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Book Review

Mind as Motion. Edited by Robert F. Port and Timothy Van Gelder. Cambridge, MA: MIT Press, 1995; 590 p. + x.

This edited collection had its origins in a conference held at Indiana University in 1991. It aims to articulate and clarify the conceptual foundations of the dynamical approach to human cognition and action, and to introduce the dynamical approach to a wider audience through presenting a representative sample of dynamical research.

The editors have worked hard to realise these aims. The introductory chapter by Van Gelder and Port begins by providing a lucid overview of the dynamical approach to cognition. For this purpose, dynamical systems are defined as state-determined systems, whose evolution in numerical space can be described, in continuous or discrete terms, by differential or difference equations. Such systems are distinguished from computational systems, whose evolution is specified by a rule-governed sequence of symbol configurations. The central conjecture of the dynamical approach is that natural cognitive systems constitute single, unified dynamical systems—although, in practice, it is assumed that these can be broken down into relatively self-contained sub-systems. In contrast, the computational approach holds that physical symbol systems, and their associated transition rules, are necessary and sufficient for explaining at least the central processes underlying intelligent behavior.

From this opposition follow many detailed differences in analytic procedures and in the characterisation of cognitive systems. Whereas the computational approach seeks to understand cognitive phenomena in terms of if-then rules or algorithmic procedures relating stimuli and responses, the dynamical approach attempts to describe the evolution of cognitive processes in time, either by means of equations or—failing that—in terms of the qualitative patterns of change exhibited by particular classes of nonlinear dynamical systems. Whereas the computational approach emphasises the high-level representation of knowledge by means of static symbol configurations, discrete sequential transactions between hierarchically organised, specialised processing modules, and a clear separation between

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environmental, peripheral and central mechanisms, the dynamical approach provides scope for representation in temporal patterns of change (attractors, trajectories and bifurcations) and in the parameter settings that govern them. Further, the dynamical approach emphasises the temporal evolution of entire systems, characterised by multiple simultaneous interactions and self-organisation, and embedded within the nervous system, the body and the environment.

Unlike many introductions written for conference proceedings, which often have the conceptual integrity of a patchwork quilt, Van Gelder and Port's chapter (together with the more general, final chapter by Giunti) provides a comprehensive overview of the dynamical approach to cognition and its relation to other approaches, such as the computational approach, connectionism, and neuroscience. It also serves as both an excellent preparation for the chapters that follow and a recapitulation of some of their main developments. Its usefulness is enhanced by the introductions provided by the editors to each chapter, which help the reader to maintain a coherent perspective. The volume is also complemented by a glossary which makes a genuine attempt to explain and illustrate key concepts. Meanwhile, the mathematical basics of the dynamical approach are dealt with in a separate chapter by Norton. Although admirably succinct, this is perhaps more useful as refresher than as an elementary introduction for the outright newcomer. Like all of the other chapters, however, it features a critical guide to further reading.

The remaining sixteen chapters vary with respect to the problems addressed, the methods of analysis employed, and their level of difficulty. Among the most accessible for the novice are Thelen's chapter on the development of reaching and of coordinated kicking movements in infants, Van Geert's chapter on the explaining developmental phenomena by means of simple dynamical growth models, Metzger's application of multiprocess models to the problem of dynamic strategy shifts in prediction tasks, and Reidbord and Redington's chapter on the correlation between styles of patient behavior in a therapy session and characteristic trajectories observed in heart rate data. Thelen, for example, questions the Piagetian picture of development as the progressive construction of abstract logical structures. Instead, she argues, cognitive development arises as an inevitable consequence of the local dynamics of an organism's activity, its interactions with the environment and its physical development. More specifically, the overall pattern of a particular repeated action is conceptualised as an attractor that is governed by parameters that change as a function of both experience and bodily growth. As Thelen shows, this dynamical perspective not only makes it easier to understand transitions and individual differences in development, it also shifts the focus away from averaged behavior towards

the detailed changes that occur with each individual subject. In the process, it provides a good example of the extent to which the conceptual framework within which we understand simple behavior can be radically altered and enriched by a dynamical description that relies entirely on qualitative properties of the underlying system.

Several other chapters are much harder. However, whatever their topic or level of difficulty, all of them share three notable features. First, they are clearly written, in a direct, tutorial style. Second, they all begin with an extended account of the theoretical background to the research in question. (Although this inevitably leads to some repetition, it makes it easier for the non-specialist to choose a chapter at random and get a quick picture of the main issues.) Third, all of the chapters present the results—albeit preliminary in several instances—of research that can only be described as ground-breaking. For example, Townsend and Busemeyer present a dynamical stochastic model of decision-making, in which a stochastic decision process is prefaced by a detailed valence system that represents the weighted sums of the motivational values of each consequence. The resultant valences drive preference states, with the force of the valence on the preference state and the translation of that state into a response movement both being governed by linear difference equations. In this model, choice probabilities and mean response times can be derived both for binary choices and for those permitting a third, indifference alternative. This last serves as the critical mechanism in a dynamic matching process by which a decision-maker can arrive at a selling price. While I feel that to describe the evolution of the preference state as a race is potentially confusing, the suggested mechanism for indifference responses is novel and intriguing. Meanwhile, the general theory not only accounts for data addressed by static and deterministic approaches, based on subjective expected utility theory, but also predicts certain phenomena that appear paradoxical from traditional perspectives, notably the discrepancies between preference ordering measured by choice and by selling price. It also provides a strong example of the usefulness of applying the dynamical approach to aspects of cognition traditionally regarded as 'high-level'.

The remaining chapters are equally representative of pioneering theoretical developments with respect to various aspects of cognition. For example, representing the ecological program of research into human perceptual and motor skills, Turvey and Carello show how haptic perception of the physical dimensions of a wielded object is linked to an invariant of the dynamical system involved. Conversely, the production of coordinated movements as complex as juggling can be understood in terms of adjustments in the value of control parameters that exploit certain regularities in the task dynamics. In a general theoretical article, Beer goes on to apply

the dynamical systems approach to the study of simple autonomous agents (or embodied systems), whose complex behaviors (chemotaxis and six-legged locomotion) follow from the global properties of many distributed, cooperative processes in interaction with an environment.

Within the field of language processing, Saltzman and Browman and Goldstein address the traditionally conceived problem of translating between the intrinsically incommensurate phonological and articulatory domains involved in speech production. Saltzman begins by reviewing evidence from the ecological program that illustrates how simple repetitive coordinated actions can be modeled by limit-cycle oscillators with nonlinear bidirectional coupling. He goes on to argue that the relevant state variables that mediate this coupling cannot be specified in terms of anatomical or biomechanical coordinates but must be defined in abstract terms. Saltzman then describes a dynamical model of the interarticulatory coordination of the speech organs in accordance with an abstract gestural score, which defines a set of dynamical systems, specified by characteristic sets of parameter values, and which functions like an intentional system that is coupled with the articulatory system. In line with this, Browman and Goldstein present useful background and give an overview of this 'articulatory phonology' approach. This constitutes a major collaborative research endeavour that reconceptualises cognitive units in terms of the parameters of dynamical systems, thereby dissolving the traditional separation between cognition and action.

Also within the field of language processing, Elman questions traditional approaches to language in terms of rule-governed computations on static, context-free lexical structures, and contrasts these with the dynamics of a simple recurrent network that learns to predict the next word in a sentence. The behavior of the network is conceptualised in terms of trajectories through a multidimensional representational space. These echo phenomena of polysemy and contextual accommodation, and show empirically familiar patterns of sensitivity to center-embedded and right-branching sentence structures in the presence of varying degrees of semantic constraint. Meanwhile, in a subsequent chapter on the induction of dynamical recognizers, Pollack addresses the fundamental language acquisition problem of how we come to distinguish accurately between an unlimited number of grammatical and ungrammatical sentences on the basis of only a finite sample of utterances. Like Elman, he develops a recurrent network, but involving a 'backspace' feedback mechanism and operating within a classification, rather than a prediction paradigm. Such a noncomputational, dynamical system can learn to classify symbol strings from a restricted set of artificial languages. Moreover, the state space graphs show a fractal structure, reflecting the complexity of the generated language, and leading to

the conjecture that such dynamical recognizers have the potential for discriminating grammatical structures in natural language.

Turning to the field of speech perception, Port, Cummins, and McAuley tackle the crucial question of how the human auditory system times the perceptual events relevant to speech recognition. They argue persuasively against the plausibility and utility of a short term memory buffer in which auditory events are measured in absolute time by an internal clock, like a (rapidly decaying) sound spectrogram. Instead, they propose, the human auditory system makes use of two weaker sources of temporal information: serial order and relative duration. The first might be extracted by a recurrent network, capable of recognising serial order and relatively insensitive to repetition (or rate of presentation). The second could be achieved by a bank of adaptive oscillators, with preferred periods, to which they slowly return in the absence of an entraining input. These provide a source of time measurement and comparison that is automatically scaled to the periodicity of the relevant stimulus. While some possible questions remain (such as the need to train the recurrent network), these dynamic models provide theoretical possibilities with potential applications that extend well beyond the field of speech recognition.

In the field of vision, Bingham addresses what some might say is *the* problem of perception—namely, how we perceive the essential nature of elastic objects and fluid events, given the limited and partial nature of their visual images. Using the example of the image of a ball oscillating from side to side in a horizontal tube (as seen from above), he shows how, in principle at least, it is possible to use symmetries in the disconnected trajectories of points on the surface to specify a coherent structure in motion. The question now becomes one of discovering how this is achieved by the perceptual system. In an attempt to tackle such questions at a level much closer to the neurophysiological, Grossberg presents two detailed models whose properties are best understood by analysing their interactive dynamics in real time. The first accounts for phenomena of apparent motion, while the second, adaptive resonance theory model illustrates how a combination of adaptive filtering, learned expectations, attentive resonance and novelty sensitive memory search can accommodate some essential characteristics of autonomous categorisation that is both rapid and stable.

Finally, in one of the most difficult and challenging chapters, Petitot tackles the problem of devising a dynamical account of the relations between linguistic structures, psychological language processes and perceptual organisation. If the terms of sentences are modeled by attractors of some underlying dynamics, he asks, then what is the dynamical status of a syntax relating these attractors? What might an attractor syntax be? According to Petitot, the difference between terms and relations corresponds to the dif-

ference between attractors and bifurcations of attractors. That is, configurations of attractors correspond to syntagmatic trees in the symbolic conception of formal grammar. Key elements in Petitot's synthesis are the image schemas of the cognitive grammar of Langacker, Talmy and Lakoff and the catastrophe theory developed by Thom and Zeeman.

This collection of papers is understandably biased towards work in language processing and the analysis of simple actions. Some topics in perception that seem to invite a dynamical approach (like perceptual reversals) are absent. There is no contribution devoted exclusively to memory, and there is no work explicitly directed towards an explanation of reasoning and thinking in geometric terms. Although it is referred to, Gregson's pioneering work in psychophysics is not featured. However, it is clearly asking too much of such a collection that it should be all things to all people. Indeed, it is a strength of the volume that it should inspire us to think of further fields of application. According to the argument presented by Giunti in the final chapter, *all* explanations of cognition might fruitfully be formulated in dynamical terms, and, in particular, in terms of a special type of Galilean dynamical model, in which each component of the model has a direct interpretation in terms of a temporally varying magnitude of some aspect of the cognitive system. Whether this will be possible is a challenge for future empirical research.

In the meantime, many themes, such as those of cognitive grammar or the seminal work of the ecological program, recur throughout this collection, and weave together articles with otherwise quite different orientations. Besides explicitly dynamical themes, such as embodied action, we also catch fleeting glimpses of other deep ideas having to do with symmetries, transformations and expressions of some minimum principle. It is still far too early to recover an overall, coherent picture of human cognition and action from the various fragmentary trajectories illustrated in these chapters. However, if we ever do achieve such an understanding, it will be due, in no small measure, to such collective endeavours at the cutting-edge of research as are represented in this volume.

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