Guest Editorial: Advances in Parallel Graph Processing: Algorithms, Architectures, and Application Frameworks

Ananth Kalyanaraman, Member, IEEE and Mahantesh Halappanavar

In the sphere of modern data science and data-driven applications, graph algorithms have achieved a pivotal place in advancing the state of scientific discovery and knowledge. Nearly three centuries of ideas have made graph theory and its applications a mature area in computational sciences. Yet, today we find ourselves at a crossroads between theory and application. Spurred by the digital revolution, data from a diverse range of high throughput channels and devices, from across internet-scale applications, are starting to mark a new era in data-driven computing and discovery. Building robust graph models and implementing scalable graph application frameworks in the context of this new era are proving to be significant challenges. Concomitant to the digital revolution, we have also experienced an explosion in computing architectures, with a broad range of multicores, manycores, heterogeneous platforms, and hardware accelerators (CPUs, GPUs) being actively developed and deployed within servers and multi-node clusters. Recent advances have started to show that in more than one way, these two fields—graph theory and architectures—are capable of benefiting and in fact spurring new research directions in one another.

This special section is aimed at introducing some of the new avenues of cutting-edge research happening at the intersection of graph algorithm design and their implementation on advanced parallel architectures. More specifically, the section highlights several key challenges that underlie parallel graph algorithm design on modern architectures, and presents new approaches that are designed to overcome those challenges and deliver scalable performance on various architectures. The special section has four articles that cover various aspects of parallel graph analytics—from different algorithmic techniques that are capable of exploiting input or problem characteristics toward generating parallelism on irregular workloads, to implementations that are suited to exploit parallelism on various parallel manycore and multicore architectures. Parallel algorithm design for graph analytics is a complex, broad, and active area of research, and while it is not possible to cover the entire breadth of topics in this short special section, we believe that the techniques and approaches discussed in these articles will serve to highlight some of the key challenges in this emerging area and potential solutions that can be extended beyond the scope of their presented work. In what follows, we present a brief synopsis for each of the four articles of the special section.

Despite offering a large degree of parallelism in their cores, GPUs are still considered a challenging platform for parallelizing graph applications. The article “Scalable and Performant Graph Processing on GPUs Using Approximate Computing” by Somesh Singh and Rupesh Nasre addresses the scalability issues in graph parallelization on GPU platforms. In particular, the paper proposes several approximate computing techniques and shows how those techniques can be leveraged to effectively parallelize graph computations on a single GPU. The key contribution here is to exploit the trade-offs between performance and precision of computation.

Harnessing the power of architectural heterogeneity available from multiple layers of a supercomputer has become essential for scaling up very large graph computations. The article “Multilevel Parallelism for the Exploration of Large-Scale Graphs” by Massimo Bernaschi, Mauro Bisson, Enrico Mastrostefano, and Flavio Vella presents a multi-level parallel processing approach for scaling up graph applications on a multi-GPU cluster running CUDA kernels within each node and MPI for communication across nodes. Using this approach, the paper presents efficient parallel implementations for Breadth-First Search (BFS) and Betweenness Centrality (BC) algorithms, and demonstrates peak performance of 200 Giga TEPs (Traversed Edges Per Second) on a single GPU and 5.5 Tera TEPs on 1024 Pascal GPUs.

Several subgraph isomorphism related problems (finding, counting, estimating, etc.) arise in numerous real world applications including social network analysis and modeling infectious disease spread. The article “Finding and Counting Tree-Like Subgraphs Using MapReduce” by Zhao Zhao, Langshi Chen, Mihai Avram, Meng Li, Guanying Wang, Ali Butt, Maleq Khan, Madhav Marathe, Judy Qiu, and Anil Vullikanti presents an efficient MapReduce algorithm, further accelerated by a new coloring technique, for detecting and counting trees of a certain bounded size, and...
subsequently demonstrate over two orders of magnitude speedup in processing billion-edge scale graphs.

The ability to deal with changes in real world graphs in an incremental fashion has become an essential function in many graph applications. The key challenge is to be able to locate the effects of a change so that computation is reserved only for those essential parts which are affected (thereby avoiding the revisiting of the entire graph). The paper “Incremental Maintenance of Maximal Bicliques in a Dynamic Bipartite Graph” by Apurba Das and Srikanta Tirthapura considers this challenge for the problem of enumerating maximal bicliques in dynamic bipartite graphs, and presents an efficient and intelligent incremental algorithm that builds on theoretical results that guarantee provable performance results.

The slow down in single processor performance (Dennard scaling) has coincided with the emergence of large-scale data from domains beyond scientific computing, introducing a need to develop novel algorithms and techniques in combination of architectural innovations to scale many inherently sequential graph computations. The four papers featured in this special section are intended to be a representative sample of ongoing research to tackle the key challenges in scaling graph algorithms on modern architectures and data characteristics. We hope that you will enjoy reading these papers and benefit from their insights in your own research and practice.

Ananth Kalyanaraman, Mahantesh Halappanavar, Guest Editors

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Ananth Kalyanaraman received the bachelor’s degree from the Visvesvaraya National Institute of Technology, Nagpur, India, in 1998, and the MS and PhD degrees from Iowa State University, in 2002 and 2006, respectively. He is a professor and Boeing Centennial Chair in computer science at the School of Electrical Engineering and Computer Science, Washington State University, Pullman, Washington. He works at the intersection of parallel computing, graph analytics, and bioinformatics/computational biology. His research focus is on developing algorithms and software for scalable analysis of large-scale data from various scientific domains and particularly the life sciences. Research in his lab has been supported by various funding agencies including the National Science Foundation, US Department of Energy, US Department of Agriculture, and the Center for Disease Control and Prevention. He is a recipient of the US Department of Energy Early Career Research Award, and his student-led research works have received multiple conference best paper awards and a prestigious graph challenge award. He serves on the editorial boards of several reputed journals in parallel processing and bioinformatics, and also regularly serves in various capacities including organizational capacities at conferences in the areas of parallel processing and bioinformatics. He is a member of the ACM, the IEEE, and SIAM.

Mahantesh Halappanavar received the master’s and PhD degree in computer science from Old Dominion University, in 2003 and 2009, respectively. He is a senior research scientist and team lead in the physical and computational sciences directorate at the Pacific Northwest National Laboratory. His research has spanned multiple technical foci, and includes combinatorial scientific computing, design and implementation of parallel graph algorithms, machine learning, and application of graph theory and game theory to solve problems in application domains such as scientific computing, power grids, cyber security, and life sciences. He has developed novel algorithms for graph matching, stochastic coordinate descent, graph coloring, graph clustering, extraction of chordal subgraphs, and influence maximization. He has developed innovative techniques to solve challenging problems in power grids through generative graph modeling and clustering. He has developed novel schemes to enable automated decision making in cyber security by combining techniques from graph theory, game theory, and uncertainty quantification. In scientific computing, he has developed novel methods for fault tolerant data distribution, efficient and robust techniques for scheduling of workflows, and graph-theoretic methods for solving problems in life sciences. He has authored more than 50 technical publications in peer-reviewed journals and conferences, and is a member of SIAM and the ACM.

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