The Dynamics of Learning Behaviour and Memory
3rd Year Progress Report
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This report comprises a short-version of the motivation for my PhD work (section 1), the things I have accomplished towards my PhD training during this 3rd academic year (section 2), an outlook into the current table of contents of my thesis (section 3), and the plan ahead (section 4).

1 Project Motivation

Living organisms show a variety of behaviours that are modulated by environmental conditions and previous experience. Such behaviour we call learning. A major goal of this thesis is to elucidate the dynamical bases of such experience-dependent adaptive behaviour. The approach taken is a situated, embodied, dynamical systems and evolutionary one. The work involves evolving and analysing agents that learn during their lifetime without introducing learning mechanisms a priori into the agent's structure or internal mechanisms. Several tasks are studied. These are loosely inspired on learning behaviours in simple organisms. They have been chosen because of their simplicity but also because of their cognitive relevance. All of the tasks involve remembering, categorising and decision-making behaviours. The interest in the synthesis of such agents is in the analysis of the evolutionary dynamics as well as the evolved mechanisms and interactions using the language of dynamical systems theory. The main outcome of this thesis will be to provide an understanding of learning and memory behaviour that helps shift the focus from 'accurately representing the environment' to dynamically engaging it (with a body) so as to generate coordinated patterns of behaviour which are modulated by its history of interactions.

2 Accomplishments during the 3rd year

In this last funded year of my doctoral studies I have done the following:

1. Organisation of scientific meetings
    a. Life and Mind seminars, a philosophy-oriented CCNR group.
    b. Evolution and Dynamics of Learning Behaviour workshop as part of ECAL07
2. Reviewing of papers for conference and journal
    a. I was asked by Peter Todd to review and eventually re-review an Adaptive Behavior Journal submission.
    b. Formed part of the ECAL 2007 programme committee and ended up reviewing 7 contributions.
3. Publishing peer-reviewed papers in conference proceedings
    a. IEEE Symposium on Artificial Life 2007: Hebbian Learning using Fixed Weight Evolved Dynamical 'Neural' Networks.
    b. ECAL 2007: The Dynamics of Associative Learning in an Evolved Situated Agent.
    c. Collaborated as co-author on two other papers ECAL 2007 papers as well:
        i. Froese, Virgo, Izquierdo. Autonomy: a review and reappraisal
        ii. Fine, Di Paolo, and Izquierdo. Adapting to your Body.
4. Teaching, marking and co-supervising
    a. Foundations of Computation
    b. Non-Symbolic AI
    c. Help supervising one EASy Master thesis: On the dynamics of small CTRNNs with different transfer functions.

5. Writing a grant proposal for the BBSRC after a successful pre-proposal. Tentatively titled: Homeostasis and Ultrastability in Living Organisms and Machines.

3 Current Table of Contents of the Thesis

1. Introduction

   Where I describe what the thesis of the work is, its motivation and the layout. This chapter will be produced last.

2. The Study of Learning Behaviour and Memory

   This chapter will provide an overview of the literature of research learning and memory in several different areas. From neurosciences (e.g. Marder et al., 1996; Kandel et al., 2000; Major & Tank, 2004), psychology (e.g. Thorndike, 1898), AI and evolutionary robotics (e.g. Yamauchi and Beer, 1994; Tuci et al., 2002; Phattanasri et al., in press) to philosophy and other areas such as cybernetics (e.g. Ashby, 1952; Maturana, 1970; Maturana & Varela 1973). I am working on this chapter at the moment.

3. A Situated, Embodied, Dynamical Systems, and Evolutionary Approach

   This chapter will provide a detailed description of the conceptual and practical details of the methodology used in this thesis (i.e. artificial evolution, dynamical systems controllers and analysis, situatedness/embodiment, and the minimal-but-cognitively-interesting-tasks). A justification for the relevance of the approach will also be given. A particular emphasis of this chapter will be on explaining the importance of multi-timescale and transient dynamics and the irrelevance of parameter-changing mechanisms for learning behaviour. Another important point of this chapter will be on minimization of the techniques used. While a good proportion of work in evolutionary robotics goes into length into introducing multiple 'novel' ways of doing things (GA variations, CTRNN variations, etc.), the emphasis on this thesis is to keep the variations of the methodology at a minimum, as long as it can be made to solve the task.

4. (Exp Chap 1) Hebbian Learning Behaviour

   This chapter shows that applying the Hebb rule on the weights of a nonlinear dynamical system controller does not necessarily lead to strengthening the correlation of firing. It then demonstrates that a dynamical system controller with fixed parameters can exhibit Hebbian learning behaviour. An explanation in terms of the structure and dynamics of the best-evolved system is given. Finally, the time-scales of all successfully evolved agents are analysed and generalisations about what is required for Hebbian learning to occur is given. The importance of this chapter is that this demonstration, because of its simplicity, lays the foundation for much of the rest of the work on 'learning without synaptic plasticity'. The material for this chapter will be taken from work published and presented in the IEEE Alife 2007 conference (in collaboration with Inman).

5. (Exp Chap 2) Associative Learning in an Abstract Model

   This chapter proposes an associative learning task inspired on thermal-preference behaviour observed in the nematode worm. The task is modelled at an abstract level: non-situated and non-embodied. The dynamical system controller is required to learn the temperature associated with food and then remember it for further testing. Also, the task requires the system to re-learn new preferred temperatures when re-associated with food. The chapter is divided into two sections. First is the case when the stimuli to be remembered are discrete (n=2). The dynamics of the best-evolved agent are analysed and shown to instantiate a finite state machine. Second is the case when the stimuli are on a continuum. The dynamics of the best-evolved agent for this task, on the other hand, instantiate what we define as a continuous state machine. The chapter also provides a discussion for the differences. The material for this chapter will be taken from work done over the summer of 2006 at Indiana University (in collaboration with Randall Beer). This work is 90% done. I expect to submit this work to the Adaptive Behavior Journal (in the not too distant future).

6. (Exp Chap 3) Non-Reactive Behaviours in Reactive but Situated Agents
   The two experimental chapters shown up to this point (4 and 5) deal with abstract models. This chapter shows the role of the agent's situatedness for behaviour. The idea of the chapter is to serve as a transition into the rest of the thesis, which gives more emphasis to the role of the agent's history of interactions with its environment in learning and memory. Although the chapter is meant to be a transitional one with a strong conceptual grounding, it provides two concrete examples: orientation with visual inversion and categorical perception experiments. The material for this chapter will be taken from work published and presented in the ECAL 2005 conference (in collaboration with Ezequiel).

7. (Exp Chap 4) Situated Memory on an Imprinting Task
   This chapter provides the first set of experiments in learning on a continuum in an embodied model. The task is loosely abstracted from imprinting in birds. The chapter shows how memory behaviour can arise from the agent's situatedness, provided the environment has sufficient invariants the agent can exploit. The material for this chapter will be taken from work published in the Alife 2006 proceedings (in collaboration with Inman) as well as unpublished work presented at the Memory and Learning workshop at ECAL 2005.

8. (Exp Chap 5) Situated Associative Learning
   The agent/environment/task in this case is loosely inspired on behavioural plasticity observed in *C. elegans* – which is a similar form of learning to imprinting (i.e. animals that were cultivated normally with food at temperatures ranging from 15C to 25C migrate to the cultivation temperature on a temperature gradient and move isothermally at that temperature. By contrast, the animals migrate away from the temperature at which they were previously starved). They don't call it imprinting, but it is a very appropriate behavioural paradigm to continue to study learning and memory in the embodied version. This is the last experimental chapter and it is the extension to the associative learning task in chapter §5. The difference is in the embodiment and situatedness of the agent. This chapter explores the differences in required internal dynamics when the agent has the potential to be active in choosing its own stimuli by being situated. A good proportion of the material for this chapter I have recently produced for ECAL 2007. I am working on the material for one extension of it at the moment.

9. Philosophical Considerations
   This chapter will discuss the philosophical implications of evolved dynamical system agents, with a particular emphasis on the ones analysed in this thesis. The main argument for this chapter is that it is too tempting for researchers in the

adaptive behaviour community (i.e. those doing artificial/computational models to shed light on what it means for a system to be cognitive) to draw parallels between observed behaviour and internal mechanisms. The case that this thesis tackles directly is that of synaptic plasticity and learning behaviour. However, there are a number of other aspects of cognition that can be viewed in the same light. The topics I will discuss include: the possible role of synaptic plasticity, developmental rules, von Uexkull's functional circles, homeostatic adaptation, and a finally autonomy in evolutionary robotics methodologies. I will also use this chapter to associate my work with Ashby's notion of an ultrastable system. The material for this chapter is new. Perhaps some of the ECAL 2007 collaboration with Tom Froese and Nathaniel Virgo will be reflected in it.

10. Concluding Remarks
    Where the contributions of my work are summarised and made concise. Also where an outlook of the work that my thesis opens up to explore is overviewed.

5. Plan Ahead

The plan is simple: to dedicate my full time to writing and finishing the thesis.

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