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I/O Bottleneck Detection and Tuning: Towards Connecting the Dots using Interactive Log Analysis

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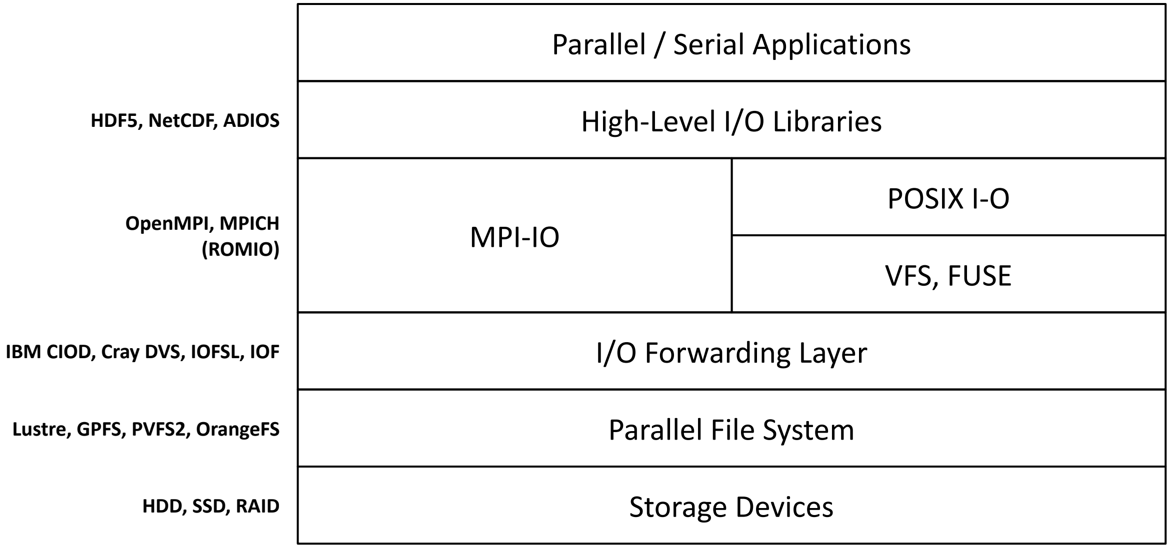
Agenda

- Overview of the HPC I/O Stack
- Darshan and DXT
- The Missing Dots...
- Interactive Exploration & Optimization
- The DXT Explorer Tool
- DXT Explorer in Practice
- Conclusion

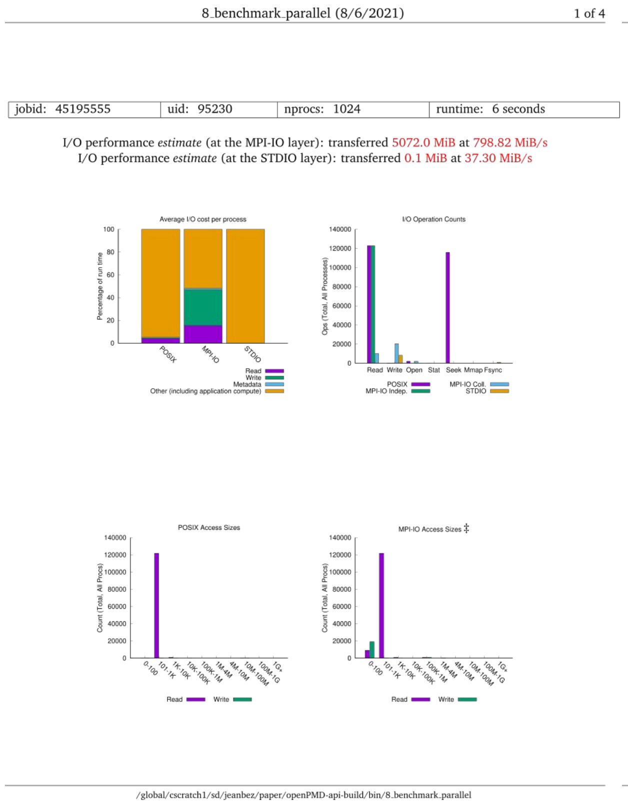
Overview of the HPC I/O Stack

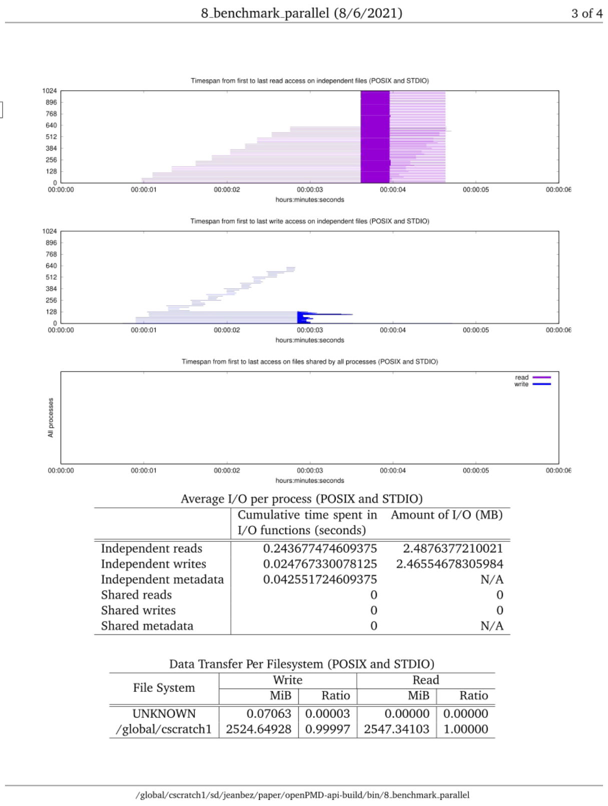
- HPC **I/O stack** is complex (multiple layers)
- Interplay of factors can affect I/O performance
- Various **optimizations techniques** available
- Plethora of **tunable parameters**
  - Each layer brings a new set of parameters
- Using the all layers **efficiently** is a **tricky** problem



Darshan and DXT

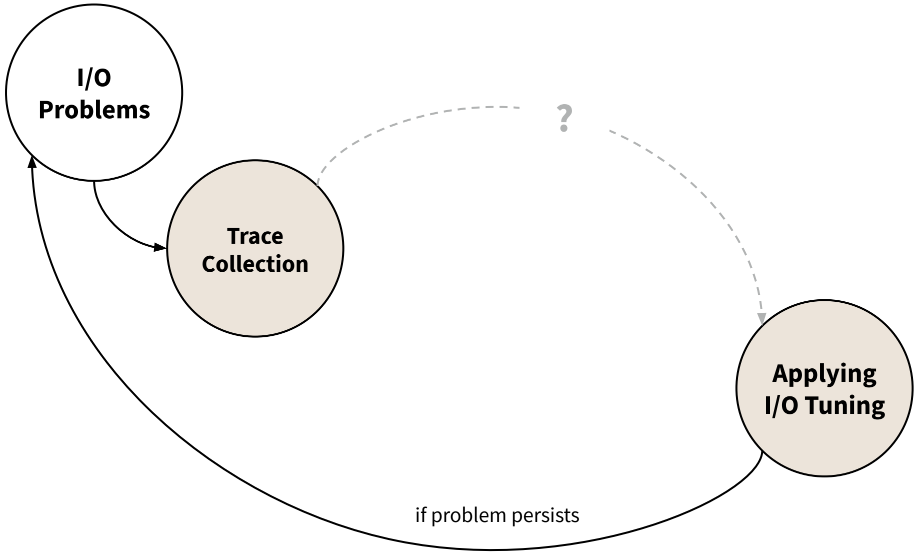
- Darshan is a popular tool to collect **I/O profiling**
- It **aggregates** information to provide insights
- **Extended tracing** mode (DXT)
  - Provide a fine grain view of the application behavior
  - Interface (POSIX or MPI-IO), operation (read/write)
  - Rank, segment, offset, request size
  - Start and end timestamp
- How to **visualize** and extract insights DXT data?
  - Identify I/O bottlenecks
  - Optimize the application



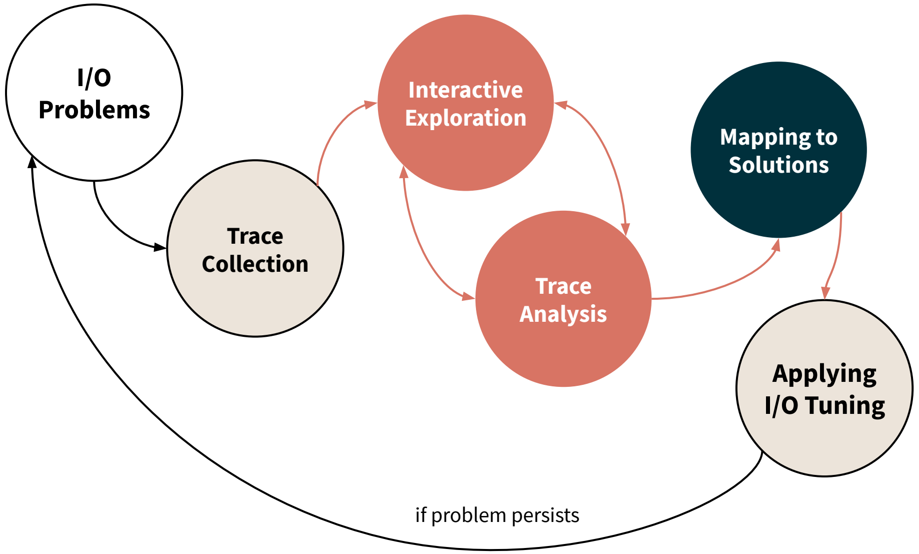


The Missing Dots...

- Lack of knowledge of **available** tunable **options**
- Little **guidance** on **when** to use them
  - In Cori (NERSC) Darshan logs from January 2019 report:
    - 94% of the files used the default 1MB stripe size
    - 36% of the files are striped over a single storage server
  - Collective buffering and data sieving (>20 years ago)
    - Aggregators, placement, and matching to the concurrency at the PFS
- Between a performance bottleneck and its tuning solution, there remain **dots to be connected**...



Interactive Optimization Approach



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The DXT Explorer Tool

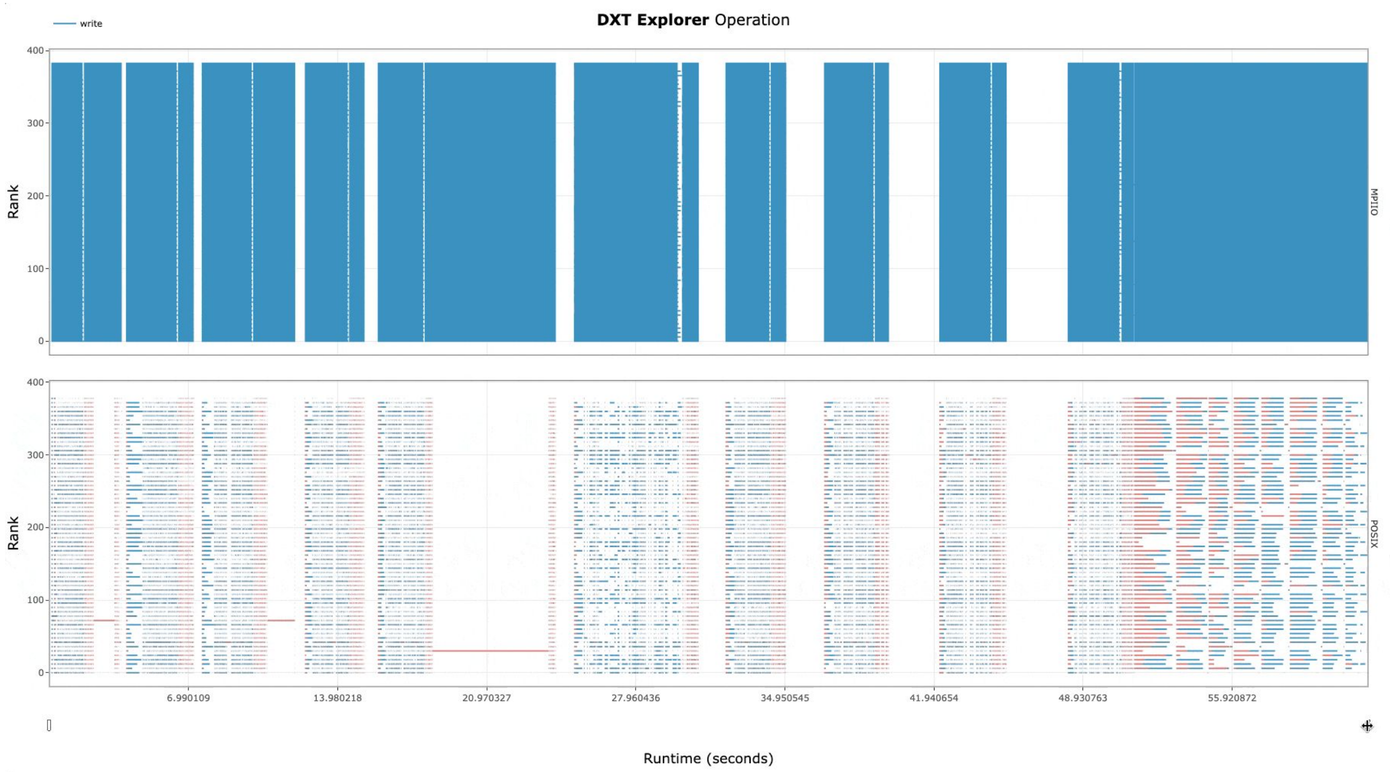
- Darshan can collect fine grain traces with **DXT**
  - **No tool** to visualize and **explore** yet
  - Static plots have **limitations**
- **Features** we seek:
  - Observe POSIX and MPI-IO together
  - Zoom-in/zoom-out in time and subset of ranks
  - Contextual information about I/O calls
  - Focus on operation, size, or spatiality
- By visualizing the application behavior, we are **one step closer** to optimize the application
- There is still a lack of translation from I/O bottlenecks to optimizations

github.com/hpc-io/dxt-explorer

docker pull hpcio/dxt-explorer

DXT Explorer

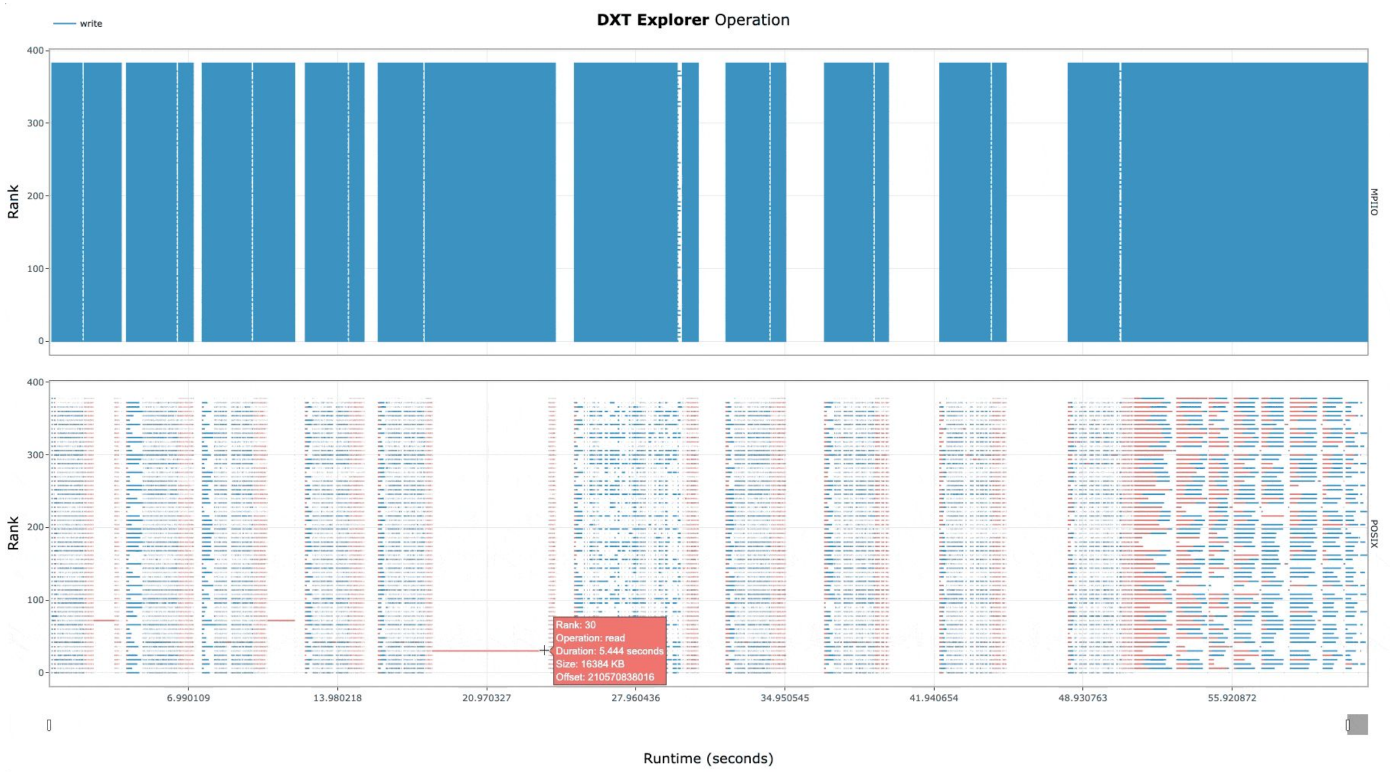
Interactive Features



Explore the timeline by **zooming in and out** and observing how the **MPI-IO** calls are translated to the **POSIX** layer. For instance, you can use this feature to detect stragglers.

DXT Explorer

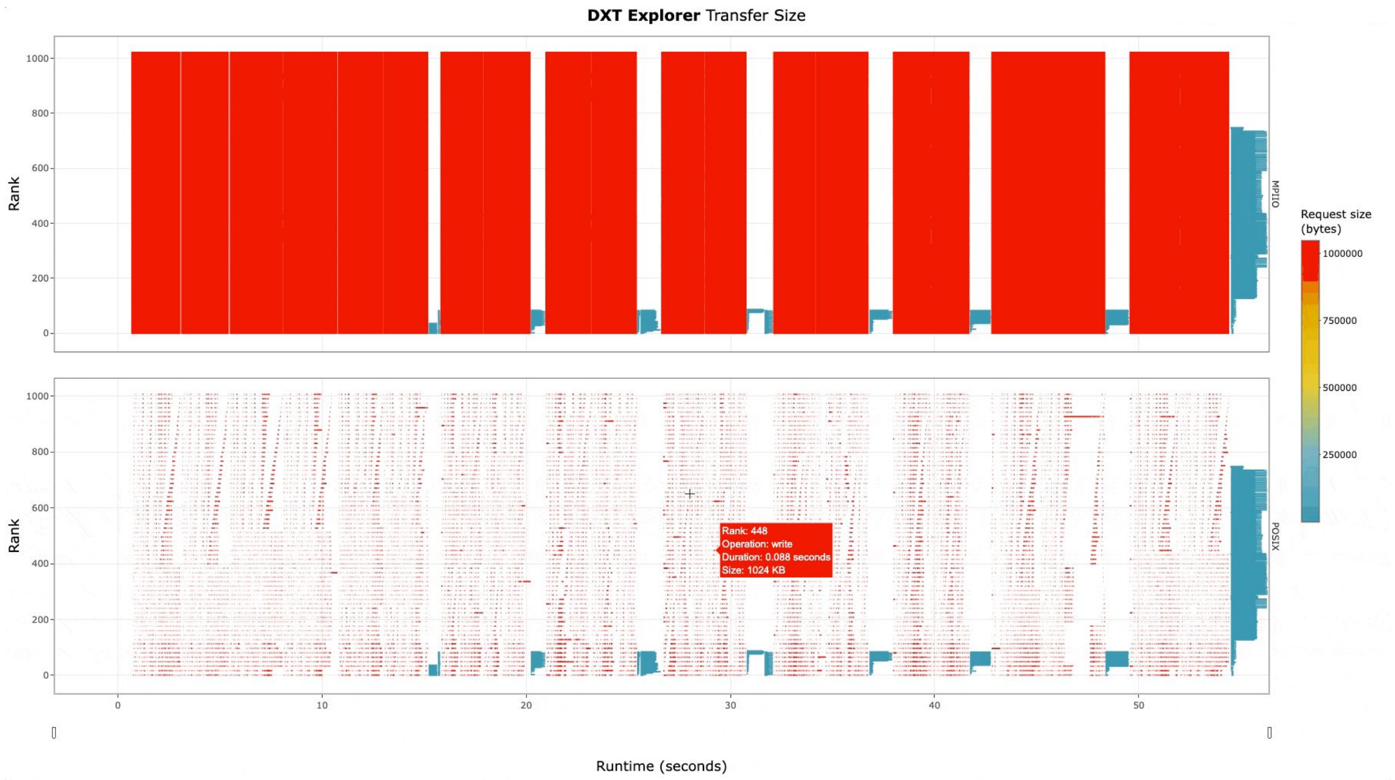
Interactive Features



Visualize relevant information in the **context** of **each I/O call** (rank, operation, duration, request size, and OSTs if Lustre) by hovering over a given operation.

DXT Explorer

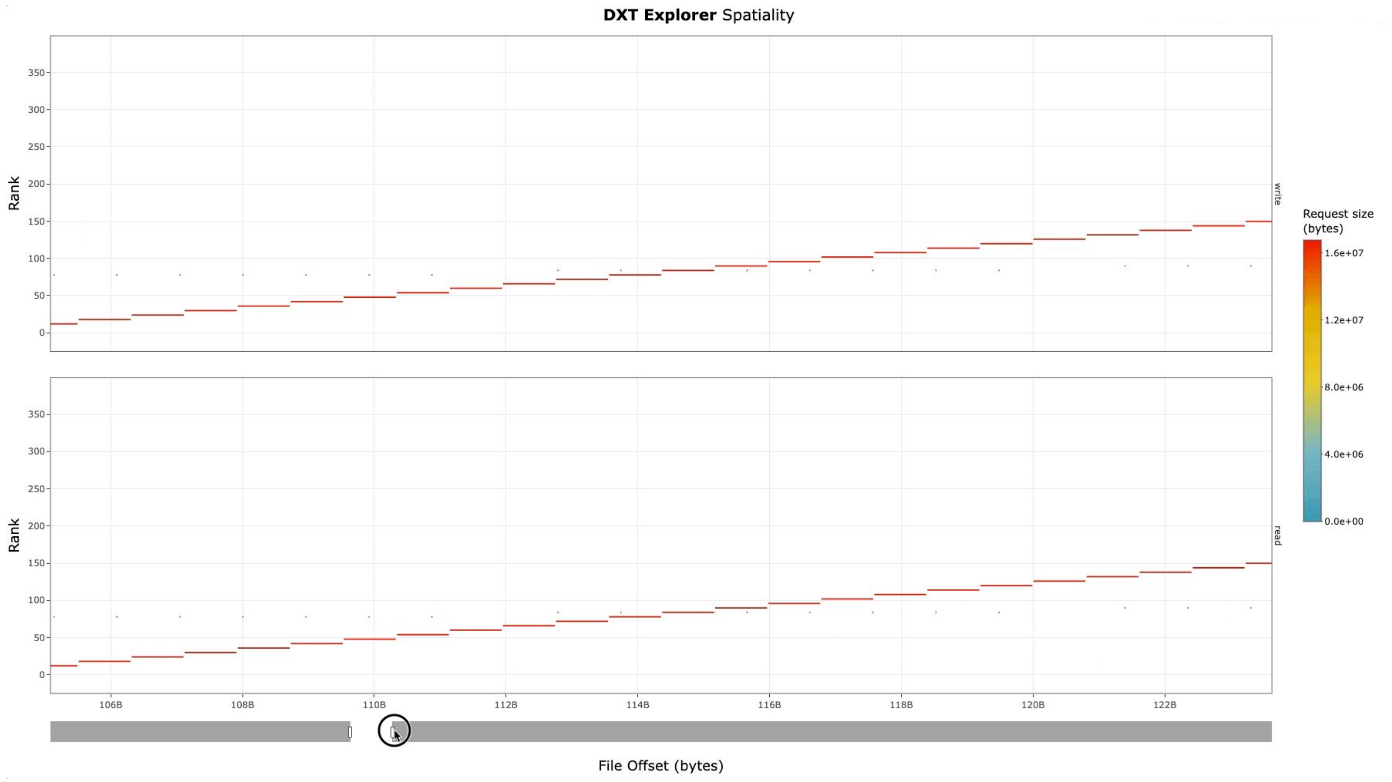
Interactive Features



Explore the **operations by size** in POSIX and MPI-IO. You can, for instance, identify small or metadata operations from this visualization.

DXT Explorer

Interactive Features



Explore the **spatiality** of accesses in file by each rank with **contextual** information.

DXT Explorer in Practice

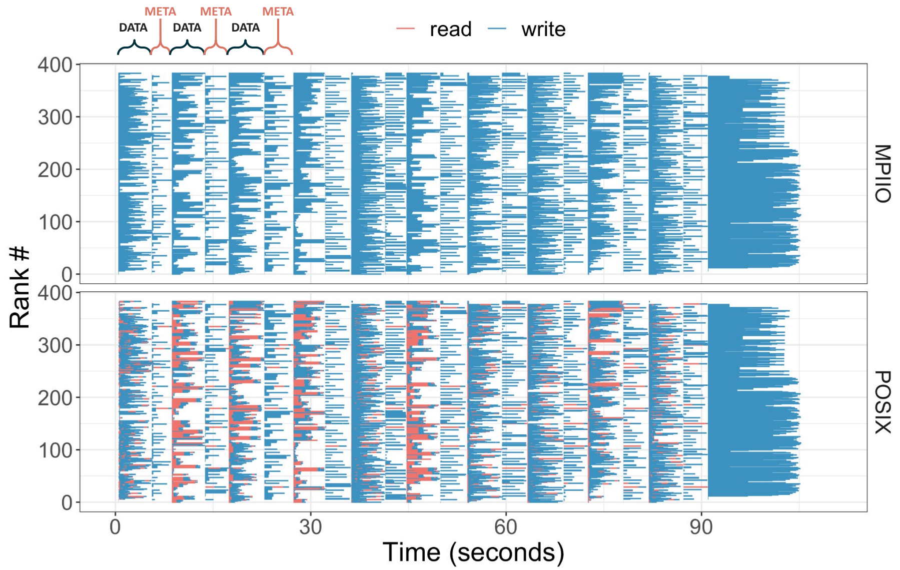
- **Summit** (Oak Ridge) and **Cori** (NERSC) supercomputers
- **Four** application **kernels**, best of five repetitions

I/O Kernel	Context	Summit (OLCF)		Cori (NERSC)	
		Baseline (s)	Optimized (s)	Baseline (s)	Optimized (s)
OpenPMD	Particle and mesh based data	110.6		54.8	
E2E benchmarks	Domain decomposition	15.9		80.0	
Block-cyclic I/O	Linear algebra	-		> 8h	
FLASH-IO	Astrophysics	1495.0		-	

OpenPMD

Baseline

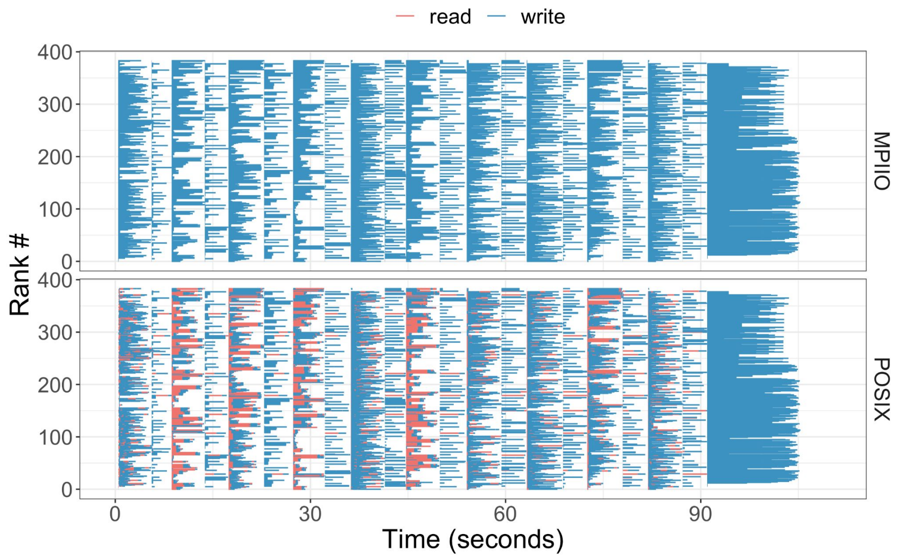
- **Summit** with 64 compute nodes, 6 ranks per node, and a total of 384 MPI ranks
  - Mesh size is [65536 × 256 × 256], 10 iterations, total file size is ≈121GB

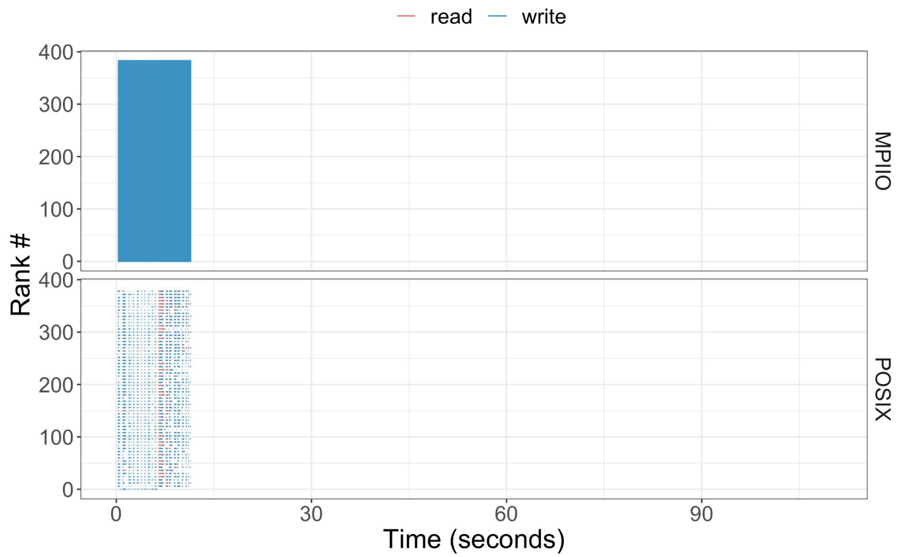


OpenPMD

Optimized

- Collective I/O using **ROMIO** hints with 1 agg/node and 16 MB collective **buffer size** provides **1.54x** speedup
- GPFS **large block** I/O with **HDF5 collective metadata** gives additional **3.8x** speedup
- Collective HDF5 **metadata** were **not actually collective** due to an issue introduced in HDF5 1.10.5
- With **HDF5 1.10.4** combined with previous optimizations gives a total of **6.8x** speedup from baseline





BASELINE

110.6s

6.8x

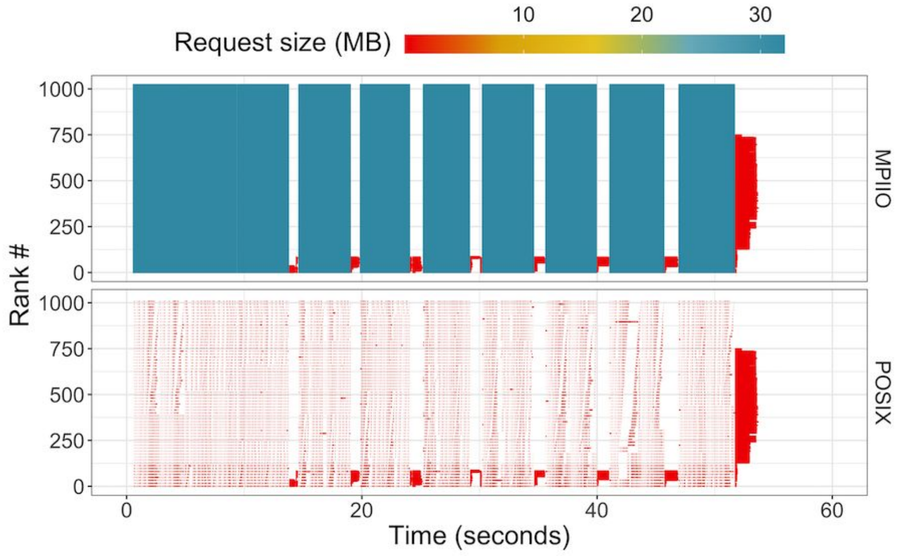
OPTIMIZED

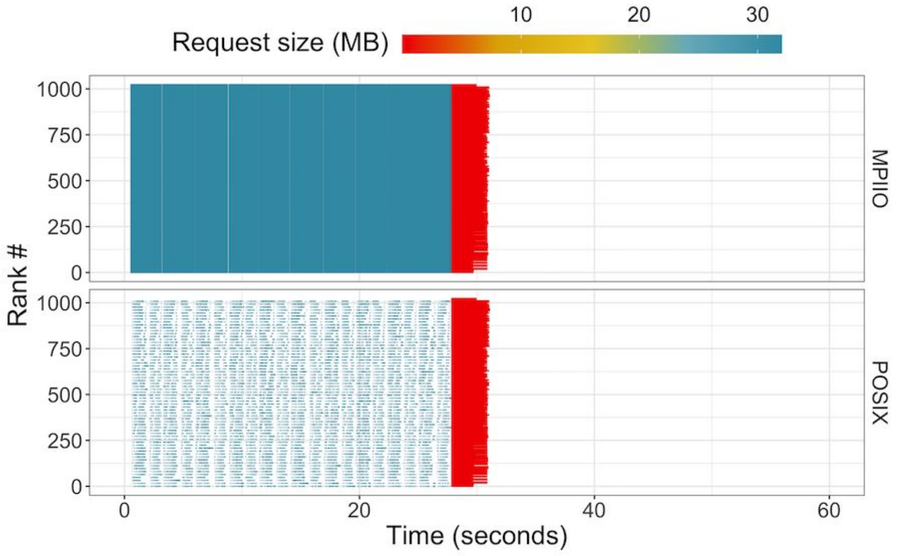
16.1s

OpenPMD

Optimized

- **Cori** with 64 compute nodes, 16 ranks per node, and a total of 1024 MPI ranks
  - Mesh size is [65536 × 256 × 256], 10 iterations, total file size is ≈320GB
- **Collective** HDF5 **metadata** were **not actually collective** due to an issue introduced in HDF5 1.10.5





BASELINE
54.8s

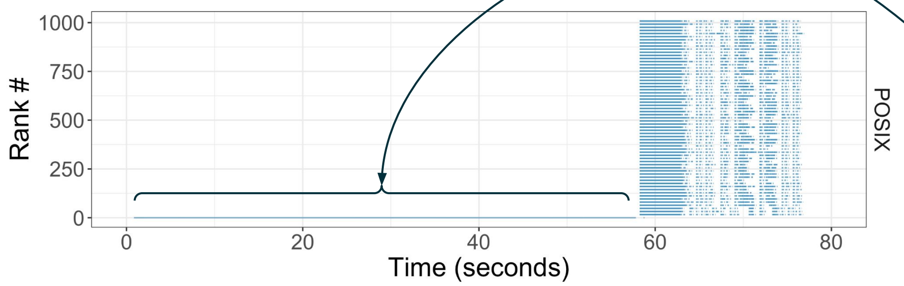
43.8%

OPTIMIZED
30.8s

E2E Benchmarks

Baseline

- **Cori** with 64 compute nodes, 6 ranks per node, and a total of 1024 MPI ranks
  - 1024 processes arranged in a 32 x 32 x 16 distribution, total file size is ≈41GB
- **44%** of the time is taken by rank 0!

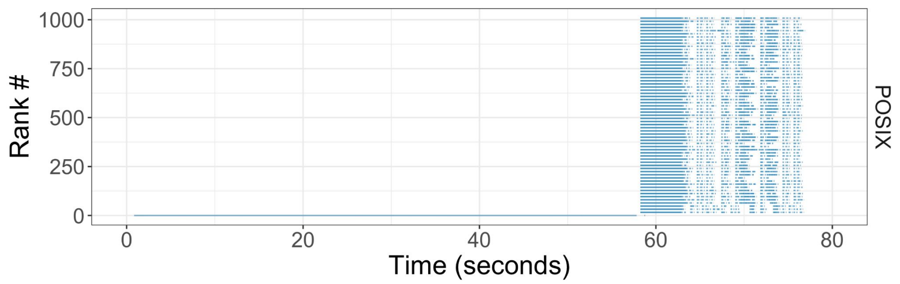


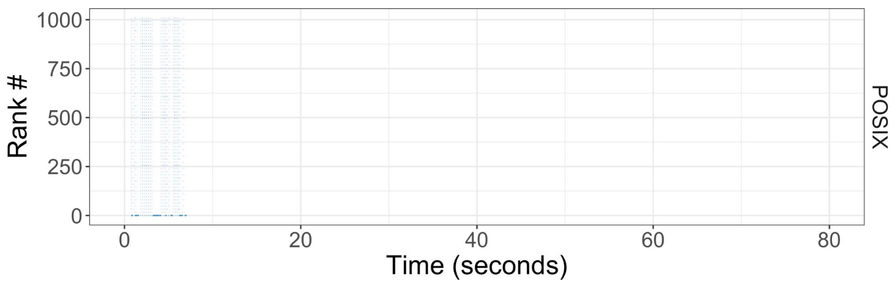
Rank 0 is **sequentially writing fill values** to all of the defined variables (10 in this workload), issuing over 40 thousand write requests with of ≈1MB

E2E Benchmarks

Optimized

- **Cori** with 64 compute nodes, 6 ranks per node, and a total of 1024 MPI ranks
    - 1024 processes arranged in a 32 x 32 x 16 distribution, total file size is ≈41GB
- **44%** of the time is taken by rank 0!
- **Disabling** the data filling (`NC_NOFILL` in NetCDF) translates to **7.3x** speedup





BASELINE

80s

10x

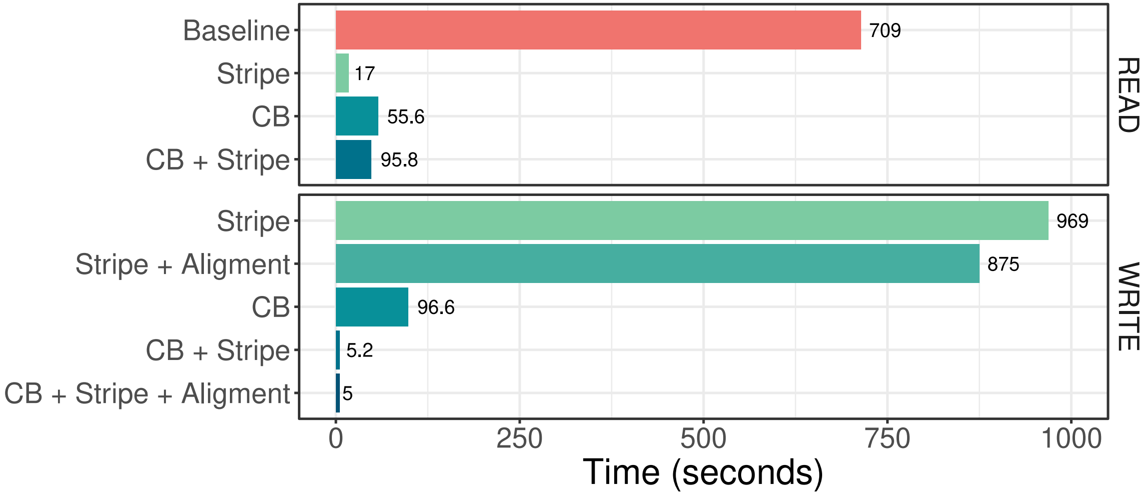
OPTIMIZED

8s

Block-cyclic I/O

Baseline

- **Cori** with 32 compute nodes, 32 ranks per node, and a total of 1024 MPI ranks
  - Square matrix with 81250 x 81250 with FP64 data, total of ≈50GB
  - **Block-cyclic** data structures with 128 x 128 with 1024 processes arranged in a 32 x 32 process grid
- Lustre striping, MPI-IO collective buffering, and HDF5 alignment **optimizations**

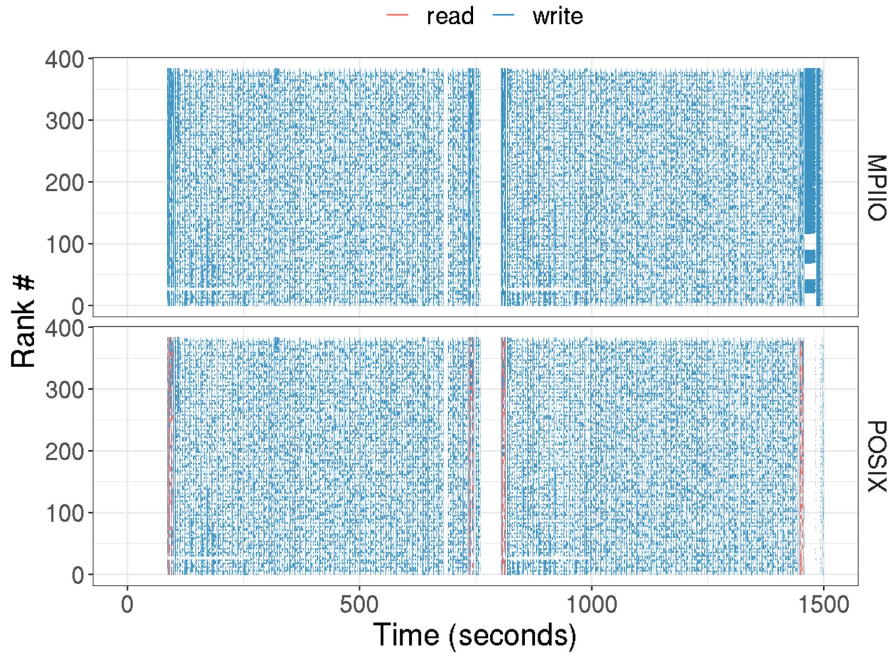


BASELINE	BASELINE
709s	969s ~~8h~~
READ 41x	WRITE 193x
OPTIMIZED	OPTIMIZED
17s	5s

FLASH

Baseline

- **Summit** with 64 compute nodes, 6 ranks per node, and a total of 384 MPI ranks
  - 2 checkpoint files (≈2.3TB each) and 2 plot file (≈14GB each) both using HDF5 backend
- MPI **not** issuing **collective I/O** operations

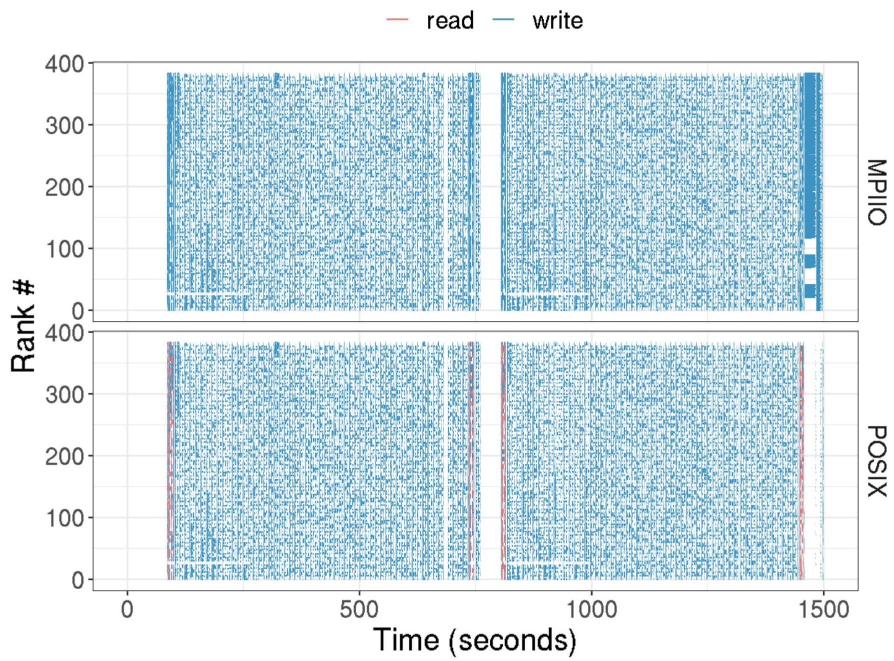


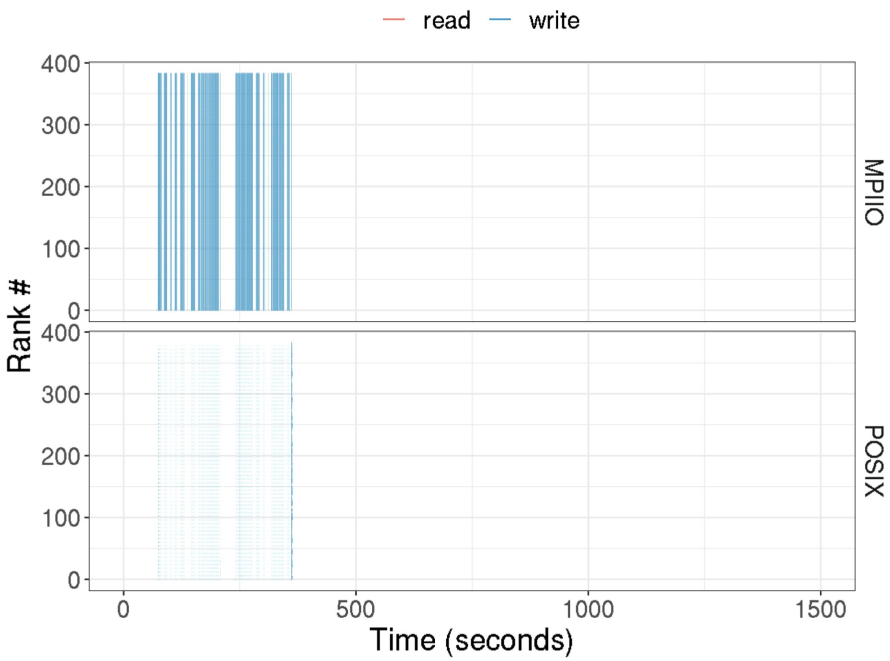
Looking at the **MPI-IO** and **POSIX** levels, each rank is writing its own data

FLASH

Optimized

- Collective I/O using **ROMIO** hints with 1 agg/node and 16 MB collective **buffer size** provides **3.2x** speedup
- Setting the HDF5 **alignment** size to 16 MB provides an additional **1.18**x speedup
- **Deferring** the HDF5 metadata flush provides another **1.1x** speedup





BASELINE

1495s

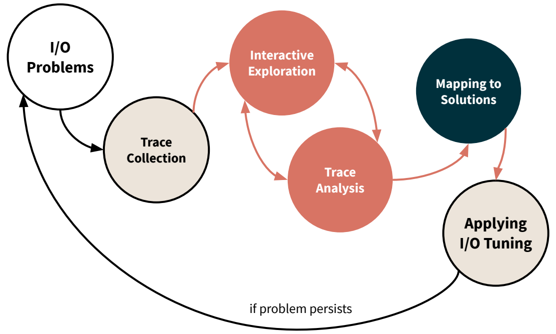
4.1x

OPTIMIZED

361s

Conclusion

- We targeted the gaps between data collection and tuning
  - Seek to identifying bottlenecks and re-shape the I/O behavior
- **DXT Explorer** tool to interactively visualize the I/O behavior
- Case study with four application kernels in two supercomputers



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Block-cyclic I/O	Linear algebra	-	-	> 8h	22.0
FLASH-IO	Astrophysics	1495.0	361.0	-	-

Conclusion

- **DXT Explorer**
  - Adds an **interactive** component to Darshan DXT trace analysis
  - Moves a **step closer** towards connecting the dots between bottleneck detection and tuning
- There is still the need for **further R&D**
  - Tools to better report findings to end-users
  - Automatically mapping performance problems to tuning options, e.g. recommendations

docker pull hpcio/dxt-explorer

github.com/hpc-io/dxt-explorer

jeanbez.gitlab.io/pdsw-2021 (Companion Repository)

You can reach us by email:

jlbez@lbl.gov

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