The several uses of computational models as scientific tools

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Abstract

Computational modeling has been playing an ever increasing role in science in general, and in the sciences of life and cognition in particular. However, the role that they play in the scientific endeavor is far from clear, and confusion on this important topic is widespread. Those who argue for the importance of computational models in science generally assume that there is only one way to do computational models that are useful for scientific understanding (typically their own). In contrast, I argue that there are several different kinds of computational models that can be used for different purposes. All of them have their own pros and cons, their best practices, and their criteria for success. Understanding the several ways in which computational models can help scientific research, especially in the life and cognitive sciences, will greatly facilitate the actualization of their huge potential.

Open question addressed:

(11) What are the characteristics and roles of synthetic models?

Computer simulations and synthetic artifacts in general are being used more and more as scientific tools, in every field of science: from physics, to biology, to the sciences of brain and behavior, to those of human societies. Here I will refer to computational models as computer programs that are either run on a computer or embedded in a behaving physical system that interacts with its environment (robot) and that attempts to reproduce and explain some real phenomenon.

Notwithstanding the importance that computational models have been assuming in science, there is a widespread confusion with respect to the reasons why they are assuming such an importance. In particular, it is not clear what role computational models do (or can) play in science, what are their advantages, what their limitations, what their value, and, in sum, what is the meaning of doing computational models in the first place.

This lack of clarity is present not only in traditional, empirical scientists, who do not do computational models and do not know them enough, but also within the communities of researchers that do models themselves. For example, in the various fields where models of brain and behavior (and Mind) are proposed, e.g. Artificial Intelligence, Artificial Life, Adaptive Behavior research, Cognitive Modeling, Developmental and Autonomous Robotics, Computational Neuroscience, it is not clear what is (or can be) the contribution to scientific knowledge that computational models can bring. This is a problem because this confusion may hinder the huge beneficial impact that computational models can have for science in general, and for the sciences of life and cognition in particular.

Indeed, several attempts have been made to clarify the possible role that computational models can play in science, and to explain the difficulty for such kind of research to impact on traditional sciences (e.g. Bedau, 1998; Bonabeau and Theraulaz, 1994; Dennett, 1994; Di Paolo, Noble, and Bullock, 2000, Langton, 1989; Pattee, 1989; Taylor and Jefferson, 1994, Webb, 2009). However, typically those that discuss about the role of computational modeling in the brain and behavioral sciences try to identify *the* right way to do simulations, and *the* methodology that must be followed if one wants to use models for scientific purposes. The more or less explicit assumption is that there is only one proper way to use computer models in science, and that those who do not follow the rules that are prescribed for that use do not do (anything good for) science.

I argue on the contrary that there are instead several different ways to use computer models for scientific purposes, and that each of these ways has its utility, its advantages, its potentialities, its limitations, and its conditions for success.

Here is a (probably not exhaustive) list of different uses of computational models:

1. Clarifying concepts through their operationalization (e.g. Tummolini, Mirolli and Castefranchi, 2009);
2. Testing already existing theories (e.g. Mirolli and Parisi, 2005);
3. Developing/clarifying already existing theories (e.g. Mannella et al., 2008);
4. Comparing already existing theories (e.g. Di Ferdinando et al. 2005);
5. Express new theories (e.g. Mirolli and Parisi, 2006);
6. Developing new theories (e.g. Mirolli and Parisi, 2008);
7. Developing new conceptual tools and methods of analysis (e.g. Beer, 2003);
8. Developing new general principles, ideas, visions, and paradigms (e.g. Nolfi, 1998);
9. Testing/comparing different general visions/approaches (e.g. Mirolli, 2012).

Clearly, some of these uses can overlap in practice (i.e. the same research can serve more than one of these purposes), but it is useful to keep them distinct not only in order to classify them, but, more importantly, to recognize their differences, and to realize that different uses have different purposes and different best practices.

In my presentation I will briefly describe some of these uses of computational models for science and highlighting their respective merits and limits through examples taken mostly from my own research. Even though the discussed examples all deal with the study of behavior, the points I make are meant to be general, and hold for all computational modeling researches that have scientific rather than technological aspirations.

My hope is that this exercise can help to increase the awareness of the both the potentialities and the limitations of computational models as scientific tools for understanding life and cognition, and, through this, to contribute to the full development and actualization of these potentialities.

References

1. Bedau, M. A. (1998), Philosophical content and method of artificial life, in T. W. Bynam & J. H. Moor, ed.,'The Digital Phoenix: How Computers are Changing Philosophy', Basil Blackwell, Oxford, pp. 135--152.
2. Beer, R. D. (2003), 'The dynamics of active categorical perception in an evolved model agent', *Adaptive Behavior* **11**(4), 209--243.
3. Bonabeau, E. W. & Theraulaz, G. (1994), 'Why do we need artificial life?', Artificial Life 1(3), 303--325.
4. Bryden, J. & Noble, J. (2006), Computational modelling, explicit mathematical treatments, and scientific explanation, *in* L. M. Rocha; L. S. Yaeger; M. A. Bedau; D. Floreano; R. L. Goldstone & A. Vespignani, ed.,'Artificial Life X: Proceedings of the Tenth International Conference on Artificial Life', MIT Press, Cambridge, MA, pp. 520--526.
5. Dennett, D. C. (1994), 'Artificial Life as Philosophy', Artificial Life 1(1), 291--292.
6. Di Ferdinando, A.; Casarotti, M.; Vallar, G. & Zorzi, M. (2005), Hemispheric asymmetries in the neglect syndrome: a computational study, *in* A. Cangelosi; G. Bugmann & R. Borisyuk, ed.,'Modelling Language, Cognition and Action', World Scientific, Singapore, pp. 249--258.
7. Di Paolo, E. A.; Noble, J. & Bullock, S. (2000), Simulation models as opaque thought experiments, in Mark Bedau; J. McCaskill; N. Packard & S. Rasmussen, ed.,'Artificial Life

VII', MIT Press, Cambridge, MA, pp. 497-- 506.

8. Langton, C. G. (1989), Artificial Life, in 'Artificial Life', Addison-Wesley, Redwood City, CA, pp. 1--47.
9. Mannella, F.; Zappacosta, S.; Mirolli, M. & Baldassarre, G. (2008), A Computational Model of the Amygdala Nuclei's Role in Second Order Conditioning, *in* 'From Animals to Animats 10: Proceedings of the 10th International Conference on the Simulation of Adaptive Behaviour'.
10. Mirolli M. (2012): Representations in Dynamical Embodied Agents: Re-Analyzing a Minimally Cognitive Model Agent, Cognitive Science, 36: 870-895.
11. Mirolli, M. & Parisi, D. (2005), 'How can we explain the emergence of a language which benefits the hearer but not the speaker?', *Connection Science* **17**(3-4), 325--341.
12. Mirolli, M. & Parisi, D. (2006), Talking to oneself as a selective pressure for the emergence of language, *in* Angelos Cangelosi; Andrew Smith & Kenneth Smith, ed.,'The Evolution of Language: Proceedings of the 6th International Conference on the Evolution of Language', World Scientific Publishing, , pp. 214--221.
13. Mirolli, M. & Parisi, D. (2008), 'How producer biases can favour the evolution of communication: An analysis of evolutionary dynamics', *Adaptive Behavior* **16**(1), 27--52.
14. Nolfi, S. (1998), 'Evolutionary Robotics: Exploiting the full power of self- organization', *Connection Science* **10**(3-4), 167--183.
15. Pattee, H. H. (1989), Simulations, realizations, and theories of life, in Christopher Langton, ed.,'Artificial life', Addison-Wesley, Redwood City, CA, pp. 63--77.
16. Taylor, C. & Jefferson, D. (1994), 'Artificial Life as a tool for biological inquiry', Artificial Life 1(1--2), 1--13.
17. Tummolini, L., Mirolli, M., Castelfranchi, C. (2009): The Evolution of Stigmergy: A Simulative Approach to Indirect Communication of Behavioral Messages with Implicit Signals. In Adelinde M. Uhrmacher; Danny Weyns (Eds.) Agents, Simulation and Applications. London, Taylor & Francis: 243-265
18. Webb, B. (2009) Animals versus animats: or why not model the real iguana? *Adaptive Behaviour*. 17:269-286