Hariharan Devarajan

PERSONAL INFORMATION

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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 support a conflict set of I/O requirements dynamically.

Challenge 3 : I/O optimization needs to 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 extrin the application layer to automatically extract I/O Requirements in the applications. Then, we use distributed log 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. candidate 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:

- **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, (pre-print)

Workshops:

- 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

Extended Abstracts and Posters:

- **Hariharan Devarajan**, Anthony Kougkas, and Xian-He Sun. "HFetch: Hierarchical Data Prefetching in Multi-Tiered Storage Environments (Poster)" Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis (SC'19), 2019
- J Cernuda, H Trivino, **H. Devarajan**, A Kougkas, XH Sun. “Efficient Data Eviction across Multiple Tiers of Storage” (Poster) Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis (SC'19), 2019
- Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun, "A Study of NVRAM Performance Variability under Concurrent I/O Accesses", in Proceedings of 2nd Joint International Workshop on Parallel Data Storage & Data-Intensive Scalable Computing Systems, PDSW-DISCS'17, in conjunction with SC'17, 2017. (WIP session)
- **Hariharan Devarajan**, Anthony Kougkas, and Xian-He Sun, "Micro-Storage Services for Open Ethernet Drive", in Proceedings of 2nd Joint International Workshop on Parallel Data Storage & Data-Intensive Scalable Computing Systems, PDSW-DISCS'17, in conjunction with SC'17, 2017. (WIP session)
- Anthony Kougkas, **Hariharan Devarajan**, and Xian-He Sun, "IRIS: I/O Redirection via Integrated Storage", in PhD Forum of the 31st IEEE International Parallel & Distributed Processing Symposium (IPDPS), Orlando, FL, USA, June 2017

RESEARCH EXPERIENCE

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

- **I/O Performance and Portability**
  - 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.

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**.

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

- ➔ Outstanding service Award at Cluster 2021 for organizing the virtual platform and managing registrations for the conference.
- ➔ 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.