Evolution of Heterogeneous Multirobot Systems Through Behavioural Diversity

(Doctoral Consortium)

Jorge Gomes
Instituto de Telecomunicações, Lisboa, Portugal
LabMAg – Faculdade de Ciências da Universidade de Lisboa, Portugal
jgomes@di.fc.ul.pt

ABSTRACT

Heterogeneity is present in many collective systems found in nature and considered fundamental for effective task execution in several complex, real-world scenarios. Evolutionary computation has the potential to automate the design of multirobot systems, but to date, it has mostly been applied to the design of homogeneous systems. We have recently demonstrated that novelty search can overcome deception and bootstrapping issues in the evolution of homogeneous robot swarms. In this research, we study how evolutionary techniques based on behavioural diversity (such as novelty search) can contribute to the evolution of heterogeneous multirobot systems. The results obtained so far show that novelty search can overcome open issues in the cooperative coevolution of multiagent systems, and lead to more effective and diverse solutions.

Keywords

Coevolution, behavioural diversity, novelty search, evolutionary robotics, swarm robotics

1. INTRODUCTION

Heterogeneity is key in many natural systems and social organisations [2]. Nature provides us with several examples of how heterogeneity can increase efficiency and promote self-organisation through the division of labour and specialisation. Canonical examples include colonies of honeybees, where thousands of individuals cooperate under a clear division of tasks, achieved with individual specialisation.

Swarm robotics systems are characterised by decentralised control, limited communication, use of local information, and self-organised global behaviour. Such systems have shown their potential for flexibility and robustness [1]. However, existing swarm robotics systems still only display limited and simple proof-of-concept behaviours under laboratory conditions. Researchers have just recently begun to study heterogeneous swarm robotics systems [3]. In [3], it is argued that heterogeneity might be fundamental to overcome the limitations of swarm robotics systems, and achieve the complexity necessary to solve real-world tasks.

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Evolutionary robotics represents an effective way of designing swarm robotics systems, as it can overcome the problem of decomposing the desired swarm behaviour into simple individual behaviours [12]. The design problem is exacerbated in heterogeneous systems [3], however, evolutionary robotics has been applied almost exclusively to homogeneous systems. Evolution of heterogeneous multiagent systems is possible through cooperative coevolution [11], where multiple species are coevolved in separate populations, effectively resulting in a solution decomposed in multiple roles.

Cooperative coevolution has shown a number of advantages over the non-evolutionary approaches for the design of heterogeneous multiagent systems [9], such as specialisation and emergence of agent roles [2, 14]. However, cooperative coevolution also introduces a number of challenges [13, 10], such as the need of *synchronised learning* among the species, potential premature convergence of populations (*mediocre stable states*), and the difficulty of assessing the contribution of each species to the global behaviour (*credit assignment problem*).

Evolutionary techniques based on behavioural diversity, such as novelty search [7], have been shown to be effective in overcoming premature convergence, especially in the domain of evolutionary robotics [8]. The distinctive aspect of these approaches is that the population is driven towards behavioural diversity instead of a predefined fixed objective. In previous work, we have shown that novelty search can overcome bootstrapping issues and deception in swarm robotics systems [6], and that novelty search can be used to unveil a diversity of effective solutions for a given problem. This research focus on the study of novelty search, and other evolutionary techniques based on behavioural diversity, as an effective way to cooperatively coevolve heterogeneous multirobot systems. Since one of the key issues in cooperative coevolution is the premature convergence of populations [10], diversity-based evolutionary techniques can potentially offer a significant contribution to the coevolution of heterogeneous multirobot systems.

2. OBJECTIVES

This research focus on the application of behavioural diversity techniques to the evolution of cooperative heterogeneous robotics systems. The ultimate objective of our research is to study and develop novel coevolution methods that are capable of evolving heterogeneous multirobot systems for real-world complex tasks. Although our research is focused on embodied multiagent systems, we expect that some of our results generalise to other multiagent systems, in which specialisation plays a major role.

The results obtained so far, using relatively small groups of agents, showed that our approach can overcome the problem of premature convergence in cooperative coevolution [5]. Overcoming this issue allows for the exploration of other related challenges in heterogeneous multirobot systems, including:

1. Scale the approach to large groups of agents. This may require the study of techniques for sharing individuals between different populations.
2. Behavioural specialisation and emergence of roles in swarms of morphologically homogeneous robots.
3. Morphological specialisation in groups of robots.

By exploring these intertwined challenges, we will work towards solutions for evolving heterogeneous multirobot systems for complex tasks, based on behavioural diversity, and with a minimal intervention from the experimenter.

3. AVOIDING STABLE STATES

Previous research has shown that cooperative coevolutionary algorithms are biased towards stability [10]: they tend to converge prematurely to equilibrium states, instead of converging to (near-)optimal solutions. The first goal of our research was to overcome this pathology. We proposed two methods for overcoming convergence to equilibrium states in cooperative coevolution, based on novelty search. The first method relies on team-level behaviour characterisations and promotes novel collaborations (*NS-T*), while the second method tries to promotes diversity at the level of the individual agents (*NS-I*).

Our experimental results in simulated multiagent tasks confirmed that fitness-based coevolution often converges to very narrow regions of the solution space. These regions often do not contain high quality solutions for the task, which results in an overall poor effectiveness of the evolutionary process. On the contrary, *NS-T* was able to overcome premature convergence to equilibrium states. By rewarding individuals that generate novel collaborations, an evolutionary pressure towards novel equilibrium states is created. The populations still converge, but the focus of convergence changes throughout the evolutionary process. As there is a more effective exploration of the solution space, *NS-T* can reach collaborations associated with higher fitness scores more often, and can evolve a diverse set of solutions for a given task in a single evolutionary run.

4. FUTURE WORK

The performance of novelty search with individual-level characterisations (*NS-I*) was significantly inferior to *NS-T*. However, individual-level characterisations have considerable potential, which is being explored in ongoing work. For instance, they can be used to promote heterogeneity in the teams, and to identify populations that are evolving similar agents. The later can potentially be useful when dealing with high number of agents, since it can allow exchanges of individuals between similar coevolving populations.

One current limitation of using novelty search is the necessity of providing behaviour characterisations, which are typically task-specific. In recent studies [4], we showed that generic behaviour characterisations also perform well in some scenarios. In ongoing work, we are studying how to develop more effective behaviour characterisations that do not rely on task-specific knowledge.

The results obtained so far in our research are promising, and suggest that using diversity-based evolutionary techniques may facilitate a sustained and productive interplay between coevolving populations. With more effective coevolution techniques, we can potentially strive for more ambitious forms of cooperation, including, for instance, the coevolution of morphologies or controllers for large-scale multiagent systems.

5. REFERENCES

[1] E. Bonabeau, M. Dorigo, and G. Theraulaz. *Swarm intelligence: from natural to artificial systems*, volume 4. Oxford University Press, 1999.

[2] A. Campbell and A. S. Wu. Multi-agent role allocation: issues, approaches, and multiple perspectives. *Autonomous Agents & Multi-Agent Systems*, 22(2):317–355, 2011.

[3] M. Dorigo, D. Floreano, et al. Swarmanoid: a novel concept for the study of heterogeneous robotic swarms. *IEEE Robotics & Automation Magazine*, 2012.

[4] J. Gomes and A. L. Christensen. Generic behaviour similarity measures for evolutionary swarm robotics. In *Genetic and Evolutionary Computation Conference (GECCO)*, pages 199–206. ACM Press, 2013.

[5] J. Gomes, P. Mariano, and A. L. Christensen. Avoiding convergence in cooperative coevolution with novelty search. In *AAMAS*. IFAAMAS, 2014. *In press*.

[6] J. Gomes, P. Urbano, and A. L. Christensen. Evolution of swarm robotics systems with novelty search. *Swarm Intelligence*, 7(2–3):115–144, 2013.

[7] J. Lehman and K. O. Stanley. Abandoning objectives: Evolution through the search for novelty alone. *Evolutionary Computation*, 19(2):189–223, 2011.

[8] J.-B. Mouret and S. Doncieux. Encouraging behavioral diversity in evolutionary robotics: An empirical study. *Evolutionary Computation*, 20(1):91–133, 2012.

[9] L. Panait and S. Luke. Cooperative multi-agent learning: The state of the art. *Autonomous Agents & Multi-Agent Systems*, 11(3):387–434, 2005.

[10] L. Panait, R. P. Wiegand, and S. Luke. A visual demonstration of convergence properties of cooperative coevolution. In *Parallel Problem Solving from Nature (PPSN)*, volume 3242 of *LNCS*, pages 892–901. Springer-Verlag, 2004.

[11] M. A. Potter and K. A. D. Jong. Cooperative coevolution: An architecture for evolving coadapted subcomponents. *Evolutionary Computation*, 8(1):1–29, 2000.

[12] V. Trianni, S. Nolfi, and M. Dorigo. Evolution, self-organization and swarm robotics. In *Swarm Intelligence*, pages 163–191. Springer-Verlag, 2008.

[13] R. P. Wiegand. *An Analysis of Cooperative Coevolutionary Algorithms*. PhD thesis, George Mason University, 2003.

[14] C. H. Yong and R. Miikkulainen. Coevolution of role-based cooperation in multiagent systems. *IEEE Transactions on Autonomous Mental Development*, 1(3):170–186, 2009.