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. Researchers 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.

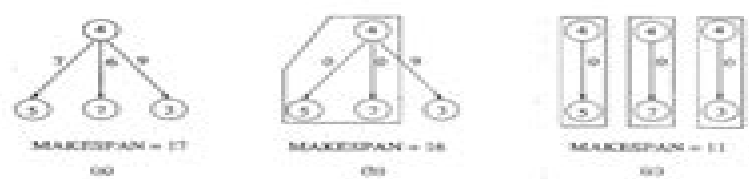

Fig. 1. (a) A fork DAG; (b) optimal clustering with no task duplication; (c) optimal clustering with task duplication.

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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