Conflict-Based Search for Optimal Multi-Agent Path Finding

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Abstract

We present a new two-level search algorithm for optimal multi-agent path finding called Conflict Based Search (CBS). At the high level, a search is performed on a tree based on conflicts between agents. At the low level, a search is performed only for a single agent at a time. Experimental results on various problems shows a speedup of up to a full order of magnitude over previous approaches.

Multi-agent path finding

In the *multi-agent path finding* (MAPF) problem, we are given a graph and a set of agents. Each agent has a start position and goal position . At each time step an agent can either *move* to a neighboring location or can *wait* in its current location. The task is to return a set of actions for each agent, that will move each of the agents to its goal without *conflicting* with other agents while minimizing a cumulative cost function such as the summation of time steps required by each of the agents.

The Conflict Based Search Algorithm

We present a new algorithm called Conflicts-based Search (CBS) for optimally solving MAPF. It has two levels. The high level searches a global *constraint tree* (CT) while the low-level searches for paths for individual agents. CT is a binary tree. Each node N in the CT contains the following fields of data:

(1) A set of constraints: A *constraint* is a tuple (a_i, v, t) where agent a_i is prohibited from occupying vertex v at time step t.

(2) Solutions: A set of k paths for the given set of k agents. For each agent a_i, the low level phase is invoked. The low-level finds a path for a_i that is consistent with its own constraints.

(3) The total cost of the current solution (summation over all the single-agent path costs).

Node N in the CT is a goal if its solution is valid, i.e., the set of paths for all agents have no inter-agent conflicts. This is done by a *validation process* which simultaneously executes the different paths until all agents reach their solutions or until an inter-agent conflict occurs.

The high-level performs a best-first search on the CT where nodes are ordered by their costs. When it finds a valid node it halts and returns its solution which is guarantied to be optimal.

Given a non-goal CT node N whose solution includes a *conflict* at (v,t) between agents a_i and a_j we know that in any valid solution at most one of the conflicting agents may occupy vertex v at time t. Therefore, in any valid solution, at least one of the conflicting agents must add this constraint to its list of constraints. To guarantee optimality, both possibilities are examined and N, is split into two children. Both children inherit the set of constraints from N. The right (left) child adds the constraint (a_i, v, t) ((a_j, v, t)) to the list of constraints. The high-level search then further proceeds.

Experiments We experimented with open grids and with testbed maps from Sturtevant's repository (Sturtevant 2012) while comparing CBS to other existing algorithms such as A*+ID+OD (Standley 2010) and ICTS (Sharon et al. 2011). We observed a known phenomenon that different algorithms behave differently under different circumstances and there is no universal winner. In particular, we observed that CBS performs very well in cases which include many long corridors and bottlenecks. By contrast CBS performs poorly where many large open spaces exist ; the other algorithms are preferable in such cases.

Full treatment of CBS appears in AAAI-2012 (Sharon et al. 2012a). Furthermore, an enhancement called Meta-Agent CBS (MA-CBS) appears in SoCS12 (Sharon et al. 2012b). The interested reader is referred to these papers for more information on CBS and its variants.

References

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