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ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Parallel I/O

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Introduction

Reading and Writing data is a problem usually underestimated.

However it can become crucial for the performance of a code.

A code with highly parallelized algorithms can spend most of its time reading/writing data.

Amdahl's law holds also for I/O:

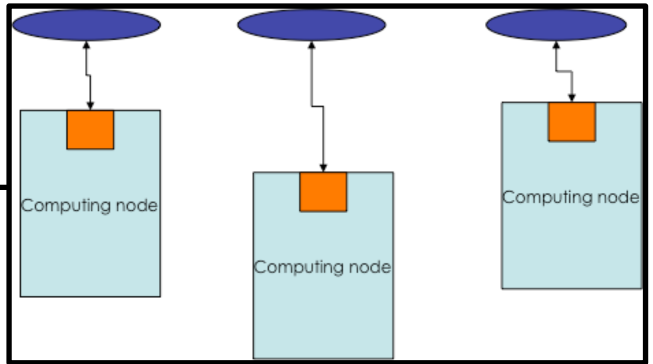
$$\textbf{performance gain} = \frac{1}{(1-F)+\frac{F}{N}}.$$

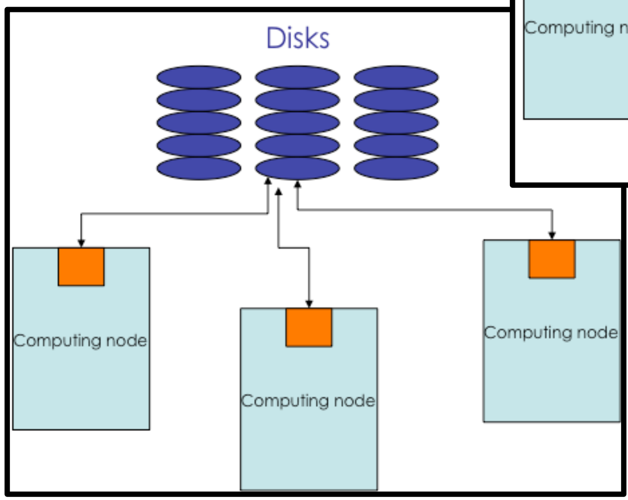
Parallel I/O

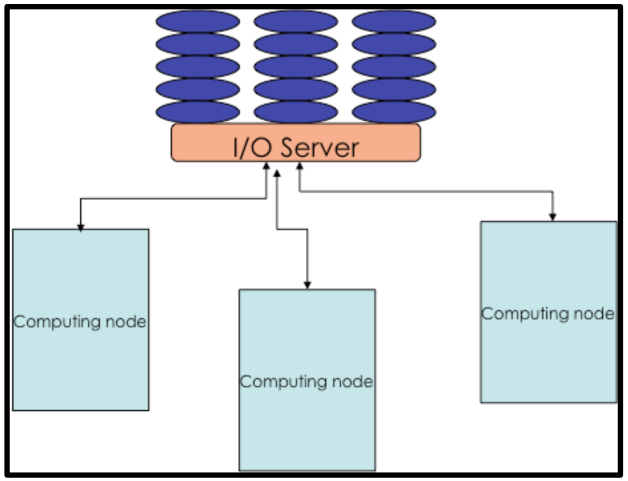
So, we need to parallelize also the I/O

However, challenges and solutions are different from the rest of the code

This is due to the different hardware/software taking care of the I/O







...and many others...

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Parallel I/O: Main Goals

- **Improve the performance, parallel read/write MUST be faster (at least, not slower!) than sequential**
  - Minimize communication
  - Do not introduce latencies/overheads
  - Overlap I/O to computation
  - Read/Write in big chunks
  - Exploit the hardware
- **Preserve usability**
  - Parallel I/O can lead to messy outcomes
  - Parallel I/O can limit the usability of files

Parallel I/O: possible strategies

- **Master-Slave**
  - Only one processor takes care of the I/O
- **Distributed**
  - All processors perform the I/O independently
- **Coordinated**
  - All processors perform the I/O in an “organized” way
- **MPI I/O**
  - The most efficient solution
- **High level libraries (HDF5, NetCDF, Adios, FITS…)**
  - The most “elegant” (and sometimes efficient) solution

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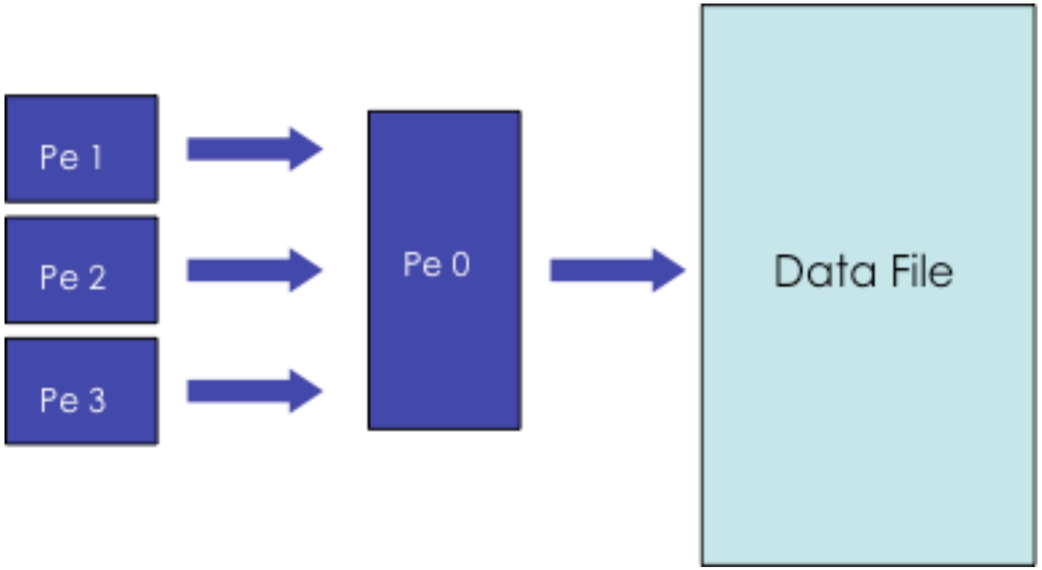
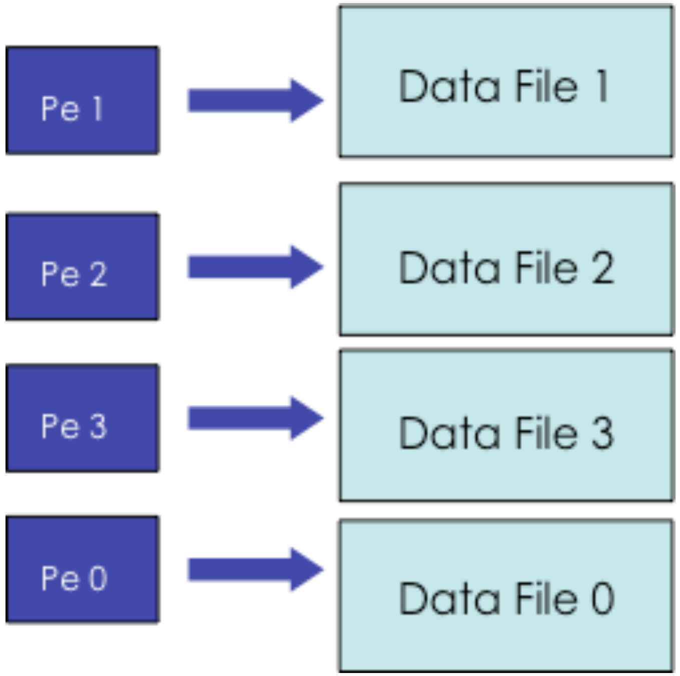
Master-Slave

- **Only one processor performs the I/O**
- **Improves the performance? NO (unless async)**
- **Degrades usability? NO**



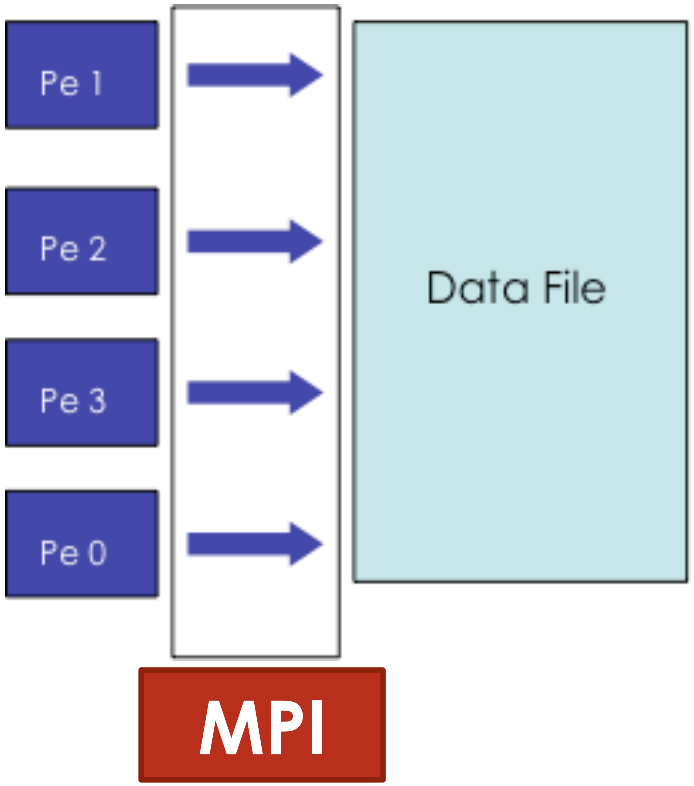
Distributed

- **Each processor reads/writes its own file**
- **Improves the performance?**
  YES (But don't expect linear scaling!)
- **Degrades usability? YES**



Coordinated

- **Each processor reads/writes the same file**
- **Improves the performance?**
  YES (But don't expect linear scaling!)
- **Degrades usability? NO**



MPI I/O

- **MPI extends the same concepts introduced for parallelizing an algorithm to I/O**
- **MPI I/O can be interpreted as message passing to (write) or from (read) a disk**
- **A file written with MPI I/O has NOTHING special. It can be read by a sequential (non MPI) code**

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MPI FILES

MPI FILE

- **An MPI file is an ordered collection of data items.**
- **MPI supports random or sequential access to any set of these items.**
- **A file is opened collectively by a group of processes (communicator).**

File OPEN

Both opening and closing files are **collective** operations within a communicator. Files are opened using **MPI_FILE_OPEN**:

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

Each process within the communicator **must specify the same filename and access mode** (`amode`).

`info` = optimization parameter (`info` = MPI_INFO_NULL always possible)
`fh` = file handle, used to reference the file while it is open
The possible `amode` are:

`MPI_MODE_RDONLY` --- read only,
`MPI_MODE_RDWR` --- reading and writing,
`MPI_MODE_WRONLY` --- write only,
`MPI_MODE_CREATE` --- create the file if it does not exist,
`MPI_MODE_EXCL` --- error if creating file that already exists,
`MPI_MODE_DELETE_ON_CLOSE` --- delete file on close,
`MPI_MODE_UNIQUE_OPEN` --- file will not be concurrently opened elsewhere,
`MPI_MODE_SEQUENTIAL` --- file will only be accessed sequentially,
`MPI_MODE_APPEND` --- set initial position of all file pointers to end of file.

File CLOSE

Collective call:

```
MPI_FILE_CLOSE(fh)
```

Reading/Writing Data

```
MPI_File_seek(MPI_File fh, MPI_Offset
        offset, int whence)
```

bytes → offset

whence values
MPI_SEEK_CUR
the file pointer is set to its current position plus offset
MPI_SEEK_END
the file pointer is set to the end of the file position plus offset
MPI_SEEK_SET
the file pointer is set to offset

```
MPI_File_read(MPI_File fh, void *buf, int count, MPI_Datatype
datatype, MPI_Status *status)
```

```
MPI_File_write(MPI_File fh, void *buf, int count, MPI_Datatype
datatype, MPI_Status *status)
```

Individual file pointers are used:

- Each processor has **its own pointer** to the file
- Pointer on a processor **is not influenced** by any other processor

Reading/Writing "at"

```
MPI_File_read_at(MPI_File fh, MPI_Offset offset, void *buf,
int count, MPI_Datatype datatype, MPI_Status *status)

MPI_File_write_at(MPI_File fh, MPI_Offset offset, void *buf,
int count, MPI_Datatype datatype, MPI_Status *status)
```

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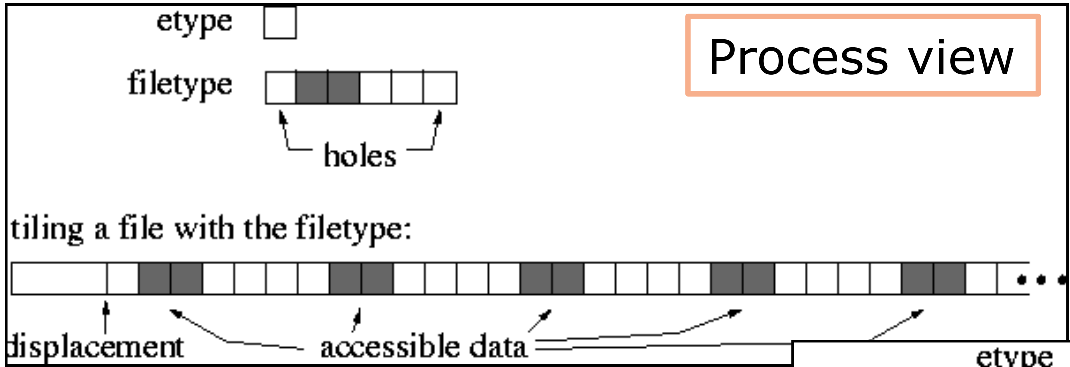
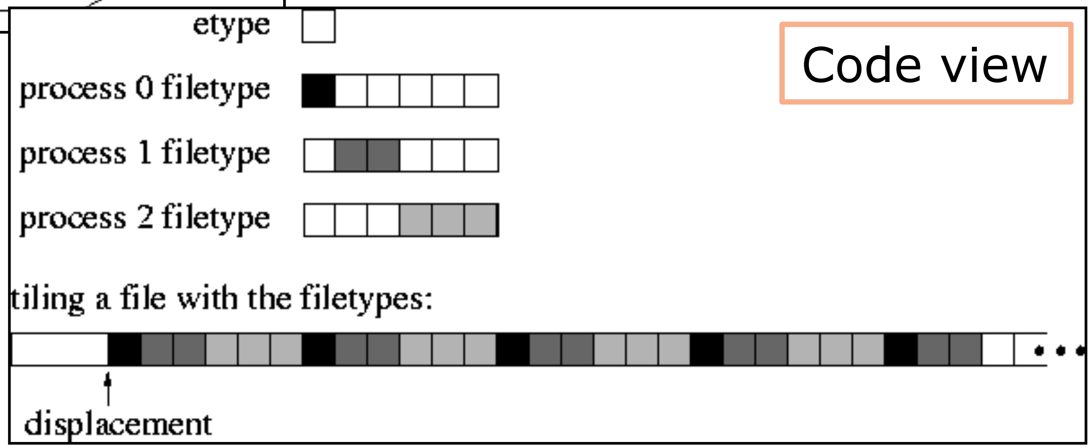
Views

- **So far nothing new…**
- **Full exploitation of MPI I/O requires the introduction of a new concept: the VIEW**

A file View defines which parts of the file are visible to a MPI process





Creating a VIEW

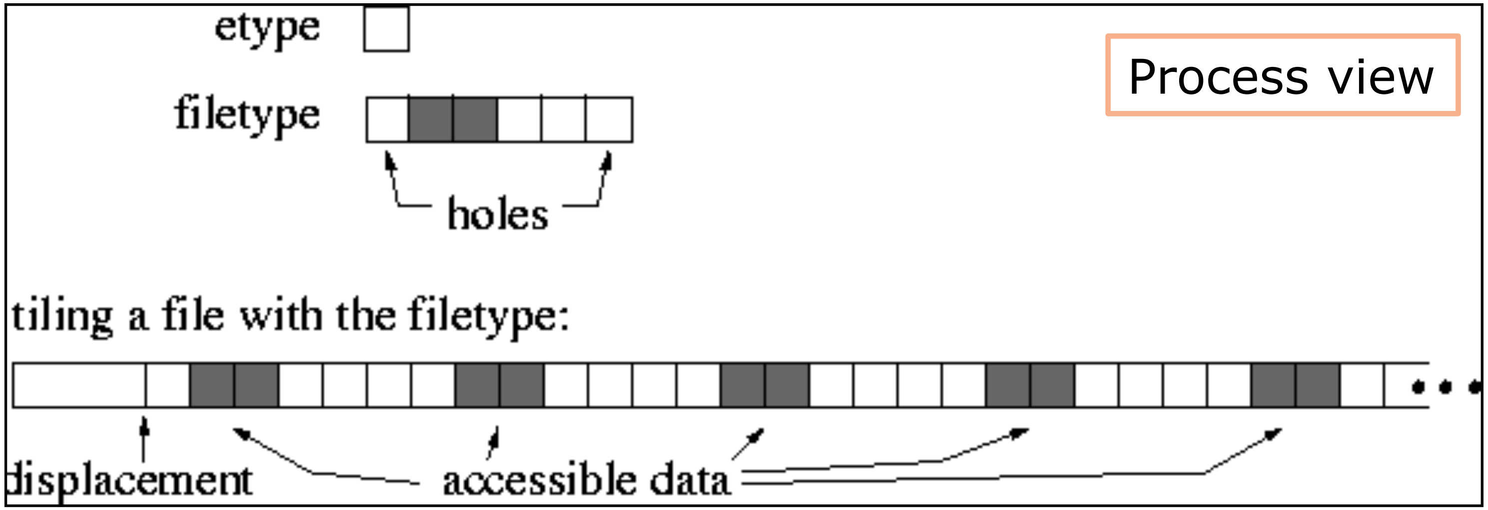
The **MPI_FILE_SET_VIEW** routine is used by each process to describe the layout of the data in the file.

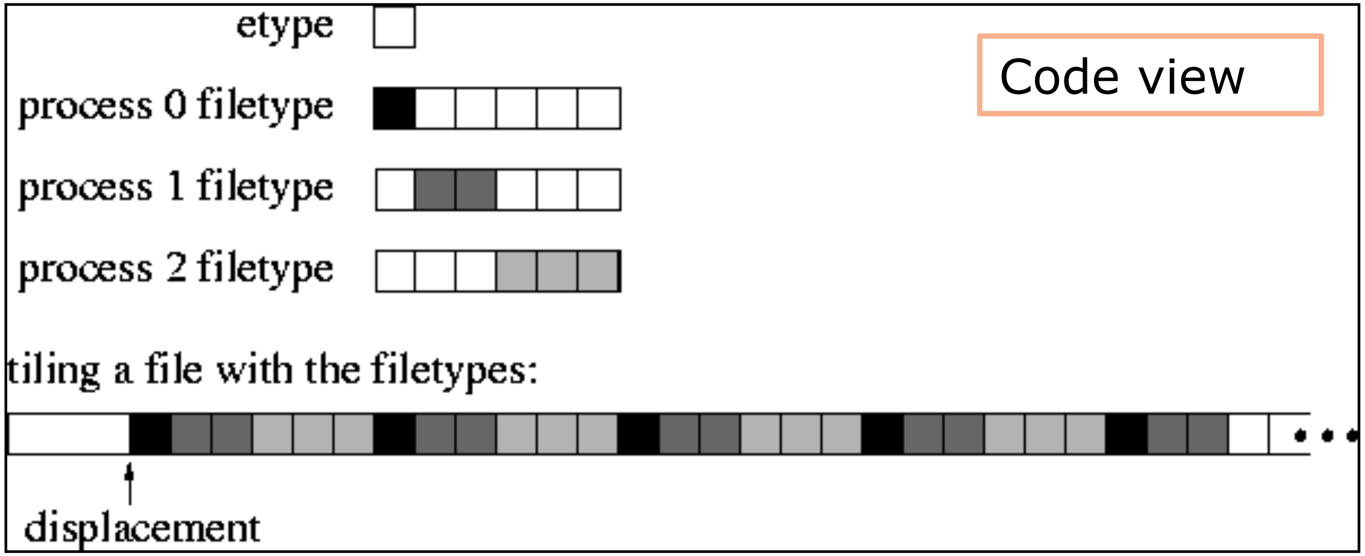
```
MPI_FILE_SET_VIEW(fh, disp, etype, filetype, datarep, info)
```

Where:

- `fh` is the file handle.
- `disp` is the displacement from the beginning of the file. In units of bytes.
- `etype` is the elementary datatype. This can be either a pre-defined or a derived datatype but it must have the same value on each process.
- `filetype` is the datatype describing each processes view of the file. These are constructed from units of etypes.
- `datarep` is the data representation (same in all process)

MPI provides functions for creating datatypes for subarrays which can be used in the filetype argument.


etype
filetype
holes
tiling a file with the filetype:
displacement
accessible data
Process view


etype
process 0 filetype
process 1 filetype
process 2 filetype
tiling a file with the filetypes:
displacement
Code view

Data representation (datarep parameter)

- **‘native’: highest performance – data are written as they are in memory**
- **‘internal’: implementation-defined. If necessary data are converted – useful for heterogeneous distributed computing platforms**
- **‘external32’: highest portability: All floating point values are in big-endian 32-bit IEEE format**

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Basic MPI data type (etype, filetype)

elementary datatypes in C

MPI datatype	C datatype
MPI_CHAR	signed char
MPI_SHORT	signed short int
MPI_INT	signed int
MPI_LONG	signed long int
MPI_UNSIGNED_CHAR	unsigned char
MPI_UNSIGNED_SHORT	unsigned short int
MPI_UNSIGNED	unsigned int
MPI_UNSIGNED_LONG	unsigned long int
MPI_FLOAT	float
MPI_DOUBLE	double
MPI_LONG_DOUBLE	long double
MPI_BYTE	
MPI_PACKED	

elementary datatypes in Fortran

MPI datatype	Fortan datatype
MPI_INTEGER	INTEGER
MPI_REAL	REAL
MPI_DOUBLE_PRECISION	DOUBLE PRECISION
MPI_COMPLEX	COMPLEX
MPI_LOGICAL	LOGICAL
MPI_CHARACTER	CHARACTER(1)
MPI_BYTE	
MPI_PACKED	

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MPI Derived Data Type (etype, filetype)

Derived datatypes are new datatypes that are built from the basic MPI datatypes or other derived datatypes.

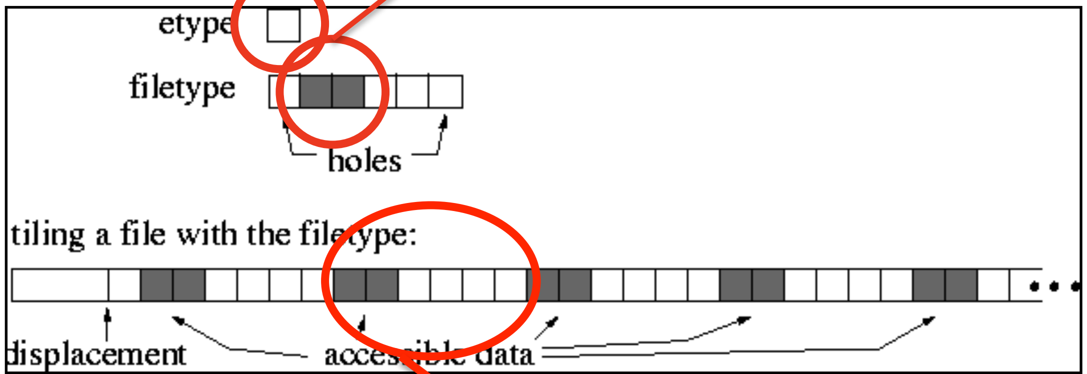
Four steps:

- **Construct the datatype;**
  - MPI_Type_contiguous
  - MPI_Type_vector
  - MPI_Type_indexed
  - MPI_Type_struct
- **Commit the datatype;**
  - MPI_Type_Commit
- **Use the datatype;**
- **Destroy the datatype;**
  - MPI_Type_free

Example

etype= MPI_INT

```
MPI_Type_contiguous(2, MPI_INT, &contig);
```




```
extent = 6 * sizeof(int);
MPI_Type_create_resized(contig, lb, extent, &filetype);
MPI_Type_commit(&filetype);
```

```
MPI_File_set_view(fh, disp, etype, filetype, "native",
                  MPI_INFO_NULL);
MPI_File_write(fh, buf, 1000, MPI_INT, MPI_STATUS_IGNORE);
```

Putting all together

```
MPI_Aint lb, extent;
MPI_Datatype etype, filetype, contig;
MPI_Offset disp;
MPI_File fh;
int buf[1000];

MPI_File_open(MPI_COMM_WORLD, "/pfs/datafile",
              MPI_MODE_CREATE | MPI_MODE_RDWR, MPI_INFO_NULL, &fh);

MPI_Type_contiguous(2, MPI_INT, &contig);
lb = 0;
extent = 6 * sizeof(int);
MPI_Type_create_resized(contig, lb, extent, &filetype);
MPI_Type_commit(&filetype);

disp = 5 * sizeof(int);    /* assume displacement in this file view
                              is of size equal to 5 integers */
etype = MPI_INT;

MPI_File_set_view(fh, disp, etype, filetype, "native",
                  MPI_INFO_NULL);
MPI_File_write(fh, buf, 1000, MPI_INT, MPI_STATUS_IGNORE);
```

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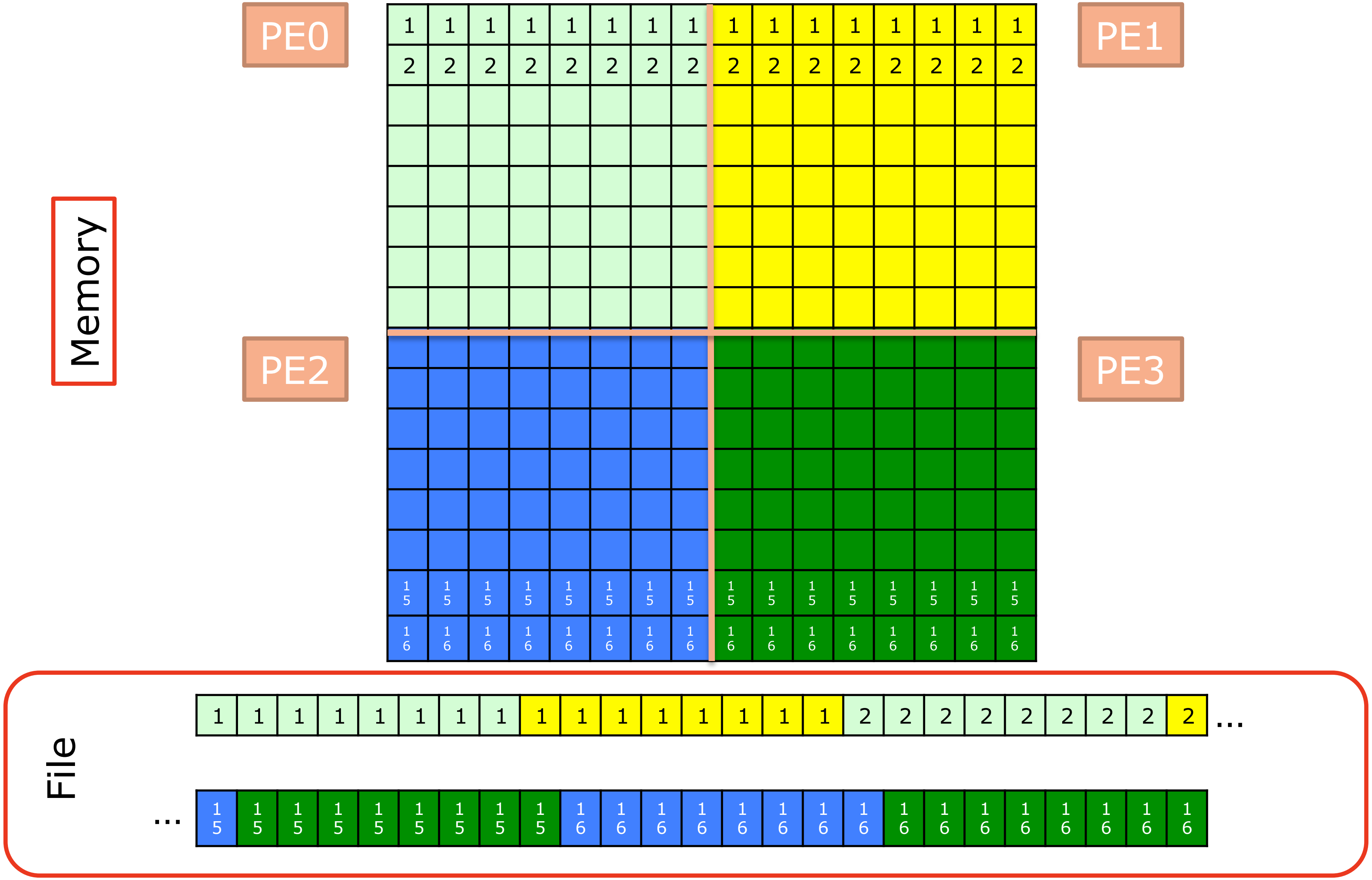
Why should this be useful?



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...so what?

Positioning	Synchronisation	Coordination	
		Noncollective	*Collective*
Explicit offsets	*Blocking*	MPI_FILE_READ_AT MPI_FILE_WRITE_AT	MPI_FILE_READ_AT_ALL MPI_FILE_WRITE_AT_ALL
	Non-blocking & ...llective	MPI_FILE_IREAD_AT MPI_FILE_IWRITE_AT	..._BEGIN ..._END ...LL_BEGIN MPI_FILE_WRITE_AT_ALL_END
Individual file pointers	*Blocking*	MPI_FILE_READ MPI_FILE_WRITE	MPI_FILE_READ_ALL MPI_FILE_WRITE_ALL
	Non-blocking & split collective	MPI_FILE_IREAD MPI_FILE_IWRITE	MPI_FILE_READ_ALL_BEGIN MPI_FILE_READ_ALL_END MPI_FILE_WRITE_ALL_BEGIN MPI_FILE_WRITE_ALL_END
Shared file pointer	*Blocking*	MPI_FILE_READ_SHARED MPI_FILE_WRITE_SHARED	MPI_FILE_READ_ORDERED MPI_FILE_WRITE_ORDERED
	Non-blocking & split collective	MPI_FILE_IREAD_SHARED MPI_FILE_IWRITE_SHARED	MPI_FILE_READ_ORDERED_BEGIN MPI_FILE_READ_ORDERED_END MPI_FILE_WRITE_ORDERED_BEGIN MPI_FILE_WRITE_ORDERED_END

Overlap I/O to computation

Coordinate I/O to optimise it

Non-Blocking I/O

This is just like non blocking communication, BUT with the filesystem

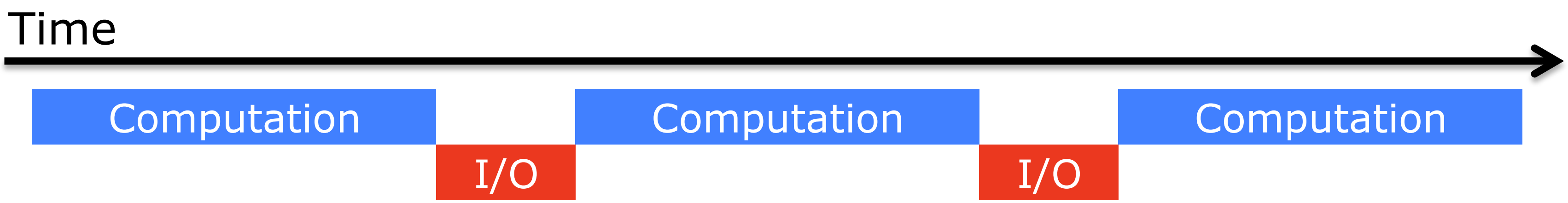
I/O proceed together with computation, so it is hidden

```
MPI_File_iread( MPI_File mpi_fh, void *buf, int count,
MPI_Datatype datatype, MPI_Request *request )
```

Etc. for `write`, `read_at`, `write_at`

`MPI_Wait` **must be used for syncronization.**

Non-Blocking I/O



Total Time = Tc1 + Tio1 + Tc2 + Tio2 + Tc3

Total Time = Tc1 + Tc2 + Tc3 + ε

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Collective I/O

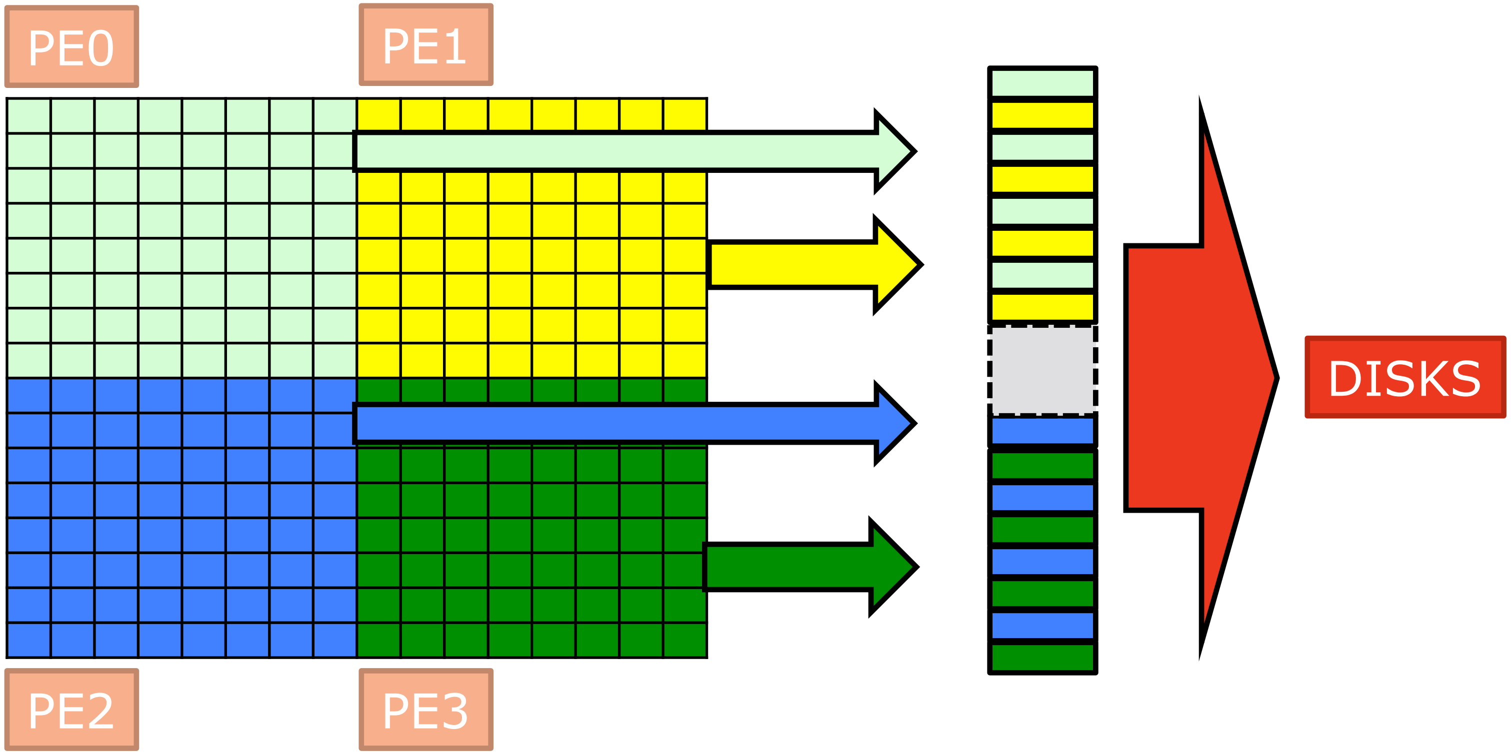
With collective I/O ALL the processors defined in a communicator execute the I/O operation

This permits to optimize the read/write procedure, thanks, in particular, to the VIEW.

```
MPI_File_read_all( MPI_File mpi_fh, void *buf, int count,
MPI_Datatype datatype, MPI_Status *status )
```

```
MPI_File_write_all(MPI_File fh, void *buf, int count,
MPI_Datatype datatype, MPI_Status *status)
```

Collective Write



Split Collective I/O

For collective I/O only a restricted form of nonblocking I/O is supported, called Split Collective:

```
MPI_File_read_all_begin( MPI_File mpi_fh, void *buf, int
count, MPI_Datatype datatype );
     …computation…
MPI_File_read_all_end( MPI_File mpi_fh, void *buf,
MPI_Status *status );
```

The same for write.

Restriction: only one active split operation on a file at a time.

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NEXT → HDF5