Optimizing data staging based on autotuning, coordination, and locality exploitation on large scale supercomputers

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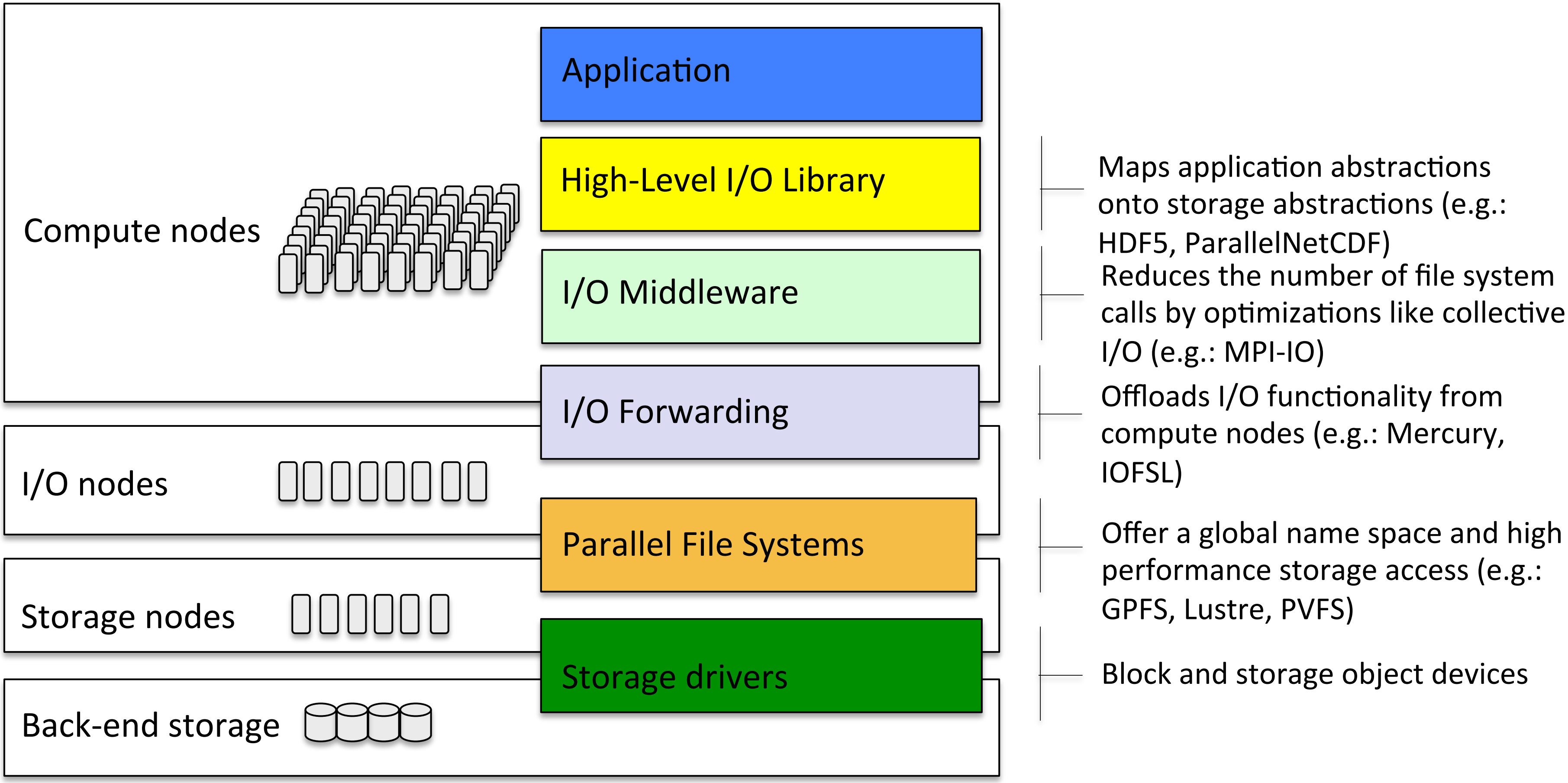
Current problems of storage I/O software stack



- Optimization: complex stack, deep distributed storage hierarchy
- Coordination: poor state of programmable control mechanisms are not available (e.g., for data staging, dynamic load balancing, resilience)
- Exploit data locality

Outline

- ***Optimization*: Model-based autotuning of collective I/O**

- *Coordination*: Data staging coordination

- *Exploit data locality*: Improving the scalability and performance of the Swift workflow language by leveraging data locality through Hercules

Parallel I/O tuning

- Huge parameter space of the storage I/O software stack
- Domain knowledge is increasingly harder: software and hardware complexity

Application

High-Level I/O Library — Block alignment, chunking, etc.

I/O Middleware — Collective/independent I/O, data sieving, collective buffer size, number of aggregators, etc.

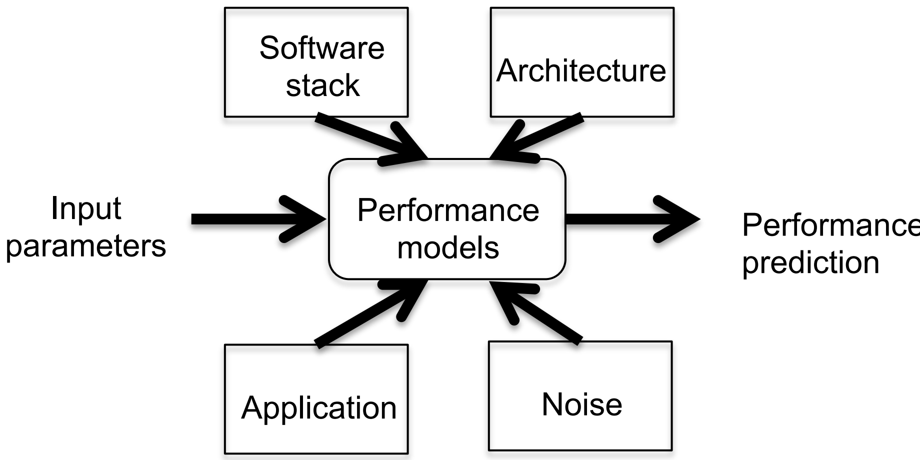
I/O Forwarding

Parallel File Systems — Striping unit, striping factor, striping layout, caching, prefetching, etc.

Storage drivers

Parallel I/O autotuning approaches

- Model based tuning
  - Analytical: Extensive domain knowledge required: software stack, architectural characteristics
  - Machine learning [Kumar2013, Yu2012]
- Search-based tuning
  - Genetic algorithms [Bezhad2013]
  - Simulated annealing [Chen2000]
- Hybrid [Bezhad2014]

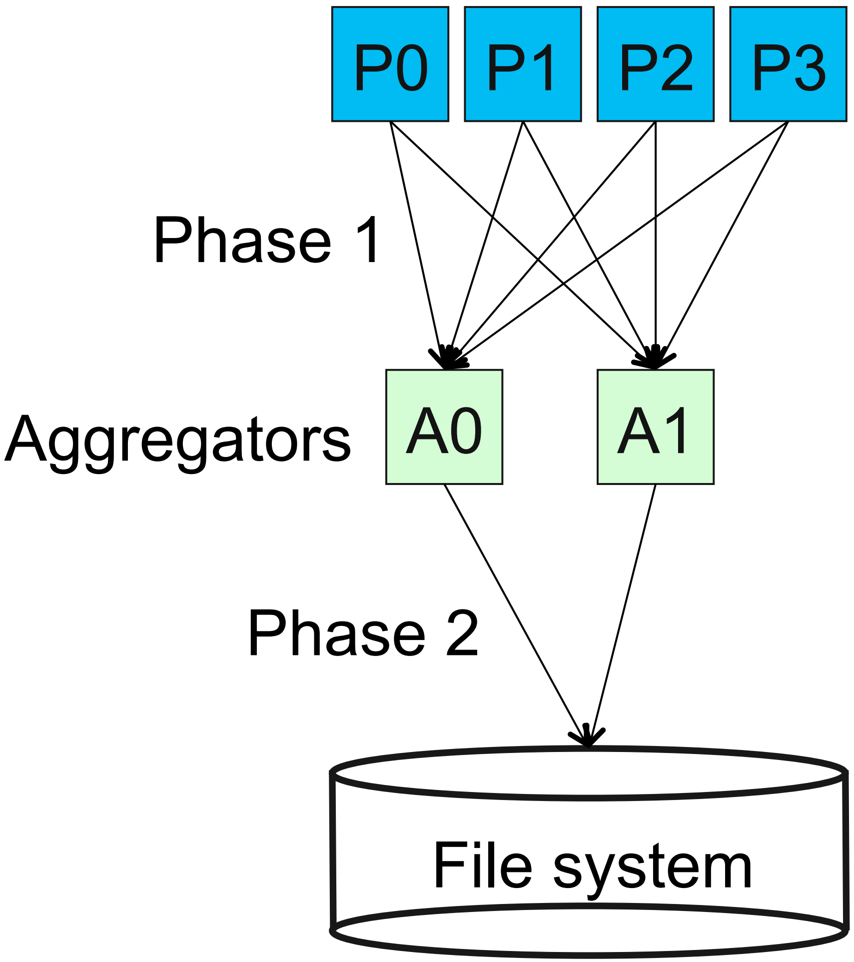


This work

- Model-based tuning of two-phase-I/O, the most popular collective I/O implementation from ROMIO
- Combination of analytical and machine learning models
- IEEE Cluster 2015 paper

Collective I/O

- N processes collectively write or read to a file
- Two-phase I/O write
  - Computation and communication for mapping writes to the file domain
  - Communication for sending data to aggregators
  - Storage I/O for storing the data to the file system



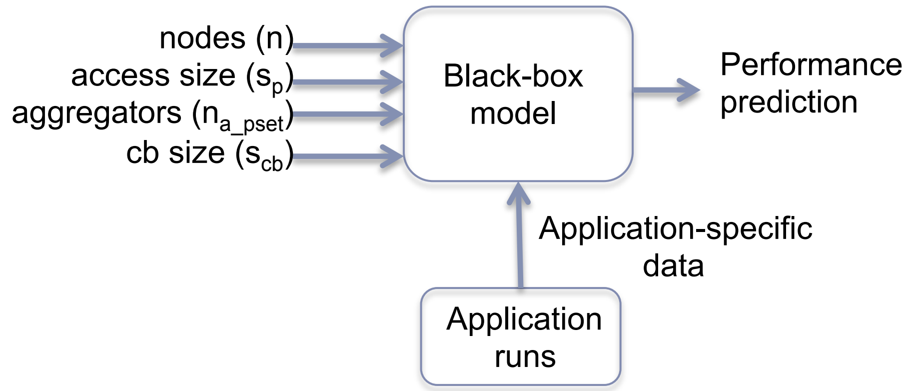
Modeling framework

4 parameters

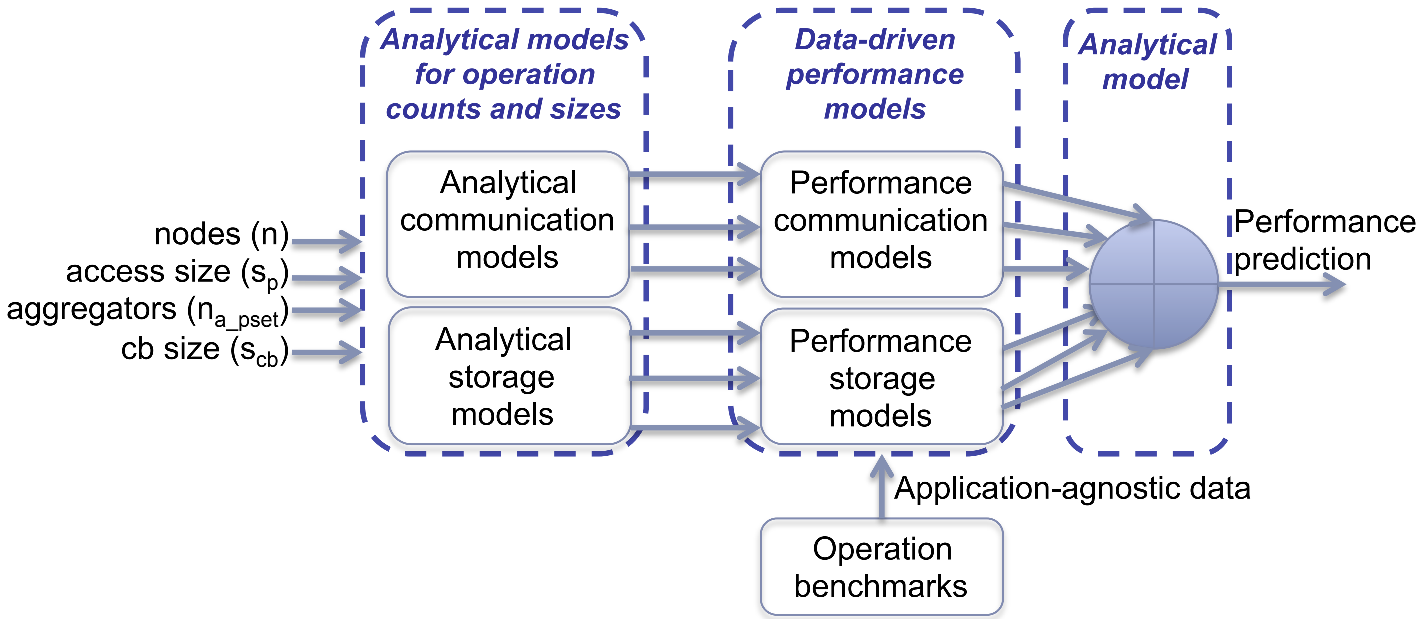
- n: number of nodes
- s: access size
- n_a: number of aggregators
- s_{cb}: collective buffer size

Goal: tune n_a and s_{cb}

Black box model



Hybrid model



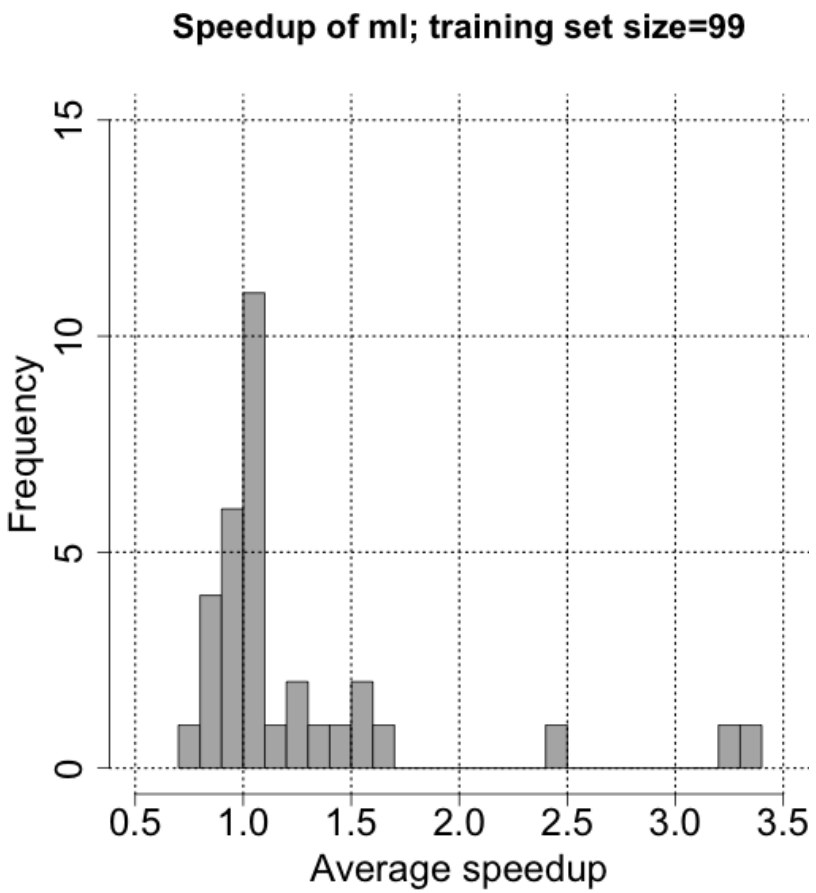
Experimental evaluation

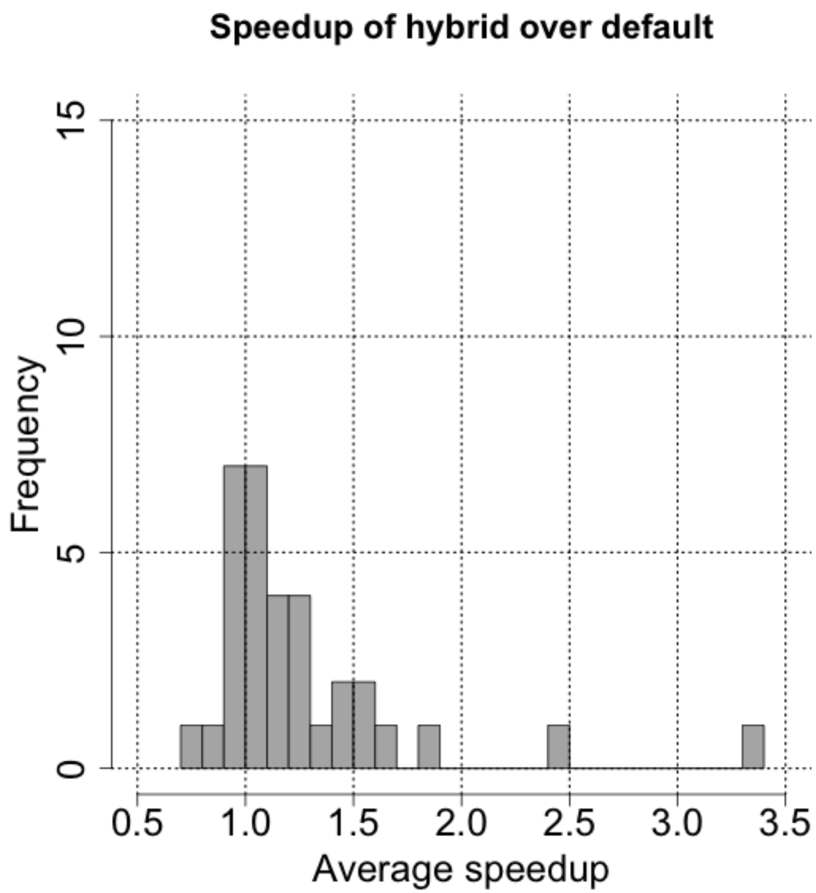
- IOR benchmark: N processes concurrently write and non-overlapping region to the file system through MPI-IO
- MPICH 3.1
- Vesta Blue Gene/Q
  - 2048 compute nodes 1.6 GHz 16 cores 16GB RAM
  - 5D torus network interconnecting compute nodes
  - 1 I/O node per 32 compute nodes
  - Client (I/O node) cache: 4GB
  - GPFS 3.5: Block size: 8MB, 40 NSD SATA data drives (Max throughput: 250 MB/s)
- Benchmark for performance models: ALCF MPI benchmark

Machine learning model

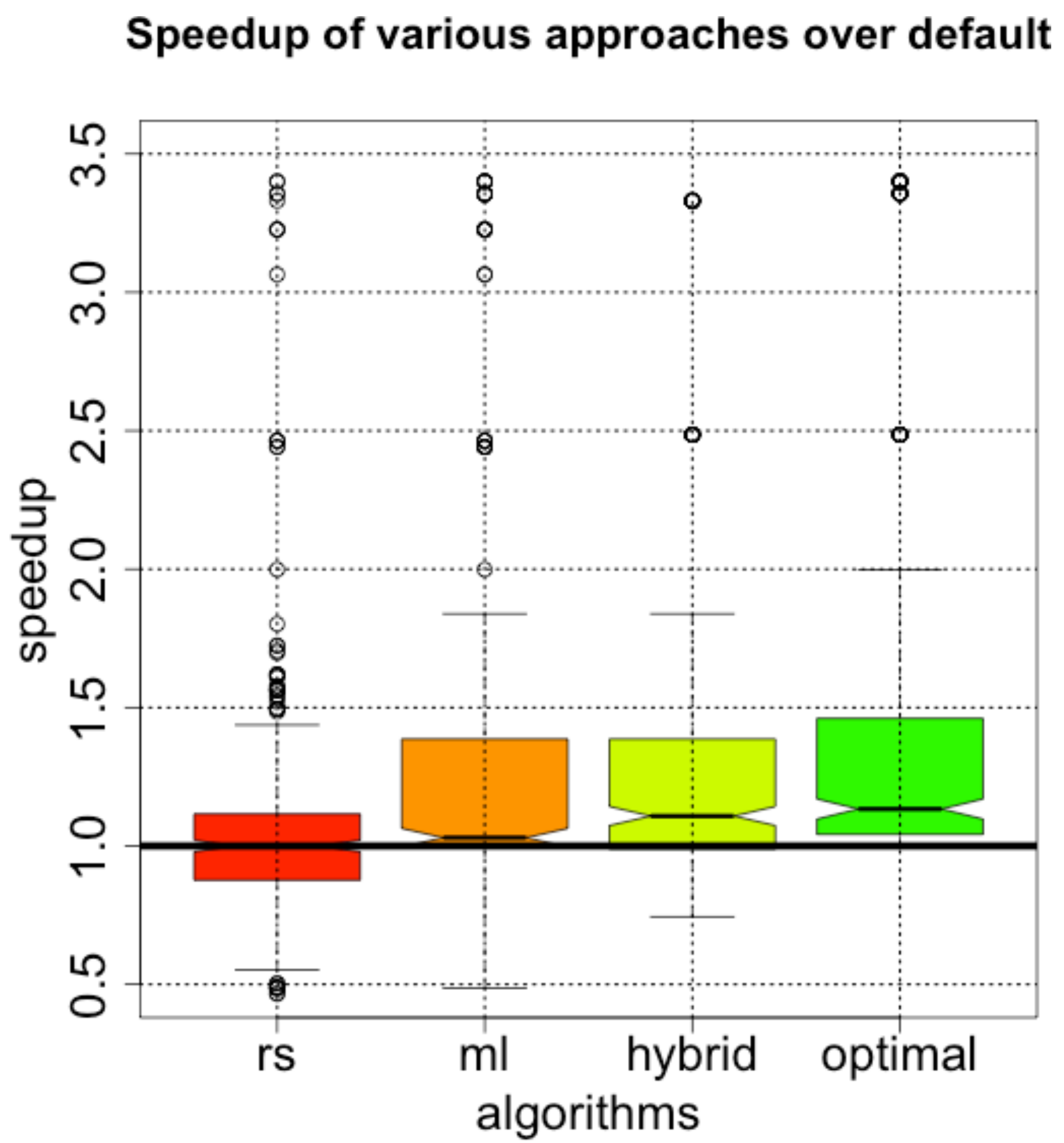
- Black box models and performance models
  - linear regression, neural networks, support vector machines, random forests, and cubist
  - Selected the model with best RMSE and R^2
- Data set:
  - Black box model: 297 points
    - Processes: 2048 (128 nodes on 16 cores), 4196, and 8392
    - Transfer sizes/core (MB): 1, 2, 4, 8,16, 32, 64, 96, 128, 192, 256
    - Collective buffer size (MB): 8, 16 (default), 32
    - Number of aggregators per 128 nodes: 40, 136, 520 (default)
  - Performance models
    - Alltoall: : 51 points for 2,048, 4,096, and 8,192 ranks and for message sizes between 1 byte and 256KB.
    - Alltoallv: 1,044 points for distributing message sizes between 1 byte and 64 MB (in powers of 2) for subsets of 2,048, 4,096, and 8,192 ranks.
    - Allreduce: 57 points for 2,048, 4,096, and 8,192 ranks and for message sizes between 4 bytes and 1 MB.
    - POSIX: 567 points for various sizes and various subsets of 2,048, 4,096, and 8,192 ranks.

Comparison between black-box and hybrid models

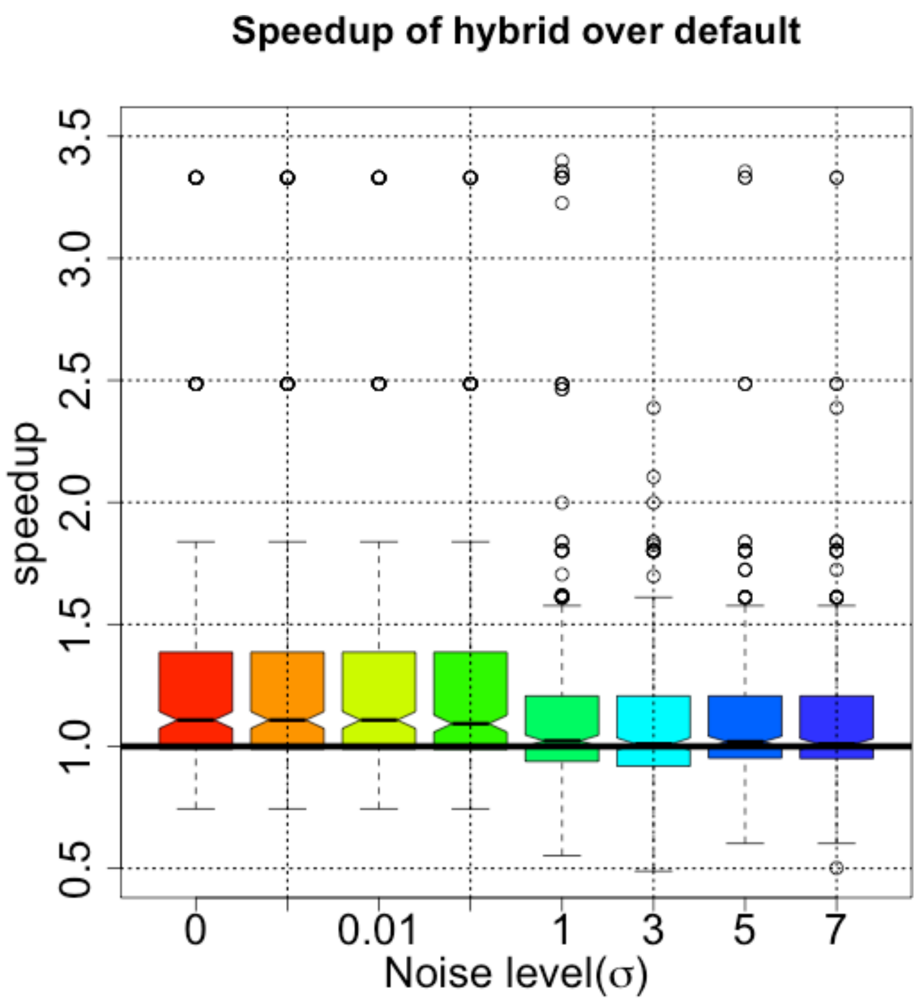


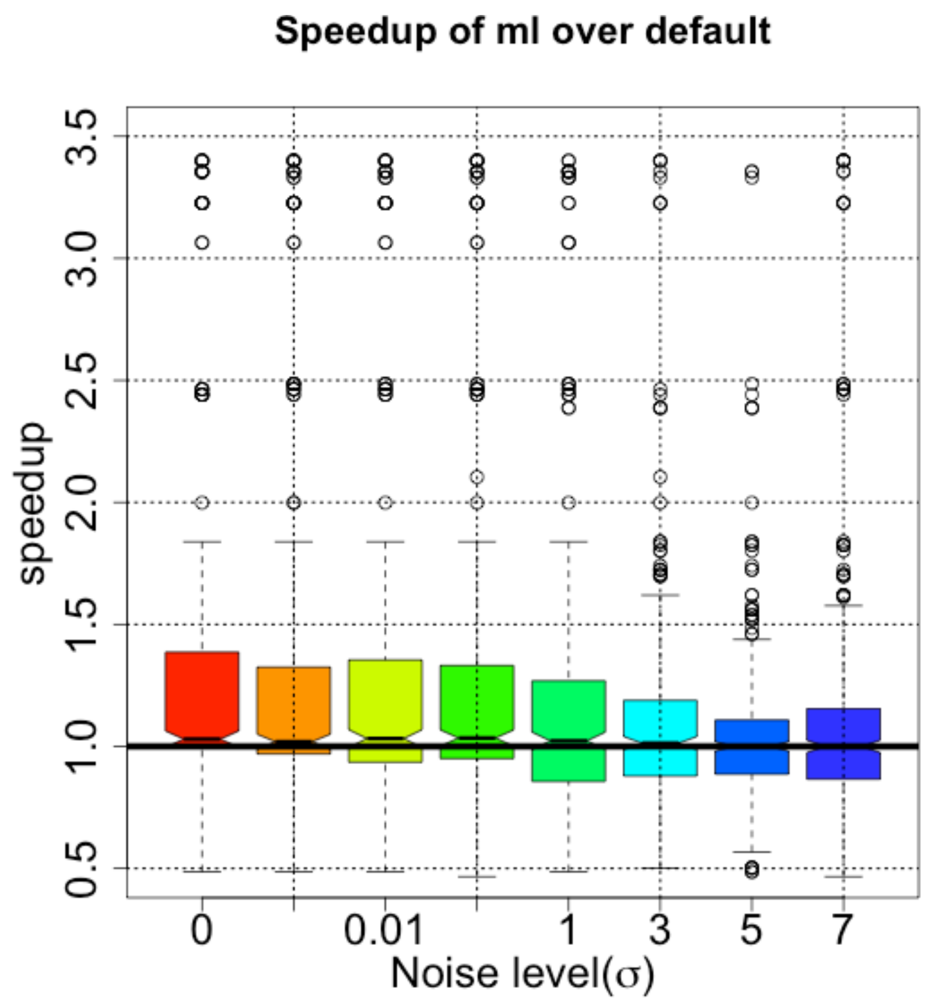


Comparison among various approaches



Impact of noise





Outline

- *Optimization*: Model-based autotuning of collective I/O

- ***Coordination*: Data staging coordination**

- *Exploit data locality*: Improving the scalability and performance of the Swift workflow language by leveraging data locality through Hercules

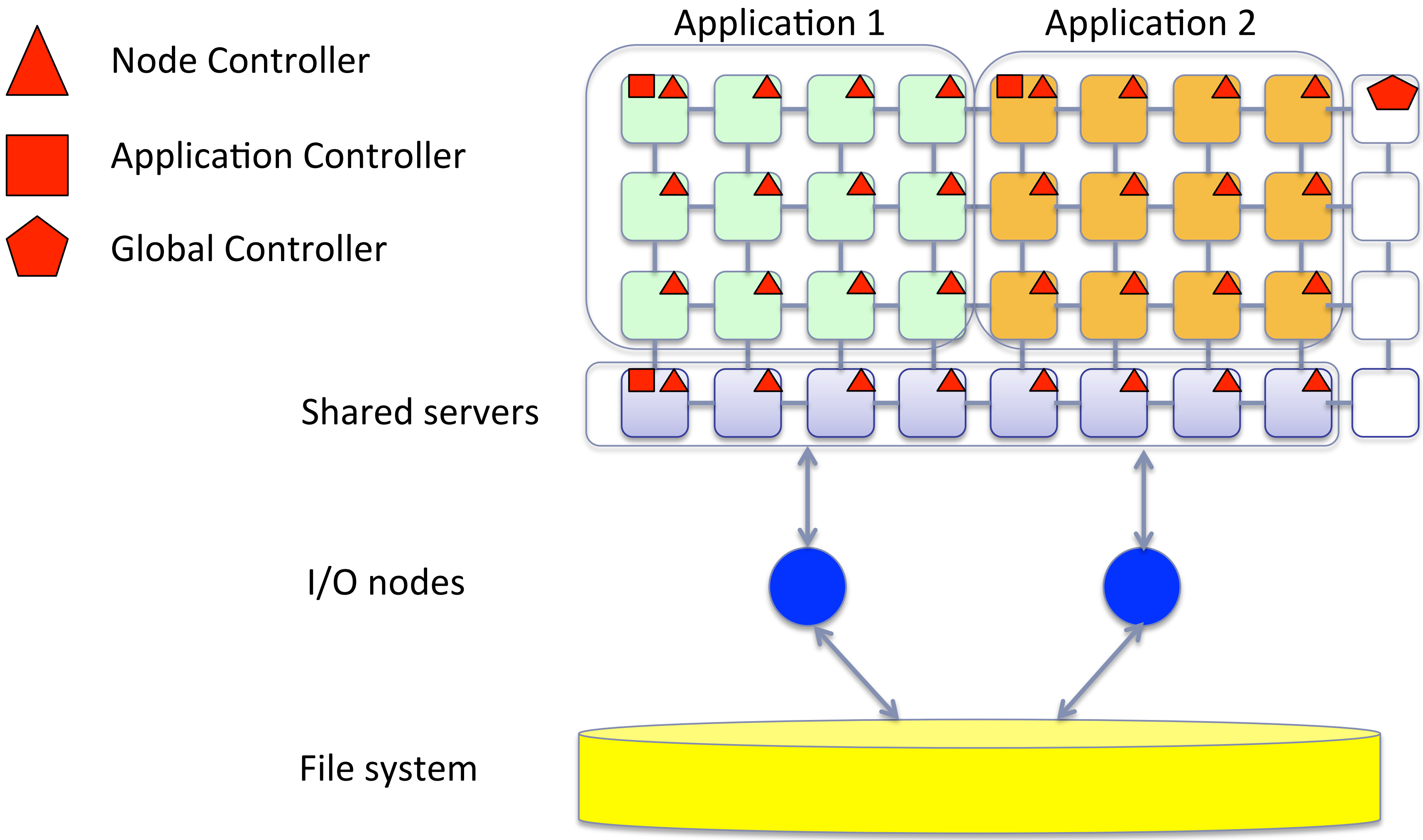
Data staging challenges

- Concurrent parallel data flows
  - Lack of data staging coordination
    - Among applications
    - Between applications and the system
- Increasing storage hierarchy
- Lack of standards for dynamic monitoring of large scale infrastructures (e.g. load, faults)
- Coupled control and data mechanisms
- Goal: offer novel mechanisms for data staging coordination to improve
  - Load balance
  - Resilience
  - Parallel I/O scheduling

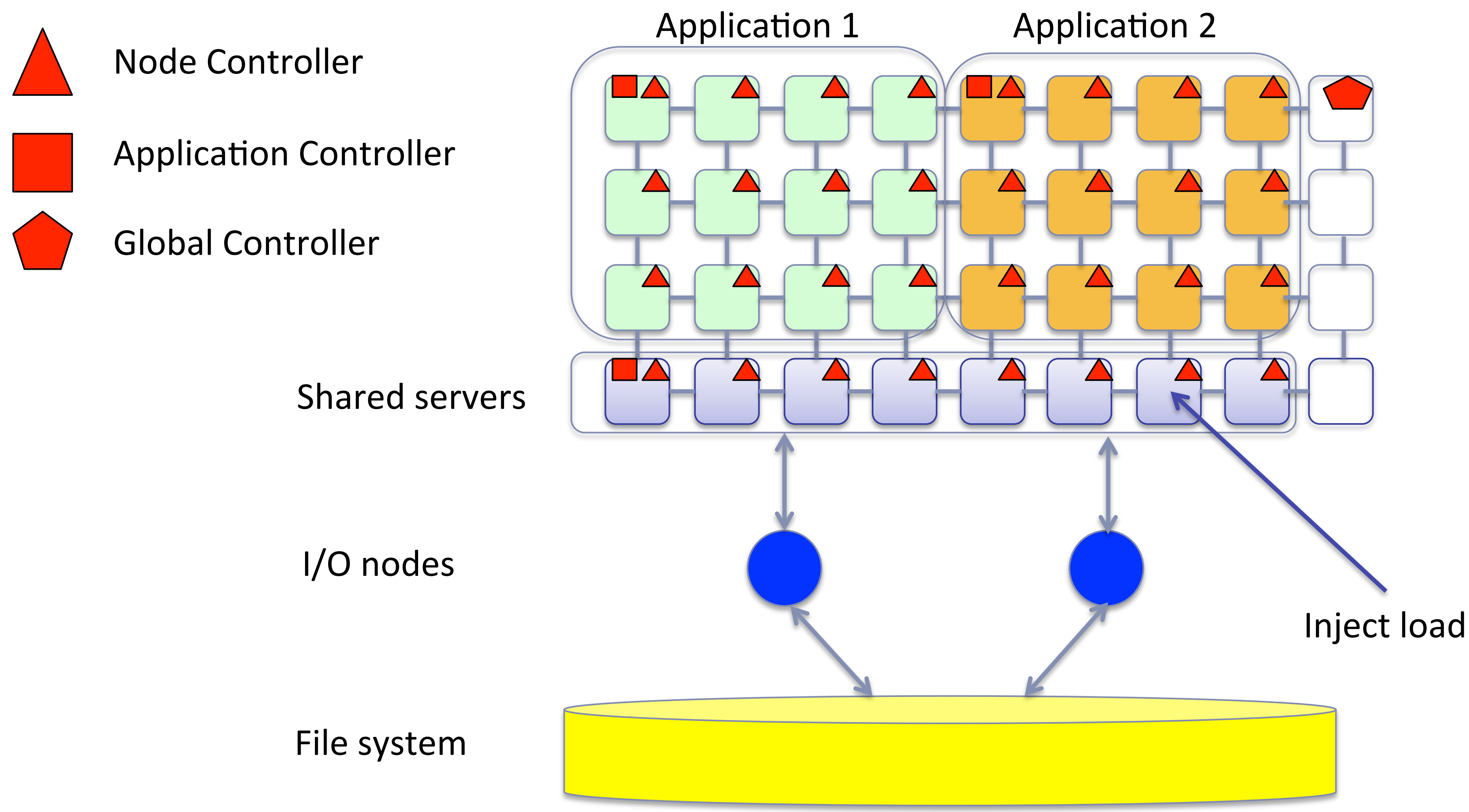
Coordination approach : CLARISSE library

- Decouple the data and control paths
- Data-path: abstractions used to implement data access operations
  - Collective I/O
    - 2 implementation: view based I/O, list-IO (can be used as both server-based I/O and client-based I/O)
- Control path: Based on a publish/subscribe substrate (e.g. Beacon)
  - Processes can subscribe to events having certain properties
    - Associate call-back
    - Wait for an event
    - Check for the arrival of an event
- Hierarchical control
  - Global controller
  - Application controller
  - Node controller
  - All nodes participate in control

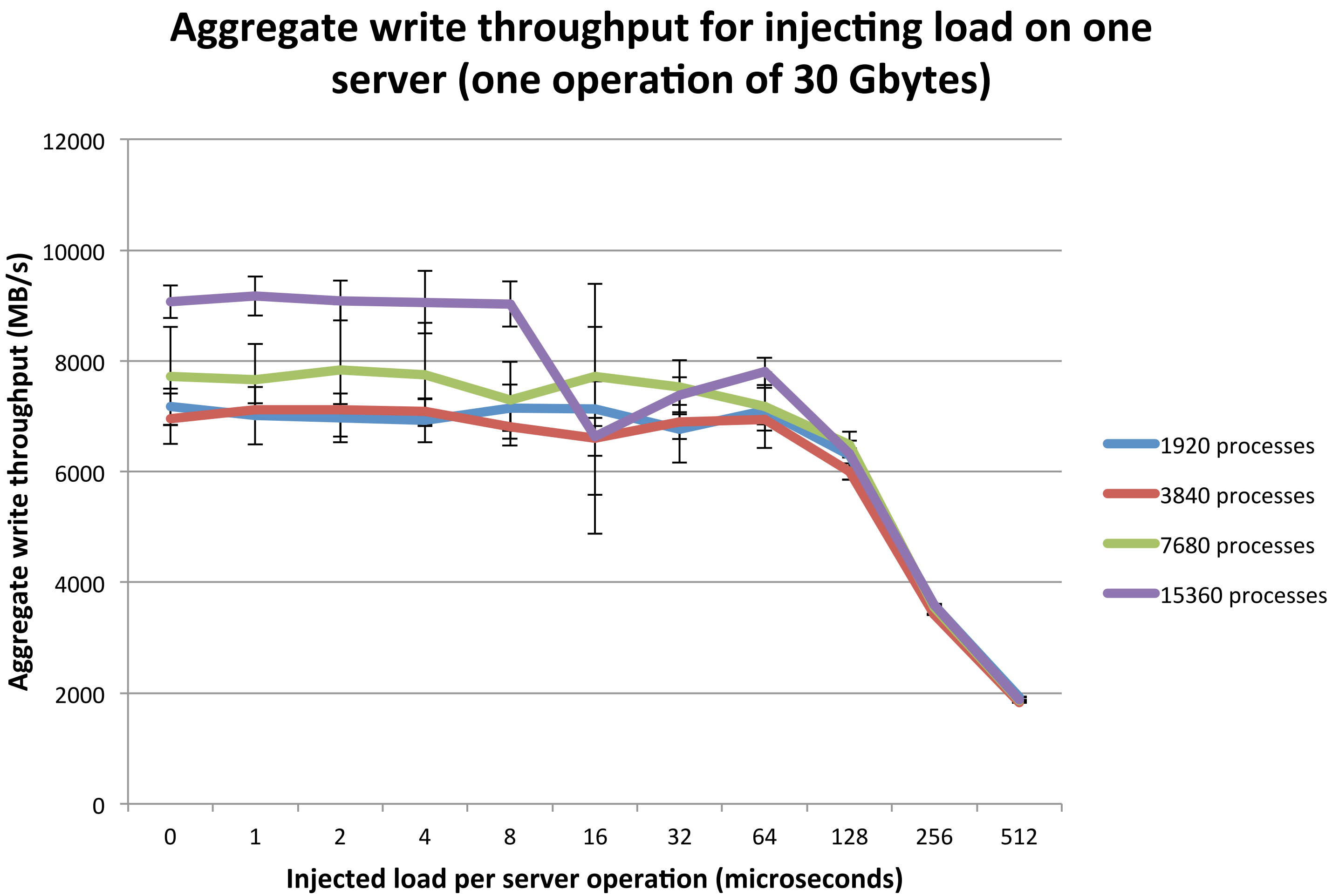
CLARISSE hierarchical control infrastructure



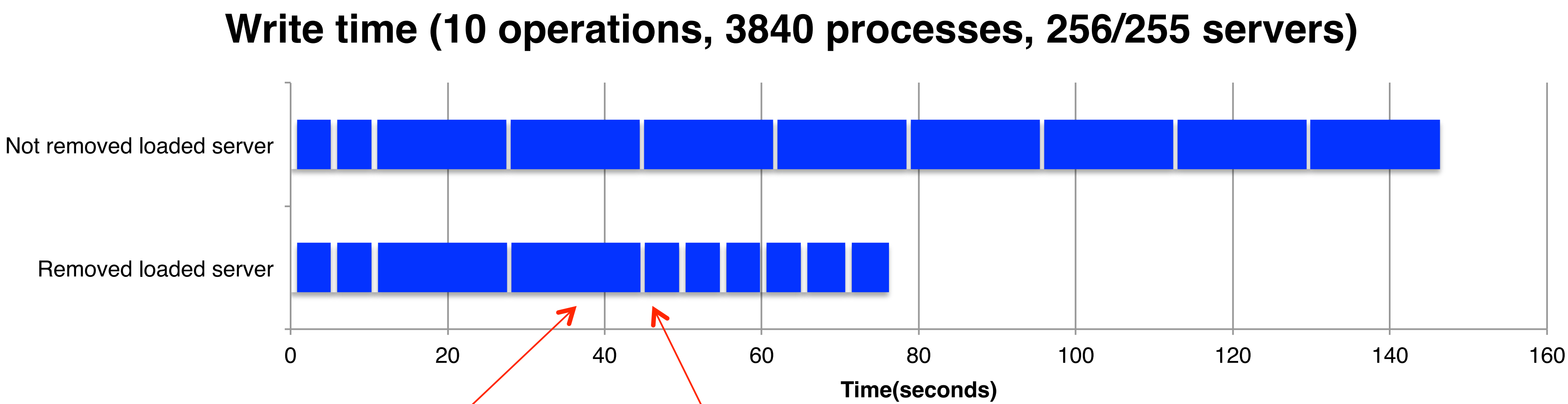
CLARISSE hierarchical control infrastructure



Load injection at 1 server (1 application)



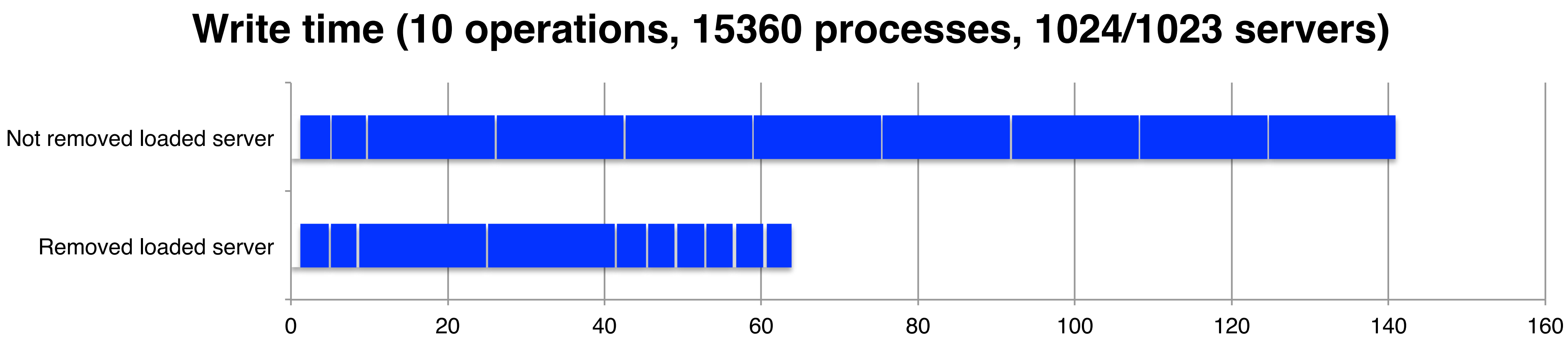
Dynamically scaling-down



Detect loaded server
Reconstruct server map

New epoch with fewer servers

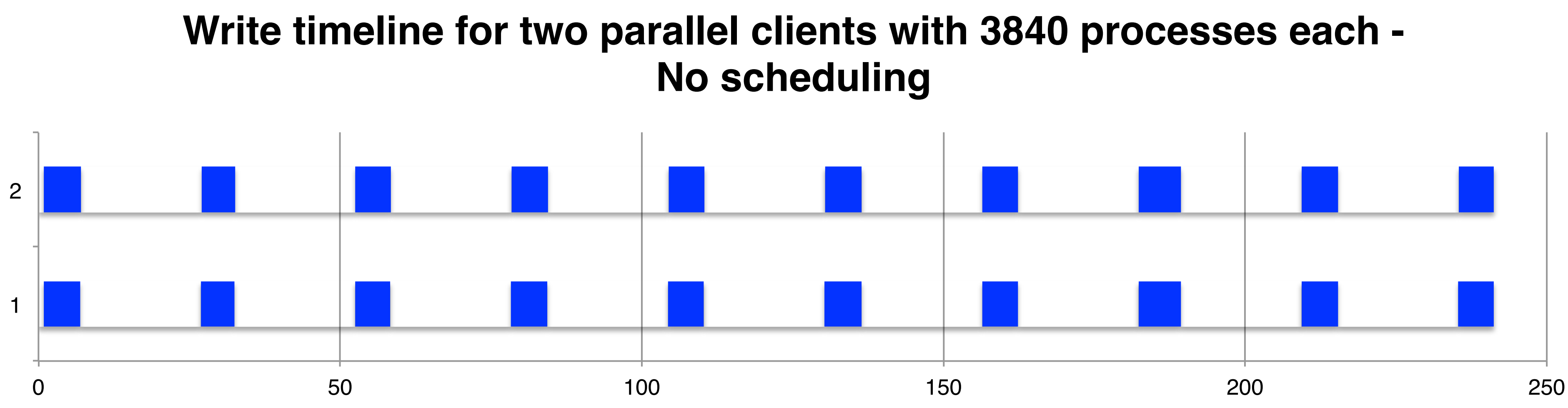
Dynamically scaling-down

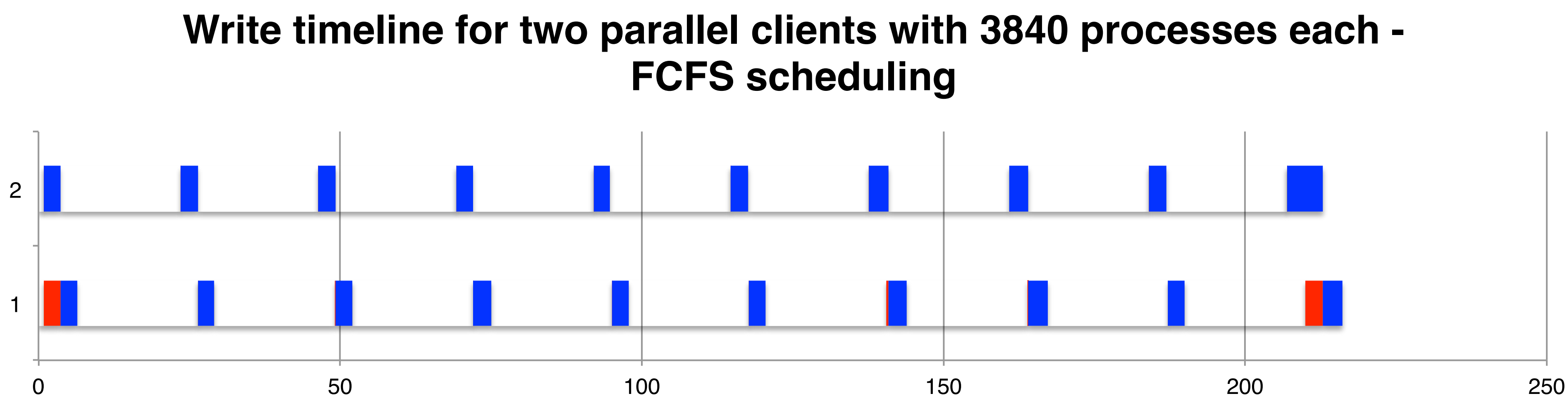


Parallel I/O scheduling

- Several applications share
- The application controller notifies the global controller
- The global controller schedules the next application to be run
- Several policies possible
  - FCFS evaluation

FCFS scheduling versus no scheduling





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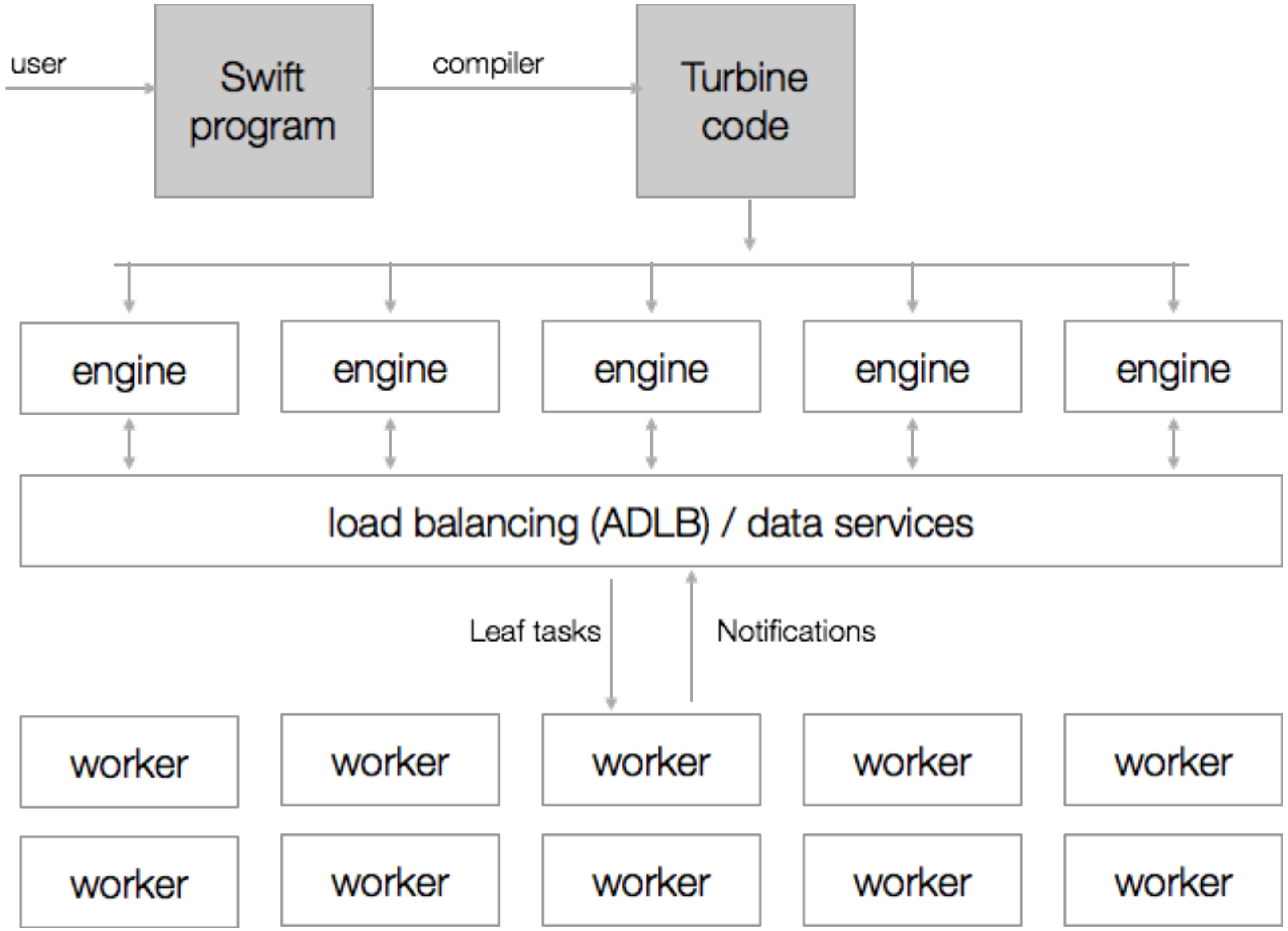
Swift/T

- Swift/T: Language and runtime for dataflow applications

```
(int r) myproc (int i, int j)
{
    int f = F(i);
    int g = G(j);
    r = f + g;
}
```

- F( ) and G( ) implemented in native code or external programs
- F( ) and G( ) run concurrently in different processes
- r is computed when they are both done

Swift/T architecture

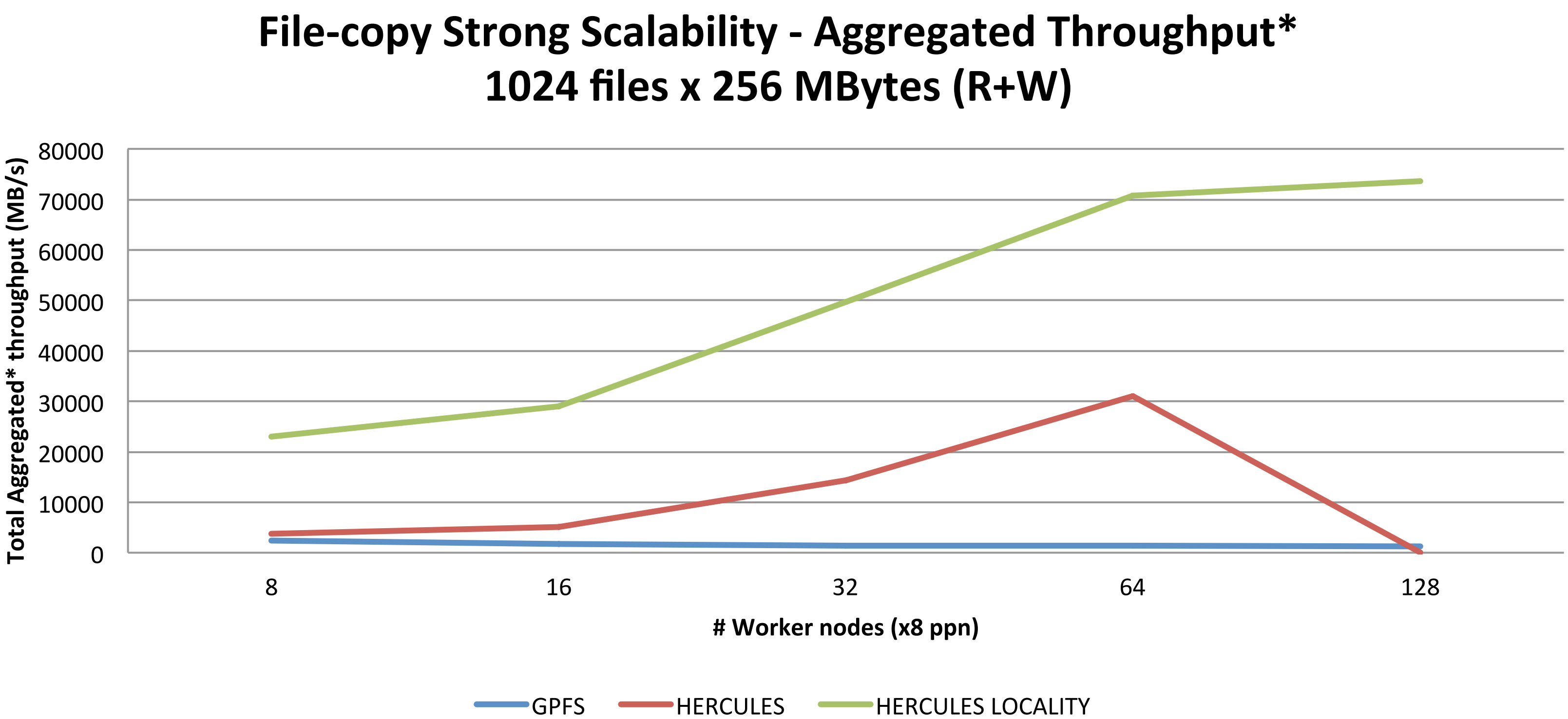


Problem description

- Load balancer is not locality-aware
- Tasks communicate through the parallel file system (bottleneck)
- Objectives:
  - Improve the performance of inter-task communication
    - Data locality
  - Investigate the tradeoffs between data locality and load-balance in workflow execution
    - Ideal load balance, but poor locality
    - Ideal data locality, but poor load balance (not all nodes used)

Approach

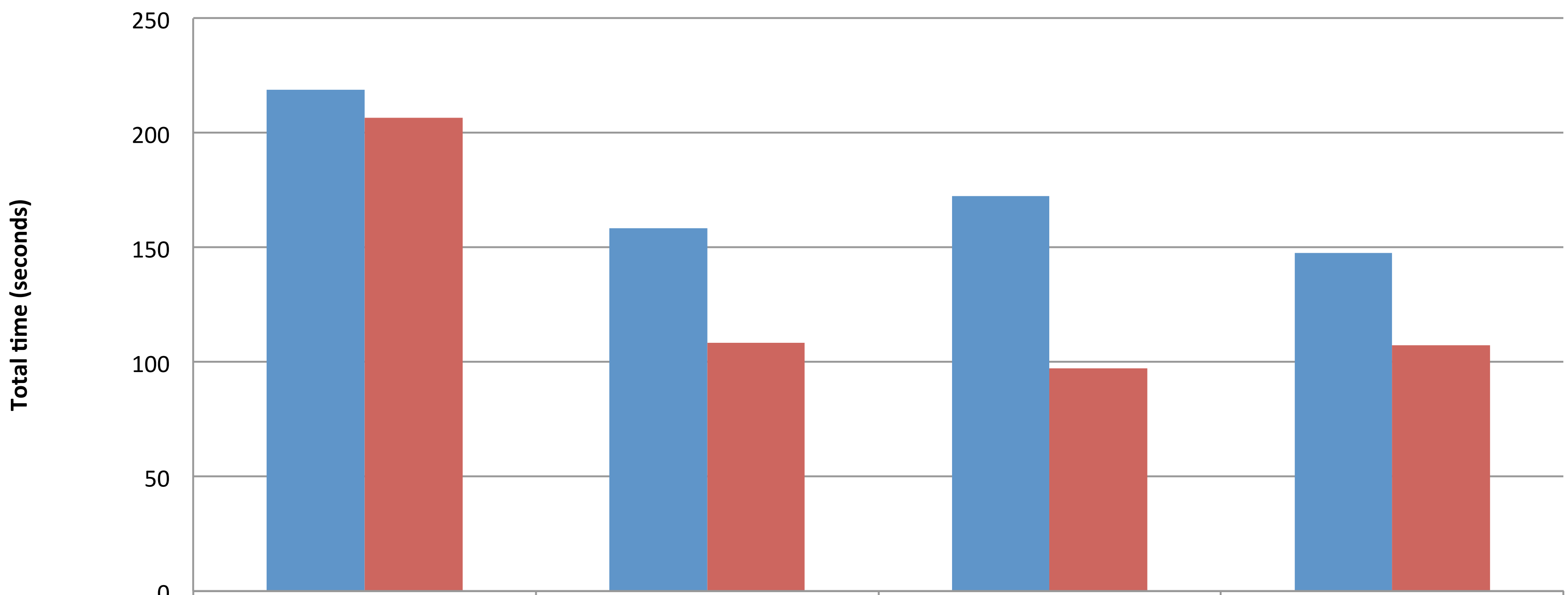
- Hercules
  - persistent key value store based on Memcached
  - On-demand deployment of servers on application nodes
- Data placement over the servers
  - Consistent hashing (original Memcached)
  - Locality-aware (implemented)
  - Load-aware (under implementation)
  - Capacity aware
- New Swift language constructs
  - Soft location: best effort task placement
  - Hard location: enforce data locality



Fusion Linux cluster

- 320 nodes, 2 x quad core, 36 GB RAM
- Infiniband QDR (4 GB/s) and gigabit ethernet
- GPFS: up to 2500 MB/s

MapReduce-like WC application
256 files x 256 MB - 64 GB
Total execution time



	GPFS	Hercules	Hercules Locality - SOFT	Hercules Locality HARD
8x8 workers	218.731	158.384	172.57	147.741
32x8 workers	206.769	108.34	97.32	107.45

Ongoing and future work

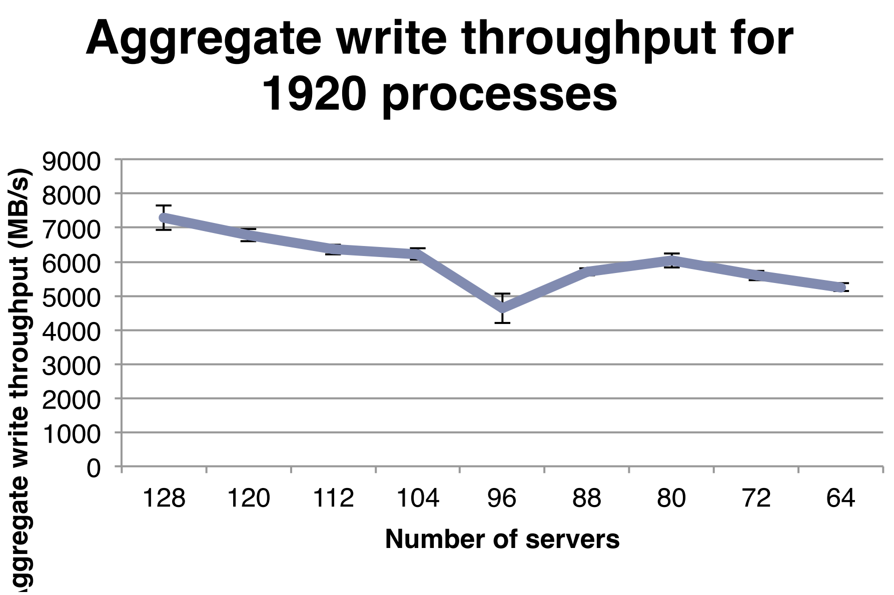
- Model-based autotuning I/O
  - Performance predictability
  - Improve individual models
  - Noise
    - Load and noise modeling for load detection in data staging (multiple servers)
- Data staging coordination
  - Topology-aware server/aggregator placement - JL Colaboration with E. Jeannot, F. Tessier (INRIA), V. Vishnavath (ANL)
  - Multiple stage coordination (aggregation – burst buffer – file system)
  - Load prediction based on Omnisc'IO (Mathieu Dorrier – ANL)
  - Adaptive buffering in parallel applications workflows (Decaf project)
  - Adopt Global Information Bus from Argo and Hobbes (Beacon, Exposé)
  - Need for sub-second monitoring and notification
- Exploit locality in workflows
  - Load-aware placement
  - Tradeoff locality – load balance
- New applications? New architectures? New coordination scenarios?

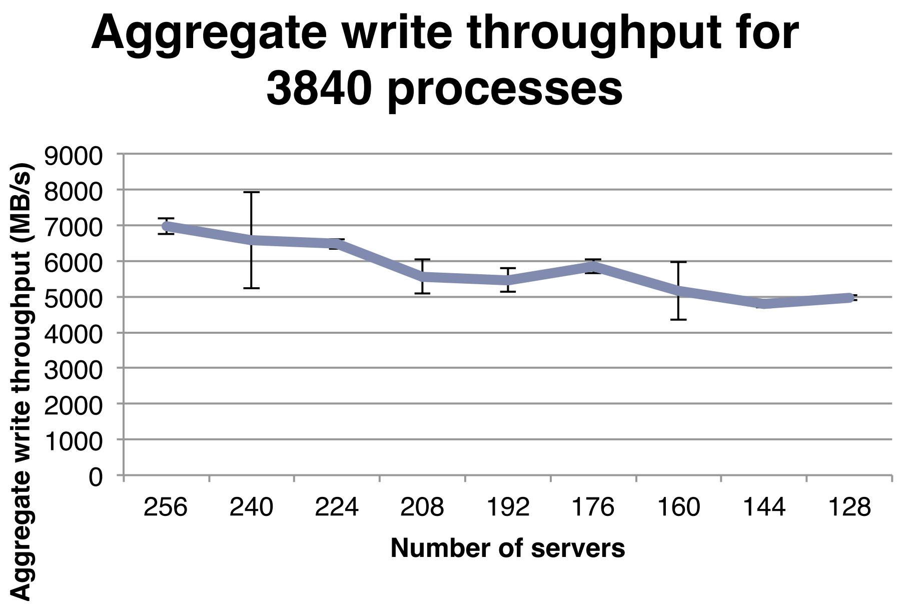
Thank you

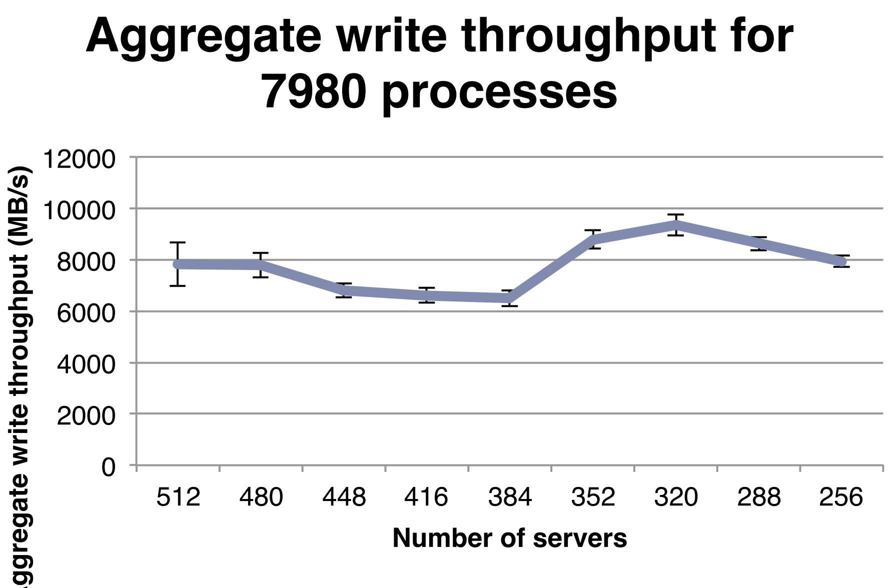
Conclusions - autotuning

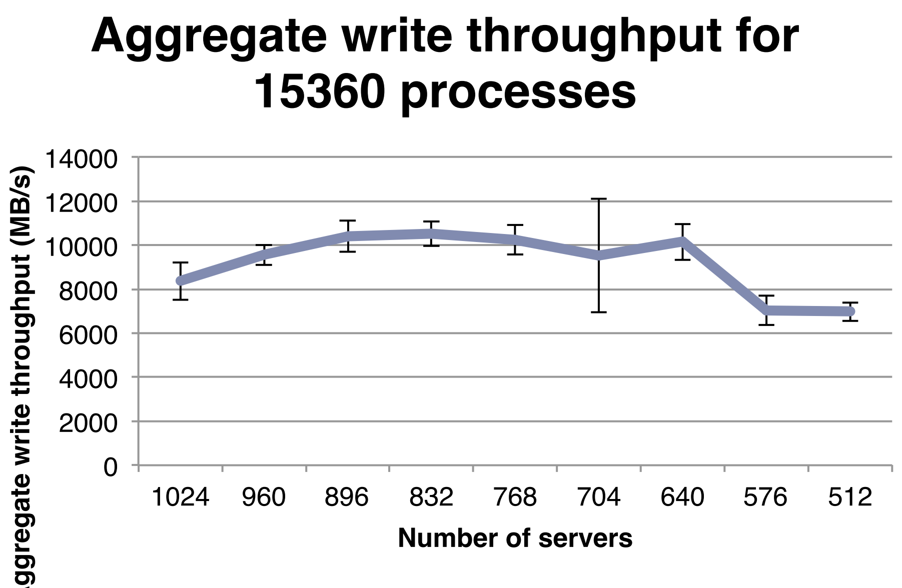
- Automatic parameter configuration
  - Machine learning and hybrid models approaches outperform the default values in most cases
  - Hybrid models higher robustness to noise than pure machine learning
  - Hybrid model do not require application reruns
- Factors that limit efficiency of the I/O stack optimization
  - POSIX consistency semantics: File locking
  - File system noise
  - The lack of information about the state of storage hierarchy (e.g. cached versus non-cached)
  - Performance predictability needs to improve

Scale-down number of servers (1 application)









Dynamic removal of loaded server

- Assumes the availability of a load detection mechanism
- One application process detects a loaded server
- Notifies the application controller
- Application controller informs all node controllers and ask them to prepare to start a new epoch with less servers
- Node controller
  - Decides the last operations to be executed from the current epoch
  - Suspends all operation from the future epoch
  - Updates the server map
  - Notifies the application controller
  - Application controller ask all nodes to start a new epoch
- Each node controller resumes the suspended operations if any

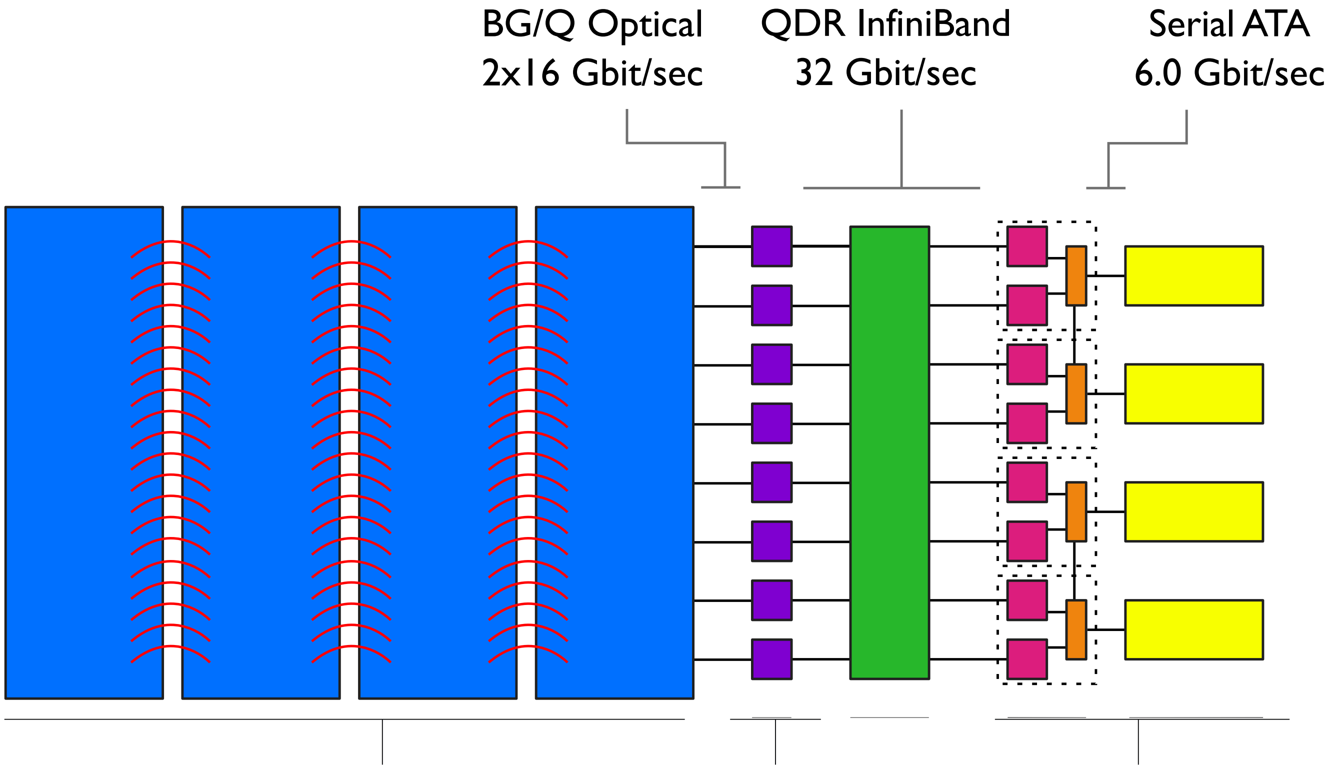
Conclusions - coordination

- Data staging coordination
- Separation of data and control
- Hierarchical controlling
- Significant benefits
  - Load/Fault aware sever-scale down
  - Parallel I/O scheduling
- Scalable load and fault monitoring is required

Conclusions – data locality

- Integration Swift/T - Hercules
- Substantially improves the throughput over shared file systems
- I/O performance scales up with the number of application nodes
- Exploit data locality in workflows
- Less sensitive to file system noise and contention

Vesta Blue Gene/Q system at ANL



2048 compute nodes 1.6 GHz 16 cores 16GB RAM

5D torus network interconnecting compute nodes

1 I/O node per 32 compute nodes

Client (I/O node) cache: 4GB

GPFS 3.5

- Data: 40 NSD SATA drives
- Max disk throughput: 250 MB/s (cache 1000 MB/s)
- Block size: 8MB