Toward new I/O Approaches for Scalable Post-petascale HPC Simulations

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Let’s start with pictures

April 14 to 16, 2011 – Tornado outbreak in USA – 43 deaths

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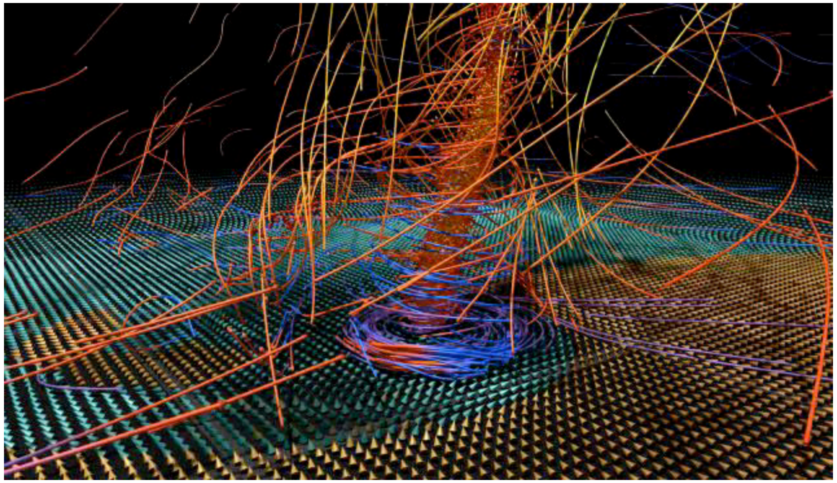
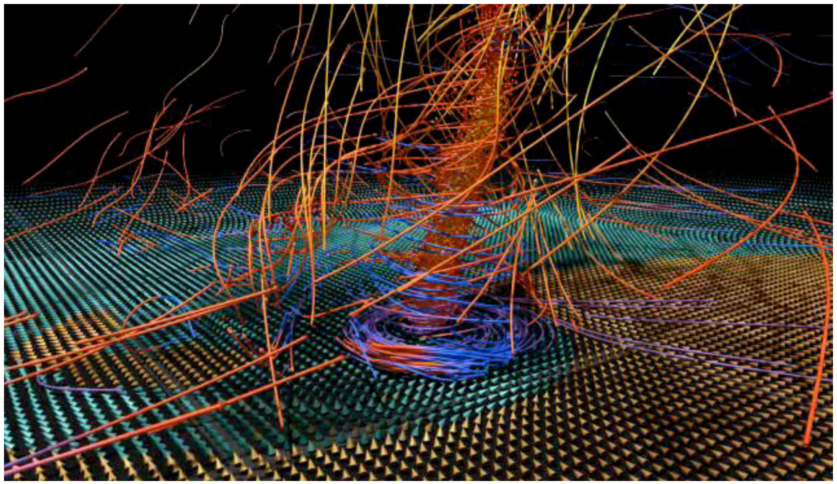
Could we have predicted this?

Understanding climate



- ✧ Large-scale simulations help understanding climate
- ✧ Require high performance

HPC simulations on BlueWaters



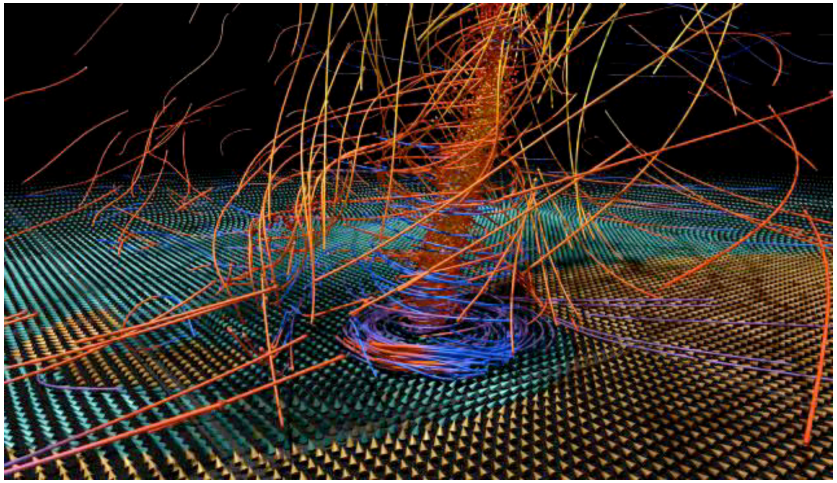
Context: *Joint Laboratory for Petascale Computing*, targeting **Blue Waters**

✧ More than 300.000 cores

✧ 11 petaflops (10^{15} op/sec) peak performance

(http://www.ncsa.illinois.edu/BlueWaters/)

HPC simulations on BlueWaters



Context: *Joint Laboratory for Petascale Computing*, targeting **Blue Waters**

✧ More than 300.000 cores

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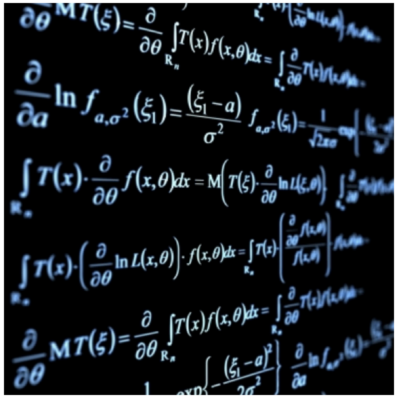
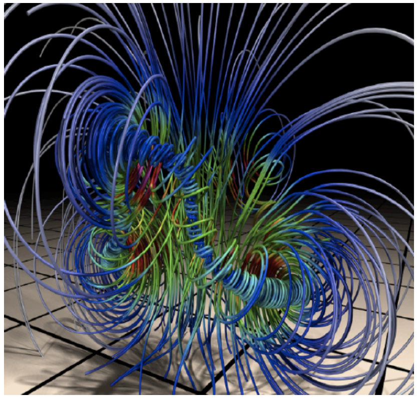
✧ **Simulations generating extremely large amounts of data** (terabytes every minute)

How to handle such large amounts of data?





- ✧ How to efficiently **store** and **move** data?
- ✧ How to **index**, **process**, **compress** these data?
- ✧ How to **analyze**, **visualize** and **understand** them?

Outline

1. I/O and data management in HPC
2. Understanding I/O jitter
3. Damaris: our new approach to I/O
4. Experimental evaluations
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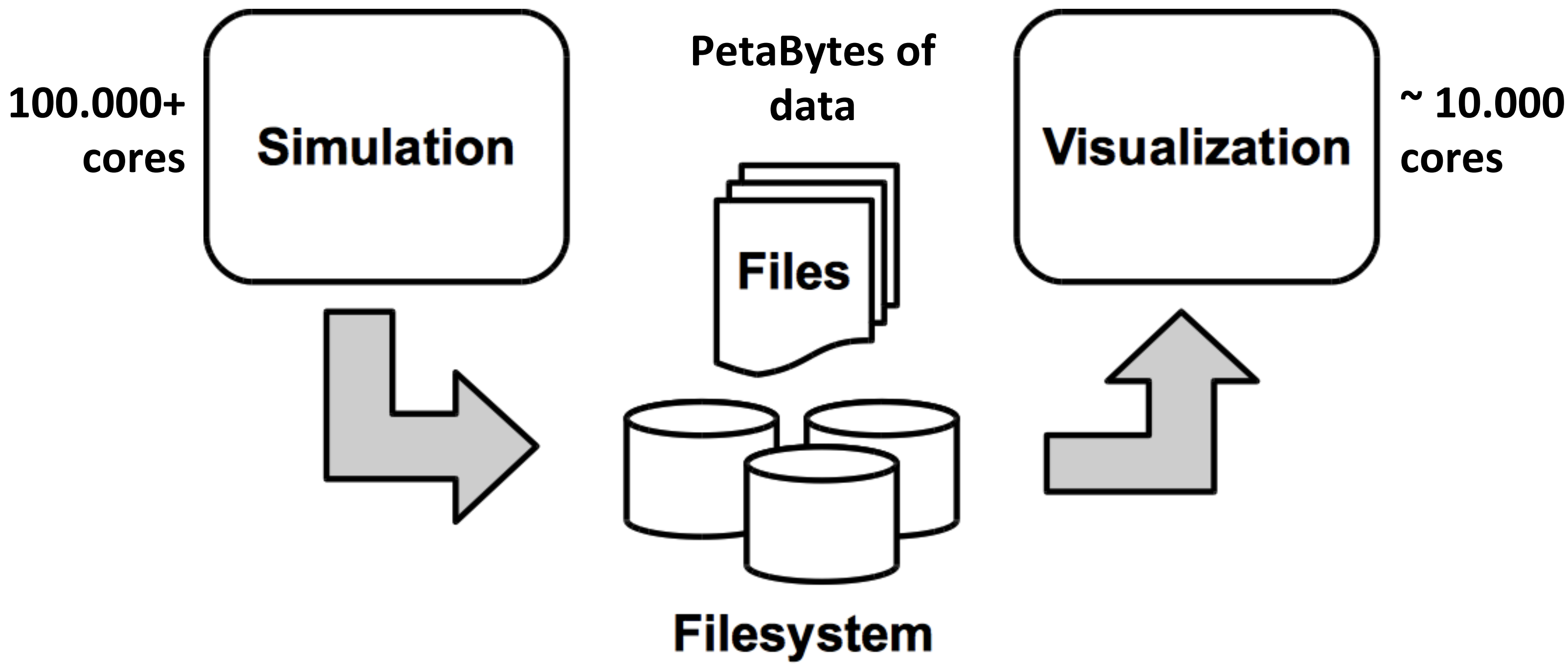
Standard I/O flow



- ✧**Periodic** data generation from the simulation
- ✧Storage in a **parallel file system**
- ✧**Offline** analysis and visualization [Childs,2010]

The key component: Parallel File Systems

[Carns et al.,2000]

[Schmuck et al.,2002]

[Donovan et al.,2003]

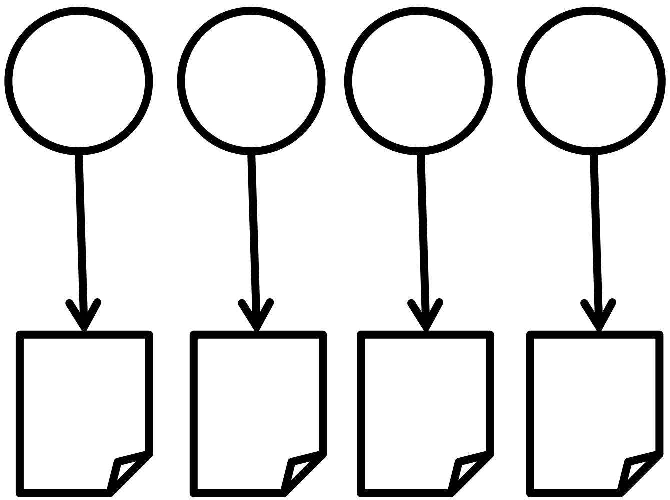
✧ Deployed on a set of **dedicated servers**

✧ **Shared** by all users (e.g. 100 GPFS servers on Blue Waters)

✧ Breaks files in **chunks** distributed across servers

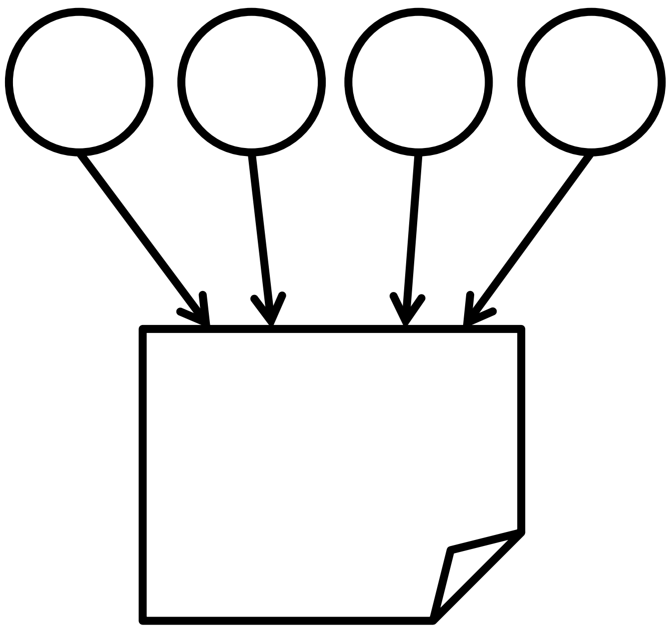
Handling I/O in simulations: Two main approaches

Independent I/O (file-per-process)



✧ Huge metadata overhead
✧ Hard to read back
✧ Easy (natural) to implement

Collective I/O



✧ Requires synchronization
✧ Hard to implement
✧ Optimizes communications

Problem #1: Unbalanced load, Periodic bursts of I/O

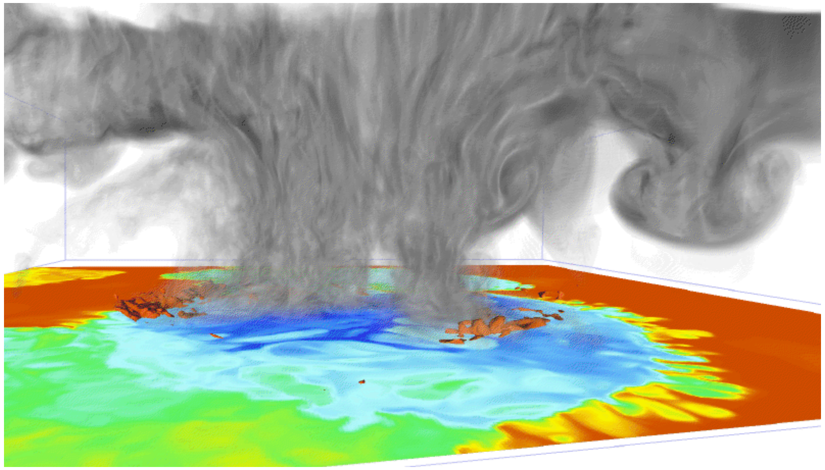
"Cardiogram" of a data server
(network activity when running a simulation)

Problem #2: I/O bottleneck

- **Too many files**: pressure on the metadata servers
  (e.g. Blue Waters 300.000 files/min)
- **Too much data**: pressure on the data servers
  (e.g. several Terabytes per minute)

Problem #3: data analysis

- ✧ All data are not useful
- ✧ How to process data, adapt data layout?
- ✧ When, where and how to perform visualization?



- ✧ **From offline visualization to inline visualization?**

Problem #4: I/O jitter

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I/O variability (or “jitter”)

Variability = difference between write time

✧From a process to another

✧From a write phase to another

Leads to unpredictable run time!

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Origins of jitter

✧Network and file system contentions between processes

  ✧Internal interferences (processes of the same application)

  ✧External interferences (cross-applications)

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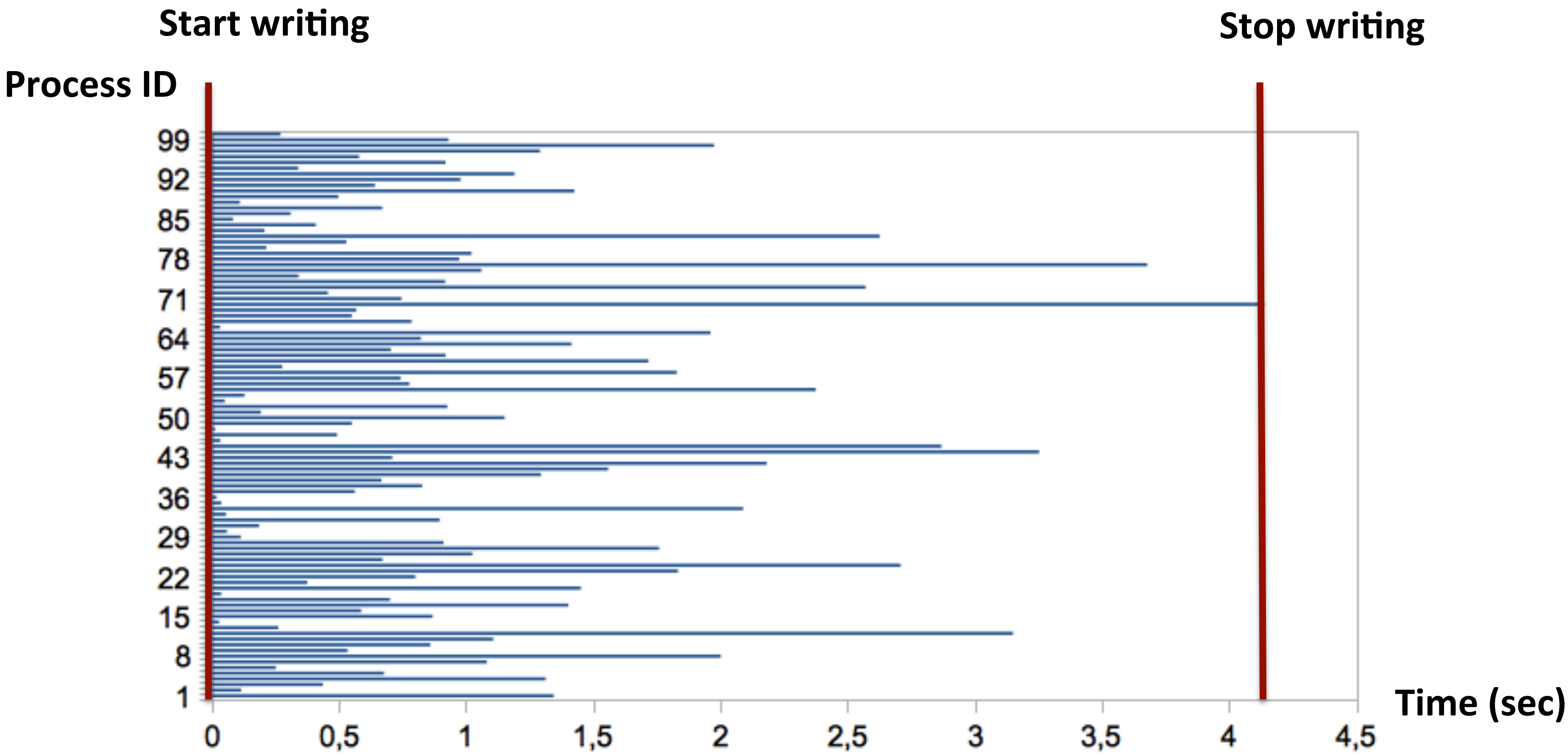
Understanding the jitter

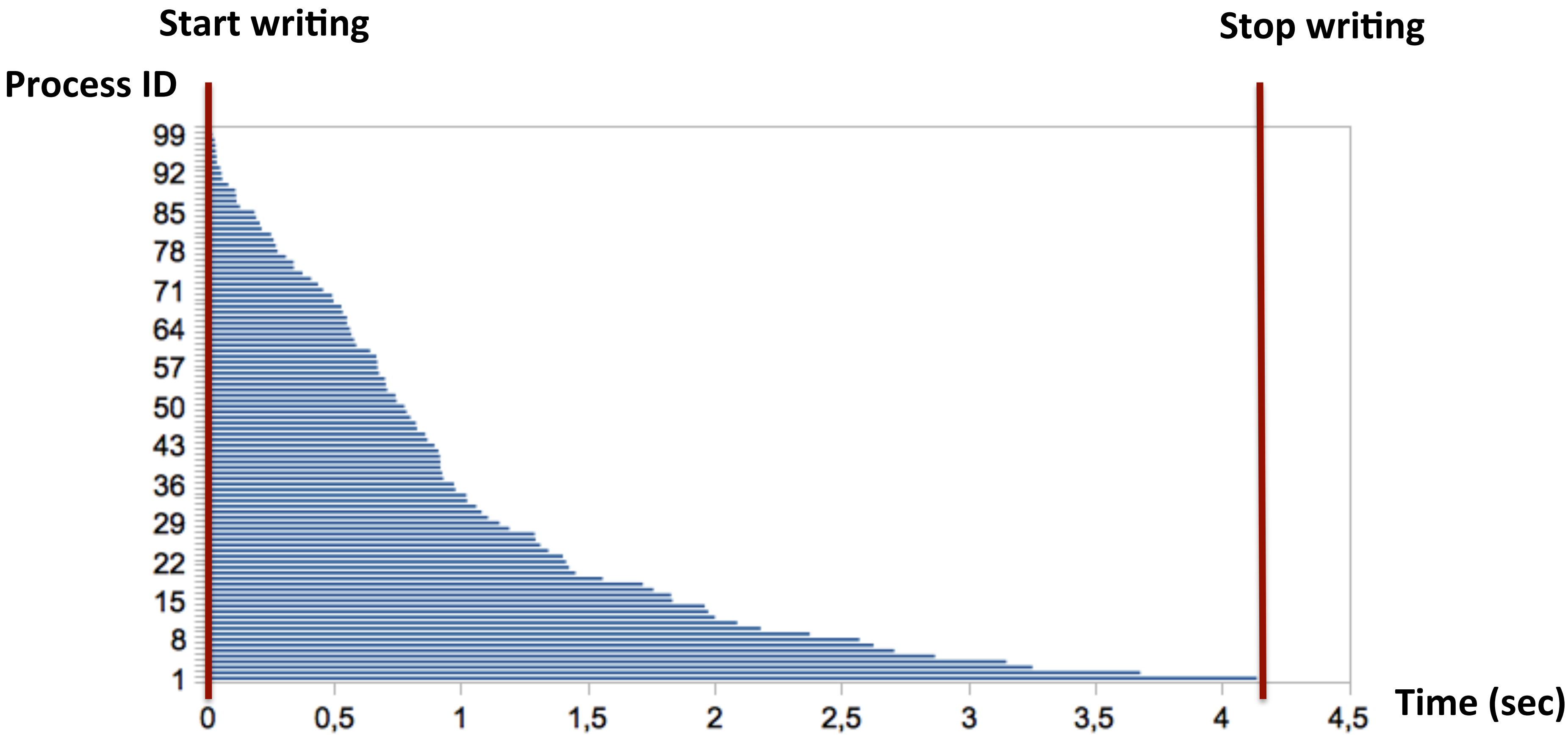
✧Statistical analysis (variance): intractable

How to interpret I/O variability?



Average = *X*, Standard deviation = *Y* … OK, and?

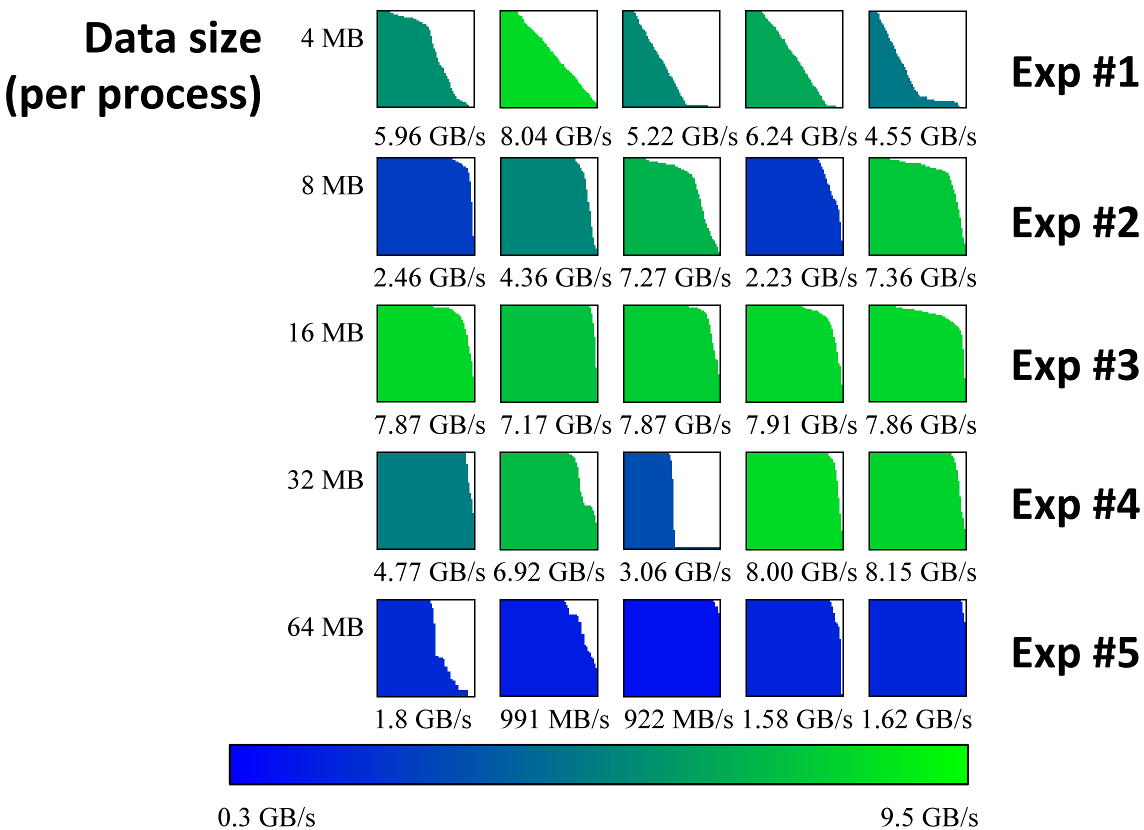
How to interpret I/O variability?



Let's sort this trace

- *White part corresponds to wasted time*

Contribution #1: Graphical comparison of traces



Color scale for aggregate throughput

Contribution #1: Summary

✧ A methodology to **visualize** and **interpret** variability

✧ Used on a set of 400 experiments (230400 mesures)

✧ **Validity**: from 400 MB/s to 21 GB/s on Grid'5000
(with PVFS and the IOR benchmark) by playing with 3 different parameters

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*Tuning a parallel file system is hard, couldn't we simply **hide this variability**?*

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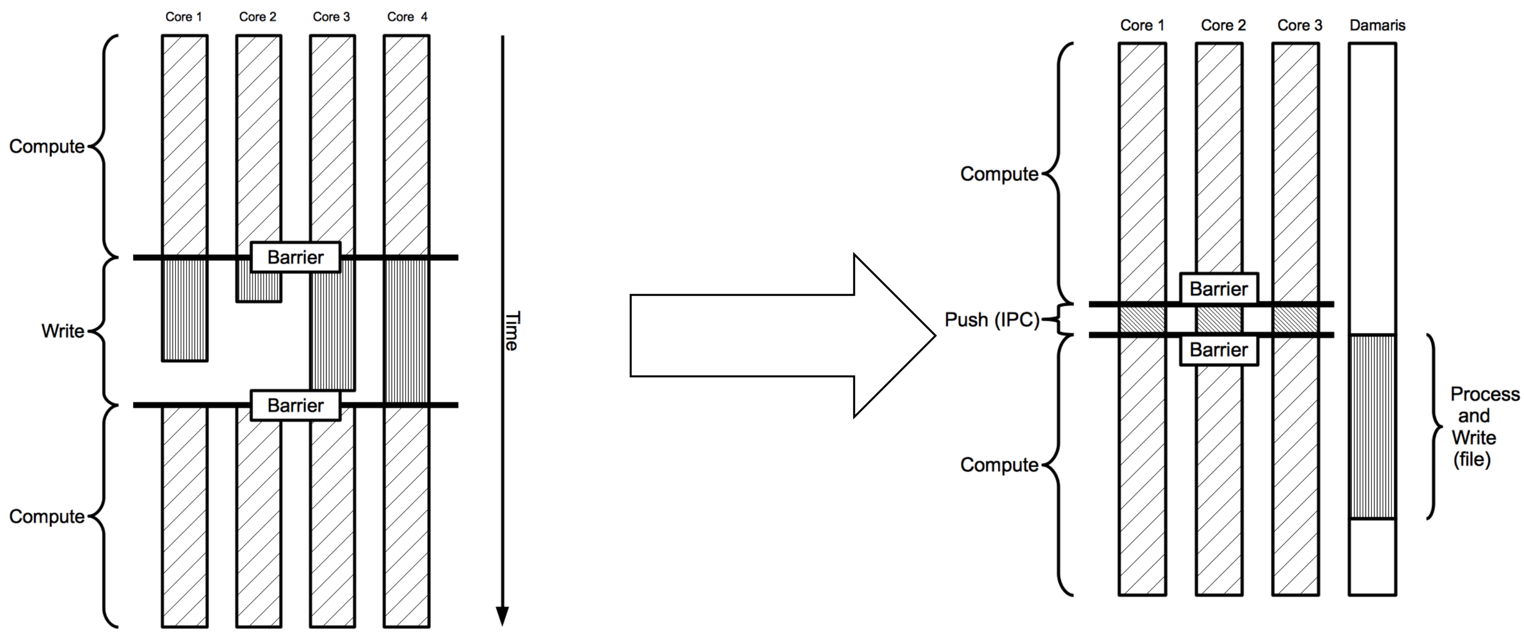
On multicore SMP nodes…

Leave a core, go faster!

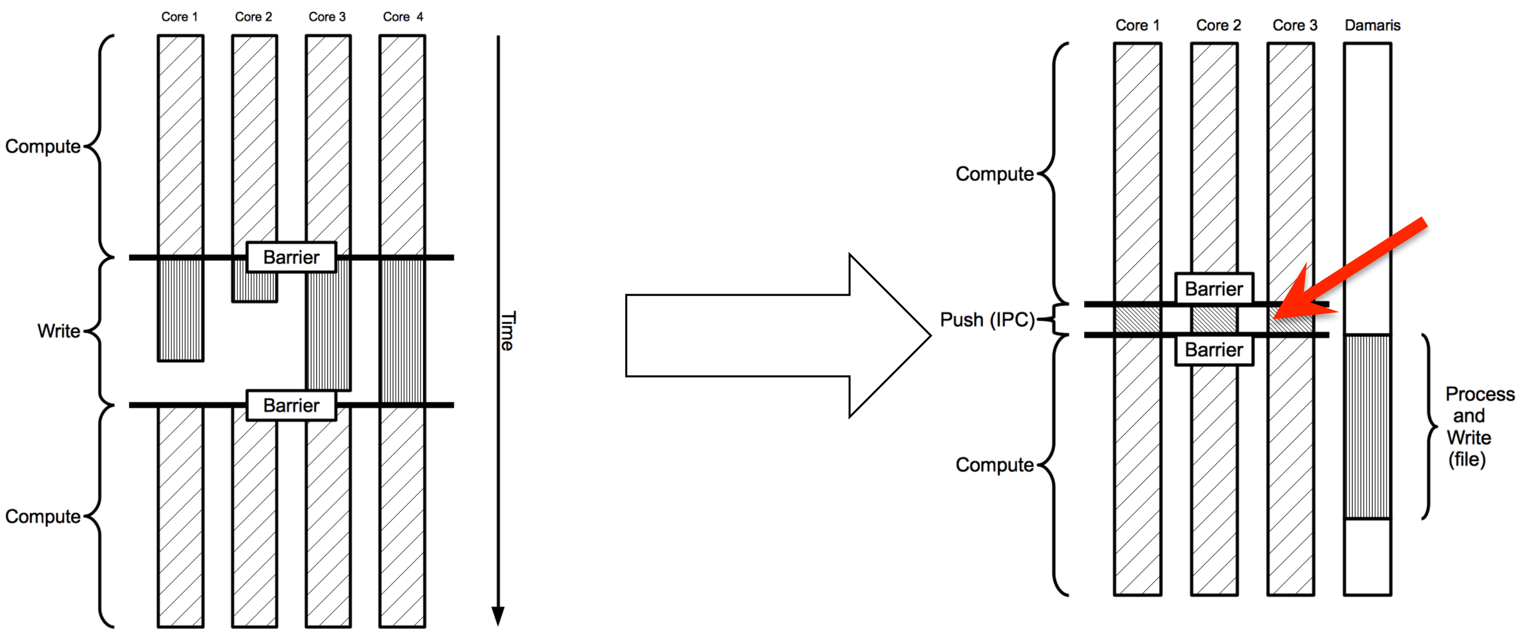
The Damaris approach: dedicated I/O cores



Note: these behaviors are periodic

The Damaris approach: dedicated I/O cores

✧ Use the SMP's intra-node shared memory



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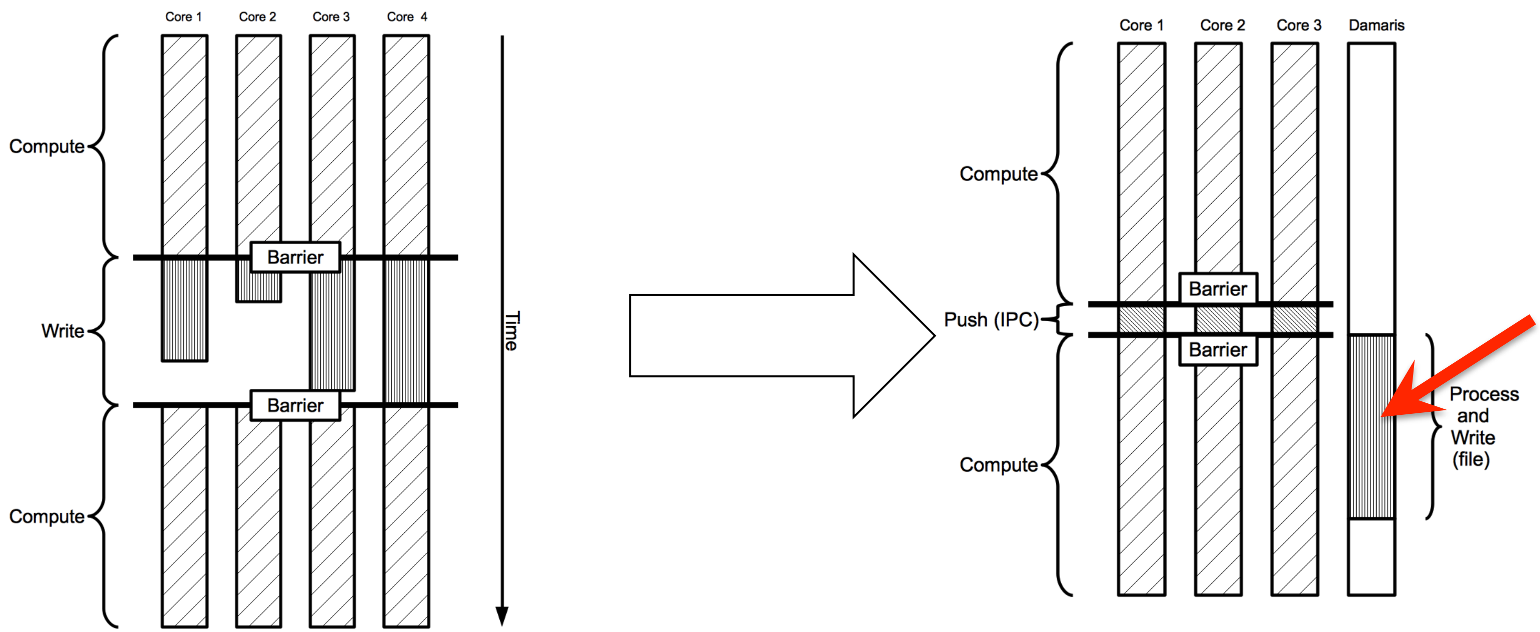
✧ Overlap I/O with computation



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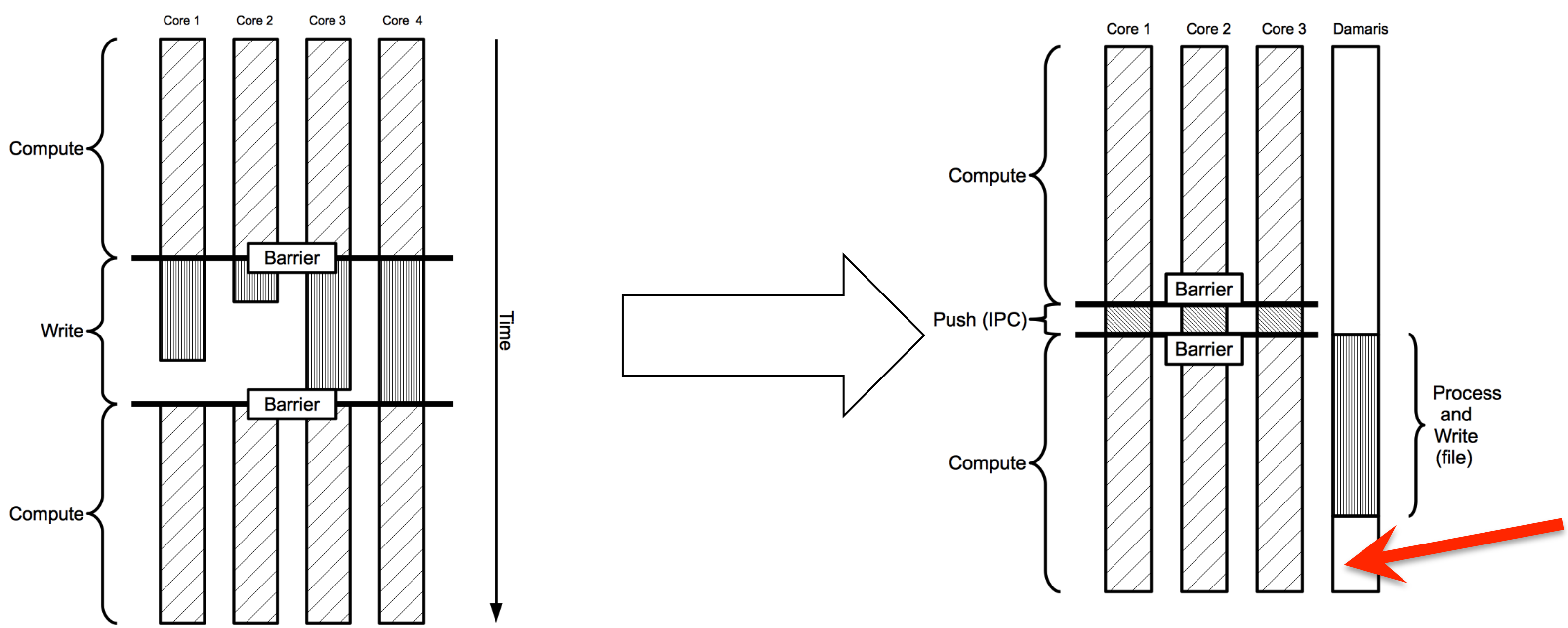
The Damaris approach: dedicated I/O cores

✧ Spare time in the I/O core



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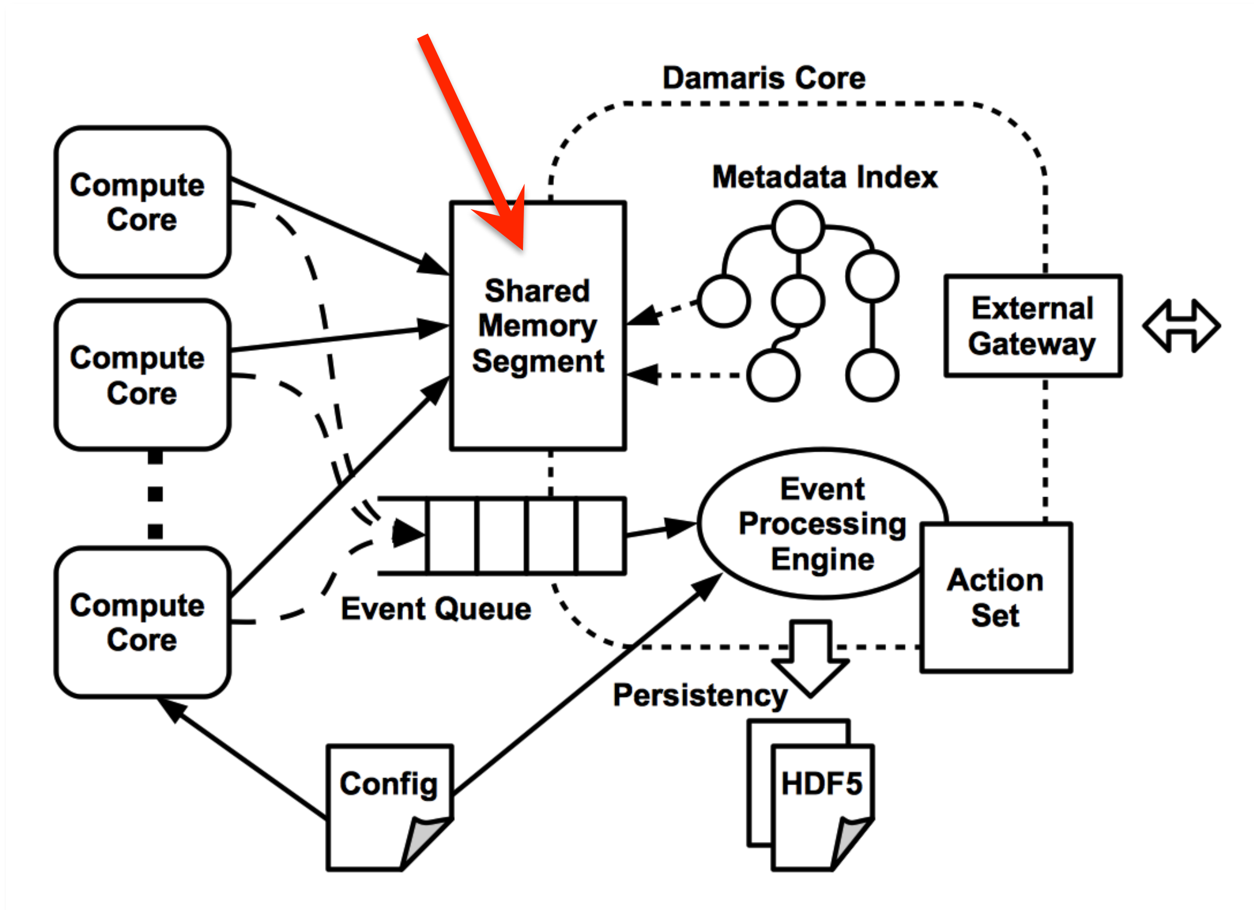
Damaris: architecture overview



Within one multicore node

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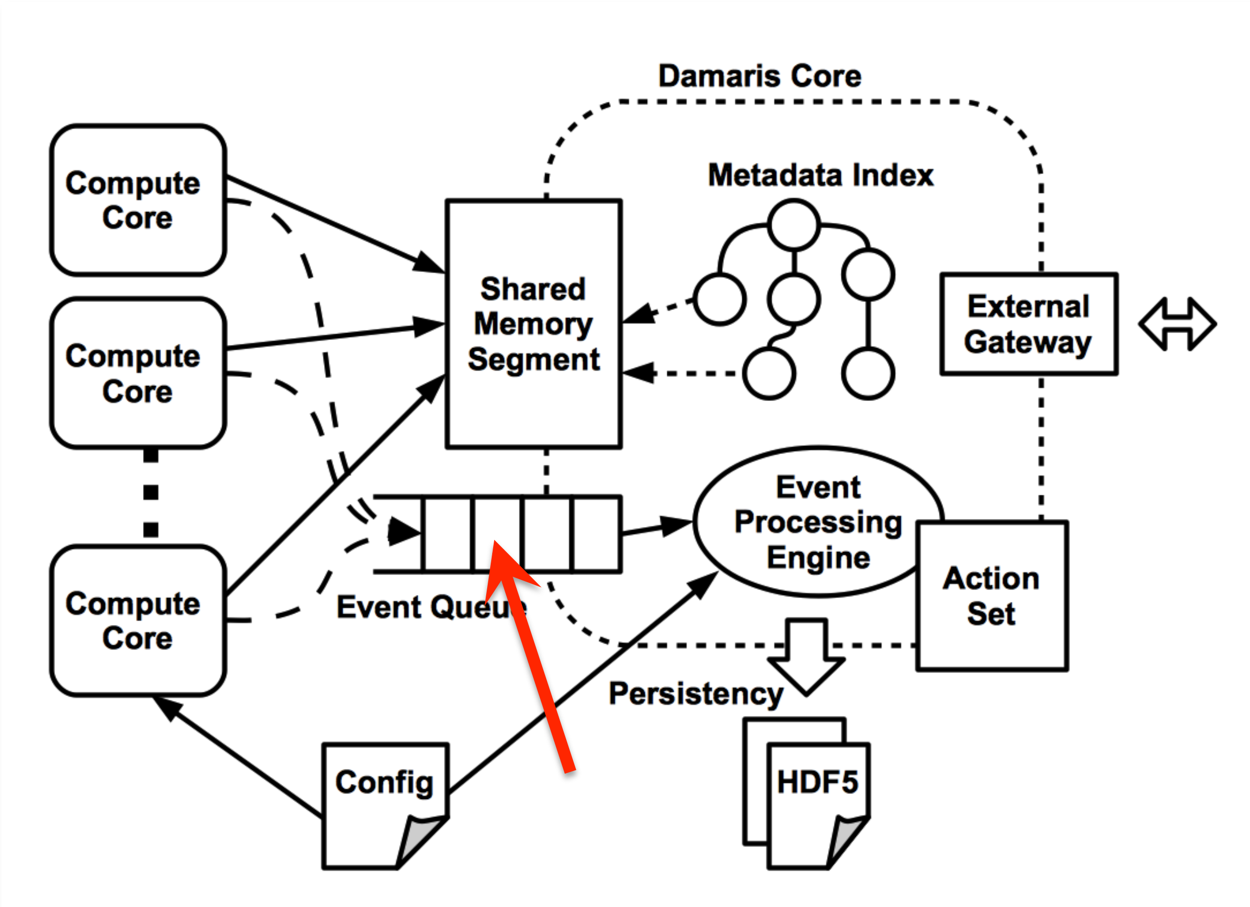

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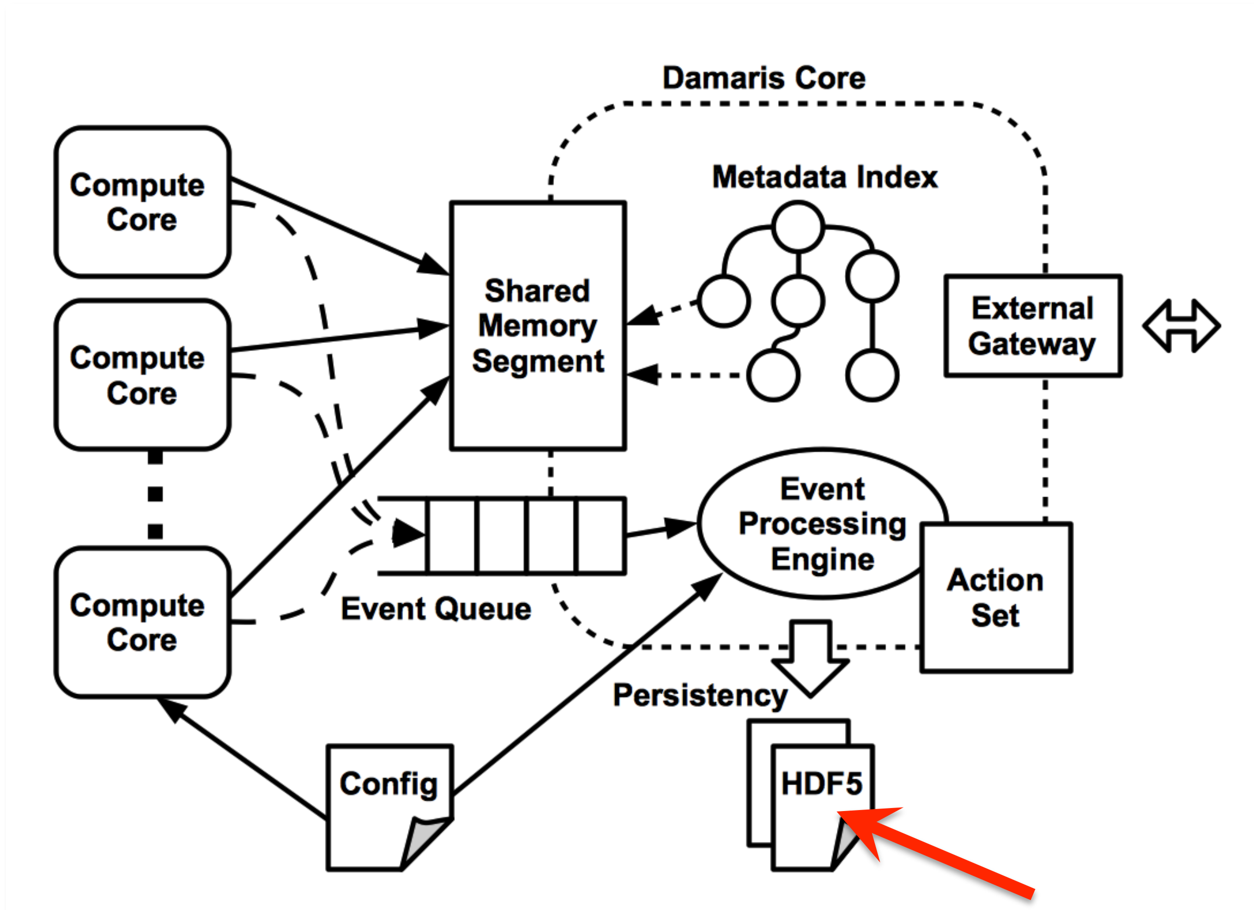

Within one multicore node

Damaris: implementation

✧ Written in **C++** (currently 3400 lines of code)

✧ **Boost** library for **interprocess** communications and **shared memory**

✧ Client-side libraries for **C**, **C++** and **Fortran**

✧ External **XML configuration**
(e.g. configuring buffer size, events, actions)

✧ **Take a look! http://damaris.gforge.inria.fr/**

The Damaris approach: benefits

- ✧ Hides I/O-related costs by overlapping computation and I/O
- ✧ Fewer files thanks to data aggregation
- ✧ No synchronization compared to collective I/O
- ✧ No more jitter
- ✧ Spares time

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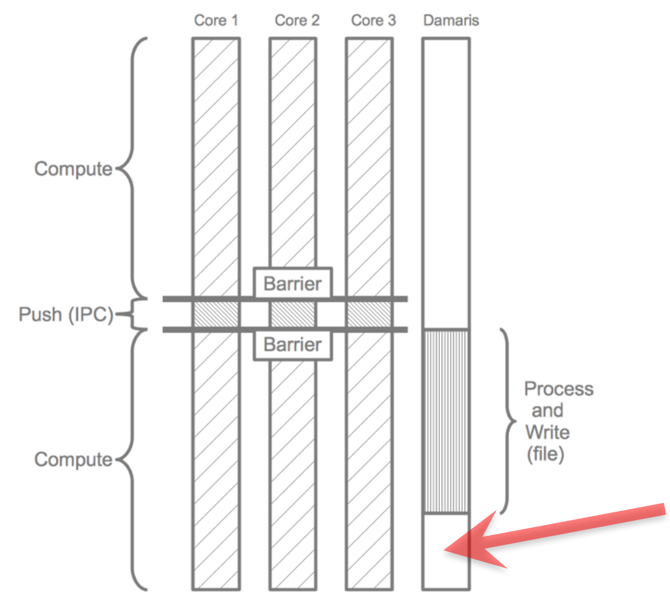
How to use the spare time?



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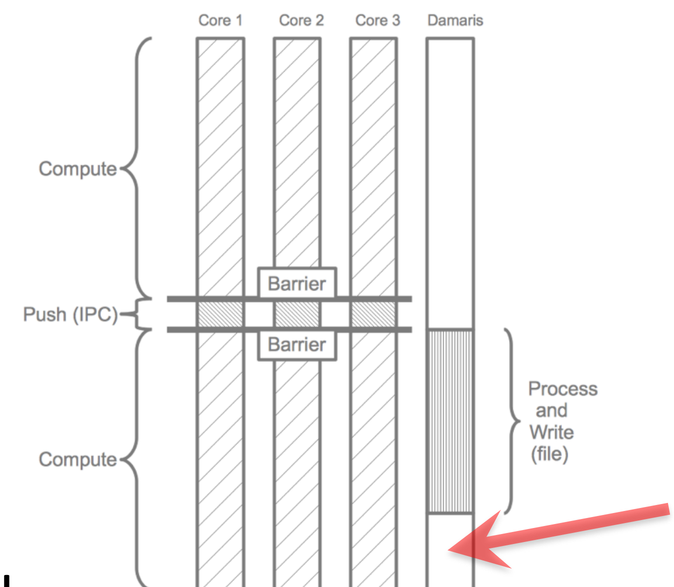

How to use the spare time?

- ✧ **Custom plugin system:**
  - ✧ Data post-processing,
  - ✧ Indexing, analysis
- ✧ **End-to-end scientific process**
  - ✧ Connect visualization/analysis tools
  - ➔ inline visualization

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The CM1 tornado simulation

- ✧ **CM1 = Georges Bryan's Cloud model version 1**
  - ✧ Three-dimensional, non-hydrostatic, non-linear, time-dependent numerical model suitable for idealized studies of atmospheric phenomena

- ✧ Currently writes using HDF5: **file-per-process**
- ✧ Development version allowing **collective-I/O**

Integration with the CM1 tornado simulation

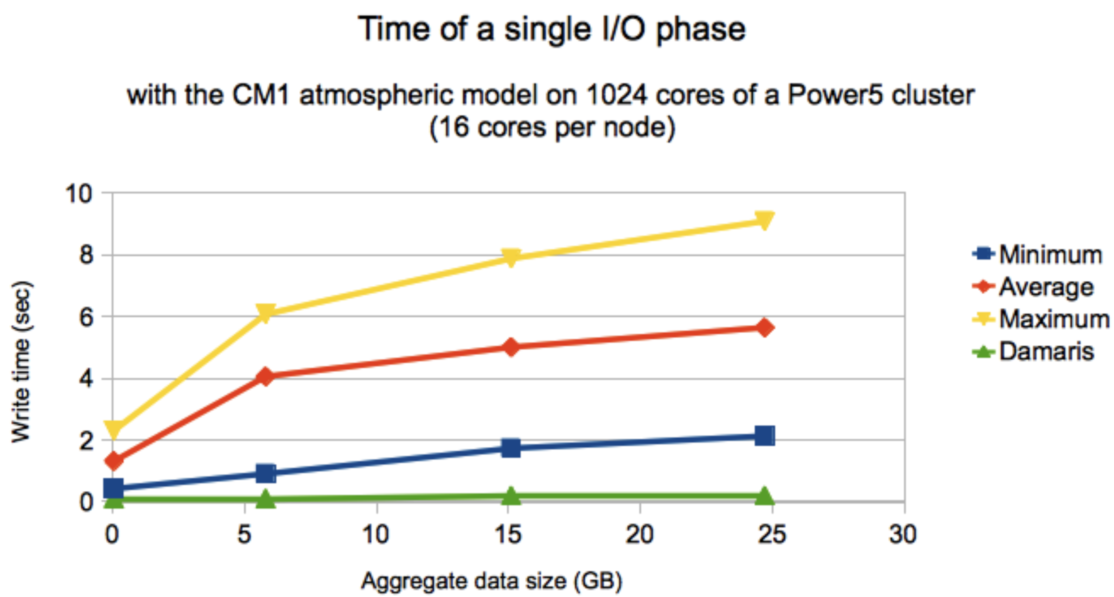
- **On Grid'5000: French national testbed (24 cores/node, 672 cores), with PVFS, comparison with collective I/O**
  - Communication overhead → leaving a core is more efficient
  - No synchronization
  - 6 times higher write throughput

Integration with the CM1 tornado simulation

- **BluePrint: Power5 BlueWaters interim system at NCSA (16 cores/node, 1024 cores), with GPFS, comparison with file-per-process approach**
  - On 64 nodes ➔ 64 files instead of 1024
  - More efficient data aggregation

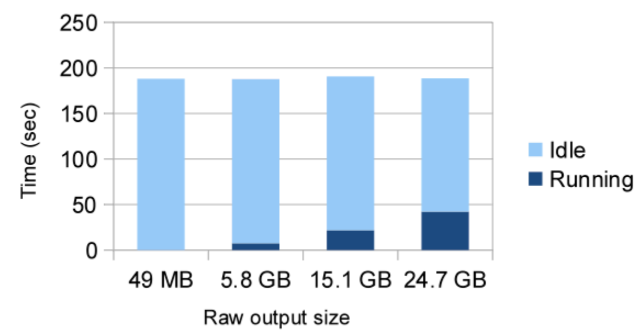
IBM GPFS®

Integration with the CM1 tornado simulation



No more I/O jitter, no more I/O overhead!

Spares more than 75% of time for data processing



Integration with the CM1 tornado simulation

- **In both cases:**
  - Spare time usage
    - Data layout adaptation for subsequent analysis
    - Overhead-free compression (600%)
  - No more I/O jitter and I/O related costs

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- ✧ **Contribution #1 :** study and representation of I/O variability
  - ✧ Allows simple and fast study of parameters influence

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- ✧ **Contribution #1 :** study and representation of I/O variability
  - ✧ Allows simple and fast study of parameters influence

- ✧ **Contribution #2 :** the Damaris approach
  - ✧ Dedicates one core to I/O
  - ✧ Hides I/O variability and overhead
  - ✧ Achieves better throughput (6x on G5k)
  - ✧ Aggregates and compress data (600%)
  - ✧ Tested on Grid’5000 and BluePrint

Outcomes of this work

- ✧ **Poster** presented at **ICS'11** (June 1-3, Tucson, AZ)
    - ✧ **2nd price** at the ICS section of the ACM **Student Research Competition**

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Future work

- ✧ Submission to IPDPS 2012
- ✧ Integrating Damaris in other simulations:
  Enzo, GTC, CESM, WRF…
- ✧ Testing at larger scales *(Kraken)*
- ✧ Using Damaris to perform inline visualization
- ✧ …

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Thank you, questions?

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