Task Clustering and Scheduling for Distributed Memory Parallel Architectures

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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.

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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.
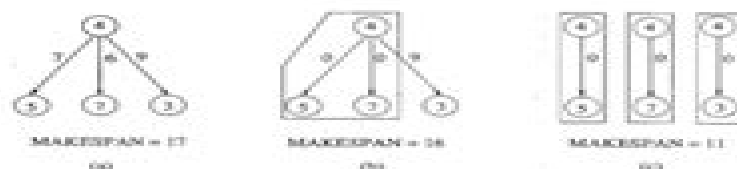

Fig. 1. (a) A fork DAG; (b) optimal clustering with no task duplication; (c) optimal clustering with task duplication.

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

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Task Scheduling In Parallel And Distributed Systems

Jack Dongarra

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** Evripidis Bampis,1999   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   **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   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   **Applied Parallel Computing** Jack Dongarra,2006-03-03 This book constitutes the refereed proceedings of the 7th International Conference on Applied Parallel

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Workshop on Job Scheduling Strategies for Parallel Processing The workshop was held in New York City on June 13 2004 at Columbia University in conjunction with the SIGMETRICS 2004 conference Although it is a workshop the papers were conference reviewed with the full versions being read and evaluated by at least five and usually seven members of the Program Committee We refer to it as a workshop because of the very fast turnaround time the intimate nature of the actual presentations and the ability of the authors to revise their papers after getting feedback from workshop attendees On the other hand it was actually a conference in that the papers were accepted solely on their merits as decided upon by the Program Committee We would like to thank the Program Committee members Su Hui Chiang Walfredo Cirne Allen Downey Eitan Frachtenberg Wolfgang Gentzsch Allan Gottlieb Moe Jette Richard Lagerstrom Virginia Lo Reagan Moore Bill Nitzberg Mark Squillante and John Towns for an excellent job Thanks are also due to the authors for their submissions presentations and final revisions for this volume Finally we would like to thank the MIT Computer Science and Artificial Intelligence Laboratory CSAIL The Hebrew University and Columbia University for the use of their facilities in the preparation of the workshop and these proceedings   Proceedings of the 36th Annual Symposium on Simulation ,2003 The growing awareness of the effects that simulation is having on the way we design our computing communication and control systems is leading to an increased demand for a better understanding of all aspects of simulation ANSS 03 covers broad topics in the areas of distributed systems network modeling and advances in simulation methodology and practices   *Applied Parallel Computing* ,2004   **Intelligent Information and Database Systems** Manh Thanh Le,Jerzy Swiatek,Ngoc Thanh Nguyen,2010-03-05 The 2010 Asian Conference on Intelligent Information and Database Systems ACIIDS was the second event of the series of international scientific conferences for research and applications in the field of intelligent information and database systems The aim of ACIIDS 2010 was to provide an international forum for scientific research in the technologies and applications of intelligent information database systems and their applications ACIIDS 2010 was co organized by Hue University Vietnam and Wroclaw University of Technology Poland and took place in Hue city Vietnam during March 24 26 2010 We received almost 330 papers from 35 countries Each paper was peer reviewed by at least two members of the International Program Committee and International Reviewer Board Only 96 best papers were selected for oral presentation and publi tion in the two volumes of the ACIIDS 2010 proceedings The papers included in the proceedings cover the following topics artificial social systems case studies and reports on deployments collaborative learning collaborative systems and applications data warehousing and data mining database management technologies database models and query languages database security and integrity business e commerce e finance e learning systems information modeling and quirements engineering information retrieval systems intelligent agents and mul agent systems intelligent information systems intelligent internet systems intelligent optimization techniques object relational DBMS ontologies and information sharing semi structured and XML database systems unified modeling language and unified processes Web

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