

**-EDITORIAL-**

**A Counterexample to  
All Future Dynamic Systems Theories  
of Cognition.**

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**1. A perhaps plausible but false proposition: Toward a book of counterexamples.**

Years ago, when I was an undergraduate math major at the University of Wyoming, I came across an interesting book in our library. It was a book of counterexamples to propositions in real analysis (the mathematics of the real numbers). Mathematicians work more or less like the rest of us. They consider propositions. If one seems to them to be plausibly true, then they set about to prove it, to establish the proposition as a theorem. Instead of setting out to prove propositions, the psychologists, neuroscientists, and other empirical types among us, set out to show that a proposition is supported by the data, and that it is the best such proposition so supported. The philosophers among us, when they are not causing trouble by arguing that AI is a dead end or that cognitive science can get along without representations, work pretty much like the mathematicians: we set out to prove certain propositions true on the basis of logic, first principles, plausible assumptions, and others' data. But, back to the book of real analysis counterexamples. If some mathematician happened to think that some proposition about continuity, say, was plausibly true, he or she would then set out to prove it. If the proposition was in fact not a theorem, then a lot of precious time would be wasted trying to prove it. Wouldn't it be great to have a book that listed plausibly true propositions that were in fact not true, and listed with each such proposition a counterexample to it? Of course it would.

Mathematics is such a robust field, that the book I found is only useful for students. But cognitive science is not such a robust field (we have no over-arching, deep theory like physicists, chemists, and biologists do). So a book of counterexamples in cognitive science would be useful not just to our students, but to mature, working scientists getting grants and presenting keynote addresses.

We cognitive scientists don't have such a book, but I offer to begin one. Here is the first counterexample to a proposition some seem to regard as plausible but which in fact is false.

*The Proposition.*

Cognitive systems are dynamical systems, and are best understood as such (see, e.g., Port and van Gelder, 1995, and van Gelder, 1998).

What is a dynamical system? It is any system characterizable by a numerical phase space and rules of evolution (differential equations, typically) specifying paths in this phase space. Dynamical systems are time-dependent: they change continuously in time. They are also *coupled*, which is to say that such systems are complexes of mutually determining numerical quantities (this property will be important later).

So, then, the proposition is that a cognitive system is situated in time and that mind, nervous system, body, and environment (described at detailed, numerical levels) all continuously change and evolve, and simultaneously mutually determine one another as described by a set of differential equations (see Port and van Gelder, 1995).

This proposition does seem plausible, doesn't it? To quote Port and van Gelder: "Natural cognitive systems are enormously subtle and complex entities in constant interaction with their environments." What could be more plausible than that such systems are dynamical?

But, alas, the proposition is false. Here is a counterexample to it and hence to all dynamic systems theories of cognitive systems.

Imagine two, small meteors screaming toward Earth. They are close together, and as they enter the Earth's atmosphere, they remain close together. They slam into Earth. One into a farmer's fallow field, and the other into the river next to the field. Both meteorites leave sizable, but not huge, craters -- the one in the field and the other in the river.

As so often happens in such cases, two space aliens in their invisible space ship are near by. They are dynamic systems types themselves (just because they have advanced technology like warp drive and the like doesn't mean they can't be benighted cognitive scientists). Our space aliens' theory of cognition is based solely on complex, interacting "equations of motion". These are differential equations that lay out the way a cognitive system evolves or changes from one state to the next. They regard the impact of the meteorites as an excellent opportunity to observe the intelligent life on planet Earth. So, hovering in their invisible ship, they sit back and watch. Here is what they observe.

The river rapidly forms a lake where the meteorite hit. (The space aliens of course don't know that it is a river -- they don't have rivers on their home planet. Indeed, their planet is waterless. They just think of the river as a large, flowing entity. They got the concept "flowing" from studying plasmas.) Now, all rivers carry sediment in their water. The amount of sediment carried is a direct function of the speed of the water (the total, complete function of the amount of sediment a river can carry has to take into account what the river bed is made of, e.g., granite or sandstone or loam, and parameters like the temperature of the water). Since water flows through a lake less swiftly than it does through a river (due to the fact that the same, fixed amount of energy is spread out over a larger volume), the water in the lake formed by the meteorite slows down relative to the water flowing in the river. As the water slows down, it drops some of its sediment. This sediment begins to fill up the lake. The space aliens note this in their log book: "The large, flowing entity is filling up the crater that formed in its midst" (i.e., what we would call a lake). The space aliens, being very smart but benighted, write down the differential equations which describe all the river's behavior, including the river's filling in of the lake with sediment.

The space aliens also observe a small, solid entity: the farmer who farms the field. (The space aliens of course don't know that it is a farmer -- they don't have farmers on their home

planet. Indeed, their planet is farmerless. They just think of the farmer as a small, solid entity.) They observe the solid entity drive up in what we would call a tractor. The entity walks around the crater, which of course is surrounded by all the earth blown out of the crater as the meteor plowed into the ground there. The entity gets back into the thing we could call a tractor and proceeds to push all the earth surrounding the crater back into the crater, thereby filling it in. The space aliens note this in their log book: "The small, solid entity is filling up the crater that formed in its area." The space aliens, being very smart, write down the differential equations which describe all the farmer's behavior, including driving the tractor and the pushing the earth around.

Then the aliens leave. They report to the chief alien in charge of the Bureau of Understanding Strange New Life Forms. Their report says that there are at least two types of cognitive agents on planet Earth (of course, they don't call it planet Earth): large, flowing entities and small, solid entities. Their differential equations describe and predict all the relevant crater filling in behavior. The chief alien is very pleased. He treats his colleagues to a round of malted battery acid (of course, they don't call it malted battery acid).

Something has gone terribly wrong here. We know, but the aliens don't, that rivers are not cognitive beings. Humans are. Because they limit themselves to differential equations describing state changes only, the space aliens cannot distinguish between cognitive humans and noncognitive rivers. It won't do to say that if the space aliens had just observed a bit longer they would have seen the differences between humans and rivers. What differences would they have seen? From the aliens perspective, both the river and the farmer engage in similar behaviors described by differential equations, and according to their theory of cognition, cognitive systems are things describable by differential equations. The space aliens would never see any interesting differences between humans and rivers.

One might object that the aliens would see huge differences: humans but not rivers engage in, e.g., linguistic behavior. But our space aliens can't see our linguistic behavior. Indeed, the space aliens would miss what is most distinctive about our linguistic behavior -- the communication of abstract ideas and the like -- because all they could do would be to describe at a numerical level the sound waves and their continuous effects on what we would call the

listeners. They could go on to describe other downstream brain changes that also continuously vary with the sound waves, and so on to "output", but that is not a theory that explains what is interesting about linguistic behavior. By their own admission, the space aliens -- and all dynamic systems types -- will not explain communication as the exchange of *ideas* and the like, because on all dynamic systems models there are no ideas to communicate; there are only numbers in the void. Basically, on the dynamic systems approach, everything cognitive systems do gets relegated to a complex tropism, not unlike a plant turning to face the sun.

We need to be a little careful here characterizing the space aliens' reasoning. They are benighted, but not stupid: they are not guilty of the fallacy of affirming the consequent (nor the fallacy of the undistributed middle). They don't reason as follows:

All cognitive systems are describable by differential equations.

The flowing entity and the solid entity are describable by differential equations.

Hence, the flowing entity and the solid entity are cognitive systems.

Rather, they reason as follows:

All cognitive systems are describable by differential equations, *and vice versa*.

The flowing entity and the solid entity are describable by differential equations.

Hence, the flowing entity and the solid entity are cognitive systems.

Why on Earth (or on their home world, whose name is unpronounceable) would they accept the first premise? Why precisely because they are dynamic systems types.

Consider an analogy. Suppose there were another species of space aliens from another world. These second space aliens think that all living things are made up of atoms. We humans also believe this. But whereas we humans also have theories about living things that crucially use higher-order structures like molecules, cell organelles, cells, tissues, and organs, this second species of space aliens *only thinks in terms of atoms*. Consequently, rocks, doorknobs, trees, and crickets all look alike to them: all of these are made up of atoms. This second group of space aliens are incapable of seeing life; they are incapable of distinguishing life from nonlife

because their preferred theory of life is too low-level. This is what is wrong with our first group of space aliens -- the dynamic systems aliens. Their preferred theory of cognition is too low-level. To distinguish one thing from another, you need a theory couched at the right level.

First conclusion: the dynamic systems approach to cognition is completely unable to distinguish between those systems that are cognitive and those that are not. It's hard to do the science of something if you can't distinguish that something from all the other somethings in the universe. (Ironically, since the dynamic systems types cannot distinguish cognitive systems from noncognitive ones, they have to rely on us classical cognitive scientists, who use discrete representations in our theories, to draw the distinction for them: they have to rely on us to find the cognitive systems in the world.)

Second conclusion: differential equations are the wrong description language for describing and theorizing about cognition. It's too low level. The right description language, as we all know, is computation and representation. Hence, the proposition with which we started is false, and dynamic systems are not a good way to understand cognitive systems, and hence cognitive systems aren't dynamic systems. (They are perhaps a good way to understand sensorimotor behaviors, see Markman and Dietrich, 2000.)

End of Counterexample.

## **2. Intelligence, cognition, and going beyond the information given.**

All well and good, you might say, but how do classical information processing types distinguish between cognitive systems and other things in the universe? Good question. And we information processing types have a good answer. The best way to draw this distinction is to use the notion of *going beyond the information given* (I borrowed this idea from Bruner's classic paper, "Going beyond the information given," 1957).

All cognitive systems can go beyond the information given. This is because all cognitive systems are *intelligent* to some degree (that is part of what makes them cognitive), and going beyond the information given is a good definition of intelligence. (I have discussed this definition previously in these pages; see Dietrich, 1996. I refer the reader there for the

arguments). To paraphrase F. C. Bartlett:

whenever any system interprets evidence from any source, and its interpretation contains characteristics that cannot be referred wholly to direct sensory observation or perception, then that system is intelligent. <sup>1</sup>

Cognitive systems, are more than just intelligent, of course. Intuitively, a cognitive system responds satisfactorily to its dynamic environment. One usually cashes out "satisfactorily" in terms of maintaining the integrity of the system, "surviving," in other words. For example, rocks respond to the dynamics of their environment, but mostly by eroding, a process interesting to chemists and geologists, not to cognitive scientists. So this intuition excludes rocks, which seems correct. But the intuition is too broad because it equates being cognitive with being alive. All living things respond to a dynamic environment while maintaining their system-integrity, but we don't want to count as cognitive all living things -- at least I don't. Pine trees are not cognitive systems. Not even all animals are cognitive systems. Paramecia aren't cognitive. So, our intuition is too broad. (There is the interesting question of whether the intuition is too narrow, too: are expert systems and other AI systems cognitive even though they are unable to survive and satisfactorily respond to their environment? No. I think the correct answer here is to say that some AI systems are *intelligent without being cognitive*. AI systems can go beyond the information given, but they are not cognitive. Indeed, AI showed us that dividing these two notions was possible. AI systems solve problems, learn, and plan, etc. without maintaining themselves in their environment because the problems they solve have nothing to do with their survival. For example, most AI systems do not secure their own electricity, nor do they perform hardware or software maintenance on themselves. So, I don't think AI systems are cognitive systems, but I do think some of them are intelligent. Which just shows that there is more to being cognitive than being intelligent.)

The best definition of a cognitive system is this:

A cognitive system is a system that in responding satisfactorily to conditions in its dynamic environment, uses representations to go beyond the information given. In short, cognitive systems are intelligent systems that survive.

This definition doesn't beg the question against the dynamic systems types because dynamic systems do have representations (see Bechtel, 1998, and Markman and Dietrich, 2000).

Now the question is, can we distinguish between a dynamic system with representations that responds to its environment and a cognitive system. The answer is "Yes, we can." The dynamic system cannot go beyond the information given. In fact, a dynamic system cannot go beyond the information given, *by definition*. Why? Because of the much-touted notion that cognitive systems are *coupled* to their environments, each other, and -- mostly importantly, what they represent. As noted above, coupling is a crucial notion in defining dynamic systems. But coupling ties a dynamic system so closely to the information coming into it that the system *cannot* go beyond the information given at all. Coupling is the antithesis of going beyond the information given. Coupling is flowing with and being ultra-sensitive to the information given. Hence, a dynamic system can't be a cognitive system (of course, a cognitive system can have dynamic systems as subsystems, like sensorimotor systems; see Markman and Dietrich, 2000).

Only a cognitive system can go beyond the information given. Dynamic systems can't because they are coupled to their incoming information. It is in *abstracting* from its dynamic subsystems that cognitive systems obtain information in discretized form which they can then use to make inferences, plan, problem-solve, and find higher-order patterns. So dynamic systems, while important to cognitive systems cannot be responsible for the cognition in cognitive systems -- they are not responsible for the intelligent thoughts in a cognitive system. In the vernacular, we wouldn't say that dynamic systems don't go beyond the information given -- we'd say that dynamic systems are stupid. Which is to say that smart systems can have stupid subsystems. Indeed, they probably have to have them, and this is probably a deep truth.

So, the counterexample shows that researchers enamoured of dynamic systems are going to be unable to distinguish cognitive systems from noncognitive systems, hence that cognitive systems are not dynamical systems. And, it shows why this is true: dynamical systems are too low-level. Classical, information processing cognitive scientists can draw this distinction: they look for those systems that go beyond the information given, something the dynamic systems researchers cannot look for because they can't see them. Going beyond the



information given is a theoretical notion that makes sense to, and is useful to, information processing cognitive scientists *but not to dynamic systems researchers* because only we enlightened researchers have the required concepts with which to understand this notion: discrete, time-independent representations and processes like inference. If you think the world is one big, coupled, continuously varying soup, then you are going to have a hard time seeing anything move beyond the information given, and hence you are going to have a hard time doing cognitive science. It would be much better if you worked on warp drive.

**Endnotes.**

1. Here's the actual quotation from Bartlett. "... whenever anybody interprets evidence from any source, and his interpretation contains characteristics that cannot be referred wholly to direct sensory observation or perception, this person thinks" (Bartlett, 1951).

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