

Autopoiesis and *Knowing*: Reflections on Maturana's Biogenic Explanation of Cognition

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Maturana advanced the first systematic explanation of cognition based solely on biological principles since Aristotle. This was a risky strategy to adopt, given the intellectual currents of his time. Had it been more influential, the autopoietic theory of cognition might well have brought us much sooner to the trends currently at the forefront of the cognitive sciences, including dynamical systems, embodied and situated cognition, the emphasis on action and interaction, and other biologically based challenges to the computational paradigm, which Maturana opposed. I argue that the autopoietic theory of cognition was premature for several reasons. While it could be said that developments in the cognitive sciences have overtaken it, I believe Maturana's theory, which he developed with Varela and others, still has much to offer contemporary theorists, despite its limitations.

Keywords: Cognition, autopoiesis, biogenic approach, anthropogenic approach, prematurity in scientific discovery, embodied cognition, computationalism, agency

Introduction

In the 1960s the Chilean neurobiologist Humberto Maturana Romesin began developing an explanation of cognition that rendered in modern scientific terms a very old idea and, at the same time, was radically new. Although Aristotle had demonstrated, millennia earlier, the intimate connection of cognition and biology (Aristotle, 2001), Maturana was very possibly the first to assert that cognition can *only* be understood properly in biological terms. Maturana outlined in detail how cognition is the necessary result of a particular sort of material organization, that of a living system, rather than a disjunctive, emergent property of a specific kind of functional structure, such as a nervous system or brain.

Maturana's autopoietic theory² of cognition, which he developed with his student Francisco Varela, might well have been revolutionary, had it been more influential. As it happened, for the first two decades after its introduction Maturana's theory was

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 2. It is hard to know how accurately to characterize Maturana's "conceptual edifice," as Ernst von Glasersfeld (1997) aptly puts it. Maturana himself does not describe the body of thought referred to in this essay as a theory, and indeed some have noted that it does not have some of the classical features of a scientific theory (Scheper & Scheper, 1996). Yet this work provides a coherent explanatory framework for an important phenomenon, cognition, that arises in a "praxis of living" (in Maturana's terms) of a certain type, namely, science. Further, it appears to meet important requirements of explanatory adequacy within the domain of scientific practice. Specifically, it appears to explain a larger number of cognitive phenomena than do other available explanations, and plausibly links those explanations to the canonical knowledge of the superordinate domain within which the study of cognition falls, that is, biology. These non-trivial matters in the philosophy of science exceed my purpose here, however. Throughout the essay I will refer to Maturana's explanation of cognition, without prejudice, as a theory.

virtually ignored in the explosion of theorizing collectively labelled the cognitive revolution, which continues unabated to this day. Reformulated in the theory of enaction by Varela and others (Varela, 1992; Varela, Thompson, & Rosch, 1991), elements of Maturana's autopoietic approach to cognition began to seep into the mainstream scientific and philosophical discourse on cognition, particularly the growing field of embodied cognition. But the wellspring from which these ideas flow remains largely obscure to most current debates. Indeed, it is possible for a recent review billing itself as a "field guide" to embodied cognition (Anderson, 2003), of which Maturana was arguably a major pioneer, not to mention him at all.

In this paper I will argue that Maturana's autopoietic theory of cognition has not been as influential as it might be because it was *premature* in the way that Gunther Stent (2002) advances the concept in the context of scientific discovery. Further, it was neglected for several of the reasons proposed by Ernest Hook (2002) in his commentary on Stent. One could suggest that while this neglect is unfortunate for Maturana, those are the breaks in science; the caravan has moved on. Quite independently of Maturana, many of his insights have been reinvented in the past decade and are now the subject of increasing thought and application. Among these is Maturana's seminal contribution, now taken almost completely for granted, regarding the inseparability of biology and cognition and all that entails. This includes, most especially, the importance to epistemology as well as to the cognitive sciences of the continual, mutual interaction and adaptation of the cognizing organism and the medium in which it lives—what Maturana termed *structural coupling*.

I will defend the claim that, on the contrary, Maturana's autopoietic theory, and particularly his concept of structural coupling, have much to offer contemporary debates, not least because he unites in a single coherent framework a variety of cognitive concepts, problems and mechanisms currently being developed by different thinkers in different ways. The continued consignment to the penumbra of the cognitive sciences of Maturana's original theory and its later development by the man himself, quite apart from the important elaborations made by Varela and others, is indeed unfortunate, not only for Maturana but for all those who seek a plausible, biologically respectable explanation that can account for cognition in all its forms. This is not to say that Maturana's theory does not have limitations (it does, in my opinion) or that it is easily penetrated (emphatically not). But the benefits of rediscovering Maturana's complex and subtle theory considerably outweigh the costs.

The paper is structured as follows. The first section will provide the context of Maturana's theory, which I distinguish as a particular kind of framework, a biogenic framework, and will situate his approach within some of the intellectual currents of his time. In the second section I will sketch what I consider to be the major advantages of Maturana's approach to cognition. The third section will explain why the theory was premature and advance some reasons for its neglect. The fourth and final section will outline developments in the cognitive sciences in the past decade that suggest, paradoxically, that the time is both ripe for a reconsideration of Maturana's thinking

about cognition and that the time has passed. I will argue that the former, not the latter, is the case—despite some problems I find with Maturana’s approach to cognition.

Maturana’s body of thought relating to cognition is wide-ranging, so I must be clear about what I will address and what I will not include. Von Glasersfeld (1997) describes Maturana as a systematic thinker in the way that Plato and Leibniz were systematic thinkers. Although he disregarded traditional philosophy almost utterly, Maturana followed his biological insights into the classical philosophical domains (metaphysics, epistemology, ethics) and elaborated them from their simplest to their most complex forms, including language, self-consciousness and social organization, from the loving pair to complex societies. This paper is concerned only with the biological fundamentals of Maturana’s theory, not its extrapolations and extensions.

Importantly, I will deal only obliquely with what many perceive as Maturana’s radical constructivism. Maturana was profoundly influenced—as were Vico, Berkeley and Kant before him—by the realization that we cannot have access to, and therefore have no justified basis for believing in what Maturana calls “objectivity without parentheses” (Maturana, 1990, p. 57), that is, a reality of things-in-themselves separate from our observations, which in turn are determined by the questions we ask, the perspective from which we ask them and the cognitive equipment with which our biology endows us.³ As it did to Kant, this insight suggested to Maturana profound consequences for how we characterize knowledge. Maturana’s theory of cognition, therefore, is intimately linked to his acceptance that there is no subject-independent basis for objective knowledge.

Although Maturana’s explanation of cognition is deeply embedded in the metaphysical-ontological⁴ question, *Does an observer-independent reality exist?*, I believe that the adequacy (conceptual utility) of his account can be assessed independently of an answer to that question. Maturana claims that an affirmative answer is incoherent and mistaken, and his explanation of cognition is entirely consistent with that position. However, his empirical-theoretical explanation of cognition does not necessitate his preferred metaphysical ontology. In my view, one may remain agnostic—or even maintain a weakly realistic position—on the metaphysics and yet accept the broad features of Maturana’s empirical explanation. As von Glasersfeld correctly observes, Maturana’s contribution was to take account of the sceptical conclusion and provide, in wholly biological terms, “a new explanation for the relation between our knowledge (i.e. every conceptual structure we use

3. The role of the observer was scientifically institutionalised in the Copenhagen interpretation of quantum mechanics, which by the 1950s, when Maturana was engaged in his doctorate at Harvard, was already becoming widely accepted, if not with philosophical good grace.

4. Ontological issues, as far as I can tell, come in two sorts. *Empirical-ontological* issues relate to the entities and their possible relations that comprise a particular conceptual framework (e.g., quark, enzyme, co-valent bond, tectonic plate, emotion, tree, photosynthesis, etc.) and are more or less open to tests of empirical adequacy. *Metaphysical-ontological* issues relate to speculative preferences about the nature of the world, which are logically arguable but very possibly beyond empirical test. However, metaphysical-ontological issues may become empirical-ontological issues through reconceptualization.

successfully) and the ‘medium’ in which we find ourselves living.” (Glaserfeld, 1997) It is with this explanation that I am solely concerned.

1. Maturana’s biogenic approach

There are, broadly speaking, two ways of approaching the problem of cognition. The two approaches are defined by a methodological assumption that is rarely explicit and is sometimes denied. This assumption relates to the starting point of inquiry. Do we start from the human case and work our way down to a more general explanatory concept, or do we start from the facts of biology and work our way up to the human case? I call the tradition that takes the human case as its starting point for the study of cognition the *anthropogenic* approach (from the Greek; literally, human + birth, origin). Anthropogenic is an adjective long used in plant ecology to refer to plants introduced by humans; it increasingly refers to climate change associated with human activity (e.g., Forster & Solomon, 2003). By contrast, the tradition that takes the facts of biology as its starting point is the *biogenic* approach (life or living + birth, *origin*). Biogenic is used in geology to refer to the origins of certain rock strata. Limestone is biogenic, for example, because its origin is material that once formed part of living organisms. I develop the anthropogenic/biogenic distinction in more detail elsewhere.⁵

The important thing to keep in mind here is that the anthropogenic/biogenic distinction refers to a *methodological bias*, a strategic calculation, not an ontological preference or belief.⁶ The suffix is the key; genic is intended to convey the notion of a starting point. Thus, an investigator adopting an anthropogenic approach to cognition starts with the human case in the belief that the features of human cognition are the most plausible and potentially fruitful (possibly the only) guide to understanding the phenomenon of cognition generally. By contrast, an investigator adopting a biogenic approach assumes that the principles of biological organization present the most productive route to a general understanding of the principles of cognition. This is because cognition is a biological process, which, like circulation, respiration and elimination, is understood best in the context of living organization.

The anthropogenic-biogenic distinction, as I draw it, can be applied to any sort of investigation related to mental phenomena. An anthropogenic or a biogenic approach can be adopted in relation to 1) the *ontology* of the mental, both in terms of delineating a general domain or framework of analysis as well as enumerating the entities or processes captured by that domain; 2) *epistemology*, the nature of knowledge and the processes by which it is generated, including language; and 3) *ethics*, the normative regulation of behaviour. Although it may seem more appropriate to apply a biogenic approach to an ontological issue, say, rather than to an epistemological concern, where an anthropogenic approach might seem to have the natural advantage, this is not

5. *The Agent in the Organism: Toward a Biogenic Theory of Mind*, Ph.D. thesis, the Australian National University, forthcoming.

6. Of course, an ontological preference or belief may lurk behind the choice of methodology, but need not.

necessarily the case. On the contrary, biogenic approaches can be applied just as easily to general epistemological issues—as Maturana’s work demonstrates—as they can to ontological issues. Anthropogenic approaches may have an edge in relation to epistemological and ethical issues in which language-mediated behaviour is the central concern, but not necessarily so.

The anthropogenic and biogenic approaches, while dichotomous, are complementary. Each has an important role to play in a full description and explanation of mind. We need to understand cognition both from a purely biological standpoint and in terms of human psychological experience—what in the context of Maturana’s work might be called “the psychology of the observer.” The brilliance of Maturana’s approach, I believe, is that he recognized, in a way that many thinkers do not, that perspective—starting point—profoundly influences how a phenomenon is described and explained, and this is particularly so in the study of cognition. Maturana writes:

We human beings assess cognition in any domain, by specifying the domain with a question and demanding adequate behaviour or adequate action in that domain...[A]dequate behaviour (or adequate action) is the only criterion we have and can use to assess cognition. (Maturana, 1990, pp. 48-49)

What, then, is the criterion of adequacy for evaluating behaviour or action that will provide evidence of cognition? Needless to say, this issue is the subject of a monumental and growing literature within which there is nothing approaching consensus. It should be obvious, however, that the criterion of adequacy for ascertaining cognition will differ depending on one’s approach, whether anthropogenic or biogenic, and whether that methodological bias is strong or weak or something in between. In Maturana’s terms, the criterion of adequacy will be different if the perspective is that of the *system under observation*, in this case the living system, or whether the perspective is that of an *observer* of the system.

In my view, Maturana’s *Biology of Cognition* (1970/1980) provided the first truly biogenic explanation of cognition since Aristotle’s *De Anima*.⁷ This alone was no small achievement. But he also produced, as far as I can tell, the only explicitly dual explanation. Maturana recognized that an account of cognition *from the perspective of the living system* must be biogenic, because cognition as a function and a process arises (naturally, at least) from the facts of living organization and can be explained in

7. This is not to say there were no biogenic thinkers entertaining the problem of cognition between Aristotle’s time and Maturana’s. Erasmus Darwin, Herbert Spencer, Charles Darwin, William James and the Pragmatist philosophers Charles Sanders Peirce and John Dewey also approached cognition as an intrinsically biological phenomenon. Spencer came to the conclusion, similar to Maturana’s, that life and cognition share the same general character, what Spencer called, “*The continuous adjustment of internal relations to external relations.*” (Spencer, 1855/1970, pp. 374) Spencer’s view influenced both Charles Darwin and William James, who was part of the Pragmatic movement, but neither the 19th century scientists nor the philosophers produced a coherent scientific explanation of cognition. Donald Campbell and Karl Popper independently developed the principles of a biogenic ‘evolutionary epistemology’ at roughly the same time Maturana was developing his ideas (Campbell, 1956, 1960, 1974; Popper, 1972, 1974), but Maturana’s framework emerged first in a more complete form.

no other terms. On the other hand, *the perspective of an observer* is necessarily anthropogenic, for Maturana at least, because only human beings are observers.⁸ According to Maturana, observations arise to co-orient attention and coordinate action through language, and language, which he differentiates from communication, is the cognitive domain of *Homo sapiens*. However, as Maturana also points out, the observer is herself a living system, and “an understanding of cognition as a biological phenomenon” must take account of this fact and how it shapes understanding (Maturana, 1970/1980, pp. 9). Thus, cognition demands a biogenic explanation as a basis, but human (anthropogenic, observer-dependent) interests necessarily colour that explanation. The trick is to see clearly when and how the colour is applied.

Maturana holds, correctly in my view, that *cognition* is a distinction that is only made by an observer, never by the cognizing system itself. Like respiration, circulation, elimination and other essential biological processes, cognition is something a living system does and cannot fail to do so long as it lives. Cognition, as Maturana delineates (if not defines) the concept, is the relational interface between the organism and the medium in which it lives. Cognition is the means by which the system interacts with the medium in which it lives; it is inseparable from the action and behaviour without which life cannot be sustained. For Maturana, therefore, cognition is intrinsic to the “realization of the living” (Maturana & Varela, 1975/1980); it is not an added extra that emerged in some species but not others at some point in evolution.

However, cognition, like any biological process, can only be distinguished as a function⁹ by an observer, because a functional description “suppose[s] a larger conceptual scheme which is more embracing: circulation in something, support of something” (Varela & Maturana, 1972, p. 381). A functional description of a subsystem thus is a product of an observer’s interests relative to the larger system of which the subsystem is a part.¹⁰ Those interests may carve out genuine (replicable, verifiable) regularities, as when a scientific domain (e.g., the autonomic nervous system) is delineated by a particular community (physiologists, neuroscientists). Nevertheless, such delineations are made for the purposes of communication within a community; the boundaries implied by the categorization are not intrinsic to the system. In the classic formulation, the map is not the territory. From the system’s perspective—and this was one of Maturana’s key insights, in my view—cognition can no more be demarcated from respiration, circulation and elimination than these processes can be differentiated from any other fundamental process that sustains living organization.

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8. I disagree with Maturana on this point, mainly because I do not think our grasp of animal communication systems is adequate to make the judgment with confidence.
 9. I will adopt Gilbert and Sarkar’s generic description of function as “the type of physiological behavior that is seen in all biological systems.” (Gilbert & Sarkar, 2000, p. 1, ff. 1)
 10. Varela and Maturana (1972) go further and claim that, “a functional description, when not dispensable, is symptomatic of the lack of a theory for the structure of the system in which the subsystem, described in functional terms, occurs.” (p. 381) That is, if a theory of the overall system is lacking, functional descriptions are needed to explain observed features.

In his work with Varela on biological organization, Maturana was struck by the fact that life is sustained at the molecular level (Maturana, 2003). In the molecular domain, processes are concatenations that ramify and loop back; they dynamically overlap, interweave and interact. What an observer designates as an organism's cognitive subsystems will always have substantial linked, if not shared, molecular pathways with other systems usually considered to be non-cognitive—just as the brain, so often equated with mind,¹¹ supports physical functions as well as mental ones, and it is difficult to determine where one sort ends and the other sort begins.

At the time Maturana was developing the explanatory framework that coalesced into *Biology of Cognition* (1970/1980), taking a biogenic approach was a fairly radical and, professionally, a somewhat dangerous thing to do. It was radical because no one appeared to be attempting an explanation of cognition in terms of biological principles alone, at least not in America in the 1950s when Maturana was earning his doctorate at Harvard. This is not to say that no one was interested in taking a biological approach to cognition.¹² However, cognition was delineated anthropogenically in terms of human cognitive capacities (e.g., language, rational problem-solving) and human brain structures. The perceptual systems of simpler organisms were necessary to the scientific study of cognition because they were more tractable, both structurally and ethically, but human capacities were the main target of the emerging cognitive sciences (see especially Brooks, 1991). The Turing machine, for example, was based on human symbol-processing abilities, specifically, mathematical computation and language use.

More importantly, psychology at the time offered no framework for considering the two questions Maturana took to be central to the biological problem of cognition: *What is cognition as a function? What is cognition as a process?* (Maturana, 1970/1980, p. 7). Behaviourism, which was explicitly unconcerned with the physiology of the “black box” between stimulus and response, still dominated American experimental psychology in the 1960s. Developmental psychologists influenced by Piaget, among others, were certainly concerned with biology and adaptation, but principally as they related to human cognitive maturation and knowledge. Maturana devised his own framework. As a neurobiologist working on the visual systems of frogs and pigeons, he drew on what he knew.

Taking a biogenic approach to cognition was professionally dangerous because vitalism had not been fully exorcised from biology, and, arguably, still has not been.¹³ Vitalism comes in at least three forms (Deutsch, 1951). The most common referent of the term is what could be termed *metaphysical vitalism*, the belief in special substances or essences associated with life (e.g., *Élan vital*, entelechies, colloidal chemistry). When Ernst Mayr agrees with J. S. Haldane that biologists had “abandoned vitalism as an acknowledged belief” by 1931 (Mayr, 1997, p. 16), it is

11. Not by Maturana. (See Maturana, 1985)

12. See in particular (Corning & Balaban, 1968)

13. See, for example, (Hameroff, 1997)

principally to metaphysical vitalism that he refers. The second form is *methodological vitalism*, the belief that physical and chemical laws are inadequate to explain biological phenomena fully and that new principles and laws will be required. This sort of vitalism—now referred to more benignly as non-reductionism—motivated physicists such as Erwin Schrödinger, Max Delbrück and Walter Elsasser to divert their theoretical energies to biology. The third form, *epistemological vitalism*, is the belief that a full explanation of vitality is beyond science; it is roughly comparable to “mysterianism” in consciousness studies.

Because of these different forms of vitalism, and the confusions attendant upon them, it was still possible as recently as the 1960s for a reputable professor of experimental zoology at the University of Vienna to examine the “philosophical aspects of biology” from the standpoint of mechanism and vitalism, and to judge vitalism the more explanatorily useful framework (Schubert-Soldern, 1962). Schubert-Soldern’s monograph is instructive because it is an excellent example of how vitalism and biological holism (organicism) are often conflated, even by those who endured the fiercest debates regarding these overlapping, yet differentiable and individually heterogeneous doctrines. Holism in biology is the by-now axiomatic doctrine that the “whole is more than the sum of its parts”; the organization of the system determines its properties and characteristics, not the composition of its components. (See in particular Mayr, 1997, pp. 16-22.) Concerns with emergence, complexity and system dynamics are, classically, holistic concerns. Unfortunately, the erroneous conflation of metaphysical vitalism with methodological holism continues to this day (Gilbert & Sarkar, 2000), despite the growing consensus that a systems approach¹⁴ is necessary if biological organization is to be fully understood (Kitano, 2002).

Maturana, therefore, was pursuing a doubly risky course in terms of the potential for being dismissed as a vitalist. First, despite an allegiance to mechanistic determinism¹⁵ and a critical view of the organismic approach,¹⁶ as a systems thinker Maturana was a methodological holist. Moreover, he explicitly set out to explain cognition at the level not only of the organism but also the observer of the organism. Second, Maturana became convinced that the questions relating to the function and process of cognition could not be addressed until the nature of the type of organization that cognition serves was adequately characterized. To explain cognition, he would first have to explain life. Uniting cognition and life in a single explanatory project skirted dangerously close to psychovitalism, the 19th century notion that mental forces are the guiding principle of vitality (Mayr, 1997).

But Maturana may have had little choice. The problem of cognition was at the heart of his neuroscientific research on visual perception. His interest in the problem

14. Systems approach’ is used here generically.

15. Some take issue with the description of Maturana as a mechanist. I discuss this further in section 2.3. Suffice to say that *mechanistic* is the adjective Maturana and Varela (1975/1980, p. 75) use to describe their approach.

16. Maturana claims that the organismic approach does not answer, but merely restates, the question, “in what sense are [a system’s] component properties its parts?” (Maturana 1970/1980, p. 5).

of living organization, which dated to his own student days, was revived in 1960 with a medical student's question: "What began [3.8 billion] years ago so that you can now say that living systems began then?" (Maturana, 2003, p. 6). The question became Maturana's. His answer was *autopoiesis*.

2. The autopoietic theory of cognition

Although Maturana's fascination with the problem of life predated his concern with the problem of cognition, and despite his realization that the encompassing system must be characterized before the subserving function can be, the *Biology of Cognition*, which he wrote alone, preceded the classic works on the theory of living organization that he developed with others (Maturana & Varela, 1975/1980; Varela, Maturana, & Uribe, 1974). Although the concept of self-production, which gives the theory of living organization its name,¹⁷ is not emphasized, the main principles of autopoietic theory are present in the earlier work on cognition. Let us look at the main principles of biological organization Maturana considered necessary for understanding cognition as a function and a process.

2.1 Circular organization and interaction

Recursive feedback is a central tenet of cybernetics, an intellectual movement in which Maturana's research mentor, neuroscientist Warren McCulloch,¹⁸ was a leading figure (Dupuy, 2000). The cybernetic notion of circular causality is closely linked with the physiological principle of homeostasis (Rosenblueth, Wiener, & Bigelow, 1943),¹⁹ the system of regulation by which an organism maintains a stable internal chemical environment despite environmental variations and disturbances. Homeostatic regulation involves interaction among the components that comprise a living system as well as between the system and a surrounding medium.

Maturana recognized that circular causation was the key to *every aspect of living organization* and that its maintenance involved continual interaction, both in the (exergonic) flow of matter and energy from the surrounding medium through an organism and in the (endergonic) transformation of matter and energy into the molecular components necessary to sustain life. *Autopoiesis* is the name Maturana and Varela (1975/1980) gave to the continual production by a network of the very components that comprise and sustain the network and its processes of production.²⁰ For example, for a Boeing 747 to be autopoietic, it would have to be capable of synthesizing the machinery that manufactures the vast array of components that make up the aircraft, and simultaneously produce those components, *while in flight*.²¹ This

17. From the Greek, *auto* = self + *poiesis* = produce, make.

18. Maturana and McCulloch co-authored a classic paper on the visual system of the frog (Lettvin, Maturana, McCulloch, & Pitts, 1959/1968).

19. Arturo Rosenblueth, lead author of this seminal paper on cybernetics, was a physiologist at Harvard Medical School when Walter Cannon was developing the concept of homeostasis.

20. Henceforth I will use *circular organization* and *autopoiesis* interchangeably.

emphasis on continual self-production and its maintenance, not merely self-organization, is what distinguishes autopoiesis from thermodynamic approaches to life and cognition (e.g., Bickhard & Terveen, 1995; Kauffman, 2000; Prigogine, 1996; Bertalanffy, 1968).

The relation of an organism to its surrounding medium is highly dynamic. If a living system ceases to interact with its surrounding medium it dies; it can no longer produce the components that sustain its organization. If it interacts inadequately with its surrounding medium it also dies. Autopoiesis, therefore, makes a living system (from its own standpoint) “a unit of interactions” with a medium and (from the standpoint of the observer) a “unit of relations” with that medium (Maturana, 1970/1980 p. 8). In later work Maturana refers to the compatible interaction or relation of an autopoietic system to its medium simply as *adaptation*. Thus the two “necessary conditions” for living beings to exist involve the *conservation* of two mutually informing patterns: autopoiesis, or the pattern of self-producing organization, and adaptation, the pattern of interaction or relation of a system with its medium that sustains autopoiesis (Maturana & Varela, 1992, pp. 102-103).

The medium with which a system interacts is also heterogeneous; it contains many more elements than are relevant to the maintenance of a particular system’s autopoiesis. It follows that a system cannot interact adequately with its surrounding medium unless it can *differentiate states within the medium relevant to its own maintenance*—for example, states relating to food, noxious substances, mates, allies and enemies. An important (and, I take it, uncontroversial) function of cognition is to differentiate states of various kinds. A living system’s “domain of interactions”—as Maturana denotes the sphere in which a system responds differentially to maintain autopoiesis as the states of the medium change—is also, therefore, the “domain of cognition” (Maturana, 1970/1980, p. 10).²²

The domain of interaction is also cognitive for Maturana in another way. Circular organization that depends for its maintenance upon interaction, both within the system and between the system and its medium, implies a sort of prediction,²³ that an interaction that took place once will take place again. “Accordingly, predictions implied in the organization of living systems are not predictions of particular events, but of classes of interactions.” (Maturana, 1970/1980, p. 10) The projection into the future of a class of event or object, based on one or more past experiences of that class of event or object, is an *inference* (Copi & Cohen, 1999).²⁴ According to Maturana

21. This is not to suggest that any human-made machine is as complex as a single-celled bacterium, the simplest autopoietic system known.

22. Maturana’s linkage of cognition to homeostasis and autopoiesis foreshadows by nearly 30 years Antonio Damasio’s *somatic marker hypothesis*, the central idea of which is that “homeostasis is a key to the biology of consciousness” (Damasio 1999, p. 40).

23. In later work (Maturana & Varela, 1992), Maturana acknowledges that *prediction* and making *inferences* are activities apparent only to an observer, so these terms are not really appropriate for describing what happens from the system’s perspective. However, the concepts of prediction and inference are crucial to Maturana’s initial case for equating interaction with cognition, so I have stuck to the original terminology.

(1970/1980, p. 10), “this makes living systems inferential systems,” which is further evidence that “their domain of interactions [is] a cognitive domain.”

Maturana recognized that everything a living system does is aimed at maintaining the particular sort of autopoietic organization that makes the organism a member of the class it is. Different phyla, genera and species maintain autopoiesis in different ways, but they all maintain autopoiesis. Autopoietic organization thus determines the types of interaction that comprise an organism’s cognitive domain. Organization on this picture does not equate with structure, however. A system’s material structure continually changes; its organization does not and cannot, because autopoietic organization is what sustains the system’s vitality.

Because all biological organisms have a domain of interaction due to their circular organization, Maturana says it is a mistake to equate cognition with possession of a nervous system, an equation that has persisted essentially unquestioned since Lamarck first proposed it at the turn of the 19th century (Bateson, 1979). According to Maturana, a nervous system does not create cognition but, rather, expands an organism’s sphere of possible interactions (Maturana, 1970/1980, p. 13). For every living system, possessed of a nervous system or not, cognition consists in the generation of behaviour in a domain of interaction.

2.2 Operational closure = autonomy = self-reference

At the time Maturana advanced his ideas on cognition, thermodynamic ‘openness’ was emphasized as the defining physical feature of the animate (Schrödinger, 1967; Bertalanffy, 1940, 1968), and this remains an important aspect of accounts based on thermodynamics (Bickhard & Terveen, 1995; Christensen & Hooker, 2000; Prigogine, 1996; Rosen, 1970). Indeed, before Ludwig von Bertalanffy advanced the concept of an *open system*, the sustained order of living systems seemed to contravene the second law of thermodynamics, which buoyed metaphysical vitalism for a time. By contrast, while he never disputed the thermodynamic openness of organisms, Maturana was struck early in his intellectual life by the *closed* nature of biological systems from an operational standpoint. He recalls that during a sojourn in a tuberculosis sanatorium in 1949,

I had realized that what was peculiar to living systems was that they were discrete autonomous entities such that all the processes that they lived, they lived in reference to themselves. Accordingly, I thought then, whether a dog bites me or doesn’t bite me, it is doing something that has to do with itself. (Maturana, 2003, p. 6)

Although a living system is open to matter and energy flowing through it, it is not open to every form of matter and energy. What forms of matter and energy can or cannot pass through an organism is determined by the boundary of its organization, a

24. The question of whether inferences need to be ‘conscious’ remains controversial. However, two decades ago Bernard Baars (1981), among others, argued that they need not be, and contemporary experimental evidence indicates that much mental processing, including inference, is nonconscious.

membrane or skin, which also determines the outer limit of its processes of self-production. There is no organism, therefore, without operational closure. Operational closure makes a living system *autonomous*, which, minimally, is the capacity to robustly sustain processes relevant to system maintenance despite changes in the surrounding medium. Autopoiesis—indeed, homeostasis of any kind—is impossible without operational closure (see also Rosen, 2000, p. 184).

Operational closure, or boundedness, influences a living system's cognitive domain primarily in two ways. First, it provides the reference point for *self* and the distinction of *non-self*, which also form the basis of affective response (see especially Damasio, 1999). All components within the system boundary that interact to maintain autopoiesis constitute self. The manner in which a system differentiates self may be mimicked, as by some parasites, or masked, as in the case of endogenous retroviruses that trigger an autoimmune response. Some living systems may also regard some or all of the products of their activity as self, as in the relation of human beings to some of their artefacts. But the reference point for such attributions, as well as mimicking and masking, is the operational closure of the affected or the attributing system.²⁵

Second, because operational closure is the requisite condition for autopoiesis it also defines the organism's domain of interactions and, thereby, the objects or events it is capable of cognising or experiencing. Although the medium of any living system offers a wide variety of possible stimuli, as Maturana and Bunnell (2001) observe, a living system is capable of perceiving only what it encounters. A living system can only encounter what it is capable of encountering, however, and that depends on its structure, including its sensory capacities. The capacity for sense perception of any kind depends upon the sort of living system it is, which in turn is determined by operational closure.

2.3 Structural determinism

In advancing the autopoietic framework, Maturana and Varela explicitly describe their approach as “mechanistic” (see Maturana & Varela, 1975/1980, p. 75, all of Chapter 1; 1992, p. 254; Varela & Maturana, 1972). However, it is important to emphasize that their approach is mechanistic in a particular way, indeed, in a way that is *antithetical* to the methodological reductionism and linear causality of classical, Cartesian mechanism. Maturana and Varela define their approach as mechanistic, first, to distinguish it from vitalism; that is, they invoke “no forces or principles “which are not found in the physical universe” (Maturana & Varela, 1975/1980, p. 75). Second, their approach is mechanistic because it focuses on machines as organized dynamic unities whose components interact and undergo transformation.

Whereas classical mechanists usually characterize a machine in terms of its components and the purpose(s) its operations fulfil “as a human artefact” (Varela & Maturana, 1972, p. 378), Maturana and Varela are concerned strictly with

25. John Stewart and Antonio Coutinho (2004) recently proposed a fascinating “new perspective on the immune system” and the self—non-self distinction based on autopoiesis.

organization, the “processes and relations between processes realized through [the] components” (Maturana & Varela, 1975/1980, p. 75). To understand a particular machine, they claim, it is not enough to produce a parts list and ascertain its function; what is needed is knowledge of “the permitted interrelations of the machine components which define the possible transitions that the machine can undergo” (Varela & Maturana, 1972, p. 378). What makes a Turing machine a machine is not the tape, the moveable marker and their container but, rather, the program that specifies what happens to these parts when the device is in such-and-such state. What makes an organism a machine,²⁶ on this reckoning, is the fact that its organization determines the sorts of interactions the system can enter into and the sorts of transformations the system can undergo as a result of its (internal or external) interaction. As Maturana (1970/1980, p. 10) puts it, “living systems cannot enter into interactions that are not specified by their organization,” which in turn specifies the processes necessary for continued autopoiesis.

However, it is the organism’s *structure*, the molecular and macro-molecular components that constitute a system’s class-specific organization, that performs the interactions the system engages in. Moreover, it is at the molecular level that autopoiesis actually occurs (Maturana & Varela, 1975/1980) and where every interaction effects an immediate change in the system. Maturana and Varela call this feature of organisms—which animate systems share with inanimate systems capable of interaction (Maturana & Varela, 1992, p. 96)—*structural determinism*.²⁷

Structural determinism implies nothing at all about the predictability of the system’s behaviour, however. Autopoietic theory is not mechanistic or deterministic in a clockwork, La Placian sense. Von Glasersfeld (1997) puts it nicely: “In an autopoietic organism, every perturbation, every experience, every internal event changes the structure of the network that constitutes the organism. These changes, of course, are not all of the same kind.” Changes can form new pathways for interaction or activate and reinforce (weakly or strongly) existing ones. The weight each change carries within the economy of the system varies from moment to moment, and an incomprehensible multitude of changes are occurring at every instant.

A key insight of Maturana’s *Biology of Cognition*, especially given the behaviourism dominant at the time, is that the result of an interaction is not determined *in any way* by a stimulus external to the organism but only by the aggregate state of the organism itself at a given moment. All an external stimulus can do is trigger a structural change within the organism. Determinism in Maturana’s account runs in two directions, from the bottom up and from the top down. The effects of molecular interactions ramify and amplify into behaviour at the macro-molecular

26. Maturana and Varela repeatedly refer to living systems as ‘machines’ in *Autopoiesis: The Organization of the Living*. Machine language is almost non-existent in recent work, however.

27. Robert Rosen came to a similar conclusion regarding ‘state determinism’ in his biological rendering of dynamical systems theory. “In a nutshell, a system which is both [thermodynamically] open and autonomous “must have the property that *the flows from environment to system, and from system to environment, are determined by what is inside the system.*” (Rosen, 2000, p. 183)

level, all the way to the level of the organism. The same is true in the other direction. How an organism behaves in its surrounding medium has ramifications to all its internal dynamics, and thus determines whether autopoiesis is maintained at the molecular level.

Herein lies the implication of structural determinism for cognition, in the adequacy or inadequacy of a systemic interaction, or behaviour. Here, too, Maturana draws an important distinction between the adequacy of an interaction as a normative evaluation performed by an observer and adequacy as determined by the interacting system. Adequacy from the perspective of an observer is interest relative; it depends on the interests of the observer in making the observation of the interaction and of the conceptual framework from which the observation is made. Adequacy from the perspective of the interacting system, on the other hand, is more straightforward and pragmatic. Does the interaction *work*? Given this interaction, are autopoiesis and adaptation conserved? For example, positive chemotaxis in a bacterium in the presence of glucose molecules may be an inadequate indicator of cognition for an observer interested in, say, abduction. For the bacterium, however, positive chemotaxis is cognitively adequate if the interaction secures sufficient energy resources for maintaining biological organization to enable the bacterium to interact again.

For Maturana, knowledge is an ascription made by an observer when a behaviour meets some standard of adequacy (Maturana, 2003, p. 26-27), a standard that may be independent of the observed system, and very likely is so if the system is not human. However, for a behaving system to *know* is to interact in a manner that is both 1) familiar to the system, usually the result of a repetition of a previous interaction (Maturana, 1970/1980, p. 24), and 2) adequate to maintain autopoiesis and adaptation. The domain of knowing, the cognitive domain, is thus the *domain of adequate action*, and this domain changes continually as the structure of the system and the structure of the medium in which the system operates continually change.

2.4 Inseparability of system and niche (structural coupling)

The observer/observed distinction also shapes Maturana's differentiation of 'niche' and 'environment'. As noted, the medium in which a biological system makes a living has many more features than are relevant to the system's autopoiesis. *Niche*, defined from the system's perspective, comprises "the classes of interactions into which an organism can enter" with its surrounding medium (Maturana, 1970/1980, p. 10). *Environment*, by contrast, is observer-dependent and encompasses a broader range of elements in the surrounding medium than merely those with which the observed system is capable of interacting—just how broad depends on the observer's interests.

"From a purely biological point of view," according to Maturana, a living system cannot be understood independently of its niche and the interactions the system undergoes to sustain autopoiesis (Maturana, 1970/1980, p. 9).²⁸ If interaction with the niche is inadequate, the system disintegrates; it ceases to exist. Because it is defined by the interactions into which an organism may enter, the niche constitutes the

“cognitive reality” of the organism. Trivially, a niche cannot be understood separately from the system whose interactions with it bring the niche into existence by definition.

Structural coupling denotes the interdependence of organism and niche such that a change in one brings about a change in the other (Maturana, 2003; Maturana & Varela, 1975/1980). Structural coupling is the conjoint result of thermodynamic openness, which allows the flow of matter and energy through the organism, and operational closure, which enables autopoiesis and homeostasis. As the interface of interaction between organism and niche, the domain of structural coupling defines the organism’s cognitive domain. For this reason, Maturana’s theory could just as easily be called the “structural coupling view of cognition” as it could the “autopoietic view of cognition.”

Finally, Maturana refers to the adaptation of organism to niche as the “operational coherence” between the biological system and its medium of living (Maturana, 2003, p. 17). In contrast to the traditional view, Maturana asserts that adaptation is not “a variable in the evolutionary discourse” but, rather, “*an invariant relation* that constitutes a condition of existence for living systems (and in fact for all systems)” (Maturana, 2003, p. 17; my italics). A living system that maintains autopoiesis is adapted to its niche because its operations cohere with—they are not contradicted or thwarted by—the surrounding medium. If the organism were maladapted in this sense, it could not survive. An organism’s interactions may be more or less *optimal* according to some criterion, but optimality, in Maturana’s view, is strictly an observer-dependent distinction.²⁹ Adaptation, therefore, is an intrinsically cognitive phenomenon because it is determined by the adequacy of the organism’s interaction with its niche.³⁰

In summary, the biological principles sketched above—circular causation and interaction; operational closure, autonomy and self-reference; structural determinism, and structural coupling—are what I take to be the fundamentals of Maturana’s theory of cognition, which is more detailed and far-reaching than I have outlined here. These points are apposite to my purposes for two reasons: 1) they constitute the parts of Maturana’s framework most valuable to contemporary debates about cognition; and 2) they provide justification for Maturana’s central, and quite radical, conclusion: “*Living systems are cognitive systems, and living as a process is a process of cognition.*” (Maturana, 1970/1980, p. 13) John Stewart (1996) abbreviates this view as “life=cognition.”

This is not a trivial equation or an empty tautology, not least because Maturana spells out in detail how and why the equation holds and what its implications are for more complex elaborations of cognition, such as language. The theory of evolution by

28. Richard Lewontin (1983) would make a similar observation a decade later: “Just as there is no organism without an environment, so there is no environment without an organism.”

29. I am not convinced by this ascription. Surely, some systems have means of assessing the optimality of their functioning. Sickness behaviour might be considered a response to such an assessment.

30. Peter Godfrey-Smith’s ‘environmental complexity thesis’, which holds that the function of cognition is to help the organism adapt to environmental complexity, resonates somewhat with this idea (Godfrey-Smith, 1998).

natural selection has been criticized for being similarly tautological: The fittest are fit because they survive, and they survive because they are fit (Richards, 1987). Nevertheless, natural selection is arguably the most successful theory in biology because it makes sense of a wide variety of biological phenomena. We have nothing even remotely comparable for making sense of cognition (de Waal, 2002). Maturana's account is a significant step in that direction.

The comparison with Darwin may seem exaggerated and grandiose, but I believe it is justified. Maturana was the first to put theoretical flesh on the bones of Darwin's conjecture that the difference in cognitive capacity between humans and other animals is one of degree, not of kind. What Maturana did with cognition—as Aristotle, millennia before, had done with *psuche*—was to extend his observations about the phenomenon wherever his investigations and reflections led him, which was to all living systems. As Maturana puts it:

Our cognitive process (the [human] cognitive process of the observer) differs from the cognitive processes of other organisms *only in the kinds of interactions into which we can enter*, such as linguistic interactions, *and not in the nature of the cognitive process itself*. (Maturana, 1970/1980, p. 49; my italics)

What should be abundantly clear to anyone familiar with current debates in the cognitive sciences is that Maturana's explanation of cognition, precisely because it is derived wholly from biological principles, is also dynamic, embodied, embedded situated, and interactive. It anticipates, by three decades, a cluster of issues of major concern today, a claim I will flesh out in more detail in section four. It is not unwarranted to surmise that we might have arrived at contemporary thinking about cognition much sooner, and advanced these lines of thought further, had Maturana's proposals been more influential in the years after their introduction. Instead, Maturana's explanation of cognition was virtually ignored. In the next section we will look at some of the possible reasons why.

3. Prematurity and Maturana

In 1972, Gunther Stent proposed an explanation of why some theoretical ideas or empirical discoveries that later come to be seen as important nevertheless are dismissed or ignored at the time of their introduction. Stent called these instances of “prematurity,” and he produced as examples Mendel's laws, Oswald Avery's identification of DNA as the vehicle of hereditary transmission in bacteria, and Michael Polanyi's theory of the adsorption of gases (Stent, 2002). Ironically, Stent's proposal about prematurity in scientific discovery itself proved premature (Hull, 2002) and was largely ignored by historians, philosophers and social students of science, if not by scientists, until very recently. Stent himself wondered “whether it is [explanatorily] meaningful, or merely tautological, to allege that a discovery is ‘ahead of its time’” (Stent, 2002, p. 22). Others worry that the concept of prematurity is “heuristic only with hindsight” (Hook, 2002, p. 9) and thus, in historians' parlance,

“Whiggish” (Comfort, 2002). However, other scholars have found the concept of prematurity useful in explaining the delayed acceptance of novel ideas in diverse fields, including evolutionary biology (Ghiselin, 2002; Ruse, 2002), medicine (Carpenter, 2002; Sacks, 2002), physics (Townes, 2002), cosmology (Hetherington, 2002), and geology (Glen, 2002).

Stent’s criterion for prematurity is as follows. “A *discovery is premature if its implications cannot be connected by a series of simple logical steps to contemporary canonical [or generally accepted] knowledge.*” (Stent, 2002, p. 24) Does Maturana’s theory of cognition meet Stent’s criterion for prematurity? I think the answer is affirmative but qualified. The qualification is this: At the time Maturana published *Biology of Cognition*, he had over the previous decade regularly contributed, jointly and as sole author, to leading scientific journals such as *Nature*, *Science*, the *Journal of Anatomy*, and the *Journal of General Physiology*. However, a distinction must be drawn between Maturana’s experimental work on the vertebrate visual system and his more abstract theoretical efforts on general biological processes. The work on visual perception, which contributed to an emerging canon, made his scientific reputation. The theoretical work on autopoiesis, in some respects, undid it. After his “theoretical turn” his publications in leading journals fell off dramatically.

Maturana’s theoretical proposals about cognition and living organization were premature in Stent’s sense because while his experimental work could be linked to generally accepted knowledge, his theoretical work could not. First and foremost, his was a systems, or process, account. Although systems thinking received a great deal of attention with the advent of cybernetics particularly, it was unclear how these new ideas could be put to empirical use. The problem remains today with the application to specific biological problems of complexity and dynamical systems theories. Given the great promise of molecular biology and genetics at the time Maturana introduced his ideas, there was no sufficiently compelling reason to abandon the classical reductionist approach, which had proved so successful, for a systems approach that had little or no demonstrable relevance to much biological research then under way.

Secondly, and just as importantly, was the presence of a compelling rival framework for considering the problem of cognition, computationalism, which despite growing challenges remains the dominant paradigm of the cognitive sciences. Taking the human capacities for mathematical calculation and language use as a model for intelligence, Alan Turing suggested how these capacities might be mechanized, while McCulloch and Pitts demonstrated how the neurons of the brain might operate as such a machine. Thus was born the idea that cognition is best thought of as a computational process. Input to the process was information from the environment, somehow coded within the organism to represent a state of affairs and in a form amenable to manipulation, like symbols. Although biological principles, particularly evolutionary concepts, were enlisted to add empirical flesh to the theoretical bones of computationalism, the approach followed the long dominant anthropogenic tradition of taking human cognition as the starting point and main target of explanation.

Maturana's biogenic theory, by contrast, was explicitly anti-computational and anti-representational. In Maturana's view it is a mistake to think of biological behaviour as an organism's output to an environmental input. There is no 'information' at large in the environment that is somehow passed to or accessed by the organism. There is only the organism's interpretation of what is occurring at a given moment, evidenced by the sort of interaction in which it is engaged. That interaction, in turn, is determined entirely by the system's structural state at the given moment. The same stimulus (e.g., the presence of glucose molecules) will mean different things to different organisms, and even different things to the same organism at different times (e.g., conditions of hunger and satiety), and therefore will trigger different interactions, both within the organism and between the organism and its niche. There is no information floating free in the environment to be picked up and understood correctly or incorrectly; there are only structurally determined, perspective-dependent interactions.³¹

Maturana uses the analogy of a pilot in the cockpit of a flight simulator (Maturana, 1970/1980) or a submariner at the controls of a submersible (Maturana & Varela, 1992). The pilot or submariner interacts only with instruments, which comprise the system of which he is a component. The instruments detect conditions in the niche within a certain range and effect changes within the system in response. Adequate interaction within the niche (the sea, the simulated sky) requires action A when conditions are within range B , action A_I when conditions are within range B_I , and so on—although the number of variables at a given moment in an actual biological system would be greater by many orders of magnitude. The detecting instruments need only co-vary with changes in niche conditions. These trigger changes within the system, which bring about further interaction with the niche. Persisting entities, such as representations, are unnecessary for cognition, on Maturana's account. What is necessary for cognition is an operationally closed, autopoietic system, open to the flow of matter and energy, whose organization is capable of specifying the range of interactions the system's structural components may enter into.³²

Ernest Hook (2002) suggests several additional factors that contribute to resistance and neglect of novel scientific proposals. Four of these factors relate to lack of awareness, three of which pertain to Maturana's situation: 1) "the limitation of publication to a language other than the lingua franca of the period"; 2) "presentation of the work in difficult-to-comprehend and/or atypical, unfamiliar prose or terminology;" and 3) "publication in an article or monograph...in an obscure outlet read by an audience highly unlikely to appreciate the work" (Hook, 2002, p. 5).

Maturana's theoretical ideas were first published as technical reports of Heinz von Foerster's Biological Computer Laboratory in the Department of Electrical

31. Gibson's non-computational concept of ecological 'affordances' is similar, but also different in important respects.

32. In the life forms of Earth, the (highly variable) expression of DNA is the universal invariant of organizational development. However, it should be clear, on Maturana's account, that autopoietic organization need not require DNA.

Engineering at the University of Illinois—the *Biology of Cognition* in 1970 and *Autopoietic Systems*, co-authored by Varela, in 1975. Although the audience for these reports perhaps would have been more appreciative than most, it also would have been extremely limited. The book-length treatments of these ideas, on the other hand, were published in Spanish and not translated into English until 1980. Indeed, most of Maturana's books are written in Spanish and relatively few have appeared in English. For the first decade after the introduction of Maturana's core ideas, publication in English was limited to two articles, which appeared in relatively obscure journals.³³

Maturana's mode of expression also hampered understanding of his thought, to say nothing of acceptance of it. In my view, his rhetorical style remains the greatest impediment to his appreciation.³⁴ Maturana's writing reflects his subject; his sentences are recursive and complex and often require (at least for this reader) multiple readings to fully comprehend. His logic is notoriously circular, although, it can be argued, necessarily so (Glaserfeld, 1997). Maturana's style, which is declamatory and axiomatic, can be irritating to those who require argument of a more traditional sort, especially as he makes little effort to place his work in the context of other intellectual currents, either in epistemology or biology. This is particular damaging because he pitches his case in novel terms at a high degree of abstraction with little empirical ballast—although once Maturana's thought is understood, examples are not hard to find.³⁵ Its potentially wide application is what makes Maturana's account attractive.

4. An idea whose time has come or has passed?

Developments in the cognitive sciences over the past 15 years would suggest that perhaps the time has finally arrived for Maturana's biogenic explanation of cognition to receive due attention. Although reports of its demise (Bringsjord, 1998) are decidedly premature, computationalism is under siege from many quarters (Eliasmith, 2002; Fetzer, 1998; Scheutz, 2002). Computationalism's future is more unclear than at any time in the past half century due to its inability to answer satisfactorily three questions regarding cognition—how it works, what it does, and what it is (Bechtel,

33. Barry McMullin (2004) reports that publication in English of the autopoietic theory "proved difficult," despite Maturana's substantial profile. Both *Biology of Cognition* and a shorter collaborative article were rejected by several publishers and journals before the article (Varela, Maturana, & Uribe, 1974) was finally published in *BioSystems*, thanks to von Foerster's influence on the editorial board. The article today "occupies a seminal position" in the A-Life literature, according to McMullin (2004, p. 280), "as the first application of agent-based computer modelling demarcating the living from the nonliving state."

34. *The Tree of Knowledge* (1987), considered by some to be Maturana and Varela's most accessible full-length work on autopoiesis and cognition, was translated from Spanish into English.

35. On the importance of empirical ballast, it is salutary to note that evolution was a relatively venerable but vaguely articulated idea and the theory of natural selection conceived not once but twice before *Origin of Species*, and independent of Wallace. What Darwin did, arguably, was to provide the massive empirical evidence necessary to support the theory of evolution as the right framework for thinking about how living organization came to be the way it is, and for a theory of natural selection as the proper way of thinking about evolution (Ruse, 2002).

Abrahamsen, & Graham, 1998). The latter question is particularly relevant to whether information processing remains at the heart of the cognitive sciences:

A comprehensive answer to the question of what cognition is, if it is not limited to information processing within the brain, has not yet been developed. Accordingly, it is not yet clear whether information processing will turn out to be a component of a more comprehensive characterization of cognition, or whether it will have been a false step. (Bechtel, Abrahamsen, & Graham, 1998, p. 92)

The common denominator among the current challengers to computationalism is, arguably, that they are more *biological* to varying extents. Each in its own way reflects concern with an aspect of cognition for which computationalism has yet to account and, in some cases, shows increasingly little promise of doing so. Maturana's preoccupations are well represented among the challengers. These include: 1) *dynamical systems theory* (Beer, 1995; Serra & Zanarini, 1990; van Gelder, 1998; Ward, 2002) and theories relating to complex adaptive systems generally (Beer, 1990); 2) the *embodied (embedded, situated) cognition* movement (Clark, 1997; Godfrey-Smith, 1998; Lakoff & Johnson, 1999; Millikan, 1989; Sterelny, 2001; Varela, Thompson, & Rosch, 1991; Winograd & Flores, 1986), which "refocused attention on how cognition facilitates life" through the organism-world relation (Bechtel, Abrahamsen, & Graham, 1998, p. 91); 3) theorists emphasizing the role of *action and interaction* in cognition (Bickhard, 2001; Bickhard & Terveen, 1995; Hurley, 1998; Jeannerod, 1997); 4) those who stress system *autonomy* in the generation of cognition (Christensen, 2004; Christensen & Hooker, 2000; Moreno, Umerez, & Ibañez, 1997; Rosen, 1985); 5) explicitly *anti-representational* accounts (Brooks, 1991; Keijzer, 2001); and 6) *biosemiotics*, a framework based on the idea that every organizationally specified interaction in a biological system, whether at the molecular or organismic level, is an act of interpretation, or semiosis, relative to and determined by the interacting system (Hoffmeyer & Emmeche, 1991; Kull, 1999; Pattee, 1969; Sebeok, 2001)

Maturana anticipated many of these ideas in one way or another,³⁶ but with some notable exceptions (e.g., Winograd & Flores, R. Beer, Keijzer)³⁷ few of the thinkers noted above are explicitly influenced by him. John Stewart, for example, has explicitly and consistently employed autopoietic theory to address issues relating to cognition—from explaining the putatively cognitive capacities of the immune system (Stewart, 1993; Stewart & Coutinho, 2004) to developing a definition and mathematical model of cognition (Bourguin & Stewart, 2004)—but his work has appeared nowhere in the mainstream cognitive scientific literature to date.

Given this profusion of compatible theorizing, do we need Maturana's explanation? I believe the answer is yes, for three main reasons. First and foremost is the importance of the notion, specific to Maturana's thought, of structural coupling. Within a single concept, Maturana unites a multitude of concerns relevant to

36. Rosen excepted. *Dynamical Systems Theory in Biology* was published the same year as *Biology of Cognition*.

37. I am indebted to Fred Keijzer for pointing out these exceptions.

cognition: embodiment, interaction, adaptation, perspectively generated reference, niche construction (including the Baldwin Effect), and structurally determined dynamism. Although Maturana rejects cognition as information processing, I believe structural coupling suggests an avenue for explicating the currently wildly ambiguous concept of information, at least in Bateson's terms of "differences that make a difference" (Bateson, 1979, p. 99). A "difference" arguably is discernible only by an operationally closed system for which coherence with its surrounding medium is necessary, as it is for autopoietic systems.³⁸ Autopoietic systems must interact to exist, and interaction requires *differentiation* between one sort of interaction and another.

Second, Maturana's account scales relatively seamlessly from simpler to more complex orders of cognition. This is a significant virtue, as Darwin clearly saw in his study of the emotional life of earthworms (Darwin, 1872). This is not to say that, were the autopoietic explanation accepted, there is nothing left to explain about the nature of abduction, language and mathematics; how the brain gives rise to the various aspects of cognition; the evolution of complex cognitive systems; and so on. However, Maturana's unified framework facilitates the understanding of more complex cognitive systems by making principles derived from the study of very simple cognitive systems, both on an individual and a collective level, relevant in ways they currently are not. In other words, it may provide a stable platform for a truly comparative psychology between species. Although every comparative situation would require some tweaking and adjustment, as does every practical application of the fundamental physical laws,³⁹ it would fill a void currently rued by some cognitive ethologists (Shettleworth, 1993).

Third, the autopoietic framework promises to narrow the chasm between the molecular and macroscopic domains of cognition currently papered over with the common but somewhat empty label *emergent property*.⁴⁰ According to Maturana, to call something an emergent property is to make an observation that requires a perspective larger than the cognizing system; emergence does not exist at the system level (Maturana, 2003, p. 13). What exists at the system level are nested domains of interaction, what Dupuy and Varela (1992) describe as "tangled hierarchies," which influence one another in both directions, from the bottom up and from the top down. What appears to an observer as separable, qualitatively different levels of functioning to the system are indistinguishable. This does not mean that we, as observers, cannot differentiate for our own purposes what appear to us to be qualitatively different levels of organization; but we should not confuse our descriptions with the phenomena we are describing.

Although these are significant advantages, Maturana's explanation does not come to us problem-free. Although a detailed critique is beyond the limited ambitions of this

38. This is not to say that information exists only for autopoietic systems but that understanding information in the autopoietic context will help to make better sense of information generally.

39. This is not to imply that the principles of the autopoietic explanation of cognition are equivalent to so-called natural laws.

40. As Mark H. Bickhard often and so aptly puts it, *everything* has emerged since the Big Bang.

paper (to say nothing of the space limitations of this journal), I will mention two broad classes of problems that are serious, but possibly avoidable. First are some of the implications Maturana draws from the notion of structural determinism. In his later work, Maturana describes a system's interaction with its niche, as well as its development during its lifetime, as "a process without alternatives" (Maturana, 1990, p. 76). This seems to imply that the way things are is the only way they could ever have been. If that is what Maturana is saying, then it is an empty tautology—things are the way they are; therefore, they could not be any other way. If, on the other hand, Maturana is implying that there is no such thing as genuine novelty, or that organisms are never capable of altering their structurally determined patterns of interaction (e.g., as is the case in cognitive behavioural therapy), then in my view he is mistaken. Maturana might say that novelty and intentional changes in interactive patterning are designations of an observer, but I think a case can be made *from the system's standpoint* that novel interactions and intended change in interactive patterning take place at every order of cognitive complexity. For example, in bacteria novel interactions are enabled by lateral gene transfer and intended change in interactive patterning occurs, under stress conditions, via targeted mutagenesis.⁴¹

The "process without alternatives" view has important implications for agency. Simply put, on Maturana's account there is none. No alternatives mean no "decision points" (Maturana, 1990, p. 87). No decision points mean no purposes or goals. No goal orientation means no agency. Maturana's stridently anti-teleological view is, I think, influenced by an understandable concern with vitalism, but I believe he goes too far, unnecessarily. Maturana's account is saturated with interaction, after all. Agency, minimally, is the ability to engage in action (interaction) to further system-determined goals, and there is nothing in structural determinism to prevent a system having goals, implicit or even explicit. Existence conditions, such as the maintenance of continued autopoiesis, are, arguably, implicit goals *for the system*, not merely something imputed by an observer. Continued autopoiesis is an end toward which interaction is directed.

Maturana seems concerned that to concede agency, or an end to which development tends (equifinality), is to concede the presence of "a general organizational principle or force guiding the operation of the molecules that compose [the system]," over and above the local interactions of those molecules (Maturana, 2003, p. 17). I see no such implication. Global as well as local constraints shape a system, as Maturana well knows. The possible interactions of structural components are specified by the system's organization as an integrated, operationally closed whole, after all. Additionally, Maturana's assertion that organisms cannot have goals because they exist in a continuous present (Maturana, 1990, p. 81) does not wash if, as he also claims, interaction implies prediction and inference. Predictive inference, which depends upon projection, necessarily entails future. Biological systems are

41. See in particular Lynn Helena Caporale's excellent *Darwin in the Genome: Molecular Strategies in Biological Evolution* (2003), New York: McGraw-Hill.

time-circumscribed systems. A system's accumulated history, which constitutes its structure at a given moment, is transformed in the continuous present through continual interaction and thereby transmitted to a future.

The second general class of problems relates to Maturana's definition of knowing as "effective action" (Maturana & Varela, 1992, p. 29). Knowing, or cognition, is thus characterized as "an action that will enable a living being to continue its existence in a definite environment" (Maturana & Varela, 1992, pp. 29-30). Maturana extracts from this principle the following claim—that "a living system is *necessarily* always engaged in adequate action" so long as autopoiesis is maintained (Maturana, 1990, p. 89; my italics)—and an observation: "Living systems do not use or misuse an environment in their operation as autopoietic unities, nor do they commit mistakes in their ontogenetic drift." (Maturana, 1990, p. 81)

I am not entirely sure what Maturana means or intends with these statements, but surely it is not that biological systems never make mistakes, or that an error that fails to kill the system (cause autopoiesis to cease) is just another sort of interaction on a par with all other interactions. If this were the case, it would imply that biological systems have no norms of effective operation *from the system's perspective* relative to different pathways of interaction. On this story, near enough should always be good enough. Clearly, this is not the case. An animal can be sick, a plant diseased; an interaction may cause pain or damage but not death. A system's interaction with its medium may so alter the medium that the system's continued existence is threatened. How can potentially catastrophic anthropogenic climate change be anything but a mistake—from both the perspectives of the observer and of the (human) living systems whose interactions are bringing it about. Existential parameters may vary across a range, but presumably homeostatic regulation tends toward balance that is optimal *from the system's standpoint*. It is unclear how Maturana accounts for internal processes of control and their evolution if there are no norms. But norms are relative—to implicit goals, at the very least the implicit goal of continued autopoiesis.

Conclusion

The time seems right for a broad rediscovery of the autopoietic account of cognition proposed by Maturana and developed with Varela and others. Most accounts of cognition, both traditional and modern, are anthropogenic; overtly or covertly, they take the human case as the starting point and the main target of investigation. Many of the most intractable problems encountered by the computational approach (e.g., the frame problem, the symbol-grounding problem) arguably have stemmed from this initial methodological bias. Maturana, by contrast, takes a biogenic approach to the basic problem of cognition, while recognizing the inescapable influence of human observation on any explanation. Constructed wholly from biological principles, the autopoietic framework provides the most unified and consistent way available to us of explicating not only the *what* but also the *how* of cognition, from the simplest

examples to the most complex. The framework may have problems, but the general principle that cognition and living organization mutually and indistinguishably shape and inform one another is the appropriate starting point for understanding the most fascinating phenomenon of our experience, *knowing*.

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