Intel® MPI Benchmarks

Users Guide and Methodology Description

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Disclaimer and Legal Information

1 Introduction

This document presents the Intel® MPI Benchmarks (IMB) suite. Its objectives are:

- provide a concise set of benchmarks targeted at measuring the most important MPI functions.
- set forth a precise benchmark methodology.
- don't impose much of an interpretation on the measured results: report bare timings instead. Show throughput values, if and only if these are well defined.

The package is the successor of the quite well known package PMB (Version 2.2) from Pallas GmbH and the Intel MPI Benchmarks (IMB) 2.3.

This document accompanies version 3.0 of IMB. The code is written in *ANSI C plus standard MPI* (about 10,000 lines of code, 108 functions in 37 source files).

The IMB 3.0 package consists of 3 parts:

- IMB-MPI1
- 2 MPI-2 functionality parts
  IMB-EXT (One-sided Communications benchmarks),
  IMB-IO (I/O benchmarks).

For each part, a separate executable can be built. Users, who do not have the MPI-2 extensions available, can install and use just IMB-MPI1. Only standard MPI-1 functions are used, no dummy library is needed.

Section 2 is a brief installation guide.

Section 3 is dedicated to IMB-MPI1. Section 3.3 defines the single benchmarks in detail. IMB introduces a classification of its benchmarks. *Single Transfer, Parallel Transfer, and Collective* are the classes. Roughly speaking, single transfers run *dedicated*, without obstructions from other transfers, undisturbed results are to be expected (`PingPong` being the most well known example). Parallel transfers test the system under global load, with concurrent actions going on. Finally, collective is a proper MPI classification, where these benchmarks test the quality of the implementation for the higher level collective functions.

Chapter 4 is dedicated to the MPI-2 functionality of IMB.

Section 5 defines the methodology and rules of IMB, section 6 shows templates of output tables. In section 7, further important details are explained, in particular a results checking mode for IMB.

1.1 Changes vs. IMB_2.3

The changes vs. the previous version, 2.3, are:

- added a call to the function "`MPI_Init_thread`" to determine the MPI threading environment. The MPI threading environment is reported to the user each time an Intel MPI Benchmark application is executed.
- added a call to the function "`MPI_Get_version`" to report the version of the MPI library implementation that the three benchmark applications are linking to.
- added the "`Alltoallv`" benchmark.
- added a command-line flag "-h[elp]" to display the calling sequence for each benchmark application.

- removed outdated Makefile templates. Now there are three complete makefiles called `Makefile`, `make_ict`, and `make_mpich`.
- better user argument checking, clean message and break on most invalid user arguments.

2 Installation and Quick Start of IMB

In order to run IMB-MPI1, one needs:

- `cpp`, ANSI C compiler, `make`.
- MPI installation, including startup mechanism for parallel MPI programs.

See 7.1 for the memory requirements of IMB.

2.1 Installing and running

After unpacking, the directory contains

File `ReadMe_first`

and 5 subdirectories

`./doc` (ReadMe_IMB.txt; IMB_ug-3.0.pdf, this file)

`./src` (program source- and Make-files)

`./license` (license agreements text)

`./versions_news` (version history and news)

Please read the license agreements first:

- *license.txt specifies the source code license granted to you*
- *use-of-trademark-license.txt specifies the license for using the name and/or trademark "Intel® MPI Benchmarks"*

To get a quick start, see `./doc/ReadMe_IMB.txt`.

3 IMB-MPI1

This section is dedicated to the part of IMB measuring the ‘classical’ message passing functionality of MPI-1.

3.1 General

The idea of IMB is to provide a concise set of elementary MPI benchmark kernels. With one executable, all of the supported benchmarks, or a subset specified by the command line, can be run. The rules, such as time measurement (including a repetitive call of the kernels for better clock synchronization), message lengths, selection of communicators to run a particular benchmark (inside the group of all started processes) are program parameters.

IMB has a *standard* and an *optional* configuration (see 5.2.1). In the standard case, all parameters mentioned above are fixed and must not be changed.

In standard mode, message lengths are varied from 0,1,2,4,8,16 … to 4194304 bytes. Through a command line flag, an arbitrary set of message lengths can be input by a file (flag `–msglen`, see 5.1.2.5).

The minimum `P_min` and maximum number `P` of processes can be selected by the user via command line, the benchmarks run on `P_min, 2P_min, 4P_min, ...` 2^x`P_min<P` and `P` processes. See chapter 5.1.2.2 for the details.

The user has some choice for the mapping of processes. E.g., when running on a clustered system, a benchmark such as `PingPong`, can be run intra node and inter node, without changing a mapping file (`-map` flag, see 5.1.2.6)

3.2 The benchmarks

The current version of IMB-MPI1 contains the benchmarks

- `PingPong`
- `PingPing`
- `Sendrecv`
- `Exchange`
- `Bcast`
- `Allgather`
- `Allgatherv`
- `Alltoall`
- `Alltoallv`
- `Reduce`
- `Reduce_scatter`
- `Allreduce`
- `Barrier`

The exact definitions will be given in section 3.3. Section 5 describes the benchmark methodology.

IMB-MPI1 allows for running all benchmarks in more than one process group. E.g., when running `PingPong` on `N≥4` processes, on user request (see 5.1.2.3) `N/2` disjoint groups of 2 processes each will be formed, all and simultaneously running `PingPong`.

Note that these multiple versions have to be carefully distinguished from their standard equivalents. They will be called

- `Multi-PingPong`
- `Multi-PingPing`
- `Multi-Sendrecv`
- `Multi-Exchange`
- `Multi-Bcast`
- `Multi-Allgather`
- `Multi-Allgatherv`
- `Multi-Alltoall`
- `Multi-Alltoallv`
- `Multi-Reduce`
- `Multi-Reduce_scatter`
- `Multi-Allreduce`
- `Multi-Barrier`

For a distinction, sometimes we will refer to the standard (non `Multi`) benchmarks as *primary* benchmarks.

The way of interpreting the timings of the `Multi`-benchmarks is quite easy, given a definition for the primary cases: per group, this is as in the standard case. Finally, the max timing (min throughput) over all groups is displayed. On request, all per group information can be reported, see 5.1.2.3.

3.3 IMB-MPI1 benchmark definitions

In this chapter, the single benchmarks are described. Here we focus on the elementary *patterns* of the benchmarks. The methodology of measuring these patterns (message lengths, sample repetition counts, timer, synchronization, number of processes and communicator management, display of results) are defined in chapters 5 and 6.

3.3.1 Benchmark classification

For a clear structuring of the set of benchmarks, IMB introduces classes of benchmarks: *Single Transfer, Parallel Transfer, and Collective*. This classification refers to different ways of interpreting results, and to a structuring of the code itself. It does not actually influence the way of using IMB. Also holds this classification hold for IMB-MPI2 (see 4.2.1).

IMB-MPI1		
Single Transfer	Parallel Transfer	Collective
`PingPong`	`Sendrecv`	`Bcast`
`PingPing`	`Exchange`	`Allgather`
		`Allgatherv`
	`Multi-PingPong`	`Alltoall`
	`Multi-PingPing`	`Alltoallv`
	`Multi-Sendrecv`	`Reduce`
	`Multi-Exchange`	`Reduce_scatter`
		`Allreduce`
		`Barrier`
		Multi-versions of these

3.3.1.1 Single Transfer benchmarks

The benchmarks in this class are to focus on a *single* message transferred between two processes. As to `PingPong`, this is the usual way of looking at. In IMB interpretation, `PingPing` measures the same as `PingPong`, under the particular circumstance that a message is obstructed by an oncoming one (sent simultaneously by the same process that receives the own one).

Single transfer benchmarks only run with 2 active processes (see 5.2.2 for the definition of *active*).

For `PingPing`, pure timings will be reported, and the throughput is related to a *single* message. Expected numbers, very likely, are between half and full `PingPong` throughput. With this, `PingPing` determines the throughput of messages under non optimal conditions (namely, oncoming traffic).

See 3.3.2.1 and 0 for exact definitions.

3.3.1.2 Parallel Transfer benchmarks

Benchmarks focusing on *global mode*, say, patterns. The activity at a certain process is in concurrency with other processes, the benchmark measures message passing efficiency under global load.

For the interpretation of `Sendrecv` and `Exchange`, more than 1 message (per sample) counts. As to the throughput numbers, the *total turnover* (the number of *sent plus the number of received bytes*) at a certain process is taken into account. E.g., for the case of 2 processes, `Sendrecv` becomes the *bi-directional* test: perfectly bi-directional systems are rewarded by a double `PingPong` throughput here.

Thus, the throughputs are scaled by certain factors. See 3.3.3.1 and 3.3.3.2 for exact definitions. As to the timings, raw results without scaling will be reported.

The `Multi` mode secondarily introduces into this class

- `Multi-PingPong`
- `Multi-PingPing`
- `Multi-Sendrecv`
- `Multi-Exchange`

3.3.1.3 Collective benchmarks

This class contains all benchmarks that are collective in proper MPI convention. Not only is the message passing power of the system relevant here, but also the quality of the implementation.

For simplicity, we also include the `Multi` versions of these benchmarks into this class.

Raw timings and no throughput are reported.

Note that certain collective benchmarks (namely the reductions) play a particular role as they are not pure message passing tests, but also depend on an efficient implementation of certain numerical operations.

3.3.2 Definition of Single Transfer benchmarks

This section describes the single transfer benchmarks in detail. Each benchmark is run with varying message lengths `X` bytes, and timings are averaged over multiple samples. See 5.2.4 for the description of the methodology. Here we describe the view of one single sample, with a fixed message length `X` bytes. Basic MPI data-type for all messages is `MPI_BYTE`.

Throughput values are defined in `MBytes / sec` = 2^{20} `bytes / sec scale` (i.e. `throughput = X /` 2^{20} `*` 10^{6} `/ time = X / 1.048576 / time`, when `time` is in μsec).

3.3.2.1 PingPong

`PingPong` is the classical pattern used for measuring startup and throughput of a single message sent between two processes.

Measured pattern	As symbolized between ⇇ in Figure 1; two active processes only (`Q`=2, see 5.2.2)
based on	`MPI_Send, MPI_Recv`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`time` = Δt/2 (in μsec) as indicated in Figure 1
reported throughput	`X/1.048576/time`

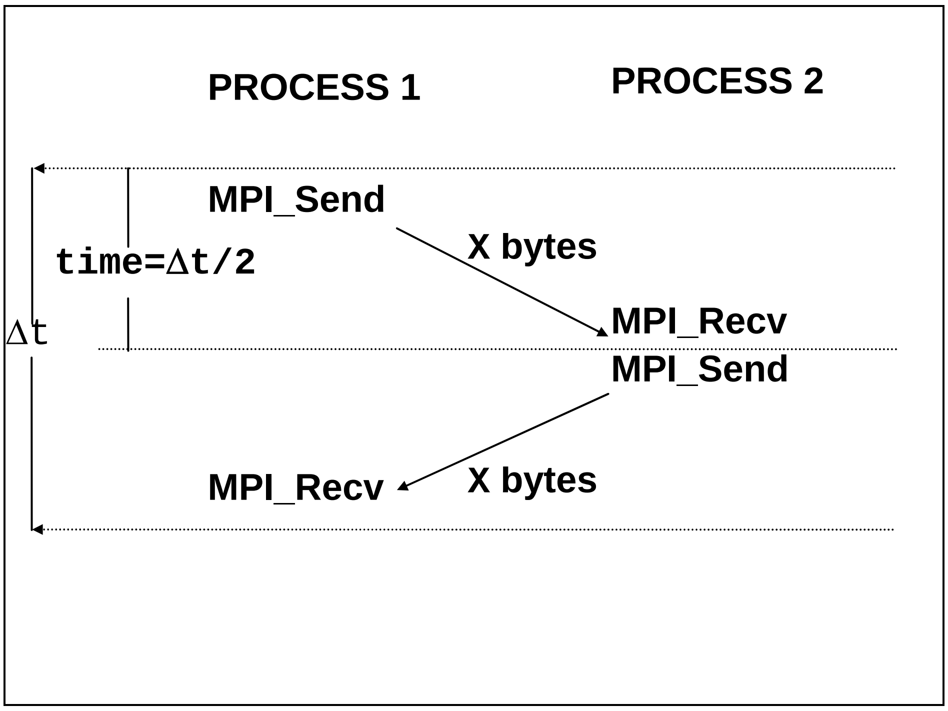


Figure 1:`PingPong` pattern

3.3.2.2 PingPing

As `PingPong`, `PingPing` measures startup and throughput of single messages, with the crucial difference that messages are obstructed by oncoming messages. For this, two processes communicate (`MPI_Isend/MPI_Recv/MPI_Wait`) with each other, with the `MPI_Isend`'s issued simultaneously.

Measured pattern	As symbolized between ⇇ in Figure 2; two active processes only (`Q=2`, 5.2.2)
based on	`MPI_Isend/MPI_Wait, MPI_Recv`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`time = Δt` (in `μsec`) as indicated in Figure 2
reported throughput	`X/1.048576/time`

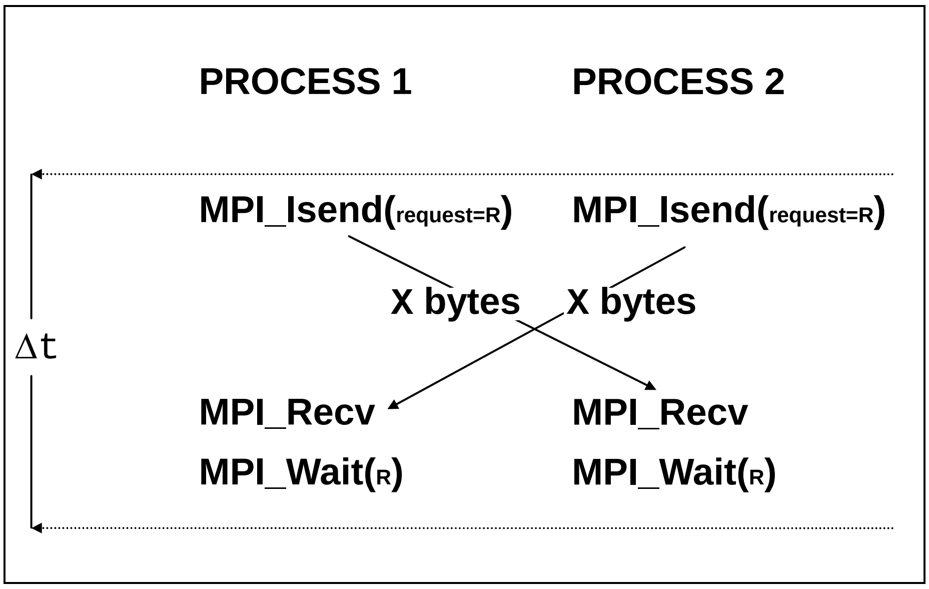


Figure 2: `PingPing` pattern

3.3.3 Definition of Parallel Transfer benchmarks

This section describes the parallel transfer benchmarks in detail. Each benchmark is run with varying message lengths `X` bytes, and timings are averaged over multiple samples. See 5 for the description of the methodology. Here we describe the view of one single sample, with a fixed message length `X` bytes. Basic MPI data-type for all messages is `MPI_BYTE`.

The throughput calculations of the benchmarks described here take into account the (per sample) multiplicity `nmsg` of messages outgoing from or incoming at a particular process. In the `Sendrecv` benchmark, a particular process sends and receives `X` bytes, the turnover is `2X bytes`, `nmsg=2`. In the `Exchange` case, we have `4X bytes` turnover, `nmsg=4`.

Throughput values are defined in `MBytes/sec` = 2^{20} `bytes / sec` scale (i.e.
`throughput = nmsg*X/`2^{20} `*` 10^6`/time = nmsg*X / 1.048576 / time`, when `time` is in µ`sec`).

3.3.3.1 Sendrecv

Based on `MPI_Sendrecv`, the processes form a periodic communication chain. Each process sends to the right and receives from the left neighbor in the chain.

The turnover count is 2 messages per sample (1 in, 1 out) for each process.

`Sendrecv` is equivalent with the `Cshift` benchmark and, in case of 2 processes, the `PingPing` benchmark of IMB1.x. For 2 processes, it will report the bi-directional bandwidth of the system, as obtained by the (optimized) `MPI_Sendrecv` function.

Measured pattern	As symbolized between ⇠ ⇠ in Figure 3
based on	`MPI_Sendrecv`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`time` = Δt (in μsec) as indicated in Figure 3
reported throughput	`2X/1.048576/time`

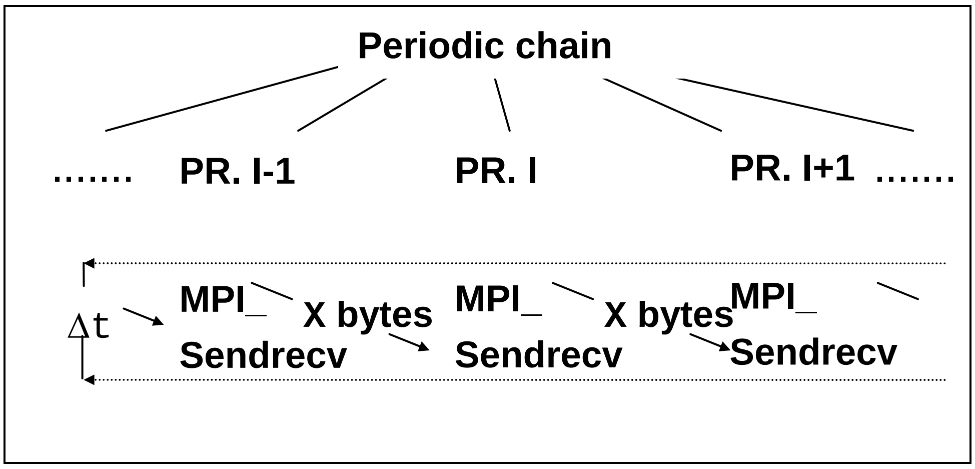


Figure 3: Sendrecv pattern

3.3.3.2 Exchange

`Exchange` is a communications pattern that often occurs in grid splitting algorithms (boundary exchanges). The group of processes is seen as a periodic chain, and each process exchanges data with both left and right neighbor in the chain.

The turnover count is 4 messages per sample (2 in, 2 out) for each process.

Measured pattern	As symbolized between ⇠ ⇠ in Figure 4
based on	`MPI_Isend/MPI_Waitall, MPI_Recv`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`time` = Δt (in μsec) as indicated in Figure 4
reported throughput	`4X/1.048576/time`

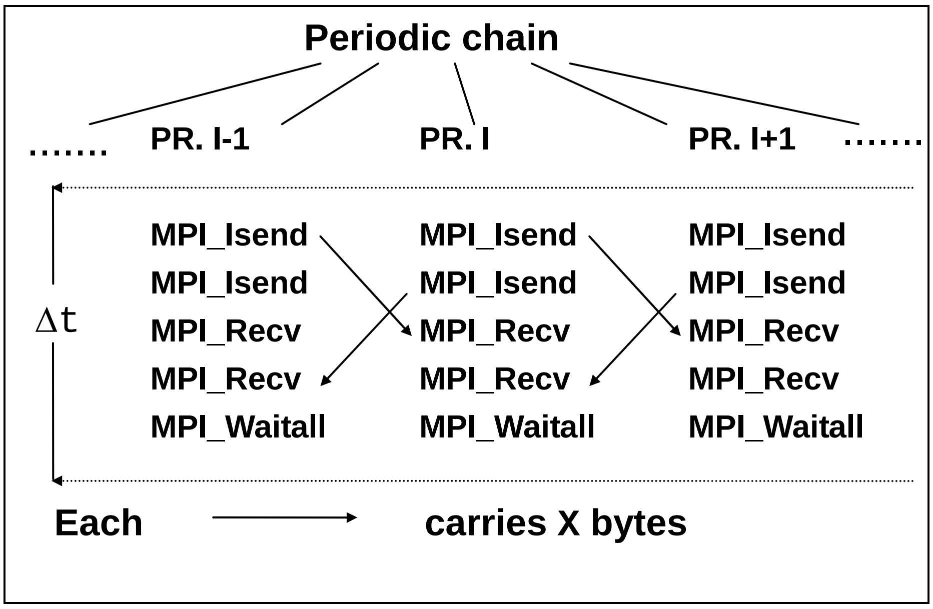


Figure 4: `Exchange` pattern

3.3.4 Definition of Collective benchmarks

This section describes the Collective benchmarks in detail. Each benchmark is run with varying message lengths `X` bytes, and timings are averaged over multiple samples. See 5 for the description of the methodology. Here we describe the view of one single sample, with a fixed message length `X` bytes. Basic MPI data-type for all messages is `MPI_BYTE` for the pure data movement functions, and `MPI_FLOAT` for the reductions.

For all Collective benchmarks, only bare timings and no throughput data is displayed.

3.3.4.1 Reduce

Benchmark for the `MPI_Reduce` function. Reduces a vector of length `L = X/sizeof(float)` float items. The MPI data-type is `MPI_FLOAT`, the MPI operation is `MPI_SUM`.

The root of the operation is changed cyclically.

See also the remark in the end of 3.3.1.3.

measured pattern	`MPI_Reduce`
`MPI_Datatype`	`MPI_FLOAT`
`MPI_Op`	`MPI_SUM`
root	changing
reported timings	bare time
reported throughput	none

3.3.4.2 Reduce_scatter

Benchmark for the `MPI_Reduce_scatter` function. Reduces a vector of length
`L = X/sizeof(float)`float items. The MPI data-type is `MPI_FLOAT`, the MPI operation is `MPI_SUM`. In the scatter phase, the `L` items are split as evenly as possible. Exactly, when

`np = #processes, L = r*np+s (s = L mod np),`

then process with rank `i` gets `r+1` items when `i<s`, and `r` items when `i≥s`.

See also the remark in the end of 3.3.1.3.

measured pattern	`MPI_Reduce_scatter`
`MPI_Datatype`	`MPI_FLOAT`
`MPI_Op`	`MPI_SUM`
reported timings	bare time
reported throughput	none

3.3.4.3 Allreduce

Benchmark for the `MPI_Allreduce` function. Reduces a vector of length `L = X/sizeof(float)` float items. The MPI data-type is `MPI_FLOAT`, the MPI operation is `MPI_SUM`.

See also the remark in the end of 3.3.1.3.

measured pattern	`MPI_Allreduce`
`MPI_Datatype`	`MPI_FLOAT`
`MPI_Op`	`MPI_SUM`
reported timings	bare time
reported throughput	none

3.3.4.4 Allgather

Benchmark for the `MPI_Allgather` function. Every process inputs `X` bytes and receives the gathered `X*(#processes)` bytes.

Measured pattern	`MPI_Allgather`
`MPI_Datatype`	`MPI_BYTE`
reported timings	bare time
reported throughput	none

3.3.4.5 Allgatherv

Functionally is the same as `Allgather`. However, with the `MPI_Allgatherv` function it shows whether MPI produces overhead due to the more complicated situation as compared to `MPI_Allgather.`

Measured pattern	`MPI_Allgatherv`
`MPI_Datatype`	`MPI_BYTE`
reported timings	bare time
reported throughput	none

3.3.4.6 Alltoall

Benchmark for the `MPI_Alltoall` function. Every process inputs `X*(#processes)` bytes (`X` for each process) and receives `X*(#processes)` bytes (`X` from each process).

Measured pattern	`MPI_Alltoall`
`MPI_Datatype`	`MPI_BYTE`
reported timings	bare time
reported throughput	none

3.3.4.7 Alltoallv

Benchmark for the `MPI_Alltoall` function. Every process inputs `X*(#processes)` bytes (`X` for each process) and receives `X*(#processes)` bytes (`X` from each process).

Measured pattern	`MPI_Alltoallv`
`MPI_Datatype`	`MPI_BYTE`
reported timings	bare time
reported throughput	none

3.3.4.8 Bcast

Benchmark for `MPI_Bcast`. A root process broadcasts `X` bytes to all.

The root of the operation is changed cyclically.

measured pattern	`MPI_Bcast`
`MPI_Datatype`	`MPI_BYTE`
root	Changing
reported timings	bare time
reported throughput	None

3.3.4.9 Barrier

measured pattern	`MPI_Barrier`
reported timings	bare time
reported throughput	none

4 MPI-2 part of IMB

This section the MPI-2 sections of IMB, IMB-EXT and IMB-IO, are handled.

4.1 The benchmarks

Table 1 below contains a list of all IMB-MPI2 benchmarks. The exact definitions are given in section 4.2, in particular refer to 4.2.2.2 for an explanation of the *Aggregate Mode*, 4.2.5 for the *Non-blocking Mode* column. Section 5 describes the benchmark methodology.

The non-blocking modes of IMB-IO `read / write` benchmarks are defined as different benchmarks, with `Read / Write` replaced by `IRead / IWrite` in the benchmark names.

Benchmark	Aggregate Mode	Non-blocking Mode
IMB-EXT		
`Window`		
`Unidir_Put`	×	
`Unidir_Get`	×	
`Bidir_Get`	×	
`Bidir_Put`	×	
`Accumulate`	×	
Multi- versions of the above	×	
Benchmark	Aggregate Mode	Nonblocking Mode
`IMB-IO`		
`Open_Close`		
`S_Write_indv`	×	`S_IWrite_indv`
`S_Read_indv`		`S_IRead_indv`
`S_Write_expl`	×	`S_IWrite_expl`
`S_Read_expl`		`S_IRead_expl`
`P_Write_indv`	×	`P_IWrite_indv`
`P_Read_indv`		`P_IRead_indv`
`P_Write_expl`	×	`P_IWrite_expl`
`P_Read_expl`		`P_IRead_expl`
`P_Write_shared`	×	`P_IWrite_shared`
`P_Read_shared`		`P_IRead_shared`
`P_Write_priv`	×	`P_IWrite_priv`
`P_Read_priv`		`P_IRead_priv`
`C_Write_indv`	×	`C_IWrite_indv`
`C_Read_indv`		`C_IRead_indv`
`C_Write_expl`	×	`C_IWrite_expl`
`C_Read_expl`		`C_IRead_expl`
`C_Write_shared`	×	`C_IWrite_shared`
`C_Read_shared`		`C_IRead_shared`
Multi-versions of the above	(×)	Multi-versions of the above

Table 1: IMB-MPI-2 benchmarks

The naming conventions for the benchmarks are as follows:

- `Unidir/Bidir` stand for unidirectional/bidirectional one-sided communications. These are the *one-sided equivalents of* `PingPong` *and* `PingPing`.
- the `Multi-` prefix is defined as in 3.2. It is to be interpreted as multi-group version of the benchmark.
- prefixes `S_/P_/C_` mean Single/Parallel/Collective. The classification is the same as in the MPI1 case. In the I/O case, a *Single* transfer is defined as a data transfer between *one* MPI process and *one* individual window or file. *Parallel* means that eventually more than 1 process participates in the overall pattern, whereas *Collective* is meant in proper MPI sense. See 3.3.1.
- the postfixes mean: `expl`: I/O with explicit offset; `indv`: I/O with an individual file pointer; `shared:` I/O with a shared file pointer; `priv`: I/O with an individual file pointer to one *private* file for each process (opened for `MPI_COMM_SELF` on each process).

4.2 IMB-MPI2 benchmark definitions

In this section, all IMB-MPI2 benchmarks are described. The definitions focus on the elementary *patterns* of the benchmarks. The methodology of measuring these patterns (transfer sizes, sample repetition counts, timer, synchronization, number of processes and communicator management, display of results) is defined in sections 5 and 6.

4.2.1 Benchmark classification

To clearly structure the set of benchmarks, IMB introduces three classes of benchmarks: *Single Transfer*, *Parallel Transfer*, and *Collective*. This classification refers to different ways of interpreting results, and to a structuring of the benchmark codes. It does not actually influence the way of using IMB. Note that this is the classification already introduced for IMB-MPI1 (3.3.1). Two special benchmarks, measuring accompanying overheads of one sided communications (`MPI_Win_create / MPI_Win_free`) and of I/O (`MPI_File_open / MPI_File_close`), have not been assigned a class.

Single Transfer	Parallel Transfer	Collective	Other

`Unidir_Get`
`Unidir_Put`
`Bidir_Get`
`Bidir_Put`
	`Multi-Unidir_Get`
	`Multi-Unidir_Put`
	`Multi-Bidir_Get`
	`Multi-Bidir_Put`
		`Accumulate`
		`Multi-Accumulate`
			`Window`
			(also Multi)

`S_[I]Write_indv`
`S_[I]Read_indv`
`S_[I]Write_expl`
`S_[I]Read_expl`
	`P_[I]Write_indv`
	`P_[I]Read_indv`
	`P_[I]Write_expl`
	`P_[I]Read_expl`
	`P_[I]Write_shared`
	`P_[I]Read_shared`
	`P_[I]Write_priv`
	`P_[I]Read_priv`
		`C_[I]Write_indv`
		`C_[I]Read_indv`
		`C_[I]Write_expl`
		`C_[I]Read_expl`
		`C_[I]Write_shared`
		`C_[I]Read_shared`
		Multi- versions
			`Open_close`
			(also Multi)

Table 2: IMB-MPI2 benchmark classification

4.2.1.1 Single Transfer benchmarks

The benchmarks in this class focus on a *single* data transferred between *one* source and *one* target. In IMB-MPI2, the source of the data transfer can be an MPI process or, in case of `Read` benchmarks, an MPI file. Analogously, the target can be an MPI process or an MPI file. Note that with this definition,

- single transfer IMB-EXT benchmarks only run with 2 active processes
- single transfer IMB-IO benchmarks only run with 1 active process (see 5.2.2 for the definition of "active").

Single transfer benchmarks, roughly speaking, are *local mode*. The particular pattern is purely local to the participating processes. There is no concurrency with other activities. Best case results are to be expected.

Raw timings will be reported, and the well-defined throughput.

4.2.1.2 Parallel Transfer benchmarks

These benchmarks focus on *global mode*, say, patterns. The activity at a certain process is in concurrency with other processes, the benchmark timings are produced under global load. The number of participating processes is arbitrary.

Time is measured as maximum over all single processes' timings, throughput is related to that time and the overall, additive amount of transferred data (sum over all processes).

This definition is applied *per group* in the `Multi` - cases, see 5.1.2.3, and the results of the worst group are displayed.

4.2.1.3 Collective benchmarks

This class contains benchmarks of functions that are collective in the proper MPI sense. Not only is the power of the system relevant here, but also the quality of the implementation for the corresponding higher level functions.

Time is measured as maximum over all single processes' timings, no throughput is calculated.

4.2.2 Benchmark modes

Certain benchmarks have different *modes* to run.

4.2.2.1 Blocking / non-blocking mode (only IMB-IO)

This distinction is in the proper MPI-IO sense. Blocking and non-blocking mode of a benchmark are separated in two single benchmarks, see Table 1. See 4.2.5 for the methodology.

4.2.2.2 Aggregate / Non Aggregate mode

For certain benchmarks, IMB defines a distinction between aggregate and non aggregate mode:

- all one sided communications benchmarks
- all blocking (!) IMB-IO `Write` benchmarks, using some flavor of MPI-IO file writing.

The basic pattern of these benchmarks is shown in Figure 5. Here,

- `M` is some repetition count
- a transfer is issued by the corresponding one sided communication call (for IMB-EXT) and by an MPI-IO write call (IMB-IO)
- *disjoint* means: the multiple transfers (if `M>1`) are to/from disjoint sections of the window or file. This is to circumvent misleading optimizations when using the same locations for multiple transfers.
- assure completion means
  `MPI_Win_fence` (IMB-EXT),
  `MPI_File_sync` (IMB-IO `Write`).

IMB runs the corresponding benchmarks with two settings:

- `M = 1` (non aggregate mode)
- `M = n_sample` (aggregate mode), with `n_sample` as defined later, refer to 5.2.8.

```
Select some repetition count M

 time = MPI_Wtime();

        issue M  disjoint transfers

        assure completion of all transfers

 time = (MPI_Wtime() - time) / M
```

Figure 5: Aggregation of M transfers (IMB-EXT and blocking Write benchmarks)

The variation of `M` should provide important information about the system and the implementation, crucial for application code optimizations. E.g., the following possible internal strategies of an implementation could highly influence the timing outcome of the above pattern.

- *accumulative strategy*. Several successive transfers (up to `M` in Figure 5) are accumulated (e.g., by a caching mechanism), without an immediate completion. At certain stages (system and runtime dependent), at best only in the assure completion part, the accumulated transfers are completed as a whole. This approach may save expensive synchronizations. The expectation is that this strategy would provide for (much) better results in the aggregate case as compared to the non aggregate one.
- *non-accumulative strategy*. Every single transfer is automatically completed before the return from the corresponding function. Expensive synchronizations are taken into account eventually. The expectation is that this strategy would produce (about) equal results for aggregate and non aggregate case.

4.2.3 Definition of the IMB-EXT benchmarks

This section describes the benchmarks in detail. They will run with varying transfer sizes `X` (in bytes), and timings will be averaged over multiple samples. See 5 for the description of the methodology. Here we describe the view of one single sample, with a fixed transfer size `X`.

Note that the `Unidir (Bidir)` benchmarks are exact equivalents of the message passing `PingPong` (`PingPing`, respectively). Their interpretation and output is analogous to their message passing equivalents.

4.2.3.1 Unidir_Put

Benchmark for the `MPI_Put` function. Table 3 below shows the basic definitions. Figure 6 is a schematic view of the pattern.

measured pattern	as symbolized between ◄┈┈┈ ◄┈┈┈ in Figure 6; 2 active processes only
based on	`MPI_Put`
`MPI_Datatype`	`MPI_BYTE` (origin and target)
reported timings	`t=t(M)` (in μsec) as indicated in Figure 6, non aggregate (`M=1`) and aggregate (cf. 4.2.2.2; `M=n_sample`, see 5.2.8)
reported throughput	`X/t`, aggregate and non aggregate

Table 3 : Unidir_Put definition

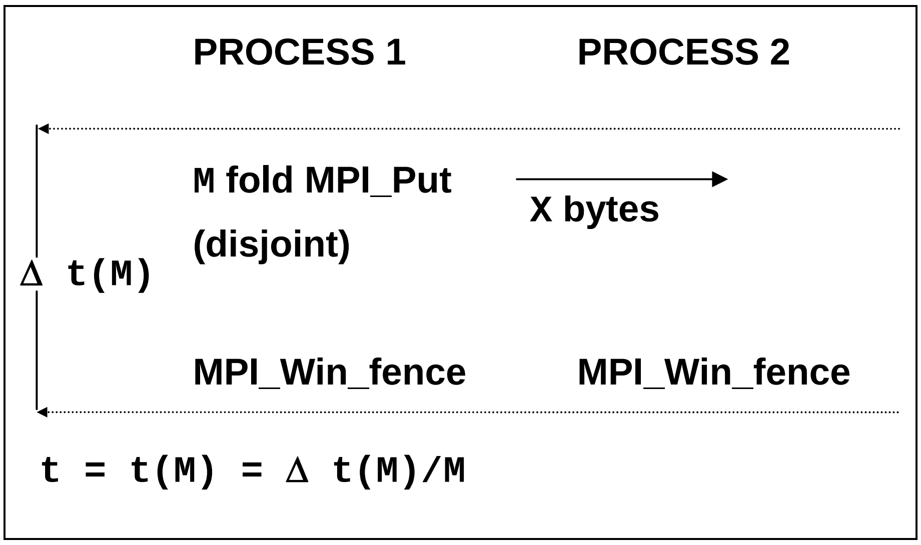


Figure 6: Unidir_Put pattern

4.2.3.2 Unidir_Get

Benchmark for the `MPI_Get` function.

Table 4 below shows the basic definitions. Figure 7 is a schematic view of the pattern.

measured pattern	as symbolized between ⟵ ⟵ in Figure 7; 2 active processes only
based on	`MPI_Get`
`MPI_Datatype`	`MPI_BYTE` (origin and target)
reported timings	`t=t(M)` (in μ`sec`) as indicated in Figure 7, non aggregate (`M=1`) and aggregate (cf. 4.2.2.2; `M=n_sample`, see 5.2.8)
reported throughput	`X/t`, aggregate and non aggregate

Table 4: Unidir_Get definition

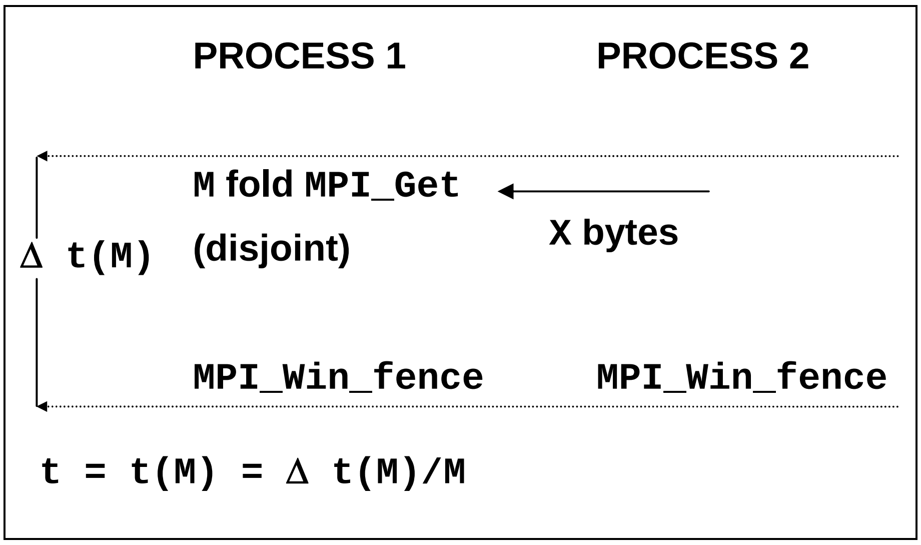


Figure 7: Unidir_Get pattern

4.2.3.3 Bidir_Put

Benchmark for `MPI_Put`, with bi-directional transfers.

Table 5 below shows the basic definitions. Figure 8 is a schematic view of the pattern.

measured pattern	as symbolized between ⇠ ⇠ in Figure 8; 2 active processes only
based on	`MPI_Put`
`MPI_Datatype`	`MPI_BYTE` (origin and target)
reported timings	`t=t(M)` (in μsec) as indicated in Figure 8, non aggregate (`M=1`) and aggregate (cf. 4.2.2.2; `M=n_sample`, see 5.2.8)
reported throughput	`X/t`, aggregate and non aggregate

Table 5: Bidir_Put definition

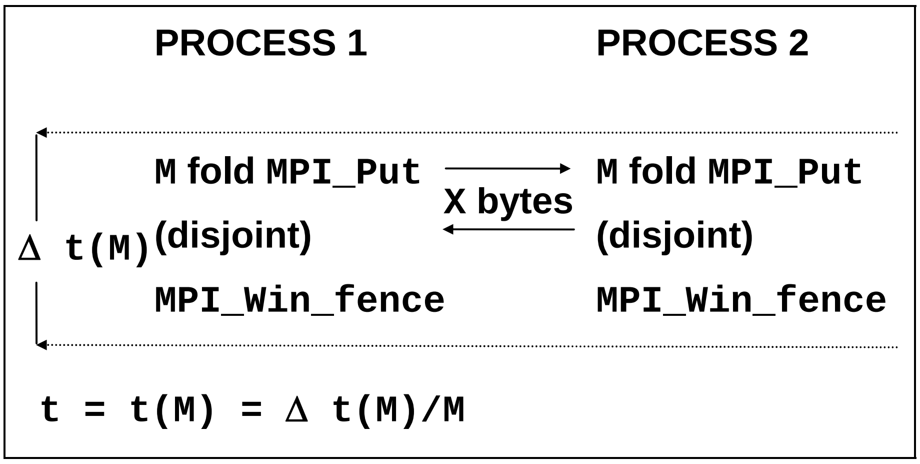


Figure 8: Bidir_Put pattern

4.2.3.4 Bidir_Get

Benchmark for the `MPI_Get` function, with bi-directional transfers.

Table 6 below shows the basic definitions. Figure 9 is a schematic view of the pattern.

measured pattern	as symbolized between ← ← in Figure 9; 2 active processes only
based on	MPI_Get
`MPI_Datatype`	MPI_BYTE (origin and target)
reported timings	`t=t(M)` (in μsec) as indicated in Figure 9, non aggregate (`M=1`) and aggregate (cf. 4.2.2.2; `M=n_sample`, see 5.2.8)
reported throughput	`X/t`, aggregate and non aggregate

Table 6: Bidir_Get definition

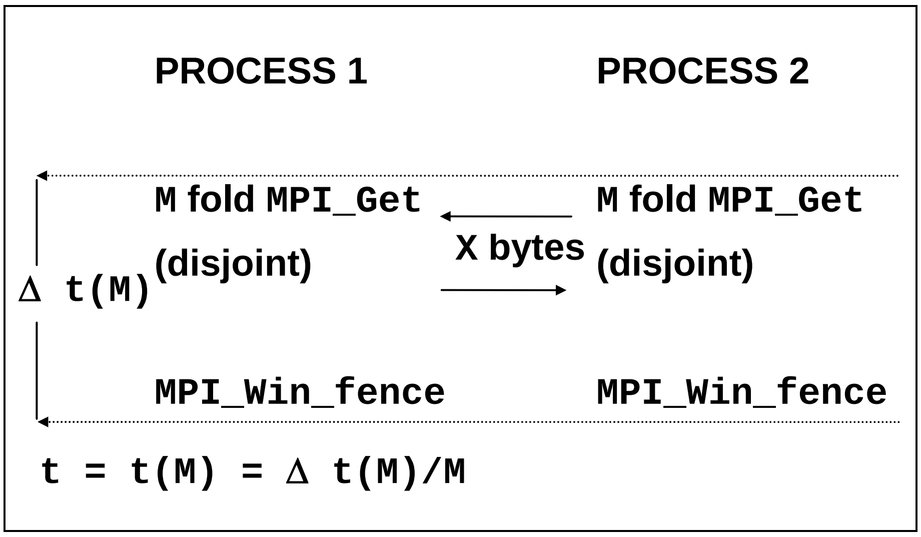


Figure 9: Bidir_Get pattern

4.2.3.5 Accumulate

Benchmark for the `MPI_Accumulate` function. Reduces a vector of length `L = X/sizeof(float)` float items. The MPI data-type is `MPI_FLOAT`, the MPI operation is `MPI_SUM`.

Table 7 below shows the basic definitions. Figure 10 is a schematic view of the pattern.

measured pattern	as symbolized between ⇇ in Figure 10
based on	`MPI_Accumulate`
`MPI_Datatype`	`MPI_FLOAT`
`MPI_Op`	`MPI_SUM`
Root	0
reported timings	`t=t(M)` (in μsec) as indicated in Figure 10, non aggregate `(M=1)` and aggregate (cf. 4.2.2.2; `M=n_sample`, see 5.2.8)
reported throughput	none

Table 7: Accumulate definition

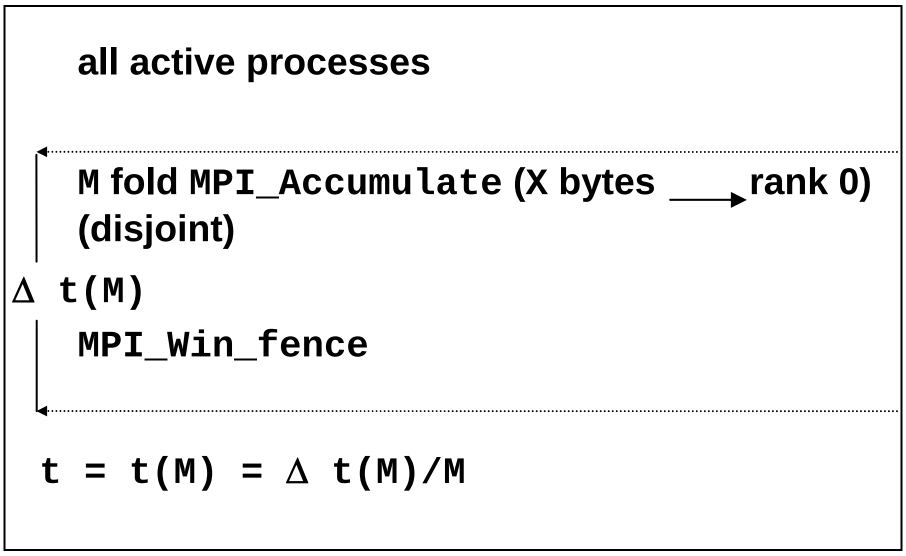


Figure 10: Accumulate pattern

4.2.3.6 Window

Benchmark measuring the overhead of an `MPI_Win_create / MPI_Win_fence / MPI_Win_free` combination. In order to prevent the implementation from optimizations in case of an unused window, a negligible non trivial action is performed inside the window. The `MPI_Win_fence` is to properly initialize an access epoch (this is a correction in version 2.2 as compared to earlier releases).

Table 8 below shows the basic definitions.

Figure 11 is a schematic view of the pattern.

measured pattern	`MPI_Win_create / MPI_Win_fence / MPI_Win_free`
reported timings	`t=Δt` (in μsec) as indicated in Figure 11
reported throughput	none

Table 8: Window definition

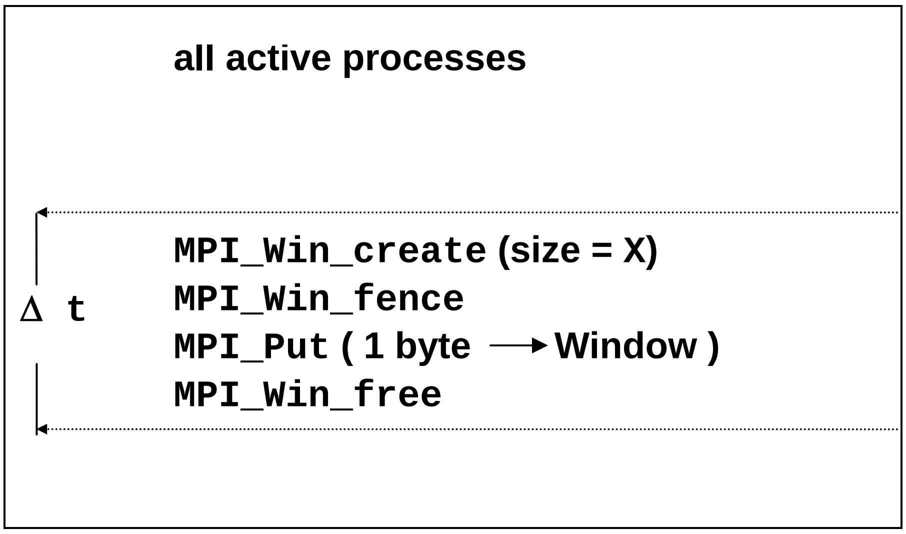


Figure 11: Window pattern

4.2.4 Definition of the IMB-IO benchmarks (blocking case)

This section describes the blocking I/O benchmarks in detail (see 4.2.5 for the non-blocking case). The benchmarks will run with varying transfer sizes `X` (in bytes), and timings are averaged over multiple samples. See section 5 for the description of the methodology. Here we describe the view of one single sample with a fixed I/O size of `X`. Basic MPI data-type for all data buffers is `MPI_BYTE`.

All benchmark flavors have a `Write` and a `Read` component. In the sequel, a symbol `[ACTION]` will be used to denote `Read` or `Write` alternatively.

Every benchmark contains an elementary I/O action, denoting the pure read/write. Moreover, in the `Write` cases, a file synchronization is included, with different placements for aggregate and non aggregate mode.

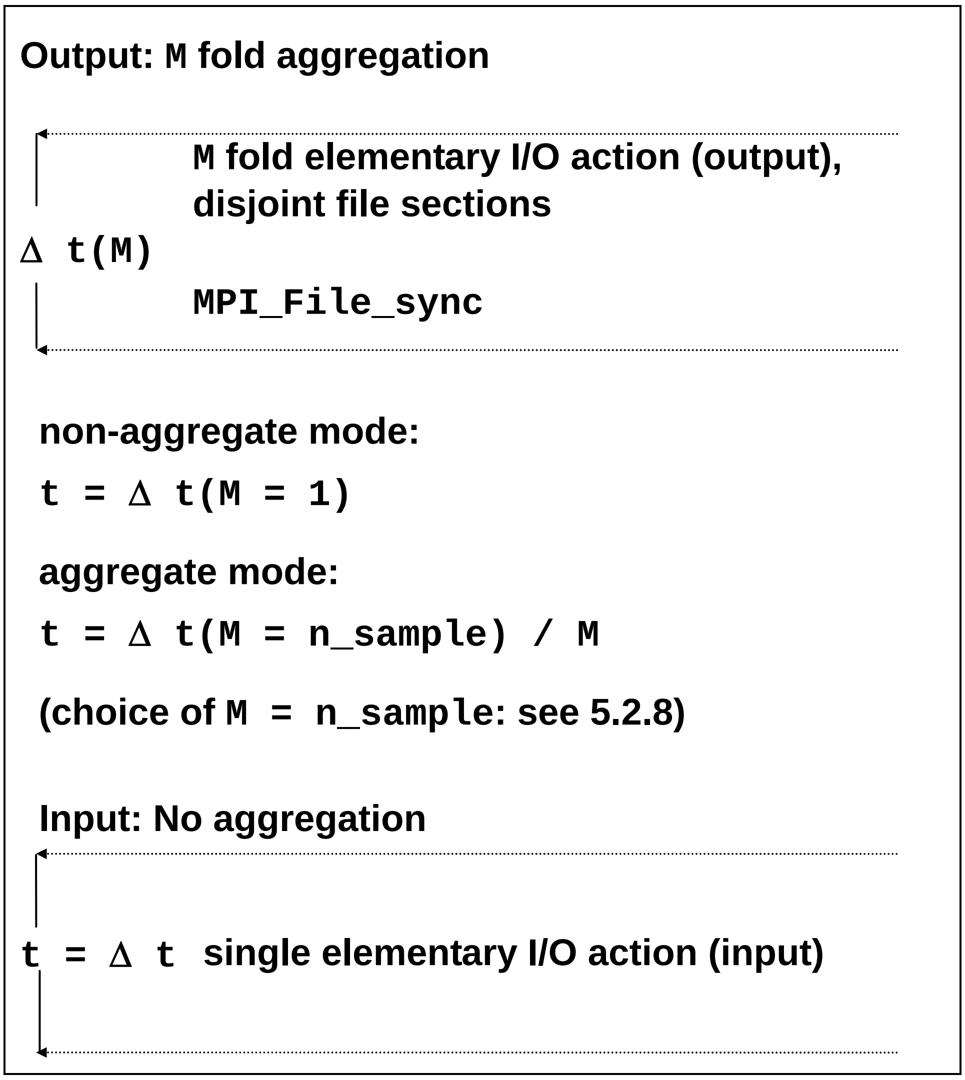

Output: M fold aggregation
M fold elementary I/O action (output), disjoint file sections
Δ t(M)
MPI_File_sync
non-aggregate mode:
t = Δ t(M = 1)
aggregate mode:
t = Δ t(M = n_sample) / M
(choice of M = n_sample: see 5.2.8)
Input: No aggregation
t = Δ t single elementary I/O action (input)

Figure 12: I/O benchmarks, aggregation for output

4.2.4.1 S_[ACTION]_indv

File I/O performed by a single process. This pattern mimics the typical case that one particular (master) process performs all of the I/O.

Table 9 below shows the basic definitions. Figure 13 is a schematic view of the pattern.

measured pattern	as symbolized in Figure 12
elementary I/O action	as symbolized in Figure 1

based on
resp. for nonblocking mode
	`MPI_File_write / MPI_File_read`
	`MPI_File_iwrite / MPI_File_iread`

etype	`MPI_BYTE`
filetype	`MPI_BYTE`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`t` (in `μsec`) as indicated in Figure 12, aggregate and non aggregate for `Write` case
reported throughput	`X/t`, aggregate and non aggregate for `Write` case

Table 9: S_[ACTION]_indv definition

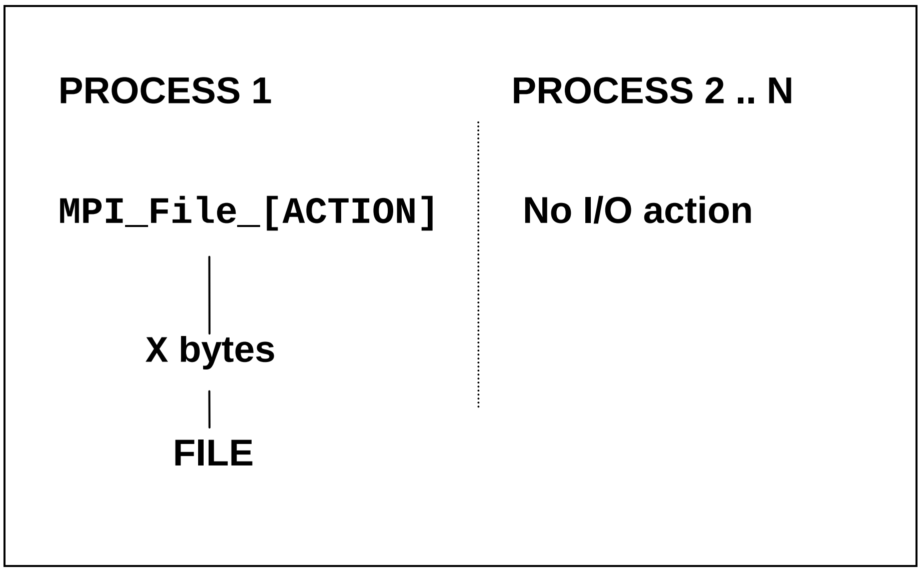


Figure 13: S_[ACTION]_indv pattern

4.2.4.2 S_[ACTION]_expl

Mimics the same situation as `S_[ACTION]_indv`, with a different strategy to access files, however.

Table 10 below shows the basic definitions. Figure 14 is a schematic view of the pattern.

measured pattern	as symbolized in Figure 12
elementary I/O action	as symbolized in Figure 14

based on
resp. for nonblocking mode
	`MPI_File_write_at / MPI_File_read_at`
	`MPI_File_iwrite_at / MPI_File_iread_at`

etype	`MPI_BYTE`
filetype	`MPI_BYTE`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`t` (in `μsec`) as indicated in Figure 12, aggregate and non aggregate for `Write` case
reported throughput	`X/t`, aggregate and non aggregate for `Write` case

Table 10: S_[ACTION]_expl definition

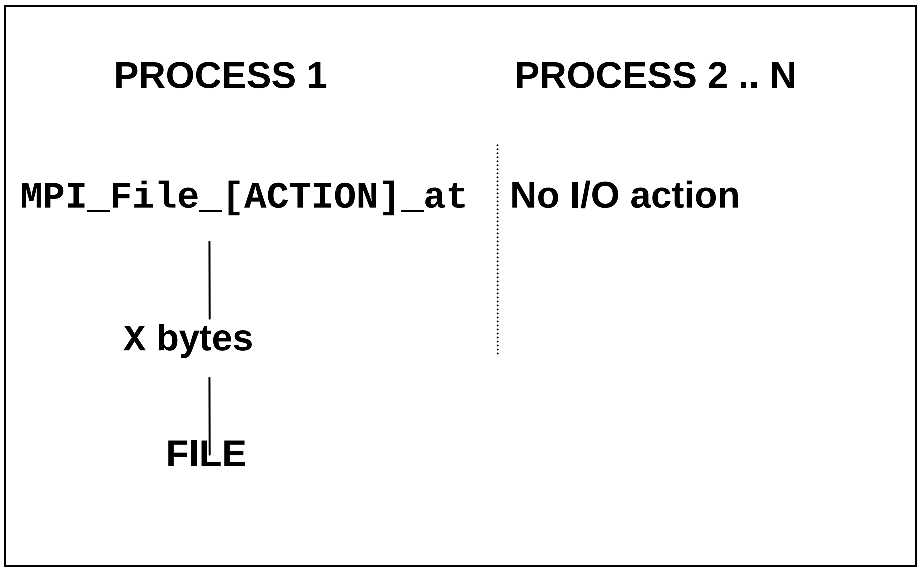


Figure 14: S_[ACTION]_expl pattern

4.2.4.3 P_[ACTION]_indv

This pattern accesses the file in a concurrent manner. All participating processes access a common file.

Table 11 below shows the basic definitions. Figure 15 is a schematic view of the pattern.

measured pattern	as symbolized in Figure 12
elementary I/O action	as symbolized in Figure 15 (Nproc = number of processes)

based on
resp. for nonblocking mode
	`MPI_File_write / MPI_File_read`
	`MPI_File_iwrite / MPI_File_iread`

etype	`MPI_BYTE`
filetype	tiled view, disjoint contiguous blocks
`MPI_Datatype`	`MPI_BYTE`
reported timings	`t` (in μ`sec`) as indicated in Figure 12, aggregate and non aggregate for `Write` case
reported throughput	`X/t`, aggregate and non aggregate for `Write` case

Table 11: P_[ACTION]_indv definition

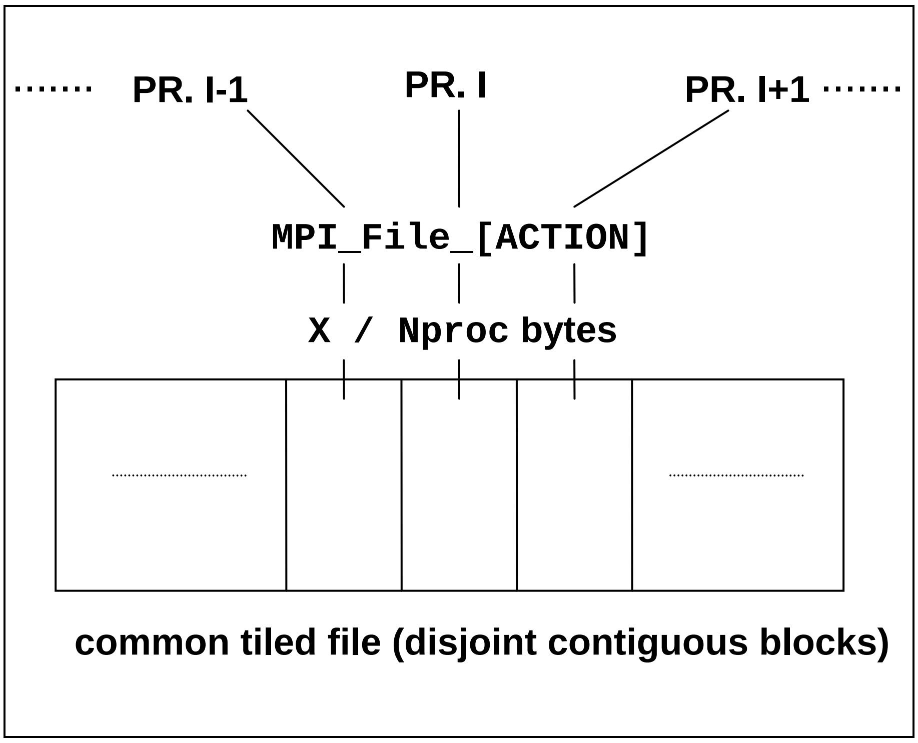


Figure 15: P_[ACTION]_indv pattern

4.2.4.4 P_[ACTION]_expl

`P_[ACTION]_expl` follows the same access pattern as `P_[ACTION]_indv`, with an explicit file pointer type, however.

Table 12 below shows the basic definitions. Figure 16 is a schematic view of the pattern.

measured pattern	as symbolized in Figure 12
elementary I/O action	as symbolized in Figure 16 (`Nproc` = number of processes)

based on
resp. for nonblocking mode
	`MPI_File_write_at / MPI_File_read_at`
	`MPI_File_iwrite_at / MPI_File_iread_at`

etype	`MPI_BYTE`
filetype	`MPI_BYTE`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`t` (in μ`sec`) as indicated in Figure 12, aggregate and non aggregate for `Write` case
reported throughput	`X/t`, aggregate and non aggregate for `Write` case

Table 12: P_[ACTION]_expl definition

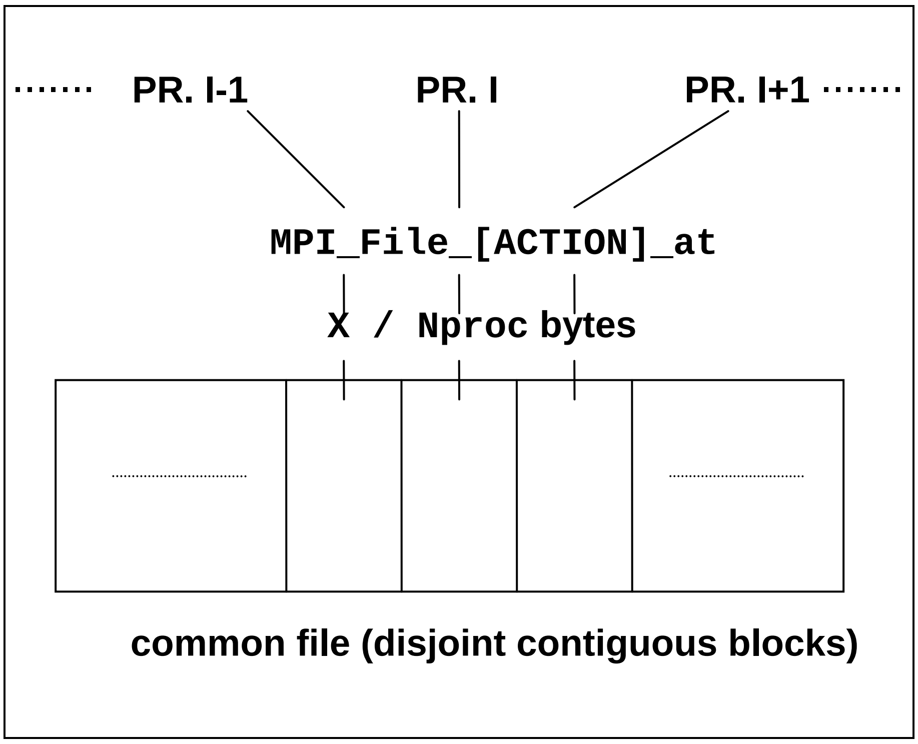


Figure 16: P_[ACTION]_expl pattern

4.2.4.5 P_[ACTION]_shared

Concurrent access to a common file by all participating processes, with a shared file pointer.

Table 13 below shows the basic definitions. Figure 17 is a schematic view of the pattern.

measured pattern	as symbolized in Figure 12
elementary I/O action	as symbolized in Figure 17 (`Nproc` = number of processes)

based on
resp. for nonblocking mode
	`MPI_File_write_shared` /
	`MPI_File_read_shared`
	`MPI_File_iwrite_shared` /
	`MPI_File_iread_shared`

etype	`MPI_BYTE`
filetype	`MPI_BYTE`
`MPI_Datatype`	`MPI_BYTE`
reported timings	`t` (in `μsec`) as indicated in Figure 12, aggregate and non aggregate for `Write` case
reported throughput	`X/t`, aggregate and non aggregate for `Write` case

Table 13: P_[ACTION]_shared definition

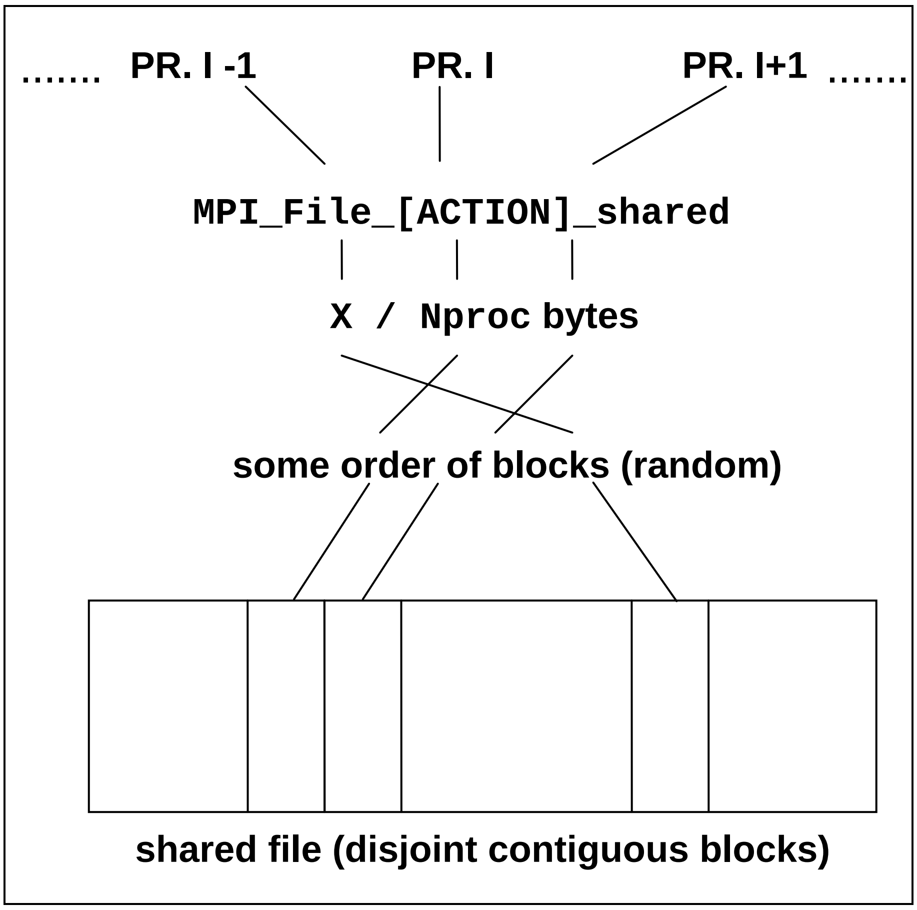

……. PR. I -1
PR. I
PR. I+1 …….
MPI_File_[ACTION]_shared
X / Nproc bytes
some order of blocks (random)
shared file (disjoint contiguous blocks)

Figure 17: P_[ACTION]_shared pattern

4.2.4.6 P_[ACTION]_priv

This pattern tests the (very important) case that all participating processes perform concurrent I/O, however to different (private) files. It is of particular interest for systems allowing completely independent I/O from different processes. In this case, this pattern should show parallel scaling and optimum results.

Table 14 below shows the basic definitions. Figure 18 is a schematic view of the pattern.

measured pattern	as symbolized in Figure 12
elementary I/O action	as symbolized in Figure 18 (`Nproc` = number of processes)

based on
resp. for nonblocking mode
	`MPI_File_write / MPI_File_read`
	`MPI_File_iwrite / MPI_File_iread`

etype	`MPI_BYTE`
filetype	`MPI_BYTE`
`MPI_Datatype`	`MPI_BYTE`
reported timings	Δt (in μsec) as indicated in Figure 12, aggregate and non aggregate for `Write` case
reported throughput	$X/\Delta t$, aggregate and non aggregate for `Write` case

Table 14: P_[ACTION]_priv definition

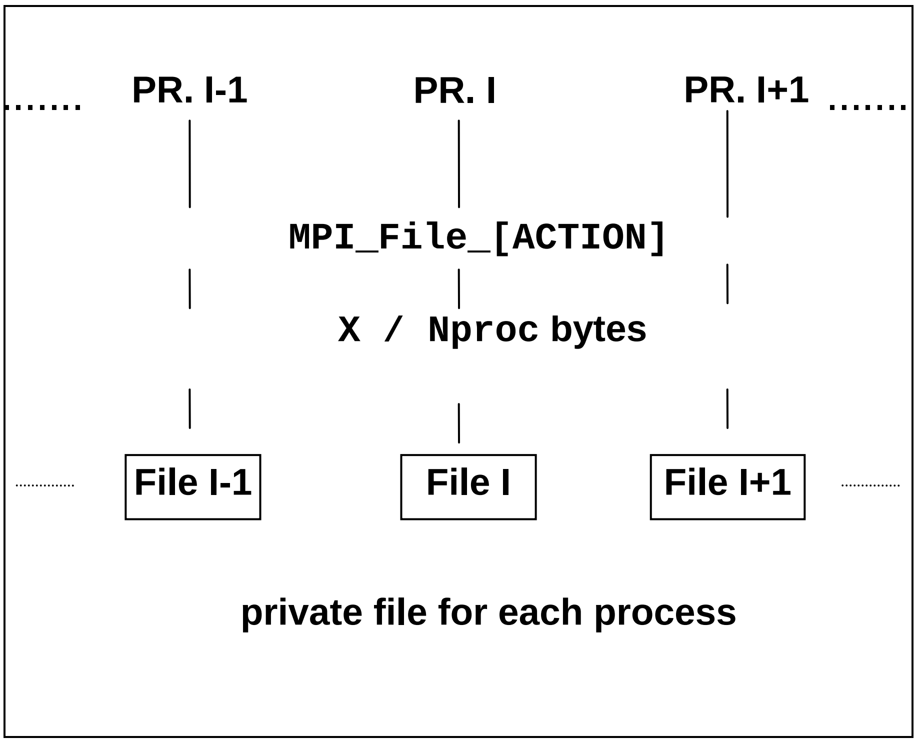


Figure 18: P_[ACTION]_priv pattern

4.2.4.7 C_[ACTION]_indv

`C_[ACTION]_indv` tests collective access from all processes to a common file, with an individual file pointer.

Table 15 below shows the basic definitions, and a schematic view of the pattern is shown in Figure 15.

based on
resp. for nonblocking mode
	`MPI_File_read_all /`
	`MPI_File_write_all`
	`MPI_File_..._all_begin -`
	`MPI_File_..._all_end`

all other parameters, measuring method	see 4.2.4.3

Table 15: C_[ACTION]_indv definition

4.2.4.8 C_[ACTION]_expl

This pattern performs collective access from all processes to a common file, with an explicit file pointer

Table 16 below shows the basic definitions, and a schematic view of the pattern is shown in Figure 16.

based on
resp. for nonblocking mode
	`MPI_File_read_at_all /`
	`MPI_File_write_at_all`
	`MPI_File_..._at_all_begin -`
	`MPI_File_..._at_all_end`

all other parameters, measuring method	see 4.2.4.4

Table 16: C_[ACTION]_expl definition

4.2.4.9 C_[ACTION]_shared

Finally, here a collective access from all processes to a common file, with a shared file pointer is benchmarked.

Table 17 below shows the basic definitions, and a schematic view of the pattern is shown in Figure 17, with the crucial difference that here the order of blocks is preserved.

based on
resp. for nonblocking mode
	`MPI_File_read_ordered /`
	`MPI_File_write_ordered`
	`MPI_File_..._ordered_begin-`
	`MPI_File_..._ordered_end`

all other parameters, measuring method	see 4.2.4.5

Table 17: C_[ACTION]_shared definition

4.2.4.10 Open_Close

Benchmark of an `MPI_File_open / MPI_File_close` pair. All processes open the same file. In order to prevent the implementation from optimizations in case of an unused file, a negligible non trivial action is performed with the file, see Figure 19. Table 18 below shows the basic definitions.

measured pattern	`MPI_File_open / MPI_File_close`
etype	`MPI_BYTE`
filetype	`MPI_BYTE`
reported timings	`t=Δt` (in `μsec`) as indicated in Figure 19
reported throughput	none

Table 18: Open_Close definition

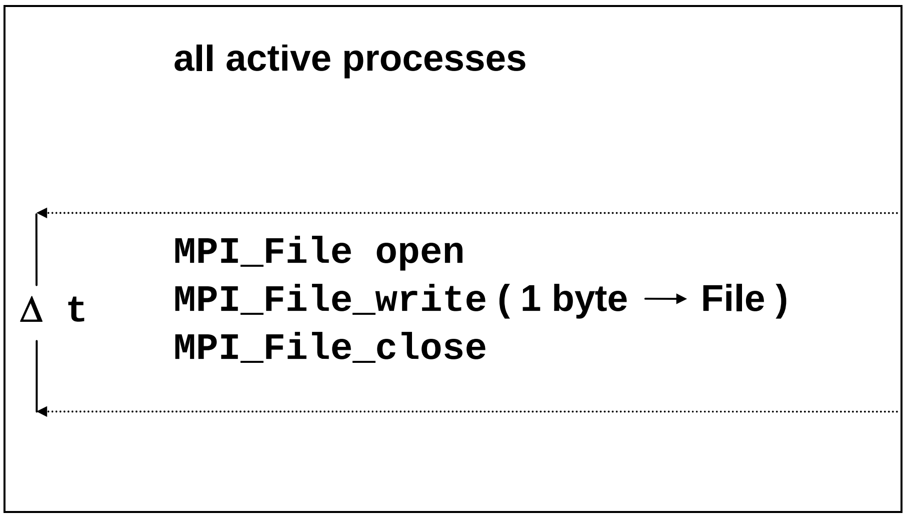


Figure 19: Open_Close pattern

4.2.5 Non-blocking I/O Benchmarks

Each of the non-blocking benchmarks, see Table 1, has a blocking equivalent explained in section 4.2.4. All the definitions can be transferred identical, except their behavior with respect to

- aggregation (the non-blocking versions only run in aggregate mode)
- synchronism

As to synchronism, only the meaning of an elementary transfer differs from the equivalent blocking benchmark. Basically, an elementary transfer looks as follows.

```
time = MPI_Wtime()

for ( i=0; i<n_sample; i++ )
     {
     Initiate transfer
     Exploit CPU
     Wait for end of transfer
     }

time = (MPI_Wtime()-time)/n_sample
```

The “Exploit CPU“ section is arbitrary. A benchmark such as IMB can only decide for one particular way of exploiting the CPU, and will answer certain questions in that special case. There is *no way to cover generality*, only hints can be expected.

4.2.5.1 Exploiting CPU

IMB uses the following method to exploit CPU. A kernel loop is executed repeatedly. The kernel is a fully vectorizable multiply of a 100×100 matrix with a vector. The function is scaleable in the following way:

```
CPU_Exploit(float desired_time, int initialize);
```

The input value of `desired_time` determines the time for the function to execute the kernel loop (with a slight variance, of course). In the very beginning, the function has to be called with `initialize=1` and an input value for `desired_time`. It will determine an Mflop/s rate and a timing `t_CPU` (as close as possible to `desired_time`), obtained by running without any obstruction. Then, during the proper benchmark, it will be called (concurrent with the particular I/O action), with `initialize=0` and always performing the same type and number of operations as in the initialization step.

4.2.5.2 Displaying results

Three timings are crucial to interpret the behavior of non-blocking I/O, overlapped with CPU exploitation:

- `t_pure =` time for the corresponding pure blocking I/O action, non overlapping with CPU activity
- `t_CPU =` time the CPU_Exploit periods (running concurrently with nonblocking I/O) would use when running dedicated
- `t_ovrl =` time for the analogous non-blocking I/O action, concurrent with CPU activity (exploiting `t_CPU` when running dedicated)

A perfect overlap would mean: `t_ovrl = max(t_pure,t_CPU).`
No overlap would mean: `t_ovrl = t_pure+t_CPU.`
The actual amount of overlap is

```
overlap  =  (t_pure + t_CPU - t_ovrl)/min(t_pure,t_CPU)   (*)
```

IMB results tables will report the timings `t_ovrl,t_pure,t_CPU` and the estimated overlap obtained by (*) above. In the beginning of a run the Mflop/s rate corresponding to `t_CPU` is displayed.

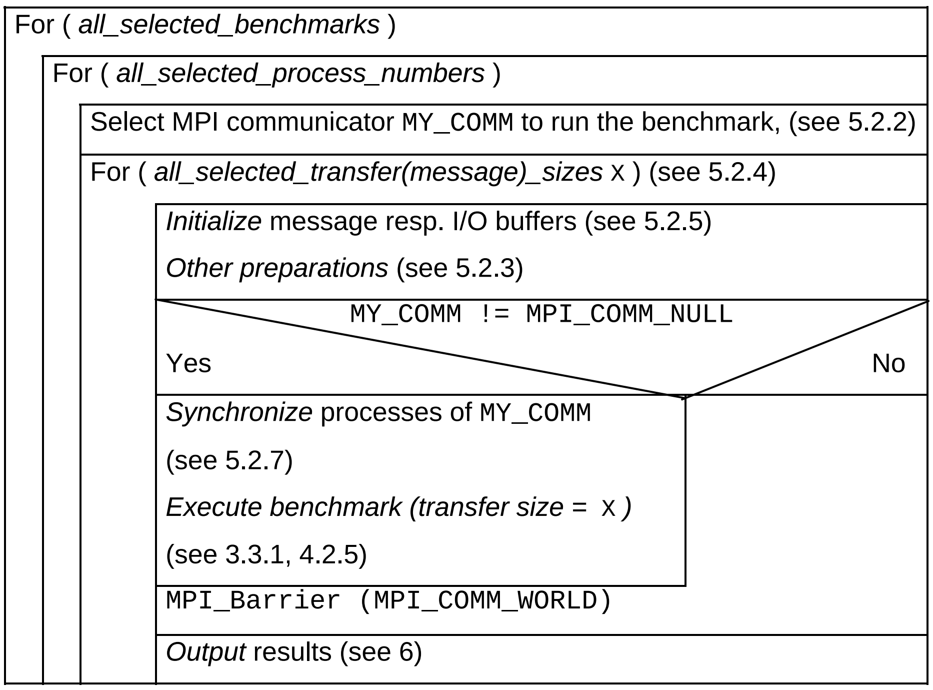
4.2.6 Multi - versions

The definition and interpretation of the `Multi-` prefix is analogous to the definition in the MPI1 section (see 3.2).

5 Benchmark Methodology

Some control mechanisms are hard coded (like the selection of process numbers to run the benchmarks on), some are set by preprocessor parameters in a central include file. There is a *standard* and an *optional* mode to control IMB. In standard mode, all configurable sizes are predefined and should not be changed. This assures comparability for a result tables in standard mode. In optional mode, the user can set those parameters at own choice. For instance, this mode can be used to extend the results tables as to larger transfer sizes.

The following graph shows the flow of control inside IMB. All *emphasized* items will be explained in more detail.



```
For ( all_selected_benchmarks )
  For ( all_selected_process_numbers )
    Select MPI communicator MY_COMM to run the benchmark, (see 5.2.2)
    For ( all_selected_transfer(message)_sizes X ) (see 5.2.4)
      Initialize message resp. I/O buffers (see 5.2.5)
      Other preparations (see 5.2.3)
      MY_COMM != MPI_COMM_NULL
        Yes
          Synchronize processes of MY_COMM
          (see 5.2.7)
          Execute benchmark (transfer size = X )
          (see 3.3.1, 4.2.5)
        No
      MPI_Barrier (MPI_COMM_WORLD)
      Output results (see 6)
```

Figure 20: Control flow of IMB

The control parameters obviously necessary are either *command line arguments* (see 5.1.2) or parameter selections inside the IMB include files `settings.h / settting_io.h` (see 5.2).

5.1 Running IMB, command line control

After installation, the executables `IMB-MPI1`, `IMB-EXT` and/or `IMB-IO` should exist.

Given `P`**,** the (normally user selected) number of MPI processes to run IMB, a startup procedure has to load parallel IMB. Lets assume, for sake of simplicity, that this done by

```
mpirun -np P IMB-<..> [arguments]
```

`P=1` is allowed and sensible for all IO and (if one likes) also for all message passing benchmarks except the Single Transfer ones. Control arguments (in addition to `P`) can be passed to IMB via (`argc,argv`). Command line arguments are only read by process 0 in `MPI_COMM_WORLD`. However, the command line options are broadcast to all other processes.

5.1.1 Default case

Just invoke

```
mpirun -np P IMB-<..>
```

All benchmarks will run on `Q=[1,] 2, 4, 8, ..., largest` 2^x`<P, P` processes (`Q=1` as discussed above IMB-IO). E.g. `P=11`, then `Q=[1,]2,4,8,11` processes will be selected. Single Transfer IMB-IO benchmarks will run only with `Q=1`, Single Transfer IMB-EXT benchmarks only with `Q=2`.

The `Q` processes driving the benchmark are called the *active processes*.

5.1.2 Command line control

The general syntax is

```
mpirun -np P IMB-<..>
      [-h[elp]]
      [Benchmark1 [Benchmark2 [ ... ] ] ]
      [-npmin P_min]
      [-multi  Outflag]
      [-input <Input_file>]
      [-msglen <File>]
      [-map <P>x<Q>]
```

(where the 6 major [ ] may appear in any order).

– Examples:

```
mpirun -np 8  IMB-IO
mpirun –np 10 IMB-MPI1 PingPing Reduce
mpirun -np 11 IMB-EXT  -npmin 5
mpirun -np 14 IMB-IO   P_Read_shared -npmin 7
mpirun -np 3  IMB-EXT  -input IMB_SELECT_EXT
mpirun –np 14 IMB-MPI1 –multi 0 PingPong Barrier
                       -map 2x7
```

5.1.2.1 Benchmark selection arguments

A sequence of blank-separated strings, each being the name of one IMB-<..> benchmark (in exact spelling, case insensitive). The benchmark names are listed in Table 1.

Default (no benchmark selection): select all benchmarks.

5.1.2.2 `-npmin` selection

The argument after `-npmin` has to be an integer `P_min`, specifying the minimum number of processes to run all selected benchmarks.

- `P_min` may be `1`
- `P_min > P` is handled as `P_min = P`
- *Default* (no `-npmin` selection): see 5.1.1.

Given `P_min`, the selected process numbers are `P_min, 2P_min, 4P_min, ..., largest` 2^x`P_min <P, P`.

5.1.2.3 `-multi` <outflag> selection

For selecting `Multi/non-Multi` mode. The argument after `–multi` is the meta-symbol <`outflag`> and this meta-symbol represents an integer value of either 0 or 1. This flag just controls the way of displaying results.

- `Outflag = 0`: only display max timings (min throughputs) over all active groups
- `Outflag = 1`: report on all groups separately (may become longish)
- *Default* (no `–multi` selection): run primary (non `Multi`) versions.

5.1.2.4 `-input` <File> selection

An ASCII input file is used to select the benchmarks to run, e.g. a file `IMB_SELECT_EXT` looking as follows:

```
#
# IMB benchmark selection file
#
# every line must be a comment (beginning with #), or it
# must contain exactly 1 IMB benchmark name
#
#Window
Unidir_Get
#Unidir_Put
#Bidir_Get
#Bidir_Put
Accumulate
```

By aid of this file,

```
mpirun .... IMB-EXT -input IMB_SELECT_EXT
```

would run IMB-EXT benchmarks `Unidir_Get` and `Accumulate`.

5.1.2.5 `–msglen` <File> selection

Enter any set of nonnegative message lengths to an ASCII file, line by line. Call it, e.g., “Lengths” and call IMB with arguments

```
            -msglen Lengths
```

This lengths value then overrides the default message lengths (see 5.2.4). For `IMB-IO`, the file defines the I/O portion lengths.

5.1.2.6 `–map` PxQ selection

Numbers processes along rows of the matrix

0	P	..	(Q-2)P	(Q-1)P
1				
…				
P-1	2P-1		(Q-1)P-1	QP-1

E.g., in order to run `Multi-PingPong` between two nodes of size P, with each process on one node communicating with its counterpart on the other, call

```
mpirun –np <2P> IMB-MPI1 –map <P>x2 PingPong
```

5.2 IMB parameters and hard-coded settings

5.2.1 Parameters controlling IMB

There are 9 parameters (set by preprocessor definition) controlling IMB. The definition is in the files

`settings.h` (IMB-MPI1, IMB-EXT) and `settings_io.h (`IMB-IO`).`

A complete list and explanation of `settings.h` is in Table 19 below.

Both include files are almost identical in structure, but differ in the standard settings. Note that some names in `settings_io.h` contain `MSG` (for "mes-sage"), in consistency with `settings.h`.

Parameter (standard mode value)	Meaning
`IMB_OPTIONAL` (not set)	has to be set when user optional settings are to be activated
`MINMSGLOG` (0)	second smallest data transfer size is max(unit,$2^{\text{MINMSGLOG}}$) (the smallest always being 0), where unit = sizeof(float) for reductions, unit = 1 else
`MAXMSGLOG` (22)	largest message size is $2^{\text{MAXMSGLOG}}$ Sizes `0`, 2^i `(i=MINMSGLOG,..,MAXMSGLOG)` are used
`MSGSPERSAMPLE` (1000)	max. repetition count for all IMB-MPI1 benchmarks
`MSGS_NONAGGR` (100)	max. repetition count for non aggregate benchmarks (relevant only for IMB-EXT)

`OVERALL_VOL` (40 MBytes)	for all sizes < `OVERALL_VOL`, the repetition count is eventually reduced so that not more than `OVERALL_VOL` bytes overall are processed. This avoids unnecessary repetitions for large message sizes. Finally, the real repetition count for message size X is
	`MSGSPERSAMPLE (X=0),`
	`min(MSGSPERSAMPLE,max(1,OVERALL_VOL/X)) (X>0)`
	NOTE: `OVERALL_VOL` does *not* restrict the size of the max. data transfer. $2^{\text{MAXMSGLOG}}$ is the largest size, independent of `OVERALL_VOL`

`N_WARMUP` (2)	Number of *Warmup* sweeps (see5.2.6)
`N_BARR` (2)	Number of `MPI_Barrier` for synchronization (5.2.7)
`TARGET_CPU_SECS` (0.01)	CPU seconds (as float) to run concurrent with non-blocking benchmarks (currently irrelevant for IMB-MPI1)

Table 19: IMB (MPI1/EXT) parameters (`settings.h`)

IMB allows for two sets of parameters: *standard* and *optional*.

Below a sample of file `settings_io.h` is shown. Here, `IMB_OPTIONAL` is set, so that user defined parameters are used. I/O sizes 32 and 64 Mbytes (and a smaller repetition count) are selected, extending the standard mode tables.

If `IMB_OPTIONAL` is deactivated, the obvious standard mode values are taken.

Note:
IMB has to be re-compiled after a change of `settings.h/settings_io.h`.

```
#define FILENAME "IMB_out"
#define IMB_OPTIONAL
#ifdef IMB_OPTIONAL
#define MINMSGLOG 25
#define MAXMSGLOG 26
#define MSGSPERSAMPLE 10
#define MSGS_NONAGGR  10
#define OVERALL_VOL 16*1048576
#define TARGET_CPU_SECS 0.1 /* unit seconds */
#define N_BARR   2
#else
/*DON'T change anything below here !!*/
#define MINMSGLOG 0
#define MAXMSGLOG 24
#define MSGSPERSAMPLE 50
#define MSGS_NONAGGR  10
#define OVERALL_VOL 16*1048576
#define TARGET_CPU_SECS 0.1 /* unit seconds */
#define N_BARR   2
#endif
```

5.2.2 Communicators, active processes

Communicator management is repeated in every “select `MY_COMM`“ step in Figure 20. If exists, the previous communicator is freed. When running Q<=P processes, the first `Q` ranks of `MPI_COMM_WORLD` are put into one group, the remaining `P-Q` get `MPI_COMM_NULL` in Figure 20.

The group of MY_COMM is called *active processes* group.

5.2.3 Other preparations

5.2.3.1 Window (IMB_EXT)

An Info is set (see section 5.2.3.3) and `MPI_Win_create` is called, creating a window of size `X` for `MY_COMM`. Then, `MPI_Win_fence` is called to start an access epoch.

5.2.3.2 File (IMB-IO)

The file initialization consists of

- selecting a file name:
  Parameter in include file `settings_io.h`. In a `Multi` case, a suffix `_g<groupid>` is appended to the name. If the file name is per process, a (second evt.) suffix `_<rank>` will be appended
- deleting the file if exists:
  open it with `MPI_MODE_DELETE_ON_CLOSE`
  close it
- selecting a communicator to open the file, which will be:
  `MPI_COMM_SELF` for `S_` benchmarks and `P_[ACTION]_priv`,
  `MY_COMM` as selected in 5.2.2 above else.
- selecting `amode = MPI_MODE_CREATE | MPI_MODE_RDWR`
- selecting an info, see 5.2.3.3

5.2.3.3 Info

IMB uses an external function `User_Set_Info` which the *user is allowed to implement at best for the current machine*. The default version is:

```
#include "mpi.h"
void User_Set_Info ( MPI_Info* opt_info)
#ifdef MPIIO
{/*  Set info for all MPI_File_open calls  */
*opt_info = MPI_INFO_NULL;
}
#endif
#ifdef EXT
{/*  Set info for all MPI_Win_create calls  */
*opt_info = MPI_INFO_NULL;
}
#endif
```

IMB uses no assumptions and imposes no restrictions on how this routine will be implemented.

5.2.3.4 View (IMB-IO)

The file view is the determined by the settings

- `disp = 0`
- `datarep = native`
- etype, filetype as defined in the single definitions in section 0
- info as defined in 5.2.3.3

5.2.4 Message / I-O buffer lengths

5.2.4.1 IMB-MPI1, IMB-EXT

Set in `settings.h` (see 5.2.1), used unless `–msglen` flag is selected (ref. 5.1.2.5).

5.2.4.2 IMB-IO

Set in `settings_io.h` (see 5.2.1) , used unless `–msglen` flag is selected (ref. 5.1.2.5).

5.2.5 Buffer initialization

Communication and I/O buffers are dynamically allocated as `void*` and used as `MPI_BYTE` buffers for all benchmarks except `Accumulate`. See 7.1 for the memory requirements. To assign the buffer contents, a cast to an assignment type is performed. On the one hand, a sensible data-type is mandatory for `Accumulate`. On the other hand, this facilitates results checking which may become necessary eventually (see 7.2).

IMB sets the buffer assignment type by `typedef assign_type` in

`settings.h/settings_io.h`

Currently, `int` is used for IMB-IO, `float` for IMB-EXT (as this is sensible for `Accumulate`). The values are set by a CPP macro, currently

```
#define BUF_VALUE(rank,i) (0.1*((rank)+1)+(float)( i)
```

(IMB-EXT), and

```
#define BUF_VALUE(rank,i) 10000000*(1+rank)+i%10000000
```

(IMB-IO).

In every initialization, communication buffers are seen as typed arrays and initialized as to

```
((assign_type*)buffer)[i] = BUF_VALUE(rank,i);
```

where rank is the MPI rank of the calling process.

5.2.6 Warm-up phase (MPI1, EXT)

Before starting the actual benchmark measurement for `IMB-MPI1` and `IMB-EXT`, the selected benchmark is executed `N_WARMUP` (defined in `settings.h`, see 5.2.1) times with the maximum message length. This is to hide eventual initialization overheads of the message passing system.

5.2.7 Synchronization

Before the actual benchmark, `N_BARR` (constant defined in `settings.h` and `settings_io.h`, current value 2) many

```
MPI_Barrier(MY_COMM)
```

(ref. Figure 20) assure that all processes are synchronized.

5.2.8 The actual benchmark

In order to reduce measurement errors caused by to insufficient clock resolution, every benchmark is run repeatedly. The repetition count for MPI1- or aggregate EXT / IO benchmarks is `MSGSPERSAMPLE` (constant defined in `settings.h/settings_io.h`, current values 1000 / 50). In order to avoid excessive runtimes for large transfer sizes `X`, an upper bound is set to `OVERALL_VOL/X (OVERALL_VOL` constant defined in `settings.h / settings_io.h`, current values `4 / 16 Mbytes`). Finally,

```
n_sample = MSGSPERSAMPLE (X=0)

n_sample = max(1,min(MSGSPERSAMPLE,OVERALL_VOL/X)) (X>0)
```

is the repetition count for all aggregate benchmarks, given transfer size `X`.

The repetition count for non aggregate benchmarks is defined completely analogously, with `MSGSPERSAMPLE` replaced by `MSGS_NONAGGR (`a reduced count is sensible as non aggregate runtimes are normally much longer).

In the following, *elementary transfer* means the pure function (`MPI_[Send,…], MPI_Put, MPI_Get, MPI_Accumulate, MPI_File_write_XX, MPI_File_read_XX`), without any further function call. Recall that assure transfer completion means `MPI_Win_fence` (one sided communications), `MPI_File_sync` (I/O `Write` benchmarks), and is empty for all other benchmarks.

5.2.8.1 MPI1 case

```
for ( i=0; i<N_BARR; i++ ) MPI_Barrier(MY_COMM)
time = MPI_Wtime()
for ( i=0; i<n_sample; i++ )
      execute MPI pattern
time = (MPI_Wtime()-time)/n_sample
```

5.2.8.2 EXT and blocking I/O case

For the aggregate case, the kernel loop looks like:

```
for ( i=0; i<N_BARR; i++ )MPI_Barrier(MY_COMM)
/* Negligible integer (offset) calculations ... */
time = MPI_Wtime()
for ( i=0; i<n_sample; i++ )
              execute elementary transfer
assure completion of all transfers
time = (MPI_Wtime()-time)/n_sample
```

In the non aggregate case, every single transfer is safely completed:

```
for ( i=0; i<N_BARR; i++ )MPI_Barrier(MY_COMM)
/* Negligible integer (offset) calculations ... */
time = MPI_Wtime()
for ( i=0; i<n_sample; i++ )
              {
              execute elementary transfer
              assure completion of transfer
              }
time = (MPI_Wtime()-time)/n_sample
```

5.2.8.3 Non-blocking I/O case

As explained in 4.2.5, a non-blocking benchmark has to provide three timings (blocking pure I/O time `t_pure`, non-blocking I/O time `t_ovrl` (concurrent with CPU activity), pure CPU activity time `t_CPU`). Thus, the actual benchmark consists of

- Calling the equivalent blocking benchmark as defined in 5.2.8 and taking benchmark time as `t_pure`
- Closing and re-opening the particular file(s)
- Once again synchronizing the processes
- Running the non blocking case, concurrent with CPU activity (exploiting `t_CPU` when running undisturbed), taking the effective time as `t_ovrl`.

The desired CPU time to be matched (approximately) by `t_CPU` is set in `settings_io.h:`

```
#define TARGET_CPU_SECS 0.1 /* unit seconds */
```

6 Output

Output is most easily explained by sample outputs, and therefore one should examine the tables below. What one sees is the following.

- *General information*
  Machine, System, Release, Version are obtained by the code `IMB_g_info.c`:

```
    #include <sys/utsname.h>
    void IMB_make_sys_info()
{
  int dont_care, mpi_subversion, mpi_version;
  struct utsname info;
  uname( &info );
  dont_care = MPI_Get_version(&mpi_version,&mpi_subversion);

  fprintf(unit,"# Machine               : %s\n",info.machine);
  fprintf(unit,"# System                : %s\n",info.sysname);
  fprintf(unit,"# Release               : %s\n",info.release);
  fprintf(unit,"# Version               : %s\n",info.version);
  fprintf(unit,"# MPI Version           : %-d.%-d\n",mpi_version,mpi_subversion);
  fprintf(unit,"# MPI Thread Environment: ");

  switch (mpi_thread_environment) {
  case MPI_THREAD_SINGLE :
    fprintf(unit,"MPI_THREAD_SINGLE\n");
    break;
  case MPI_THREAD_FUNNELED :
    fprintf(unit,"MPI_THREAD_FUNNELED\n");
    break;
  case MPI_THREAD_SERIALIZED :
    fprintf(unit,"MPI_THREAD_SERIALIZED\n");}
    break;
  default :
    fprintf(unit,"MPI_THREAD_MULTIPLE\n");
    break;
  }
}
```

- *Non multi case numbers*
  After a benchmark completes, 3 time values are available: `Tmax`, `Tmin`, `Tavg`, the maximum, minimum and average time, respectively, extended over the group of active processes. The time unit is μ`sec`.

Single Transfer Benchmarks:
Display `X = message size [bytes], T=Tmax[μsec], bandwidth = X / 1.048576 / T`
Parallel Transfer Benchmarks:
Display `X = message size, Tmax, Tmin and Tavg`, `bandwidth` based on `time = Tmax`
Collective Benchmarks:
Display `X = message size` (except for `Barrier`), `Tmax, Tmin` and `Tavg`

- *Multi case numbers*
  `–multi 0`: the same as above, with `max, min, avg` over all groups.
  `–multi 1`: the same for all groups, `max, min, avg` over single groups.

6.1 Sample 1

```
<..> np 2 IMB-MPI1 PingPong Allreduce
```

```
#---------------------------------------------------
#    Intel (R) MPI Benchmark Suite V3.0, MPI-1 part
#---------------------------------------------------
# Date                  : Tue Jul 11 16:23:46 2006
# Machine               : x86_64
# System                : Linux
# Release               : 2.6.9-34.ELsmp
# Version               : #1 SMP Fri Feb 24 16:56:28 EST 2006
# MPI Version           : 2.0
# MPI Thread Environment: MPI_THREAD_SINGLE
#
# Minimum message length in bytes:   0
# Maximum message length in bytes:   4194304
#
# MPI_Datatype                   :   MPI_BYTE
# MPI_Datatype for reductions    :   MPI_FLOAT
# MPI_Op                         :   MPI_SUM
#
#

# List of Benchmarks to run:

# PingPong
# Allreduce

#---------------------------------------------------
# Benchmarking PingPong
# #processes = 2
#---------------------------------------------------
 #bytes #repetitions      t[usec]   Mbytes/sec
      0         1000         ..       ..
      1         1000
      2         1000
      4         1000
      8         1000
     16         1000
     32         1000
     64         1000
    128         1000
    256         1000
    512         1000
   1024         1000
   2048         1000
   4096         1000
   8192         1000
  16384         1000
  32768         1000
  65536          640
 131072          320
 262144          160
 524288           80
1048576           40
2097152           20
4194304           10
#-------------------------------------------------------
# Benchmarking Allreduce
# ( #processes = 2 )
#-------------------------------------------------------
 #bytes #repetitions  t_min[usec]  t_max[usec]   t_avg[usec]
      0         1000         ..           ..            ..
      4         1000
      8         1000
     16         1000
     32         1000
     64         1000
    128         1000
    256         1000
    512         1000
   1024         1000
   2048         1000
   4096         1000
   8192         1000
  16384         1000
  32768         1000
  65536          640
 131072          320
 262144          160
 524288           80
1048576           40
2097152           20
4194304           10
```

6.2 Sample 2

```
<..> –np 6 IMB-MPI1
  pingping allreduce -map 2x3 -msglen Lengths -multi 0

Lengths file:
0
100
1000
10000
100000
1000000
```

```
#---------------------------------------------------
#    Intel (R) MPI Benchmark Suite V3.0, MPI-1 part
#---------------------------------------------------
# Date                  : Tue Jul 11 16:54:11 2006
# Machine               : x86_64
# System                : Linux
# Release               : 2.6.9-34.ELsmp
# Version               : #1 SMP Fri Feb 24 16:56:28 EST 2006
# MPI Version           : 2.0
# MPI Thread Environment: MPI_THREAD_SINGLE
#
# Minimum message length in bytes:   0
# Maximum message length in bytes:   4194304
#
# MPI_Datatype                   :   MPI_BYTE
# MPI_Datatype for reductions    :   MPI_FLOAT
# MPI_Op                         :   MPI_SUM
#
#

# List of Benchmarks to run:

# (Multi-)PingPing
# (Multi-)Allreduce

#----------------------------------------------------------------
# Benchmarking Multi-PingPing
# ( 2 groups of 2 processes each running simultaneous )
# Group  0:     0    2
#
# Group  1:     1    3
#
#----------------------------------------------------------------
-----------
 #bytes #rep.s t_min[usec] t_max[usec] t_avg[usec] Mbytes/sec
      0   1000       ..          ..          ..          ..
    100   1000
   1000   1000
  10000   1000
 100000    419
1000000     41
```

```
#-----------------------------------------------------------------
# Benchmarking Multi-Allreduce
# ( 2 groups of 2 processes each running simultaneous )
# Group  0:     0    2
#
# Group  1:     1    3
#
#-----------------------------------------------------------------
 #bytes #repetitions  t_min[usec]  t_max[usec]  t_avg[usec]
      0         1000         ..          ..           ..
    100         1000
   1000         1000
  10000         1000
 100000          419
1000000           41

#-----------------------------------------------------------------
# Benchmarking Allreduce
# #processes = 4; rank order (rowwise):
#     0    2
#
#     1    3
#
#-----------------------------------------------------------------
 #bytes #repetitions  t_min[usec]  t_max[usec]  t_avg[usec]
      0         1000         ..          ..           ..
    100         1000
   1000         1000
  10000         1000
 100000          419
1000000           41
```

6.3 Sample 3

<..> IMB-IO –np 2 p_write_indv -npmin 2

```
#----------------------------------------------------
#    Intel (R) MPI Benchmark Suite V3.0, MPI-IO part
#----------------------------------------------------
# Date                 : Tue Jul 11 17:21:34 2006
# Machine              : x86_64
# System               : Linux
# Release              : 2.6.9-34.ELsmp
# Version              : #1 SMP Fri Feb 24 16:56:28 EST 2006
# MPI Version          : 2.0
# MPI Thread Environment: MPI_THREAD_SINGLE
#
# Minimum io portion in bytes:   0
# Maximum io portion in bytes:   16777216
#
#
#

# List of Benchmarks to run:

# P_Write_Indv

#-----------------------------------------------------------------
# Benchmarking P_Write_Indv
# #processes = 2
#-----------------------------------------------------------------
#
#    MODE: AGGREGATE
#
  #bytes #rep.s t_min[usec]     t_max     t_avg Mb/sec
       0     50       ..         ..        ..      ..
       1     50
       2     50
       4     50
       8     50
      16     50
      32     50
```

```
       64      50
      128      50
      256      50
      512      50
     1024      50
     2048      50
     4096      50
     8192      50
    16384      50
    32768      50
    65536      50
   131072      50
   262144      50
   524288      32
  1048576      16
  2097152       8
  4194304       4
  8388608       2
 16777216       1

#---------------------------------------------------------------
# Benchmarking P_Write_Indv
# #processes = 2
#---------------------------------------------------------------
#
#    MODE: NON-AGGREGATE
#
  #bytes #rep.s t_min[usec]     t_max     t_avg Mb/sec
       0      10      ..            ..          ..    ..
       1      10
       2      10
       4      10
       8      10
      16      10
      32      10
      64      10
     128      10
     256      10
     512      10
    1024      10
    2048      10
    4096      10
    8192      10
   16384      10
   32768      10
   65536      10
  131072      10
  262144      10
  524288      10
 1048576      10
 2097152       8
 4194304       4
 8388608       2
16777216       1
```

7 Further details

7.1 Memory requirements

Benchmarks	Standard mode memory demand per process (Q active processes)	Optional mode memory demand per process (X = $2^{MAXMSGLOG}$)
`Alltoall`	`Q × 8 MBytes`	`Q × 2X bytes`
`Allgather, Allgatherv`	`(Q+1) × 4 MBytes`	`(Q+1) × X bytes`
`All other MPI1 benchmarks`	`8 MBytes`	`2X bytes`
`IMB-EXT`	`80 Mbytes`	`2 max(X,OVERALL_VOL) bytes`
`IMB-IO`	`32 Mbytes`	`2X bytes`
	`disk space overall`	`disk space overall`
`IMB-IO`	`16 Mbytes`	`max(X,OVERALL_VOL) bytes`

Table 20 : Memory requirements with standard settings

7.2 Results checking

By activating the `cpp` flag `–DCHECK` through the `CPPFLAGS` variable (see 2.1), and recompiling, at IMB runtime every message passing result will be checked against the expected outcome (note that the contents of each buffer is well defined, see 5.2.5). Output tables will contain an additional column displaying the diffs as floats (named *defects*).

`Attention``: -DCHECK` results are not valid as real benchmark data! Don't forget to deactivate DCHECK and recompile in order to get proper results.

8 Revision History

Release No.	Date
2.3	Nov. 2004
3.0	June 2006