I/O Scheduling Service for Multi-Application Clusters

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Plan

Part 1 - Parallel Input/Output and Clusters
Part 2 - Controlling and Scheduling Multi-application I/O
Part 3 - aIOLi, an Input/Output Scheduler for *HPC*
Part 4 - Conclusion

Plan

Part 1 - Parallel Input/Output and Clusters

1 Introduction
- Context
- Parallel I/O

2 Parallel I/O and Clusters
- Available Solutions

3 Objectives

Part 2 - Controlling and Scheduling Multi-application I/O
Part 3 - aIOLi, an Input/Output Scheduler for *HPC*
Part 4 - Conclusion

Context

Environment

- Clusters of SMPs
- Linux
- High Performance Computing
- Intensive I/O applications
  - CPU bounded application ⇒ I/O bounded application
  - Remote hard drive I/O

Parallel I/O

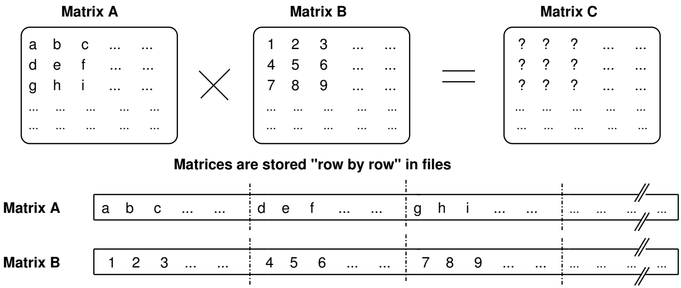
- Handling concurrent accesses to a same resource (a file)
- Accesses: different in size, in offset

Example: a parallel matrix product

Parallel I/O - Example

Parallel matrix product

- Specific parts to fetch according to the data distribution (columns/rows, BLOCK/BLOCK ...)



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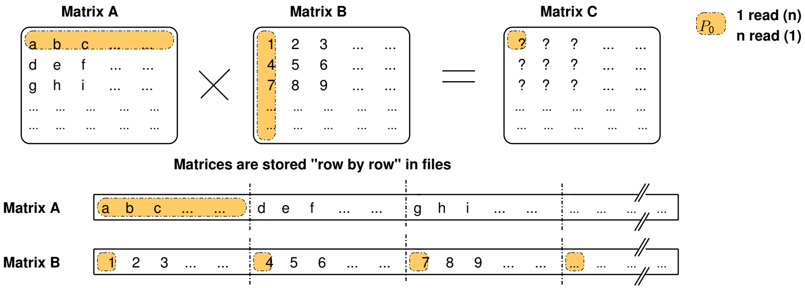

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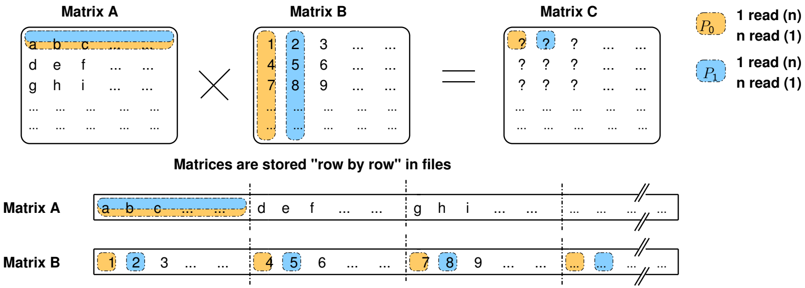
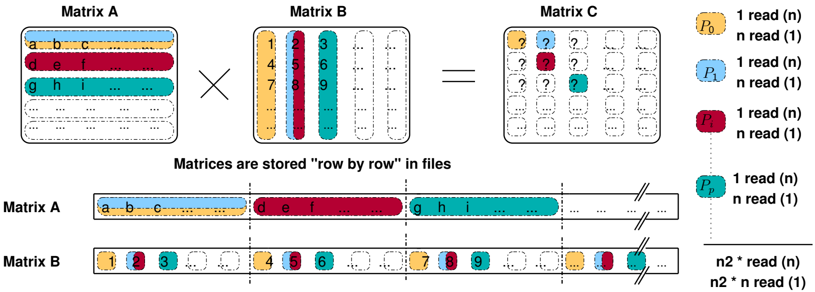


Parallel I/O - Example

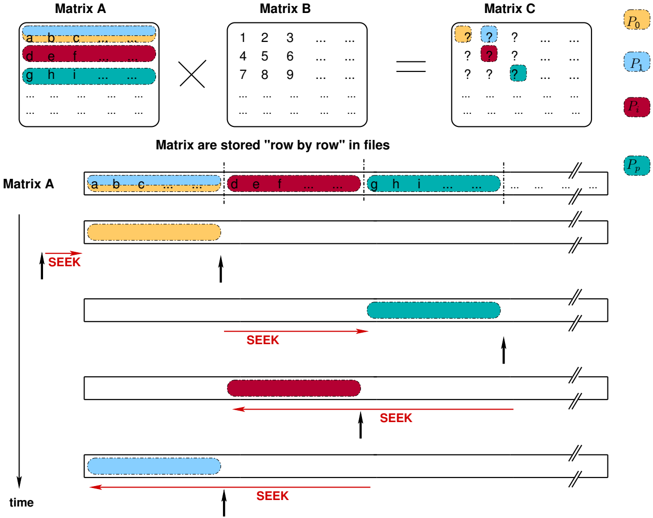
Parallel matrix product

- Specific parts to fetch according to the data distribution (columns/rows, BLOCK/BLOCK ...)
- File decomposition: Lot of disjoint/contiguous requests at the same time ⇒ "lethal" behaviour for I/O subsystem



Parallel I/O - Example

No defined order between requests ⇒ many disk head movements



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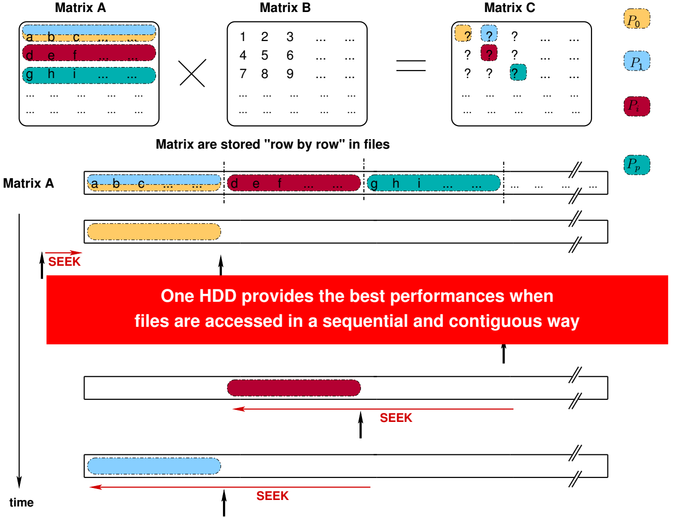

One HDD provides the best performances when files are accessed in a sequential and contiguous way

Parallel I/O - Example

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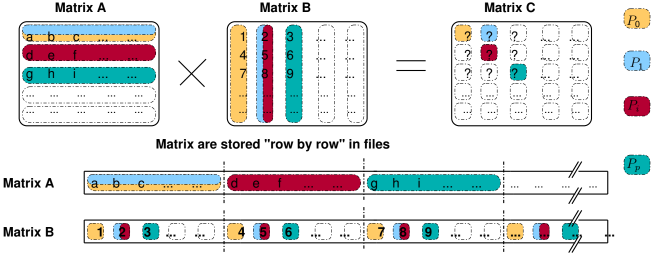
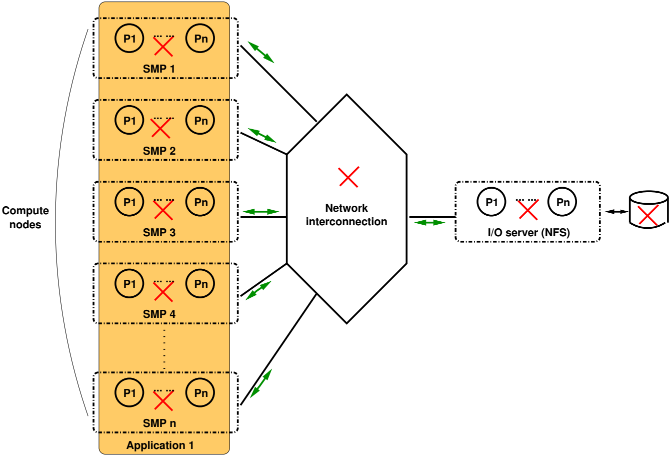


Similar behavior for the matrix B
"Random order" between requests

The bigger the number of requests
the bigger the potential number of seeks
⇒ performance degradation (bottlenecks)

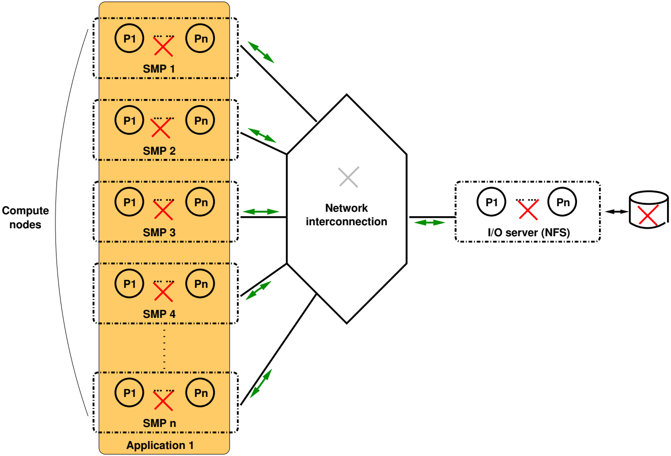
Parallel I/O and Clusters

Parallel I/O ⇒ bottlenecks



Parallel I/O and Clusters

Parallel I/O $\Rightarrow$ bottlenecks



Hypothesis: network has fewer impact than the I/O subsystems.

Parallel I/O Requirements

Performance constraints

- Reduce the number of requests:
  decrease overhead implied by the different syscalls
- Requests Scheduling:
  avoid expensive seeks and maximize large accessses
- Exploit cache mechanisms:
  benefit from read-ahead strategies, ...

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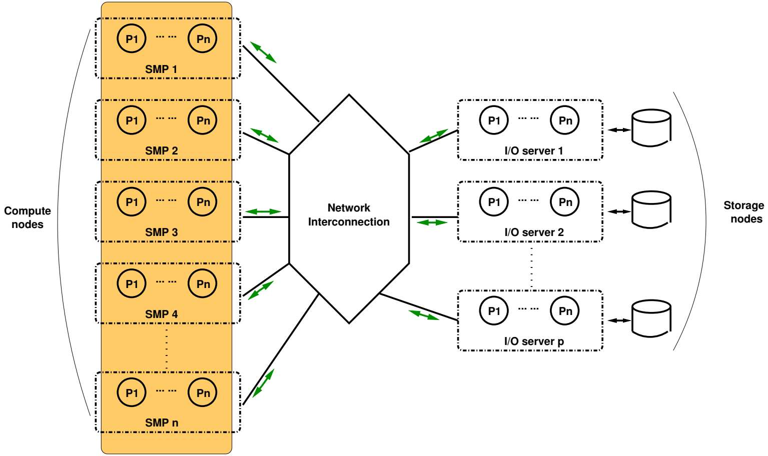
Parallel I/O Solutions (1/4)



Solution 1: Parallel File Systems ⇒ Balance requests between several servers

Parallel I/O Solutions (1/4)

Parallel File Systems

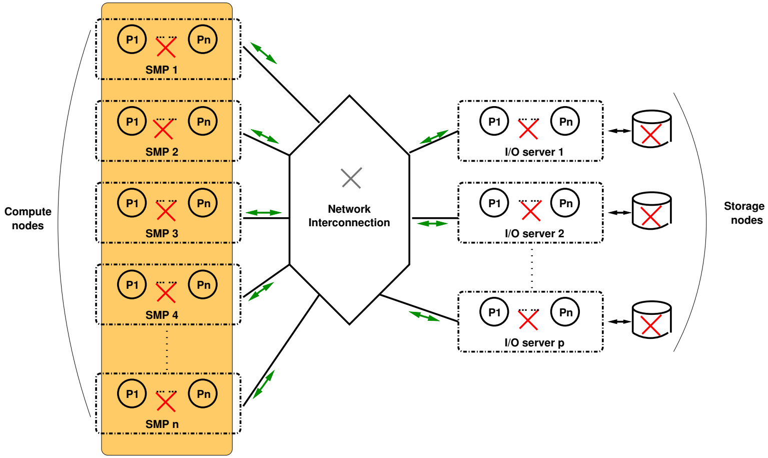
- Load balancing on several servers
- 2 types :
  - Designed for "Parallel I/O": PIOUS, VESTA, ...
    (logical view/physical placement, gave up in the time)
  - More generic : PVFS, Parallel NFS, GPFS, Lustre
    (performance/coherency/fault tolerance...)
- +/- complete
- +/- efficient / +/ - intrusive (dedicated APIs at client side)
- No "real" scheduling policy (most of them rely on low level schedulers)

The performance depends on the striping policy of the file system

From a general point of view, they do not take into account application striping !

Parallel I/O Solutions (2/4)

Parallel I/O ⇒ bottlenecks



Parallel I/O Solutions (2/4)

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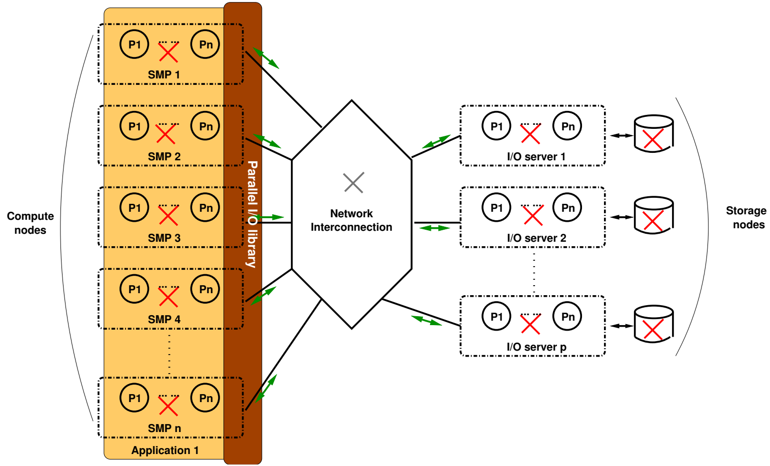
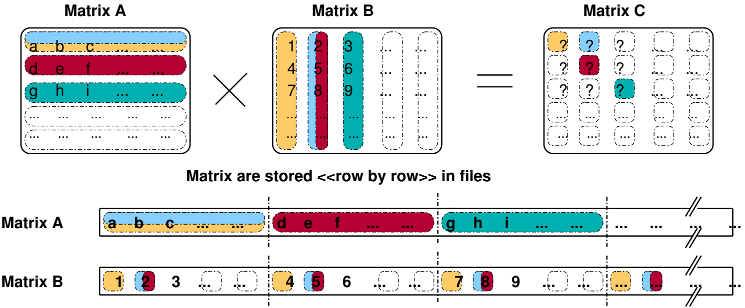


Solution 2: Libraries $\Rightarrow$ MPI I/O, the standard

Parallel I/O Solutions (3/4)

Libraries - MPI I/O [MPI2-97]

- Definition of access patterns ⇒ Reduce number of requests (equivalent to "views" / access vectors like for `readv/writev`)



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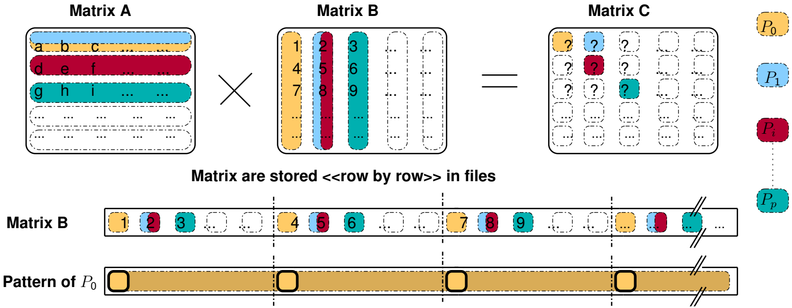

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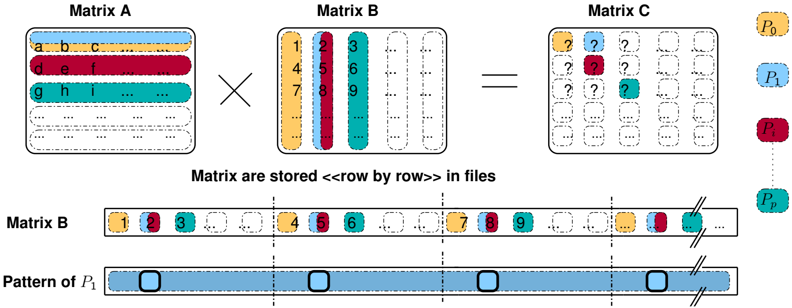

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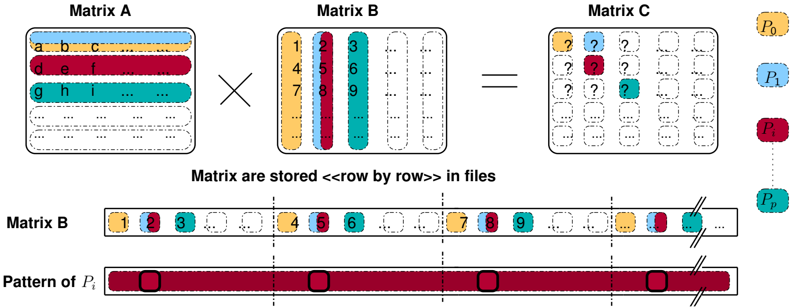

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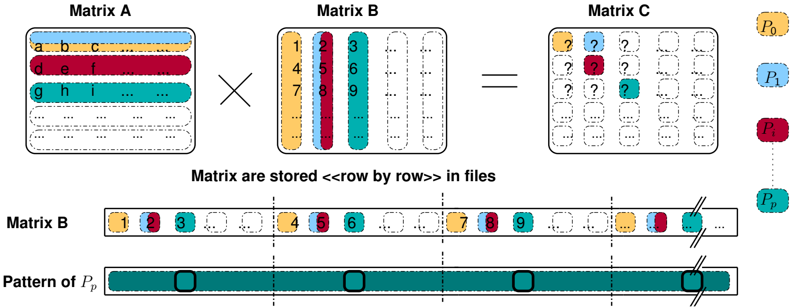

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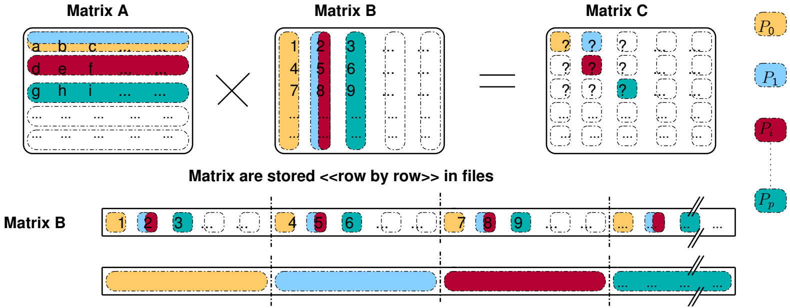

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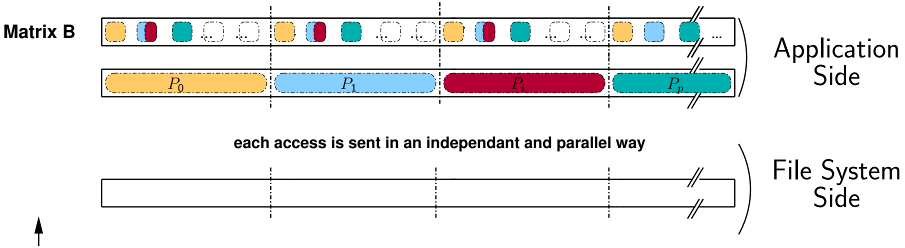

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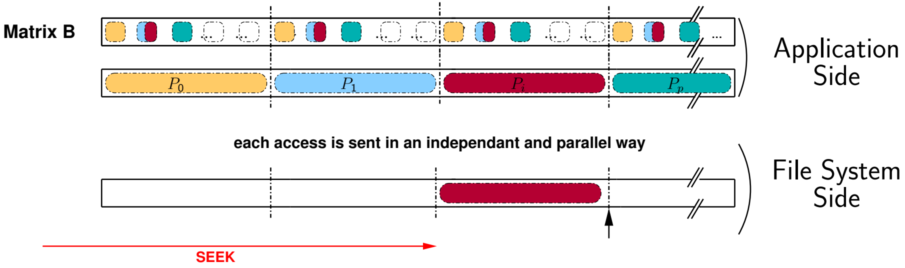

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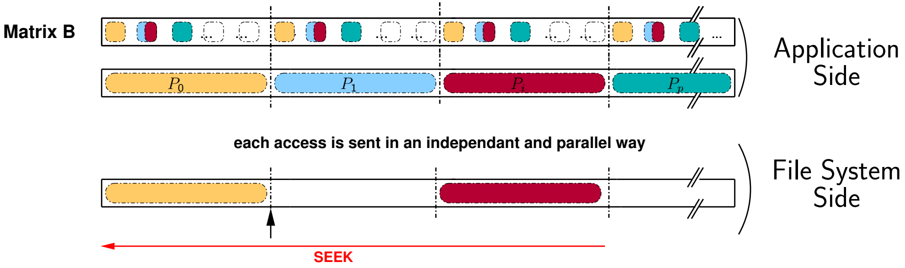

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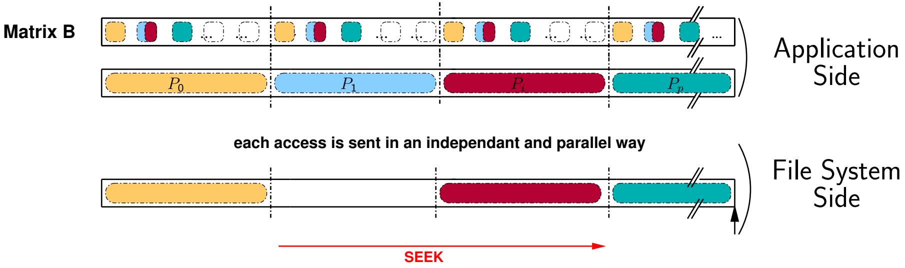

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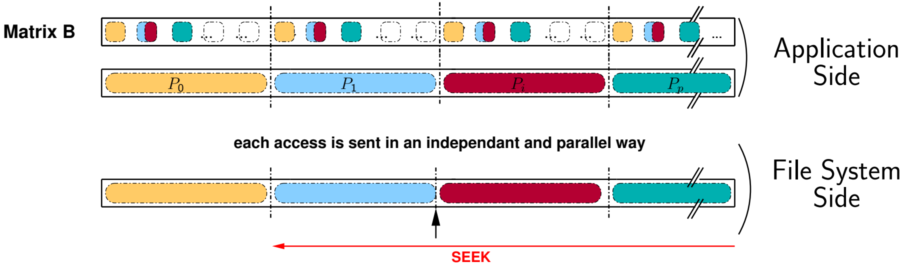

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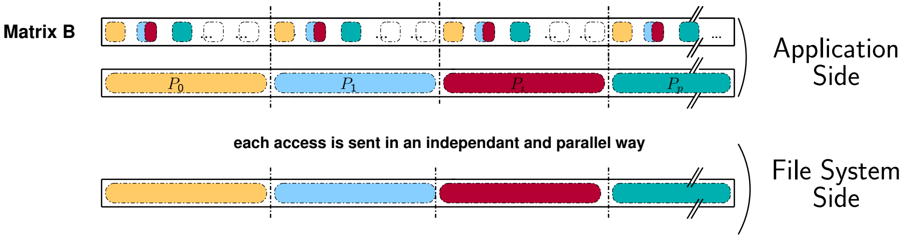

Use of complementary routines to define a particular order

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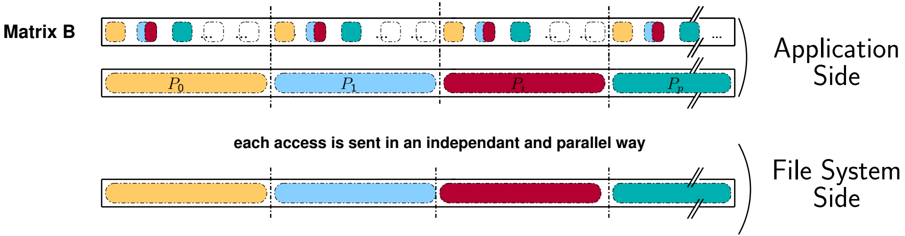
- Definition of access patterns ⇒ Reduce number of requests (equivalent to "views" / access vectors like for `readv/writev`)
- Processes coordination to efficiently balance requests (aggregation, load balancing but still no efficient order ...)
- From a global point of view, the performance are improved but :
  Sophisticated API ⇒ Development overhead/Language bindings
  No global coordination ⇒ Impact on performances



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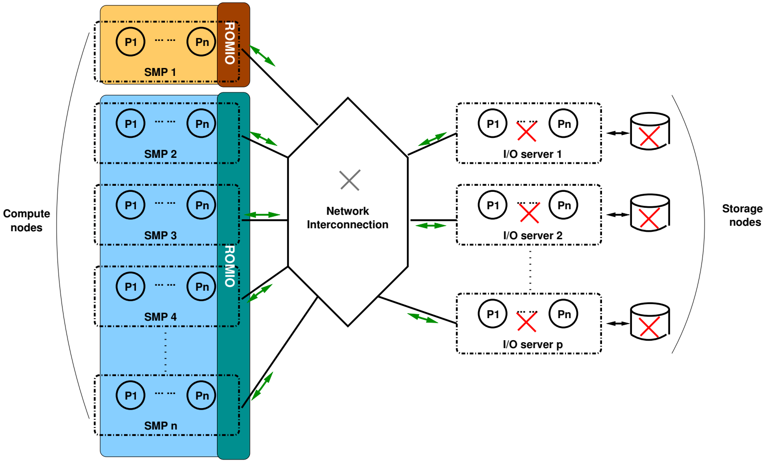
Libraries in multi-application environment



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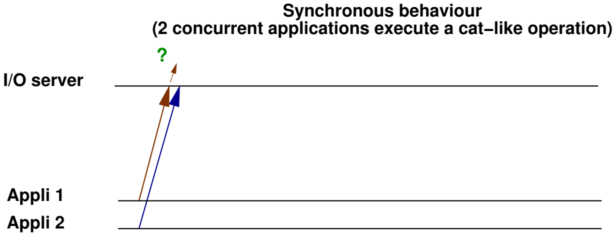

No informations about applications, only about files

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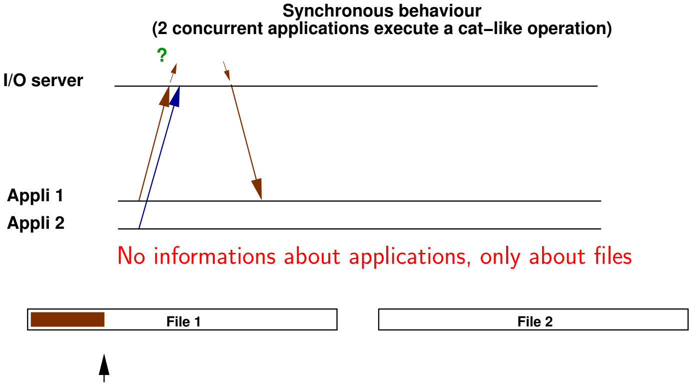

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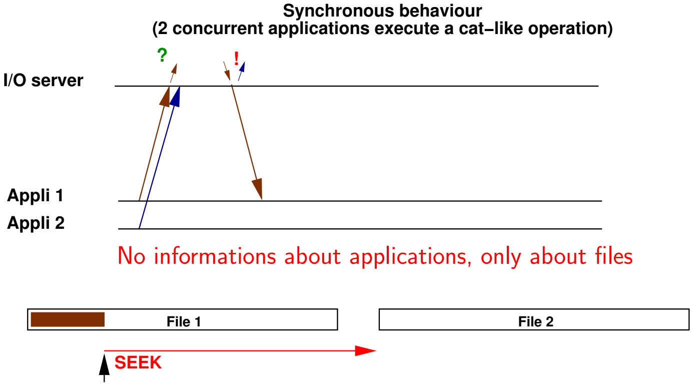

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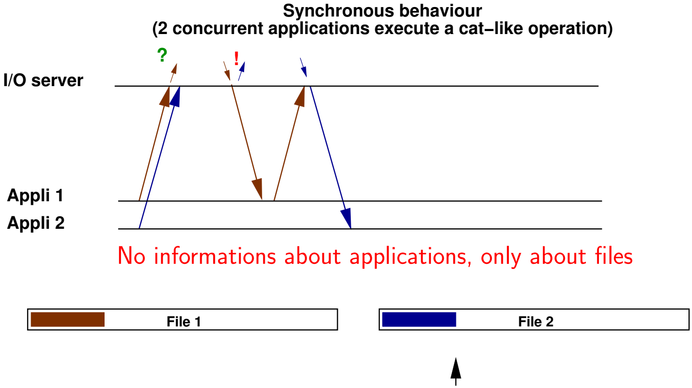

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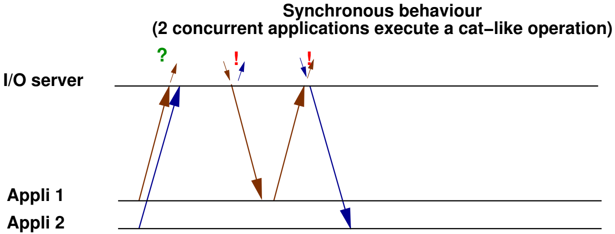

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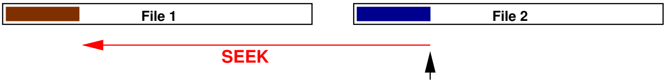

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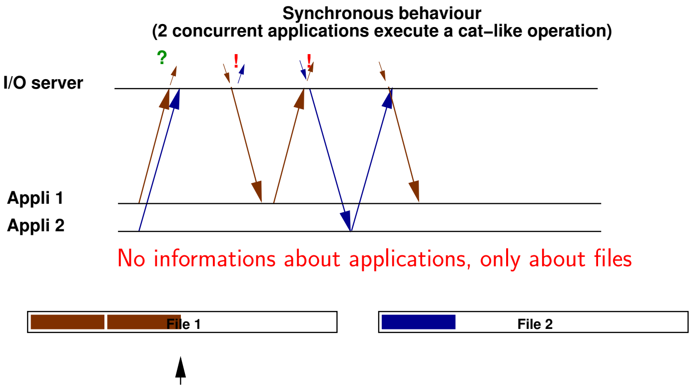

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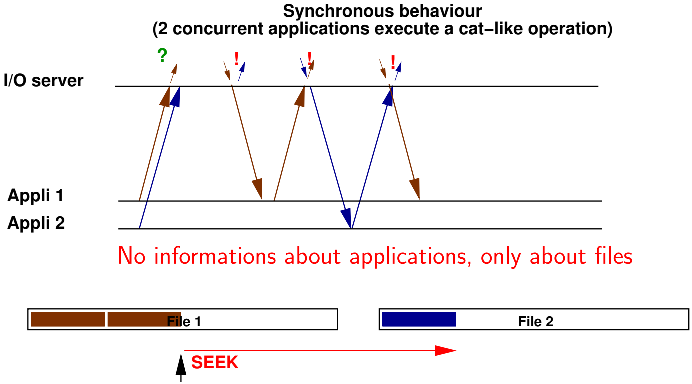

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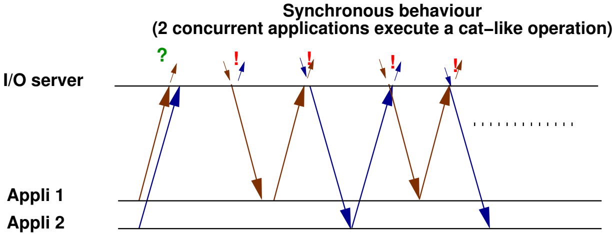

To switch from one file to the other implies a disk head movement

Libraries are not suited

global synchronization is required

A New Approach

Objectives

- Supply Parallel I/O algorithms
  scheduling / aggregating / overlapping access ⇒ mono-application efficiency
- Only through the use of the ubiquitous POSIX calls:
  `open/read/write/lseek/close` ⇒ portability / simplicity
- Address requests in a global manner ⇒ multi-application efficiency

  Naive approach:
  Processing all the requests from one application before serving another one
  Not suited for a cluster ⇒ Tradeoff between "fairness" and performance

Plan

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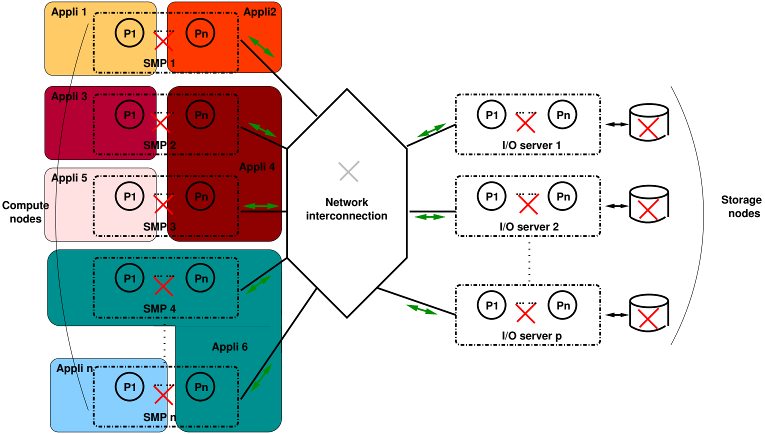
Part 2 - Controlling and Scheduling Multi-application I/O

4 Scheduling in Multi-application Environment
- General Algorithm

5 Synchronous Behaviour

Part 4 - Conclusion

Multi-application Scheduling



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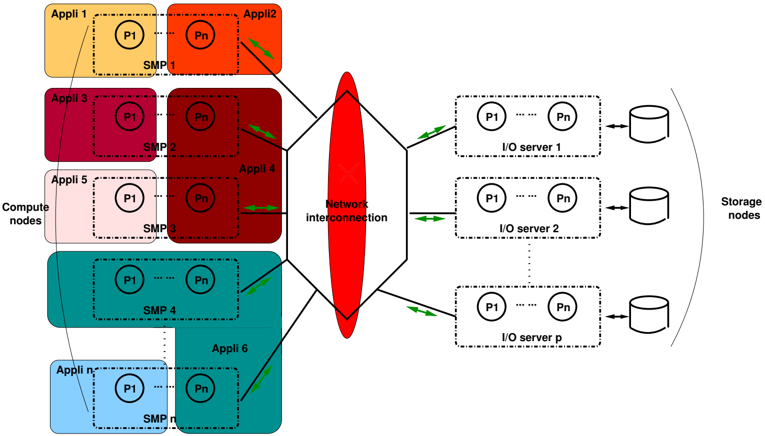

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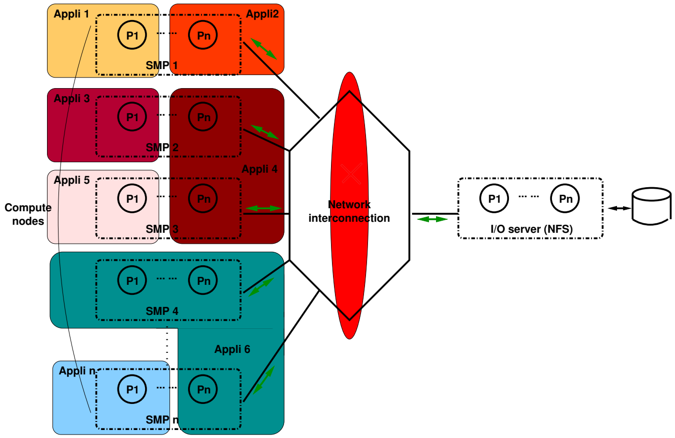
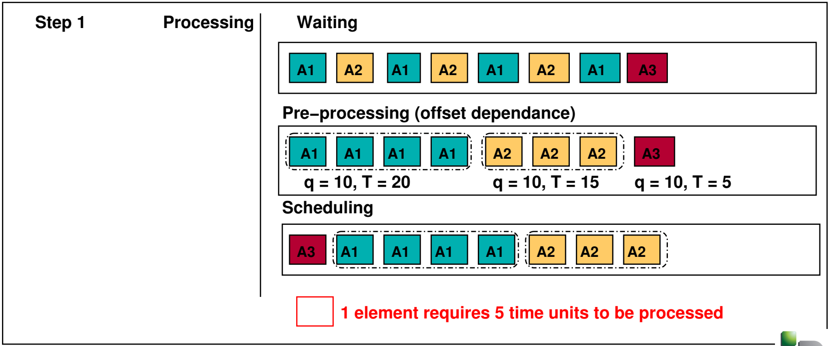


Multi-application Scheduling

- "*Online*" problem: several requests from distinct applications are delivered to the file systems.
- Wished criteria : "Efficiency" with "fairness" constraints
  $\Rightarrow$ Maximize the minimum of instantaneous throughput for each application
- Algorithm : "Multi-Level Feedback" variant (quantum approach)



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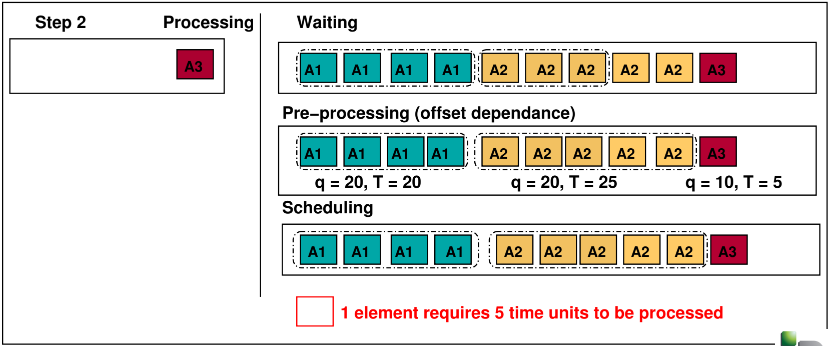

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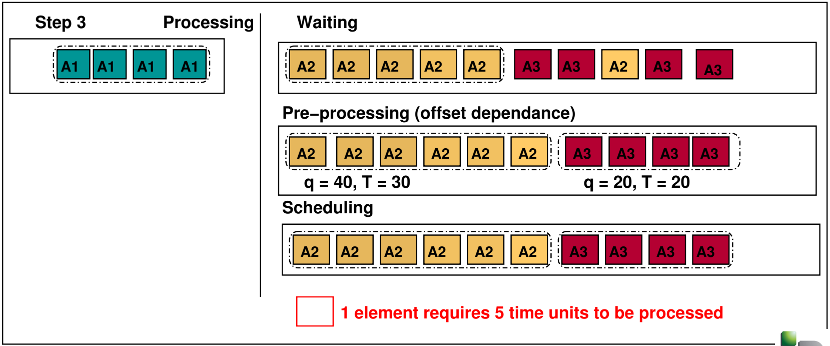

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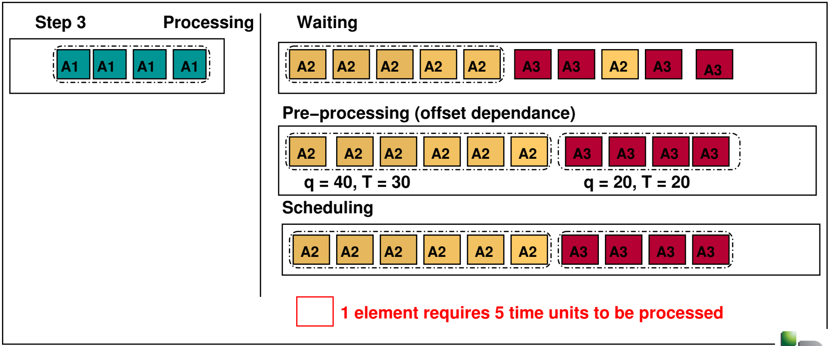
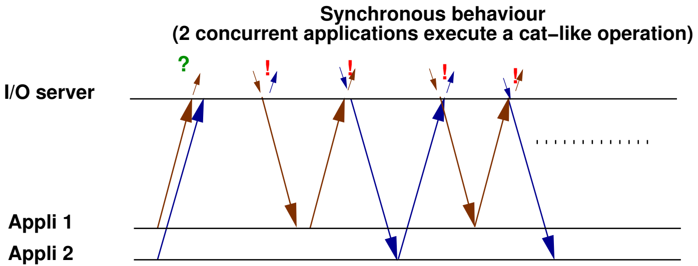
- The grow of a quantum could be set for each application (QoS)



Manage Synchronous Behaviour in an Efficient Way



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⇒ Serialize and define "dedicated" windows

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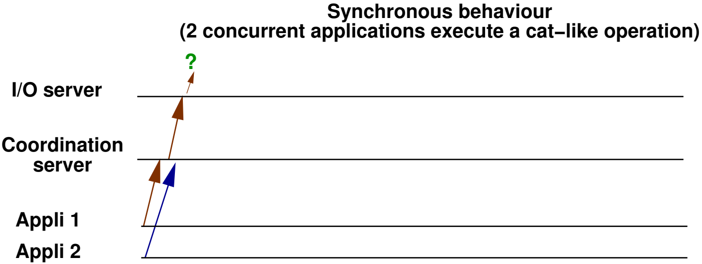

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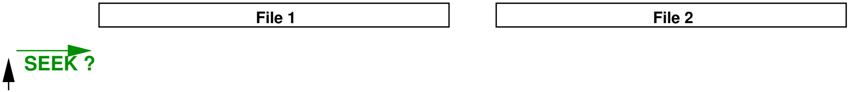

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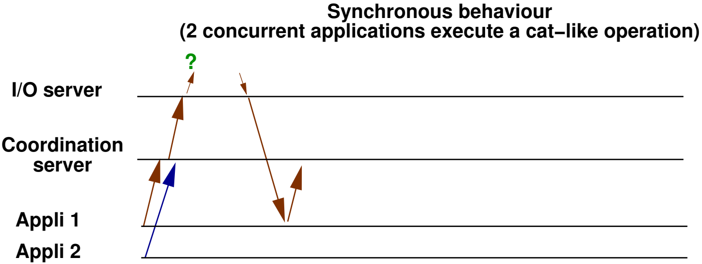

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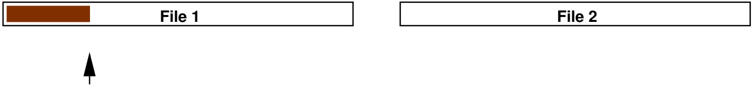

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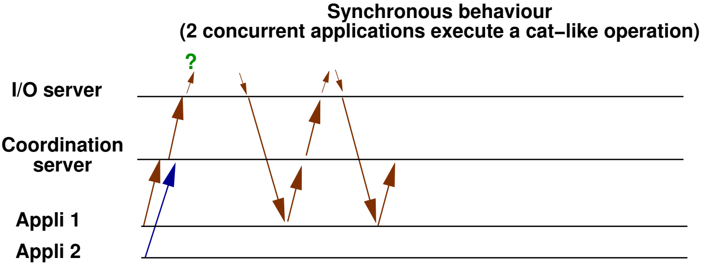

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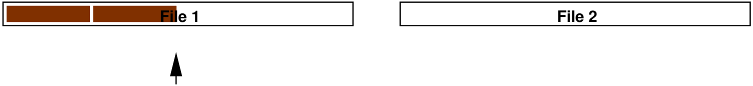
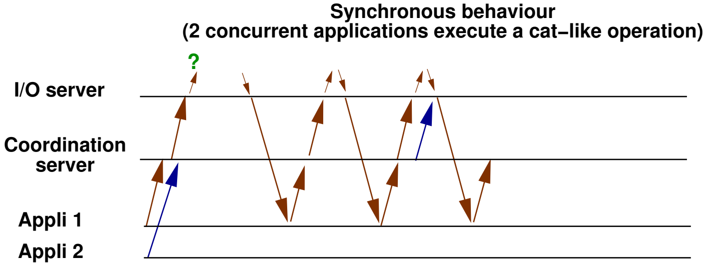


Manage Synchronous Behaviour in an Efficient Way



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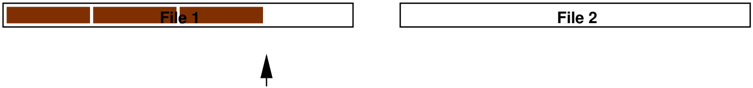

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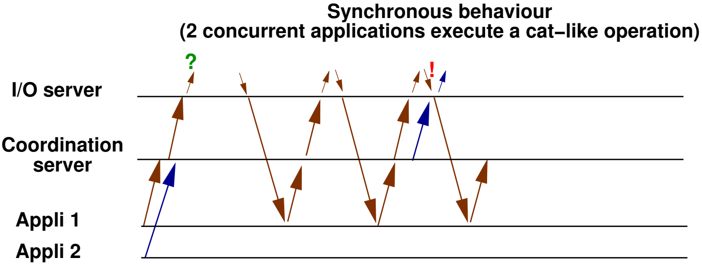

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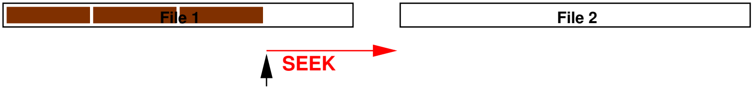

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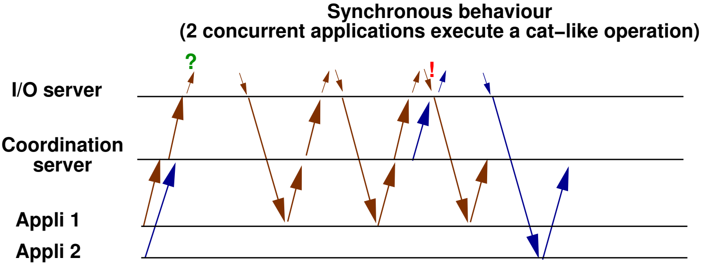
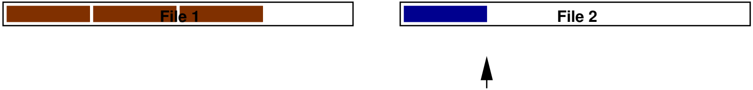


Serialize and define dedicated windows



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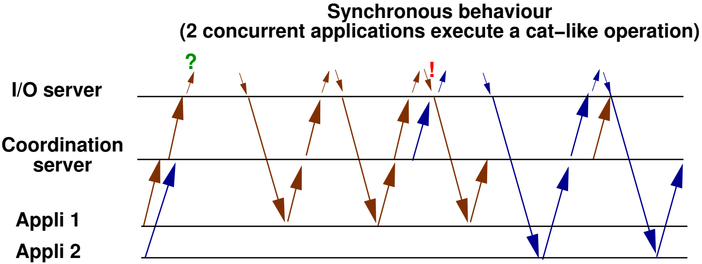


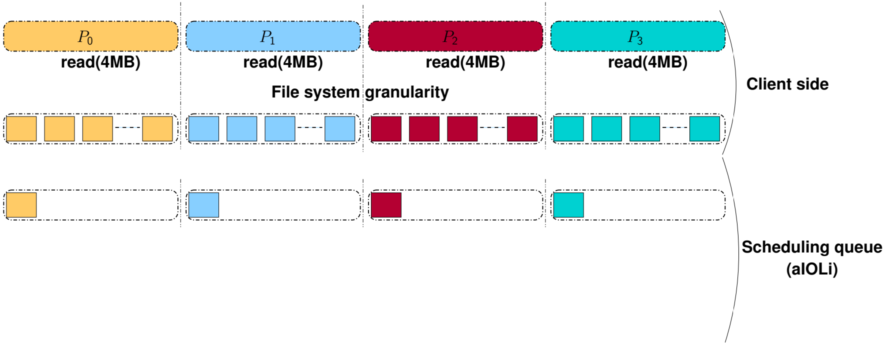
Serialize and define dedicated windows

Decrease the number of seeks and exploit read-ahead mechanism

Synchronous behaviour and Parallel I/O

Synchronous behaviour within parallel I/O

- Due to the file system granularity
  Equivalent to n synchronous accesses sent in a parallel way



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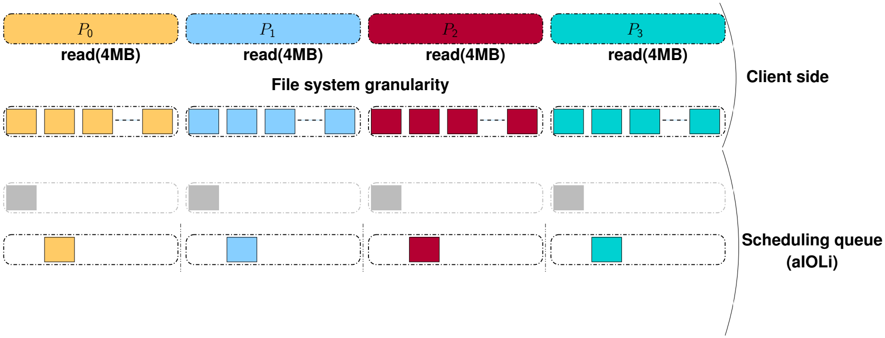

Synchronous behaviour and Parallel I/O

Synchronous behaviour within parallel I/O

- Due to the file system granularity
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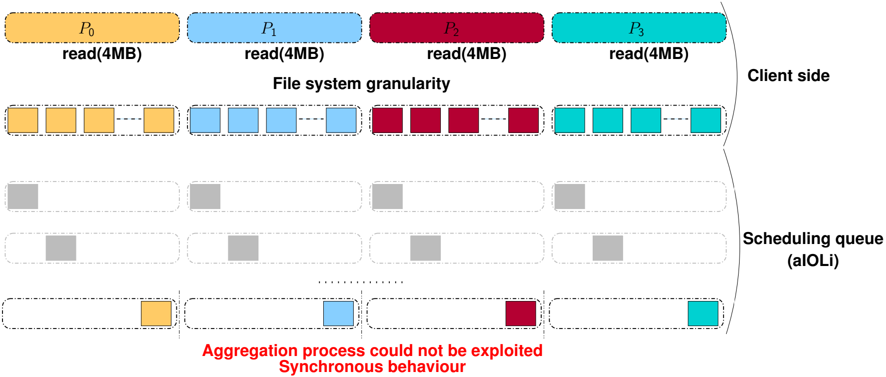
  ⇒ The quantum size is adapted according to the file access history



Synchronous behaviour and Parallel I/O

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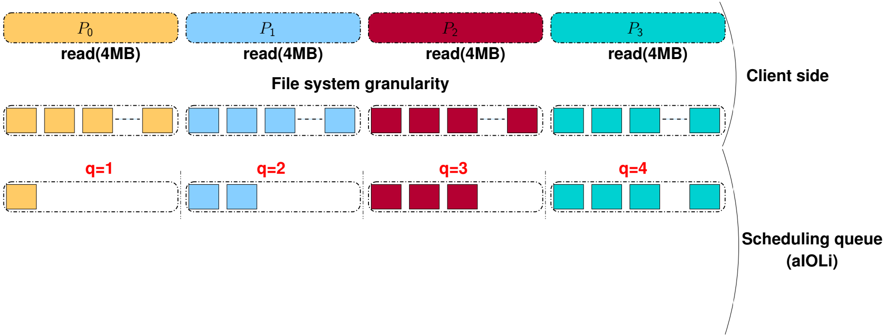

Synchronous behaviour and Parallel I/O

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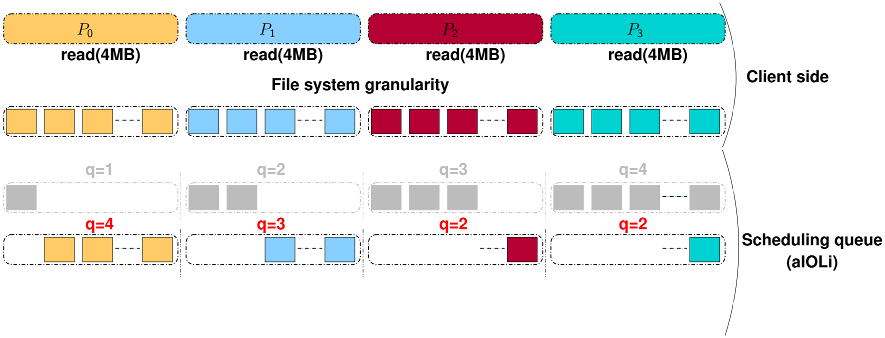

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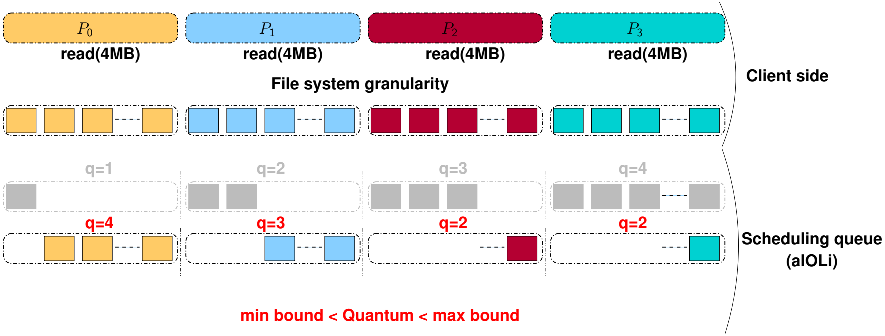


Plan

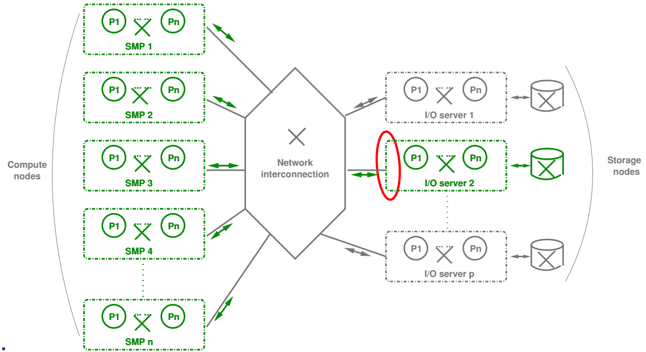
Part 1 - Parallel Input/Output and Clusters

Part 2 - Controlling and Scheduling Multi-application I/O

Part 3 - aIOLi, an Input/Output Scheduler for *HPC*

Part 4 - Conclusion

aIOLi - "Generic" Framework



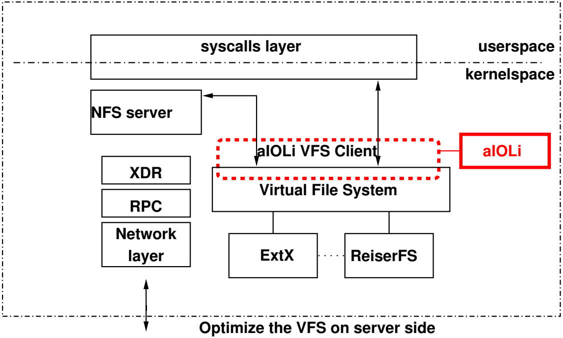
Objectives

- A central point is required to apply our global strategy : model Client/Server like PANDA (explicit centralization) is not scalable
  $\Rightarrow$Exploit available "central" point
- Major change : I/O systems become clients of our framework!

aIOLi - Framework

Implementation

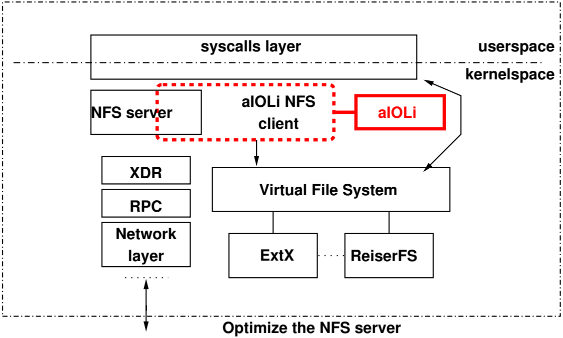
- *"Virtual File System" (server side)*



aIOLi - Framework

Implementation

- *"Virtual File System" (server side)*
- NFS server (Version 3)



Optimize the NFS server

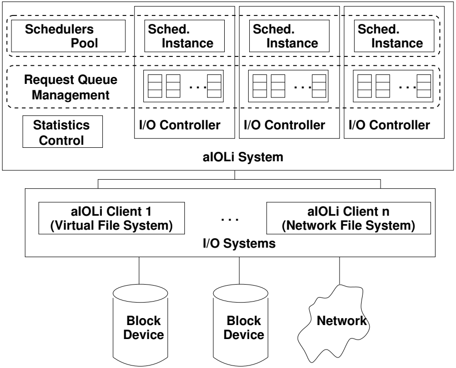
aIOLi - Framework

Implementation

- *"Virtual File System" (server side)*
- NFS server (Version 3)

Technical aspects

- Linux kernel module - 3 functions to plug an I/O system



aIOLi - Evaluations

Platform

- Grid5000 : Sophia-Antipolis cluster (AMD 64, IDE HDD, Giga Ethernet)
- 1 to 96 nodes
- 1 dedicated NFS server
- IOR benchmark (LLNL)

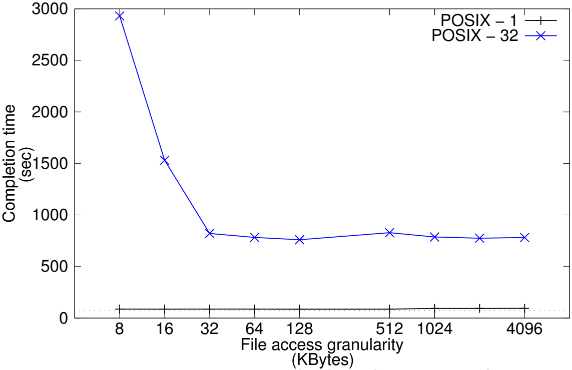
Experiments

- 1 parallel application :
  Valid parallel I/O detection and transparent optimisations
- 2 applications :
  Analyse mutual impact and interest of a global strategy
- 10 applications :
  Evaluate a "real" case

Evaluations : One Parallel Application

4 GB File decomposition including 32 MPI instances

kernel 2.6.12, sophia cluster, NFS version 3, mpich 1.2.5, ROMIO



32 processes deployed on 32 nodes

Observations

- Time !

Evaluations : One Parallel Application

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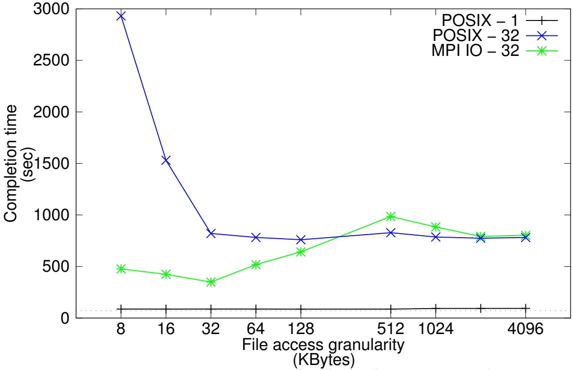

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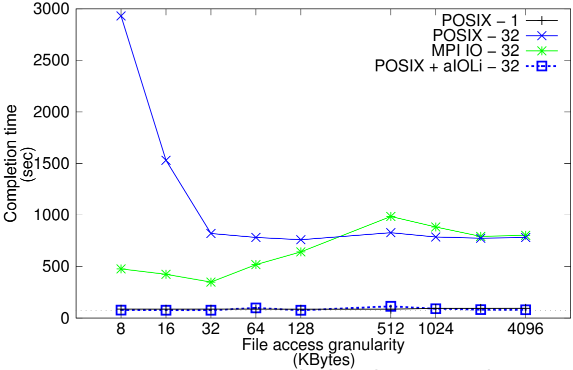

32 processes deployed on 32 nodes

Observations

- Time !
- aIOLi provides significant improvements

$$11 < \frac{TPosix}{TaIOLi} < 50$$

$$3.5 < \frac{TMPIIO}{TaIOLi} < 6.5$$

Evaluations : One Parallel Application

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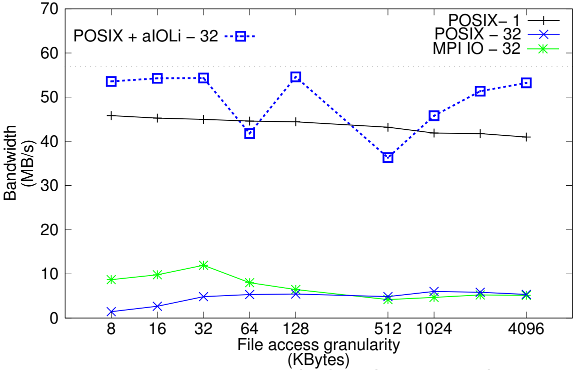

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Evaluations : One Parallel Application

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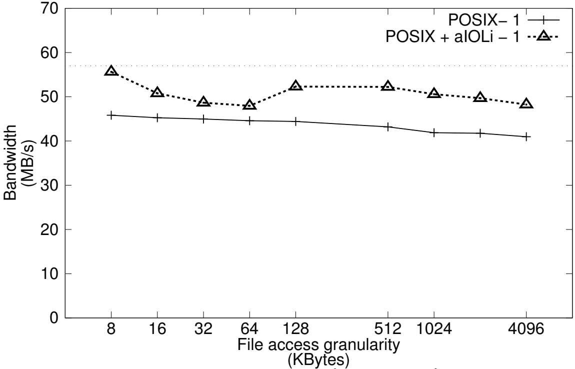

1 process ('prefetch')

Observations

- Time !
- aIOLi provides significant improvements

  $11 < \frac{TPosix}{TaIOLi} < 50$

  $3.5 < \frac{TMPIIO}{TaIOLi} < 6.5$
- Synchronous behaviours benefit from aIOLi

Evaluations : One Parallel Application

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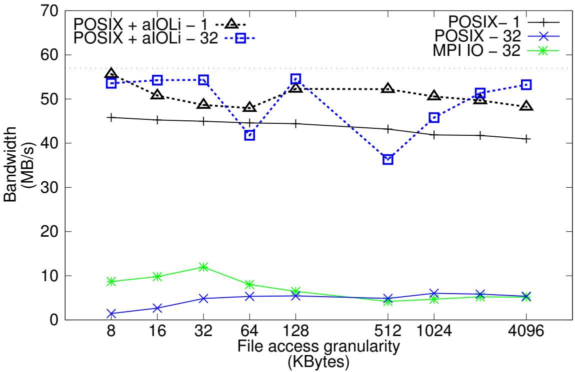

Observations

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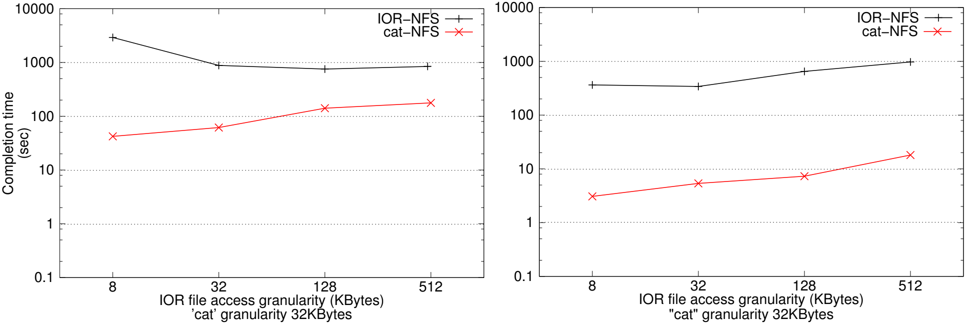
- Synchronous behaviours benefit from aIOLi

Mono-application OK ! next step: global coordination

Evaluations : Multi-application Mode - Case 1

Impact of a 4 GB decomposition (32 processes - 32 nodes) over a cat of 16 MB
kernel 2.6.15, sophia cluster, NFS version 3, mpich 1.2.5, ROMIO



read - POSIX   read - MPI I/O

Observations

- Impact : 16MB in 100 sec (Y axis : "log" scale)
  The use of MPI I/O reduces the load on the server

Evaluations : Multi-application Mode - Case 1

Impact of a 4 GB decomposition (32 processes - 32 nodes) over a cat of 16 MB

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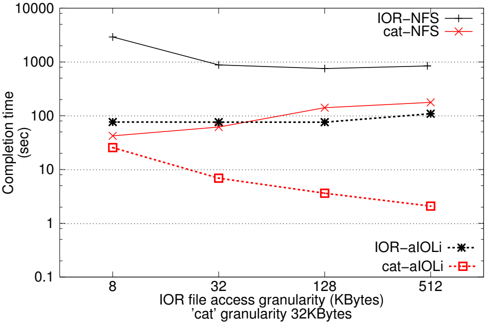
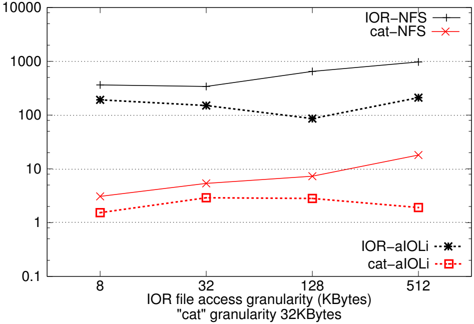


read - POSIX



read - MPI I/O

Observations

- Impact : 16MB in 100 sec (Y axis : "log" scale)
  The use of MPI I/O reduces the load on the server
- aIOLi improves the performances for both applications

Evaluations : Multi-application Mode - Case 2

10 concurrent applications, 96 nodes, 6 GB

kernel 2.6.12, sophia cluster, NFS version 3, mpich 1.2.5, ROMIO

Application details	Completion time	
	POSIX	MPI IO
4 decompos. 6 sequential. 6 GB	595	840

Time are given in seconds.

Evaluations : Multi-application Mode - Case 2

10 concurrent applications, 96 nodes, 6 GB

kernel 2.6.12, sophia cluster, NFS version 3, mpich 1.2.5, ROMIO

Application details	Completion time NFS POSIX	Completion time NFS MPI IO
read decompos. - 2GB (32 nodes, granularity=128KB)	490	840
write decompos. - 2GB (32 nodes, granularity=128KB)	409	815
read decompos. - 256MB (16 nodes, granularity=8KB)	595	728
write decompos. - 128MB (8 nodes, granularity=64KB)	51	257
read sequential. - 1GB (1 node, granularity=2MB)	558	59
write sequential. - 512MB (1 node, granularity=2MB)	192	71
read sequential. - 32MB (1 node, granularity=4KB)	531	9
write sequential. - 32MB (1 node, granularity=4KB)	208	9
read sequential. - 4MB (1 node, granularity=32KB)	57	1.5
write sequential. - 4MB (1 node, granularity=32KB)	39	2

Time are given in seconds.

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Evaluations : Multi-application Mode - Case 2

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4 decompos. 6 sequential. 6 GB	595	840	143	604

Time are given in seconds.

Evaluations : Multi-application Mode - Case 2

10 concurrent applications, 96 nodes, 6 GB

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write decompos. - 2GB (32 nodes, granularity=128KB)	409	815	107	604
read decompos. - 256MB (16 nodes, granularity=8KB)	595	728	104	415
write decompos. - 128MB (8 nodes, granularity=64KB)	51	257	14.5	247
read sequential - 1GB (1 node, granularity=2MB)	558	59	143	54
write sequential. - 512MB (1 node, granularity=2MB)	192	71	84	61.5
read sequential. - 32MB (1 node, granularity=4KB)	531	9	48.5	3
write sequential. - 32MB (1 node, granularity=4KB)	208	9	47	6
read sequential. - 4MB (1 node, granularity=32KB)	57	1.5	6	1
write sequential. - 4MB (1 node, granularity=32KB)	39	2	19	2

Time are given in seconds.

Evaluations : Multi-application Mode - Case 2

10 concurrent applications, 96 nodes, 6 GB

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`read` sequential. - 4MB (1 node, granularity=32KB)	57	1.5	6	1
`write` sequential. - 4MB (1 node, granularity=32KB)	39	2	19	2

Time are given in seconds.

Plan

Conclusion

Performances and I/O in multi-application environment

- Control and schedule I/O requests in a global way :
  multi-criteria problem : efficiency and fairness ⇒ MLF variant proposal

aIOLi, an I/O scheduler for *HPC*

- Generic framework to evaluate new strategies for I/O scheduling
- Implementation in kernel space : intrusive from system point of view but efficient
- Code available under GPL
- Joint project since the end of 2005 with ICIS University (Poland)

Current and Future Works

aIOLi, works in progress

- Take into account data stripping (on RAID devices and Parallel File Systems)
- Collaboration around a parallel version of NFS to evaluate the interest of an higher I/O scheduler (Brasil/France/Poland)
- Interconnexion with *Lustre* File system

Future

- Control I/O requests at different points : multi-level scheduler
  on client side (compute node) / on server and hard drive side $\Rightarrow$ *cascade scheduling*
- Exploiting the meta-node concept used by modern FS to provide consistency as a central point to plug aIOLi

Questions ?

http://aioli.imag.fr

LIPS Project

BULL - INRIA - ID-IMAG Laboratory - ICIS Institute

Thanks