Towards Parallel Access of Multi-dimensional, Multi-resolution Scientific Data

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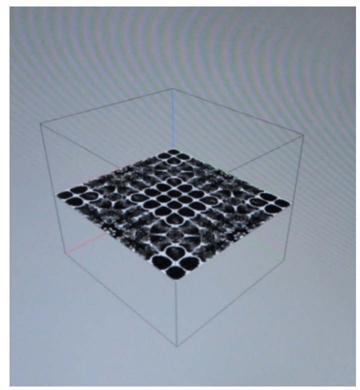
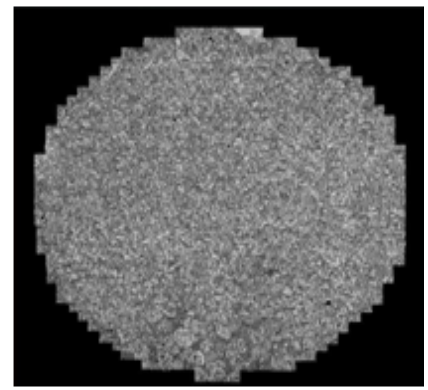
ViSUS : IDX Data Format

ViSUS : Technology to Analyze and Visualize Multi-dimensional data
IDX : Data type generated by ViSUS i/o API

iPhone Application



Visualizing 3D Data



Visualizing 2D Data

Applications in Digital Photography

IDX Data Type

- ***Cache Friendly***
  - **H**ierarchical **Z** Ordering
- ***Progressive access***
  - Multiple Levels of Resolution

HZ Ordering

Input Data stored in normal XY Ordering

13	12	14	15
8	9	10	11
4	5	6	7
0	1	2	3

XY Location

IDX Data Stored in HZ ordering

10(4)	11(4)	14(4)	15(4)
2(2)	5(3)	3(2)	7(3)
8(4)	9(4)	12(4)	13(4)
0(0)	4(3)	1(1)	6(3)

Assigned HZ Order (Level)

HZ Order = compute HZ(X, Y)

HZ Level = floor ((log$_2$ (HZ Order))) + 1

HZ Ordering

Input Data stored in normal XY Ordering

IDX Data Stored in HZ ordering

13	12	14	15
8	9	10	11
4	5	6	7
0	1	2	3

XY Location

10	11	14	15
2	5	3	7
8	9	12	13
0	4	1	6

Assigned HZ Order (Level)

4	4	4	4
2	3	2	3
4	4	4	4
0	3	1	3

HZ Level

HZ Order = compute HZ(X, Y)

HZ Level = floor ((log$_2$ (HZ Order))) + 1

IDX File Format

Progressive access : Multiple Levels of Resolution

Level 0

Level 1

Level 2

Level 3

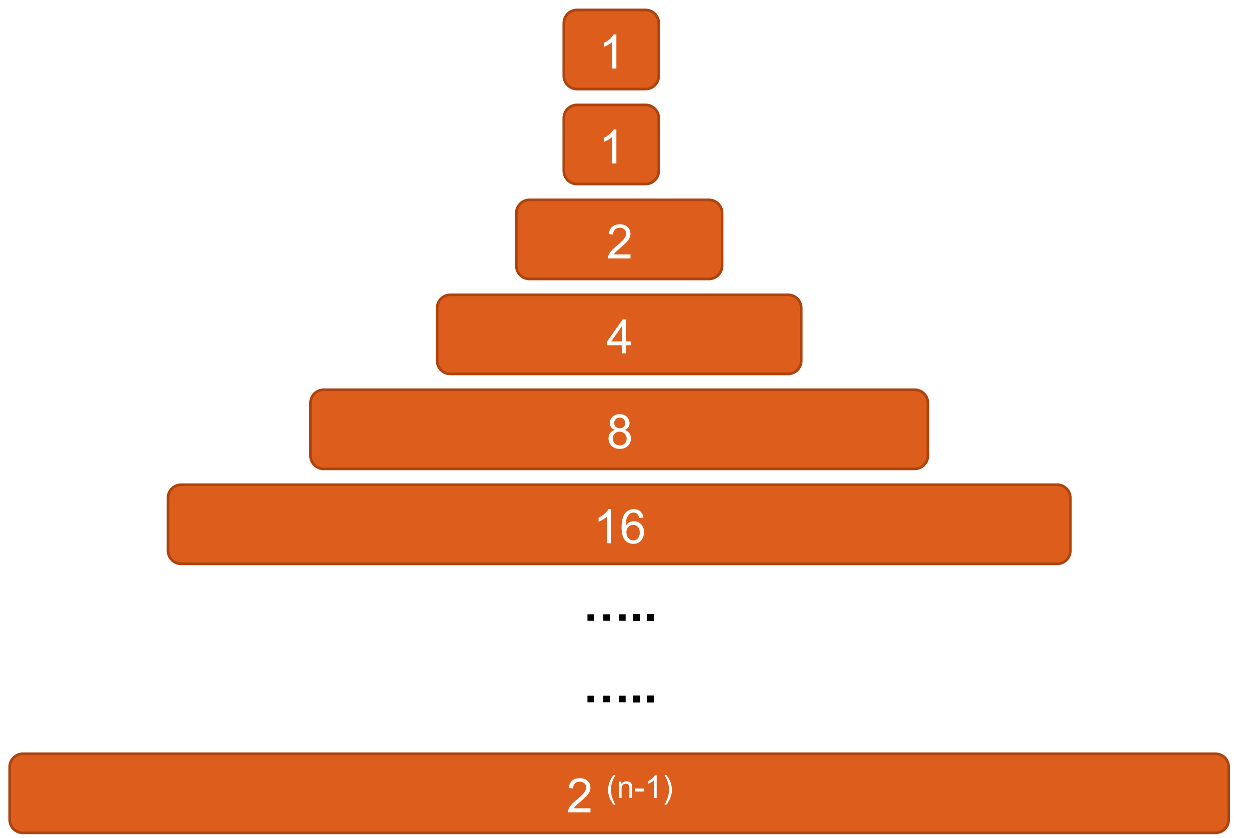
Level 4

Level 5

…..

…..

Level **n**



Motivation: IDX in HPC Application

HPC simulations generate enormous amounts of **Scientific Data**

Analysis and visualization of the data is a limiting factor in scientific research

IDX data format is promising in this scenario

- Interactive navigation of simulation data.
- Real-time Zoom in on regions of interest.

Motivation: Parallelizing ViSUS

Problem with current implementation

Existing tools for writing/reading IDX data only provides a serial interface.

HPC applications fails to utilize available parallel I/O resources.

Solution

Develop methods for writing IDX data in parallel

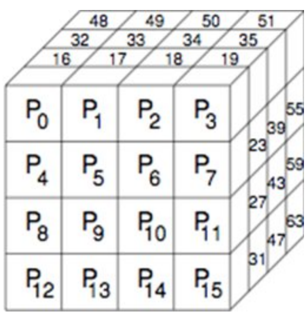
Enable HPC applications to write IDX data with scalable performance

Blue Gene/P : Making ViSUS scalable to run on Large Parallel Machines

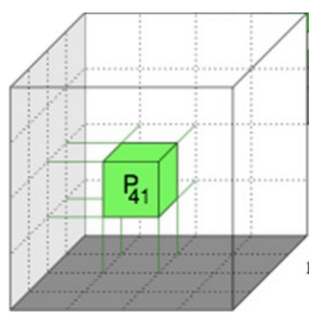
ViSUS : Serial Writer

Parallel application using ViSUS I/O to write directly into IDX format.

Divides the entire data volume into smaller 3D chunks



Each process independently writes to an IDX data set



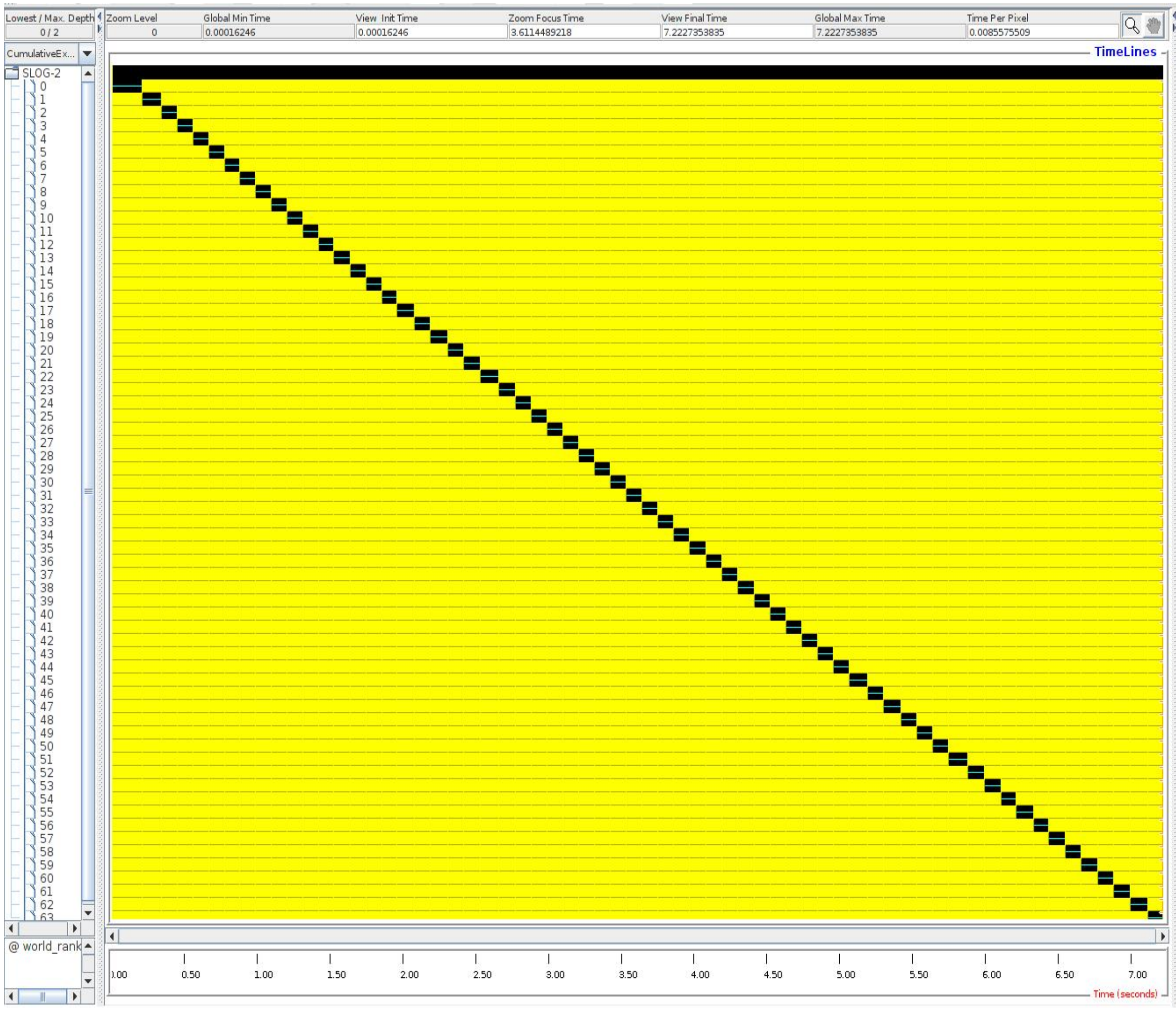
Visus Writes

Process with rank **r** writes to an IDX file only after the process with rank **r–1** has finished writing.

The processes cannot write concurrently due to conflicts in updating metadata and block layouts.

ViSUS Serial Writer : Performance

Processes



Time

MPI_Barrier

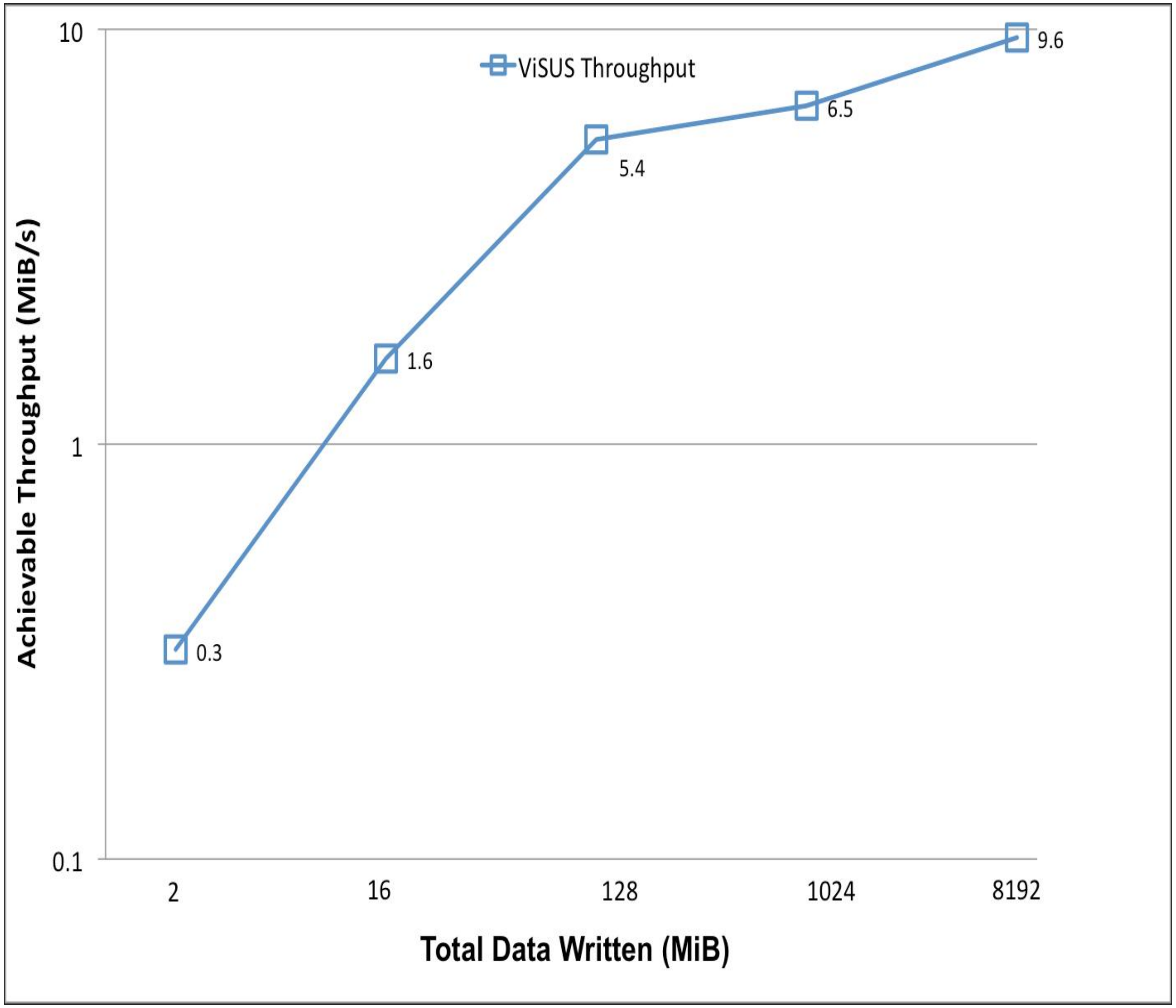
ViSUS Write

64 Processes : 2 MiB

Total Time = 7 Sec

Speed = 2.9 MiB/ Sec

ViSUS Serial Writer : Throughput



Best performance : 9.5MiB/s (8 GiB)

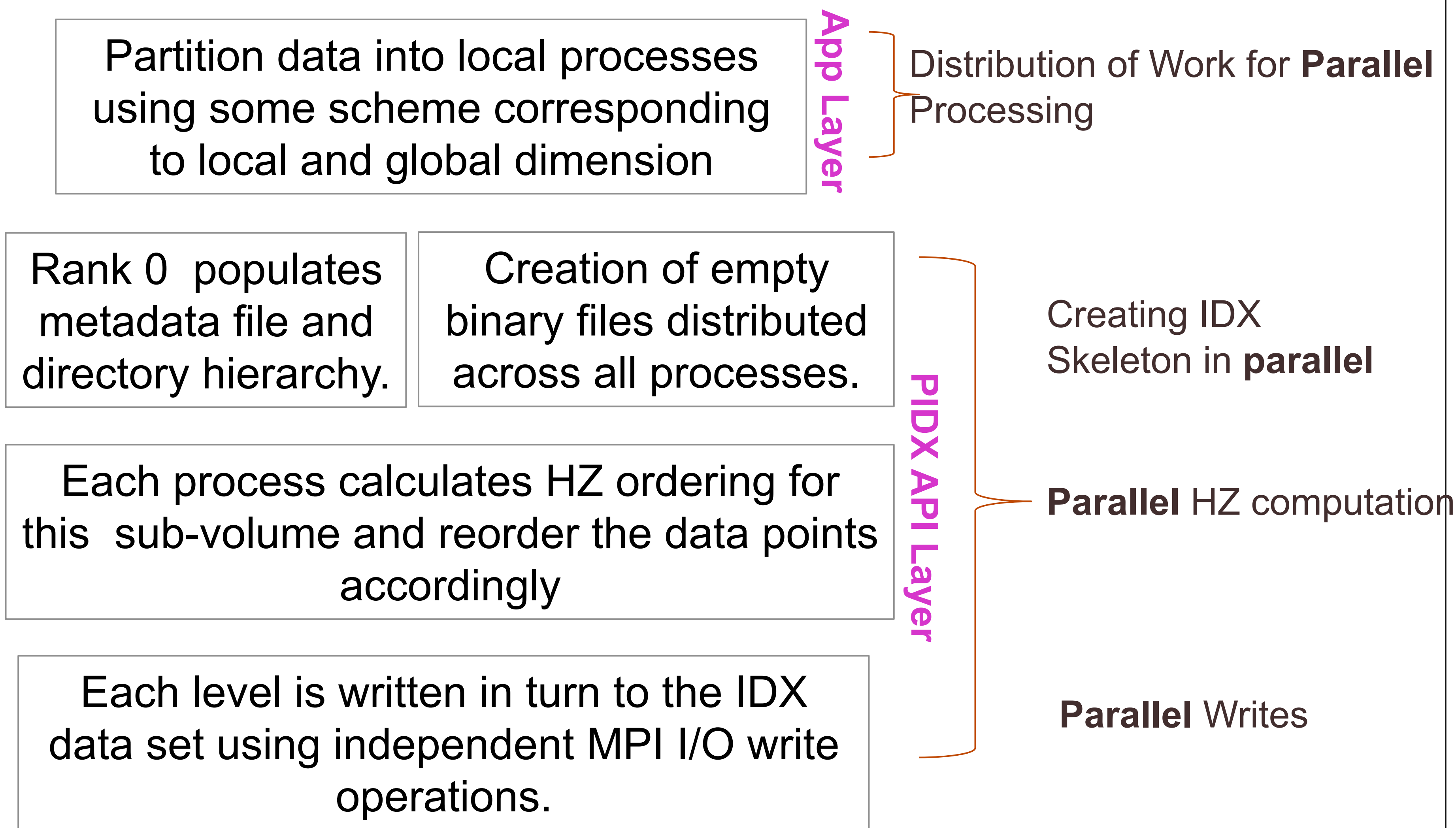
IOR Maximum Throughput: 218MiB/s (8GiB)

(4% of the max throughput)

PIDX : Prototype Parallel IDX Write API

- Concurrent I/O to an IDX data set.
- Functions patterned after ViSUS for ***creating***, ***opening***, ***reading***, and ***writing*** IDX data sets.
- PIDX functions performs collective operation by accepting an MPI communicator as an argument.

Parallel IDX Write



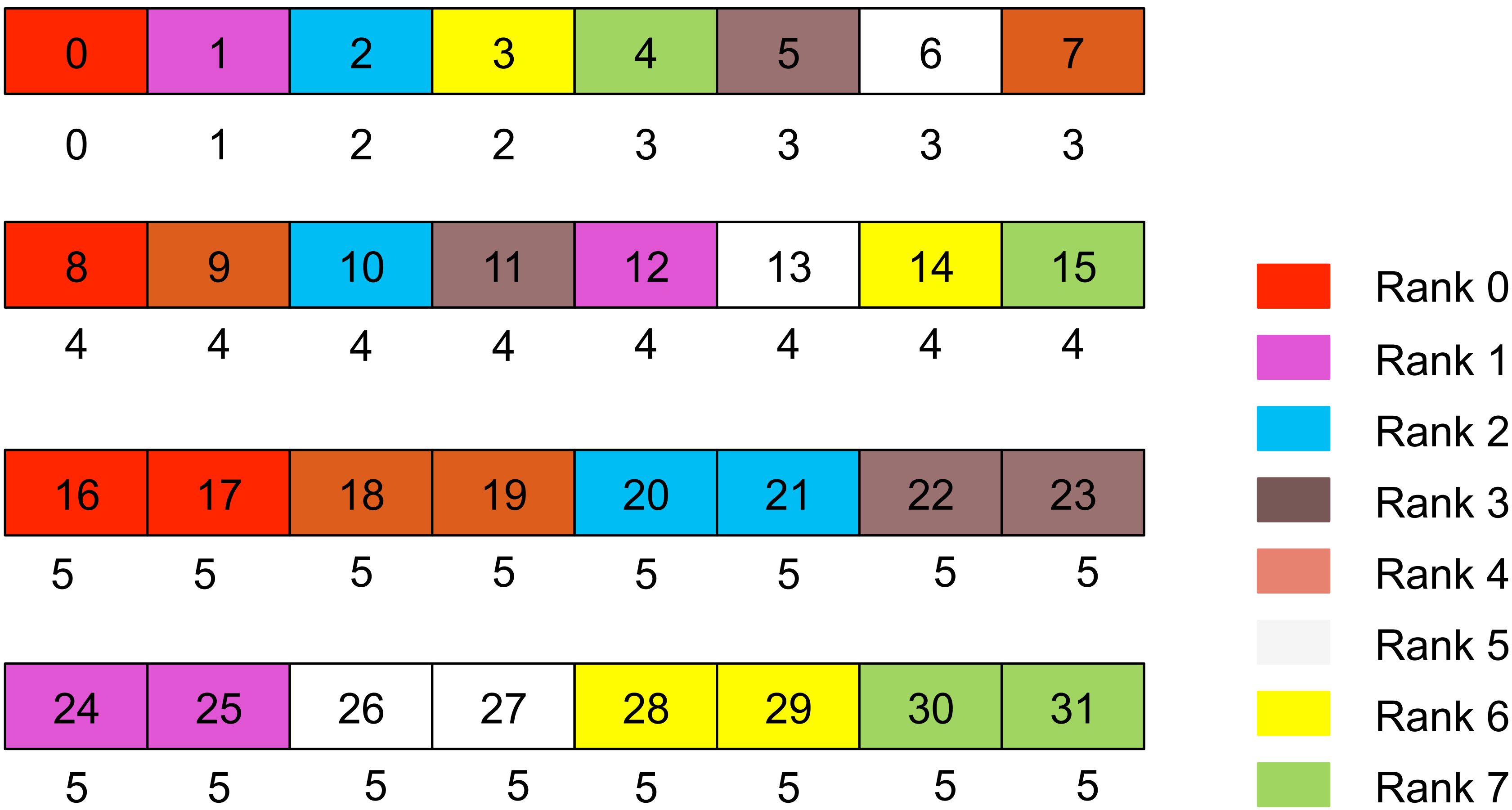
IDX : File Structure

0	1	2	3	4	5	6	7	HZ Order
0	1	2	2	3	3	3	3	HZ Level
8	9	10	11	12	13	14	15	
4	4	4	4	4	4	4	4	
16	17	18	19	20	21	22	23	
5	5	5	5	5	5	5	5	
24	25	26	27	28	29	30	31	
5	5	5	5	5	5	5	5	
32	33	34	35	36	37	38	39	
6	6	6	6	6	6	6	6	
40	41	42	43	44	45	46	47	
6	6	6	6	6	6	6	6	
48	49	50	51	52	53	54	55	
6	6	6	6	6	6	6	6	
56	57	58	59	60	61	62	63	
6	6	6	6	6	6	6	6	

64 Elements
7 Levels (0 inc)

PIDX : Discontinuous in File System

64 Elements **7** Levels (0 inc) **8** Processes **8** Elements / Proc



PIDX : Discontinuous in Memory

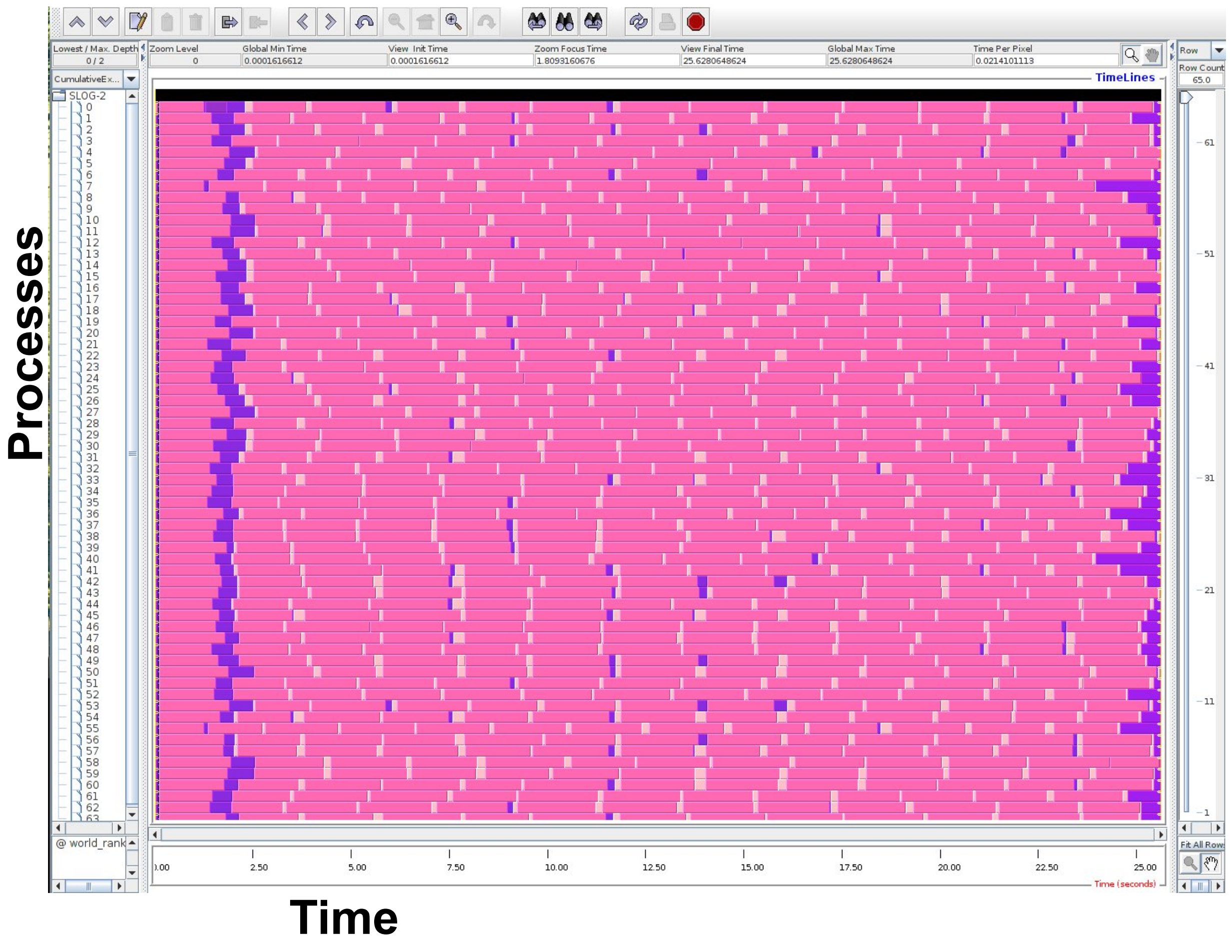
HZ Order	0	…	8	…	16	17	…	32	33	34	35
HZ Level	**0**		**4**		**5**	**5**		**6**	**6**	**6**	**6**

Data arrangement of **Rank 0**

Data is discontinuous in memory as well

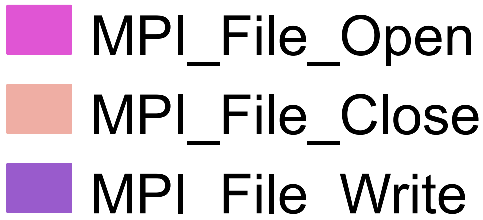
Continuous chunks of elements exists per level

ViSUS Parallel Writer : Performance



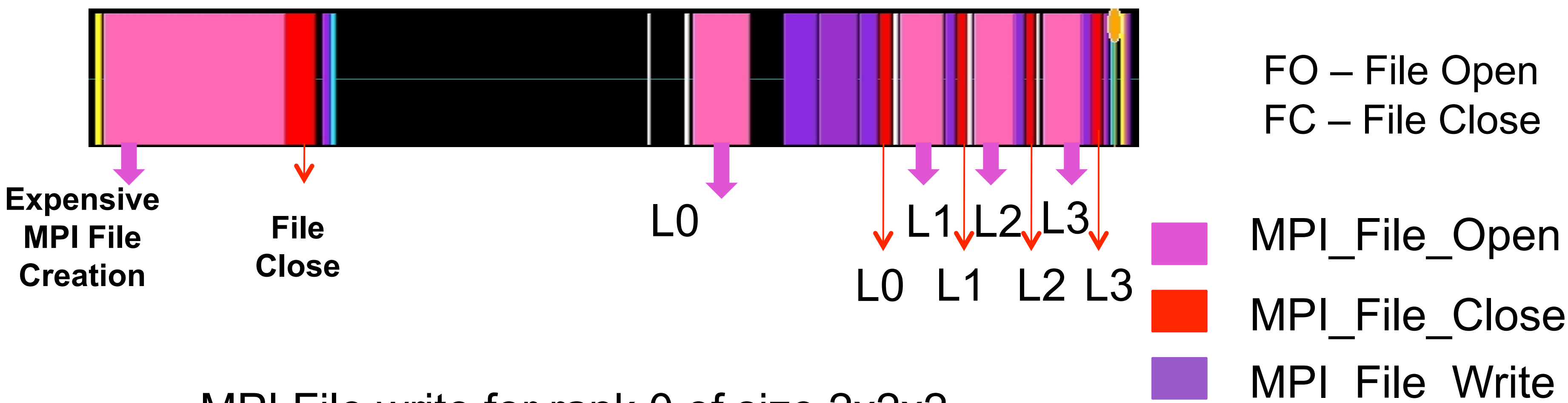
Concurrent Data Writes

Large Time Spent in File open and File Close

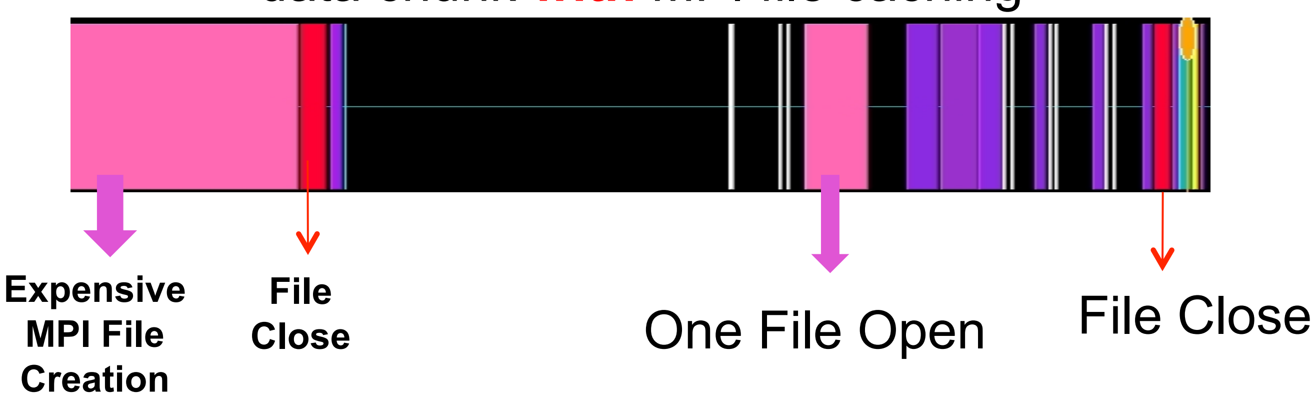


MPI File Caching

MPI File write for rank 0 of size 2x2x2 data chunk **without** MPI file caching

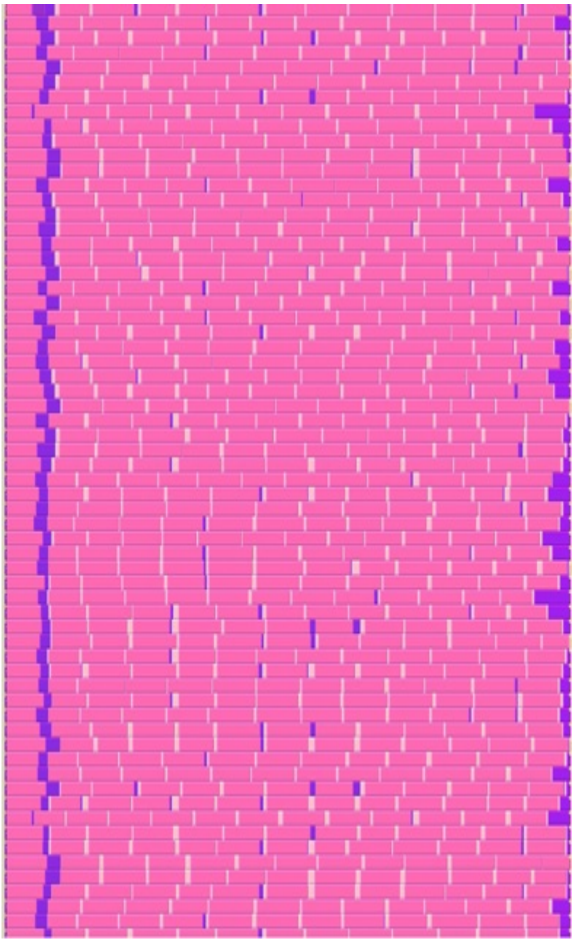


MPI File write for rank 0 of size 2x2x2 data chunk **with** MPI file caching

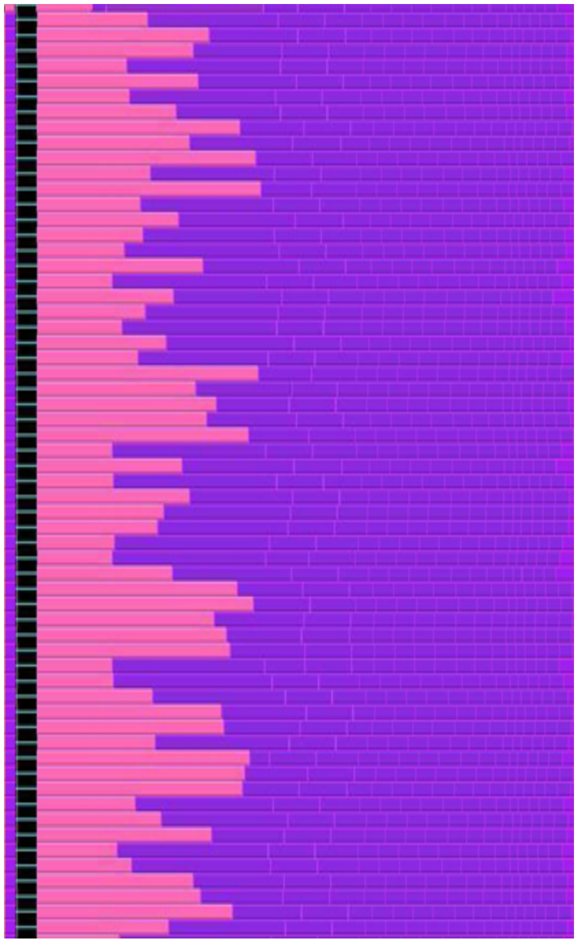


MPI File Caching Saves on 3 File opens.

Effect of MPI File Caching



Before



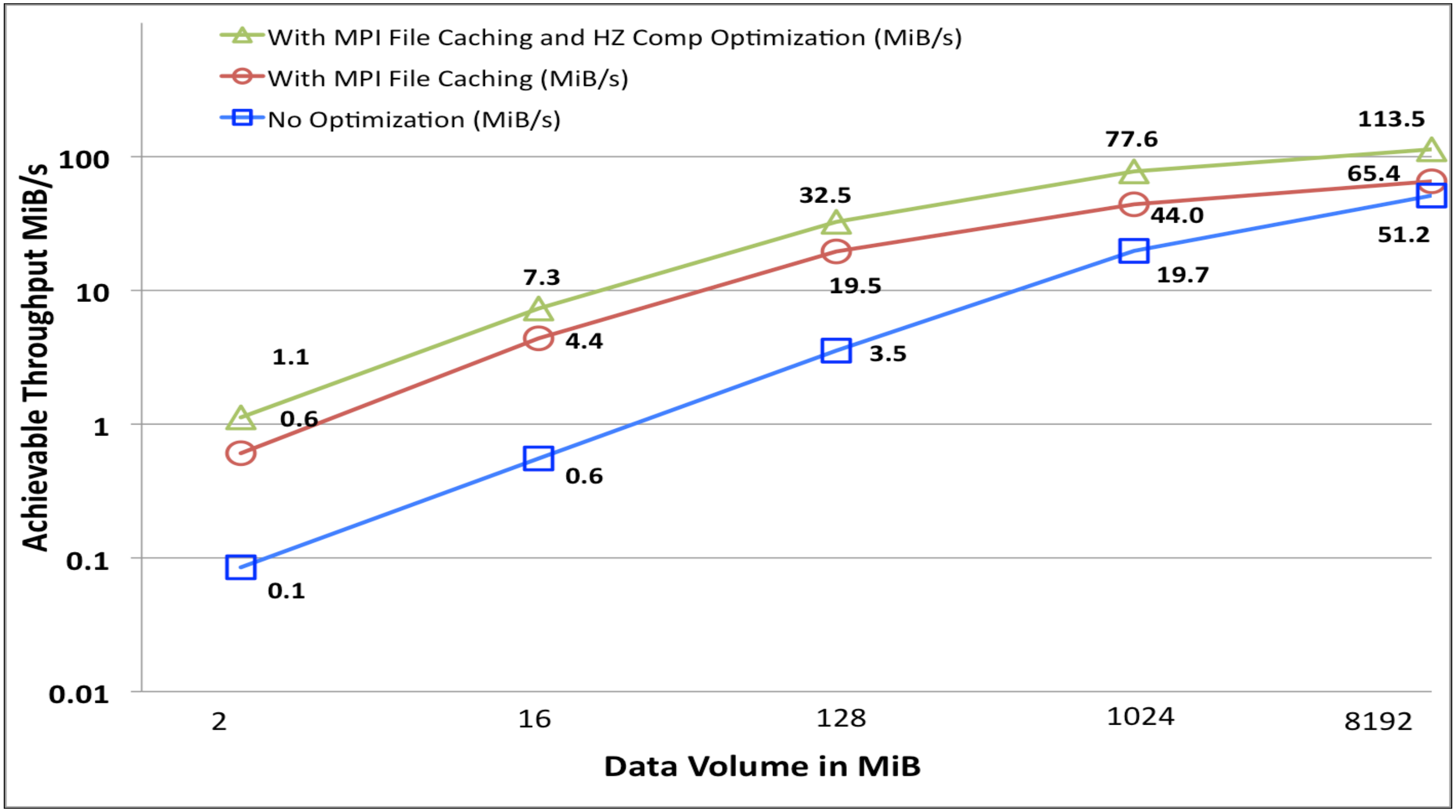
After

Total Data Written	Speed with MPI File Caching (MiB/S)	Speed with out MPI File Caching (MiB/S)
8 GiB	65	51
1 GiB	44	19
128 MiB	19.5	3.5

HZ optimization

- Significant amount of the I/O time spent in the computation to generate the HZ ordering.
- Identification of bottlenecks associated with redundant computations.
- 75% improvement in I/O throughput over the file handle improvements and up to a 10-fold improvement over the default implementation.

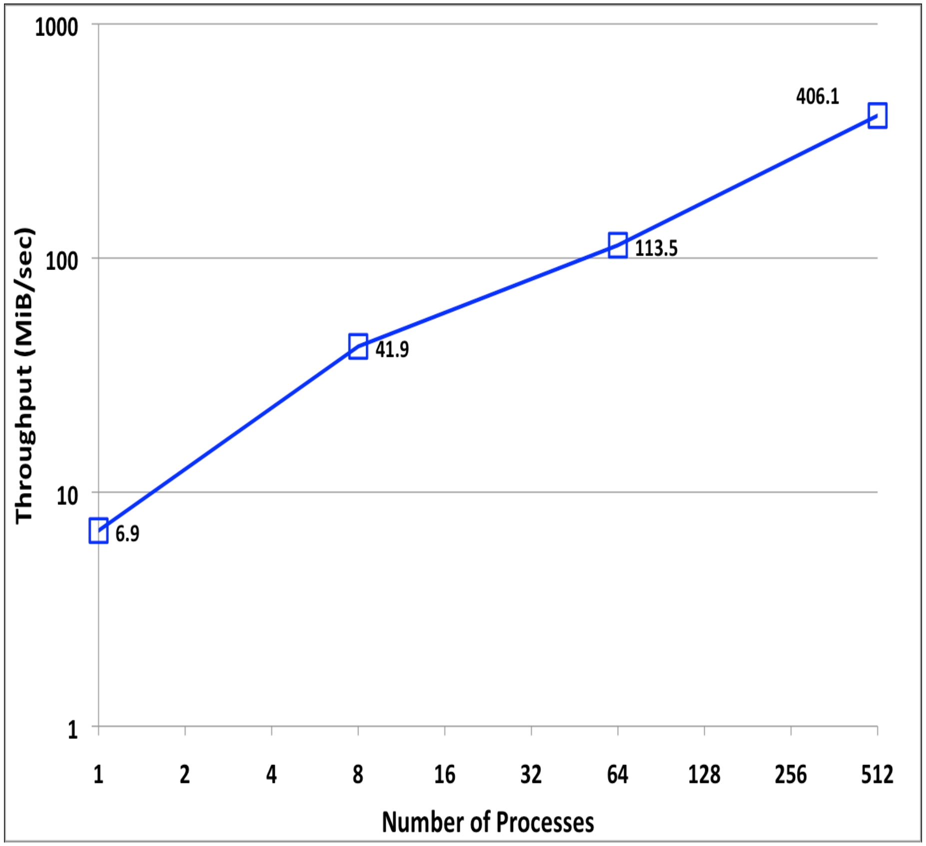
Optimizations



Two Fold improvement over default implementation writing 8GiB data using 64 nodes.

Scalability Analysis – Weak Scaling

- Constant load of 128 MB per process.
- Processes varied from 1 to 512.
- 1 process achieves 6.85 MiB/s, comparable to the speed of serial writer for an equal volume of data.
- The peak aggregate performance of 406 MiB/s is reached with 512 processes. This is approximately 60% of the peak IOR throughput achievable (667MiB/s) on 512 cores of surveyor.



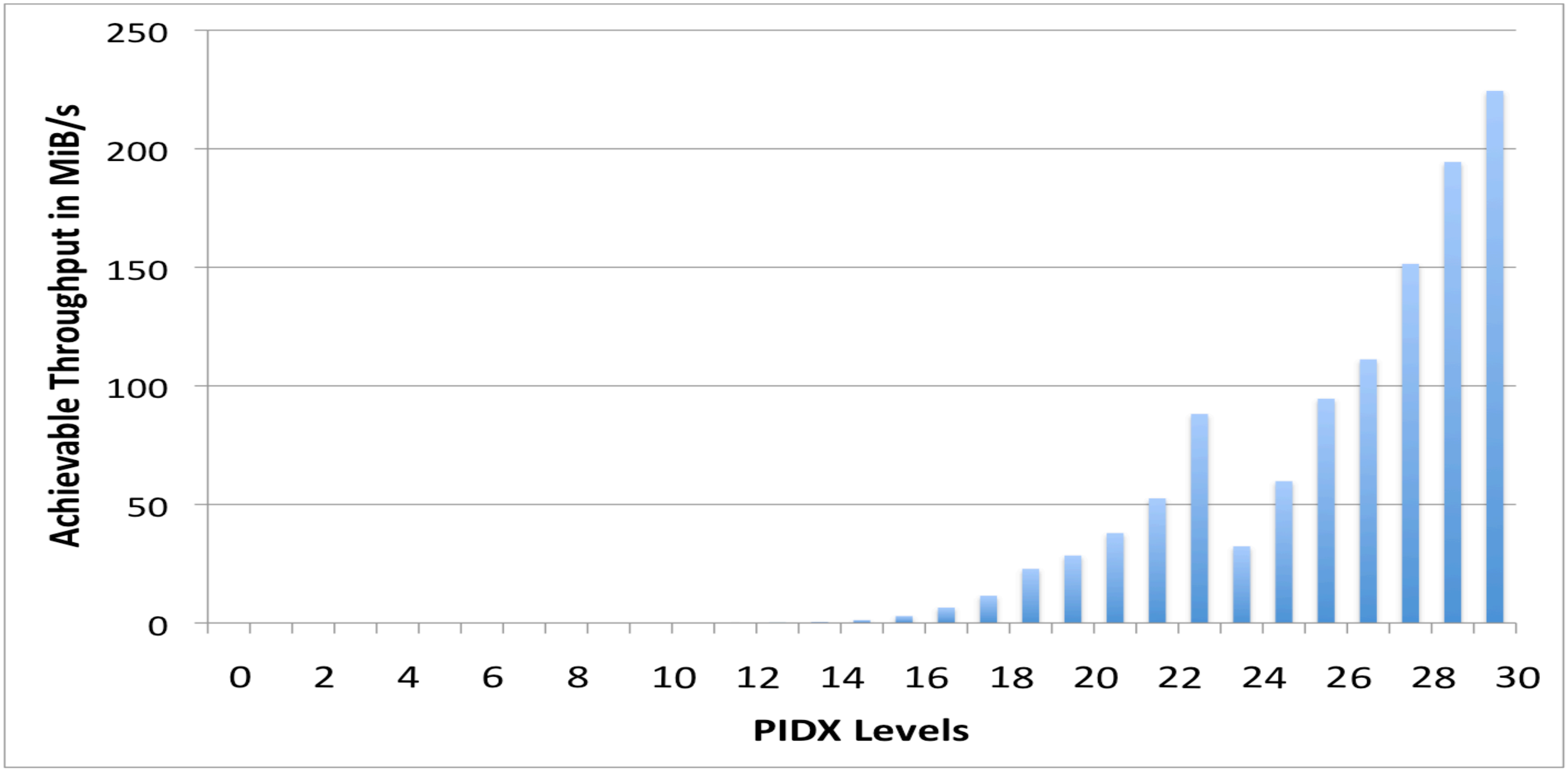
Scalability Analysis – Strong Scaling

Number of Processes	PIDX Throughput in MiB/s
64	120.3
512	143.9

Total Data Volume Of 8GiB

Maximum throughput achieved with 512 processes

PIDX Analysis



- Low throughput for levels up to 16.
- Limit hit on scalability with current implementation, falling short of the peak surveyor write performance achieved by IOR.
- Desired throughput achieved only at higher levels

Proposed Solution

Problem
Contention and metadata overhead caused levels 0 through 14 to take disproportionate amount of time relative to the amount of data that they were writing.

Solution
Plan to leverage aggregation strategies to better coordinate I/O in the first few cases where many processes contribute data to the same level of the IDX data set.

Conclusion

- Completed parallel write of IDX data format
  - Achieved a significant fraction of peak performance, at least at moderate scale
- Discovered overhead from unexpected sources in metadata operations and HZ computation
- More work needed to implement aggregation routines.

Project Members

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Thank You!!!!!!!!

Questions

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