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Research Statement

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My research aims to provide a comprehensive framework for high-performance data movement, critical in extracting meaningful insights from large-scale data. In particular, I have interests in bringing interactivity to data-intensive processing tasks. The research requires effective use of a range of techniques encompassing data management, analytics, machine learning, high performance computing, and visualization.

In recent times, we have seen data creation consistently outpace the infrastructure for its storage and utilization. With the growing size of scientific simulations, increasing resolution of sensors and advent of big data, this chasm between production and utilization is wider than ever. The ability to represent large amounts of data is leading to major bottlenecks when it comes to its movement be it across memory or network or to the storage system [1]. As a result, it is increasingly a challenge to extract knowledge from massive amounts of data. Existing approaches fail to scale as data movement suffers from several, often unaligned challenges. For instance, when writing data (parallel I/O), the primary concern is sustaining high throughput (bandwidth) through large-sized accesses, whereas interactive data processing (analysis/visualization) requires fast access (latency) to either localized subsets or some multiresolution representation of the data. My research addresses some of these challenges by providing a unified solution that facilitates key requirements of large-scale data management, including parallel I/O, out-of-core processing, data streaming and remote visualization.

The main idea of this work is the design and development of the first fully parallel framework for high-performance movement of analysis and visualization-appropriate, multiresolution data formats. The framework uses hierarchical space-filling curves as a storage scheme that enables cache friendly use of modern memory/disk hierarchies without knowing the characteristics of the given hardware (cache-oblivious approaches). The layout grants users flexibility with respect to the scale at which they want to process data, making it possible to interact with large volumes of data with low latency on a variety of platforms ranging from the largest supercomputers to regular workstations. Using the framework, applications can save data in a format that is already friendly for analytics queries and that enables immediate streaming of data to remote clients, thus alleviating impediments of data transformations and preprocessing commonly needed by standard analysis and visualization tasks.

This work was published at the Supercomputing conference (SC) [2]. Attended by roughly 10,000 HPC professionals and academics from a variety of disciplines, and with an acceptance rate of around 20%, SC is the most prestigious venue for this community. The research also led to the open-source parallel I/O library PIDX [3], which has shown scalability to 768K cores and has been deployed on some of the fastest supercomputers in the world - Mira (ANL), Titan (ORNL), Quartz (LLNL) and Edison (LBNL). The technology has also enabled international collaborations with HPC centers (RIKEN in Japan and KAUST in Saudi Arabia). It has also been put into production by the Uintah simulation framework [4]. Uintah is a multidisciplinary effort used in the development of numerical modeling of simulations (CFD and multiphysics) at extreme scales. Running on Mira at 260K cores, the simulation used 100 million compute hours and generated 300 Terabytes of data. With PIDX, simulation time dedicated to data management dropped from 50% of total time to under 2%, saving millions of compute hours. My research has also been recognized by the DOE Office of Science through a Phase 1 SBIR grant. I am the PI from the University of Utah with the responsibility of translating my research into a robust industry-standard product.

A complementary direction of my research is to design scalable data reduction techniques to...
alleviate the burdens of data movement and processing. In a paper I published at SC 2014 [5], I presented a technique to facilitate transformation of the typical dense multidimensional array output of an application into a light-weight sparse representation. An example of this approach is region-of-interest (ROI) based writes that allow regions/subsets of a simulations domain to be written at varying resolutions. This method is very effective as many simulations are heavily padded to avoid boundary artifacts, and often the phenomena of interest, e.g., ignition, extinction, etc., are confined to a comparatively small part of the domain. Therefore, writing data that stores the ROI according to some importance measure significantly reduces the overall datasize without impacting the results.

I am also interested in performance modeling and autotuning of HPC systems. HPC is a rapidly evolving field; there is an increasing degree of heterogeneity (architecture, network, storage) across platforms. The differences make it difficult to design optimized software that can cater to all platforms. My research addresses this problem by constructing a performance model to aid in the exploration of the parameter space and use it to autotune the system. Earlier work in HPC research has proposed analytical models, heuristic models, and trial-and-error based approaches. All these methods have limitations and do not generalize well to a wide variety of settings. I use machine-learning techniques to build a generic knowledge-based model independent of any specific hardware or software stack. The work was published at SC in 2013 [6].

Research plans: Interactivity in accessing and processing of scientific data is key to achieving effective insights; it maximizes the cognitive load of a user who is engaged in a hypothesis-driven investigation. I am interested in designing scalable out-of-core computing algorithms and smart paging techniques, with the ultimate goal of adding a component of interactivity to data intensive tasks. Out-of-core techniques will directly address the challenges of big data while paging techniques assuring progressive access will facilitate interactivity. An example could be as simple as providing an interface to extend the standard STL containers to support paging and out-of-core access for handling large datasets. Overall, the work not only will supplement a standalone processing task, but also lay the foundation for the design of scalable algorithms that can foster a data management ecosystem for exascale applications and beyond.

Moving forward, the memory/storage hierarchy is becoming increasingly complex, and using it effectively presents a challenge. I am keen to study the implications of new hardware such as NVRAMs and burst buffers on the data movement software stack. In particular, I want to extend my work on autotuning to address the challenge by constructing deep learning based systems that can help users navigate the complex system.

Spatially progressive algorithms have been extensively explored in the field of data analytics, most notably in areas such as rendering and isosurface computation. I want to investigate data analysis algorithms that also exploit progressive precision i.e. by ordering the data by bitplane from most to least significant bit. The work will enable progressivity in both space and precision allowing a user to refine a dataset in a manner most appropriate for the task at hand. In particular, such a representation would allow a new class of algorithms to be developed that are guaranteed to access, transmit, and process only the minimal amount of required data.

I am also interested in designing insitu analysis techniques. Specifically, I want to explore ways to exploit the high-performance networks of supercomputers to organize data in a layout that is more conducive to analysis tasks. I would also like to couple state-of-the-art distributed I/O systems with rendering systems to develop interactive scientific visualization of large-scale time-varying simulation data. I am collaborating with teams from Paraview, Visit and Ospray, three of the most commonly used visualization systems in HPC. I also want to develop scalable techniques for data movement of unstructured data, which is challenging due to its inherent load
imbalanced nature. I intend to keep pushing for open-source software releases and deployments of my research, hoping to build a vibrant user community. This will lead to new collaborations and funding opportunities.

I am always on the lookout to apply HPC to other fields. For a project with collaborators from The University of Maryland and University of Sydney, I am using HPC to solve the computationally difficult problem of performing control flow analysis (CFA) of large programs. CFA statically models the possible propagations of data and control through a target program, finitely obtaining a bound on reachable expressions and environments. The traditional worklist algorithms for CFAs are inefficient and scale poorly. We are working on the design of a functional CFA using an encoding in Datalog, which can be parallelized on a multicore platform. While we have published preliminary results at the Scheme workshop [7] (with ICFP), the goal is to write research grants to help us develop a data parallel engine to solve complex CFAs.

The interdisciplinary nature of my research allows me to work on a wide spectrum of problems and collaborate with researchers in various fields. I intend to keep working with my existing collaborators (UoU, ANL, LLNL, KAUST), while fostering new ones. I look forward to lead a data management lab and am eager to collaborate with my colleagues to develop a department-wide data science agenda.

References


