Towards biologically plausible distributed evolutionary algorithms in Swarm Robotics.

Matt Oates (Matt.Oates.08@bristol.ac.uk)

11th December 2009

• Supervisors: Dr James Marshal (Computer Science UoB) and Prof Alan Winfield (Bristol Robotics Lab. UWE)

• Prospective Advisor: Prof Nigel Franks (School of Biological Sciences UoB)

• PhD Route: Continuation of Winter project with a change in direction.

Swarm robotics simply put is the study of robotic systems taking advantage of swarming or colony level behaviours similar to those found in social insects like Ants or Bees. The sum of the parts is greater than the whole. Heavy constraints are made on the mechanical and computational quality of an individual robot, to both reduce unit complexity and cost whilst maximising population size. Insect colonies rely on limited individuals that act as a whole with much greater force and intelligence, this is the same working paradigm for Swarm Robotics. The hope is that the colony or swarm level behaviour is robust against the loss of any particular robotic unit that can be cheaply replaced. In the long term the qualitative difference in the practical use case of robotic swarms to other forms of robotics is that of persistence and maintenance. An expensive deliberative humanoid robot is likely to be repaired and returned to its owner or replaced with a new model, swarm robotics instead relies on an influx of new cheap units that integrate into the already running swarm that adapts to change over time or new environ. This makes Swarm Robotics a unique frontier for artificial evolutionary systems where it is preferable to have very long lived algorithms that can adapt to change in real world environments.

In recent years the methodology of Embodied Evolution has risen as a response to the growing challenges in Evolutionary Robotics [3] . Challenges such as the problem of transference between evolved controllers in simulation and the same controller being unfit on a real world robotic device. Evolutionary algorithms exploit the nature of their environment; in simulation this leaves the possibility that a controller is found to be fit because of an exploitation in the simulation software, or from a trait that does not transfer where simplifying assumptions are no longer made. Instead the Embodied Evolution methodology takes advantage of robotic experiments with a real world population of robots evolving in parallel [6, 7, 2] . This has the advantage of removing the problem of transference and having evolution take place in the task environment, both of which are limited in a simulator. However the obvious drawback is the evolutionary depth that can be reached. This can be reduced through a mixed methodology of both simulation and embodied evaluation to gain depth and real world plausibility.

New challenges arise in the paradigm of Swarm Robotics as the use of online evolutionary algorithms to adapt to the environment and optimise performance require that the algorithm be truly distributed in nature. Global information or evaluation of the population as a whole is limited or not possible, as each robot is only endowed with limited sensing, cpu and communications performance and centralised control is not permitted. Instead an accommodation has to be made for each robot to select its own mate to cross controller information with from the environment, and evaluate its own perceived fitness or contribution to the swarm task. This raises many challenges familiar from a background in Complexity. How can the sum of naive individual behaviour be proven to converge on a desired global behaviour from specified start condition of each individual where a real world environment is involved. Worse how can it be shown that such a thing will evolve in a heterogeneous population changing through time, or that this will be robust and always safe to the surrounding human population. Given a desired swarm task how can this be decomposed to individual behaviour of each robot controller. This last challenge is directly met through evolutionary algorithms over a population, however with a distributed algorithm the problem becomes how can you decompose a global fitness function to fitness an individual can measure that is analogous to fitness of the global task that is hidden.
Currently distributed evolutionary algorithms for swarms are in their infancy, strong statements have been made in the literature of what properties are required of an algorithm with some work done in simulation to illustrate the merits of such arguments. However little has been done in hardware [4] or in unbounded (open-ended) evolutionary systems in swarms [1]. Importantly many properties of a swarm over a single robot evolving are unbounded or at least open to a larger evolutionary space. Individuals in a swarm can come together to form local morphologies for a given task such as moving in formation to increase their effective force. These morphologies can be thought of as behaviours rather than evolutionary traits of an individual control, so the focus of evolution in swarms is to evolve typical behaviour required for common tasks.

The proposed project hopes to create an open-ended distributed evolutionary algorithm for a swarm of E-Puck robots in a forced behavioural setting, such as that of a predator-prey competition. This allows for some of the selection operator to be environmental through a *survival of the fittest* mechanism as well as programmed mate selection involving a decision task similar to that of the Multi-armed Bandit problem [5] where the relative fitness of other robots needs to be ascertained locally before choosing to cross with them. Global fitness can also be approximated in this way through a robot comparing itself with other controllers that it obtains from the environment. Selection gives the sense of global fitness where the fitness function itself is purely proprioceptive and related to open-ended survival [2]. This is far more biologically plausible than traditional artificial evolutionary algorithms. In nature fitness is a property of an individuals ability to survive to reproduce not an explicit measurement that can be taken instantaneously out of context of the rest of the population or replicating. Thus a fitness function should return a state that the robots equivalent of metabolism and historical ability to reproduce, not its fitness in relation to a global population or desired task. Again selection is biologically plausible as a mate selection task will dominate. Hopefully behaviour in the form of evolved and developed swarm morphology should be seen for mate selection, and survival requirement including that of the forced behavior of predator-prey roles.

References


