Task Clustering and Scheduling for Distributed Memory Parallel Architectures

Michael A. Palis, *Senior Member, IEEE*, Jing-Chiou Liou, *Student Member, IEEE*,
and David S.L. Wei, *Member, IEEE*

Abstract—This paper addresses the problem of scheduling parallel programs represented as directed acyclic task graphs for execution on distributed memory parallel architectures. Because of the high communication overhead in existing parallel machines, a crucial step in scheduling is task clustering, the process of coalescing fine grain tasks into single coarser ones so that the overall execution time is minimized. The task clustering problem is NP-hard, even when the number of processors is unbounded and task duplication is allowed. A simple greedy algorithm is presented for this problem which, for a task graph with arbitrary granularity, produces a schedule whose makespan is at most twice optimal. Indeed, the quality of the schedule improves as the granularity of the task graph becomes larger. For example, if the granularity is at least 1/2, the makespan of the schedule is at most 5/3 times optimal. For a task graph with *n* tasks and *r* inter-task communication constraints, the algorithm runs in $O(n(n \lg n + r))$ time, which is *n* times faster than the currently best known algorithm for this problem. Similar algorithms are developed that produce: (1) optimal schedules for coarse grain graphs; (2) 2-optimal schedules for trees with no task duplication; and (3) optimal schedules for coarse grain trees with no task duplication.

Index Terms—Program task graph, task granularity, task scheduling, distributed memory architectures, approximation algorithms.

1 INTRODUCTION

THE efficiency of execution of parallel programs on distributed memory parallel architectures critically depends on the strategies used to partition the program into modules or tasks and to schedule these tasks onto physical processors. In a distributed memory architecture, tasks mapped to different processors communicate solely by message-passing. In existing parallel machines, the message-passing overhead is quite large, typically in excess of 500 instruction cycles [6]. This imposes a minimum threshold on task granularity below which performance degrades significantly. To avoid performance degradation, one solution would be to coalesce several fine grain tasks into single coarser grain tasks. This reduces the communication overhead but increases the processing time of the (now coarser grain) tasks. Because of this inherent tradeoff, the goal is to determine the optimal task granularity that results in the fastest overall execution time.

The aforementioned problem, called *grain packing* in [10] or *task clustering* in [7], is well studied. The most commonly used program model is a weighted directed acyclic graph (DAG) in which the node weights represent task execution times and the arc weights represent communication times between tasks when mapped to different processors. Re-

searchers have investigated two versions of this problem, depending on whether or not task duplication (or recomputation) is allowed. In task clustering without duplication, the tasks are partitioned into disjoint sets or clusters and exactly one copy of each task is scheduled. In task clustering with duplication, a task may have several copies belonging to different clusters, each of which is independently scheduled. In general, for the same DAG, task clustering with duplication produces a schedule with a smaller makespan (i.e., total execution time) than when task duplication is not allowed.

For example, for the *fork* DAG shown in Fig. 1a, the optimal makespan with no task duplication is 16 while that with task duplication is 11. Note that when two communicating tasks are mapped to the same processor, the communication delay becomes zero because the data transfer is effectively a local memory write followed by a local memory read.

MAKESPAN = 17   MAKESPAN = 16   MAKESPAN = 11
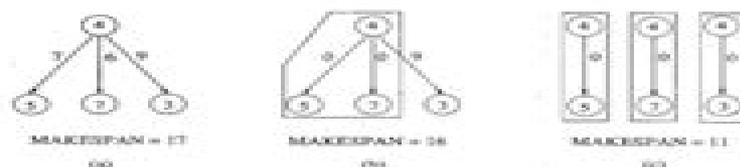(a)   (b)   (c)

Fig. 1. (a) A fork DAG; (b) optimal clustering with no task duplication; (c) optimal clustering with task duplication.

Task clustering—with or without task duplication—is an NP-hard problem [3], [15], [17]. Consequently, practical solutions will have to sacrifice optimality for the sake of

• M. A. Palis and J.-C. Liou are with the Department of Electrical and Computer Engineering, New Jersey Institute of Technology, Newark, NJ 07102-1982. E-mail: {palis,jing}@homer.njit.edu.
• D.S.L. Wei is with the School of Computer Science and Engineering, The University of Aizu, Aizu-Wakamatsu, Fukushima 965, Japan. E-mail: d-wei@u-aizu.ac.jp.

Task Scheduling In Parallel And Distributed Systems

Albert Y. Zomaya

Task Scheduling In Parallel And Distributed Systems:

Task Scheduling in Parallel and Distributed Systems Hesham El-Rewini,Theodore Gyle Lewis,Hesham H. Ali,1994 El Rewini and Lewis were among the first researchers to recognize the problem of resource allocation scheduling inherent in parallel and distributed programs Here they offer a clear explanation of the problems methods to solve the problems under a variety of conditions and an evaluation of the goodness of the solutions **Task Scheduling for Parallel Systems** Oliver Sinnen,2007-05-18 A new model for task scheduling that dramatically improves the efficiency of parallel systems Task scheduling for parallel systems can become a quagmire of heuristics models and methods that have been developed over the past decades The author of this innovative text cuts through the confusion and complexity by presenting a consistent and comprehensive theoretical framework along with realistic parallel system models These new models based on an investigation of the concepts and principles underlying task scheduling take into account heterogeneity contention for communication resources and the involvement of the processor in communications For readers who may be new to task scheduling the first chapters are essential They serve as an excellent introduction to programming parallel systems and they place task scheduling within the context of the program parallelization process The author then reviews the basics of graph theory discussing the major graph models used to represent parallel programs Next the author introduces his task scheduling framework He carefully explains the theoretical background of this framework and provides several examples to enable readers to fully understand how it greatly simplifies and at the same time enhances the ability to schedule The second half of the text examines both basic and advanced scheduling techniques offering readers a thorough understanding of the principles underlying scheduling algorithms The final two chapters address communication contention in scheduling and processor involvement in communications Each chapter features exercises that help readers put their new skills into practice An extensive bibliography leads to additional information for further research Finally the use of figures and examples helps readers better visualize and understand complex concepts and processes Researchers and students in distributed and parallel computer systems will find that this text dramatically improves their ability to schedule tasks accurately and efficiently **Task Scheduling Problems for Parallel and Distributed Systems** ,1999 Parallel and Distributed Computing Handbook Albert Y. Zomaya,1996 With over 1 000 pages and a wealth of illustrations and data tables this handbook offers readers the first information source with the scope to encompass the parallel and distributed computing revolution Written by an international team of experts the book summarizes the current state of the art interprets the most promising trends and spotlights commercial applications **Special Issue: Task Scheduling Problems for Parallel and Distributed Systems** Evripidis Bampis,1999 *Scheduling for Parallel Processing* Maciej Drozdowski,2010-03-14 Overview and Goals This book is dedicated to scheduling for parallel processing Presenting a research eld as broad as this one poses considerable dif culties Scheduling for parallel computing is an interdisciplinary subject joining many elds of science and te

nology Thus to understand the scheduling problems and the methods of solving them it is necessary to know the limitations in related areas Another dif culty is that the subject of scheduling parallel computations is immense Even simple search in bibliographical databases reveals thousands of publications on this topic The versity in understanding scheduling problems is so great that it seems impossible to juxtapose them in one scheduling taxonomy Therefore most of the papers on scheduling for parallel processing refer to one scheduling problem resulting from one way of perceiving the reality Only a few publications attempt to arrange this eld of knowledge systematically In this book we will follow two guidelines One guideline is a distinction tween scheduling models which comprise a set of scheduling problems solved by dedicated algorithms Thus the aim of this book is to present scheduling models for parallel processing problems de ned on the grounds of certain scheduling models and algorithms solving the scheduling problems Most of the scheduling problems are combinatorial in nature Therefore the second guideline is the methodology of computational complexity theory Inthisbookwepresentfourexamplesofschedulingmodels Wewillgodeepinto the models problems and algorithms so that after acquiring some understanding of them we will attempt to draw conclusions on their mutual relationships **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 **Parallel and Distributed Processing and Applications** Minyi Guo,2003 This book constitutes the refereed proceedings of the International Symposium on Parallel and Distributed Processing and Applications ISPA 2003 held in Aizu Japan in July 2003 The 30 revised full papers and 9 revised short papers presented together with abstracts of 4 keynotes were carefully reviewed and selected from numerous submissions The papers are organized in topical sections on applications on Web based and intranet systems compiler and optimization techniques network routing performance evaluation of parallel systems wireless communication and mobile computing parallel topology data mining and evolutionary computing image processing and modeling network security and database and multimedia systems <u>Modeling and Evaluation of Task Scheduling Techniques in Parallel and Distributed Systems</u> Gyung-Leen Park,ProQuest Dissertations and Theses (Electronic resource collection),University of Texas at Arlington. College of Engineering,1997 *Task Scheduling and Communication*

Support for Parallel and Distributed Real-time Systems Jong-Pyng Li,1993 **Algorithms and Architectures for Parallel Processing** Yang Xiang,Ivan Stojmenovic,Bernady O. Apduhan,Guojun Wang,Koji Nakano,Albert Y. Zomaya,2012-09-04 The two volume set LNCS 7439 and 7440 comprises the proceedings of the 12th International Conference on Algorithms and Architectures for Parallel Processing ICA3PP 2012 as well as some workshop papers of the CDCN 2012 workshop which was held in conjunction with this conference The 40 regular paper and 26 short papers included in these proceedings were carefully reviewed and selected from 156 submissions The CDCN workshop attracted a total of 19 original submissions 8 of which are included in part II of these proceedings The papers cover many dimensions of parallel algorithms and architectures encompassing fundamental theoretical approaches practical experimental results and commercial components and systems *Advances in Parallel, Distributed Computing* Dhinaharan Nagamalai,Eric Renault,Murugan Dhanuskodi,2011-09-14 This book constitutes the refereed proceedings of the First International Conference on Advances in Parallel Distributed Computing Technologies and Applications PDCTA 2011 held in Tirunelveli India in September 2011 The 64 revised full papers were carefully reviewed and selected from over 400 submissions Providing an excellent international forum for sharing knowledge and results in theory methodology and applications of parallel distributed computing the papers address all current issues in this field with special focus on algorithms and applications computer networks cyber trust and security wireless networks as well as mobile computing and bioinformatics Large Scale Network-Centric Distributed Systems Hamid Sarbazi-Azad,Albert Y. Zomaya,2013-10-10 A highly accessible reference offering a broad range of topics and insights on large scale network centric distributed systems Evolving from the fields of high performance computing and networking large scale network centric distributed systems continues to grow as one of the most important topics in computing and communication and many interdisciplinary areas Dealing with both wired and wireless networks this book focuses on the design and performance issues of such systems Large Scale Network Centric Distributed Systems provides in depth coverage ranging from ground level hardware issues such as buffer organization router delay and flow control to the high level issues immediately concerning application or system users including parallel programming middleware and OS support for such computing systems Arranged in five parts it explains and analyzes complex topics to an unprecedented degree Part 1 Multicore and Many Core Mc Systems on Chip Part 2 Pervasive Ubiquitous Computing and Peer to Peer Systems Part 3 Wireless Mobile Networks Part 4 Grid and Cloud Computing Part 5 Other Topics Related to Network Centric Computing and Its Applications Large Scale Network Centric Distributed Systems is an incredibly useful resource for practitioners postgraduate students postdocs and researchers **Applied Parallel Computing** Jack Dongarra,2006-03-03 This book constitutes the refereed proceedings of the 7th International Conference on Applied Parallel Computing PARA 2004 held in June 2004 The 118 revised full papers presented together with five invited lectures and 15 contributed talks were carefully reviewed and selected for inclusion in the proceedings The papers are organized in topical sections High

Performance Computing for Computational Science - VECPAR 2006 Michel Daydé,2007-04-02 This book constitutes the thoroughly refereed post proceedings of the 7th International Conference on High Performance Computing for Computational Science VECPAR 2006 held in Rio de Janeiro Brazil in June 2006 The 44 revised full papers presented together with one invited paper and 12 revised workshop papers cover Grid computing cluster computing numerical methods large scale simulations in Physics and computing in Biosciences *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 **Job Scheduling Strategies for Parallel Processing** Dror G. Feitelson,Larry Rudolph,2000-10-18 This book constitutes the thoroughly refereed post workshop proceedings of the 6th International Workshop on Job Scheduling Strategies for Parallel Processing JSSPP 2000 held in Cancun Mexico in May 2000 as a satelite meeting of IPDPS 2000 The 12 revised full papers presented were carefully reviewed during an iterated evaluation process and present the state of the art in the area *Techniques for Task Scheduling in Practical Parallel and Distributed System* ,1999 M Phil Dept of Electronic and Information Engineering The Hong Kong Polytechnic University 1999 *8th IEEE Symposium on Parallel and Distributed Processing* ,1996 Proceedings of the October 1996 symposium with 84 papers in sections on applications networks and routing distributed systems scheduling and data mapping graph theory and networks parallel architectures wormhole routing sorting and selection synchronization techniques load balancing datab *1997 International Conference on Parallel and Distributed Systems* IEEE Computer Society. TC on Distributed Processing,1997 Aimed at researchers professors practitioners students and other computing professionals this work looks at architectures parallel and distributed computation networks mobile computing and communication parallel language and compiler and cache memory

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