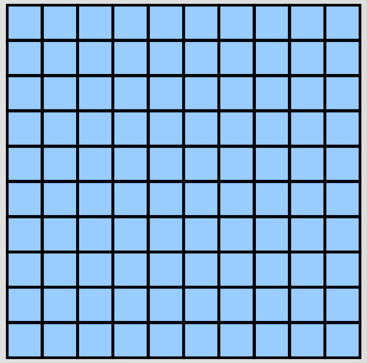
rank = 3
coords = (1, 0)
starts = (10, 0)
garray(11:20, 1:10)
= larray (1:10, 1:10)
	rank = 4
	coords = (1, 1)
	starts = (10, 10)
	garray(11:20, 11:20)
	= larray (1:10, 1:10)
		rank = 5
		coords = (1, 2)
		starts = (10, 20)
		garray(11:20, 21:30)
		= larray (1:10, 1:10)

Example with Darray, I.

- Distribution scheme: (CYCLIC(2), BLOCK)
- Cyclic distribution in first dimension with strips of length 2
- Block distribution in second dimension
- distribution of global garray onto the larray in each of the 2x3 processes
- garray on the file: • e.g., larray on process (0,1):







Example with Darray, II.

```
!!!!   real garray(20,30)                                   ! these HPF-like comment lines  !
!!!!   PROCESSORS   procs(2,  3)                            !      explain the data distribution !
!!!!   DISTRIBUTE garray(CYCLIC(2),BLOCK) onto procs  !used in this MPI program!
       real larray(10,10); integer (kind=MPI_OFFSET_KIND) disp, offset; disp=0; offset=0
       call MPI_COMM_SIZE(comm, size, ierror)
       ndims=2 ; psizes(1)=2 ; period(1)=.false. ; psizes(2)=3 ; period(2)=.false.
       call MPI_CART_CREATE(MPI_COMM_WORLD, ndims, psizes, period,
                                                        .TRUE., comm, ierror)
       call MPI_COMM_RANK(comm, rank, ierror)
       call MPI_CART_COORDS(comm, rank, ndims, coords, ierror)
       gsizes(1)=20 ;  distribs(1)= MPI_DISTRIBUTE_CYCLIC;  dargs(1)=2
       gsizes(2)=30 ;  distribs(2)= MPI_DISTRIBUTE_BLOCK;   dargs(2)=
                                          MPI_DISTRIBUTE_DFLT_DARG
       call MPI_TYPE_CREATE_DARRAY(size, rank, ndims, gsizes, distribs, dargs,
                 psizes, MPI_ORDER_FORTRAN, MPI_REAL, darray_type, ierror)
       call MPI_TYPE_COMMIT(darray_type , ierror)
       call MPI_FILE_OPEN(comm, 'exa_subarray_testfile', MPI_MODE_CREATE +
                              MPI_MODE_RDWR, MPI_INFO_NULL, fh, ierror)
       call MPI_FILE_SET_VIEW (fh, disp, MPI_REAL, darray_type, 'native',
                                   MPI_INFO_NULL, ierror)
       call MPI_FILE_READ_AT_ALL(fh, offset, larray, 10*10, MPI_REAL, istatus, ierror)
```

Example with Darray, III.

- Cyclic distribution in first dimension with strips of length 2
- Block distribution in second dimension
- Processes’ tasks:

rank = 0
coords = (0, 0)
garray($\begin{bmatrix}1:2\\5:6\\9:10\\13:14\\17:18\end{bmatrix}$, 1:10)
= larray (1:10, 1:10)
	rank = 1
	coords = (0, 1)
	garray($\begin{bmatrix}1:2\\5:6\\9:10\\13:14\\17:18\end{bmatrix}$, 11:20)
	= larray (1:10, 1:10)
		rank = 2
		coords = (0, 2)
		garray($\begin{bmatrix}1:2\\5:6\\9:10\\13:14\\17:18\end{bmatrix}$, 21:30)
		= larray (1:10, 1:10)

rank = 3
coords = (1, 0)
garray($\begin{bmatrix}3:4\\7:8\\11:12\\15:16\\19:20\end{bmatrix}$, 1:10)
= larray (1:10, 1:10)
	rank = 4
	coords = (1, 1)
	garray($\begin{bmatrix}3:4\\7:8\\11:12\\15:16\\19:20\end{bmatrix}$, 11:20)
	= larray (1:10, 1:10)
		rank = 5
		coords = (1, 2)
		garray($\begin{bmatrix}3:4\\7:8\\11:12\\15:16\\19:20\end{bmatrix}$, 21:30)
		= larray (1:10, 1:10)

5 Aspects of Data Access

- Direction: Read / Write
- Positioning [realized via routine names]
  - explicit offset (_AT)
  - individual file pointer (no positional qualifier)
  - shared file pointer (_SHARED or _ORDERED)
    (different names used depending on whether non-collective or collective)
- Coordination
  - non-collective
  - collective (_ALL)
- Synchronism
  - blocking
  - nonblocking (I) and split collective (_BEGIN, _END)
- Atomicity, [realized with a separate API: MPI_File_set_atomicity]
  - non-atomic (default)
  - atomic: to achieve sequential consistency for conflicting accesses
    on same fh in different processes

All Data Access Routines

positioning	synchronism	coordination		
		noncollective	collective	split collective
explicit offsets	blocking	READ_AT WRITE_AT	READ_AT_ALL WRITE_AT_ALL	READ_AT_ALL_BEGIN READ_AT_ALL_END
	nonblocking	IREAD_AT IWRITE_AT	IREAD_AT_ALL IWRITE_AT_ALL	WRITE_AT_ALL_BEGIN WRITE_AT_ALL_END
individual file pointers	blocking	READ WRITE	READ_ALL WRITE_ALL	READ_ALL_BEGIN READ_ALL_END
	nonblocking	IREAD IWRITE	IREAD_ALL IWRITE_ALL	WRITE_ALL_BEGIN WRITE_ALL_END
shared file pointer	blocking	READ_SHARED WRITE_SHARED	READ_**ORDERED** WRITE_**ORDERED**	READ_**ORDERED**_BEGIN READ_**ORDERED**_END
	nonblocking	IREAD_SHARED IWRITE_SHARED	N/A	WRITE_**ORDERED**_BEGIN WRITE_**ORDERED**_END

Read e.g. **MPI_FILE**_READ_AT

New in MPI-3.1

Explicit Offsets

e.g. MPI_FILE_READ_AT(fh,offset,*buf*,count,datatype,*status*)

- attempts to read **count** elements of **datatype**
- starting **offset *** units of **etype**
  from begin of view (= **displacement**)
- the sequence of basic datatypes of **datatype**
  (= signature of **datatype**)
  must match
  contiguous copies of the **etype** of the current view
- EOF can be detected by noting that the amount of data read is less than **count**
  - i.e. EOF is no error!
  - use MPI_GET_COUNT(status,datatype,*recv_count*)

Individual File Pointer, I.

e.g. MPI_FILE_READ(fh, *buf*,count,datatype,*status*)

- same as *"Explicit Offsets"*, except:
- the offset is the current value of the **individual file pointer** of the calling process
- the individual file pointer is updated by

$$\text{new\_fp} = \text{old\_fp} + \frac{\text{elements(datatype)}}{} * \text{count}$$

i.e. it points to the next etype after the last one that will be accessed

(*formula is not valid if EOF is reached*)

Individual File Pointer, II.

MPI_FILE_SEEK(fh, offset, whence)

- set individual file pointer fp:
  - set fp to offset – if whence=MPI_SEEK_SET
  - advance fp by offset – if whence=MPI_SEEK_CUR
  - set fp to EOF+offset – if whence=MPI_SEEK_EOF

MPI_FILE_GET_POSITION(fh, *offset*)

MPI_FILE_GET_BYTE_OFFSET(fh, offset, disp)

- to inquire offset
- to convert offset into byte displacement
  [e.g. for disp argument in a new view]

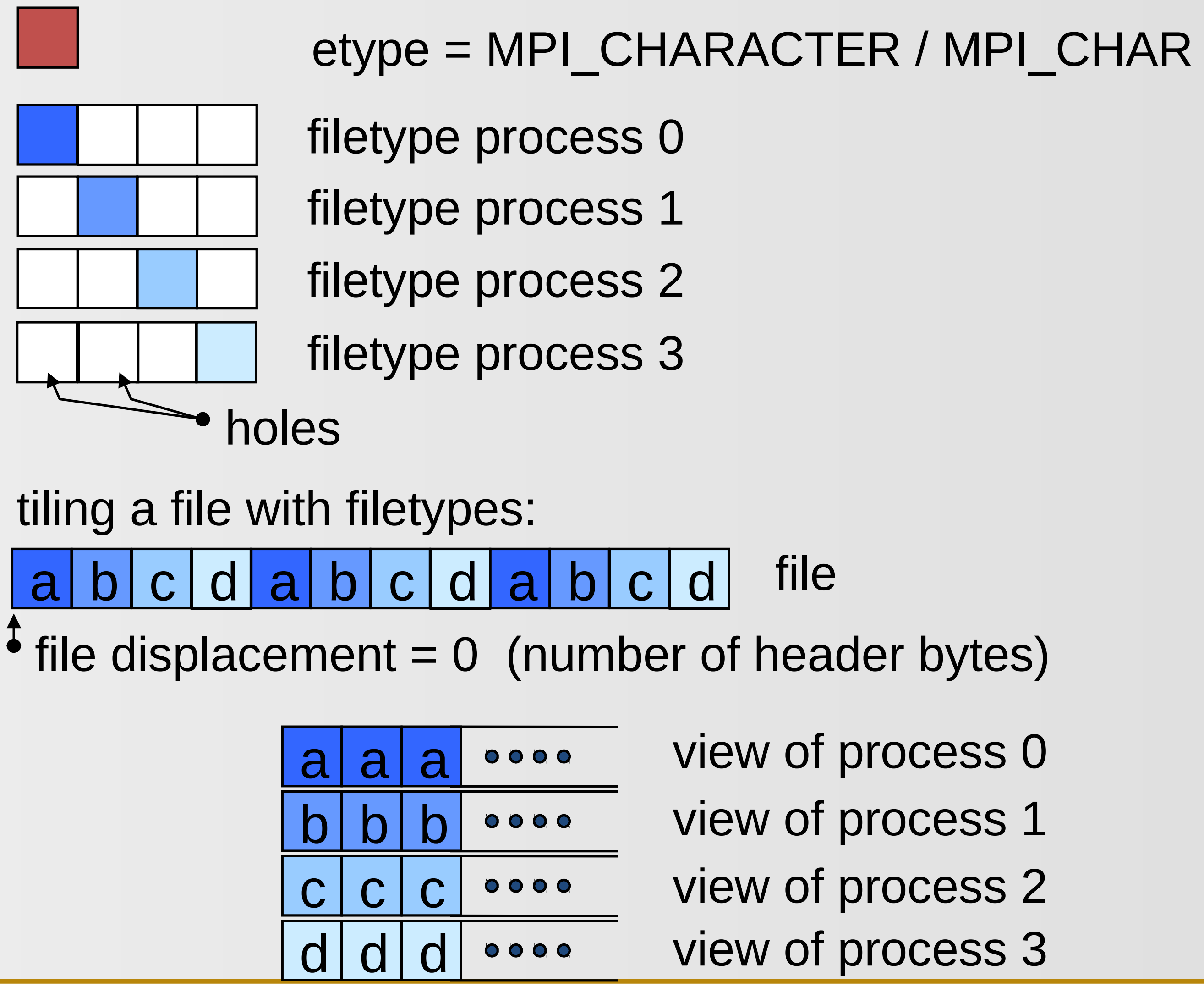
MPI–IO Exercise 2: Using fileviews and individual filepointers

- Copy to your local directory:

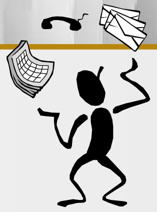
```
cp ~/MPI/tasks/C/Ch13/mpi_io_exa2_skel.c  my_exa2.c

cp ~/MPI/tasks/F_30/Ch13/mpi_io_exa2_skel_30.f90   my_exa2_30.f90
```

- Tasks:
  - Each MPI-process of `my_exa2` should write one character to a file:
    - process "rank=0" should write an 'a'
    - process "rank=1" should write an 'b'
    - ...
  - Use a 1-dimensional fileview with MPI_TYPE_CREATE_SUBARRAY
  - The pattern should be repeated 3 times, i.e., four processes should write: "`abcdabcdabcd`"
  - Please, substitute "____" in your `my_exa2.c / _30.f90`
  - Compile and run your `my_exa2.c / _30.f90`

MPI–IO Exercise 2:
Using fileviews and individual filepointers, continued

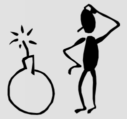


During the Exercise



Please **stay here in the main room** while you do this exercise

And have fun with this short exercise



Please do not look at the solution before you finished this exercise,

otherwise,

90% of your learning outcome may be lost

As soon as you finished the exercise,

please **go to your breakout room**

and continue your discussions with your fellow learners:

Ask yourself, whether the datatype is a 1- or higher-dimensional array?

And don't forget that counts are normally elements and not bytes!

And to look at the declaration of the buffer is also helpful

to answer tha last ____ question

Outline – Block 3

Shared File Pointer, I.

- same view at all processes mandatory!
- the offset is the current, *global* value of the

  shared file pointer of **`fh`**
- multiple calls [*e.g. by different processes*] behave as if the calls were serialized
- non-collective, e.g.

```
MPI_FILE_READ_SHARED(fh, buf, count, datatype, status)
```

- collective calls are *serialized* in the **order** of the processes' ranks, e.g.:

```
MPI_FILE_READ_ORDERED(fh,buf,count,datatype,status)
```

Shared File Pointer, II.

```
MPI_FILE_SEEK_SHARED(fh, offset, whence)
MPI_FILE_GET_POSITION_SHARED(fh, offset)
MPI_FILE_GET_BYTE_OFFSET(fh, offset, disp)
```

- same rules as with individual file pointers

Collective Data Access

- Explicit offsets / individual file pointer:
  - same as non-collective calls by all processes “of **`fh`**”
  - ***opportunity for best speed!!!***
- shared file pointer:
  - accesses are ordered by the ranks of the processes
  - optimization opportunity:
    - first, locations within the file for all processes can be computed
    - then parallel physical data access by all processes

Application Scenery, I.

- Scenery A:
  - Task: Each process has to read the whole file
  - Solution: MPI_FILE_READ_ALL

    = collective with individual file pointers,

    with same view (displacement+etype+filetype)

    on all processes

    [*internally: striped-reading by several process, only once from disk, then distributing with bcast*]
- Scenery B:
  - Task: The file contains a list of tasks,

    each task requires different compute time
  - Solution: MPI_FILE_READ_SHARED

    = non-collective with a shared file pointer

    (same view is necessary for shared file p.)

Application Scenery, II.

- Scenery C:
  - Task: The file contains a list of tasks,
    each task requires **the same** compute time
  - Solution: MPI_FILE_READ_ORDERED
    = **collective** with a **shared** file pointer
    (same view is necessary for shared file p.)
  - or: MPI_FILE_READ_ALL
    = **collective** with **individual** file pointers,
    different views: *filetype* with
    MPI_TYPE_CREATE_SUBARRAY(1,nproc,
    1, myrank, ..., datatype_of_task, *filetype*)
    [*internally: both may be implemented the same*
    and equally with following scenery D]

Application Scenery, III.

- Scenery D:
  - Task: The file contains a matrix,
    block partitioning,
    each process should get a block
  - Solution: generate different filetypes with
    MPI_TYPE_CREATE_DARRAY,
    the view on each process represents the block
    that should be read by this process,
    MPI_FILE_READ_AT_ALL with offset=0
    (= collective with explicit offsets)
    reads the whole matrix collectively
    [*internally: striped-reading of contiguous blocks*
    by several process,
    then distributed with "alltoall"]

Nonblocking Data Access

```
e.g.    MPI_FILE_IREAD(fh, buf, count, datatype, request)
        MPI_WAIT(request, status)
        MPI_TEST(request, flag, status)
```

- analogous to MPI-1 nonblocking

Split Collective Data Access, I.

- collective operations may be **split** into two parts:
  - start the split collective operation

e.g. MPI_FILE_READ_ALL_BEGIN(fh, *buf*, count, datatype)

  - complete the operation and return the **`status`**

MPI_FILE_READ_ALL_END(fh, *buf*, *status*)

Split Collective Data Access, II.

- Rules and Restrictions:
  - the MPI_...BEGIN calls are collective
  - the MPI_...END calls are collective, too
  - only one active (pending) split or regular collective operation per file handle at any time
  - split collective does not match ordinary collective
  - same **`buf`** argument in MPI_...BEGIN and ..._END call
- opportunity to overlap file I/O and computation
- but also a valid implementation:
  - does all work within the MPI_...BEGIN routine,
    passes status in the MPI_...END routine
  - passes arguments from MPI_...BEGIN to MPI_...END,
    does all work within the MPI_...END routine

Scenery – Split Collective

- Scenery A:
  - Task:Each process has to read the whole file
  - Solution: o MPI_FILE_READ_ALL_BEGIN

    = collective with individual file pointers,

    with same view (displacement+etype+filetype)

    on all processes

    [*internally: starting asynchronous striped-reading*

    by several process]

    o then computing some other initialization,

    o MPI_FILE_READ_ALL_END.

    [*internally: waiting until striped-reading finished,*

    then distributing the data with bcast]

Other File Manipulation Routines

- Pre-allocating space for a file [*collective call, may be expensive*]
  MPI_FILE_ PREALLOCATE(fh, size)
- Resizing a file [*collective call, may speed up first writing on a file*]
  MPI_FILE_SET_SIZE(fh, size)
- Querying file size
  MPI_FILE_GET_SIZE(filename, ***size***)
- Querying file parameters
  MPI_FILE_GET_GROUP(fh, ***group***)
  MPI_FILE_GET_AMODE(fh, ***amode***)
- File info object
  MPI_FILE_SET_INFO(fh, info) [*collective call*]
  MPI_FILE_GET_INFO(fh, ***info_used***)

Returns a new info object that contains the current setting of **all hints** used by the system related to this open file:

- provided by the application, and
- provided by the system

MPI I/O Error Handling

- File handles have their own error handler
- Default is MPI_ERRORS_RETURN,
  i.e. **non-fatal**
  [vs message passing: MPI_ERRORS_ARE_FATAL]
- Default is associated with MPI_FILE_NULL
  [vs message passing: with MPI_COMM_WORLD]
- Changing the default, e.g., after MPI_Init:

```
MPI_File_set_errhandler(MPI_FILE_NULL, MPI_ERRORS_ARE_FATAL);
CALL MPI_FILE_SET_ERRHANDLER(MPI_FILE_NULL,MPI_ERRORS_ARE_FATAL,ierr)
```

- MPI is *undefined* after first erroneous MPI call
- but a **high quality** implementation
  will support I/O error handling facilities

Implementation-Restrictions

- ROMIO based MPI libraries:
  - datarep = “internal” and “external32” is still not implemented
  - User-defined data representations are not supported

MPI-I/O: Summary

- Rich functionality provided to support various data representation and access
- MPI I/O routines provide flexibility as well as portability
- Collective I/O routines can improve I/O performance
- Initial implementations of MPI I/O available

  (eg, ROMIO from Argonne)
- Available nearly on every MPI implementation

MPI–IO Exercise 3: Collective ordered I/O

- Copy to your local directory:

  cp ~/MPI/tasks/**C**/Ch13/mpi_io_exa3_skel.c **my_exa3.c**

  cp ~/MPI/tasks/**F_30**/Ch13/mpi_io_exa3_skel_30.f90 **my_exa3_30.f90**

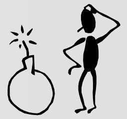
- Tasks:
  - Substitute the write call with individual filepointers

    by a collective write call with shared filepointers
  - Compile and run your `my_exa3.c / _30.f90`

During the Exercise

Please **stay here in the main room** while you do this exercise

And have fun with this short exercise



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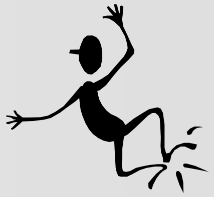
otherwise,

90% of your learning outcome may be lost

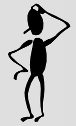


As soon as you finished the exercise,

please **go to your breakout room**

and continue your discussions with your fellow learners:

This exercise is mainly removing all about the fileview.



With the shared file pointer and collective writing, this exercise

is a one-line problem, isn't it?

Good luck!

MPI–IO Exercise 4: I/O Benchmark

- Use:

  `MPI/tasks/F_30/Ch13/mpi_io_exa4_30.f90`

  (my apologies that there is only a Fortran version)
- Tasks:
  - Compile and execute mpi_io_exa4 on 2, 4 and 8 MPI processes.
  - Duplicate “WRITE_ALL & READ_ALL” block

    and substitute by non-collective “WRITE & READ”.
  - Compare collective and non-collective I/O.
  - Double the value of gsize and compile and execute again.

Chapter 12-(1), Exercise 1:
MPI_TYPE_CONTIGUOUS Scenery, III.

C

MPI/tasks/C/Ch12/solutions/derived-contiguous.c

```
struct buff{
     int   i;
     int   j;
} snd_buf, rcv_buf, sum;
```

Provided in the skeleton

```
TYPE(MPI_Datatype) :: send_recv_type
```

```
CALL MPI_Type_contiguous(2, MPI_INTEGER, send_recv_type)
CALL MPI_Type_commit(send_recv_type)
```

```
sum.i = 0;                    sum.f = 0;
snd_buf.i = my_rank;  snd_buf.j = 10*my_rank;
for( i = 0; i < size; i++)
{ MPI_Issend(&snd_buf,1,send_recv_type,right,17,MPI_COMM_WORLD, &request);
  MPI_Recv ( &rcv_buf,1,send_recv_type,left, 17,MPI_COMM_WORLD, &status);
  MPI_Wait(&request, &status);
  snd_buf = rcv_buf;
  sum.i += rcv_buf.i;  sum.j += rcv_buf.j;
}

printf ("PE %i: Sum = %i and %i \n", my_rank, sum.i, sum.j);
```

APPENDIX: Solution to exercises

Chapter 13-(1):

Parallel file I/O exercise 1 – explicit file-pointer

C

MPI/tasks/C/Ch13/solutions/mpi_io_exa1.c

```
MPI_Offset offset;
…

    MPI_File_open(MPI_COMM_WORLD, "my_test_file",
                  MPI_MODE_RDWR | MPI_MODE_CREATE,
                  MPI_INFO_NULL, &fh);

    for (i=0; i<10; i++) {
      buf = '0' + (char)my_rank;
      offset = my_rank + size*i;
      MPI_File_write_at(fh, offset, &buf, 1, MPI_CHAR, &status);
    }
```

or MPI_MODE_**WRONLY**

Fortran

```
        INTEGER (KIND=MPI_OFFSET_KIND) offset
        …

        CALL MPI_FILE_OPEN(MPI_COMM_WORLD, 'my_test_file',
     &                       IOR(MPI_MODE_RDWR, MPI_MODE_CREATE),
     &                       MPI_INFO_NULL, fh, ierror)

        DO I=1,10
          buf = CHAR( ICHAR('0') + my_rank )
          offset = my_rank + size*(i-1)
          CALL MPI_FILE_WRITE_AT(fh, offset, buf, 1, MPI_CHARACTER,
     &                             status, ierror)
        END DO
```

or MPI_MODE_**WRONLY**

MPI/tasks/F_30/Ch13/solutions/mpi_io_exa1.f

Chapter 13-(2):Parallel file I/O exercise 2 – with fileview

C

MPI/tasks/C/Ch13/solutions/mpi_io_exa2.c

```
MPI_Offset disp;
…
    ndims = 1;
    array_of_sizes[0]    = size;
    array_of_subsizes[0] = 1;
    array_of_starts[0]   = my_rank;
    …
    MPI_Type_create_subarray(…);
    MPI_Type_commit(&filetype);
    MPI_File_open(…, MPI_MODE_RDWR | MPI_MODE_CREATE, …);
    disp = 0;
    MPI_File_set_view(…);
    for (i=0; i<3; i++) {
      buf = 'a' + (char)my_rank;
      MPI_File_write(fh, &buf, 1, etype, &status);
    }
```

or MPI_MODE_**WRONLY**

or **MPI_CHAR**

Fortran

MPI/tasks/F_30/Ch13/solutions/mpi_io_exa2.f

```
INTEGER (KIND=MPI_OFFSET_KIND) disp
…
ndims = 1
array_of_sizes(1)    = size
array_of_subsizes(1) = 1
array_of_starts(1)   = my_rank
…
CALL MPI_TYPE_CREATE_SUBARRAY(…)
CALL MPI_TYPE_COMMIT(filetype, ierror)
CALL MPI_FILE_OPEN( …, IOR(MPI_MODE_RDWR, MPI_MODE_CREATE), …)
disp = 0
CALL MPI_FILE_SET_VIEW(…)
DO I=1,3
  buf = CHAR( ICHAR('a') + my_rank )
  CALL MPI_FILE_WRITE(fh, buf, 1, etype, status, ierror)
END DO
```

or MPI_MODE_**WRONLY**

or **MPI_CHARACTER**

Chapter 13-(3): Parallel file I/O exercise 3 – shared filepointer

MPI/tasks/C/Ch13/solutions/mpi_io_exa3.c

C

```
~~MPI_Datatype etype;~~
~~MPI_Datatype filetype;~~
~~MPI_Offset disp;~~
~~   etype = MPI_CHAR;~~
~~   ndims = 1;~~
~~   array_of_sizes[0]    = size;~~
~~   array_of_subsizes[0] = 1;~~
~~   array_of_starts[0]   = my_rank;~~
~~   order = MPI_ORDER_C;~~
~~   MPI_Type_create_subarray(ndims, array_of_sizes,~~
~~                            array_of_subsizes, array_of_starts, order, etype, &filetype);~~
~~   MPI_Type_commit(&filetype);~~
~~   disp = 0;~~
~~   MPI_File_set_view(fh, disp, etype, filetype, "native", MPI_INFO_NULL);~~
  MPI_File_open(MPI_COMM_WORLD, "my_test_file",
                MPI_MODE_RDWR | MPI_MODE_CREATE, MPI_INFO_NULL, &fh);
  for (i=0; i<3; i++) {
    buf = 'a' + (char)my_rank;
    MPI_File_write_ordered(fh, &buf, 1, MPI_CHAR, &status);
  }
  MPI_File_close(&fh);
```

Fortran

MPI/tasks/F_30/Ch13/solutions/mpi_io_exa3.f

```
TYPE(MPI_Datatype) :: etype
…
  ~~CALL MPI_FILE_OPEN~~(MPI_COMM_WORLD, 'my_test_file', &
     ~~&~~                        IOR(MPI_MODE_RDWR, MPI_MODE_CREATE), &
     &                        MPI_INFO_NULL, fh, ierror)
  DO I=1,3
    buf = CHAR( ICHAR('a') + my_rank )
    CALL MPI_FILE_WRITE_ORDERED(fh, buf, 1, MPI_CHARACTER, status, ierror)
  END DO
  CALL MPI_FILE_CLOSE(fh, ierror)
```

Thanks!

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