Using Stigmergy to Study Societies
Animal and Machine Intelligence Coursewor

Candidate Number: 73495
Course: Animal and Machine Intelligence
MSc Evolutionary and Adaptive Systems
COGS-GRC

January 12, 2003

1 Introduction

Stigmergy is an indirect communication mechanism. It was first introduced by Pierre-Paul Grassé to explain the amazing coordination observed in insect societies. The concept of stigmergy has been used to study and reproduce collective behaviour in robots[5]. Stigmergy solves the 'coordination paradox' in social insects - namely that the colony as a whole looks organized while each individual seems to be behaving erratically[3]. Stigmergy has also been used to model particular behaviours of a society, and this can be mistaken to the issue of creating an artificial society. In this essay I discus the issue of modelling societies, and point out the difference between synthesising an artificial society and reproducing a particular behaviour observed on an animal society.

2 Before Stigmergy

Before the concept of stigmergy was developed, two antagonistic theories existed, and attempted to explain the emergence of regulation and control at the level of the colony in insect societies. The first theory looked at the colony as a social organism with several properties such as growth, differentiation of structures and functions within those structures, division of labour, and in particular, the properties of the social organism are very similar to the properties of each of its constituent units.

The other theory treats the colony as a result of many individuals working on its own and for themselves. Rabaud was the first to propose this idea[12]. He argued that any division of labour should be the result of individuals signalling each other, and this was not happening in insect societies. His ideas have lost popularity, since examples of coordination among insect societies have been spotted. But he introduced some key ideas in the development of the concept of *stigmergy*.

Rabaud introduced the concept of *interaction*. If several individuals are close to each other, one individual's actions can influence another individual's behaviour. The other idea he introduced is the concept of *interattraction*, which means that every individual is attracted toward individuals of the same species, and this attraction can be the result of an individual implicitly stimulating the others. A consequence is that their spatial distribution has some constraints, it is not random anymore.

3 Stigmergy

In stigmergy each individual stimulates the other individuals (or maybe even himself) by changing the environment. Stigmergy is an animal-animal interaction mechanism. Individuals have a stimulus-response reaction towards the environment, that is, specific configurations of the environment trigger specific action within the individuals. By means of this actions, the agent is organizing the environment in a stimulating way that can trigger a response in any other individual within the society. The new action taken (by any of the members of the colony), can again change the configuration of the environment into some other stimulating state, which can again trigger another behaviour (or action) from any of the individuals.

Each individual acts on its own. He is responding to a certain set of rules, and each of this rules determine an action to be taken for a particular configurations of the environment.

Stigmergy can be divided into *quantitative* and *qualitative* stigmergy.

- An example of *quantitative* stigmergy can be the construction of pillars of mud by termites. Termites start piling pellets of mud in random locations. Mud pellets emit a pheromone which stimulate termites to place a pellet next to it. When a pile reach a threshold size, it begins to grow exponentially, the increase in pheromone stimulates more termites to place their mud pellet in that same place. This is a positive feedback phase, which characterizes *self-organization* process. The pile reach a point where it is too big, and so, the density of termite workers becomes too small. At this point the pheromone diffuses very quickly, and will not continue stimulating many more termites. This is a negative feedback phase, also part of a *self-organization* process. Termites start to place the pellets randomly again.

  There is some regulation in the size of the pillar, the pillar will grow first because of a positive feedback, and stop because of a negative one. A definition of a *self-organization* process is given below.

- *Qualitative* stigmergy differs from quantitative stigmergy in that the respond of each individual is triggered by a particular act and not by a particular quantity. Actions follow a sequence. One action can trigger or stimulate an agent to perform another action, like a self-assembly process. Until phase A is not entirely completed, phase B will not be started.

The particular finalization of phase A is what triggers labour toward the fulfilment of phase B.

4 Coordination without Communication

Coordination in real time is a behaviour very difficult to obtain from 2 or more agents communicating by any form of signalling. Instead the mechanism of stigmergy helps explain the amazing coordination observed in insect societies. Stan Franklin[7] describes coordination as: *"... the result of every agent frequently sampling the environment and reacting to it"*. Agents behave on their own, each agent is acting on a local environment without taking into account the implication of their behaviour. A termite doesn't really know that it is building up a nest, it is pure reactive behaviour to a certain type of pheromone on the mud.

Coordination cannot be solved by stigmergy alone. The concept of self organization is needed. *Self-organisation* is defined by Camazine[13](p.8),

> "As a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern."

A *self-organization* process has four ingredients according to [14]:

- Positive Feedback. An example is the 'attractiveness' towards a particular location that a particular type of pheromone can have on termites.
- Negative Feedback. Counterbalances positive feedback and stabilizes the overall behaviour.
- Amplification of fluctuations. Self-organization relies in random fluctuations such as random walk, or small errors in order to find new solutions for a particular task. This implies some variation in each process.
- Multiple interactions. An individual can be stimulated by any other individual including himself, but usually there is a minimum number of agents needed.

In order to be able to have coordination you need a multi-agent system.

Communication results to be very expensive, you need a communication module on each one of the agents involved. The cost grows exponentially with the number of agents involved. Coordination will also need a control system. Planning is expensive, and needs as well, additional architecture. Is Computationally more expensive as well.

Finding a way to solve collective tasks without communication and/or planning can be very useful.

Solving a task can be much faster if it is done by more than one agent, or simply, there might be a case where more than one agent is absolutely necessary.

Stigmergy has shown to solve sorting problems [5] similar to the ones solved by ants with a few simple rules.

5 Modelling Societies

By looking at the behaviour of the system it is very difficult to guess how the internal structure of the system really looks like. As Braitenberg says [2]

> ... it is much difficult to start from the outside and try to guess internal structure just from the observation of behaviour.

Similar types of behaviour in a system can be obtained from many different configurations of the internal structure, and similar configurations of internal structure can emerge very different behaviours of the system. In other words the P-type can not be predicted from the G-type.

Many results on modelling social societies have been obtained with perturbation experiments on insect societies. It is much easier and ethical than experimenting on humans, but it is sometimes very difficult to experiment on real (animal) societies, especially human. Social system involve a huge number of factors and parameters, also behaviour is often observed on very large time-scales. It is sometimes impossible to restrict an interaction, or change parameters in a social system, and observe the influence that this have on the system.

Braitenberg suggests to *synthesize* social systems instead of trying to analyze them. Synthesising an artificial model of a social society can be easy, but as Dautenhahn points it out, creating a realistic model has its own difficulties[1].

One term which is relevant to the modelling of societies is *social embeddedness*. Bruce Edmonds[11] defines it as:

> "An agent is socially embedded in a collection of other agents to the extent that it is more appropriate to model that agent as part of the total system of agents and their interactions as opposed to modelling it as a single agent that is interacting with as essentially unitary environment."

Dautenhahn discuss the issue of modelling societies. How close are we going to really model an intelligent society. He designed an analogy of the Turing test for machines, to 'rate' social society models[1]. He argues that human (or primates) have a social intelligence and that this precise fact is what makes it difficult to model a human society. Individuals within a human society have special relations with other members of the society, as well as having complex mental maps. In human societies, individuals posses an identity. Human society is an *individualized* society, while insect societies are said to be *anonymous*. I Insects don't worry about missing relatives, they don't have an identity. As a consequence humans can't be treated anymore in the same way as you do with insects, using stigmergy.

Dautenhahn gives a definition of social intelligence so as to help in the characterization of models of societies.

> Social Intelligence is "the individual's capability to develop and manage relationships between individualized, autobiographic agents which, by means of communication, build up shared social interaction structures which help to integrate and manage the individuals basic ('selfish') interests in relationship to the interests of the social system at the next higher level. The term artificial social intelligence is then an instantiation of social intelligence in artifacts."[1]

Which in the case of stigmergy and *swarm intelligence* doesn't apply, this definition can be useful when dealing with *individualized* societies only. He points out that

> "By introducing mechanisms of stigmergy we could even observe collective behaviour and global (temporal spatial) patterns similar to those of social insect societies. But without modelling a socially embedded agent possessing social intelligence as defined above, we are unlikely to *synthesize* artificial societies rather than simulation models of (selected characteristics of) animal/human societies. However, the more elaborate computer simulations of societies become, the more we tend to label them as *artificial societies*."[1]

6 Traffic

The concept of stigmergy is being used for modelling societies. An interesting example, is a road traffic model developed using *Swarm Intelligence*[14] (http://www.swarm.org/).

Previous attempts to model traffic where made from statistical data from observed traffic, they where models of a global behaviour.

This new attempt made by Hoar, Penner and Jacob [6] confronts the problem from a stigmergy point of view. They model the problem by looking at drivers as a group of individuals following particular rules, interacting with (and changing) the environment. By changing the environment they influencing the response of the other drivers.

With this model they simulate *"traffic dynamics as emergent patterns arising from the interactions of a large number of individual drivers."*[6] and are able to optimize the timings on traffic lights so as to minimize the waiting time of each driver.

In their model cars smell and drop pheromone trails which spread according to their speed. Traffic signal drop scents too. Cars also have specific pheromones to signal lane changes or stopping at a traffic light. The signals are left in the environment and decay with time.

There is not explicit communication within the individual, but still a collective behaviour emerges. Each car is behaving according to local rules determined by the amount of pheromone they scent, and at any time know where the other cars and traffic signals are.

Stigmergy is a very good approach for modelling societies such as the city roads, because roads are full of drivers following rules imposed by traffic signals and by the actions taken by the other drivers.

7 Discussion

Stigmergy has lots of applications such as the ones mentioned before. It has also shown to be good at modelling particular aspects of a society (as in the traffic example).

We have seen that although there is some discussion about how relevant is to model human society using stigmergy. 'Successful' models of a behaviour within the human society (such as the traffic model) continue to appear in literature. It is important to specify what is your model attempting to explain. When designing models you are not taking into account every single issue. That is what *modelling* is all about.

As Dautenhahn points it out, it might be very difficult to model a society of intelligent individuals, each having a particular identity. But if your only concern is to direct traffic and adjust the timings on the traffic lights, stigmergy seems a good approach. Stigmergy is appropriate to model traffic since each car is going to behave relatively similar (with very few exceptions) toward a particular configuration of the environment (i.e. almost everybody stops at a red light with a similar reaction time), and by using quantitative stigmergy you can adjust your model to resemble reality pretty much. Traffic is a global problem, and what each driver is swearing, or what the driver's wife is cooking for dinner, or even how many member constitute his family, is of no concern when adjusting traffic lights timing.

A model of traffic such as the one mentioned before would classify as a *toy model of a human society* on Dautenhahn Turing Test hierarchy[1] for artificial societies. The description fro this category is as follows:

- St1: *Toy models of human societies.* At present, most existing systems of artificial societies and social simulation show particular, specific aspects of human societies. None of the systems shows the full capacity of human societies.

What this means is that there is still much to do in modelling societies, and that the present models of society, can help us solve simple problems where individuality is not an issue. The tool of stigmergy and swarm intelligence helps to model *anonymous* systems, but will not help to model a more social intelligent system, or to create an artificial society.

When modelling societies, you have to establish what kind of society you are going to model. It is not the same to model a human society, than to model an insect society. The concept of *individualized* and *anonymous* societies is of great importance. An *anonymous* society can be modelled with stigmergy and using swarm intelligence, while a model of an *individualized* society would have to include a model where each particular individual has his own relations and mental map.

Langton says

> "Artificial Life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be."[15]

Models inspired from coordination and observed collective behaviour in insect societies, can reproduce similar behaviour to that observed in social (human) societies. It is important to take into account that simple rules can emerge impressive collective behaviour and coordination, which can be useful when designing robots or modelling an *anonymous* society. I think what matters when you are going to reproduce a behaviour (e.g. of ants piling dead bodies), that you stick to that, and that if your model of ants are indistinguishable from real ants is irrelevant to the issue of what simple rules they follow (to pile up dead bodies).

Synthesising a society as Braitenberg suggests us to do, can help us visualize the behaviour at a global level can emerge from simple rules at the level of the individual. Right now, this helps us design coordinated robot systems or study a particular aspect of a society. Whether if robots displaying collective behaviour constitute a society? They do. In the same way as the model of traffic does. But you still have to distinguish if the robots where designed to solve a sorting problem or so as to synthesize a society. Dautenhahn's Turing Test analogy for societies can be very helpful to classify what type of society you are talking about.

8 Conclusion

Is different to create artificial societies, than to use the stigmergy mechanism to model a particular behaviour of a society. Artificial Life worries with both, and is important to understand whether you are want to reproduce a behaviour observed in biology rather for scientific or for engineering purposes, or whether you want to synthesize an artificial intelligent society such as those described by Dautenhahn.

References

[1] Dautenhahn Kerstin, *Reverse Engineering of Societies - A Biological Perspective* University of Hertfordshire, Adaptive Systems Research Group.

[2] Braitenberg Valentino, *Vehicles: Experiments in Synthetic Psychology.* MIT Press, Cambridge, 1984.

[3] Bonabeau Eric, *Editor's Introduction: Stigmergy*, Artificial Life Volume 5, Number 2, pag 95-96 (1999).

[4] Bonabeau Eric, Theraulaz Guy, *A Brief History of Stigmergy*, Artificial Life Volume 5, Number 2, pag 97-116 (1999).

[5] Holland Owen, Melhuish Chris, *Stigmergy, Self-Organization, and Sorting in Collective Robotics*, Artificial Life Volume 5, Number 2, pag 173-202 (1999).

[6] Hoar R. Penner J. Jacob C. *Evolutionary Swarm Traffic: If Ant Roads Had Traffic Lights.* 0-7803-7282-4/02, 2002 IEEE.
http://www.dsg.cs.tcd.ie/˜biegelg/research/stigmergy/papers/SwarmTraffic.pdf

[7] Franklin Stan, *Coordination without Communication*,
http://www.msci.memphis.edu/$\tilde{()}$franklin/coord.html.

[8] Anderson Carl, *The Fuzzy boundaries of three self-organization-like mechanisms*, Regensbury University.
http://www.mbl.edu/CASSLS/anderson_wh.pdf

[9] D'Angelo Antonio, Pagello Enrico, Using Stigmergy to Make Emerging Collective Behaviours, Dipartimento di Matematica e Informatica, Universitá di Udine.
http://www-dii.ing.unisi.it/aiia2002/paper/ROBOTICA/dangelo-aiia02.pdf

[10] C. Ronald Kube, Zhang Hong, *Collective Robotics: From Social Insects to Robots*, Adaptive Behaviour 2(2):189-219, 1993.

[11] Edmonds Bruce, *Capturing Social Embeddedness: a Contructivist Approach.* Adaptive Behaviour 7:323-348, 1999.

[12] Rabaud E. *Phénomène social et société animale.* Paris: F. Alcan.

[13] Camazine S. (1991). Self-organizing pattern formation on the combs of honeybee colonies. *Behavioral Ecology and Sociobiology,* 28,61-76.

[14] Bonabeau Eric, Dorigo MArco, and Theraulaz Guy. *Swarm intelligence. From Natural to Artificial Systems.* Oxford University Press, New York, Oxford, 1999.

[15] Christopher G. Langton. Artificial Life. In C. G. Langton, editor , *Proc. of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems, Los Alamos, New mexico, September 1997*, pag. 1-47,1989.