The Dynamic Perspective to Cognitive Science

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Abstract
The paper describes specific current dynamic approaches to cognitive modelling alternative to the computational approach. Then a more general modelling framework is suggested that could accommodate both the computational and the dynamic approach, at least for what concerns the formalisms used.
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Introduction

In cognitive science the last decade has been characterised by the awareness that a dynamic perspective in modelling cognitive processes might be promising. I refer to the Dynamic System Theory (DST) perspective which can be traced back to Ashby (1952) but did not have sufficient resonance mostly due to the predominance of the computational theory of mind (CTM) paradigm.
Although one can find in the recent literature several studies employing system theory as a frame of reference in biology (Haken et al., 1985), sociology (Luhmann, 1990), natural language processing (Vaccari and Delaney, 1986), etc, only after the so called contextual revolution (Bruner, 1992) the DST paradigm began to be considered by the cognitive science community.
The work of Damasio (1994), Maturana (1990), Maturana and Varela (1992), Edelman (1992), etc. on living organisms focused attention on the dynamical aspect of living systems and organisations both with respect to their inner dynamics and their dynamic interaction with a physical and sociocultural environment. Further the arguments of many scientists concerned with fundamental items such as intentionality, self, mind-body, etc opened the way to a critical re-examination of the basic hypothesis underlying CTM which now appears to many researchers to be inadequate for real problems.
This new perspective is a system science perspective which constitute the most broad and experimented paradigm in science. Let us define few terms frequently used in the paper.
System: a part of reality
Conceptual System Model (CSM): a system perceived as a unit by an observer (i.e. the modeller)
In general a modeller formulates a CSM for some specific purpose which determines the aspect (i.e. selection of specific significant attributes among the infinity of

potentially distinguishable ones) or the process (i.e. time function relations between attributes) to conceptualise.

Symbolic System Model (SSM): the description of a conceptual system model (CSM) in a natural or formal language

A symbolic system model is a *representation* which involves: what is represented, the representation and the modeller i.e. the user of the representation.

Thus, an SSM of a cognitive process, formulated either in the CTM or in the DST paradigm, constitutes a more or less valid representation of the modelled process. However the metaphysical assumptions of the modeller (concerning whether the cognitive system itself uses or not representations in performing specific cognitive tasks) determine the type of CSM and the choice of the language to describe it, i.e. the type of SSM. This issue of representation and the strategy of explanation are the major differences advocated between CTM and DST approaches (Bechtel, 1998). In our opinion also the modelling tools (i.e. formalisms) used in the different approaches are very significant since the languages/formalisms mediate our knowledge.

In the following after briefly recalling the basic assumptions adopted by CTM we describe current outstanding approaches to cognitive modelling and their claims concerning fundamental differences with CTM. Specifically we refer to the Biomimetic approach based on connectionist principles and constraint satisfaction (Roitblat, 1995) and to the dynamic systems theory (DST) approach (Port and Van Gelder, 1995).

Finally we will discuss the possibility of considering a DST integrated framework (Vaccari, 1998a, 1998b) for modelling cognitive processes which offers the possibility to unify the above mentioned approaches and also include the CTM approach as a specific limiting case.

2 The Computational Approach (CTM)

Basic underlying metaphysical assumptions underlying CTM are the existence of a language of thoughts (Fodor, 1975) and the independence (based on the notion of computational equivalence) of a cognitive process performance from the medium carrying on the process itself.

The approach is based on the assumed similarity between the mind and a universal Turing machine (Newell, Show, Simon, 1958) from which the notion of a physical symbol system as an information processing device has been derived.

A physical symbol system necessary and sufficient to produce intelligent behaviour (Newell and Simon 1976), is a set of physical patterns/discrete symbol strings and a set of explicit rules. The rules can also be coded as symbolic structures and they describe how to manipulate the symbols.

Knowledge is explicitly represented since the symbols can be given a semantic interpretation.

Time has no significance in this approach. Computational models specify only a sequence of states that a system goes through and there is no concern about real amounts of time.
We do not mention here the limitations and merits of CTM in all its variants, since they are well known .

3 The Biomimetic Approach

The Biomimetic (or equivalently 'animat') approach envisions organisms as collections of hierarchically organised agents. In this framework the conviction that studies on animals furnish a useful base for comparison of cognitive theories is central and *animats* (i.e. artificial organisms like simulated animals or animal-like robots, with structure and functions based substantially on observations of biological animals) have been proposed as investigation devices (Wilson, 1991).
This approach is based on a view of cognition as constraint satisfaction. The constraints are suggested by observations on animal behaviour in performing real life activities. The cognitive process being modelled is considered continuous time and treated by means of analog or digital computing devices; of course, in the latter case it must be discretized. It focuses on performance of whole organisms including sensorimotor tasks. The formalisms used include neural nets, simulation and heuristics inspired by biological, psychological and evolutionary theories.
The approach is presented by Herbert Roitblat as alternative to the CTM in many aspects:
'Even if it turns out to be true that reasoning, problem solving and similar behaviours characteristic of human achievement are mediated by something like language, evolutionary continuity suggests that a substantial part of intelligence, both human and non human, is mediated by substantially different mechanisms.
The Biomimetic approach advocates the modelling of whole, albeit simple, organisms in a real environment, performing real biological tasks (excaping predators, feeding, etc)'
(Roitblat, 1995 pp 21)

This approach is called subsymbolic since it is semantically opaque in the sense that the symbols used cannot be given a systematic semantic interpretation (as in CTM, where the rules of transformations constitute the syntax of the language of thoughts).

In order to furnish a better understanding of this approach we mention a few applications from the pertinent literature.

Dyer (1995) discusses a 'synthetic approach' to language/communication skills acquisition and two specific applications (under development at UCLA, University of California) in which specific models are utilised at different phenomenological levels. The processing system, named DETE, is a procedural/neural hybrid and includes:

- a socio-evolutionary level regarding the acquisition of communication skills through evolutionary processes;

- a cognitive symbolic level regarding how language relates to abstract symbolic thoughts;
- a neural level which regards language acquisition via self-organisation in artificial neural network;
- a level concerning perceptual motor activities regarding 'how language is grounded in the physical world via association with perceptual/motor experiences.

The procedural modules deal with transforming initial visual input with internal neural representations that are then processed by memory subsystems, which are implemented as neural networks.

Others applications are described in Meyer (1995,pp 27-28) where he defines, by quoting Wilson (1991) the objective of the Biomimetic approach as follows '*obviously, we can't yet simulate human intelligence holistically. But the basic hypothesis of the animat approach is that by simulating and understanding complete animal-like systems at a simple level, we can build up gradually to the human. At each point we will be careful to include full connection with a sensory environment, together with maximum use of perception, categorisation, and adaptation. Thus when we reach the human level these crucial abilities will not be missing. We hope to reach human intelligence from below instead of piecemeal through high level competencies as in standard AI.*'

The type of applications discussed regard:

- ·*animats with pre programmed behaviour*

  A model developed by Beer (1990): it enables an artificial insect to display a variety of behaviours -local motion, wondering, edge following, feeding- so as to insure its survival in a simulated environment. It is implemented as a hierarchy of neural networks

- *animats with learned behaviours*

  It regards learning situations where an animat discovers which actions it must perform to maximise an external reinforcement signal. The specific model of Barto and Sutton (1981) is discussed, it regards an animat learning to use landmarks to orient itself in a two dimensional environment. This task is performed using a neural network having special neurones developed by Klopf (1980). Learning takes place when the animat's neurones have been adapted in such a way that when it is at a specific point in its environment it will move in a direction which increases the reinforcement signal.

- *animats with evolved behaviours*

  An application of Koza (1992) is discussed which regards the evolution of control computer programs that give an autonomous robot the capability of following the walls of an irregularly shaped wall.

  Another application with the same objective of Cliff et al. (1993) is implemented in terms of the evolution of neural networks instead of evolving computer programs.

Positive aspects in the above mentioned Biomimetic/Animats applications regard the treatment of different phenomenological levels in the same overall model and the use of different formalisms. However it seems that, the dynamic aspect, although present, is not central to the approach used and this may lead to problems regarding a correct time synchronisation when more realistic applications will be affronted.

4 The Dynamic System Theory Approach

We attribute to Port and Van Gelder the great merit of having focused (with the volume Mind as Motion (1995)) the attention of many researchers on the Dynamic System Theory (DST) paradigm for modelling cognitive processes. The DST approach focuses on time; it is based on the consideration that cognitive processes always unfold in time; thus a framework for their description must be able to describe not only what processes occur but how these processes unfold in time.

In the above mentioned volume Port and Van Gelder stress the importance of considering natural cognitive systems as dynamical systems and also they include a representative sampling of contemporary specific papers/researches adopting a DST approach to cognition.

Their main claims, with which we completely agree, are the following:

Cognitive systems are composed of multiple subsystems which are simultaneously active and interacting; their cognitive behaviours are pervaded by both continuities and discreteness and their kind of structures emerge over time. Further cognitive processes operate over many time scales and events at different time scales interact.

Dynamics provides a wide resource of concepts and tools for system analysis and model synthesis and constitutes a framework within which continuity and discreteness in time can be accounted for, even within the same model. The total state of a DST model, representing the system's state, is changing from one time to the next. Instead computational models assume that most aspects of a system do not change from one moment to the next; change is assumed to be replacement of one symbol by another.

The crucial difference between computational models and DST models is that in the former the rules that govern behaviour are defined over the entities that have representational status, whereas in dynamical models the rules are defined over numerical states i. e. DST models can be representational without having their rules of evolution defined over representations.

Nonetheless DST models can store knowledge and have this stored knowledge influence their behaviour.

The point of view that we do not share with Port and van Gelder (discussed in the next section) concerns their holistic attitude in modelling a cognitive system or subsystem.

Although they recognise that the total system can be broken down into smaller dynamical interacting subsystems, their attitude is to freeze their interactions and study their independent dynamics.

In the above mentioned DST approach the dynamic aspect is central The approach can be used satisfactorily in simple context, but it is difficult to imagine its use for modelling problems of organised complexity like cognitive processes.

4.1 An Integrated DST framework

In the DST approach to cognition mentioned above *the dynamics of central cognitive processes are nothing more than aggregate dynamics of low level neural processes described in higher level, lower dimensional terms* (Port and Van Gelder, 1995). The above implies that the models representing the cognitive process considered are formulated at the level of the global process that is: one generative model represents the considered process. Of course this approach relies on excluding or coarsening variables in order to reduce descriptive complexity.

We claim that an holistic attitude in DST modelling does not seem sufficient to represent cognitive processes emerging from the internal self-*referential* dynamics of living systems and from their interaction with a physical and sociocultural environment since:

a) it is not possible to manage descriptive complexity without a tremendous increase in uncertainty
b) the classical DST formalisms do not foresee the possibility of representing hierarchical relations which are necessary, in our opinion, to represent peculiar features of living systems such as variable structure, self-organisation, feed-forward mechanisms, etc.;

For the above reasons, we suggest a DST approach to cognition (Vaccari, 1998a, 1998b) based on the notion of functional system conceptually equivalent to a Cognitive Dynamic Unit of Analysis (Mandelblit and Zachar, 1999), on Bertalanffy's hierarchy principle (Bertalanffy, 1968), on the development of discrete event simulation in the systems theory paradigm (Delaney and Vaccari, 1989; Zeigler, 1976), and on the possibility of using different formalisms (neural nets, differential and finite difference equations, rules, etc) in the same global DST model. In this approach holism and reductionism are complementary in the sense that one global cognitive process is represented as a structured model, i.e. a set of N generative DST models described by N formally independent laws of behaviour, connected by coupling input-output relations. Here the strategy adopted for reducing descriptive complexity is to conceptually break the cognitive system/process (that we conceive as a functional system) into appropriate functional sub-systems amenable to being formally modelled separately and solved simultaneously taking into account their interactions. In this way it is possible to avoid drastic assumptions and simplifications which amounts to minimising loss of information while obtaining a consistent reduction of descriptive complexity. Conceptualising systems as structured systems/models refers to the process of structuring models (i.e. using composition) from a conceptual point of view and not simply at the implementation level by means of mathematical artifices.

The generative models forming a structured model might be structured models themselves; in such a case we obtain a second order structured model and it is possible to recursively define higher order structured models. This possibility to represent a sub-model, in turn, as a structured model allows hierarchical representations in a well established theoretical framework such as systems theory.

Our point of view also differs from the dynamic approach proposed by Port and Van Gelder in its sharp demarcations from the computational theory of the mind (CTM). Although the application of the CTM methodology is limited to specific, high level cognitive tasks and is thus inadequate to model cognitive system which are very complex dynamical systems, we claim that CTM can be regarded as a limiting case in the systems theory paradigm: as a matter of fact, in the Turing machine, the law of behaviour, formalised as a functional matrix, determines the transitions between states at successive times. These times individuate a series of symbolic, discrete, successive states. In a dynamic perspective, the Turing machine might be considered as a special limiting case of a discrete time / discrete space model, where the time between state changes is of no significance.
Thus we claim the possible integration of the CTM (formalism) in a broad DST modelling framework.
Some limitations/problems inherent in the modelling frameworks discussed above, could be overcome by using structured DST models.

5 Conclusions

Cognitive modelling is a very difficult and ambitious task since we lack sound theories concerning many aspects of cognition. Looking at living organisms as 'systems' as conceived in System Science, puts them in a more realistic perspective. The adoption of the DST paradigm constitutes, in our opinion, a big step toward a fruitful reorganisation of cognitive science. The DST paradigm in its brood sense (classical DST modelling, structured modelling, discrete event simulation, connectionism, etc) is so far the most experimented and successful paradigm in science. It furnishes concepts which permit to unify equivalent notions used in specific disciplinary applications thus it can accommodate the transdisciplinary nature of cognitive studies. It furnishes tools and formalisms which allow time and space representations at different degree of precision as well as the treatment of deterministic and probabilistic situations. It furnishes principles and methodologies to formulate and to validate system's models.
As a final conclusion we note that System Theory basically is a formulation of the idea of science in terms of experimentation and theory which can be validated by (real or simulated) experimentation. Cognitive science can benefit from a system theoretic formulation in that it can elucidate to researchers working in the field what science means for them. In other words, if we believe that science can serve the purposes of cognitive research, certainly the DST paradigm is the best suited. Even if the results of investigations in the DST paradigm will not succeed in revealing aspects of cognition of interest then we will have learned that it is necessary to go beyond science, as presently understood, to find answers to the problems we face.

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