Journal of Adaptive Behaviour

Introductory article to the
Special Issue on the Dynamical Systems Approach to Cognition, vol. 14.2
(forthcoming)

Fernando Almeida e Costa and **Eduardo Izquierdo-Torres**

Centre for Computational Neuroscience and Robotics, University of Sussex.
Emails: F.AlmeidaCosta@sussex.ac.uk ; E.J.Izquierdo-Torres@sussex.ac.uk

Perhaps the deepest philosophical insight of research in cognitive science and New A.I. in the last twenty years has been the realization that cognition is not "something done by the brain". According to this view, cognitive activity must be understood as the result of interactions occurring within a set of coupled sub-systems belonging both to the agent and to the environment, inextricably intertwined, co-evolving and co-adapting in real time. It is potentially misguiding and often counter-productive to define features observable in the system's behavior as functionally a property of the agent's internal dynamics, its body morphology or the environment it is in; a canonic example is the coordination of the legs' motion in insect-robots (Beer, 1995) whose architectures have no coordinating centre and which critically depend on the local interaction between the leg morphodynamics and environment.

At around the time this shift was taking place, the research on neural networks was undergoing the boost that became known as "connectionism". Although classic connectionism draws on the old computational metaphors about cognition, and technically aimed at a form of computation, a trend quickly developed to explore neural networks as dynamical systems, e.g. networks incorporating real time dynamics, as opposed to input-output timeless devices.

The old strategy for constructing robots or understanding cognition, presupposed a previous representation by an agent of the exterior world, its mapping and the construction of "internal" models of the world (for a critique of this view see (Harvey, 1996)). So, cognitive activity was seen as the control of physical action or physical properties by an information-theoretic centered system and its specification was to be found at the algorithmic level. Only as far as physical properties could be constrained and dominated by the algorithmic level, would one be able to deal with "interesting" cognitive behavior. The environment was treated as a static provider of information input.

For the *new* approach, cognitive activity arises from the interaction between the agent's internal dynamics, its body morphodynamical properties and the history of interactions with its environment. From this point of view, roboticists and cognitive scientists reject, as Varela put it, that an agent's cognitive activity can be described as aiming at a

> (…) goal (which) is to find endogenous activity that corresponds to an optimal characterization of the surroundings. (Varela, 1995, p.213)

Hence, we should

> eschew any form of optimal fitness, by taking the cognitive system into a situation where endogenous and exogenous features are mutually definitory over a prolonged history that requires only a viable coupling (Varela, 1995, p.213)

Such an approach to cognition denies one of the most profoundly engrained human beliefs: that cognition is something done by the brain. Even among the scientifically literate who know that the central nervous system (CNS) is a dynamic network without coordinating locus, the pervasive view is that the CNS as a whole is the *locus par excellence* of cognitive activity. One result, for example, is very often an excessive expectation regarding the contribution that neuroscience can bring to the explanation of cognitive phenomena.

In the last two decades, various research groups have enhanced the understanding of the coupling between agents and their environment with concrete models which take time and physical properties seriously, giving rise to what can be currently dubbed a dynamical systems approach to understanding cognition (see for examples (Thelen & Smith, 1992), (Port & van Gelder, 1995), (Beer, 1997), (Harvey et al., 1997) and (Pfeifer & Sheier, 2002)).

During ECAL 2005, VIII European Conference on Artificial Life, the activate.d reading group* of the University of Sussex, organized a workshop on *active agents and their environments as dynamical systems*. This workshop brought together researchers to discuss relevant conceptual and technical issues regarding the dynamical systems approach to life and cognition applied to brain-body-environment interactions.

The mathematics of dynamical systems is a natural candidate to provide the appropriate language and formalisms for the modeling of cognitive phenomena, because its aim is precisely to study systems that unfold over time and because it can capture in the same theoretical framework the physical properties of both agent and environment. For those less familiar with dynamical systems theory (Abraham & Shaw, 1992) and (Strogatz, 1994) provide good introductions, for an account of the concepts of dynamical systems theory in the context of cognitive science see (Beer, 1997).

The present issue covers a broad spectrum of topics in the dynamical systems approach to cognition: from adaptation on physical devices to work on more abstract systems, from technical models and philosophical inspiration for doing evolutionary robotics to the conceptual debate on minimal requirements for cognition.

The first five papers explore mechanisms, organizational principles and architectures for generating appropriate dynamic behavior in changing environments, while the last two papers discuss conceptual issues concerning a dynamical systems understanding of what it means to be a cognitive system.

The articles by Der et al., Wischmann et al., David Michael, and Macinnes & Di Paolo provide examples of adaptive behavior as arising from the body-environment interactions as well as the robots internal dynamics, while placing emphasis on particular aspects of this interaction: body dynamics (e.g. David Michael), the sensory dynamics (e.g. Macinnes & Di Paolo), body-environment interaction (e.g. Der et al.) or agent-agent interactions (e.g. Wischmann et al.).

The ability to adjust in appropriate ways to ongoing changes in the environment is a remarkable aspect of cognitive activity. In different ways, the articles by Der et al., Berry & Quoy and Macinnes & Di Paolo all deal with issues concerning such online adaptations to changing environments.

The articles by Duijn et al. and Barandiaran & Moreno raise critical issues regarding the definition of what makes something cognitive. Both articles draw partially on Varela's concept of autopoiesis and can be read as tackling similar issues from different critical standpoints.

In the first article, Der et al. propose a mechanism for adjusting the parameters of the agent's internal dynamics so as to maximize the complexity of the coupled agent-environment system while maintaining predictability. The general motivation is

* www.informatics.sussex.ac.uk/activate.d/

to circumvent the design problem through a self-regulating mechanism. They analyze the agent/environment dynamics in two different applications: a physical device and a simulated snake-like agent displaying rocking and jumping behaviors.

In the second article, Wischmann et al. show behavioral entrainment in a collective of robots through neural synchronization using phase resetting in a foraging and nesting task. A pattern generator creates an internal rhythm that is used to switch between these two behaviors. The work describes how collisions are reduced and the energy collected in the nest increases over time as a product of the group's synchronization.

In the third article, Berry & Quoy, investigate the dynamics of randomly connected neural systems undergoing weight changes through a Hebbian learning mechanism. This article deals with dynamics in an abstract scenario where the interest is in the analysis of the resulting structure of the neural system. The authors argue that the networks display "small world" properties as a result of the learning rule, whilst the dynamics of the activations reduce from chaos to a limit cycle and finally to a fixed point.

David Michael explores some possibilities of a dynamical systems treatment of artificial autonomous musical behaviour. This article lays out the specification/novelty problem inherent in any symbolic notational system and argues that dynamical systems provide a break-out strategy. Through the study of the biophysics of a birdsong a dynamical model, or rather, as the author puts it, "a dynamics-based agent template", mainly focused on the actuator, is proposed. His work can be seen as the branching out of dynamical systems approaches to areas where the traditional computational view is still very much engrained in the collective mind of researchers.

In the fifth article, Macinnes & Di Paolo discuss Jacob von Uexküll's functional circles hypothesis. Drawing on that hypothesis this article puts forward an alternative methodology for evolutionary robotics which facilitates the synthesis of agents capable of selecting *their own* stimuli from the interaction with environment as well as of attributing different meanings to the same sensor patterns.

In the sixth article, van Duijn et al. put forth a proposal for the minimal requirements of cognition, explicitly aimed at lowering the boundaries down the phylogenetic scale. Using detailed evidence from mechanisms of *E. coli* bacteria to illustrate their points, the authors engage the debate around the continuity between life and cognition.

In the last article, Barandiaran & Moreno pull together different strands of philosophical, neurobiological, cognitive science and robotics research to propose a *minimally cognitive organization* program as complementary of Beer's *minimally cognitive behaviour* program. The article aims at answering what cognition is by arguing that a particular dynamic organisation of the nervous system (defined as a "web of dynamic sensorimotor structures sustained by continuous interactions with the environment and the body") is necessary for cognitive behaviour.

This issue will have served its purpose if it helps to widen the discussion of the current research using a dynamical systems approach to understanding cognition. As guest editors, we would like to thank all the anonymous reviewers for their invaluable work in the two phases of the reviewing process: for the workshop and during the editing process. We are also very grateful to the Adaptive Behavior Journal and in particular to its editor Peter Todd for accepting our proposal for this special issue. Thanks are also due to Ezequiel Di Paolo for his encouragement and support. Finally we would like to thank the ECAL2005 organizing committee for having

generated the space and right atmosphere for the discussion from which this special issues stems.

References:

Abraham, R.H. and Shaw, C.D. (1992) *Dynamics – The Geometry of Behavior*. 2nd Ed. Addison-Wesley. Redwood City, CA.

Beer, R. D. (1995). A dynamical systems perspective on agent-environment interaction. In *Artificial Intelligence*, **72:**173-215.

Beer, R.D. (1997). The dynamics of adaptive behavior: A research program. In *Robotics and Autonomous Systems*, **20**:257-289.

Harvey, I. (1996) Untimed and misrepresented: connectionism and the computer metaphor. In *AISB Quarterly*, no. 96, pp. 20—27.

Harvey, I., Husbands, P., Cliff, D., Thompson, A. and Jakobi, N. (1997) Evolutionary Robotics: the Sussex Approach. In *Robotics and Autonomous Systems*, **20**:205--224.

Port, R. F. and van Gelder, T., (1995) *Mind as Motion: Explorations in the Dynamics of Cognition*. MIT Press, Cambridge, MA.

Strogatz, S. H. (1994) *Nonlinear dynamics and chaos (studies in nonlinearity)*. Perseus Books, Cambridge, MA.

Thelen, E. and Smith, L.B. (1994). *A Dynamic Systems Approach to the Development of Perception and Action*. Bradford Books/MIT Press, Cambridge, MA.

Pfeifer, R. and Scheier. C. (2002) *Understanding Intelligence*. MIT Press, Cambridge, MA.

Varela, F.J., Thompson, E. and Rosch, E. (1995, 1st ed.:1991) *The Embodied Mind: Cognitive Science and Human Experience*. MIT Press, Cambridge, MA.