# More bang for the buck: minimal models as tools for exploring ontogeny

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## Abstract

Modelling is an essential tool in the study of behaviour, one aim of epigenetic robotics is to construct artificial developmental systems in order to model and hence understand processes of ontogenetic adaptation. We propose that 'minimal' systems modelling can be useful in this context by providing abstract, idealised platforms for experimenting with developmental process and for formulating hypotheses which can be further tested in real and artificial systems.

## 1. Introduction

Modelling entails a trade-off between generality, realism and tractability (Weisberg, 2006). In robotics the value of a model may also be affected by the broadest aims of the work (i.e. engineering or scientific outcomes) . In *developmental* robotics there is also the problem of knowing what a given acquisition comprises. Dynamical analysis of newborn stepping exemplifies this point (Thelen et al., 1984). Thelen et al use the physical properties of the infant's body to explain the presence, absence and later reappearance of stepping behaviour in terms of the infant's strength to weight ratio, a factor neglected in accounts based on maturing neural control. The dynamic systems approach to stepping illustrates a principle shared with computational neuroethology that behaviour cannot be explained purely in terms of neural control(Cliff, 1991). Computational neuroethology lies at the intersection of neuroscience and ethology using simple animals and robots as model systems for exploring interactions between neural function, morphology and context in the generation of adaptive behaviour. Evolutionary robotics (ER) is a conjunct methodology which uses simulated evolutionary search to take an explicitly 'hands-off' approach to the design of model systems. These approaches share a strong emphasis on the reduction of designer bias and a priori assumptions about the mechanisms underpinning behaviour with concomitant stress on the importance of modelling complete brain-body systems situated in a context. Such approaches are necessarily abstract and their value lies in the insights generated about general principles of behaviour applicable both to real and artificial systems.

## 2. Computational Neuroethology and Minimal Systems

Beer's work with minimally cognitive systems is arguably the primary exemplar of this approach and the basis for the developmental method advocated here. Beer and co-workers use ER methods to model *minimally cognitive* behaviour. The aim of this work is to explore systems instantiated at the minimal level of complexity required to produce 'interestingly' cognitive behaviour (Slocum et al., 2000). The specification for a minimal system requires that model agents should be simple enough to be computationally and analytically tractable using currently available techniques. Though aimed at the 'simplest' level of interestingly cognitive behaviour, minimal systems have been used to model visual orientation and attention, object discrimination, perception of affordance, self/non-self discrimination, short-term memory and selective attention. From this evolutionary approach we can abstract principles for modelling which are equally applicable to the developmental domain. Thus, a minimal *developmental* model employs the simplest level of implementation required to explore interesting questions about ontogenetic adaptation. Beer's minimal cognition experiments use continuous time recurrent neural networks (CTRNNs) to instantiate neural dynamics. This approach is founded on the principle that coupled intra-agent and agent-environment dynamics are necessary and sufficient conditions for the production of adaptive behaviour (Harvey et al., 2005). Minimal developmental models cannot show how species $X$ acquires behaviour $Y$, rather such models can be used, like their evolutionary robotics counterparts, as intuition pumps and proofs of concept and to generate new hypotheses for test.

## 3. Minimal developmental models

The potential value of a minimal systems approach to modelling development can be seen in experiments with Piaget's delayed manual search task (the ' A not B' error). Infants of between 7 and 10 months make perseverative errors when delayed in searching for a hidden object (Piaget, 1980). In an experiment designed to test the application of minimal modelling to a nontrivial task domain, a simulated evolutionary process is used to design agents able to *learn* a modified version of the 'A not B' task (Wood and Di Paolo, 2007). The fitness function employed selects for correct performance of the search task (thus perseveration is selected *against*) yet agents make systematic perseverative search errors. Analysis of the error pattern produced during extended series of trials indicates a developmental trend in the error pattern such that perseverative errors become less frequent over developmental time (*ibid.*). 'A not B' errors decrease in frequency as a result of the intrinsic dynamics of interaction between intra and extra agent factors. This highly abstract, idealised, minimal model reproduces the error pattern and overall developmental trajectory observed in a complex task with human infants. The error pattern observed results from the interaction of neural dynamics operating at multiple time-scales and a constrained developmental trajectory instantiated by learning mechanism which is homeostatically mediated[1]. These results allow the generation of a hypothesis about the mechanisms underlying perseverative errors in human infants such that there is some process for the regulation of plasticity which plays a role similar to the homeostatic mediation of plasticity instantiated in the model. This process supports the conservation of patterns of neural activity with the effect of adapting to repeated sensorimotor requirements (*ibid.*). While this minimal model cannot be the basis for any specific claim about the mechanisms underlying infant perseveration it can demonstrate the minimal or 'base set' conditions for exploring the phenomena of interest. In this respect minimal approaches can be most valuable for what they tell us about what we can do without.

## 4. Conclusion

This paper has presented an argument for the value of minimal developmental modelling techniques as tools for exploring and experimenting with ontogenetic adaptation. Minimal models can provide abstract, idealised test-beds for the generation of new hypotheses about developmental process which can then be used to guide the design of new experiments with natural empirical populations. As such the minimal systems approach can be a valuable new addition to the toolbox of dynamic approaches for experimenting with ontogenetic adaptation. Minimal systems have their roots in evolutionary robotics techniques with a proven track record for minimisation of designer bias and the discovery of new mechanisms for the production of adaptive behaviour. By bringing evolutionary techniques to bear on problems in developmental process we stand to exploit both this track record and the fundamental relationship between mechanisms for adaptation at both ontogenetic and phylogenetic time-scales.

[1] A full account of this model and the learning mechanism employed is given in Wood and Di Paolo, 2007.

## References


Cliff, D. (1991). Computational neuroethology: a provisional manifesto. In Meyer, J.-A. and Wilson, S., (Eds.), *From Animals to Animats; Proceedings of the First International Conference on Simulation of Adaptive Behaviour*, pages 29–39. MIT Press. Cambs. Mass.

Harvey, I., Di Paolo, E., Wood, R., Quinn, M., and Tuci, E. (2005). Evolutionary robotics: A new scientific tool for studying cognition. *Artificial Life*, 11(1-2):79–98.

Piaget, J. (1980). *Six Psychological Studies*. Harvester Press.

Slocum, A., Downey, D., and Beer, R. (2000). Further experiments in the evolution of minimally cognitive behaviour: from percieving affordances to selective attention. In Meyer, J.-A., Berthoz, A., Floreano, D., Roitblat, H., and Wilson, S., (Eds.), *From Animals to Animats 6; Proceedings of the Sixth International Conference on Simulation of Adaptive Behaviour*, pages 430–439. MIT Press.

Thelen, E., Fisher, D., and Ridley-Johnson, R. (1984). The relationship between physical growth and a newborn reflex. *Infant behaviour and Development.*, 7:479–493.

Weisberg, M. (2006). Forty years of 'the strategy': Levins on model building and idealization. *Biology and Philosophy*, 21:623–645.

Wood, R. and Di Paolo, E. (2007). New models for old questions: evolutionary robotics and the 'a not b' error. In Almeida e Costa, F., (Ed.), *Advances in Artificial Life 9th European Conference ECAL 2007, Lisbon, Portugal*, volume 4648 of *Lecture Notes in Computer Science*, pages 1141–1150. Springer, Berlin.