Scalable Robotic Intra-Logistics with Answer Set Programming

Philipp Obermeier
Institute of Computer Science, University of Potsdam
Germany
phil@cs.uni-potsdam.de

Abstract
Over time, Answer Set Programming (ASP) has gained traction as a versatile logic program-
ming semantics with performant processing systems, used by a growing number of significant
applications in academia and industry. However, this development is threatened by a lack of
commonly accepted design patterns and techniques for ASP to address dynamic application on
a real-world scale. To this end, we identified robotic intra-logistics as representative scenario, a
major domain of interest in the context of the fourth industrial revolution. For this setting, we
aim to provide a scalable and efficient ASP-based solutions by (1) stipulating a standardized test
and benchmark framework; (2) leveraging existing ASP techniques through new design patterns;
and (3) extending ASP with new functionalities. In this paper we will expand on the subject
matter as well as detail our current progress and future plans.

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1 Introduction

Answer Set Programming (ASP; [4]) has come a long way, starting as a semantics for
logic programming, over having increasingly performant systems, to a growing number of
significant applications in academia and industry. In contrast to other solver paradigms, ASP
offers an unprecedented degree of versatility and brevity, which is best put in perspective
by solving multi-faceted problems. However, this development is threatened by a lack of
commonly accepted design patterns and techniques for ASP to address dynamic application
on a real-world scale. In addition, many industrial applications require the integration
of multiple types of knowledge and forms of reasoning, a feature commonly neglected by
existing approaches. As a first step to overcome these problems, we have identified robotic
intra-logistics as representative scenario for our investigation. This domain is a major subject
of interest in the context of the fourth industrial revolution, as witnessed by Amazon’s Kiva,
GreyOrange’s Butler, and Swisslog’s CarryPick systems. All of them aim at automatizing
warehouse operations (illustrated by Figure 1) by using robot vehicles that drive underneath
mobile shelves and deliver them to picking stations. From there, workers pick and place the
requested items in shipping boxes. For this setting, we aim to provide scalable and efficient

Optimal Target Assignment and Path Finding for Teams of Agents
Hang Ma

ABSTRACT

Task assignment and path finding (TAPF; [5]) is a generalization of MAPF. TAPF groups agents into teams. Although teams are (non-anonymously) pre-assigned to groups of destinations, any robot in the team can be (anonymously) selected for a destination in the assigned group. G-TAPF [7] is a generalization of TAPF aiming at more realistic settings by allowing the number of tasks to be greater than the number of agents and considering deadlines, orderings, and checkpoints. That is, deadlines are associated with order lines, orders are completed in a pre-defined ordering and all lines in a single order need to be fulfilled before any line of another order is completed, and while fulfilling an order, a robot is required to go through a sequence of locations, called checkpoints. Regarding previous uses of ASP, [1] address several aspects of multi-agent path finding problems.

[6] address an online version of path finding, where not all destination tasks\(^2\) are given initially but may arrive over time.

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\(^2\) Actually, this work also uses pick-up and delivery tasks to simulate a warehouse system.
3 Current Research Progress

So far, we introduced a scalable approach for a generalized variant of TAPF, formally laid out the problem domain, and conducted a real-life case study for car assembly: 
asprilo: Robotic Intra-Logistics Benchmark Suite [2]. We introduce the 
asprilo framework to facilitate experimental studies of approaches addressing complex dynamic applications. For this purpose, we have chosen the domain of robotic intra-logistics. This domain is not only highly relevant in the context of today’s fourth industrial revolution but it moreover combines a multitude of challenging issues within a single uniform framework. This includes multi-agent planning, reasoning about action, change, resources, strategies, etc. In return, 
asprilo allows users to study alternative solutions as regards effectiveness and scalability. Although 
asprilo relies on Answer Set Programming and Python, it is readily usable by any system complying with its fact-oriented interface format. This makes it attractive for benchmarking and teaching well beyond logic programming. More precisely, 
asprilo consists of a versatile benchmark generator, solution checker and visualizer (see Figure 2) as well as a bunch of reference encodings featuring various ASP techniques. Importantly, the visualizer’s animation capabilities are indispensable for complex scenarios like intra-logistics in order to inspect valid as well as invalid solution candidates. Also, it allows for graphically editing benchmark layouts that can be used as a basis for generating benchmark suites. The 
asprilo framework is freely available at https://potassco.org/asprilo.

Generalized Target Assignment and Path Finding [7]. Both MAPF and TAPF models suffer from their limiting assumption that the number of agents and targets are equal. We propose the Generalized TAPF (G-TAPF) formulation that allows for (1) unequal

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asprilo stands for Answer Set Programming for robotic intra-logistics.
number of agents and tasks; (2) tasks to have deadlines by which they must be completed; (3) ordering of groups of tasks to be completed; and (4) tasks that are composed of a sequence of checkpoints that must be visited in a specific order. As different G-TAPF variants may be applicable in different domains, we model them using ASP, which allows one to easily customize the desired variant by choosing appropriate combinations of rules to enforce. Our experimental results show that the popular CBM (conflict-based min-flow) algorithm is better in simple TAPF problems with few conflicts, but worse in difficult problems with more conflicts. We also show that ASP technologies can easily exploit domain-specific information to improve its scalability and efficiency. The contributions in this paper thus make a notable jump towards deploying MAPF and TAPF algorithms in practical applications.

Routing Driverless Transport Vehicles in Car Assembly [3]. Automated storage and retrieval systems are principal components of modern production and warehouse facilities. In particular, automated guided vehicles nowadays substitute human-operated pallet trucks in transporting production materials between storage locations and assembly stations. While low-level control systems take care of navigating such driverless vehicles along programmed routes and avoid collisions even under unforeseen circumstances, in the common case of multiple vehicles sharing the same operation area, the problem remains how to set up routes such that a collection of transport tasks is accomplished most effectively. We address this prevalent problem in the context of car assembly (see Figure 3) at Mercedes-Benz Ludwigsfelde GmbH, a large-scale producer of commercial vehicles, where routes for automated guided vehicles used in the production process have traditionally been hand-coded by human engineers. Such ad-hoc methods may suffice as long as a running production process remains in place, while any change in the factory layout or production targets necessitates tedious manual reconfiguration, not to mention the missing portability between different production plants. Unlike this, we propose a declarative approach based on Answer Set Programming to optimize the routes taken by automated guided vehicles for accomplishing transport tasks. The advantages include a transparent and executable problem formalization, provable optimality of routes relative to objective criteria, as well as elaboration tolerance towards particular factory layouts and production targets. Moreover, we demonstrate that our approach is efficient enough to deal with the transport tasks evolving in realistic production processes at the car factory of Mercedes-Benz Ludwigsfelde GmbH.
4 Open Issues and Expected Achievements

To sum up, we expect the following major achievements through our research:

1. A standardized framework for experimental studies of dynamic systems, specifically in the intra-logistics domains
2. Novel ASP design patterns and extensions for solving various problems in dynamic systems on an industrial scale

References