

# Task Clustering and Scheduling for Distributed Memory Parallel Architectures

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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 coarsening 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  $O(n \log n + r)$  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.

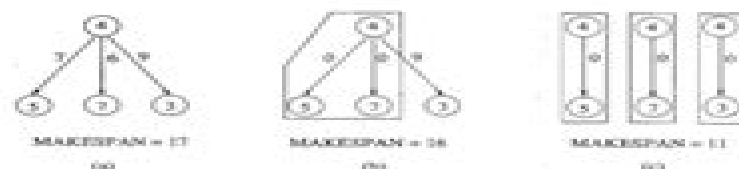


Fig. 1. (a) A fork DAG; (b) optimal clustering with no task duplication; (c) optimal clustering with task duplication.

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

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## **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, 2007-05-04 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

**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

[Task Scheduling Problems for Parallel and Distributed Systems](#) ,1999 *Special Issue: Task Scheduling Problems for Parallel and Distributed Systems* Evripidis Bampis, 1999

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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.

*Scheduling for Parallel Processing*  
Maciej Drozdowski, 2010-03-14

**Overview and Goals** This book is dedicated to scheduling for parallel processing. Presenting a research field as broad as this one poses considerable difficulties. Scheduling for parallel computing is an interdisciplinary subject joining many fields of science and technology. Thus, to understand the scheduling problems and the methods of solving them, it is necessary to know the limitations in related areas. Another difficulty is that the subject of scheduling parallel computations is immense. Even simple search in bibliographical databases reveals thousands of publications on this topic. The diversity 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 field of knowledge systematically. In this book, we will follow two guidelines. One guideline is a distinction between 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 defined 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. In this book, we present four examples of scheduling models. We will go deep into the models' problems and algorithms so that after acquiring some understanding of them, we will attempt to draw conclusions on their mutual relationships.

**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 *Modeling and Evaluation of Task Scheduling Techniques in Parallel and Distributed Systems* Gyung-Leen Park, ProQuest Dissertations and Theses (Electronic resource collection), University of Texas at Arlington. College of Engineering, 1997 **New Horizons of Parallel and Distributed Computing** Minyi Guo, Laurence Tianruo Yang, 2006-01-27 Parallel and distributed computing is one of the foremost technologies for shaping future research and development activities in academia and industry Hyperthreading in Intel processors hypertransport links in next generation AMD processors multicore silicon in today's high end microprocessors and emerging cluster and grid computing have moved parallel distributed computing into the mainstream of computing New Horizons of Parallel and Distributed Computing is a collection of self contained chapters written by pioneering researchers to provide solutions for newly emerging problems in this field This volume will not only provide novel ideas work in progress and state of the art techniques in the field but will also stimulate future research activities in the area of parallel and distributed computing with applications New Horizons of Parallel and Distributed Computing is intended for industry researchers and developers as well as for academic researchers and advanced level students in computer science and electrical engineering A valuable reference work it is also suitable as a textbook

**Advances in Informatics** Yannis Manolopoulos, Skevos Evripidou, Antonis C. Kakas, 2003-04-22 This book constitutes the thoroughly refereed post proceedings of the 8th Panhellenic Conference on Informatics PCI 2001 held in Nicosia Cyprus in November 2001 The 31 revised full papers presented were carefully selected and improved during two months of reviewing from 104 conference papers The papers cover the areas of databases data mining and intelligent systems e learning human computer interaction image processing networks and systems software and languages and theoretical computer science

*Metaheuristics for Scheduling in Distributed Computing Environments* Fatos Xhafa, Ajith Abraham, 2008-09-08 Grid computing has emerged as one of the most promising computing paradigms of the new millennium Achieving high performance Grid computing requires techniques to efficiently and adaptively allocate jobs and applications to available resources in a large scale highly heterogeneous and dynamic environment This volume presents meta heuristic approaches for Grid scheduling problems Due to the complex nature of the problem meta heuristics are primary techniques for the design and implementation of efficient Grid schedulers The volume brings new ideas analysis implementations and evaluation of meta heuristic techniques for Grid scheduling which make this volume novel in several aspects The 14 chapters of this

volume have identified several important formulations of the problem which we believe will serve as a reference for the researchers in the Grid computing community Important features include the detailed overview of the various novel metaheuristic scheduling approaches excellent coverage of timely advanced scheduling topics state of the art theoretical research and application developments and chapters authored by pioneers in the field Academics scientists as well as engineers engaged in research development and scheduling will find the comprehensive coverage of this book invaluable

**Handbook of Energy-Aware and Green Computing - Two Volume Set** Ishfaq Ahmad, Sanjay Ranka, 2016-02-03  
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*Handbook on Data Centers* Samee U. Khan, Albert Y. Zomaya, 2015-03-16 This handbook offers a comprehensive review of the state of the art research achievements in the field of data centers Contributions from international leading researchers and scholars offer topics in cloud computing virtualization in data centers energy efficient data centers and next generation data center architecture It also comprises current research trends in emerging areas such as data security data protection management and network resource management in data centers Specific attention is devoted to industry needs associated with the challenges faced by data centers such as various power cooling floor space and associated environmental health and safety issues while still working to support growth without disrupting quality of service The contributions cut across various IT data technology domains as a single source to discuss the interdependencies that need to be supported to enable a virtualized next generation energy efficient economical and environmentally friendly data center This book appeals to a broad spectrum of readers including server storage networking database and applications analysts administrators and architects It is intended for those seeking to gain a stronger grasp on data center networks the fundamental protocol used by the applications and the network the typical network technologies and their design aspects The Handbook of Data Centers is a leading reference on design and implementation for planning implementing and operating data center networks

Advances in Computer Systems Architecture Chris Jesshope, 2006-08-31 This book constitutes the refereed proceedings of the 11th Asia Pacific Computer Systems Architecture Conference ACSAC 2006 The book presents 60 revised full papers together with 3 invited lectures addressing such issues as processor and network design reconfigurable computing and operating systems and low level design issues in both hardware and systems Coverage includes large and significant computer based infrastructure projects the challenges of stricter budgets in power dissipation and more High Performance Computing and Grids in Action Lucio Grandinetti, 2008 Collects in four chapters single monographs related to the fundamental advances in parallel computer systems and their developments from different points of view from computer scientists computer manufacturers end users and related to the establishment and evolution of grids fundamentals

implementation and deployment      Models for Parallel and Distributed Computation R. Correa, Ines de Castro Dutra, Mario Fiallos, Luiz Fernando Gomes da Silva, 2013-06-29 Parallel and distributed computation has been gaining a great lot of attention in the last decades During this period the advances attained in computing and communication technologies and the reduction in the costs of those technologies played a central role in the rapid growth of the interest in the use of parallel and distributed computation in a number of areas of engineering and sciences Many actual applications have been successfully implemented in various platforms varying from pure shared memory to totally distributed models passing through hybrid approaches such as distributed shared memory architectures Parallel and distributed computation differs from classical sequential computation in some of the following major aspects the number of processing units independent local clock for each unit the number of memory units and the programming model For representing this diversity and depending on what level we are looking at the problem researchers have proposed some models to abstract the main characteristics or parameters physical components or logical mechanisms of parallel computers The problem of establishing a suitable model is to find a reasonable trade off among simplicity power of expression and universality Then be able to study and analyze more precisely the behavior of parallel applications      **Development of Distributed Systems from Design to Application and Maintenance** Bessis, Nik, 2012-12-31 This book is a collection of research on the strategies used in the design and development of distributed systems applications Provided by publisher      **High Performance Computing -- HiPC 2003** Timothy Mark Pinkston, V. K. Prasanna Kumar, 2003-12-03 This book constitutes the refereed proceedings of the 10th International Conference on High Performance Computing HiPC 2003 held in Hyderabad India in December 2003 The 48 revised full papers presented together with 5 keynote abstracts were carefully reviewed and selected from 164 submissions The papers are organized in topical sections on performance issues and power aware systems distributed and network algorithms routing in wireless mobile and cut through networks scientific and engineering applications overlay networks clusters and grids scheduling and software algorithms network design and performance grid applications and architecture support performance analysis scheduling and migration      **Grid and Cooperative Computing. Part 2** Minglu Li, 2004-04-28 The two volume set LNCS 3032 and LNCS 3033 constitute the thoroughly refereed post proceedings of the Second International Workshop on Grid and Cooperative Computing GCC 2003 held in Shanghai China in December 2003 The 176 full papers and 173 poster papers presented were carefully selected from a total of over 550 paper submissions during two rounds of reviewing and revision The papers are organized in topical sections on grid applications peer to peer computing grid architectures grid middleware and toolkits Web security and Web services resource management scheduling and monitoring network communication and information retrieval grid QoS algorithms economic models and theoretical models of the grid semantic grid and knowledge grid remote data access storage and sharing and computer supported cooperative work and cooperative middleware

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