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Dynamical Explanation and Mental Representations

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Markman and Dietrich[1] recently recommended extending our understanding of representation to incorporate insights from some "alternative" theories of cognition: perceptual symbol systems, situated action, embodied cognition, and dynamical systems. In particular, they suggest that allowances be made for new types of representation which had been previously under-emphasized in cognitive science. The amendments they recommend are based upon the assumption that the alternative positions each agree with the classical view that cognition requires representations, internal mediating states that bear information.[2] In the case of one of the alternatives, dynamical systems[3], this is simply false: many dynamically-oriented cognitive scientists are anti-representationalists.[4,5,6]

The Dynamical Approach to Cognition

Most basically, dynamicists take cognitive agents to be dynamical systems, and argue that cognitive agents best explained using the tools of dynamical systems theory. A dynamical system is a set of quantitative variables changing continually, concurrently, and interdependently over time in accordance with dynamical laws that can, in principle, be described by some set of equations[7,8]. To say that cognition is best described using the tools of dynamical systems theory is to say that cognitive scientists ought to try to understand human behavior using a particular sort of mathematics, most often sets of differential equations. The rationale behind this approach is that using mathematics has been an extraordinarily successful strategy for understanding dynamical systems in physics and other sciences. Similar mathematical modeling should also, therefore, be useful for understanding the mind.

The HKB Model

The dynamical strategy is best appreciated via example. One oft-cited example, included by Markman and Dietrich, is the Haken-Kelso-Bunz (HKB) model of bimanual coordination[9,10]. The HKB model rests upon a very simple and robust experimental result. Subjects asked to wag their index fingers left-to-right can produce only two stable patterns of bimanual coordination. In one, called *in-phase* or *relative phase 0*, the fingers approach one another at the mid-line of the body; in the other, called *out-of-phase* or *relative phase .5*, the fingers move simultaneously to the left, then to the right, like the windshield wipers on many cars. As subjects were asked to wag their fingers out-of-phase at gradually increasing rates, they eventually were unable to do so, and slipped into in-phase wagging. The HKB model for this behavior applies a vector field to the relative phase of the fingers. At slower rates, this field has two attractors, one at relative phase .5, another at relative phase 0. This means that any finger wagging will tend to be stable only when one of these values for relative phase is maintained. But as the rate increases (and passes what HKB call the *critical point*), the attractor at .5 disappears, so the only remaining attractor is at relative phase 0. So finger-wagging at higher rates will tend to be stable only when it is in-phase.

The mathematical model of this behavior, the actual HKB model, is the following function
$V = -a\cos\phi - b\cos 2\phi$,
where ϕ is the relative phase and the ratio b/a is inversely related to rate. This function, it is worth noting, is the simplest that will accommodate all the data. The HKB model is an example of a general strategy for describing constraints on behavior. First, observe patterns of macroscopic behavior; then seek collective variables (like relative phase) and control parameters (like rate) that govern the behavior; finally, search for the simplest mathematical function that accounts for the behavior. Because, HKB argue, complex systems (like the one involving the muscles, portions of the central nervous system, ears, and metronome in the finger-wagging task) have a tendency to behave like much simpler systems, one will often be able to model these systems in terms of extremely simple functions, with only a few easily observable parameters, which reflect the dynamic behavior. So it might be possible to develop similar models for many complex behaviors using this method. Indeed, the HKB model itself can be applied to many facets of limb coordination. Furthermore, the model makes very specific predictions. First, it predicts that as rates increase, experimental subjects will be unable to maintain out-of-phase performance. Second, even at slow rates only relative phase of 0 and .5 will be stable. Third, the behavior should exhibit *critical fluctuations*: as the rate approaches the critical value, attempts to maintain out-of-phase performance will result in erratic fluctuations of relative phase. Fourth, the behavior should exhibit critical slowing down: at rates near the critical value, disruptions from out-of-phase performance should take longer to correct than at slower rates.

Dynamical (Mis)representation

Markman and Dietrich[1] neither specify nor explicitly consider what parts of limb-swinging animals are thought to be representations according to the explanation provided by the HKB model; nor do they suggest what such representations might be representations of. So it is unclear what they have in mind when they suggest that dynamical models such as HKB ascribe non-discrete and non-enduring representations to the agents whose behavior they describe. The fact is, though, that there simply is no likely candidate in the system as described by the HKB model that might serve as an information-bearing state of the animal that mediates between it and the world. The control parameter in the HKB model, the ratio b/a, is not a candidate: neither b nor a map in an obvious way onto aspects of the organism or its environment. The only other possibility, ϕ, is a measure of the relationship between the positions of the limbs themselves. Why, then, might Markman and Dietrich think that dynamical models posit internal, animal-side representations of the environment.

The most likely reason is that Markman and Dietrich[1,2] presume that any entity that does something in the world must be doing it in terms of internal representations of aspects of the environment. But this in fact is exactly what is at issue in the disagreement between proponents of dynamical systems explanations and their more classically minded colleagues[6,7]. And it is far from obvious that the lawful relation between an animal's behavior and some part of its environment requires that the animal use an internal analogue of that part of its environment to guide its behavior. Indeed, to say that the HKB model necessarily entails or implies that there are representations in animals as they move their limbs is akin to saying that the fact that the gravitational attraction between any two medium-sized objects implies that they must be representing one another.

Dynamical Explanation

Just as those who use mechanics to describe the gravitational attraction between two bodies do not assume that they represent one another—or to parallel the case of a explanation of an organism in its environment more closely, that just one body represents the other—dynamically-minded cognitive scientists do not assume that an animal must represent the world to interact with it. Instead, they think of the animal and the relevant parts of the environment as together comprising a single, coupled system. An animal is coupled with its environment when there is a history of continuous, recurrent interactions between them that leads to structural congruence between them. When coupled in this way, the animal is constantly changing and being changed by the environment. In dynamical models, coupling is represented in one of two ways: in terms of collective variables or with interacting differential equations.

The former of these can be seen in the case of the HKB model: the variable □ is a collective variable that maps the relative phase of the coordinated limbs. By representing the positions of both limbs with one variable, one directly links their changes and rates of change in the model. The second way that one might model coupling is by having two separate differential equations, where each equation has a parameter that is a variable in the other equation. That is, we might explain the behavior of the agent in its environment over time as coupled dynamical systems, using something like the following equations, from Beer[3,11]:

$$\dot{x}_{\mathrm{A}} = \mathrm{A}(x_{\mathrm{A}}; S(x_{\mathrm{E}}))$$

$$\dot{x}_{\mathrm{E}} = \mathrm{E}(x_{\mathrm{E}}; M(x_{\mathrm{A}})),$$

where A and E are continuous-time dynamical systems, modeling the organism and its environment, respectively, and $S(x_E)$ and $M(x_A)$ are coupling functions from environmental variables to organismic parameters and from organismic variables to environmental parameters, respectively. It is only for convenience (and from habit) that we think of the organism and environment as separate; in fact, they are best thought of as comprising just one system, U. Rather than describing the way external (and internal) factors cause changes in the organism's behavior, such a model would explain the way U, the system as a whole, unfolds over time.

In neither of these two cases is it necessary to posit internal mediators for aspects of the environment; nor is it necessary to posit schemas for actions. The animal doesn't need representations to put it in contact with the environment because the animal and environment are not separate to begin with. And despite Markman and Dietrich's claims[1,2], many dynamically-oriented cognitive scientists simply do not posit such mediators; instead, they explain behavior in terms of interaction with the environment itself.

Conclusion

Markman and Dietrich[1] claim that dynamical systems modeling will ultimately be unable to account for so-called "higher cognition" (abstract reasoning and the like).

They say the same of perceptual symbol systems, situated action, and embodied cognition, the other "alternatives" to the classical view they discuss. They argue, therefore, that the insights of these alternatives ought to be assimilated (i.e., buried) into the classical worldview. But, at least in the case of dynamical modeling, such absorption will not be as easy as positing a supplemental type of representation. This is the case because the dynamical modeling is in many ways diametrically opposed to the classical, representationalist picture. That dynamicists do not posit representations to explain behavior is just one manifestation of a deeper, more general disagreement.

Furthermore, how much dynamical systems and the other alternatives will be able to explain is surely an empirical matter, one that will have to wait for the results of years of experimentation and modeling. The alternatives that Markman and Dietrich hope to assimilate are much newer than the classical picture that they would like to amend. Although the alternatives may ultimately fail to provide the sort of explanations of cognition (higher and otherwise) that we want, they ought to be given time to fail on their own.

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