Learn to Live with Yourself: A Developmental Perspective on Morphology and Motion.

Rachel Wood[1,2], Ezequiel Di Paolo[1,2]
[1] Center for Computational Neuroscience and Robotics,
University of Sussex, Brighton, UK, BN1 9QH
[2] Informatics, University of Sussex, Brighton, UK, BN1 9QN
r.k.wood@sussex.ac.uk

Abstract

There is considerable evidence to support the notion that we can further our understanding of cognition by looking at the physical embodiment of agents and the ways in which agents physically interact with their environments. Beer's minimal cognition studies are a paradigmatic example of this principle (Beer, 1996; Slocum et al., 2000). On this view the behaviours which we understand as cognitive are fundamentally produced by dynamic interactions between agent and environment and the intra-agent dynamics of morphology and control. By this *enactive* perspective, the physical means by which an agent acts on its environment and the methods it employs whether they involve walking, sliding, grasping or biting; these modes of interaction have determining effects on an agent's cognition.

There is a clear developmental element to this view, the concept of enaction entails notions of continuous, dynamic, construction and production of behaviour; functional assemblies dynamically constructed through the interaction of morphology and medium (Maturana and Varela, 1980; Maturana and Varela, 1998). Put simply, this approach puts the notions of *what* and *where* an agent is at the heart of what it can *do*. We are already able to make certain firm statements about developmental processes, we can say that development is directional, that ontogenetic processes do not reverse themselves and that development acts to increase the adaptive fit between agent and environment. From this perspective, we might also contend that ontogenetic adaptation entails processes which act on intra-agent dynamics; finessing and refining the adaptive fit between body and behaviour. These processes could be seen as a mirror to those which shape the interaction between agent and environment. If we take seriously the notion that cognitive function is founded on the interplay between morphology and behaviour, then we can considerably deepen our understanding of those dynamics by examining their formation.

By taking an ontogenetic approach to exploring ideas of how the embodiment of an agent feeds into its cognitive function we can tackle some of the most interesting open questions in this area. For example, the issue of plasticity: how does morpho-functional plasticity affect the the construction of cognitive function? Many species are born with largely fixed mechanisms for exploiting their morphological characteristics. A herring-gull is limited in the ways in which it can use its wings in order to fly. The gull gains nothing from trying to use its wings to catch fish and its beak for flying. This example is obviously extreme, but it becomes informative when we consider the obverse position. Human infants, are born with a relatively high degree of morphological plasticity; the infant goes through an extended period of post-natal development in which control of the body is dynamically organised and refined. One, key characteristic of development is regularity of outcome, in the case of the human infant, the majority of children learn to walk having passed through a series of remarkably similar stages on the way. Again, the majority learn to reach toward interesting objects and to grasp them in such a way that they can be moved toward the body. However, due to the particular form of the human body, the infant has a range of options available to it when interacting with the world.

The child can use its body in a variety of ways in order to explore the world of objects, hands can be used to hold, to prod to strike and to stroke, all of which provide different feedback about what an object *is* and what it can be made to *do*. As mentioned earlier, humans walk in roughly the same way but we can choose to crawl on hands and knees, to scoot on our hunkers, to run or even to walk on our hands, choices which each affect the way that we perceive objects and other agents. The extended flexibility our bodies afford is something we have to learn to exploit and which provides a concomitant extension in the flexibility with which we can interact with the world. Human infants are born into a body over which they have little control: they are forced to explore its possibilities as part and parcel of the process of exploring the world. On this analysis, there are interesting questions to be addressed about how plasticity at the level of how an agent physically interacts with the world feeds into that agent's development as a cognizer.

There have been a number of projects which have attempted to implement complex morphologies on embod-

ied, situated agents in order to explore the kinds of question mentioned above, however there are considerable difficulties associated with the construction of complex mobile agents. An alternative route into these questions is sign-posted by Beer's experiments with minimally cognitive systems (Beer, 1996; Slocum et al., 2000), these models, the simplest agent-environment systems capable of generating 'cognitively interesting' behaviour, demonstrate the rich potential of the approach for exploring morphology and cognition in tractable ways. The 'minimally cognitive systems' method came out of evolutionary robotics work and shares with it a relative freedom from *a priori* assumptions about the cognitive requirements of adaptive behaviour and the ways in which agents solve tasks. Furthermore, Beer argues, we can use simple, idealized, models as "frictionless planes" in which the basic theoretical principles of agent-environment dynamics can be observed (Beer, 1996). On this view, reducing assumptions and starting to model at the simplest possible level of complexity can produce results which have both scientific and engineering applications: questions about how behaviour is organised in natural systems may be tackled incrementally with detailed models and at the same time we may find minimal answers to questions of how to implement adaptive responding in artificial systems.

We propose that a useful next step in this approach is to extend the minimal systems paradigm to take account of ontogenetic processes. On this view *minimal developmental systems* can provide a means by which we can explore issues such as plasticity and the ontogeny of intra-agent and agent-environment dynamics. A primary advantage of this methodology is that it allows detailed modelling of simple systems with considerable scope for experimental manipulation. In recent years a number of authors have come to stress the importance of contingency in a systems view of ontogeny (Oyama, 2000; Oyama et al., 2001; Griffiths and Gray, 2001). From this perspective, the apparent regularity of developmental outcome masks the contingent nature of developmental process. In real development it is not often possible to precisely manipulate the conditions of an agent's ontogeny and it is generally impossible to 'rewind the tape' and explore would would have happened if the agent had grown up in environment *A* as opposed to environment *B*. This type of manipulation is made relatively simple by the minimal modelling approach and coupled with the possibility of in depth dynamical analysis of agents and their behaviour, makes minimal developmental systems modelling a potentially valuable tool in the undertstanding of adaptive behaviour.

Some very preliminary steps in this direction have been taken with models of agents engaged in social interaction via acoustic signals. This work is an extension of Di Paolo's acoustic approach paradigm in which simple wheeled robots are required to perform an auditory localisation task in an unbounded 2-D environment (Di Paolo, 2000). Agents are placed in the test arena in pairs, their task being to locate and remain in close proximity with each other. The test scenario requires interaction over the acoustic channel as the interactors have no other sensory means by which to track their partners. There is a strong morphological element to the task as discrimination of the direction of a sound source depends on a 'self-shadowing' factor whereby sound is additionally attenuated according to the distance it travels through the body of an agent. Analysis of the behaviour of successful agent pairs indicates that coordinated patterns of rhythmic signalling and movement are used in solving the localisation and tracking problem. In addition, through their on-going interaction, agents become structurally coupled so that we may regard the pair as comprising a distributed developmental system.

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