Hariharan Devarajan

PERSONAL INFORMATION

Email : devarajan1@llnl.gov

Phone : +1(312)383-9795

Website : https://hariharan-devarajan.github.io/

Social Media : https://www.linkedin.com/in/dhariharan/

Repos : https://github.com/hariharan-devarajan | https://bitbucket.org/scs-io/

RESEARCH STATEMENT

Storage and retrieval of data is becoming increasingly complex in modern supercomputer environments with heterogeneous storage systems and diverse application requirements.

Challenge 1: Characterizing I/O behavior of complex applications such as large-scale simulations, Big data analytics, and AI with minimal cost and high accuracy.

Challenge 2: A new memory and storage hierarchy is a reality, and modern storage subsystems need to efficiently utilize heterogeneous hardware to maximize I/O performance and dynamically support a conflict set of I/O requirements.

Challenge 3: I/O optimization must evolve towards multi-application and multi-storage environments and optimize these complex environments dynamically and intelligently.

"Accelerate I/O in data-intensive scientific applications through a self-programmable storage system."

My work aims to address the above challenges by proposing innovative solutions to build a self-programmable storage system called Jal. First, we propose a source-code-based application profiler that can extend the application layer to automatically extract I/O Requirements in the applications. Then, we use distributed logs to efficiently unify several heterogeneous storage resources under a single data representation and provide dynamic configuration. Finally, we build reactive algorithms that utilize application and heterogeneous storage information in the transfer Layer for data access optimizations, which dynamically maps diverse I/O requirements to heterogeneous storage resources for best optimizations. Through these components, we can build a Self-Programmable storage system that can automatically adapt to diverse applications and storage resources and provide optimal I/O for applications.

SUMMARY

- Interested in applying my technical expertise in distributed storage architecture for AI workloads.
- A specialist on High-Performance and Distributed Computing Storage
- Expertise in Parallel and Distributed I/O, Object Stores, I/O optimizations (i.e., buffering, prefetching, and compression)
- Expertise in RDMA technologies such as IB, RoCE, and NVMe over the fabric.
- Three years of experience developing software solutions for Oracle Financial Software Solutions.

EDUCATION

Illinois Institute of Technology — Chicago, IL, USA
Ph.D. in Computer Science. CGPA: 3.66/4 — 2016-2021

National Institute of Technology — Jamshedpur, India
B.Tech (Hons) in Computer Science and Engineering. CGPA: 8.61/10 — 2009-2013

PUBLICATIONS

Conferences:

- ➔ Yiheng Xu, Pranav Sivaraman, **Hariharan Devarajan**, Kathryn Mohror, and Abhinav Bhatele. “ML-based Modeling to Predict I/O Performance on Different Storage Sub-systems.”, In 2024, 31st edition of the IEEE International Conference on High Performance Computing, Data, and Analytics. IEEE, 2024. **(accepted)**
- ➔ **Hariharan Devarajan**, Loic Pottier, Kaushik Velusamy, Huihuo Zheng, Izzet Yildirim, Olga Kogiou, Weikuan Yu, Anthony Kougkas, Xian-He Sun, Jae Seung Yeom, and Kathryn Mohror, “DFTracer: An Analysis-Friendly Data Flow Tracer for AI-Driven Workflows,” in SC24: International Conference for High Performance Computing, Networking, Storage and Analysis. Atlanta, GA: IEEE, Dec. 2024. **(accepted)**
- ➔ **Hariharan Devarajan** and Kathryn Mohror. “Mimir: Extending I/O Interfaces to Express User Intent for Complex Workloads in HPC.” 2023 IEEE International Parallel and Distributed Processing Symposium (IPDPS) St. Petersburg, Florida: iEEE, May 2023.
- ➔ **Hariharan Devarajan** and Kathryn Mohror. "Extracting and characterizing I/O behavior of HPC workloads". The 2022 IEEE International Conference on Cluster Computing (CLUSTER'22), September 6-9, 2022, Heidelberg, Germany.
- ➔ **Hariharan Devarajan**, Anthony Kougkas, Huihuo Zheng, Venkatram Vishwanath, and Xian-He Sun, "Stimulus: Accelerate Data Management for Scientific AI applications in HPC," In the proceedings of the 2022 IEEE/ACM International Symposium in Cluster, Cloud, and Internet Computing (CCGrid'22), Taormina, Italy, May 16-19, 2022.
- ➔ Jaime Cernuda Garcia, **Hariharan Devarajan**, Luke Logan, Keith Bateman, Neeraj Rajesh, Jie Ye, Anthony Kougkas, and Xian-He Sun.” HFlow: A Dynamic and Elastic Multi-Layered Data Forwarder”. The 2021 IEEE International Conference on Cluster Computing (CLUSTER'2021), IEEE Portland, OR.
- ➔ Neeraj Rajesh, **Hariharan Devarajan**, Jaime Cernuda Garcia, Keith Bateman, Luke Logan, Jie Ye, Anthony Kougkas, and Xian-He Sun. “Apollo: An ML-assisted Real-Time Storage Resource Observer”. In Proceedings of the 30th International Symposium on High-Performance Parallel and Distributed Computing (HPDC '21). Association for Computing Machinery, New York, NY, USA, 147–159.
- ➔ **Hariharan Devarajan,** Huihuo Zheng, Anthony Kougkas, Xian-He Sun, and Venkatram Vishwanath. "DLIO: A Data-Centric Benchmark for Scientific Deep Learning Applications". In 2021 21st IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGRID). IEEE. **Best Paper**.
- ➔ **Hariharan Devarajan,** Anthony Kougkas, and Xian-He Sun. HReplica: A Dynamic Data Replication Engine with Adaptive Compression for Multi-Tiered Storage." 2020 IEEE International Conference on Big Data (Big Data), Atlanta, Georgia, USA, 2020.
- ➔ **Hariharan Devarajan,** Anthony Kougkas, Keith Bateman, and Xian-He Sun. "HCL: Distributing Parallel Data Structures in Extreme Scales." In 2020 IEEE International Conference on Cluster Computing (CLUSTER). IEEE, 2020.
- ➔ Anthony Kougkas, **Hariharan Devarajan,** and Xian-He Sun. "Bridging Storage Semantics using Data Labels and Asynchronous I/O" In Transactions on Storage (TOS), Vol 1, No 1, Article 1, 2020 (accepted and scheduled to appear). ACM, 2020.
- ➔ Anthony Kougkas, **Hariharan Devarajan**, Keith Bateman, Jaime Cernuda, Neeraj Rajesh and Xian-He Sun. ChronoLog: A Distributed Shared Tiered Log Store with Time-based Data Ordering" Proceedings of the 36th International Conference on Massive Storage Systems and Technology (MSST 2020).
- ➔ **Hariharan Devarajan**, Anthony Kougkas, Luke Logan, and Xian-He Sun. "HCompress: Hierarchical Data Compression for Multi-Tiered Storage Environments," *2020 IEEE International Parallel and Distributed Processing Symposium*, New Orleans, Louisiana, USA.
- ➔ **Hariharan Devarajan**, Anthony Kougkas, and Xian-He Sun. "HFetch: Hierarchical Data Prefetching for Scientific Workflows in Multi-Tiered Storage Environments," *2020 IEEE International Parallel and Distributed Processing Symposium (IPDPS)*, New Orleans, Louisiana, USA.
- ➔ K. Feng, **H. Devarajan,** A. Kougkas, and X.-H. Sun. "NIOBE: An Intelligent I/O Bridging Engine for Complex and Distributed Workflows,” IEEE International Conference on Big Data, 2019
- ➔ Anthony Kougkas, **Hariharan Devarajan**, Jay Lofstead, and Xian-He Sun. "LABIOS: A Distributed Label-Based I/O System", In Proceedings of the ACM 28th International Symposium on High-Performance Parallel and Distributed Computing (**HPDC'19**) **Best Paper**.
- ➔ **Hariharan Devarajan**, Anthony Kougkas, and Xian-He Sun. "An Intelligent, Adaptive, and Flexible Data Compression Framework", In Proceedings of the IEEE/ACM International Symposium in Cluster, Cloud, and Grid Computing (**CCGrid'19**).
- ➔ **Hariharan Devarajan**, Anthony Kougkas, Prajwal Challa, and Xian-He Sun. "Vidya: Performing Code-Block I/O Characterization for Data Access Optimization", In Proceedings of the IEEE International Conference on High Performance Computing, Data, and Analytics 2018.
- ➔ Anthony Kougkas, **Hariharan Devarajan**, Xian-He Sun, and Jay Lofstead. "Harmonia: An Interference-Aware Dynamic I/O Scheduler for Shared Non-Volatile Burst Buffers", In Proceedings of the IEEE International Conference on Cluster Computing 2018 (**Cluster'18**)
- ➔ Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun. "Hermes: A Heterogeneous-Aware Multi-Tiered Distributed I/O Buffering System", In Proceedings of the ACM 27th International Symposium on High-Performance Parallel and Distributed Computing (**HPDC'18**).
- ➔ Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun. "IRIS: I/O Redirection via Integrated Storage" (Slides), In Proceedings of the 32nd ACM International Conference on Supercomputing (**ICS'18**)

Journals:

- ➔ Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun, "I/O Acceleration via Multi-Tiered Data Buffering and Prefetching", Journal of Computer Science and Technology, 2019

Patents:

- ➔ Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun, "I/O Acceleration via Multi-Tiered Data Buffering and Prefetching", Journal of Computer Science and Technology, 2019

Workshops:

- Olga Kogiou, **Hariharan Devarajan**, Chen Wang, Weikuan Yu, and Kathryn Mohror, “Understanding Highly Configurable Storage for Diverse Workloads” In 2024, 4th Workshop on Re-envisioning Extreme-Scale I/O for Emerging Hybrid HPC Workloads (REX-IO), IEEE, 2024.
- **Hariharan Devarajan,** Adam Moody, Donglai Dai, Cameron Stanavige, Elsa Gonsiorowski, Marty McFadden, Olaf Faaland, Greg Kosinovsky, and Kathryn Mohror. "The impact of asynchronous I/O in checkpoint-restart workloads." In 2024, 5th Workshop on Extreme-Scale Storage and Analysis (ESSA). IEEE, 2024.
- Ian Lumsden, **Hariharan Devarajan,** Jack Marquez, Stephanie Brink, David Boehme, Olga Pearce, Jae-Seung Yeom, and Michela Taufer. "Empirical Study of Molecular Dynamics Workflow Data Movement: DYAD vs. Traditional I/O Systems." In 2024, 23rd IEEE International Workshop on High Performance Computational Biology (HICOMB). IEEE, 2024.
- Izzet Yildirim, **Hariharan Devarajan,** Anthony Kougkas, Xian-He Sun, and Kathryn Mohror, “IOMax: Maximizing Out-of-Core I/O Analysis Performance on HPC Systems,” in Workshops of the International Conference on High Performance Computing, Network, Storage, and Analysis (SC-W 2023 in IPDPS’23), November 12–17, 2023, Denver, CO, USA
- Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun. "Enosis: Bridging the Semantic Gap between File-based and Object-based Data Models", In Proceedings of the ACM SIGHPC Datacloud'17, 8th International Workshop on Data-Intensive Computing in the Clouds.
- Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun. "Syndesis: Mapping Objects to Files for a Unified Data Access System", In Proceedings of the ACM SIGHPC MTAGS'17, 10th International Workshop on Many-Task Computing on Clouds, Grids, and Supercomputers, in conjunction with SC'17.
- **Hariharan Devarajan**, Anthony Kougkas, Hsing-Bung Chen, and Xian-He Sun. "Open Ethernet Drive: Evolution of Energy-Efficient Storage Technology", In Proceedings of the ACM SIGHPC Datacloud'17, 8th International Workshop on Data-Intensive Computing in the Clouds in conjunction with SC'17

Publication Distinctions

- Best Student Paper Award from the Computer Science Department at Illinois Tech 2021.
- Best Paper Award at the 21st IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing CCGrid (May'21)
- Karsten Schwan Best Paper Award at the 28th International ACM Symposium on High-Performance Parallel and Distributed Computing - HPDC (June'19)
- Citation Rate:
  - All citations: 348 with h-index: 11

Peer Review

Journals:

- Reviewer of Journal of Computer Science and Technology 2020 (1 paper)
- Reviewer of Transactions on Parallel and Distributed Systems 2022 (1 paper)
- Reviewer of ACM Computing Surveys 2023 (1 paper)
- Reviewer of IEEE Transaction on Knowledge and Data Engineering 2023 (1 paper)
- Reviewer of Journal of Computer Science and Technology 2023 (1 paper)
- Reviewer of Transactions on Parallel and Distributed Systems 2024 (2 papers)

Conference:

- Reviewer in Exhibitor Forum in 2021 The International Conference for High Performance Computing, Networking, Storage, and Analysis (10 submission)
- Reviewer in Data, Storage, and Visualization Track in the IEEE Cluster Conference 2022. (7 submissions)
- Reviewer in Programming Environments & System Software Track in High Performance Computing, Machine Learning, Data Analytics & Quantum Computing 2022 (8 submissions)
- Reviewer in Data, Storage, and Visualization Track in the IEEE Cluster Conference 2023. (8 submissions)
- Reviewer in Hardware Systems and Networking (for Cluster, Cloud and Internet Computing) Track in 23rd IEEE/ACM international Symposium on Cluster, Cloud and Internet Computing (CCGrid 2023) (6 submissions)
- Reviewer in “File and storage systems, I/O, and data management” in The ACM International Symposium on High-Performance Parallel and Distributed Computing 2023 (8 submissions)
- Reviewer in Software Track in 52nd International Conference on Parallel Processing 2023 (6 submission)
- Reviewer in Appendix description and evaluation in 2023 The International Conference for High Performance Computing, Networking, Storage, and Analysis (10 submission)
- Reviewer in Appendix description and evaluation in 52nd International Conference on Parallel Processing 2023 (8 submission)
- Reviewer in Hardware Systems and Networking (for Cluster, Cloud and Internet Computing) Track in 24rd IEEE/ACM international Symposium on Cluster, Cloud and Internet Computing (CCGrid 2024) (8 submissions)
- Reviewer in Appendix description and evaluation in 53nd International Conference on Parallel Processing 2024 (8 submission)
- Reviewer in Tutorials in 2024 The International Conference for High Performance Computing, Networking, Storage, and Analysis (9 submission)

Workshops:

- ➔ Reviewer in 2021 First Workshop on Reproducible Workflows, Data, and Security (6 submissions)
- ➔ Reviewer in the 2nd Workshop on Re-envisioning Extreme-Scale I/O for Emerging Hybrid HPC Workloads (REX-IO) (5 submissions).
- ➔ Reviewer in 2nd Workshop on Reproducible Workflows, Data Management, and Security (Rewords 2022) (4 submissions)
- ➔ Reviewer in Practically FAIR 2023 Workshop (5 submissions)

Review Board:

- ➔ Review Board Member for Transactions on Parallel and Distributed Systems.

Invited Talks

- ➔ 2021 Dagstuhl Seminar on Data Management
- ➔ Data management workshop in Advanced Scientific Computing Research (ASCR) 2021.
- ➔ “Challenges in Characterizing I/O in Large Scientific Workflows” in the 2nd Workshop on Re-envisioning Extreme-Scale I/O for Emerging Hybrid HPC Workloads (REX-IO) 2022
- ➔ “DLIO Benchmark: Data-driven benchmark for deep learning workload in HPC” in storage seminar at Lawrence Berkley National Laboratory 2022.
- ➔ “DLIO Benchmark: Data-driven benchmark for deep learning workload in HPC” in storage seminar at Centre for High Performance Computing, South Africa National Meeting 2023
- ➔ Talk on Intent driven HDF5 optimization at The HDF User Group Meeting 2023
- ➔ Invited talk at ALCF Seminar at Argonne National Laboratory 2024
- ➔ “DLIO Benchmark and Profiler” in storage seminar at NCSA 2024
- ➔ Talk for AI4S seminar at 2024 Scientific Machine Learning Research Group, Rutherford Appleton Laboratory, Science and Technology Facilities Council (STFC), UK
- ➔ Talk on HDF5 use case for MD AI workload at The HDF User Group Meeting 2023

Conference Leadership

- ➔ Registration and Online Chair for IEEE Cluster Conference 2021.
- ➔ Session Chair for IEEE Cluster Conference 2021.
- ➔ Poster Judge for IEEE International Parallel and Distributed Processing Symposium 2023.
- ➔ Session Chair for IEEE Cluster Conference 2023.
- ➔ Web Chair for IEEE Cluster Conference 2023.
- ➔ Poster Judge for PhD Forum in IEEE International Parallel and Distributed Processing Symposium 2024.

RESEARCH EXPERIENCE

Lawrence Livermore National Laboratory — Livermore, CA, USA
Computer Scientist — Sep 2023-Current

- ➔ **I/O Performance and Portability (IOPP)**
  - ◆ Experience with containerized storage technologies for El Capitan.
  - ◆ Experience with building I/O tracing and analysis tools for AI workloads.
- ➔ **Dynamic and Asynchronous Data Streamliner**
  - ◆ Architecting inter-node data movement mechanisms.
  - ◆ Performance engineering to identify and solve performance bottlenecks on large-scale supercomputers.
- ➔ **FRACTALE**
  - ◆ Experience with Flux scheduler.
  - ◆ Investigating the role of I/O behaviors in scheduling.
- ➔ **Scalable Checkpoint and Restart (SCR)**
  - ◆ Investigating the performance of checkpoint and restart in large language models.
  - ◆ Investigating the configurability of SCR with complex multi-stage workflows.

Lawrence Livermore National Laboratory — Livermore, CA, USA
Post Doctoral Researcher — June 2021-Sep 2023

- ➔ **I/O Performance and Portability (IOPP)**
  - ◆ Experience with characterizing the I/O requirement of AI application in HPC systems.
  - ◆ Experience with building a comprehensive taxonomy of AI applications.
  - ◆ Experience with designing I/O systems which utilizes user’s preferences and transparently

optimizes I/O in a multi-tenant HPC system.
    - Invented I/O intents for storage system and demonstrated its benefits in designing workload-aware storage systems.
- **Scalable Checkpoint and Restart (SCR)**
    - Experience with the internal architecture of SCR.
    - Study of the impact of Async I/O on applications using SCR
- **DYnamic and Asynchronous Data Streamliner (DYAD)**
    - Experience with sharing data across producer-consumer workflows.
    - Demonstrating the need for efficient caching through DYAD in deep learning workloads.
- **GOTCHA**
    - Maintainer of the GOTCHA toolkit.
    - Experience with application compilation, execution, and assembly-level instructions.
    - Contributed to the GOTCHA toolkit to support newer Glibc kernes.

Illinois Institute of Technology — Chicago, IL, USA
Research Assistant — Aug 2016 - May 2021

- **AI in HPC:** Accelerating data management for Scientific AI workloads.
    - Experience with characterizing I/O behavior of Scientific AI application in ALCF.
    - Experience with data management in existing AI frameworks such as TensorFlow and PyTorch.
    - Experience with profiling I/O and data operations in AI frameworks.
    - Currently working on accelerating data ingestion in AI workloads using deep memory and storage hierarchy.
- **I/O Integration:** Convergence of the semantic gap between the **Cloud and HPC** ecosystems.
    - Experience with various data representations of storage solutions for applications.
    - Designed novel transformations between object and file data representations.
    - Deployed various software solutions such as OrangeFS, Lustre, Hyperdex, MongoDB, and redis.
- **Multi-tiered storage**: Design **I/O optimizations** for new **multi-tiered** environments.
    - Experience with various storage devices along with kernel models to deploy NVMe-over-fabric.
    - Deployed I/O hierarchical buffering VOL software for HDF5 library on Cori supercomputer.
    - Designed a data-centric hierarchical prefetching solution for HPC environments.
- LABIOS: A Label-based I/O System
    - Experience with building decoupled architecture and deploying it at scale.
    - Designed and developed the label based system and deployed it on Chameleon Cloud.
- **Data Compression**: Study the variability of **compression performance** for different data characteristics and requirements.
    - Experience with many lossless data compression libraries and their usage.
    - Unified all compression libraries under a single framework with a novel decision engine.
    - Deployed the compression framework on multiple nodes on Theta supercomputer.
- **Profiling**: Design an **application-profiler** to estimate the application's I/O based on its **source code**.
    - Experience with open compilers such as GCC and LLVM.
    - Designed python based tool to extract I/O features from application source code.
    - Developed a linear regression model to predict I/O intensity based on source code features.
- Designed and developed **a distributed data structure library** (HCL).
    - Experience with RDMA technologies such as IBVerbs, RoCE, NVMe over fabric.
    - Experience with parallel programming languages (e.g., Chappel and UPC++).

Argonne National Laboratory — Lemont, IL, USA
Research Aid — May 2020 - Aug 2020

- Understanding data access and processing API in TensorFlow and PyTorch
- Explored various profiling tools for high-level framework profiling (e.g., TensorBoard) and low-level I/O profiling (e.g., Darshan)
- Characterized I/O behavior for AI applications in ALCF.
- Built an analysis tool VaniDL which combines Darshan Traces with TensorBoard and provides a high-level analysis of I/O behavior.

The HDF Group — Champaign, IL, USA
Research Intern — May 2018 - Aug 2018

- Designed framework for **Hierarchical Buffering Platform** as a VOL Plugin in HDF5.
- Tested the new software on **Cori Supercomputer**.

Project Leadership

- ➔ Task Lead for FRACRALE Project since Oct 2023 till Sept 2028 for the laboratory directed research and development (LDRD)'s for strategic initiative: to a) enable data intent-driven scheduling of high-performance computing workloads in the Flux scheduler developed at LLNL, and b) develop dynamic systems to enable the scheduler to move data in ways that accelerate workloads.
- ➔ Lead developer and maintainer of GOTCHA project since June 2023 to provide a robust tooling infrastructure of optimization and performance debugging. The project supports applications, software, and tools within the DOE and NNSA ecosystem.
- ➔ Lead researcher for IOPP Project since June 2021 for Dr. Kathryn Mohror's early career award with Advanced Scientific Computing Research (ASCR) in DOE. In the project, I investigate the role of I/O intents in building workload-aware storage to make smarter storage systems that can dynamically adapt to workloads.

Code Development with Impact

DLIO Benchmark — 44 Github Stars
https://github.com/argonne-lcf/dlio_benchmark — Jan 2021 - Current

- ➔ Used as a benchmark for **acceptance testing and debugging for Aurora** for AI workloads in ALCF.
- ➔ It is used a benchmark by many researchers in Germany (Radita Liam and Sarah Neuwirth)
- ➔ Jean Luca Bez and Suren Byna Lawrence Berkeley National Laboratory, USA
- ➔ Takaaki Fukai National Institute of Advanced Industrial Science and Technology (AIST), Tokyo
- ➔ It is part of **MLPerf benchmark suite for benchmarking Storage** (https://mlcommons.org/working-groups/benchmarks/storage/)

PROFESSIONAL EXPERIENCE

Oracle Financial Services Software — Mumbai, India
Application Developer 2 — Sept 2013 - July 2016

- ➔ Designed framework for **REST API** for product's middleware impacting cloud integrations.
- ➔ Developed utility for **inter-release** activities for clients enabling migration to a newer version in a day.
- ➔ Mentoring new employees on **product framework and design**, helping them deliver faster.
- ➔ Awarded "**We Applaud Award**" for designing a framework affecting the whole organization.

HONORS AND AWARDS

- ➔ R&D 100 Award for UnifyFS.
- ➔ Outstanding service Award at Cluster 2021 for organizing the virtual platform and managing registrations for the conference.
- ➔ Best Student Paper Award from the Computer Science Department at Illinois Tech 2021.
- ➔ Best Paper Award at the 21st IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing CCGrid (May'21)
- ➔ Best Poster Nominee at the Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis 2019.
- ➔ Karsten Schwan Best Paper Award at the 28th International ACM Symposium on High-Performance Parallel and Distributed Computing - HPDC (June'19)
- ➔ Awarded "We Applaud Award" for designing a framework affecting the whole organization at Oracle Financial Services Software.