Medusa: A Parallel Graph Processing System on Graphics Processors

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ABSTRACT

Medusa is a parallel graph processing system on graphics processors (GPUs). The core design of Medusa is to enable developers to leverage the massive parallelism and other hardware features of GPUs by writing sequential C/C++ code for a small set of APIs. This simplifies the implementation of parallel graph processing on the GPU. The runtime system of Medusa automatically executes the user-defined APIs in parallel on the GPU, with a series of optimizations based on the architecture features of GPUs and characteristics of graph applications. In this paper, we present an overview of the Medusa system and a case study of adopting Medusa to a research project on social network simulations. With Medusa, users without GPU programming experience can quickly implement their graph operations on the GPU, which accelerates the discovery and findings of domain-specific applications.

1. INTRODUCTION

GPGPU (General-Purpose Computation on Graphics Processing Units) is gaining increasing popularity in performance acceleration for many applications, including graph processing [8, 10]. A Modern GPU can have over an order of magnitude higher memory bandwidth and computation power than a multi-core CPU. With intensive and application-specific optimizations, GPU-based graph algorithms have shown significant performance improvement over CPU-based implementations. For example, the GPU accelerated breadth first search (BFS) algorithm is up tp 14 times faster than multi-core implementation [10]. However, despite the recent improvements on GPGPU programmability, writing a correct and efficient GPU program is challenging in general and even more difficult for the highly irregular graph applications.

To address the above-mentioned issues and simplify programming graph processing algorithms on the GPU, we propose the Medusa parallel graph processing programming framework. Like existing programming frameworks such as Hadoop [17] and Mars [9]. Medusa provides a small set of APIs for developers to implement their applications by writing sequential (C/C++) code. Different from Hadoop and Mars, which adopts the MapReduce programming model [3], Medusa adopts our novel "Edge-Message-Vertex" (EMV) graph programming model for fine-grained processing on edges, messages and vertices. Medusa embraces an efficient message passing based runtime. It automatically executes user-defined APIs in parallel within one GPU and across multiple GPUs, and hides the complexity of GPU programming from developers. Thus, developers can write the same APIs, which automatically run on one or multiple GPUs. To maximally leverage the power of GPUs, Medusa embraces a series of optimizations based on the architecture features of GPUs and characteristics of graph applications.

As a case study, we adopt Medusa to implement GPU accelerated simulation of information propagation over social networks. Simulation of information propagation is computationally intensive and fortunately highly parallelizable, which makes it viable for GPU acceleration. By the case study, we demonstrate that Medusa both improves the coding productivity and brings significant performance speedups.

This paper gives an overview of Medusa based on work reported in [20, 18, 11, 12, 13]. We first present the design of the main components of Medusa's system architecture and evaluation results. We then present the case study developed based on Medusa. Finally, we conclude this paper and present the future work.

2. RELATED WORK

Parallel graph processing. It has been observed that many common graph algorithms can be formulated using a form of the bulk synchronous parallel (BSP) model [14] (we call it *GBSP*). Under

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John Hulskamp,David Jones

Medusa A Parallel Graph Processing System On Graphics:

Principles of Big Graph: In-depth Insight ,2023-01-24 Principles of Big Graph In depth Insight Volume 128 in the Advances in Computer series highlights new advances in the field with this new volume presenting interesting chapters on a variety of topics including CESDAM Centered subgraph data matrix for large graph representation Bivariate cluster and suitability analysis of NoSQL Solutions for big graph applications An empirical investigation on Big Graph using deep learning Analyzing correlation between quality and accuracy of graph clustering geneBF Filtering protein coded gene graph data using bloom filter Processing large graphs with an alternative representation MapReduce based convolutional graph neural networks A comprehensive review Fast exact triangle counting in large graphs using SIMD acceleration A comprehensive investigation on attack graphs Qubit representation of a binary tree and its operations in quantum computation Modified ML KNN Role of similarity measures and nearest neighbor configuration in multi label text classification on big social network graph data Big graph based online learning through social networks Community detection in large scale real world networks Power rank An interactive web page ranking algorithm GA based energy efficient modelling of a wireless sensor network The major challenges of big graph and their solutions A review and An investigation on socio cyber crime graph Provides an update on the issues and challenges faced by current researchers Updates on future research agendas Includes advanced topics for intensive research for researchers **Web and Big Data. APWeb-WAIM 2020 International Workshops** Qun Chen,Jianxin Li,2021-03-31 This book constitutes revised selected papers from the workshops of the 4th Asia Pacific Web and Web Age Information Management International Joint Conference on Web and Big Data APWeb WAIM 2020 The Third International Workshop on Knowledge Graph Management and Applications KGMA 2020 The Second International Workshop on Semi structured Big Data Management and Applications SemiBDMA 2020 and The First International Workshop on Deep Learning in Large scale Unstructured Data Analytics DeepLUDA 2020 held in Tianjin China in September 2020 Due to the COVID 19 pandemic the conference was held online The 13 papers were thoroughly reviewed and selected from the numerous submissions and present recent research on the theory design and implementation of data management systems *Information and Communication Technology for Intelligent Systems* Suresh Chandra Satapathy,Amit Joshi,2018-12-30 The book gathers papers addressing state of the art research in all areas of Information and Communication Technologies and their applications in intelligent computing cloud storage data mining and software analysis It presents the outcomes of the third International Conference on Information and Communication Technology for Intelligent Systems which was held on April 6 7 2018 in Ahmedabad India Divided into two volumes the book discusses the fundamentals of various data analytics and algorithms making it a valuable resource for researchers future studies **Distributed Graph Analytics** Unnikrishnan Cheramangalath,Rupesh Nasre,Y. N. Srikant,2020-04-17 This book brings together two important trends graph algorithms and high performance computing

Efficient and scalable execution of graph processing applications in data or network analysis requires innovations at multiple levels algorithms associated data structures their implementation and tuning to a particular hardware Further programming languages and the associated compilers play a crucial role when it comes to automating efficient code generation for various architectures This book discusses the essentials of all these aspects The book is divided into three parts programming languages and their compilation The first part examines the manual parallelization of graph algorithms revealing various parallelization patterns encountered especially when dealing with graphs The second part uses these patterns to provide language constructs that allow a graph algorithm to be specified Programmers can work with these language constructs without worrying about their implementation which is the focus of the third part Implementation is handled by a compiler which can specialize code generation for a backend device The book also includes suggestive results on different platforms which illustrate and justify the theory and practice covered Together the three parts provide the essential ingredients for creating a high performance graph application The book ends with a section on future directions which offers several pointers to promising topics for future research This book is intended for new researchers as well as graduate and advanced undergraduate students Most of the chapters can be read independently by those familiar with the basics of parallel programming and graph algorithms However to make the material more accessible the book includes a brief background on elementary graph algorithms parallel computing and GPUs Moreover it presents a case study using Falcon a domain specific language for graph algorithms to illustrate the concepts   Domain-Specific Computer Architectures for Emerging Applications Chao Wang,2024-06-04 With the end of Moore s Law domain specific architecture DSA has become a crucial mode of implementing future computing architectures This book discusses the system level design methodology of DSAs and their applications providing a unified design process that guarantees functionality performance energy efficiency and real time responsiveness for the target application DSAs often start from domain specific algorithms or applications analyzing the characteristics of algorithmic applications such as computation memory access and communication and proposing the heterogeneous accelerator architecture suitable for that particular application This book places particular focus on accelerator hardware platforms and distributed systems for various novel applications such as machine learning data mining neural networks and graph algorithms and also covers RISC V open source instruction sets It briefly describes the system design methodology based on DSAs and presents the latest research results in academia around domain specific acceleration architectures Providing cutting edge discussion of big data and artificial intelligence scenarios in contemporary industry and typical DSA applications this book appeals to industry professionals as well as academicians researching the future of computing in these areas   Cloud Computing for Data-Intensive Applications Xiaolin Li,Judy Qiu,2014-12-02 This book presents a range of cloud computing platforms for data intensive scientific applications It covers systems that deliver infrastructure as a service including HPC as a service virtual networks as a service scalable and reliable storage algorithms

that manage vast cloud resources and applications runtime and programming models that enable pragmatic programming and implementation toolkits for eScience applications Many scientific applications in clouds are also introduced such as bioinformatics biology weather forecasting and social networks Most chapters include case studies Cloud Computing for Data Intensive Applications targets advanced level students and researchers studying computer science and electrical engineering Professionals working in cloud computing networks databases and more will also find this book useful as a reference

Advances in GPU Research and Practice Hamid Sarbazi-Azad,2016-09-15 Advances in GPU Research and Practice focuses on research and practices in GPU based systems The topics treated cover a range of issues ranging from hardware and architectural issues to high level issues such as application systems parallel programming middleware and power and energy issues Divided into six parts this edited volume provides the latest research on GPU computing Part I Architectural Solutions focuses on the architectural topics that improve on performance of GPUs Part II System Software discusses OS compilers libraries programming environment languages and paradigms that are proposed and analyzed to help and support GPU programmers Part III Power and Reliability Issues covers different aspects of energy power and reliability concerns in GPUs Part IV Performance Analysis illustrates mathematical and analytical techniques to predict different performance metrics in GPUs Part V Algorithms presents how to design efficient algorithms and analyze their complexity for GPUs Part VI Applications and Related Topics provides use cases and examples of how GPUs are used across many sectors Discusses how to maximize power and obtain peak reliability when designing building and using GPUs Covers system software OS compilers programming environments languages and paradigms proposed to help and support GPU programmers Explains how to use mathematical and analytical techniques to predict different performance metrics in GPUs Illustrates the design of efficient GPU algorithms in areas such as bioinformatics complex systems social networks and cryptography Provides applications and use case scenarios in several different verticals including medicine social sciences image processing and telecommunications

Languages and Compilers for Parallel Computing Chen Ding,John Criswell,Peng Wu,2017-01-20 This book constitutes the thoroughly refereed post conference proceedings of the 29th International Workshop on Languages and Compilers for Parallel Computing LCPC 2016 held in Rochester NY USA in September 2016 The 20 revised full papers presented together with 4 short papers were carefully reviewed The papers are organized in topical sections on large scale parallelism resilience and persistence compiler analysis and optimization dynamic computation and languages GPUs and private memory and runt time and performance analysis   **Web Information Systems Engineering – WISE 2021** Wenjie Zhang,Lei Zou,Zakaria Maamar,Lu Chen,2021-12-02 This two volume set constitutes the proceedings of the 22nd International Conference on Web Information Systems Engineering WISE 2021 held in Melbourne VIC Australia in October 2021 The 55 full 29 short and 5 demo papers plus 2 tutorials were carefully reviewed and selected from 229 submissions The papers are organized in the following topical sections Part I BlockChain and Crowdsourcing Database System and Workflow Data Mining and

Applications Knowledge Graph and Entity Linking Graph Neural Network Graph Query Social Network Spatial and Temporal Data Analysis Part II Deep Learning 1 Deep Learning 2 Recommender Systems 1 Recommender Systems 2 Text Mining 1 Text Mining 2 Service Computing and Cloud Computing 1 Service Computing and Cloud Computing 2 Tutorial and Demo

Transactions on Large-Scale Data- and Knowledge-Centered Systems XV Abdelkader Hameurlain,Josef Küng,Roland Wagner,Barbara Catania,Giovanna Guerrini,Themis Palpanas,Jaroslav Pokorný,Athena Vakali,2014-12-11 The LNCS journal Transactions on Large Scale Data and Knowledge Centered Systems focuses on data management knowledge discovery and knowledge processing which are core and hot topics in computer science Since the 1990s the Internet has become the main driving force behind application development in all domains An increase in the demand for resource sharing across different sites connected through networks has led to an evolution of data and knowledge management systems from centralized systems to decentralized systems enabling large scale distributed applications providing high scalability Current decentralized systems still focus on data and knowledge as their main resource Feasibility of these systems relies basically on P2P peer to peer techniques and the support of agent systems with scaling and decentralized control Synergy between grids P2P systems and agent technologies is the key to data and knowledge centered systems in large scale environments This special issue contains extended and revised versions of 4 papers selected from the 25 papers presented at the satellite events associated with the 17th East European Conference on Advances in Databases and Information Systems ADBIS 2013 held on September 1 4 2013 in Genoa Italy The three satellite events were GID 2013 the Second International Workshop on GPUs in Databases SoBI 2013 the First International Workshop on Social Business Intelligence Integrating Social Content in Decision Making and OAIS 2013 the Second International Workshop on Ontologies Meet Advanced Information Systems The papers cover various topics in large scale data and knowledge centered systems including GPU accelerated database systems and GPU based compression for large time series databases design of parallel data warehouses and schema matching The special issue content which combines both theoretical and application based contributions gives a useful overview of some of the current trends in large scale data and knowledge management and will stimulate new ideas for further research and development within both the scientific and industrial communities

Scheduling in Distributed Computing Systems Deo Prakash Vidyarthi,Biplab Kumer Sarker,Anil Kumar Tripathi,Laurence Tianruo Yang,2008-10-20 Scheduling in Distributed Computing Systems Analysis Design and Models intends to inculcate the innovative ideas for the scheduling aspect Although the models in this book are designed for distributed systems the same information is applicable for any type of system i e where distributed processing is required Scheduling in Distributed Computing Systems Analysis Design and Models will dramatically improve the design and management of the processes for industry professionals This book deals exclusively with the scheduling aspect which finds little space in other distributed operating system books Scheduling in Distributed Computing Systems Analysis Design and

Models is structured for a professional audience composed of researchers and practitioners in industry This book is also suitable as a reference for graduate level students in management sciences and computer science for distributed computing system classes **Database Systems for Advanced Applications** Matthias Renz,Cyrus Shahabi,Xiaofang Zhou,Muhammad Aamir Cheema,2015-04-08 This two volume set LNCS 9049 and LNCS 9050 constitutes the refereed proceedings of the 20th International Conference on Database Systems for Advanced Applications DASFAA 2015 held in Hanoi Vietnam in April 2015 The 63 full papers presented were carefully reviewed and selected from a total of 287 submissions The papers cover the following topics data mining data streams and time series database storage and index spatio temporal data modern computing platform social networks information integration and data quality information retrieval and summarization security and privacy outlier and imbalanced data analysis probabilistic and uncertain data query processing Parallel Computing Architectures and APIs Vivek Kale,2019-12-06 Parallel Computing Architectures and APIs IoT Big Data Stream Processing commences from the point high performance uniprocessors were becoming increasingly complex expensive and power hungry A basic trade off exists between the use of one or a small number of such complex processors at one extreme and a moderate to very large number of simpler processors at the other When combined with a high bandwidth interprocessor communication facility leads to significant simplification of the design process However two major roadblocks prevent the widespread adoption of such moderately to massively parallel architectures the interprocessor communication bottleneck and the difficulty and high cost of algorithm software development One of the most important reasons for studying parallel computing architectures is to learn how to extract the best performance from parallel systems Specifically you must understand its architectures so that you will be able to exploit those architectures during programming via the standardized APIs This book would be useful for analysts designers and developers of high throughput computing systems essential for big data stream processing emanating from IoT driven cyber physical systems CPS This pragmatic book Devolves uniprocessors in terms of a ladder of abstractions to ascertain say performance characteristics at a particular level of abstraction Explains limitations of uniprocessor high performance because of Moore s Law Introduces basics of processors networks and distributed systems Explains characteristics of parallel systems parallel computing models and parallel algorithms Explains the three primary categorical representatives of parallel computing architectures namely shared memory message passing and stream processing Introduces the three primary categorical representatives of parallel programming APIs namely OpenMP MPI and CUDA Provides an overview of Internet of Things IoT wireless sensor networks WSN sensor data processing Big Data and stream processing Provides introduction to 5G communications Edge and Fog computing Parallel Computing Architectures and APIs IoT Big Data Stream Processing discusses stream processing that enables the gathering processing and analysis of high volume heterogeneous continuous Internet of Things IoT big data streams to extract insights and actionable results in real time Application domains requiring data stream management include military

homeland security sensor networks financial applications network management web site performance tracking real time credit card fraud detection etc **Transputers and Parallel Applications** John Hulskamp,David Jones,1992-11 Presents the proceedings of a Transputer and OCCAM User Group Conference held in Melbourne in November 1992 discussing recent developments in the field of transputers and parallel applications **Japanese Technical Abstracts** ,1988 **Scheduling and Load Balancing in Parallel and Distributed Systems** Behrooz A. Shirazi,Ali R. Hurson,Krishna M. Kavi,1995-05-14 This book focuses on the future directions of the static scheduling and dynamic load balancing methods in parallel and distributed systems It provides an overview and a detailed discussion of a wide range of topics from theoretical background to practical state of the art scheduling and load balancing techniques **Data Sources** ,2000 **Automatic Control and Computer Sciences** ,1987 **Signal and Image Analysis for Biomedical and Life Sciences** Changming Sun,Tomasz Bednarz,Tuan D. Pham,Pascal Vallotton,Dadong Wang,2014-11-07 With an emphasis on applications of computational models for solving modern challenging problems in biomedical and life sciences this book aims to bring collections of articles from biologists medical biomedical and health science researchers together with computational scientists to focus on problems at the frontier of biomedical and life sciences The goals of this book are to build interactions of scientists across several disciplines and to help industrial users apply advanced computational techniques for solving practical biomedical and life science problems This book is for users in the fields of biomedical and life sciences who wish to keep abreast with the latest techniques in signal and image analysis The book presents a detailed description to each of the applications It can be used by those both at graduate and specialist levels **The Chemical Engineer** ,1989

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