-EDITORIAL-

Dynamic Systems and Paradise Regained,
or
How to avoid being a calculator

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1. Computation and human specialness.

The new kid on the block in cognitive science these days is *dynamic systems*. This way of thinking about the mind is, as usual, radically opposed to computationalism -- the hypothesis that thinking is computing. The use of dynamic systems is just the latest in a series of attempts, from Searle's Chinese Room Argument, through the weirdnesses of postmodernism, to overthrown computationalism, which as we all know is a perfectly nice hypothesis about the mind that never hurt anyone.

Well, actually that's not true. I suspect that everyone is out gunning for computationalism precisely *because* it has hurt several people and stepped on several toes. As I have mentioned before in these pages, I believe that the real problem with the general acceptance of computationalism is its perceived association with what I call "The Mechanistic Forces of Darkness." No one wants to be a computer; no one wants to be told that their mother was a computer. I think part of this fear is that most people think of computers as things to type letters on, things for playing games, and things for email. Computers are tools. Since humans aren’t merely word processors, Gameboys, nor emailers -- since humans aren’t tools -- it follows that humans aren’t computers. But beyond this mistaken focus on computers as tools, there lies another, deeper dissatisfaction, which focuses on computation itself. This is the feeling that computation just seems like the wrong way to think about the wonderful complexity that is the human mind. Most anticomputationalists do not want a theory of the human mind that in their eyes does not do justice to the marvelousness, the uniqueness, the specialness of human beings. They instead want a theory that justifies their belief in our specialness.

We all know that the belief that we are special has been damnably hard to hang on to. First, Copernicus and Galileo kicked us out of the center of the universe. Then Kepler squashed the perfect circles of Earth's and the other planets' orbits around the sun into ugly ellipses. Then Darwin said that we were a kind of ape. Now along come the cognitive scientists claiming that we share important similarities with fancy calculators. No one wants to hear this. We want a theory of the mind that enshrines us as the pinnacle of creation, that explains why humans are special, rather than why we aren’t . . . why we are unpredictable and wonderful, rather than why we aren’t. Which brings us back to dynamic systems.

Using dynamic systems to explain human thinking allows us to continue thinking of ourselves as special. Indeed it enhances our ability to think of ourselves as special. And this now brings me to today's topic: the book *Connectionism and the Philosophy of Psychology* by Terence Horgan and John Tienson. I want to discuss their portrayal of computational cognitive science as well as their positive program for using dynamic systems to understand the mind. Their positions and arguments are typical of the genre, so understanding the real force of these arguments will shed light on the dynamic systems approach in general.

Before I discuss Horgan and Tienson's book, I need to, first, rehearse computationalism, and then explain what the dynamical systems approach to cognition is all about.

2. The computational hypothesis.

The computational hypothesis is a version of functionalism where all the functions are computable. It claims that cognition is the execution of Turing-computable functions defined over various kinds of representational entities. There is a long and rather complicated story about how computationalism works, which I will spare you here (but see Dietrich, 1990). All I need for present purposes so to say what computationalism is *not:*

> Computationalism is only a foundational hypothesis. Computationalism does not get specific about which particular functions cognition is. Indeed we aren't sure which functions cognition is. Therefore, computationalism does *not* tell us what models to build, nor which experiments to run. All computationalism gives us is a framework within which to work.
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> Computationalism (as with computation on garden variety computers) is *not* committed to mental representations of any particular variety. Rather, it is compatible with lots of different kinds of representations from numerical quantities to propositional nodes in a semantic network (for more on this see Markman and Dietrich, 1998).

I'll need to refer to these two properties later on, so call the first the "Foundation Property" and the second the "Multiple Representations Property."

In sum, assuming computationalism leaves all the hard work left to do. Which means it is not really a theory. Computationalism is a *theory schema*. We still need to roll up our sleeves and get down to the difficult business of developing a theory of mind. Computationalism does tell us what this theory will look like -- but only broadly.

3. Dynamic systems defined.

What are dynamic systems, and what is their role in cognitive science? My colleague Art Markman and I have recently developed nice, succinct answers to these questions, which I excerpt here (see Dietrich and Markman, 1999). I begin with van Gelder's (1998) answer to the second of the above two questions. Van Gelder claims that cognitive systems (e.g., humans) *are* dynamical systems, and that the study of cognition ought to be couched in the language of dynamical systems. He calls this the *dynamical hypothesis.* Note, the dynamical hypothesis, like the representational-computational hypothesis with which it contrasts, is really two claims: an ontological claim about the nature of cognitive systems, and an epistemological claim about the science of cognitive systems, i.e., about how best to study cognitive systems. (For more on dynamical systems, see Horgan and Tienson (1996), Port and van Gelder (1995), Thelen and Smith (1994), and van Gelder (1995).)

What's a dynamic system? I begin with the notion of a *system*. A system is any collection of physical objects and properties that interact with each other. Any system whatsoever can be described by a set of interdependent variables. What distinguishes a dynamical system from a representational-computational system is what these variables range over. In a representational-computational system, the variables -- the data structures -- can range over anything: numbers, people, bank balances, cake ingredients, etc. But in a dynamical system, the variables range over numbers, and only numbers. These numbers denote *quantities* that measure certain time-dependent properties of the physical objects which make up the system in question. Of central importance in any description of a dynamical system is the notion of the *rate of change* of its relevant quantities. This is what it means to be interested only in time-dependent properties, and why all descriptions of dynamical systems involve differential equations of one sort or another. Examples of time-dependent properties of a system are temperature, velocity, chemical density, firing rate, and recovery rate. All of the measured quantities of a given system considered together define what is called a *state-space* (sometimes called a phase space). At any given time, the system in question is completely defined by its position in this abstract space. The behavior of the system over time is, from the dynamic systems' perspective, just its path through this space. Differential equations describe this path.

An important assumption of dynamic systems is that the rates of change of the relevant quantities are continuous (in the mathematical sense) and not discrete. Rates of change need not actually be continuous, but the dynamical hypothesis takes it as a given that the best way to view such rates of change is as continuous processes. Whether or not a given dynamical system is in fact made up of continuously varying quantities, it is almost always best to describe and theorize about it using the mathematical language of continuous change: differential equations. The way to see this is to assume that the system under scrutiny is composed of such fine-grained, minute constituents that for all practical purposes (such as explanation) it is easiest to view property change as a continuous process. For example, it is implausible that the processes that govern neural firing patterns are genuinely continuous (e.g., sodium and potassium ions are discrete entities), but it may be plausible to assume that such processes are best *explained* as continuous processes.

The assumption about continuity and its utility in explaining cognition puts the dynamical hypothesis squarely at odds with the representational-computational hypothesis, for the representational-computational hypothesis holds that cognition is (or is best described as) the execution of algorithms over discrete symbolic representations.

Another important property of dynamical systems is their reliance on tight feedback loops to achieve equilibrium with their environment. Such equilibration is often called "self-organization." Proponents of the dynamic systems approach frequently point to Watt's steam engine governor as an example of such equilibration (e.g., Bechtel, 1998; van Gelder, 1995). The steam engine governor is a device designed to keep steam engines from exploding. The governor, consisting of two balls mounted on arms attached to, and spinning around, a spindle, is fixed to a steam pipe. As the engine runs faster, the spindle spins faster causing the balls on the either side of it to rise due to centrifugal force. The rising balls cause a valve to close because of mechanical connections between the arms and the valve. The restricted valve decreases the amount of steam flowing, and hence the pressure, which causes the engine to slow down, which in turn causes the governor to spin more slowly. The slower spin causes the balls on the arms to drop, opening the valve, which causes more steam to flow, which increases the pressure, which causes the engine to accelerate, etc. In this way, a relatively constant pressure inside the engine can be maintained. This equilibration can be described as a path in a dynamic systems phase space, usually as a cycle around an attractor. The Watt governor is touted as an analogy for cognitive processing. I give a much better analogy in the next section.

The final, and crucial property of dynamic systems is that they give rise to *emergent behavior*. A dissertation should be written on the topic of emergent behavior, but briefly, what the dynamic systems crowd (and others) are hoping will happen is that given the right differential equations, meanderings through various phase spaces, and subtle, fluidic interactions, cognition will somehow emerge in all its unprogrammable glory. Such emergent cognition (and concomitant behavior) is the proverbial free lunch. To the dynamic systems crowd, the absolutely crucial aspect of emergent cognition, or emergent anything, for that matter, is that *the emergent phenomenon is not reducible to the underlying substrate out of which it emerges.* Notice how good this is if your goal is to keep human cognition special and unsullied by nasty machines.

Interestingly, dynamical systems have found a natural home in cognitive science, describing certain low level sensorimotor processes, as well as learning how to control our sensorimotor actions like walking, throwing, etc. But dynamic systems are woefully inadequate at explaining any aspect of higher cognition. Yet, as with any new kid on the block, the dynamic systems types want it all -- from low level sensorimotor control to all of higher cognition, including language, planning, problem solving, and creativity.
In trying to get it all, the dynamic systems types misrepresent the computational hypothesis, and pretend to have a robust positive theory of higher cognition when all they really have is what we all have: the hope that something will turn up, to quote Wilkins Micawber. Horgan and Tienson's book is a paradigmatic case in point.

4. The aquarium of colored oils model of cognition.

Horgan and Tienson reject classical cognitive science which they define as committed to exceptionless rule-governed symbol manipulation. From this notion, they suggest that classical cognitive science won't work, and then from this they infer that their dynamic systems approach is the way to go.

First of all, they assume without argument that if classical cognitive science is not the right methodology that then the dynamic systems methodology must be the right one. This is a false dichotomy. There are problems, as we all painfully know, with classical cognitive science. We have failed to explain the plasticity of human intelligence, we have failed to tell an integrative story about cognitive and sensorimotor behavior, and our explanations of human development and maturation typically do not characterize the trajectory of development, to name just three problems. But what about a methodology that merged an embodied cognition approach for lower level sensorimotor skills with one that used structured representations of various types for higher cognitive processes? Or what about an approach that tried to explain the nature structured representations using some sort of connectionist approach (see Hummel and Holyoak (1997)). There are, in general, several different kinds of such *hybrid approaches* that we might use to great advantage. Such hybrid methodologies are an alternative Horgan and Tienson don't even consider. We do not have to leap to the dynamics systems as the only strategy just because we have encountered problems in the classical paradigm. (Although, to be fair, Horgan and Tienson's positive view is something of a hybrid approach: they want to marry structured representations -- indeed, a language of thought -- with dynamic systems. But how this is to be accomplished is left unexplained.)

Secondly, their definition of classical cognitive science is a straw man. I don't know a single classical cognitive scientist who believes that exceptionless rule-governed symbol manipulation explains any part of cognition. There is an entire subfield of classical cognitive science devoted to understanding how intelligence uses exceptions. All of this falls under the rubric of *defeasible reasoning*. In general, Horgan and Tiensen seem to completely ignore all the work going on in AI and the rest of cognitive science devoted to understanding human plasticity. They ignore everything from defeasible reasoning to models of conceptual change in analogical reasoning to case-based reasoning.

It is clear from their discussion that Horgan and Tiensen ignore both the Foundation Property and the Multiple Representations Property of computationalism discussed above. They want to insist that classical cognitive science is a theory committed to specific kinds of functions and specific kinds of representations -- roughly, functions defined over propositional representations. But again, computationalism is committed to no such thing. (By the way, they also make the commonest mistake of referring to the computational hypothesis as a "metaphor," thus making their misdefinition of it seem ok -- after all, metaphors don't have strict definitions and are meant to be loosely interpreted.)

Now on to their positive program. Horgan and Tienson want to replace classical cognitive science with some sort of dynamic systems. But they have no genuine proposal. They appeal to connectionism, but all connectionist work to date is completely computational. They also appeal to some notion of "cognitive force" right on page one. It is unclear what a cognitive force is. The idea of competing cognitive forces allows them to highlight a fact about cognitive systems, namely their defeasible causal tendencies, which can described by ceteris paribus laws (like the heuristic rules in expert systems). I have just told you everything there is to know about their notion of "cognitive force." They place a lot of weight on this notion, but it is obviously just a thin metaphor, an IOU they hope to be able to cash later. This is pretty much all there is to their positive program. There is no robust theory or even a theory schema on offer.

The crucial thing to note about "cognitive force" is that it is vague enough and suggestive enough to let Horgan and Tienson wax poetical about human specialness. They say things like "... human cognition is too rich to be simulated by computer programs" (p. 1), and "...human (and other natural) cognition is too subtle and sophisticated to conform to programmable representational rules" (p. 145). How on earth could they know this? They are in the grip of the a view of human cognition that seeks to explain why we are special, rather than why we are just fancy calculators.

There are today very robust computer models of lots of aspects of cognition. But there is not a single artifactual working model of any aspect of cognition from the dynamic systems camp. I suspect this is no accident. How would you build one? If Horgan and Tienson were to ever build an intelligent artifact, what would it look like? I imagine it would be something like an aquarium filled with different colored oils of different weights all swirling about and intermingling with each other and giving rise to beautiful colored, fractal paisleys. And out of this beautiful, chaotic interaction would emerge wonderful cognition. Apparently, according to Horgan and Tienson, we are wellmodeled by such aquariums. But of course what would really happen is that all those colors would run together and produce a black sludge, out of which would emerge nothing.

Cognitive science is part of that dark legion which has been kicking us out of paradise ever since Copernicus. The use of dynamic systems is just a smoke screen designed to make it seem like explanations of cognition are in the offing (via emergence), when all the while fortifications protecting our wonderfulness, our specialness, are being erected.*

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