ARTICLE IN PRESS

Progress in Biophysics and Molecular Biology xxx (2017) 1-3





Progress in Biophysics and Molecular Biology

journal homepage: www.elsevier.com/locate/pbiomolbio

Preface: Towards a global understanding of development and evolution

1. An incomplete narrative

It is generally acknowledged that the ascendancy of Western science owes largely to the formulation of the four force laws of physics. As Nobel Laureates Stephen Weinberg, David Gross and Murray Gell-Mann agree, "All causality is from below, and there is nothing down there but the [force] laws of physics." (Kauffman, 2008) Little wonder, then, that contemporary biology harbors the goal of reducing biology to the laws of physics.

In his introduction to the 2015 issue in this series, Denis Noble extolled how much progress had been made under this reductionistic hypothesis. Nevertheless, he noted, "Something is missing!" As one progresses up the hierarchy to ecology, that which is missing becomes central to the scientific narrative, because attempts at mechanical treatments of ecological systems are notable for their lack of success.

2. Life as not derivative of physics

Noble astutely put his finger on a major difference between physics and biology in that the former is essentially timeless, whereas irreversible time is a prominent feature of biota. Difference in dimensions reflect a logical disconnect as well, and this dissonance was cogently portrayed by Walter Elsasser, who noted how Whitehead and Russell over a century ago demonstrated that the force laws of physics can be mapped onto operations among homogeneous sets. This revealed a tacit assumption of physics, severely limiting what phenomena it could deal with. Elsasser concluded that any putative laws of heterogeneous biology cannot resemble those of physics (Elsasser, 1981).

Elsasser noted how in order to achieve universality, physics has to deal entirely with homogeneous systems, such as mass, charge, energy, etc. Biology, by contrast, is all about *massive* heterogeneity. In order to apply the homogeneous methods of physics to heterogeneous biology, separate variables must be defined for each distinguishable element of a biological system and the boundary values (which actually drive the system) for the many variables must be woven into an integral statement.

Unfortunately, the combinatorics of many categories makes the boundary statement "unprestateable" (Longo et al., 2012). Epistemologically, the problem cannot be formulated, because the combinations of compound events quickly exceeds the estimate of 10¹⁰⁶ simple events that could possible have occurred in the universe since the Big Bang (Elsasser, 1969). More significantly, the laws of physics fail the ontological test as well. Combinations of the half-dozen or so physical laws number in the hundreds, whereas those among the many distinguishable variables in biological systems become hyper-astronomical, so that any combined conditions among physical laws are likely to be equally satisfied by many, or

at least a few different combinations. The laws of physics are not broken, they continue to constrain, but they lose their power to *determine* outcomes.

physics & ecular Biology

3. The contingent origins of order

Bluntly stated, the desire to fully explain biology in terms of physical laws is fatuous. But how then to explain the manifest order that one observes in nature, if not via laws? The empirical correspondence between genomes and phenotypic traits is enormously helpful in codifying organic order, but as Noble aptly pointed out, "DNA on its own does nothing!" Furthermore, as Sidney Brenner long ago pointed out, the correspondence is not determinate, and recent advances in epigenetics only underscore that result (Lewin, 1984). What, then, accounts for organization in living systems?

A fruitful way forward might be to face the obvious difference between biology and physics and treat the former as process instead of timeless dynamics. As Karl Popper ecstatically exclaimed, "We are not things, but flames ... nets of coupled chemical and biochemical processes!" (Popper, 1990) This really amounts to invoking Heraclitus to provide a different ontology for the sciences. However, in invoking nets as well as Heraclitian fire, Popper was offering a new perspective not only on biology, but on science more generally. Certainly, interest in networks has burgeoned over the past two decades, but the bulk of current work searches ensembles of binary connections for mechanical reasons why certain patterns are observed. Almost no concern is given to networks of processes and the altered causality that emerges when multiple processes interact.

A notable exception to this narrow perspective has been the field of ecology, where for the past seventy-five years networks of relationships between trophic processes (who eats whom, and at what rate?) have been the focus of ongoing research (Lindeman, 1942). Ecology in this regard is a maverick science (Ulanowicz, 2000). It is forging ahead whenever it can get a foothold in universities, exploring radically new ways of thinking that often have more in common with branches of Eastern rather than Western thought. Ecology offers some leads in bringing about the revolution required to overcome the aporias of mainstream reductionist science. In particular, the search has been for what drives the dynamics of ecosystem network development? Here an observation by Gregory Bateson has been key, "In general, random inputs to causal cycles generate non-random outputs." (Bateson, 1972) That is, causal feedback generates order.

4. Non-mechanical dynamics of development

One particular type of feedback operating in a milieu of

http://dx.doi.org/10.1016/j.pbiomolbio.2017.07.008 0079-6107/© 2017 Published by Elsevier Ltd.

Please cite this article in press as: Ulanowicz, R.E., Preface: Towards a global understanding of development and evolution, Progress in Biophysics and Molecular Biology (2017), http://dx.doi.org/10.1016/j.pbiomolbio.2017.07.008

impacting contingencies is seen to give rise to decidedly nonmechanical outcomes. Autocatalysis, or indirect mutualism, is a condition whereby processes benefit one another in cyclical fashion. For example, in nutrient-poor waters carnivorous aquatic plants of the genus *Utricularia* provide a surface on which a film of algae can prosper due to being held stationary in a stream of oncoming dissolved nutrients. Those algae attract populations of micro animals, like copepods and water fleas that feed on them, and occasionally these animals are captured in utricles on the host plant, providing sustenance to the *Utricularia* (Ulanowicz, 1995).

The positive reinforcement inherent in autocatalysis means that any contingent change in any element of the cycle that augments its contribution to the dynamic will be rewarded, and vice-versa. Autocatalysis exerts an endogenous and facultative selection pressure upon all its components that tends to stabilize the overall dynamic. Furthermore, any change that happens to bring more resources into a component so that it can function more effectively will also be rewarded. Over time, the net result will appear as a "centripetal" flow whereby the system captures progressively more resources into its orbit (Ulanowicz, 1997). The phenomenon is obvious, for example, in relatively nutrient-rich coral reefs that exist in the midst of a virtual oceanic desert.

Such centripetality is a ubiquitous feature of living systems, and yet it appears on almost no list of the attributes of life. One exception has been that the phenomenon was labeled "chemical imperialism" by Bertrand Russell, who pointed to it as the "drive behind *all* of evolution" (Russell, 1960)! Order, then, is built by living systems in autocatalytic fashion as an historical series of "frozen contingencies". Such development proceeds via a nonrandom, but indeterminate fashion. The exact sequence is not determined by the physical force laws. They do constrain what can happen, but are unable to specify a particular pathway – numerous variational principles stated in homogeneous terms (e.g., maximum entropy production) notwithstanding (Ulanowicz, 2016).

5. Eastern perspectives of causality

This heuristically straightforward but mostly neglected dynamic differs in several ways from the common Neo-Darwinian narrative. Selection is endogenous and facultative. Directionality is progressive, but indeterminate. Unlike the linear progression of physical reductionism, which eschews Aristotelian circular causality, process ecology is grounded upon circular phenomena – an observation that hints at Eastern modes of thought.

Yet another deficiency of physics as putative exegesis for living phenomena is the overwhelming reliance of that discipline on positivism. As Bateson also pointed out, physics deals almost exclusively with what exists. Statements about what is missing are rare (e.g., the Pauli Exclusion Principle). In heterogeneous systems what is missing can play a major role in system dynamics. In ecology, for example, a missing predator or prey item can drastically alter the dynamics of a population.

Fortunately, there is a sub-discipline of mathematics, information theory (IT), which is predicated on what does *not* exist. Claude Shannon's fundamental formula (formally identical to an earlier one by Ludwig Boltzman) quantifies the *lack* of certainty. It can be resolved into two separate but formally similar terms, the first of which reveals the degree of constraint in a distribution and the second the residual lack of constraint.

6. Networks as metaphors for entwined constraint and indeterminacy

This separation is readily applicable to process networks

(Rutledge et al., 1976). Such networks stand as examples of amalgams of constraint and indeterminacy. From any node in a network, one usually is constrained from interacting with most other nodes. At the same time, it remains indeterminate which of the still accessible nodes will be next be contacted. IT allows quantitative assessment of the degree of order (constraint) and freedom (indeterminacy) inhering in a given network.

When this assessment of relative order and disorder was applied to ecological trophic networks, it was surprising to discover that ecosystems do not progress to the most ordered (efficient) possible configurations, but rather towards a balance between constraint (40%) and reliability (60%) (Ulanowicz, 2009a). Common sense indicates that systems cannot endure at either extreme of order or disorder, although the actual balance is likely to be different for, say, organisms (more order) and economic systems (more freedom).

7. Reality as dialectic

What such balance reveals is an ongoing tension between countervailing tendencies that plays out in living systems. That is, the prevailing dynamic is not one of uniform progression towards some maximal efficiency, but rather a Heraclitean dialectic between order building and decay. This new dynamic also mirrors well the Eastern emphasis on the importance of the nonexistent, and the Chinese dialectic between Yan (constraint) and Yin (freedom). With its roots in both Western and Eastern philosophies, process ecology holds forth the possibility of a more equitable common developmental road towards scientific progress (Xu et al., 2017).

Furthermore, the change in perspective that emphasizes processes demands that the metaphysical assumptions that have guided science since the dawn of the Enlightenment be reassessed and, if necessary, amended to accommodate the new image of reality (Ulanowicz, 2009b). It's not that the heterogeneous world contradicts the timeless domain of physics, but that the laws of the latter now appear as limiting endpoints within a wider conception. For it is becoming increasingly clear that the physical world as we now see it is the outcome of an evolutionary process that bears all the markings of the expanded evolutionary narrative.

After the initial Big Bang, a very subtle asymmetry (reportedly one in 10⁹) led to the formation of more matter than anti-matter (Chaisson, 2001). Contemporaneous with the formation of equilibrium material forms at the time of the Recombination (ca. 370,000y after the BB), nonlinearities (feedbacks) arose in space-time to separate the strong, weak and electromagnetic forces from the more generalized force (known as GUT.) Through successive feedback forms grew quite stable on their own, and their interactions (forces) grew precise, until the physical world with its accompanying laws and constants eventually took shape. As Mark Bickhardt and Donald Campbell wrote, "... quantum field processes have no existence independent of configuration of process ... it is patterns of process all the way down, and all the way up." (Bickhardt and Campbell, 1999).

8. New perspective – new image of life

What the new perspective means for biophysics and molecular biology is only slowly emerging. The need for metaphysical reform has already been mentioned. To reiterate Noble, we must to pay less attention on DNA/RNA per se and explore in greater depth the dynamics of the configuration of processes that read and edit the material genome. Necessary also are advances in mathematics that can address the world of processes with the same generality and elegance that Newton, Leibniz and Euler provided to early physics.

Please cite this article in press as: Ulanowicz, R.E., Preface: Towards a global understanding of development and evolution, Progress in Biophysics and Molecular Biology (2017), http://dx.doi.org/10.1016/j.pbiomolbio.2017.07.008

ARTICLE IN PRESS

Popper's recommendation was that we need to develop a "calculus of conditional probabilities".

The new evolutionary drama is both challenging and uplifting. Its challenge lies in the recognition that the cosmos is open and indeterminate. While precise prediction will remain impossible, ways can be developed to assess Kauffman's "adjacent possible" in a statistical sense. The new narrative restores balance to humanity's place in the cosmos. Natural selection no longer involves only elimination, but is driven by a more fundamental mutualism that takes precedence over competition (Ulanowicz, 2009c). Heat death is no longer the exclusive fate of the cosmos (Ulanowicz, 2009d).

The authors in this volume touch upon most of the same themes that characterize process ecology in their collective efforts to paint a new Eastern/Western perspective on living systems. The contributions by Bettinger and Eastman and Cardier, for example, emphasize the contrast between the timeless and temporal, while Vrobel and Roden focus on dimensionality as playing a key role in life. Torday focuses on boundary drivers, rather than laws, as immersing living systems in "an innate state of ambiguity".

The need for modifying logical underpinnings in order to understand life looms large in the chapters that follow. Brenner and Vallverdu challenge the adequacy of Aristotelian logic to the task of portraying life, while Simeonov and Ehresman extol a gathering logical consensus (Wandering Logic Intelligence Memory Evolutive Systems), and Abraham re-examines formal logical models for living systems. Matsuno goes so far as to propose "retrocausality" as a scenario that could culminate in living order, while Pylkkanen reconsiders Bohm's hypothesis that order is already implicate in seemingly indeterminate systems.

Order resulting as a consequence of cyclical causality is also a dominant theme of several contributions. Gunji, adopting Rössler's notion of "endo-perspective", supports the existence of internal, facultative selection. That order arises in stepwise, episodic fashion in conjunction with historical contingencies is proposed by Torday in terms of "a response to uncertainty in iterative conformity with ... initiating parameters". Kineman in his chapter urges abandonment of the conventional "struggle to formalize uncertainty" in favor of reinterpreting uncertainty in terms on non-mechanical complexity.

A consensus seems to be building away from the Western monism of mechanical reductionism towards a revival of a dualist interpretation of reality, albeit not in Cartesian terms. Tozzi, for example, points to a tension between information and energy, while Rosen and Hu et al. elaborate on the Yin – Yang dialectical nature of the living dynamic. Ford perceives this dynamic in "cellular intelligence" and emphasizes how such dialectics are "not amenable to computer analysis".

The chapters in this issue, taken as a body, constitute a manifesto calling for a new image of reality (Longo) expressed as "an extended framework for science" (Cazalis). As Brier notes, it follows in the footsteps of C.S. Peirce by attempting to narrate the living world while emphasizing processes over objects, just as Gare saw evident in Waddington's earlier work with "chreods".

Finally, the new narrative is more universal and inclusive than a physics-only perspective on reality. It rests not only on Western Enlightenment principles, but equally on Milesian Greek thought and the Eastern *I Ching*, as indicated by Hu et al. With its adoption, science moves into a truly global theatre and is recognized as the creation of *all* humanity.¹

References

Bateson, G., 1972. Steps to an Ecology of Mind. Ballantine Books, New York.

- Bickhardt, M.H., Campbell, D.T., 1999. Emergence. In: Andersen, P.B., Emmeche, C., Finnemann, N.O., Christiansen, P.V. (Eds.), Downward Causation, 322–348. Aarhus University Press, Aarhus, DK.
- Chaisson, E.J., 2001. Cosmic Evolution: the Rise of Complexity in Nature. Harvard University Press, Cambridge, MA.
- Elsasser, W.M., 1969. Acausal phenomena in physics and biology: a case for reconstruction. Am. Sci. 57, 502–516.
- Elsasser, W.M., 1981. A form of logic suited for biology?. In: Rosen, Robert (Ed.), Progress in Theoretical Biology, vol. 6. Academic Press, New York, pp. 23–62.
- Kauffman, S.A., 2008. Reinventing the Sacred. A New View of Science, Reason, and the Sacred. Basic Books, New York.
- Roger Lewin interviews Sidney Brenner in: Lewin, R., 1984. Why is development so illogical? Science 224, 1327–1329.
- Lindeman, R.L., 1942. The trophic-dynamic aspect of ecology. Ecology 23, 399–418. Longo, J., Montévil, M., Kauffman, S.A., 2012. No Entailing Laws, but Enablement in the Evolution of the Biosphere. ArXiv:1201.2069.
- Popper, K.R., 1990. A World of Propensities. Thoemmes, Bristol, UK.
- Russell, B., 1960. An Outline of Philosophy. Routledge, New York.
- Rutledge, R.W., Basorre, B.L., Mulholland, R.J., 1976. Ecological stability: an information theory viewpoint. J. Theor. Biol. 57, 355–371.
- Ulanowicz, R.E., 1995. Utricularia's secret: the advantage of positive feedback in oligotrophic environments. Ecol. Model. 79, 49–57.
- Ulanowicz, R.E., 1997. Ecology. the Ascendent Perspective Columbia University Press, New York.
- Ulanowicz, R.E., 2000. Ecology, the subversive science? Episteme 11, 137–152.
- Ulanowicz, R.E., 2009. The dual nature of ecosystem dynamics. Ecol. Model. 220, 1886–1892.
- Ulanowicz, R.E 2009. A Third Window: Natural Life beyond Newton Templeton Foundation Press, West Conshohocken, Pennsylvania. 196pp. For yet another direction see: Brenner, J. 2008. Logic in Reality. Springer Science and Business Media, Berlin. 359pp.
- Ulanowicz, R.E., 2009. A Third Window. Natural Life beyond Newton Templeton Foundation Press, West Conshohocken, Pennsylvania, 196pp.
- Ulanowicz, R.E., 2009. Increasing entropy: Heat death or perpetual harmonies? Des. Nat. Ecodynamics 4 (2), 1–14.
- Ulanowicz, R.E., 2016. Process Ecology: Philosophy Passes into Praxis Process Studies, 45.2, pp. 72–95.
- Xu, Z., Cheng, G., Ulanowicz, R.E., Song, X., Deng, X., Zhong, F., 2017. The common developmental road: tensions among centripetal and centrifugal dynamics. Natl. Sci. Rev. https://doi.org/10.1093/nsr/nwx033.

Robert E. Ulanowicz University of Florida, United States

University of Maryland, United States E-mail address: ulan@umces.edu.

Available online xxx

3

Please cite this article in press as: Ulanowicz, R.E., Preface: Towards a global understanding of development and evolution, Progress in Biophysics and Molecular Biology (2017), http://dx.doi.org/10.1016/j.pbiomolbio.2017.07.008

¹ The author wishes to thank Arran Gare for several helpful insertions.