Unbinding Biological Autonomy: Francisco Varela's Contributions to Artificial Life

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To say that artificial life is a young discipline in name only is to exaggerate, but it would be mistaken to think that its goals are new. The marriage of synthetic scientific aims with computational techniques makes artificial life a product of the last fifteen years, but its motivations have much deeper roots in cybernetics, theoretical biology, and the age-old drive to comprehend the mysteries of life and mind. Little wonder that a good part of the work in this field has been one of rediscovery and renewal of hard questions. Other disciplines have sidestepped such questions, often for very valid reasons, or have put them out of the focus of everyday research; yet these questions are particularly amenable to be treated with novel techniques such as computational modeling and other synthetic methodologies. What is an organism? What is cognition? Where do purposes come from?

To rediscover and reinvent can be a pleasurable but difficult job. As historians of science know very well, concepts and methods evolve, disfavored theories get buried under successful ones (and not necessarily because they are any less valuable), metaphors and languages change, and social perception and pressures influence the directions of research. In view of this, how fortunate that an exceptional and multifaceted scientist like Francisco Varela has not only provided us with a rich legacy of ideas that, both in content and in perspective, are worthy of serious and active (re-)discovery and exploration, but has also himself been a predecessor and supporter of the field. Concrete examples of his work follow the methods of artificial life, both from when the label did not exist and from afterwards. We also have direct collaborators, many of whom are contributors to this special issue, who worry about many of the same problems as Varela did and whose work is directly connected to research lines in this field.

Varela's key scientific worry was the understanding of biological systems in their full autonomy—neither as a collection of inert components nor as something magical, but as introducing into the universe of physical interactions a special kind of novelty: an autonomously organized system with a formal identity and a point of view. This central worry led him in the 1970s to formulate, together with Humberto Maturana, the theory of autopoiesis, which radically alters the perspective on many biological phenomena by taking seriously (actually by founding itself on) the self-producing nature of bounded metabolic activity. The organism provides us with our primary biological unity, not only as an ontological foundation for biology but, more importantly, from an everyday pragmatic and scientific perspective. Dobzhansky's famous motto could well be paraphrased as: "Nothing in biology makes sense except in the light of the organism." The obviousness in the new version is apparent, for understanding what makes an organism remains our problem and is what separates biology from physics.

Following the principle of biological autonomy has allowed Varela to formulate radically novel theoretical proposals for key unsolved problems such as the origin of life, the artificial synthesis of minimal cells, the somatic ecology of the extra-cellular

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matrix, the self-assertive dynamics of immune networks, the problem of biological hierarchies and circular processes, the autonomously generated dynamics of neural systems that give rise to action and perception and are in turn modulated by them, and the emergence of the self and intentionality in living systems.

This conceptual framework differs from many current theories in biology. It has two main characteristics, seen at play in all the major problems that Varela has worked on. It is *nonreductionist* without being hazy; it recognizes the methodological value of shifting perspectives from a system as a whole to its components and to its interactions with other systems. But at the same time it is extremely careful (self-conscious even) of not falling into linguistic pitfalls or errors of misplaced concreteness, of meticulously separating the operational and mechanistic from the functional and symbolic. The perspective of biological autonomy is also *synthetic*. It proposes a study of biology by construction (understood as either actual construction, modeling, or theoretical construction) and not just by control and prediction. It locates explanatory efficiency as much in the interaction and commerce between a system's parts as in the parts themselves, thus naturally allowing for the possibility of novelty and emergence that will always escape purely analytical methods.

These are properties whose market value is on the increase in a biological science faced with problems such as the integration of full genome data, major evolutionary transitions, and the recovery of half-destroyed ecosystems. But at the same time, they are properties that have limited the impact of these ideas in a field where the tools and the problems are fitted to a different sort of method. It is now clear that Varela's pioneering involvement in simulation modeling was not fortuitous. Such techniques are better prepared for a synthetic, nonreductive approach than traditional analytical methodologies. And if his ideas are going to be further developed it will almost certainly be hand in hand with the use of simulation modeling and empirical synthesis in the lab or on the roboticist's bench. In short, the study of biological autonomy is perfectly suited for the work style of artificial life.

To put these concepts to work, to give them enough friction so as to engage in everyday research—these are the main motivations of this special issue. We would like to go beyond the due recognition to a rich set of ideas that are the legacy of a great scientist and thinker. We are especially concerned with seeing these ideas on the move. Contributors have thus been asked to look forward, to criticize, to fill in gaps, to propose developments and explore novel implications.

Some aspects of the concept of autopoiesis are explored by Beer, using a powerful pedagogical device that allows him to raise important issues about a dynamical systems perspective on life and adaptive behavior. Work on minimal computational autopoiesis is critically reviewed by McMullin by confronting both conceptual and methodological problems. Varela's important work on self-assertion in immune networks is assessed by Stewart and Coutinho—two of his colleagues in this area of research—through exploring the successes, failures, and open issues of this line of work, and showing how taking biological autonomy seriously (at the level of the somatic ecology) can offer radically different predictions and therapeutic implications.

The rather abstract original formulation of autopoietic theory has sometimes been seen as limiting its impact on everyday research; the contribution by Ruiz-Mirazo and Moreno addresses this problem by exploring the implications of basic biological autonomy within thermodynamic constraints and in systems for which evolvability is crucial. The sometimes controversial link between life and cognition proposed by the theory of autopoiesis is critically examined by Bourgine and Stewart in a thought-provoking article that makes use of dynamical systems modeling. The tension between the primacy of the organism in biological autonomy and evolutionary thinking based on the concept of genetic information is examined by Exteberria in the light of recent developments linking evolutionary and epigenetic processes. And finally, achieving reproductive minimal cellular systems is the motivation that drives the work of Luisi, Stano, Rasi, and Mavelli in a new study adding to their ongoing research on wet artificial life that examines same-size vesicle reproduction in the context of the matrix effect.

The seven contributions cover only part of the range of Varela's preoccupations, leaving important areas untouched. In those parts that are covered, the authors fortunately do a great job in introducing subtle concepts to the reader. However, there will be disappointment if these texts are taken as introductory. On the contrary, they represent a snapshot of the cutting edge of research in biological autonomy, and they leave the way open for novel creative modeling, experimental, and theoretical work. The success of this special issue will be measured by the new research stimulated by the problems raised in the contributions and by the extent to which they help further unbind the theory of biological autonomy.

Apart from the contributors themselves, I'd like to acknowledge the excellent work of the anonymous reviewers whose insightful, often article-length comments have significantly influenced the published versions. Mark Bedau, who came up with the original idea, has also been very helpful throughout the process of editing this issue; thanks to him. Finally, my warmest thanks to Amy Cohen-Varela for her support and for providing and permitting the publication of Francisco Varela's picture.