EVOLUTION IN ROBOTIC ISLANDS: ENHANCING THE POTENTIAL OF AUTOMATIC DESIGN TECHNIQUES THROUGH A PARALLEL DISTRIBUTED ENVIRONMENT (STUDY REFERENCE NUMBER: 09-8301)

Type of activity: Standard study (25 k€)

Background and motivation

Evolutionary Robotics [1] is a machine learning technique, which has recently received growing attention from the robotics research community as it promises the automatic synthesis of controllers. Such an automated framework is based on the use of artificial evolution (optimisation) to reinforce the learning of robots populations, by effectively tuning the parameters of randomly generated sets of controllers. The controllers commonly used are artificial neural networks (ANNs) due to their versatility, generalisation capabilities and tolerance to noisy sensory input. So, if the controller is represented as an ANN, an evolutionary algorithm can be applied in order to optimise the weights, and possibly the morphology, of the networks that guide the agents to the accomplishment of their task.

Evolutionary algorithms are inspired by the Darwinian principle of selective reproduction of the fittest individual in a population. This means that the individual (in this case a neuro-controller) that adapts best to its environment has more chances to reproduce and to pass its genetic material to subsequent generations. The search through the universe of potential solutions is guided by a fitness function, which simply evaluates the quality of a certain solution.

This approach has been widely applied to several problems, ranging from generating controllers for walking robots, for homogeneous and heterogeneous groups of robots that cooperate to accomplish a given task, to designing optimal interplanetary trajectories for low-thrust spacecrafts [2]. Controllers designed with this approach have been successful in controlling both simulated and real robots [3][4].

Such a machine learning methodology can significantly contribute to alleviating the burden of a particularly cumbersome design problem. By using such a methodology, the experimenter escapes a difficult design problem that includes among others the decomposition into sub-behaviours and analysis and understanding of the dynamics of the interaction between agents and their environment. An automatic process can find solutions to the problem at hand that were not a priori evident to the experimenter, and it can generate elegant solutions which may be very hard to hand-design, even for an expert.

On the other hand, failure to predict all that might go wrong, and that the robot will encounter, can lead to machines unable to adapt to changing and unpredictable environments. It has been demonstrated that such an automatic design process is able to exploit the richness of dynamical interactions between agents and environment and subtle properties of the sensory input space to create adaptive and general controllers for autonomous agents.

However, to-date, the complexity of the tasks solved by agents controlled by evolved neuro-controllers is lower than the complexity achieved by other methods using hand-coded controllers driven by expert knowledge. Also, even if automatic techniques could in principle reduce the human effort required to design controllers, this is usually not the case [5][6]. In other words, the complexity achieved by automatic approaches seems incommensurate with the effort expended in setting up and configuring the evolutionary system. Therefore, despite the theoretical advantages of automating the design problem for autonomous agents, the control community cannot yet claim to

having ripped its benefits. More effort should be put by the research community in reducing the computation time required until a solution to a problem at hand is obtained with these techniques, and at the same time in creating a framework that can generate more complex solutions without a significant effort overhead on the side of the experimenter.

Various approaches in the literature have explored the possibility of enhancing the efficiency of automatic design tools, such as incremental evolution and symbiotic evolution [7], but the focus of such methods is not on creating a generic and simple design framework and certainly not on the algorithmic side. In the present study, we wish to contribute to overcoming the shortcomings of existing automatic design techniques, by incorporating into their methodology insights from global optimisation research, and in particular from the island model for parallel global optimisation and from the more recent results obtained by making different algorithms cooperate on a single problem [10].

The island model for parallel optimisation

Parallelisation of evolutionary algorithms has been extensively studied in the context of global optimisation, resulting in a significant speedup of the optimisation process. Besides, island-based models have proved that migration of individuals between independent runs of an algorithm improves the performance of the optimisation process, both in terms of function evaluations required and in terms of the quality of the solution obtained [8][9] and also for large dimensional and for difficult engineering problems [11].

The island model paradigm seems very suitable for application to Evolutionary Robotics for various reasons:

1) It could significantly speedup the design process by exploiting parallelism, while improving the quality of the solutions found.
2) It could relieve the experimenter from a significant part of the burden required to properly set up the evolutionary process. Cooperating algorithms via migration without well-tuned parameters have proved to work as well as single instances of a well-tuned algorithm in global optimisation [10][11].
3) When designing controllers for robots, the exchange of individuals corresponds to introducing different types of solutions in a pool of already existing ones. This might increase the diversity in a population and via the recombination of genetic material, it might endow agents with capabilities that would be extremely unlikely to evolve in one run. In other words, it could facilitate the progressive composition of a rich behavioural repertoire.

Study description

The main objective of the study is to perform the optimisation of a neuro-controller in an island model, with a vision to demonstrate empirically an improvement of the automatic design methodology. The framework to be used for the island model implementation is PaGMO, an open source project developed and maintained by the ACT researchers [http://repo.or.cz/w/PaGMO.git], while the robot dynamics and its environment simulation has to be provided by the University. The University is free to propose research directions within this wider objective. Potential study topics could include:

1) The study of how different global optimisation algorithms, such as Particle Swarm Optimisers, Differential Evolution, Simulated Annealing etc., could complement genetic and, in general, evolutionary algorithms in controller design.
2) The study of how interacting and cooperative algorithms via the island model could facilitate obtaining robust and general controllers for a given task.

3) The study of how migration affects solution generation in the course of the optimisation process. For example, how does a migration of a controller exhibiting different behavioural capabilities from the ones present in a given population affect the latter?
4) The study of how the island model may facilitate the design of heterogeneous teams of robots, displaying inherent task allocation and division of labour properties.

Interaction with the Advanced Concepts Team

The Advanced Concepts Team has developed a unified framework for distributing parallel optimisation tasks (PaGMO, http://repo.or.cz/w/PaGMO.git). Different global and local optimisation algorithms (these are currently including a simple genetic algorithm, differential evolution, particle swarm optimisation, simulated annealing, Nelder-Mead, harmony search) can be deployed over available CPUs or in independent threads within the same CPU. This environment (written in C++ and exposed in Python) will need to be used to conduct the experimentation on the influence of the island model on the evolutionary robotics methodology. The software allows distributed computations to be run in single CPUs or CPUs clusters should these be made available by the participating University.

The study will need to include experiments on at least three tasks:

1. The ACT will provide the fitness function and environment dynamics for a spacecraft docking problem. In particular, we want to assess the potential of an evolved neuro-controller to guide a spacecraft to attach to a base station with a given orientation and relative final speed.
2. A benchmarking single agent evolutionary robotics task, not space related, jointly agreed upon by the university and the ACT, where the speed of obtaining solutions and the reliability of the process should be assessed when the island model is used.
3. Another task, also not directly representing a space scenario and jointly agreed upon by the university and the ACT, either single or multi-agent, whose complexity is prohibitive for state-of-the-art evolutionary approaches to generate solutions.

References

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