Dynamic and Adaptive optimization techniques to enhance the performance of MPI applications by using **HECToR** and **Eddie** clusters.

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edinburgh data-intensive research

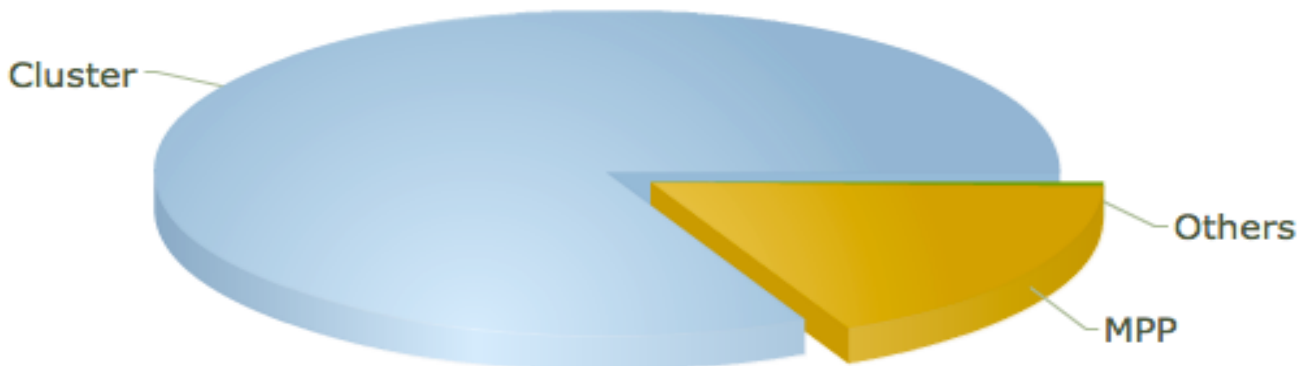
Summary

1. Problem description
2. Main Objectives
3. Strategies for improve the performance of collective I/O operation
4. Strategies for improve the performance communication operations
5. Evaluations

Summary

Problem description

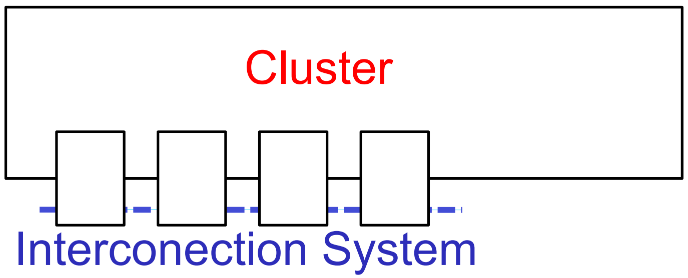
- Parallel computation on cluster has become the most common solution for HPC application.



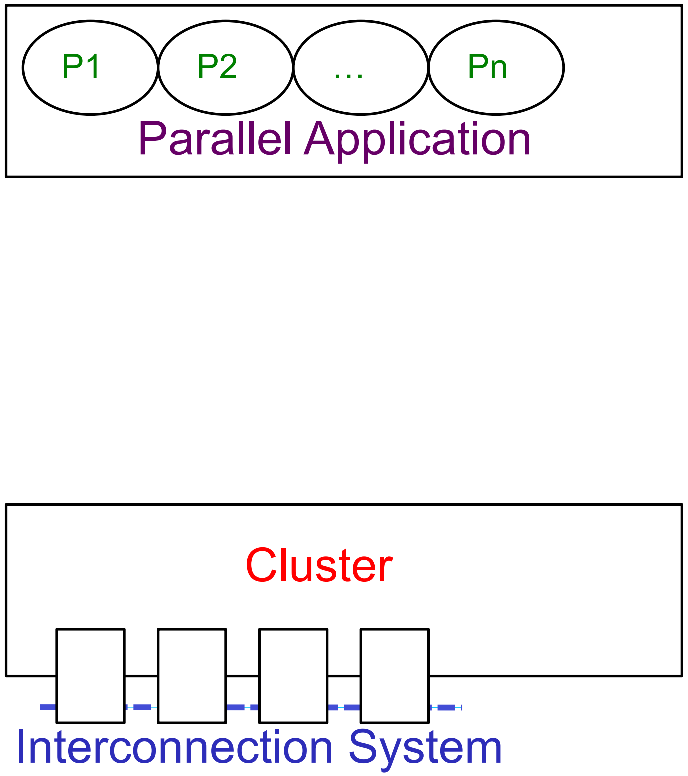
TOP 500
June2011

Problem description

- Cluster is a group of linked computers, working together closely thus in many respects forming a single computer.

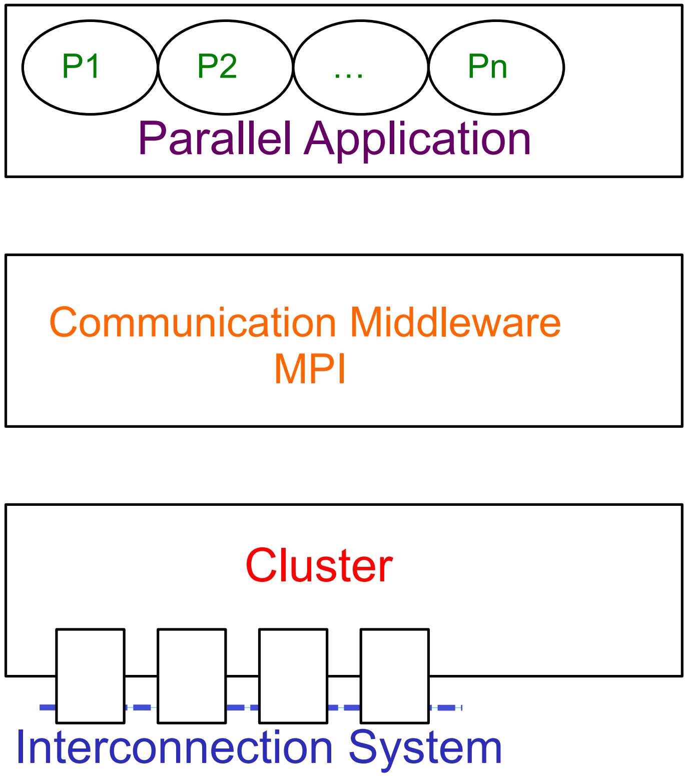


Problem description



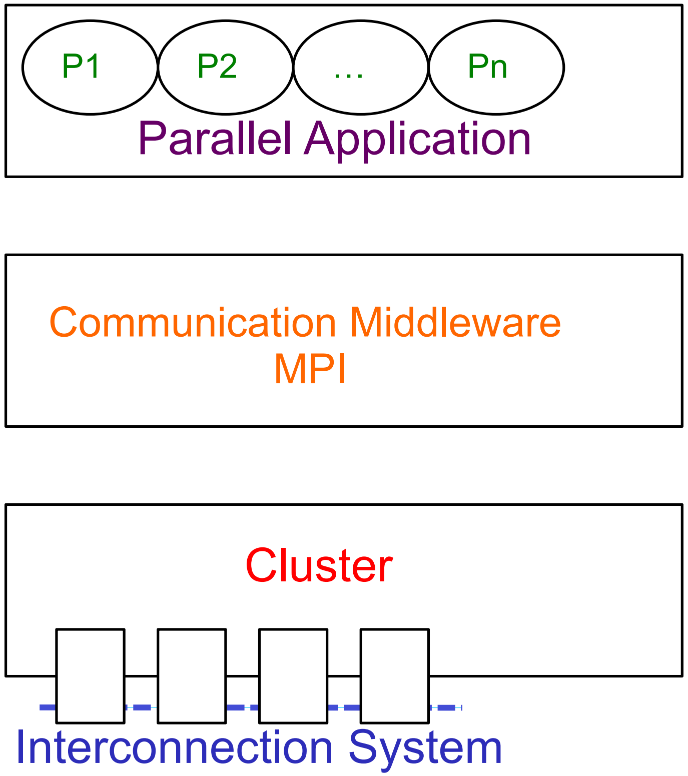
- On a cluster, one/many parallel applications could be running.

Problem description



- One of most communication middleware used is the standard **MPI** (Message Passing Interface).

Problem description

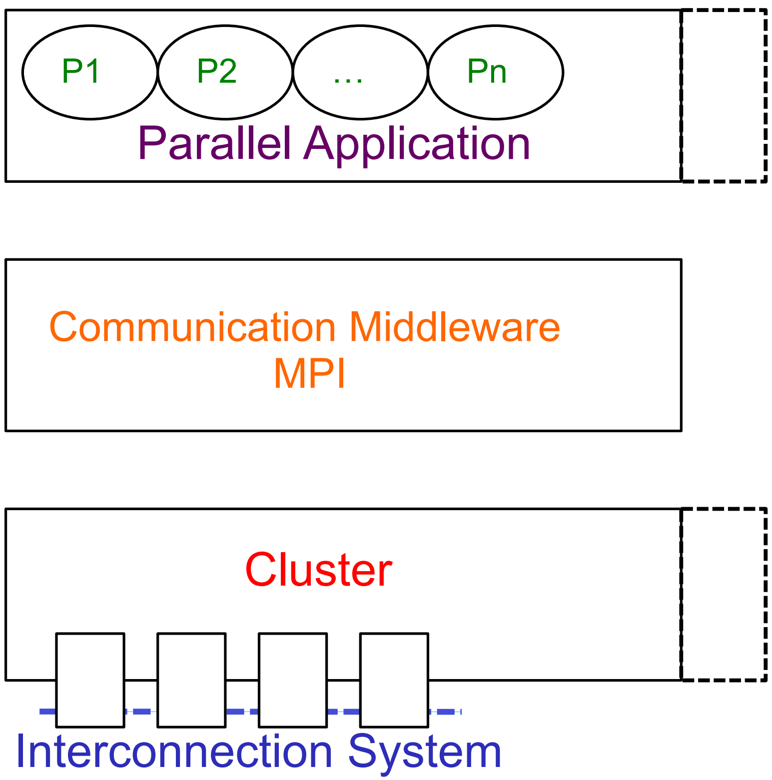


- One of most communication middleware used is the standard **MPI** (Message Passing Interface).
- Different implementations:
  - **MPICH**
  - OpenMPI
  - LAM
  - CHIMP-MPI …

Phd.Thesis:
MPICH 1.2

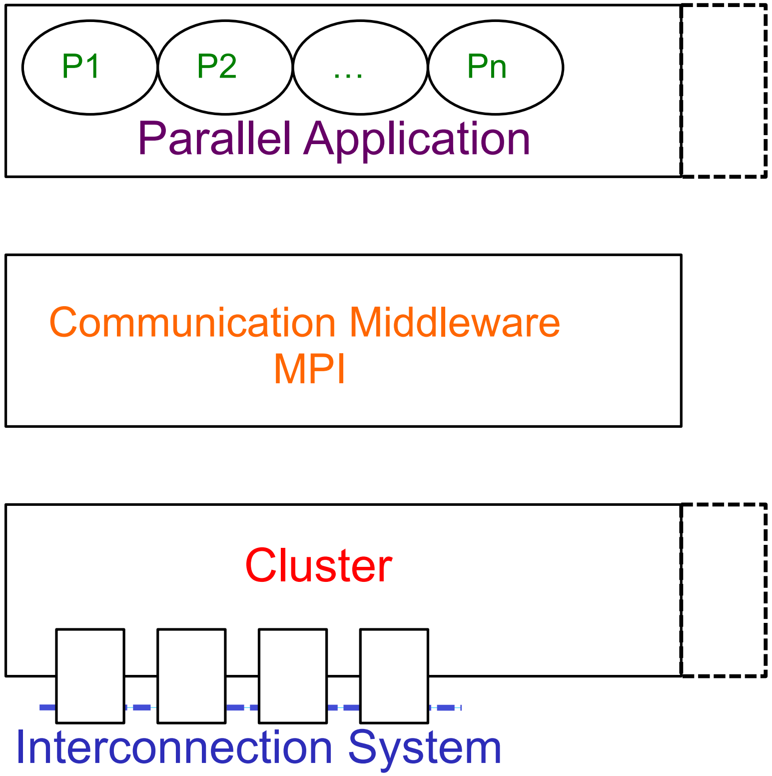
Now : MPICH 2

Problem description: trend



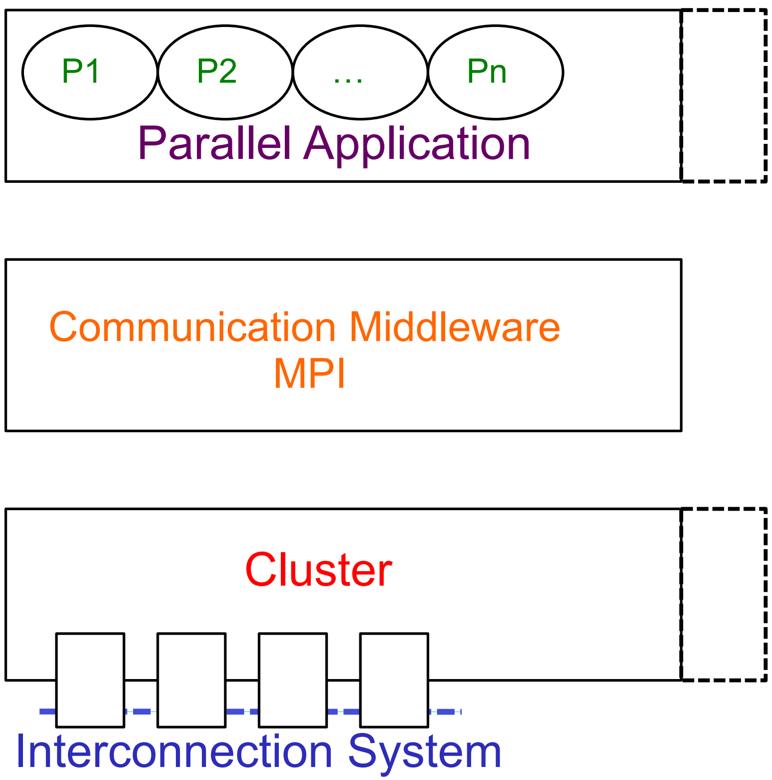
- Multicore processors provides a flexible way to increase the computation capability of cluster
- System performance may be improved with multicore but bottleneck from other components could reduce the scalability.

Problem description: Bottleneck



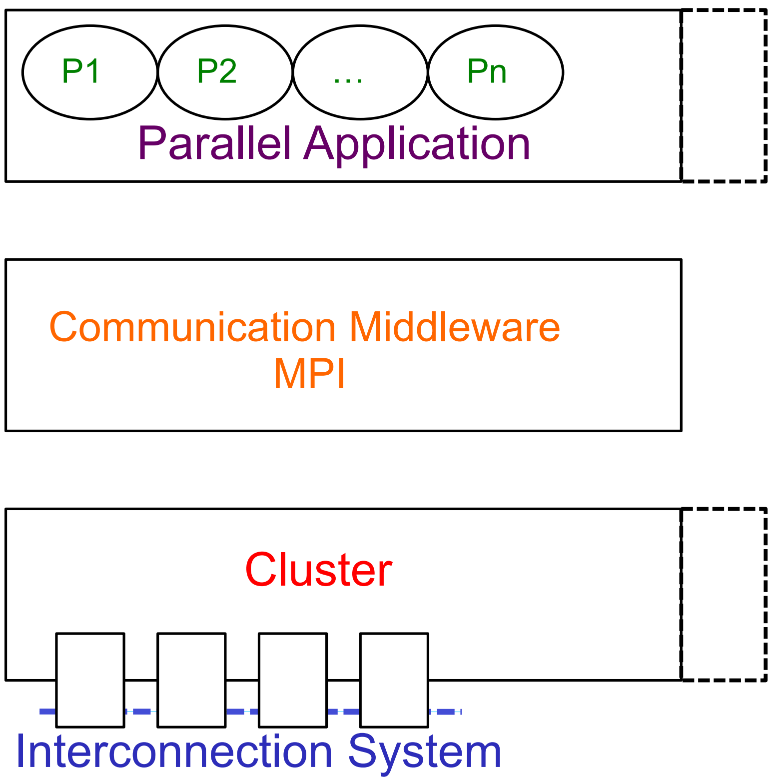
- Bottleneck :
  - I/O subsystem
  - Communication subsystem

Problem description: Bottleneck



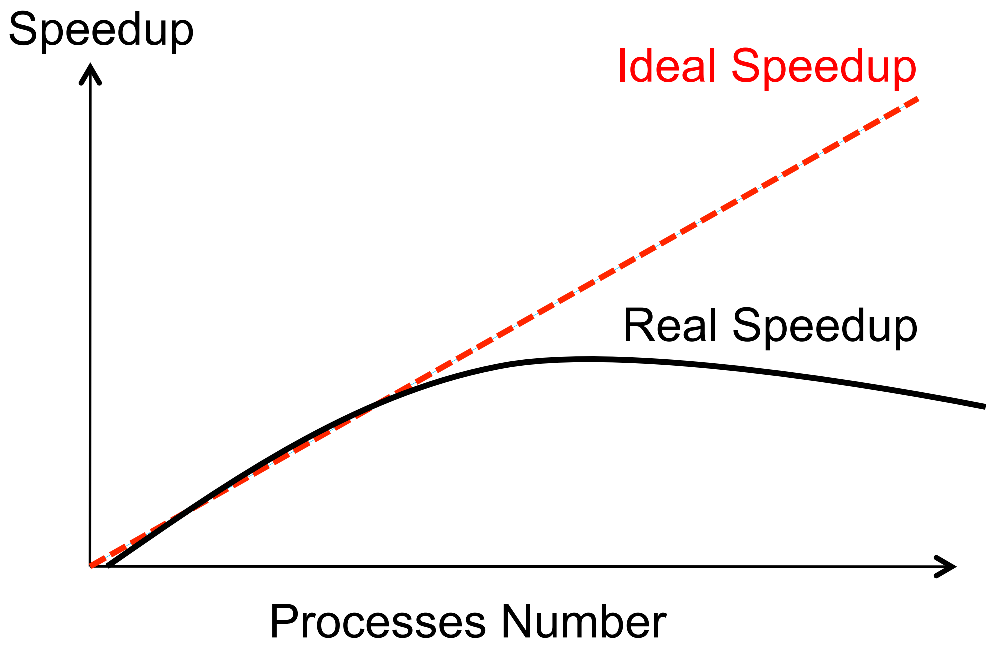
- I/O Bottleneck:
  - I/O requests initiated by multiple cores and besides when non-contiguous disk accesses is used

Problem description: Bottleneck



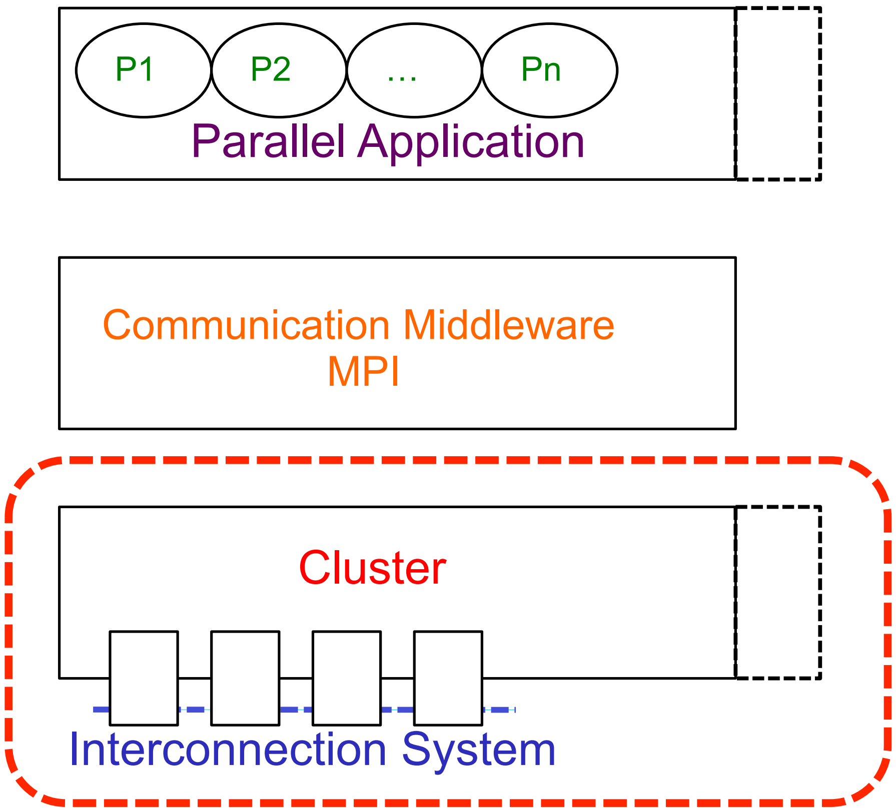
- Communication Bottleneck:
  - Network used are very fast and low latency.
  - Computational capability in multicore very high.
  - The frequency of message increase a lot → insufficient the increase of the bandwidth and latency

Problem description: Bottleneck



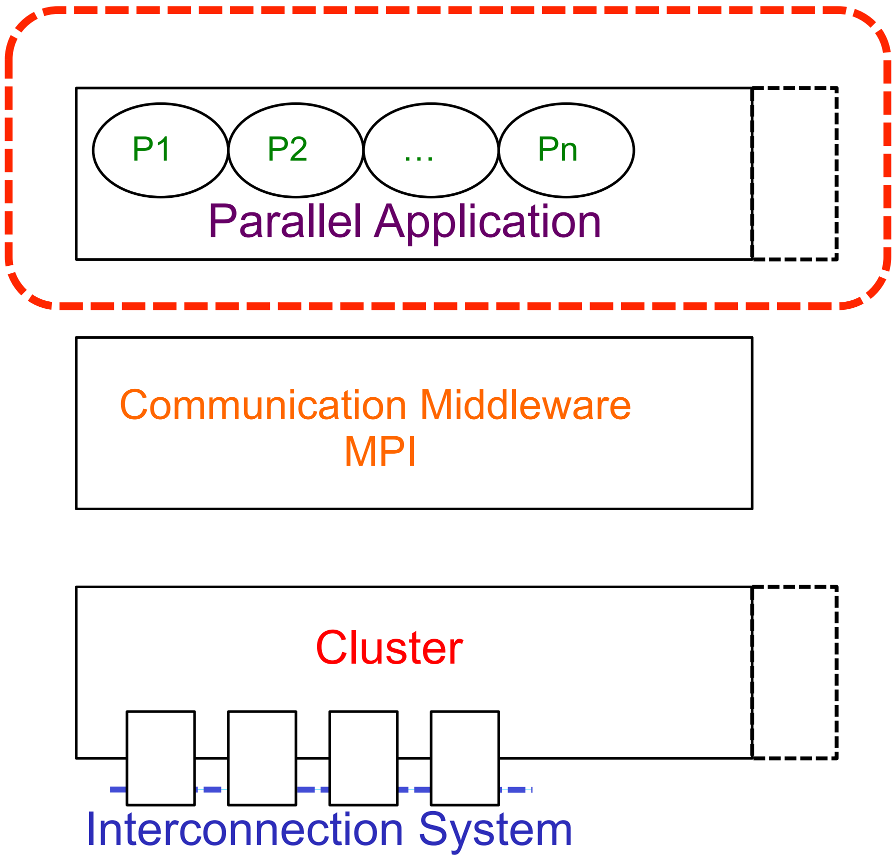
- Communication and I/O saturation:
  - Scalability problem
  - Performance problem

Problem description: possible solutions



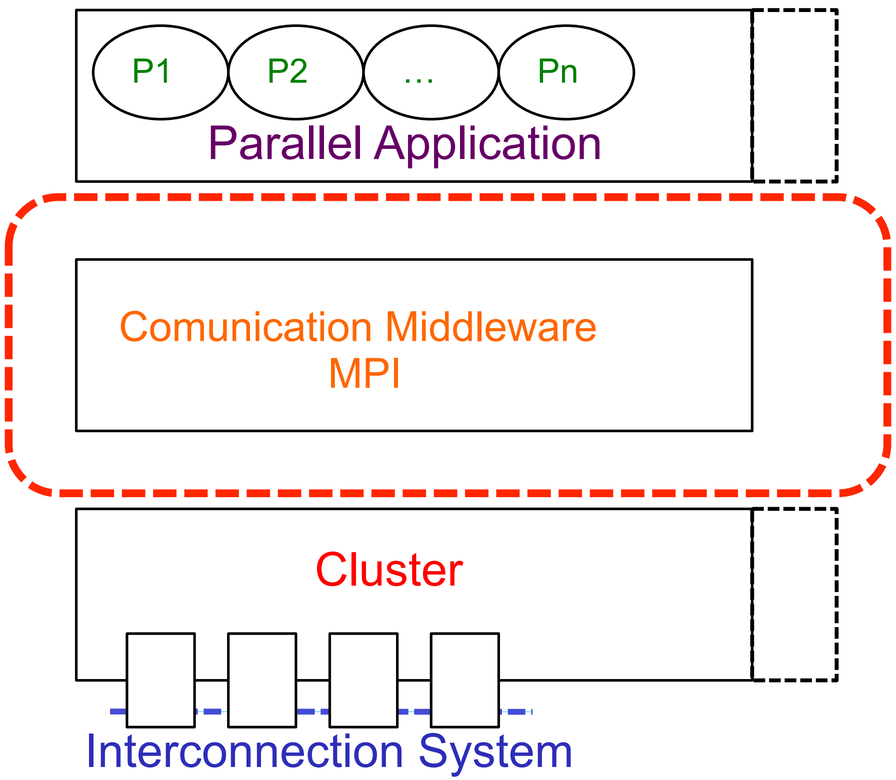
- 1) Improve network
  - Expensive.
  - Limited to current technology

Problem description: possible solutions



- 2) Improve the applications:
  - More effort in the design
  - Not always possible
  - The improvement affects few users

Problem description: possible solutions



- 3) Improve the communication middleware
  - Portability
  - Greater user benefited
  - Lower Cost
  - Transparent:
    - Users
    - Applications

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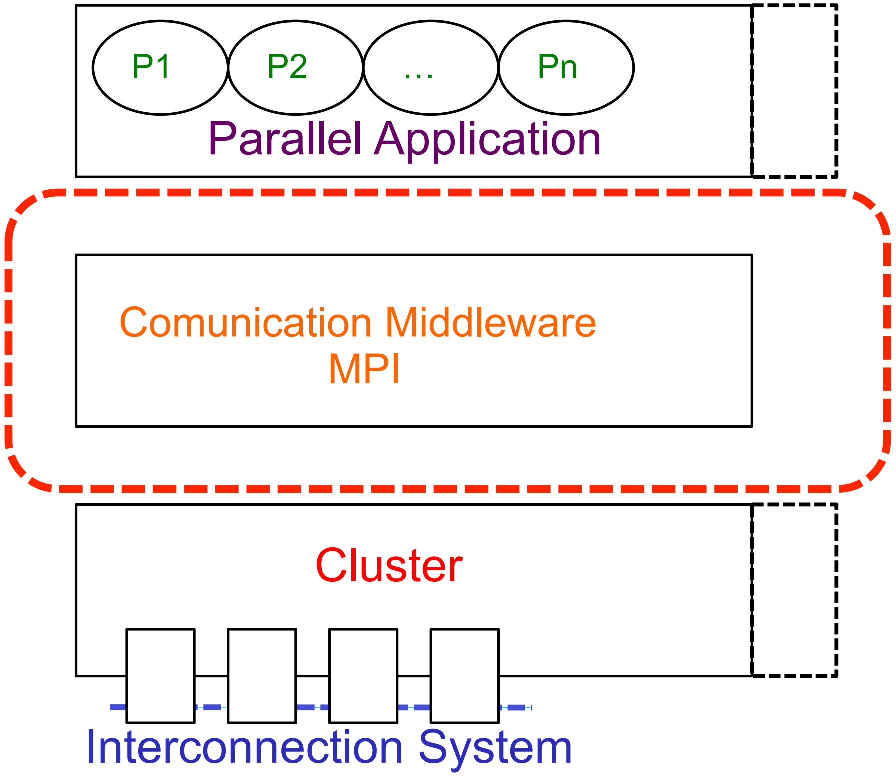
Main objetives



- Improve the scalability and the performance of MPI based applications executed on Multicore cluster
- How? Improving the Middleware MPI

Specific objectives

1. Reduction of the number of communications in collective I/O operations:
   a) Dynamic and Adaptive I/O aggregator pattern

2. Reduction of transferred data volume in communications.
   a) Compression techniques by using message passing interface profiling (PMPI)

Summary

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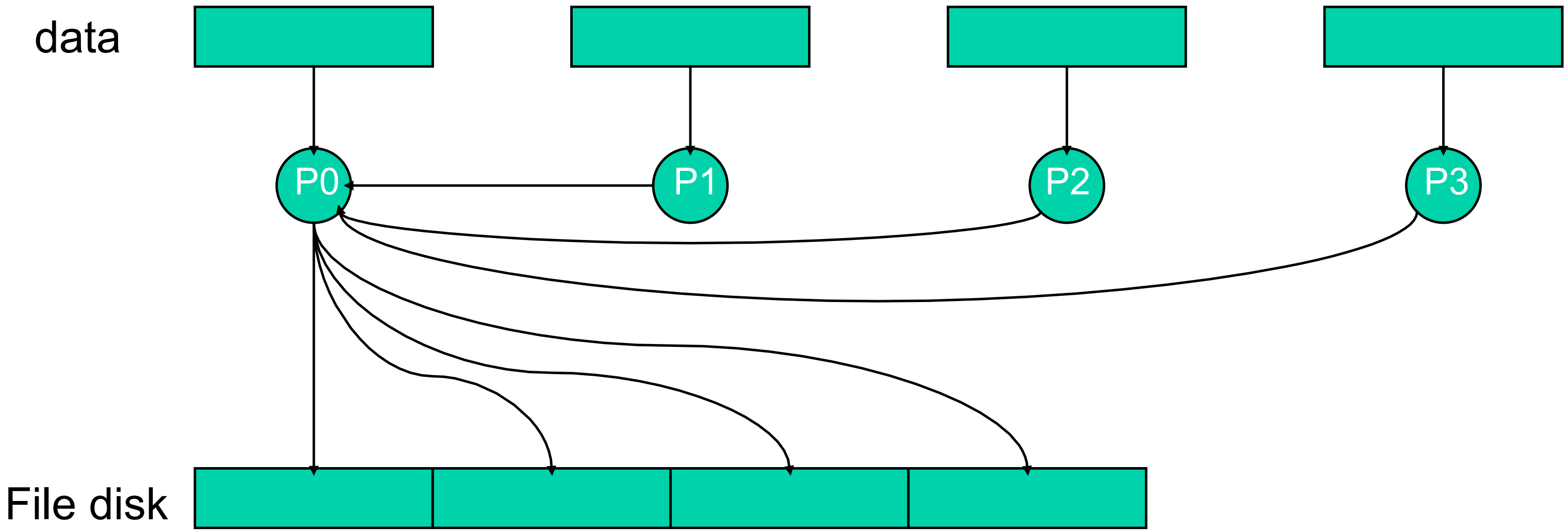
Strategies for improve the performance of collective I/O operation

- Parallel scientific applications generate a lot of data to write/ read in/from disk.
- Access pattern:
  - Sequential access
  - Individual access
  - Collective access

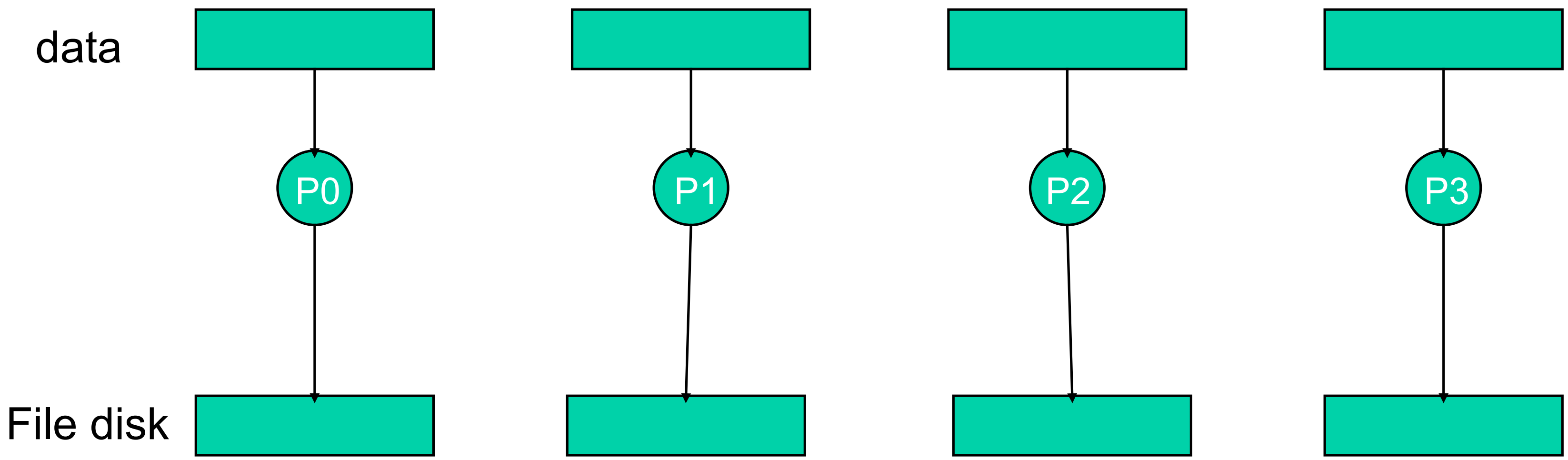
Sequential I/O

- All processes send data to one process (usually process 0), and this process writes it to the file



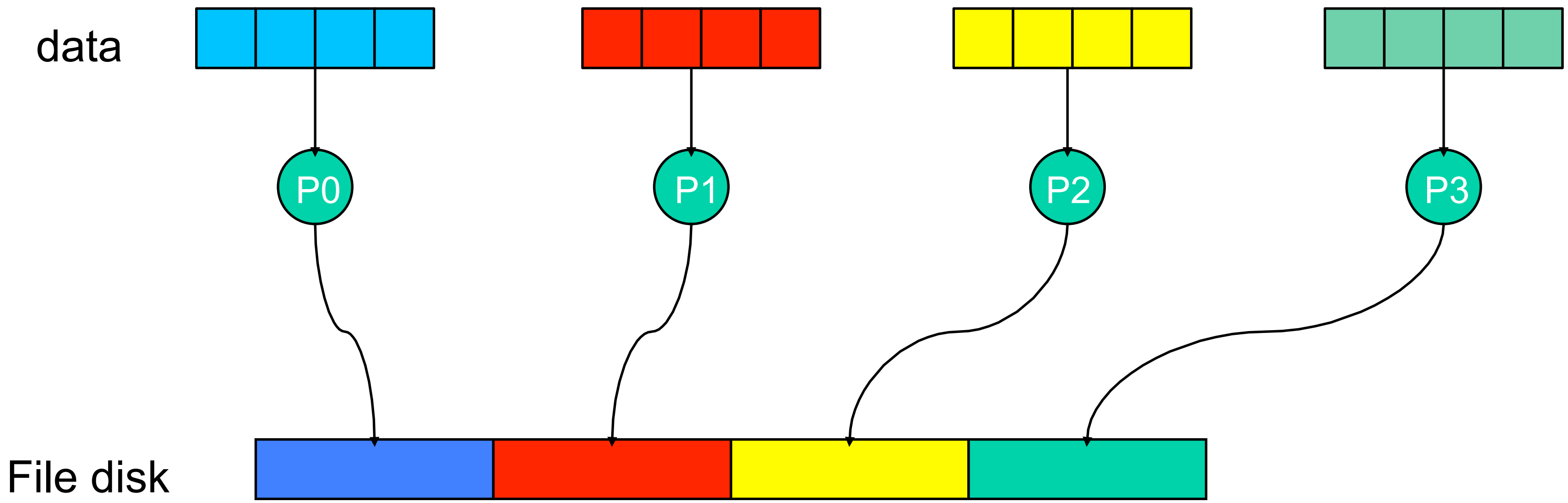
Individual I/O

- Each process writes to a separate file



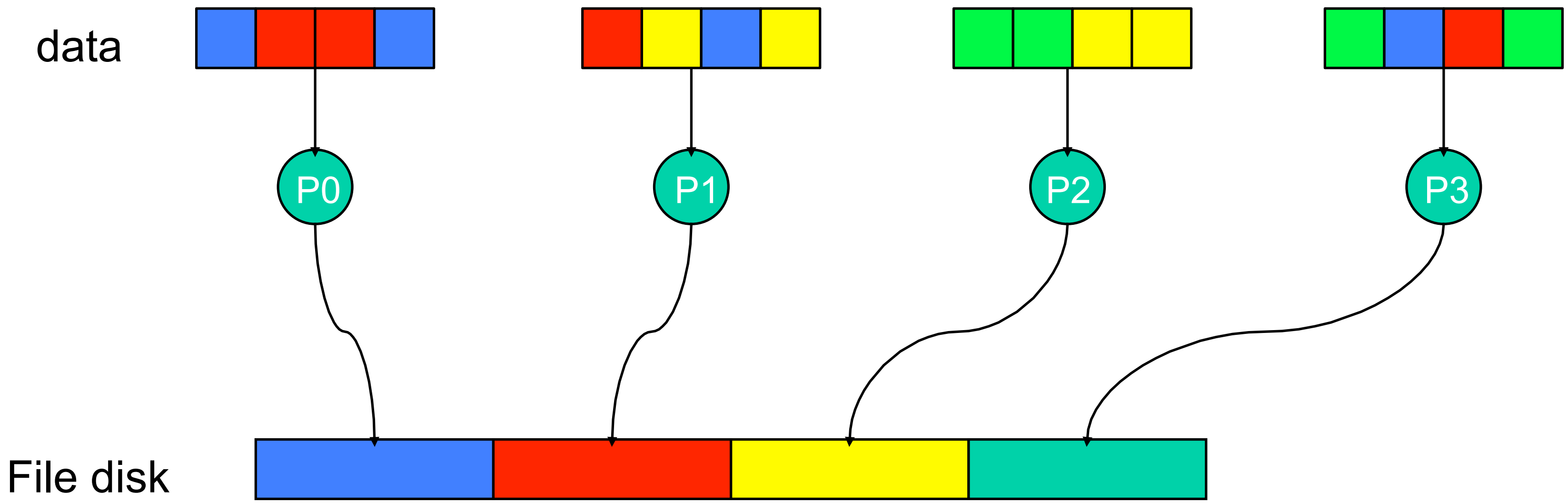
Collective I/O

- Processes write to shared file
- Contiguous data
- Two Phase I/O technique



Collective I/O

- Processes write to shared file
- Non-Contiguous data
- Two Phase I/O technique



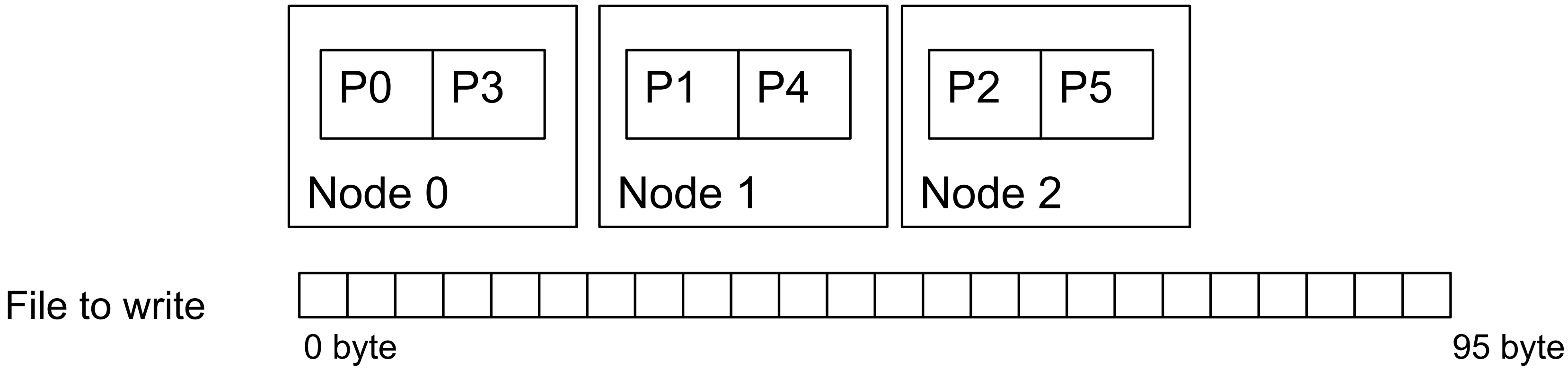
Two_Phase I/O

- Two-Phase I/O phases:
  - Shuffle: aggregate data into contiguous buffers.
  - I/O: transfer contiguous buffer to file system.
- Before these two phases:
  - File region is divided into equal contiguous regions
    - Called File Domains (FD).
  - Each FD is assigned to a subset of compute nodes (aggregators).
    - Each aggregator is responsible for transferring all data from its FD to the file system.
- Cause of inefficiency: The assignment of FD to aggregators is independent of data distribution.

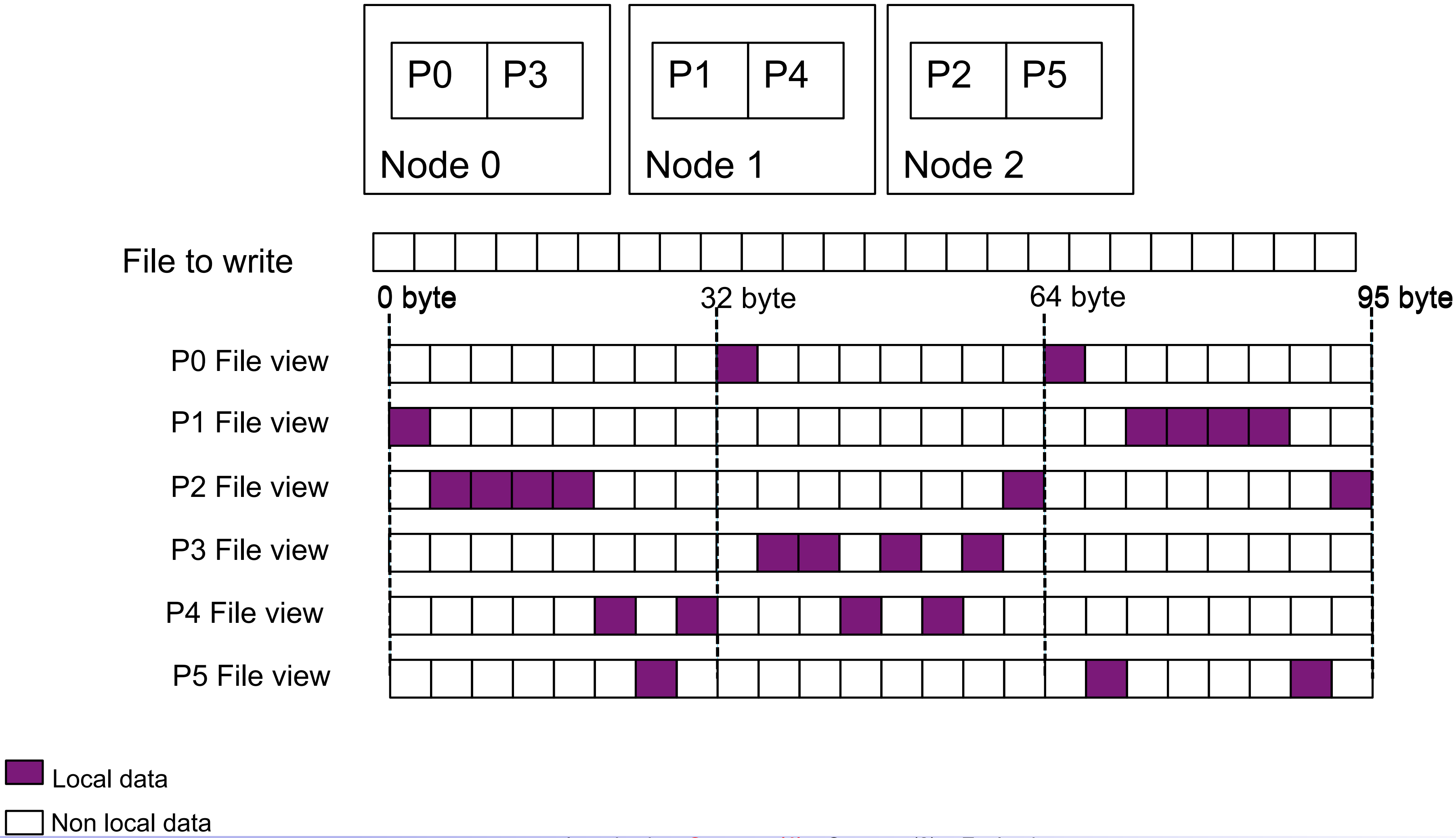
Two_Phase I/O "problem"

- The assignment of FD to aggregators is fixed.
- Independent of data distribution.
- Default aggregator Pattern:
  - So many aggregator as nodes.
  - Create an array of nodes, ordered by rank (process identifier in MPI), and assign each aggregator one process.
  - When there are more than process per node:
    - The process with the smallest rank is chosen as aggregator.

Example of Two-Phase I/O



Example of Two-Phase I/O



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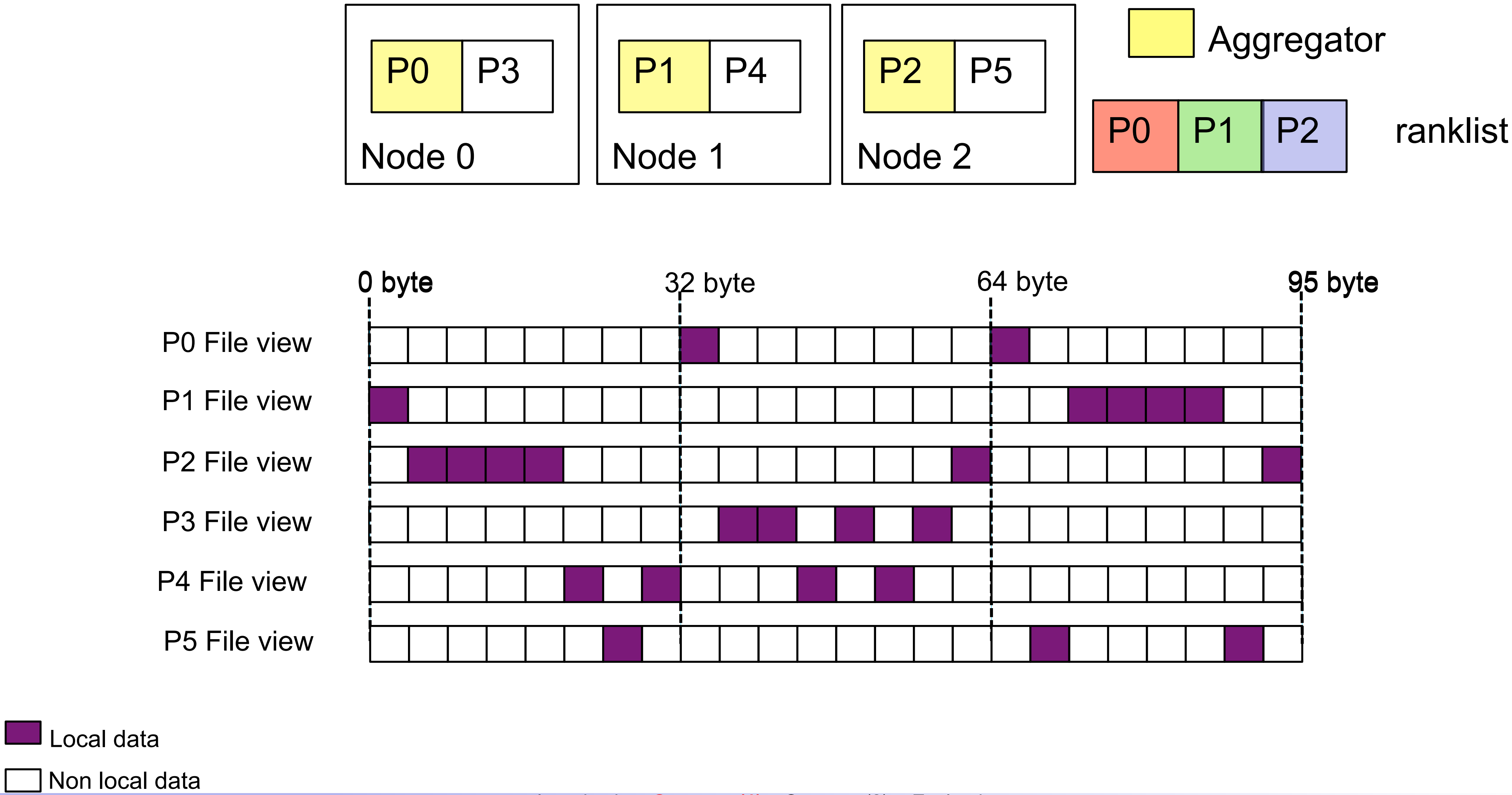

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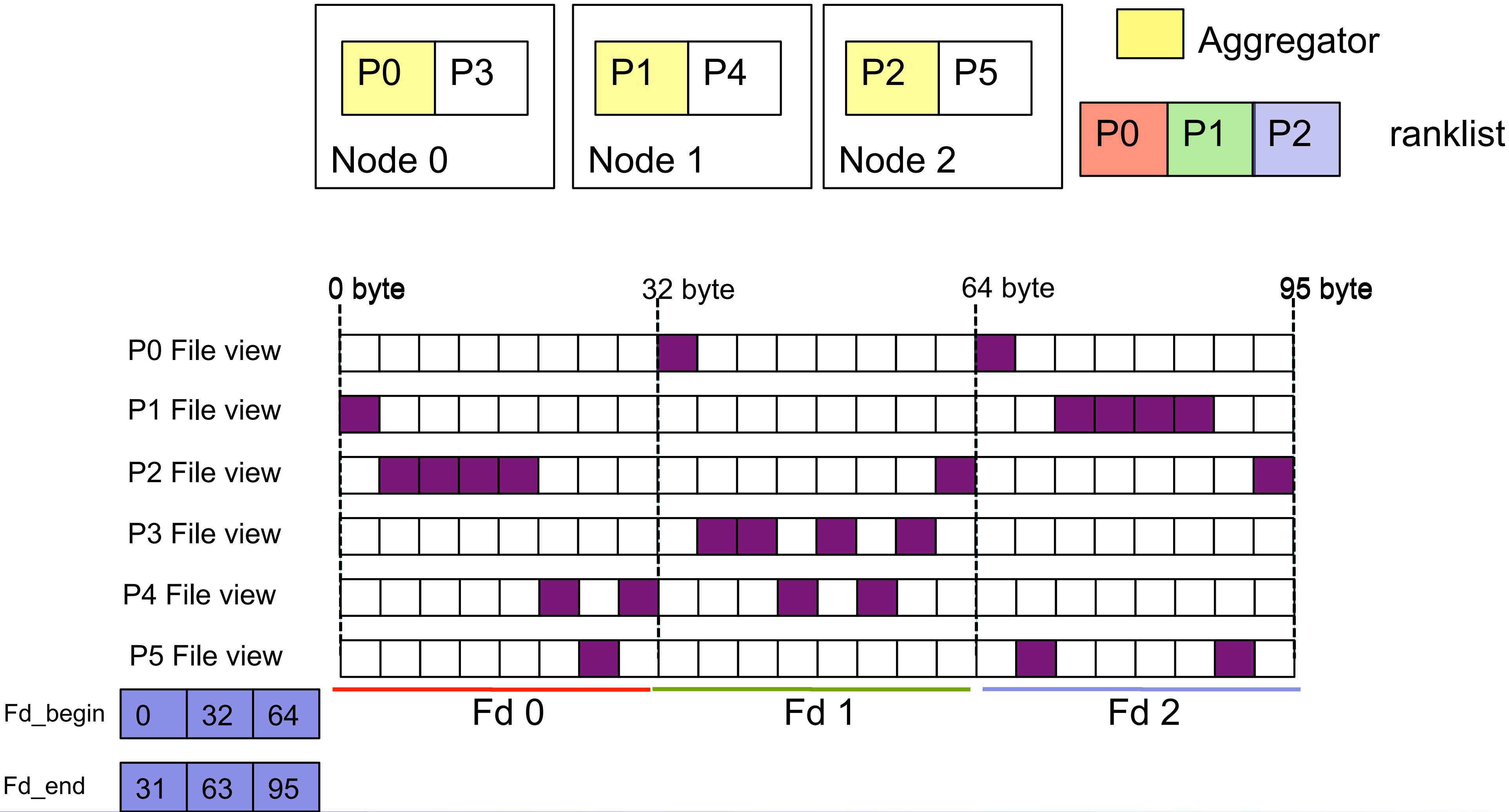
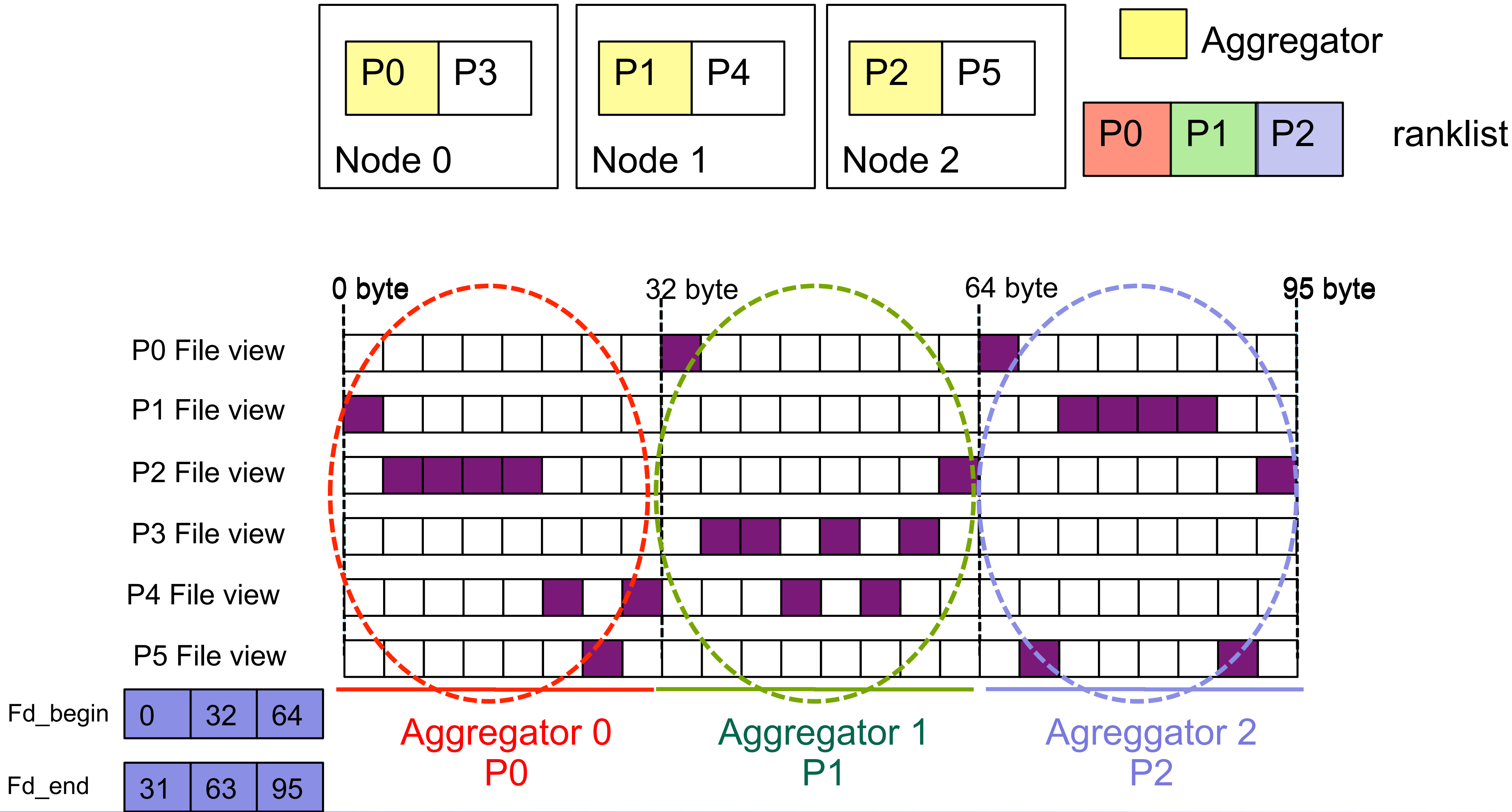


Example of Two-Phase I/O



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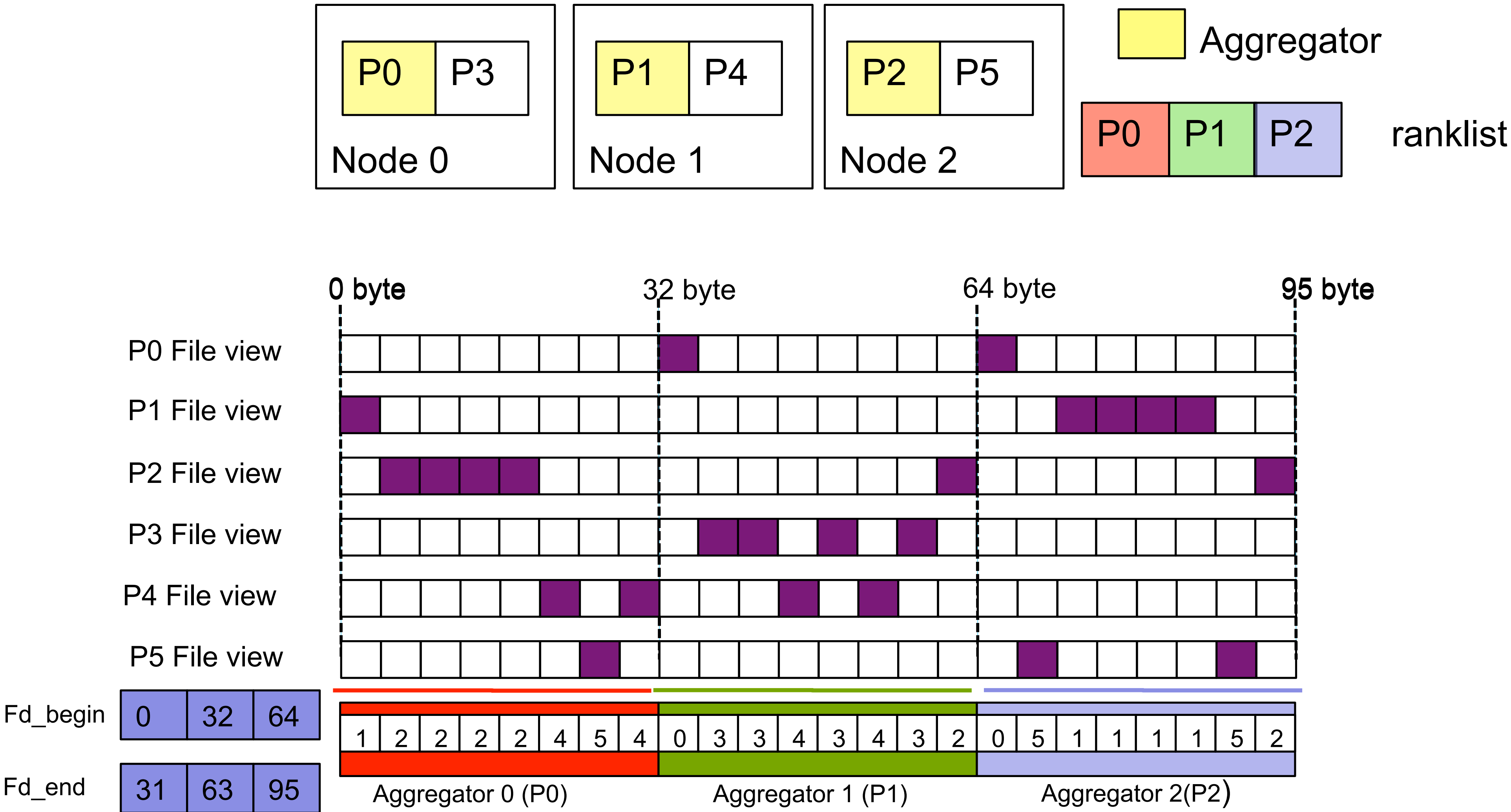

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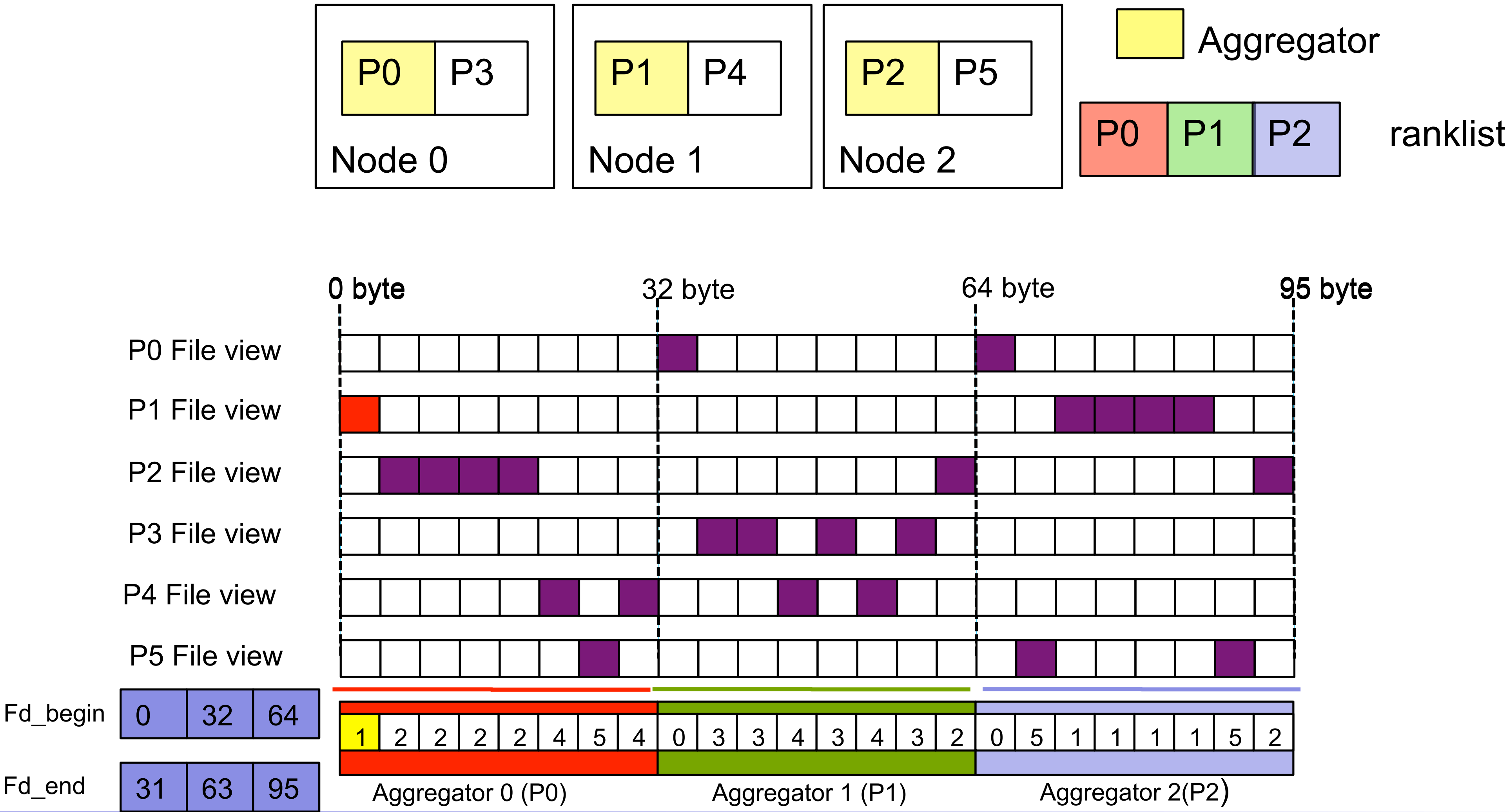

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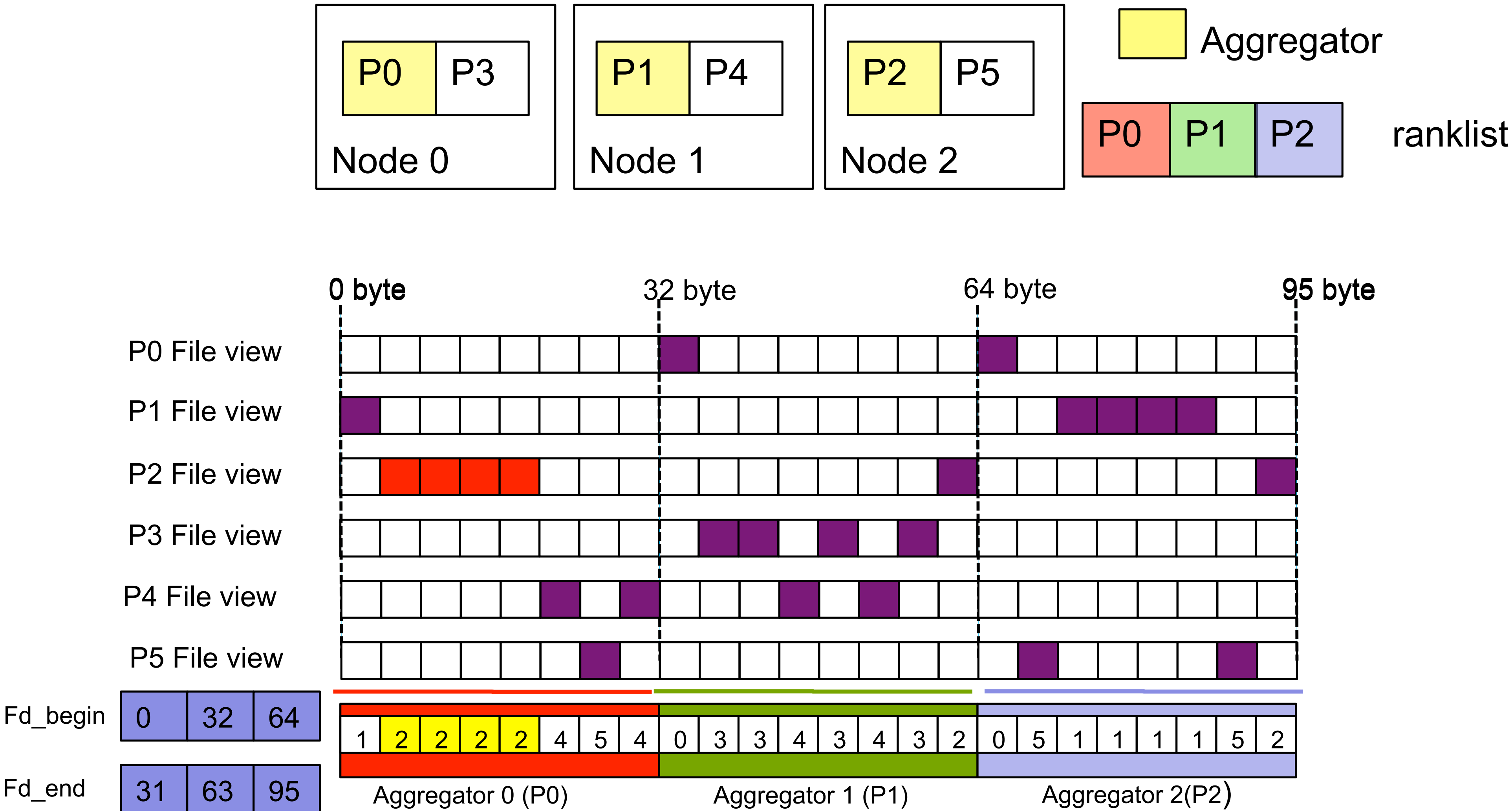

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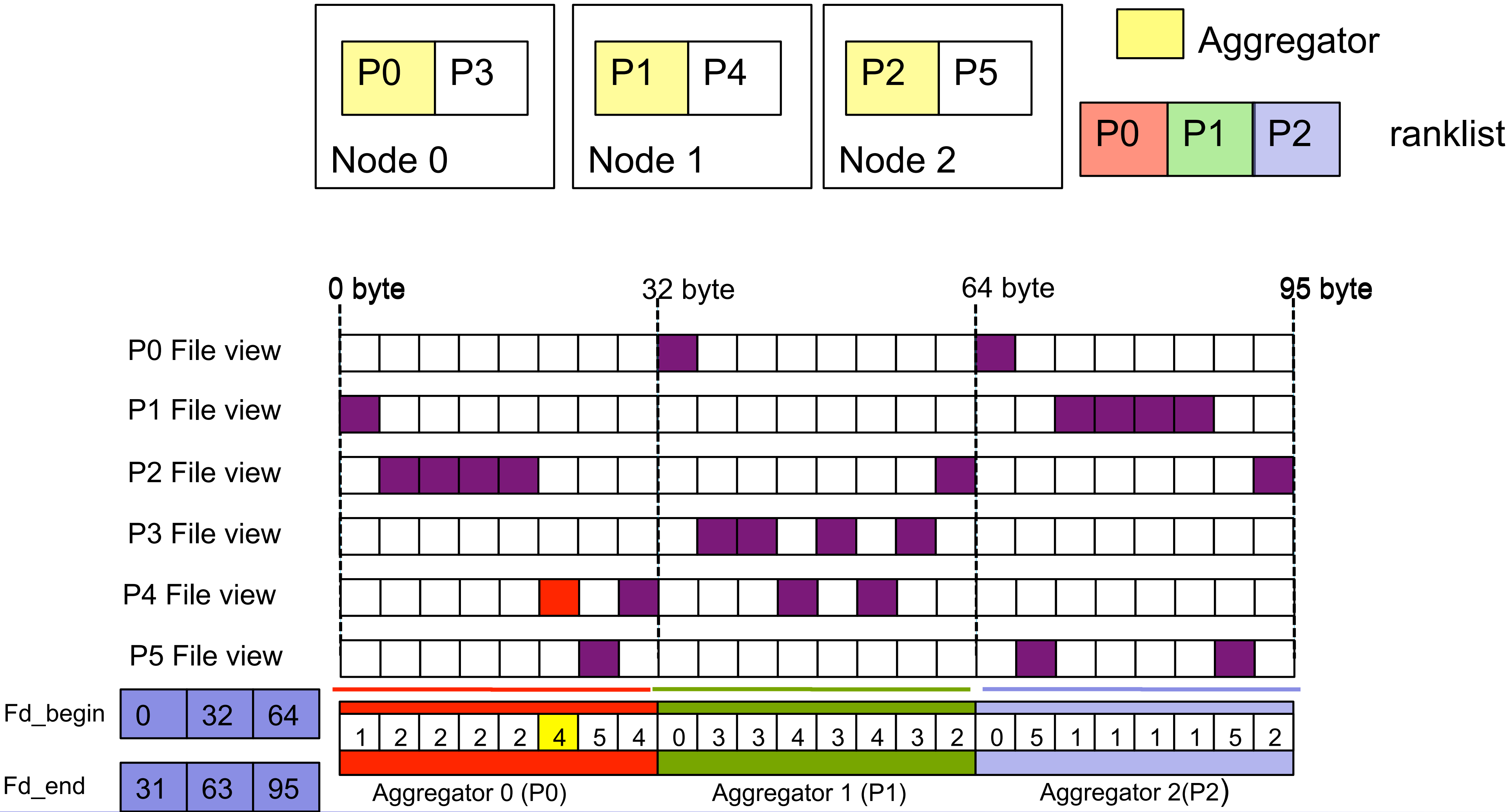

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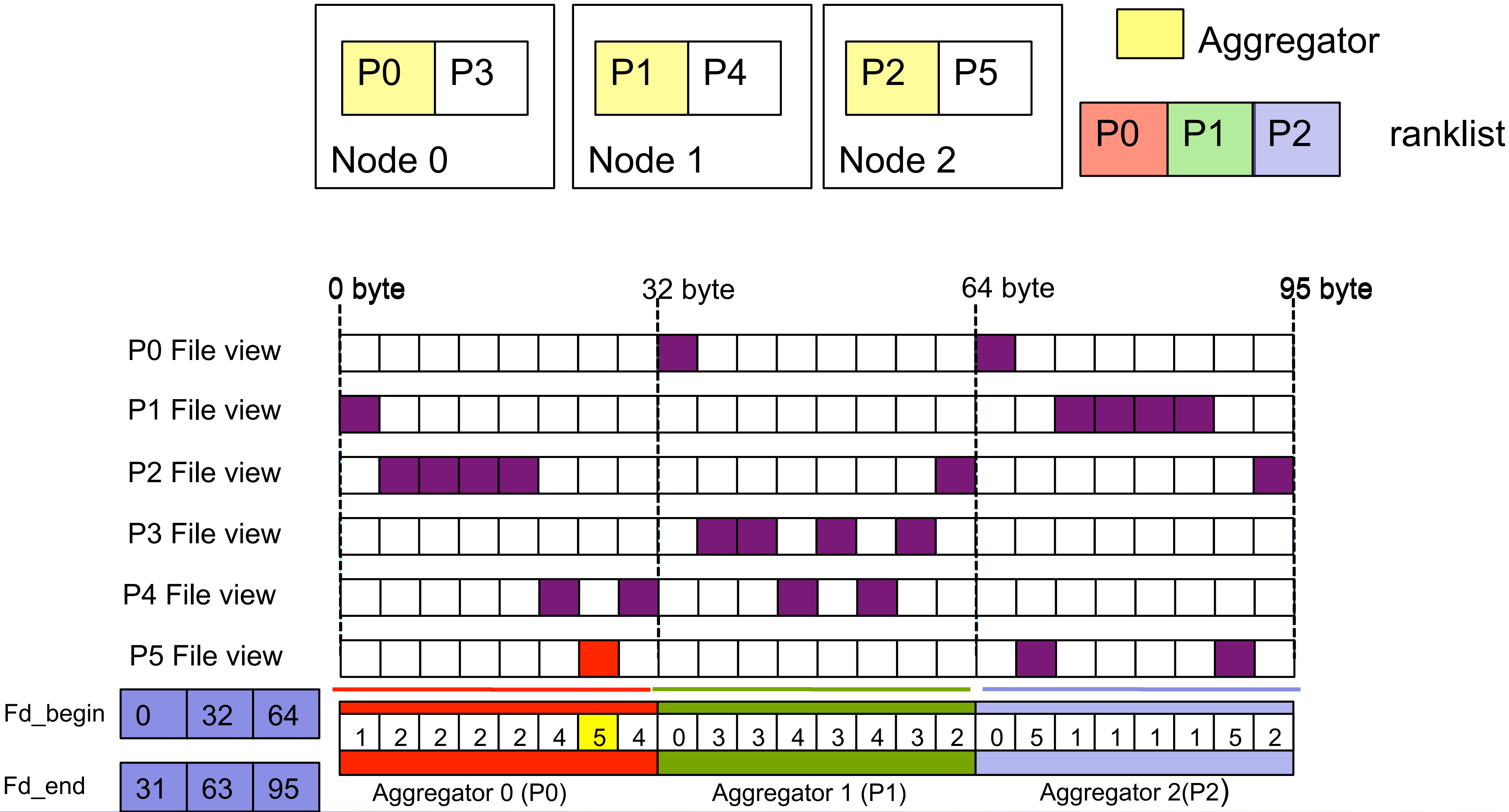

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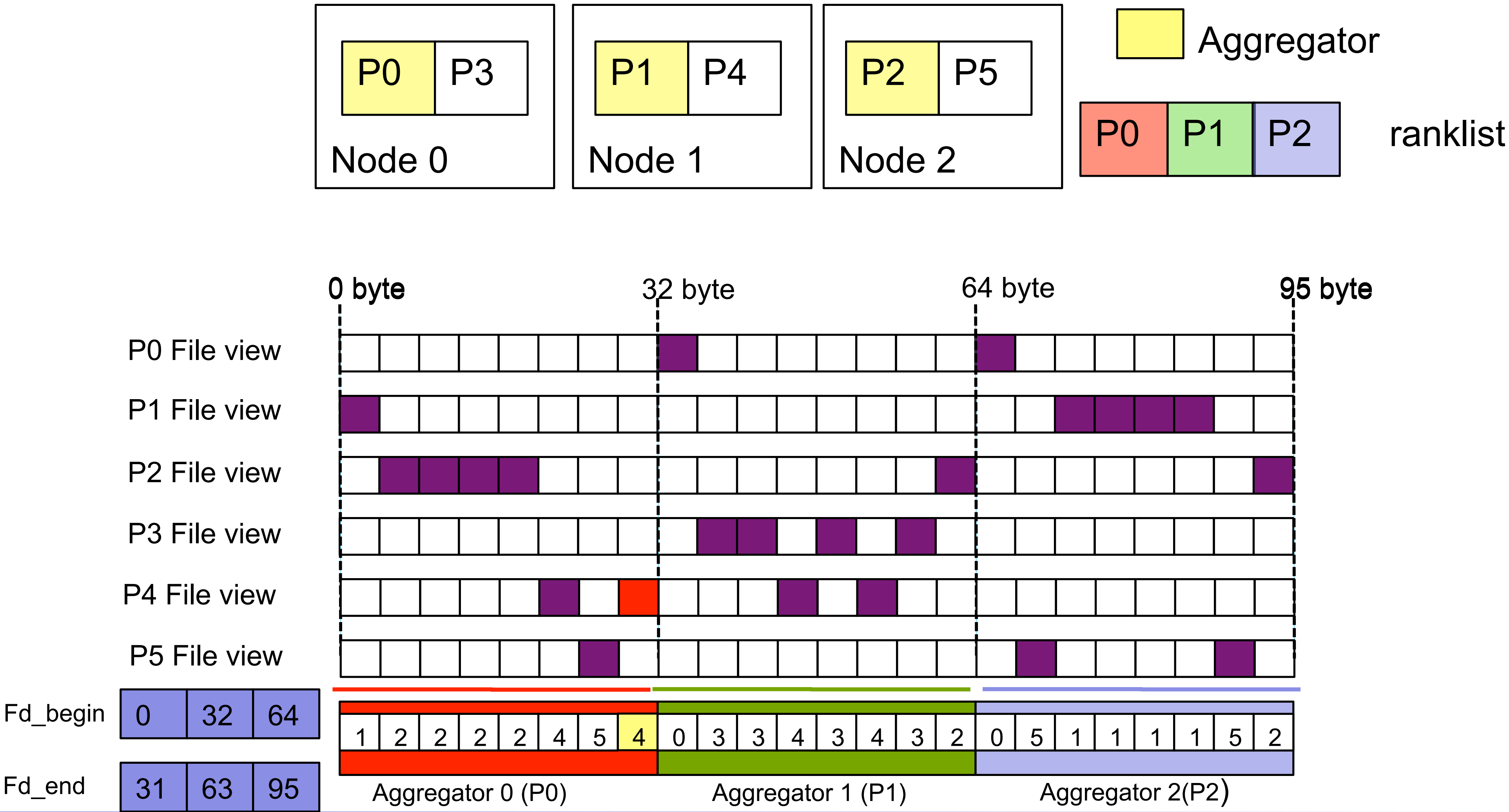

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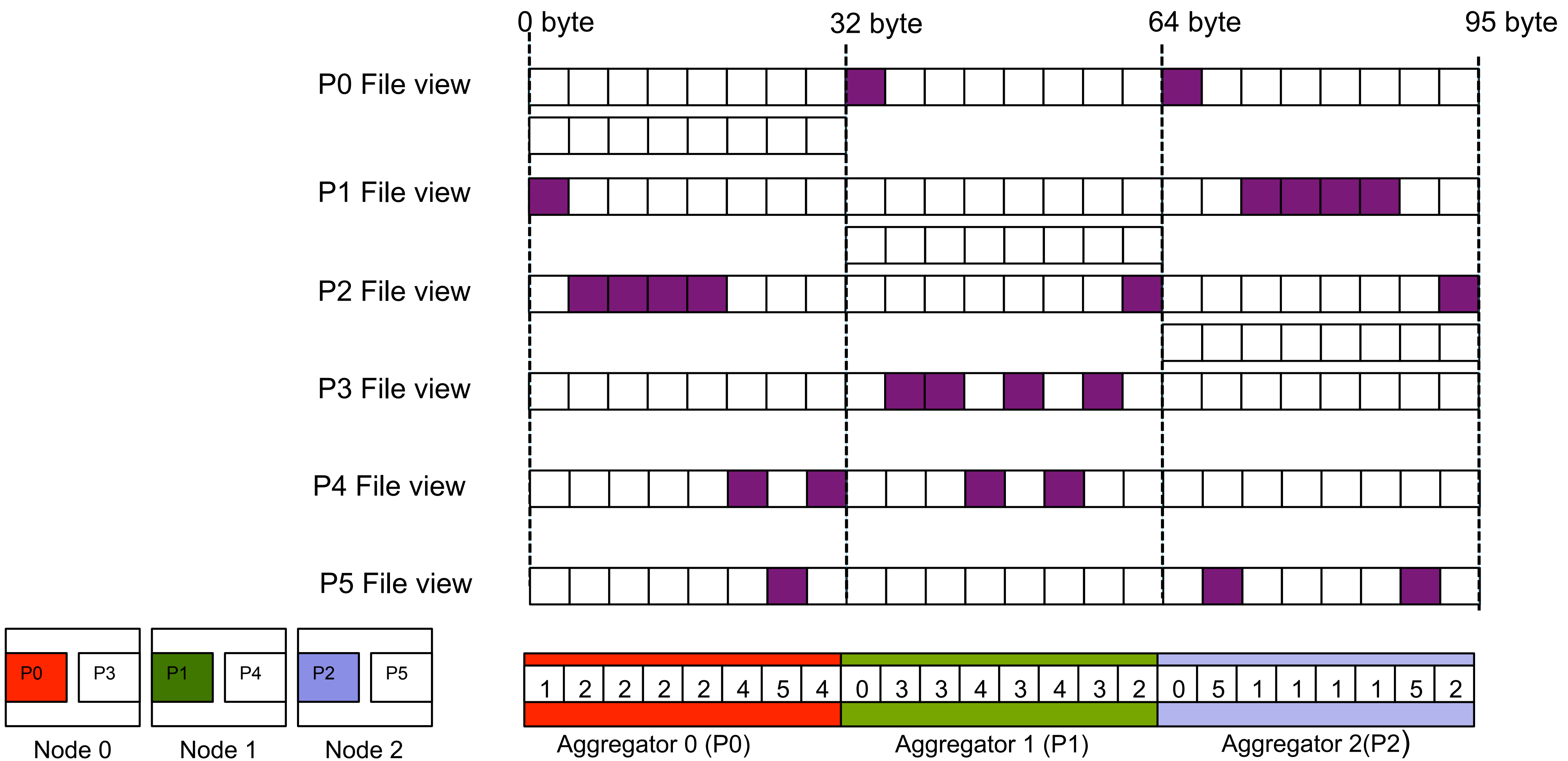

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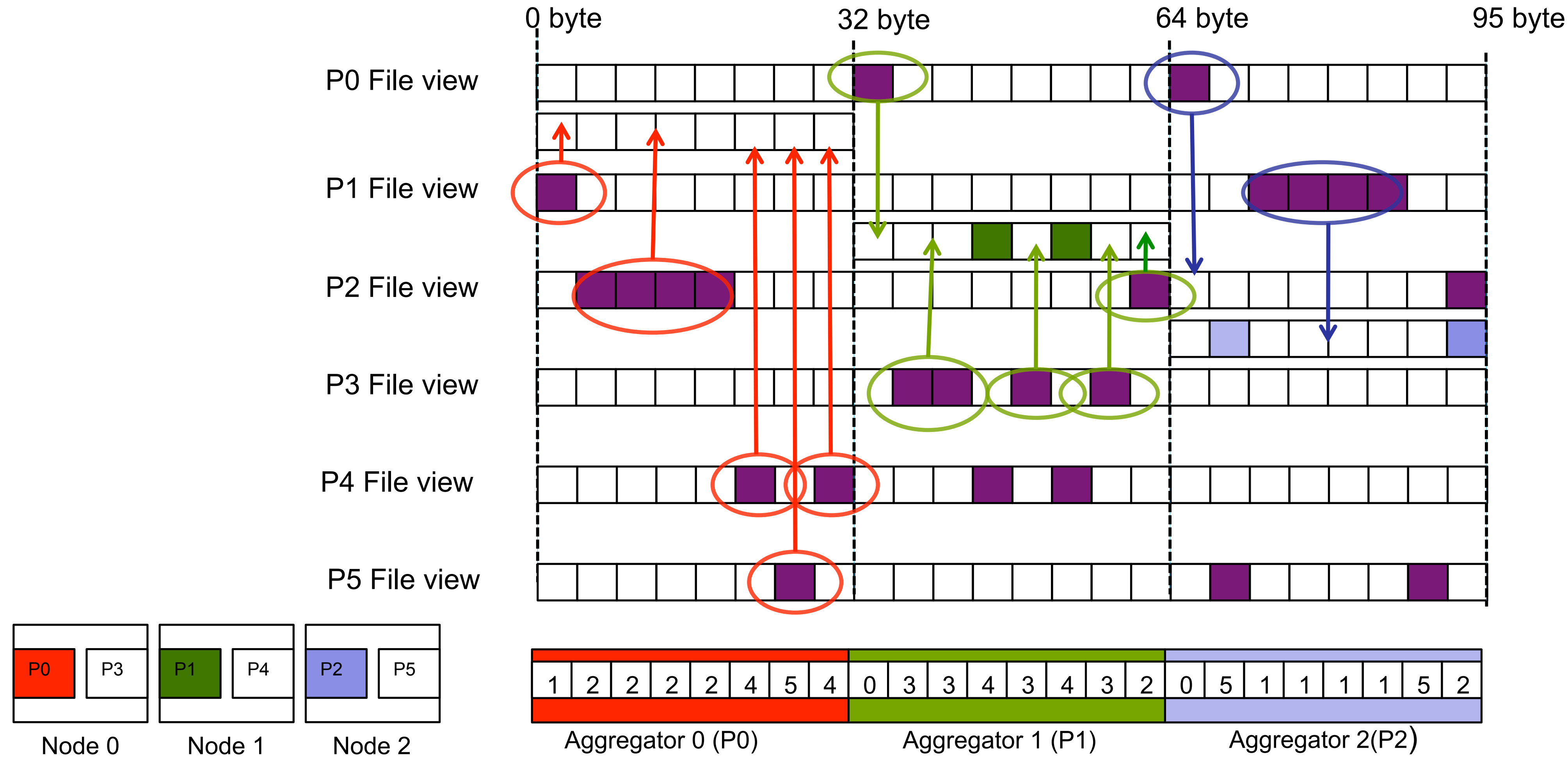
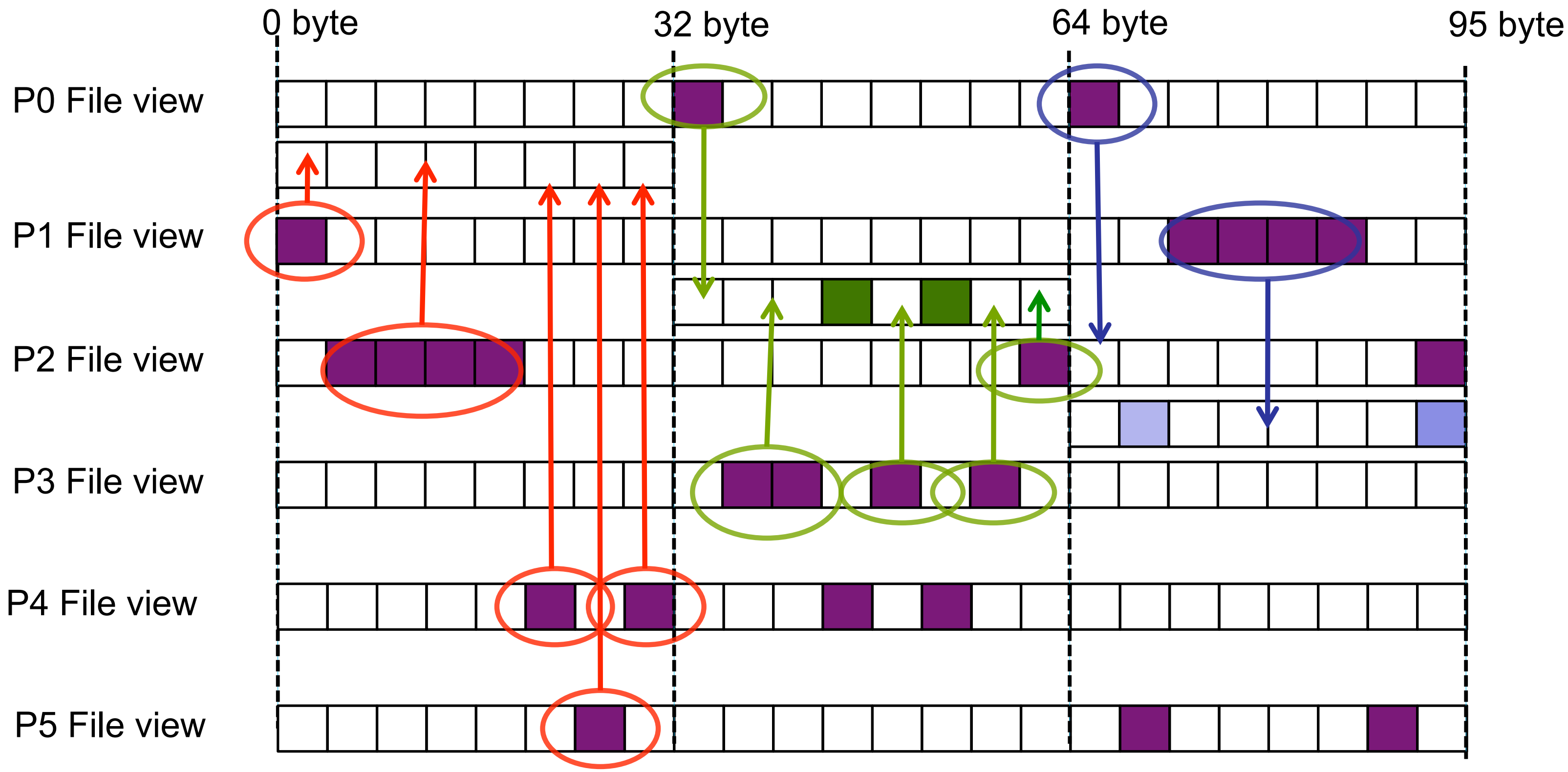
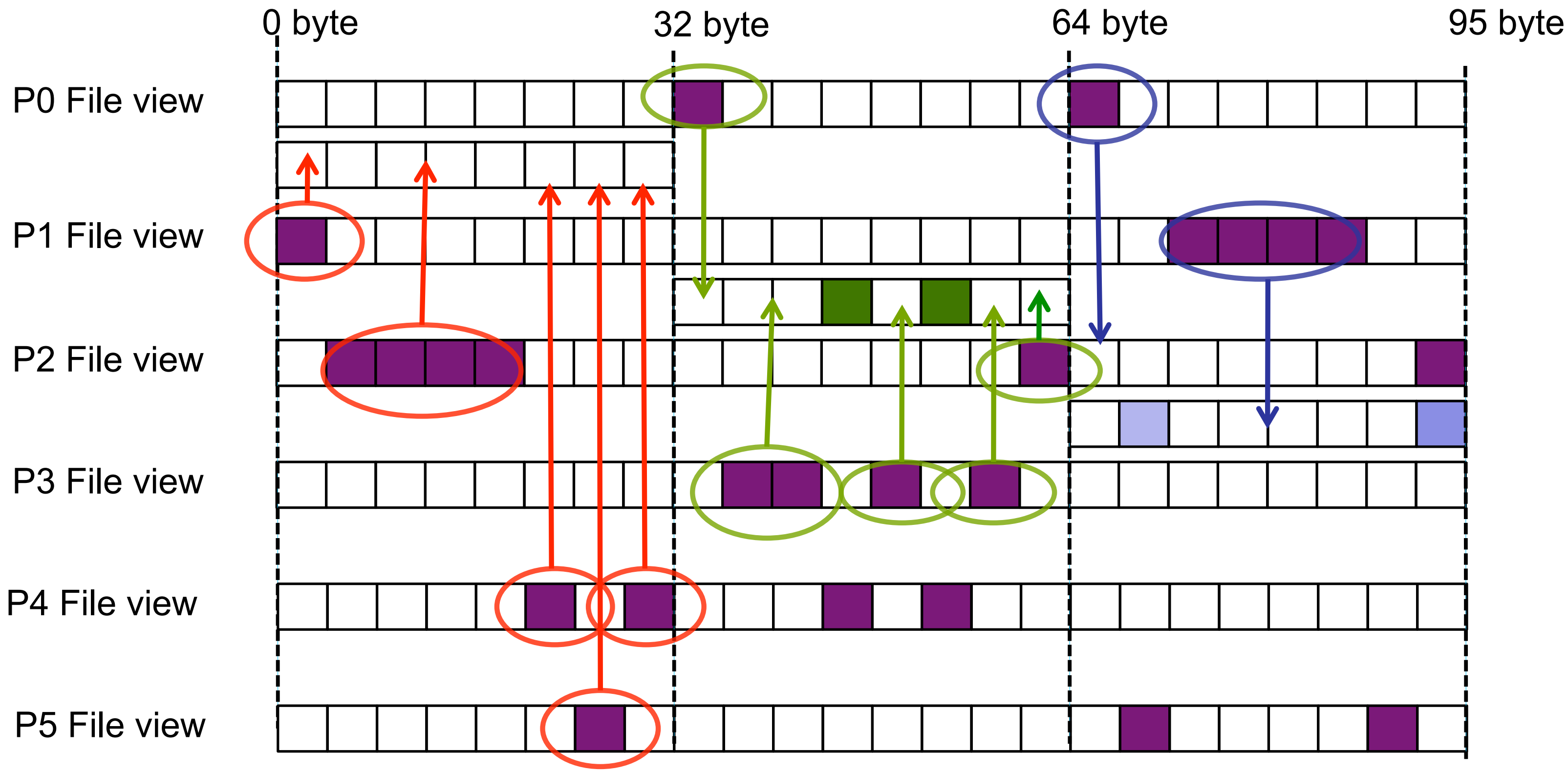


Example of Two-Phase I/O



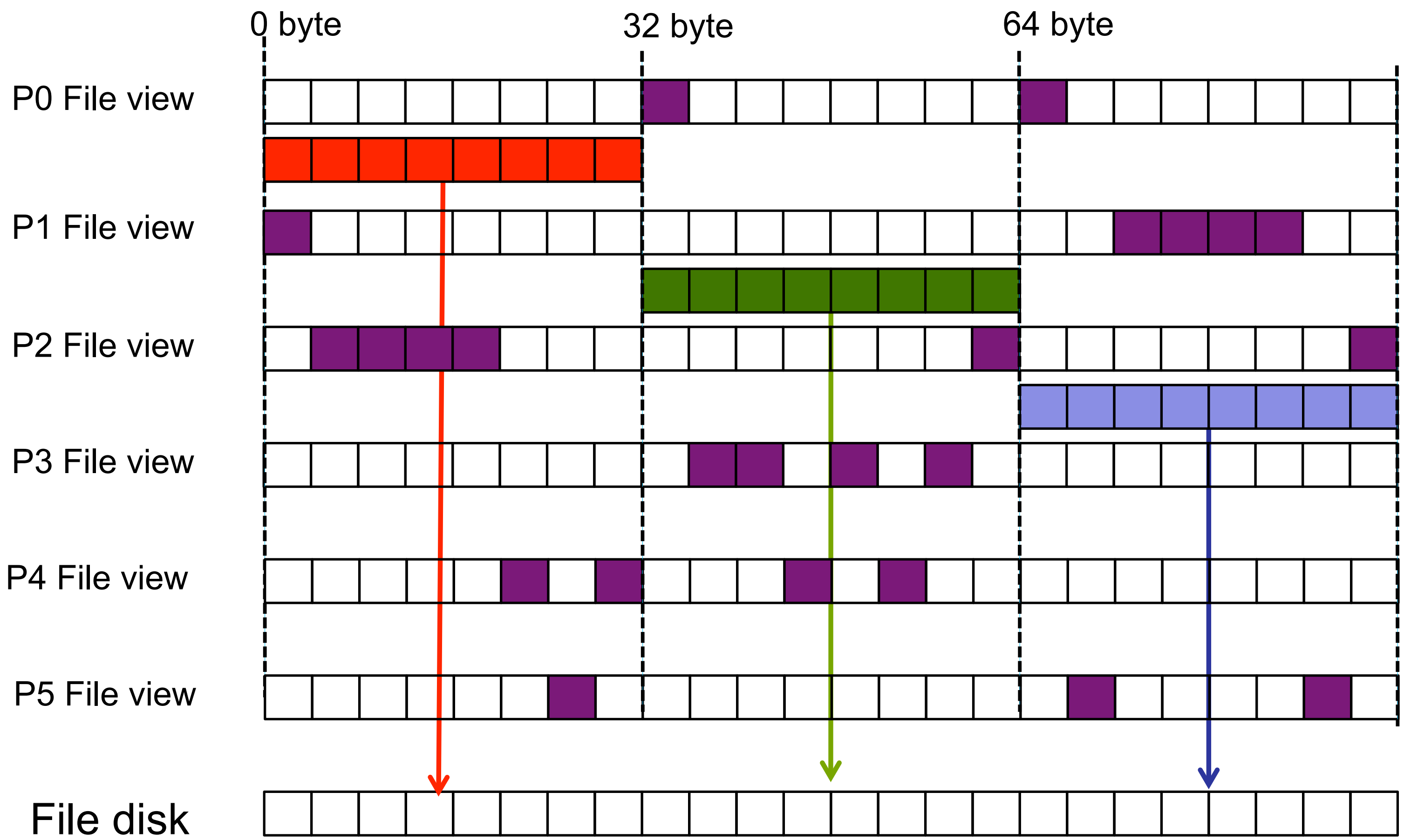
Communication: 12 message
72bytes of 96 bytes are transferred among the processes.

Example of Two-Phase I/O

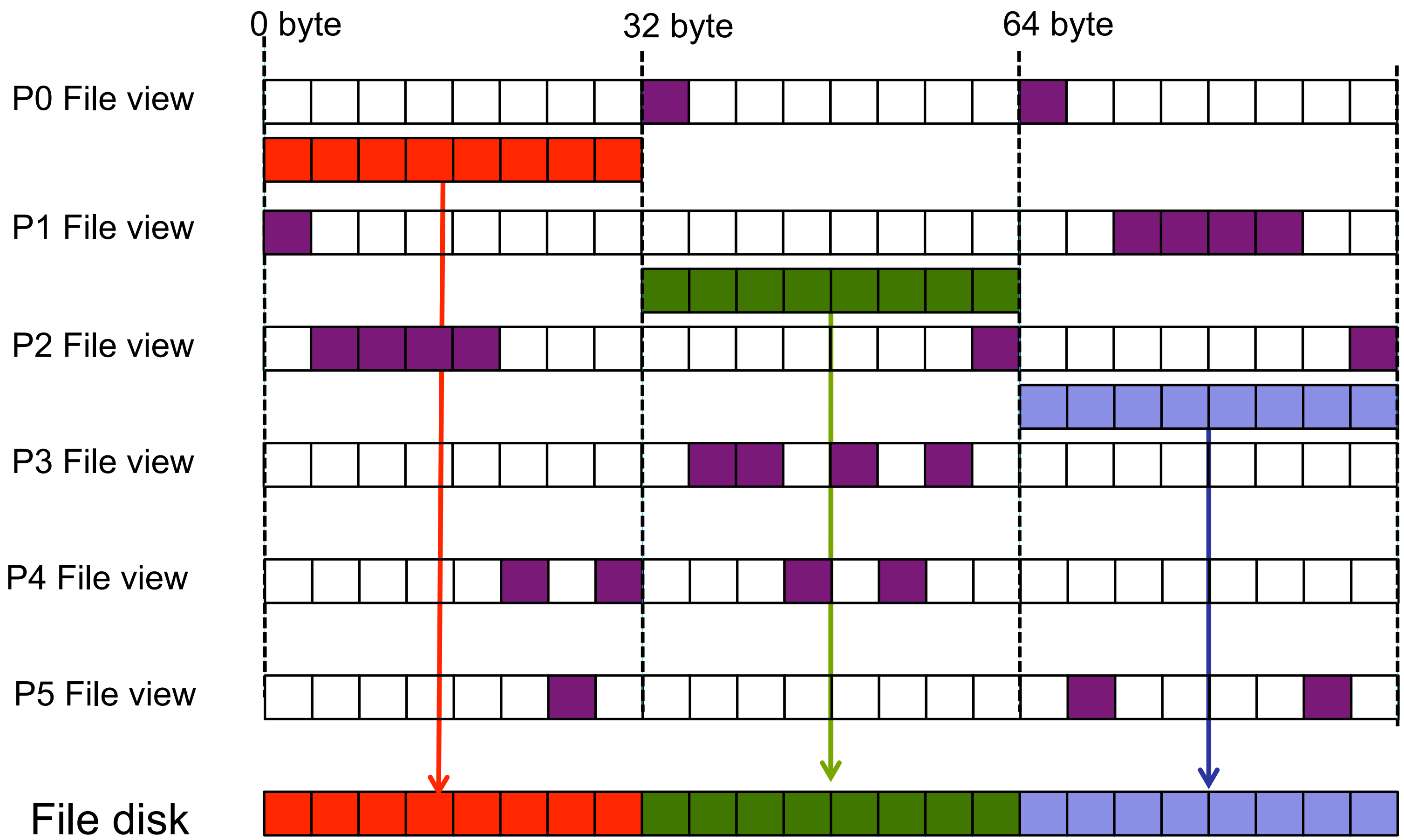


The number of communications could be reduced if each aggregator is assigned to the process **more adequate**.

Example of Two-Phase I/O



Example of Two-Phase I/O



Phd. Thesis Proposal

- Replace the rigid assignment of aggregator by new one based on the next aggregation-criteria:
  - Aggregation by communication number (ACN):
    - Each aggregator is assigned to the **process** who has the highest number of contiguous data blocks.
- MPICH1.2

HPC-Programme Proposal (I)

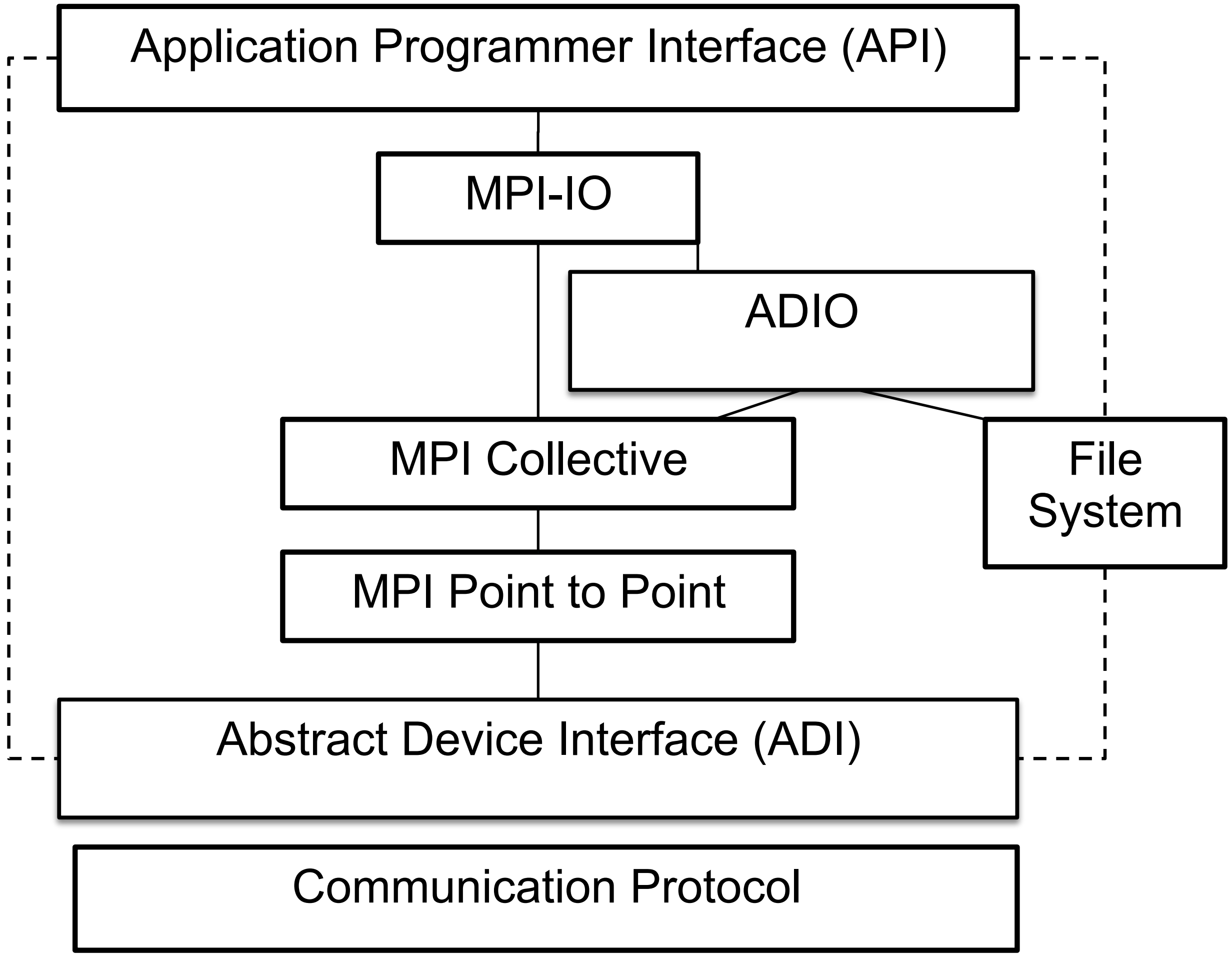
- Replace the rigid assignment of the aggregators by one of the next two aggregation-criteria:
  - Aggregation by communication number (ACN):
    - Each aggregator is assigned to the (New!!) **node** who has the highest number of contiguous data blocks.
  - (New!!) Aggregation by volume number (AVN):
    - Each aggregator is assigned to the node who has more volume of data.

- (New!!) MPICH2:
  - Communication among the cores of the same node by shared memory.

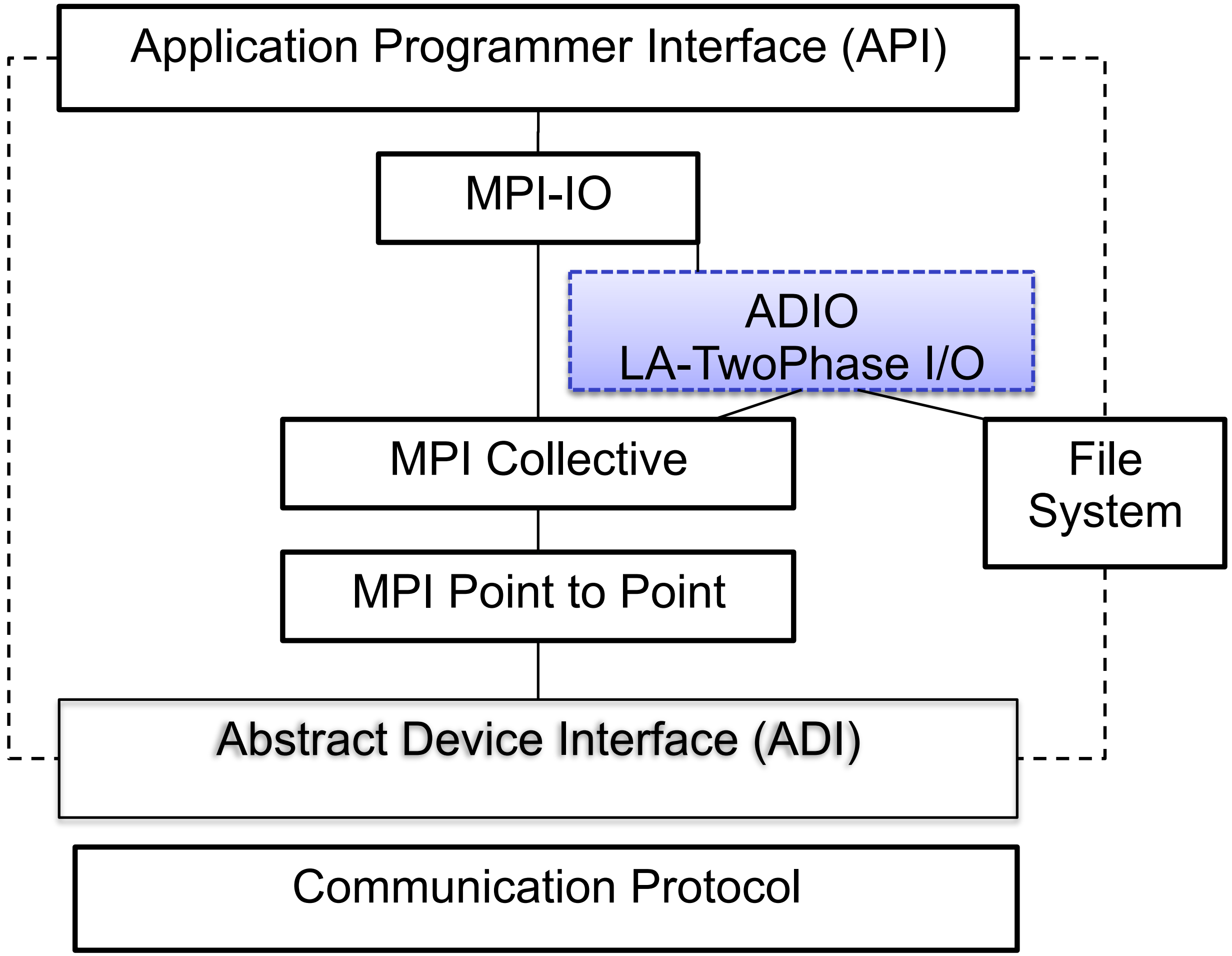
Implementation of the proposal

- The new two dynamic aggregator patters are implemented in two different ways:
  - New version of Two_Phase I/O in MPICH2:
    - Locality_Aware_Two_Phase I/O (LA_TwoPhase I/O)
  - Library at application level:
    - Aggregation_Pattern_Calculation
    - The MPI based application call this library to calculate the aggregators.
    - Use MPI-IO Hint (**variables can be used to control the behavior of collective operations**) to modified the default aggregator pattern:
      - cb_config_list: Provides explicit control over aggregators.

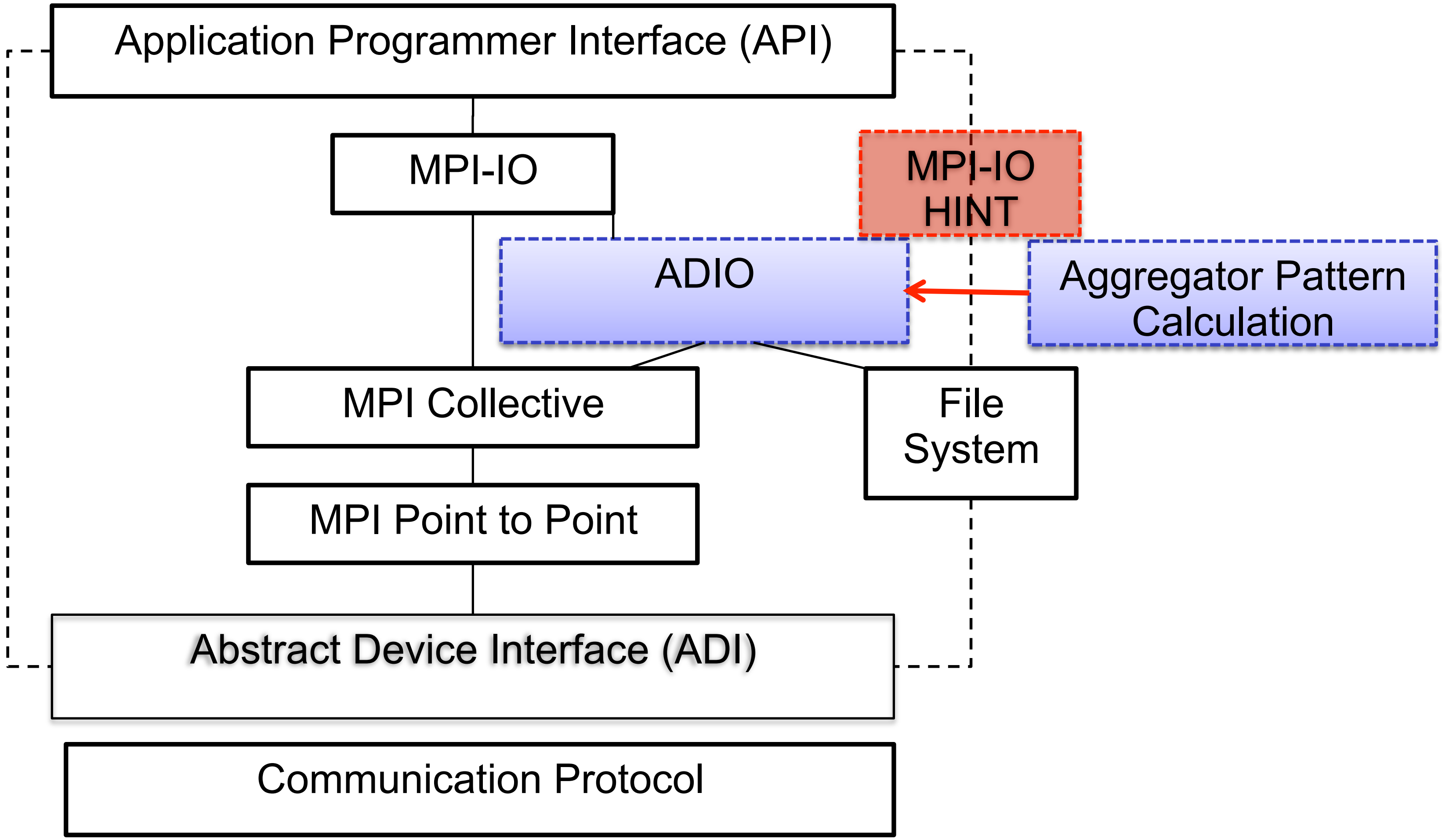
MPICH2 Architecture



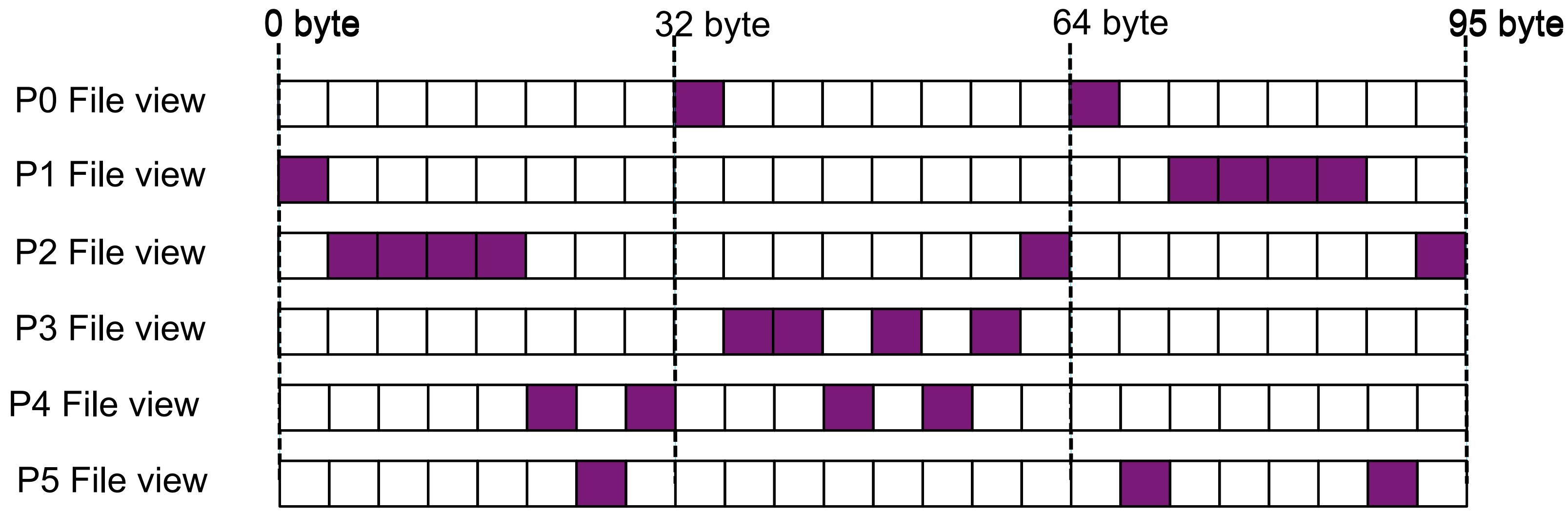
MPICH2 Modification (I)



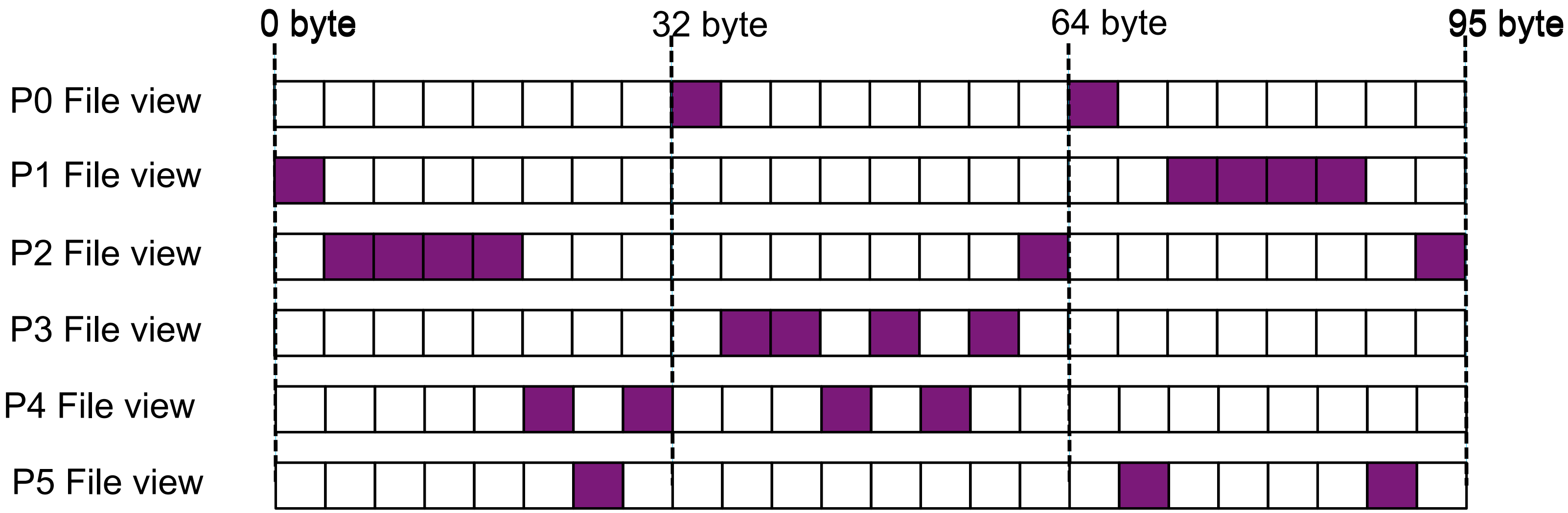
MPICH2 Modification (II)



Example of ACN aggregator pattern



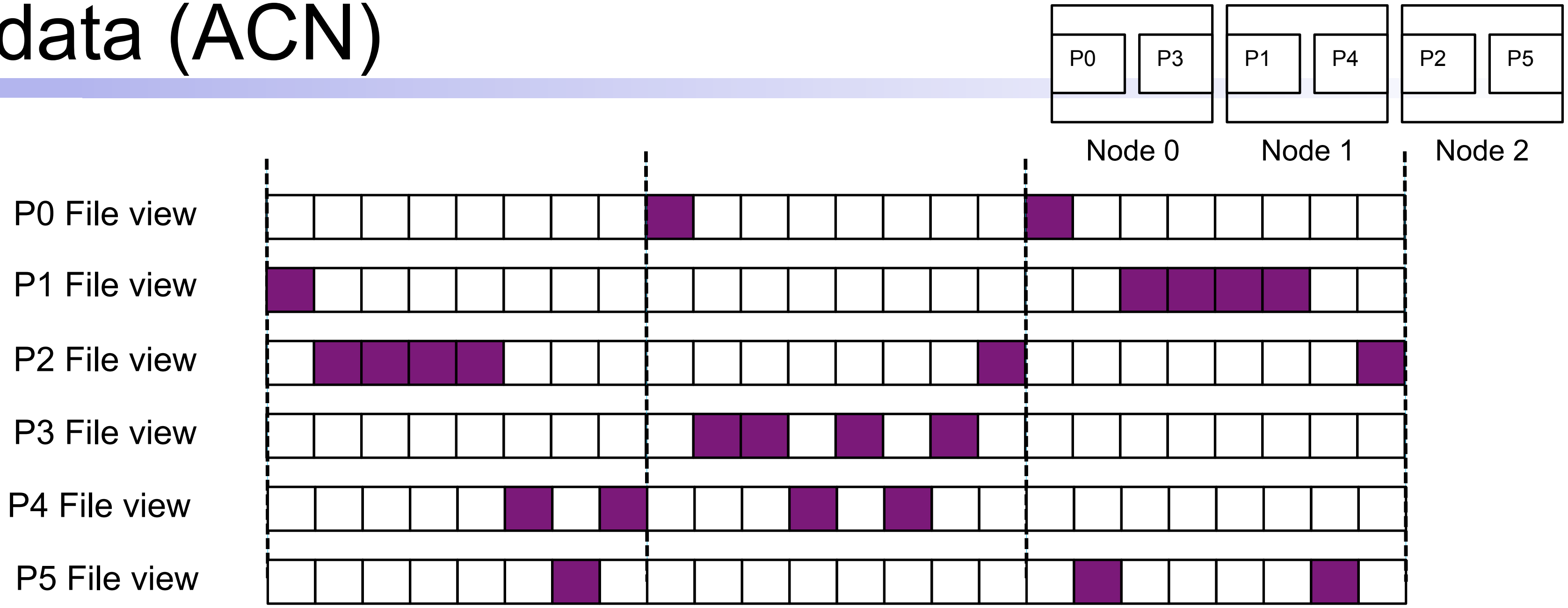
Calculation and recollection of distribution data (ACN)

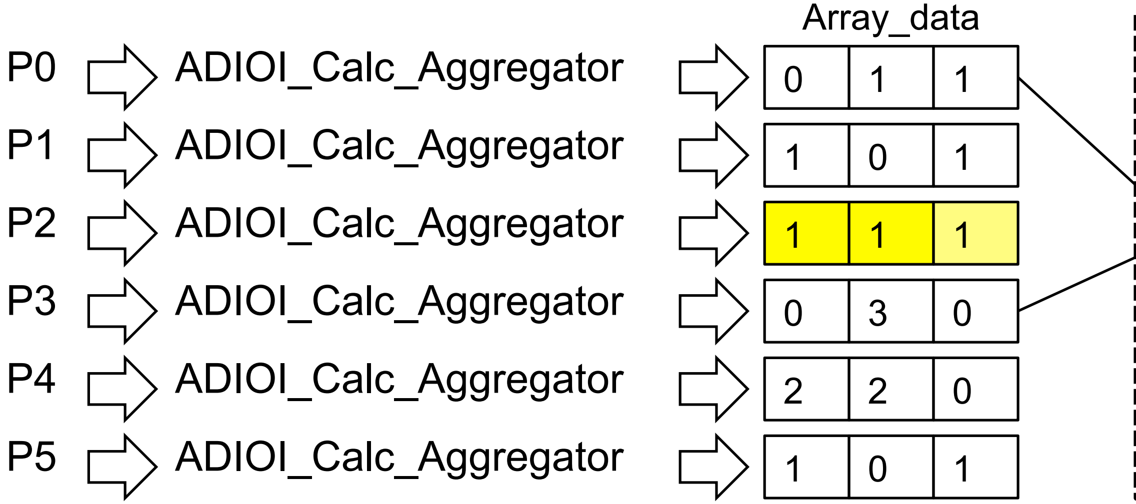


Array_data

P0	ADIOI_Calc_Aggregator	0	1	1
P1	ADIOI_Calc_Aggregator	1	0	1
P2	ADIOI_Calc_Aggregator	1	1	1
P3	ADIOI_Calc_Aggregator	0	3	0
P3	ADIOI_Calc_Aggregator	2	2	0
P3	ADIOI_Calc_Aggregator	1	0	1

Calculation and recollection of distribution data (ACN)





	FD0	FD1	FD2
N0	0	4	1
N1	3	2	1
N2	2	1	3

Calculation of ACN pattern

P0

Assigment_matrix_ACN

LAP ⇨

	FD0	FD1	FD2
N0	0	4	1
N1	3	2	1
N2	2	1	3

Aj=Max(Pi,FD)

Calculation of ACN pattern

P0

Assigment_matrix_ACN

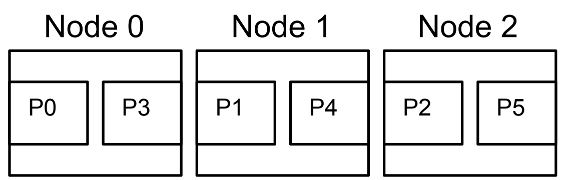
LAP ⇨

	FD0	**FD1**	**FD2**
N0	0	**4**	1
N1	**3**	2	1
N2	2	1	**3**

Aj=Max(Pi,FD)

New ranklist

P1	P0	P2



Calculation of ACN pattern

P0

Assigment_matrix_ACN

LAP ⇨

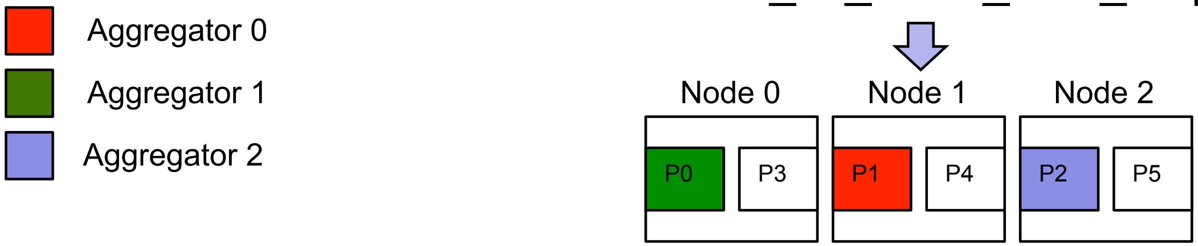
	FD0	FD1	FD2
N0	0	**4**	1
N1	**3**	2	1
N2	2	1	**3**

Aj=Max(Pi,FD)

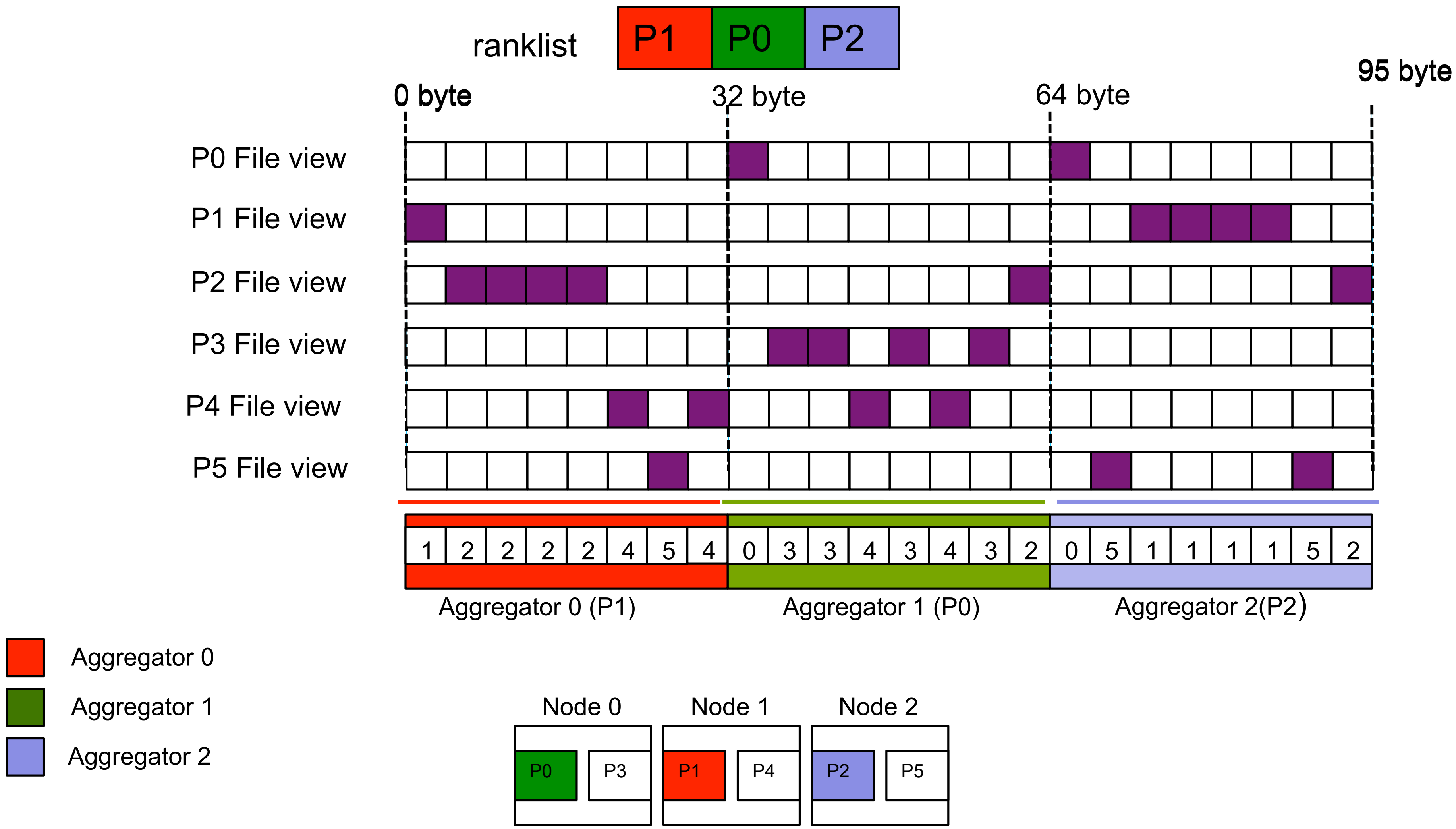
New ranklist

P1	P0	P2

ADIOI_cb_bcast_rank_map



Reduction in the number of communication with the ACN pattern.



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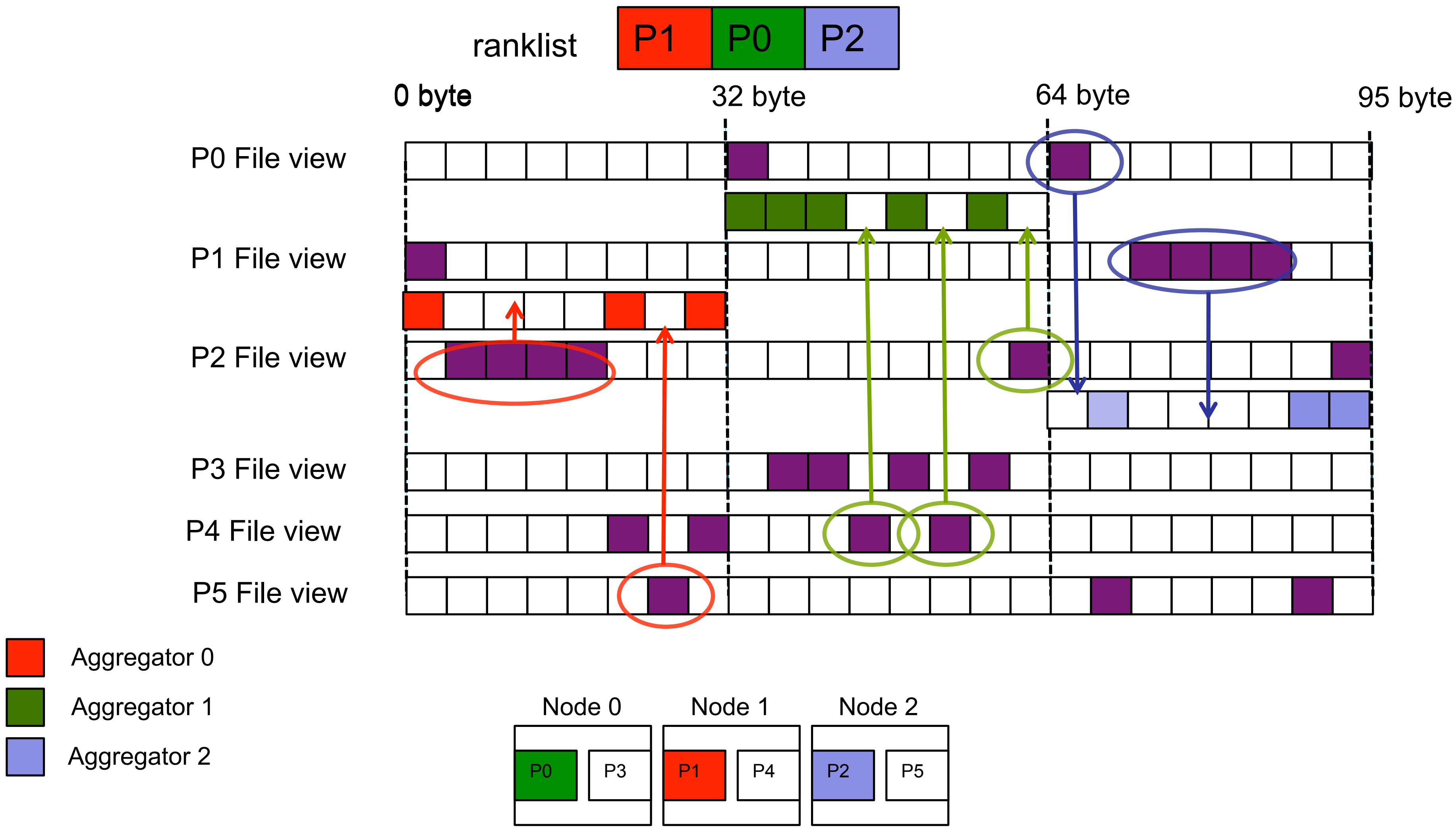

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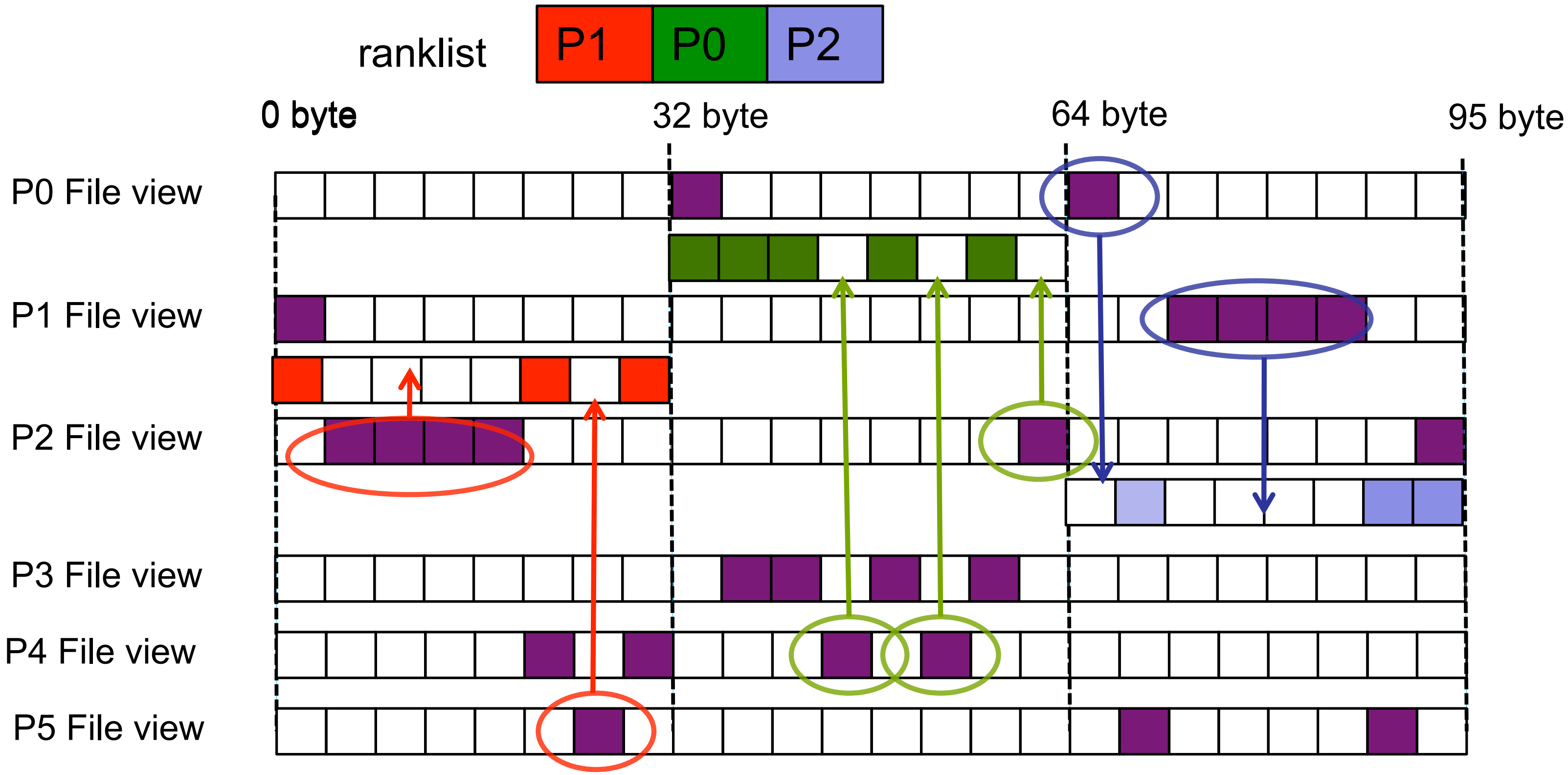
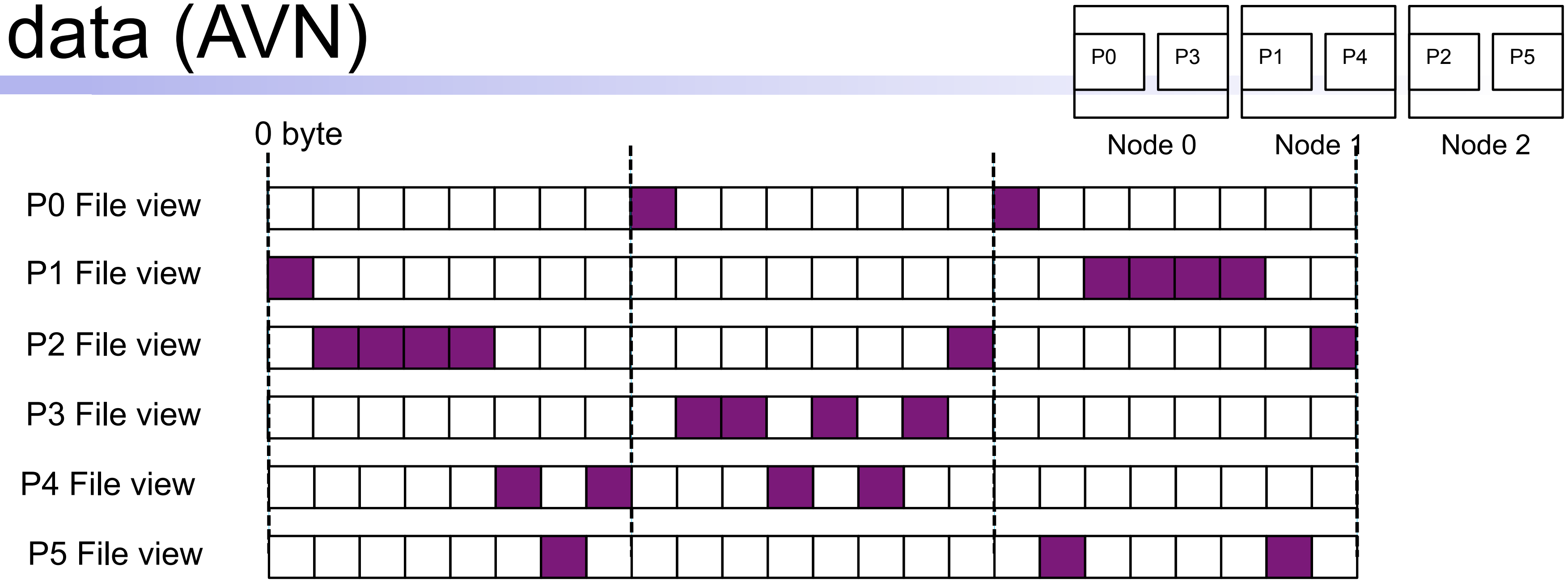
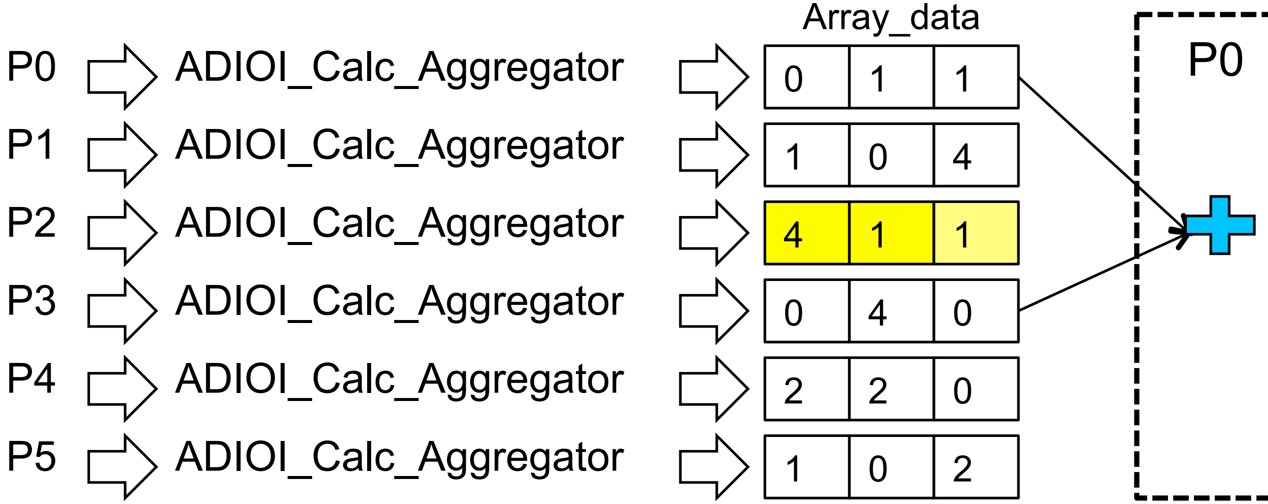


Two_Phase	ACN
12 messages	7 messages

ACN target:
Reduce the number of communications

Calculation and recollection of distribution data (AVN)





P0 Assigment_matrix_AVN

	FD0	FD1	FD2
N0	0	5	1
N1	3	2	4
N2	5	1	3

Calculation of AVN pattern

P0

Assigment_matrix_AVN

LAP ⇨

	FD0	FD1	FD2
N0	0	**5**	1
N1	3	2	**4**
N2	**5**	1	3

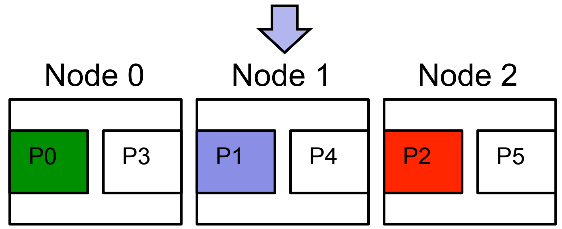
Aj=Max(Pi,FD)

New ranklist

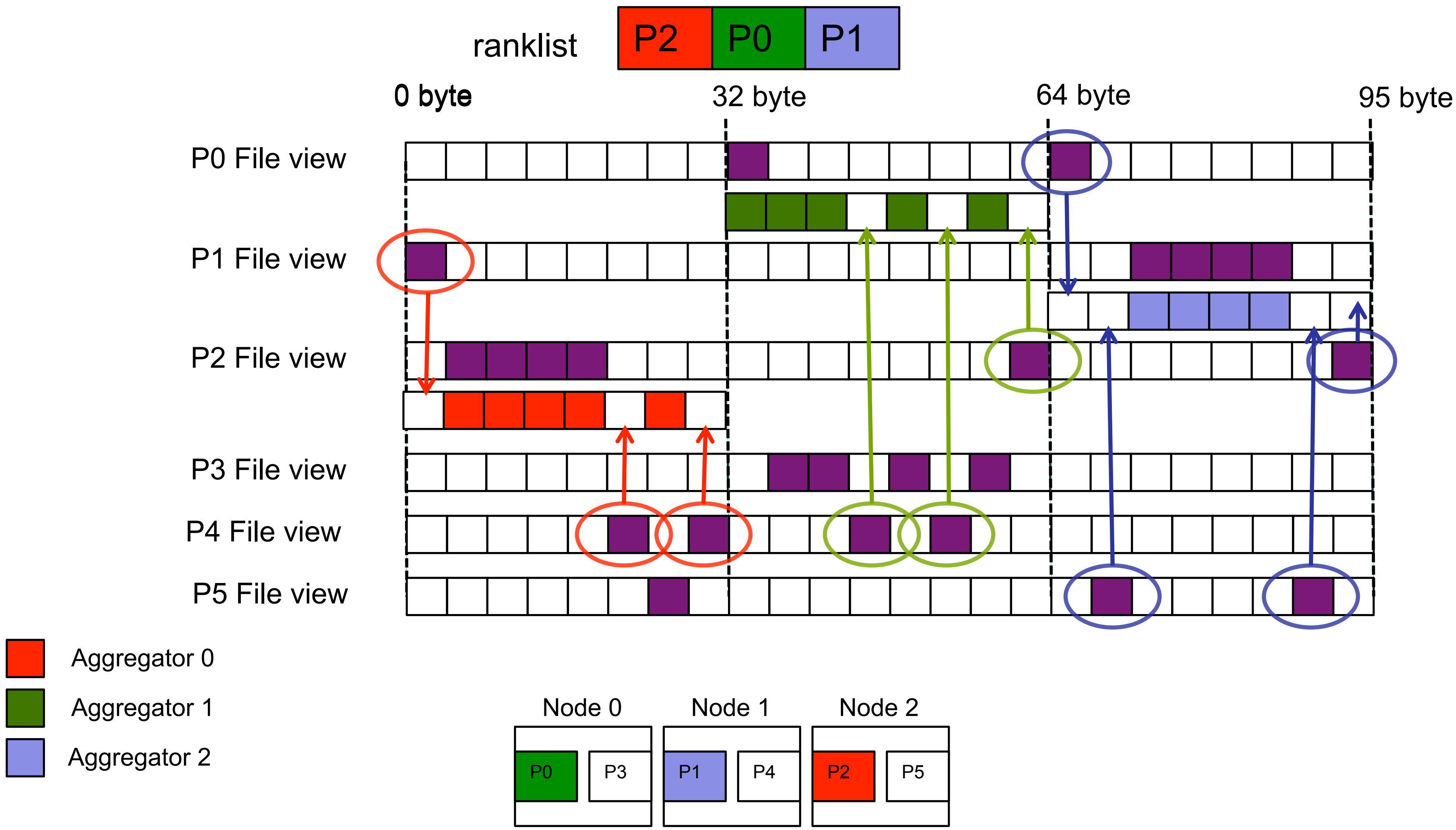
P2	P0	P1

ADIOI_cb_bcast_rank_map

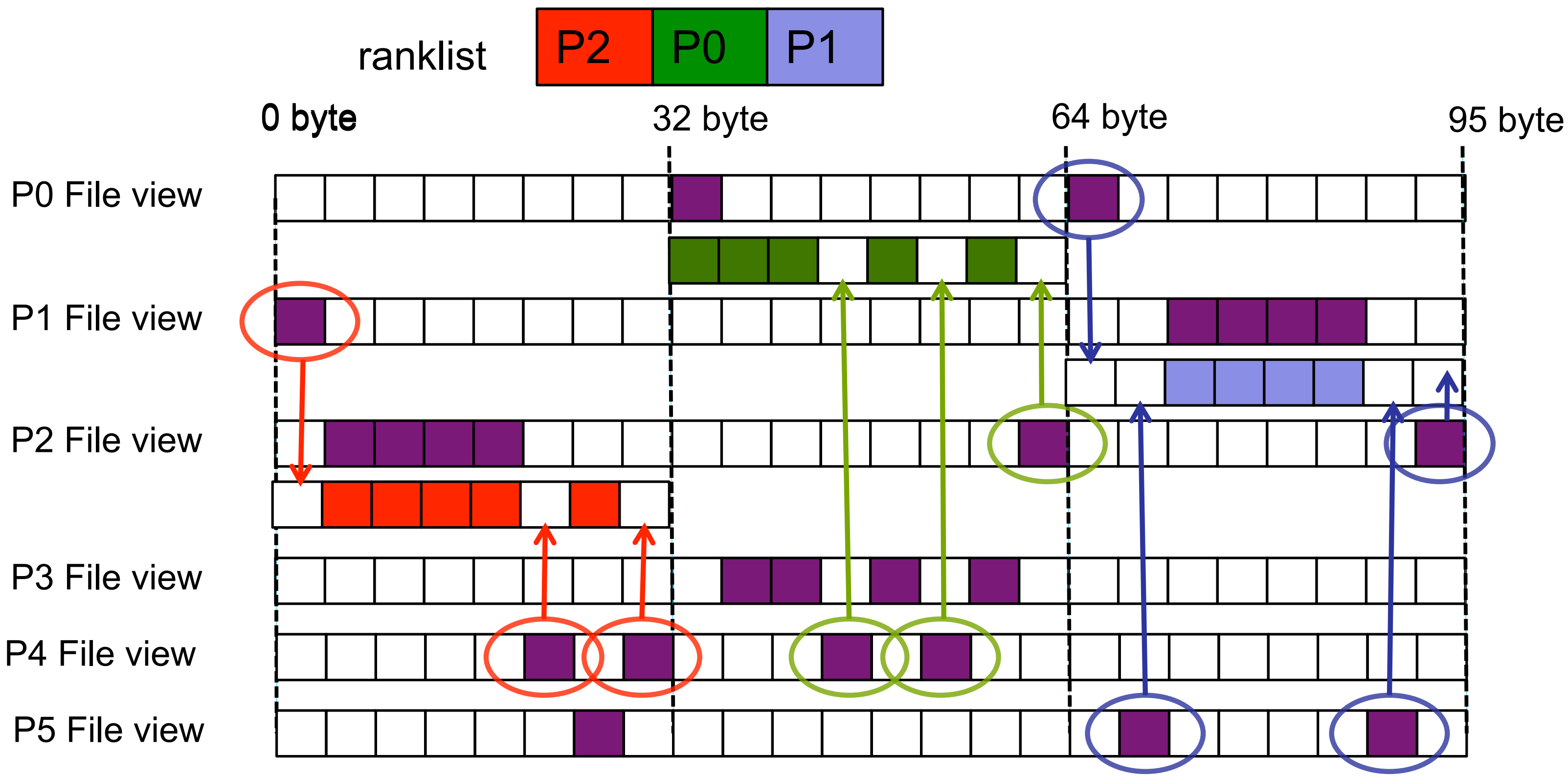
- Aggregator 0
- Aggregator 1
- Aggregator 2



Reduction in the number of communication with the AVN pattern.



Reduction in the number of communication with the AVN pattern.



Two_Phase	AVN
72 bytes	40 bytes

AVN target:
Reduce the volume of communications

ACN vs AVN

Two_Phase	ACN
12 messages	7 messages

Two_Phase	AVN
72 bytes	40 bytes

ACN target:
Reduce the number of communications

AVN target:
Reduce the volume of communications

- Which is the best ??
  - Depends of the data distribution among the processes.
    - Data very distributed, small contiguous data blocks :
      - High number of communications
      - Best aggregator pattern: **ACN**
    - Data less distributed, big contiguous data blocks:
      - High volume of data in the communications
      - Best aggregator pattern: **AVN**

New Proposal: Intelligent aggregator pattern for collective I/O pattern

- Select the aggregation-criterion that the reduce more the communication phase.
- Open question

Why two implementation of ACN and AVN?

- Aggregator patters are implemented in two different ways:
  - New version of Two_Phase I/O in MPICH2:
    - Locality_Aware_Two_Phase I/O (LA_TwoPhase I/O)
  - Library at application level:
    - Aggregation_Pattern_Calculation
    - The MPI based application call this library to calculate the aggregator list.
    - The application use one MPI-IO Hint to modified the default aggregator list:
      - cb_config_list: Provides explicit control over aggregators

Why two implementation of ACN and AVN? (II)

- First idea:
  - Install my own library of MPICH2 in HECToR.
  - Modify the source code of Two_Phase IO (inside MPICH2) to implement both aggregator patterns (Locality_Aware_Two_Phase I/O)
  - Problem: HECToR→ No install own MPI library.
- Second idea:
  - MPI-IO hints are used to provide information to a MPI program to assist the performance of the MPI file I/O routines.
  - Use **cb_config_list** hint to indicate to XT MPI my "new aggregator list".
  - Implement the aggregator patterns at application level. (Aggregation_Pattern_Calculation)

Lists MPI-IO hints supported on Cray XT systems.

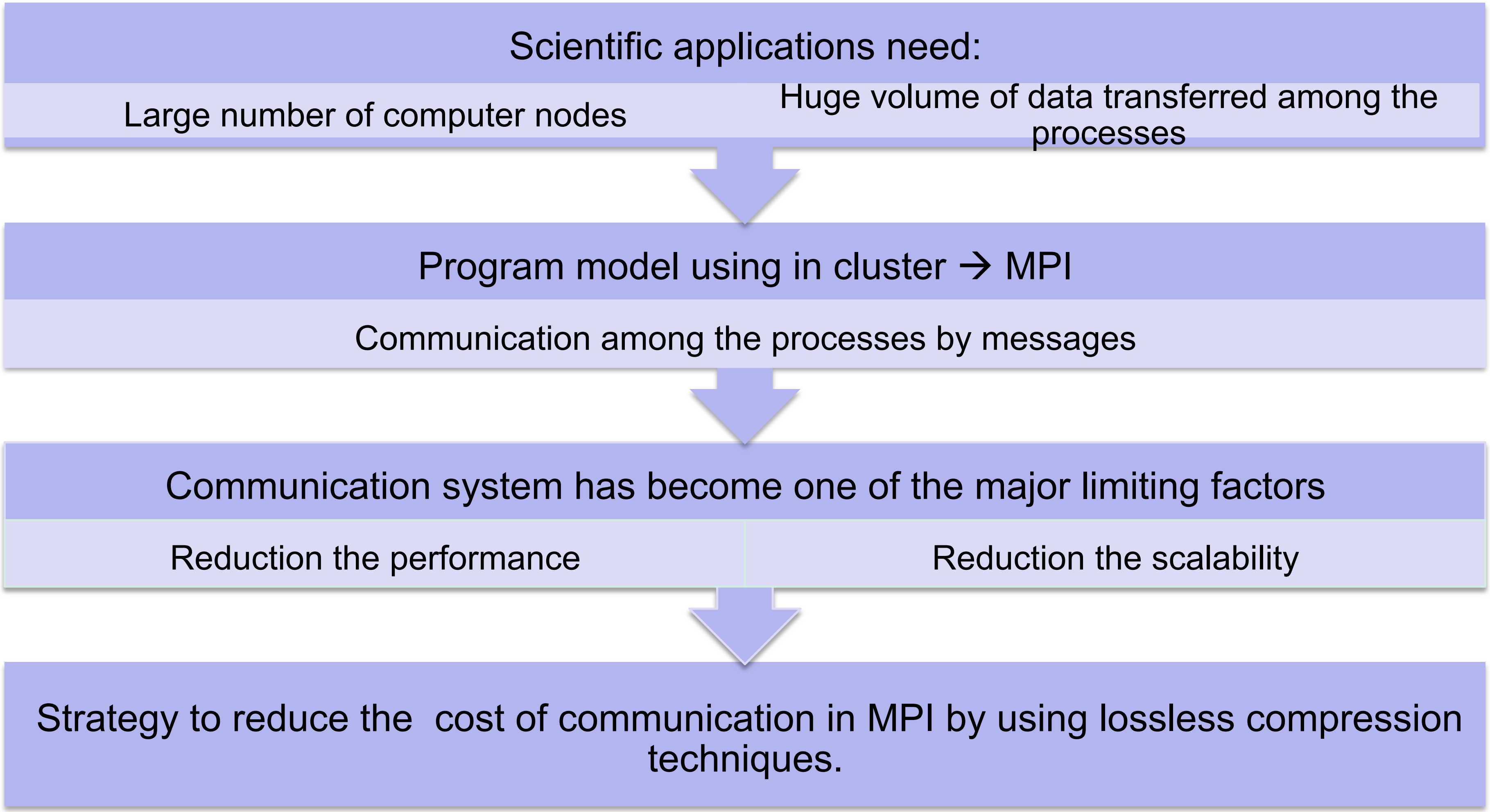
direct_io	cb_config_list	ind_rd_buffer_size
romio_cb_read	romio_no_indep_rw	ind_wr_buffer_size
romio_cb_write	romio_ds_read	cb_nodes
cb_buffer_size	romio_ds_write	

- Problem: cb_confing_list “seems” not work in XT MPI
  - Cray developer responsible for MPI-IO recognised my problem:
    - "We have raised a bug on the issue however right now and there doesn't seem to be an obvious workaround".
- Solution: Implement both ideas by using Eddie cluster.

Summary

1. Problem description
2. Main Objectives
3. Strategies for improve the performance of collective I/O operation
4. Strategies for improve the performance communication operations
5. Evaluations

Strategies for improve the performance of communication operations.



Phd. Thesis Proposal: Communication Compression

- Reduce the cost of communications:
  - By MPI messages compression in run-time
- Lossless compressions algorithms
- Compress all MPI primitives.
- We have developed three different strategies:
  - Runtime Compression (RC)
  - Runtime Adaptive Compression (RAC)
  - Guided Strategy (GS)
- Implementation of the strategies by modifying the source code of MPICH1.2

HPC-Programme Proposal (II)

- Implement Runtime Adaptive Compression (RAC) by using (New!!) message passing interface profiling (PMPI).
- Why ??
  - HECToR → No install own MPICH
  - DEISA/PRACE Spring School: Tools and Techniques for Extreme Scalability
    - The Scalasca Performance Analysis Toolset → PROFILING!!
    - New idea: Use the MPI standard profiling interface (PMPI) to implement the adaptive compression strategy

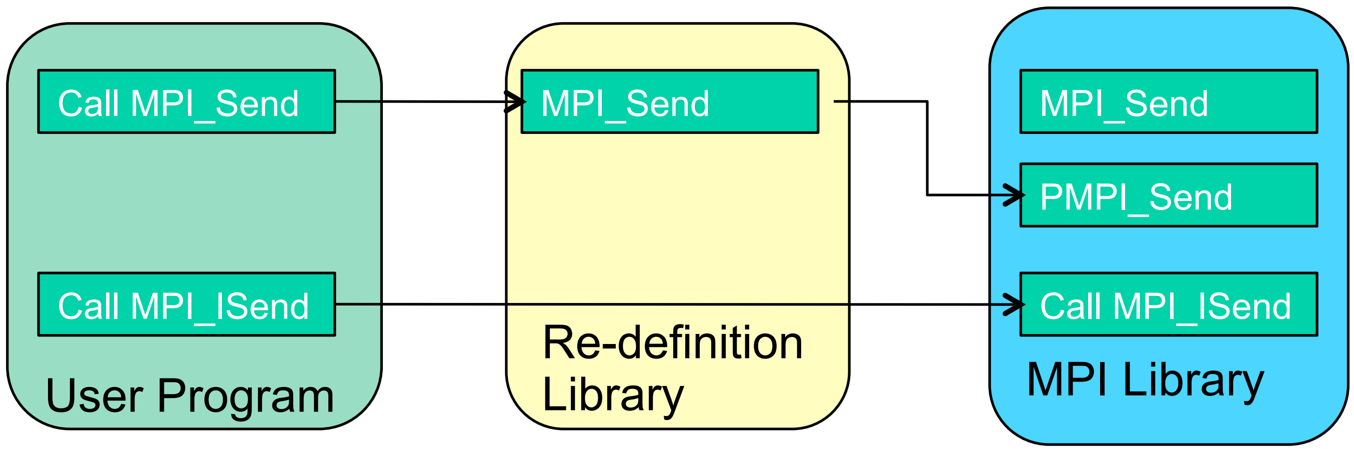
HPC-Programme Proposal (II)

- PMPI allows replacement of MPI routines at link time (not need to recompile)
  - No modification of the source code of the MPI implementation
  - No modification of the source code of the application

- Portable, independent of the MPI implementation (XT MPI, MPICH2, OPENMPI …).

PMPI

- Each standard MPI function can be called with an MPI_ or PMPI_ prefix.
- PMPI such wrapper functions to customize MPI behavior: implement RAC strategy



Example of Use of Profiling Interface


```
// extern.c
int MPI_Send( void *start, int count, MPI_Datatype datatype,
int dest, int tag, MPI_Comm comm )
{
    printf ("Before send the message to process %d\n",dest);
    return PMPI_send(start, count, datatype, dest, tag, comm);
}
```

```
// my_application.c
if (my_rank==0)
{   for (i=0;i<5;i++)
        array[i]=i;
    for (j=1;j<num_processes;j++)
        MPI_Send( array,5,MPI_INT,i,tag,MPI_COMM_WORLD);
 }
```

```
> mpicc -c extern.c
> mpicc -c my_application.c

> mpicc -g my_application.o extern.o -o executable
```

Example of Use of Profiling Interface


```
> mpirun –np 10 ./executable > output.txt
> cat output.txt

Before send the message to process 1
Before send the message to process 2
Before send the message to process 3
Before send the message to process 4
Before send the message to process 5
Before send the message to process 6
Before send the message to process 7
Before send the message to process 8
Before send the message to process 9
```

Runtime Adaptive Compression

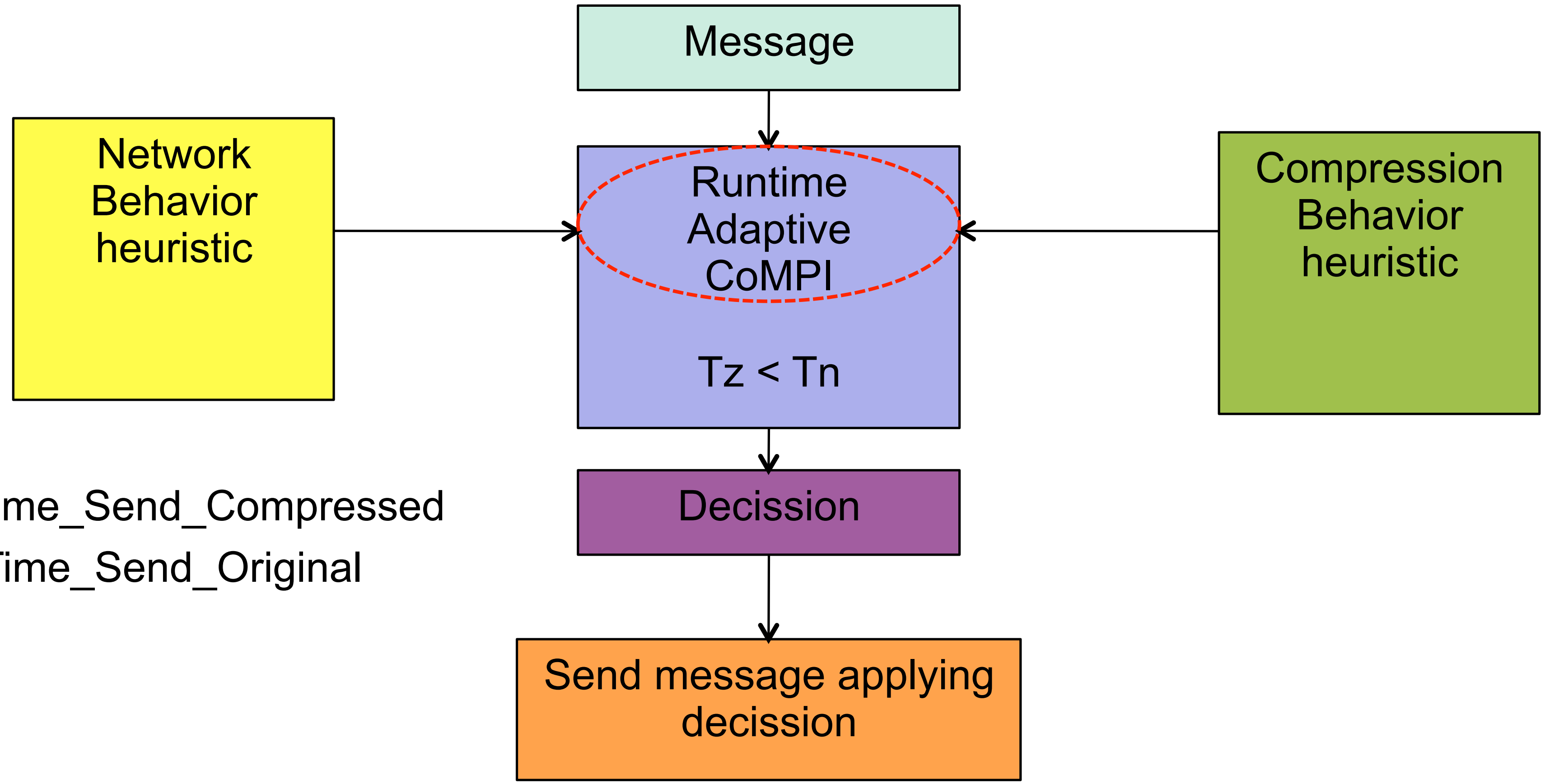
- Runtime Adaptive Compression Strategy (RAC), per message transferred takes two decision:
  - Turn on and off the compression.
  - Select itself the best compression algorithm:
    - LZO, RLE, HUFFMAN, RICE, FPC.
- Learn in run-time from previous messages
- Decision depending on:
  - Message feature:
    - Datatype and length
  - Network performance:
    - Latency and bandwidth
  - Compression algorithms

Decisions → Speedup

- Speedup to decide if send the message with/without compression.
- So the decission depends:
  - Original message transmisision time
  - Compressed messaged transmission time
  - Compression and decompression time

$$Speedup = \frac{Time\_Sent\_Orig.}{(Time\_Sent\_Compr. + time\_compress. + time\_decompr.)}$$

Decisions → Speedup

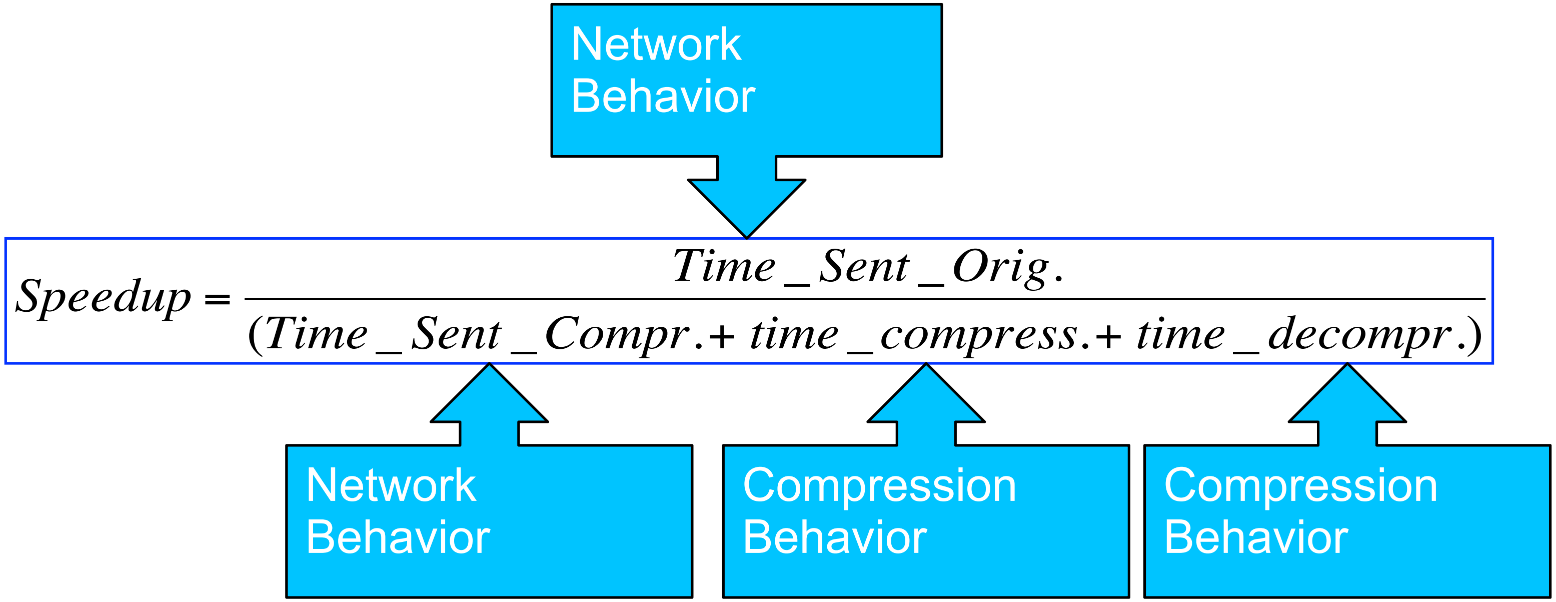


Tz=Time_Send_Compressed

Tn=Time_Send_Original

Compression behavior

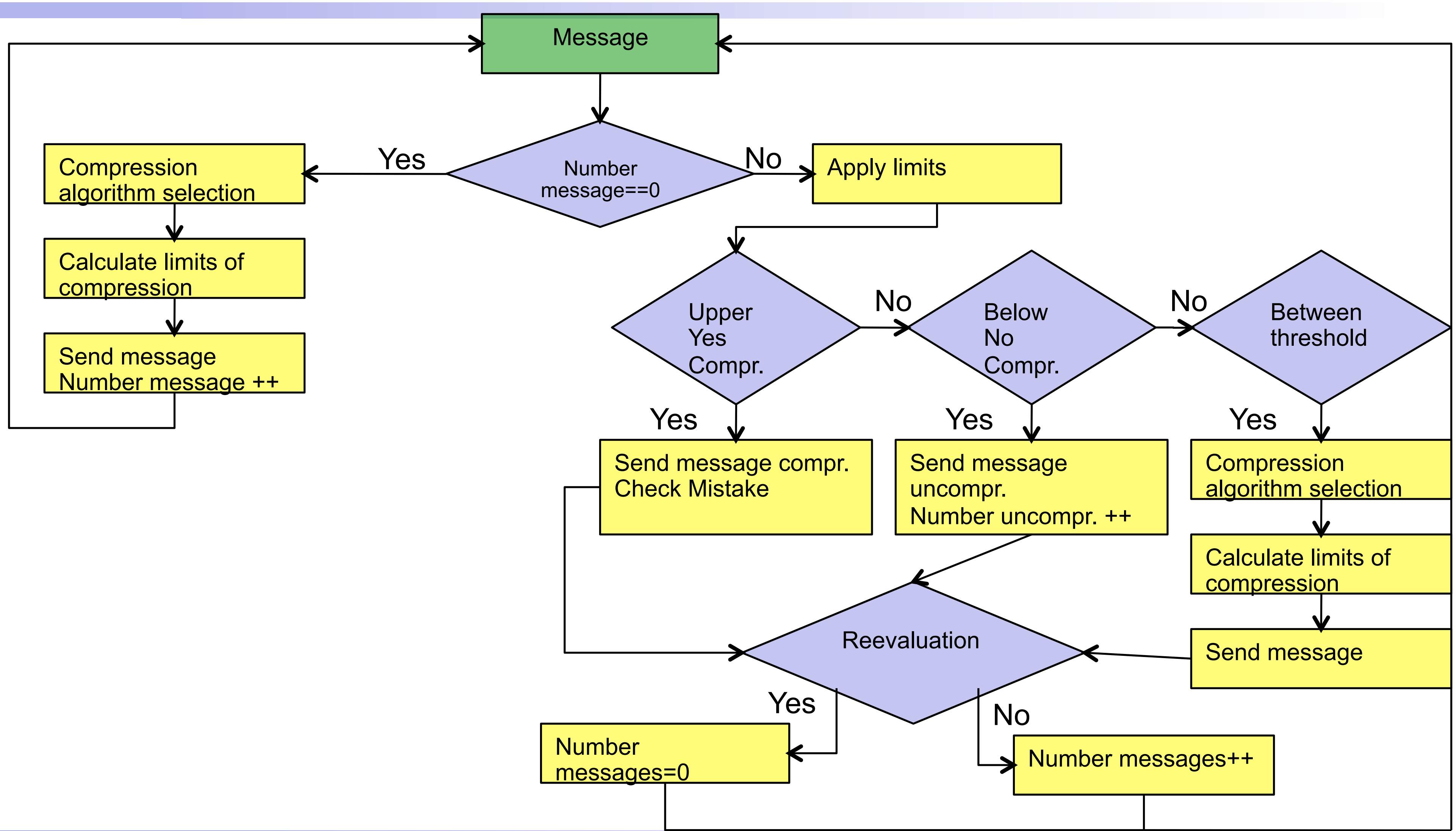
$$Speedup = \frac{Time\_Sent\_Orig.}{(Time\_Sent\_Compr. + time\_compress. + time\_decompr.)}$$



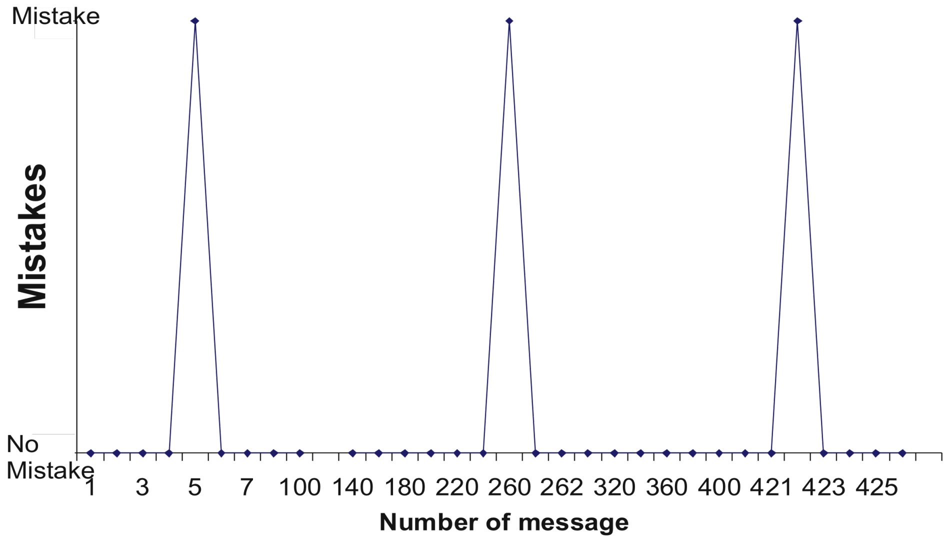
Decision Methodology

- Calculate the speedup per message? No → high overhead computation time
- According to Compression Behavior and Network data Behavior, RAS decides:
  - Datatype:
    - Integer y Float → LZO
    - Double → LZO or FPC
    - Others → LZO, RLE, RICE or HUFFMAN
  - Message size → Decision Threshold:
    - Each datatype has its thresholds
      - Length_yes_compression
      - Length_no_compression

Decision Methodology

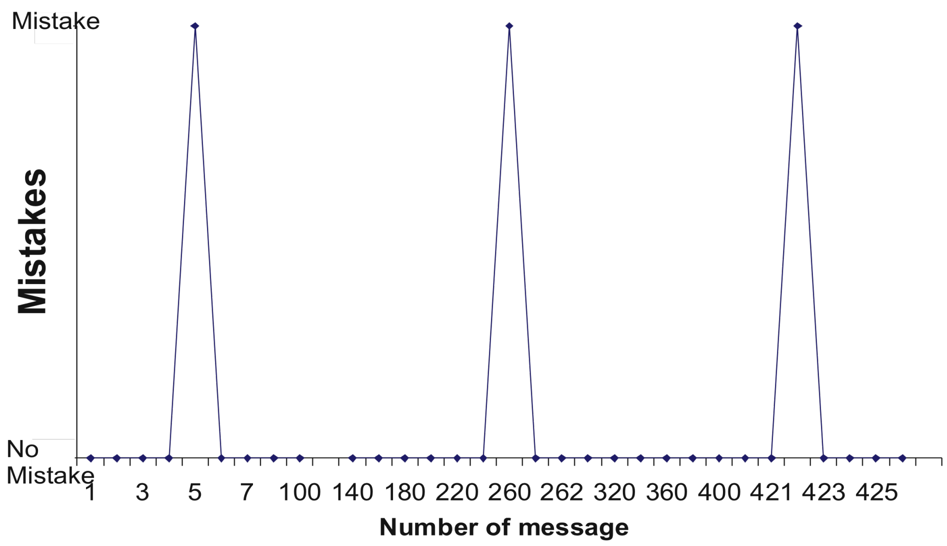


Different cases of re-evaluation

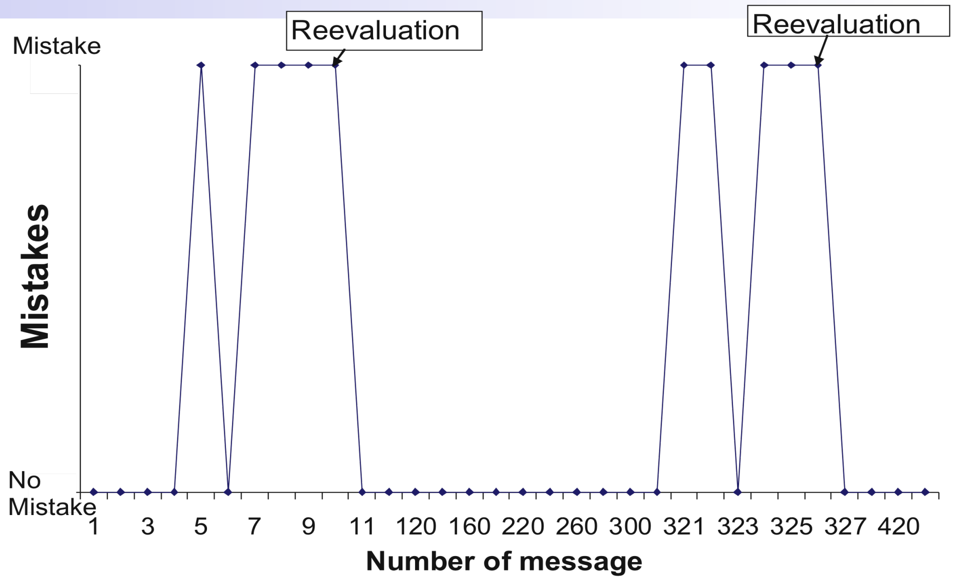


Low frequency mistakes

Different cases of re-evaluation

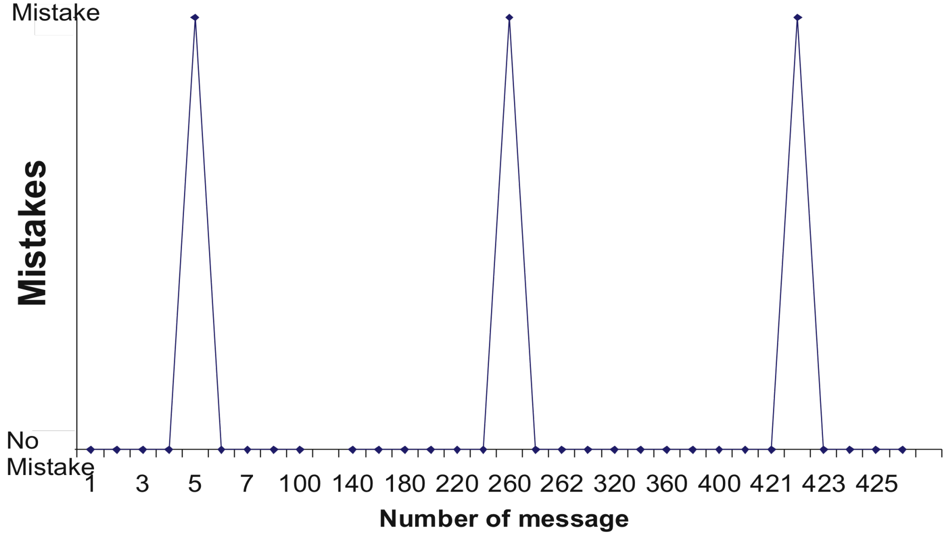


Low frequency mistakes

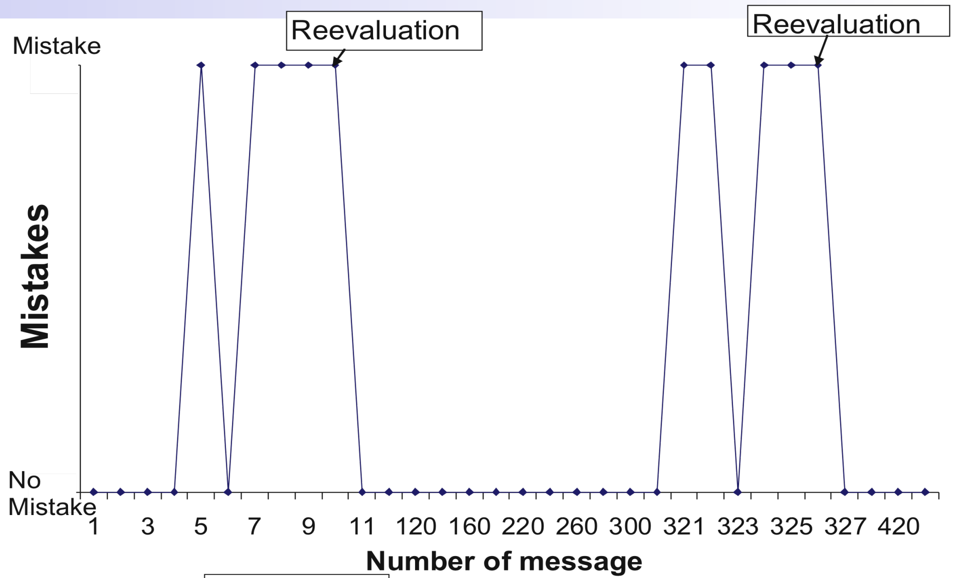


High frequency mistakes

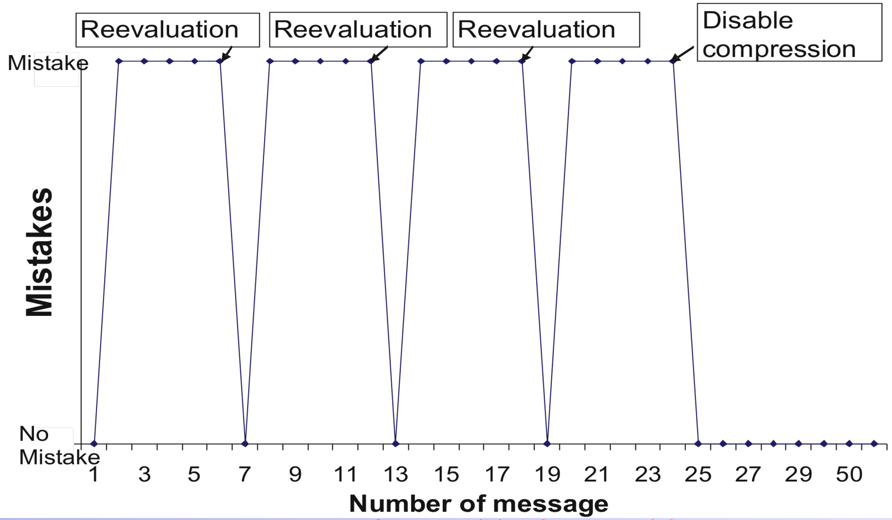
Different cases of re-evaluation



Low frequency mistakes



High frequency mistakes



Many reevaluations
in a short time

New Proposal: PRAcTICaL-MPI

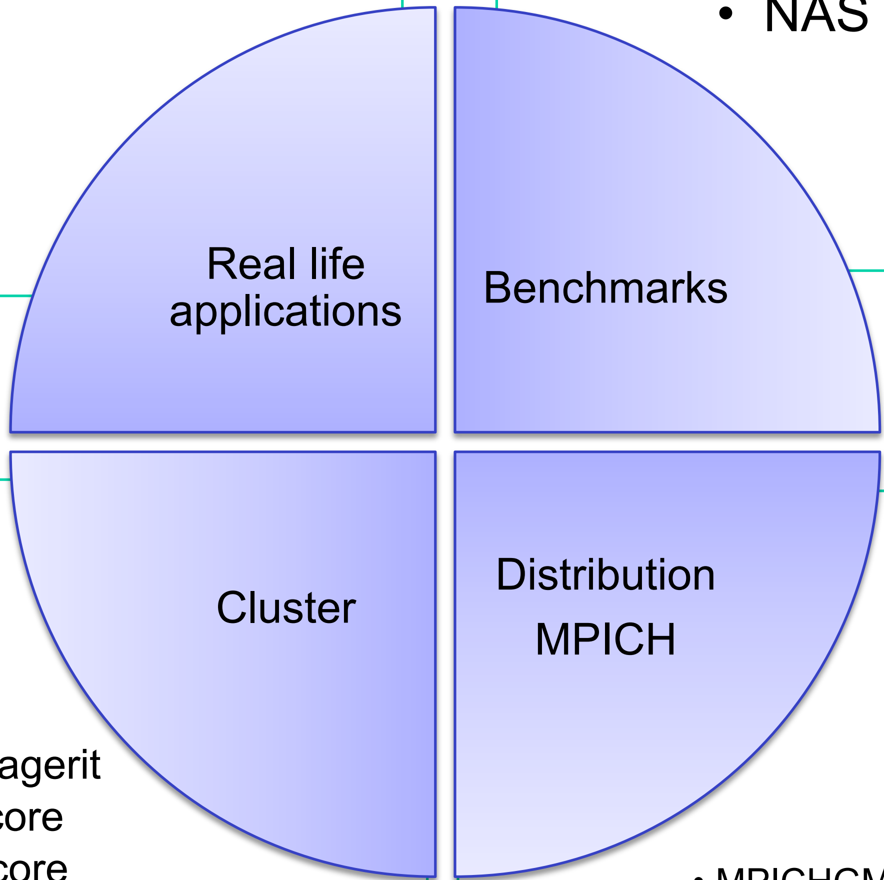
- PRAcTICaL-MPI: PoRtable AdpaTIve Compression Library
- New compression algorithms:
  - Snappy or PFOR
- Evaluate using OPEN MPI, XT MPI.
- Open question

Summary

Phd. Thesis evaluation tools

- BISP3D
- PSRG
- STEM-II

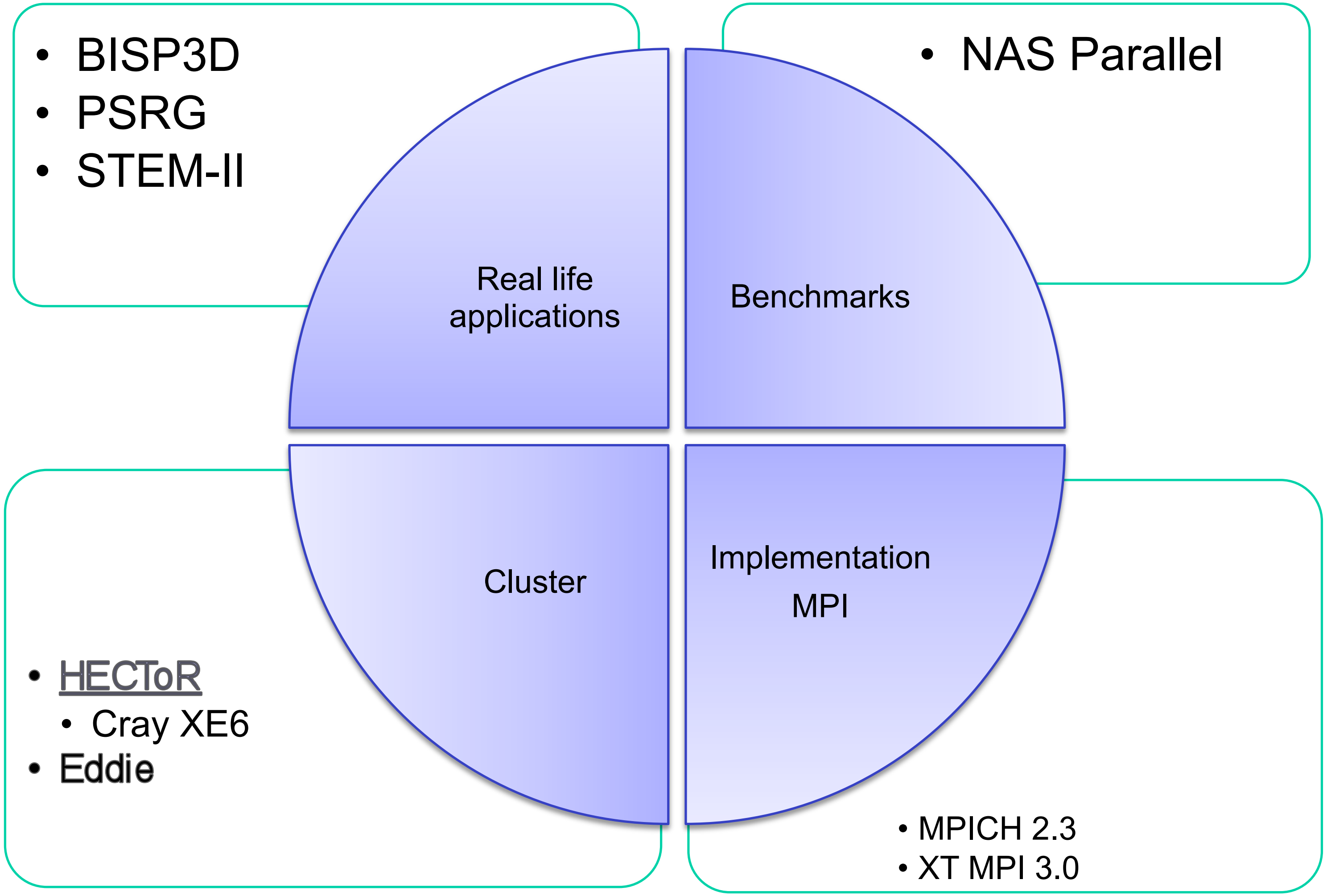
- NAS Parallel



- CESVIMA: Magerit
- UC3M: dual core
- UC3M: tetra core
- UC3M: dual core2

- MPICHGM-1.2.7.15NOGM

HPC Programme



HECToR

High End Computing Terascale Resource

"HECToR is the UK's high-end computing resource, funded by the UK Research Councils. It is available for use by academia and industry in the UK and Europe."

Features on HECToR Phase 2b

- 1856 compute nodes which contain two AMD 2.1 GHz 12-core Opteron processors => 44,544 cores

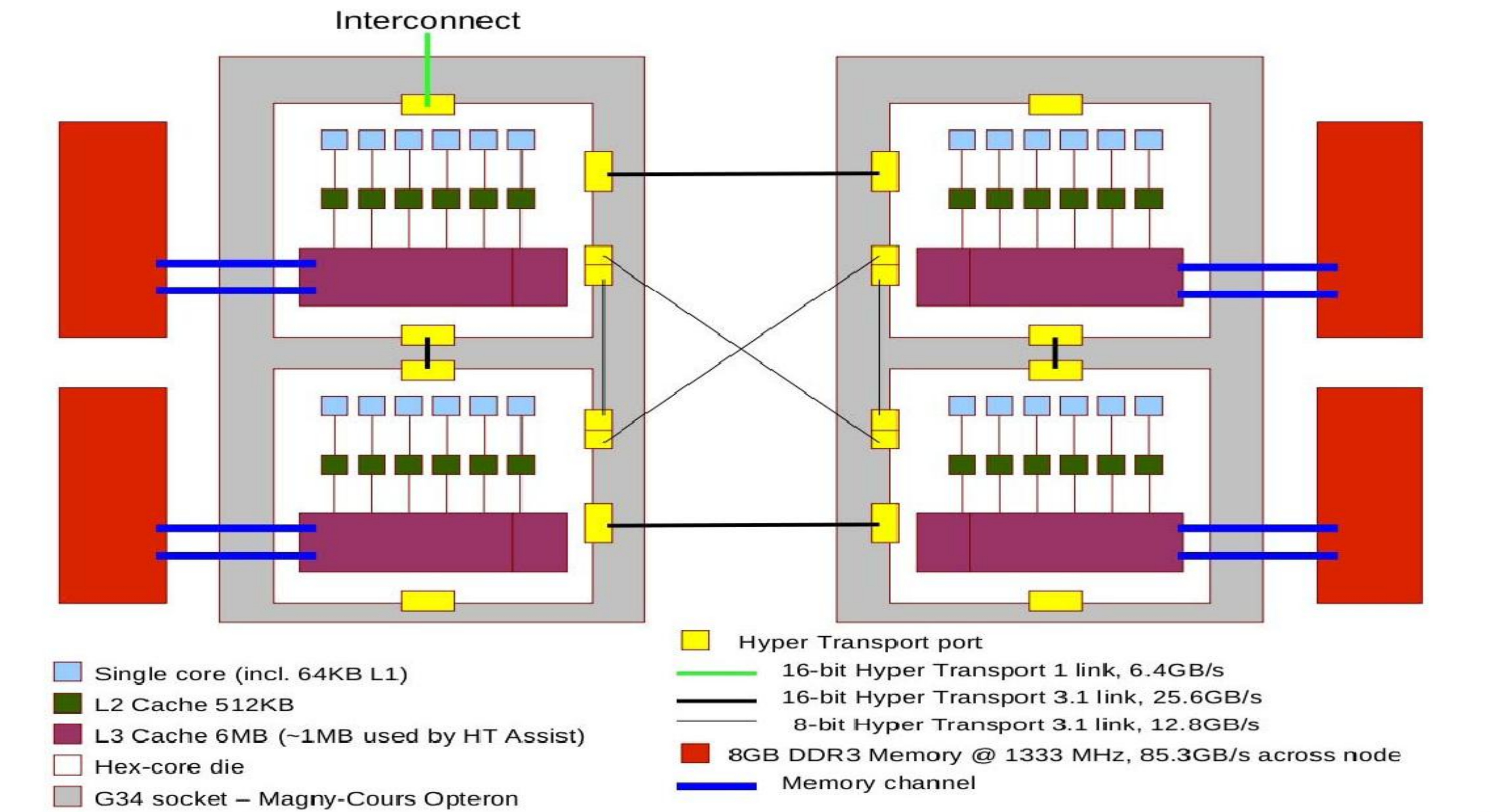
- Theoretical peak performance of 373 Tflops

- 32 GB main memory per processor, shared between 24 cores => total memory of 58 TB

- Gemini interconnect

- 12 IO nodes

XE6 24-core Magny Cours node



Running Jobs in HECToR


```
#!/bin/bash –login
#PBS -N My_rosa
#PBS -l mppwidth=20
#PBS -l mppnppn=2
#PBS -l walltime=00:20:00
#PBS -A x01-rfil

# Change to the direcotry that the job was
 submitted from cd $PBS_O_WORKDIR

# Launch the parallel job
aprun –n 20 -N 2 ./bisp3d arg1 arg2
```

- mppwidth: Request the total number of MPI tasks for your job.
- mppnppn: Tells the scheduler how many processes to place on a node

My example: 20 MPI processes, 2 processes per Node → 10 Nodes

EDDIE

- The compute component of Edinburgh Compute and Data Facility (ECDF), known as Eddie, offers a number of services aimed to satisy as best as possible all researchers' computational requirements.

Features of EDDIE on Mark2Phase1

- My experiments by using Mark2Phase1
- 130 IBM dx360M3 iDataPlex servers:
  - Two Intel Xeon E5620 quad-core processors (8 cores per node).
- Gigabit Ethernet network.
- Now it is available Mark2Phase2:
  - 156 IBM dx360M3 iDataPlex servers:
    - Two Intel Xeon E5645 six-core processors (12 cores per node).
    - Gigabit Ethernet network.

Running Jobs in EDDIE


```
#!/bin/sh
#$ -N My_rosa
#$ -cwd
#$ -pe openmpi_smp8_mark2 20
#$ -l h_rt=00:30:00


# Launch the parallel job
mpirun –np $NSLOTS ./bisp3d arg1 arg2
```

•NSLOTS: Request the total number of MPI tasks for your job.
•But you can not configure the number of nodes per core.

My example: 20 MPI processes

Running Jobs in EDDIE


```
#!/bin/sh
#$ -N My_rosa
#$ -cwd
#$ -pe openmpi_smp8_mark2 20
#$ -l h_rt=00:30:00


# Launch the parallel job
mpirun –np $NSLOTS ./bisp3d arg1 arg2
```

The file contained in $PE_HOSFILE have this:

eddie296.ecdf.ed.ac.uk **1**
ecdf@eddie296.ecdf.ed.ac.uk UNDEFINED

eddie328.ecdf.ed.ac.uk **2**
ecdf@eddie328.ecdf.ed.ac.uk UNDEFINED

eddie335.ecdf.ed.ac.uk **2**
ecdf@eddie335.ecdf.ed.ac.uk UNDEFINED

eddie336.ecdf.ed.ac.uk **2**
ecdf@eddie336.ecdf.ed.ac.uk UNDEFINED

eddie341.ecdf.ed.ac.uk **3**
ecdf@eddie341.ecdf.ed.ac.uk UNDEFINED

eddie350.ecdf.ed.ac.uk **3**
ecdf@eddie350.ecdf.ed.ac.uk UNDEFINED

eddie353.ecdf.ed.ac.uk **4**
ecdf@eddie353.ecdf.ed.ac.uk UNDEFINED

eddie364.ecdf.ed.ac.uk **3**
ecdf@eddie364.ecdf.ed.ac.uk UNDEFINED

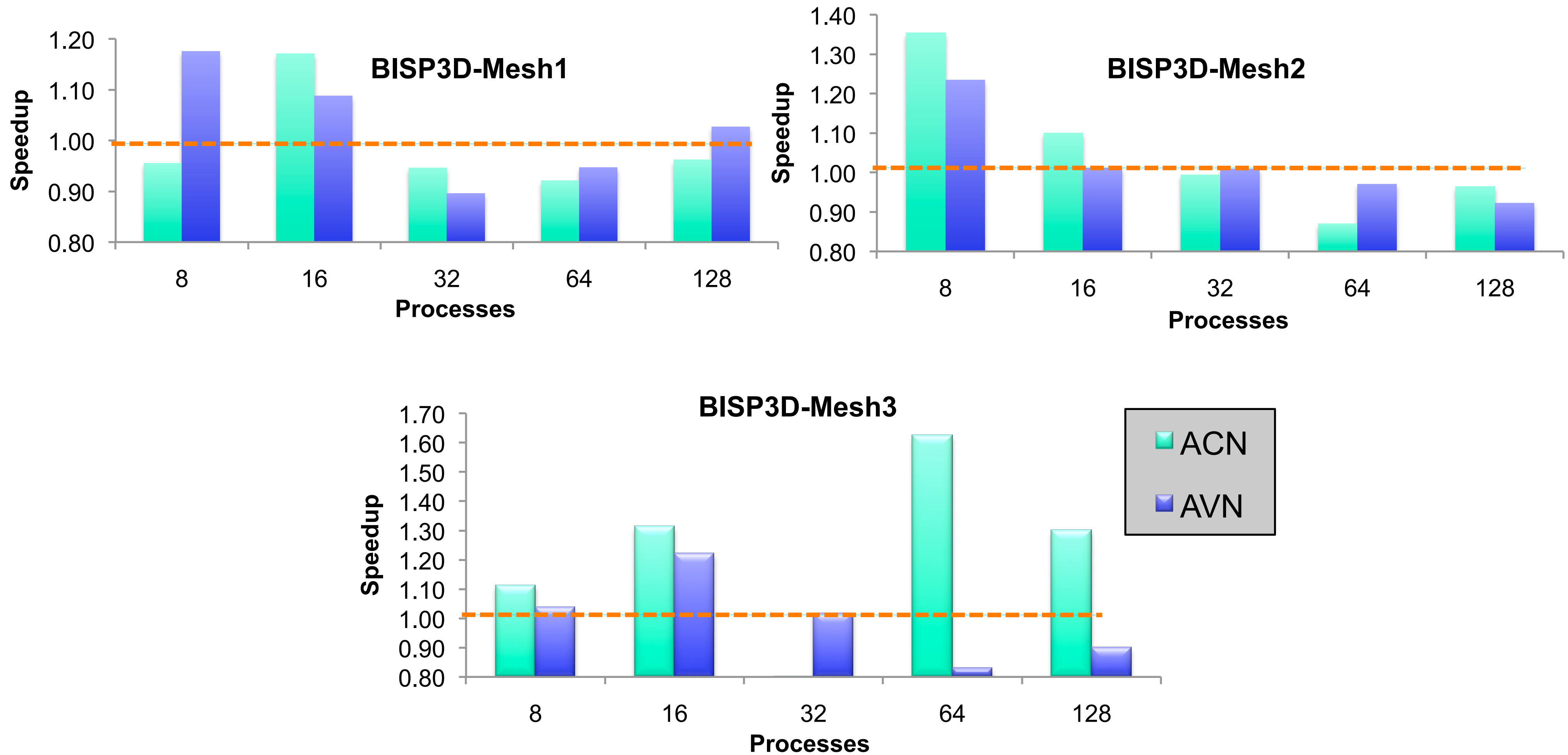
•NSLOTS: Request the total number of MPI tasks for your job.
•But you can not configure the number of nodes per core.

My example: 20 MPI processes

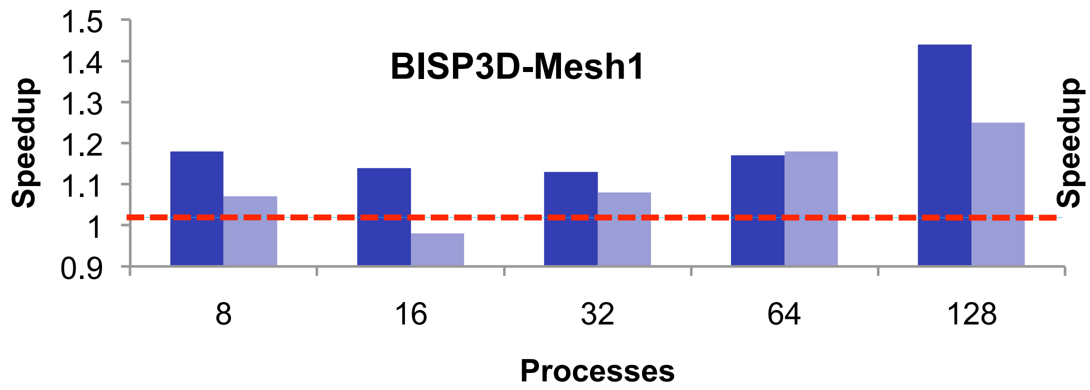
BISP3D

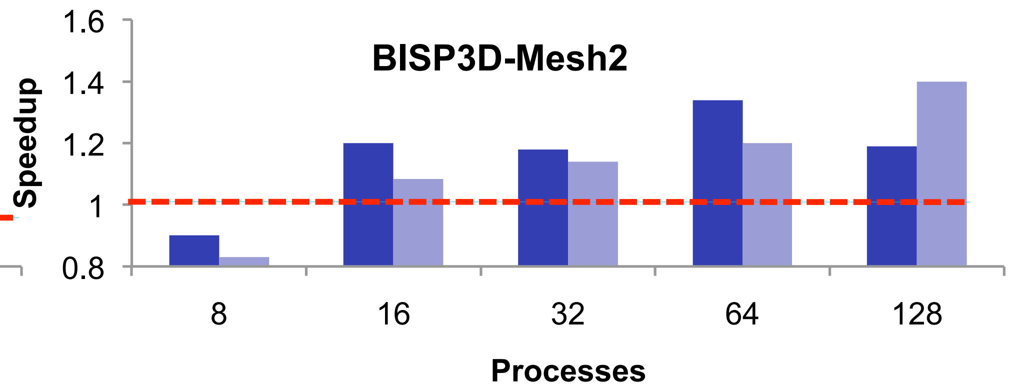
- 3-Dimensional simulator of BJT and HBT bipolar devices:
  - The goal is to relate electrical characteristics of the device with its physical and geometrical parameters.
- We have use 3 different different devices
  - Each bipolar device it is represented by a mesh.
  - Load represent the number of elements per node (in a mesh).
- Uses Two_Phase IO to write results in disk
  - Original BISP3D sequential writes.
- Irregular application (non contiguous data).

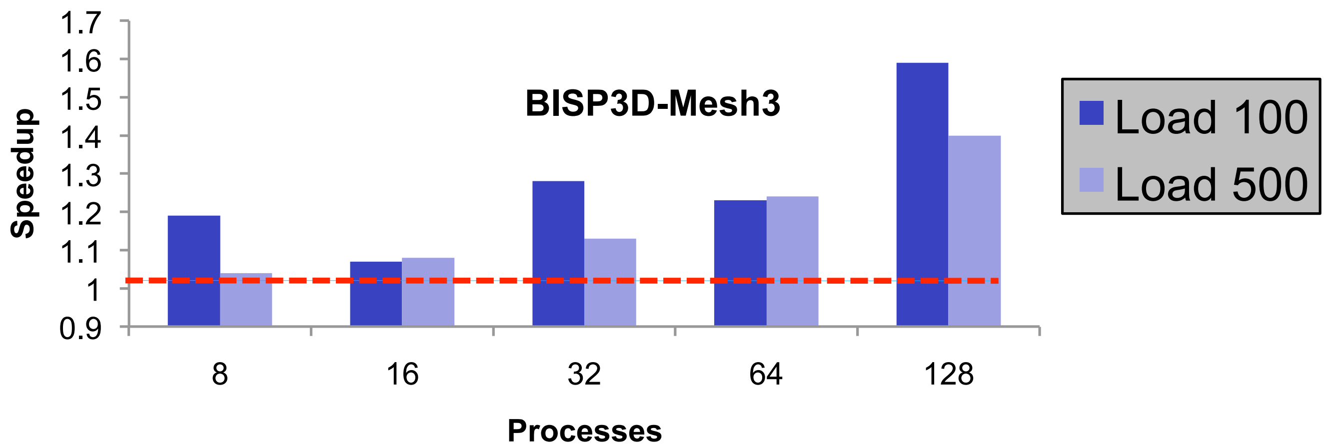
Evaluations of IO aggregator patterns (EDDIE)



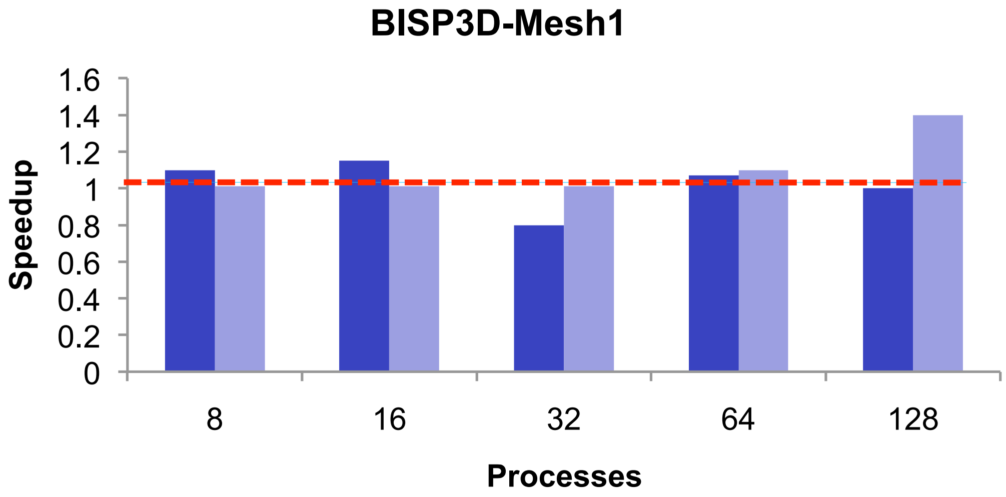
Evaluations of Run Adaptive Compression (EDDIE)

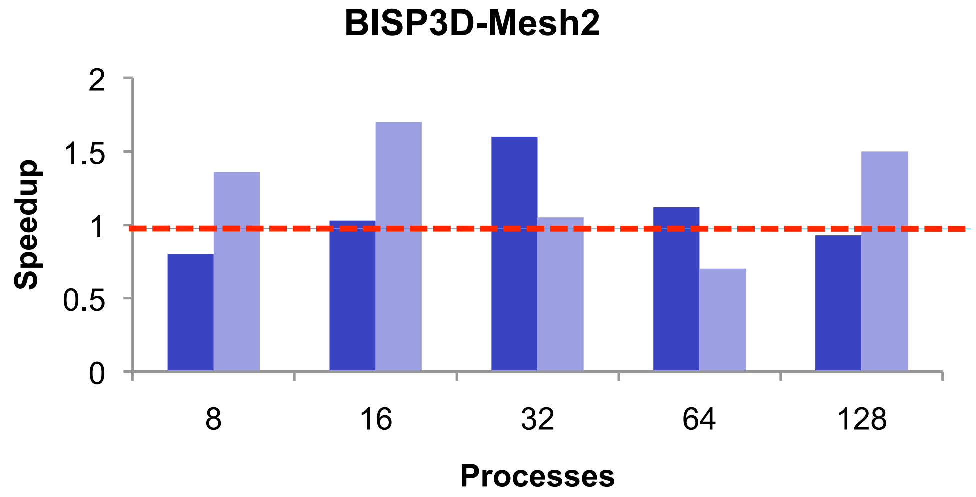


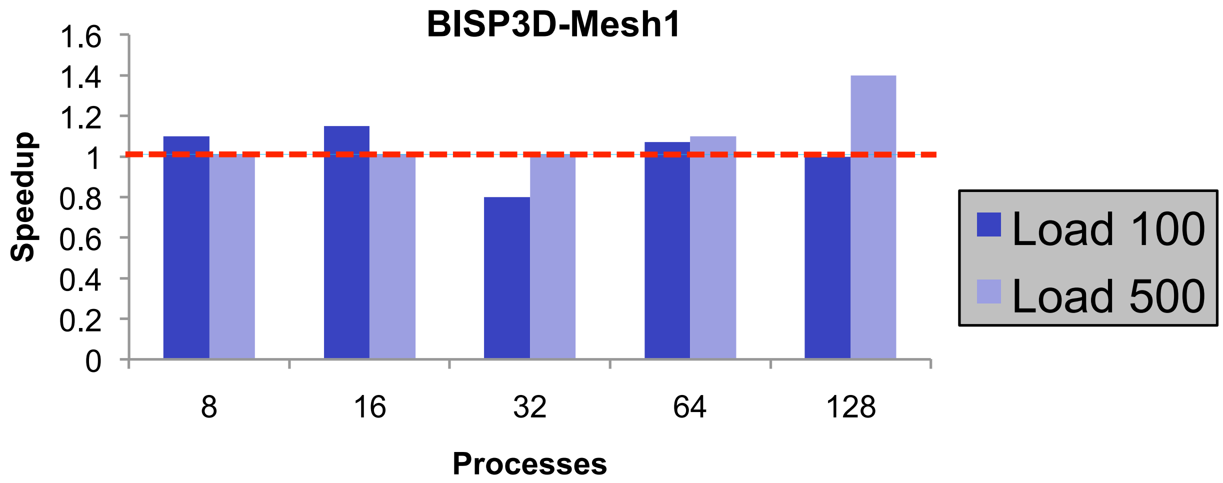




Evaluations of Run Adaptive Compression (HECToR)







Questions??

- Thanks!!

Dynamic and Adaptive optimization techniques to enhance the performance of MPI applications by using **HECToR** and **Eddie** clusters**.**

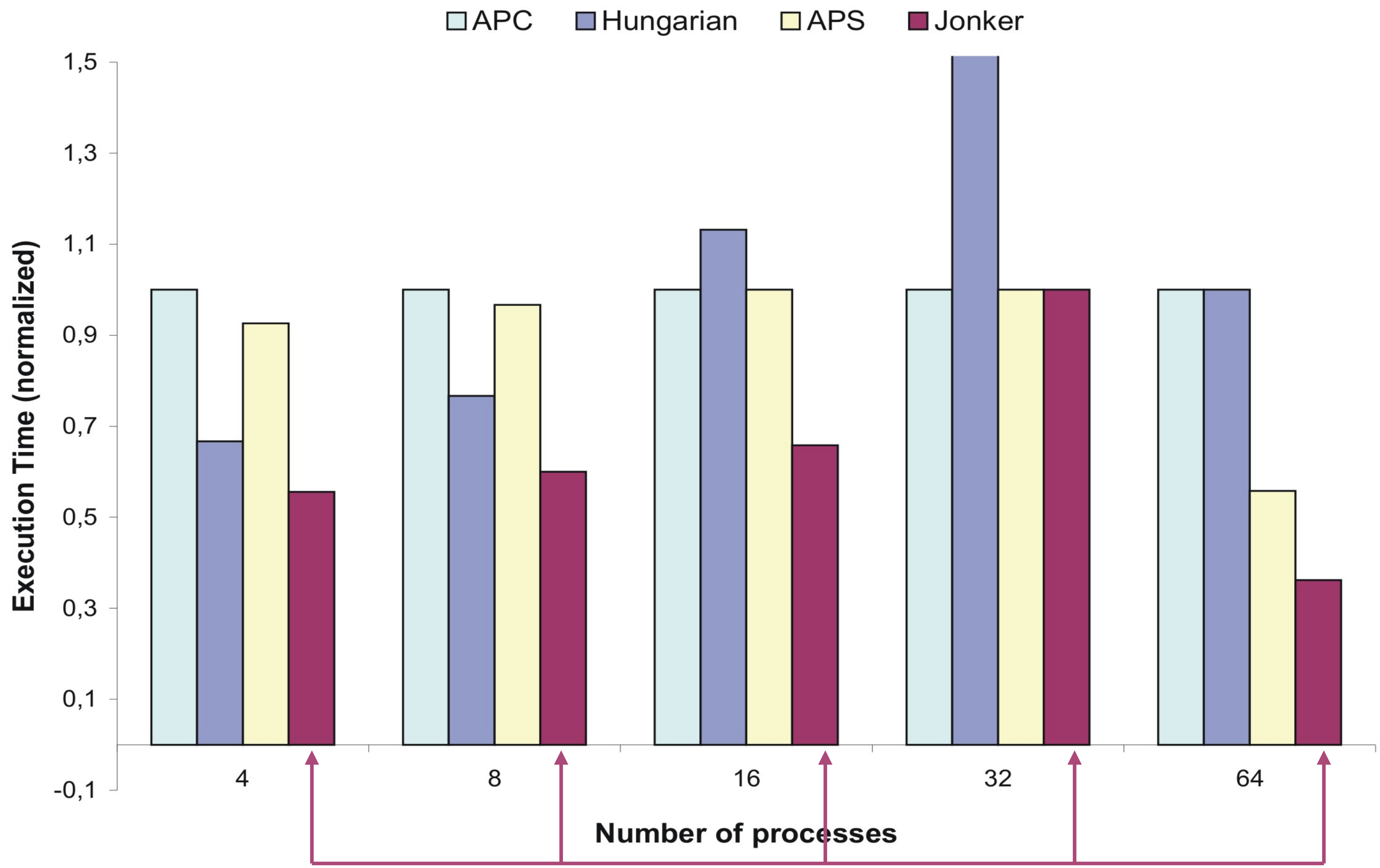
Author: Rosa Filgueira Vicente
University of Edinburgh

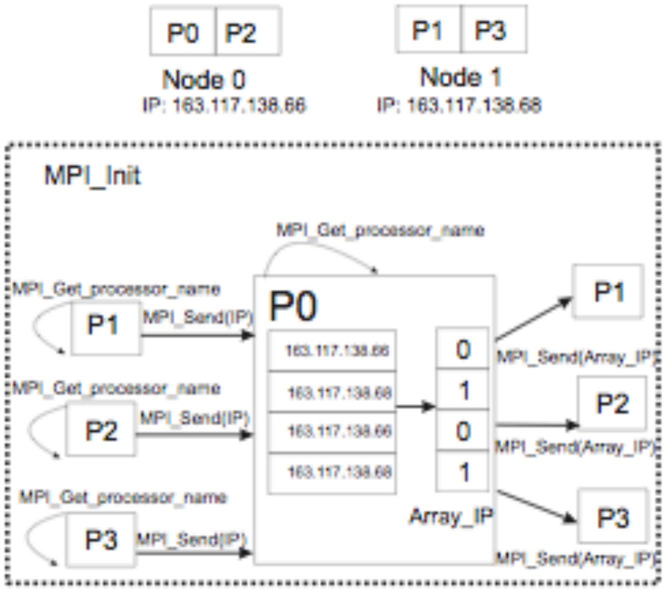
Linear Assignment Problem (I)

- LAP computes the optimal assignment of m items to n elements given an m x n cost matrix.

- Several algorithms have been developed for LAP:
  - Hungarian algorithm.
  - Jonker and Volgenant algorithm.
  - APC and APS Algorithms.
- All algorithms produce the same assignment.
- The difference is the time to compute the optimal allocation.

3.1 Linear Assigment Problem (II)




P0
P2
P1
P3
Node 0
IP: 163.117.138.66
Node 1
IP: 163.117.138.68
MPI_Init
MPI_Get_processor_name
MPI_Get_processor_name
P1
MPI_Send(IP)
MPI_Get_processor_name
P2
MPI_Send(IP)
MPI_Get_processor_name
P3
MPI_Send(IP)
P0
163.117.138.66
163.117.138.68
163.117.138.66
163.117.138.68
0
1
0
1
Array_IP
P1
MPI_Send(Array_IP)
P2
MPI_Send(Array_IP)
P3
MPI_Send(Array_IP)