Context-Aware Route Planning

Extended Abstract[1]

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1 Introduction

In context-aware route planning, there is a set of transportation agents each with a start and destination location on a shared infrastructure. Each agent wants to find a shortest-time route plan without colliding with any of the other agents, or ending up in a deadlock situation. This problem arises in the deployment of Automated Guided Vehicle Systems (AGVSs), for instance in manufacturing where the vehicles carry materials between production stations, or at container terminals such as Hamburg and Singapore, where they carry containers to and from ships [7]. Another application domain of multi-agent transportation is taxi routing at airports [2], where aircraft have to taxi, e.g. from a runway to a gate, while avoiding close proximity with other aircraft. Avoiding collisions and deadlocks can be achieved by constructing a set of conflict-free route plans. A route plan for a single agent specifies which infrastructure *resources* (such as roads and intersections) the agent will visit, and at which times it will visit these resources. The set of agent route plans should ensure that there are never more agents in a resource than its *capacity* allows. Finding an optimal set of conflict-free route plans is an NP-hard problem [5], and optimal centralized approaches have difficulty finding plans for more than a handful of agents (four agents, in [1]).

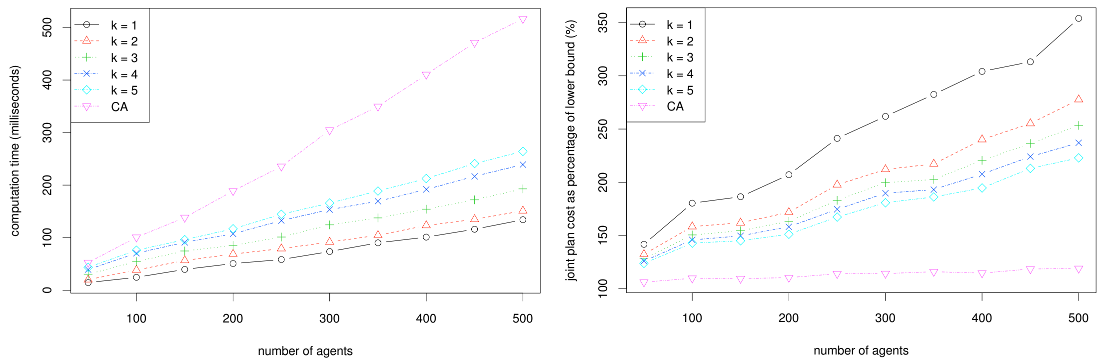
In the full version of this paper, we present a *context-aware* route planning algorithm, which finds an optimal route plan for a single agent, given a set of existing route plans that have been constructed earlier by other agents. From the set of existing agent plans, we can derive the set of *free time windows* on each resource, which represent time intervals during which a resource has capacity left for at least one more agent. In our approach we construct a graph of these free time windows, and our algorithm performs an A*-like search through the free time window graph, which results in an optimal (shortest-time), conflict-free route plan. The worst-case complexity of our algorithm is $O(|\mathcal{A}||R| \log(|\mathcal{A}||R|) + |\mathcal{A}||R|^2)$, where $\mathcal{A}$ is the set of agents (vehicles), and R is the set of infrastructure resources. This is an improvement over an earlier context-aware route planning algorithm with a complexity of $O(|\mathcal{A}|^4|R|^2)$ by Kim and Tanchoco [3].

A further trade-off between plan quality and computation time can be achieved by finding an optimal *schedule* along a *fixed path*. In fixed-path scheduling, an agent has one or more pre-determined paths from its start location to its destination location, and it will choose the path along which it can find the shortest-time conflict-free schedule. Lee et al. [4] suggest finding a conflict-free schedule along one of k shortest paths. The fixed-path scheduling approach cannot guarantee individually optimal route plans, because it may be faster to take a longer but less congested path.

2 Evaluating global plan quality

Although context-aware route planning produces locally optimal plans, there is no guarantee that a set of sequentially obtained plans is also globally optimal (for example if we measure global plan cost as the sum of the costs of the agent plans). Moreover, it is possible to construct examples (in the full paper) in which the fixed-path scheduling approach actually produces better global plans. We therefore conducted a set of experiments to compare the global plan quality of context-aware route planning and fixed-path scheduling.

[1] This paper is an extended abstract of [6], which can be found at `http://www.st.ewi.tudelft.nl/~adriaan/pubs/terMorsWitteveenZuttKuipersMates2010.pdf`



(a) CPU time (b) Global plan cost

Figure 1: Comparison of Context-Aware (CA) routing and fixed-path scheduling ($k = 1, \ldots, 5$).

In our experiments we ran both approaches on the same problem instances, which varied in the number of agents for which a plan needed to be found (from 100 to 500 agents), and in the type of infrastructure (we tested on random graphs, but also on a realistic model of Amsterdam Airport Schiphol). Figure 1(a) shows the CPU times required by both algorithms for problem instances on random graphs of 180 nodes and 300 edges. Although fixed-path scheduling is clearly faster, context-aware route planning still manages to find plans for all 500 agents within half a second. Figure 1(b) depicts the global plan cost of both approaches on the infrastructure of Schiphol airport, relative to a lower bound on global plan cost[2]. From figure 1(b) it is clear that context-aware routing produces much better global plans, a picture that also emerges from the experiments on other infrastructures. Fixed-path scheduling, on the other hand, suffers from over-use of bottleneck resources, especially in case each agent has only a single path.

References

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[7] Iris F.A. Vis. Survey of research in the design and control of automated guided vehicle systems. *European Journal of Operational Research*, 170(3):677–709, May 2006.

[2] The lower bound on the cost of a single agent plan is simply the shortest path in the graph between its start location and its destination location without taking into account the plans of the other agents. A lower bound on global plan cost is then simply the sum of the shortest paths of all the agents.