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

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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 “Multi-level 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.

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