not to question the sufficiency of the Newtonian description: *Life itself cannot exist in a wholly deterministic world!*" (pp. 144–145). Actually, I don't question sufficiency at all, but I do hold to necessity. The Newtonian paradigm in the sphere where humanity operates is a necessary precursor to anything more. The music metaphor may help clarify what I mean. To become a virtuoso performer on, say, piano, one must first, usually in childhood while the brain is still open, learn the notes, rules, and mechanics. This is rigid, disciplined, and anything but "creative;" sequences of notes first hammered out by young fingers on suffering instruments are hardly "music." Music comes later, once the elements are mastered; then and only then might creativity be unleashed. The same applies to any learning, such as of written language or mathematics. It is a long way from ABCs and counting numbers to the genius of a Shakespeare or Gödel. Of matter itself the same is also true, as registered in the atoms and element transmutation rules of the periodic table that allow unbounded biochemical proliferation at higher scales of organization. Only when a certain level of ascendency is reached, then and only then is takeoff to another level enabled. "Newtonian creativity" is embodied in the pileup of complexity across the canyons of enormous numbers of organizational levels, and this accrual from reductionist origins in Ulanowicz' "netherworlds" of the small is the origin of holism. It is "holistic takeover" from *necessary* mechanics that undergirds the emergence of new properties and creation of new states of existence. And, as I said at the start, it is Ulanowicz' ascendent networks at least as much as any other model that are at the heart of the process. If ontic creativity can only emerge from chance events in matter and forces, then why should it not also be able to emerge from deterministic processes whose outputs are not produced by chance, but *seem* as though they are?

In Chapter 4, Ulanowicz describes a "game of chance" (Fig. 4.4) where coins inserted in a slot at the top fall 10 steps through a pyramid of nails they hit head-on, and then drop into one of 11 final positions at the bottom. This is a simple physical analogue of the virtual reticulum alluded to earlier—"[S]end a rigorously deterministic causal impulse into a ... network of enormous proportions, and there is no telling what will come out the other side." The game digraph is only a *tree* in graph theory terms, and not of "enormous proportions" at that, but it still has enough complexity for present purposes. Since each nail encountered in the coin drop is a place for a binary choice to occur (to go left or right), there are $2^{10} = 1024$ unique paths to the bottom. In an ideal world, with a 50–50 chance for left or right at each nail, the probability of traveling a particular path to the bottom is 1/1024; all pathways are equiprobable. But the real world is not so perfectly symmetric and ideal. Here, for example, is Ulanowicz' description of asymmetries that might cause unequal probabilities; "[L]et us say that the probability of falling left becomes 70% and that of going right drops to 30%. Exactly how this asymmetry comes about we need not specify. It could be, for example, that the cross-section of the nail shafts is oval rather than perfectly circular, and the orientation of the irregularity with respect to the direction of fall is such that most encounters roll off to the left. It could be simply that the entire array is not exactly plumb, that the left corner is slightly lower than the right. [It could also be that the coins are not fair, and due to marring and other imperfections differ in their fairness.] Whatever the actual mechanism, this change in probability assignment reduces the complexity of the system, as calculated by Shannon's average, by 0.119k bits" (pp. 70–71). The "mechanisms" accounting for this removal of uncertainty, reduction of complexity, and increase of information in the system are exactly that—mechanisms, manifesting a strictly Newtonian array of material and efficient causes, and they cause *deterministically* the "propensity", specified by change in probability assignment, for the coins to have a left-dropping bias.

Extrapolate this simple, graphic example to the intractable, multiscale networks of nature and you have, it seems to me, a rather full and complete explanation within the Newtonian framework for "the new world of chaos, uncertainty, and surprise" that Ulanowicz is addressing in his book. The fact that, in general, underlying mechanical details are obscured by complexity and cannot be known in no way, at least to me, compromises confidence in their existence. To meet pragmatic ends, whatever probabilistic structure is needed to acquire sufficiency can be added, and this in fact has been the scientific response. Furthermore, lest the machine-universe be denied its creative potential, let me repeat the statement above for emphasis. If ontic creativity can only emerge from chance events in matter and forces, then why should it not also be able to emerge from deterministic processes whose outputs are not produced by chance, but *seem* as though they are? No piano player, novice or virtuoso, could play a composition exactly the same way twice no matter how determined the intent to do so. The linkages from page to brain to muscles to keys are too manifold across too many levels of organization to enable this possibility. Emergence and creativity are therefore everywhere in the cosmos, until we have clear evidence to the contrary, and they come right out of the clockworks.

Let me put it this way for my amicus who is a pilot. Sometime, perhaps near the middle or end of the next century, when some of the ascendency principles enunciated in his book have pruned (a word he likes) the world's airlines down to two giant international carriers, will you choose, at a premium price, the staid organization that gets you where you want to go the old fashioned way—*Newtonian Airlines*, or will you pick instead, at considerable savings, the cut-rate, flashier, and certainly more exciting carrier of the in-crowd—*Popperian Air*, whose planes have a well-known propensity to fly?

My choice is clear, and through all the cognitive complexity behind it, it still comes out—determinedly deterministic!

Should you buy this book? Have I left any doubt?

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OUT OF THE CLOCKWORKS: A RESPONSE

It is not my practice to respond to critical reviews of my work. Unless the reviewer has distorted or egregiously misunderstood my positions, neither of which pertains to the above review, I would prefer to "take my lumps" and address any criticisms in future publications. Nevertheless, I have been asked by Bernie Patten, my close friend, mentor and longtime role model to respond to his gentlemanly critique and was further encouraged to do so by Don Scavia, the Associate Editor for *Estuaries*. Theirs is a request I can hardly refuse, and they kindly provide me with the opportunity to clear up some possible misconceptions about my book.

Soon after *Ecology, the Ascendent Perspective* was published it dawned on me that, in my zeal to deconstruct the notion that ecosystems are Newtonian clockworks, some readers might come away with the impression that I leave no role for mechanism in the narrative of ecosystem behavior. (For example, throughout the text I consciously eschewed the use of the word, "mechanism".) Such is hardly the case, however, and as an antidote to potential misconception I have recently written an article entitled, "Life after Newton", (*BioSystems* 50:127–142). In this paper the word "after" is interpreted not only in the deconstructionist sense of "post," but also in the constructivist vein of "in the image of". The reader of this forthcoming essay will see how, in a larger, probabilistic sense, I agree with Bernie when he writes, "I think all Newton's laws can fairly be said to

underlie ecosystem models no matter how complex the ontic systems. . ." Furthermore, I have always acknowledged how mechanisms have played, and will continue to play, a very legitimate and dominant role in ecology. My point, simply, is that I do not believe they are the *whole* story.

One should note that the hypothesis of increasing ascendency quantifies the tendency of ecosystems towards progressively more rigid and mechanical-like behavior. The system, however, never achieves the true status of a clockwork—chance or indeterminacy always remains a *necessary* element of any ecosystem repertoire. When Bernie interprets my thoughts on creativity as implying that it "can only emerge from chance events in matter and forces" he conveys my opinion that chance is necessary for creativity, but his phrasing easily can be misinterpreted to imply that I regard chance as sufficient for creativity. In fact, one of the key papers that prompted my hypothesis of increasing ascendency was Henri Atlan's 1974 discourse (*Journal of Theoretical Biology* 45:295–304) on how one might quantify the threshold of machine-like constraint that is *necessary* before creativity can occur.

Furthermore, Bernie is correct when he points out how in the "game of chance" that I use to illustrate the computation of information, I do identify mechanisms as the agencies that, in this particular simplistic example, give rise to information. In general, mechanisms can, and often do contribute to the magnitude of a "propensity", *but* they decidedly are not what keeps the propensity from being a "force" in the Newtonian sense. Mechanisms are but one type of agency that can effect the constraints inherent in a propensity, and they remain irrelevant to that which distinguishes a propensity from a force.

An important aspect of the Popperian argument for contingency in living systems is that it usually does not take the guise of the unconditional chance commonly invoked in physics. Probabilities are almost always affected by conditions elsewhere in the system—they are conditional. Popper, therefore, urges us to develop a "calculus of conditional probabilities." Developing such a calculus can be a delicate task, and my reason for not using the model of Matis and Patten to incorporate stocks into the ascendency was simply due to its mathematical incompatibility with information theory and not to any inherent defect in their model. Furthermore, I remain unsatisfied with the artifice of adding unconditional noise to ecosystem model parameters, precisely because such models ignore the conditional nature of most chance that arises in ecology. One might, of course, try writing conditional probabilities into model parameters, but it is difficult for me to envision how this could be done without predetermining the outcomes. I leave such attempts to those better schooled in probability theory.

Bernie does identify one significant lapse on my part. He is right in asserting that cyclic, as opposed to acyclic networks do not in themselves qualify as the basis for a whole different category of existence. If all parts of a loop were to function in strictly mechanical fashion when isolated, there would indeed be no reason for the completed cycle to function otherwise. Contingency must be inherent in the elemental segments as well. Only when chance is active at lower levels can autocatalysis exhibit the properties of selectivity, centripetality and autonomy that are so uncharacteristic of Newtonian systems. (Recent experimental work in physics [*Science* 282:602–603] has increased the likelihood that irreversibility is a characteristic of even the smallest systems.)

This one omission notwithstanding, Bernie does not criticize my logic as a whole. Nor do I impugn his reasoning, or that of those upon whom he draws (Zadeh, Mesarovic, Takahara, et al.) The focus of our disagreement is upon conflicting sets of assumptions. Unfortunately, there appears to be no way to test those assumptions unequivocally. In the end, it all boils down to what one *believes* about nature. Irresolvable ambiguities were not supposed to occur in the Modern scheme of things, but we appear to have entered the Postmodern age.

Most scientists I know tend to dismiss postmodernism as the rantings of disgruntled innumerati—much the way E.O. Wilson derides the movement in his best-seller, *Consilience* (Knopf, 1998.) Wilson's serious error, however, is that he fails even to mention the postmodern constructivists, led by such thinkers as David Ray Griffen and Frederick Ferre. This school is postmodern insofar as they do not accept the Newtonian strictures that are the kernel of the Modern synthesis. One is free instead to include elements of either ancient, modern or postmodern thought in synthesizing a new worldview. What is most important, however, is that any forthcoming construct be a coherent, faithful, and, if possible, quantitative description of nature as it is observed. This was the spirit in which *Ecology, the Ascendent Perspective* was written.

One element of modernity usually omitted from postmodern constructs is reductionism. Conventional wisdom holds that only those scientists whose interests lie in the scalar extremes of particle physics can be considered to engage in "fundamental" research (although cosmology is sometimes also included.) From the largely ecological perspective of postmodern constructivism it is not necessary to peer at images created from bubble chambers or radio telescopes to encounter the fundamentals of nature. Sometimes it suffices merely to wade with a net into an estuary.

It is noteworthy that this friendly debate between Bernie and me is appearing on the pages of *Estuaries*, and not in *Science* or *Nature*, which ostensibly are concerned with issues of fundamental importance. It's publication here owes to the progressive mindset of the editors of *Estuaries* and to a long-standing tradition of ecology as the "subversive science."

Finally, as regards whether one should fly Newtonian or Popperian Airways, I must acknowledge the irony that Bernie sees in a pilot who inveighs against mechanical thinking. I have often joked about how I go from my office, where I rant against the idea of nature as machine, to the cockpit, where I pray I am seated in the most finely-tuned clockwork that ever existed! My appraisal of the two airways is different from Bernie's, however: Newtonian Airways believes their machines are guaranteed by law to fly. Popperian Airways, chastened by the conviction that their machines have only a strong propensity to fly, invest in much redundancy so as to increase the probability that, when novel and threatening circumstances do arise, their planes will fail-safe.

Choosing between Newtonian and Popperian Airways is a difficult proposition. The wrong choice could have very serious consequences, yet it is impossible to know with certainty which is the right decision. The analogy for ecologists is obvious. The necessity for exercising choice and belief in science probably will seem novel and strange to many and discomfiting to some, but it should grow increasingly familiar as the Postmodern era unfolds.

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