Solving the division of labour problem using stigmergy and evolved heterogeneity

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Evolving cooperative teams is a research area with applications in the fields of robotics and software agents. Progress on this problem could also help us to understand the evolution of cooperation in natural systems such as the social insects. The overarching question is how cooperative teams should be represented in order to promote efficient evolutionary search. More specifically, what should serve as our basic unit of selection — the individual or the team? — and how can the division-of-labour problem be solved? In order to answer these questions we have taken a benchmark problem from the genetic programming (GP) literature, the artificial ant problem, and extended it so that teams of ants must cooperate to complete the task.

In this model, the ants are centrally placed in a bounded grid with each square containing food. The goal of the team is to harvest all the food in the environment in as few moves as possible. In the initial version of the problem, the members of the team are all clones, each having exactly the same GP controller program. Many solutions will have poor performance as the team members will all behave in the same way, and will therefore fail to cover the grid efficiently. To perform better, the ants must evolve to take advantage of stigmergic interactions to break the symmetry of the problem and clear the world of food efficiently. This division of labour through stigmergy is indeed what is seen to evolve during the simulations.

A further extension is made by assigning each member of the team an identity tag, and adding the ability to execute different subtrees of the cloned controller based on this tag. When these operations are allowed, higher fitnesses are achieved than with the purely stigmergic situation above.

During evolution, selection acts at the team level. We can therefore view the members of the team as being equivalent to cells in a multicellular organism. The identity branching operation is analogous to cell differentiation within this abstract organism. Using this scheme, the degree of differentiation is not specified a-priori and is controllable through evolution. This allows the full continuum from purely homogeneous teams to entirely heterogeneous teams to be expressed. There is also the potential to use this method as a way of measuring the degree to which a task demands heterogeneous solutions.

The relative importance of stigmergy and innate heterogeneity in achieving the necessary division of labour were compared with a third experimental manipulation. The ability to influence each other stigmergically was removed by placing each ant in it's own world and tallying the pieces of food consumed by the team as a whole. In this scenario, the most efficient way to tackle the problem is for the team to evolve complete heterogeneity.

We conclude that the division-of-labour problem in the evolution of cooperative teams can be solved by both stigmergic communication and innate heterogeneity. Furthermore, the technique of allowing the level of heterogeneity of the team to be open to selection shows promise for future work.