Collective Adaptation through Concurrent Planning: the Case of Sustainable Urban Mobility

Extended Abstract

Antonio Bucchiarone
Fondazione Bruno Kessler
Trento, Italy
bucchiarone@fbk.eu

Daniel Furelos-Blanco
Universitat Pompeu Fabra
Barcelona, Spain
daniel.furelos@upf.edu

Anders Jonsson
Universitat Pompeu Fabra
Barcelona, Spain
anders.jonsson@upf.edu

Fahmida Khandokar
Cardiff University
Cardiff, United Kingdom
fkhandokar@gmail.com

Monjur Mourshed
Cardiff University
Cardiff, United Kingdom
mourshedm@cardiff.ac.uk

ABSTRACT

In this paper we address the challenges that impede collective adaptation in smart mobility systems by proposing a notion of *ensembles*. Ensembles enable systems with collective adaptability to be built as emergent aggregations of autonomous and self-adaptive agents. Adaptation in these systems is triggered by a run-time occurrence, which is known as an issue. The novel aspect of our approach is, it allows agents affected by an *issue* in the context of a smart mobility scenario to adapt collaboratively with minimal impact on their own preferences through an issue resolution process based on concurrent planning algorithms.

KEYWORDS

Socio-Technical Systems; Collective Adaptation; Ensembles; Sustainable Urban Mobility; Concurrent Planning

ACM Reference Format:
Antonio Bucchiarone, Daniel Furelos-Blanco, Anders Jonsson, Fahmida Khandokar, and Monjur Mourshed. 2018. Collective Adaptation through Concurrent Planning: the Case of Sustainable Urban Mobility. In *Proc. of the 17th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2018), Stockholm, Sweden, July 10–15, 2018,* IFAAMAS, 3 pages.

1 INTRODUCTION

Sustainable urban mobility fundamentally relies on social, economic, and environmental dimensions [18]. However, the high reliance on car use and associated issues, such as low accessibility to alternatives, high congestion, and environmental pollution reflect how modern urban mobility systems focus on meeting individual needs at the cost of collective benefits [8, 15]. The trends emerging from the urban transport sector question its long-term sustainability in meeting complex travel needs of a growing urban population without adversely affecting the climate or environment. In-depth exploration suggests that, above all, the urban mobility system has to be adaptable and dynamic to sustain the challenges arising from complex interactions between urban systems [3].

Collective Adaptive Systems (CASs) consist of diverse heterogeneous agents composing a socio-technical system [1, 20]. Individual agents 'opportunistically' enter a system and self-adapt in order to leverage other agents' resources and capabilities to perform tasks more efficiently or effectively. Self-adaptation within a collaborative system is a challenging task [19]. Changes in the behavior of one agent may break the consistency of the whole collaboration, or have negative repercussions on other agents. Therefore, self-adaptation of an individual agent does not only aim at achieving its own goals but also the emerging goals of dynamically formed sub-systems.

Previous studies attempted to compute joint plans for multiple agents in navigation scenarios using *concurrent planning* [11, 14]. However, they usually focused on satisfying certain constraints such as not colliding rather than fostering collaboration. *Numeric planning* [17] allows the identification of the optimal choice based on costs and resources during navigation. The key disadvantages of numeric planners include they are usually more complex, and unable to plan simultaneously for more than one agent.

In the given context, this paper addresses collective adaptation by proposing a notion of *ensembles* that enables systems with collective adaptability to be built as emergent aggregations of autonomous and self-adaptive agents. We introduce *concurrent planning* to enable collective planning for ensembles of agents. Since planning for each ensemble is decentralized, it eliminates the single point of failure, and the potential bottleneck in the system.

2 METHODOLOGY

In this section we explain the theoretical framework for defining CASs, and how we model mobility tasks using concurrent planning.

2.1 Roles and Ensembles

The term *ensemble* denotes large-scale systems of systems that may present substantial socio-technical embedding [10, 20]. Ensembles typify systems with complex design, engineering and management, whose level of complexity comes specifically from gathering and combining in the same operating environment many heterogeneous and autonomous components, systems and users, with specific concerns. Ensembles must self-adapt to sustain the continuous variations induced by their socio-technical nature as well as the

Proc. of the 17th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2018), M. Dastani, G. Sukthankar, E. André, S. Koenig (eds.), July 10–15, 2018, Stockholm, Sweden.

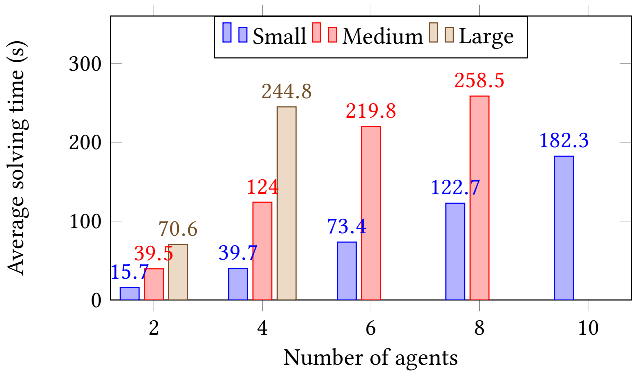

Figure 1: Average solving times for different combinations of maps and number of agents.

high degree of unpredictability and dynamism of their operating environments.

Our approach addresses the challenge of collective adaptation by proposing a new notion of ensembles that enables systems with collective adaptability to be built as emergent aggregations of autonomous and self-adaptive agents. Each agent is defined by a set of *roles* (e.g. carpool driver or passenger). A role is determined by its collaborations with other roles. Collaboration involves taking *actions* and generating *issues*, i.e. formation of critical situations. In our context, issues could be blocked streets that force an agent to change its planned route. When an issue arises, a role can choose to handle the issue using one of its *solvers*.

Key properties of our approach include (i) the emphasis on collaboration towards fulfillment of individual, diverse goals, and (ii) the heterogeneous nature of an ensemble with respect to the roles, behaviors and goals of its participants. These properties distinguish our approach from other types of ensemble models, such as swarms, multiagent systems, and agent-based organizations. All elements in a swarm exhibit a uniform behavior, and global shared goal [5, 13]. In contrast, those within a multiagent system and agent-based organization may display several distinct roles and behaviors, but the differentiation is still limited and often pre-designed [6].

2.2 Concurrent Planning

We adopt the formalism of *temporal planning* [7, 16] to generate concurrent solutions. Even though temporal planning was not specifically invented with multiple agents in mind, *temporal* (or *durative*) actions are concurrent and have variable duration. Temporal planning also makes it possible to model complex features such as deadlines, conditions during the application of actions, and effects occurring at arbitrary time points. Thus, we can express and exploit concurrency using temporal actions.

The smart carpooling problem is modeled as follows. There are two types of agents (passengers and carpools) distributed in a map. Each agent has an starting and a target location. The problems have the following characteristics:

- Each link between two locations has a fixed distance.
- Each link may represent a footpath (used by passengers), a street (used by carpools), or both.
- Passengers move uniformly at 1 m/s. Carpools move uniformly at a speed that depends on the street's speed limit.
- A passenger can embark a carpool only if they are at the same location. This action takes 1 time unit.
- A passenger can debark a carpool at any location reached by the carpool. This action takes 1 time unit.

The TPSHE temporal planner [12] is used to compute solutions for the carpooling problems. This planner converts the original temporal planning problem into a classical planning problem that can be solved using an off-the-shelf classical planner. The resulting classical plan is converted into a temporal plan specifying which actions are done and at which time.

3 EVALUATION

To evaluate the scalability of our approach, we extended the Collective Adaptation Engine (CAE) [2, 4] to solve carpooling problems using a concurrent planner[1].

Problems are built from a real map of Trento obtained from OpenStreetMap (OSM) [9] and a given number of agents (carpools and passengers). The origin and target locations of the agents are randomly set within the input map. The resulting scenarios are converted into planning problems, which are solved by TPSHE.

The time required to get a solution is measured for each problem. We generated 5 problems for different combinations of maps and number of agents. Three different maps were used, each with a different number of links/streets (2700, 5500 and 8200). The total number of agents ranged from 2 to 10. About 45 instances were used for each combination. All experiments ran on Intel Xeon E5-2673 v4 @ 2.3GHz processors. They had a time limit of 5 minutes and a memory limit of 4 GB.

Figure 1 shows the average solving time for some combinations of maps and agents. Average times are only shown if more than half of the instances were solved. The more agents and the bigger the map, the more time is needed to solve the problems. Moreover, the number of solved instances decreases as the map grows: 99.8% were solved for the small map, 70.4% for the medium one and 39.6% for the largest one.

In the future, a hierarchical approach could be used to reduce the number of streets in the problem (e.g. by building "clusters" that are formed by diverse locations), thus reducing the amount of time required to get a solution.

4 CONCLUSIONS

In this paper, we have presented an approach to CASs that is resilient to changes. Adaptation issues are solved within an ensemble, taking advantage of agents' solver abilities for minimal impact. We use concurrent planning techniques to solve issues collectively.

ACKNOWLEDGMENTS

This work has been partially supported by the Maria de Maeztu Units of Excellence Programme (MDM-2015-0502).

REFERENCES

[1] 2016. FoCAS Manifesto – A roadmap to the future of Collective Adaptive Systems. (2016). http://www.focas.eu/focas-manifesto.pdf.

[1] The software is available at https://github.com/aig-upf/smart-carpooling-demo.

[2] D. Bozhinoski, A. Bucchiarone, I. Malavolta, A. Marconi, and P. Pelliccione. 2016. Leveraging Collective Run-Time Adaptation for UAV-Based Systems. In *SEAA'16*. 214–221.

[3] A. Bucchiarone, M. De Sanctis, and A. Marconi. 2016. Decentralized Dynamic Adaptation for Service-Based Collective Adaptive Systems. In *Service-Oriented Computing - ICSOC 2016 Workshops*. 5–20.

[4] A. Bucchiarone, N. Dulay, A. Lavygina, A. Marconi, H. Raik, and A. Russo. 2015. An Approach for Collective Adaptation in Socio-Technical Systems. In *IEEE SASO Workshops*. 43–48.

[5] C. Pinciroli et al. 2011. ARGoS: A modular, multi-engine simulator for heterogeneous swarm robotics. In *IROS*. 5027–5034.

[6] B. H. Far, T. Wanyama, and S. O. Soueina. 2006. A negotiation model for large scale multi-agent systems. In *IRI*. 589–594.

[7] M. Fox and D. Long. 2003. PDDL2.1: An Extension to PDDL for Expressing Temporal Planning Domains. *J. Artif. Intell. Res. (JAIR)* 20 (2003), 61–124.

[8] S. Gössling. 2016. Urban transport justice. *Journal of Transport Geography* 54, Supplement C (2016), 1–9.

[9] M. Haklay and P. Weber. 2008. OpenStreetMap: User-Generated Street Maps. *IEEE Pervasive Computing* 7, 4 (2008), 12–18. https://doi.org/10.1109/MPRV.2008.80

[10] M. Holzl, A. Rauschmayer, and M. Wirsing. 2008. Engineering of software-intensive systems. In *Software- Intensive Systems and New Computing Paradigms*. LNCS, Vol. 5380. Springer, 1–44.

[11] W. Hönig, S. Kumar, L. Cohen, H. Ma, H. Xu, N. Ayanian, and S. Koenig. 2016. Multi-Agent Path Finding with Kinematic Constraints. In *ICAPS'16*. 477–485.

[12] S. Jiménez, A. Jonsson, and H. Palacios. 2015. Temporal Planning With Required Concurrency Using Classical Planning. In *ICAPS'15*. 129–137.

[13] P. Levi and S. Kernbach. 2010. *Symbiotic-Robot Organisms: Reliability, Adaptability, Evolution*. Vol. 7. Springer Verlag.

[14] H. Ma, C. Tovey, G. Sharon, S. Kumar, and S. Koenig. 2016. Multi-Agent Path Finding with Payload Transfers and the Package-Exchange Robot-Routing Problem. In *AAAI'16*. 3166–3173.

[15] G. Mattioli, J. Anable, and K. Vrotsou. 2016. Car dependent practices: Findings from a sequence pattern mining study of UK time use data. *Transportation Research Part A: Policy and Practice* 89, Supplement C (2016), 56–72.

[16] J. Rintanen. 2007. Complexity of Concurrent Temporal Planning. In *ICAPS'07*. 280–287.

[17] E. Scala, M. Ramírez, P. Haslum, and S. Thiébaux. 2016. Numeric Planning with Disjunctive Global Constraints via SMT. In *ICAPS'16*. 276–284.

[18] A. Silva, M. da Silva Costa, and M. Helena Macedo. 2008. Multiple views of sustainable urban mobility: The case of Brazil. *Transport Policy* 15, 6 (2008), 350–360.

[19] D. Weyns and J. Andersson. 2013. On the challenges of self-adaptation in systems of systems. In *SESoS@ECOOP, 2013*. 47–51.

[20] F. Zambonelli, N. Bicocchi, G. Cabri, L. Leonardi, and M. Puviani. 2011. On Self-Adaptation, Self-Expression, and Self-Awareness in Autonomic Service Component Ensembles. In *SASOW*. 108–113.