CLARISSE: Cross-Layer Abstractions and Run-time for I/O Software Stack of Extreme-Scale Systems

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ARCOS

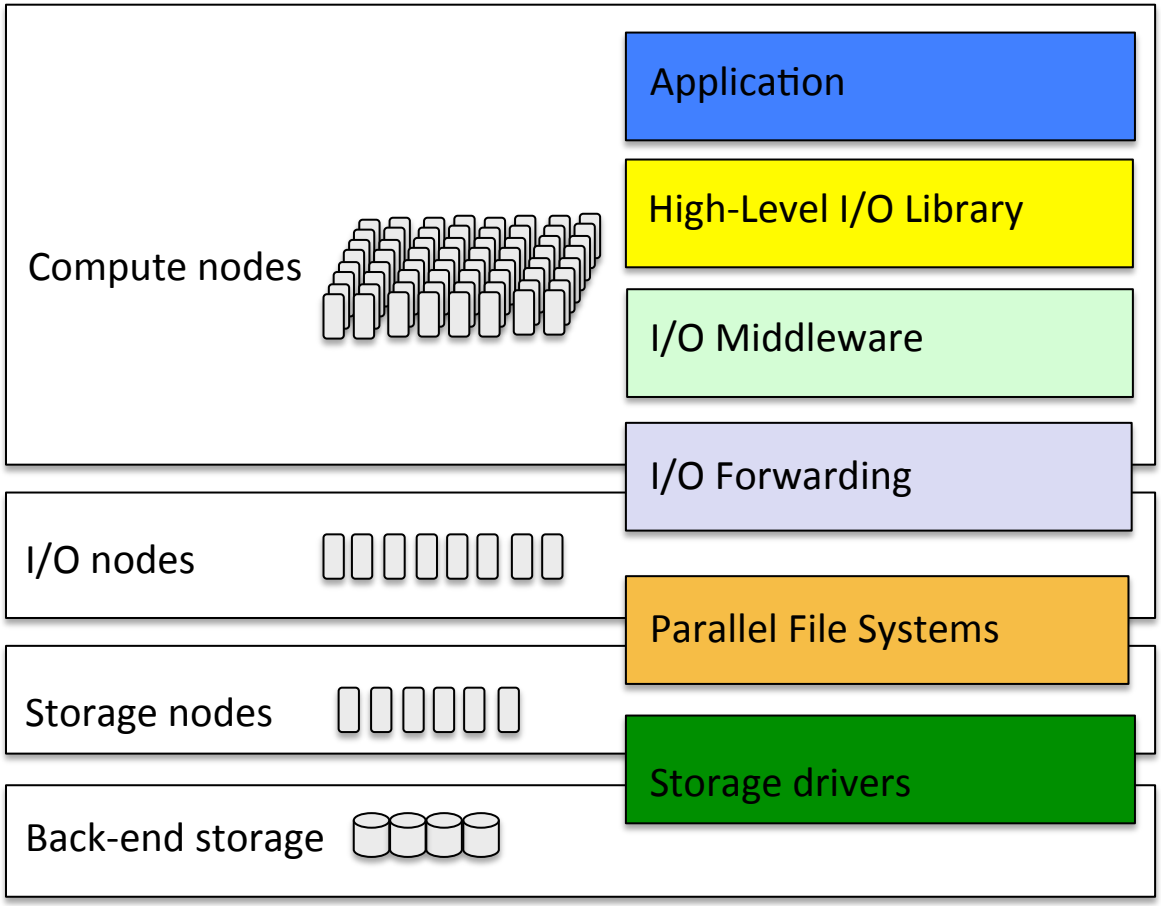
Outline

- Introduction
- CLARISSE overview
- Model-based I/O stack optimization
- Conclusions

Introduction

- Scientific applications (climate, genomics, high energy physics, etc.) process increasingly larger data sets
- Future high scale supercomputers need to deal efficiently with big data
- I/O software stack needs to evolve in terms of performance, programmability, resilience, energy efficiency
- This talk will concentrate on performance

Current problems of storage I/O stack



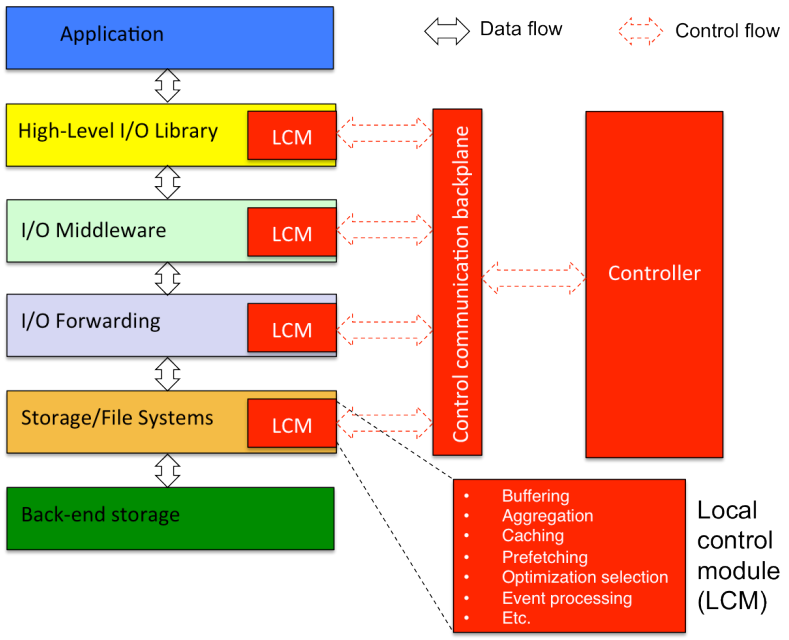
- Long path from compute nodes to final storage impacts performance (latency, throughput)
- Storage I/O optimizations are local: Difficult to perform global optimizations
- Cross-layer control mechanisms are not available (e.g., for data staging, dynamic load balancing, resilience)

CLARISSE overview

- Cross-Layer Abstractions and Runtime for I/O Software Stack (CLARISSE)
  - A 3-year project started October 2013
  - European “Marie Curie” International Outgoing Fellowship
  - Collaboration between ANL and UC3M (Spain)
- Goals
  - Enable global optimizations of the software I/O stack
  - Design novel cross layer control abstractions and mechanisms for supporting data flow optimizations
    - Collective I/O, data staging, exploit data locality

CLARISSE overview

- Global logical view of optimizations space
  - Distributed application of global optimization
  - Facilitate the combination of local optimizations based on a global view
- Cross-layer abstractions and run-time
  - Facilitate the flow of control and data across the I/O stack
  - Decouple the data and control planes
    - Control backplane (e.g. Argo project)
    - Data plane (e.g. Mercury)
- Data flow optimizations
  - Coordinated cross-layer buffering, caching, prefetching
  - Run-time optimizations (e.g. load-aware data staging)



Related work

- Software Defined Networking (e.g. Open Flow): global control based on separation of control and data flow
- I/O Flow (Microsoft Research): A Software Defined Storage Architecture for virtualized data centers
- Fast Forward (Intel et al.): redesign of the storage I/O stack
- Argo (ANL et al.), Hobbes (Sandia et al.): system software for exascale based on an OS/Run-time environment
- Cross-layer optimizations for current I/O stack
  - Parallel I/O autotuning (UIUC & LBNL)
  - Reduce performance interference (CaLCioM, INRIA & Argonne):

Outline

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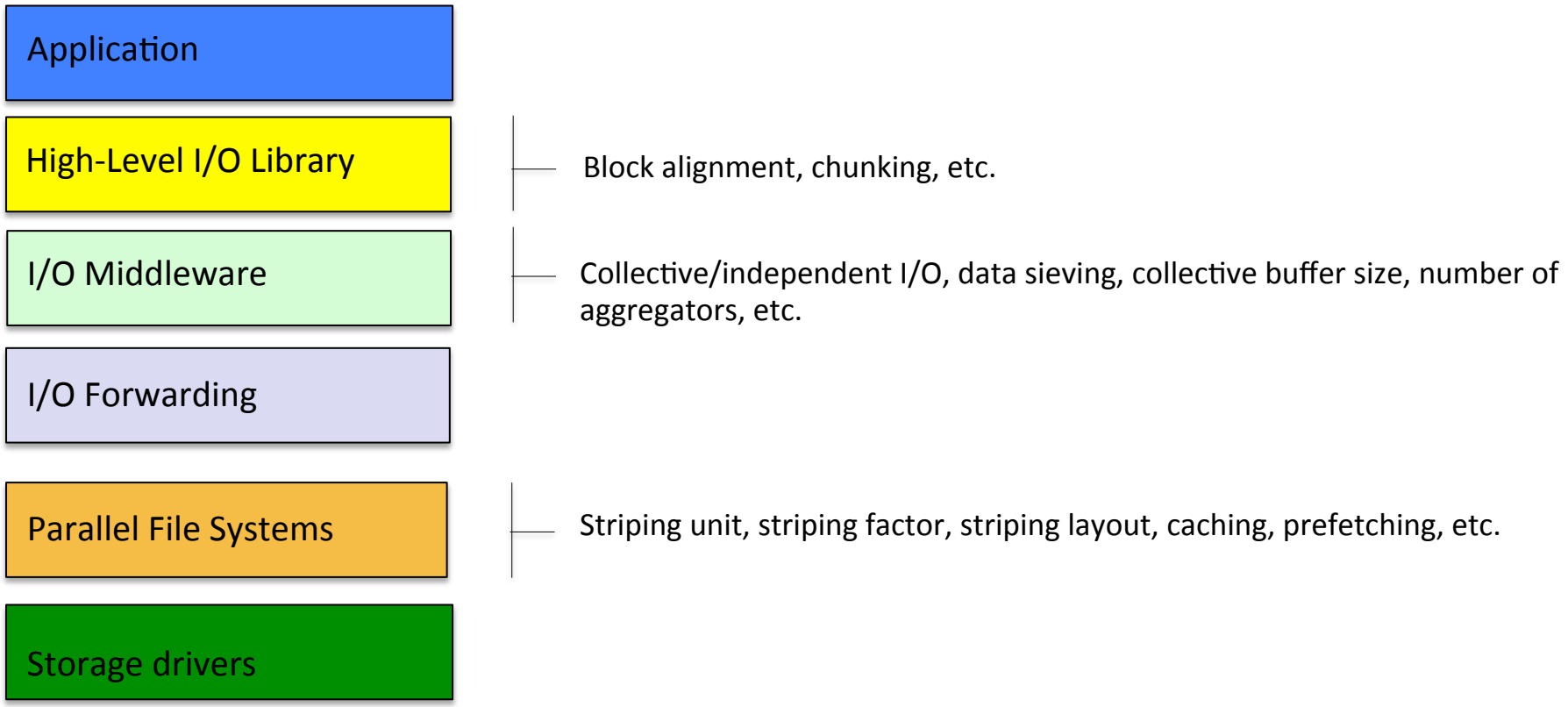
- **I/O stack optimization**
- Conclusions

Optimizing the I/O stack

- How complex is to optimize the current I/O stack?
- How does storage I/O use system resources?
- How predictable is the performance?
- Where are the inefficiencies?
- Which are the causes?
- What do we need to address?

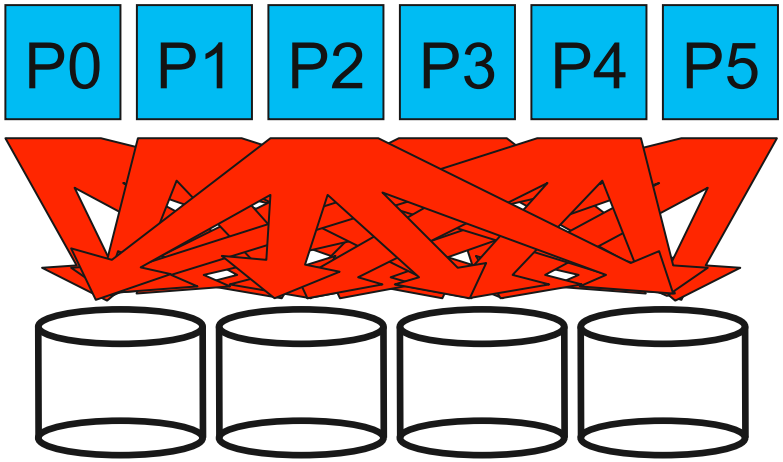
Current I/O stack optimization



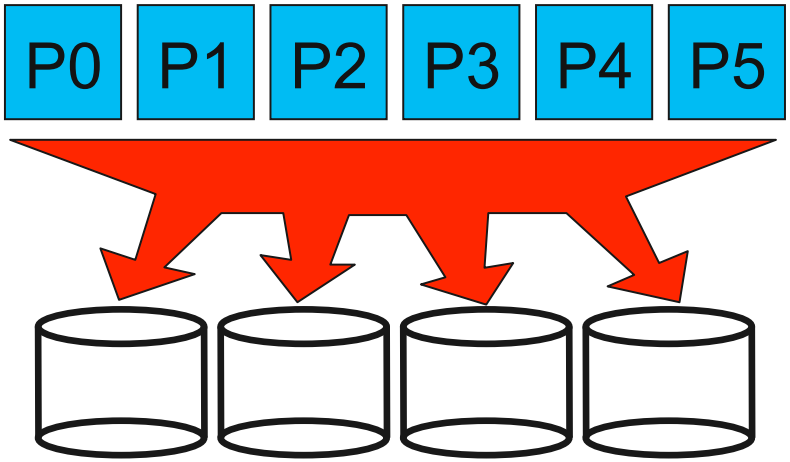
- Huge parameter space
- How can the optimization be approached?
  - domain knowledge, black-box, combination of the two
- Domain knowledge is increasingly harder
  - Which are the hurdles?

Motivational experiment

- IOR benchmark: N processes concurrently write and non-overlapping region to the file system through MPI-IO (MPICH 3.1)
- MPICH 3.1
- Darshan 2.2.8 HPC I/O characterization tool
- Access methods
  - Independent I/O shared file
  - Independent I/O file per processs
  - Collective I/O

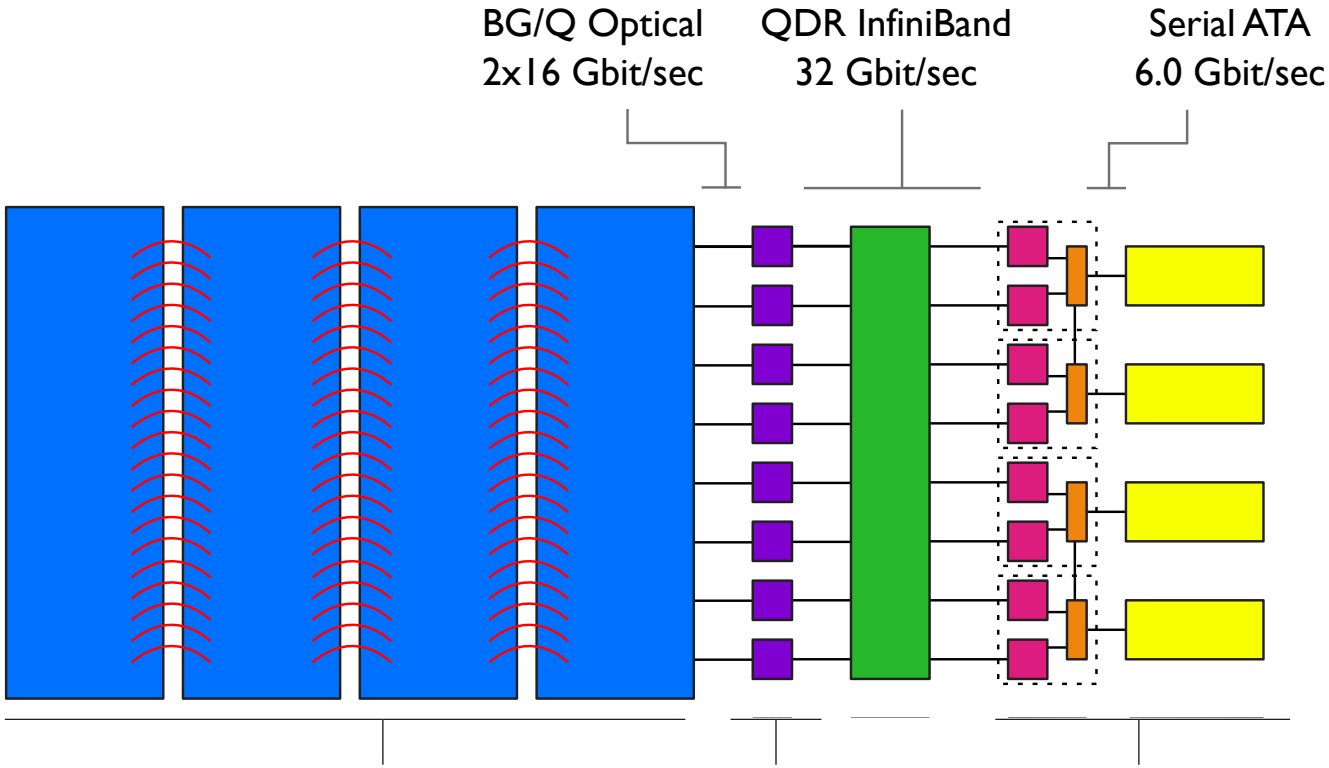


Independent I/O



Collective I/O

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

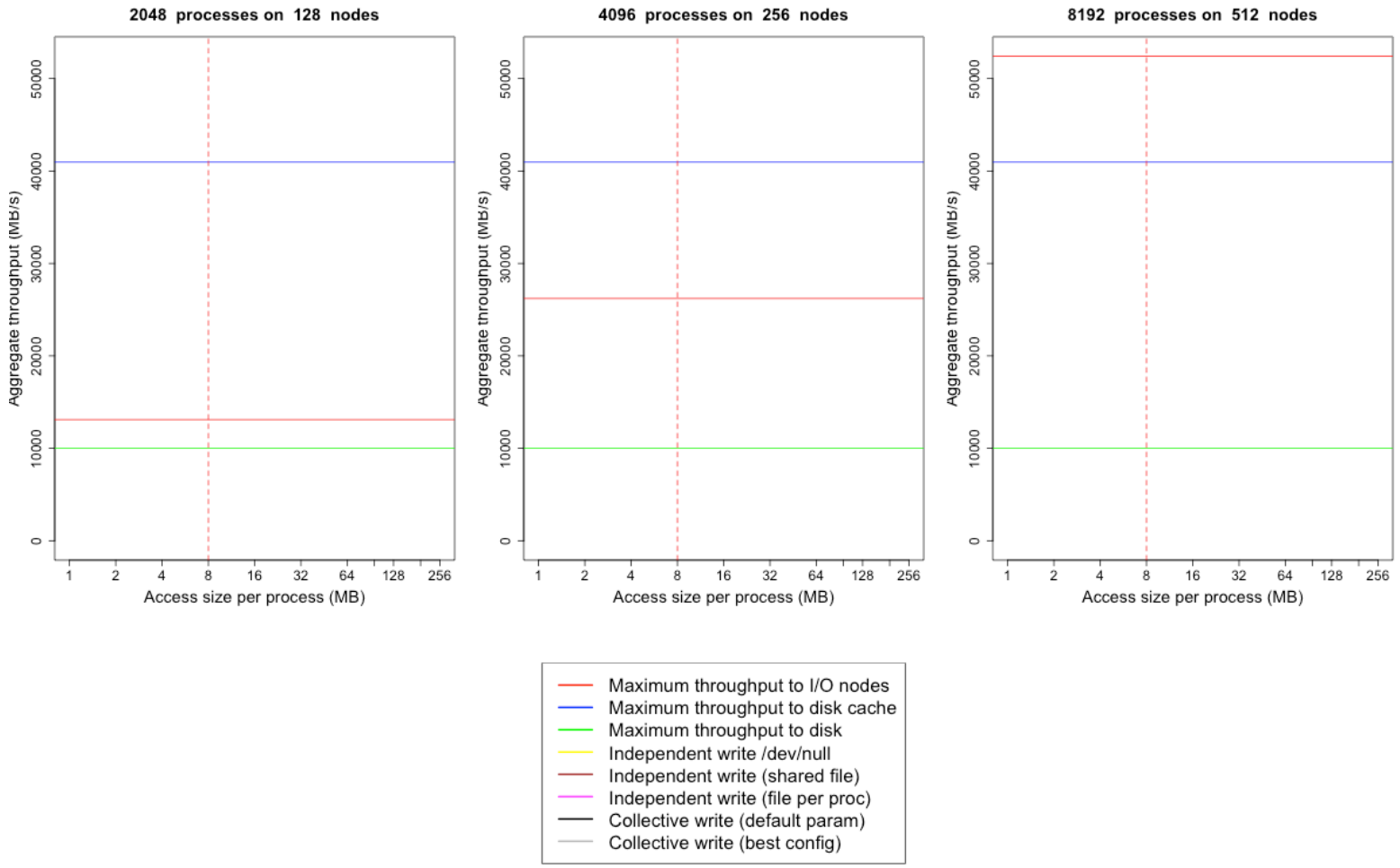
GPFS 3.5

Data: 40 NSD SATA drives

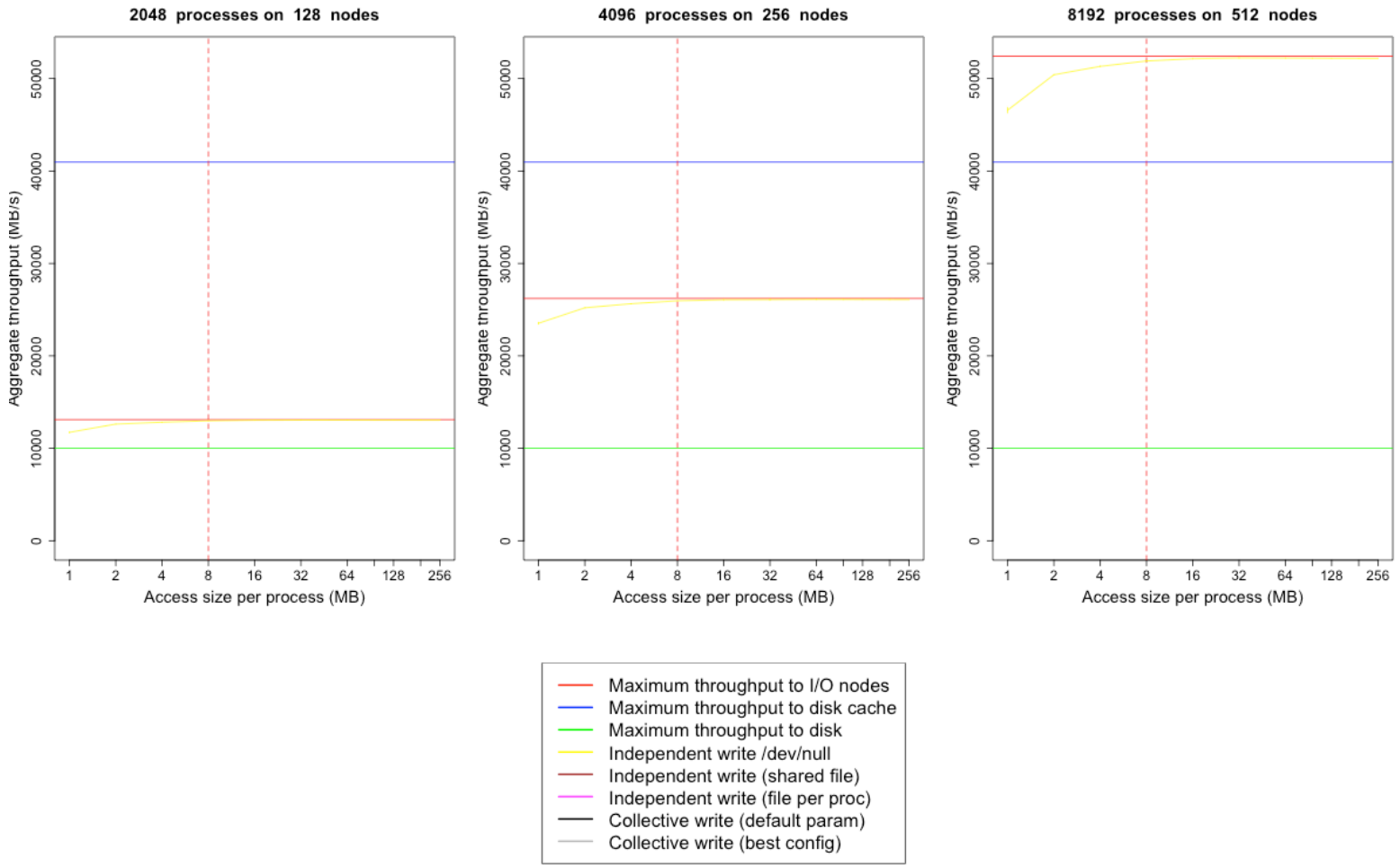
Max disk throughput: 250 MB/s (cache 1000 MB/s)

Block size: 8MB

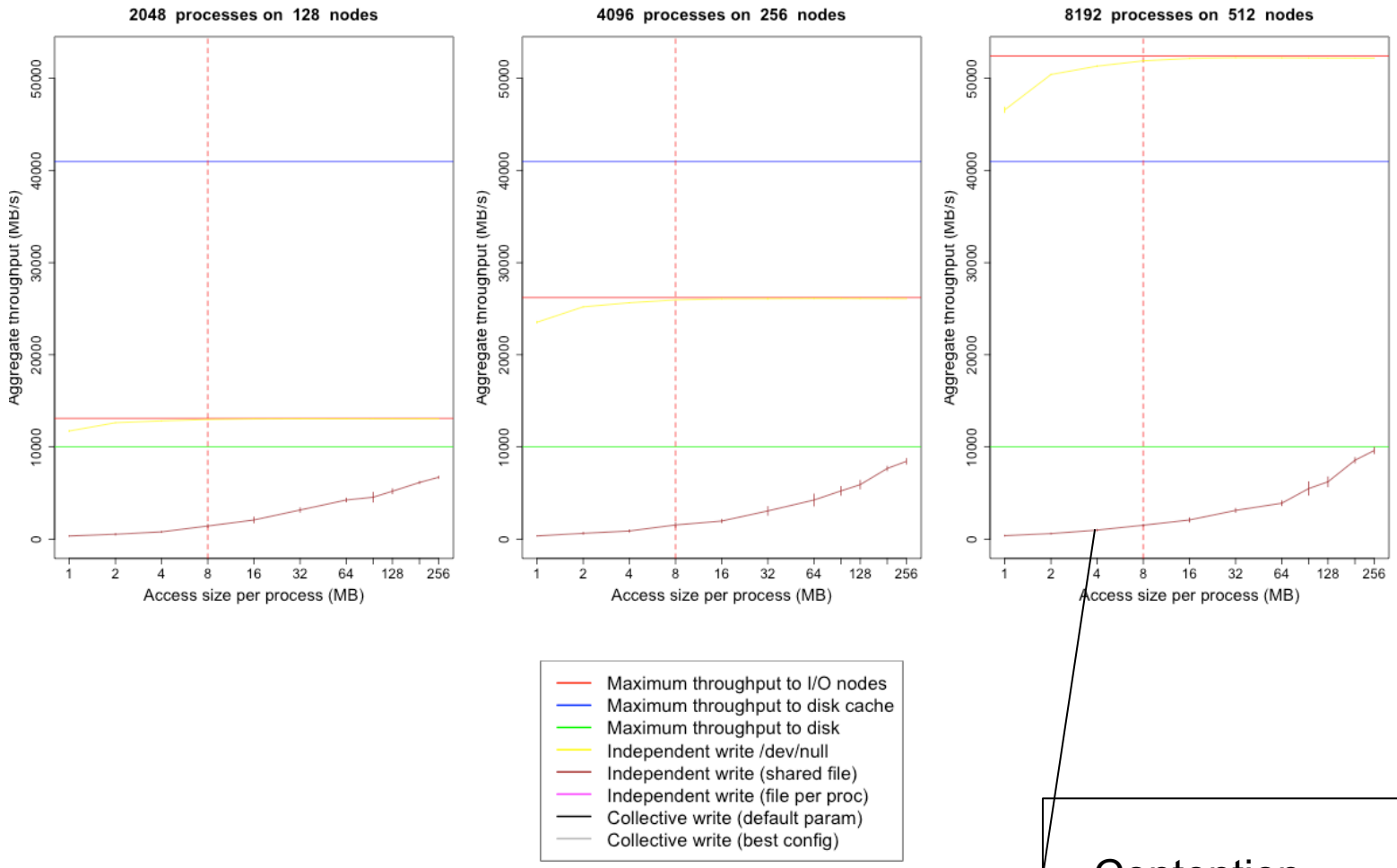
Aggregate write throughput on BG/Q



Aggregate write throughput on BG/Q



Aggregate write throughput on BG/Q



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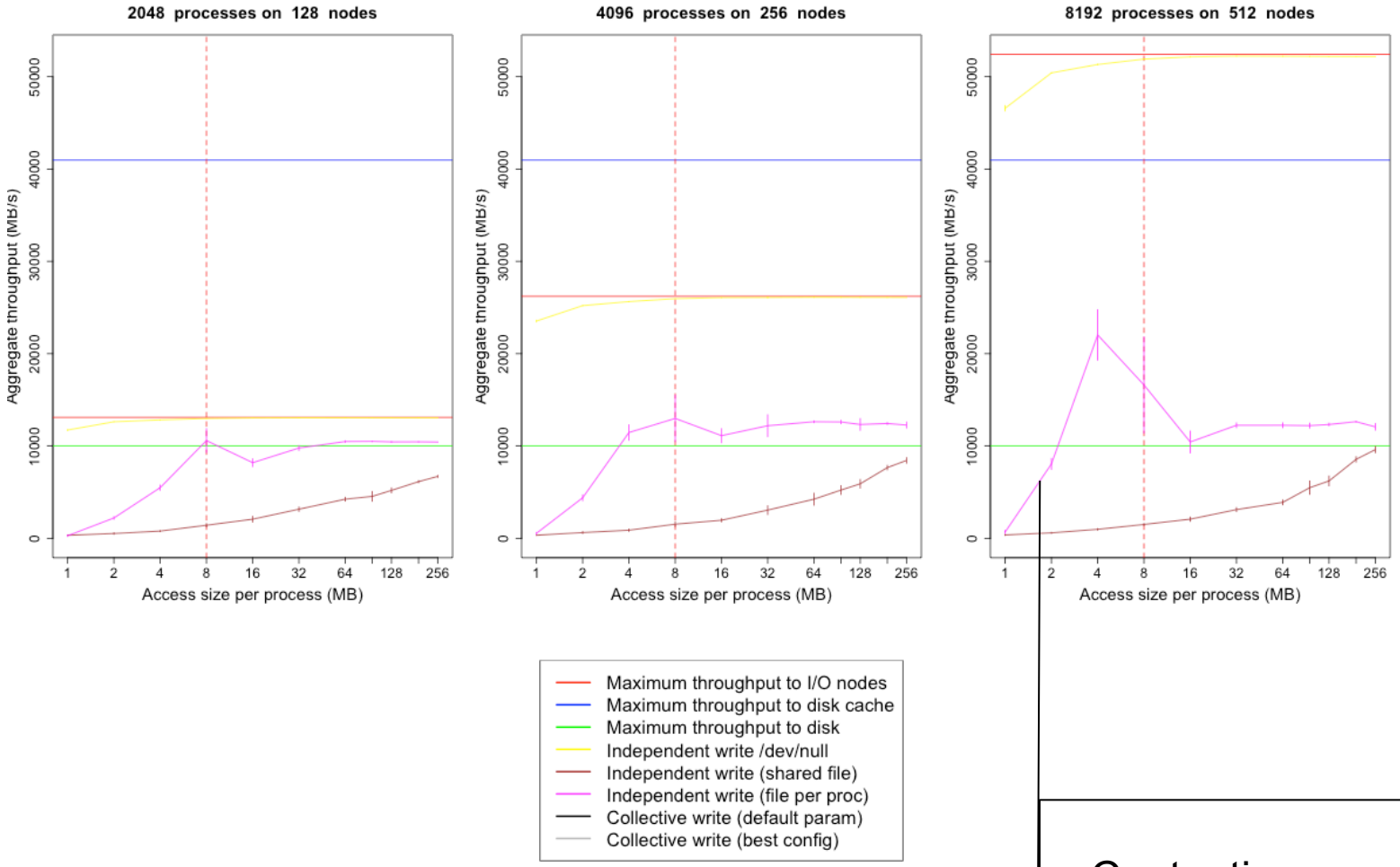
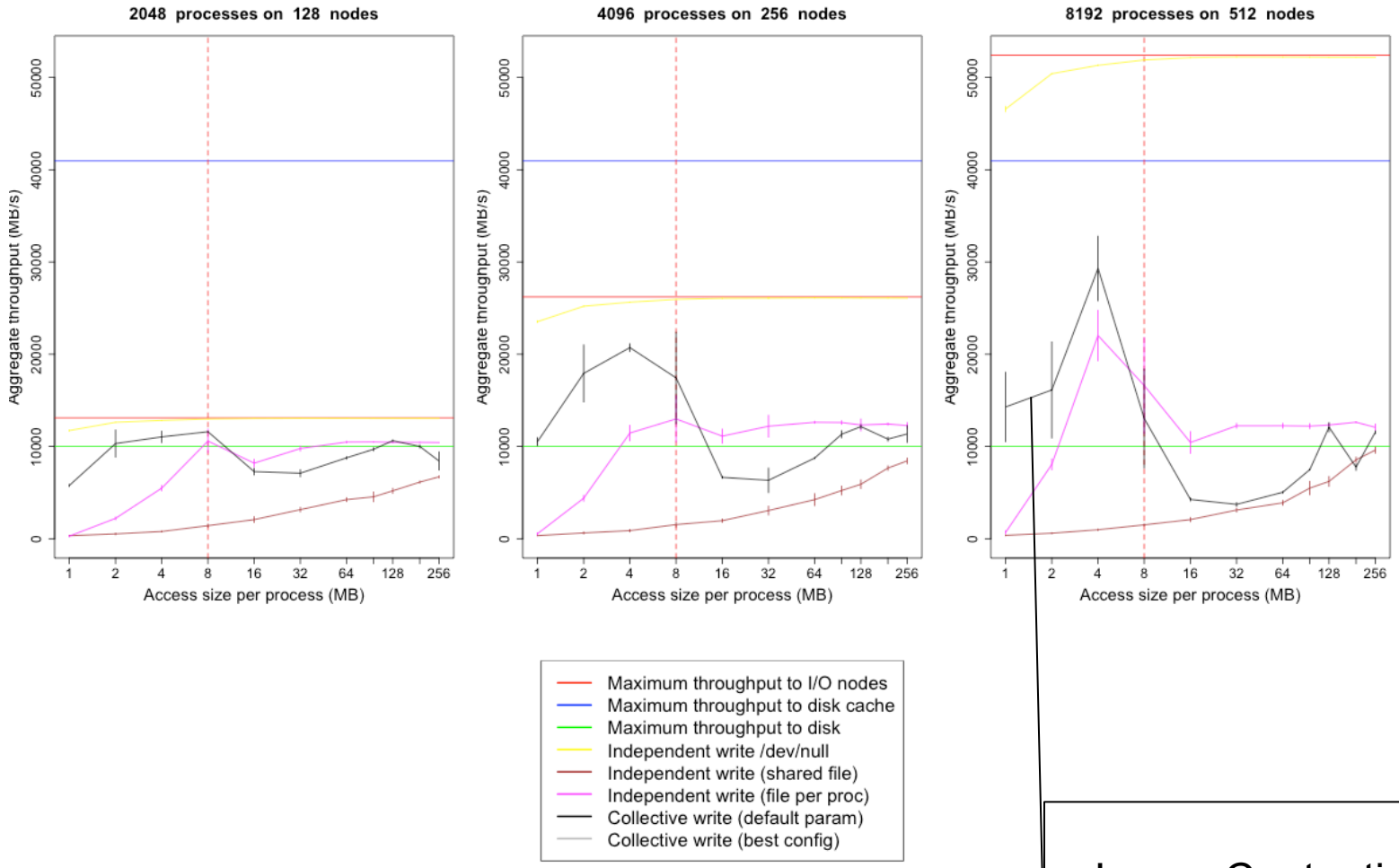
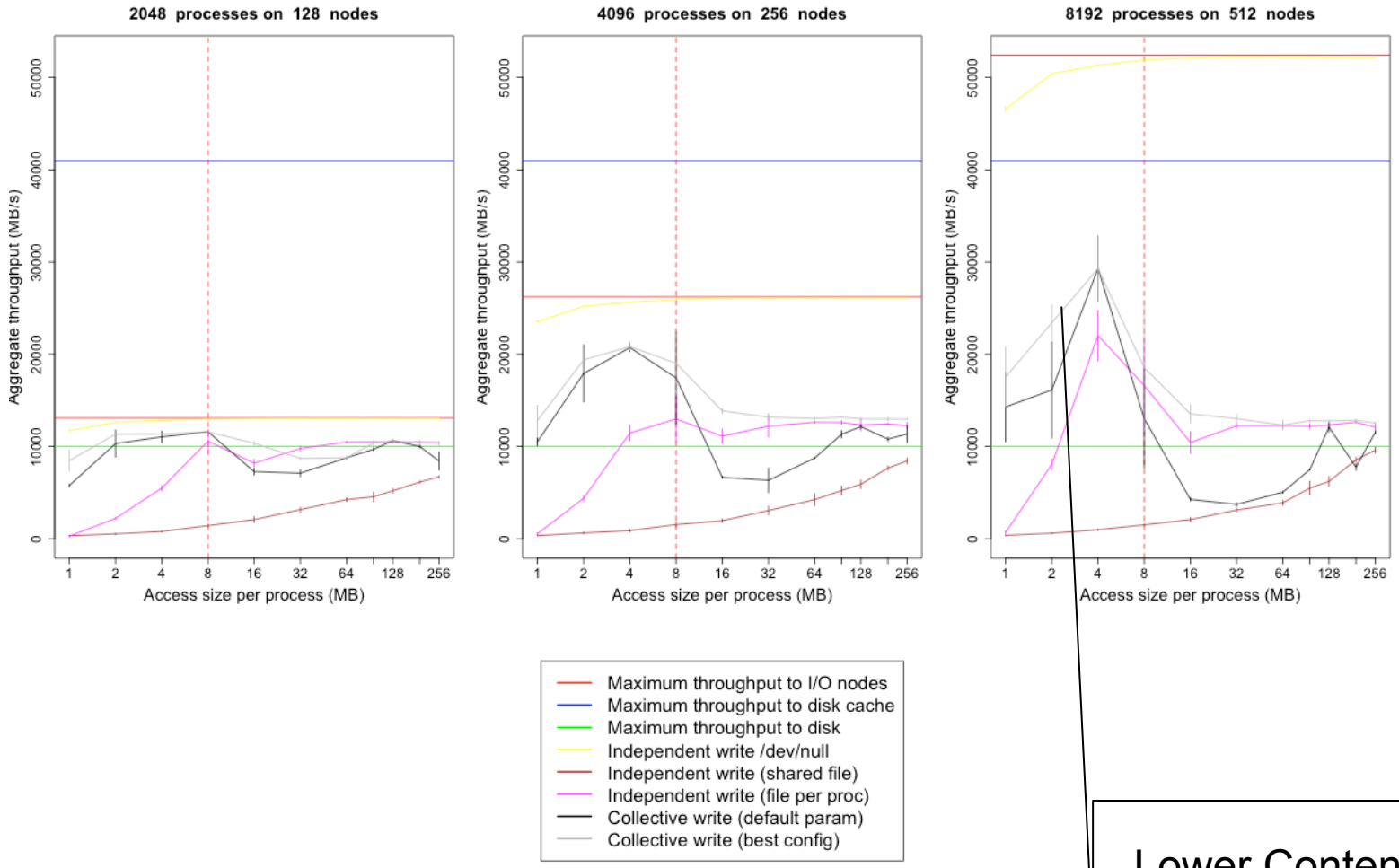


Aggregate write throughput on BG/Q



Lower Contention
GFS locking cost

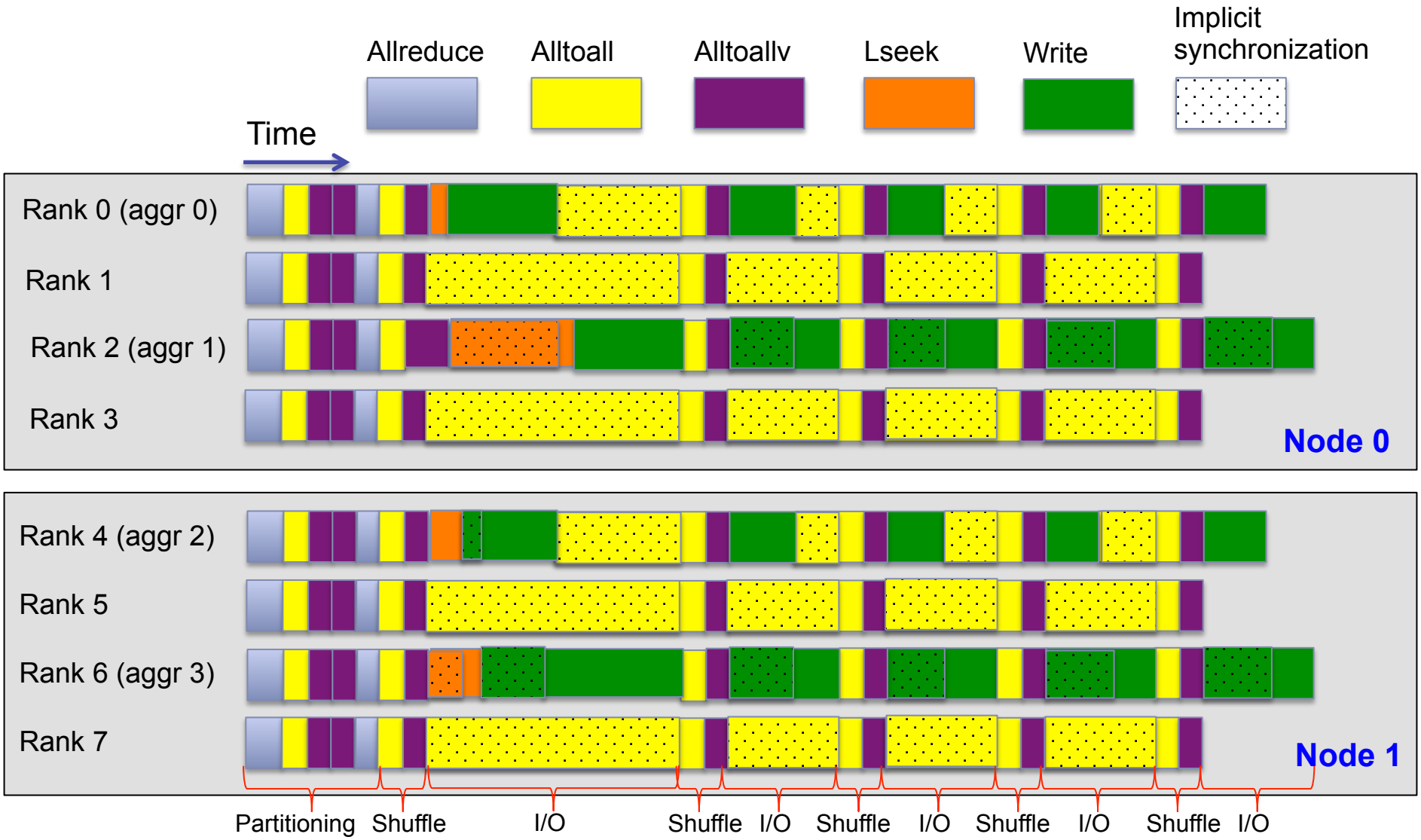
Aggregate write throughput on BG/Q



- Collective buffer size: 8MB, 16MB (default), 32MB
- Aggregators per 128 nodes: 40, 136, 520 (default)

Lower Contention
GFS locking cost
Lower implicit synch.

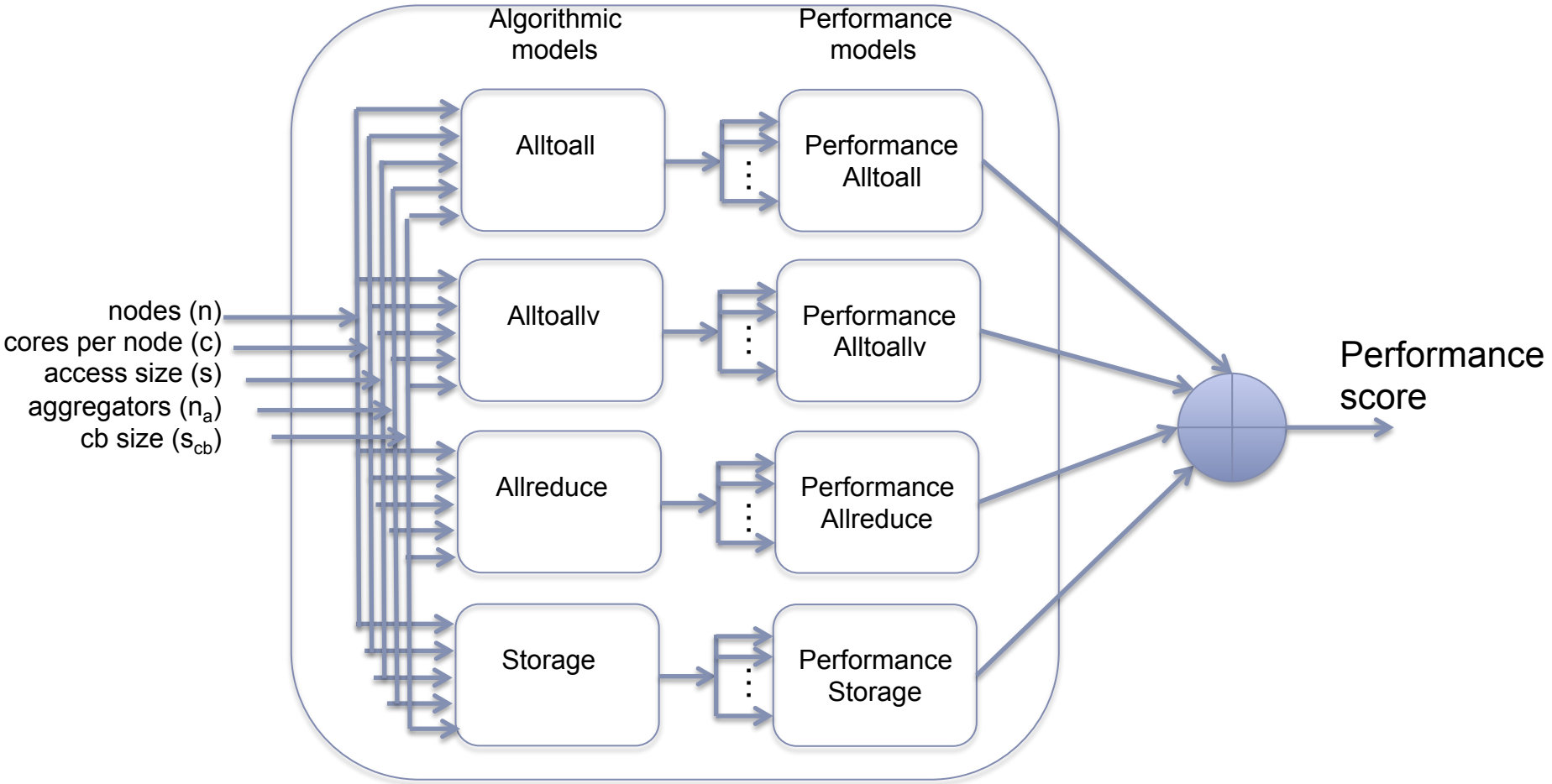
Anatomy of collective I/O



Model for ROMIO Collective I/O

- 5 parameters
  - n: number of nodes
  - c: cores per node
  - s: access size
  - n_a: number of aggregators
  - s_{cb}: collective buffer size
- For contiguous accesses closed form expressions for network and storage activity
  - Number of operations
  - Transfer size
- Goal: predict n_a and s_{cb}

Modeling framework



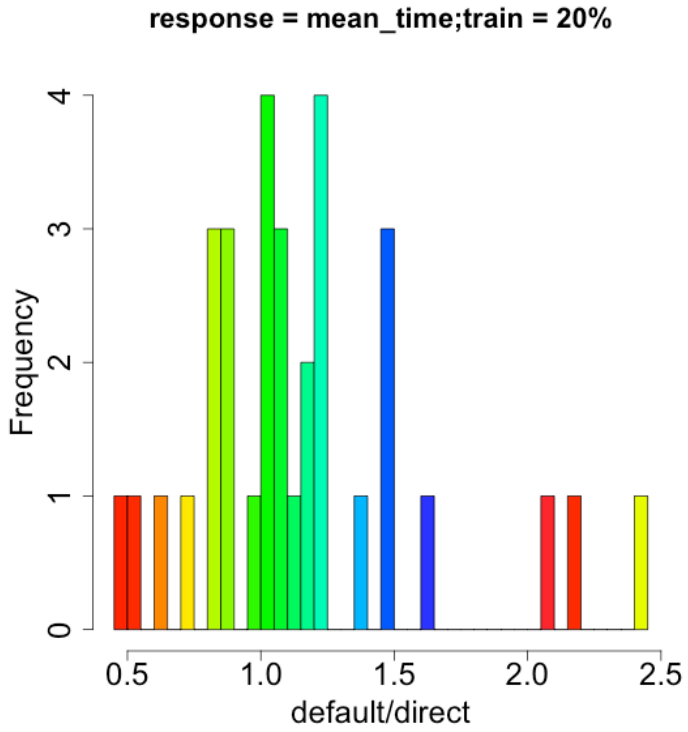
Network and storage performance

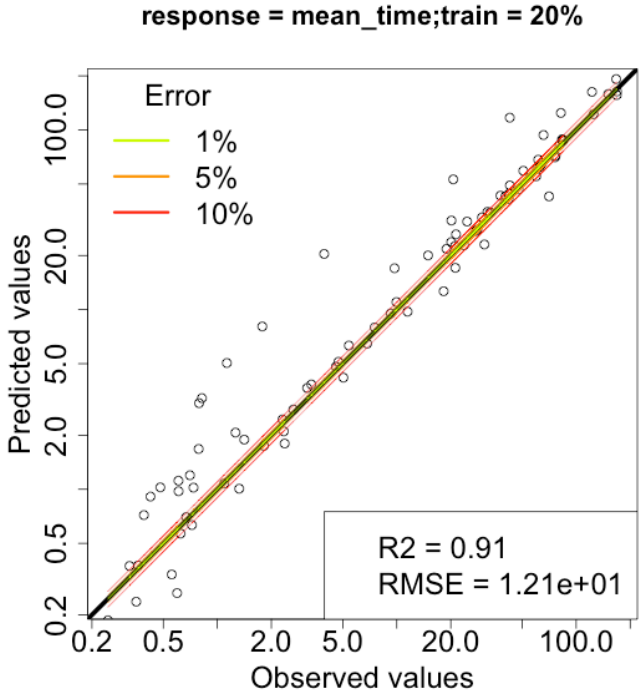
- Given a predictable network and storage performance, it is possible to exactly predict n_a and s_{cb}
- Network performance
  - On BG/Q stable performance
  - Implicit synchronization due to reuse of the collective buffer
    - exclusively due to storage I/O
- Storage performance
  - Storage hierarchy: compute node -> I/O node -> disk caches -> disks
  - Noise due to other applications accessing the file system
  - I/O forwarding layer implementation: calls forwarded from the cores of a compute node are serialized (e.g. a lseek arriving shortly after a write waits until the write is forwarded)
  - Concurrency: parallel access from several aggregators
  - POSIX consistency semantics for sharing the file

Statistical model

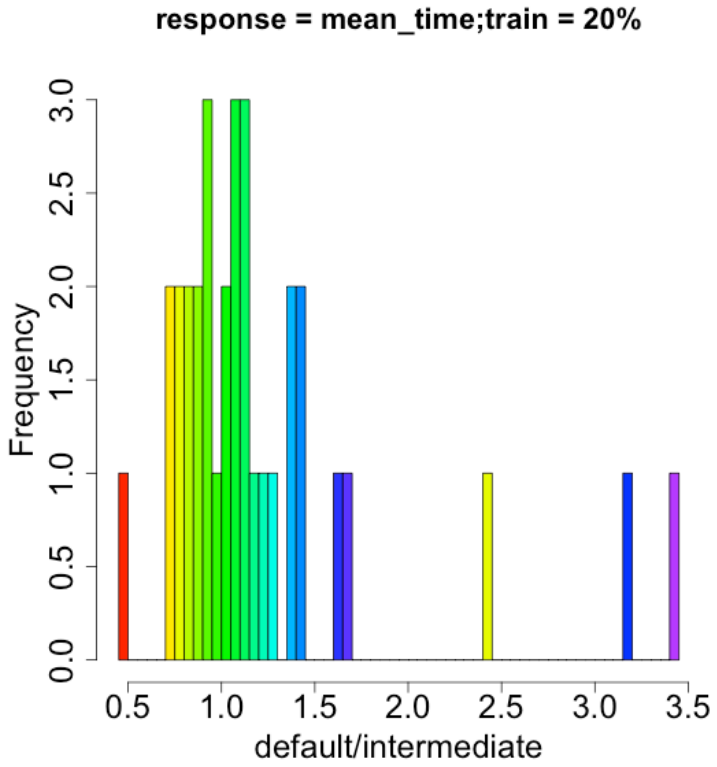
- Data set:
  - Nodes: 128, 256, 512
  - Cores per node: 16
  - Transfer sizes/core (MB): 1, 2, 4, 8,16, 32, 64, 96, 128, 192, 256
  - Collective buffer size (MB): 8, 16 (default), 32
  - Number of aggregators per 128 nodes: 40, 136, 520 (default)
  - 3 x 1 x 11 x 3 x 3 = 297 data points
- Pure statistical model
  - Boosted regression trees (cubist)
  - 20% training set
  - 80% testing set (including the optimal parameters)
- Mixed model
  - Analytical models for predicting the number of operations and operation size
  - Statistical models for the performance of individual operations

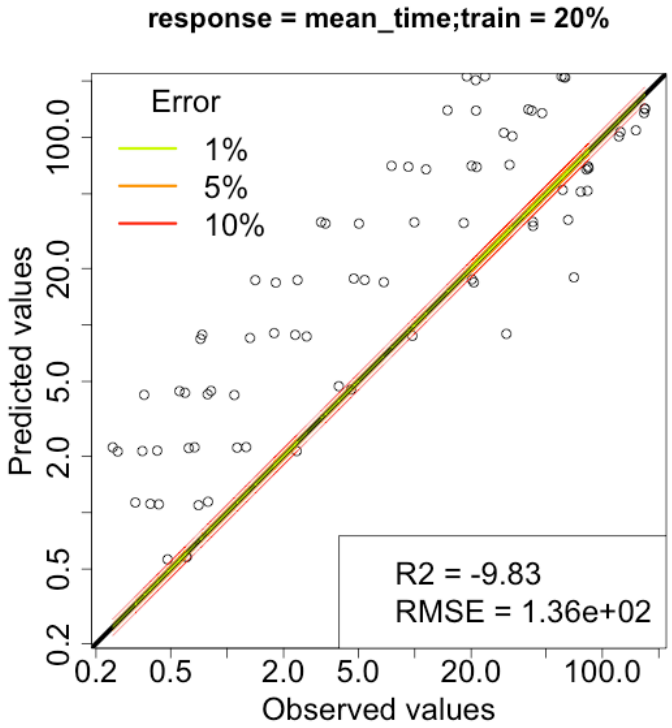
Pure statistical model





Analytical/statistical model





Conclusions

- Automatic parameter configuration
  - Black box modeling offers a limited benefit
  - Mixed model: Unstable performance of storage system a great hurdle
    - Having the complete knowledge of number of operations and operation size
    - But same operation radically different
- Factors that limit efficiency of the I/O stack optimization
  - Serialization in the I/O forwarding layer
  - File system noise
  - Implicit synchronization
  - POSIX consistency semantics
  - The lack of information about the state of other stack layers

Conclusions

- What is needed?
  - Better I/O scheduling
    - De-serialization of concurrent independent operations
    - Aggregation
  - Asynchrony (throughout the data stack and storage hierarchy)
  - Burst buffers (probably on I/O nodes)
  - An adequate consistency semantics for HPC (get rid of POSIX)
  - Mechanisms for facilitating the global reasoning about the optimization process

Thank you