Abstract—Extreme Heterogeneity (EH) resulting from diverse processors, accelerators, and memory devices impose urgent challenges to support scientific workflows in the post-Moore era. The position taken is that in-the-loop runtime machine learning and big-data approaches can offer feasible and efficient mechanisms to manage vast resources by realizing a thin autonomous layer of control and optimization. Research on autonomous middleware, residing between diverse hardware resources and existing system software primitives, is worthy of community discussion towards developer-transparent support for EH challenges. Furthermore, by prioritizing a self-aware, self-organizing, and self-optimization perspective, a thin middleware layer could be readily-transportable despite changes to the underlying computing stack. Overall, it will be advocated such an approach could transform EH from a “formidable foe of HPC” into a “valuable ally of HPC” on an incremental path to 2025-2040.

Keywords—Runtime Systems for Extreme Heterogeneity; Machine Learning; Data Clustering; Fault-Propagation Classifier; Correctness Despite Silent Data Corruption; Energy-Aware High Performance Computing; Runtime Dynamic Resource Optimization.

I. CHALLENGES & PERSPECTIVE OF EXTREME HETEROGENEITY

This position paper advocates the potential of online and offline machine-learning approaches to provide a feasible yet high-payoff computer science research direction to address the following Extreme Heterogeneity (EH) Challenges:

C1: efficient resource utilization across disparate computing paradigms/components including multi/many-core CPU, GPU, TPU, FPGA, and future neuromorphic-based accelerators,

C2: mitigating the perils of Silent Data Corruption (SDC) propagation that are not neglectable in HPC applications at the vastness of post-exascale component cardinalities, and

C3: intractability for human optimization of resilience vs. energy tradeoffs [4], whereby reducing supply voltage or cooling to save energy may actually increase energy consumption, because running time is lengthened due to errors impacting convergence.

Research Direction: Unsupervised and semi-supervised learning offer promising research approaches to EH challenges. Large-scale analysis of operational measures and vulnerability metrics could provide a wealth of orthogonal input data to machine learning approaches. Aided by its diversity, such data empowers runtime and offline learning strategies developed to attain pre-established {throughput, resilience, energy} objectives [6][8][11]. These could be researched for the execution behavior of individual jobs first and then layered later for a typical multiuser scenario.

State of the Art: Energy-aware HPC methods have an extensive basis, as do various methods for achieving sufficient correctness despite SDC during execution. However, the management of both of these goals simultaneously as competing objectives remains an urgent, vital, and open research issue. Moreover, EH will act to further exacerbate their interaction and intractability to manage without some form of machine learning support. It is promulgated herein that feasible extensions to existing infrastructures for runtime dynamic resource
optimization could be infused with both proven and continuing research in semi-supervised machine learning. Across the research community, well-established methods as elementary as k-means clustering have demonstrated feature-based learning as unsupervised and semi-supervised learning. Meanwhile, deep learning algorithms have been utilized for unsupervised learning of unlabeled data, of which deep belief networks have excelled and may be especially effective given runtime constraints of C1 and C3. Genetic algorithm approaches leveraging emergent behavior and component/software diversity could be ideal to address C2 [7][10].

II. POTENTIAL FOR MACHINE-LEARNING TO ADVANCE EH

Approach & Maturity: Runtime-monitored metrics could be researched for learning optimization of execution parameters, program characteristics, and hardware configurations that are specific to applications, and thus refined over time to combat EH. Clustering methods and deep learning mechanisms could be encapsulated within a new middleware supervisor-layer. It could recast the perils of unpredictable execution behavior and massive plurality to become highly-beneficial cooperating advantages. By encapsulating these as an active middleware observer/controller service, it can become possible to achieve new proficiencies in resource abstractions needed to deal with EH. Simultaneously, this middleware could autonomously benefit energy consumption profiles and the overall availability of large-scale heterogeneous architectures. This is similar to the case for resilience where for exascale machines the MTTF can be reduced substantially due to scale [2]. A worthy vision is towards an open-source machine learning middleware community. Its collaborators design components to autonomously remodel the execution of scientific workflows through intelligent management of critical tasks. These methods would leverage component diversity and software recasting to explore the runtime execution “search space” of EH conditions. Via feedback mechanisms, they learn how to improve performance incrementally while EH rises, in lockstep for use by 2025-2040.

Timeliness: Two pillars of advancement recently occurred.

T1: The first is a tunable technology pillar. DARPA and industry have completed the PERFECT project to instrument processing platforms for tunable operation. This allows dynamic variation in execution speed via VDD supply-voltage scaling, and various temperature or frequency-scaling modes upon demand.

T2: Second, from the application pillar, our understanding of fault-propagation in HPC applications has advanced significantly in recent years [1]. This includes a number of new metrics and development of benchmark Suite for Embedded Applications and Kernels (SEAK) supported by DOE/DARPA over the last 5 years. These advancements are now ripe to be combined to enable machine learning via their metrics, e.g. the Fault Coverage Energy Ratio (FCER) for leveraging tradeoffs within iso-energy constraints at Near-Threshold Voltage [3].

Uniqueness: Challenges unique to the scientific applications of supercomputing arise within a vast scale of diversity which is intractable for human optimization. Yet, some execution errors are tolerable, depending on disparate characteristics of the particular applications in simulation & data-intensive science. ‘What makes this so’ is that reducing voltage or cooling to save energy may paradoxically increase energy consumption because running time is lengthened due to errors impacting convergence.

Novelty: The extent that this approach is novel to EH in supercomputing for scientific simulation and data science spans:

N1: the need for autonomous management of resource interactions across massive core-level parallelism and multiple component genres, while also minimizing energy consumption. Thus, automations could realize energy-efficient abstractions of EH through a transformative middleware method of consensus-based redundancy management at runtime as a new research area,

N2: reductions in operational cost and runtime complexity which result in the more feasible use of future HPC systems,

N3: new useful interactions between system software, compiler optimization levels, and self-aware middleware techniques could result, thus leveraging emergent behavior within EH,

N4: mining of data to uncover trends to construct application execution models using multiple performance and health metrics from disparate sources, which can help EH-era HPC be viable.

III. SELF-ORGANIZING MIDDLEWARE RESEARCH DISCUSSIONS

Figure 1 graphically depicts the unique challenges of EH within the context of the approaches being advocated. Discussions are worthy on resource management in HPC via automated learning of the most salient characteristics
of data-intensive vs. compute-intensive applications. These highlight application vulnerability analysis integrated with a runtime system to meet multi-objective optimization of throughput, energy, and resilience. Especially interesting are new research fields in real-time management of diverse HPC resources using big-data analytics.

Figure 2 depicts discussions on three potential research topics. For instance, discussion of community interest in frameworks for EH energy and fault propagation analysis in data/computation-intensive distributed applications. Leveraging the LLVM compiler framework for enabling application analysis could be discussed to provide insights into EH sensitivities, thus covering a broad range of HPC applications implemented in multiple programming languages [12]. Compiler optimizations have been usually considered of secondary order methods, but compilers can exploit hardware-specific optimizations, such as special instructions and vector units, transparently to the user. The impact of these code transformations and optimizations on performance is substantial to the point that compiler optimizations are considered essential to achieve high performance, efficiency, and resilience of the computing system [5][9][13]. For example, application execution models would be an interesting discussion regarding metrics of large-scale data analysis and novel vulnerability avoidance despite EH. These would need to be agreed within the community towards an open source machine learning collaboration effort, in order to attain the greatest impact on EH.

REFERENCES


Figure 1: EH challenges using autonomous feedback driven by software diversity.

Figure 2: Proposed discussions on machine learning roles in EH.


