Periodic I/O Scheduling for Supercomputers

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Slides available at `https://project.inria.fr/dash/`

IO congestion in HPC systems

Some numbers for motivation:

- Computational power keeps increasing (Intrepid: 0.56 PFlop/s, Mira: 10 PFlop/s, Aurora: 450 PFlop/s (?)).
- IO Bandwidth increases at slowlier rate (Intrepid: 88 GB/s, Mira: 240 GB/s, Aurora: 1 TB/s (?)).

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In other terms:

Intrepid can process 160 GB for every PFlop
Mira can process 24 GB for every PFlop
Aurora will (?) process 2.2 GB for every PFlop

Congestion is coming.

Burst buffers: the solution?

Simplistically:

- If IO bandwidth available: use it
- Else, fill the burst buffers
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Given a set of data-intensive applications running conjointly:

- on Intrepid have a max average I/O occupation of **25%**
- on Mira have an average I/O occupation of **120 to 300%**!

Previously in IO cong.

"Online" scheduling (Gainaru et al. IPDPS'15):

- When an application is ready to do I/O, it sends a message to an I/O scheduler;
- Based on the other applications running and a priority function, the I/O scheduler will give a **GO** or **NOGO** to the application.
- If the application receives a **NOGO**, it pauses until a **GO** instruction.
- Else, it performs I/O.

Previously in IO cong.

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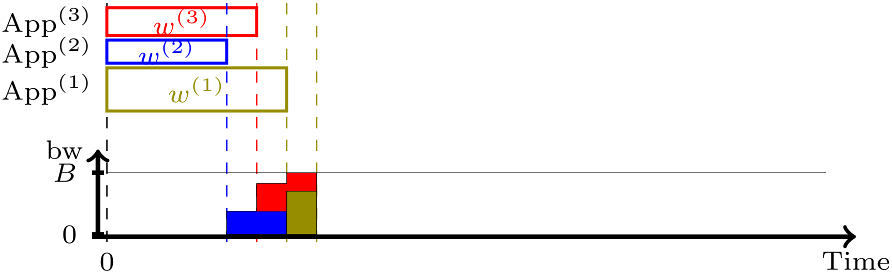

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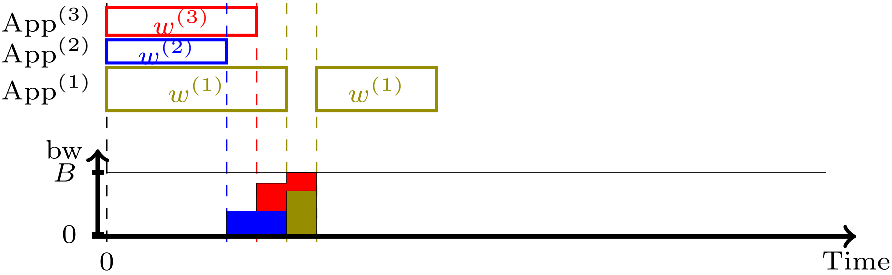

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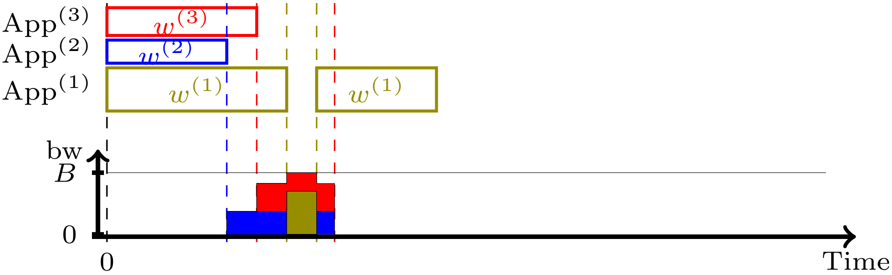

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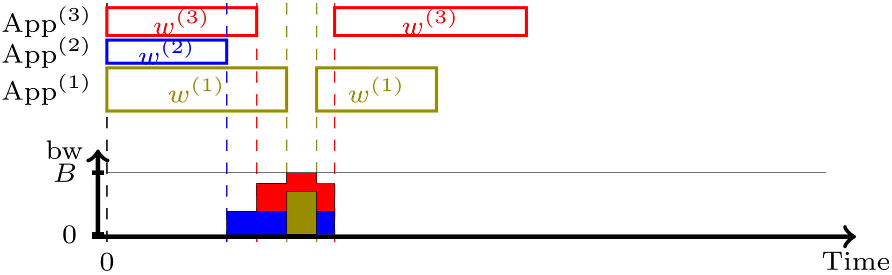

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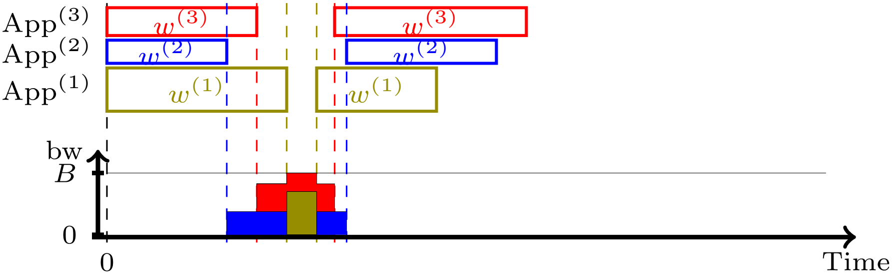

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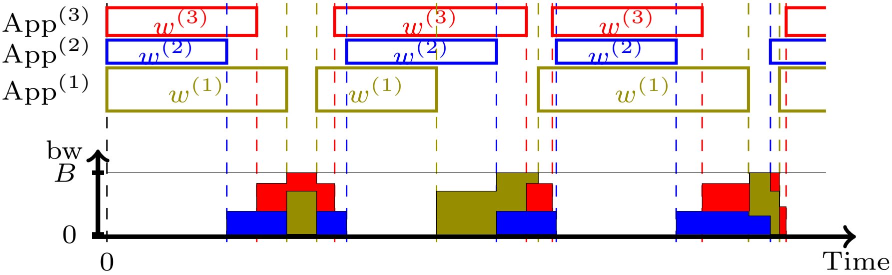


Approx 10% improvement in application performance with 5% gain in system performance on Intrepid.

This work

Assumption: Applications follow I/O patterns[1] that we can obtain (based on historical data for intance).

- We use this information to compute an I/O *time* schedule;
- Each application then knows its **GO/NOGO** information and uses it to perform I/O.

Spoiler: it works very well (at least it seems)

[1] *periodic pattern*, to be defined

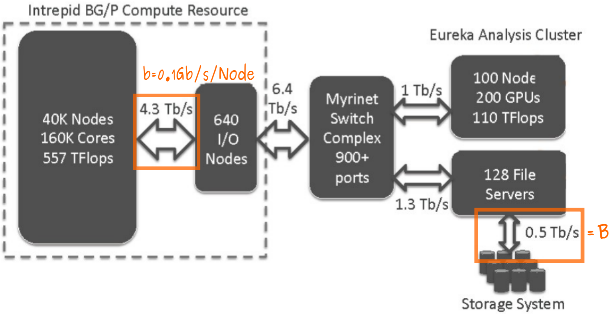
I/O characterization of HPC applis

Hu et al. 2016

1. Periodicity: computation and I/O phases (write operations such as checkpoints).
2. Synchronization: parallel identical jobs lead to synchronized I/O operations.
3. Repeatability: jobs run several times with different inputs.
4. Burstiness: short burst of write operations.

Idea: use the periodic behavior to compute periodic schedules.

- N unit-speed processors, equipped with an I/O card of bandwidth b
- Centralized I/O system with total bandwidth B

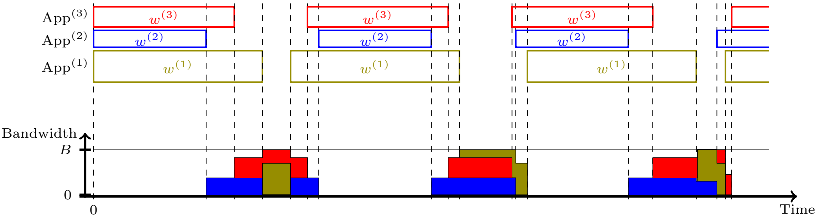


Model instantiation for the Intrepid platform.

K periodic applications **already scheduled in the system**: $\text{App}^{(k)}(\beta^{(k)}, w^{(k)}, \text{vol}_{\text{io}}^{(k)})$.

- $\beta^{(k)}$ is the number of processors onto which $\text{App}^{(k)}$ is assigned
- $w^{(k)}$ is the computation time of a period
- $\text{vol}_{\text{io}}^{(k)}$ is the volume of I/O to transfor after the $w^{(k)}$ units of time

$$\text{time}_{\text{io}}^{(k)} = \frac{\text{vol}_{\text{io}}^{(k)}}{\min(\beta^{(k)} \cdot b, B)}$$



If App$^{(k)}$ runs during a total time T_k and performs $n^{(k)}$ instances, we define:

$$\rho^{(k)} = \frac{w^{(k)}}{w^{(k)} + \text{time}_{\text{io}}^{(k)}}, \qquad \tilde{\rho}^{(k)} = \frac{n^{(k)} w^{(k)}}{T_k}$$

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maximize peak performance
(average number of Flops):

maximize $\frac{1}{N} \sum_{k=1}^{K} \beta^{(k)} \tilde{\rho}^{(k)}$.

Objectives

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Dilation

minimize largest slowdown
(fairness between users):

minimize $\max_{k=1..K} \frac{\rho^{(k)}}{\tilde{\rho}^{(k)}}$.

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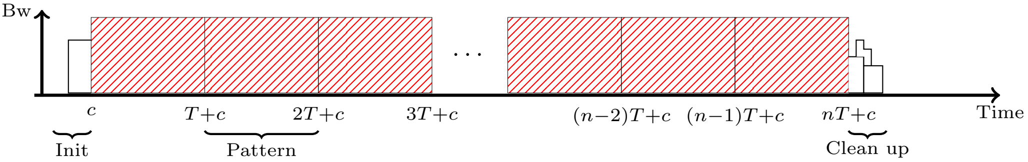
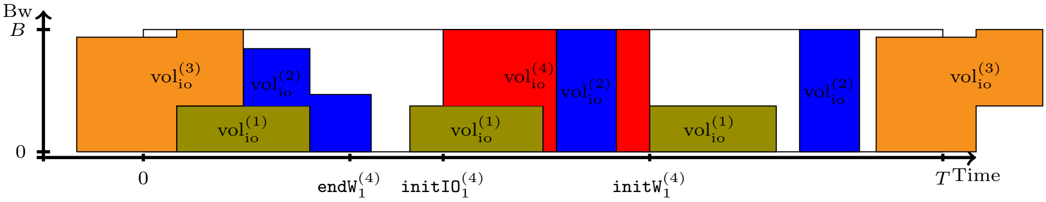
We introduce Periodic Scheduling.

Periodic schedules

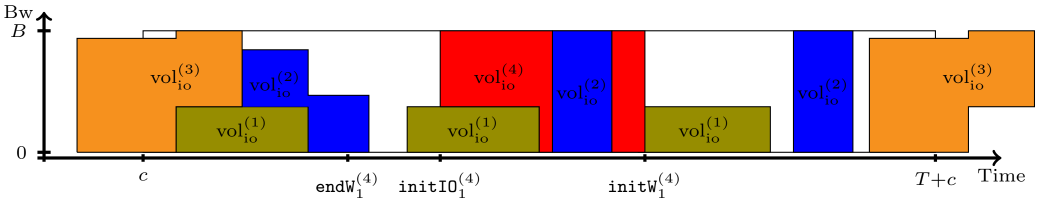


(a) Periodic schedule (phases)



(b) Detail of I/O in a period/pattern

Time Schedule vs what Application 4 sees



- Distributed information
- Low complexity
- Minimum overhead

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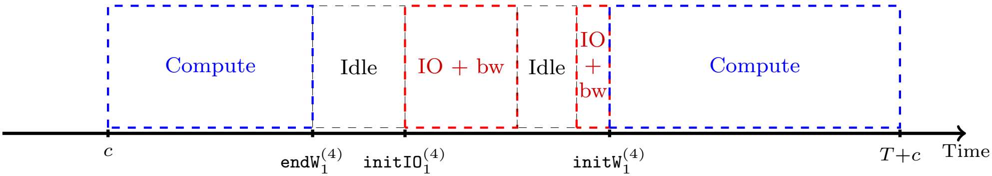

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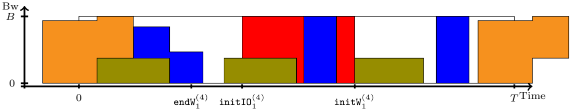
Finding a schedule

Obj: algorithm with good SysEfficiency and Dilation perf.

Questions:

1. Pattern length T?
2. How many instances of each application?
3. How to schedule them efficiently?



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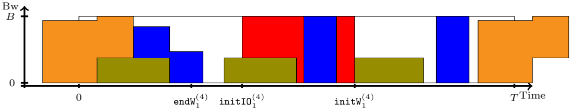

Answers:

1. Iterative search, exponential growth ($T_{\min}$ to $T_{\max}$).
2. Bound on the number of instances of each application $O\left(\frac{\max_k(w^{(k)}+\text{time}_{\text{io}}^{(k)})}{\min_k(w^{(k)}+\text{time}_{\text{io}}^{(k)})}\right)$.
3. Greedy insertion of instances, priority to applis with small Dilation.

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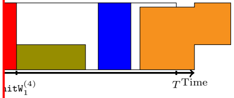

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Announcement:

It's hard to find appli data $(w^{(k)}, \mathrm{vol}_{\mathrm{io}}^{(k)}, \beta^{(k)})$.
If you have some, let's talk ☺.

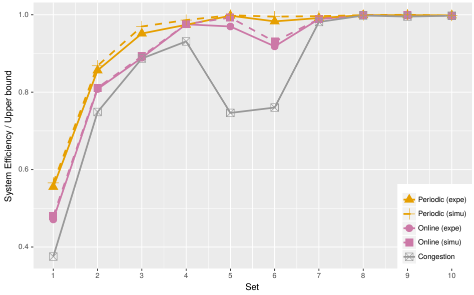
Model validation (I)

- Four periodic behaviors from the literature to instantiate the applications.
- Comparison between simulations and a real machine (Jupiter @Mellanox: 640 cores, $b = 0.01GB/s$, $B = 3GB/s$).
- We use IOR benchmark to instantiate the applications on the cluster (ideal world, no other communication than I/O transfers).

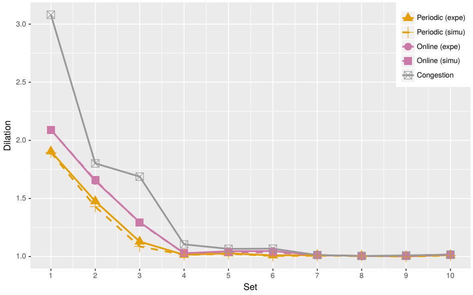
$\text{App}^{(k)}$		$w^{(k)}$ (s)	$\text{vol}_{\text{io}}^{(k)}$ (GB)	$\beta^{(k)}$
Turbulence1	(T1)	70	128.2	32,768
Turbulence2	(T2)	1.2	235.8	4,096
AstroPhysics	(AP)	240	423.4	8,192
PlasmaPhysics	(PP)	7554	34304	32,768

Set #	T1	T2	AP	PP
1	0	**10**	0	0
2	0	**8**	**1**	0
3	0	**6**	**2**	0
4	0	**4**	**3**	0
5	0	**2**	0	**1**
6	0	**2**	**4**	0
7	**1**	**2**	0	0
8	0	0	**1**	**1**
9	0	0	**5**	0
10	**1**	0	**1**	0

Model validation (II)



(c) SysEfficiency/Upper bound



(d) Dilation

The performance estimated by our model is accurate within 3.8% for periodic schedules and 2.3% for online schedules.

Results

- Periodic: our periodic algorithm;
- Online: the best performance (Dilation or SysEff resp.) of any online algorithm in Gainaru et al. Ipdps'15;
- Congestion: Current performance on the machine.

Set	Dilation	SysEff
1	-9.33%	+17.94%
2	-13.81%	+7.01%
3	-15.81%	+8.60%
4	-1.46%	+1.09%
5	-0.49%	+0.62%
6	-2.90%	+6.96%
7	-0.49%	+0.73%
8	-0.00%	+0.00%
9	-0.40%	+0.10%
10	-0.59%	+0.10%

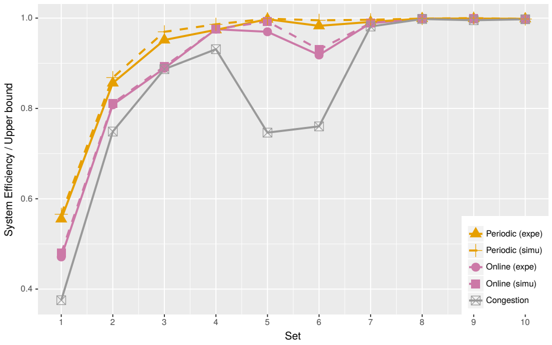


Figure: SysEfficiency/Upper bound

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6	-2.90%	+6.96%
7	-0.49%	+0.73%
8	-0.00%	+0.00%
9	-0.40%	+0.10%
10	-0.59%	+0.10%

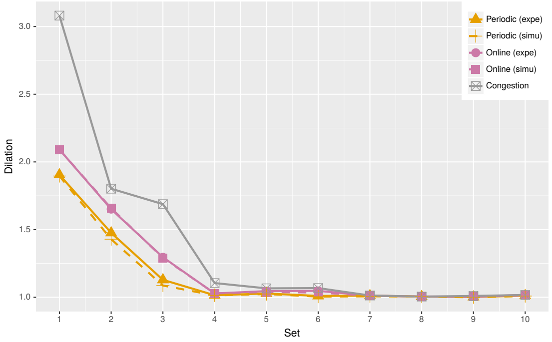
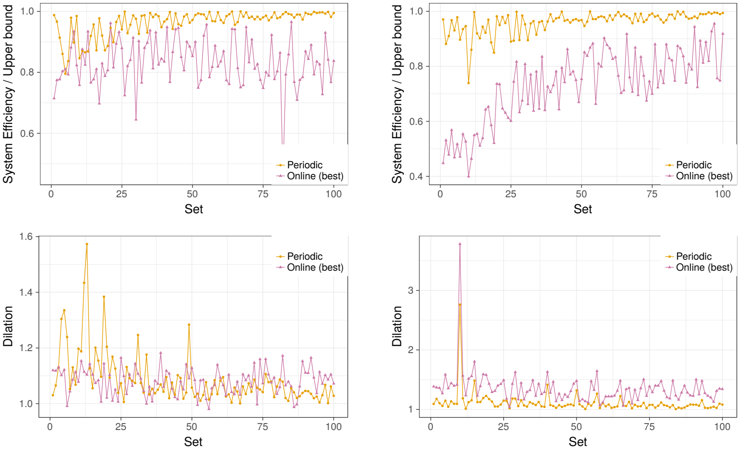


Figure: DILATION

More data

- We generate more sets of applications
- Simulate on instanciations of Intrepid and Mira.



Intrepid Mira

List of open issues / Future steps

- Study of robustness: what if $w^{(k)}$ and $\text{vol}_{\text{io}}^{(k)}$ are not exactly known?
- Integrating non-periodic application
- Burst-buffers integration/modeling
- Coupling application scheduler to IO scheduler
- Evaluation on real applications

Conclusion

- Offline periodic scheduling algorithm for periodic applications. Algorithm scales well (complexity depends on the unmber of applications, not on the size of the machine).
- Very good expected performance.
- Very precise model on very friendly benchmarks.
- Right now, more a proof of concept.

Paper, data, code: `https://github.com/vlefevre/IO-scheduling-simu`