Efficient Declarative Solutions in Picat for Optimal Multi-Agent Pathfinding

Neng-Fa Zhou[1] and Roman Barták[2]

1 **CUNY Brooklyn College and Graduate Center, New York, USA**
nzhou@sci.brooklyn.cuny.edu

2 **Charles University, Praha, Czech Republic**
bartak@ktiml.mff.cuni.cz

Abstract

The multi-agent pathfinding (MAPF) problem has attracted considerable attention because of its relation to practical applications. The majority of solutions for MAPF are algorithmic. Recently, declarative solutions that reduce MAPF to encodings for off-the-shelf solvers have achieved remarkable success. We present a constraint-based declarative model for MAPF, together with its implementation in Picat, which uses SAT and MIP. We consider both the makespan and the sum-of-costs objectives, and propose a preprocessing technique for improving the performance of the model. Experimental results show that the implementation using SAT is highly competitive. We also analyze the high performance of the SAT solution by relating it to the SAT encoding algorithms that are used in the Picat compiler.

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1 Brief Overview

The multi-agent pathfinding (MAPF) problem amounts to finding a plan for agents to move within a graph from their starting locations to their destinations, such that no agents collide with each other at any time. While MAPF can be solved suboptimally in polynomial time [4], the optimization version with the objective of minimizing the makespan or the sum-of-costs is NP-hard [9, 13]. MAPF has been intensively studied, because the problem occurs in various forms in practical applications, such as robotics and games [1, 7], and the problem also provides a platform for studying search algorithms [6, 8, 12].

Recently, studies of MAPF have proposed using declarative models that rely on off-the-shelf solvers to find solutions. These solvers include CSP (Constraint Satisfaction Problems) [5], SAT (Satisfiability) [10, 11], ASP (Answer Set Programming) [2], and MIP (Mixed Integer Programming) [14]. Declarative models are easy to implement and maintain, can easily be altered for other variants, and are amenable to new domain-specific constraints. SAT-based MAPF solutions are especially promising; they have been shown to be competitive with some well-designed heuristic search algorithms [11].

All of the constraint-based models follow the planning-as-satisfiability approach [3], which finds a sequence of states of a bounded length, where the first state corresponds to the initial state, the last state satisfies the goal condition, and each pair of successive states constitutes a valid action. An efficient declarative solution requires a good model of variables and constraints, a fast solver, and a decent encoding of the model for the solver.

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We give a constraint-based declarative model for MAPF. The model is very natural; it uses a Boolean variable to indicate whether an agent occupies a vertex of the graph in a state, and uses constraints to ensure the validity of all of the states and state transitions. The basic model minimizes the makespan objective. This model is easily extended to deal with the sum-of-costs objective. We adapt a preprocessing technique for eliminating some of the variables in the model that can never be set to 1. The model is implemented in Picat [15], a general-purpose language that provides several tools for modeling and solving combinatorial problems. Experiments with the SAT and MIP modules show that the SAT solution is more competitive than the MIP solution. A comparison with ASP also reveals the high performance of the SAT solution. We also analyze the performance of the SAT solution by relating it to the encoding algorithms used in the Picat SAT compiler.

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