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EDITORIAL

The maximum entropy principle: A critical discussion

An Editorial Comment

Ken Caldeira

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There is a thin line between quasi-religious belief and a yet-to-be-proven scientific hypothesis, and that thin but important line is the empirical test. Before being proven, a scientific hypothesis is an insight, a hunch, and perhaps even a belief, but what separates it from religion is that it is testable (at least, in principle).

The claim that complex systems evolve to maximize entropy has been around for some time, as noted by Kleidon (2004). But anything that does not grow to infinity is maximized under some constraint. Volk (2007) provides examples of systems that appear not to evolve to a state of maximum entropy, but Kleidon (2007) rejects these examples claiming that Volk has not properly represented the constraints on these systems.

For example, Kleidon (2007) rejects Volk's (2007) example of a hypothetical tree with superfluous entropy-producing black leaves by saying that this is a pseudo-counter-example because, as Volk (2007) agrees, such a tree would not satisfy constraints imposed by Darwinian selection.

Let us say, paralleling the discussion of Kleidon (2007) and Volk (2007) appearing in this issue, that we have a system with sunlight falling on a ball in space. If the ball were mirrored, the sunlight would be reflected as low-entropy sunlight. If the ball were black, the sunlight would be absorbed and radiated as high-entropy heat. So, the maximum entropy principal might be applied to conclude that all balls in space must be black. So, is a grey ball in space a refutation of the maximum entropy principle? No, advocates say, if constraints on the system are properly understood, you will see that this ball became as black as it could become; it became black "to the extent possible".

Kleidon (2007) notes that he is claiming that the system evolves to maximize entropy production "to the extent possible." So, any state of the system that generates more entropy (our black orb in space) is deemed "impossible," and the people who present that state as a counter-example are presenting an "impossible" state of the system (it is like those science

K. Caldeira (✉)
Department of Global Ecology, Carnegie Institution of Washington, 260 Panama Street, Stanford, CA 94305-4150, USA
e-mail: kcaldeira@globalecology.stanford.edu

fiction stories in which we cannot go back in time to kill our grandfathers, because of some barrier to creating logically impossible states).

So, how does the maximum entropy principle differ from claims that systems maximize their temperature, their mass, their spatial extent, their *anything* "to the extent possible." (Or, for that matter, perhaps they minimize those same quantities "to the extent possible.") If a counter-example were given in which the system in question were warmer or colder, more or less massive, larger or smaller, the response could always be made that the system was not warmer, more massive, and more voluminous because there were other constraints on the system that prevented it from being so.

And what are these other constraints? They are the everyday laws of physics that from which we could predict system behavior without any reference to a maximum entropy principle.

Either the maximum entropy principle is an unrecognized tautology, true by the very logic of our world and language, such that there could be no conceivable counter-example, no possible test that can fail, or there is an empirical test for the maximum entropy principle. (We recognize that 2+2=4, but can we construct an empirical test that could possibly falsify this statement?)

Perhaps the maximum entropy principle is not a hypothesis about the world, but is true tautologically: the system is the way it is because of the laws of physics and there is no way it could generate any more entropy without violating the laws of physics. I'll sign on to this, but it isn't very useful.

Kleidon's (2004) tries to subject the maximum entropy principle to an empirical test using a climate model. In this model, there are adjustable parameters. Kleidon finds that these parameters must be "adjusted" close to real world values to maximize entropy production in the model "to the extent possible."

This is a view of the world, in which there are in some sense adjustable parameters in the real world, and that these parameters "adjust themselves" in the real world to maximize some global property of the system.

Biologic systems, through the process of selection on heritable variation, appear to have the capacity to at least approximately optimize systems. There are in some sense parameters of the system being optimized through time – an elephant's neck differs from a giraffe's neck in part because they are solving different ecological problems. But each individual neck develops at the interface between genetics and environment, following the laws of physics. No individual neck has free parameters.

With sometimes brittle bones encasing a delicate spinal cord, our own mammalian necks can feel dangerously delicate, far from the optimal necks we might design ourselves. Necks of elephants or giraffes or humans seem optimal only in retrospective abstraction from a series of particulars – "Given the constraints they were under, that's the best they could do with those seven bones." But in what meaningful sense is my own fragile neck optimal? It's the one I have got, and it came without free parameters.

The maximum entropy principle depends on being able to partition the real world of particulars into constraints and adjustable parameters. We then adjust parameters to maximize entropy production subject to those constraints and, *voilá*, we describe the real world.

However, every adjustable parameter in every model I have ever created was adjustable only because of my ignorance of the real world and not because of any fundamental adjustability in the world. I believe the partitioning of the world into constraint and adjustable parameter to be a product of our minds and not a property of the world itself. "Adjustable parameter" is a way of saying that we are uncertain what value to apply to that

parameter. Were we given as complete a description of the universe as possible, I think we would find the parameter to be highly constrained.

If all is constraint and nothing is adjustable parameter, then the universe trivially maximizes and minimizes everything simultaneously "to the extent possible."

Indeed, I suspect the universe is all constraint and no adjustable parameter, in which case the maximum entropy principle may be true, but trivially so.

References

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