Multi-agent tree-based solution for the TERMES problem

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***Abstract*—Inspired by the TERMES project of Harvard University, robots in this domain collect construction blocks from a reservoir and build user-specified structures by stacking the blocks together. The robots are of roughly the same size as the blocks and as they can climb only one step at once, they can scale greater heights only by using temporarily constructed ramps in the substructures. We consider the problem of minimizing the number of pickup and drop-off operations performed on blocks along with minimizing the total makespan (total time taken for all pickup and drop-offs) in building user-specified structures. The already proposed polynomial-time algorithm heuristically solves this problem and is based on the idea of performing dynamic programming on a spanning tree in the inner loop and searching for a good tree to do so in the outer loop. Multiple agents are concurrently used on paths that are considered as non-conflicting paths. The tree-based solution along with multiple agents is also polynomial in time. The algorithm performs very well in simulation and scales easily to large problem instances.**

***Index Terms*—TERMES, Tree-based solution, Non-conflicting paths**

I. Introduction

Although sophisticated equipment are used, humans are still directly involved in several critical phases of construction tasks. Automated robots can be assigned tasks hence avoiding such risk dealing works by us. Such automated scheduling robots are effective, decrease the costs and risks involved in construction and it is observed that a team of smaller robots are often more effective than a few larger robots as smaller robots are usually cheaper, easier to program, and easier to deploy. Moreover, teams of smaller robots are more reliable, fault tolerant, provide more parallelism and hence take lesser time than a few larger robots. Teams of smaller robots coordinating amongst themselves is analogous to many examples of collective construction in nature. Inspired by termites and their building capabilities, the Harvard TERMES project investigated how teams of robots can cooperate to build user specified 3-dimensional structures much larger than the robots. The TERMES architecture has small autonomous mobile robots and a reservoir of passive building blocks, simply referred to as blocks. The blocks are roughly the same size as the robots. A robot can carry only a single block at once and can climb or descend one unit height at once. The robots stack blocks together by building ramps in conjunction to scale heights more than one to build user defined structures. The ramps are deconstructed once the user defined structure is built.

II. Problem Formulation

Given an empty configuration of cells where blocks are to be placed and a blueprint 2D matrix with the height at a cell being the number of blocks needed to be placed at that particular location in the final structure. The objective of the problem is to minimize the number of pickups and drop-offs of the blocks from and to the source respectively along with minimizing the makespan.

III. Proposed solution

An already proposed tree-based solution solves the problem heuristically. It has an outer and an inner loop. The inner loop, given a spanning tree of the graph of the 2D input, provides a solution as the order of block installments and removals along with the paths from the source. The inner loop does this by creating event trees which have a macro and a micro structure. An event tree is a batch of tasks. Blocks are placed and removed in consecutive batches (event trees) respectively. The macro structure refers to the cell and the micro structure refers to the height variations the cell undergoes represented in the form of subnodes. The outer loop provides the inner loop with a good spanning tree.
Multiple agents can be used on cells with non-conflicting paths for reducing the overall makespan. Two paths are defined as non-conflicting if their corresponding paths from the source in an event tree differ by a maximum difference of one in the micro structure until they have a common path along the macro structure. It exploits the condition that blocks need not be placed and removed in the order of the subnodes in a cell.

IV. Results

Experimentation has been done on several well defined models and also on randomly generated structures varying in the percentage emptiness. Figure 1 shows the time taken for varying number of multiple agents across increasing percentage of emptiness for randomly generated 7×7 structures with maximum height of 15.

		Multiple agent times			
%Empty	Single agent time	X = 3	X = 5	X = 7	X = 9
0	25632	14224	10682	9143	8582
20	21505	12013	8886	7964	7216
40	18379	10267	7504	6437	6067
60	12522	7826	7071	6172	5949
80	8895	6635	6128	5984	5832

Fig. 1. Time taken for randomly generated 7×7 strucutres with maximum height 15

V. Discussion and Conclusion

The proposed multi-agent solution is 50 to 60% percent faster than using a single agent with the average number of agents being the number of edges from the source to the work space. Also, it can be observed from figure 1 that the decrease in time taken as the number of agents is increased, saturates as the number of agents increases. The proposed polynomial solution performs well and also scales well for considerably large instances.